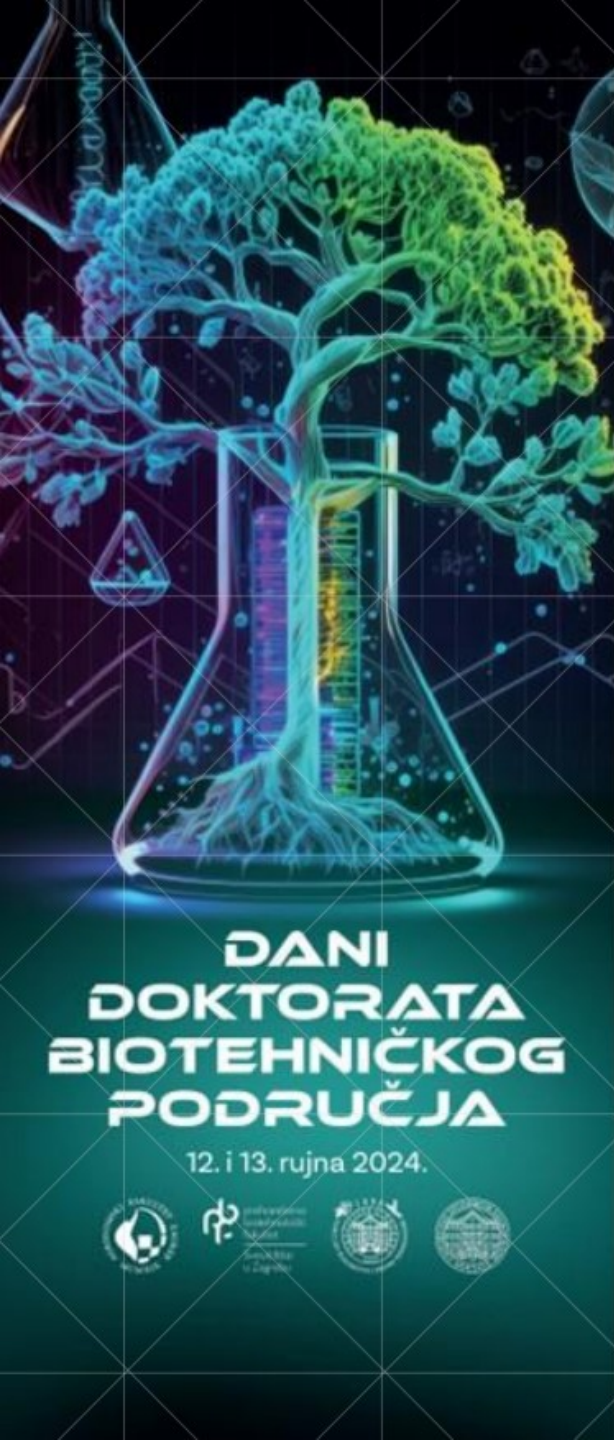


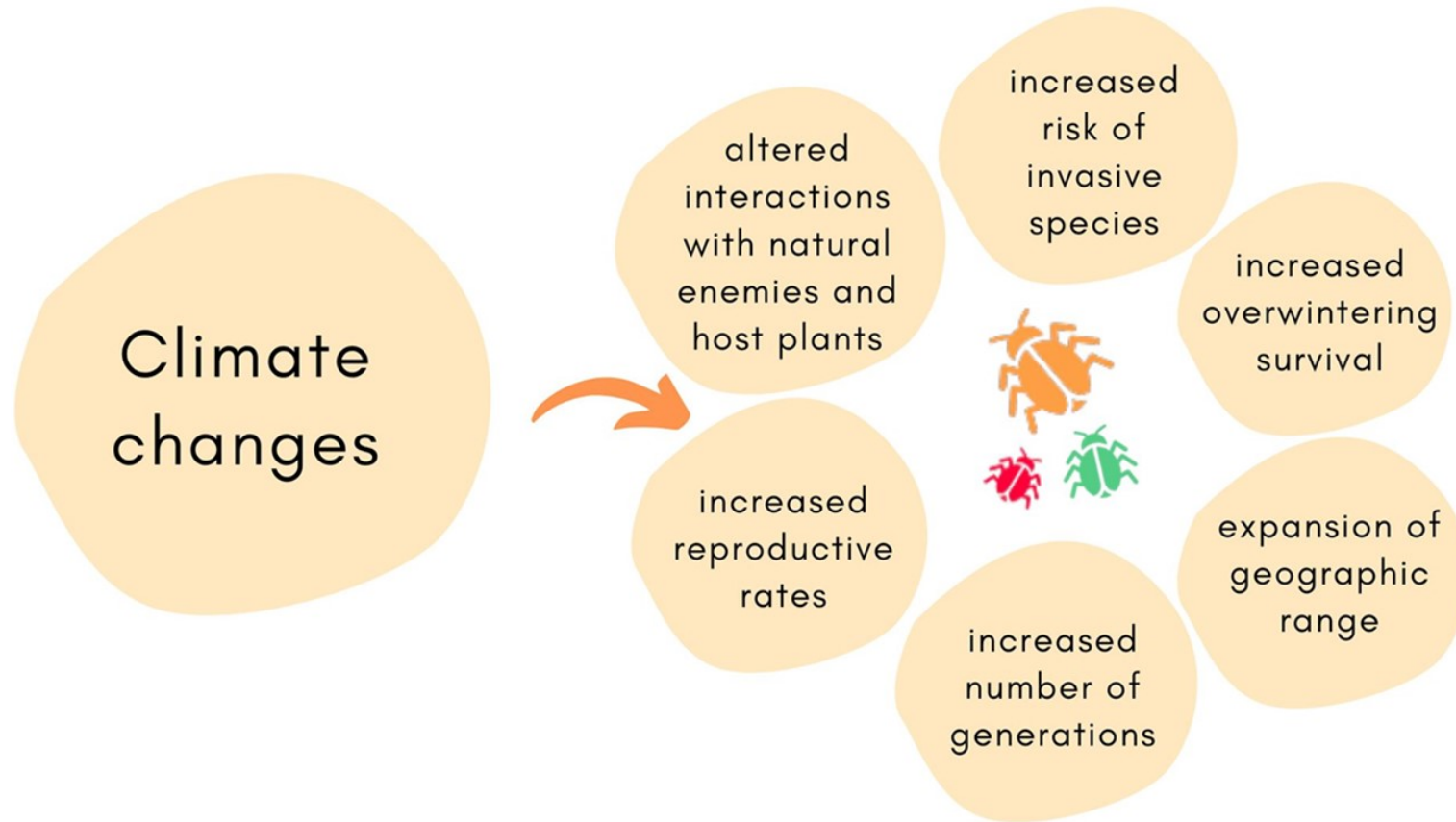
# Effectiveness of analytical models based on artificial neural networks in monitoring codling moth, pear leaf blister moth and its damage

Čirjak Dana, Pajač Živković Ivana, Aleksi Ivan

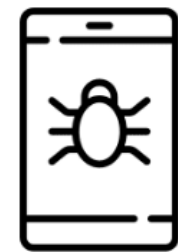
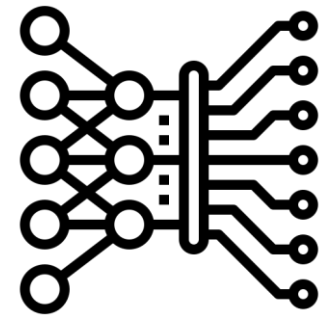
Sveučilište u Zagrebu, Agronomski fakultet



- Long-term insecticide use – permanent environmental and health consequences
- Climate changes – agricultural systems are under increasing pressure
- Significant changes in pest phenology
- Irregularities in pest occurrence
- Traditional monitoring methods do not reflect the real behavior of insect pest populations – reduced accuracy of IPM
- Adapt monitoring methods to current conditions



- An alternative for more reliable monitoring - implementation of artificial intelligence (AI) in pest monitoring – automatic pest monitoring
- Artificial neural networks (ANNs)
  - Continuous learning from large amounts of repetitive data – patterns of neurons in the human brain
  - Used for insect detection and recognition – the best method for object detection
  - Distinguishing between different insect species, life stages, and damaged or healthy plants
  - Accurate pest monitoring in real time – great potential for early pest detection



# Advantages of automatic pest monitoring

- Automatic pest monitoring – based on standard monitoring methods
- Improvements – real-time monitoring and less need for human labor
- Constant crop monitoring – targeted pest control and sustainable production
- The implementation of automatic monitoring systems in IPM – improves pest monitoring and early warning





# Apple (*Malus domestica* Borkh., 1803)

- Economically important crops cultivated on large areas – require the use of ANNs in pest monitoring
- One of the most important fruit crops in the world
- Great economic importance
- In 2022 – global apple production – 93 million tons
- The most consumed fruit – 36% of total fruit production in Croatia
- Methods for pest control in apple production – unreliable and not adapted to current changes

- **World – 4.8 mil ha**
- **Europe – 1 mil ha**
- **Croatia – 3 650 ha**

**FAOSTAT, 2022.**



<https://www.istockphoto.com/photo/apple-orchard-gm658414030-120150883>

# Codling moth - *Cydia pomonella* (L.)

- The most serious and widespread apple pest
- Larvae directly damage apple fruit – targeted control methods are required
- Causes up to 80% yield loss
- Requirement for the market - fruits without symptoms caused by codling moth
- Climate change – irregularities in biology and ecology – current monitoring methods unreliable



# Pear leaf blister moth (*Leucoptera maifoliella* (O. Costa, 1836))

- Important economic apple pest
- Typical physiological pest – circular mines
- Heavy infestation – cause premature leaf drop
- The overwintering developmental stage – noticed too late
- Late targeted chemical protection – worse results
- The optimal time for insecticide treatment – occurrence of the first generation of mines
- The critical number of mines per leaf – two to three





# Commercially available devices for automatic monitoring of codling moth

Pest	Trap	Website
Codling moth <i>Cydia pomonella</i> (Linnaeus, 1758)	TrapView (Slovenia)	<a href="https://trapview.com/">https://trapview.com/</a>
	SightTrap™ (USA)	<a href="https://www.insectslimited.com/">https://www.insectslimited.com/</a>
	DTN Smart Trap (USA)	<a href="https://www.dtn.com/">https://www.dtn.com/</a>
	iSCOUT® PHEROMONE (Austria)	<a href="https://metos.at/">https://metos.at/</a>
	Semios trap (Canada)	<a href="https://semios.com/">https://semios.com/</a>
	CropVue trap (Canada)	<a href="https://www.cropvue.com/">https://www.cropvue.com/</a>



<https://trapview.com/>



<https://metos.at/>



# Gaps and limitations in current approaches

- Real-time monitoring of codling moth and leaf mines (Albanese et al., 2021; Grünig et al., 2021) – no developed model for monitoring pear leaf blister moth
- Significant improvements in accuracy, precision, sensitivity, and power consumption - needed
- Better detection parameters – by collecting large and reliable data set in the field conditions
- Reduced energy consumption and faster data processing – optimizing the model
- The model for monitoring adult individuals and leaf damage – damage prevention
- Comprehensive monitoring tool – accurate ANN-based models for monitoring codling moth, pear leaf blister moth and its damage on apple leaves
- Complete insight into the apple orchard situation – timely reaction and economic damage prevention

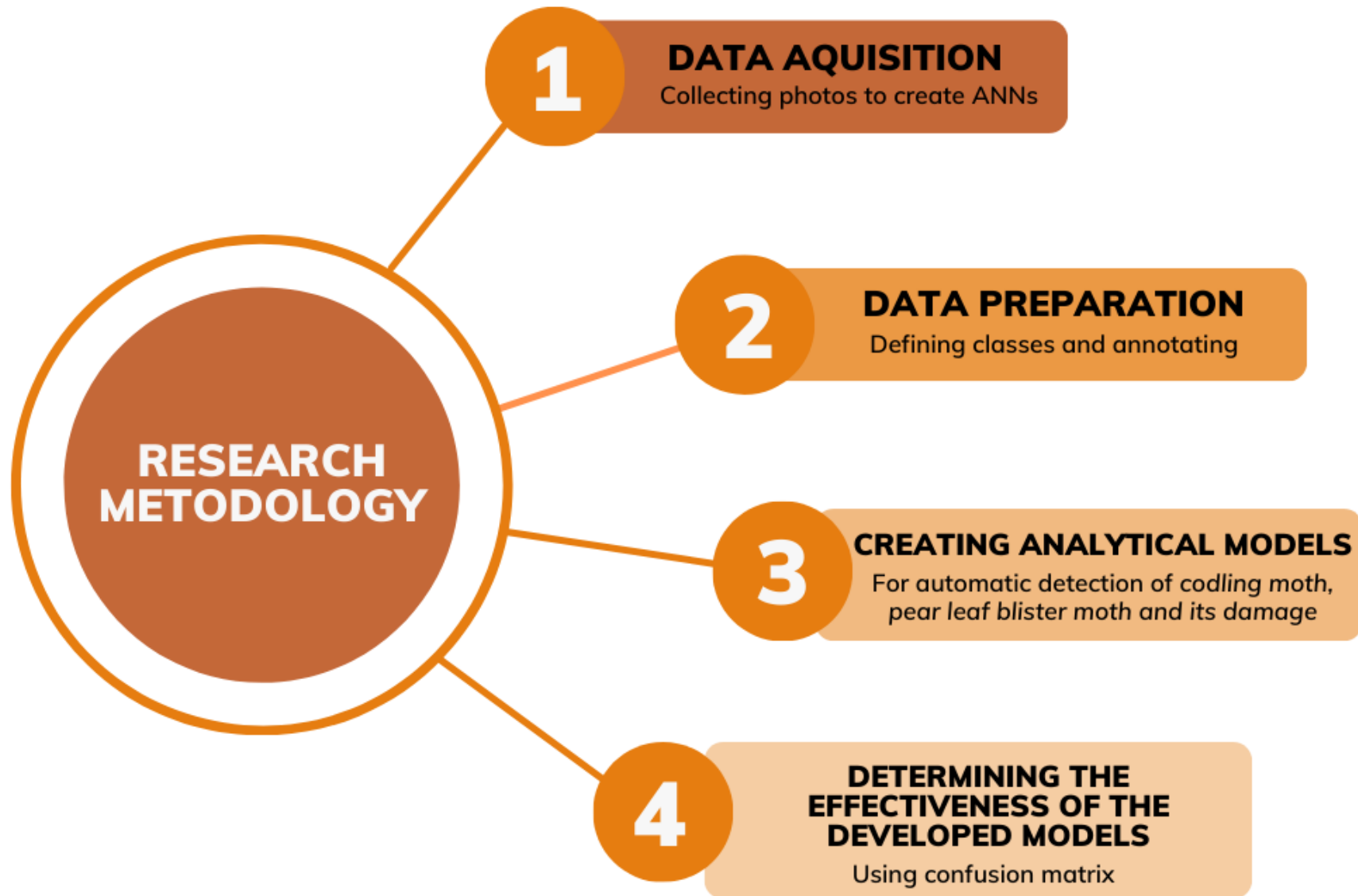
# Hypothesis

- **H1:** The artificial neural network-based analytical model has more than 90% accuracy in detecting and counting individuals of codling moth and pear leaf blister moth compared to an expert
- **H2:** The artificial neural network-based analytical model has more than 90% accuracy in detecting and counting leaf damage caused by pear leaf blister moth compared to an expert

# Objectives

- **O1:** To create an artificial neural network based analytical model for detecting and counting individuals of codling moth and pear leaf blister moth and determine its effectiveness
- **O2:** To create an artificial neural network based analytical model for detecting and counting leaf damage caused by the pear leaf blister moth and determine its effectiveness

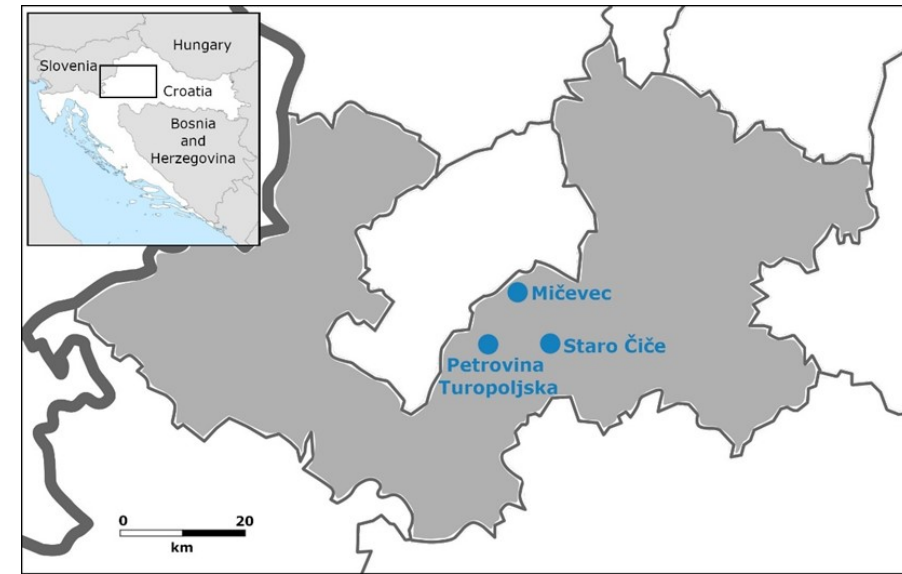




# Materials and methods

## Data acquisition

- Three apple orchards in Zagreb county – Mičevec, Staro Čiče, Petrovina Turopoljska
- Weekly catches with Delta traps – codling moth and pear leaf blister moth adults
- Image acquisition – adult individuals – RGB (*red-green-blue*) camera implemented in housing – imitates the prototype of smart trap
- Damage on the leaves – RGB camera – central part of the tree – distance of 50 cm



Sampling sites of images in Croatian orchards



Delta traps with pheromone lure and adhesive pad

# Image acquisition – adult individuals (codling moth and pear leaf blister moth)



Image of adhesive pad with pear leaf blister moth individuals

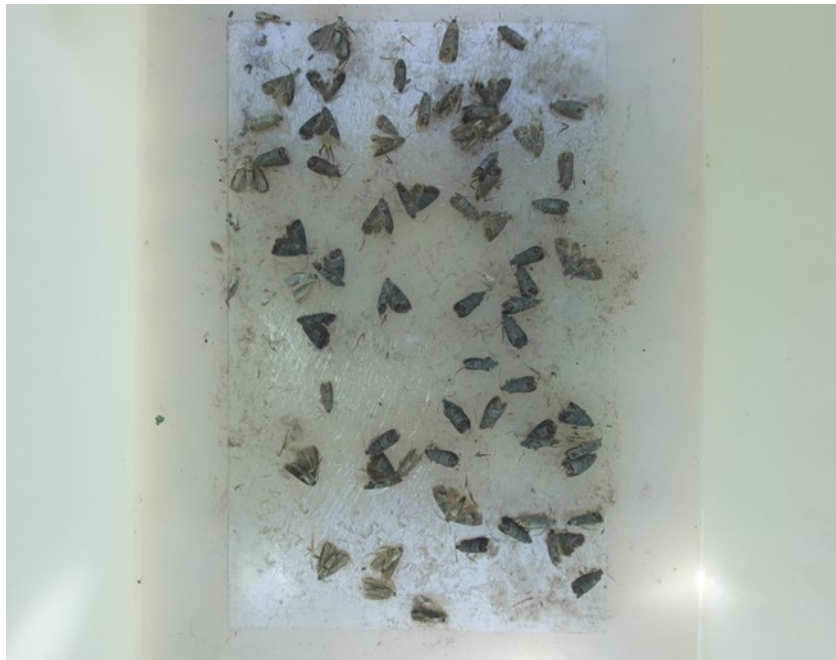


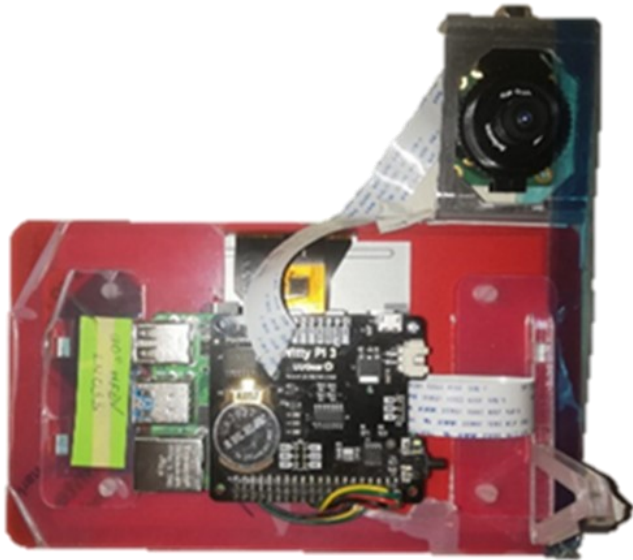
Image of adhesive pad with codling moth individuals



RGB camera in a housing that mimics the prototype of a smart trap for taking photos of adhesive pads



# Image acquisition – leaf damage caused by pear leaf blister moth



RGB camera for taking photos of vegetation



Photo of the central part of the tree and damage from the pear leaf blister moth (mines on the leaves)

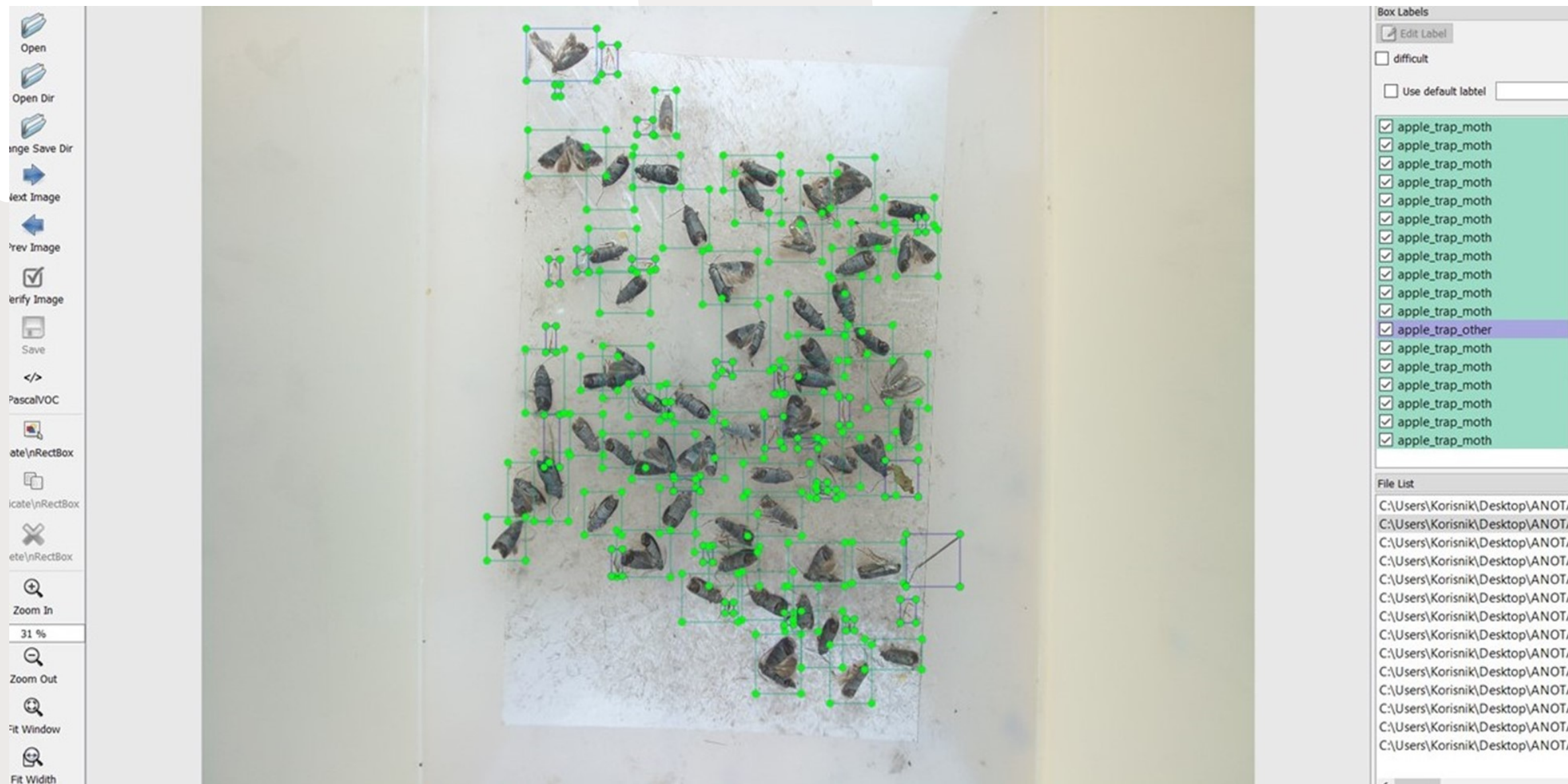
# Materials and methods

## Data preparation

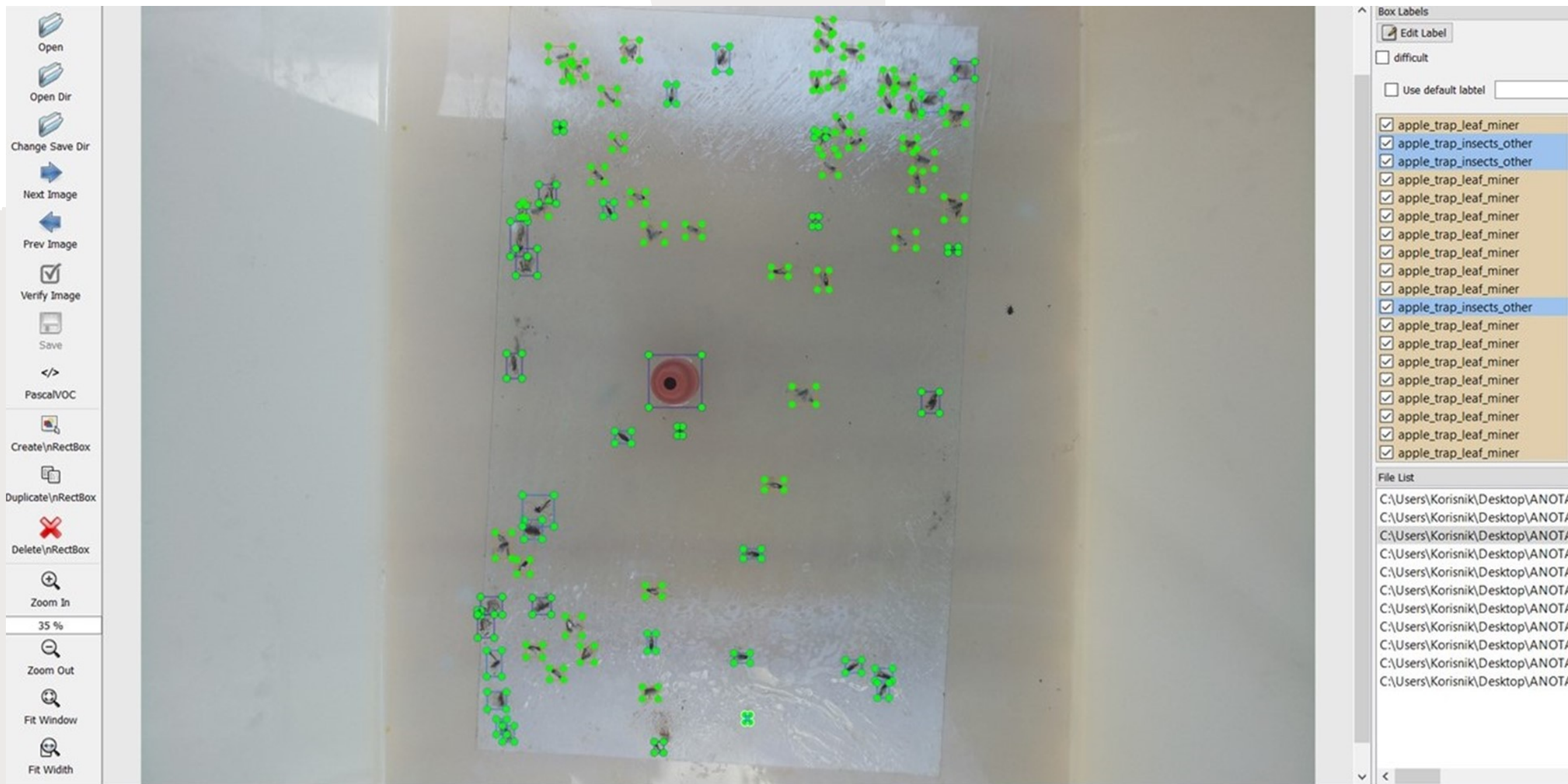
- 430 photos of adhesive pads – codling moth
- 400 photos of adhesive pads – pear leaf blister moth
- 400 photos of the central part of the tree – damage on the leaves caused by pear leaf blister moth
- Labellmg program
- Visual identification and annotating
- Annotated photo format – PascalVOC, XML structure













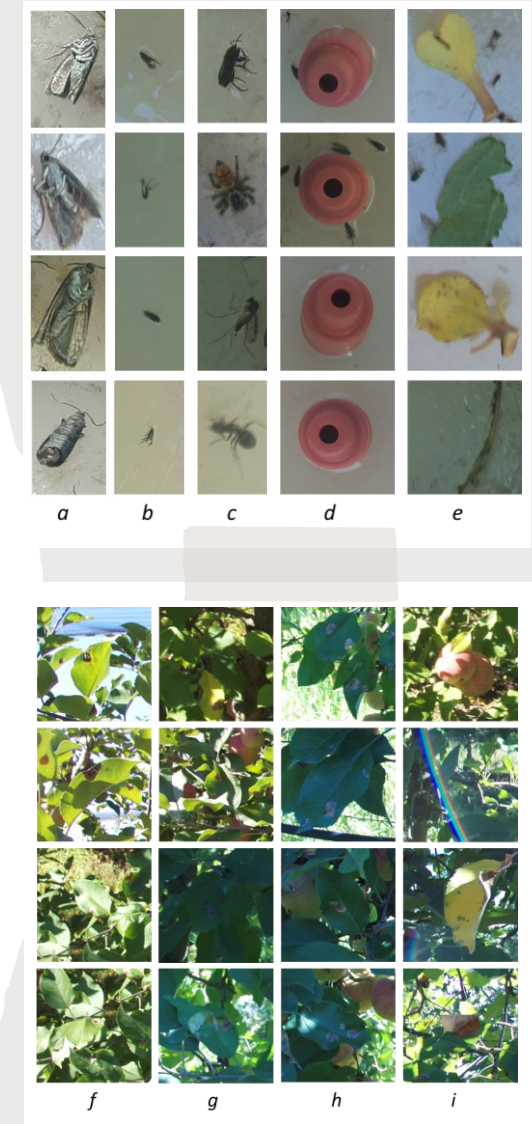




# Materials and methods

## Data preparation

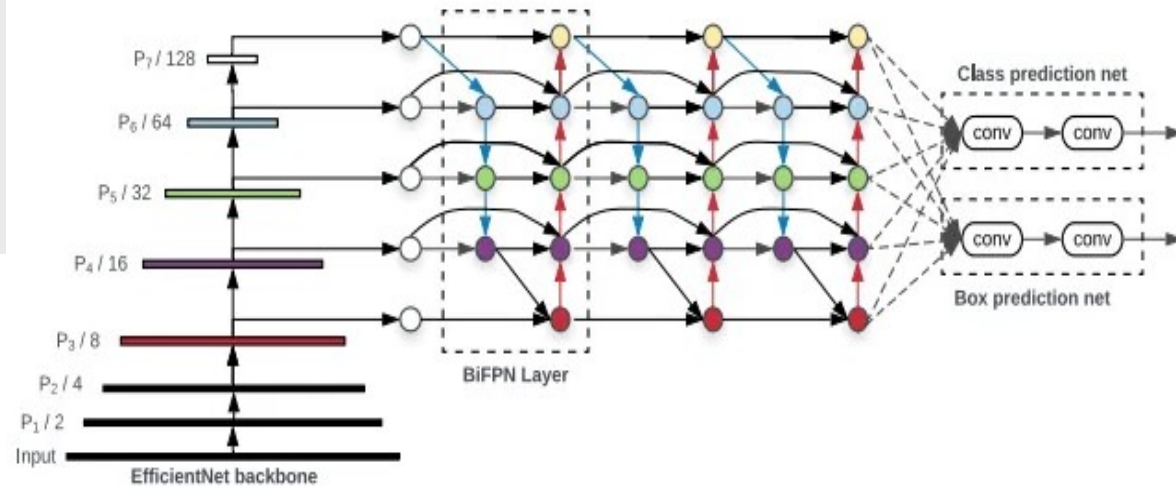
- Classes in the model for pest detection:
  1. MOTH i.e., codling moth adults (*a*)
  2. MINER i.e., pear leaf blister moth adults (*b*)
  3. INSECT i.e., other insects (*c*)
  4. OTHER i.e., other objects (e.g., remains of leaves, branches, etc.) (*d-e*)
- Classes in the model for damage detection:
  1. MINES i.e., damage caused by pear leaf blister moth (*f-h*)
  2. OTHER i.e., other objects (e.g., healthy leaves, fruit coloration, etc.) (*i*)
- Class MOTH (pests) – 8100 annotations
- Class MINER (pests) – 4700 annotations
- Class MINES (damage) – 1880 annotations





# Materials and methods

## Creating an analytical models

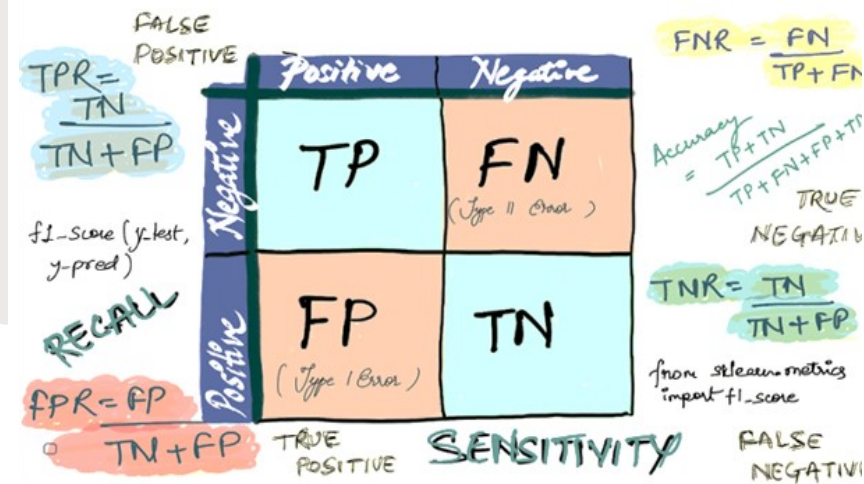


<https://medium.com/swlh/efficientnet-and-efficientdet-explained-297ff81a1267>

- The creation of an ANN model – definition of a set of input and output variables – data adaptation
- Transformations of the input photo – increasing the number of photos for input – flipping and rotating
- The architecture of ANN – EfficientDet-lite 4 – the best quality of object detection in photography
- The programming language Python 3.6
- AI library Tensorflow – model creation
- Once a model is created, each one must be tested and adjusted

# Materials and methods

## Determining the effectiveness of the developed models



- Three sets:
  - Training set – 80 - 95% images
  - Validation set – 5 - 20% images
  - Test set – new, the most complicated images
- Confusion matrix (CM) – statistic evaluation of test results – represents the number of predicted and actual values
- Accuracy, precision, recall and F1 score
- 4 categories:
  - TP - true positive
  - TN - true negative
  - FP - false positive
  - FN - false negative

# Pest Monitoring Device (PMD) and Vegetation Monitoring Device (VMD)

- PMD – camera housed in a polycarbonate shell (*a*)
- Contains – RGB camera, temperature sensor for the battery and electronics, antenna, adhesive pad, pheromone lure, power supply system with a battery and solar panel
- VMD – camera placed in a separate housing (*b*)
- External structure – designed to be used throughout the vegetation – resistant to weather conditions



*a*

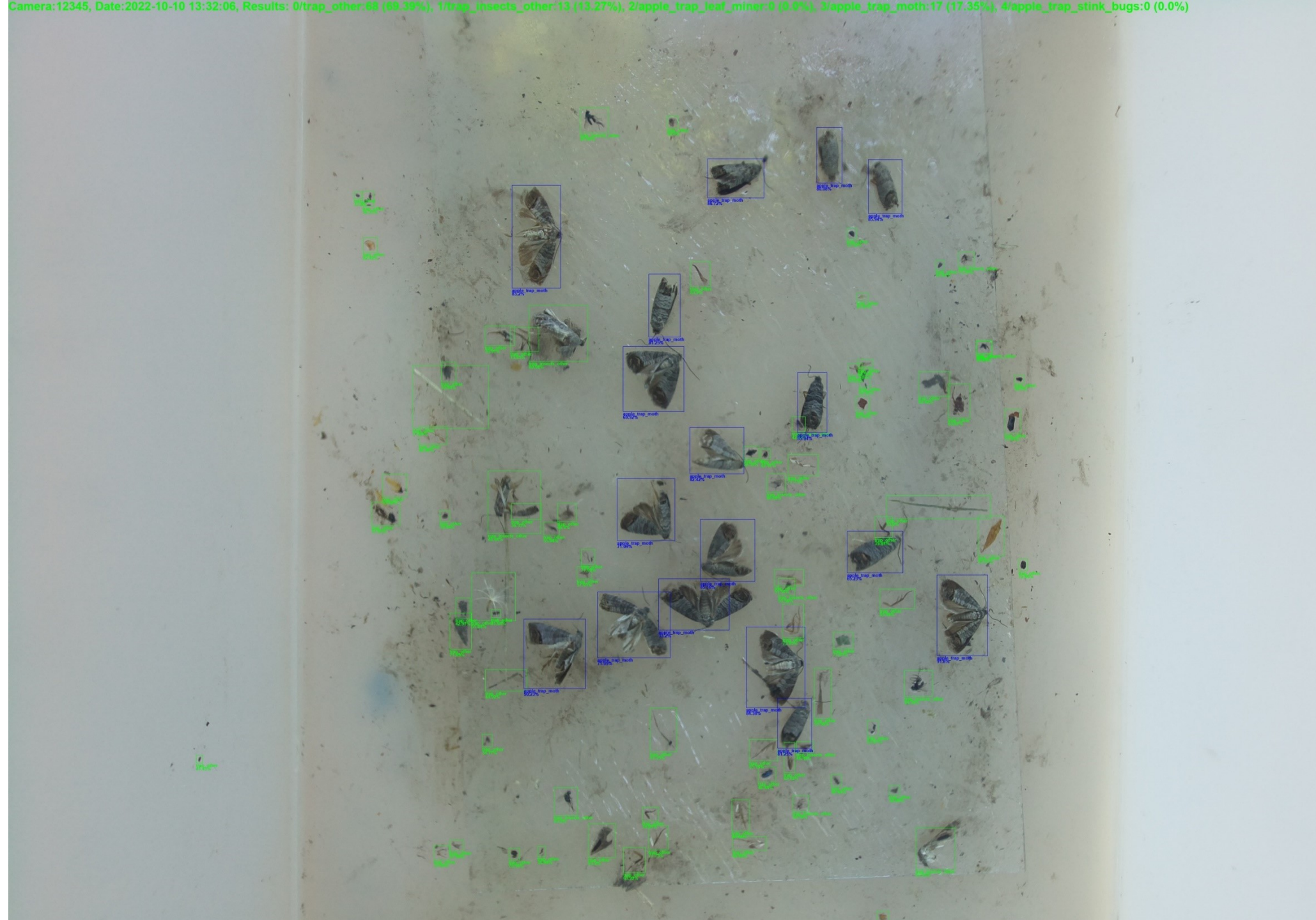


*b*

# Results

- Two ANN based analytical models were established:
  1. For the automatic detection of codling moth and pear leaf blister moth adults
  2. For the automatic detection of mines on apple leaves
- Due to importance of the model's work in practice – model test (quality check after overall creation)
- In used devices – data processing is done on-the-node, only the detection results are sent – makes it suitable for rural areas, lower energy consumption – longer lifetime of the entire system – less need for human intervention
- Larger models require more storage space and more time to run – difficult to use
- The optimization phase of the model allows faster evaluation, while minimizing accuracy loss





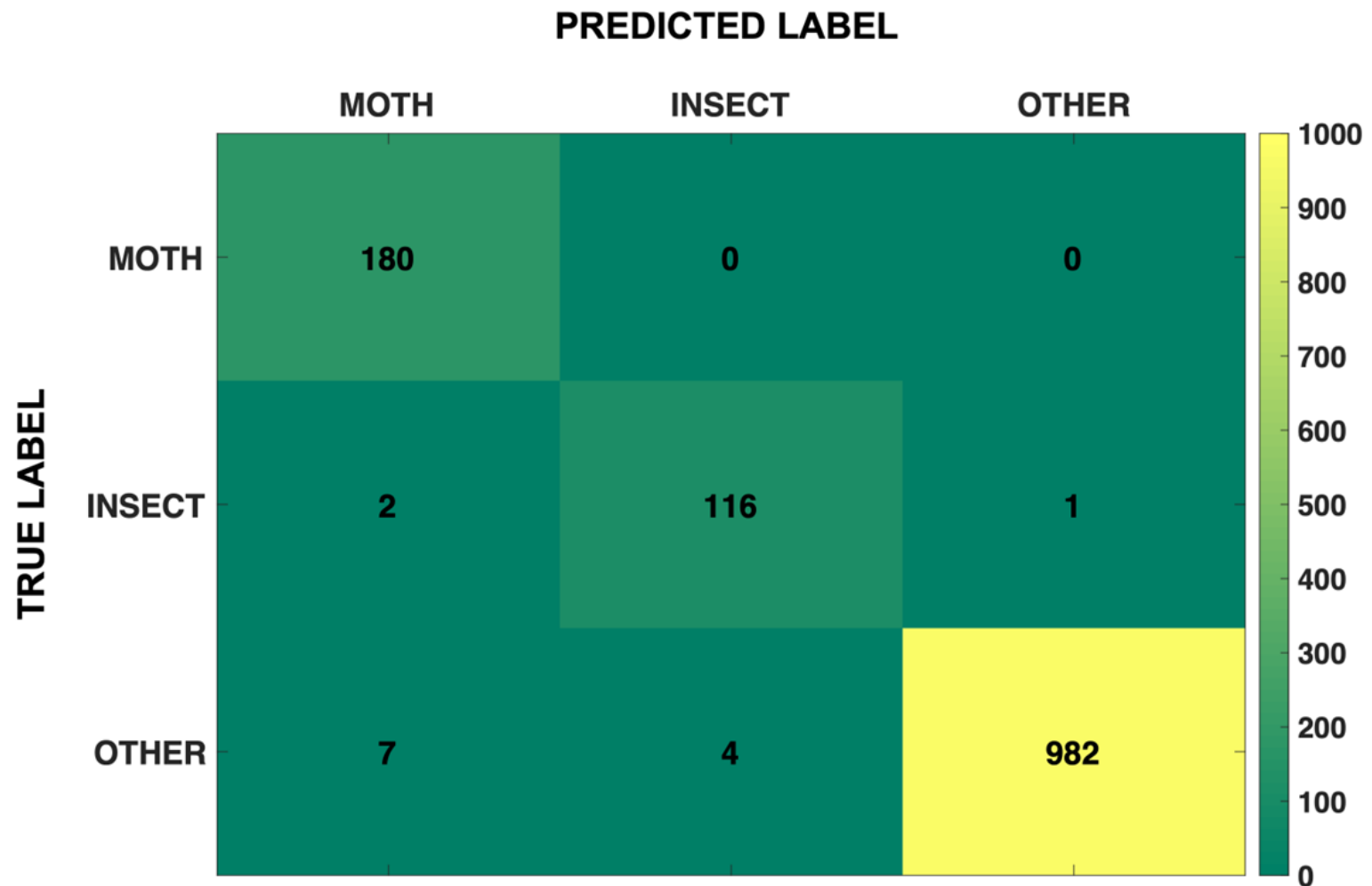








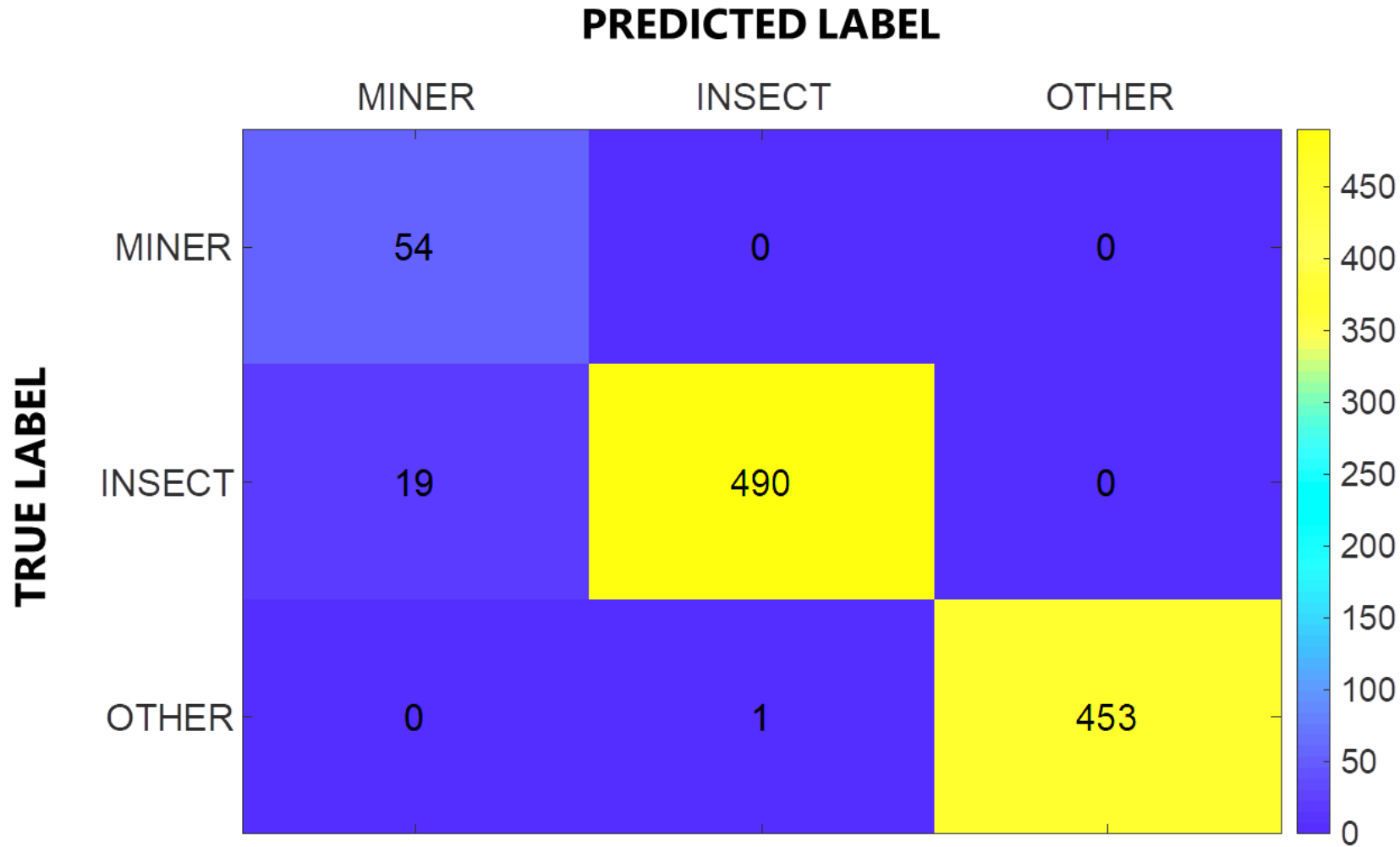
Test results of  
the model for  
monitoring  
codling moth



Class	(n) truth	(n) classified	Accuracy	Precision	Recall	F1 Score
MOTH	189	180	99.3%	1.0	0.95	0.98
INSECT	120	199	99.46%	0.97	0.97	0.97
OTHER	983	993	99.07%	0.99	1.0	0.99

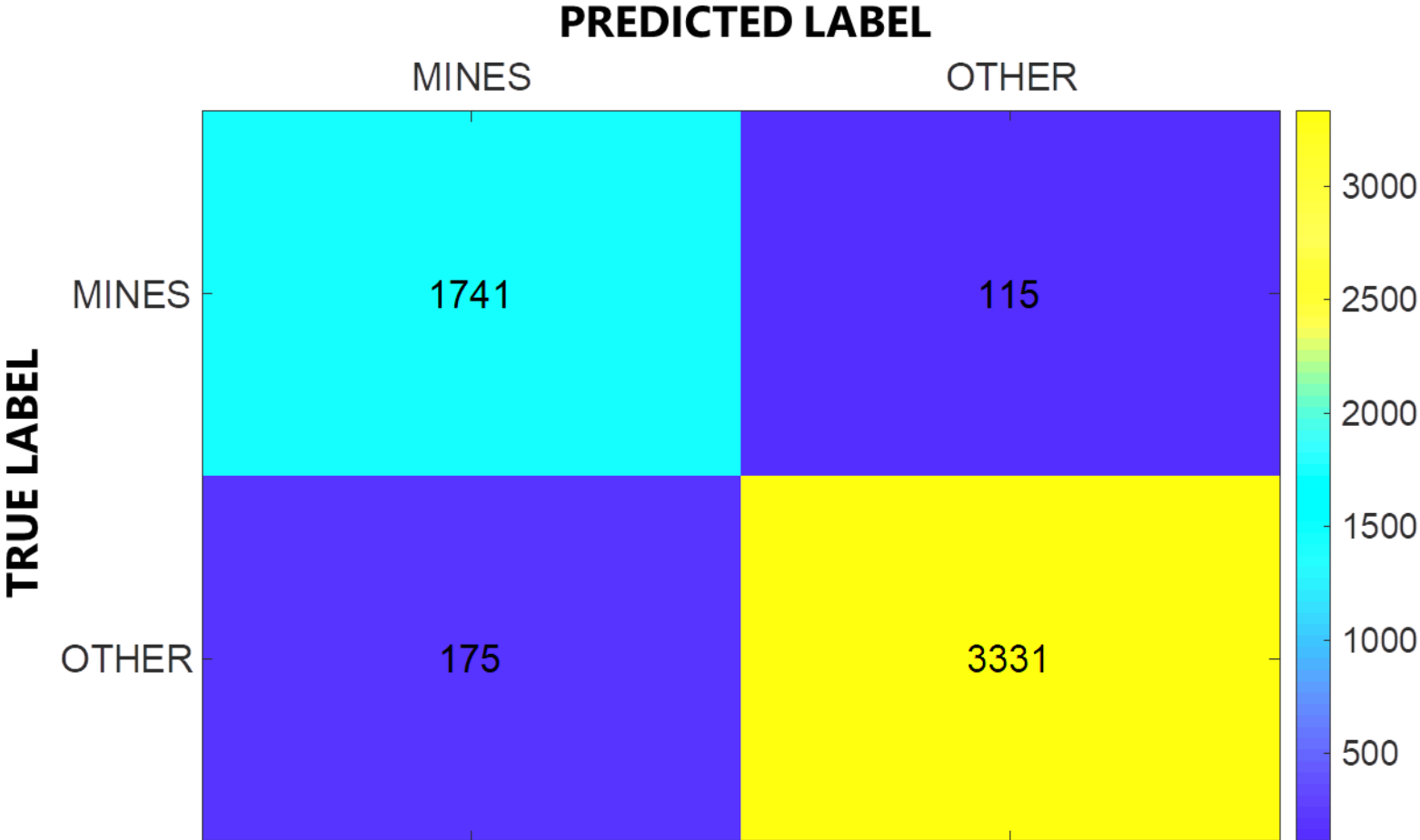


Test results of the  
model for  
monitoring pear  
leaf blister moth



Class	(n) truth	(n) classified	Accuracy	Precision	Recall	F1 Score
<i>MINER</i>	73	54	98.13%	1.0	0.74	0.85
<i>INSECT</i>	491	509	98.03%	0.96	1.0	0.98
<i>OTHER</i>	453	454	99.9%	1.0	1.0	1.0

# Test results of the model for monitoring mines



Class	(n) truth	(n) classified	Accuracy	Precision	Recall	F1 Score
<i><b>MINES</b></i>	1916	1856	94.59%	0.94	0.91	0.92
<i><b>OTHER</b></i>	3446	3506	94.59%	0.95	0.97	0.96

# Conclusions

- The ANN based analytical model for detecting and counting codling moth and pear leaf blister moth was created
- **Objective O1** of this thesis is achieved ✓
- The detection accuracy of the model for codling moth was **99.3%** and for pear leaf blister moth was **98.13%** compared to visual inspection by an expert
- The proposed model is effective for monitoring codling moth and pear leaf blister moth
- **Hypothesis H1** is accepted ✓

# Conclusions

- The ANN based analytical model for detecting and counting damage to apple leaves caused by pear leaf blister moth was created
- **Objective O2** of this thesis is achieved ✓
- The developed analytical model showed **94.6%** accuracy in detecting leaf damage caused by pear leaf blister moth compared to visual inspection by an expert
- The proposed model is an effective for monitoring leaf damage caused by pear leaf blister moths
- **Hypothesis H2** is accepted ✓



# Conclusions

- Developed models – significant improvements in terms of detection parameters
- The used method – better performances than previous works
- The first development of a model for monitoring the pear leaf blister moth
- ANNs - effective tool for counting and detecting the pear leaf blister moths
- Monitoring the pear leaf blister moths + leaf damage – earlier intervention and damage prevention
- Detailed and comprehensive insight in apple orchard situation

# Conclusions

- Contribution to the improvement of automatic pest monitoring and to its wider application
- The use of these models – targeted pest control – reduced use of pesticides and decreased negative impact on the environment – in response to climate change
- Implementation of new technologies in the field of crop protection
- Improvement of apple production and reduced environmental footprint
- The models developed in this thesis are effective and applicable in practice
- In future research, this method should be further used to develop models for monitoring other apple pests to get a more comprehensive picture

# Thank you for your attention!

