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ORIGINAL ARTICLE

# FRUITFLYRISKMANAGE: A Euphresco project for *Ceratitis capitata* Wiedemann (Diptera: Tephritidae) risk management applied in some European countries

**David Lopes**[1] | **Eugenia de Andrade**[2] | **Alois Egartner**[3] | **Francisco Beitia**[4] | **Mojca Rot**[5] | **Constantina Chireceanu**[6] | **Valerie Balmés**[7] | **Antoon Loomans**[8] | **Tomasz Konefal**[9] | **Sanja Radonjić**[10]

[1]Azorean Biodiversity Group, Faculdade de Ciências Agrárias e Ambiente, Universidade dos Açores, Angra do Heroismo, Portugal

[2]Instituto Nacional de Investigação Agrária e Veterinária, I.P., Lisbon, Portugal

[3]Austrian Agency for Health and Food Safety, Wien, Austria

[4]IVIA, Valencian Institute of Agricultural Research, Valencia, Spain

[5]Institute of Agriculture and Forestry Nova Gorica, Nova Gorica, Slovenia

[6]Research and Development Institute for Plant Protection Bucharest, Romania

[7]Agence Nationale de Sécurité Sanitaire de l'alimentation, de l'environnement et du travail, Montferrier-sur-Lez, France

[8]Nederlandse Voesdel-en-Warenautoriteit, Wageningen, The Netherlands

[9]Główny Inspektorat Ochrony Roślin i Nasiennictwa, Toruń, Poland

[10]University of Montenegro Biotechnical Faculty, Podgorica, Montenegro

**Correspondence**
David Lopes, Azorean Biodiversity Group, Faculdade de Ciências Agrárias e Ambiente, Universidade dos Açores, Angra do Heroismo, Portugal.
Email: david.jh.lopes@uac.pt

**Abstract**

*Ceratitis capitata* (Wiedemann), the Mediterranean fruit fly or medfly, is one of the world's most serious threats to fresh fruits. It is highly polyphagous (recorded from over 300 hosts) and capable of adapting to a wide range of climates. This pest has spread to the EPPO region and is mainly present in the southern part, damaging *Citrus* and *Prunus*. In Northern and Central Europe records refer to interceptions or short-lived adventive populations only. Sustainable programs for surveillance, spread assessment using models and control strategies for pests such as *C. capitata* represent a major plant health challenge for all countries in Europe. This article includes a review of pest distribution and monitoring techniques in 11 countries of the EPPO region. This work compiles information that was crucial for a better understanding of pest occurrence and contributes to identifying areas susceptible to potential invasion and establishment. The key outputs and results obtained in the Euphresco project included knowledge transfer about early detection tools and methods used in different countries for pest monitoring. A MaxEnt software model resulted in risk maps for *C. capitata* in different climatic regions. This is an important tool to help decision making and to develop actions against this pest in the different partner countries.

**KEYWORDS**
Mediterranean fruit fly, models, pest management, risk maps

**FRUITFLYRISKMANAGE: Un projet Euphresco pour la gestion du risque relatif à *Ceratitis capitata* Wiedemann (Diptera: Tephritidae) appliqué dans certains pays européens**

*Ceratitis capitata* (Wiedemann), la mouche méditerranéenne des fruits, est l'une des menaces les plus sérieuses au monde pour les fruits frais. Elle est très polyphage (plus de 300 hôtes signalés) et capable de s'adapter à une grande diversité de climats. Ce ravageur s'est disséminé jusqu'à la région OEPP, et est principalement présent dans la partie sud, endommageant les *Citrus* et les *Prunus*. En Europe du Nord ou centrale, les signalements ne concernent que des interceptions ou des incursions. Des programmes durables de surveillance, d'évaluation de la dissémination à l'aide de modèles et de stratégies de lutte contre des organismes nuisibles tels que *C. capitata*, représentent un défi phytosanitaire majeur pour tous les pays d'Europe. Cet article comprend une revue de la répartition géographique du ravageur et des techniques de surveillance dans 11 pays de la région de l'OEPP. Ce travail compile des informations cruciales pour une meilleure compréhension de sa présence et contribue à identifier les zones potentielles d'incursion et d'établissement. Les principales productions et résultats obtenus dans le cadre du projet Euphresco comprennent le transfert de connaissances sur les outils et méthodes de détection précoce utilisés dans différents pays pour la surveillance de *C. capitata*. Un modèle réalisé à partir du logiciel MaxEnt a permis d'établir des cartes de risque pour *C. capitata* dans différentes régions climatiques. Il s'agit d'un outil important pour aider à la prise de décision et au développement d'actions contre ce ravageur dans les différents pays partenaires.

**FRUITFLYRISKMANAGE: проект Euphresco по управлению фитосанитарным риском, связанным с *Ceratitis capitata* Wiedemann (Diptera: Tephritidae) и применяемым в некоторых европейских странах**

*Ceratitis capitata* (Wiedemann), средиземноморская плодовая муха, является одной из самых серьезных мировых угроз для свежих плодов. Она отличается высокой полифагией (отмечено более 300 хозяев) и способна адаптироваться к широкому диапазону климатических условий. Этот вредный организм распространился в регионе ЕОКЗР и присутствует в основном в южной его части, повреждая растения родов *Citrus* и *Prunus*. В северной и центральной Европе регистрируются только выявления в грузах или первичные недолговечные очаги. Стабильные программы надзора, оценки распространения с использованием моделей и стратегии борьбы с такими вредными организмами, как *C. capitata*, представляют собой серьезный фитосанитарный вызов для всех стран в Европе. Статья включает обзор распространения вредного организма и его мониторинга в 11 странах региона ЕОКЗР. В работе собрана информация, имевшая решающее значение для лучшего понимания присутствия вредного организма и способствующая определению зон, подверженных риску потенциальной инвазии и акклиматизации. Основные выводы и результаты, полученные в рамках проекта Euphresco, включали передачу знаний о средствах раннего выявления и методах, используемых в разных странах для мониторинга этого вредного организма. С помощью программы MaxEnt были составлены карты риска для *C. capitata* в различных климатических регионах. Это важный инструмент для принятия решений и разработки действий по борьбе с этим вредным организмом в различных странах-партнерах.

## 1 | INTRODUCTION

*Ceratitis capitata* (Wiedemann), also known as the Mediterranean fruit fly or medfly, is one of the world's most destructive plant pests. It is a highly polyphagous species recorded from over 300 hosts, belonging to 70 plant families, worldwide and it is known to adapt to a wide range of climates (EPPO, 2022; Lopes et al., 2006; White & Elson-Harris, 1992). It is an important pest because it is cosmopolitan and multivoltine, standing out from other species due to its high invasive potential. Diamantidis et al. (2009) showed that *C. capitata* populations have evolved resulting in different life-history strategies under different environmental conditions. Resistance to the effects of climate stress, demography, population fluctuations and number of annual generations also differ according to the environmental situation and local bioclimatic conditions (Nyamukondiwa et al., 2013). The medfly occurs during most of the year, where climate allows, mainly during fruit maturation (Copeland et al., 2002; Yuval & Hendrichs, 2000). Its dispersive capabilities allow *C. capitata* to find areas with high levels of available fruit (Bateman, 1972, 1976).

*C. capitata* is of Sub-Saharan African origin (probably Eastern or Southern Africa). From Africa it spread first to the Mediterranean Basin and then to different parts of the world (Ruiz-Arce et al., 2020). In addition to direct impact, it is a quarantine species in many countries and therefore can affect the export of fruit. It is mainly present in the southern part of Europe, where it is particularly damaging on *Citrus* and *Prunus*. In Northern or Central Europe, this pest has also been recorded but only as a limited number of interceptions or short-lived adventive populations.

Sustainable programmes for pest surveillance, spread assessment and implementation of control measures are among the greatest challenges for any country to protect its agricultural production. For this purpose, comprehensive information on *C. capitata* occurrence, in both spatial and temporal terms, is crucial to understand the current and historical extent of its occurrence, conditions of survival and areas susceptible to potential invasion and establishment. An understanding of the ecology and monitoring methods for the Mediterranean fruit fly is very important for the management of this pest.

Reliable methods to control the Mediterranean fruit fly depend on investigating the distribution and population abundance, and testing effective control means. Monitoring the population abundance and distribution represent important and reliable methods to know the population level and can be used as a decision tool to implement other strategies for the management of this pest (Abreu, 2019). Emphasis has been placed on implementing safer environmental measures to control *C. capitata*, such as mass trapping (Díaz-Fleischer et al., 2014; Pinero et al., 2009).

Biotechnical control strategies and mass capture methods can lead to valuable information to reduce mating in practice, and consequently decrease adult populations and reduce the damage and losses on fresh fruits (Abreu, 2019). Mass trapping should be considered as an alternative to chemical treatments because it does not leave insecticide residues in fruit and is safer for applicators and the environment (Hafsi et al., 2020). Several studies have shown that the efficacy and selectivity of mass trapping strongly depend on female choice, especially on the quality of food-based bait formulations (Broumas et al., 2002; Epsky & Heath, 1998).

Some studies showed that mass trapping has the same efficacy as chemical treatments to avoid fruit fly outbreak (Navarro-Llopis et al., 2010, 2011). Previous studies support the use of mass trapping with an adequate food-based bait to manage *C. capitata* by testing different types of traps and attractants. This gave greater effectiveness in terms of adult captures and can be used in efficient strategies against this pest (Lopes et al., 2006, 2008, 2011; Pimentel et al., 2014, 2017a; Pimentel & Lopes, 2018).

This FRUITFLYRISKMANAGE project (2017-A-236) aimed to gather more information about *C. capitata* in Europe. For that purpose, all project partners exchanged information on the current distribution of this pest population in their own country and maps of the location and areas of occurrence specific for each country.

Early detection tools and management strategies implemented by the different countries were also analysed, and data from captures and climatic parameters allowed the construction of models which identified areas of probable occurrence of this pest and therefore better supported and more focused control of *C. capitata*.

## 2 | MATERIALS AND METHODS

### 2.1 | Occurrence and geographical distribution of *C. capitata*

The FRUITFLYRISKMANAGE project (2017-A-236) involved 11 countries and research groups from the EPPO region. The countries involved were Austria, France, Germany, Montenegro, the Netherlands, Poland, Portugal, Romania, Slovenia, Spain and Ukraine.

The early detection tools used in each country are described in Table 1. Note that some countries used more than one type of trap in the field. Different traps are shown in Figure 1.

### 2.2 | Models for occurrence prediction

Comprehensive global information on *C. capitata* occurrence, in both spatial and temporal terms, is important for understanding the current and historical extent of its occurrence, the conditions where *C. capitata* is able to survive and the areas susceptible to potential invasion and establishment. Occurrence records with temporal reference are needed to understand the factors driving medfly seasonal population dynamics and can be valuable for guiding eradication and control strategies (Szyniszewska & Tatem, 2014). An extensive literature search was therefore necessary to obtain the most comprehensive data on the historical and contemporary spatio-temporal occurrence of *C. capitata* globally before choosing the model presented in this work.

One of the greatest challenges of the species model distribution (SMD) was to select the right environmental dataset predictors and the sample size. For this purpose, three datasets were chosen based on several research works, particularly those carried out for *C. capitata* abiotic tolerances from Bodenheimer (1951), Vieira (1952), Liu et al. (1995), Papadopoulos et al. (1998), (2001) and Powell (2003).

Some orographic predictors were also included, as in most of the SMD works in the literature for learning and projection purposes. The values for air humidity were relevant, as shown in Fick and Hijmans (2017), and values of temperature were also used in this work.

As a start for the modelling work a dataset from the Global Biodiversity Information Facility (http://www.gbif.org with DOI reference https://doi.org/10.15468/dl.gdwmme) containing 104 199 occurrences of Tephritidae species was used. After removing duplicates (points sharing the same coordinates) and points on the ocean, 16 723 records regarding only the Tephritidae family dataset were obtained, and from those 1647 records on the *Ceratitis* genera dataset and 587 records on the *C. capitata* species dataset were used in the modelling.

In addition, all the partner country data related to *C. capitata* captures from monitoring from the Euphresco project were used to build the model presented.

The MaxEnt program was used in niche and population distribution modelling (Elith & Leathwick, 2009; Fick & Hijmans, 2017; Pimentel et al., 2017b; Phillips et al., 2006; Phillips & Dudik, 2008). For the Maxent parameter configuration, we assumed a prevalence value

**TABLE 1** Trap type and attractant used in monitoring *C. capitata* adults in each partner country.

| Country | Trap type/lure |
|---|---|
| Austria | **Tehpri trap** (mainly) with parapheromone trimedlure |
| France | **Ceratipack** with specific attractant, also coated with insecticide (deltamethrin) |
| | **Decis trap**: 0.015 g of deltamethrin + 7.8 g of ammonium acetate + 0.5 g of chlorohydrate trimethylamine + 0.03 g of 1,5-diamineopentane per trap |
| | **Ceratrap** with food attractant [hydrolysed proteins 5.5% p/p (59 g/L)] |
| Germany | **Easy Trap** with sexual pheromone Trimedlure and an insecticide |
| Montenegro | **Tephri trap** with three-component female-biased dry-food attractant (ammonium acetate, trimethylamine and putrescine) and insecticide dichlorvos (2,2-dichlorovinyl demethyl phosphate [DDVP] strips; used since 2018) |
| | **Jackson trap** baited with para-pheromone Trimedlure (used continuously since 2013) |
| Netherlands | **Delta trap** with EGOlure (in combination with a yellow sticky trap to catch the incidental female specimens) |
| Poland | **McPhail pheromone trap** |
| Portugal/Azores Islands | **Easy Trap** with Trimedlure or UniPak, a three-component lure (ammonium acetate, trimethylamine and putrescine; in 2006–2008) |
| | **Conetrap Ceratitis**: trap with attractant (ammonium acetate, trimethylamine and diaminalkane; tested in 2018) |
| | **Jackson trap** with Trimedlure (since 2006) |
| | **Tephri trap** with three-component female-biased dry-food attractant (ammonium acetate, trimethylamine and putrescine) and insecticide dichlorvos (DDVP strips; since 2008) |
| | **CeraTrap** with hydrolysed proteins 5.5% p/p (59 g/L; since 2018) |
| Romania | **Tephri trap** with UniPack three-component lure (ammonium acetate, trimethylamine and putrescine) |
| Slovenia | **Tephri trap** baited with a three-component lure (ammonium acetate, trimethylamine and putrescine) or Biolure |
| | **Jackson trap** with Trimedlure |
| Spain | **Ceratipack:** the lid of the trap is impregnated with a contact insecticide (deltamethrin) with attractant Ceratiprotect |
| | **Decis trap** with food attractant (hydrolysed proteins 5.5% p/p (59 g/L)) |
| | **Karate trap:** specific attractant and trap composed of base and cover with insecticide with lambda-cihalotrin (0.0075 g de s.a./trap)·(RB)·p/p |
| | **Conetrap Ceratitis Pack**: trap with attractant (ammonium acetate, trimethylamine and diaminalkane) |
| | **Cera trap** with hydrolysed proteins 5.5% p/p (59 g/L) |
| | **Magnet Med**: trap coated with deltamethrin |
| | **Nadel trap** with Trimedlure or liquid attractants and insecticide |
| Ukraine | **Petal trap**: yellow with pheromone dispenser |

*Note*: Bold indicates Traps Commercial name.

of 0.5. The best model performance evaluation was achieved using two methods, one qualitative and another quantitative. The qualitative visual examination was made from the resulting projections based on partner country sampling data with QGIS. After the initial triage, we used the true statistic skill (TSS; Allouche et al., 2006; Shabani et al., 2018).

Three datasets based on several research works carried out for *C. capitata* abiotic tolerances were designed.

The values for air humidity were not available for downloading 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 of humidity and temperature, therefore solving the set of equations to get the humidity variable, one gets the following formula:

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

where vp is the vapour pressure and $T_m$ is the mean temperature. With this formula and a raster calculator of QGIS, a grid file of world air humidity can be generated.


**FIGURE 1** Traps type used in the different partner countries.

For Maxent parameter configuration, a prevalence value of 0.5 was assumed, and independent runs were done for each regularization value from 1 to 10.

The best model performance evaluation was achieved using two methods, qualitative and quantitative. First, we did a qualitative visual examination of the resulting projections based on partner country sampling data with QGIS. After the initial triage, we used the TSS. The TSS is the best statistic (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 maximized. This measurement followed a suggestion by Allouche et al. (2006) is regularly used.

## 3 | RESULTS AND DISCUSSION

World fresh fruit production is currently vulnerable to the appearance of new pests, as well as to the increased incidence of existing species, such as fruit flies like *C. capitata*, that 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, widening their geographical distribution, and has been aggravated in recent years by the absence of cold in the winter months leading to an increase in populations causing damage/loss earlier and extending their season of permanence affecting fruit crops.

### 3.1 | Occurrence of adults and geographical distribution in countries involved in the project

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). It is therefore very important to ascertain the *C. capitata* situation for each country (summaries are provided in Table 2).

In Austria the first described *C. capitata* adult finding dates back to the 1930s, but also medfly has also been caught in this country several times in the last decade, e.g. in 2012 (EPPO, 2012a). Recent monitoring activities for medfly and subsequently also for further important fruit flies (of the genus *Bactrocera*) started in Vienna in 2010 (Egartner et al., 2019a, 2019b). Surveys were extended from 2016 onwards to other federal provinces with the definition of up to 36 sampling sites to monitor per year. This monitoring resulted in the capture of 1186 *C. capitata* adults, which includes the catches until 2018. The majority of the trapped individuals (>99%)

**TABLE 2** Countries and region situation regarding *Ceratitis capitata* adults capture records.

| Country | Situation (EPPO) | Sites with registration of *C. capitata* adult captures |
|---|---|---|
| Austria | Absent, intercepted only | Mainly in Vienna, few findings of single individuals in other provinces |
| France | Present, restricted distribution Establish in the southern part | South-west along the Atlantic coast and further inland |
| Germany | Transient | Along 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 |
| Montenegro | Present, no details | Along the whole coastal area, Podgorica city suburbs, northern to sea coast in Skadar Lake, Crmnica (locality Godinje) and coastal localities Budva and Bigovo, and coastal locality Kumbor (area of the Boka Kotor Bay) |
| Netherlands | Absent, pest no longer present | |
| Poland | Absent, pest no longer present | Trzebnica |
| Portugal | Present, widespread | |
| Azores (PT) | Present | In all orchards and vineyards of the different islands |
| Romania | Present, restricted distribution | South of the country; in West, South and South-Eastern Romania |
| Slovenia | Present, restricted distribution | In Koper in the coastal part of Slovenia; some localities in the Vipava valley in the western part of Slovenia; Neblo in the western part of Slovenia |
| Spain | Present, widespread | In the Valencian Community (Eastern Spain); mainly on the Mediterranean coast (Andalusia, Catalonia and Murcia) |
| Islas Baleares (ES) | Present, restricted distribution | |
| Islas Canarias (ES) | Present, no details | |
| Ukraine | Transient | Odessa region (Chernomorsk) and occasionally in Krym and Southern Ukraine |

were recorded at sampling sites in Vienna. In 2016 and 2017 a maximum of two individuals were caught at three sites in other provinces of Austria. Furthermore, from the collection of suspicious fruits from three Viennese sampling sites medfly emerged (in low numbers) from incubated peaches, apricots and pears.

Surveys from later years provided comparable results in terms of the number of adults caught and the geographical distribution of catches. So far collected data indicate that medfly sometimes is able to develop more than one generation per year in Vienna, but the pest currently causes hardly any economic damage where it occurs. The potential of medfly to survive Austrian winter conditions is part of an ongoing international project (see https://fruitflies-ipm.eu/).

In France, *C. capitata* has been present since 1885 in the southern part of the country and isolated findings have been registered in the northern part of France (Ile-de-France region) since the 1950s, although the medfly cannot be considered as established there (EPPO, 2012b). In 2010 and 2011, isolated findings were made in the Ile-de-France region. In 2010, the pest was caught in the Yvelines department and in 2011 several specimens were caught in Paris (Jardin du Luxembourg) and in the Val d'Oise department (two sites; EPPO, 2012b). The pest has been found regularly in the south-west both along the Atlantic coast and further inland. Currently, there is no national monitoring plan and no national eradication plan. In mainland France, apples are the most affected fruit, followed by peaches, nectarines and apricots (late varieties). In Corsica, the same plants are affected but the main damage is on citrus and an endemic population is present with low densities on nectarines and peaches. Trapping is planned during August and September in the orchard areas (for fruit production) that registered the medfly presence. In some regions, producers set up traps to carry out monitoring or mass trapping, but the results are not centralized.

In Germany *C. capitata* has only been found a few times and this occurred in close vicinity to fruit markets. Established populations have never built up. Conditions are not suitable for overwintering in Germany (EPPO, 2022). In addition, peach, the main host, has almost disappeared from German orchards (EPPO, 1988). Hibernating *C. capitata* are not adapted to the phenological characteristics of available hosts, and they do not survive due to a lack of suitable fruits.

Wide scale monitoring for *C. capitata* was conducted in 2015 and 2016. In 2015, adults were 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 specimens were trapped during this year. In 2016 the number of trapped medfly specimens increased to 188 in the federal states of Baden-Württemberg, Bavaria, Berlin, Brandenburg, Lower-Saxony, North Rhine-Westphalia, Rhineland-Palatinate, Saxony, Saxony-Anhalt and Thuringia. In 2017 the number of medfly adults trapped was extremely low, with only 29 specimens trapped in Baden-Württemberg, Rhineland-Palatinate and Saxony. Those were single specimens except for Baden-Württemberg, where a few specimens were trapped at the same time in one location, close to the major location from 2016. In 2018 and 2019, the German plant protection services did not conduct any surveys for medfly, as extensive monitoring made during the years 2015 to 2017 showed that *C. capitata* does not appear to be established in Germany. Single specimens might be introduced frequently with imported fruits from infested areas in other European countries. For 2018 it was only possible to obtain data from an important apple-growing area in the single state of Lower Saxony and medfly was not found there.

In Montenegro mandarin makes up more than 85% of citrus production and the medfly is considered to have been an established pest since the early 2000s (Radonjić et al., 2013). Continuous medfly monitoring started in 2002 after serious economic damage occurred in commercial mandarin orchards (cultivar Unshiu). The results of this monitoring showed the presence of medfly along the whole coastal area on the following host plants: mandarin, orange, lemon, grapefruit, fig, persimmon, jujube and peach (Radonjić et al., 2013, 2019). *C. capitata* gradually spread from the coastal area into other areas, which are also suitable in term of climatic conditions and host fruit availability (Radonjić & Hrnčić, 2011). In fact, medfly was detected for the first time away from the Montenegrin coast in Podgorica city suburbs (2008, 2009, 2010) and in 2010 in the area of Skadar Lake, Crmnica (locality Godinje). In the area around Podgorica medfly adults were caught in low densities from mid-August to mid-November. In 2009 at the beginning of November infested persimmon fruits were recorded. In mid-September 2010, fallen apples (variety Golden Delicious) were found to be affected in Godinje. This was the first detection of *C. capitata* on apples in Montenegro. In the same year, in the coastal localities Budva and Bigovo infested apples (variety Idared) were also found. In Montenegro medfly has distinct seasonal patterns in population fluctuation and, generally, without adult activity in the winter and no adult captures in traps also in spring and early summer. The absence of host plants in spring and early summer together with decreasing temperature in December and particularly in January could be considered as determining parameters for *C. capitata* adult activity (Radonjić et al., 2013). However, in 2013–2014 during the warm winter, several medfly adults were captured at the beginning of February in some backyards in the coastal locality Kumbor (area of the Boka Kotor Bay). These findings, taken together with the evidence of low captures in December and January in several localities in this area, could lead to the assumption of possible adult activity during mild winters. Kumbor belongs to the area of Boka Kotor Bay, which is an urban area where often some unharvested mandarins and orange fruits remain in the canopy during winter and spring. In this locality temperature may be somewhat higher than in the rest of the surveyed areas. In conclusion, the population dynamics of *C. capitata* in Montenegro are influenced by host fruit availability and abundance, and the sequence of available host fruits increases in September and October (mandarins, persimmons). This can be responsible for a distinct and large population increase taking in account the importance of figs as the first available hosts in the season that will contribute to medfly population increases later in the summer months (Radonjić et al., 2013, 2019).

In the Netherlands the presence of medfly is only related to fruit imports and the risk is enhanced during the summer months. Since 1960, continuous structured monitoring of insect pests in fruit orchards throughout the country has never shown any new medfly infestation. It is concluded that the organism is not present. Necessary quarantine measures were taken to prevent introduction (EPPO, 1987). Between 2006 and 2016 survey activities have resulted in catching 54 medfly specimens. From 2017 to 2020, 28 locations were selected and a monitoring survey regarding the (seasonal) medfly adults' presence was conducted. The locations selected were high-risk locations and included nine companies which combine imports with (greenhouse) cultivation, three localities with previous findings, three locations where compost processing takes place, four vegetable and fruit market auction sites, two harbours and seven fruit-growing companies (apples, pears, cherries) located close to urban areas. From 2017 until 2020 these surveys resulted in zero findings of medfly adults.

In Poland a total of 48 traps were installed in 2017 at 43 locations in the territory of five Voivodeships (districts in west and south-western part of Poland) and there were no *C. capitata* adults trapped. In 2018 the monitoring programme resulted in the first medfly catches in Trzebnica (26 males). The circumstances of this finding suggest that the catches resulted from the introduction of infested fruit because in Dolnośląskie voivodship there are seven supermarkets, one fruit warehouse and a municipal waste landfill (approximately 4 km away). Considering the finding date (late in the growing season) and the adverse climatic conditions prevailing during Polish winters, the EPPO considered that this incidental finding cannot lead to the establishment of the pest. In 2019 only one record of a *C. capitata* adult was registered in the same place. No other symptoms of presence (pre-adult stages or damage on fruits) were found in this place. The pest status of *C. capitata* in Poland is officially declared as: absent, pest no longer present for reasons other than eradication. This insect is a species of tropical origin has not developed adaptation measures to survive to Poland cold seasons (EPPO, 2019).

In Portugal *C. capitata* has been known as a pest since the 19th century. In the Algarve, in the southern part of the country, medfly populations are high and mainly affect orange production almost all the year round from January to December (DGAV, 2020). To study and solve this problem and to limit the increasing population size and medfly spread, a regional integrated strategy to control this insect has been drawn up by the Algarve Agriculture Directorate and supported by the National Phytosanitary Authority the General Directorate of Agriculture and Veterinary (DGAV; DGAV, 2020).

In Madeira this pest has been present since 1995. The Madeira-Med programme was implemented for some years with International Atomic Energy Agency (IAEA) support. This was a good example for the use of biotechnical tools against medfly. This programme allowed the construction and operation of a Madeira Insect Biofactory (Madeira-Med programme) and the application of the sterile insect technique (SIT) to decrease medfly adult populations and damage in fruit production (Abreu, 2019).

On the Azores Islands, according to Bodenheimer (1951) and Orlando (1980), medfly was first identified in 1829. In the last 5 years (2016–2021) it has been damaging fruits in citrus orchards and some table grapes on all the islands. Climate change is creating conditions for species such as medfly to multiply much faster. The lack of rain and the abnormal temperatures create an environment in which it is possible to have five to eight generations per year. Chemical control is proving to be less and less effective.

In the Azores medfly population monitoring, particularly in Terceira Island, started with the INTERFRUTA and INTERFRUTA II projects (https://keep.eu/projects/10803/Promotion-of-the-Culture-of-EN/) and other options have since been developed, such as efficacy tests using different traps, dispersion tests using sterilized males produced in the Madeira Insect Biofactory (Madeira-Med programme), identification of medfly parasitoids, making a list of suitable hosts and infestation rate determination. Lopes et al. (2006, 2008, 2009) studied medfly population dynamics and evaluated the effect of landscape elements and host plants on medfly distribution. They identified areas with medfly populations using GIS tools. These authors established a relationship between adult captures and existing fruit species in the orchards, fruit availability and seasonal temperature variations. Pimentel et al. (2014) elaborated in their studies, in addition to pest aggregation and host-plant pest relationships, the influence of weather conditions such as temperature, air humidity and rainfall (soil humidity) in the medfly life cycle and this insect's ability to disperse. Azevedo (1996) concluded that the topography of the Azores Islands has a great influence on weather conditions, causing microclimates, which, according to Pimentel (2010) and Pimentel et al. (2014), contribute to local medfly aggregation or dispersion.

Another project, CABMEDMAC (https://keep.eu/projects/2154/CabMedMac-EN/), studied and evaluated the abundance of medfly adults in relation to some spatial characteristics of target locations in Terceira and São Jorge Islands (Pimentel et al., 2017a). This project also applied some bio-technical control strategies through the installation of traps (attract and kill) and the use of sterilized males (SIT technique) against medfly that showed great efficacy in Terceira Island conditions (Lopes et al., 2008, 2009, 2011). More recent the Cuarentagri project (www.cuarentagri.com) developed medfly adult monitoring activities on three islands of the Azores archipelago (Terceira, São Jorge and São Miguel). In 2018 an alert network was established for this pest on those islands, contributing to a better and more sustainable decision-making process and guiding the choice of sustainable means for fighting the pest with the least environmental impact and limiting pesticide applications.

In Romania the first mention of *C. capitata* appearance was in 2007, when a few larvae were observed in fruits of *Diospyros kaki* in an experimental field in the south of the country. The possible entry pathway was related to the planting material of exotic fruit trees brought into the country from China (Chireceanu et al., 2013; Stanciu, 2007). In the period of 2013–2017 a survey programme on medfly was performed within the framework of three regional projects under the coordination of the International Atomic Energy Agency (IAEA). These survey activities continued throughout 2018 and 2019 under the Euphresco FRUITFLYRISKMANAGE project (2017-F-236). Tephri traps to capture medfly adults were placed in fruit tree orchards in fruit-growing areas in different parts of Romania and in the backyards of houses and institutions, botanical gardens and experimental fields in the spring, summer and autumn seasons according to the period of fruit ripening. In the last 7 years of monitoring 130 traps were used each year. Adult medflies were detected every year in small numbers (between one and six specimens/trap/site) on all types of placements (fruit orchards, houses backyards, 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 *C. capitata* was recorded from the traps placed on jujube (*Ziziphus jujuba*) in Bucharest monitored from 2013 to 2019. Annual captures were between two and 202 flies. In the autumn of 2019, 86 flies (50 males and 36 females) were trapped in a commercial apple orchard near a supermarket selling exotic fruits, especially citrus, imported from countries including Türkiye and Greece. Based on trap catches, the official authorities concluded that medfly has a low and sporadic presence and does not represent an important phytosanitary risk for Romania. It seems that medfly can develop at least one generation per year in the Bucharest zone, from the end of August to October.

In Slovenia, adults of *C. capitata* were first detected in 1959 in Koper in the coastal part of Slovenia (Peyrek, 1960). Since then, medfly has established in the coastal part of the country (Slovenian Istria; Rot et al., 2015). From 2013 to 2019 it was found in the traps in the mainland interior in some localities in the Vipava valley in the western part of Slovenia but cannot be considered as established there. Until now, attacks and considerable yield losses have been detected only on persimmon, on which medfly is considered an important pest, and on late varieties of peaches. Since 2000, monitoring has been carried out in the coastal areas and detection surveys have been carried out in Western Slovenia. Recent monitoring activities financed by IAEA projects were made in Western Slovenia. From 2013 to 2017 monitoring of medfly and some other exotic species of Tephritidae was carried out in an extended area in the western part of the country. Stable medfly populations were recorded in coastal areas over a period of 5 years, with the highest abundance in 2013. Small, barely detectable populations occurred in some locations in the Vipava Valley (Rot et al., 2015; Žežlina, 2018). Within the Euphresco FRUITFLYRISKMANAGE project (2017-F-236) in 2018 and 2019 medfly monitoring was extended to the entire country. A 2-year survey confirmed the absence of the species in most areas of the country, except in the coastal part, where it was already present. As a result of all this work in the last 2 years some new records of medfly appeared in new locations (IAFNG/Mojca Rot pers. com. 30/12/2020). In the central part of Slovenia (Brdo pri Lukovici) one adult was caught in 2018. That was probably an interception because modelling does not suggest establishment in that area. In 2019, other medfly adults were found in a different location (Neblo) in the western part of Slovenia for the first time.

In Spain *C. capitata* has caused significant damage and direct losses in crop production in recent years, despite the permanent control activities undertaken. In the Valencian Community (eastern Spain) medfly populations cause serious damage to various fruit crops (mainly citrus). In 2004 an Integral Action Plan was established, in which the measures to be followed for the control of the pest are indicated (Pla et al., 2018), thus very precise data on adult captures for more than 10 years (2009–2019) are available. Medfly populations are found practically all over the country every year, mainly on the Mediterranean coast (Andalusia, Catalonia and Murcia) and in both archipelagos (Canary Islands and Balearic Islands) and in some inland Autonomous Communities (Aragon, Castilla-La Mancha, Extremadura, La Rioja and Navarra). The medfly situation is reported annually by the Plant Health Services of the different Autonomous Communities mentioned and is reflected in the corresponding plant health bulletins (EPPO, 2010, 2016).

In Ukraine the occurrence of *C. capitata* was first reported in 1964, and the pest appeared again in 1966/1968 but was eradicated. Every year medfly in various stages of development are detected in citrus lots imported from countries with endemic *C. capitata* populations. In Ukraine this pest is regularly detected in fruits and vegetables during import inspections. It probably enters with host products from countries such as Egypt, Cyprus, Türkiye, Greece and Spain. For that purpose, the State Plant Quarantine Service annually monitors the territory of Ukraine to detect *C. capitata* using pheromone traps. In 2007, an outbreak of medfly was detected in the Odessa region (Chernomorsk). An action plan for localization and elimination of outbreaks was developed and implemented, and the pest was successfully eradicated. In 2011, surveys were conducted using 1700 pheromone traps in an area of over 3 million ha, and an infested area of 9.9 ha was found (EPPO, 2014). During 2017–2018, in the framework of this Euphresco project, medfly traps were placed in plum trees in backyards or gardens in the Chernomorsk area. Traps were installed from July to September and no medfly adults were trapped during these years. This pest has only occasionally been found in Krym and Southern Ukraine but is always subjected to eradication campaigns.

## 3.2 | Models for occurrence prediction

One of the main objectives of the FRUITFLYRISKMANAGE project (2017-A-236) was the elaboration of risk maps with the probability of occurrence of *C. capitata* in all the partner countries. The TSSs obtained for each country are shown in Table 3.

**TABLE 3** True statistic skill for medfly obtained for each country studied.

| Country | True statistic skill |
|---|---|
| Austria | 0.57 ± 0.09 |
| France | 0.47 ± 0.09 |
| Germany | 0.55 ± 0.11 |
| Italy | 0.57 ± 0.09 |
| Montenegro | 0.55 ± 0.09 |
| Netherland | 0.57 ± 0.09 |
| Poland | 0.57 ± 0.11 |
| Portugal | 0.45 ± 0.1 |
| Portugal /Azores Islands | 0.47 ± 0.09 |
| Romania | 0.53 ± 0.08 |
| Slovenia | 0.55 ± 0.09 |
| Spain | 0.57 ± 0.09 |
| Ukraine | 0.55 ± 0.11 |

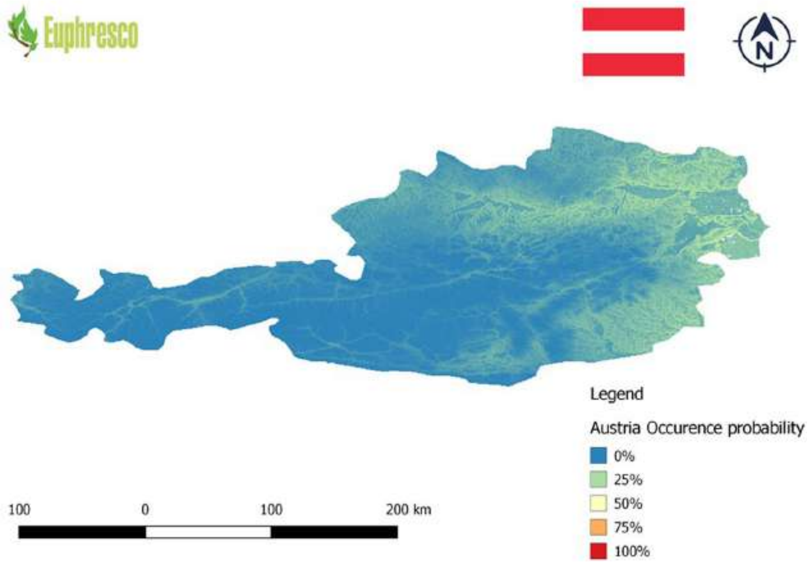


**FIGURE 2** *Ceratitis capitata* occurrence probability in Austria.

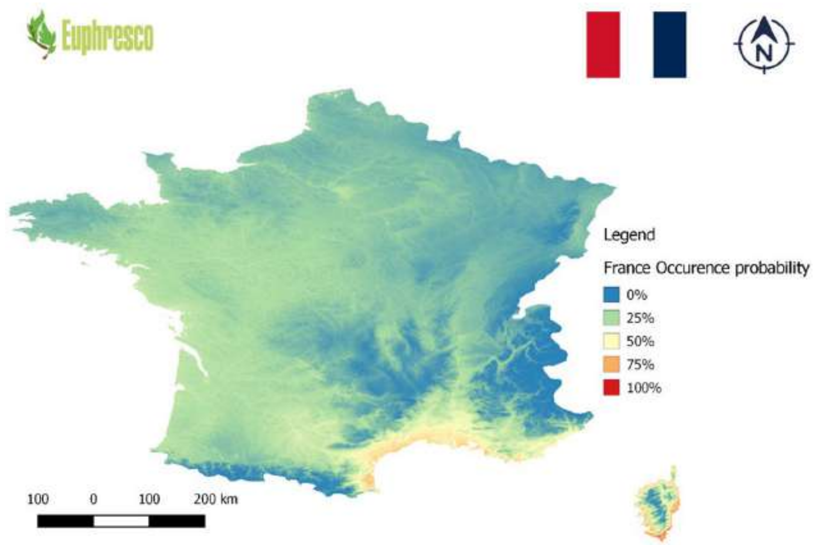


**FIGURE 3** *Ceratitis capitata* occurrence probability in France.

Using Maxent software, the occurrence probability map obtained resulted from the analysis and contribution of different predictors including temperature, precipitation, altitude, field slope and exposure.[1]

According to the MaxEnt model projection the probability of finding *C. capitata* in Austria is low all over the country (Figure 2).

For France there is mainly a low probability of occurrence for *C. capitata*, although this is moderate to high in Mediterranean areas (Figure 3).

For Germany the probability occurrence for *C. capitata* is low, with an even lower probability in the northern part of the country (Figure 4).

For Italy all coastal areas of the country have conditions and high probability for *C. capitata* occurrence reaching 100% (Figure 5).

For Montenegro *C. capitata* occurrence probability is higher in southern areas that are suitable for development and population establishment, and in those areas the occurrence probability can reach 75%–100% in some places (Figure 6).

For the Netherlands *C. capitata* occurrence probability is moderate in almost all areas of the country (25%–50%) but in some areas the occurrence probability reaches 75% (Figure 7).

[1]The authors note that scale bars are given for horizontal measurements for the MaxEnt model projection maps. Due to the output of the software the maps are slightly reduced in size vertically.

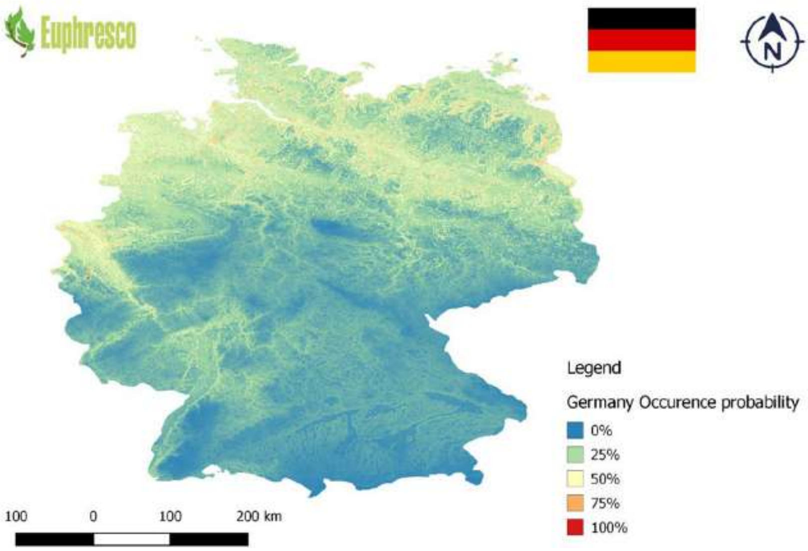


**FIGURE 4** *Ceratitis capitata* occurrence probability in Germany.

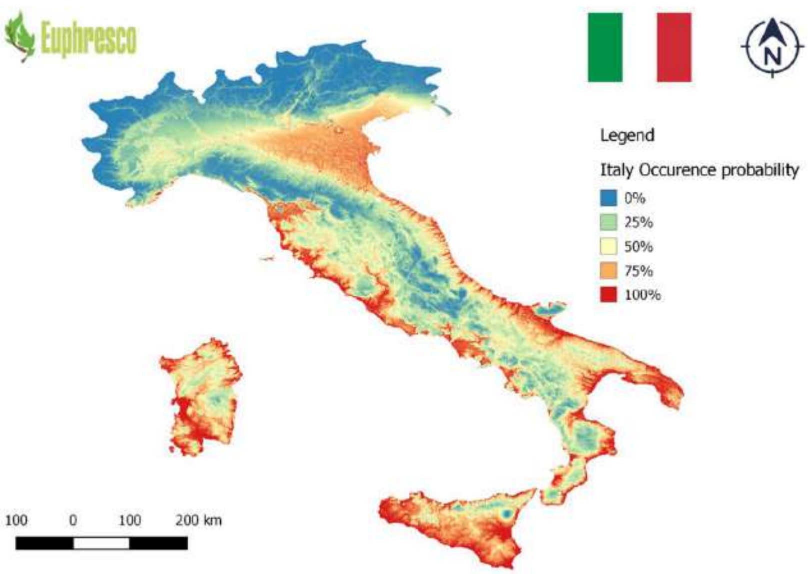


**FIGURE 5** *Ceratitis capitata* occurrence probability in Italy.

For Poland *C. capitata* occurrence probability is near to 0% in the whole country. Only areas in the north-western part have some low probability of occurrence for this pest (Figure 8).

For mainland Portugal (Figure 9), the *C. capitata* occurrence probability is moderate only in the northern part of the country and is high in most of the country, reaching a high level in the centre (75%) and 100% in the south.

In the Azores Islands the occurrence probability for *C. capitata* was studied and applied to the eight largest islands (Figure 10; it was not done for Corvo Island because there were few hosts on this, the smallest island).

In the eastern group of the Azores archipelago, there are two Islands: São Miguel and Santa Maria. In Santa Maria Island all the west part of the island has suitable conditions for medfly occurrence. In São Miguel the coastal areas around the island have suitable conditions for this pest.

In the central group, there are five Islands (Terceira, S. Jorge, Graciosa, Faial and Pico). On Terceira Island mainly the coastal areas, particularly to the south and east, have suitable conditions to develop medfly populations. In S. Jorge Island, because of its high altitudes and small width, only some of the coastal areas, namely Fajãs, Velas and Calheta, have suitable conditions for medfly occurrence. In Pico Island mainly the coastal areas to the south and west, and a well small area on the extreme point at the east have suitable conditions for medfly occurrence. In Faial Island the coastal areas in

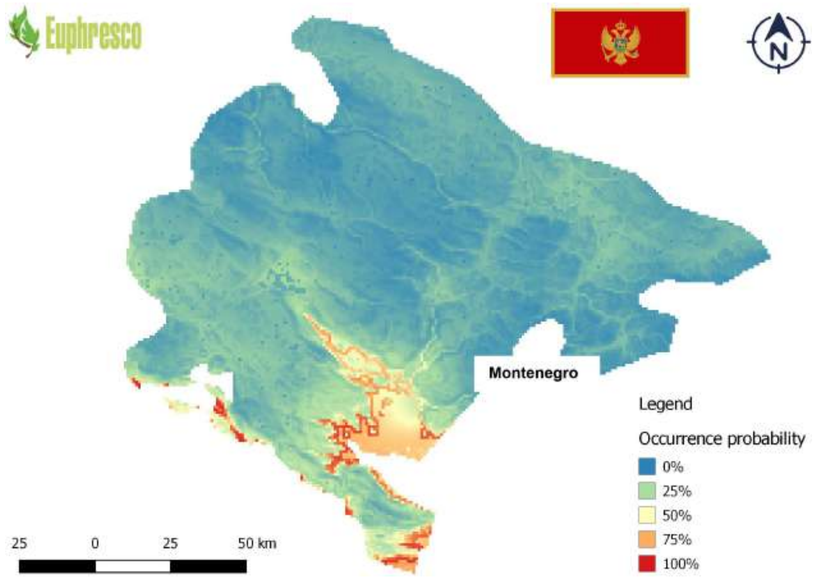


**FIGURE 6** *Ceratitis capitata* occurrence probability in Montenegro.

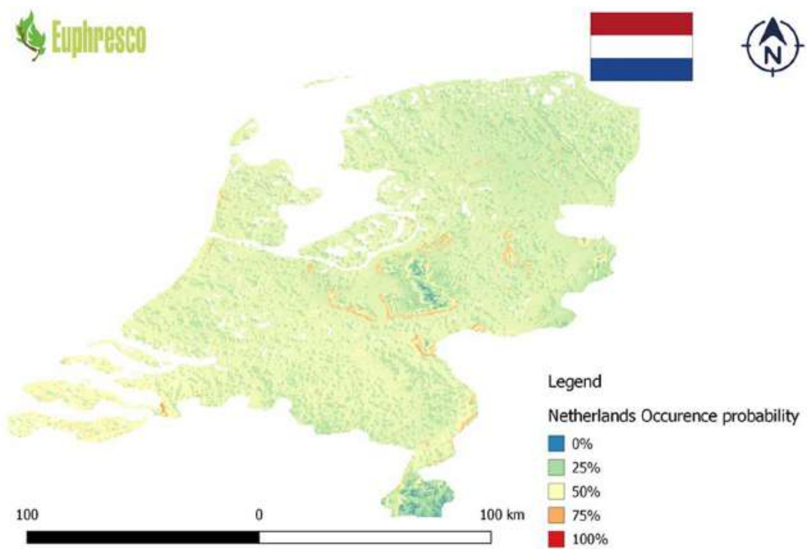


**FIGURE 7** *Ceratitis capitata* occurrence probability in the Netherlands.

the north and west of the island and the south and south-east areas of the island have suitable conditions for medfly occurrence. In Graciosa Island, because of its flat topography and warm climatic conditions, almost all areas of the island have suitable conditions for medfly occurrence, but they are mainly in the northern part. In the western group, there are two islands: Flores and Corvo. In Flores Island the entire island is shown to be unsuitable for the occurrence of *C. capitata* populations.

For Romania, areas from the north-east, east central, south and south-east along the borders are suitable for *C. capitata* occurrence and there are further suitable areas also in the western part of the country, although generally the climate is more adapted to the pest in the south (Figure 11).

For Slovenia, most of the country has a low occurrence probability for *C. capitata* and only in the south-west areas is this probability higher. In those areas, modelling points to a moderate to high occurrence probability of 75%–100% (Figure 12).

For Spain the major part of the country has 75%–100% medfly occurrence probability. Only in some small areas in the north of the country (blue areas only) is this occurrence probability low (Figure 13).

In Ukraine *C. capitata* is able to survive and establish in areas where the average monthly temperatures

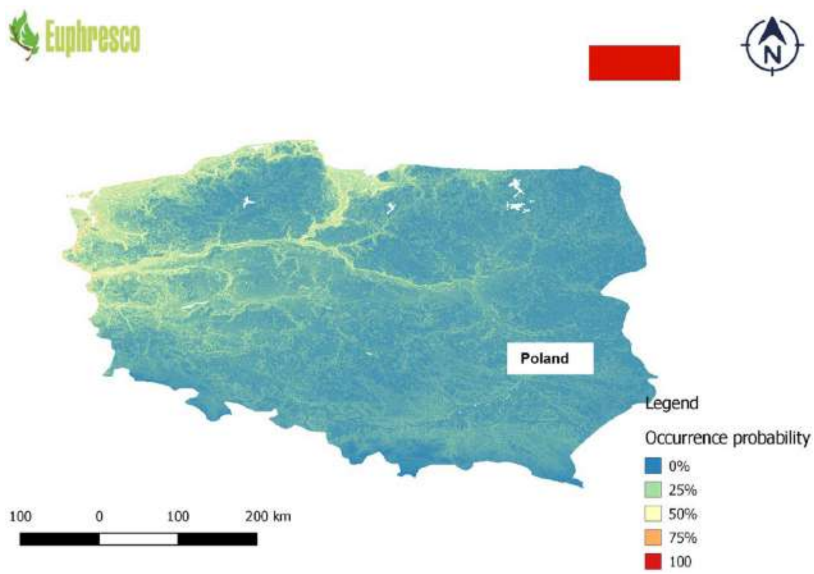


**FIGURE 8** *Ceratitis capitata* occurrence probability in Poland.

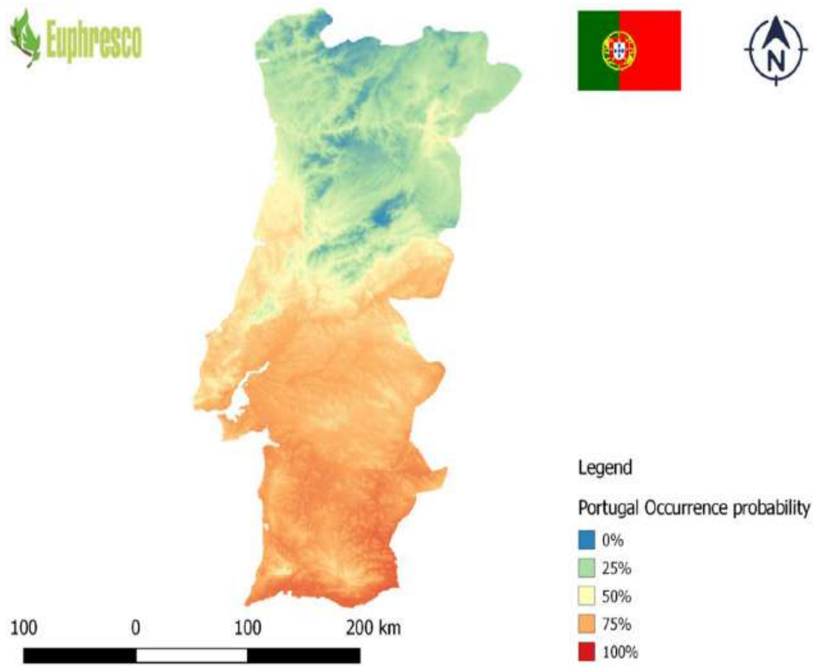


**FIGURE 9** *Ceratitis capitata* occurrence probability in Portugal.

in the winter fluctuate from +0.7 to +5°C in December, from −1.6 to +3°C in January and from −1.4 to +3°C in February, and the average annual temperatures vary from +9.4 to +12.7°C. Analysis of the average annual and average monthly temperatures in the winter period in Ukraine are similar to those in Croatia, Switzerland, Germany and France. So Medfly can develop two to three generations per year in Ukraine. Medfly occurrence probability is very low in almost the whole country. But in the southern areas of the country conditions allow *C. capitata* occurrence probability to reach 75% (Figure 14).

## 4 | CONCLUSIONS

The implementation of the Euphresco project FRUIT FLYRISKMANAGE led to a better overview of the occurrence records of the Mediterranean fruit fly in the partner countries.

This was complemented by the collection of information on the monitoring techniques in terms of the traps and attractants utilized by the different partners. The compilation of information from the partners confirmed that medfly is mainly widespread in Southern Europe

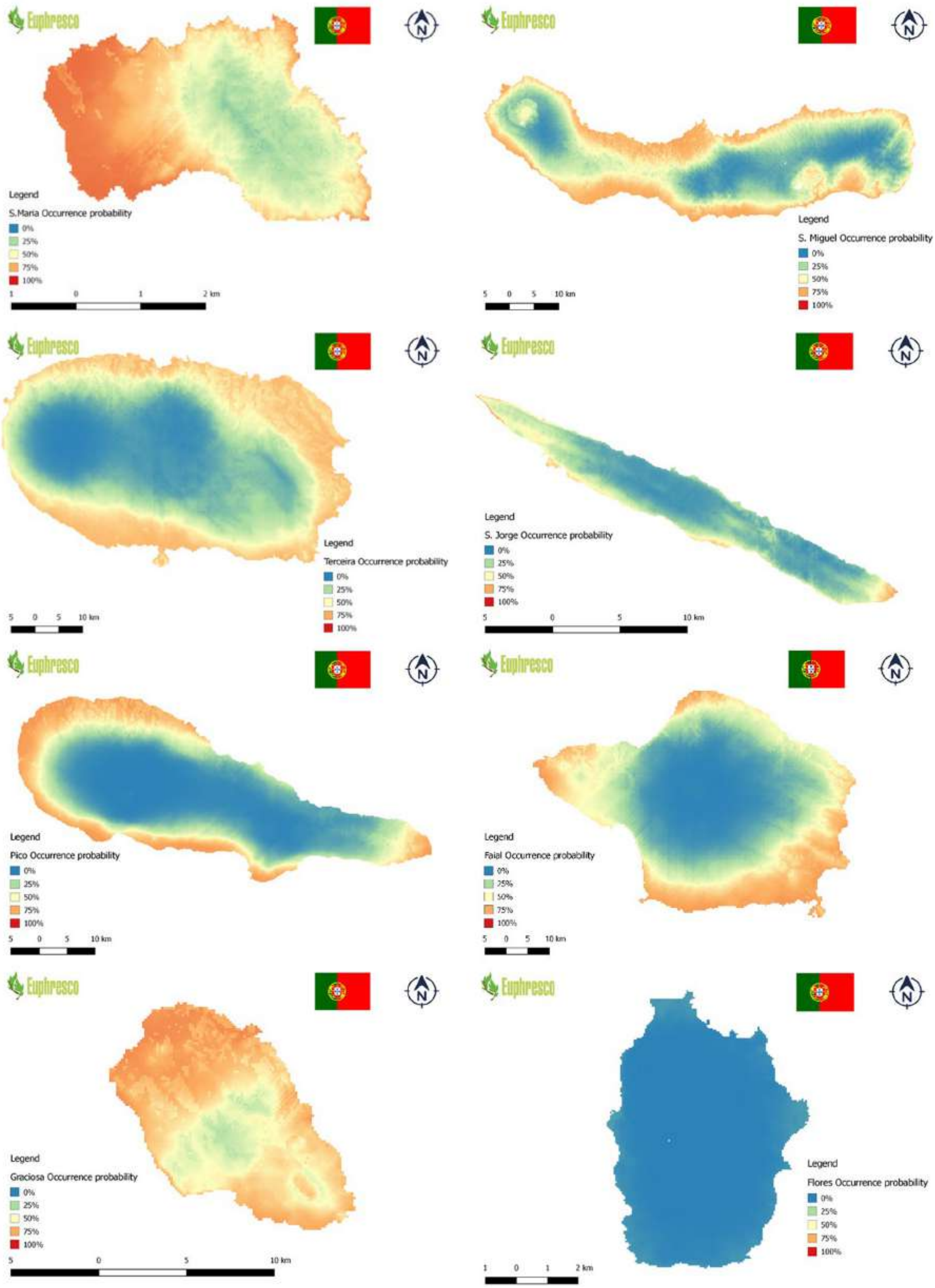


**FIGURE 10** *Ceratitis capitata* occurrence probability in the Azores Islands (Santa Maria, São Miguel, Terceira, São Jorge, Faial, Graciosa and Flores).

and causes damage, for example to *Citrus* and *Prunus*. Findings in more northerly regions (such as Central and Eastern Europe) continue to be attributed to introductions or short-lived populations.

The different data collections obtained support the hypothesis that there is a constant import of specimens, and that this is also the case in northern regions, most probably by means of infested fruits, which

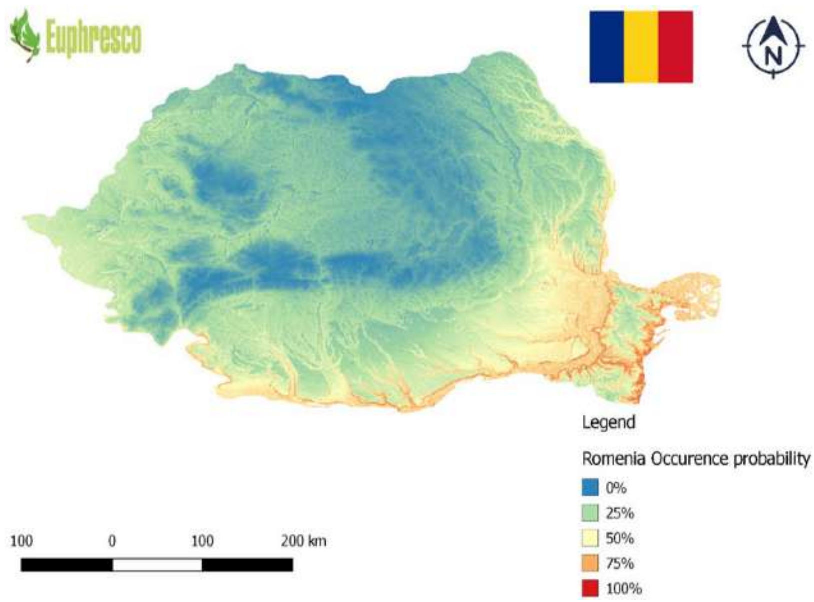


**FIGURE 11** *Ceratitis capitata* occurrence probability in Romania.

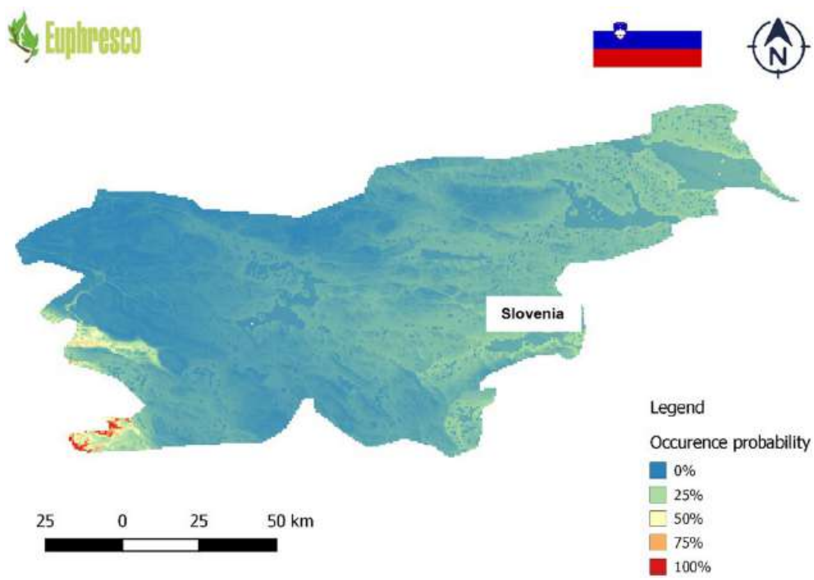


**FIGURE 12** *Ceratitis capitata* occurrence probability in Slovenia.

could serve as a basis for potential future population establishment.

Considering potential climate changes and anthropogenic activities, this pest could become more relevant for partner countries that have been less or not affected so far.

The modelling in this project was carried out with MaxEnt software using information provided by the partners, especially local climate data (temperature, humidity) as well as the latest available trapping data (when available).

The resulting models presented here will support future monitoring activities by providing information on potential occurrences in areas where medfly is not known to occur so far. However, these models will also support those countries already affected by the pest by providing additional details on the distribution in the country which probably was not fully known from previous surveys. It is also already clear that these calculations will help and support a wide range of stakeholders (e.g. policy makers, phytosanitary authorities) when making future decisions concerning eradication or management of the pest.

An important conclusion from this project is that although cooperation between many working groups is difficult to implement at times, it brings tremendous added value. This is demonstrated in this project by a

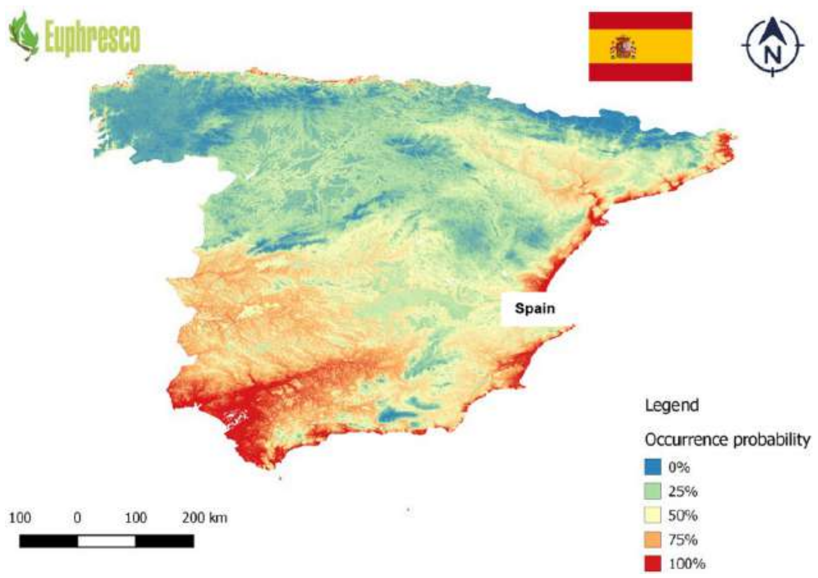


**FIGURE 13** *Ceratitis capitata* occurrence probability in Spain.

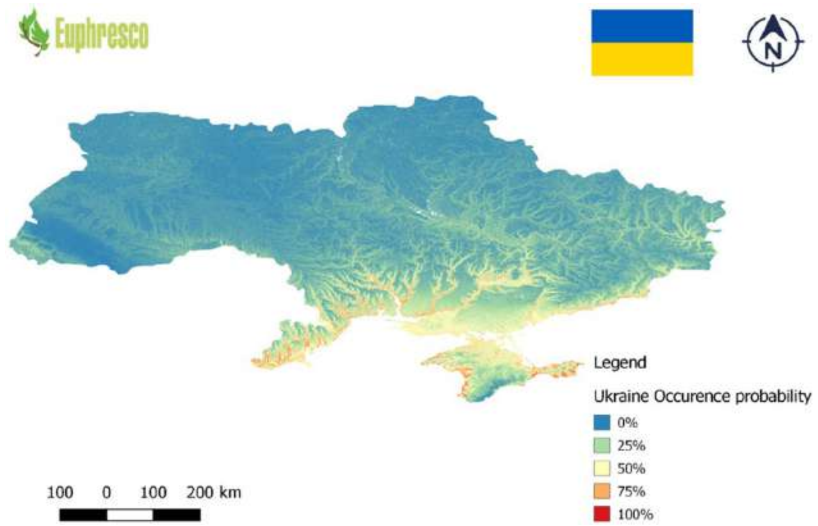


**FIGURE 14** *Ceratitis capitata* occurrence probability in Ukraine.

comprehensive overview of current (surveyed) and potential future (predicted) pest occurrence data for a large number of countries.


## ACKNOWLEDGEMENTS

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