Final Report

Project title (Acronym)
Ceratitis capitata: Better knowledge for better risk management (FRUITFLYRISKMANAGE)

Project duration:

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Contents

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2. Short project report

2.1. Short executive summary

Fruit flies (Tephritidae) are among the most important pests worldwide and among them *C. capitata* is one of the species that has increased the most its geographical expansion. Cooperation between different countries and entities is a necessity in order to better understand the drivers of its dispersal and occurrence as well as to develop appropriate management strategies to tackle this important pest.

Ceratitis capitata (Wiedemann), also known as Mediterranean fruit fly, is one of the world's most destructive plant pests. It is a highly multivoltine polyphagous species able to feed on over 300 hosts, and it is known to be able to adapt to a wide range of climates. Originating from Africa, the pest has spread in Europe, the Middle East, Oceania and South America. In the EPPO region, it is mainly present in the southern part, where it is particularly damaging for Citrus and Prunus spp.; records in Northern or Central Europe refer to interceptions or short-lived adventive populations only.

Therefore, effective surveillance programmes and control measures are of outmost importance to protect countries and their agriculture, landscape and environment. For this purpose, comprehensive information on *C. capitata* occurrence, both in spatial and temporal terms, is crucial for understanding the current and historical extent of its occurrence, make its dispersion assessment and identify areas susceptible to invasion and establishment. The project partners (Fig. 1) collaborated to share information on the distribution and abundance of *C. capitata* in the participating countries and shared their experience on the methods and tools to monitor and manage the pest. The partners developed models on the potential future occurrence of *C. capitata* in the participating countries, based on climatic conditions.

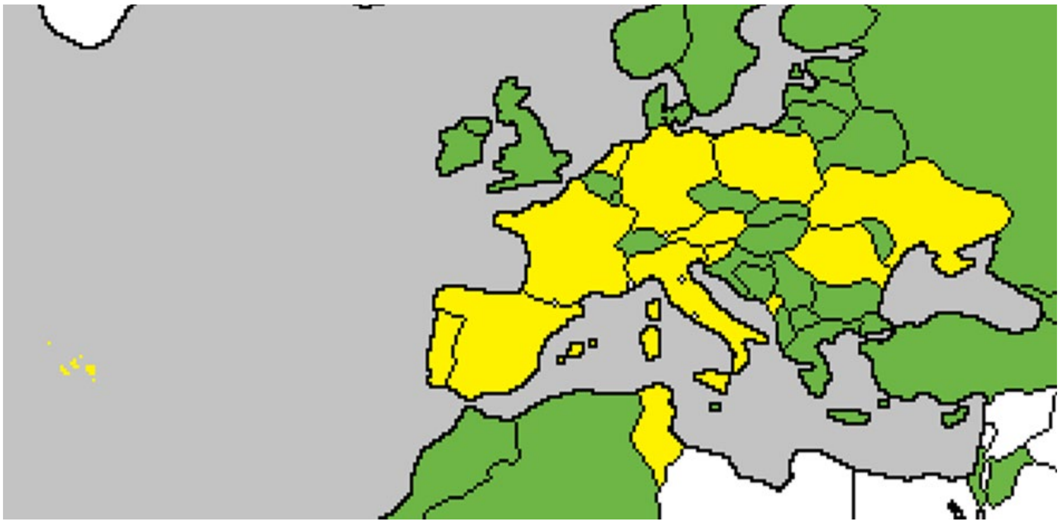


Figure 1 – Partner's countries involved in FRUITFLYMANAGE Euphresco project (yellow).

2.2. Project aims

The project aimed to improve knowledge on the biology and epidemiology of *Ceratitis capitata* and to update the information of its presence in the partner countries. The project objectives were:

1) To share information on the presence and distribution of *Ceratitis capitata* in the partner countries.
2) To support surveillance activities and evaluate the effectiveness of various traps and different attractants or lures.
3) To deepen the knowledge on the genetics of *C. capitata* populations and compare s the populations present in different countries.
4) To support pest management activities through the study and validation of biological control agents.
5) To develop tools to improve preparedness and build models to determine areas where *C. capitata* can survive and disseminate.
6) To build appearance probability models and risk maps regarding *C. capitata* using MaxEnt software and geographic systems information in the different partner's countries.

2.3. Description of the main activities

2.3.1. Occurrence and geographical distribution of *C. capitata* (more details on the activities are provided in Appendix WP2)

Project partners were asked to collect and share information on: occurrence records (time, locations and climatic and weather conditions), hosts, life stages and number of generations, mode of overwintering and further available information. The reference concerning when the *Ceratitis capitata* was introduced in each country and the actual/recent situation in each country and its evolution in the last 3 years. Annual monitoring activities were organized in the partner countries. This allowed the identification and permitted to build a list of occurrence records in each partner countries; information on the population level in each area, the locations of occurrence and identify the most susceptible host plants.

Several partners (Austria, Poland, Romania, and Slovenia) develop monitoring activities during the project. In addition, historical occurrence data and information previous monitoring activities were provided by Spain, France, Germany, the Netherlands, Portugal and others partners.

All data were used to create maps with the occurrence records and their locations.

2.3.2. Biological characterization of *C. capitata* populations based on identified molecular markers (more details on the activities are provided in the Appendix WP3)

The main aim of this task was to trace the origins of *C. capitata* across Europe but also to obtain a picture of the genetic diversity of fruit fly populations. Genetically based data on the way of spread across Europe will contribute to further pest risk assessments.

A molecular characterization of *C. capitata* was performed using protocols developed by JKI partner (Bonizzoni *et al*., 2000; König *et al*., unpublished). More precisely, a total of 121 individuals belonging to 12 European populations (Portugal continental; Azores; Spain Continental; Tenerife; Spain Rear; Spain Vienna; France continental; France Corsica; Poland, Romania; Austria; Slovenia) were genotyped using 10 highly polymorphic SSR (microsatellites) markers.

2.3.3. Biological control of *C. capitata* (more details on the activities are provided in the Appendix WP3).

Partner IVIA worked on the optimization of the laboratory rearing protocols for *C. capitata* and of 2 parasitoids to be used for thebiological control of *C. capitata*: the larvo-pupal parasitoids species from México, *Diachasmimorpha longicaudata* (Hymenoptera, Braconidae) and *Aganaspis daci* (Hymenoptera, Figitidae) an exotic species but currently naturally present in Spain.

2.3.4. Review and testing of early detection tools and management strategies used in different countries (more details on the activities are provided in the Appendix WP4)

The project allowed to exchange knowledge on the effectiveness of various traps: Jackson traps, Steiner traps, Yellow Panels, Tephri traps, McPhail pheromone traps, Champ traps, Nadel traps, Pherocon traps, Cone traps, Decis traps and Attract-and-kill traps. Different combinations of trap-attractant, food attractants and lures were considered: trimedlure (TML), trypack (trimethylamine, diamino butane and ammonium acetate), Biolure, EGOlure (in combination with a yellow sticky trap to catch the incidental female specimens), Tephri Trap, UniPak and Jackson traps with food attractants and with insecticides such as deltamethrin.

2.3.5. Models to predict pest's spread and adult's abundance in different climatic regions (more details on the activities are provided in the Appendix WP5)

Climatic data (namely temperature, rainfall, altitude, slope and sun exposure of locations where pest outbreaks where detected) obtained in different countries were used to build models to support risk assessment and to forecast pest's spread by identifying the areas with the best conditions to favour *C. capitata* colonisation. The models used the MaxEnt software. A set of risk maps on the occurrence probability of Medfly in relation to Bodeheimer's temperature were produced for each partner country.

2.4. Main results

The major project results are as follows:

2.4.1. Occurrence and geographical distribution of *C. capitata* (more details on the results are provided in Appendix WP2)

The project allowed to obtain recent information and data on the distribution of *C. capitata* from 11 countries: Austria, France, Germany, Montenegro, the Netherlands, Poland, Romania, Slovenia, Spain, Ukraine and Portugal (including the Azores islands) from the last three to four years (2017/2018 to 2020).

Fig. 2 provides an overview of the current relevance of *C. capitata* in the partner countries (qualitative assessment based on the information provided by the partners).

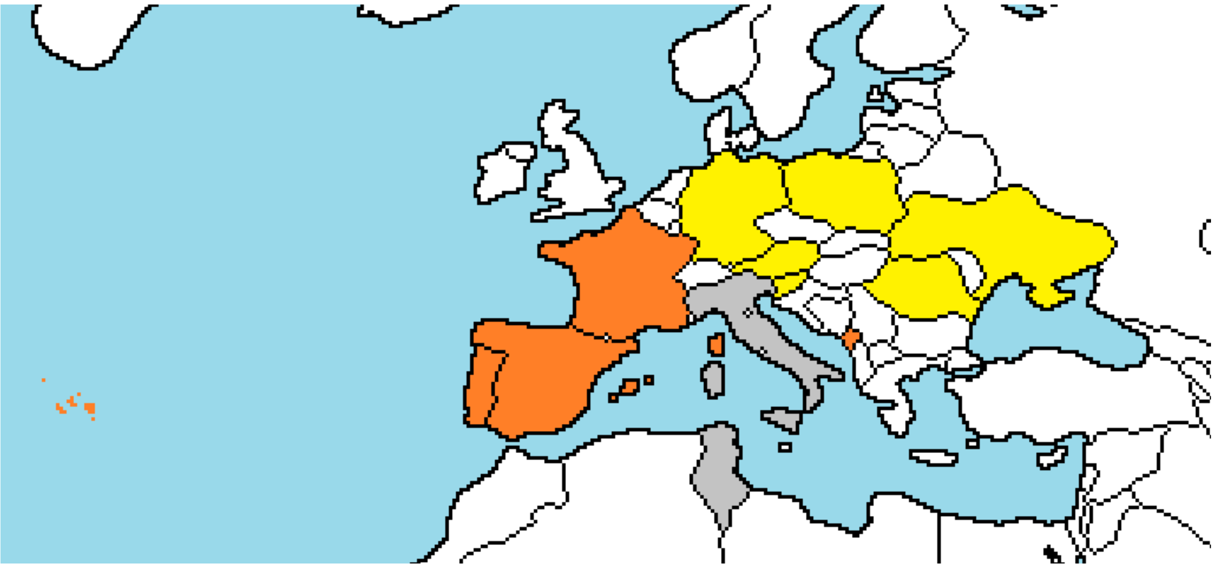


Figure 2 – Current relevance of *C. capitata* in the partner countries.

Orange	*C. capitata* widely spread	ES, FR, ME, PT (incl. Azores)
Yellow	*C. capitata* moderately spread	AT, DE,NL,PL, SI, UA, RO
Grey	no data provided within the project, but *C. capitata* occurring according to EPPO global database (present, widespread)	IT, TN

2.4.2. Biological characterization of *C. capitata* populations based on identified molecular markers (more details on the results are provided in Appendix WP3)

The results of the genetic characterization shows that the European population are distributed in two groups, clearly distinct, probably forming separate genetic clusters.
Thespecimens from Tenerife and Azores diverge along both PCoA axes.

2.4.3. Biological control (more details on the results are provided in Appendix WP3)

The IVIA team optimized the laboratory rearing of the parasitoids *Diachasmimorpha longicaudata* and *Aganaspis daci* and the rearing protocol for the medfly. Collaborating with the Grupo Tragsa allowed to start the mass rearing of *D. longicaudata* using Vienna-8 irradiated larvae of *C. capitata* as hosts.

2.4.4. Review and testing of early detection tools and management strategies used in different countries (more details on the results are provided in Appendix WP4)

The collection of data showed that a great variety of traps and lures are used in the different partner countries.
Next to the trap-lure combinations that catch the attracted flies, also attract & kill systems are used or tested. From all the tools used in the different countries the Tephri trap and Trypack attractant are the best combination to trap adult and especially females. Also the Jackson trap with Trimedlure (TML) can be used to catch the first emerged and flying males.

2.4.5. Models for pest's spread and adult's abundance predictions in different climatic regions (more details on the results are provided in Appendix WP5)

Models were built with the MaxEnt software based on the climatic data (namely temperature, rainfall, altitude, slope and exposure) some with local data and others that was not possible (limitation) permitted to obtain risk maps for the different partner countries.
By identifying areas with conditions that allow the colonization by *C. capitata* populations, the models aimed to build risk maps showing the occurrence probability in the partner countries.
In the absence of sampling data to select the best projection, the model that best presented the true statistic skill (TSS) was used. When data for validation were available, those statistical data were used to grade the most likely to least likely model.
Risk maps with the occurrence probability for the following the partner countries were obtained: Austria, Germany, Italy, Netherlands, Tunisia, Ukraine, Spain, Slovenia, Poland, France, Montenegro, Romania and Portugal (mainland and 8 Azores islands).

2.5. Conclusions and recommendations to policy makers

The occurrence data of *C. capitata* collected from the different partners revealed the actual extent of the distribution and abundance of this important pest in the participating countries. These data collected on occurrence for individual countries are much more comprehensive than what is available at EPPO or CABI.
In the western Mediterranean countries like Spain and Portugal, the Medfly is already an important pest, with the potential for regular fruit damage and requiring management strategies to protect fruit crops. On the other hand, the situation in the countries of Central or Northern Europe is quite different as only fewer catches of adults were recorded and fruit damage occurs very rarely.
However, considering the adaptability of this species and potential effects of climate change further monitoring activities as the ones developed in some of the partner's countries are highly recommended for all countries (potentially) facing problems with this pest.
The collection of data on the materials used (traps, lures, etc.) for monitoring and management activities, showed similarities but also differences between the countries and resulted in a considerable data set. This data set will serve as pool of information for countries facing increasing problems or with little experience with *C. capitata*.
Policy makers in such countries are advised to support their scientists in making use of the collected information and get in contact with the relevant project partners in order to receive additional advice if necessary.
The *Ceratitis capitata* risk maps built with local data of adult's captures and climatic data from the different partner's countries and the modelling made using MaxEnt software should be applied in all the EPPO countries that are exposed to the introduction and dispersal of this pest.
Biological control represents an alternative to insecticides for the control of *C. capitata* and allows reducing the impact of pest management on the ecosystem.

2.6. Benefits from trans-national cooperation

The transnational cooperation in the project FRUITFLYRISKMANAGE allowed obtaining a collection of available and new generated data on the occurrence and dispersal of C. capitata in the participating countries. Furthermore, information on the materials and methods for monitoring and management in various countries was collected during this project.
In addition, the trans-national collaboration enabled a straightforward exchange of samples between the partners, which facilitated the molecular analysis of specimens collected from a number of different countries.

The project also allowed:

- to establish a connection between all the scientists from the different organizations through the organization of on-line meetings
- to transfer knowledge and discuss results of the different activities;
- to review and analyse early detection tools and management strategies used against *C. capitata* in different countries;
- to transfer knowledge on the best traps, attractants and lures to be used in each of the partner's country for the monitoring *Ceratitis capitata* adults;
- to share information for the possibility to establish protocols, e.g. for the collection and preservation of samples, DNA analyses and genetic characterization of the populations
- to optimize and the possibility to establish laboratory protocols for the laboratory rearing of parasitoids and medfly
- to use geographical and climatic data for the development and validation of mathematical models using Maxent software to obtain risk maps identifying areas of possible occurrence, establishment and dispersion of *C. capitata*
- to develop several material for dissemination and training of farmers and technicians
- project partners to achieve experience in collaborative applied research activities, which permitted to strength the knowledge about the dispersion, distribution, host range and management of *C. capitata*.

3. Publications

3.1. Article(s) for publication in the EPPO Bulletin

David Lopes, Eugenia de Andrade, Alois Egartner, Francisco Beitia, Mojca Rot, Constantina Chireceanu, Valerie Balmés, Antoon Loomans, Tomasz Konefal. Fruit fly risk manage: an euphresco project for *Ceratitis capitata* wiedemann (diptera: tephritidae) risk management applied in some European countries (Manuscript submitted).

3.2. Article for publication in the EPPO Reporting Service

None.

3.3. Article(s) for publication in other journals

None.

4. Open Euphresco data

None.

WP2. Occurrence and geographical distribution of *Ceratitis capitata*. Situation regarding this pest in Europe

2.1 Austrian situation (AGES)

Author: Alois Egartner

2.1.1 Introduction

First findings of *Ceratitis capitata* in Austria (Vienna) date back to the nineteen thirties. During the following decades observations and damage records in Viennese fruit production areas were recorded, e.g. in the nineteen fifties. Recent monitoring activities, focusing on *Ceratitis* spp., started in Vienna in 2010 and have been extended from 2016 onwards to other federal provinces with up to 36 sampling sites per year (Table 2.1.1).

Table 2.1.1 - Number of sampling sites for *Ceratitis capitata* in Austrian regions (2010–2018). (Table amended after Egartner et al., 2019)

	2010-2013	**2016**	**2017**	**2018**
Vienna	1 - 4	4	8	14
Lower Austria	0	3	5	7
Upper Austria	0	1	1	1
Burgenland	0	2	3	3
Styria	0	3	3	5
Carinthia	0	4	4	4
Salzburg	0	0	1	0
Tyrol	0	0	2	2
Vorarlberg	0	0	0	0
Total	**1 - 4**	**17**	**27**	**36**

In Vienna traps were mainly installed in allotments and small gardens containing host plants (especially peach trees). Further trapping sites were at the Viennese wholesale market area, at two fruit/vegetable market areas as well as nearby a biogas and composting plant. In the other Austrian region's traps were positioned inside or near commercial orchards and small gardens containing host plants like peach trees. In addition, traps were installed at the Vienna International Airport (point of entry; Lower Austria) starting in 2018. At the sampling sites with host trees traps were installed in 2-meter height in the canopy of host trees.

Tephri trap type traps (Maxitrap®, supplier Sociedad Española de Desarrollos Químicos (SEDQ), S.L., ES) were combined with different lures (mainly: in 2010 – 2012: CERATIPROTECT®, supplier SEDQ, ES; from 2013 onwards: plugs containing trimedlure, Pherobank B.V., NL) to catch adult flies (Figure 2.1.1). Lure dispensers were changed several times during each season in accordance with suppliers' instructions.

In general, traps were installed from June to October to cover the season's fruiting periods. Control of trap catches was mainly carried out fortnightly. Collected fruit flies were identified morphologically using identification keys and diagnostic protocols. Molecular diagnostic methods were used for confirmation of some specimens.

From 2016 on potentially infested fruits (e.g. apricots, peaches, plums, and pears) were collected at sites with previous trap catches. Fruits were incubated under laboratory conditions and observed for emerging medfly larvae or pupae.

Figure 2.1.1 - Maxitrap® on host tree, Vienna, Austria (2016) ©AGES/Egartner

2.1.2 Results

Survey activities for *Ceratitis capitata* in Austria between 2010 and 2018 resulted in total captures of 1186 adult fruit fly individuals of this species. No other *Ceratitis* species were caught. Molecular analysis of selected specimens confirmed morphological identification.

While at most sites no catches of *C. capitata* were obtained at all, the majority of trapped individuals (>99 %) were recorded at sampling sites in Vienna. A maximum of two individuals were caught at three sites in other regions of Austria (Lower Austria, Burgenland and Upper Austria; one site per region) in 2016 or 2017 (Figure 2.1.2).

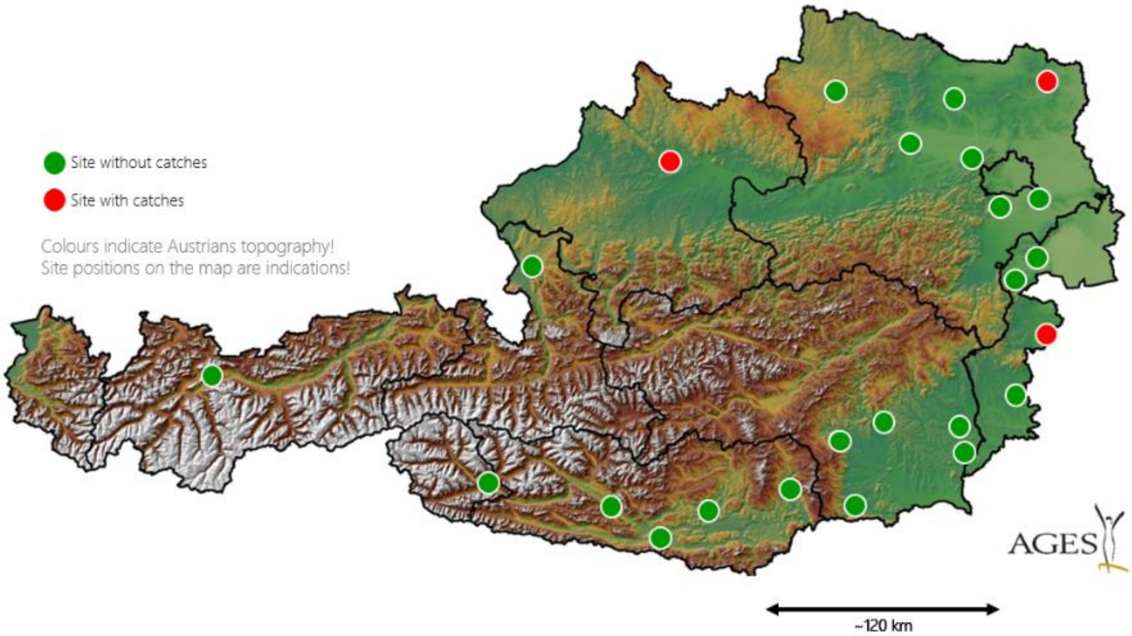


Figure 2.1.2 - Distribution of *Ceratitis capitata* sampling sites with and without catches in Austrian provinces (except Vienna), 2016-2018 (every site was sampled at least once).

In Vienna Medfly was caught at eight of the eighteen sampled sites. At most sites with catches only few individuals were observed (fewer than 25 individuals per site in total of all traps and years at that site). Comparably high numbers were only recorded at two sites, namely at 1110-A and 1150-A (Table 2.1.2, Figure 2.1.3).

Table 2.1.2 - *Ceratitis capitata* sampling sites in Vienna (Austria), 2010-2018, with number of individuals caught per site and year (sum of all traps; line (-) indicates: no sampling; * indicates: no specific *Ceratitis* survey) (See also Egartner et al., 2019).

	2010	2011	2012	2013	2014*	2015*	2016	2017	2018
1110-A	1	4	10	29	-	-	219	31	121
1110-B	-	-	-	-	-	-	-	-	0
1130-A	-	-	-	-	-	-	-	-	0
1140-A	-	-	-	-	-	-	-	1	0
1140-B	-	-	-	-	-	-	-	-	0
1150-A	-	9	52	10	1	-	536	82	47
1150-B	-	-	-	-	-	-	-	0	-
1160-A	-	-	-	-	-	-	-	0	-
1160-Z	-	0	-	-	-	-	-	-	-
1170-A	-	-	-	-	-	-	-	-	0
1190-A	-	-	-	-	-	-	-	0	8
1210-A	-	-	5	-	-	-	6	0	0
1210-B	-	-	-	-	-	-	-	-	0
1220-A	-	-	-	-	-	-	3	0	2
1220-B	-	-	-	-	-	-	-	1	2
1220-C	-	-	-	-	-	-	-	-	0
1230-A	-	-	-	-	-	-	-	-	2
1230-Z	-	0	0	-	-	-	-	-	-

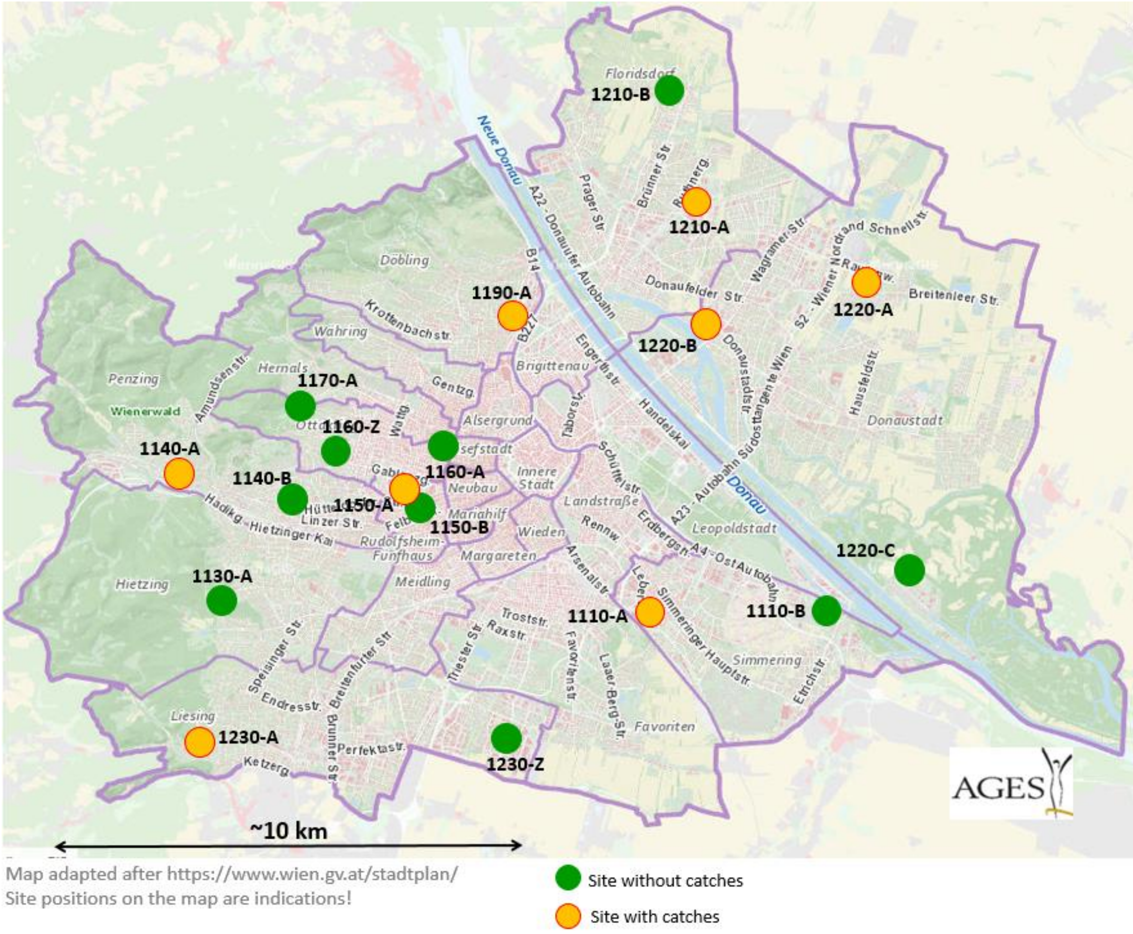


Figure 2.1.3 - *Ceratitis capitata* sampling sites in Vienna (Austria), 2010-2018, with and without catches (every site was sampled at least once) (See also Egartner et al., 2019)

The highest seasonal catches were assessed in August and September. From 2010 to 2012 most of the caught individuals were females (74%), in 2013 only males were observed, and between 2016 and 2018 approximately 95% were males.

Fruit sampling of suspicious fruits of three Viennese sampling sites resulted in records of infested apricot, peach, and pear fruits, but none from plums.

2.1.3 Discussion, notes, and references

Preliminary results of 2019 (unpublished) are comparable to those of the previous years (2016-2018) in terms of number and distribution of sites with catches and caught flies. While in 2019 the number of fruit samples was increased and included further types of fruits (e.g. apples, figs), none of the additional fruit types were found to be infested.

So far, based on the trap-catches and the available records of infestation, it seems that medfly can probably develop more than one generation in Vienna per year, but is currently not able to reach a relevant infestation level at most sites. In fact, only in certain areas medfly damages were noticed at all. However, this situation might change, as climatic conditions could be more suitable for this pest in Austria in the future.

While the origin of the caught individuals remains unknown, the potential reasons for the catches are discussed in detail in Egartner et al., 2019. Recurrent entries of infested fruits from infested areas are a probable pathway for the caught individuals (or their ancestors). However, different results of the survey activities support the theory that in certain areas the catches might be the outcome of an overwintering population. This hypothesis raises the question how this species could potentially manage to survive Austrian winter conditions, which do not favour the establishment and survival of tropical fruit flies.

The potential of *C. capitata* to overwinter in Austria and related hypotheses are addressed in an international collaboration which started in 2019 (H2020-SFS-2018-2020, "In-silico boosted, pest prevention and off-season focused IPM against new and emerging fruit flies ('OFF-Season' FF-IPM).

Survey activities on *Ceratitis capitata*, coordinated by the Austrian Agency for Health and Food Safety (AGES) in cooperation with regional plant protection services of some Austrian provinces, were established partly within the framework of two Euphresco-Network projects ("FLY DETECT", DOI 10.5281/zenodo.1326227 and "FruitFlyRiskManage").

In this context it is important to note that apart from *C. capitata* one specimen of *Bactrocera zonata* was incidentally caught in a trap in Vienna in 2011. This resulted in increasing surveillance for *Bactrocera* spp. in Vienna and other Austrian regions since 2012.

References

Egartner, A., Lethmayer, C., Gottsberger, R. A. & S. Blümel (2019): Recent records of the Mediterranean fruit fly, Ceratitis capitata (Tephritidae, Diptera) in Austria. IOBC-WPRS Bulletin Vol. 146, 143-152.

Egartner, A., Lethmayer, C., Gottsberger, R. A. & S. Blümel (2019): Survey on Bactrocera spp. (Tephritidae, Diptera) in Austria. Bulletin OEPP/EPPO Bulletin 49(3), 578-584. (https://doi.org/10.1111/epp.12604)).

2.2 Poland situation (GIORN)

Author: Tomasz Konefal

In the year **2017**, 48 traps were installed in 43 locations at the territory of 5 Voivodeships (west and south-western part of Poland) (Figure 2.2.1).

Monitoring programme was based on McPhail pheromone traps (the producer: Russell IPM Ltd, Unit 45, First Avenue, Deeside Ind. Park, Deeside, CH5 2NU; product's code: PCT-F10).

The distribution of traps was the folowing: 42 traps were in orchards of host plants (*Malus domestica, Prunus domestica*, *P. avium*, *P. persica*, *Pyrus domestica*); 6 traps were placed in storage facilities, mainly of *Citrus* fruits imported from other European countries, where pest is known to occur. **There were no detected outbreaks of *C. capitata* in 2017.**

Figure 2.2.1 - Locations in Poland of pheromone traps in 2017.

In the year **2018**, 50 pheromone traps were installed in 50 locations at the same territory of Poland as in 2017 (Figure 2.2.2), with the following distribution: 46 traps were located in orchards of host plants; 4 traps were placed in storage facilities.

Figure 2.2.2 - Locations in Poland of pheromone traps in 2018.

Monitoring with pheromone traps was carried out from the beginning of June to the end of August. Traps were officially supervised by SPHSIS inspectors at least every 2 weeks since their installation. There was a single replacement of the lure for the pheromone trap (after 40-45 days from its installation) and double replacement of the sticky plate.

The first record of *Ceratitis capitata* in the natural environment of Poland was a result of a monitoring programme in 2018 (Figures 2.2.3 and 2.2.4). Details of this record: 26♂♂, Poland, Trzebnica (UTM code: XS48), 10.09.2018, leg. A. Lejman-Popowska, E. Trubisz, peach orchard. Pheromone trap, det. T. Konefał (11.09.2018), ver. A. Klasa (18.09.2018).

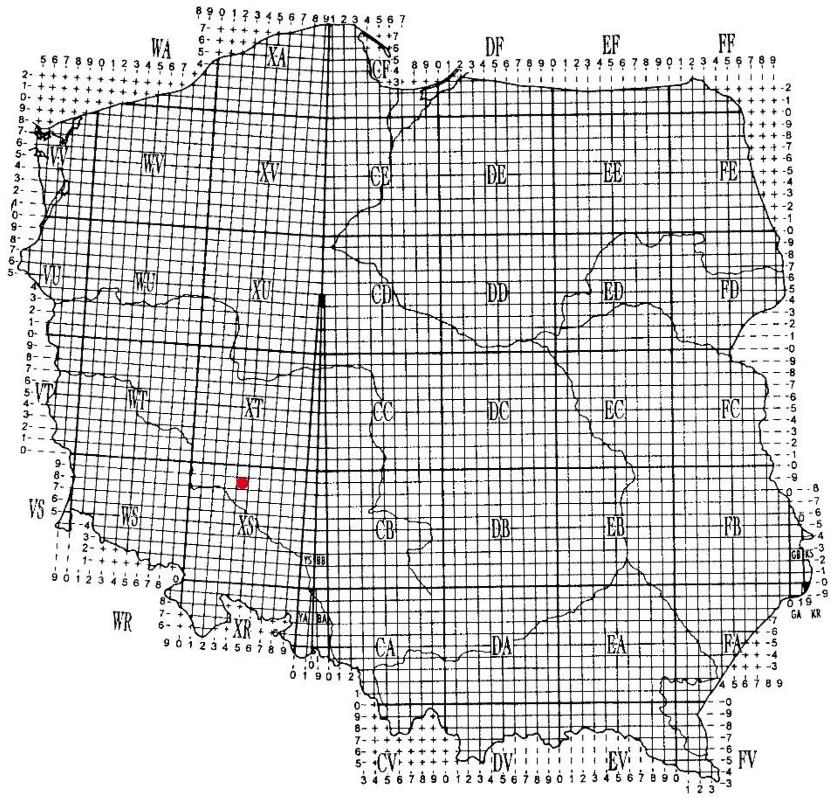


Figure 2.2.3 - The location of *Ceratitis capitata* record in Poland – 2018 (UTM code map).

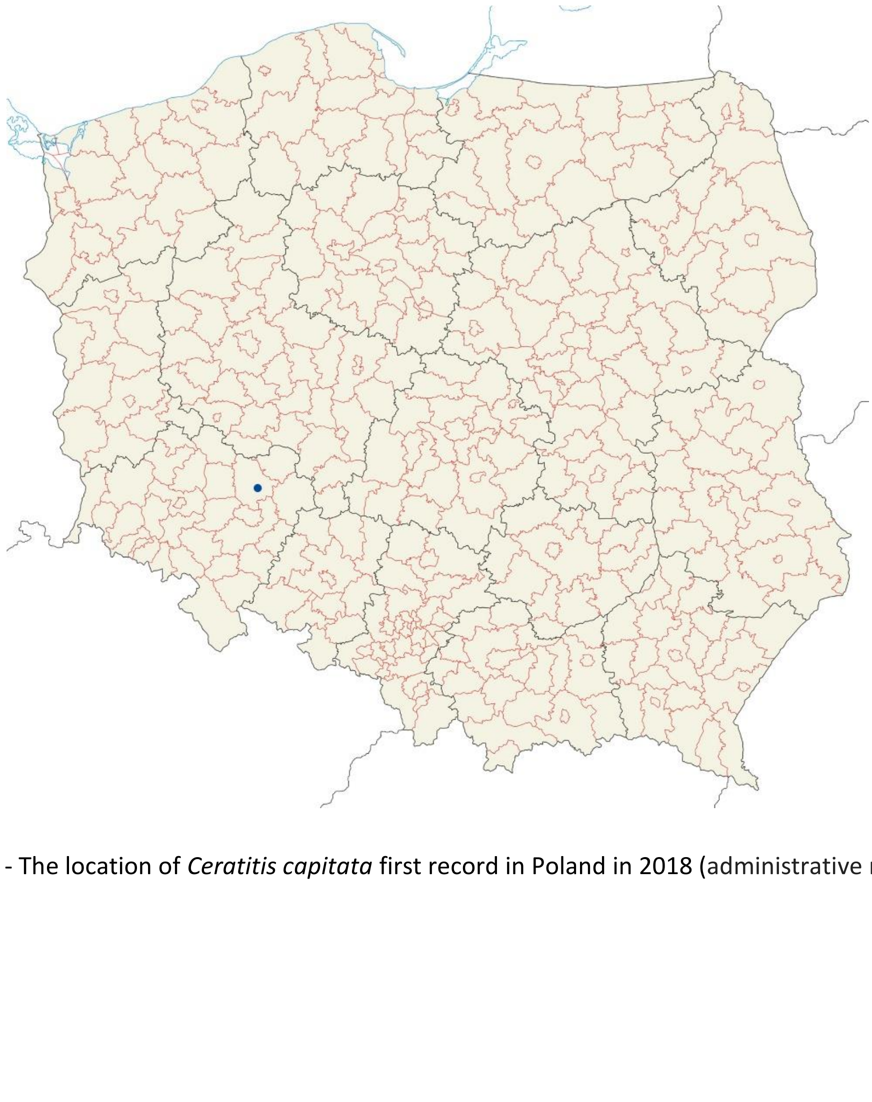


Figure 2.2.4 - The location of *Ceratitis capitata* first record in Poland in 2018 (administrative map).

The study of current environmental conditions in Poland showed that **the development of permanent populations of *Ceratitis capitata* is not possible**.

This scientific opinion was prepared by the Tephritidae family specialist (external, independent expert – not related to SPHSIS).

The circumstances of this finding suggest that it was an accidental occurrence of this pest and this outbreak was a result of the introduction of foreign infested material (late and one-off record, within the area of the orchard (ca. 1–1.5 km) there are 7 supermarkets, 1 fruit warehouse and municipal waste landfill (ca. 4 km)).

Further inspections in the next years should help to recognize the scale and the nature of *C. capitata* outbreak in Poland.

In the year of **2019**, monitoring programme was based on pheromone traps, according to the same principles as in 2017–2018 generally. The only important change was the increase the number of traps (due to the occurrence of *Ceratitis capitata,* in Poland, in 2018). For that purpose, 130 traps were installed at the territory of 16 Voivodeships (whole Poland) (Figure 2.2.5).

Figure 2.2.5 - Locations of pheromone traps in 2019 (administrative map).

One record of *Ceratitis capitata* was a result of monitoring programme in 2019. Details of this record: 1♀, Poland, Trzebnica (UTM code: XS48), 30.08.2019, leg. A. Lejman-Popowska, E. Trubisz, apple orchard – pheromone trap. The pest was collected in the same place almost as in 2018 (the same orchard complex). Only one individual was caught during the entire monitoring period. No other symptoms of *Ceratitis capitata* presence (preimaginal stages, damages on fruits) were found in the place of this occurrence.

The traps used were McPhail pheromone traps (the producer: Russell IPM Ltd, Unit 45, First Avenue, Deeside Ind. Park, Deeside, CH5 2NU; product's code: PCT-F10). These traps were located in orchards of host plants mainly, especially less intensely protected and in storage facilities as well.

Monitoring with traps was carried out from the beginning of June. Traps were officially supervised by SPHSIS inspectors at least every 2 weeks since their installation. There was a single replacement of the lure for the pheromone trap (after 40-45 days from its installation) and triple replacement of the sticky plate.

2.3 Spain situation (IVIA)

Author's: Julieta N. Herrero-Schell and Francisco J. Beitia)

The medfly, *Ceratitis capitata* (Wiedemann, 1824), is an insect considered as one of the most important citrus pests in the tropical and subtropical regions where it can be found because of its high dispersal capacity, high polyphagia and high levels of adaptability and reproductive potential.

In Spain, this pest is producing significant damages and direct losses in the agricultural fruit production in recent years, despite the permanent control activities undertaken since its consideration as a pest in the country in the 19th century.

Currently, the populations of the insect can be found in the affected areas from the end of April-beginning of May, coinciding with the end of the winter and the arrival of mild temperatures (average temperatures of 18-20ºC), until the end of October-beginning of November (with similar average temperatures). In that wide period, the medfly can find several host fruits to attack.

The Integrated Pest Management of the medfly is being applied to keep insect populations below the damage thresholds for each crop. Each Spanish Autonomous Community (AC) has the possibility to decide the appropriate control methods to be implemented against the pest, but in general the main control used is the mass trapping, along with the application of permitted insecticides, applied especially in patches. However, the main method used in the Valencian Community is the Sterile Insect Technique (SIT), at least in the case of citrus production areas where the medfly is one of the main pests.

2.3.1 Trapping system

In Spain, the main method for the population management of *C. capitata* is the use of traps, in a mass trapping system.

Tephri-type and MacPhail-type traps are used (Figure 2.3.1) and there are different kinds of traps belonging to different companies, which utilize food dry attractants with an insecticide that kills the insects trapped. Although it varies depending on the crop, 50-70 traps per hectare are applied in the plots. These traps can also be used with food liquid attractants, which do not require an insecticide since flies die from drowning.

There are two other types of traps which are also used and with well-defined functions. On the one hand, the Nadel-type traps (Figure 2.3.1) with a male sex attractant (usually TriMed lure) and an insecticide, which are used to carry out population monitoring of the medfly. On the other hand, the “attract and kill" traps (Figure 2.3.1), which do not capture adults but have a feeding substance to attract flies and an insecticide to kill them.

The last trap is mainly used for medfly population control in isolated trees but not in crops, although their use is increasing for medfly control in different fruit crops lately. The Nadel-type traps can also be used with the liquid attractants to carry out a mass trapping program.

Regarding the situation in Spain, and specifically in the Valencian Community, there are data on adult captures, at least, for ten years. In addition, the medfly is present in all the AACC in relation to the availability of fruit trees (Figure 2.3.2).

We can find the medfly infesting not only citrus but also other fruits: plum, medlar, apricot, peach, nectarine, figs and persimmon.

The infestation is following the maturation of fruits and is more severe from May to July, and September to October, when populations of the medfly are higher, in what concerns to "infestation rate in terms of number of larvae per fruit”.

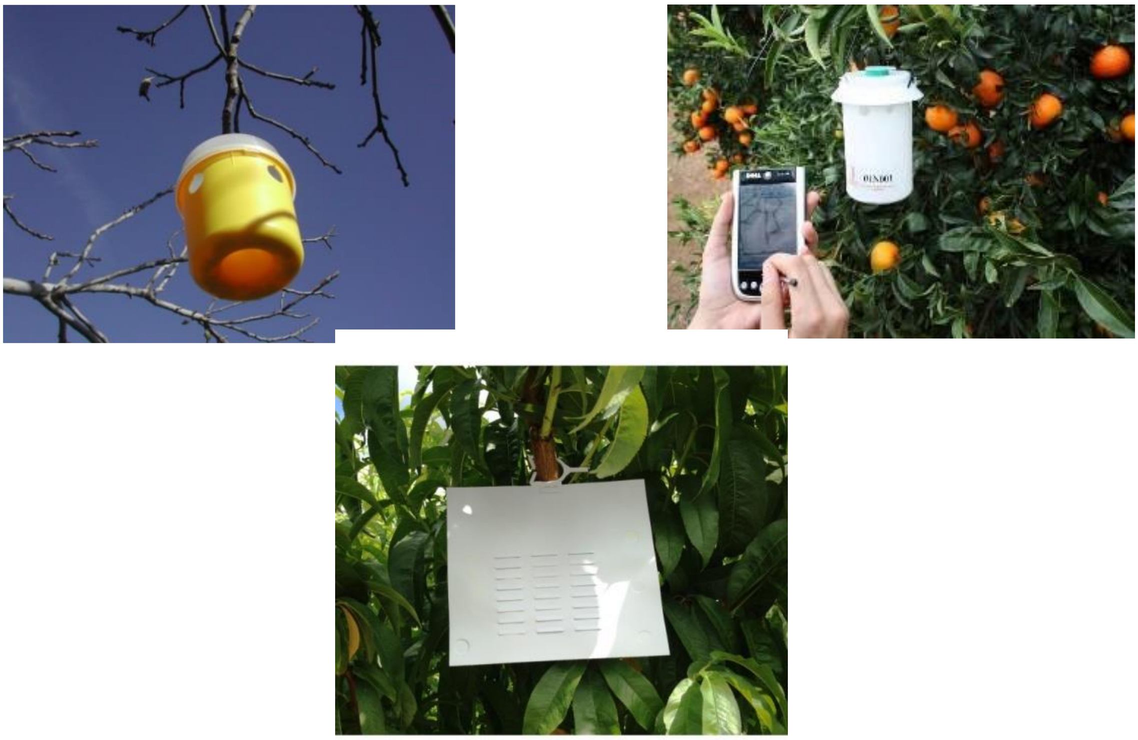


Figure 2.3.1 - Up-left: MacPhail trap; up-right: Nadel-trap; down: attract-and-kill trap.

Next, the phytosanitary situation on account of *C. capitata* in the different Spanish AACC affected is exposed. Finally, a detailed exposition of the Medfly Control Plan in the Valencian Community is offered.

2.3.2 General situation in the Spanish Autonomous Communities

For monitoring, there is a technical net in each Autonomus Community related to the location of the main fruit tree crops affected by the medfly.

Populations of the medfly are not present all over the country and mainly they can be found in the Mediterranean coastal regions and in the two Spanish archipelagos. In Figure 2.3.2, a map of Spain is shown where Autonomous Communities with the presence of the medfly are marked in red.

Figure 2.3.2 - Map of Spain is shown where Autonomous Communities with the presence of the medfly are marked in red.

Andalusia

Since the year 2010, the incidence of the pest has not been very significant because of its low populations. However, it can be pointed out that high populations in citrus crops in the provinces of Cadiz and Huelva were detected in 2010 but with low damages.

In 2017, fruit damages (in custard apples) were present but maintained at a low level, from September to November, in Huelva, Malaga and Seville, with values around 1% of damaged fruits.

Usually, damage risk starts in May for late citrus varieties, dropping in August because of the phenological state of the fruit, but remaining high in extra-early varieties. In September and October, this risk rises with early-varieties ripening.

Aragon

In Aragon, *C. capitata* affects apricots, peaches, nectarines, and plums. Adults are found since the end of May-beginning of June until September-October approximately.

Population peaks usually occur during July and August and might pose a problem in some areas if control methods are not well implemented.

Balearic Islands

The main importance of medfly populations is focused on citrus and grapevine, especially in years with mild winters. In 2015 and 2017, high presence of *C. capitata* was found during autumn, but no important damages were reported.

Canary Islands

The pest affects mainly citrus crops; even other fruit trees are included, such as mango, loquat, guava and apricot. Given that different crop zones exist because of altitude, susceptible fruits are present during nearly all year around.

Most intense attacks are produced during September, October and November. Owing to the warm and humid weather, in some areas the pest does not overwinter. Nowadays, mass trapping and attracting traps are used for monitoring.

Catalonia

The medfly is an important pest in several fruit production, mainly in apple trees and citrus. In the case of citrus, high incidence of the pest can be found in autumn, mainly on clementine, although in some years such as 2010 low presence has been detected.

Control methods used, like mass trapping and attract-and-kill traps, are quite good to keep down population levels, as well as a combination of mass trapping and chemical treatments in early varieties.

Extremadura

The medfly is present in this AC but with low populations and without significant damage to fruit tree crops.

First adults are usually found by the end of June-beginning of July, with some increases during August and September.

Murcia

The incidence of the medfly on citrus and other fruit tree crops (berry, grapevine and persimmon) in this region is quite important.

Captures usually began by the end of May and might remain until December if populations are favoured by high temperatures, with a peak at the beginning of the summer, and another by September-October.

As usual, the use of mass trapping and chemical treatments is reducing the main damages of the pest.

La Rioja

In this AC, the pest can affect fruit tree crops such as peach trees, even its incidence is usually very low and concentrated at the end of summer (August-September), coinciding with the ripening of the fruits.

Valencian Community

In general, mass trapping is used as the main system in the fruit tree crops, complemented to the use of selected pesticides. But in the citrus production area the SIT is being implemented within a complete action plan against the medfly

2.3.3 Integrated action program against the medfly in the Valencian community

The economic importance of *C. capitata* in the Valencian Community is mainly caused by the two highest population peaks of the insect that occur when the maturation of late oranges (May-June) and early clementines (September-October).

In addition, this species is capable of developing on a large variety of fruit species and even on some horticultural crops when there is no more fruit hosts available (specially in July-August), allowing it to survive and reproduce throughout the year using the progression of ripe fruits that are produced in the Valencian Community: loquat, plum, peach, orange, jujube, fig, apple, clementine and persimmon, as the most important affected crops.

Only in winter, with the low temperatures, the insect remains inactive, as larvae inside fruits can be in the tree or in the ground, and as pupae buried into the ground.

Nevertheless, the great importance of citrus production in the Valencian Community (Spain is the largest producer of citrus from the European Union and the main citrus exporting country worldwide, being this Community the greater citrus producer in Spain) has led to the development of an official program to control the medfly in the case of the citrus production.

In the Valencian Community, since the year 2002, the local government has established an Integral Action Plan against the Mediterranean fruit fly in citrus crops, based on 4 working lines:

2.3.3.1 Installation of a monitoring network

It is based on the installation of Nadel-type adult traps (more than 900) with the sexual attractant trimedlure (only males are captured) and more than 200 Tephri-type traps with feeding attractant to catch males and females, distributed among the citrus area of the Valencian Community.

All these traps are georeferenced, and this allows to determinate the evolution of *C. capitata* populations in the field. Weekly risk plans are elaborated to choose the more suitable control strategy depending on the season and particular conditions of the crop.

2.3.3.2 Sterile Insect Technique (SIT)

Starting in 2007, sterile male releases is the main method to fight against the medfly in the framework of the mentioned Plan. Medfly males are sterilized by irradiation and mass released in the field in almost all the citrus area (Figure 2.3.3). The number of released sterile males varies depending on the year season and population levels of the pest, as well the ripening state of the fruits in each plot, so that risk maps are prepared and used to this end.

Figure 2.3.3 - Citrus region in the Valencian Community (marked in green) with an indication of the area covered by the SIT (surrounded in red).

The bio factory of sterile insects, where mass production of males is carried out, is in Caudete de las Fuentes (at the province of Valencia but 70 kms from the coast) and has a maximum production capability of 500 million males/week. Currently, from 250 to 300 million males are weekly released in the target zones of the upon 140,000 hectares of citrus covered by the SIT.

2.3.3.3 Biotechnical control

This method includes mass trapping and control of *C. capitata* multiplication in isolated fruit trees.

In fruit trees and citrus, the number of installed traps for mass trapping depends on the density of *C. capitata* population. As an example, in the campaign of 2017, 335,000 traps were distributed among farmers. Therefore, the total surface protected by this method was more than 13,500 hectares.

The control of isolated fruit trees consists of reducing the medfly populations in areas where isolated fruit trees next to commercial plots are found. Attract-and-kill traps with three synthetic attractants (trimethylamine, diamino butane and ammonium acetate) and deltamethrin as an insecticide are used for that purpose. The persistency of these traps is more than 5 months in the field.

More than 15,000 trees have been georeferenced during 2017, and 20,000 traps installed in the Valencian Community.

2.3.3.4 Phytosanitary treatments

They are used during the ripening and harvesting campaign of extra-early and early varieties (October-December), when the population levels of the pest exceed the defined threshold of the citrus exportation protocol to United States. These treatments can be done with airplanes and helicopters, or with all-terrain vehicles (ATV), depending on the complexity of the area, the surface for treatment and the location. In 2017, the treated surface was 70,000 hectares approximately.

Furthermore, the Valencian Administration distributes phytosanitary product for terrestrial treatment among associations and farmers. During 2017, more than 8,700 L of product was distributed, to cover more than 30,000 hectares.

2.3.4 Biological control with parasitoids

Additionally, a research line was initiated in 2003 at the Instituto Valenciano de Investigaciones Agrarias (IVIA), focused on the viability of using parasitoids as biological control agents of *C. capitata*, to include them in the measures contemplated within the action plan against the pest.

Since then, several parasitoid species have been analysed and recently two PhD Thesis about the two more promising species for the control of the medfly in the Valencian Community (*Aganaspis daci* and *Diachasmimorpha longicaudata*) have been defended in 2017, stablishing the basis to the use of this biological control against *C. capitata* in the Valencian Community.

Further work is being continued to obtain long-lasting and stable parasitoid populations in the field or to set a protocol of regular releases of the parasitoids in the field.

References

Different volumes, since 2010, of the journal *Phytoma-España*.

The information published by the Plant Health Services from the different Spanish Autonomous Communities.

Pla N, Dembilio Ó, Peris R, Cañes MG, Dalmau V, Pérez-Hedo M, Urbaneja A, Beitia F, 2018. Control de la mosca mediterránea de la fruta en cítricos. Vida Rural, 452: 50-56.

2.4 Slovenia situation (IAFNG)

Author: Mojca Rot

Adults of *Ceratitis capitata* were first detected in Slovenia in 1959 in Koper (Costal part of Slovenia) (Figure 2.4.1). Since then the pest has been established in costal part of the country (Slovenian Istria) and in mainland in some localities in Vipava valley on the western part of Slovenia.

The current pest situation evaluated by EPPO is the following: **Present, restricted distribution**

Until now, attacks and considerable yield losses has been detected only on the late varieties of peaches and on the persimmon. It is considered an important pest of persimmon in Slovenia, but due to the low production of persimmon and problems with pesticide registrations, we are totally without effective control measures. The only pesticide registered against *C. capitata* in the county is phosmet used on peaches.

Due to the low and unstable populations which are closely related to the weather and temperature conditions in each year, it is not known much about biology and ecology of *C. capitata* in Slovenia.

Since 2000, regular monitoring has been carried out in Costal part of the country. Recent monitoring activities were related to participation in TC RER projects of IAEA.

From 2013-2017 the monitoring of *C. capitata* and some other exotic species of Tephritidae was carried out in extended range in western part of the country.

New records of *C. capitata* on new locations in Slovenia in the last five years were recorded.

In last 5 years were use Tephri traps baited with 3-component lure (ammonium acetate, trimethylamine and putrescine) or Biolure and Jackson trap with trimedlure. In each location were putted both traps (1 Tephri + 1 Jackson). Before 2013 were used TRÉCÉ, PHEROCON® traps.

The sites or locations of sampling sites monitored and where *C. capitata* is absent and present in Slovenia are exposed in Figure 2.4.1.

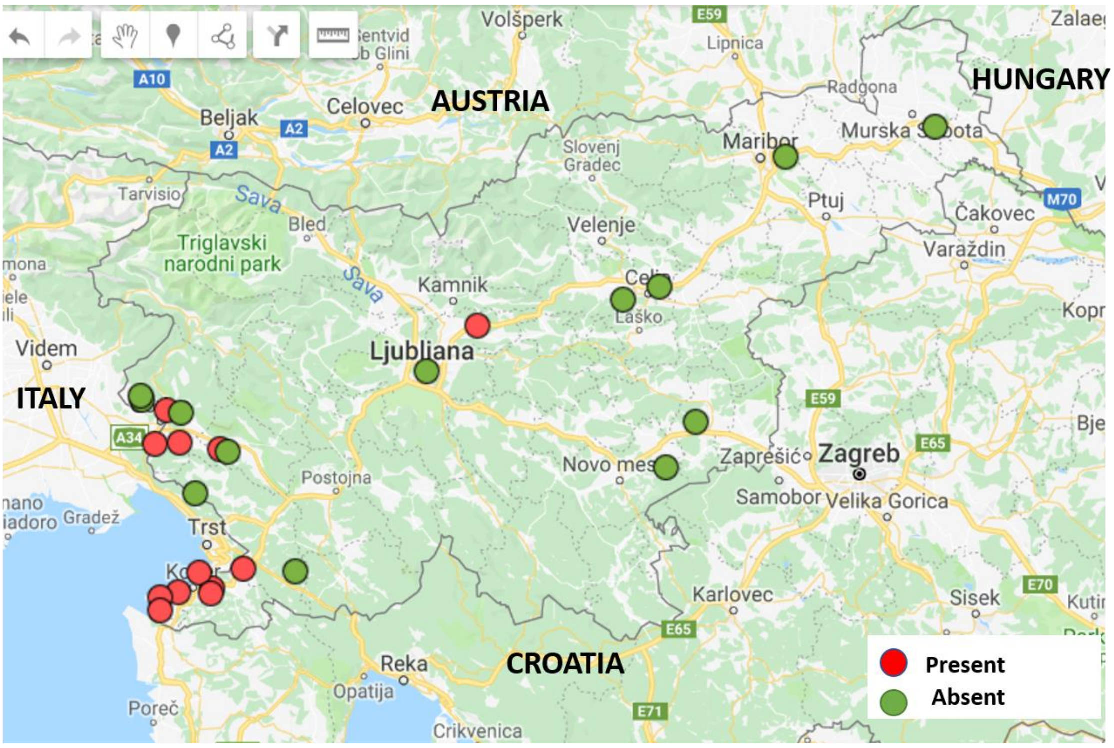


Figure 2.4.1 - *Ceratitis capitata* monitoring in Slovenia (location of sampling sites).

The traps were placed in the field according to the locations referred on the Table 2.4.1.

Table 2.4.1 - *Ceratitis capitata* monitoring in Slovenia (location name, year of the monitoring).

N°	Location name	Year of monitoring / data											
		2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
1	Strunjan												
2	Dekani												
3	Hrvatini												
4	Izola												
5	Lucija												
6	Cikuti												
7	Miren												
8	Dombrava												
9	Brje												
10	Tatre												
11	Tublje												
12	Solkan												
13	Beka												
14	Kromberk												
15	Kozana												

16	Šmartno												
17	Male Žablje												
18	Ljubljana												
19	Brdo pri Lukovici												
20	Zadobrova												
21	Kasaze												
22	Nebova												
23	Gančani												
24	Gorenja Brezovica												
25	Brezovska Gora												

2.5 Montenegro situation (BFT-UM)

Author: Sanja Radonjić

First monitoring of the Mediterranean fruit fly in Montenegro was in 1959, there is no precise data about its presence from that time. There were sporadic detections during 1980's and 1990's, and some recorded damage to mandarins (*Citrus reticulata*), although without any systematic data of its populations. The Mediterranean fruit fly has been present in Montenegro for more than a decade and for that is considered an established pest since the early 2000s. (Radonjić *et al.*, 2013).

All cultivated citrus species (mandarin, orange, lemon, grapefruit), as well fig, persimmon and ziziphus are found to be host plants. In economic sense, it is the most important for mandarins.

Although this pest has been present in the Mediterranean region for more than a century, there was previously no permanent monitoring in Montenegro. However, some records do exist, and sporadic detections of very low populations have previously been noted (Mijušković, 1959; Velimirović, 1988, 1989, 1990).

After serious damage was caused in mandarin commercial citrus orchards (Figure 2.5.1) in the areas of Bar and Ulcinj in 2000, as well as in some localities surrounding the city of Budva and in the area of Boka Kotor Bay in 2001 (Hrnčić, 2000, 2001), continuous monitoring started in 2002.

Figure 2.5.1 - Medfly adult photos on orangefruit (left), mandarin (middle) and mandarin leaf (right)

Results of monitoring have shown the presence of *C. capitata* along the whole coastal area (Figure 2.5.2) (Radonjić, 2006; Radonjić, 2008; Radonjić *et al.*, 2013).

Figure 2.5.2 – Study sites for the monitoring and detection of the presence of fruit flies (Radonjic *et al.,* 2019).

Until 2008. presence of *C. capitata* was detected only along the montenegrin seacoast. In period from middle of August until end of november 2008 its presence was detected in area of the city of Podgorica where captured flies were found in Tephri trap with attractant Biolure.

On the same location presence of larvae were detected in persimmon fruits. This was the first detection of the medfly out of the coastal area. On the same locality increasing of medfly population was noticed in 2009 and 2010.

In the second decade of September 2010, fallen apple fruits (variety Golden Delicious) were found in location Godinje (area Crmnica), as well adult of *C. capitata* on apple fruit in the canopy (Figure 2.5.3) searching for a suitable place to lay eggs (Figure 2.5.4).

Figure 2.5.3 - Adult of C. capitata on apple fruit in the canopy.

Figure 2.5.4 – Damage from adult of C. capitata oviposition and larvae development on apple fruit.

After fallen fruits (Figure 2.5.5) in which larvae were found were inspected in laboratory it was confirmed presence of C. capitata, according morphological features of larvae. This was the first detection on apple.

Figure 2.5.5 – Apple fallen fruits that were collected and inspected in laboratory.

In the same year, in locations Budva and Bigovo symptoms of attack were found in apple, variety Idared at the beginning of the second decade of October.

This finding showed that C. capitata has been gradually spread from seacoast area into other areas which are also suitable in term of climatic conditions and host fruits availability, increasing at the same time number of its host plants (Radonjić & Hrnčić, 2011).

Meanwhile *C. capitata* has spread a bit northern from the seacoast, toward the area of Podgorica (the capital of Montenegro -2008, 2009, 2010) and to the area of Crmnica (locality Godinje) where locates the most famous grapevine production area on the Skadar Lake (in 2010).

Along Montenegro seacoast (Figure 2.5.1), which is located close to the northern limits of *C. capitata* distribution in Europe, the fruit fly has distinct seasonal patterns in population fluctuation.

In general, captures of flies have been recorded from the end of June until the end of December.

Population density has been found to be very low in July and August, increasing slowly from the end of August and through the first half of September, and then peaking from mid-September through to the end of October (Radonjić *et al.*, 2019).

The adult population began decreasing in November and the last flies were captured during the second half through the end of December (Radonjić *et al.*, 2019).

Adult activity has been found to end in December (Radonjić et al., 2013).

The Montenegro seacoast is close to the northern limits of *C. capitata* distribution in Europe.

Generally, no adult activity was found in the winter. However, during the relatively warm winter of 2013-2014, several flies were captured at the beginning of February in Jackson traps with TML, which had remained in some backyards in the Kumbor locality.

These findings, taken together with the evidence of low captures in December and January in several localities, could lead to the assumption of possible adult activity during mild winters (Radonjić, 2014).

The population dynamics of the Mediterranean fruit fly have been found to be closely linked with the availability and abundance of the host fruits.

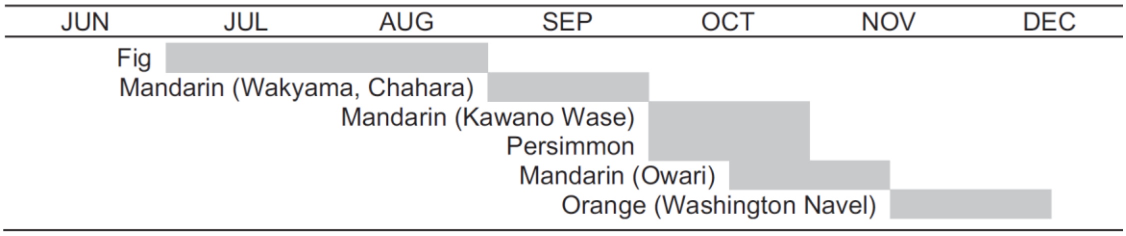
Infested plants that have been detected since 2002 include mandarins (*Citrus reticulata*), oranges (*Citrus sinensis*), lemon (cultivar *Lunario*) (*Citrus limon*), grapefruit (*Citrus paradisi*), figs (*Ficus carica*), persimmon (*Diospyros kaki*), jujube (*Ziziphus jujuba*), and apples (*Malus domestica*). Among these, in an economic sense, the most important is mandarin (cultivar *Unshiu*) that matures from mid-September to mid-November (Radonjić *et al.,* 2013).

As the presence of suitable host fruits increased during September and October (different mandarin cultivars, persimmons), this was found to result in population build-up There were sporadic detections during 1980s and 1990s, and some recorded damage to mandarins (Citrus reticulata), although without any systematic data of its populations (Radonjić et al., 2013).

The sequence of available host plants that increased from September and October resulted in a distinct and large population increase.

A diagram with the most important host plants of *C. capitata* and their ripening period in Montenegro is presented in Table 2.5.1. These are the first available hosts and contribute for the Mediterranean fruit fly population increase in the summer months, causing economic damage later to mandarins, the most economic important host for *C. capitata* in Montenegro (Radonjić *et al.,* 2013).

Table 2.5.1 - Seasonal *Ceratitis capitata* host availability and maturation period of the most important fruits in Montenegro seacoast (Radonjić *et al.*, 2013).



Population dynamics of *C. capitata* are closely linked with host fruits' availability and abundance. As the sequence of suitable host fruits increased during September and October (different mandarin cultivars, persimmon), it resulted in large population build-up (Radonjić *et al.*, 2019).

The population dynamics of the Mediterranean fruit fly have been found to be closely linked with the availability and abundance of the host fruits. Figs are the first available hosts (July-August) and were found to contribute to the *C. capitata* population increase during the summer months, which later caused economic damage to mandarins, the most economically important host in Montenegro (mid- September to November). As the presence of suitable host fruits increased during September and October (different mandarin cultivars, persimmons), this was found to result in population build-up (Radonjić *et al.,* 2013).

It was concluded that population dynamics of *C. capitata* are influenced by host fruit availability and abundance. The sequence of available host plants that increased from September and October resulted in a distinct and large population increase (Radonjić *et al.*, 2013).

Regarding the Montenegro seacoast, the absence of spring and early summer host plants, together with decreasing of the average monthly temperature in December and particularly in January, could be considered as determining parameters for the *C. capitata* adult activity (Radonjić *et al.*, 2013).

In terms of **infestation rates**, the population of *C. capitata* was low in 2018, we didn´t notice any damage in this year. The fruits sampled were persimmon fruits, but there were not found any *Ceratitis* larvae inside those.

From an economic point of view, of the established fruit fly species in the region, the most important are the tephritids, *B. oleae* and *C. capitata*, because of their negative effects (damage of a quantitative and qualitative nature) on olive and citrus production, representing the most important fruit crops on the Montenegro seacoast (Radonjić *et al.*, 2019). As a highly polyphagous species, this species can be of economic concern for a variety of fruit crops growing not only along the seacoast, but also in other parts of Montenegro (Radonjić *et al.*, 2019).

References

Radonjić Sanja & Hrnčić Snježana (2011): Mediteranska voćna muva Ceratitis capitata wiedem. – širenje na nova područja u crnoj gori i novi domaćin. [The Mediterranean Fruit Fly Ceratitis capitata WIEDEM. – spreading on new locations in Montenegro and detection on new host plant]. Biljni lekar (Plant doctor). XXXIX (5), pp. 511-517

Radonjić, Sanja, Čizmović, Miroslav & Pereira, Rui (2013). Population dynamics of the Mediterranean fruit fly in Montenegro. *International Journal of Insect Science, 5, 35-38*

Radonjić, Sanja, Hrnčić, Snježana & Tatjana Perović (2019). Overview of fruit flies important for fruit production on the Montenegro seacoast. *Biotechnol. Agron. Soc. Environ.*, 23(1), 46-56

2.6 France situation (ANSES)

Author: Valerie Blamés

Ceratitis capitata has been present in French mainland since 1885. Populations are established with certainty in Corsica, and in the regions bordering the Mediterranean Sea (Figure 2.6.1).

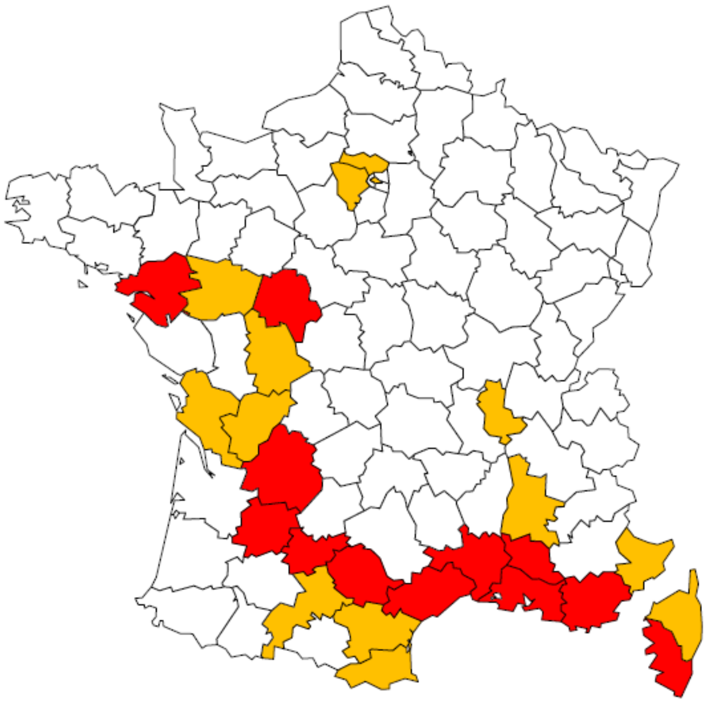


Figure 2.6.1 – Locations of presence of *C. capitata* in France.

It can be found regularly in the Southwest along the Atlantic coast and further inland. In summer, it has sometimes been trapped in the Paris area (Figure 2.6.1).
Currently, there is no national monitoring plan. There is no national eradication plan. France have not a sterile production unit.

Damages are variable according to the climatic conditions and the hostplants. In continental France, apples are the most affected and then peaches, nectarines and apricots (late varieties).

In Corsica, the same plants are affected but also and mainly citrus.

For apples exportation, in addition of prophylaxis and treatments, the fruits are placed in cold temperature condition to kill larva.

The population densities are very low, whatever the productions in different continental regions (south-west- Atlantic coast and south-east- Mediterranean coast) no damage has been reported even on apple. We suppose it is because of the climate very dry and hot this summer.

In **Corsica island**, a native population was still abundant on nectarines and peaches of end-of-season and now, on clementine (*Citrus*). Adults were captured adults from these two kinds of production that will be available to participants who request them.

Trapping is planned in August and September in targeted geographical areas (orchards for fruit production) and it is expected a recovery of fruits with symptoms of egg-laying. These fruits will be put in climatic chambers to get adults.

France does not have a surveillance plan for *Ceratitis capitata*. In some regions, producers set up traps to carry out monitoring or mass trapping but the results are not centralised. The detection of *Bactrocera dorsalis* this summer has enabled a network of traps to be set up but methyl Eugenol does not particularly attract medfly.

In the last 3 years there were either captures during export controls (self-control for the European plant passport) and captures in traps for other Tephritidae like *B. dorsalis* or *Ragholetis completa* and samples in traps. This is not an image of the presence of *C. capitata* on France.

2.7 Netherlands situation (NCR-NVWA)

Author: Antoon Loomans

The presence of *Ceratitis capitata* is related to imports and the risk is enhanced during the summer months.

Between 2006-2016 survey activities have resulted in the catching of 54 specimens of *Ceratitis capitata*. For that purpose, were selected 28 locations. There is some planning to perform a survey on the (seasonal) presence of *Ceratitis capitata* in the Netherlands. At each location will be placed 2 Delta traps with EGOlure (in combination with a yellow sticky trap to catch the incidental female specimens). Traps will be placed in the beginning of august and will be operative for a total of six weeks, while replacing the traps after three weeks (so sampling will be done for 2 intervals of 3 weeks).

The locations that are considered to be high-risk locations include 9 companies which combine imports with (greenhouse) cultivation, 3 localities with previous findings, 3 locations where compost processing takes place, 4 auction sites, 2 harbours, and 7 fruit growing companies (apples, pears, cherries) located close to urban areas.

From 2017 until 2020 survey resulted in zero findings of adults of *C. capitata*.

2.8 Ukraine situation (IPP)

Author: Natalija Skripnik

Ceratitis capitata has been manifested for several years and has caused considerable damage to the fruit plantings in Ukraine.

In 1937, the Mediterranean fruit fly was firstly detected in Odessa. It was brought from Spain with citrus fruits (Shutova,1957). Due to timely measures, settlements were abolished for two years. Later, in 1964 it was re-discovered in Odessa and in the village of Bilyaivka, Odessa region, and in Sevastopol.

Eventually, in 1967, the pest was recorded in Odessa, and in 1968, in Sevastopol. The squares were destroyed (Kryachko and others,1970).

In 2007 it was again a focus in the Odessa region (Chernomorsk) (Figure 2.8.1).

Every year there are cases of pest detection at different stages of development in citrus commodity lots imported from the countries of distribution. Mediterranean fruit fly in Ukraine is regularly detected during inspection and phytosanitary examination of imported fruits and vegetables.

The State Plant Quarantine Service annually monitors the territory of Ukraine to detect this pest using pheromone traps.

For the first time in Ukraine, the Mediterranean fruit fly was detected in 2007 in Odessa region, because of which an action plan for localization and elimination of outbreaks was developed and adopted.

In 2011, 3,848,235 ha were surveyed using 1,700 pheromone traps, but no Mediterranean fruit fly was detected.

As of 01.01.2012, the infected area remains unchanged and is 9,9 hectares.

This year, monitoring of the probable adaptation of the pest in this region will continue.

Ceratitis capitata enters in Ukraine with quarantined products from countries: Egypt, Cyprus, Turkey, Greece, Spain.

Figure 2.8.1 - Locations of the first entrance spot of *Ceratitis capitata* in Chernomorsk, Odessa region, Ukraine.

References

Cryachko Z.F., Melnikova R.G., Pyishkalo R.P. The Experience of eradication of the Mediterranean fruit fly on the area Sevastopol. Simferopol." Crimea". 1970.

Shutova N.N., Melnikova, Pyshkalo Mediterranean fruit fly Ceratitis capitata Wied.- Moscow.1957.

2.9 Germany situation (JKI - FRCCP)

Author: Stephan Konig

A German-wide monitoring for *Ceratitis capitata* was conducted in the years 2015 and 2016. The number of traps for each federal state was calculated about the overall apple growing area in each of the federal states.

The traps system used was Easy Trap®, equipped with the sexual pheromone Trimedlure and an insecticide.

In **2015** the survey was limited mainly to commercial apple orchards and major fruit trading centres. In 2016 the survey was partly extended to organic grown orchards as well as stone fruit production. In 2015 only single specimen of med-fly could be trapped in federal states along the river Rhine (Baden-Württemberg and Rhineland-Palatinate), and in the vicinity of Berlin (federal states of Berlin, Brandenburg and Saxony-Anhalt) as well as in Lower-Saxony and Thuringia. In total 15 specimen were trapped during this year.

In **2016** the number of trapped specimens increased to a total number 188 specimen in the federal states Baden-Württemberg, Bavaria, Berlin, Brandenburg, Lower-Saxony, North Rhine-Westphalia, Rhineland-Palatinate, Saxony, Saxony-Anhalt and Thuringia. Mostly these were also single specimen with the remarkable exceptions of two locations where numerous specimens could be trapped at the same dates. These were a single meadow orchard in Brandenburg and a commercial apple orchard in Baden-Württemberg were in total 119 specimen could be trapped between August and October 2016.

In **2017** the survey was carried on only by the federal states of Baden-Württemberg, Berlin, Brandenburg, Rhineland-Palatinate, Saxony, Saxony-Anhalt and Thuringia with lower intensity. The number of trapped specimens in this year was extremely low with only 29 specimens trapped in the federal states Baden-Württemberg, Rhineland-Palatinate and Saxony. Those were single specimen except for Baden-Württemberg, were a few specimens could be trapped at the same time in one location, close to the major spot in 2016.

While the low number of trapped specimens found in 2015 point to separate introduction of single specimen, presumably with imported fruits, the higher and repeated matches in 2016 are more concerning for future *Ceratitis* population development (Figure 2.9.1).

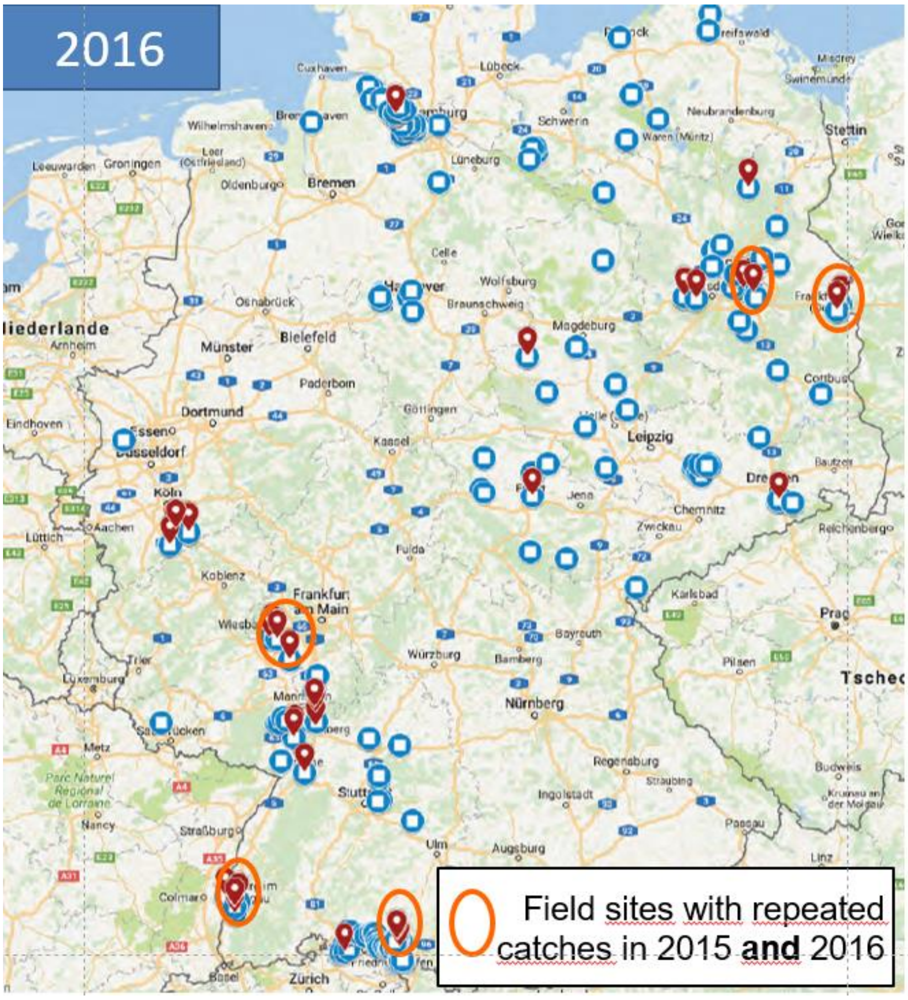


Figure 2. 15 - *Ceratitis capitata* monitoring in Germany (location of sampling sites). The red drop shaped symbols indicating sites were *C. capitata* specimen were captured in 2015; Blue circles with white square indicating sites were *C. capitata* specimen were captured in 2016.

German plant protection services did not conduct any survey for Ceratitis in the last 2 years (2018 and 2019), as an extensive monitoring made during the years 2015 to 2017. The results of the monitoring showed, that *Ceratitis capitata* is presumably not established in Germany, so single specimens might be introduced more or less frequently with imported fruits from infested areas in other European countries. Due to these results was decided to not undertake additional monitoring actions for the EUPHRESCO FruitFlyRiskManage Project.

For 2018 we have only restricted data from an important apple growing area in a single federal state out of 16 states in Germany - Lower Saxony and that showed, that *Ceratitis capitata* was not found also there.

2.10 Romania situation (RDIPP)

Author: Constantina Chireceanu

First mention of *Ceratitis capitata* in Romania appeared in 2007 when few larvae were observed in fruits of *Diospyros kaki* in an experimental field in south part of the country. The possible penetration way into the country can be related to the planting material of exotic fruit trees brought from China for different purposes.

Until 2013, no other data on the presence of the medfly was published. In the period of 2013-2017 a survey program on *C. capitata* was performed within the framework of three TC regional projects under the coordination of IAEA Vienna, using Tephri traps baited with 3 component lure (ammonium acetate, trimethylamine and putrescine) or trimedlure, Tephri Trap UniPak and an insecticide and Jackson trap with methyl eugenol.

This survey activities continued in 2018 and 2019 under EUPHRESCO project 2017-F-236. The traps baited with 3-component lure (ammonium acetate, trimethylamine and putrescine) and Jackson trap with trimedlure.

The traps were placed in fruit tree orchards in fruit growing areas from different parts of Romania (Figure 2.10.1) and in backyards of houses and institutions, botanical gardens and experimental fields, in spring, summer and autumn seasons according to period of fruit ripening. There were surveyed: species of sweet and sour cherry, apricot, peach, plum, apple, walnut in orchards and mixed in private gardens; grapevine plots; exotic fruit species as Chinese date (detected in experimental fields and in private gardens with mix fruit trees), kaki persimmon and figs (detected in private gardens with mix fruit trees).

In 2019 two traps were placed in an apple commercial orchard which borders a supermarket, more precisely the place where the supply of fruits is made, including citrus fruits. The traps were set up about 1.5 - 2-meter height in the canopy of host trees.

A total of 130 traps were used in the seven years of monitoring.

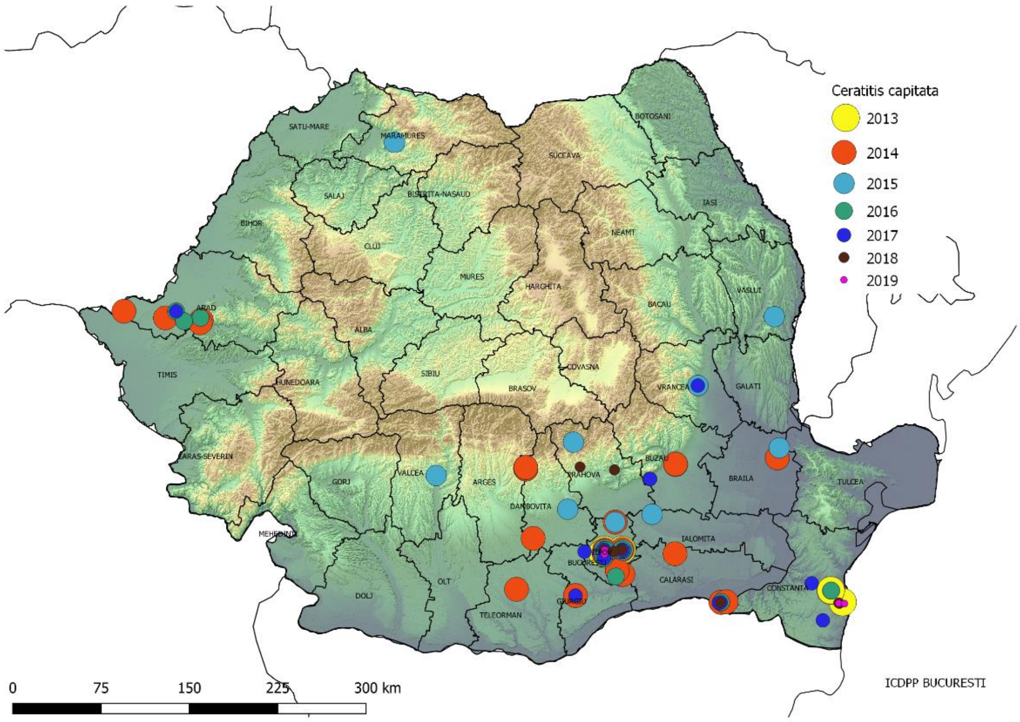


Fig. 2.10.1 - Distribution of the locations where the traps were installed for *Ceratitis capitata* detection in Romania, from 2013 to 2019.

Adults of the Medfly fly were detected every year of survey, in a small number (between 1 and 6 specimens/trap/site), in all type of emplacement (fruit orchards, houses backyard, botanical gardens and experimental fields) in West, South and South-Eastern Romania, from the end of August to the end of October.

The presence of *Ceratitis capitata* with notable adult populations was recorded in the traps placed on jujube in Bucharest (Fig 2.10.2).

No specimens of *C. capitata* were found in traps set up on sweet and sour cherry trees in the spring season, these having as ripen period of the fruits the June month.

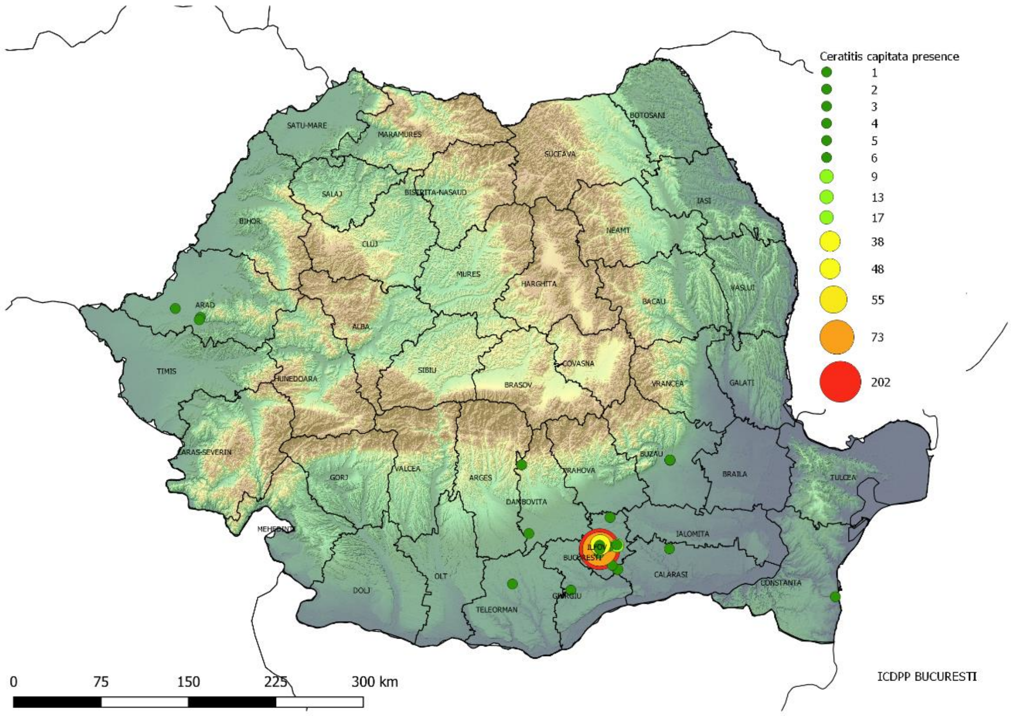


Fig. 2.10.2 - Distribution of the sites where *Ceratitis capitata* was detected in the traps from 2013 to 2019.

The presence of *Ceratitis capitata* with notable adult populations was recorded in the traps placed in the experimental plot of Chinese date trees of USAMV Bucharest, in the Northern Bucharest capital, monitored from 2013 to 2019, is presented in Figure 2.10.2. The adult's population in this location was variable from one year to the other.

The adult population monitored in this period was variable from one year to the other (Fig. 2.10.3). The total annual captures were between 2 and 202 flies. Based on the catches in the traps on Chinese date, it seems that medfly develops one generation per year in Bucharest zone, from the end of August to October.

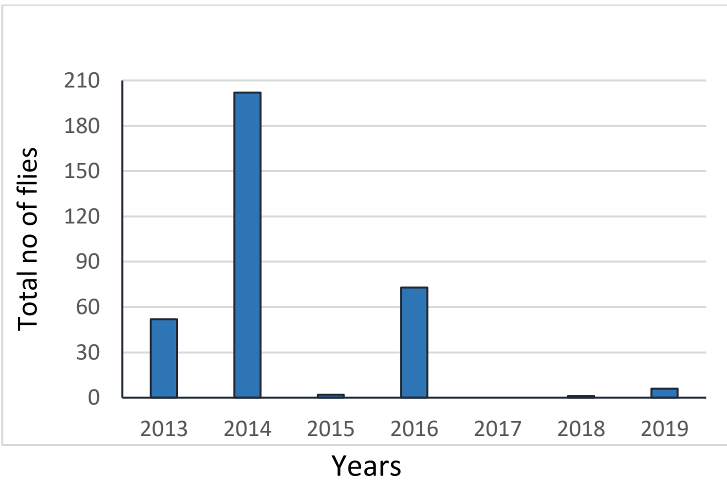


Figure 2.10.3 – Total captures number of *Ceratitis capitata* on *Ziziphus jujube* in Bucharest.

The infestation of fruits was followed during the maturation period of fruits. Larvae of *C. capitate* were found only in jujube and fig fruits, the infestation level being low (Chireceanu et al., 2013; Ciceoi et al., 2017). Damage to other fruit species was not observed in this survey.

It is worth mention that in the autumn of **2019**, a number of 86 flies (50 males and 36 females) of *C. capitata* were trapped in two Tephri trap (UniPak and trimedlure) installed from September 25 to November 11 in a commercial apple orchard near a supermarket, which makes the supply with exotic fruits for people, especially the citrus in the autumn, from citrus-growing countries like Turkey and Greece.

Based on small and fluctuating captures of *C. capitata* in the traps recorded from 2013 until 2019, we could conclude that this specie has a low and sporadic presence and does not represent an important phytosanitary risk at this time in Romania.

Nevertheless, considering the irreversible climatic changes and anthropogenic activity it is possible that in the very near future the medfly became a real threat for fruit production in the country.

In context of *C. capitata* monitoring, it is important to observe that no quarantine fruit flies of *Bactrocera* genera were detected, but specimens of the dog rose hips fly *Carpomya schinerii* and the ber fruit fly C. *vezuviana* were caught in Bucharest area.

Further investigations in the next years became necessary in order to know capability of *C. capitata* to adapt to the climatic conditions specific to Romania.

References

Chireceanu, C., Iamandei, M., Stănică, F., & Chiriloaie, A. (2013). The presence of the mediterranean fruit fly ceratitis capitata (Wied.), (Diptera: Tephritidae) in Romania. *Romanian Journal of Plant Protection. VI*, 92-97.

Ciceoi, R., Dobrin, I., Mardare, E. Ş., Dicianu, E. D., & Stănică, F. (2017). Emerging pests of Ziziphus jujuba crop in Romania. *Scientific Papers Ser. B Horticulture. 61*, 143-153.

Stanciu, I. (2007). Comportarea unor soiuri de kaki în condiţiile Câmpiei Române" Ph.D. Faculty of Horticulture, University of Agronomic Sciences and Veterinary Medicine, Bucharest, Romania.

2.11 Portugal and Azores islands situation (UAç)

Author: David João Horta Lopes

The Mediterranean fly is a pest known in Portugal since XIX, and in the last years it has been particularly active, chopping the fruit in citrus orchards mainly and in some cases the table grape vine. Climate change, technicians admit, is creating conditions for the species to multiply in an uncontrolled way. The lack of rain, and the abnormal temperatures for the season, create the right environment for the creation of new generations, reproducing five to eight times a year.

Chemical combat to this type of insect is proving to be less and less effective. Alternatively (or as a complement to plant protection products), bio-technical control has been used through the installation of capture traps (attraction and death of the adult fly) and an ingenious way of birth control with the production and release of sterile males from bio-factories where these sterile males are produced, which are able to copulate with the females but do not fertilise. An example of this kind of work and use of this strategy was the Madeira-Med programme which took place from 1995 onwards with the support of the IAEA for some years in Madeira and allowed there the creation and operation of one of these biofactories and the application of the autocide-fighting and sterilised insect technique (SIT) in the fight and population limitation of this pest in that Autonomous Region.

National fruit production is currently quite vulnerable to the appearance of new pests, as well as to the increased incidence of existing species, such as fruit flies, namely *Ceratitis capitata* (Wiedmann) and *Drosophila suzukii* (Matsumura), which cause significant damage and may even make production impossible in certain regions, where their populations are very high. This situation is likely to worsen as climate change increases the populations of these pests and widens their geographical distribution.

This situation has been aggravated in recent years by the absence of cold in the winter months, leading to an increase in populations, beginning damage/loss earlier and extending their season of permanence by affecting fruit crops.

The Mediterranean fly (Ceratitis capitata), say fruit growers in the Algarve, reproduces without end in sight. Meanwhile, to limit the increase in populations and the spread of this pest, a programme to "control and combat" this insect has been drawn up by the Algarve Agriculture Directorate and presented to the Food and Veterinary Directorate (DGAV).

This situation is tending to worsen with the climate changes that lead to an increase in the populations of these pests and widen their geographical distribution. The vulnerability of our country to the entry of other fruit flies, especially tephrites, lies in the fact that some of them are already mentioned in African countries with which Portugal has close relations in terms of movement of people and goods, which increases the risk of their introduction into the territory.

Faced with this situation, the productive sector, both on the mainland and in the Autonomous Regions of Madeira and the Azores, has expressed great concern about this problem, mainly because of the need to produce new crops, which may be totally made unviable by fruit flies because the abundant population of Mediterranean flies may make this situation impossible, and therefore solutions to be presented to the productive sector are urgently needed.

With the fruitflyprotect project (https://fruitflyprotec.webnode.pt) developed since 2018, involving partners from several entities from Caldas da Rainha, Alcobaça, Beira Interior, Torres Vedras, Lisbon, Algarve and Azores it was intended that the planned work contribute to better knowledge and combat three economically important species and contribute to a more rational and sustainable fight against fruit flies by monitoring and evaluating the effectiveness of alternative means of protection for *Ceratitis capitata* and *Drospohila suzukii* and assessing the risk of introduction and potential distribution for *Bactrocera dorsalis*. Thus, the main objectives of this operational group were for the species C. capitata: to carry out prospecting and evaluation of the activity and effectiveness of predator and parasitoid control; to evaluate baits and trap devices and plant extracts with bioactivity. This work was developed together with teams from regions where the pest exists and with some similarity of climate/relief to those existing in the possible invasion sites and with the partnership of institutions from the autonomous regions of Madeira and the Azores (University of the Azores and Gaspar Frutuoso Foundation). In addition, the aim was to assess the damage, develop and implement GIS tools for population mapping and decision support, to better disseminate information, which although it exists for the case of *C. capitata* is very scattered and unsystematised.

2.11.1 Azores Islands situation (UAç)

Medfly (*Ceratitis capitata* (Wied.) (Diptera: Tephritidae), is native from North Africa. Although because of its wide ecological capacity of adaptation, this insect can easily invade and survive in new habitats. Its ecological advantage, along with the careless transportation of infested fruits has allowed it to spread rapidly over several continental areas and to get into island regions (Leonardo, 2002). Currently, this insect has a worldwide geographic distribution because of these factors.

According to Bodenheimer (1951) and Orlando (1980), this insect was first identified in the Atlantic Islands in 1829. *C. capitata* adult is very polyphagous, which makes it very capable of infesting from 250 to 400 hosts. This fact makes this species one of the most important worldwide threats to fresh fruits.

This is due to the oviposition stings caused by the female adults laying eggs inside the fruit, which can create entrance points to several pathogenic organisms. Inside the fruit, when larvae are feeding in the fruit pulp, they can cause the fruit to rot. The larva inside the fruit can also cause the fruit to fall prematurely.

Because of the high number of possible fruit hosts *C. capitata* has been considered a serious threat in the Azores Archipelago, mainly in Terceira Island, where many surveys and efforts to protect fruit cultivation from this pest have been conducted.

In the Azores and on the island of Terceira, the first work on this subject was carried out in 2002/2003 as part of the work of internships in partnerships between the University of the Azores, Fruter Coop and the Agricultural Services.

The INTERFRUTA project (MAC/3. 1/A1) with the title "A project for the promotion and development of fruit growing and research of bioactive plants from the perspective of protection and integrated production applicable to Terceira Island, Azores" through the development of an extensive field work, in experimental plots and through the fortnightly monitoring of 28 fruit growers, from January 2004 to March 2005, as well as the exchange of knowledge and the synergisms it generated associated with the cooperation of the different partners (Azores, Madeira, Canary Islands), highlighted the institutional and individual connection of all participants, coupled with the participation of the Official Services and the Association of Producers (FRUTER).

This allowed, in an initial phase, the work of compilation and structuring of all the existing information in this area and, in a later phase, in its development, to know the areas of fruit production in Terceira Island, the various phytosanitary problems that affected the crops and to better define the objectives of what was intended to be carried out, from the point of view of responding to the desires and needs of the end user, the fruit grower.

For that, it was fundamental to identify and know, with accuracy, the main phytosanitary problems that affect fruit crops as well as the way they evolve throughout the year, also taking into account the existence of an extremely important entomofauna component, the auxiliary fauna; the seasonal succession of the hosts and the fruit ripening process and the relationships that are established with the main harmful species in this field, highlighting, in all this work, those focused on the Mediterranean fruit fly (Book of the Interfruta project, Cap. 10) (Lopes et al, 2006) and which comprised: monitoring of adults, studies of population dynamics and their dispersion, efficacy tests of different traps in capturing adults, determination of fruit infestation rates with record of their temporal evolution by host type, carrying out the first compatibility and sexual competitiveness tests on the island of Terceira and the first dispersion tests with the release, in 2005, of 114,000 sterilised males with evaluation tests on the most effective form of this release (unipoint or multipoint).

The INTERFFRUTA II project (05/MAC/3.1/A4), which followed on from the previous one, focused on the development of applied research on different crops and better addressing phytosanitary problems. This allowed the elaboration of a booklet of publicity leaves as well as two other publications, one on phytosanitary problems of citrus fruits and the other on apple trees). These publications list the phytosanitary problems of crops, their temporal evolution, characteristics, and symptoms that they cause and presented a list of both risk estimation and control measures, using various means of protection, had in its final part a leaf dedicated to the Mediterranean fly since it is a key pest across several crops. This project, among its several objectives, had a specific one which aimed at the study of Mediterranean flies and the possibility of the dispersion of sterile flies for their combat (objective 5).

This objective included: the monitoring of Mediterranean fly populations in Terceira Island and in Tenerife Island; efficacy tests of different traps in the capture of adults; the realization of the first dispersion tests of sterilized males in Terceira Island produced in Madeira bio factory (Madeira-Med programme); study of the presence of Mediterranean fly parasitoids on Terceira Island; and the determination of fruit infestation rates on Terceira Island.

These scientific surveys have been developed by the INTERFRUTA and INTERFRUTA II projects. The overall goal of those two projects was to contribute to the promotion of fruit culture and vineyards production in the three partner regions, by building bridges of knowledge concerning the studied cultures.

In addition to pest aggregation and host-plant pest relationships, weather conditions such as temperature, air humidity and rain fall (soil humidity) will also have an impact on the medfly lifecycle and its ability to disperse (Pimentel, 2010).

According to Azevedo (1996), the topography of the Azorean Islands has a great influence on weather conditions causing the existence of microclimates, which, according to Pimentel (2010) and Pimentel et al. (2014), can contribute to pest aggregation or dispersion.

Geographic information systems (GIS) are very powerful tools to organize and process spatial data to support decision-makers. One GIS dataset was fully designed and maintained through the research projects (MAC/3.1/A1) Interfruta (2004_2006) and (MAC/3.1/A4) Interfruta II (2006-2009) for monitoring adults of *Ceratitis capitata* Wiedemann. This GIS dataset played an important role to identify the main infestation sites, allowing the (MAC/3/A163) CABMEDMAC project to set areas of intervention for monitoring and evaluation of control measures for C. capitata. This medfly is one of the most important threats to the trade of fresh fruits in the world due to its ability to survive in a wide range of hosts and climatic conditions. Depending on environmental conditions, its life cycle is normally completed within 20 to 30 days, and it has a continuous life cycle throughout the year in the Azores and areas with similar climate. Therefore, quarantine is mandatory as an important measure to prevent even more dispersion of this insect through commercial trade to regions where it is still not present (Asia, most of Australasia), or has been controlled or eradicated (North America) (Joint FAO/IAEA Programme 2013).

According to Hendrichs et al. (2007), the ecological heterogeneity at within field, within farm and broader spatial scales profoundly affect the population dynamics of pests.

Knowing where pest populations are in time and space is indispensable information needed to effectively plan, implement, and evaluate area-wide integrated pest management programmes (Hendrichs et al. 2007). Some studies of spatio-temporal dynamics for C. capitata have been carried out (Lopes et al. 2009) to evaluate the effect of landscape elements and hostplants on pest distribution. In all those studies, the authors mention the importance of GIS in the identification of the focus where C. capitata are located. In the cited works, the authors have established no other relationship of captures than those related to existing fruit cultures, fruit availability, and to temperature variations due to the seasons in areas of the survey. These studies have been performed mostly over areas (individual farms or orchards) where there is a limited variation of topography.

Across the whole of a region, such as Terceira Island in the Azores, there are many topographic variations, and each place might be favourable to the presence of this insect according to its characteristics.

Therefore, one of the goals of CabMedMac project was to evaluate if there is any significant relationship between the abundance of wild adults of C. capitata and some spatial characteristics of a target location in Terceira (Fig. 2.11.1) and São Jorge islands.

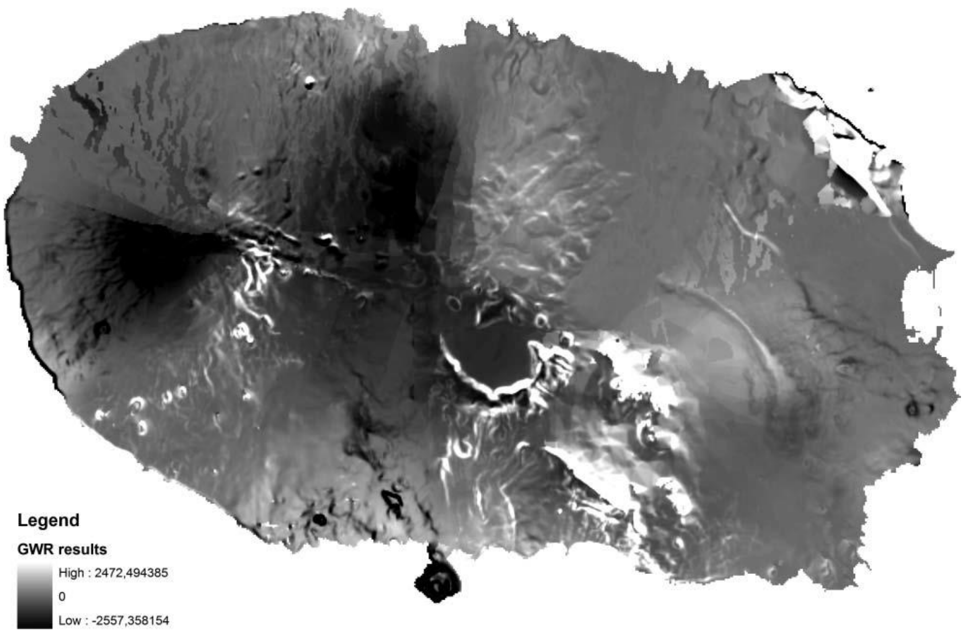


Figure 2.11.1 - Graphical representation on Terceira Island Azores of the densities of *C. capitata* based on the GWR analysis results. (Source: Pimentel et al., 2014)

This allowed a better understanding of the environmental distribution of *C. capitata*, namely finding the most favourable spatial conditions. With this awareness, area-wide control measures, such as sterile insect technique, might have better performance and even reduced programme costs through more precise spatial planning.

Decision-makers will be able to predict where higher concentrations of wild adults of *C. capitata* may be found and where sterile insects go after release.

With the fruitflyprotect project it was possible to monitor (Figure 2.11.3) and evaluate the effectiveness of various baits and traps on three islands of the archipelago (Fig. 2.11.4).

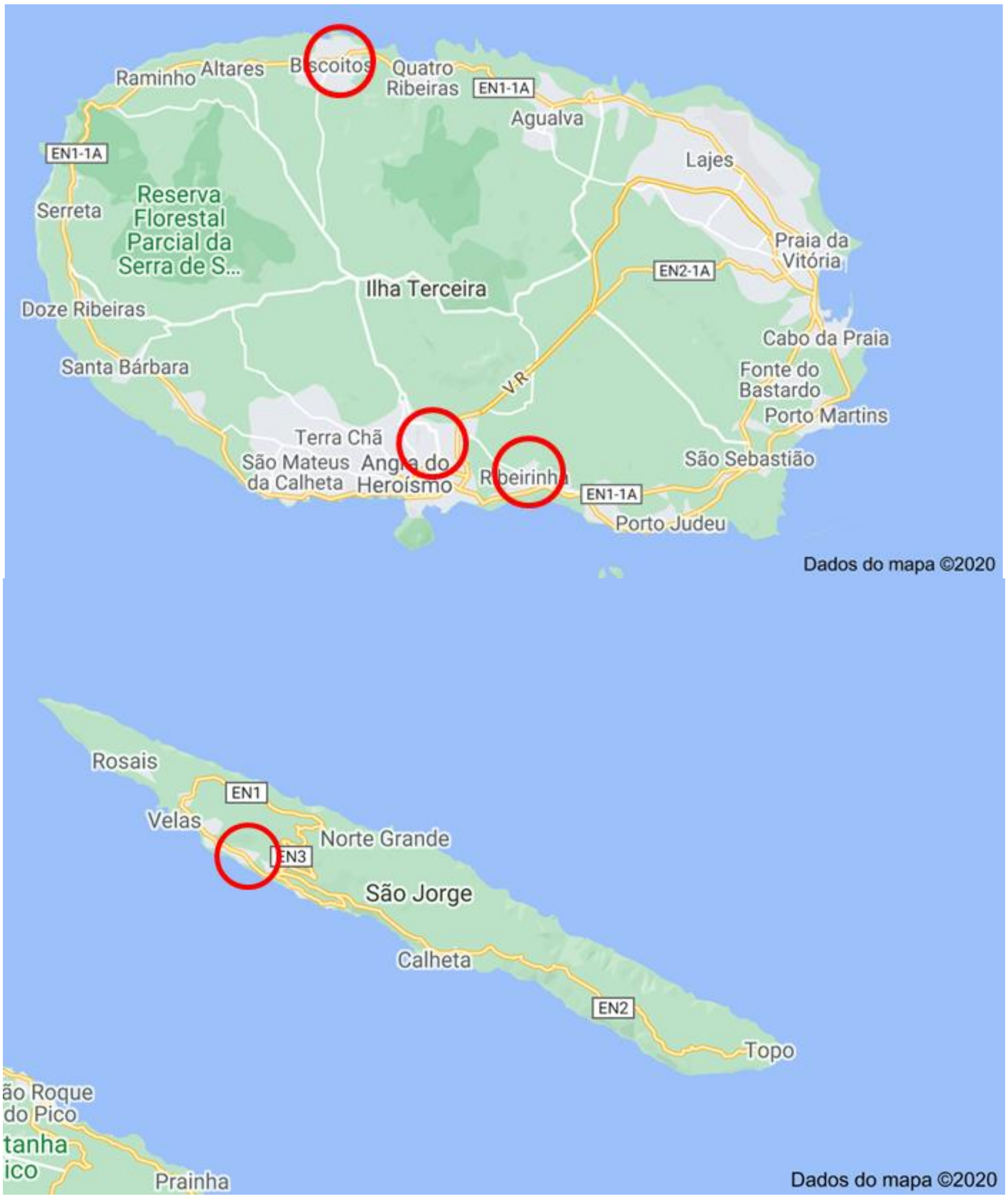


Figure 2.11.3 – The areas monitored in the three islands where *C.capitata* populations were studied (top- Terceira; middle- S.Jorge; down S.Miguel island).

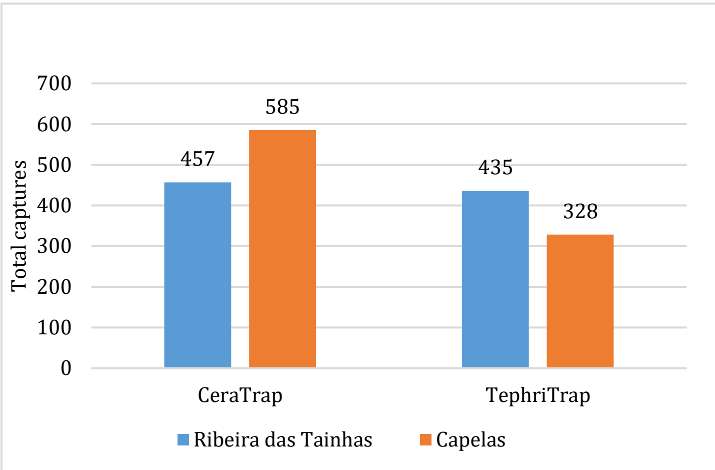


Figure 2.11.4 – Example of *C. capitata* adult captures sum in two different types of traps in S. Miguel island, Azores, for 2018.

This work was developed in conjunction with teams from regions where the pest exists and with some similarity of climate/relief to those existing in the possible invasion sites and in partnership with institutions from the autonomous regions of the Azores (University of the Azores and Gaspar Frutuoso Foundation), from 2018 to 2021.

The Cuarentagri project (www.cuarentagri.com) also continues the monitoring of C. capitata on 3 of the 9 islands of the Azores archipelago, from 2018 to 2021, in order to establish an alert network for this pest and issue warnings through the elaboration of phytosanitary leaves (Figure 2.11.5), which are periodically sent to producers on the three islands involved in order to facilitate their decision making and choice of the most sustainable means of monitoring and combating this pest with the least environmental impact, limiting as much as possible the application of chemicals in its control.

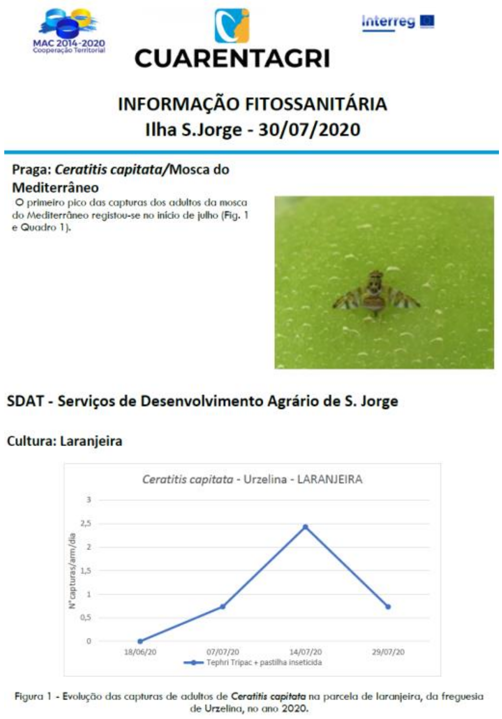


Figure 2.11.5 – Phytosanitary leaflet from Cuarentagri project on *C. capitata* for producers and technicians on the island of S. Jorge, Azores, in 2020.

References

Azevedo EMVB. 1996. Modelação do Clima Insular à Escala Local Modelo CIELO aplicado à Ilha Terceira. Modelling the local climate in island environments. CIELO model applied to Terceira Island]. Angra do Heroísmo. Universidade dos Açores.

Bodenhmeir FS. 1951. Citrus entomology in the Middle East: with special references to Egypt, Iran, Iraq, Palestine, Syria and Turkey (Hardback). 1st ed. Liverpool. Springer.

Carvalho JP, Aguiar AMF. 1997. Pragas dos citrinos na ilha da Madeira [Citrus pests in Madeira Island]. Madeira, Portugal: Secretaria Regional de Agricultura, Florestas e Pescas.

Costa RM, Nunes LVL, Pimentel R, Dantas L. & D. J. H. Lopes. 2009 Determinação de eficácia, de diferentes armadilhas, na captura de adultos de Ceratitis capitata Wiedman (Diptera: Tephritidae) na Ilha Terceira (Açores). Workshop – FRUTICULTURA: Contributo para o seu desenvolvimento. Museu de Angra do Heroísmo, Açores, Portugal: Centro de Biotecnologia dos Açores. 192-196.

Hendrichs J, Kenmore P, Robinson AS. 2007. Area-wide integrated pest management (AW-IPM): principles, practice and prospects. In: Vreysen MJB, Robinson AS, Hendrichs J, editors. Area-wide control insect pests: from research to field implementation. Dordrecht: Springer; p. 3_33.

Hendrichs J, Vreysen MJB, Enkerlin WR, Cayol JP. 2005. Strategic options in using sterile insects for area-wide integrated pest management. In: Dyck VA, Hendrichs J, Robinson AS, editors. Sterile insect technique: principles and practice in area-wide integrated pest management. Dordrecht: Springer; p. 563_600.

Joint FAO/IAEA Programme. 2013. Updated Mediterranean fruit fly global distribution map - stories, NAFA. [Internet]. [cited 2020 Dec 11]. Available from: http://www-naweb.iaea.org/nafa/news/2013-medfly-global-map.html

Leonardo J 2002. Incidência da Mosca-do-Mediterrâneo, Ceratitis capitata (Wied.) (Diptera: Thephritidae) em pomares de pessegueiros, macieiras e citrinos na Ilha Terceira e testagem de diferentes armadilhas no seu combate. Relatório de estágio de Licenciatura em Engenharia Agrícola; Universidade dos Açores, Angra do Heroísmo.

Lopes DJH, Pereira A, Mexia AMM, Mumford J, Cabrera R, editors. 2006. A fruticultura na macaronésia: O contributo do projecto INTERFRUTA para o seu desenvolvimento [The fruit culture in the Macaronesia: The contribution of INTERFRUTA project for its growth]. Angra do Heroísmo: Universidade Açores, Departamento de Ciências Agrárias, Herbário.

Lopes DJH, Pimentel R, Nunes LV, Costa RM, Silva N, Dantas L, Mumford J, Mexia AMM. 2006. A mosca-do-Mediterrâneo (Ceratitis capitata Wied.) (Diptera: Tephritidae) nos pomares da Ilha Terceira, A¸cores [The medfly (Ceratitis capitata Wied.) (Diptera: Tephritidae) in the orchards of Terceira Island, Azores]. In: Lopes DJH, Pereira A, Mexia AMM, Mumford J, Cabrera R, editors. Frutic Na Macaronésia O Contrib Proj INTERFRUTA Para O Seu Desenvolv [The fruit culture in the Macaronesia: The contribution of INTERFRUTA project for its growth]. Herbário: Universidade Açores, Departamento de Ciências Agrárias, p. 181_198.

Lopes DJH, Pimentel R, Macedo N, Zorman M, Ventura LB, Dantas L, Mexia AMM, Mumford J. 2009. Aplicabilidade dos SIG no estudo da mosca-do-Mediterraneo (Ceratitis capitata Wiedemann) (Diptera: Tephritidae) na Ilha Terceira [The GIS applicability on the study of medfly (Ceratitis capitata Wiedemann) (Diptera: Tephritidae) in the Terceira Island]. In: Lopes DJH, Mexia AMM, Mumford J, Perez RC, Pereira A, editors. Livro actas (Proceedings of the first congress of Fruit Culture and wine culture). Angra do Heroísmo, Ilha Terceira: Projeto Interfruta II; p. 72_77.

Orlando TL 1980. Estudio sobre las hospederas potenciales de la mosca del Mediterráneo Ceratitis capitata Weid. con enfásis en las presentes en el área del Soconusco, Chiapas. México. Secretaria de Agricultura y Recurso Hidráulicos.

Pimentel R. 2010. Contributo para o conhecimento da mosca-do-Mediterrâneo (Ceratitis capitata Wiedemann) (Diptera: Tephritidae) na Ilha Terceira [master of science dissertation]. Angra do Heroısmo: University of Azores, Department of Agrarian Sciences.

Rossler Y. 1988. Country-wide control of the Mediterranean fruit fly (Medfly) in Israel. In: Goren & Mendel (Ed.). Proc. Six. Inter. Citrus Cong. 1275-1283.

WP3. Biological characterization of populations occurring in all the countries involved in the project, based on selected molecular markers

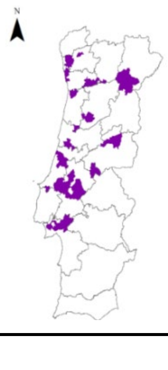
3.1 Biological characterization of *Ceratitis capitata* populations based on previously identified molecular markers

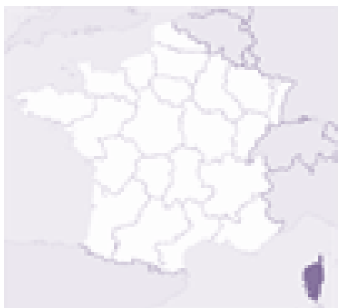
Author: Eugénia Andrade – INIAV

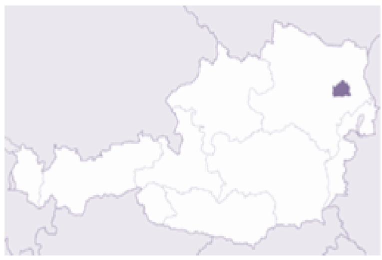
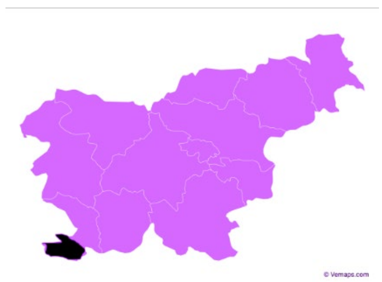
The molecular characterization of *Ceratitis capitata* will contribute to the evaluation of the existing level of genetic variability among and within the European populations. The final goal is to understand and, possibly, to correlate the widespread of this species throughout Europe, its adaptation to highly variable climatic conditions and the possible origins. This information is relevant for pest management practices.

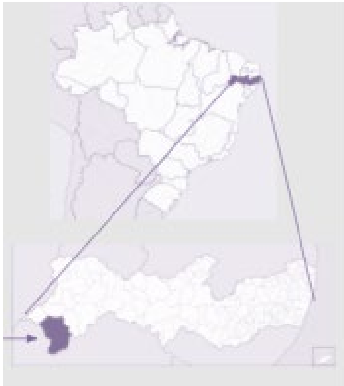
A total of 328 individuals belonging to 12 European populations (Portugal continental; Azores; Spain Continental; Tenerife; Spain Rear; Spain Vienna; France continental; France Corsica; Poland, Romania; Austria; Slovenia)were collected by the partners of the project and sent to INIAV. Due to the workload and the constraints provoked by the pandemic, only 121 individuals were genotyped with 10 highly polymorphic SSR (microsatellites) markers which were previously used on populations from other European regions (König et al., unpublished). To be able to speed up the genetic studies, pooling of DNA samples instead of individual genotyping was followed. One population from Brazil, composed of larvae collected in several consignments originated in Pernambuco in 2018 and 2019 (table 1) and intercepted at the border inspection point of the Lisbon airport, was used to correct the stutter artifacts derived by the DNA pooling. The stutter correction has been done by applying the Schnak *et al*. (2004) model and after the microssatelite frequencies were calculated.

Table 1 - Number of individuals collected per country, region and year.

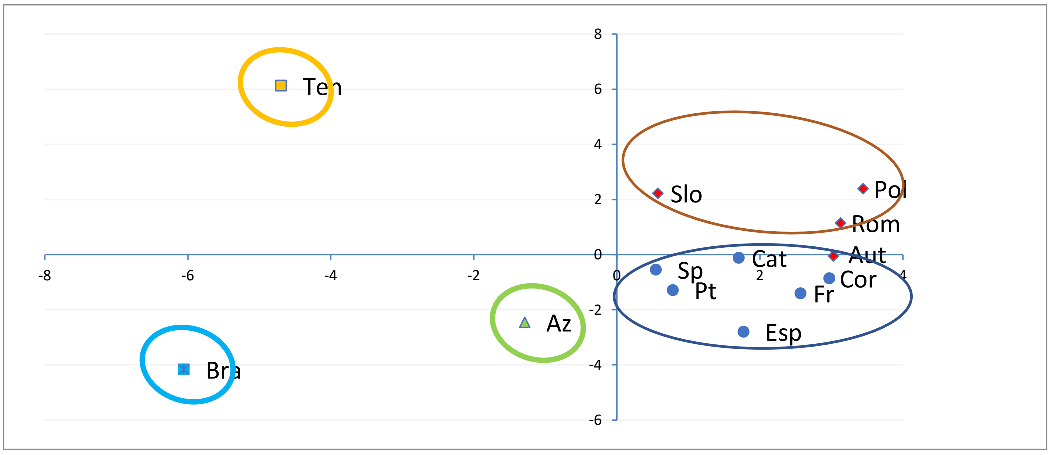
Country	No. of individuals (region) - year	maps
Portugal Continental	25 (North) - **2017** 38 (Centre) - **2019** 25 (Lisboa e Vale do Tejo) - **2018/2019**	

Portugal (**Azores**)	8 (São Jorge) - **2020** 18 (Terceira) - **2020**	
Spain (Continental)	10 (Valencia Moncada) - 2020 10 (IVIA reared in lab) - 2020 10 (V8 line) - **2020**	
	5 (Tarragona) - **2020**	
Spain (Tenerife)	5 (Tenerife) - **2020**	
France (Corsica)	20 (Corsica) - **2018**	

France (Continental)	24 (Bouches du Rhône-Maussane-les-Alpilles and Aubagne) - **2018** 6 (Pyrenees-Orientals; near Perpignan) - **2016** 14 (Vaucluse - Isle-sur-la-Sorgue and Mondragon) - **2018** 8 (Loire - Atlantique- Nantes) - **2019** 8 (Hérault -Saint-Jean-de-Védas) - **2019**	
Austria	58 males e 2 females (Vienna) - **2016** a **2018**	
Slovenia	5 (Izola) - **2018** 10 (Cikuti) - **2018/2019**	

Brazil	5 (Pernambuco) - **2018/2019**	
Poland	5 males e 1 female (Trzebnica) - **2018/2019**	
Romania	28 (Bucareste) - **2018/2019**	

The software GeneAIEX 6.5 (excel complement) was used to calculate the average number of alleles (Na), effective number of alleles (Ne), Observed heterozygocity (Ho), expected heterozygocity (He), polymorphic information content (PIC), genetic distance and the fixation index (F_{ST}). The thirteen populations were genetically characterized and the principal coordinate (PCoA) analysis using the microssatelites allowed to draw a scatter-plot



In summary, our findings showed that specimens from Tenerife and Azores diverge along both PCoA axes. Populations from Europe are distributed in two groups, clearly distinct, probably forming separate genetic clusters. The information generated with this set of markers will be conjugated with the unpolished data from König et al and published. The final set of information is expected to be used to monitor this species when colonizing new locations in Europe and help management decisions.

3.2 Biological control of *Ceratitis capitata* Wied.

Author's: Julieta N. Herrero-Schell and Francisco J. Beitia

Since 2004, a Comprehensive Action Plan against the medfly is being implemented in the Valencian Community in Spain. This Plan is based in the use of the Sterile Insect Technique (SIT) (Fig. 3.2.1 and 3.2.2) but needs the help of other techniques to accomplish a satisfactory control of medfly populations. For that, is necessary to implement the mass trapping (Fig. 3.2.3) together with the application of selected pesticides and using the biological control.

Figure 3.2.1 – Sterile male of *C. capitata*.

Figure 3.2.2 – Sterile Insect Technique (SIT) producing installation in Valecian Community, Spain.

Figure 3.2.3 – Mass traping of *C. capitata* in Valecian Community, Spain.

Recently, at the IVIA (Spain) a project to introduce biological control in the Action Plan against de medfly in the Valencian Community was started by the importation of a larvo-pupal parasitoid species (Hymenoptera, Braconidae) from México, *Diachasmimorpha longicaudata* (Figures 3.2.4) At the same time, another larvo-pupal parasitoid was found, an exotic species but currently naturally present in the field, *Aganaspis daci* (Hymenoptera, Figitidae (Figure 3.2.5).

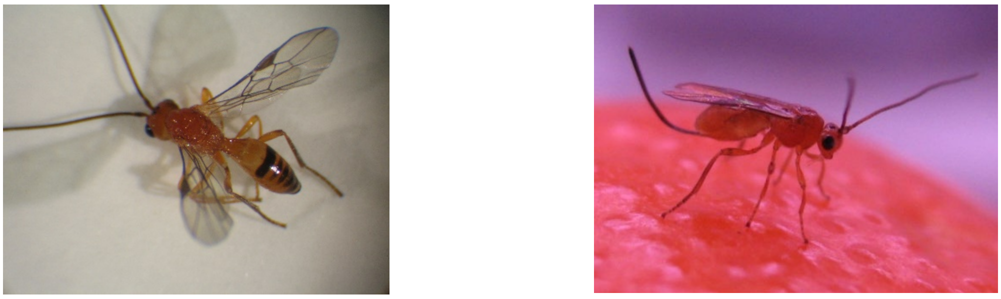


Figure 3.2.4 – *Diachasmimorpha longicaudata,* left male and right female.

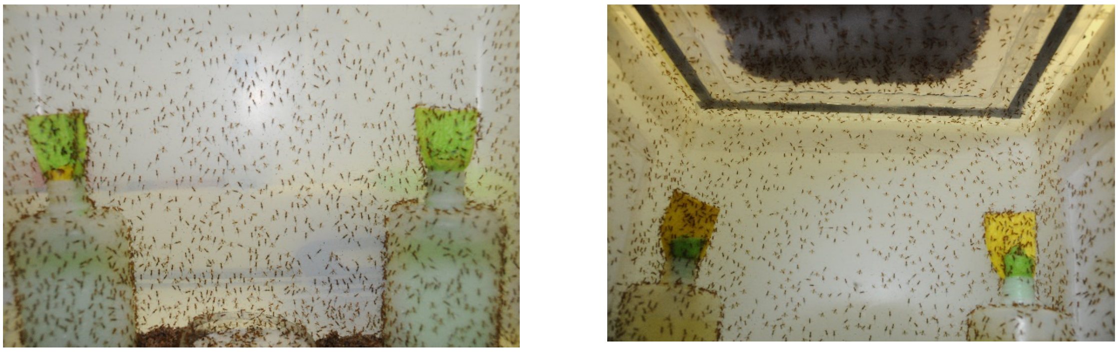


Figure 3.2.5 – Laboratory rearing of *Diachasmimorpha longicaudata.*

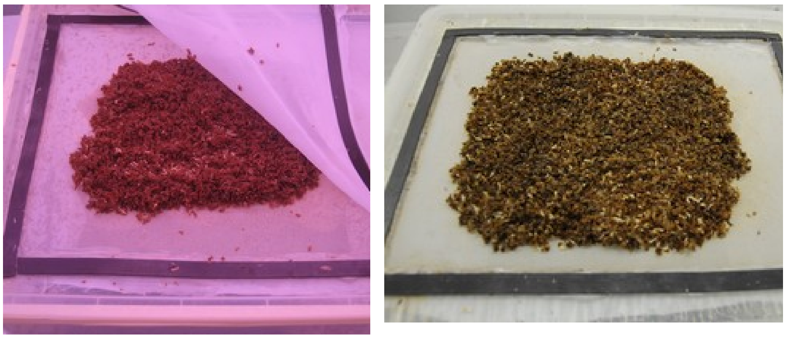


Figure 3.2.6 - Larvae of C. capitata in parasitoid cages to be parasitized by *D. longicaudata.*

Figure 3.2.7 - Females of *D. longicaudata* parasitizing medfly larvae

Figure 3.2.8 - *Aganaspis daci,* left_male and right female.

Figure 3.2.9 – Laboratory rearing of *Aganaspis daci.*

Figure 3.2.10 – Adults and larvae in fruit of *Ceratitis capitata* Wied.

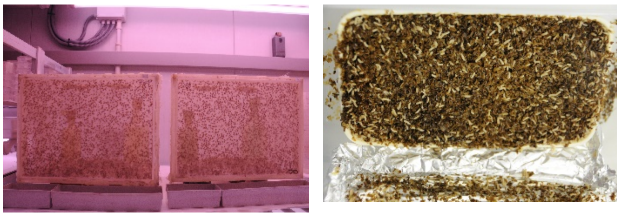


Figure 3.2.11 – *Ceratitis capitata* Wied. rearing cages (left) and larvae (right) in artificial medium.

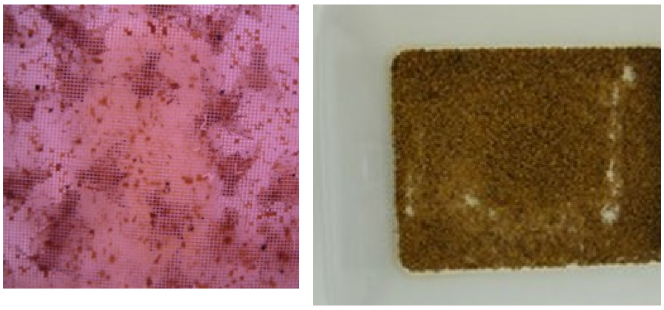


Figure 3.2.12 – Detail with eggs (left) and pupae (right) of *Ceratitis capitata* Wied.

In the framework of this Euphresco project, an optimization of the laboratory rearing of both parasitoids (Fig. 3.2.6, 3.2.7. 3.2.8 and 3.2.9), together to the medfly laboratory rearing (Figures 3.2.10, 3.2.11 and 3.2.12), has been achieved. And as one more step, the mass rearing of *D. longicaudata* has been initiated by the Grupo Tragsa using Vienna-8 irradiated larvae of *C. capitata* as hosts.

All these activities will obtain rearing diagram's and protocols (Figures 3.2.13 and 3.2.14) that are at the disposal of the Euphresco project partner's and will contribute to the future practical application of the biological control against the medfly in the Valencian Community and could help the transfer of this technique to other European countries.

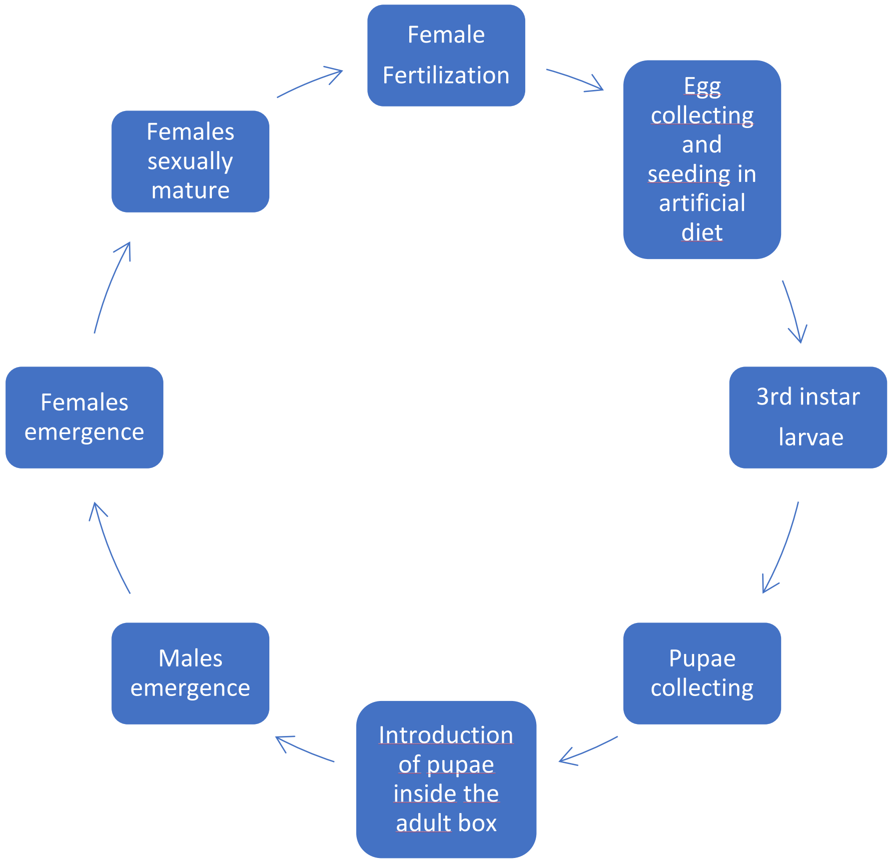


Figure 3.2.13 - Diagram of the protocol for the rearing of *Ceratitis capitata.*

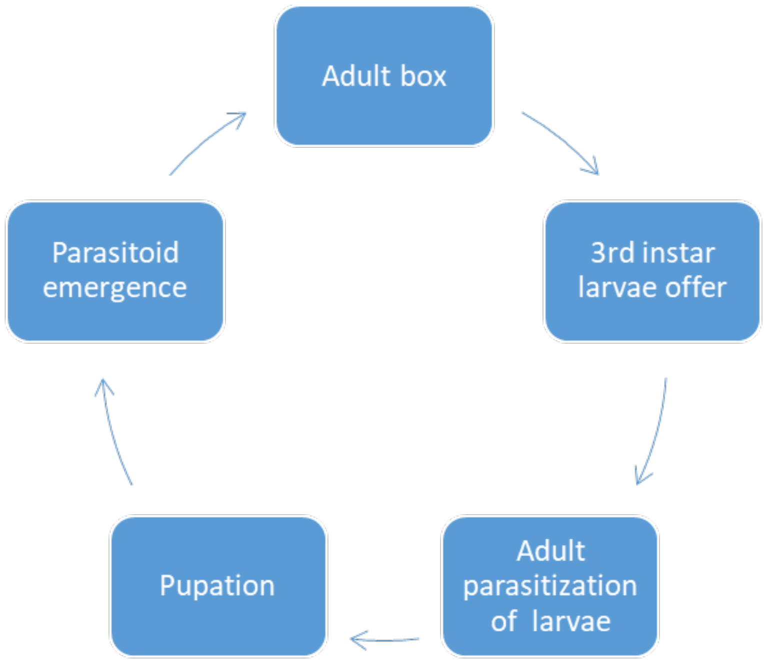


Figure 3.2.14 - Diagram of the protocol of larvo-pupal parasitoids of *Ceratitis capitata.*

And even more, all this could serve as a good preparation to face future introductions of new fruit fly invasive species in Europe by means of biological methods because one of this parasitoids (*D. longicaudata*) can, for example, be used to control the oriental fruit fly *Batrocera dorsalis*.

WP4. Review and testing of early detection tools and management strategies used in different countries

4.1 Austria (AGES)

Author: Alois Egartner

From 2010 onwards in Austrian survey activities for *Ceratitis capitata* mainly Tephri trap type traps (Maxitrap®, supplier Sociedad Española de Desarrollos Químicos (SEDQ), S.L., ES) were combined with different lures (in 2010 – 2012: CERATIPROTECT®, supplier SEDQ, ES; from 2013 onwards: plugs containing Trimedlure, Pherobank B.V., NL) to catch adult flies (Figure 4.1.1). Lure dispensers were changed several times during each season in accordance with suppliers' instructions. During the fruiting season in most of the years, the traps were installed in allotments, small gardens, orchards or other relevant sites and controlled in about two-week intervals. The number of sampling sites with traps increased over the years up to about 40, with sites in all Austrian provinces but with special focus on the city of Vienna.

Figure 4.1.1 - Maxitrap® on host tree, Vienna, Austria (2016) ©AGES/Egartner

4.2 Poland situation (GIORN)

Monitoring programme is based on McPhail pheromone traps (Fig. 4.2.1) (the producer: Russell IPM Ltd, Unit 45, First Avenue, Deeside Ind. Park, Deeside, CH5 2NU; product's code: PCT-F10).

Figure 4.2.1 – McPhail pheromone trap (components) used in Poland ©WIORiN Poznań

The program started in 2017 (Fig. 4.2.2). 48 traps were installed in 43 locations at west and south-western part of Poland.

In 2018, 50 pheromone traps were installed in 50 locations at the same territory of Poland as in 2017.

Next year, 2019, the number of traps has been increased, due to first occurrence of *Ceratitis capitata* in Poland in 2018. 130 traps were installed at the territory of whole Poland (10 traps were placed in the area where the pest was detected) (Fig. 4.3). This was supplemented by visual inspections carried out in the place where the pest was detected. Symptoms of *Ceratitis capitata* presence: preimaginal stages, damages on fruits were sought.

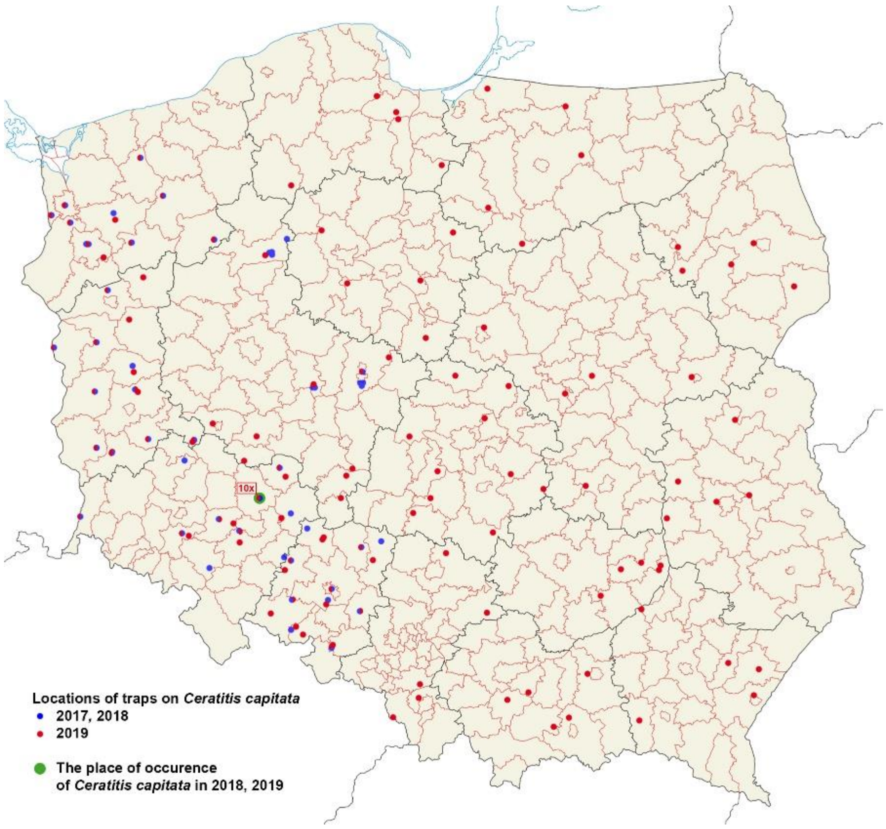


Figure 4.2.2 – Locations of pheromone traps in Poland in 2017–2019 (administrative map)

The 130 traps used were installed at the territory of whole Poland (10 traps were placed in the area where the pest was detected). This was supplemented by visual inspections carried out in the place where the pest was detected. Symptoms of *Ceratitis capitata* presence: preimaginal stages, damages on fruits were sought.

Traps are officially supervised by inspectors of the State Plant Health and Seed Inspection Service at least every 2 weeks since their installation. Currently, monitoring with traps is carried out in the period from early June to mid-October. There is a double replacement of the lure for the pheromone trap.

4.3 Spain (IVIA)

Author's: Julieta N. Herrero-Schell and Francisco J. Beitia

In Spain, the main method for the population management of *C. capitata* is the use of traps, in a mass trapping system, except to the Valencian Community where the SIT is the system on which the medlfy control is based. The traps used (there are different types of traps belonging to different companies) utilize food dry attractants with an insecticide that kills the insects trapped. Although it varies depending on the crop, 50-70 traps per hectare are applied in the plots. There are also traps with food liquid attractants, which do not require an insecticide since flies die from drowning.

- Type of traps used (Fig. 4.3.1):
  - **MacPhail-type or Tephri-type traps**, whit food dry attractants and insecticide. Used in the mass rearing of the pest.
  - **Nadel-type traps** with a male sex attractant (usually trimedlure) and an insecticide. Used to carry out population monitoring of the medfly.
  - **“Attract and Kill"** traps, with food attractant and insecticide but without captures of adults which die in the field after feeding in the trap.

Figure 4.3.1 – Different types of traps used in Spain (left-Tephri-type traps, center- MagnetTM Med Trap and right- “Attract and Kill" trap) .

The main trapping systems registered and used in Spain are:

- **Decis Trap®** (Bayer Crop Science), a Tephri-type trap with an attractant containing a mixture of ammonium acetate, trimethylamine hydrochloride and cadaverine and the inside of the cap is impregnated with deltamethrin.
- **Ceratipack®** (SEDQ Healthy Crops**),** a Tephri-type trap with a diffuser containing specific attractants for the medfly. The lid of this trap is presented impregnated with a contact insecticide (deltamethrin) to cause the death of flies captured.
- **Karate Trap™** (Syngenta España), a Tephri-type trap with specific food attractants inside and with the lid impregnated inside with LCYH that acts as a contact insecticide.
- **Conetrap Ceratitis Pack** (Probodelt), a foldable Tephri-type trap supplied with the lid impregnated in a contact insecticide and with food attractants for the medfly (ammonium acetate, trimethylamine and diaminoalkane).
- **Cera Trap®** (Bioibérica), a liquid insect food attractant, highly effective and without insecticide, specific for the capture of adults of *Ceratitis capitata*, which can be used with different kinds of traps, mainly with Nadel-type traps.
- **Magnet™ Med** (Suterra), an attract&kill-type trap, a device containing an attractant of high efficiency inside and impregnated of an insecticide (deltamethrin) on the outside, and does not capture insects but a single touch of the medfly adults with it is enough for the fly to die.

4.4 Slovenian situation (IAFNG)

Author: Mojca Rot

Different traps and lures have been used over decades to survey *Ceratitis capitata* populations in Slovenia (Fig. 4.4.1). In the mid-1980s Stainer taps baited with angelica seed oil were used. In the mid-1990s the pheromone traps were introduced. We started with *Trécé* Storgard II traps.

Since 2013 Jackson traps with trimedlure have been used and Tephri traps baited with 3 component lure (ammonium acetate, trimethylamine and putrescine) or Biolure. In each location both types of traps are usually placed (1 Tephri + 1 Jackson).

Figure 4.4.1 – Different trap types and attractants used in *C. capitata* survey in Slovenia

4.5 Montenegro situation (BFT-UM)

Author: Sanja Radonjić

The monitoring of adults of Ceratitis capitata in Montenengro was mainly in the seacoast area (Figure 4.5.1).

Figure 4.5.1 - Monitoring area on the Montenegro seacoast (divided in four areas: Boka Kotorska, Budva area, Bar area and Ulcinj area)

Throughout the years of monitoring, the following traps and attractants were used for *C. capitata* monitoring (in chronological order):

- McPhail traps with angelica seed oil (2002-2003) (Figure 4.5.2);
- Jackson traps with para-pheromone Trimedlure (TML) – a male-specific attractant (2004- 2006) (Figure 4.5.3);
- McPhail traps with a mixture of hydrolyzed protein (Buminal) + diammonium hydrogen phosphate, 4:1 (2006-2008) (Figure 4.5.4);
- Homemade traps with same components of Thephri Trap (Figure 4.5.5);
- **Tephri traps** baited with three-component female-biased dry food attractant (ammonium acetate, trimethylamine, and putrescine) from Suterra (Bend, OR, USA) and insecticide dichlorvos (DDVP stripes) from AgriSense-BSC Ltd. (Pontypridd, South Wales, UK) (used continuously since 2008) (Figure 4.5.6);
- and **Jackson traps** (Scentry Biologicals INC., Billings, MO, USA) with Trimedlure (used continuously since 2013) (Figure 4.5.7).

Figure 4.5.2 - Glass McPhail trap with angelica seed oil.

Figure 4.5.3 - Jackson trap with Trimedlure.

Figure 4.5.4. - McPhail trap with a mixture of hydrolyzed protein (Buminal) + diammonium hydrogen phosphate, 4:1.

Figure 4.5.5 - Homemade ''Tephri trap'' with the same contents of McPhail.

Figure 4.5.6 - Tephri trap with Biolure (in peach).

Figure 4.5.7 - Jackson trap with Trimedlure (in peach).

Figure 4.5.8 - Tephri trap with Biolure in fig.

Figure 4.5.9 - Tephri trap with Biolure in persimmon.

Figure 4.5.10 - Jackson trap with Trimedlure in citrus.

Figure 4.5.11 - Tephri trap with Biolure in citrus.


Figure 4.5.12 - Captured medfly (*C. capitata*) adults in Jackson trap.


Figure 4.5.13 - Medfly (*C. capitata*) adults captured in Tephri trap.

The Figures 4.5.8 and 4.5.9 show the Tephri trap with Biolure in fig and persimmon, respectively. Figure 4.5.10 shows the Jackson trap with Trimedlure in citrus. Figure 4.5.11 show the Tephri traps with Biolure used in the citrus orchards.

The Figures 4.5.12 and 4.5.13 show the C. capitata adults captured in the Jakcson traps and Tephri traps, respectively.

4.6 France situation (ANSES)

Author: Valérie Balmés

France does not have a surveillance plan for *Ceratitis capitata*. In some regions, producers set up traps to carry out monitoring or mass trapping, but the results are not centralised.

To our knowledge, the traps used are:

- Ceratipack: Deltamethrine, ammonium acetate and Trimethylamine hydrochloride
- Decitrap : Deltamethrine

- Ceratrap

Trapping is planned during the fruit production period. It is earlier in Corsica and later on the mainland.

In the last 3 years, there were either captures during export controls (self-control for the European plant passport) and, apart from these import controls, the laboratory only received about thirty samples with *Ceratitis capitata*. In half of the cases, the flies were caught in non-specific traps (as in the monitoring of *Bactrocera dorsalis*). This does not represent the presence of this fly in France.

Since 2007, our laboratory, as national reference laboratory, has produced an identification sheet that enables all professionals and plant protection officers to be autonomous in identifying *Ceratitis capitata*.

4.7 Netherlands situation (NCR-NVWA)

Author: Antoon Loomans

From 2006 to 2016 survey activities have resulted in the catching only of 54 specimens of *Ceratitis capitata*. 28 locations were selected.

There is some planning to perform a survey on the (seasonal) presence of *Ceratitis capitata* in the Netherlands.

At each location will be placed 2 Delta traps with EGOlure (in combination with a yellow sticky trap to catch the incidental female specimens).

Traps will be placed in the beginning of august and will be operative for a total of six weeks, while replacing the traps after three weeks (so sampling will be done for 2 intervals of 3 weeks).

4.8 Ukraine situation (IPP)

Author: Natalija Skripnik

For monitoring Mediterranean fruit fly in 2018-2019 were used traps" Petal" yellow color with pheromone dispenser. Supplier – company" Biochemtech" (Figure 4.8.1). The traps were placed in backyards in gardens on plums in Chornomorsk (Figure 4.8.2). In general, traps were installed from July to September. Results of monitoring have not shown the presence of *C. capitata* adults.

Figure 4.8.1 - Traps" Petal" with pheromone dispenser for *Ceratitis capitata* adults.

Figure 4.8.2 - Locations of pheromone traps in Chernomorsk, Odessa region, Ukraine.

Literature:

1. Cryachko Z.F., Melnikova R.G., Pyishkalo R.P. The Experience of eradication of the Mediterranean fruit fly on the area Sevastopol.-Simferopol." Crimea". 1970.
2. Shutova N.N., Melnikova , Pyshkalo Mediterranean fruit fly Ceratitis capitata Wied.-Moscow.1957.

4.9 Germany situation (JKI - FRCCP)

Author: Stephan Konig

The traps system used was Easy Trap®, equipped with the sexual pheromone Trimedlure and an insecticide.

4.10 Romania situation (RDIPP)

Author: Constantina Chireceanu

The 86 flies (50 males and 36 females) of *C. capitata* trapped in 2019 were in two Tephri trap (UniPak and trimedlure) installed from September 25 to November 11 in a commercial apple orchard near a supermarket.

4.11 Portugal situation

In Portugal /Azores the traps system used is Easy Trap®, equipped with the sexual pheromone Trimedlure and an insecticide and more recent because that was forbidden normally is used water and soap

In the last 2 years were tested and are in current use several types of traps (Figure 4.11.1):

- Tephri Trap (more used)
- Conetrap
- CeraTrap
- Easy Trap
- Delta or Jackson Trap

Figure 4.11.1 – Different trap types and attractants used in monitoring and trials on Azores islands and Mainland Portugal (source: Fruit fly project).

WP5. Models for pest's spread and adult's abundance predictions in different climatic regions

5.1 Introduction

5.1.1 Data-basis for the modelling

One of the biggest challenges when doing the Species Model Distribution (SMD) is to select the right environmental dataset predictors and the right size!

It is recommended to make a proficient pre-selection of a candidate predictor's dataset based on species abiotic tolerances which can provide a better model prediction (Elith & Leathwick 2009, Hijmans 2012, Royle et al. 2012).

Therefore, we designed three datasets based on several research works carried out for *C. capitata* abiotic tolerances (Table 5.1), where stands out Bodenheimer (1951), Vieira (1952), Liu et al. (1995), Papadopoulos et al. (1998), Papadopoulos et al. (2001) and Powell (2003).

Also, as most of the SMD works in the literature considers the orographic predictors for learning and projection purposes, we also included them on this modelling.

Table 5.1 - Datasets based on several research works carried out over *C. capitata* abiotic tolerances.

Dataset	Predictors	Source
EDS1	Altitude Exposure Slope	ASTER GLOBAL DEM by (U.S. Department of the Interior & U.S. Geological Survey 2018)
	Relative humidity Temperature (Bio01) Precipitation (Bio12)	(Fick & Hijmans 2017)
EDS2	Altitude Exposure Slope	ASTER GLOBAL DEM by (U.S. Department of the Interior & U.S. Geological Survey 2018)
	Temperature (Bio01) Precipitation (Bio12)	(Fick & Hijmans 2017)
EDS3	Relative humidity Temperature (Bio01) Precipitation (Bio12)	(Fick & Hijmans 2017)

The values for Air Humidity were not available to download from WorldClim2. However, in WorldClim2 a covariate holds records of water vapour pressure. This covariate value, when necessary, is calculated from a formula or a set of formulas, depending on data availability (for further details see Fick & Hijmans 2017).

One scenario for calculating this parameter assumes only the input of records from humidity and temperature.

Therefore, solving the set of equations in order to get the humidity variable, one gets the following formula:

$$rh = vp \times \frac{100}{0.611 \times 10^{\frac{7.5 \times T_m}{237.7 + T_m}}}$$

Where, vp is the vapour pressure and T_m is the mean temperature. With this formula and using the raster calculator of QGIS, one can easily generate a grid file of world air humidity.

For species occurrence, a dataset was downloaded from Global Biodiversity Information Facility (http://www.gbif.org) with the DOI reference https://doi.org/10.15468/dl.gdwmme containing 104.199 occurrences of Tephritidae species.

After performing all the cleaning operations, that is, removing the duplicates (points sharing the same coordinates) and points landing on the ocean we ended up with 16 723 records on the Tephritidae family dataset, 1 647 records on the Ceratitis genera dataset, 587 records on the *C. capitata* species dataset.

For the Maxent parameter's configuration, we assumed a prevalence value of 0.5 independent runs were done for each regularization value from 1 to 10.

The best Model performance evaluation was achieved by two methods, qualitative and quantitative.

First, we did a qualitative visual examination of the resulting projections based on partners sampling data with QGIS.

After the initial triage, we used the true statistic skill (TSS). The TSS is the best (Allouche et al. 2006, Shabani et al. 2018) and is defined as {1 – maximum (specificity + sensitivity)} where sensitivity and specificity are calculated based on the probability threshold for which their sum is maximised.

This measurement started as a suggestion by Allouche et al. (2006) as a valid alternative to Kappa that was used with regularity.

5.2 Results

5.2.1 Occurrence probability for *C. capitata* in Austria

This projection is an averaged one from 30 replicas using the same parameters configuration.

Moreover, this projection is just one of more than 3.000 evaluated models. Judging only the projection, the probability to find *C. capitata* in Austria, however, is low (Fig. 5.2.1).

These models were calculated using weather values calibrated to the whole world, and not specifically to Austria.

Also, current climate changes can quickly change that raise the probability.

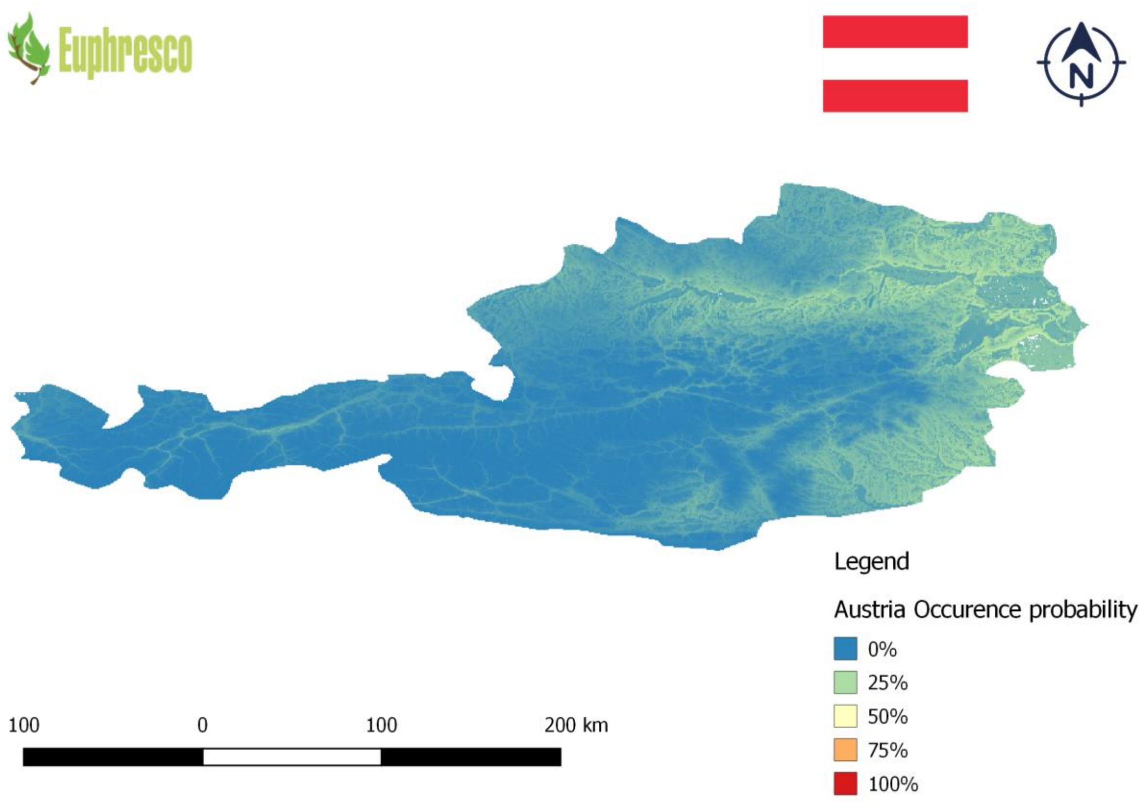


Figure 5.2.1 – *Ceratitis capitata* occurrence probability in Austria.

5.2.2 Model parameters for Austria

Prevalence: 0.5

Regularization: 1

Replica: 30

Threshold: “Maximum test sensitivity plus specificity” (maxSSS) of each replicate.

5.2.3 Results for Austria

The true statistic skill (TSS) was: 0,57 ± 0,09

In terms of predictors in Austria the contribution of abiotic factors was of 85% and the orography factors of only 15.0%, regarding the permutation importance of those predictor’s was 87.1% and 13.0% respectively (Table 5.2.1).

Table 5.2.1 – Predictors contribution for Austria.

Predictor	**Contribution**	**Permutation importance**
wc2.0_bio_30s_01 (Temperature)	50.5%	59.2%
wc2.0_bio_30s_12 (Precipitation)	24.9%	18.3%
Air Humidity *	9.6%	9.6%
Total of abiotic factors	**85%**	**87.1%**
Altitude	9.3%	9.1%
Soil Slope	4.9%	3.4%
Soil Exposure	0.8%	0.5%
Total of orography factors	**15.0%**	**13.0%**

* Air Humidity was not available to download from WorldClim2.

5.3 Germany

5.3.1 Occurrence probability for *C. capitata* in Germany

In Figure 5.3.1 is showed that **the occurrence probability for *C. capitata* in Germany is low**, only with a lower probability in the Northern part of the country.

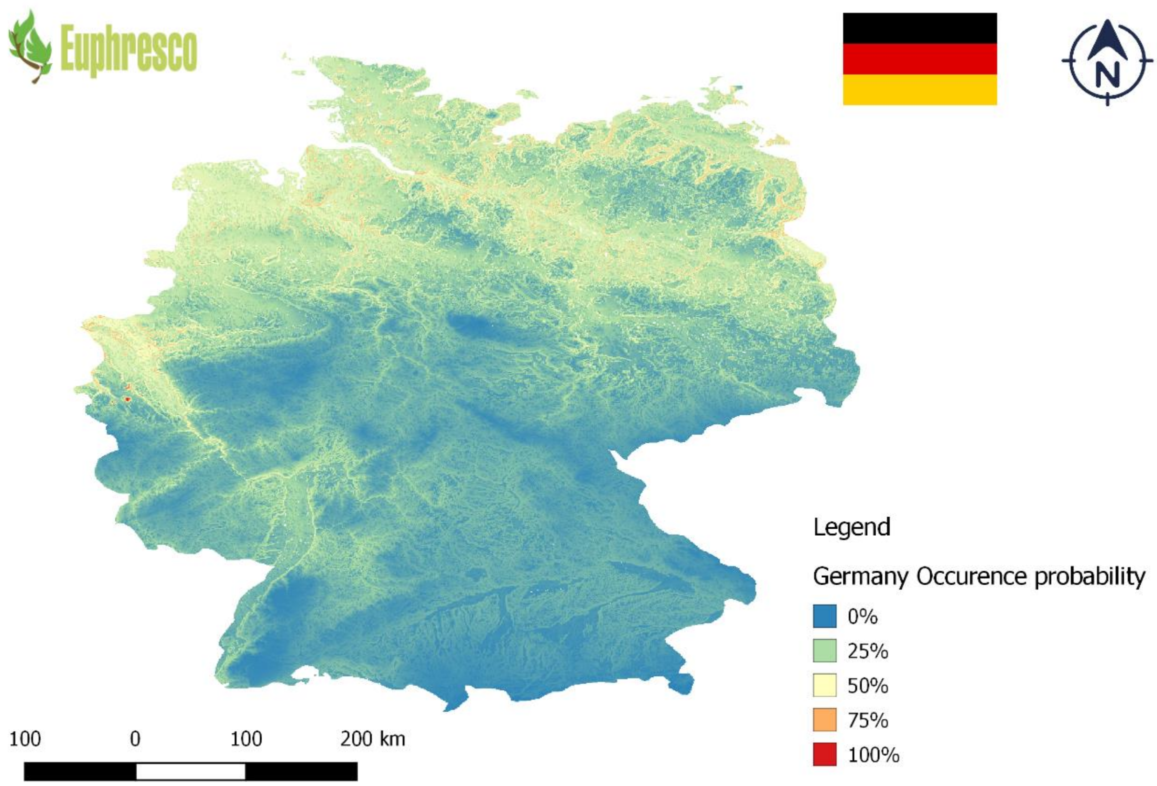


Figure 5.3.1 – *Ceratitis capitata* occurrence probability in Germany.

5.3.2 Model parameters for Germany

Prevalence: 0.5

Regularization: 1

Replica: 30

Threshold: “Maximum test sensitivity plus specificity” (maxSSS) of each replicate.

5.3.3 Results for Germany

The true statistic skill (TSS) was: 0.55 ± 0.11

In terms of predictors in Germany the contribution the abiotic factors were of 82.3% and the orography factors of only 17.7%, regarding the permutation importance of those predictor's was 82.2% and 17.8% respectively (Table 5.3).

Table 5.3.1 – Predictors contribution for Germany.

Predictor	**Contribution**	**Permutation importance**
wc2.0_bio_30s_01 (Temperature)	52.2%	55.1%
wc2.0_bio_30s_12 (Precipitation)	30.1%	27.1%
Total of abiotic factors	**82.3%**	**82.2%**
Altitude	11.4%	11.5%
Soil Slope	5.3%	5.9%
Soil Exposure	1.0%	0.4%
Total of orography factors	**17.7%**	**17.8%**

5.4 Italy

5.4.1 Occurrence probability for *C. capitata* in Italy

In Figure 5.4.1 is showed the occurrence probability for *C. capitata* in Italy, where we can see that the areas on the South of the country have conditions to register with a big probability the appearance and dissemination of this pest, pointing in some areas for the 100% occurrence probability.

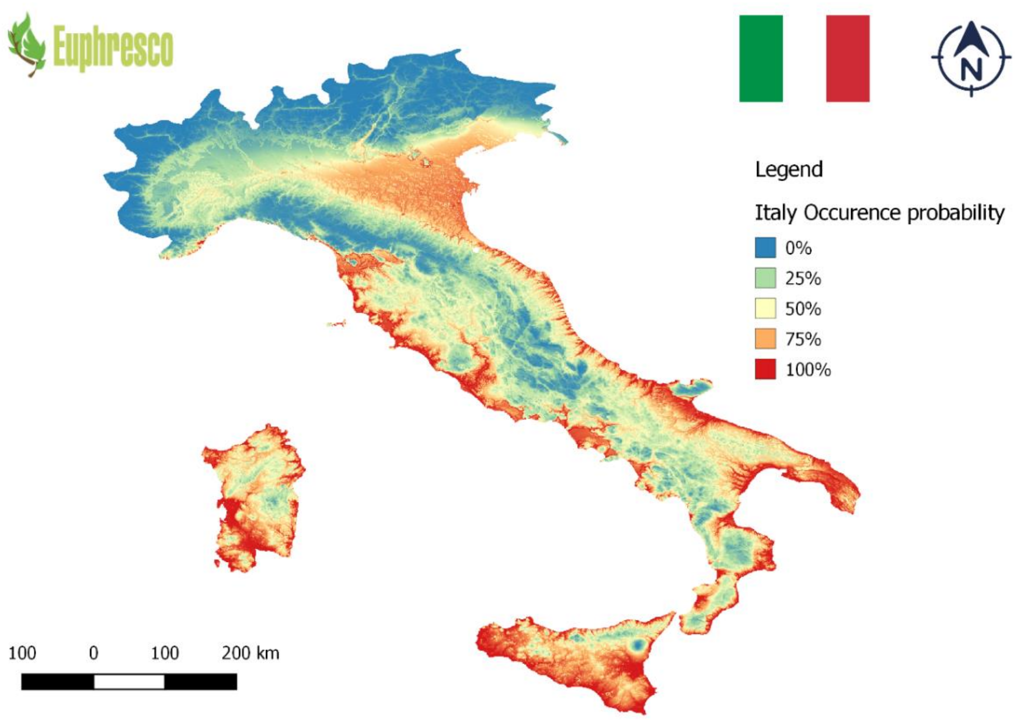


Figure 5.4.1 – *Ceratitis capitata* occurrence probability in Italy.

5.4.2 Model parameters for Italy

Prevalence: 0.5

Regularization: 1

Replica: 30

Threshold: "Maximum test sensitivity plus specificity" (maxSSS) of each replicate.

5.4.3 Results for Italy

The true statistic skill (TSS) was: 0,57 ± 0,09

In terms of predictors in Italy the contribution the abiotic factors were of 85% and the orography factors of only 15%, regarding the permutation importance of those predictor’s was 87,1% and 13% respectively (Table 5.4.1).

Table 5.4.1 – Predictors contribution for Italy.

Predictor	Contribution	Permutation importance
wc2.0_bio_30s_01 (Temperature)	50.5%	59.2%
wc2.0_bio_30s_12 (Precipitation)	24.9%	18.3%
Air Humidity *	9.6%	9.6%
Total of abiotic factors	**85%**	**87.1%**
Altitude	9.3%	9.1%
Soil Slope	4.9%	3.4%
Soil Exposure	0.8%	0.5%
Total of orography factors	**15.0%**	**13.0%**

* Air Humidity was not available to download from WorldClim2.

5.5 Netherlands

5.5.1 Occurrence probability for *C. capitata* in the Netherlands

In Figure 5.5.1 is showed the occurrence probability for *C. capitata* in the Netherlands. As can be see this **probability is very low in almost all the country**.

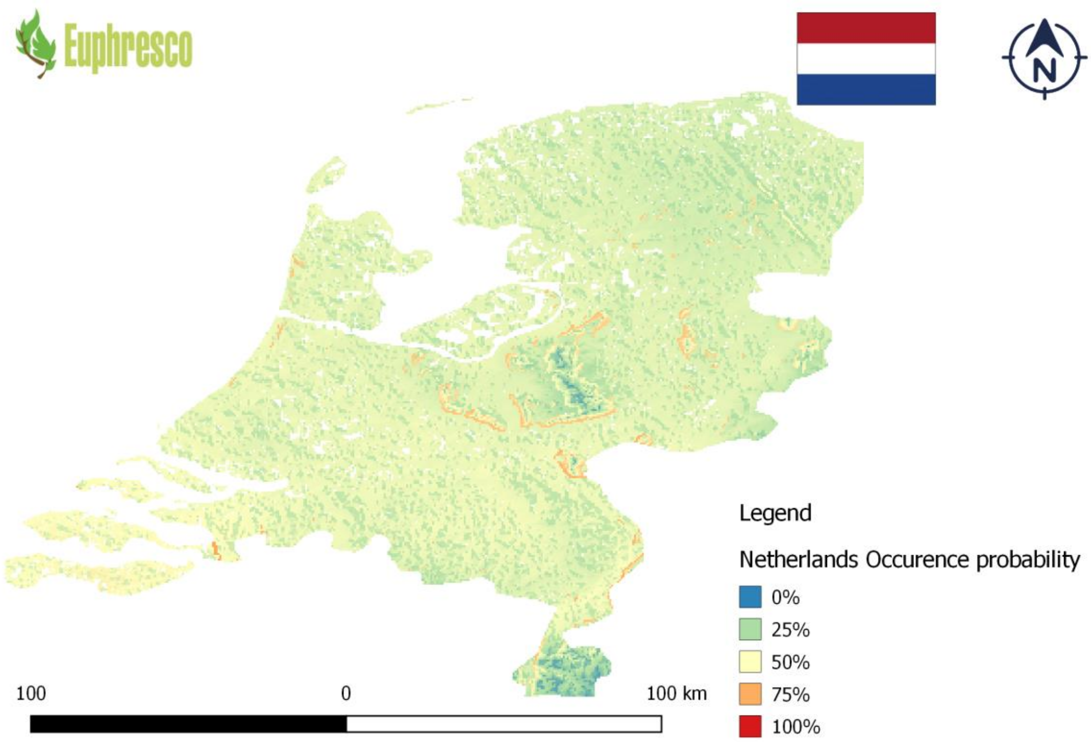


Figure 5.4.1 – *Ceratitis capitata* occurrence probability in Netherlands.

5.5.2 Model parameters for Netherlands

Prevalence: 0.5

Regularization: 1

Replica: 30

Threshold: “Maximum test sensitivity plus specificity” (maxSSS) of each replicate.

5.5.3 Results for Netherlands

The true statistic skill (TSS) was: 0.57 ± 0.09

In terms of predictors in Netherlands the contribution of the abiotic factors was 85% and the orography factors of only 15.0%, regarding the permutation importance of those predictor's was 87.1% and 13.0% respectively (Table 5.5.1).

Table 5.5.1 – Predictors contribution for Netherlands

Predictor	**Contribution**	**Permutation importance**
wc2.0_bio_30s_01 (Temperature)	50.5%	59.2%
wc2.0_bio_30s_12 (Precipitation)	24.9%	18.3%
Air Humidity *	9.6%	9.6%
Total of abiotic factors	**85.0%**	**87.1%**
Altitude	9,3%	9.1%
Soil Slope	4,9%	3.4%
Soil Exposure	0,8%	0.5%
Total of orography factors	**15.0%**	**13.0%**

* Air Humidity was not available to download from WorldClim2.

5.6 Tunisia

5.6.1 Occurrence probability for *C. capitata* in Tunisia

In Figure 5.6.1 is showed the occurrence probability for *C. capitata* in Tunisia. Can be seeing that the Northern part of the country as 100% probability for the occurrence of this pest.

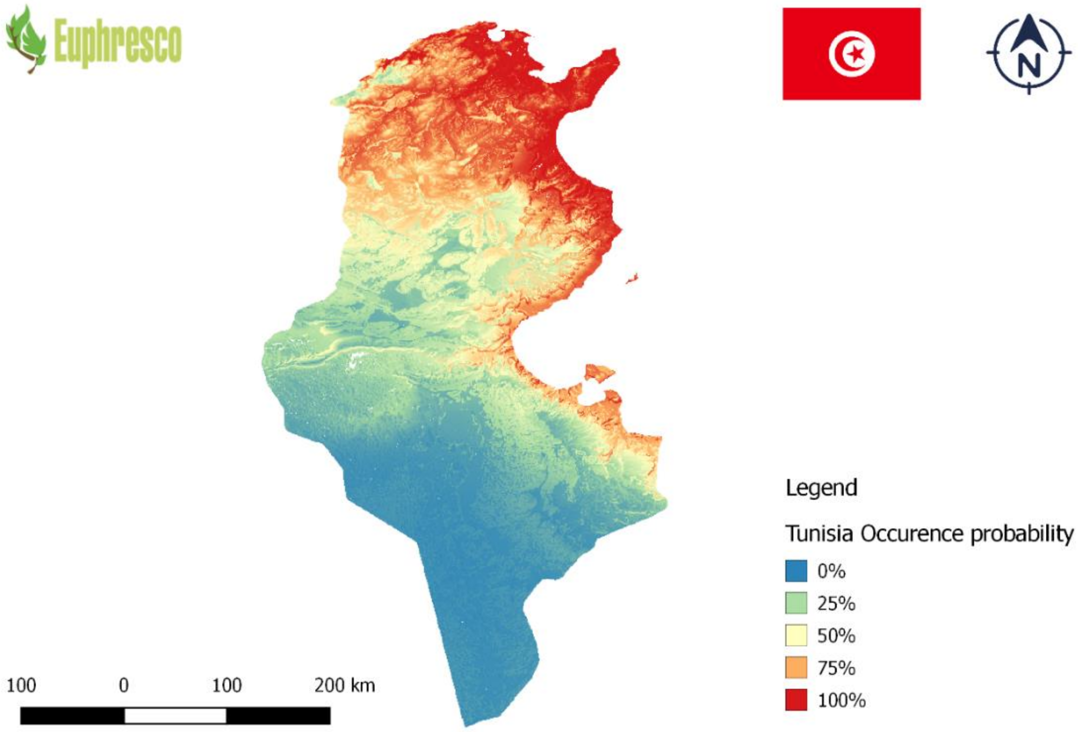


Figure 5.6.1 – *Ceratitis capitata* occurrence probability in Tunisia.

5.6.2 Model parameters for Tunisia

Prevalence: 0.5

Regularization: 1

Replica: 30

Threshold: “Maximum test sensitivity plus specificity” (maxSSS) of each replicate.

5.6.3 Results for Tunisia

The true statistic skill (TSS) was: 0,57 ± 0,09

In terms of predictors in Italy the contribution the abiotic factors were of 85.0% and the orography factors of only 15.0%, regarding the permutation importance of those predictor’s was 87.1% and 13.0%, respectively (Table 5.6.1).

Table 5.6.1 – Predictors contribution in Tunisia.

Predictor	Contribution	Permutation importance
wc2.0_bio_30s_01 (Temperature)	50.5%	59.2%
wc2.0_bio_30s_12 (Precipitation)	24.9%	18.3%
Air Humidity *	9.6%	9.6%
Total of abiotic factors	**85.0%**	**87.1%**
Altitude	9.3%	9.1%
Soil Slope	4.9%	3.4%
Soil Exposure	0.8%	0.5%
Total of orography factors	**15.0%**	**13.0%**

* Air Humidity was not available to download from WorldClim2.

5.7 Ukraine

5.7.1 Occurrence probability for *C. capitata* in Ukraine

In Western and Eastern Europe *C. capitata* is able to survive and acclimatize in the area where the average monthly temperatures of the winters months fluctuate in December from + 0,7 to + 5^{O}C, in January - from -1,6 to +3 ^{O}C, in February- from -1,4 to 3 ^{O}C at the average annual temperatures from +9,4 to 12,7 ^{O}C, the sum of active temperatures (peak value +10^{O}C) is higher 2.960 ^{O}C (Table 5.7.1).

Analysis of average annual and average monthly temperatures of the winter period of the regions of Ukraine showed that some areas of the Autonomous Republic of Crimea, Odessa, Kherson regions belong to the possible zone of the pest acclimatization village. In case of acclimatization *Ceratitis capitata* can develop in the Odessa region two generations (Klechkovskij, Palagina, 2008, Palagina 2009).

Table 5.7.1 - Average annual and average monthly temperatures of the winter period of the regions of Ukraine, with relating under possible zone acclimatization Ceratitis *capitata.*

Regions of Ukraine	Average annual temperatures, ^{O}C	Average monthly temperatures of the winter period, ^{O}C		
		December	January	February
AR Crimea	11,39	+2,79	+1,11	+1,39
Odessa	10,93	+1,18	-0,63	-0,11
Kherson	10,63	+0,41	-0,98	-0,73
Transcarpathian	10,21	-0,08	-1,73	-0,11
In the area of western and eastern Europe	+9,4 to 12,7	+0,7 to +5	-1,6 to +3	-1,4 to +3

Ceratitis capitata is distributed during transportation with plant products at the stages of eggs, larvae in fruits and of puparia on the surface of the fruit and naturally.

To clarity the possibility of acclimatization of the pest in Ukraine scientists have analyzed the geographical location the type of climate, range of temperature fluctuations.

Geographical coordinates and climatic conditions of the south-western region of Ukraine, which includes Odessa region (44-48 n.l.) are close to the performance of many European countries.

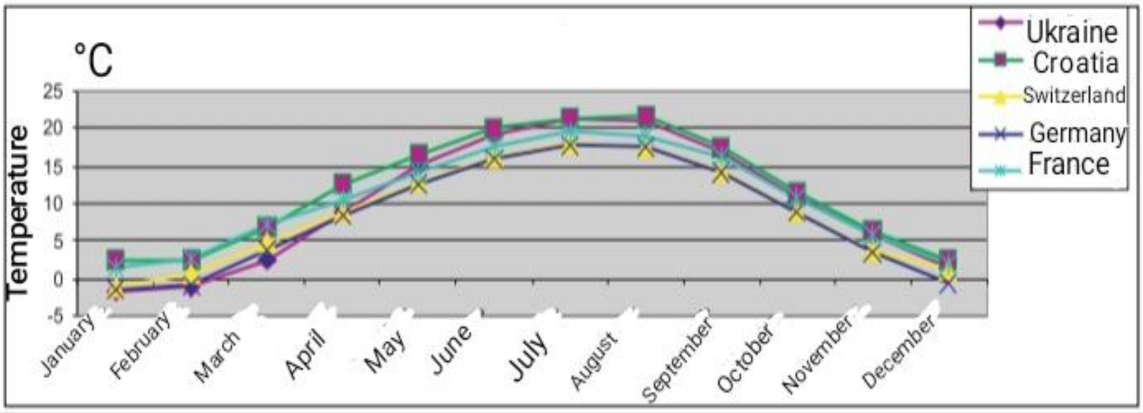


Figure 5.7.1. - The comparison of the temperature regime of countries where the *Ceratitis capitata* is spread.

In European countries, the location of with is determined by geographical coordinates close to Ukraine(Croatia, Switzerland, Germany, France) and where the Mediterranean fruit fly develops in 2-3 generations, the temperature is close or similar to the temperature conditions of Odessa region.

Regarding these observations and results from Ukraine scientists research, in Figure 5.6.2 is showed the occurrence probability for *C. capitata* in Ukraine. The **probability of appearance of this pest** is near 0,0% or and very low almost in all country, with only some **major possibility in the south areas of the country,** such as Odessa region, **with around 75% occurrence probability**.

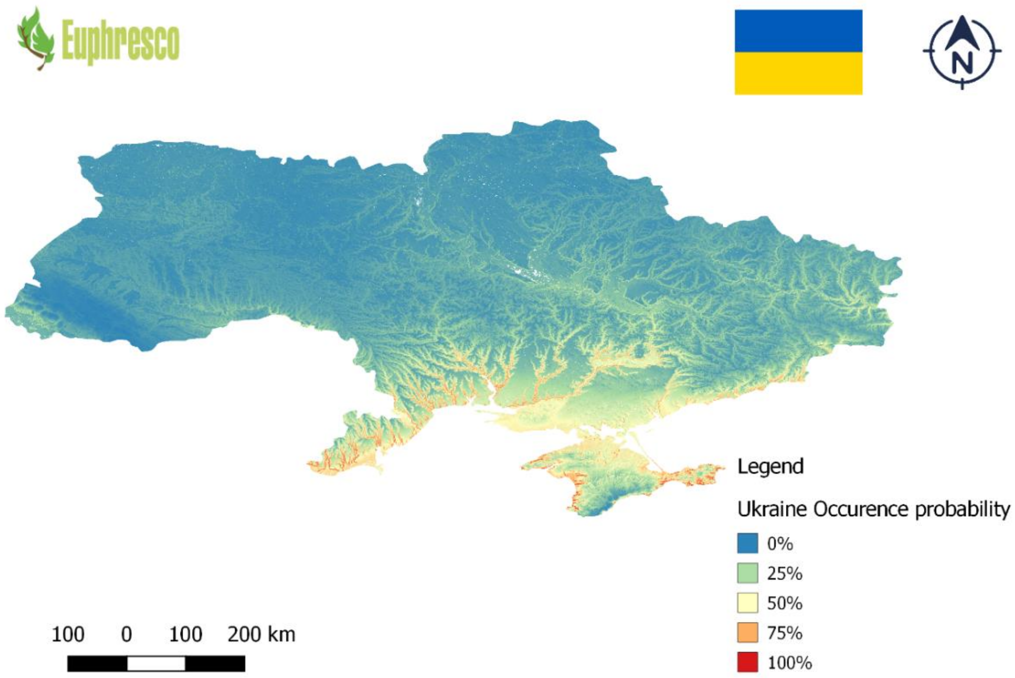


Figure 5.6.2 – *Ceratitis capitata* occurrence probability in Ukraine.

5.7.2 Model parameters in Ukraine

Prevalence: 0.5

Regularization: 1

Replica: 30

Threshold: "Maximum test sensitivity plus specificity" (maxSSS) of each replicate.

5.7.3 Results in Ukraine

The true statistic skill (TSS) was: 0.55 ± 0.11

In terms of predictors in Italy the contribution the abiotic factors were of 82.3% and the orography factors of only 17.7%, regarding the permutation importance of those predictor's was 82.2% and 17.8% respectively (Table 5.7.1).

Table 5.7.1 – Predictors contribution for Ukraine.

Predictor	Contribution	Permutation importance
wc2.0_bio_30s_01 (Temperature)	52.2%	55.1%
wc2.0_bio_30s_12 (Precipitation)	30.1%	27.1%
Total of abiotic factors	**82.3%**	**82.2%**
Altitude	11.4%	11.5%
Soil Slope	5.3%	5.9%
Soil Exposure	1.0%	0.4%
Total of orography factors	**17.7%**	**17.8%**

Literature:

1. Klechkovskij J.E., Palagina O.V. The possibility of the Mediterranean fruit fly acclimatizion in the south-west region of Ukraine. Plant protection and quarantine. 2008.v.4.s.224-230.

2. Palagina O.V. Threat acclimatization of the Mediterranean fruit fly is real. Plant protection and quarantine. 2009.

5.8 Spain

5.8.1 Occurrence probability for *C. capitata* in Spain

In Figure 5.8.1 is showed the occurrence probability for *C. capitata* in Spain. Only in the **Northern part of the country that the probability of occurrence is low, all the rest of the country is high reaching in many areas the 100%.**

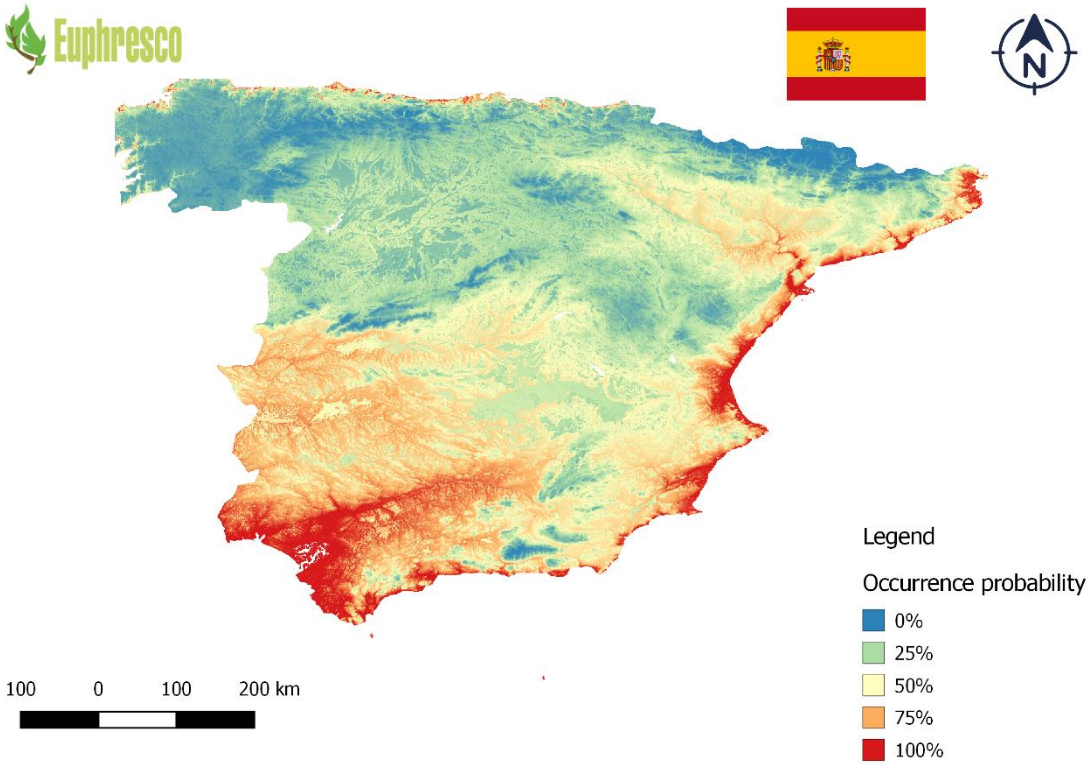


Figure 5.8.1 – *Ceratitis capitata* occurrence probability in Spain.

5.8.2 Model parameters for Spain

Prevalence: 0.5

Regularization: 1

Replica: 30

Threshold: “Maximum test sensitivity plus specificity” (maxSSS) of each replicate.

5.8.3 Results for Spain

The true statistic skill (TSS) was: 0,57 ± 0,09

In terms of predictors in Spain the contribution the abiotic factors were of 85.0% and the orography factors of only 15.0%, regarding the permutation importance of those predictor’s was 87.1% and 13.0% respectively (Table 5.8.1).

Table 5.8.1 – Predictors contribution for Spain.

Predictor	Contribution	Permutation importance
wc2.0_bio_30s_01 (Temperature)	50.5%	59.2%
wc2.0_bio_30s_12 (Precipitation)	24.9%	18.3%
Air Humidity *	9.6%	9.6%
Total of abiotic factors	**85.0%**	**87.1%**
Altitude	9.3%	9.1%
Soil Slope	4.9%	3.4%
Soil Exposure	0.8%	0.5%
Total of orography factors	**15.0%**	**13.0%**

* Air Humidity was not available to download from WorldClim2.

5.9 Poland

5.9.1 Occurrence probability for *C. capitata* in Poland

In Figure 5.9.1 is showed the occurrence probability for *C. capitata* in Poland. All the country as a near 0.0% of occurrence probability only areas on the west northern part have some low probability of appearance of this pest.

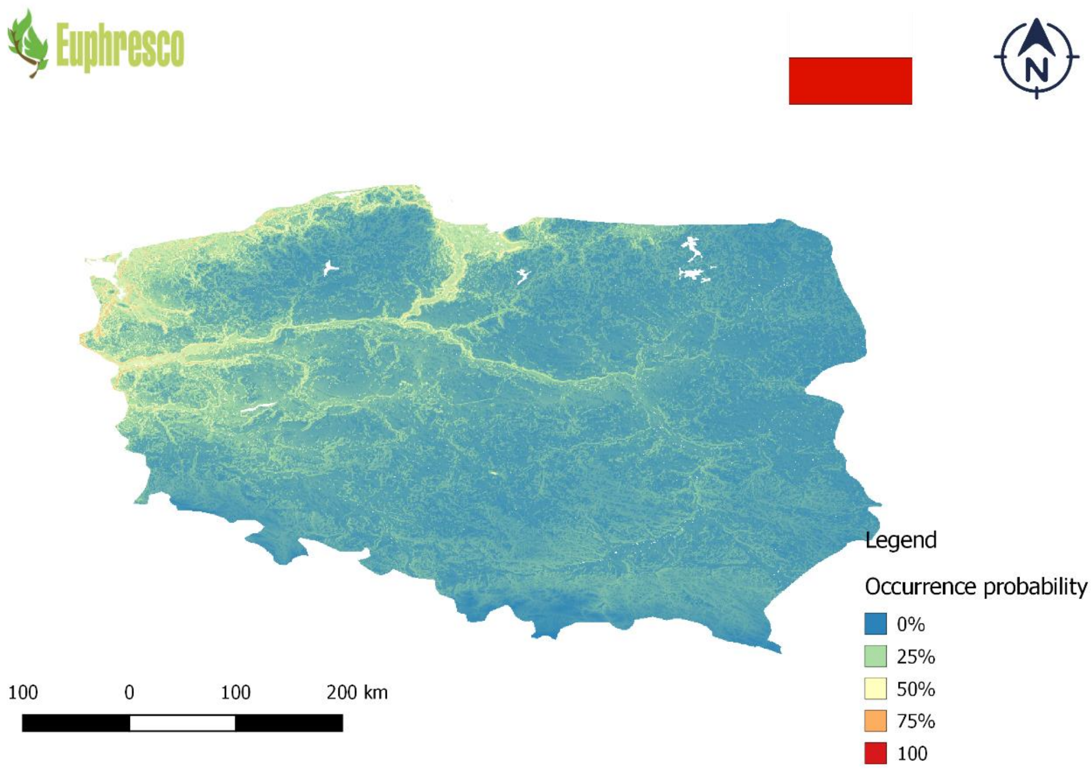


Figure 5.9.1 – *Ceratitis capitata* occurrence probability in Poland.

5.9.2 Model parameters in Poland

Prevalence: 0.5

Regularization: 1

Replica: 30

Threshold: “Maximum test sensitivity plus specificity” (maxSSS) of each replicate.

5.9.3 Results for Poland

The true statistic skill (TSS) was: 0,57 ± 0,11

In terms of predictors in Poland the contribution the abiotic factors were of 82,3% and the orography factors of only 17,7%, regarding the permutation importance of those predictor's was 82,2% and 17,8% respectively (Table 5.9.1).

Table 5.9.1 – Predictors contribution for Poland.

Predictor	**Contribution**	**Permutation importance**
wc2.0_bio_30s_01 (Temperature)	52.2%	55.1%
wc2.0_bio_30s_12 (Precipitation)	30.1%	27.1%
Total of abiotic factors	**82.3%**	**82.2%**
Altitude	11.4%	11.5%
Soil Slope	5.3%	5.9%
Soil Exposure	1.0%	0.4%
Total of orography factors	**17.7%**	**17.8%**

5.10 France

5.10.1 Occurrence probability for *C. capitata* in France

In Figure 5.10.1 is showed the occurrence probability for Ceratitis capitata in France. Can be seeing that only the Mediterranean areas have some probability for this pest appearance and dissemination.

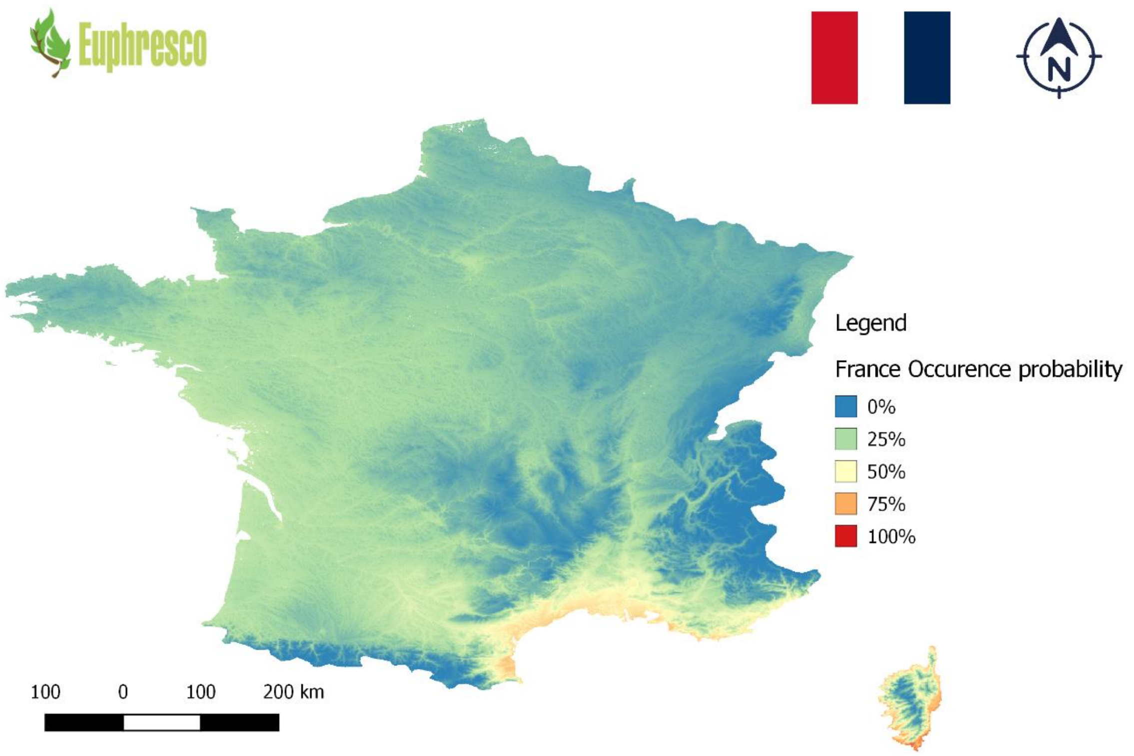


Figure 5.10.1 – *Ceratitis capitata* occurrence probability in France.

5.10.2 Model parameters for France

Prevalence: 0.5

Regularization: 4

Replica: 30

Threshold: “Maximum test sensitivity plus specificity” (maxSSS) of each replicate.

5.10.3 Results for France

The true statistic skill (TSS) was: 0.47 ± 0.09

In terms of predictors in France the contribution the abiotic factors were of 99.6% and the orography factors of only 0.4%, regarding the permutation importance of those predictor's was 99.1% and 0.9% respectively (Table 5.10.1).

Table 5.10.1 – Predictors contribution for France.

Predictor	**Contribution**	**Permutation importance**
wc2.0_bio_30s_01 (Temperature)	77.5%	67.5%
wc2.0_bio_30s_12 (Precipitation)	17.8%	23.9%
Air Humidity *	4.3%	7.7%
Total of abiotic factors	**99.6%**	**99.1%**
Altitude	0.4%	0.8%
Soil Slope	0.0%	0.0%
Soil Exposure	0.0%	0.1%
Total of orography factors	**0.4%**	**0.9%**

5.11 Slovenia

5.11.1 Occurrence probability for *C. capitata* in Slovenia

In Figure 5.11 is showed the occurrence probability for *C. capitata* in Slovenia. Most of the country the probability is low, only in a southwest part of the country is higher.

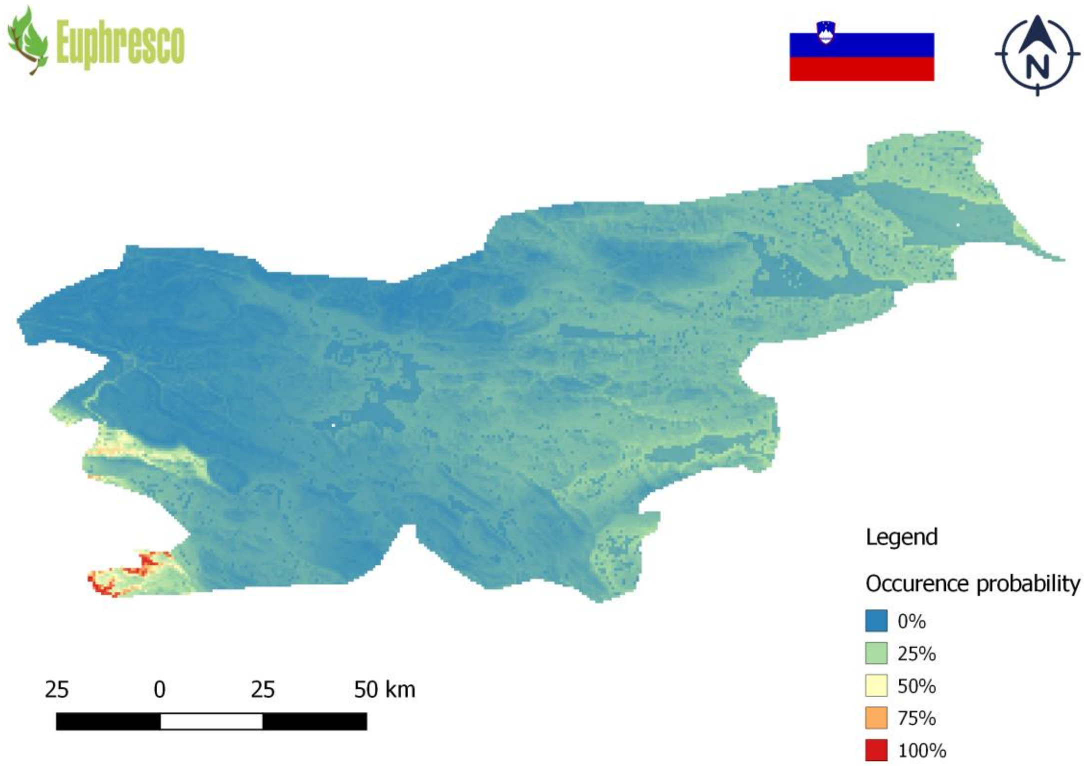


Figure 5.11 – *Ceratitis capitata* occurrence probability in Slovenia.

In a point in the central part of Slovenia (Location name: Brdo pri Lukovici), a *C. capitata* adult was found in 2018. That was probably only an interception, because modelling in Fig. 5.11.1 does not make refence to that area. In 2019 was not found any specimen on that point and its surroundings but other *C. capitata* adults were found in a new location (Neblo) in the western part of Slovenia for the first time. In this area modelling from Figure 5.11.1 pointed to an occurrence probability of 25.0%. As result of this modelling monitoring in this area was implemented in 2020.

5.11.2 Model parameters for Slovenia

Prevalence: 0.5

Regularization: 3

Replica: 30

Threshold: "Maximum test sensitivity plus specificity" (maxSSS) of each replicate.

5.11.3 Results for Slovenia

The true statistic skill (TSS) was: 0.5478 ± 0.09.

In terms of predictors in Slovenia the contribution the abiotic factors were of 82.3% and the orography factors of only 17.7%, regarding the permutation importance of those predictor's was 82.2% and 17.8% respectively (Table 5.11.1).

Table 5.11.1 – Predictors contribution for Slovenia.

Predictor	**Contribution**	**Permutation importance**
wc2.0_bio_30s_01 (Temperature)	52.2%	55.1%
wc2.0_bio_30s_12 (Precipitation)	30.1%	27.1%
Total of abiotic factors	**82.3%**	**82.2%**
Altitude	11.4%	11.5%
Soil Slope	5.3%	5.9%
Soil Exposure	1%	0,4%
Total of orography factors	**17.7%**	**17.8%**

5.12 Montenegro

5.12.1 Occurrence probability for *C. capitata* in Montenegro

In Figure 5.12.1 is showed the occurrence probability for *C. capitata* in Montenegro. In a **major part of the country the occurrence probability is low**. Only in the Southern parts of the country is higher, between 75 and 100% in some places.

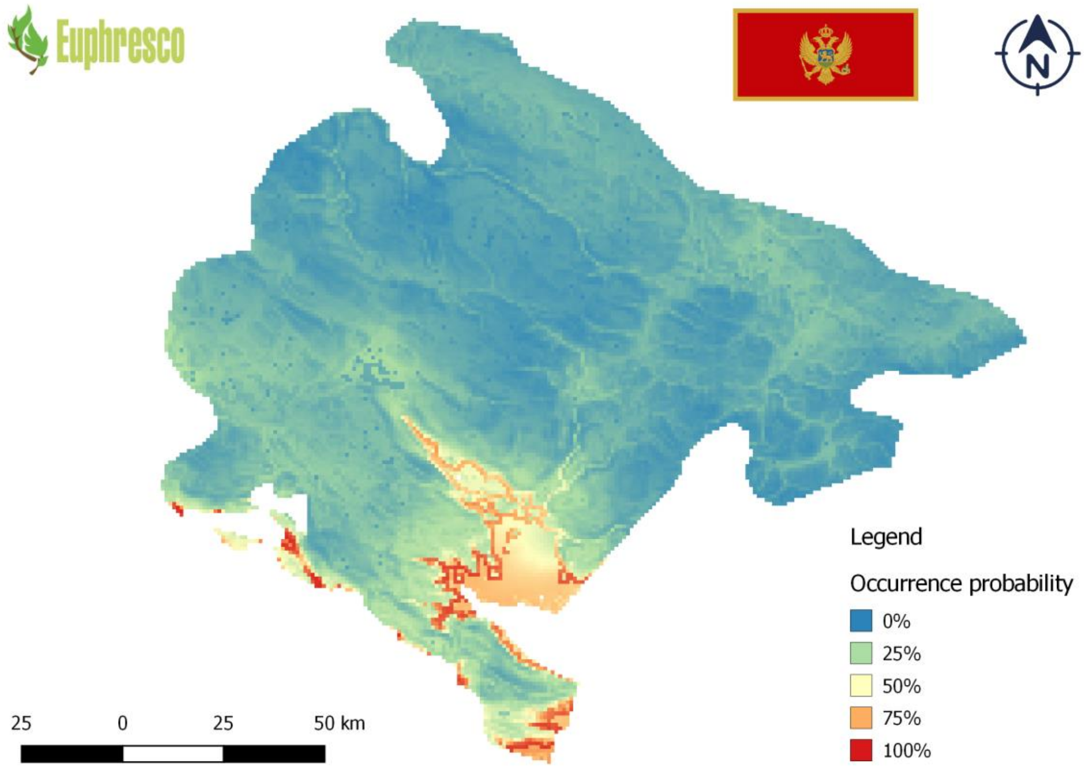


Figure 5.12.1 – *Ceratitis capitata* occurrence probability in Montenegro.

5.12.2 Model parameters for Montenegro

Prevalence: 0.5

Regularization: 3

Replica: 30

Threshold: “Maximum test sensitivity plus specificity” (maxSSS) of each replicate.

5.12.3 Results for Montenegro

The true statistic skill (TSS) was: 0.5478 ± 0.09.

In terms of predictors in Montenegro the contribution the abiotic factors were of 82,3% and the orography factors of only 17.7%, regarding the permutation importance of those predictor's was 82.2% and 17.8%, respectively (Table 5.12.1).

Table 5.12.1 – Predictors contribution for Montenegro.

Predictor	Contribution	Permutation importance
wc2.0_bio_30s_01 (Temperature)	52.2%	55.1%
wc2.0_bio_30s_12 (Precipitation)	30.1%	27.1%
Total of abiotic factors	**82.3%**	**82.2%**
Altitude	11.4%	11.5%
Soil Slope	5.3%	5.9%
Soil Exposure	1.0%	0.4%
Total of orography factors	**17.7%**	**17.8%**

5.13 Romania

5.13.1 Occurrence probability for *C. capitata* in Romania

In Figure 5.13.1 is showed the occurrence probability for *Ceratitis capitata* in Romania.

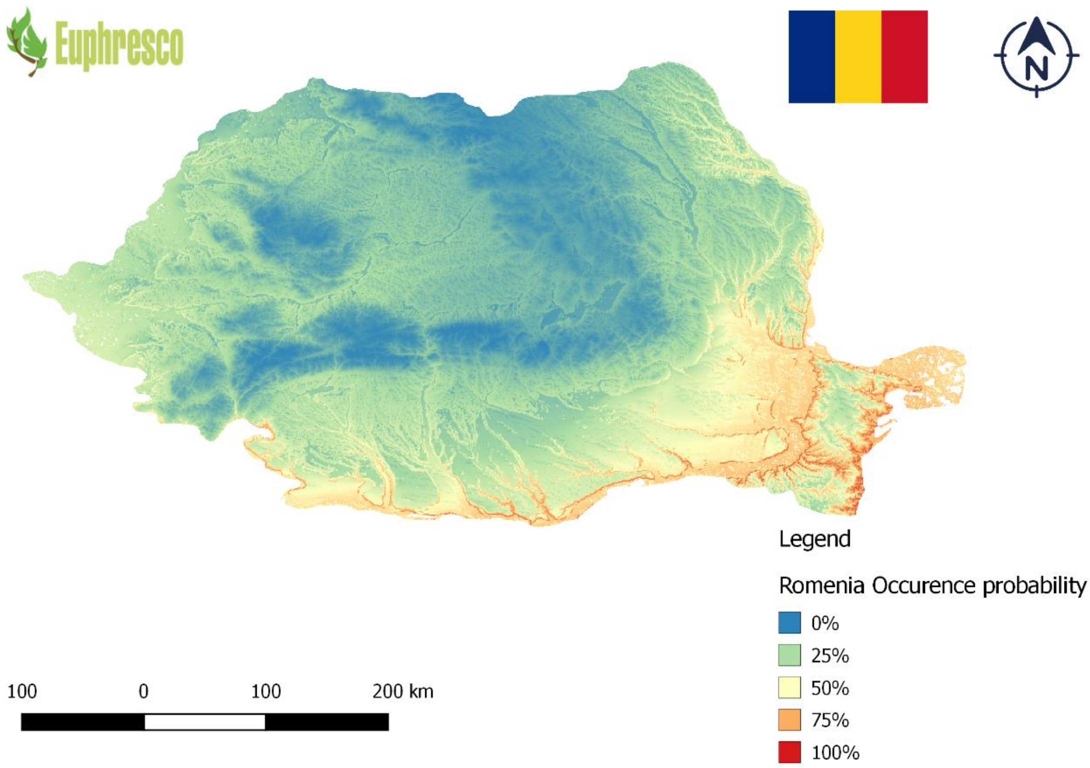


Figure 5.13.1 – *Ceratitis capitata* occurrence probability in Romania.

This Fig. 5.13.1 indicates that areas from N-E, S and S-E, along the borders, are perfect suitable for *C. capitata* presence. Good areas for *C. capitata* presence are also in the West of the country, where generally, the climate here is quite like those from South, more than the climate from East.

5.13.2 Model parameters for Romania

Prevalence: 0.5

Regularization: 3

Replica: 30

Threshold: “Maximum test sensitivity plus specificity” (maxSSS) of each replicate.

5.13.3 Results for Romania

The true statistic skill (TSS) was: 0.53 ± 0.08.

In terms of predictors in Romania the contribution the abiotic factors were of 85% and the orography factors of only 15.0%, regarding the permutation importance of those predictor’s was 87.1% and 13.0%, respectively (Table 5.13.1).

Table 5.13.1 – Predictors contribution for Romania.

Predictor	**Contribution**	**Permutation importance**
wc2.0_bio_30s_01 (Temperature)	50.5%	59.2%
wc2.0_bio_30s_12 (Precipitation)	24.9%	18.3%
Air Humidity *	9.6%	9.6%
Total of abiotic factors	**85%**	**87.1%**
Altitude	9.3%	9.1%
Soil Slope	4.9%	3.4%
Soil Exposure	0.8%	0.5%
Total of orography factors	**15.0%**	**13.0%**

5.14 Portugal

5.14.1 Occurrence probability for *C. capitata* in Portugal

In Figure 5.14.1 is showed the occurrence probability for *Ceratitis capitata* in Portugal. The occurrence probability is low in the northern part of the country but high in the centre regions and still bigger closing to 100% in South part of the country.

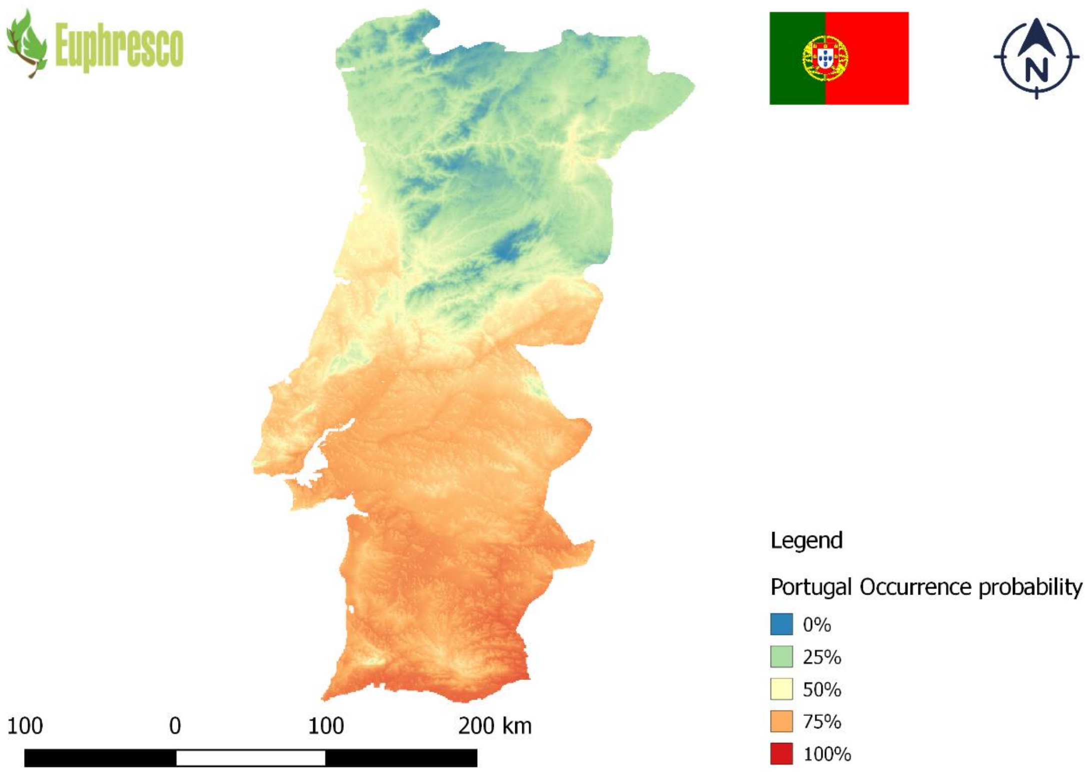


Figure 5.14.1 – *Ceratitis capitata* occurrence probability in Portugal.

5.14.2 Model parameters for Portugal

Prevalence: 0.5

Regularization: 3

Replica: 30

Threshold: "Maximum test sensitivity plus specificity" (maxSSS) of each replicate.

5.14.3 Results for Portugal

The true statistic skill (TSS) was: 0.45 ± 0.1.

In terms of predictors in Portugal the contribution the abiotic factors were of 95.8% and the orography factors of only 4.2%, regarding the permutation importance of those predictor's was 92.9% and 7.1%, respectively (Table 5.14.1).

Table 5.14.1 – Predictors contribution for Portugal.

Predictor	Contribution	Permutation importance
wc2.0_bio_30s_01 (Temperature)	73,1%	71,5%
wc2.0_bio_30s_12 (Precipitation)	22,7%	21,4%
Total of abiotic factors	**95,8%**	**92,9%**
Altitude	2,1%	4,2%
Soil Slope	1,4%	1,7%
Soil Exposure	0,7%	1,2%
Total of orography factors	**4,2%**	**7,1%**

5.14.4 Azores

The Azores Islands are a Portuguese archipelago in the North Atlantic Ocean, located about 1,500 km (930 mi) from Lisbon and about 3,900 km (2,400 mi) from the east coast of North America (Fig. 5.14.2). The Monchique islet on Flores Island, located at 31° 16' 24" W is regarded as the westernmost point in Europe, even though from a geological standpoint the two westernmost Azorean islands (Flores and Corvo) actually lie on the North American plate.

The vast extent of the islands defines an immense exclusive economic zone of 1,100,000 Km2 (420,000 square miles). The westernmost point of this area is 3,380 km (2,100 mi) from the North American continent. All the islands have volcanic origins, although Santa

Maria also has some reef contribution. Mount Pico on Pico Island, at 2,351 m (7,713 ft) in altitude, is the highest in all of Portugal.

Figure 5.14.2 – Location of Azores Archipelago. (https://azores.com/azores)

The Azores archipelago as 9 islands that forms the Autonomous Region of Azores (Figure 5.14.3).

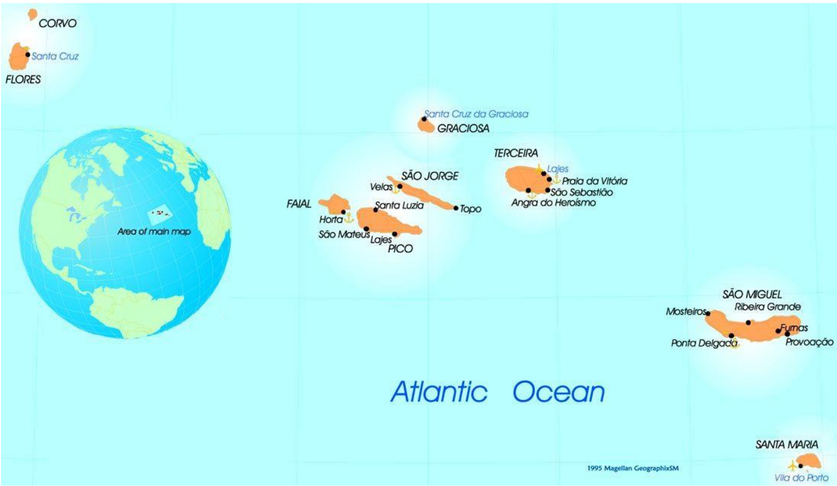


Figure 5.14.3 - The Azores archipelago with all the 9 islands. (https://www.pinterest.pt)

5.14.4.1 Occurrence probability for *C. capitata* in the different Azores Islands

In Figures 5.14.4 to 5.14.11 is showed the occurrence probability for *Ceratitis capitata* in each of the 8 islands of Azores Autonomous Region (Portugal) analysed. Corvo is the only island missing on this modelling using MaxEnt software because it has no orchards and only some vegetable hosts for C. capitata present on the houses backyards and is very small.

In the Eastern group of the Azores archipelago there are two islands: São Miguel and Santa Maria. In Santa Maria island (Fig. 5.14.4) all the West part of the island, that means almost half the island as suitable conditions to the occurrence of *C. capitata*.

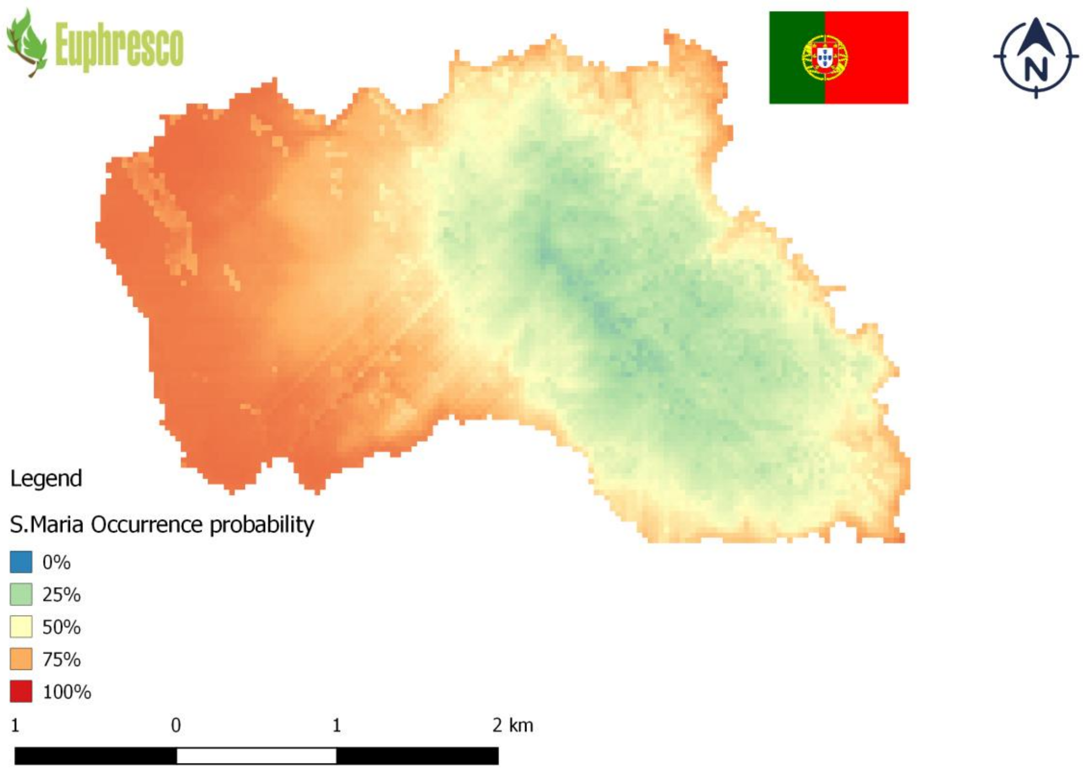


Figure 5.14.4 – *Ceratitis capitata* occurrence probability in Santa Maria Island.

In the other island from the Eastern group, São Miguel (Fig. 5.14.5) mainly the border of the coastal areas around all island have suitable conditions to the occurrence of *C. capitata.*

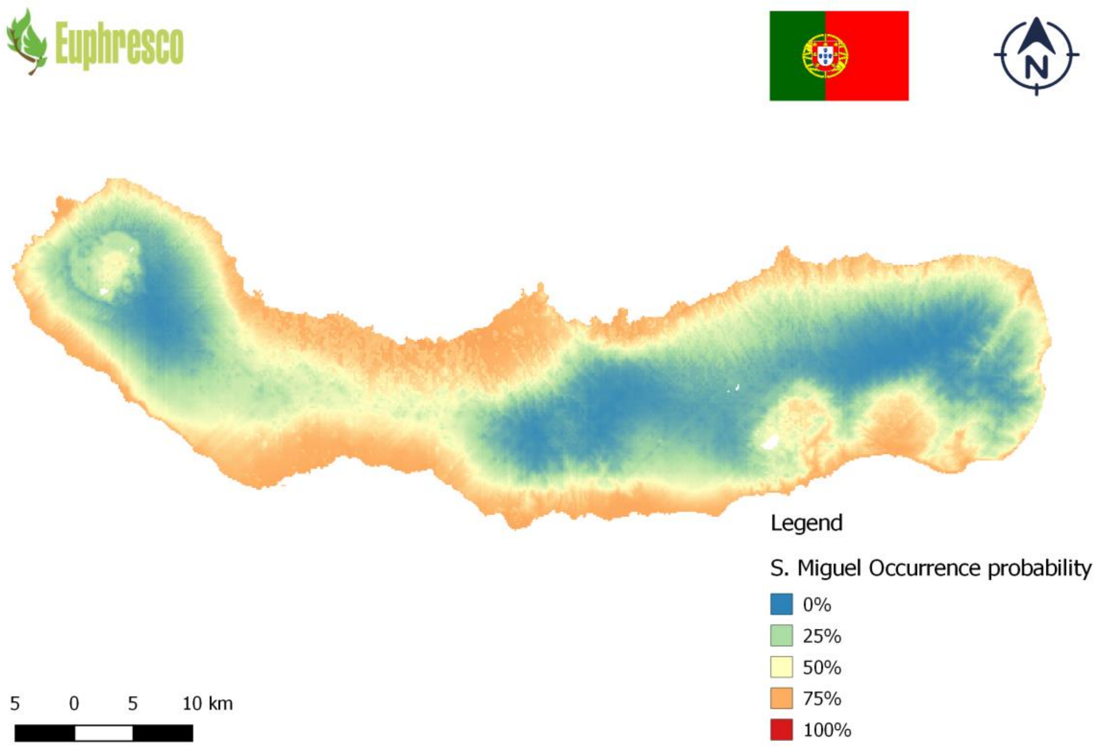


Figure 5.14.5 – *Ceratitis capitata* occurrence probability in São Miguel Island, Azores.

In the central group of islands of Azores archipelago, there are five islands (Terceira, S. Jorge, Graciosa, Faial and Pico), regarding Terceira Island (Fig. 5.14.6) mainly the border of the coastal areas around all island with the greater extension on the South and East have suitable conditions to the occurrence of *C. capitata.*

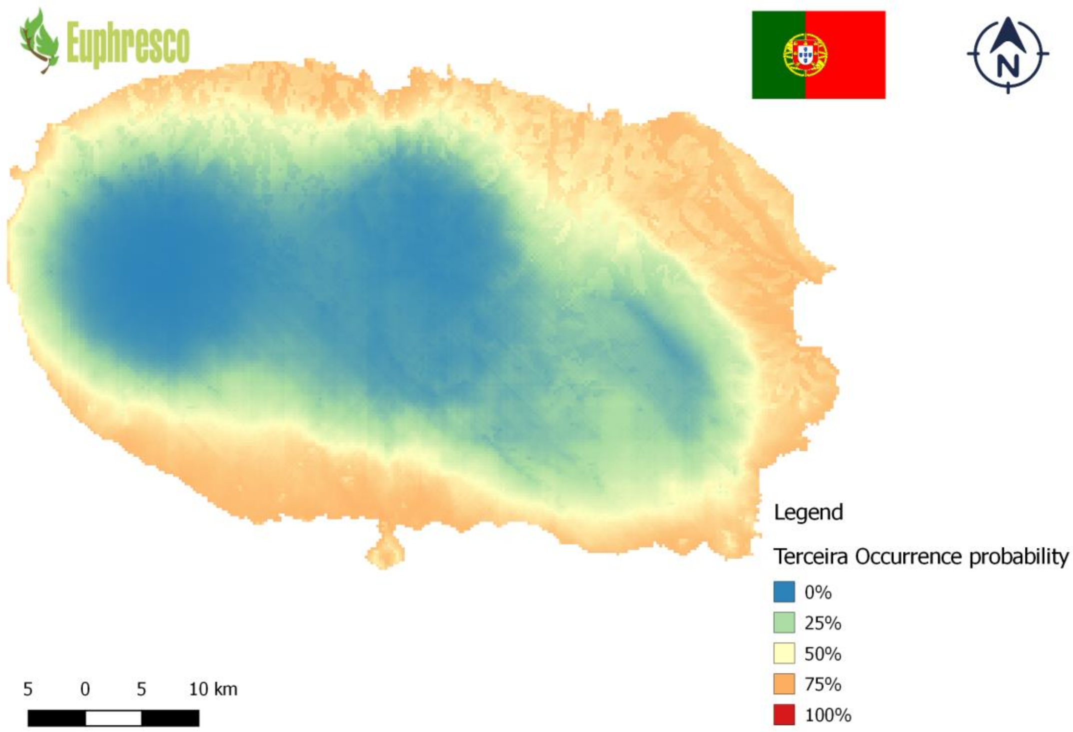


Figure 5.14.6 – *Ceratitis capitata* occurrence probability in Terceira Island.

In another island of the central group, S. Jorge Island (Fig. 5.14.7) because of its high altitude and small width, only the border of some of the coastal areas, namely the Fajãs, Velas and Calheta on the South part and the extreme West and East parts of the island, have suitable conditions to the occurrence of *C. capitata.*

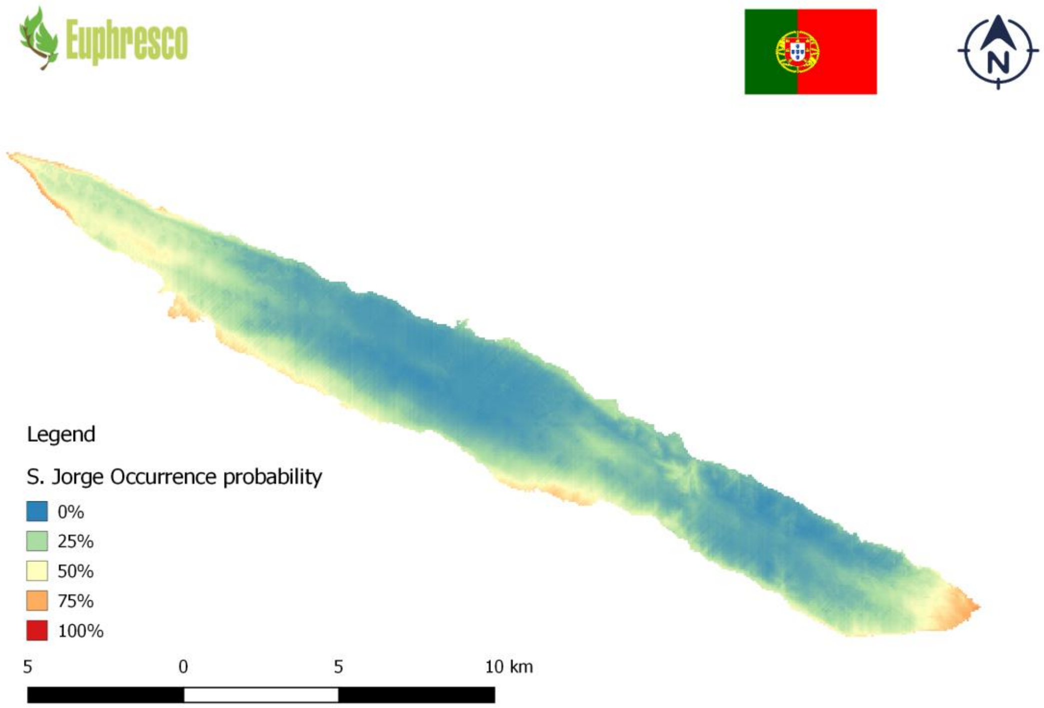


Figure 5.14.7 – *Ceratitis capitata* occurrence probability in São Jorge Island.

In another central group island, Pico (Fig. 5.14.8) mainly the border of the coastal areas around all island and mainly the West and South and a well delimitated area on the extreme point at East have suitable conditions to the occurrence of *C. capitata.*

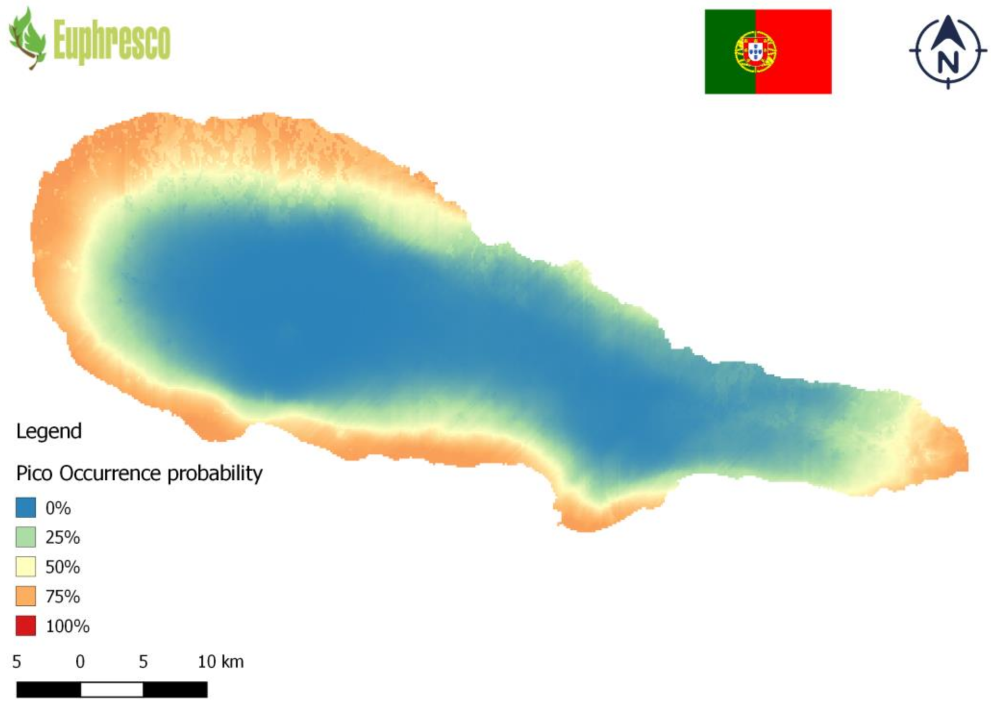


Figure 5.14.8 – *Ceratitis capitata* occurrence probability in Pico Island.

In another island of the central group, Faial Island (Fig. 5.14.9) the border of the coastal areas in the north and west of the island and mainly the South and South-East areas of the island have suitable conditions to the occurrence of *C. capitata.*

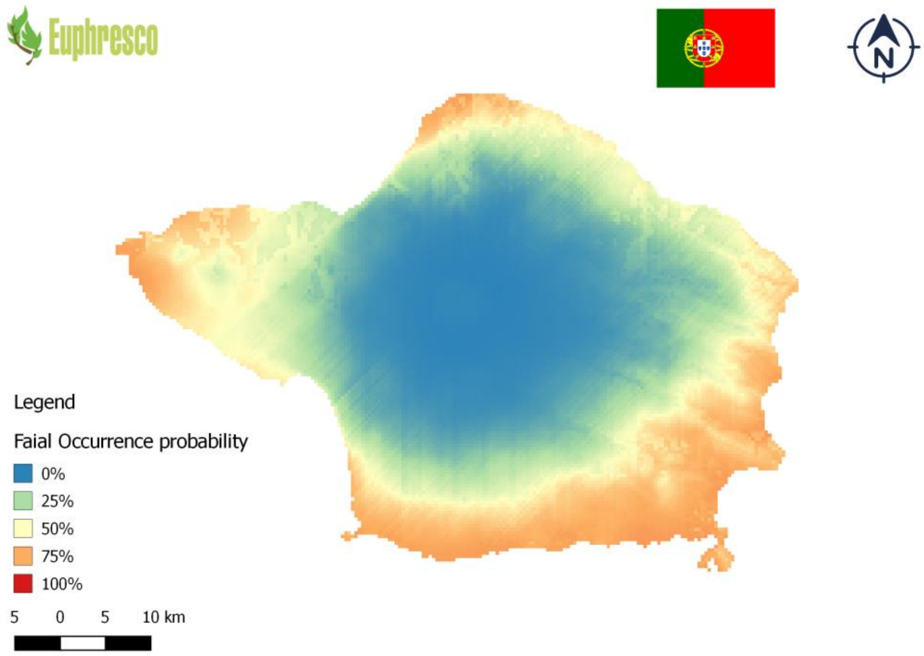


Figure 5.14.9 – *Ceratitis capitata* occurrence probability in Faial Island.

In another central group island, Graciosa because of its low altitude and flat orography and warm climatic conditions almost all areas of the island have suitable conditions to the occurrence of *C. capitata,* mainly on the northern part of it (Fig. 5.14.10).

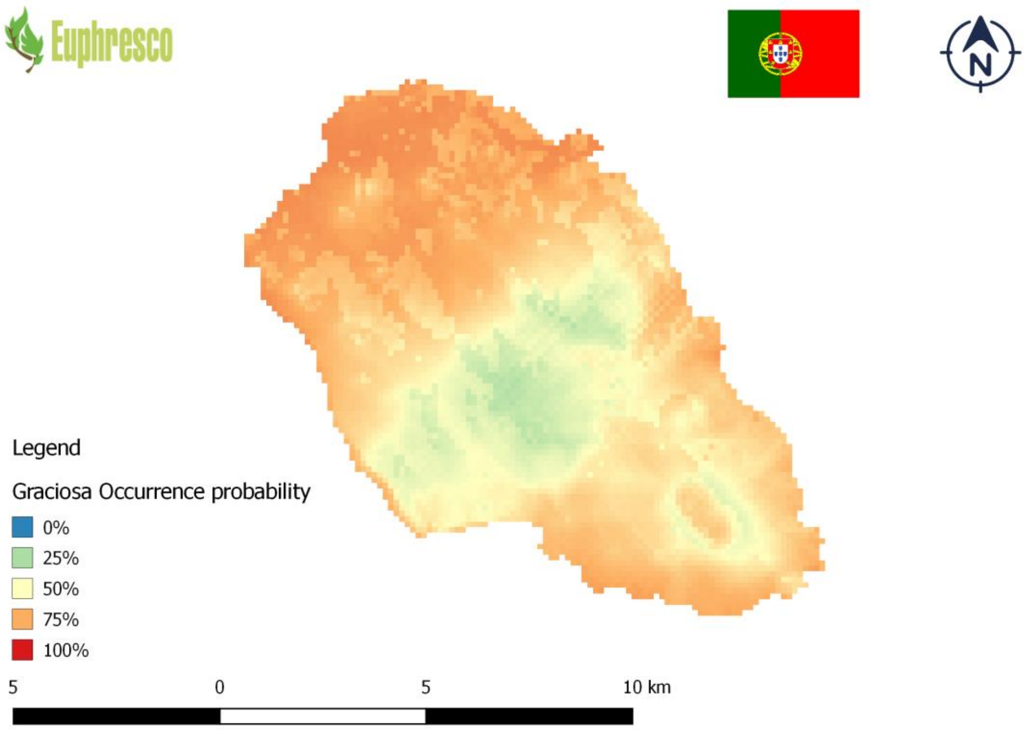


Figure 5.14.10 – *Ceratitis capitata* occurrence probability in Graciosa Island.

In the Western group there are two islands: Flores and Corvo (not modelled). In Flores (Fig. 5.14.11) all the island shows not suitable conditions to the occurrence of *C. capitata.*

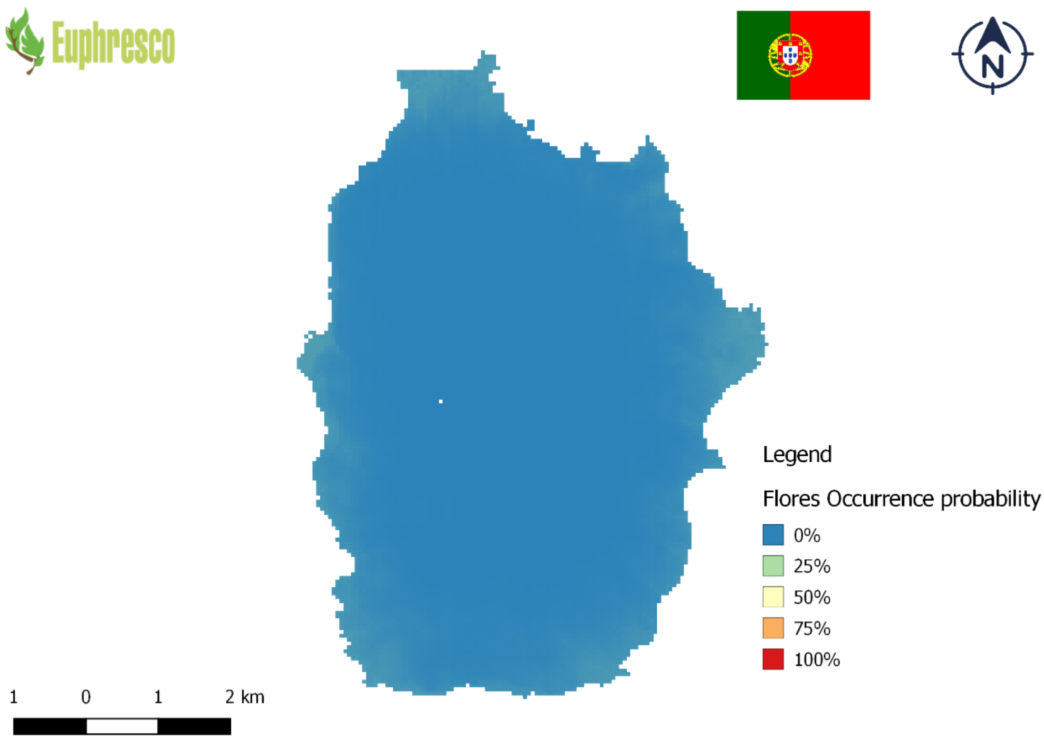


Figure 5.14.11 – *Ceratitis capitata* occurrence probability in Flores Island.

5.14.4.2 Model parameters for all Azores Islands

Prevalence: 0.5

Regularization: 4

Replica: 30

Threshold: "Maximum test sensitivity plus specificity" (maxSSS) of each replicate.

5.14.4.3 Results for all Azores Islands

The true statistic skill (TSS) was: 0.47 ± 0.09.

In terms of predictors in Azores Islands the contribution the abiotic factors were of 97.1% and the orography factors of only 2.9%, regarding the permutation importance of those predictor's was 96.7% and 3.4%, respectively (Table 5.14.1).

Table 5.14.1 – Predictors contribution for the Azores Islands.

Predictor	Contribution	Permutation importance
wc2.0_bio_30s_01 (Temperature)	70.4%	67.6%
wc2.0_bio_30s_12 (Precipitation)	19.4%	23.3%
Air Humidity *	7.3%	5.8%
Total of abiotic factors	**97.1%**	**96.7%**
Altitude	1.4%	1.4%
Soil Slope	1.1%	1.6%
Soil Exposure	0.4%	0.4%
Total of orography factors	**2.9%**	**3.4%**

References

Bodenheimer, F. S. 1951. Citrus Entomology in the Middle East: With Special References to Egypt, Iran, Iraq, Palestine, Syria and Turkey (Hardback), 1st edition. Springer, Liverpool, UK.

Elith, J., & J. R. Leathwick. 2009. Species Distribution Models: Ecological Explanation and Prediction Across Space and Time. Annual Review of Ecology, Evolution, and Systematics 40:677–697. doi: 10.1146/annurev.ecolsys.110308.120159.

Fick, S. E., & R. J. Hijmans. 2017. WorldClim 2: new 1-km spatial resolution climate surfaces for global land areas. International Journal of Climatology 37:4302–4315. doi: 10.1002/joc.5086.

Hijmans, R. J. 2012. Cross-validation of species distribution models: removing spatial sorting bias and calibration with a null model. Ecology 93:679–688. doi: 10.1890/11-0826.1.

Liu, S., G. Zhang, & J. Zhu. 1995. Influence of Temperature Variations on Rate of Development in Insects: Analysis of Case Studies from Entomological Literature. Annals of the Entomological Society of America 88:107–119.

Papadopoulos, N. T., B. I. Katsoyannos, & J. R. Carey. 1998. Temporal Changes in the Composition of the Overwintering Larval Population of the Mediterranean Fruit Fly (Diptera: Tephritidae) in Northern Greece. Annals of the Entomological Society of America 91:430–434.

Papadopoulos, N. T., B. I. Katsoyannos, J. R. Carey, & N. A. Kouloussis. 2001. Seasonal and Annual Occurrence of the Mediterranean Fruit Fly (Diptera: Tephritidae) in Northern Greece. Annals of the Entomological Society of America 94:41–50. doi: 10.1603/0013-8746(2001)094[0041:SAAOOT]2.0.CO;2.

Powell, M. R. 2003. Modeling the response of the Mediterranean fruit fly (Diptera:Tephritidae) to cold treatment. Journal of economic entomology 96:300–310.

Royle, J. A., R. B. Chandler, C. Yackulic, & J. D. Nichols. 2012. Likelihood analysis of species occurrence probability from presence-only data for modelling species distributions. Methods in Ecology and Evolution 3:545–554. doi: 10.1111/j.2041-210X.2011.00182.x.

U.S. Department of the Interior, & U.S. Geological Survey. 2018. Global Data Explorer (Powered by GeoBrain). Online spatial database. Retrieved January 17, 2018, from https://gdex.cr.usgs.gov/gdex/.

Vieira, R. M. da S. 1952. A mosca da fruta *Ceratitis capitata* (Wied.) na ilha da Madeira. Edição do Grémio dos Exportadores de Frutas e Produtos Hortícolas da Ilha da Madeira, Madeira.