PROJECT DELIVERABLE REPORT

Deliverable D5.03: Prototype for Optimizing Early detection System developed

Fruit Flies In-silico
Prevention & Management
FF•IPM

Project Title:

In-silico boosted, pest prevention and off-season focused IPM against new and emerging fruit flies ('OFF-Season' FF-IPM)

SFS-2018-2

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1. Summary

A successful biological invasion typically creates a stream of persistent negative impacts, possibly indefinitely. This usually puts a high price on failure of the surveillance and response systems. On the other hand, the cost of surveillance and other phytosanitary measures must be justified by the level of protection they afford the environmental and productive assets at risk from the invasion and their respective values. Early detection of a fruit fly invasion offers the prospect of a successful eradication, or possibly the benefits of a 'slow the spread' campaign. At the least, timely, accurate fruit fly surveillance can be used to trigger actions to protect valuable horticultural assets, as well as providing evidence of freedom from fruit fly pests.

In this Deliverable we describe an optimisation strategy for surveillance of invasive fruit flies that are the subject of the FF-IPM project (FF). This strategy sets out the overarching framework for general optimized surveillance plans that will be tested and tailored for each study area of the FF-IPM. Because these plans rely upon data that is being collected within the project, they will be developed and tested over the next two years. The strategy seeks to optimize the surveillance system in regards cost density (total annual cost per unit of area covered), timeliness of detection, and efficacy. Of course, there are trade-offs between these three considerations, and a full economic consideration of costs should include the probability and consequence of surveillance failure.

FF-IPM selected and characterized four areas in which the target fruit flies (*C. capitata*, *B. dorsalis* and *B. zonata*) are present or have been recently intercepted during the past. Northern Greece and Dalmatia (Croatia) will serve as simulation stages of the expansion of *C. capitata*, while Northern Israel will serve as scenario for *B. zonata*. The area of Mpumalanga Province in South Africa will be used to develop the strategy for *B. dorsalis*. To implement and test the proposed strategies, the four areas were characterized geographically (i.e., topography, land cover and agricultural use), and the populations of the target FF were monitored for at least 1 year (see Appendix I).

2. Introduction

Surveillance is defined as the close "watch" over somebody or something. In the case of invading pests and the National Plant Protection Organizations' (NPPOs) biosecurity requirements and activities aimed at the mitigation of alien threats, surveillance could be defined as the close watch of imminent threats (insect, plant, microorganisms and nematodes) in their known pathways and ecosystems. In this sense, NPPO's are primarily focused on border surveillance to prevent the introduction of unwanted alien species. However, NPPO's may also be concerned with helping plant-based industries to maintain market access conditions under area freedom, or low-prevalence, arrangements (surveillance for post-border pest management tends to fall under the responsibility individual industries or Agricultural agencies). In both cases, the early detection ("Early Warning") of an alien FF pest's incursion or the increase of an existing FF pest population that can compromise agricultural production and trade in the region, can be recognised as important goals of NPPOs and producer stakeholders.

Surveillance systems to detect incursions of alien fruit flies (FF) are operated in many regions by NPPOs. The general practice of FF surveillance consists of establishing attractive devices (traps and chemical attractants) in or adjacent to international trade or transport hubs or ecosystems (urban, agricultural and natural) where FF are expected to arrive or pose a direct threat to valuable assets such as orchards. These surveillance systems are usually serviced by scouts once every week or two. Typically, trapped specimens are collected, transported to a diagnostic facility, analysed and recorded.

The most well-known FF surveillance systems is the one active in California, USA (Manoukis et al., 2014). In this system, FF traps are dispersed over large geographic areas, including urban and rural settings. The number of traps per unit of area is determined by the level of risk: low-risk areas are monitored with 1-2 surveillance traps per square mile, while high-risk areas are monitored with up to 5 traps per square mile (USDA, 2015). For instance, exotic FF surveillance in urban settings of Los Angeles, California, which are considered high-risk areas for exotic FF, includes a regular density of four Trimedlure-baited Jackson traps and one protein-lure McPhail trap every mile^2 (Manoukis et al., 2014). These five traps are dispersed within the space of the mile^2 in such a way that four traps are placed at the centre of four equal peripheral rectangles delimited within the perimeter of the mile^2 space, and one trap is placed in the centre of the mile^2 expanse. In the USDA surveillance-system protocol, risk factors, possible pathways and history of past trapping, determine frequency of surveillance and intensity (USDA, 2015). Seasonal trapping is also applied in the USDA surveillance protocol following degree-day models and climatic historic data, which help them determine "windows of time" when surveillance traps can be intensified or halted (USDA, 2015). Due to the high costs of setting and maintaining FF surveillance systems over large areas [see for example, Kean and Stringer (2019) for FF surveillance costs in New Zealand], there is a need for more precise and efficient systems to determine surveillance trap-location, density and intensity. This is the aim of FF-IPM, WP5. For this aim we are incorporating technological innovations framed within tailored surveillance strategies that will improve our ability to forecast sensible locations, optimizing deployment in time and space, and will reduce costs of surveillance, and effectiveness of early-warning, by automating monitoring and surveillance with electronic traps (e-traps).

In the context of FF-IPM we are interested in developing surveillance systems that can provide early warning of the presence of *C. capitata* outside it's known dynamic range in Europe, and the presence of *B. dorsalis* or *B. zonata* in the EU. Early warning provides managers with the ability of rapid responses, lowering eradication costs (Alvarez & Solis, 2018). While we are using these important horticultural pests as case studies, much of the research is expected to be applicable to a much wider set of pests and pest problems.

A critical factor in the effectiveness of a biosecurity surveillance system is the size of the invading population at the time of detection (Epanchin-Niell & Hastings 2010). The larger the population, the fewer options there are for responding, and the larger the costs of an attempted eradication (Alvarez & Solis, 2018). Unfortunately, there is a trade-off between costs and the likely size of the population at the time of detection because the likely maximum size of the invasive population is inversely related to the density of traps. An additional aspect to take into consideration is that species that are being established in a new habitat may fail to be detected due to their low numbers and probability of capture during their establishment and naturalization phase. While Kean & Stringer (2019) found trap efficacy to be an insensitive parameter in the surveillance system, it was in the context of being able to detect the presence of the target organism at some point across the year, rather than whenever it was first present and detectable. That is, timeliness of detection was not being considered in the New Zealand study. Manoukis et al. (2014) developed a strategy of optimal trap deployment based on trap efficacy (i.e., ability to attract target insect), which is guided by parameters obtained from attraction under different landscape and climatic scenarios.

Within FF-IPM we are attempting to optimize the surveillance systems in relation to:

1. Cost-density (total annual cost per unit of area covered),
2. Timeliness of detection (i.e., Early Detection), and
3. Efficacy

Of course, there are trade-offs between these three considerations, and a full economic consideration of costs should include the probability and consequence of surveillance failure (Epanchin-Niell & Hastings 2010), costs related to sampling efficacy and density, and, especially, potential costs due to pest establishment and management (eradication) (Espanchin-Niell et al., 2012 and 2014). A successful biological invasion creates a stream of persistent negative impacts, possibly indefinitely. This usually puts a high price on failure of the surveillance and response systems (Kriticos et al. 2012). On the other hand, the cost of the surveillance effort must be justified by the value of the environmental and productive assets at risk from the invasion. As observed by Epanchin-Niell & Hastings (2010), the optimal control of invasive species depends on many factors, including economic factors, spread patterns, landscape characteristics and likelihood of reinvasion.

Within FF-IPM we will test and quantify trade-offs and explore the effect of technologies (e.g., smart traps) that modify trade-offs. In addition, surveillance-optimization will be reached by managing surveillance efforts in time (i.e., the application of CLIMEX). Management of surveillance in time is expected to derive economic benefits (Holden et al., 2016), being an additional input modifying trade-offs. Landscape characterization and landscape-risk will also be evaluated, and explored as a trade-off modifier (including technological developments to characterize risk). An additional element to take into consideration when developing optimization strategies is the limitations imposed by "landscape-reality" on effective surveillance and the need to adapt strategies to landscape, technology and human constraints (Koch et al., 2020). This aspect will also be explored by including communication networks (i.e., roads and access) as part of risk and cost. We will then work with stakeholder NPPOs to assist them to understand the trade-offs and identify their risk-return comfort zone.

The initial steps of the FF-IPM optimization-strategy described here is based on optimizing the application of surveillance in technology, geographic-space ("where"), and time ("when").

3. Strategy for the Optimization of Surveillance for Alien or Expanding FF

The optimization of surveillance being developed and that will be tested by FF-IPM includes the "where", "when" and "how". The "where" relates to the geographic space where the surveillance is (or will be) taking place. The geographical space is not homogeneous, and areas will be ranked based on their risk and suitability to harbour FF populations. To classify the entire geographic space, this will be symmetrically divided into a fishnet representing a proportion of the whole area (i.e., cells of 5-10 % of the entire area). Each cell in the fishnet will be automatically ranked based on relevant characteristics such as land cover, land use and the FF's life history (i.e., "landscape suitability"). Placement of surveillance devices will then be guided by this landscape ranking and by the availability of resources ("constraint"). Several options to determine surveillance trap location are being explored (see section 3.2.1). The optimization of the surveillance strategy will also include the "when" (i,e, the temporal dimension), which will be determined by the biology of the FFs, the phenology of hosts and the climate in the sink region, and other environmental and trade factors associated with the source areas (see 3.3). The "how" includes technological innovations such as models and algorithm adapted and developed for the optimization strategy, and tools, such as electronic devices. Outputs of the strategy will be mainly digital in the form of risk maps and alerts, and the location of trap deployment will be given as a list of geographic coordinates. We believe that all these innovations and the optimization strategy will contribute important savings to the stakeholders and will make the collection and analysis of data more efficient, and the process of decision-making more effective. The integration of the "where" and "when" into a Decision Support System (DSS) is presented in Figure 1.

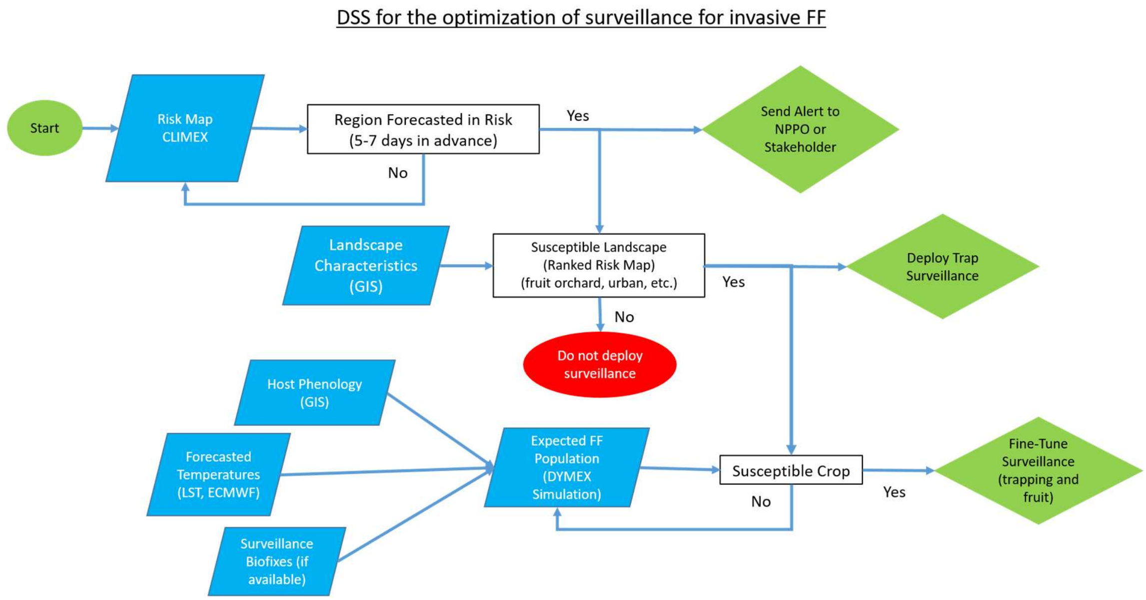
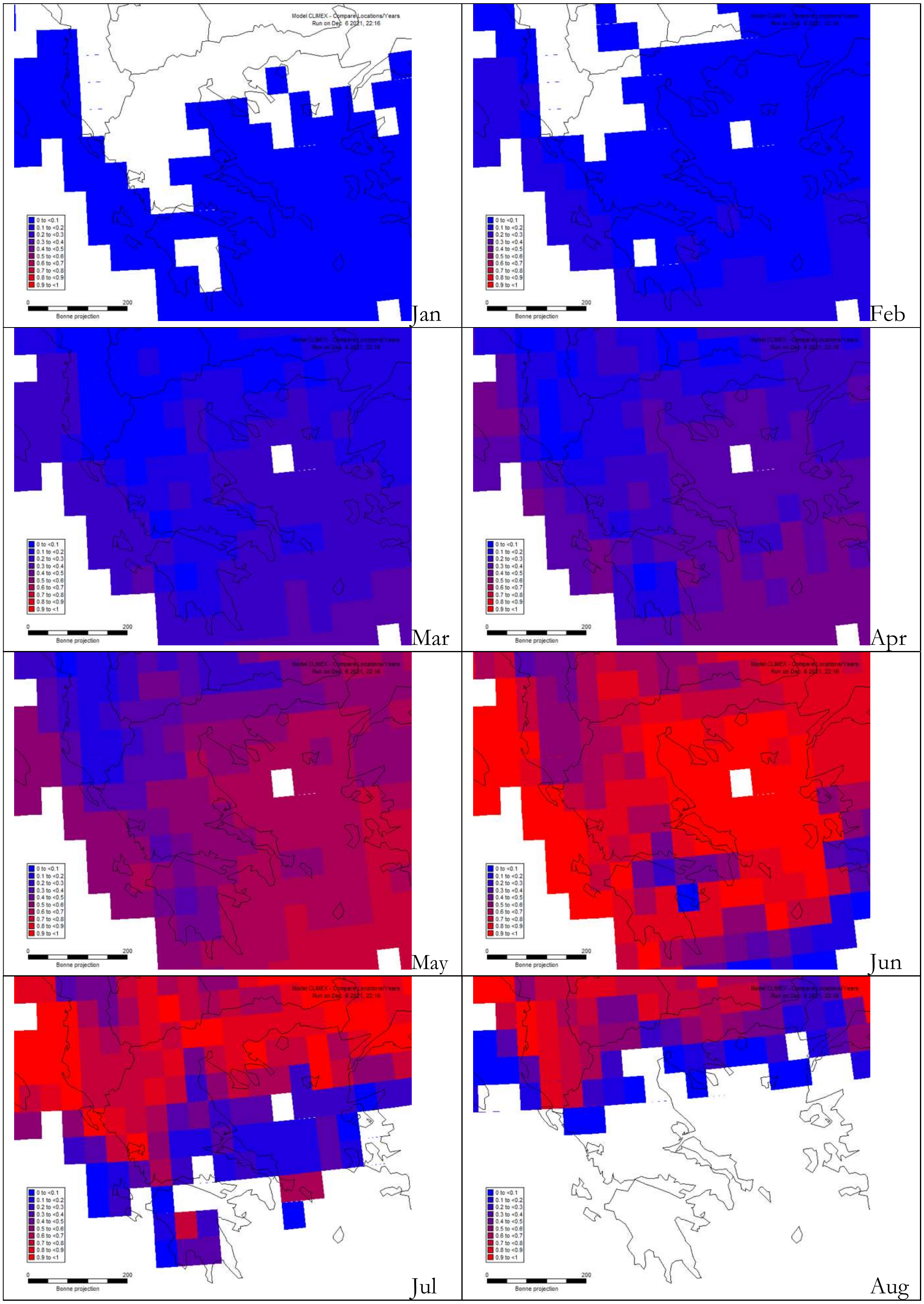


Figure 1. Flow chart describing the Decision Support System suggested for the optimization of surveillance

The first step in the DSS (Figure 1) incorporates the forecast of the "climatic" suitability of the landscape to the development of FF. The geographic implicit climatic suitability of the landscape will open the "**Time Window**" to initiate surveillance activities. Climatic suitability will be determined based on "CLIMEX" modelling, using thermal and hydric parameters determined in WP2 (described in D5.2) (see, for example, Figure 2 and 3 for the application of CLIMEX to *C. capitata* in the Greek and Croatian region for 2019). The next step in the decision incorporates the landscape characteristics, and the probability of the different areas of the heterogeneous landscape to harbour FF and be a foundation for their development. That is, we will determine the level of risk at an intermediate spatial scale ("**Susceptible-Landscape**"). This second level will be determined by applying a set of rules and an algorithm derived from land cover, land use and the life history of the FFs. This second step in the decision-making process will also be used to rank areas by risk level, which will guide the intensity of the surveillance (deployment options, type of traps, e-traps or conventional, and service periods). The third step of the decision-making process includes the phenological stage of the host, the agronomic practices of production systems, and the expected rate of FF development which will be based on climatic parameters and the utilization of population dynamics modelling ("DYMEX"). The determined level of risk will be used to establish the intensity of the surveillance and the type of traps (e-traps or conventional) to use for surveillance. This final stage of the optimization strategy is currently in the process of development and is tightly linked to D5.2.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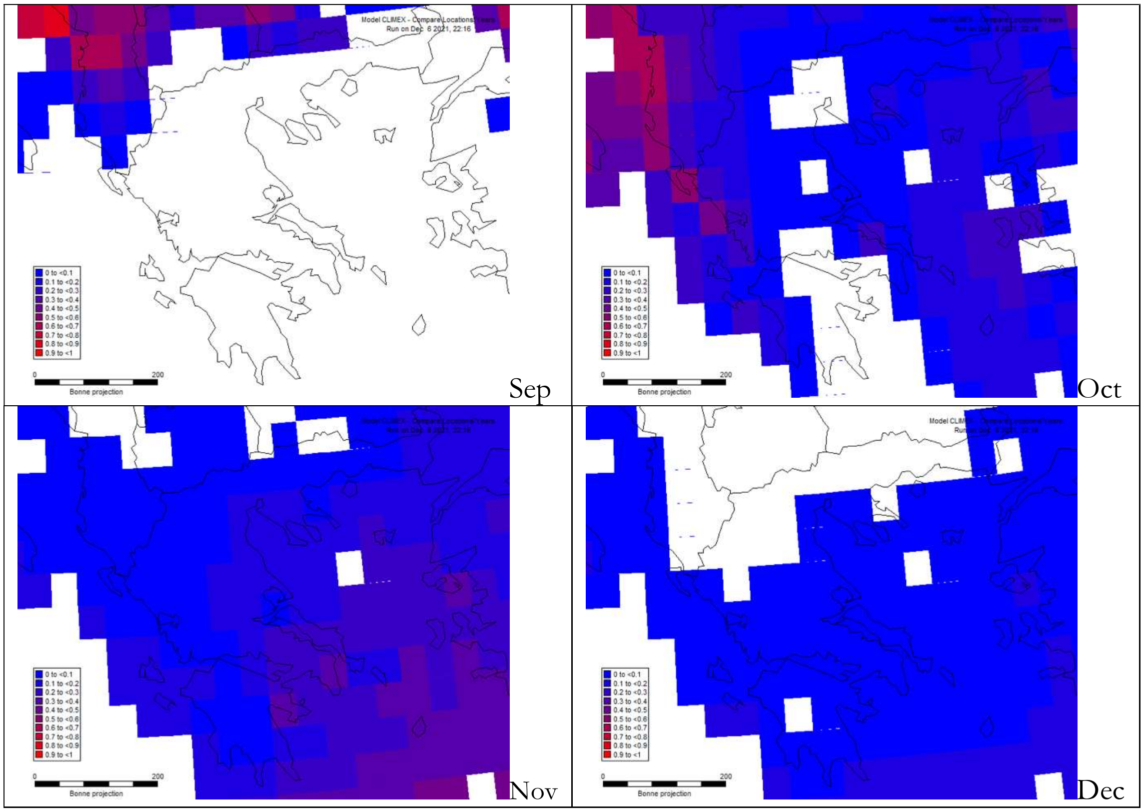
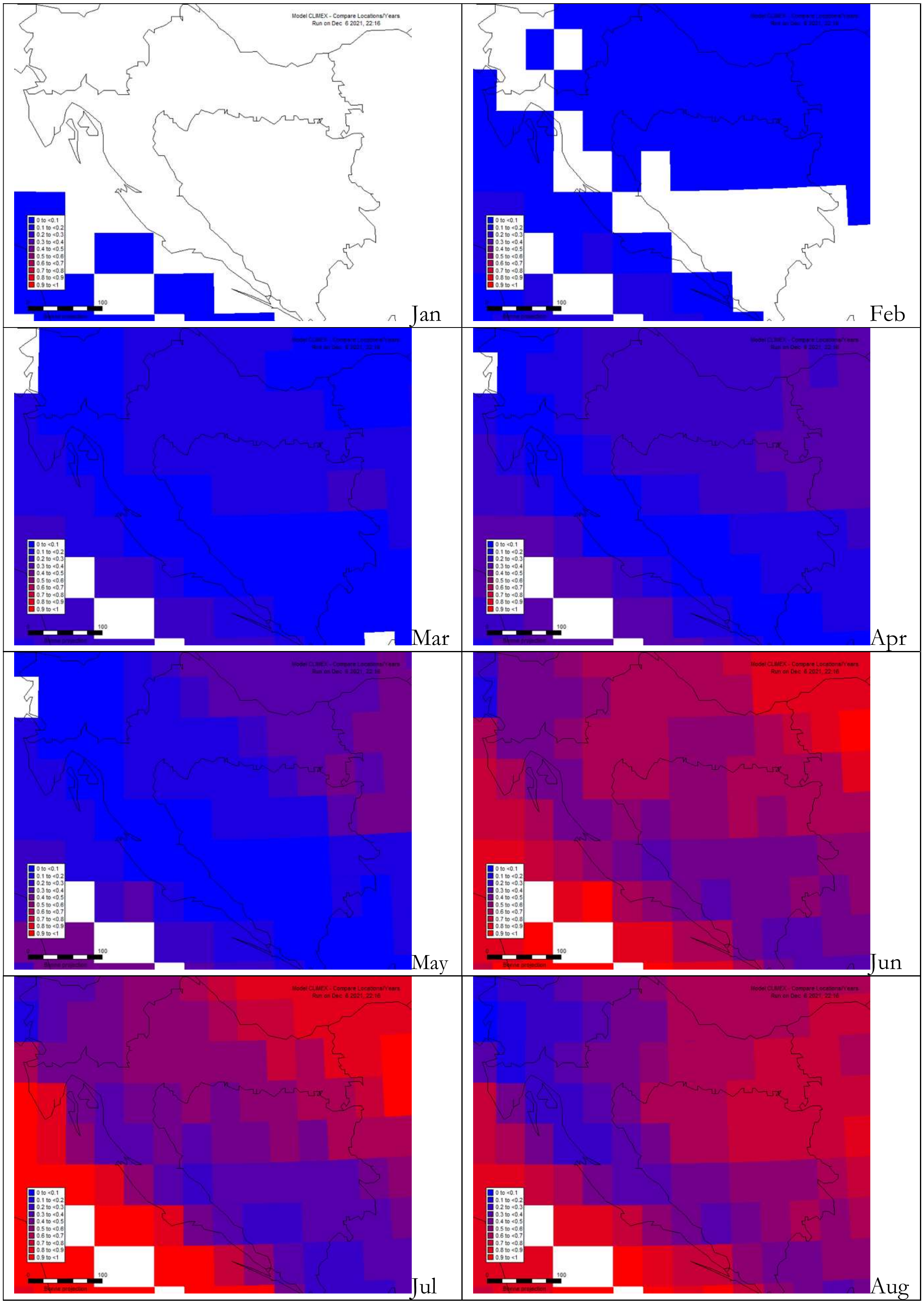


Figure 2. CLIMEX Weekly Growth Index values (GI_W) for the last week of each month for *Ceratitis capitata* for mainland **Greece** during 2019 based on a natural rainfall scenario. White is unsuitable for population growth due to temperature or soil moisture conditions being unsuitable. Relative suitability is indicated by blue (low) to red (good). The poor conditions in southern Greece during August and September are due to low soil moisture conditions. In reality, Mediterranean orchards are generally irrigated (Xiloyannis, et al 2012), and our operational system will include irrigation scenarios.


Model CLIMEX - Compare Locations/Years
Run on Dec 6 2021, 22:16
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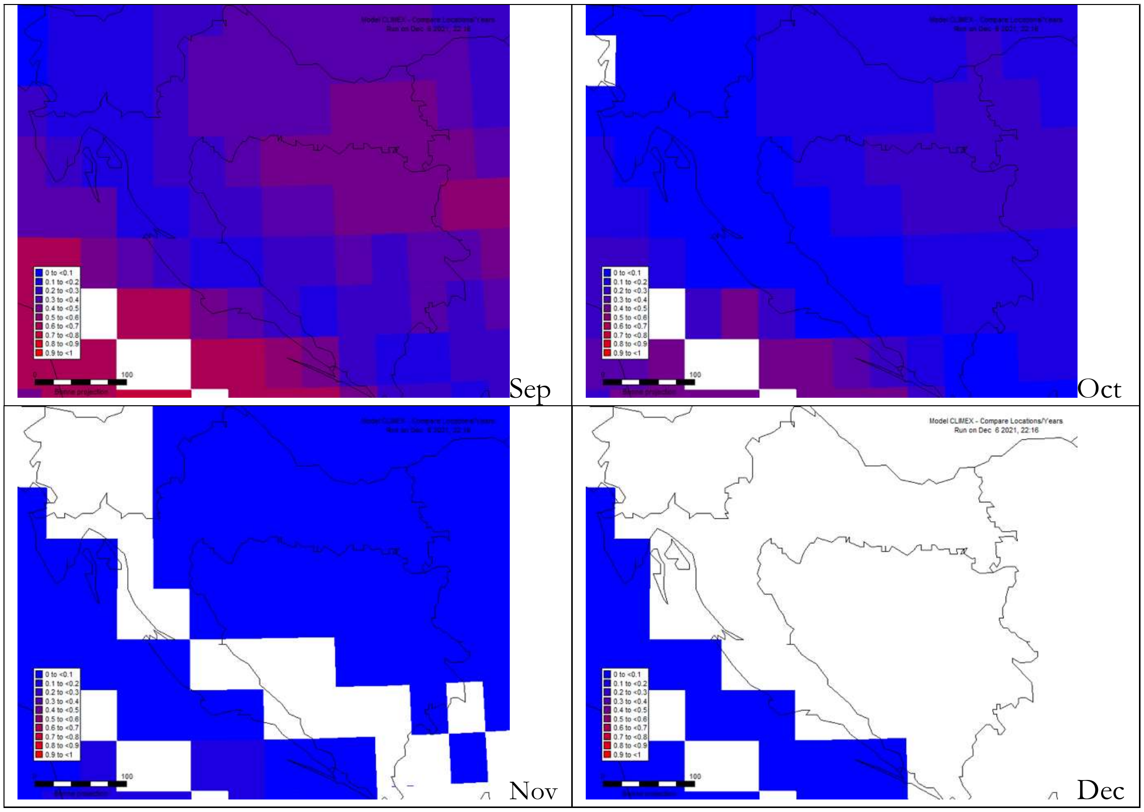

Figure 3. CLIMEX Weekly Growth Index values (GI_W) for the last week of each month for *Ceratitis capitata* for **Croatia** during 2019. White is unsuitable for population growth due to temperature or soil moisture conditions being unsuitable. Relative suitability is indicated by blue (low) to red (good).

Surveillance case-studies (see appendix I for geographically characterized regions): We will test our detection approach in several landscape, which include commercial agricultural settings, low-input agriculture and urban settings bearing host trees, and their combination. Scenarios include several levels of FF populations, with landscapes showing high levels of the FF pest and areas with low FF prevalence, and restricted windows of FF activity. Finally, detection scenarios will be tested for three different species of FF: two bearing a risk of invasion to the EC (*B. dorsalis* and *B. zonata*) and one actively expanding its range due to climatic and environmental changes (*C. capitata*).

3.1. Technological Inputs

Several technological advances are included in the optimization of surveillance and in FF-IPM strategy. These include spatio-temporal forecasting abilities (i.e., CLIMEX and DYMEX modelling), geographic-ranking algorithms, and the utilization of e-traps that are expected to improve the Early Warning abilities of the system by providing real-time information on adult FF interceptions and captures with minimal need for human maintenance. The e-trapping and technological components of the strategy were upgraded and advanced in WP2, WP3 and Task 5.1. The e-traps will make surveillance more effective and efficient, helping to optimize cost-effectiveness. The exploration of appropriate management scenarios will be conducted during the next two years as part of T5.2. The research framework for the strategy is to deploy a set of conventional and electronic traps in parallel, and over a wide seasonal variation. The study areas and scenarios have been chosen to reflect a gradient of climate suitability where either FF activity is suppressed through some seasons, or the flies need to re-invade each year. The optimization will involve a set of resampling experiments, analytically thinning out the putative surveillance network according to different rules, and assessing the effects on the variables of interest (costs, timeliness and efficacy).

3.1.1 Trap technology

We will deploy automated e-traps (see D3.1). Based on initial comparisons, these traps offer a distinct improvement in system performance in terms of reduced detection latency, reporting on a daily basis instead of a weekly or fortnightly basis (see D3.1).

3.1.2 Modelling Technology

In WP5.1 we developed CLIMEX and DYMEX models for each of the FF (D5.2). The CLIMEX models are moderately complex species niche models that can indicate where and when conditions are likely to be suitable for population growth of FF. The DYMEX models are detailed process-based population dynamics models. These models can indicate when and where different life stages may be present. The DYMEX models rely upon biofixes or suggested initial population levels to provide a starting point for simulations. For example, based on trap catch data, the DYMEX model can indicate when it might be prudent to survey fruit for developing larvae, soil for pupae, or aerial trapping for adult flies. Both types of modelling rely upon weather data, and can take advantage of short- and long-term weather forecasts to estimate future risk factors for FF.

Technology is also being developed to automate the decision on the deployment of traps in the landscape. These include, for example, algorithms to automate ranking of the landscape based on land cover and land use. We are also exploring different approaches ("tactics" to optimize trap deployment based on landscape characteristics, and on resource-constraints (e.g., labour).

3.2. The Geographic-Space Dimension in the Optimization of Surveillance:

3.2.1 Susceptible Landscapes:

An initial categorization of the landscape was conducted by using a fishnet (dimensions of the fishnet will depend on the study area size) to symmetrically divide the landscapes into square cells ("gross-ranking"). Each cell within the study area was then ranked based on its land cover and land use. Land cover was derived in most of the cases from aerial photographs (i.e., ortophotos), and further characterized as necessary by field surveys (see Appendix I). A ranking system, reflecting the habitat suitability for FF was applied to the fishnet cells, and a gradient of FF probabilities characterizing FF habitat suitability was applied to the entire fishnet. FF habitat suitability guided the initial establishment of trapping systems in the landscape (based on the number of available traps and amount of effort). FF habitat suitability index based on land cover was estimated as follows: (**a**) presence of orchard = 1.0, (**b**) Residential/Industrial area = 0.7, (**c**) Natural landscape (i.e., forest, non-agricultural, etc.) = 0.28 (**d**) water resources = 0.02. The ranking weight was determined by the following term: risk probability = **a** + **b** + **c** + **d**. The example provided here is a preliminary illustration of the process. An automatic code has been developed to modify as required the weights and parameters, and adapt the process to the different regions and conditions. The following series of Figs (Figs. 4-8) exemplify the ranking method for 3 of the 4 regions being considered for the testing of the optimization strategy (see Appendix I). The Croatian region of Dalmatia was ranked using a similar concept. However, due to the restricted availability of land cover information available (only from internet sources) and the large size of the Croatian polygon (see Appendix I on the characterization of the Croatian scenario), we are not presenting figures illustrating the risk-ranking for this area.

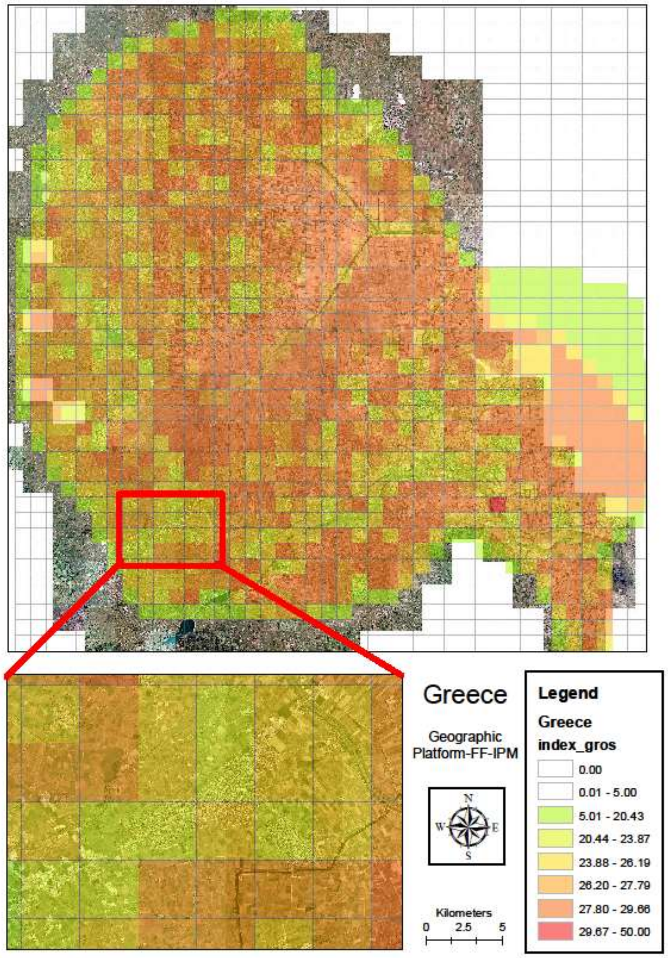

Figure 4. "Gross-ranking" of the Greek testing area and scenario. In this fruit-production valley in Northern Greece, *Ceratitis capitata* will be monitored. The index shows the expected susceptibility (probability ranging from 0 to 100) of a fine grid of cells covering the entire region. Ranking is based on land-use and land cover. The scale in the bottom of the illustration refers to the entire map (not the inset)

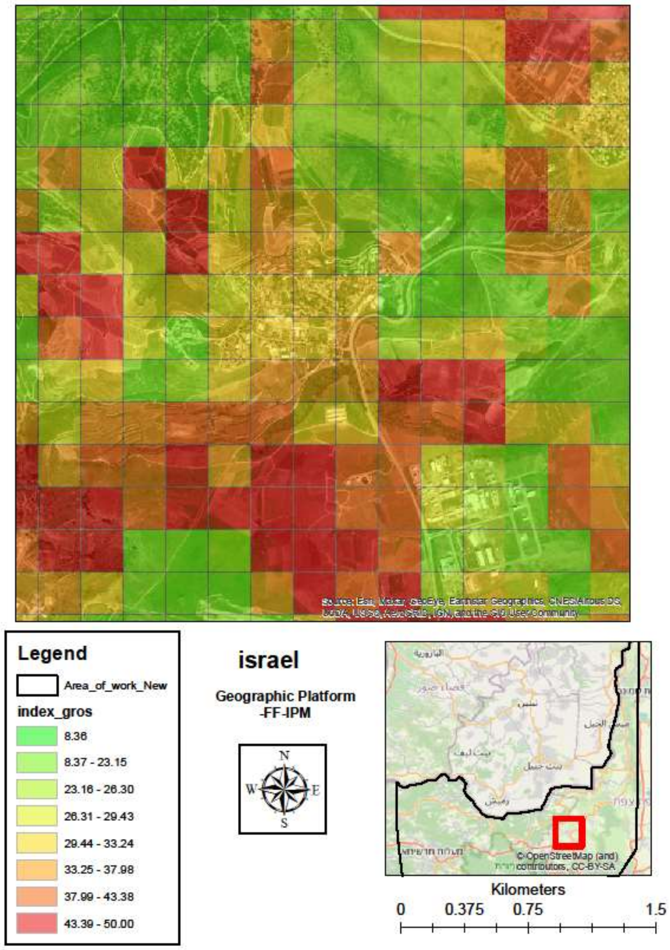

Figure 5. "Gross-ranking" of the Israeli testing area and scenario. The map focuses on a central area of the polygon, where commercial orchards and human settlements, bearing home gardens, can be found. We will test surveillance optimization strategies for *Bactrocera zonata*. The index shows the expected susceptibility (probability ranging from 0 to 100) of a fine grid of cells covering the entire region. Ranking is based and derived from land-use and land cover.

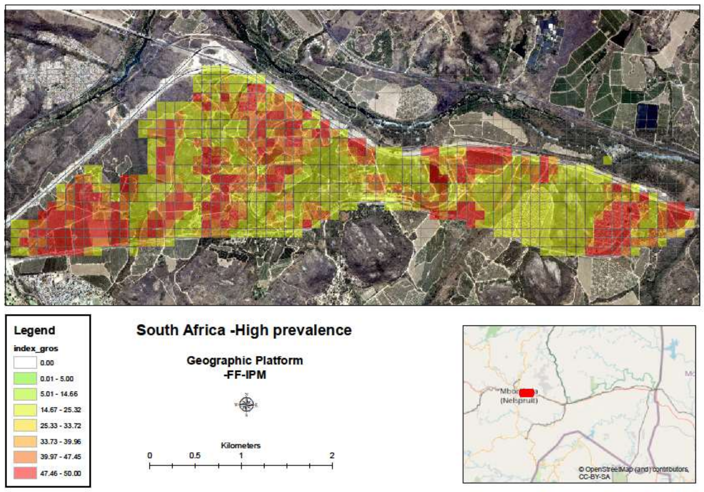

Figure 6. "Gross-ranking" of the South African testing area and scenario. The map shows the ranking of the Northern polygon of Nelspruit with commercial citrus orchards. We will test surveillance optimization strategies for *Bactrocera dorsalis*. The index shows the expected

susceptibility (probability ranging from 0 to 100) of a fine grid of quadrats covering the entire region. Ranking is based and derived from land-use and land cover.

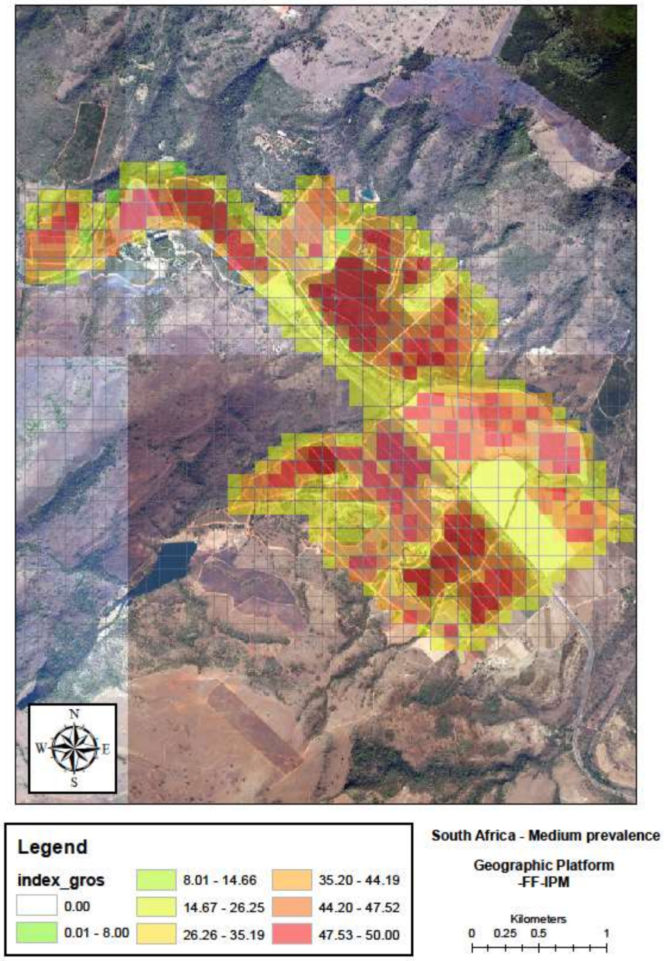

Figure 7. “Gross-ranking” of the South African testing area and scenario. The map shows the ranking of the Northern polygon of Schoemanskloof with commercial citrus orchards. We will test surveillance optimization strategies for *Bactrocera dorsalis*. The index shows the expected susceptibility (probability ranging from 0 to 100) of a fine grid of quadrats covering the entire region. Ranking is based and derived from land-use and land cover.

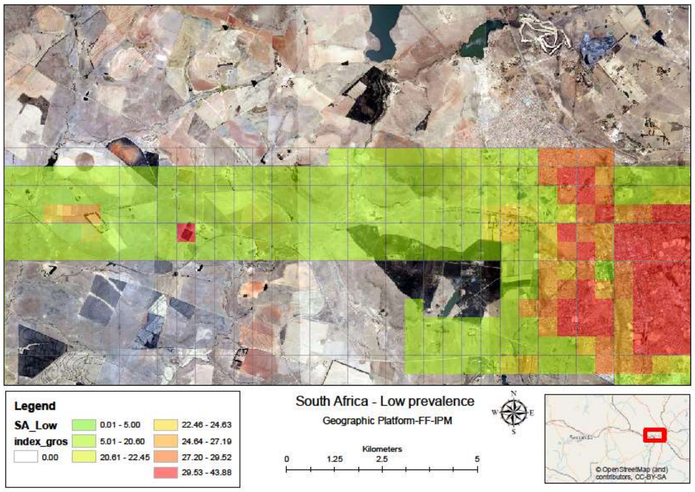

Figure 8. "Gross-ranking" of the South African testing area and scenario. The map shows the ranking of the Southern polygon of Ermelo-Davos with scatter commercial apple orchards, abandoned apple orchards and the Ermelo Town, with parks and residential areas bearing host fruit-trees. We will test surveillance optimization strategies for *Bactrocera dorsali*s. The index shows the expected susceptibility (probability ranging from 0 to 100) of a fine grid of quadrats covering the entire region. Ranking is based and derived from land-use and land cover.

3.2.2 Deployment Tactics in the "Susceptible Landscapes":

In section 3.2.1, susceptible landscapes were detected and ranked based on land cover and land use. The ranking provides a first step in the deployment strategy algorithm. The actual deployment will be based on several options in which different elements are taken into consideration: (a) the level of risk ("risk-guided" tactic), (b) the resources constraints ("effort-guided" tactic), and (c) the dispersion in space constraint ("space-guided" tactic). In the next sections, we will provide the rules for each of these tactics and will illustrate tactics using the Greek and the Croatian study area (deployment of any type of trap), and the South African Ermelo-Davos study area (deployment of e-traps) as an example. The algorithms were used to develop deployment maps, and a list of geographic coordinates to guide deployment.

"Risk-Guided" Tactic (Figure 9):

Concept: Distribution of surveillance traps is determined by the risk at the cell level

Assumptions:

- Deployment of traps follows cell risk level, from the highest, down (section 3.2.1)
- Number (n) of surveyed quadrats will be determined by effort possibilities (i.e., trap numbers and ability to serve traps)
- Spatial patterns (i.e., spatial structure), not taken into consideration. That is, the spatial "constraint" is not taken into consideration
- Traps will be located in the centre of the selected quadrat or in the element with the highest risk within the cell

Advantages: Simple determination of trap locations

Disadvantages:

- Possible non-random distribution of traps in the surveyed area and possibility of trap aggregations.
- Missing areas in the surveyed region

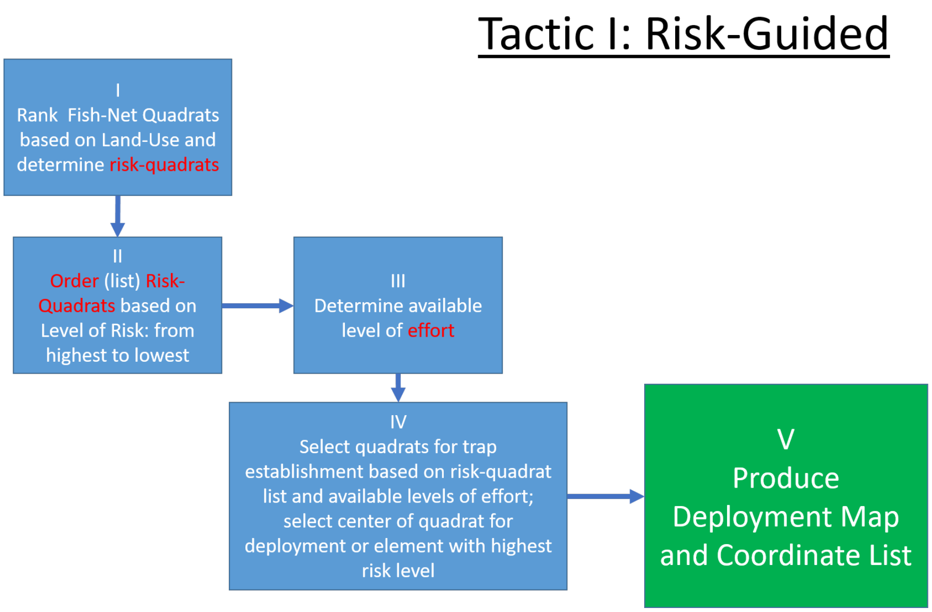

Figure 9. Flowchart showing the procedure for deployment of traps following tactic I: "Risk-Guided". Deployment maps can be automatically produced every time parameters are modified.

Figures 10, 11 and 12 provide examples (Greek Polygon, South African Ermelo-Davis Polygon and Croatian polygon) of trap distribution following Tactic I.

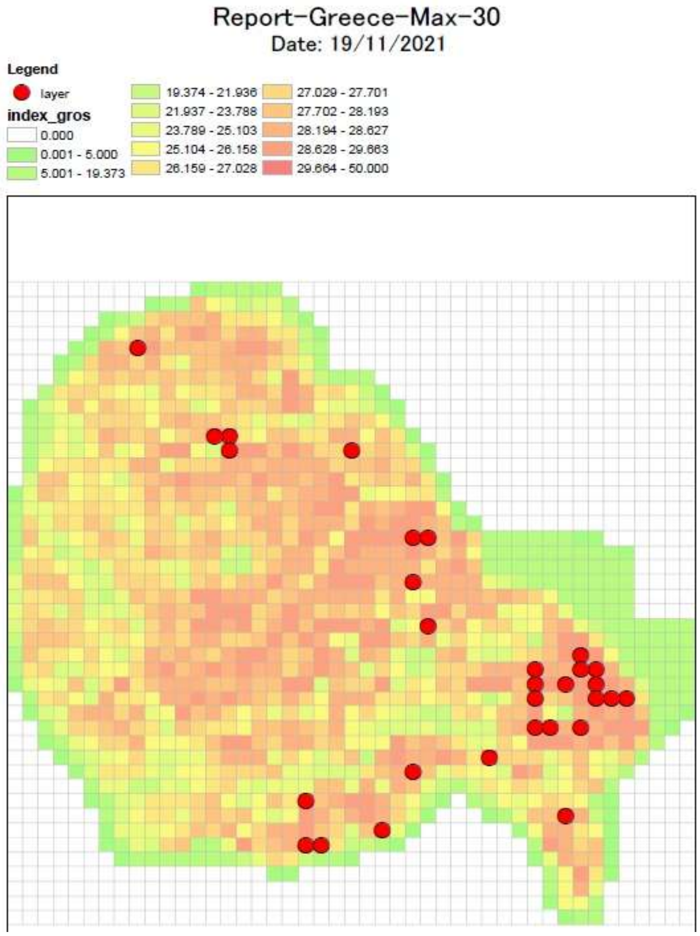

Figure 10. Distribution of traps (red circles, any type) in the Greek study area following Tactic I: "Risk-Guided". The simulation is based on the deployment of 30 traps in the entire region.

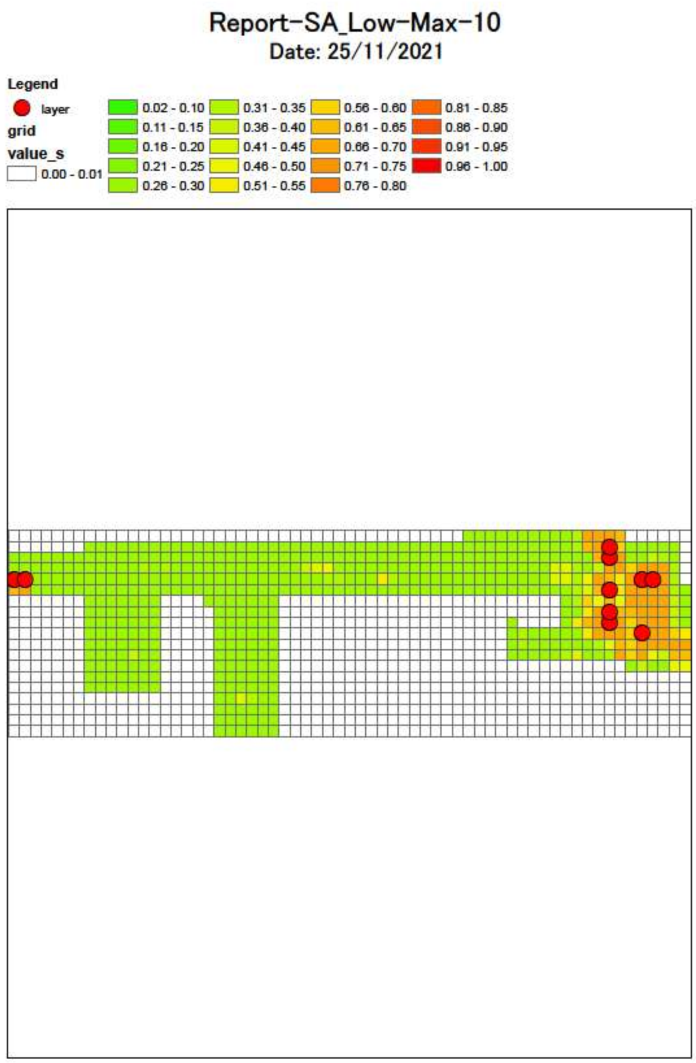

Figure 11. Distribution of traps (red circles) in the Ermelo-Davos study area following Tactic I: "Risk-Guided". The simulation is based on the deployment of 10 e-traps in the entire region.

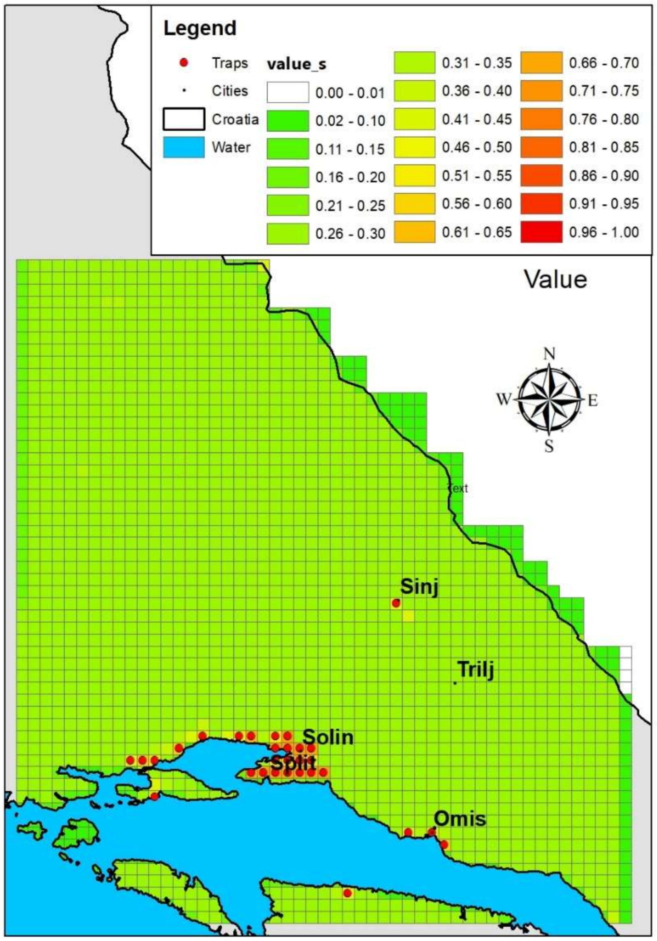

Figure 12. Distribution of traps in the Dalmatia (Croatia) study area following Tactic I: "Risk-Guided". The simulation is based on the deployment of 30 in the entire region.

"Effort-Guided" Tactic (Figure 13):

<u>Concept</u>: Distribution of surveillance traps is determined by the ability of the stakeholder to deploy and service surveillance traps

<u>Assumptions</u>:

- Deployment follows a fishnet grid covering the entire geographic space and determined by the amount of devoted effort (i.e., "effort fishnet grid"); that is, cell number in the effort fishnet determined by the number of available traps (i.e., effort) and it is juxtaposed on the risk quadrat grid (see section 3.2.1)
- Number (n) of surveyed quadrats will be determined by effort possibilities (i.e., trap numbers and ability to serve traps). That is, the amount of deployed traps will be a function of the economic resources available to the stakeholder to implement surveillance (i.e., personnel, vehicles, kilometres, accessibility to areas, etc.). Based on

the economic abilities of the stakeholder, the number of quadrats (i.e., fishnet) covering the entire region will be determined,

- Spatial patterns (i.e., spatial structure), not taken into consideration. Risk cells should be used as a secondary guide
- Traps will be located in the centre of the selected cell or in the element with the highest risk within the cell

Advantages: Simple and covering the entire geographic area of the surveyed space

Disadvantages:

- Lower sensitivity

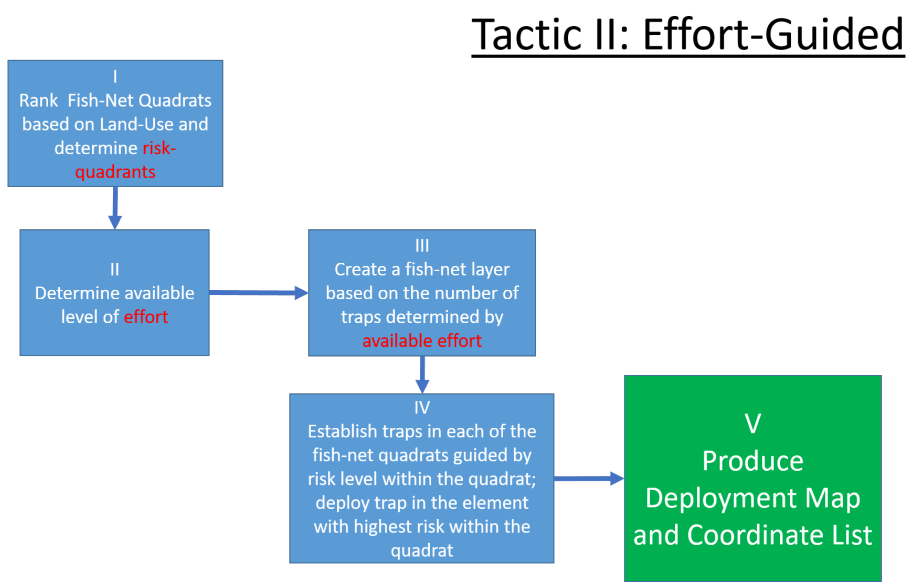

Figure 13. Flowchart showing the procedure for deployment of traps following tactic II: "Effort-Guided". Deployment maps can be automatically produced every time parameters are modified.

Figures 14, 15 and 16 provides examples (Greek Polygon, South African Ermelo-Davis Polygon and Croatian polygon) of trap distribution following tactic II.

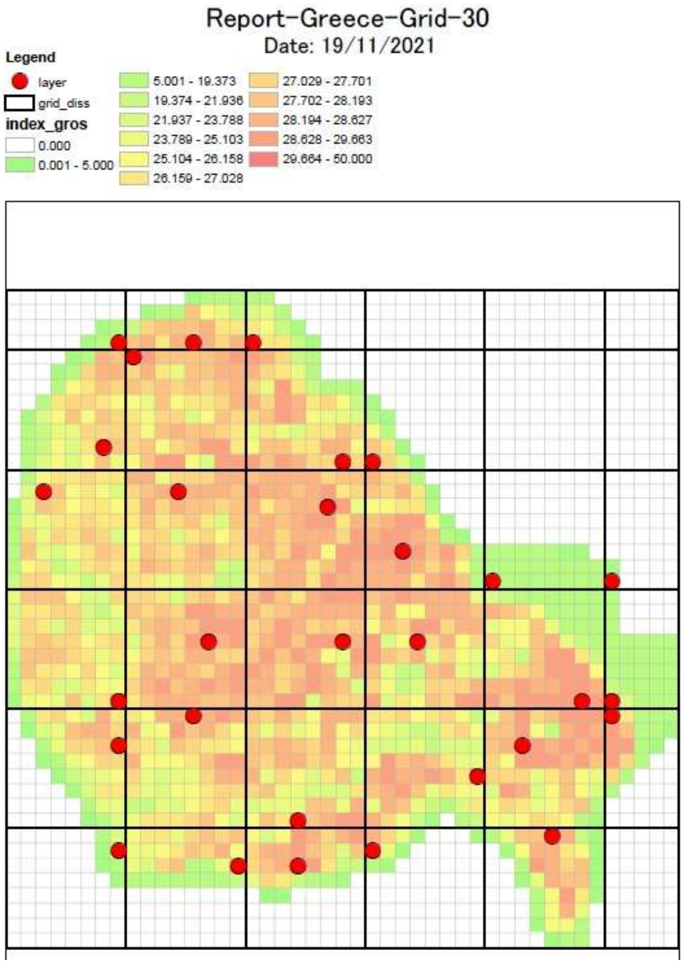

Figure 14. Distribution of traps (red points, any type) in the Greek study area following Tactic II: "Effort-Guided". The simulation is based on the deployment of 30 traps in the entire region.

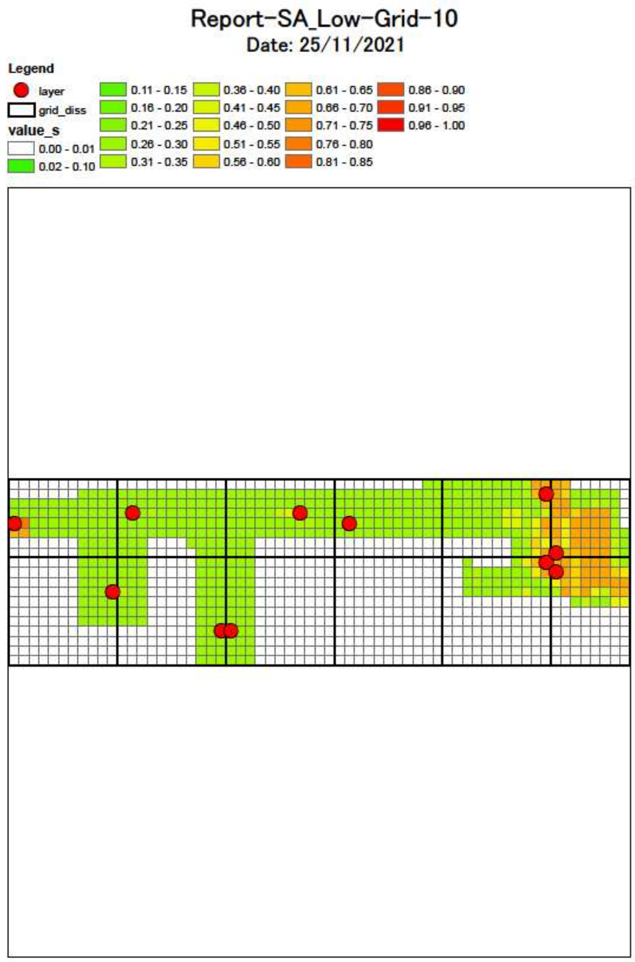

Figure 15. Distribution of traps (red points) in the Ermelo-Davos study area following Tactic II: "Effort-Guided". The simulation is based on the deployment of 10 e-traps in the entire region.

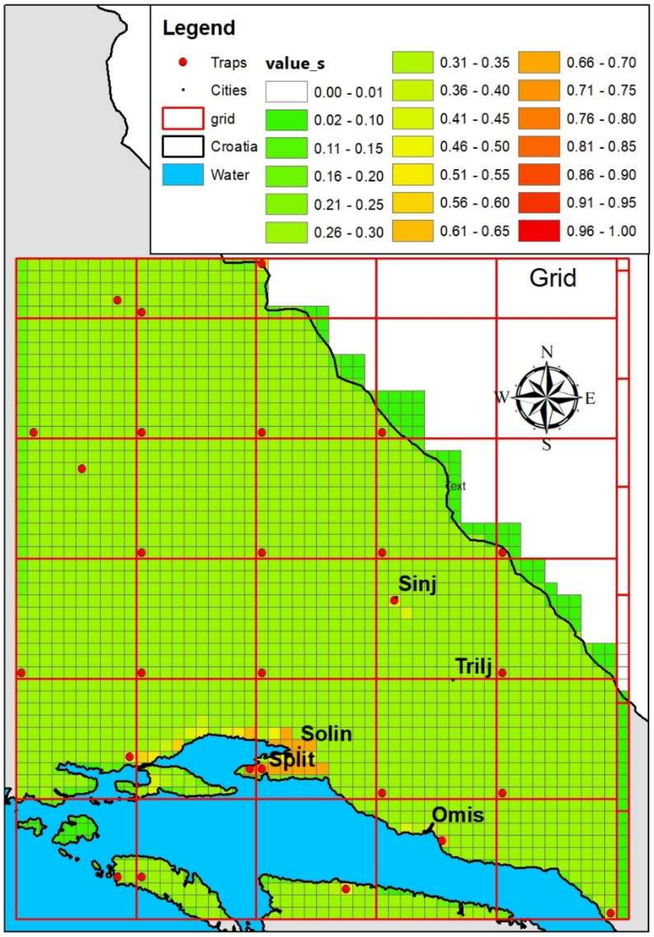

Figure 16. Distribution of traps in the Dalmatia (Croatia) study area following Tactic II: "Effort-Guided". The simulation is based on the deployment of 30 in the entire region.

"Space-Guided" Tactic (Figure 17):

Concept: Distribution of surveillance traps is determined by the spatial patterns of (quadrat) risk-level, and a predetermined minimal distance between neighbouring traps

Assumptions:

- Deployment of traps in the geographic space is guided by cell-risk level (see section 3.2.1) and their spatial patterns. Minimal distance between neighbour traps will be pre-determined
- Number (n) of surveyed cell will be determined by effort possibilities (i.e., trap numbers and ability to serve traps)
- First trap will follow cell with the highest risk level. Next trap location will be determined by the closest cell with the next highest risk level and a pre-determined minimal distance from previous trap location. Deployment of following traps will

follow the same scheme, always keeping a minimal predetermined distance between previously deployed traps.

- Traps will be located in the centre of the selected quadrat or in the element with the highest risk within the cell

Advantages:

- Distributes surveillance effort based on the spatial patterns of risk and minimal distance, thus, avoiding excessive closeness between neighbouring traps

Disadvantages:

- Requires complex analytical manipulations to determine trap deployment

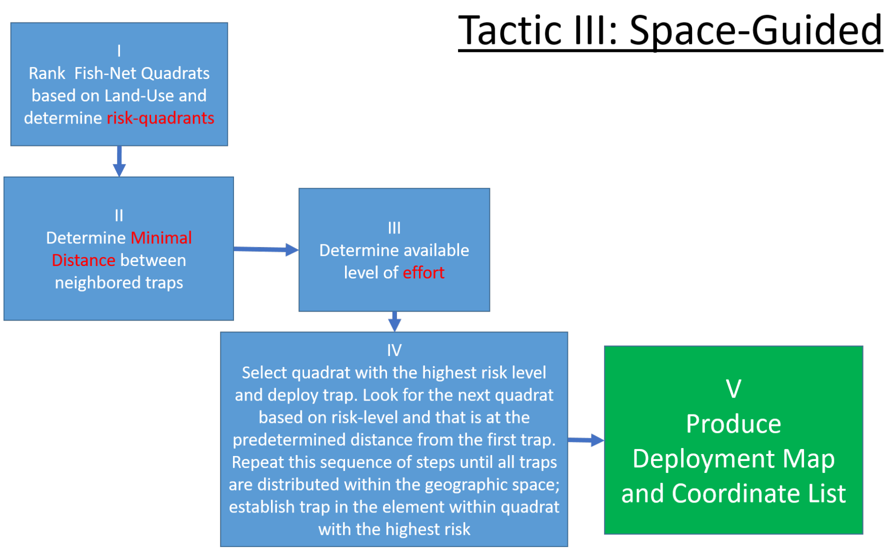

Figure 17. Flowchart showing the procedure for deployment of traps following tactic III: "Space-Guided". Deployment maps can be automatically produced every time parameters are modified.

Figures 18, 19 and 20 provides examples (Greek, Croatian and South African Ermelo-Davis study areas) of trap distribution following tactic III.

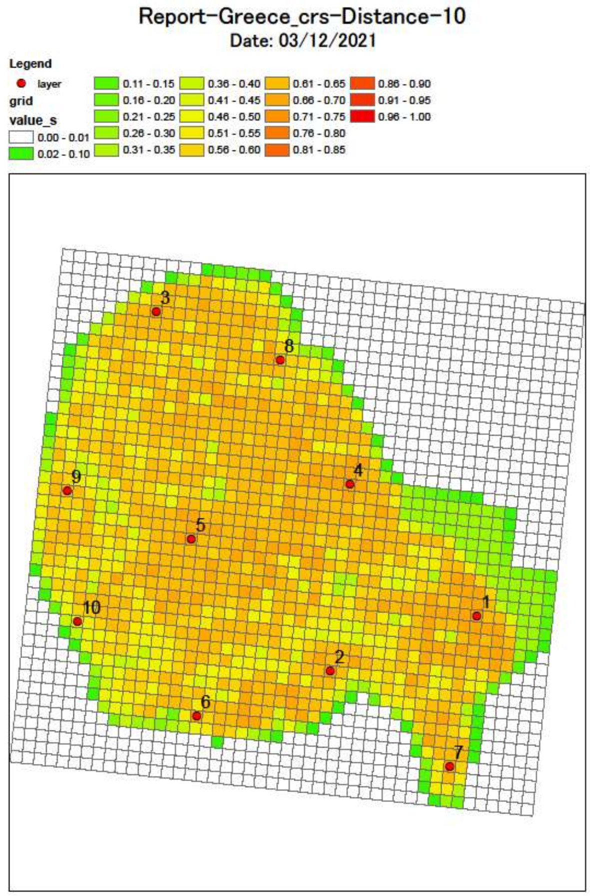

Figure 18. Distribution of traps (red points, any type) in the Greek study area following Tactic III: "Space-Guided". The simulation is based on the deployment of 10 traps in the entire region.

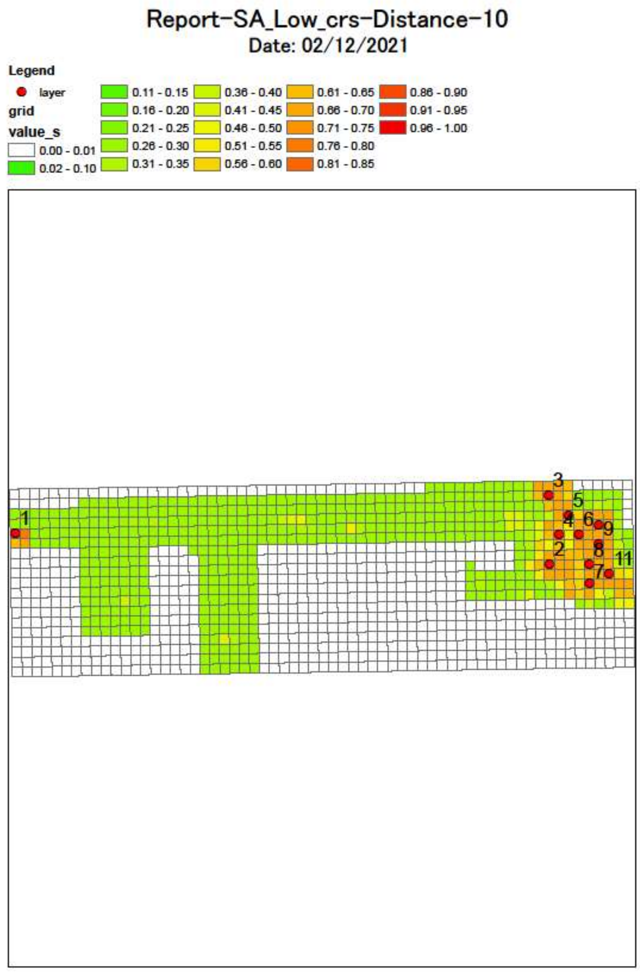

Figure 19. Distribution of traps (red points) in the Ermelo-Davos study area following Tactic III: “Space-Guided”. The simulation is based on the deployment of 10 e-traps in the entire region.

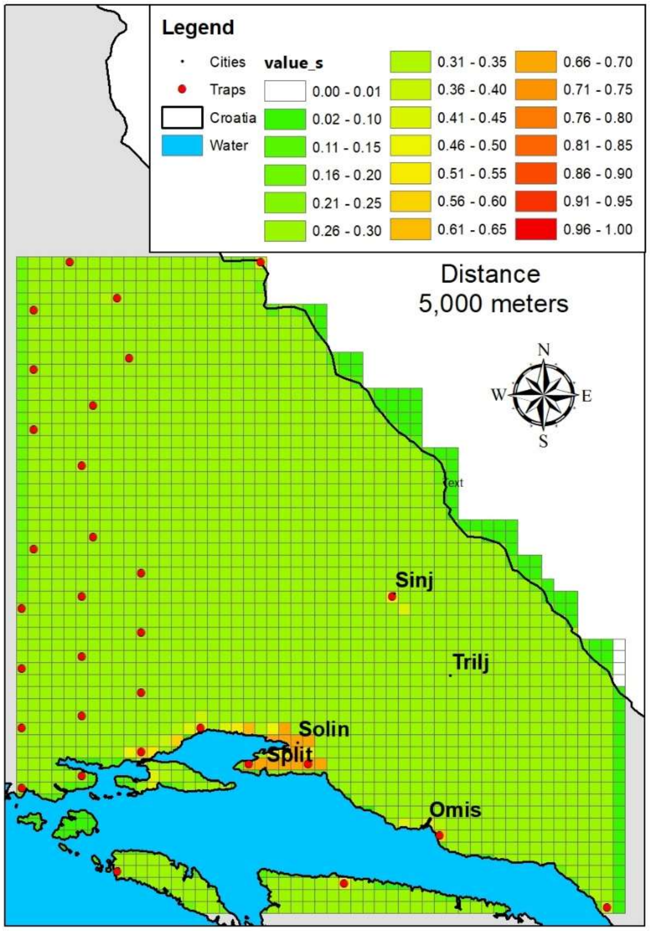

Figure 20. Distribution of traps in the Dalmatia (Croatia) study area following Tactic III: "Space-Guided". The simulation is based on the deployment of 30 in the entire region.

3.2.3 Sensitivity Test:

In order to test the sensitivity of the risk-ranking system suggested in section 3.2.1, we applied a testing format following the scenarios outlined in Table 1. The sensitivity test was run only for the Greek polygon. Table 1 provides the tested changes in the weights of the land cover/use, ranging from an increase in 15% in the weight of the orchards to a reduction of 15% in the orchards land cover. Table 2 presents the amount of traps that changed positions from the reference one (i.e., the original weight system) in each one of the three tactics (section 3.2.2). As can be seen in Table 2, the sensitivity of the reference weight-values is low, suggesting that the selected weights are appropriate for the landscape conditions of the Greek polygon. Although not tested, we expect similar result for all other testing sites.

Table 1. Sensitivity test outline. The reference weights refer to the weight determined for the 4 different categories of land cover/use described in section (3.2). We tested two scenarios: an increase in the weight of the orchard's land cover/use (Scenario I) and a decrease in the orchard's land cover/use (Scenario II). The amount of change in weight is gradual for each of the two scenarios (red letters)

Land Cover	Reference weights in % (actual weights input)	Scenario I Increase in orchards weight (% and decrease in the other land cover/use)			Scenario II Decrease in orchards weight and increase in the other land cover/use		
		5 %	10 %	15 %	-5 %	-10%	-15 %
Orchards	50 (100)	45	40	35	55	60	65
Residential/ Industrial	35 (70)	38.5	42.0	45.5	31.5	28.0	24.5
Natural landscapes	14 (28)	15.4	16.8	18.2	12.6	11.2	9.8
Water resources	1 (2)	1.1	1.2	1.3	0.9	0.8	0.7

Table 2. Results of the sensitivity test simulation applied to the 3 suggested tactics in section 3.2.1 for the Greek polygon. The numbers provide the ratio of traps changing position from the "reference-deployment" (i.e., using the reference weight of land use stipulated in section 3.2) as a ratio of the total traps deployed in each case.

Test Scenarios (% change from the Reference Weight as described in Table 1)	"Risk-Guided" (no. traps/total no. of traps)	"Effort-Guided" (no. traps/total no. of traps)	"Space-Guided" (no. traps/total no. of traps)
15	0/30	0/30	0/30
10	0/30	0/30	0/30
5	0/30	0/30	0/30
-5	1/29	1/29	3/27
-10	1/29	1/29	3/27
-15	1/29	1/29	3/27

3.2.4 Fine-Scale Landscape Characterization (crop susceptibility):

This algorithm should be applied to selected quadrats in 3.2.1 after the crop becomes susceptible (based on host phenology and expected population dynamics of target FFs). This step in the DSS is aimed at incrementing the sensitivity of the surveillance and our ability to detect invasive and/or incipient fruit flies. The aim is to intensify surveillance effort to increase the probability of detection. This fine-scale characterization requires more detailed geographical and agronomic information, which may be difficult to obtain. This information will be collected, if possible, for selected pilot areas. If we succeed in collecting good data, this aspect, which is currently under development, will be implemented during the second season (i.e., 2023) of the demonstrations in specific study areas. Elements that are being taken into consideration include:

1) Locations with high FF habitat suitability:
    a. Locations with the presence of known plant hosts (i.e., adult reproductive hosts, larval development hosts, adult nutritional hosts, refugee hosts)
    b. Locations with past knowledge of interception and trapping of FF (even non-target)
    c. Areas where harvested horticultural hosts are stored and traded.
2) Locations with important concentrations of hosts:
    a. In rural areas, all sort of fruit-producing ecosystems (i.e., commercial or self-consumption; intensive or low input agroecosystems; organic, etc.).
    b. In urban and semi-urban areas, recreational and residential areas known (or suspected) to bear important numbers of hosts of FF (> 10 productive trees per area).
3) Locations with different levels of FF management:
    a. Level of pesticide utilization
    b. Level of control practices (other than pesticides) used
4) Locations of importance for gathering and trading fruits of interest

The choice of locations to establish and deploy surveillance elements will be based on the mapping of the region aimed for surveillance. The mapping will need to indicate the location and type of agricultural production, urban and residential areas, and intensity of host-presence. Additional elements that may be incorporated in the mapping of the surveillance region include transport and trading areas of hosts, and natural ecosystems suspected of bearing host-trees. Thematic maps should emphasize the probability of intercepting and capturing a FF by ranking the areas based on the probability of FF detection. Rankings will be based on the above-mentioned risk factors. Rankings will also be determined based on factors being affected by the temporal dimension (i.e., host-phenology and susceptibility). This aspect is explained in the following section.

3.3. The Time Dimension in the Optimization of Surveillance

Knowledge of the best period in which adult FF are expected to be active (flying, mating, foraging and reproducing) can be used to make surveillance systems more effective. Optimization will involve intensifying surveillance efforts during the FF activity period and reducing effort during the periods of low and/or non-expected FF activity. FF activity is dependent on temperature and to a lesser extent soil moisture patterns. These ranges of temperature are known and were further fine-tuned in WP2 and WP5. Climate suitability for FF will be estimated dynamically using CLIMEX (see Figs. 2 and 3 exemplifying the application of CLIMEX to *C. capitata* in Greece and Croatia for the year 2019). DYMEX models will simulate FF phenological patterns in each area, providing location-specific guidance for the targeting of different surveillance methods (adult trapping, fruit surveillance, etc.). Deployment of adult traps will be guided by the set of rules based on CLIMEX risk maps:

1) Region unsuitable for FF population growth: Do not deploy surveillance system
2) Region Expected to be suitable for FF activity in the future 5-10 days: Start to deploy surveillance system (at low intensity)
3) Region suitable for FF activity, and landscape susceptible to FF: Intensify surveillance efforts

Where biofixes are available, the DYMEX models can be used to further refine the temporal deployment windows.

3.4. Implementation of Optimization Routines

The DSS strategy and deployment tactics will be implemented and tested in the four study sites (see Appendix I). The implementation will be adapted to the level of regional characterization. The format of the implementation for each region is currently being discussed and fine-tuned. Specific detection protocols will become available for the 2nd quarter of 2022 (April, 2022).

Recently a protocol for testing the optimization strategy using electronic traps against the stakeholder's surveillance strategy was developed for South Africa (Southern Hemisphere). In South Africa the testing areas are at the beginning of *B. dorsalis* population development and detection. This season test will run from December 2021 until March-April 2022. The test includes the three optimization tactics (see section 3.2.2), which will be contrasted to the stakeholders' proposal for *B. dorsalis* surveillance in each of the testing areas. Each testing polygon and area in South Africa will be tested with one of the tactics: in Ermelo-Davos we will implement the risk-guided tactic, in Schoemanskloof the effort-guided tactic, and in Nelspruit the space-guided tactic. The evaluation will include:

(1) Early Warning information provided by e-traps vs. that of scouts (visiting conventional traps every two weeks)

(2) Cost of scout surveillance (time and car) vs. costs of cellular communication and "e-trap device" (the expected cost of the device under mass production will be calculated)

The information derived from this preliminary test will be used to fine-tune protocols for the Northern hemisphere.

4. References

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Appendix I

Geographic Characterization of Regions to Test an Optimize Surveillance Strategy

1. Objective/Scope:

To characterize selected areas in four countries where case studies to validate suggested optimized surveillance systems will run between the second and fourth year of the project. The characterization includes the digital mapping of relevant agricultural and urban landscape, and the phenological and spatial patterns of the three fruit fly species inquired by the project. Characterization was conducted during the first 24 months of the project.

2. Approach:

Selection of test regions: The selection of working regions was done in consultation with involved partners and stakeholders. Selected locations include areas where plenty of host is available, where target fruit fly species have been detected, or intercepted in the past, and where surveillance strategies for low populations can be implemented and tested. To develop surveillance strategies for the expanding and invasive *C. capitata*, we selected the area of Imathia and Pella in Macedonia, Northern Greece (Figure A-I 1A), and Dalmatia in South Croatia (Figure A-I 1B). Imathia and Pella are the most important peach producing areas in Northern Greece. Effective surveillance systems are required in this region due to the larger importance that *C. capitata* seems to be taking in this area as a pest due to its expansion during the last years to this Northern regions of peach production. Dalmatia includes an altitudinal transect that extends from the coastal area to the border with Bosnia-Herzegovina, with *C. capitata* host scattered throughout the transects (in small agricultural plots and home-gardens), providing a ground to validate surveillance systems in a spatio-temporal heterogeneous landscape. In this region of Croatia, very low populations have been reported at intermediate elevations. To develop surveillance strategies for the invading species *B. zonata*, we selected the North of Israel (limiting with Lebanon) (Figure A-I 1C), where *B. zonata* interceptions have been reported in the recent past. The selection responded to the request of the Plant Protection and Inspection Services of the Ministry of Agriculture and Rural Development of Israel (PPIS), after consultations with the people in charge of surveillance of invasive pests. The North of Israel is an important fruit producing area (mainly deciduous crops), which are host of *B. zonata*. PPIS request responded to the need of having an efficient surveillance system in an area highly susceptible to this fruit fly pest, and where no information on the patterns of the fly in this neighboring country exist (Israel has no diplomatic relations with Lebanon). The areas selected to validate surveillance systems for *B. dorsalis* in South Africa include Nelspruit and Shoemansklof (Mpumalanga Province), which are important commercial citrus producing areas East from Pretoria (bearing large populations of *B. dorsalis*), and the Ermelo-Davel area, an apple and pasture region, with very low populations of *B. dorsalis* (Figure A-I 1D). The three areas in South Africa were characterized, but we expect to implement surveillance strategies and DSS for the region of Ermelo-Davel, which is a low prevalence area for B. dorsalis, allowing us to simulate invasive scenarios.

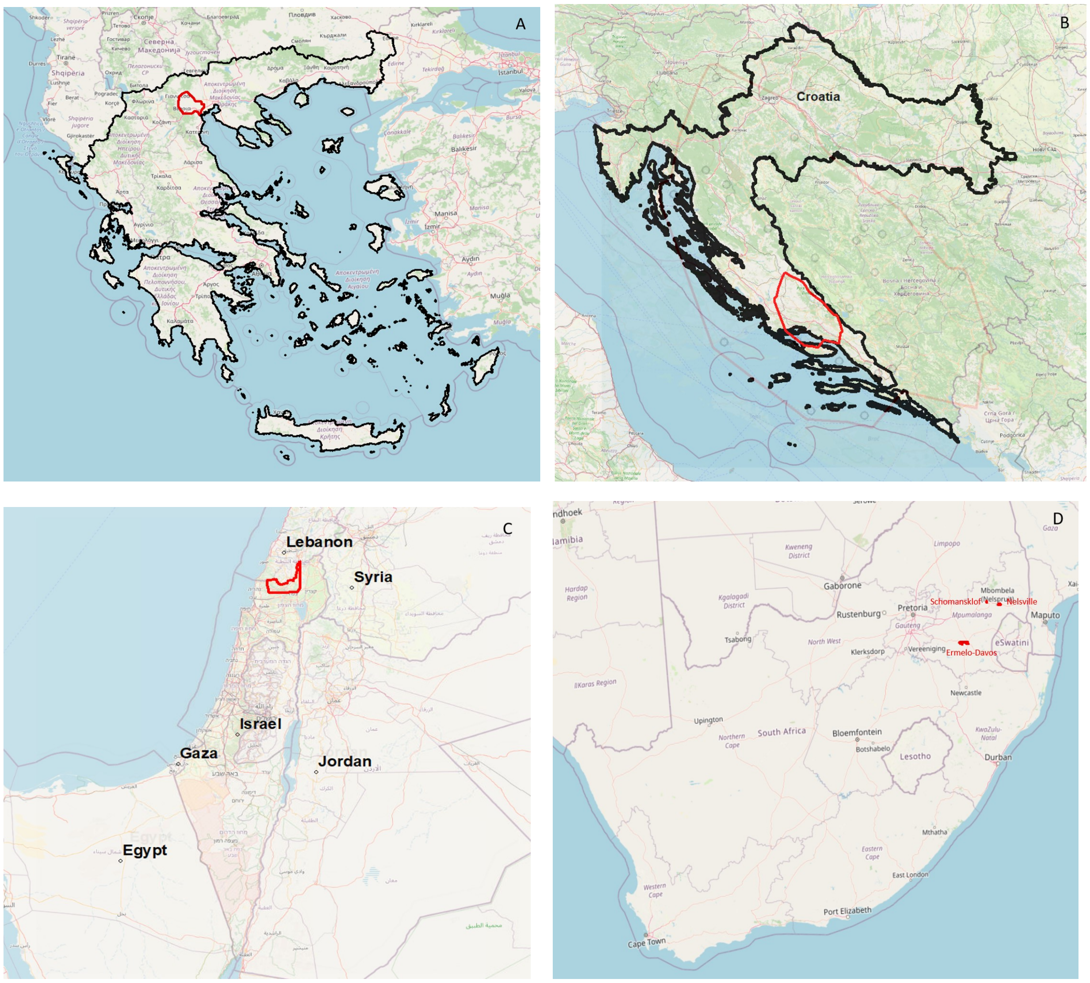


Figure 21. The four project areas (polygons in red) in the four countries that will serve as simulation stages to test and optimize surveillance strategies for the early warning of invading Fruit Flies: (A) Northern Greece; (B) Southern Croatia; (C) Northern Israel and (D) Northern-East South Africa

2.1 Development of the geographic platforms:

Geographic platforms for all regions were developed in GIS environments (ArcGIS and QGIS). The first step was to delimit working polygons, and try to extract orographic and geographic characteristics from internet sources. A second phase included the procurement of orthophotos at a good resolution to characterize landscape elements, especially agricultural plots and urban objects (e.g., home gardens). For some of the areas, these orthophotos have been incorporated to the working polygons, and characterization of observed geographic objects has proceeded in two ways: (1) creation of a layer of geographic objects found in the orthophotos, especially urban and agricultural areas, and then physical characterization on-site by partners; and (2) procurement of agricultural layers characterizing agricultural production in the working region. During the process, scripts to automate processes using python language were written (i.e., scripts to download orthophotos resolution, and hierarchically link them).

2.2 *Characterization of fruit fly spatio-temporal patterns*:

Starting in the Summer (Northern Hemisphere) of 2020, conventional traps for *C. capitata* (McPhail with Biolure and Jackson with Trimedlure) were deployed randomly in the region of Dalmatia, Croatia. A uniform grid of 5 X 5 km covering the region guided the deployment of approximately 20 sampling stations (Figure A-I 2). Traps were serviced on a regular basis during the summer-autumn months. Similarly, the same trap system and deployment strategy was followed for the region of Imathia and Pella, Macedonia, in Northern Greece (grid and trapping started in the summer of 2020) (Figure A-I 2). In Israel, characterization of the trapping patterns of *B. zonata* males are being done using the current conventional trapping system deployed by the PPIS of Israel in the region of the study (Stinner traps lured with Methyl Eugenol, ME) (Figure A-I 3). The grid used by PPIS in the area includes around 80 sampling stations (i.e., traps). Historic data exists (up to 5 years), and we collected data from 2020-21. Regarding South Africa, we followed a similar strategy to that of Croatia and Greece to characterize the spatio-temporal patterns of male and female *B. dorsalis* (males were lured with ME and females with Biolure). In South Africa, trapping grids (Figure A-I 4) were active during the Spring (October-November) and Summer (December-January) months in the Southern Hemisphere.

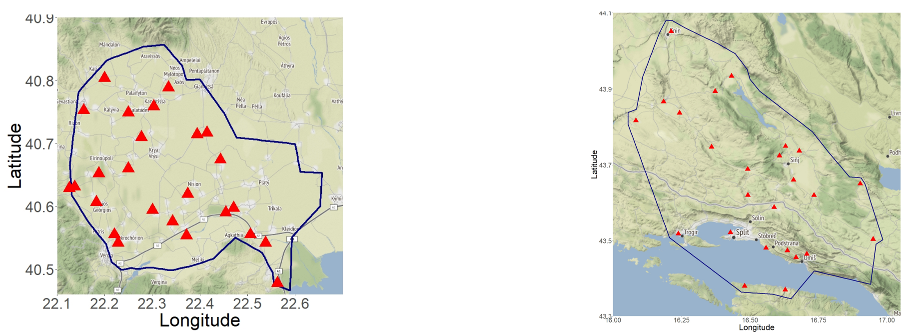


Figure 22. Greek (left) and Croatian (right) polygons showing location of sampling stations (red dots and tringles) used to follow the populations fluctations and spatial dispersion of *Ceratits capitat*a male and female flies.

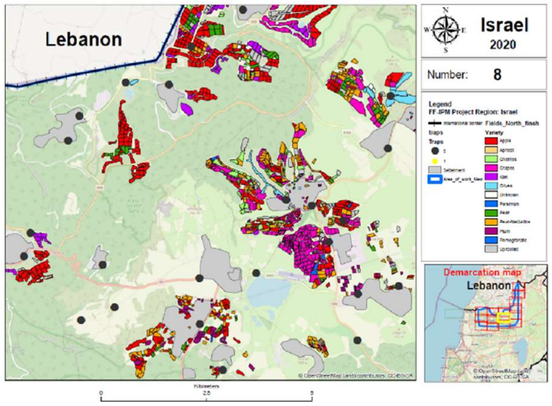


Figure 23. Map of Northern Israel showing a small area of the FF-IPM working polygon (yellow in the demarcation map). The map shows the international border with Lebanon (blue line towards the North), the agricultural characterization of orchards, and part of the sampling station grid managed by PPIS to intercept *B. zonata* (black dots).

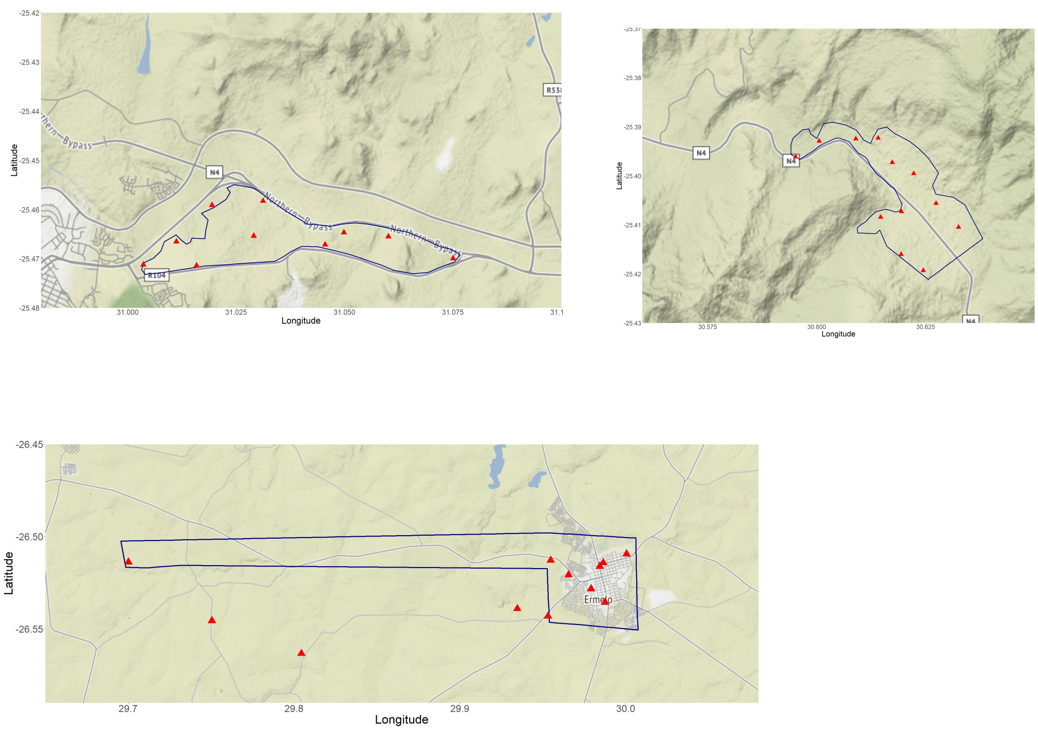


Figure 24. The three South Africa polygons (Nelspruit, Shoemansklof and Ermelo-Davos) used to characterize *B. dorsalis* spatio-temporal trends, showing the location of the trapping grid (red dots). Neillsville and Shoemansklof are agricultural areas composed mainly of citrus and macadamia orchards. The Ermelo-Davos polygon in the South of the Mpumalanga Province

includes a large area of land with a few commercial apple orchards, several abandoned apple orchards, pastures and a town (Ermelo) with residential, industrial areas and urban parks.

2.3 *The Characterized Regions*

2.3.1 *Greece test region*:

The regions of Imathia and Pella in Macedonia, Northern Greece, is the most important peach producing area of Greece. Commercial fruit producing orchards (for the agricultural industry of the region) mainly dominates the valley. Most orchards are small (a few hectares). Few towns spread throughout the agricultural valley, which extends from the sea towards the Northern mountain chain. The working polygon has an extension of 1 195 km^2. The geographic platform for the polygon was developed by obtaining good quality orthophotos with a very high resolution, and agricultural layers kindly provided by the agricultural sector (growers and administration) of the region. Figure A-I 5 shows two examples randomly taken from the polygon to illustrate the complexity of the landscape, and the composition of fruit orchards, which in the majority are host to the locally established *C. capitata*, and potential hosts of the two target invasive FF: *B. dorsalis* and *B. zonata*.

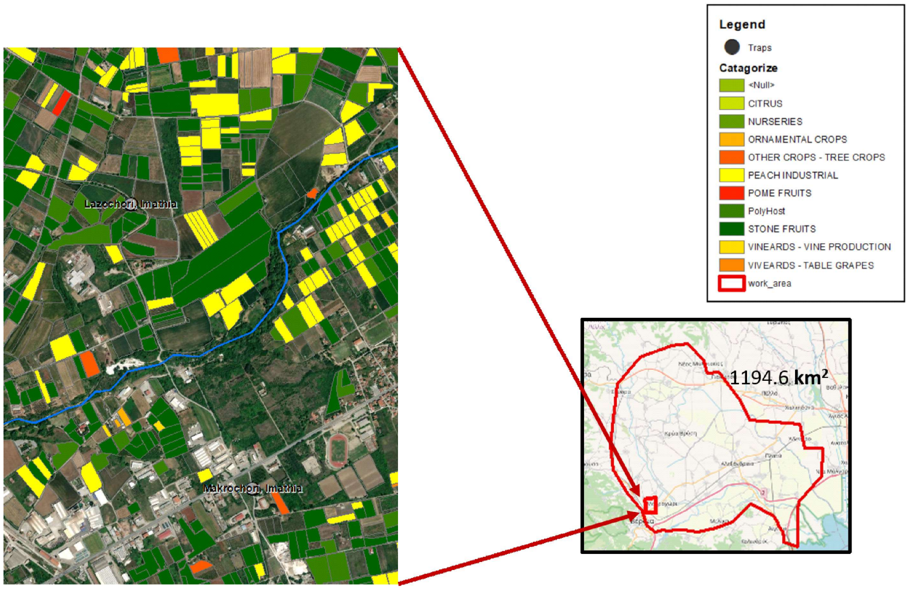


Figure 25. Two randomly selected areas within the Greek polygon showing the complexity of the Agricultural layer and landscape structure.

We also developed the ability to automatically characterize the land cover around traps fur analytical purposes. Fig A-I 6. Illustrates the process and land use characterization around a trap in the Greek study area.

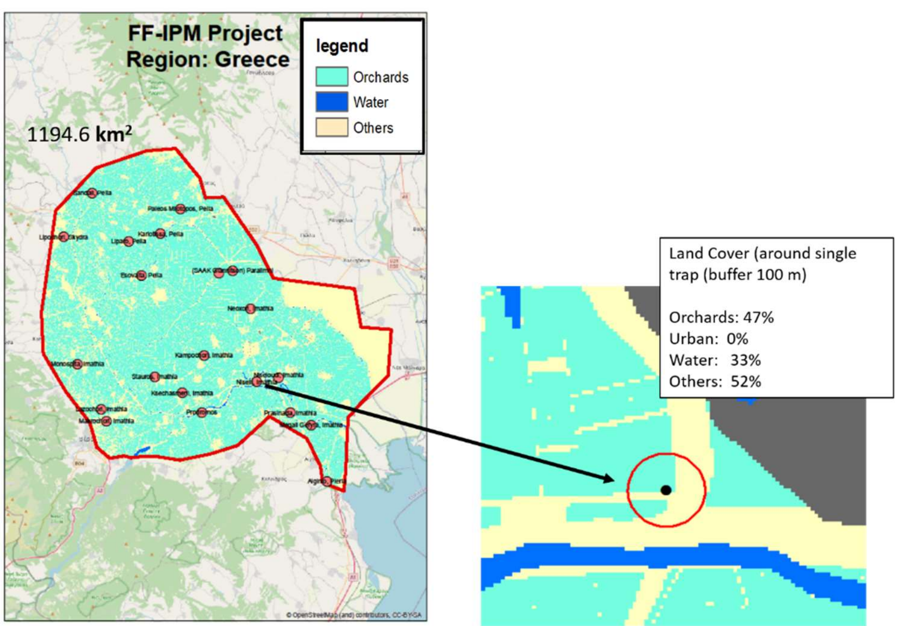


Figure 26. Illustration of the land cover characterization around a randomly selected trap in the Greek polygon. The land cover describes the percentage of the four selected categories (Table) of land cover present around a buffer of 100m in diameter.

2.3.1.1 *<u>Ceratitis capitata</u>* <u>spatio-temporal patterns in the Greek test region</u>:

Ceratitis capitata patterns in the Greek polygon was characterized during the last two year. Figure A-I 7 shows the typical monthly catches registered in the polygons landscape. Few *C. capitata* are trapped in August. Main population captures occur between September and November, declining towards December. Trapping was more intense close to the coastal areas, but a general dispersion can be seen throughout the entire polygon

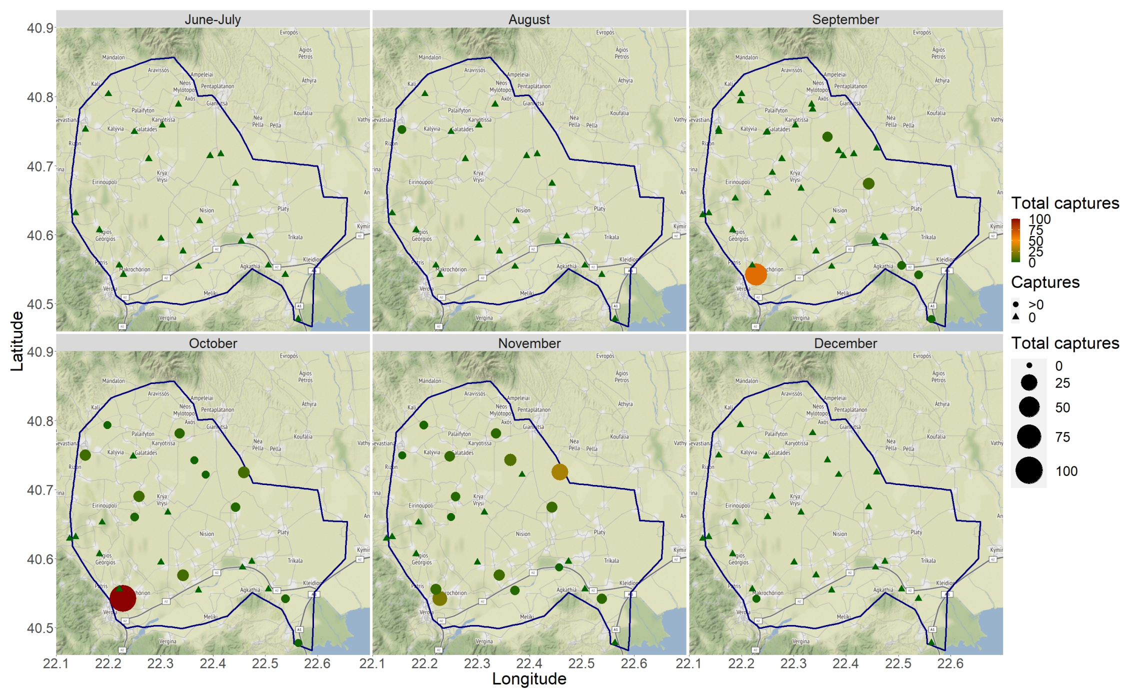


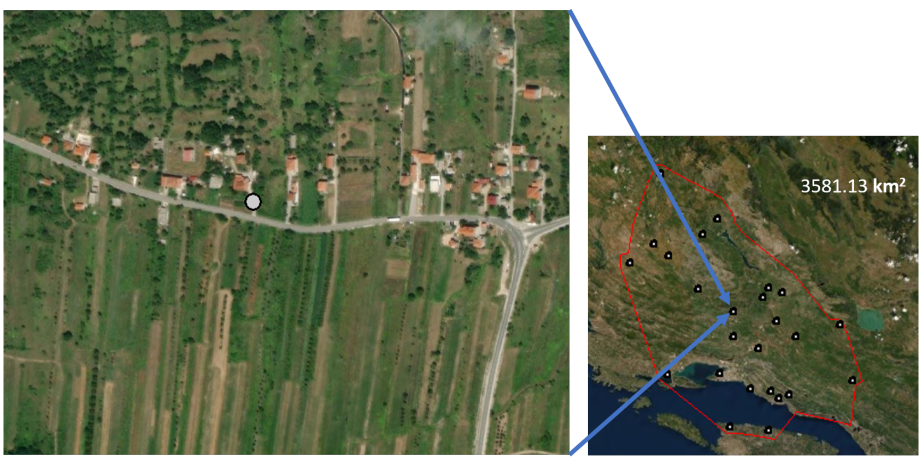
Figure 27. Series of maps showing the monthly total captures of *C. capitata* in the Greek polygon area during 2020.

2.3.2 Croatia test region:

The region of Dalmatia in Southern Croatia, is a Mediterranean area composed of typical Mediterranean vegetation and cultivars (olives, grapes, figs, etc.). The region is also crossed from South to North and East to West by mountains, creating some agricultural productive valleys. Agriculture in this area is mainly small-scale, and a mixture between self-consumption and limited local commercialization. Production takes place in small plots, which are usually close or inside the family household. The FF-IPM selected area for Croatia includes a polygon of approximately 3 581 km^2, which contains the coastal area and some nearby islands facing the town of Split, and the mountains and valleys bordering Bosnia-Herzegovina (to the East and North) and the bank of the

Kirka river (West). The orography of the selected working area creates elevation corridors (ranging from sea level up to several hundred meters) that cross from the seashore to the north, towards more temperate areas resembling Continental Europe. The small orchards found around these corridors and the increased elevation transects found from the sea-shore to the North, provides an invasive stage to test and optimize strategies to intercept and detect invasive FF. In this area *C. capitat*a is found in very low numbers, with reduced population levels following the elevation transect. Moreover, the "host" corridors are limited in space and time due to low winter and spring temperatures. This creates the opportunity to optimize detection strategies for possible FF invasive corridors to Central Europe.

Geographic characterization of the Croatian working polygon was first attempted with procured orthophotos. The quality and resolution of the orthophotos, and their continuity, was poor affecting our ability to create a more detailed geographic platform of land cover and use. The current platform is mainly based on available internet resources. Figure A-I 8 shows two areas randomly selected from the polygon where traps of the FF-IPM project were established for the *C. capitata* population characterization. Figure A-I 9 illustrates also the application of FF-IPM developed algorithms to characterize two areas around traps in the Croatian polygon.



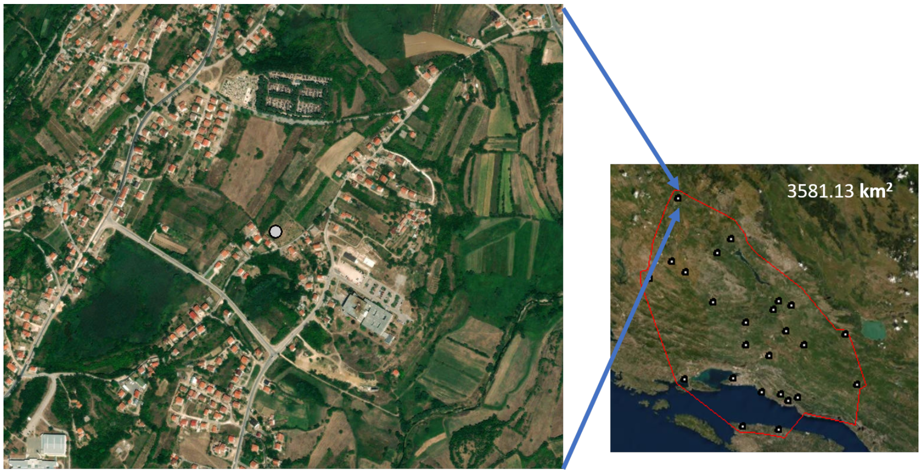
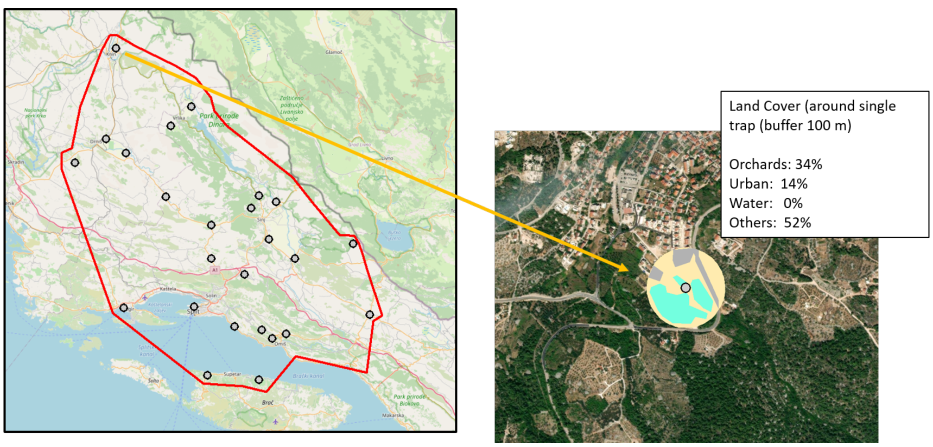


Figure 28. Focus on two different locations of the Croatian polygon. The upper image shows the landscape (mainly small agricultural plots) in the center of the polygon where a trap (close to a home bearing host trees) is located, while the lower image shows the semi urban landscape of a town in the north of the polygon. The trap can be seen (white dot) in the center of the image, close to a house and hung from a host tree.



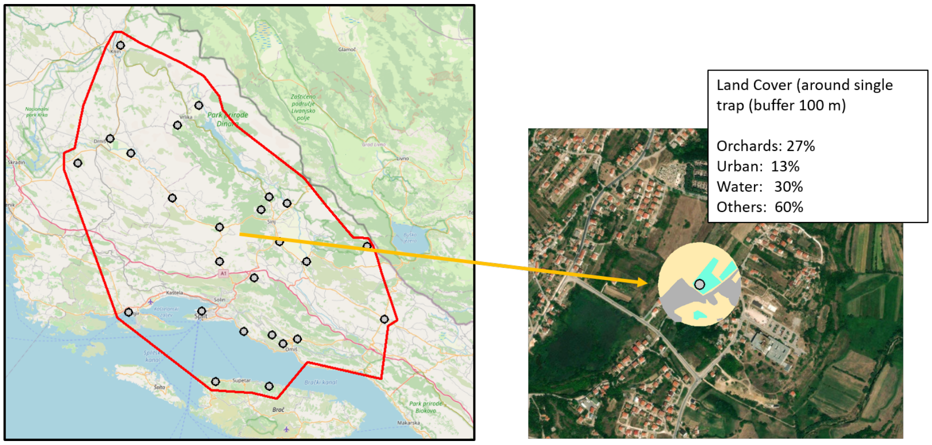


Figure 29. Two examples of land cover characterization in the Croatian landscape, illustrating the percent of the four different categories present around the traps in a buffer of 100 m diameter.

2.3.2.1 *Ceratitis capitata* spatio-temporal patterns in the Croatian test region:

Ceratitis capitata patterns in the Croatian polygon was characterized during the last two year. Figure A-I 10 shows the typical monthly catches registered in the polygons landscape. *Ceratitis capitata* was already detected in the coastal area of the polygon in June. Population captures increased in the coastal area during the following months, peaking in October. Afterward, captures decline, and become nil in December. Captures in higher areas of the polygon (inland valleys) are only observed during October and November.

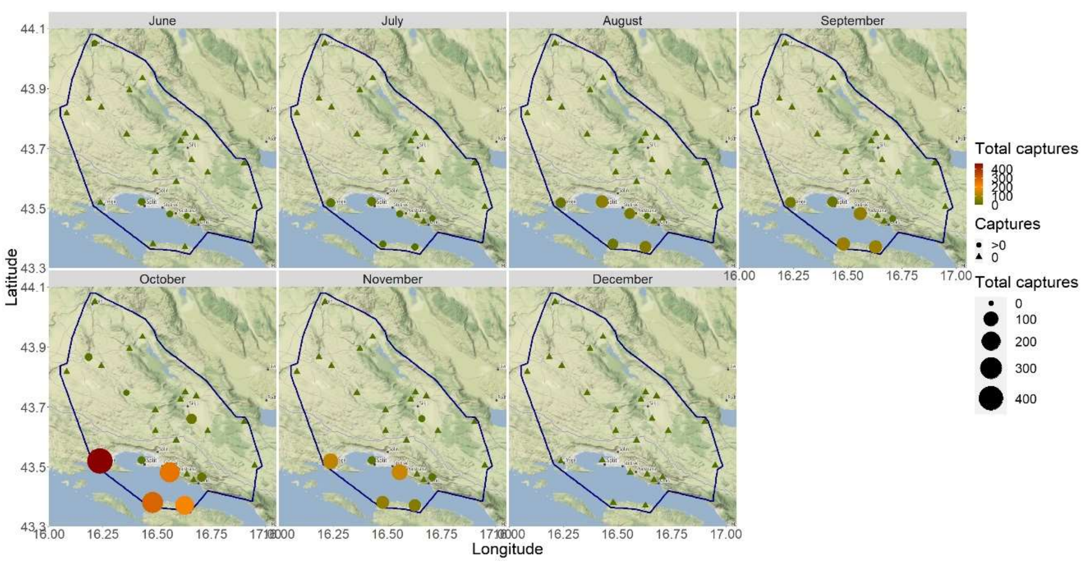


Figure 30. Series of maps showing the monthly total captures of *C. capitata* in the Croatian polygon area during 2020.

2.3.3 Israel test region:

The area selected as a scenario to optimize surveillance systems in Israel is located in the North of the country, in the border with Lebanon. The area (425 km^2) is a mountain range in the Northern border of Israel with Lebanon. The location produces highly valuable commercial deciduous fruit for the Israel's market, and was suggested by PPIS (Israel's NPPO) as the scenario to develop and optimize surveillance systems for invasive *Bactrocera* species. The closeness of this area to Lebanon makes it an important scenario to develop strategies due to the fact that *B. zonata* has been intercepted close to the border in the past, and since no information on pest status is shared by the Lebanese government to Israel due to the lack of diplomatic relations and the state of war. Thus, PPIS was interested to have an optimized early-warning surveillance system in this area. PPIS currently manage around 80 Stinner traps loaded with Methyl Eugenol in the area of the pilot. These traps are inspected on a frequency of 2 times a month, and at least two scouts serve them. This situation provides FF-IPM with an interesting scenario to optimize surveillance systems and compare them to current surveillance systems managed by the NPPO.

The Israel pilot region ranges from 300 to 800 m above sea level. The region includes several small towns and agricultural settlements, with home gardens bearing FF host fruit. The region is a typical Mediterranean landscape, with indigenous Mediterranean shrub and pine and oak forests. Commercial orchards are relatively small, and include a large variety of fruits, many of them susceptible hosts of FF (*C. capitata* has established in this region with large populations). Pest control is in place and includes the use of pesticides, and other strategies, such as sexual disruption with moth pheromones. The geographic characterization used available high-resolution orthophotos and agricultural layers. Figure A-I 11 illustrates two randomly selected areas in the working region. The thematic maps show the high variability of orchards and fruits grown in the region. Figure A-I 12 illustrates land cover around selected traps.

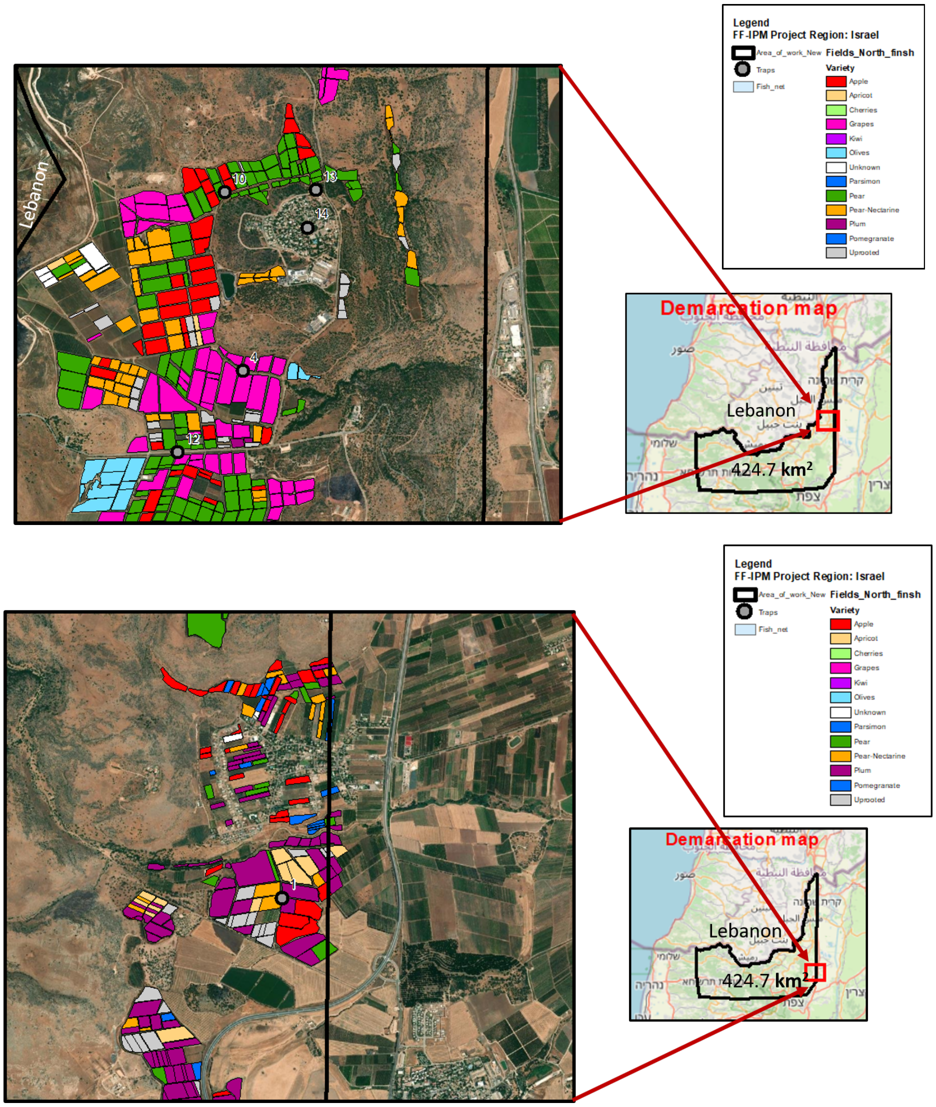


Figure 31. Illustration of two different locations of the Israel pilot region. The upper image shows the complex agricultural commercial production in the region, close to the border with Lebanon (no information on invasive FF status). It also shows a small agricultural settlement in the area. The lower images illustrate another area of the working region, with a concentration of commercial orchards producing different fruit varieties. PPIS Stinner surveillance trap locations can be seen in the maps (grey dots).

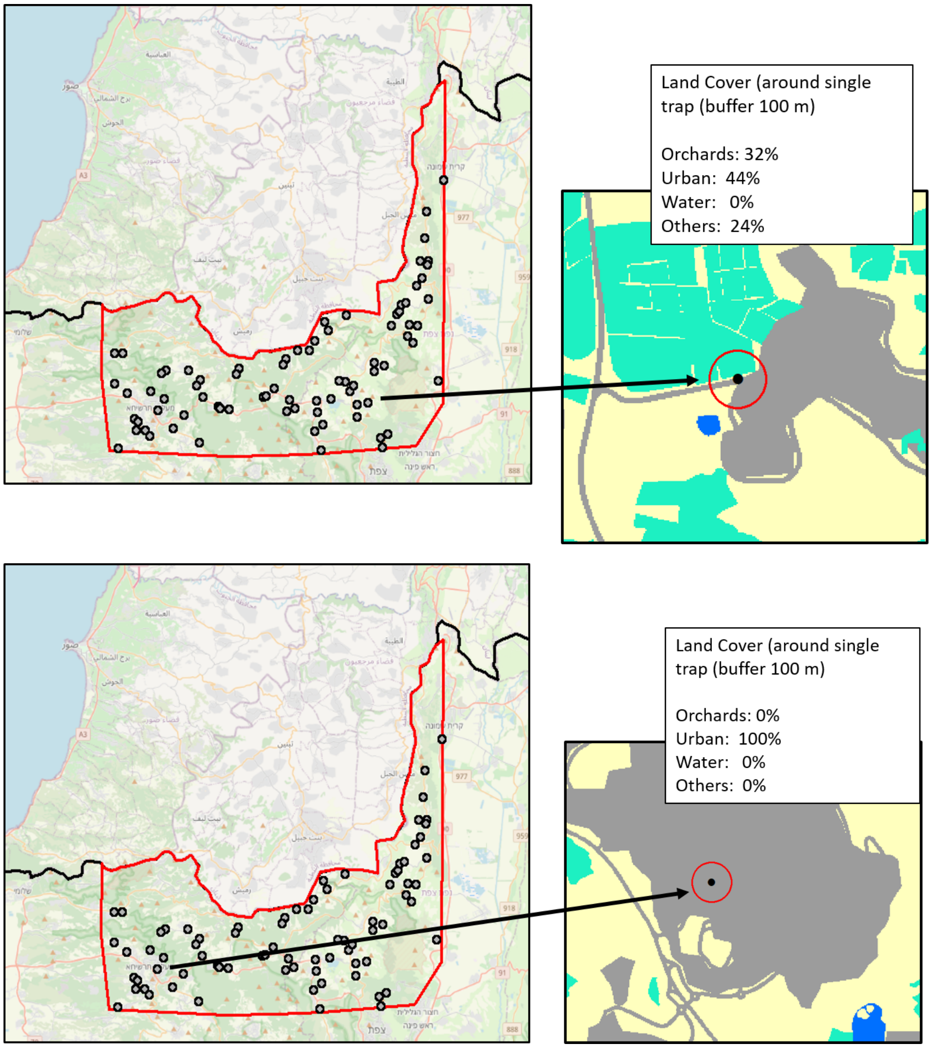


Figure 32. Two examples of land cover characterization in the Israel landscape, illustrating the percent of the four different categories present around the traps in a buffer of 100 m diameter.

2.3.3.1 <u>*Bactrocera zonata* spatio-temporal patterns in Israel's test region</u>:

Data derives from PPIS surveillance system for the last 5 years, and includes a few interceptions of *B. zonata* during the period (Figure A-I 13). Most of the interceptions were close to the border with Lebanon. First single record corresponds to 2015. I n 2016 there were two registered interceptions. A single interception was reported in 2017. No interceptions were reported between 2018-2019. Interceptions again occurred during 2020. Until September 2021, no interceptions have been reported. Most of the interceptions occurred during the fall and winter period.

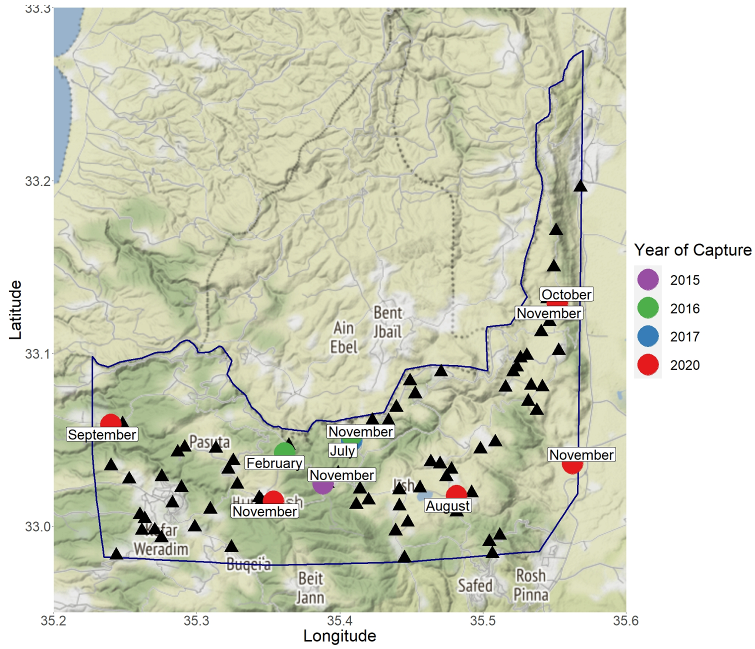
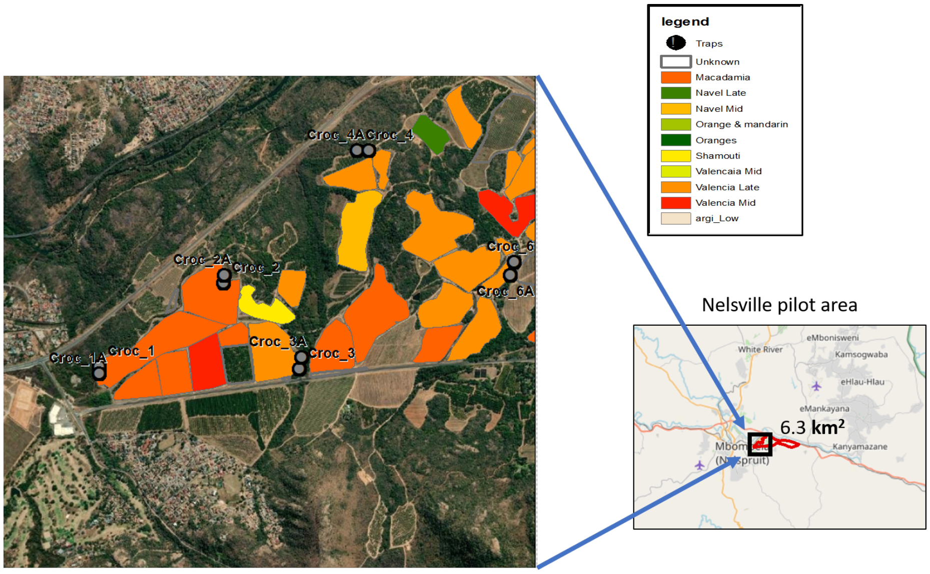


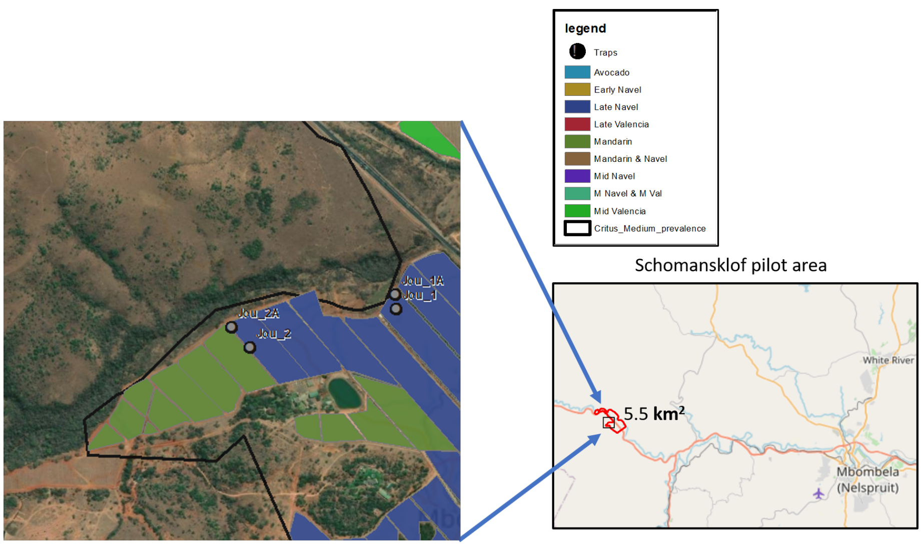
Figure 33. Maps showing the location and date of single interceptions of *B. zonata* in Northern Israel polygon area between 2015-2020.

2.3.4 South Africa test region:

The pilot region in South Africa is a very large area East from Pretoria. Due to the extension of the region and the impossibility to cover all of it for the study, we selected three smaller areas were *B. dorsalis* is known to exists with different levels of population. That is, we optimized our characterization efforts in such a way that we included two commercially citrus and macadamia producing regions towards the North, with a subtropical climate, and with high and intermediate levels of *B. dorsalis* populations. Towards the South of the region, with a temperate climate, we selected a combined area of apple producing orchards immersed in a grazing area and a town, were low populations of the fly were expected. This strategy allowed us to understand and characterize *B. dorsalis* populations (in an area with low knowledge of its patterns) following an expected population gradient from North to South, and obtain reference information for the optimization of surveillance strategies in the Southern low prevalence area of the fly. The three areas selected include the citrus and macadamia producing area of Nelspruit (6.3 km^2) towards the NE, the citrus producing area of Schomansklof (5.5 km^2) NW from Nelspruit, and Ermelo-Davos (110 km^2) apple and grazing region towards the South.

The geographic characterization of the area was conducted using high-resolution orthophotos, and field characterization of orchards and the town of Ermelo. Figure A-I 14 shows the resolution and details of the characterization in the Nelspruit and Schomansklof producing orchards. Figure A-I 14 also includes the illustration of the characterization for the Western edge of the Ermelo-Davos polygon in the South of South African region. The Ermelo town characterization, which followed the intensity of *B. dorsalis* hosts in the town, is shown in Figure A-I 15.





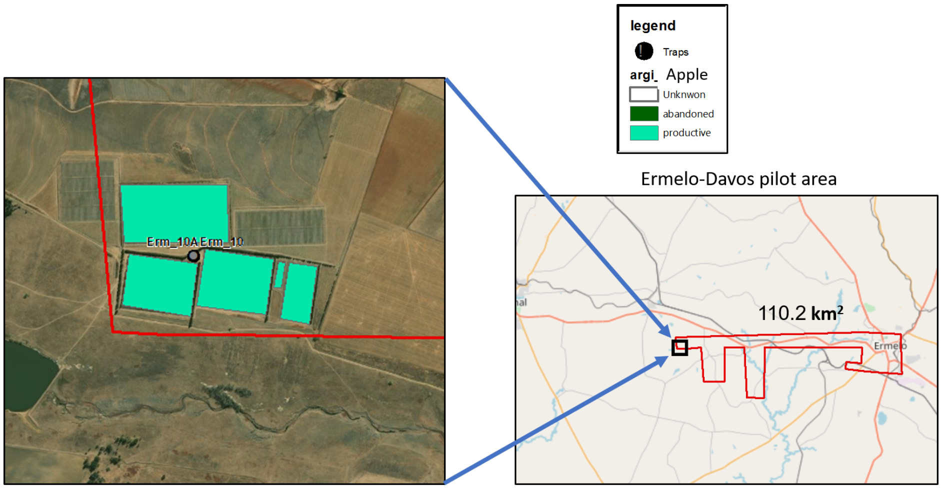


Figure 34. The three pilot areas in South Africa: Nelspruit in the NE, Schomansklof in the NW, and Ermelo-Davos, Western Edge, in the South of the Mpumalanga Province. The characterization of the town of Ermelo (Eastern Edge of the polygon), based on the intensity of hosts in the urban landscape, is shown in the following Figure A-I 15. *Bactrocera dorsalis* trap locations in the landscape are shown as gray dots. Land cover around a few traps is shown in Figure A-I 16

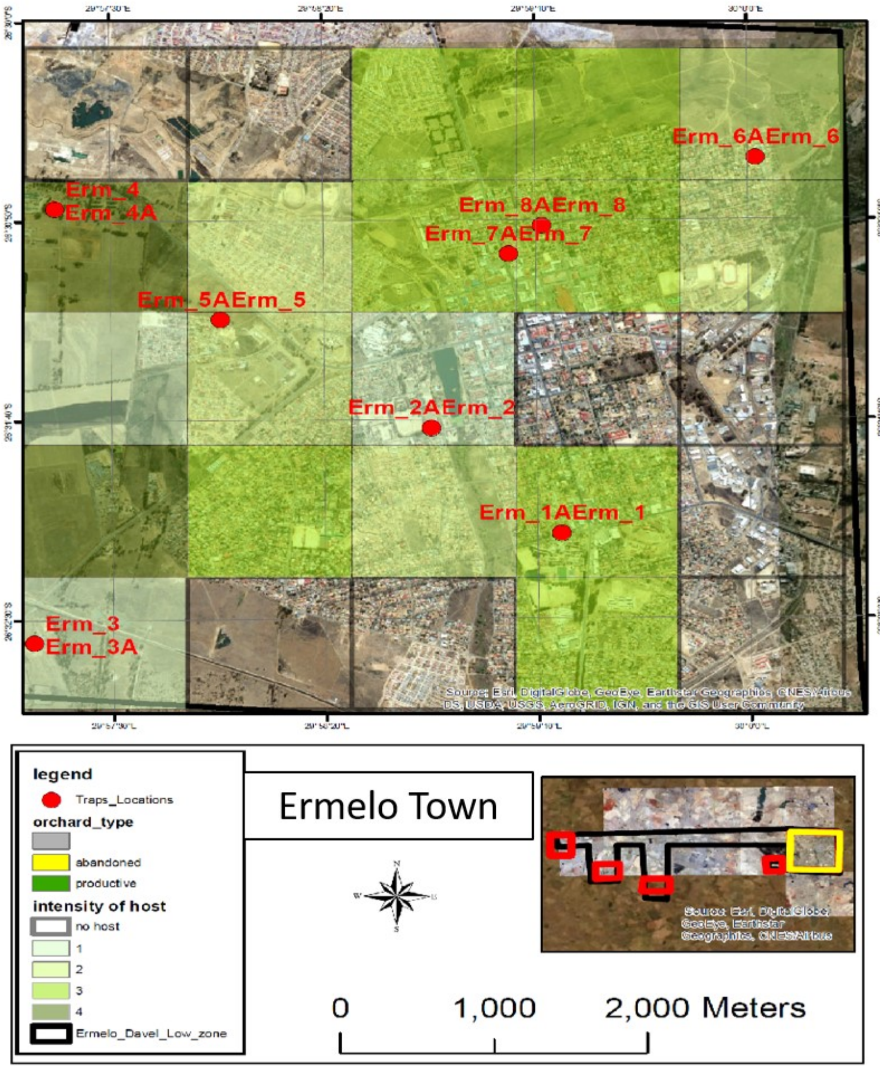


Figure 35. The characterization of the Ermelo town in Southern Africa's Ermelo-Davos polygon. Intensity of host in quadrats of the town are designated by green color

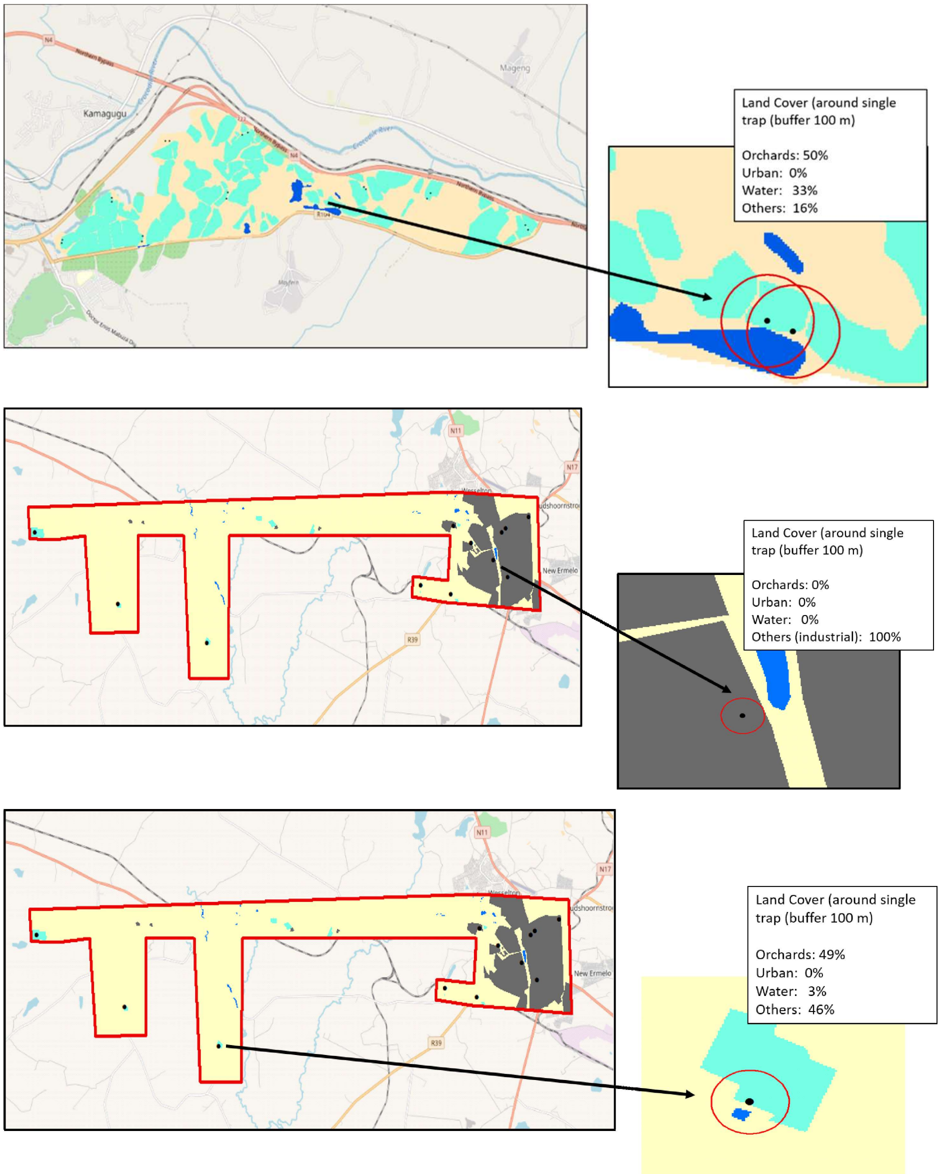


Figure 36. Three examples of land cover characterization in the South African landscape, illustrating the percent of the four different categories present around the traps in a buffer of 100 m diameter: Nelspruit pilot area (top), Ermelo town industrial area (center) and Ermelo-Davos pilot area (bottom).

2.3.4.1 <u>*Bactrocera dorsalis* spatio-temporal patterns in South Africa's test region</u>:

Bactrocera dorsalis patterns in the three South African polygons was characterized during the last year (2019-2020). Figure A-I 17 - A-I 19 shows the typical monthly catches registered in the three polygons landscape. *Bactrocera dorsalis* was already detected in the Northern areas (Nelspruit and Schomansklof) in October (Figure A-I 17 and A-I 18). *Bactrocera dorsalis* peaked in January-March in Nelspruit, and in February-May in Schomansklof (Figure A-I 17 and A-I 18). By June, capture significantly decrease in these areas. In the more Southern polygon of South Africa (Ermelo-Davos) *B. dorsalis* populations start to be captured in January, peaking in March-April, and declining in May (Figure A-I 19). Captures of *B. dorsalis* in the town of Ermelo (Eastern sector of the Ermelo-Davos polygon) are similar throughout the peak months. Apple orchards (towards the West of the polygon) show a strong peak by April. Captures of *B. dorsalis* were several times higher in the citrus orchards (Nelspruit and Schomansklof) than in the apple and deciduous colder areas.

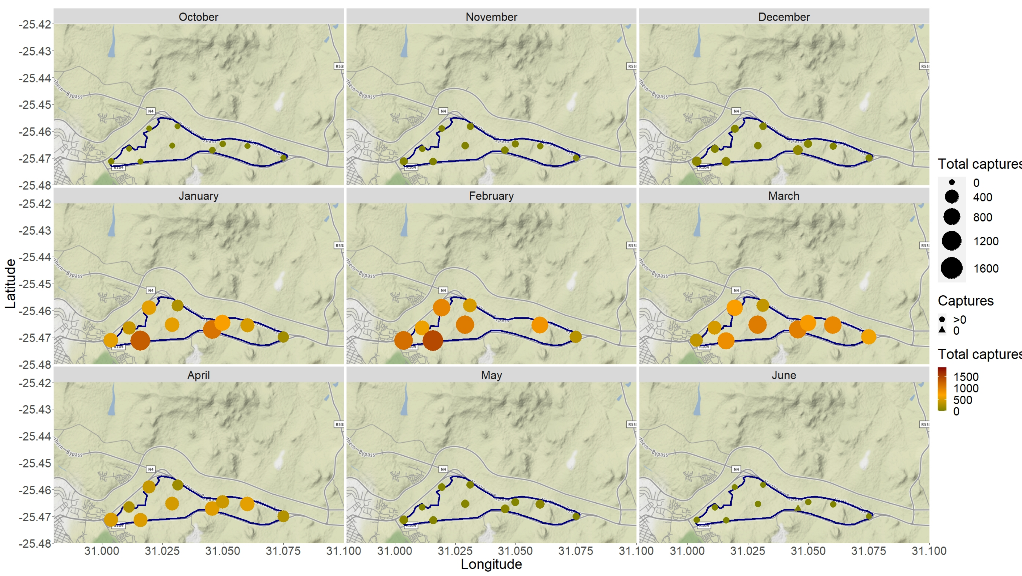


Figure 37. Series of maps showing the monthly total captures of *B. dorsalis* in the South African polygon of Nelspruit (citrus and macadamia orchards) during 2019-2020.

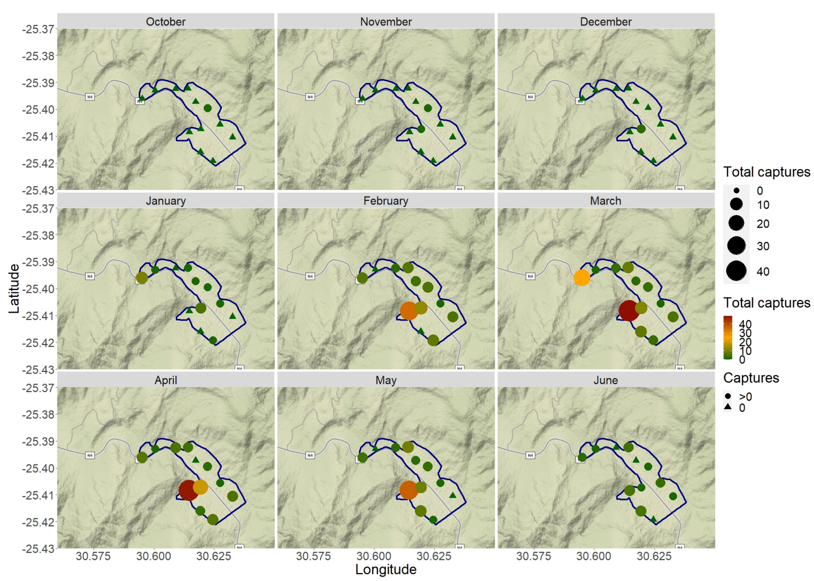


Figure 38. Series of maps showing the monthly total captures of *B. dorsalis* in the South African polygon of Schomansklof (citrus and macadamia orchards) during 2019-2020.

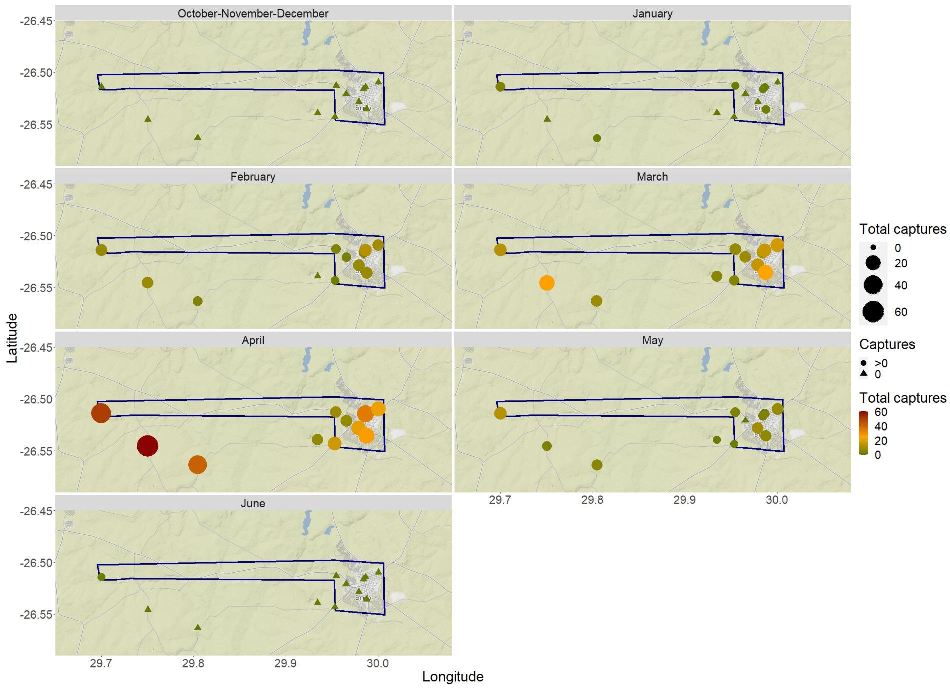


Figure 39. Series of maps showing the monthly total captures of *B. dorsalis* in the South African polygon of Ermelo-Davos (Ermelo town, to the East, and apple orchards to the West) during 2019-2020.

Appendix II

Structure of Geographic-Platform Data-Base

The structure of the geographic platform data created for FF-IPM Task 5.2 is shown in the following Figures. The data was uploaded to the UTH server to serve as a platform for the optimization of strategies. The raster-data files and organization is described in Figure A-II 1. The organization of vectors-data for the four pilot regions is shown in Figure A-II 2. Files holding thematic maps for the four pilot regions are organized in the export file (Figure A-II 3). In addition, a file containing the written scripts (python) to automatize processes, and their short description, is illustrated in Figure A-II 4.

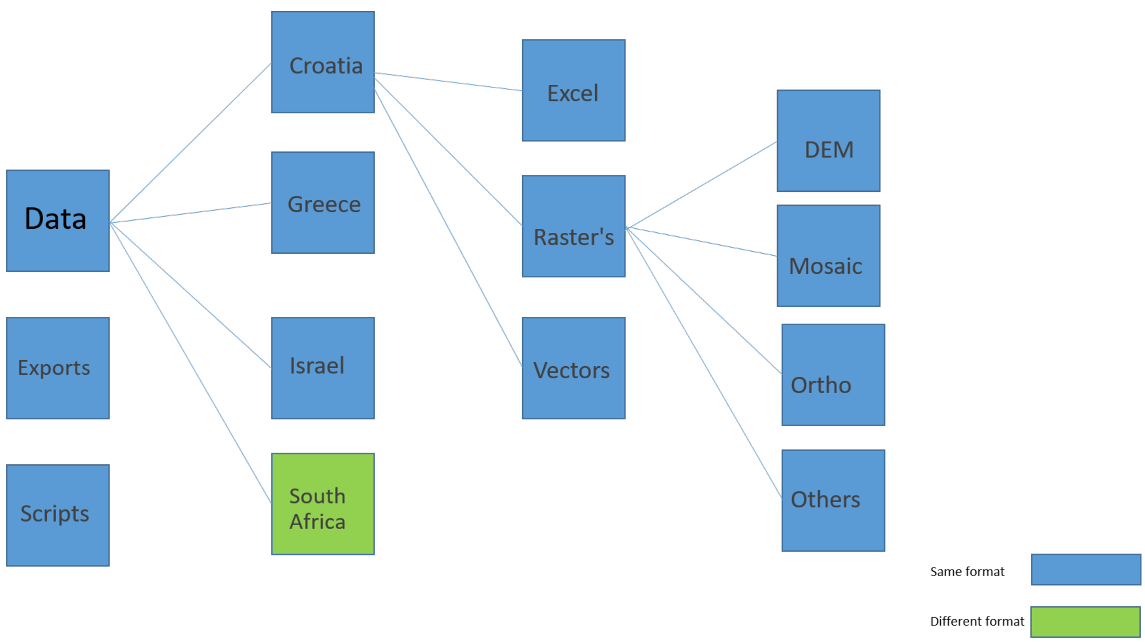


Figure 40. Organization of the geographic platform raster-data for the implementation of WP5. The data is deposited in the UTH project-server

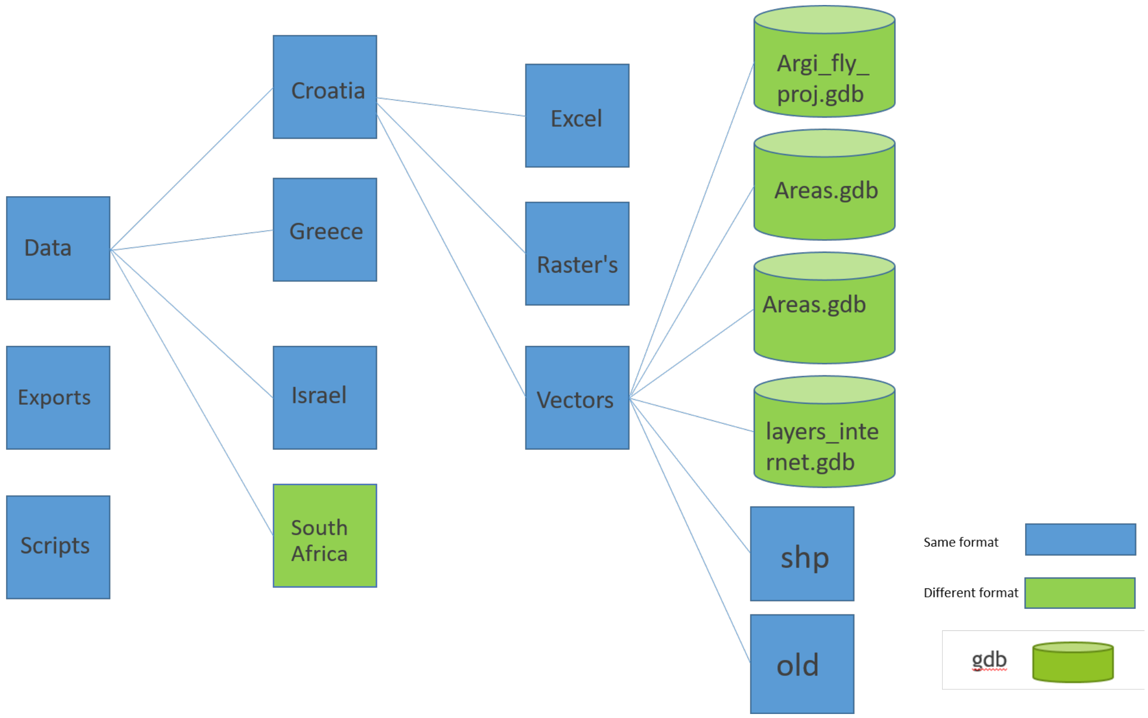


Figure 41. Organization of the geographic platform vector-data for the implementation of WP5. The data is deposited in the UTH project-server

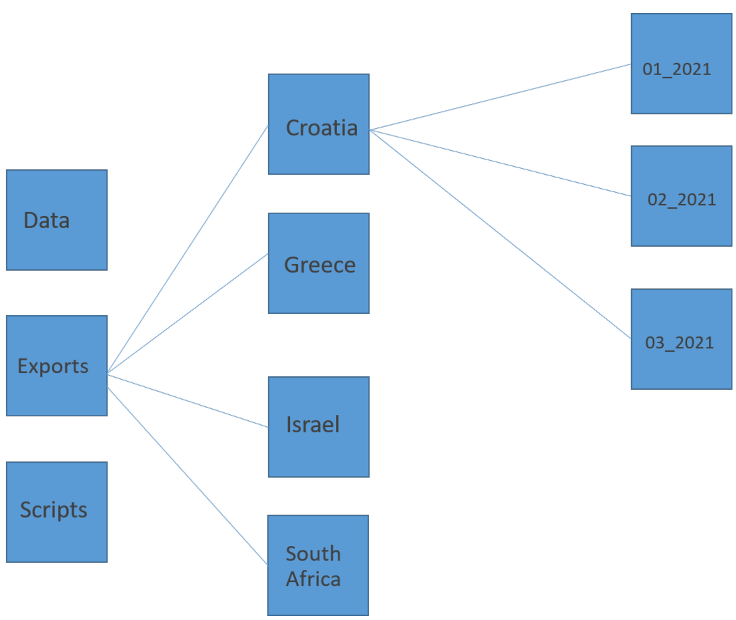


Figure 42. Organization of the geographic platform export-data with thematic maps for the implementation of WP5. The data is deposited in the UTH project-server

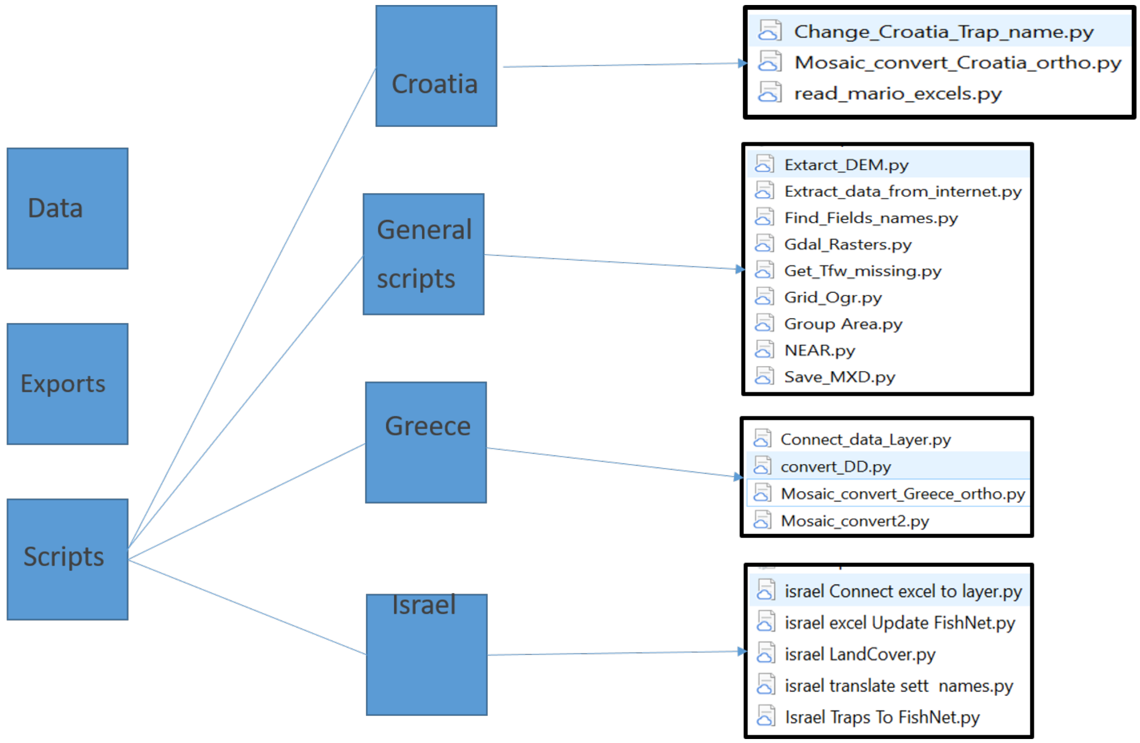


Figure 43. Organization of the python scripts produced to automatize processes in the development of the geographic platform. The scripts are deposited in the UTH project-server