Biological invasions: Economics and policies

Stelios Kartakis - *Agricultural Economics & Rural Policy Group* (WUR)

Guest lecture for Life Science Economics and Policies (AEP32806)

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Outline

- Invasive species – Background, importance, regulatory environment
- The PurPest project
- Case study: Migration extent and potential economic impact of the fall armyworm in Europe

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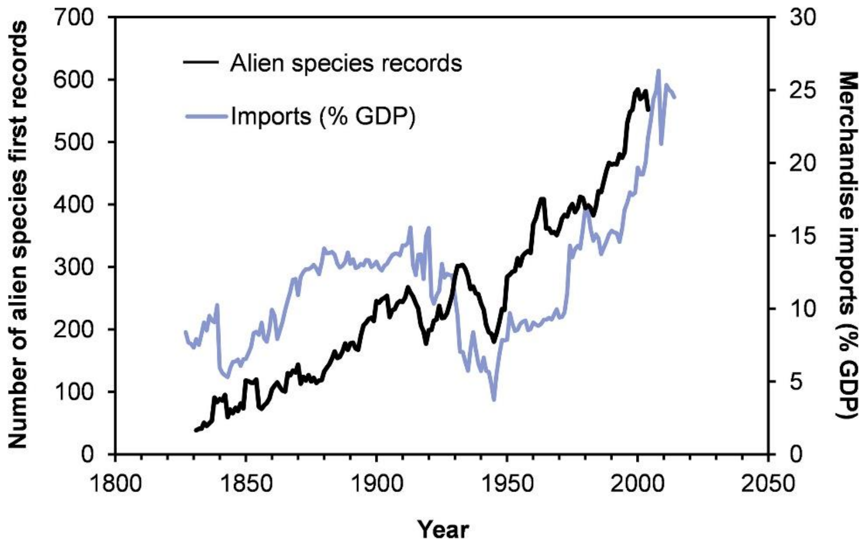
Invasive (alien) species

" (…) plants, animals, pathogens and other organisms that are non-native to an ecosystem, and which may cause economic or environmental harm or adversely affect human health" (CBD, 2009)

Background

- An ever-growing number of alien species are establishing populations outside their native range (Hulme, 2009; Hulme et al., 2009; Pyšek et al., 2010; Seebens et al., 2017)

- Global trade networks facilitate the movement of plants and plant products, and represent a major pathway for the spread of invasive non-native species (Chapman et al., 2017)



Global trade and invasions over time (Hulme, 2021)

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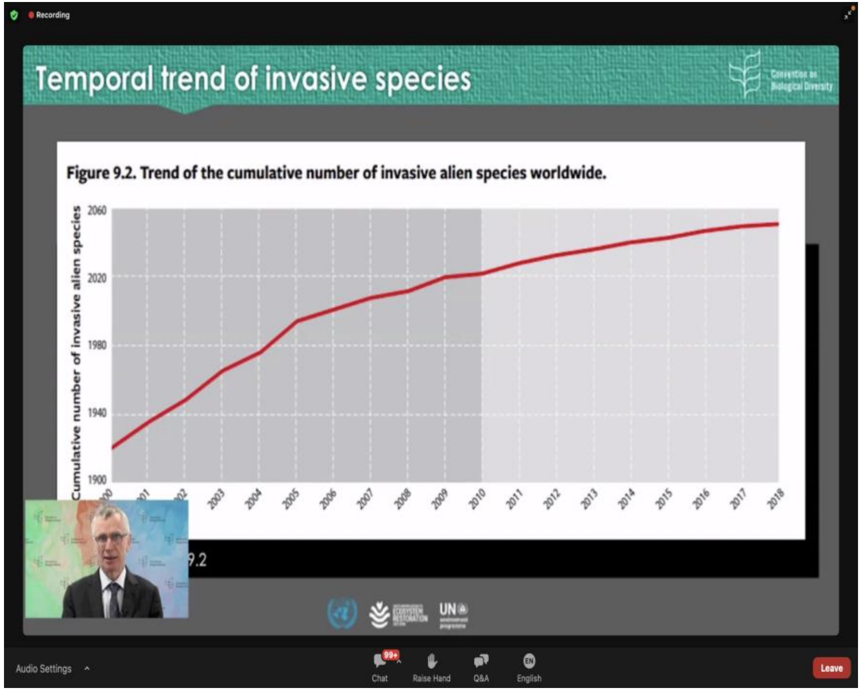
Significance



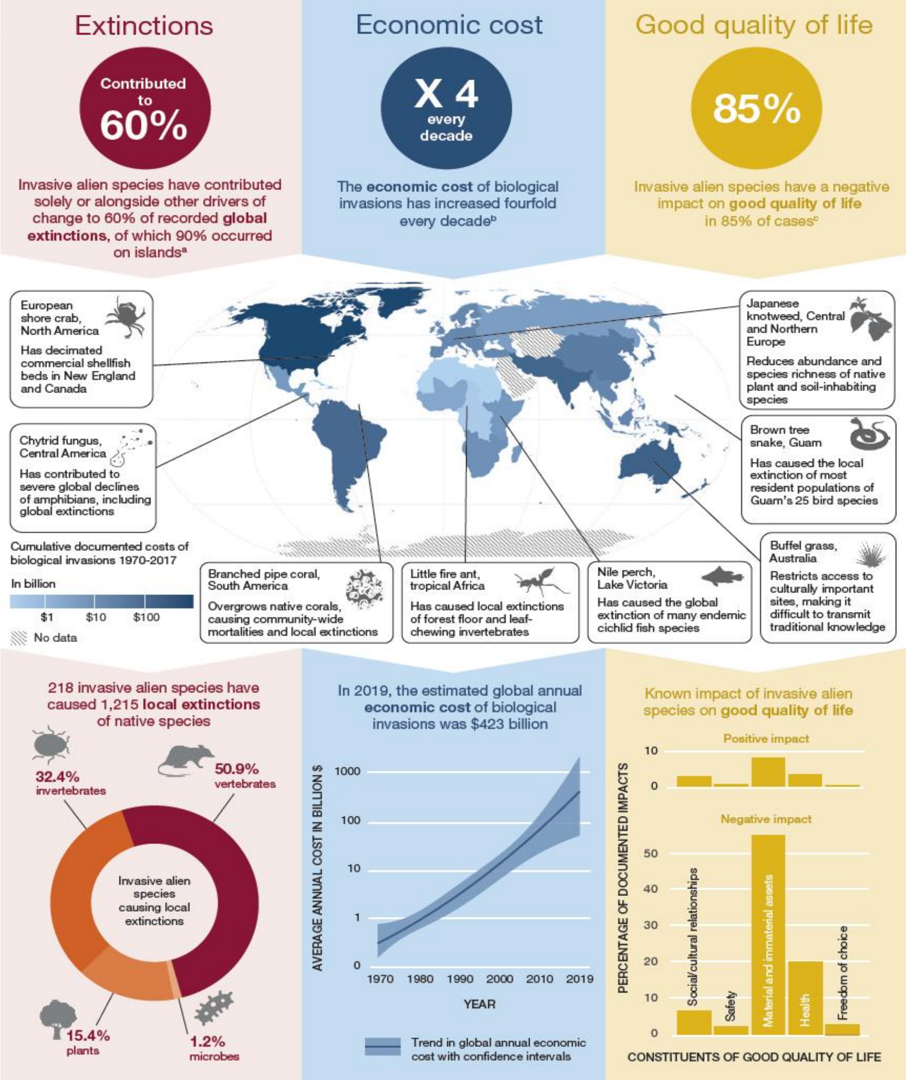
FAO Event (2023). International Day of Plant Health

Extent of the problems caused by IAS (IPBES, 2023)

Four major impact groups (EEA, 2012):

- Impacts on biodiversity
- Impacts on ecosystem services
- Impacts on human health
- Impacts on economic activities

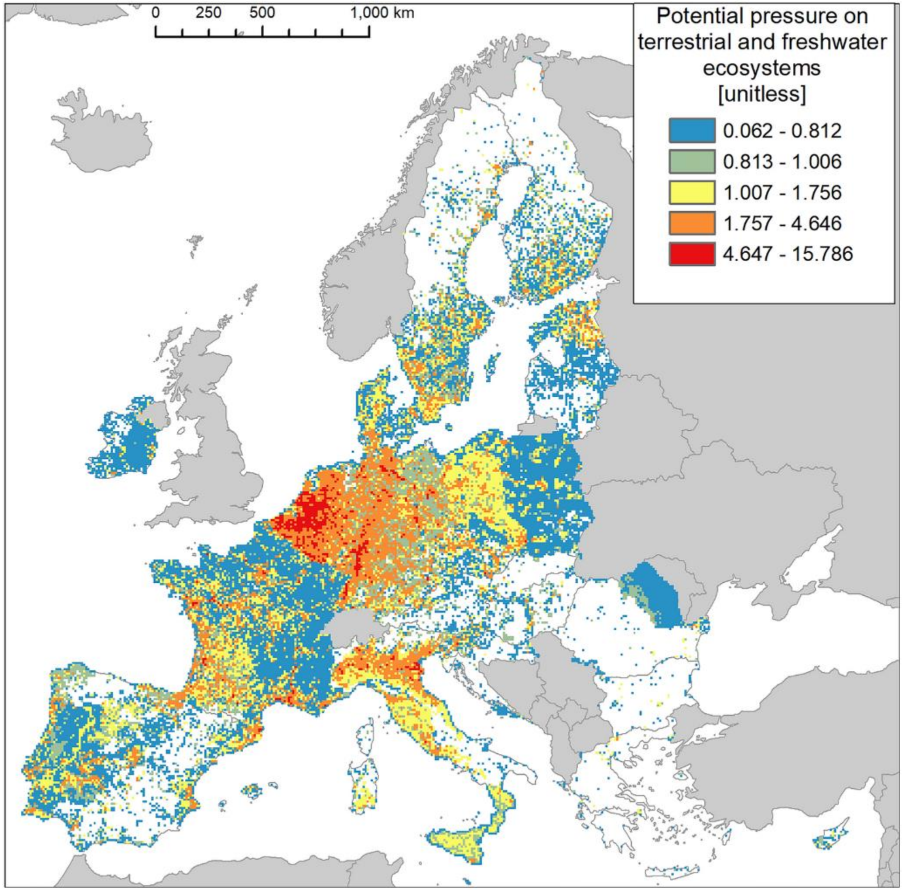
12,000 species are alien in the EU, of which roughly 10-15 % are estimated to be invasive (European Commission, 2014)



Significance (EU)

(Polce et al., 2023)

- Large areas of greater potential pressure are visible across Belgium, the Netherlands, western Germany, northern Italy, and the Mediterranean and western Atlantic coast of France.



Cumulative potential pressure by IAS of Union concern across terrestrial and freshwater ecosystems.

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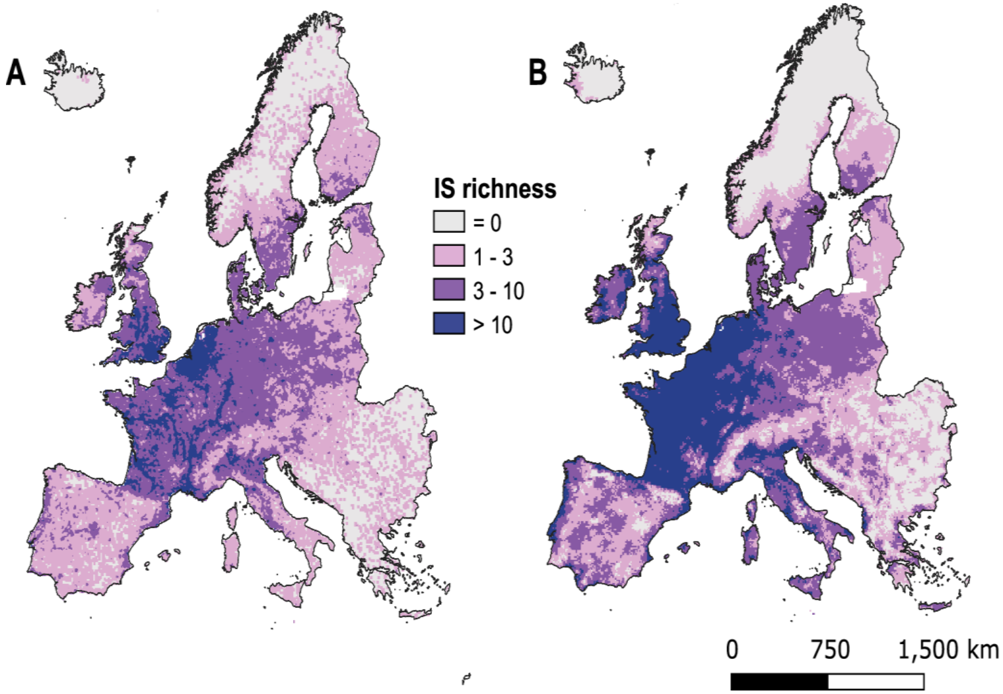
Significance (EU)

(Gallardo et al., 2024)

- The current exposure of Europe to the 94 IAS of concern is concentrated in Western Europe, specifically in countries such as the UK, the Netherlands, France, Belgium, and Ireland.
- Potential increase in the future exposure of ecosystem services to IAS of concern in Europe, particularly along coastal areas, and the Atlantic and Continental biogeographic regions



A Current exposure based on the real number of IAS currently present. **B** Potential exposure based on species distribution model prediction of IAS establishment.

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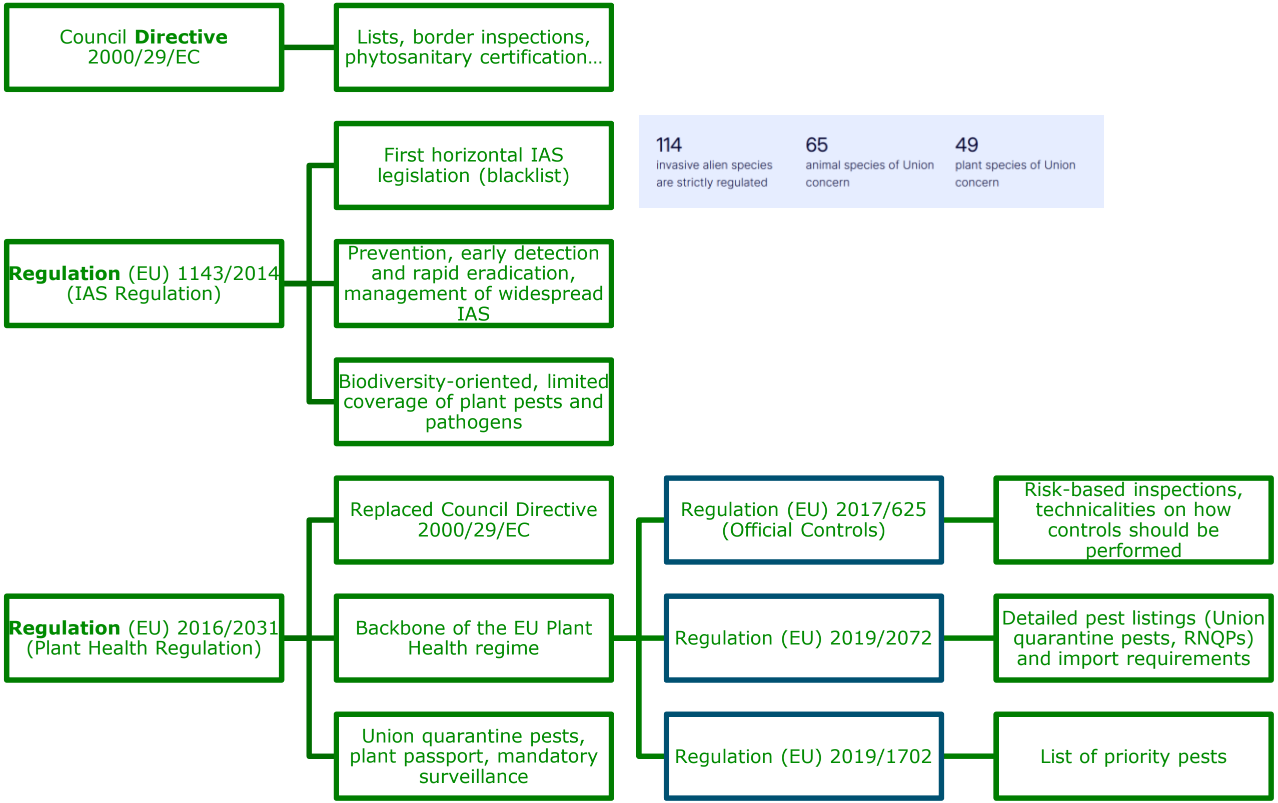
A glimpse of the international regulatory scheme

Key actions	Description
Aichi Biodiversity Targets – *Convention on Biological Diversity*	Strategic goals to protect biodiversity
2030 Targets – *Kumming-Montreal Global Biodiversity Framework*	e.g., Target 6: Reduce the introduction of IAS by 50% and minimize their impact
International Standards for Phytosanitary Measures - *International Plant Protection Organization*	Pest Risk Analysis Phytosanitary certificates Pathway management
Application of Sanitary and Phytosanitary Measures – *World Trade Organization*	International trade law Recognizes IPCC as the standard-setting body for plant health

EU policy scheme



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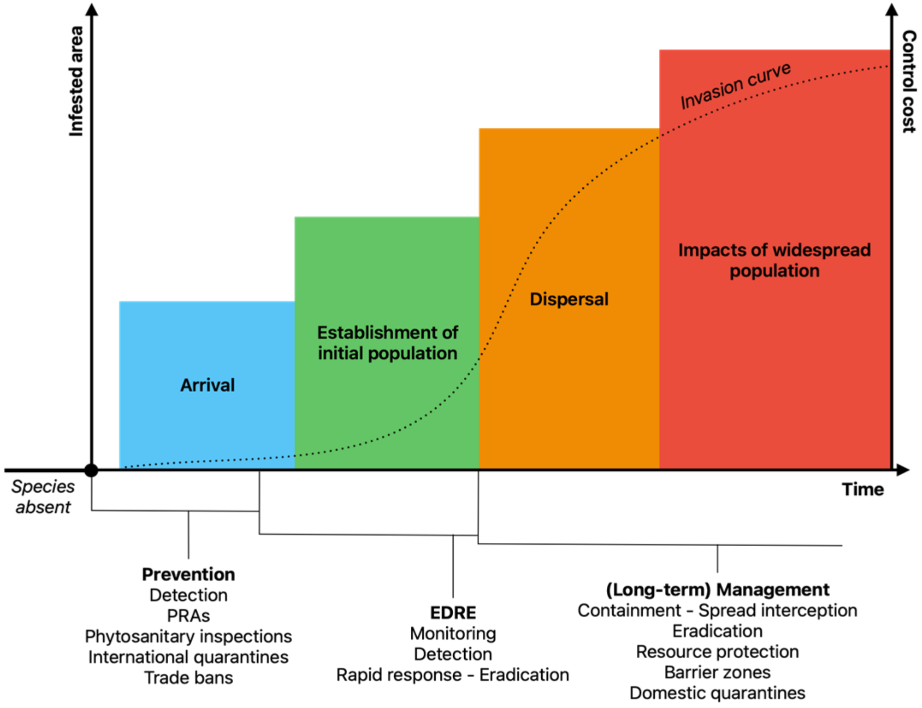
Invasion curve



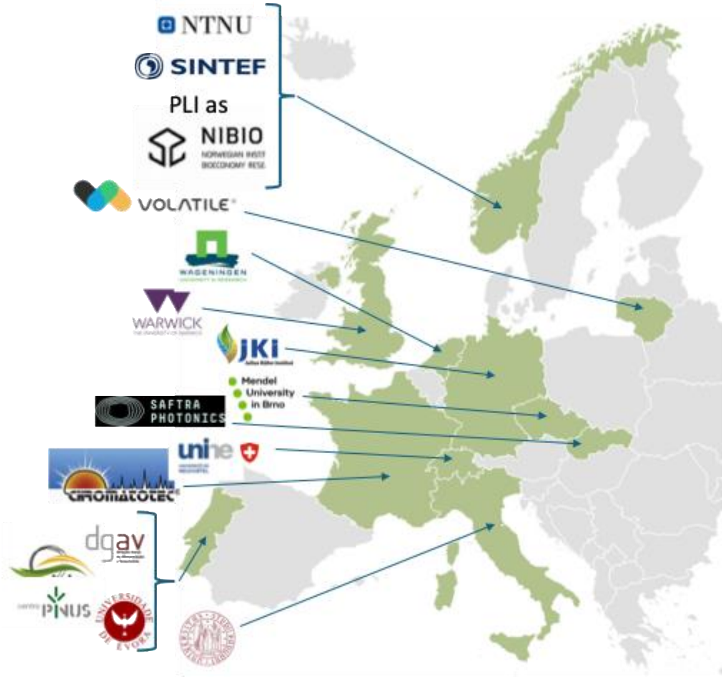
- **Prevention**

"the most environmentally desirable and cost-effective management strategy"

- **Early detection**

"It aids to prevent the invasion itself or serves as a decision-aid tool to identify the most cost-effective response to constraints and eradicate an upcoming invasion." (Mack et al., 2000)

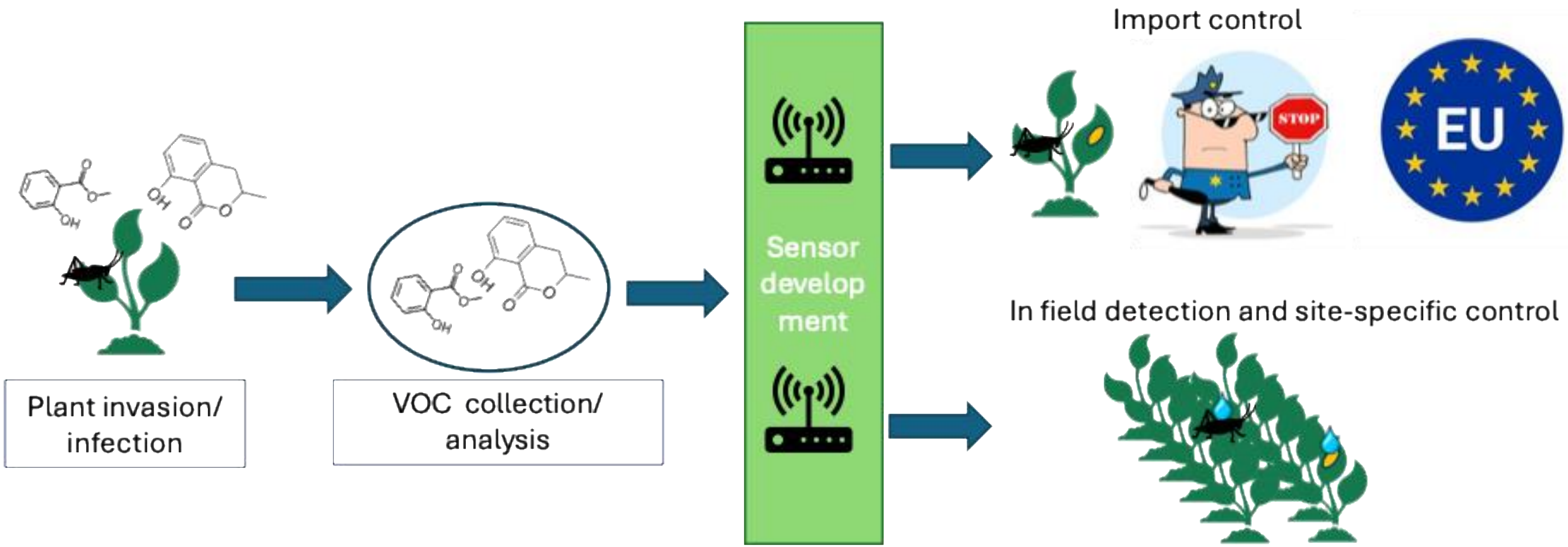
The PurPest project



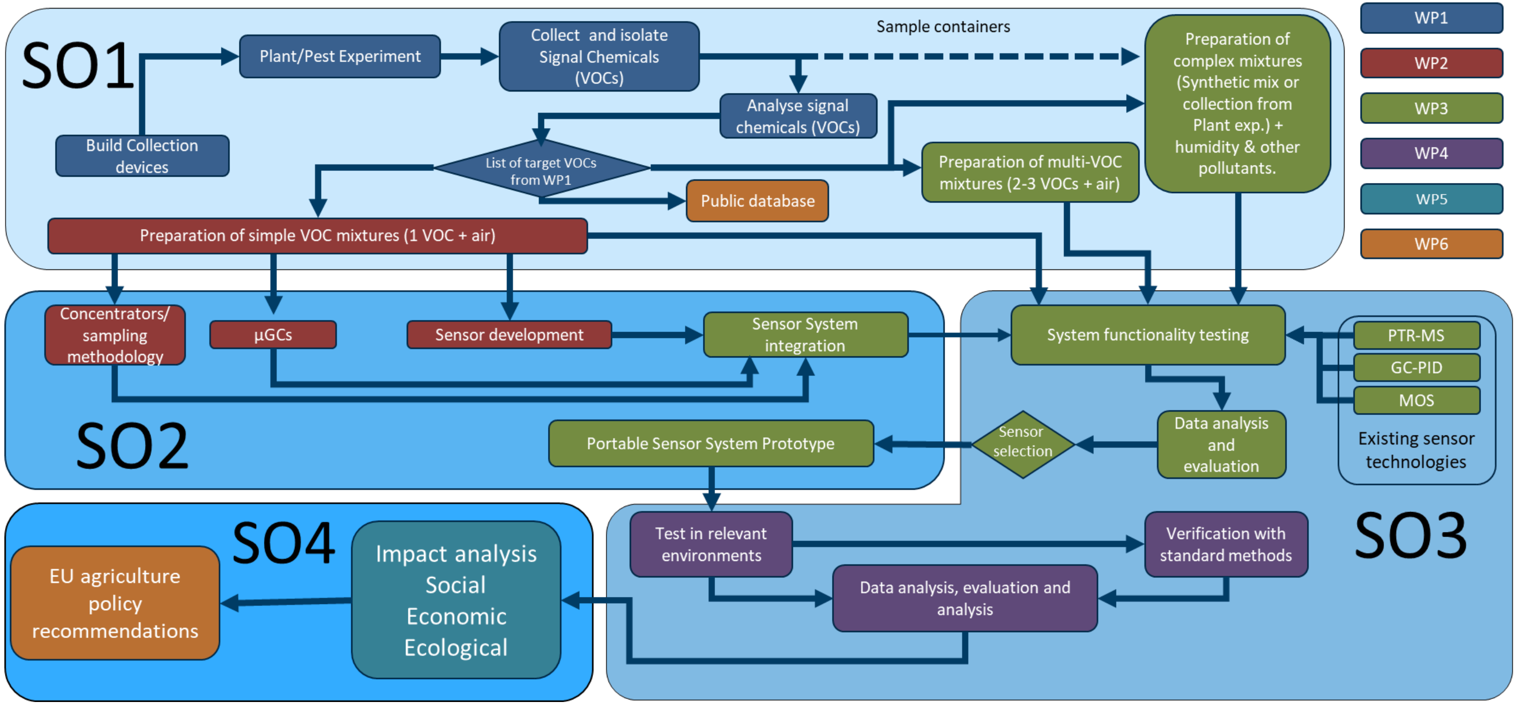
PurPest

Plant pest prevention through technology-guided monitoring and site-specific control

PurPest concept



Overall approach



More EU research projects…

BEXYL
BEYOND XYLELLA

SAFEWAX

senseApest

PONTE
Pest Organisms Threatening Europe

REACT

HOMED

FORSAID

compas

BIOVEXO

PURPEST WILL DETERMINE THE
VOC SIGNATURE FOR THESE PESTS

Cotton bollworm
(*Helicoverpa armigera*)

The butterfly "Fall armyworm“
(*Spodoptera frugiperda*)

Brown marmorated stinkbug
(*Halyomorpha halys*)

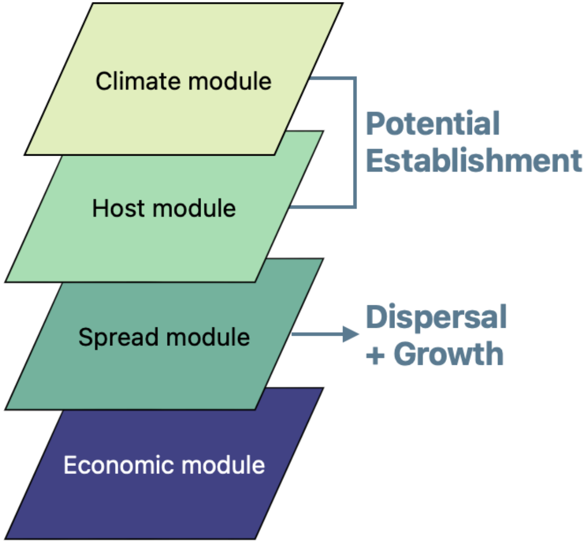
(*Phytophthora ramorum*)

Pinewood nematode
(*Bursaphelenchus xylophilus*)

Quantitative economic impact assessment

Methods to assess the potential economic impact of invasive plant pests (Mourits and Oude Lansink, 2023):

- Partial budgeting
- Partial equilibrium
- Input-Output analysis
- Computable general equilibrium



Bio-economic framework to assess the economic impacts using a quantitative approach. (Adapted and modified after Soliman et al., 2015)

Case study: Fall armyworm

(FAW, *Spodoptera frugiperda*)

- Highly **polyphagous** pest
    - >350 host plants, incl. maize, rice, sorghum, etc.

      (Kenis, et al., 2023; Montezano, et al., 2018)
- Native to the Americas → Invaded Africa (2016)
    - **Now present in 50 African countries, parts of Southeast Asia, and Oceania** (EPPO, 2025)
- Estimated annual **yield losses** of **US$9.4 billion** in Africa alone (Eschen, et al., 2021)
- Estimated annual maize **production losses** in 12 African countries **up to 53%** (Day, et al., 2017)
- **Yield loss** in maize may reach **up to 73%** (Hruska, et al., 1997)

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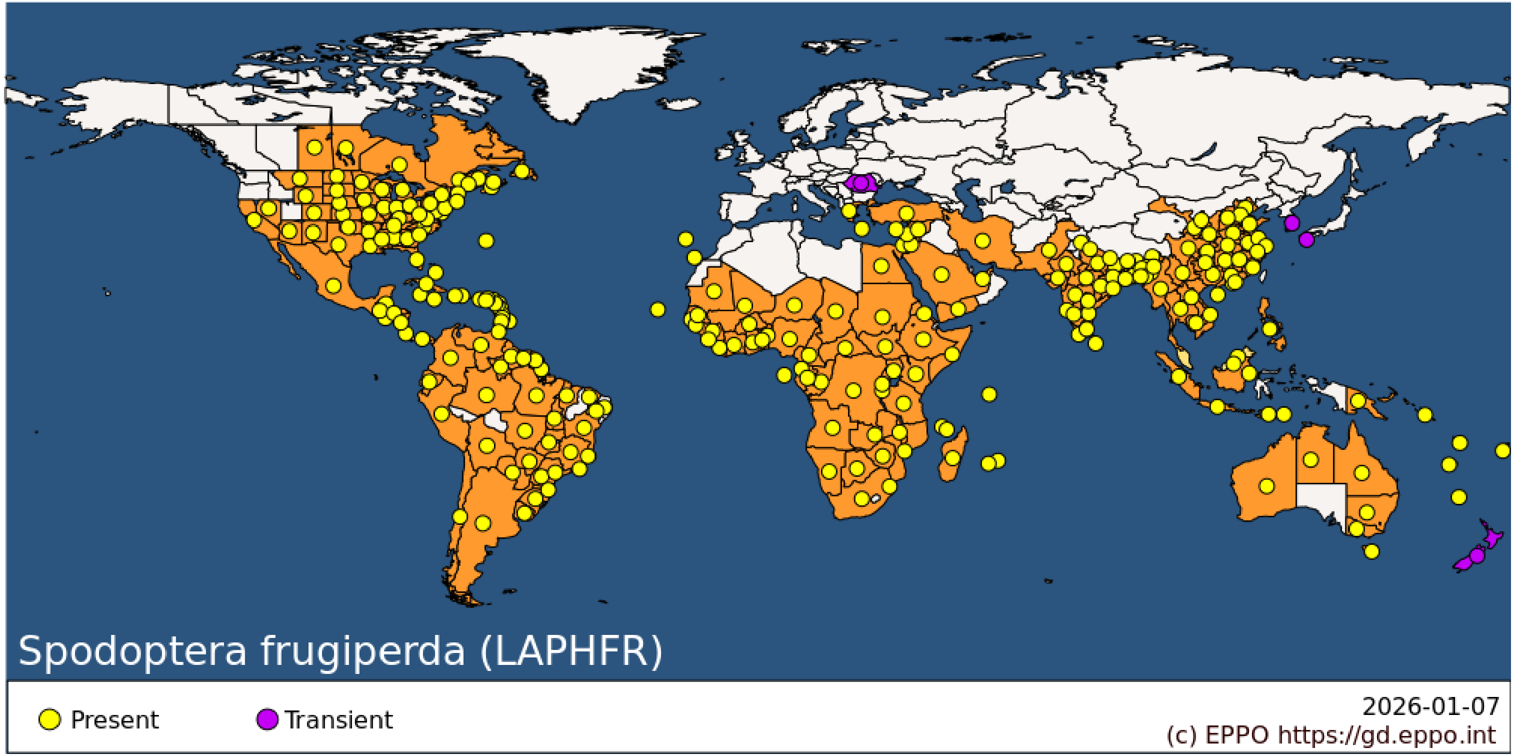
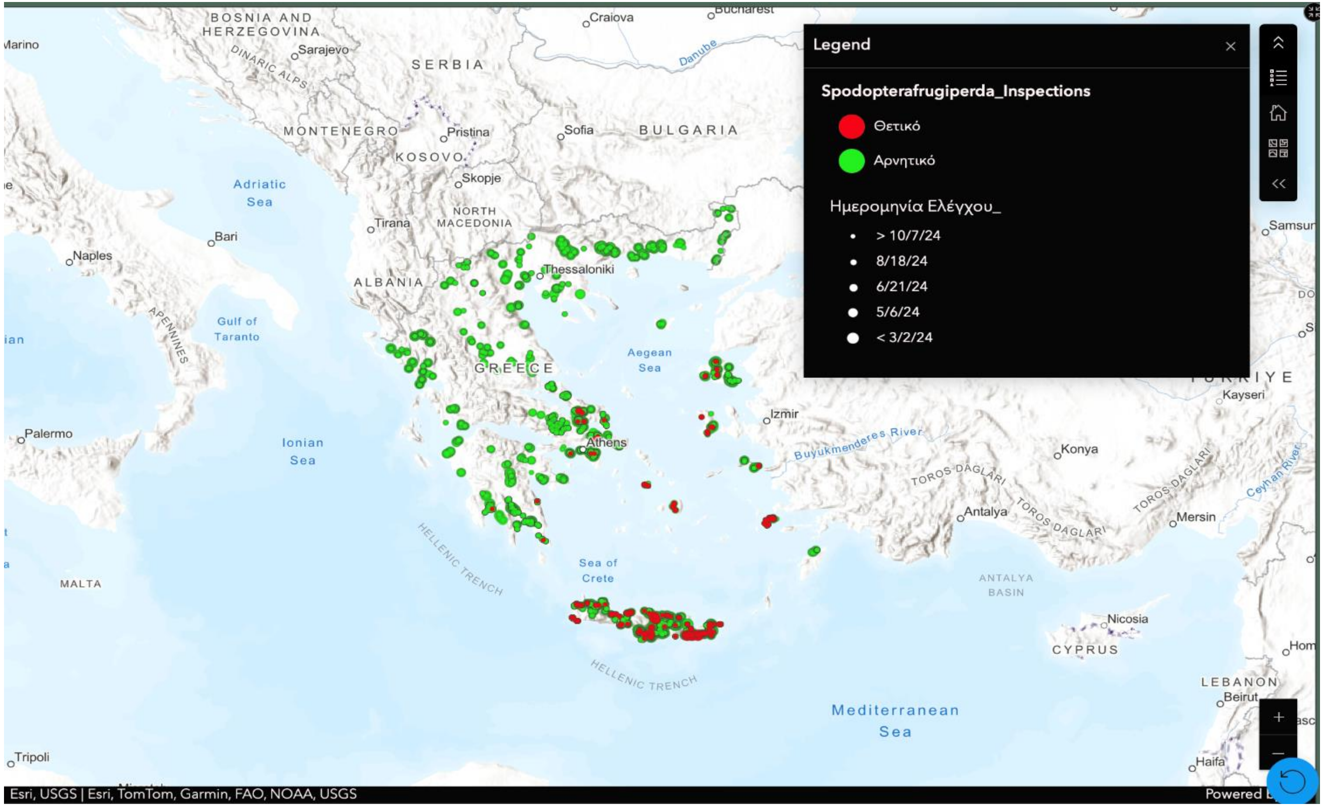
Global distribution



Inspection results in Greece



FAW presence

- Greece
- Cyprus
- Portugal (Madeira)
- Spain (Canary Islands)
- Romania*

Policy relevance in the EU

2016

EPPO A1 List

Not present in EPPO member countries

2019

Quarantine pest

Part A of Annex II
Commission Implementing Regulation (EU) 2019/2072

2019

EPPO A2 List – Priority pest

Present in EPPO member countries (Egypt, 2019)

Commission Delegated Regulation (EU) 2019/1702

2019

#9

2023

Measures to prevent entry, spread, and establishment

Commission Implementing Regulation (EU) 2023/1143

- e.g., buffer zones, annual surveys, plant passports, etc.

2025

#6

Objective(s)

01

Identify the **areas at risk in Europe**

- No consensus *wrt.* FAW potential distribution in the literature

02

Explore the **extent of seasonal natural migration** in Europe (post-invasion)

- Modeling attempts focus on migration from North Africa to Europe (Wang et al., 2023)

03

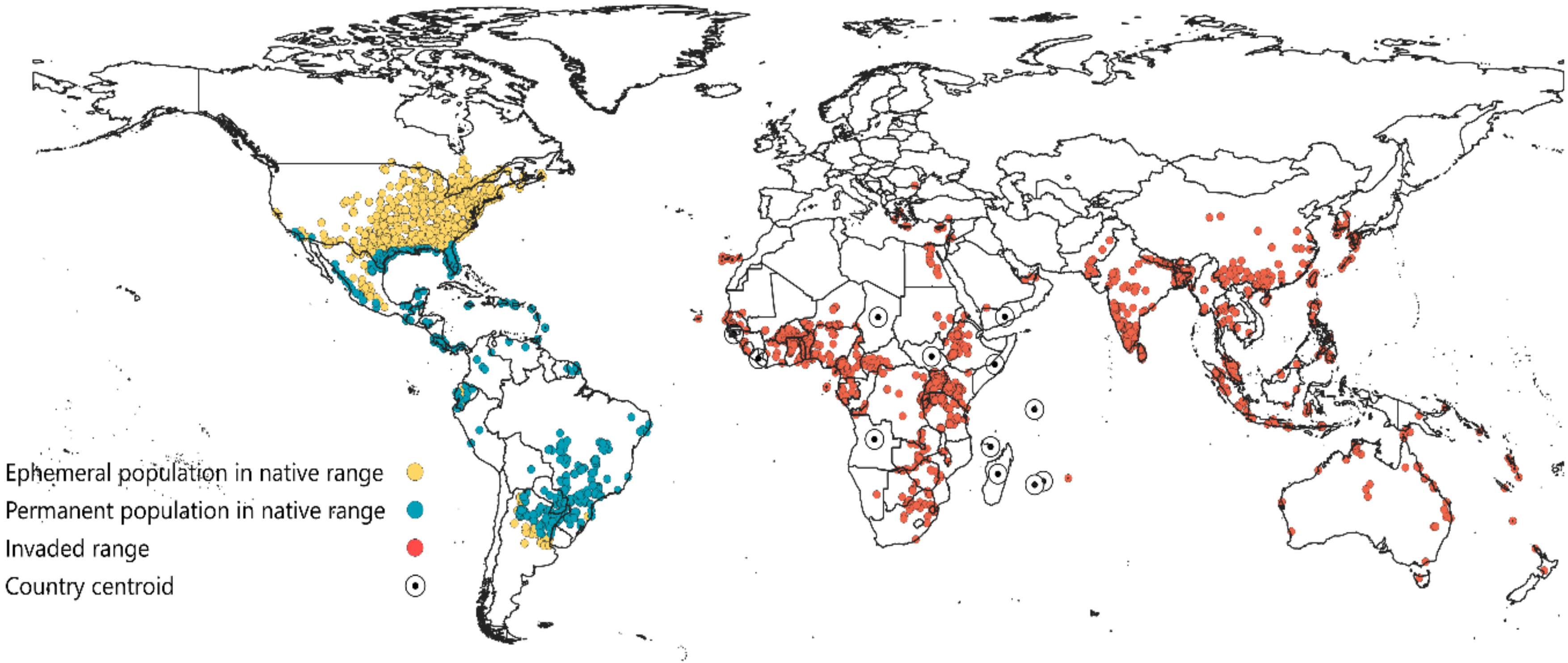
Assess the **potential direct economic impact on European grain maize production** under a "**no-control**" scenario

- Absence of such information

01 Identify the areas at risk

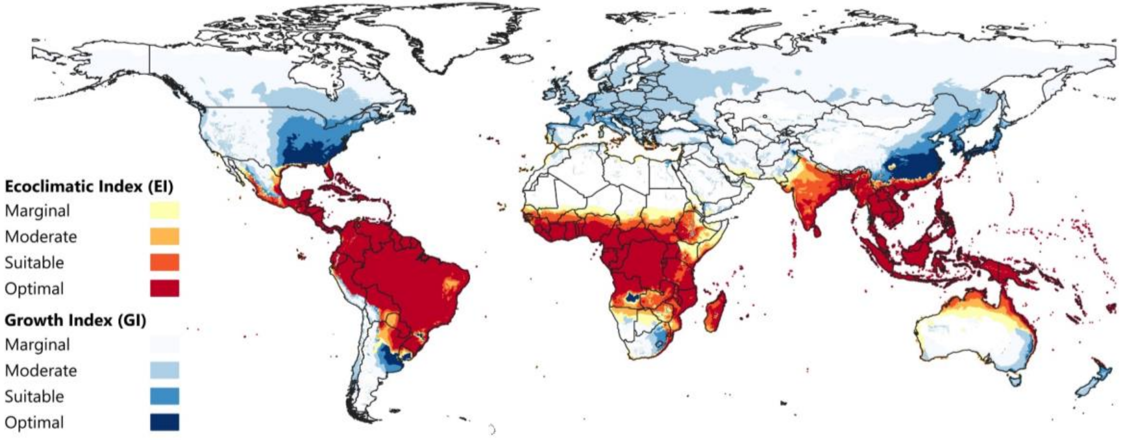
- Process-based **niche** model for **estimation of the potential distribution** of a species as a response to the **current** or **future climate**.
- The model accounts for both *favorable* periods for growth (Growth Index, $\mathbf{GI_A}$) and *unfavorable* periods characterized by **stress** indices. (Kritikos, et al., 2015; Sutherst, et al. 1985)
- The **integration of $\mathbf{GI_A}$ and stress indices** yields a single annual index of climatic suitability for a given location, known as the Ecoclimatic Index (**EI**).
- Both GI_A and EI range from 0 to a theoretical maximum of 100.
  - EI = 0: unsuitable
  - $0 < EI \leq 5$: marginally suitable
  - $5 < EI \leq 15$: moderately suitable
  - $15 < EI \leq 30$: suitable
  - EI > 30: optimal

01 Identify the areas at risk



Confirmed presence records of *S. frugiperda* around the globe. (Kartakis et al., 2025)

01 Identify the areas at risk



Global climatic suitability of *S. frugiperda* under a composite irrigation scenario (2.5 mm day^{-1} applied as top-up) (Kartakis et al., 2025)

- Areas with tropical climates, as well as subtropical climates, exhibit the highest Ecoclimatic Index values (EI > 30), indicating optimal climate conditions for FAW.
- Areas with humid continental, Mediterranean, and all humid subtropical climates are suitable for transient FAW populations, exhibiting moderate Growth Index (GI_A) values (GI_A >15, EI = 0).

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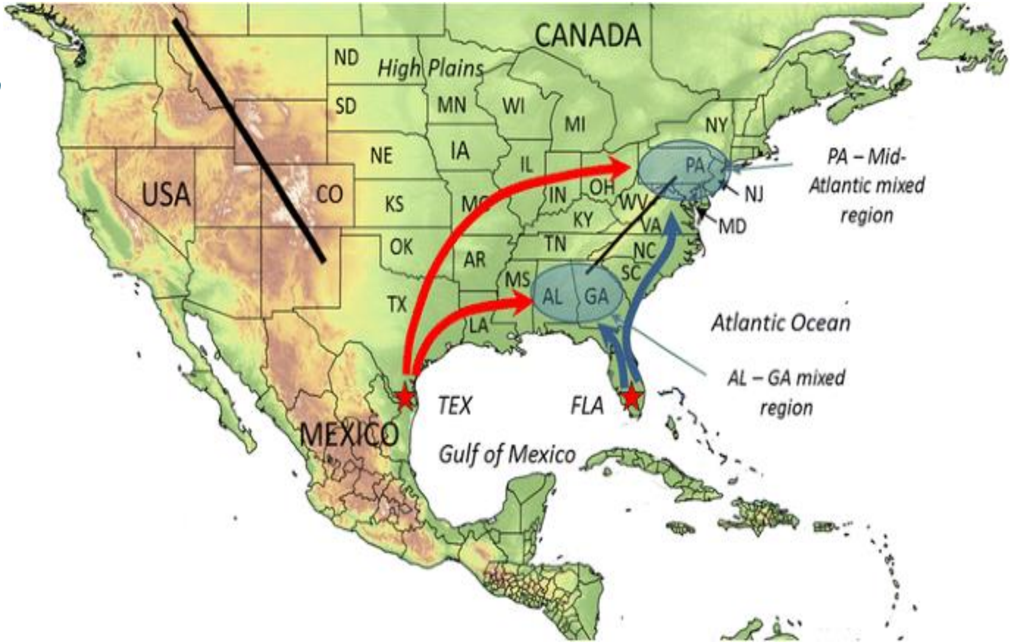
02 Explore the extent of seasonal natural migration in Europe

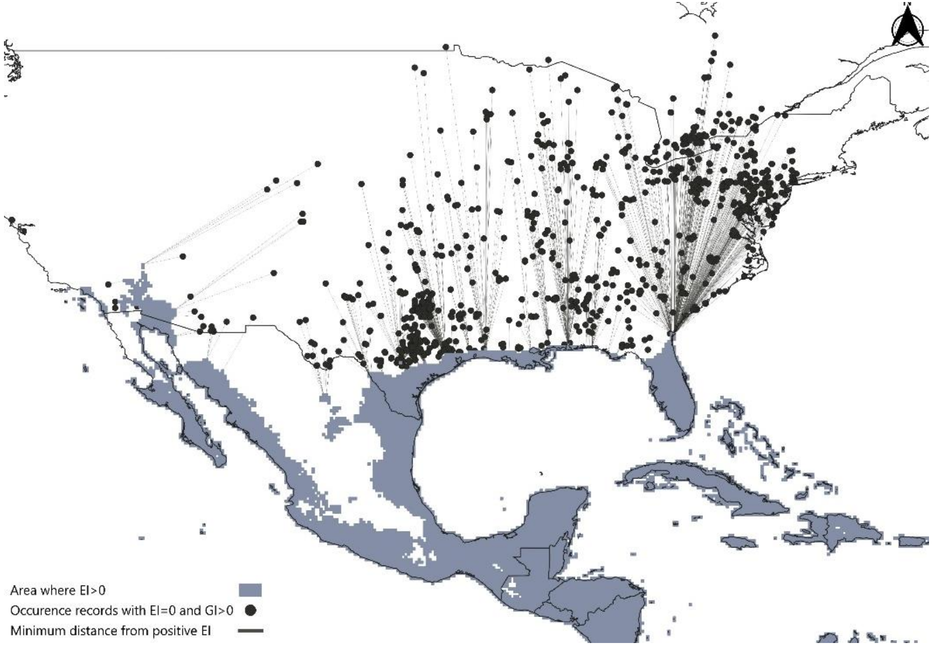
*"A critical aspect of FAW risk in Europe is its **migration capacity** during the warmer months. The pest **flies very long distances northwards**, from the **southeast coast of the USA up to Canada**, to avoid warm summer temperatures."* (Westbrook et al., 2016)



Migration pathways of FAW from two winter-breeding source locations (Texas and Florida). (Westbrook et al., 2016)

02 Explore the extent of seasonal natural migration in Europe

- **Data subset** of occurrence records in USA and Canada (*n′*=1831)
    - Records outside the area of permanent establishment ($GI_A>0$, EI=0) are **transient** populations
- “**Distance to nearest hub** (line to hub)” QGIS algorithm
- Distribution of (minimum) migration distances
- Creation of buffer zones around EI>0 areas, based on the derived distribution
- Extrapolation of buffer zones into Europe



Occurrence records of *S. frugiperda* representing ephemeral populations in the USA and Canada. (Kartakis, et al., 2025)

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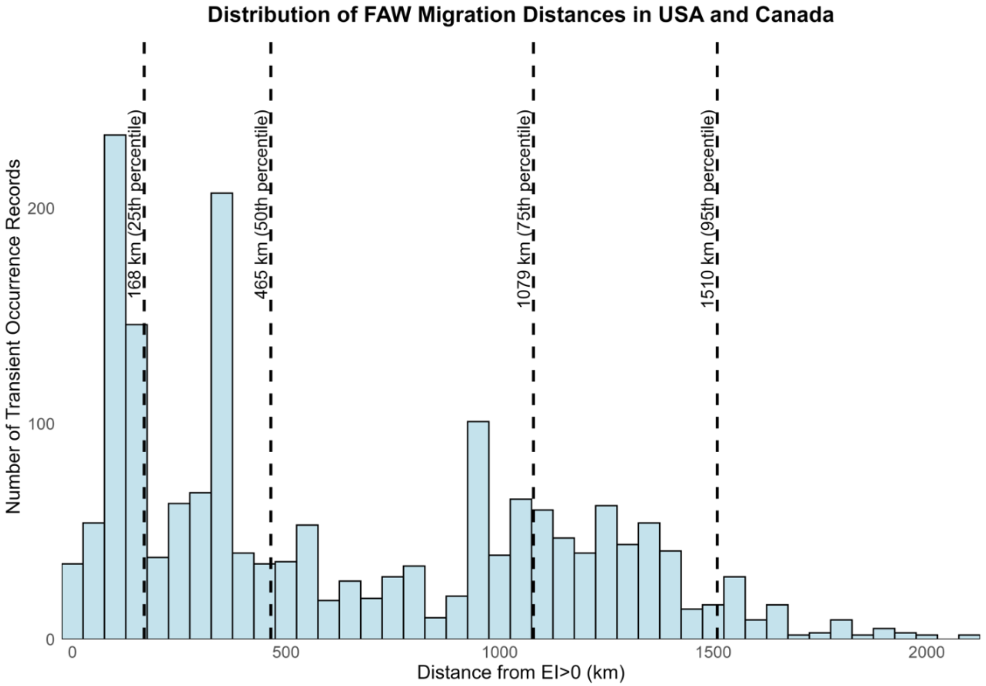

Distribution of *S. frugiperda* migration distances from the area of permanent establishment (EI>0) in the USA and Canada, using the data subset (n'=1831). (Kartakis, et al., 2025)

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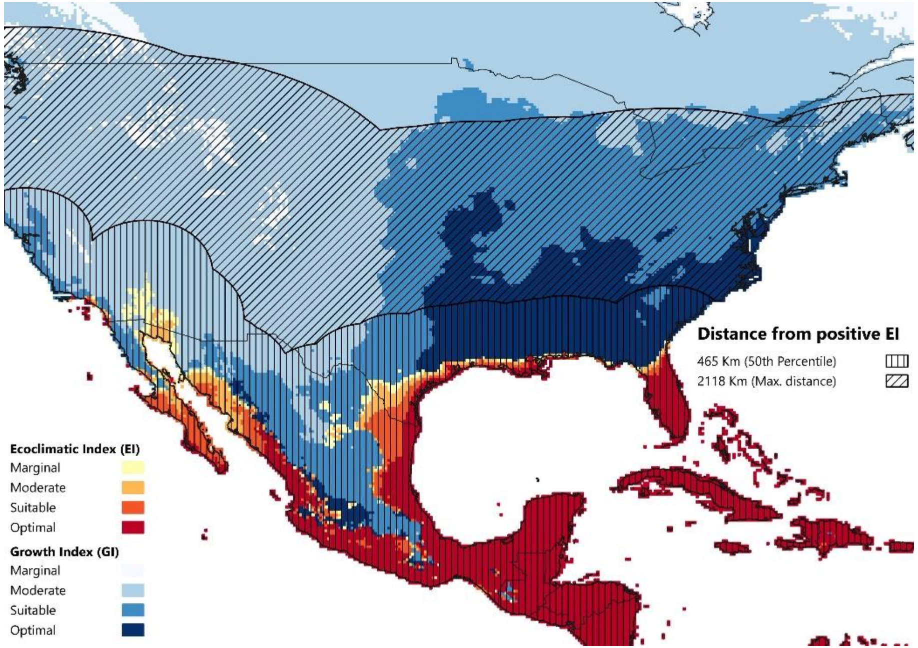

Projected climatic suitability of *S. frugiperda*. Dispersal frequency zones are depicted using cross-hatching buffer zones. (Kartakis, et al., 2025)

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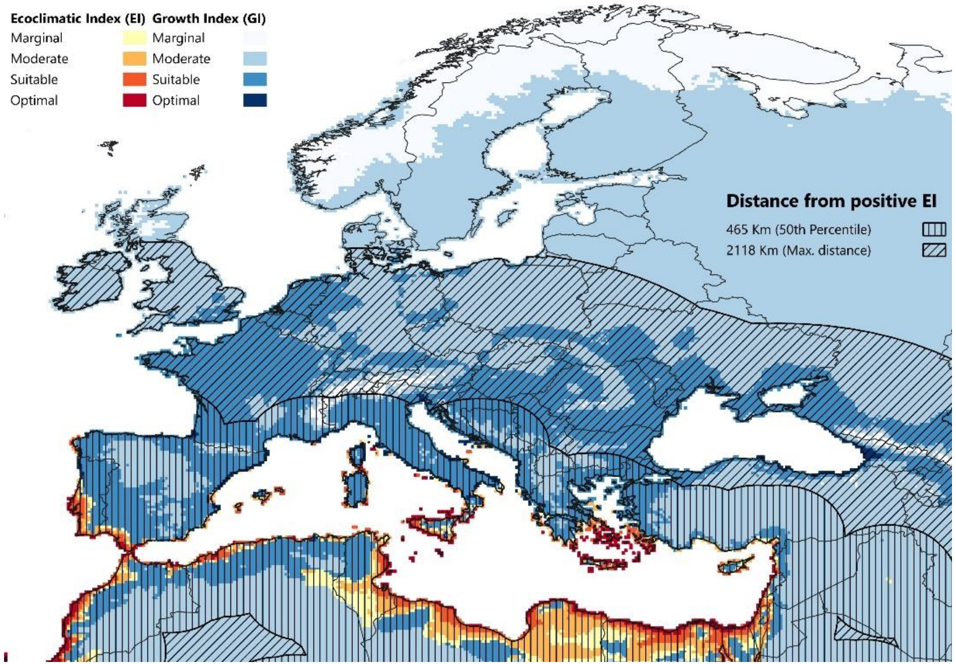

Projected climatic suitability of *S. frugiperda* in Europe. Dispersal frequency zones are depicted using cross-hatching buffer zones and are based on FAW migratory patterns in the USA and Canada. (Kartakis, et al., 2025)

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03 Assess the potential direct economic impact on European grain maize production

- **Grain maize gross margins** for 2010–2020 for 13 EU MSs (FADN EU Cereal Farms)
- **Grain maize cultivated area** (Eurostat)
- EKE data on **yield loss distribution** on grain maize due to FAW (EFSA, 2019)

03 Assess the potential direct economic impact on European grain maize production

- **Partial budgeting** to assess the potential **direct economic impact** of FAW invasion on grain maize farms in Europe (Soliman et al., 2015)
- **Direct** impacts involve solely **yield losses** + **additional operating costs**
- **“No-control” scenario →** no additional regulatory or control measures (Wesseler & Fall, 2010)
- **Assumptions**
  - Complete occupancy of climatically suitable areas in Europe (EI>0).
  - FAW migratory capacity follows a similar pattern to that in the native range.
  - The migration starts over every year from the EI>0 area.
  - The probability of attack is inversely related to the distance from the EI>0.

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03 Assess the potential direct economic impact on European grain maize production

- Gross margins **without** FAW:

$$GM_i^{baseline} = \frac{1}{n}\sum_{t=1}^{n}(R_{i,t} - OC_{i,t})$$

- Gross margins **with** FAW:

$$GM_i^{FAW} = \bar{R}_i\left(1 - PP_i\frac{YL_{i,s}}{100}\right) - \overline{OC}_i$$

where,

- $GM_i^{baseline}$ is the average grain maize **gross margin** in Member State (MS) i (€/ha) over the period 2010-2020
- $R_{i,t}$ is the grain maize **revenue** in MS i (€/ha)
- $\bar{R}_i$ is the **average revenue** for MS i (€/ha)
- $\overline{OC}_i$ is the **average operating costs** for MS i (€/ha)
- $OC_{i,t}$ is the **operating costs** in MS i (€/ha)
- GM_i^{FAW} is the grain maize **gross margin with FAW presence** in MS i (€/ha)
- $YL_{i,s}$ is the EKE **yield loss** value for MS i and scenario s
- PP_i is the **probability of FAW presence** for MS i

03 Assess the potential direct economic impact on European grain maize production

- The **migration distance** analysis resulted in a **dataset** of min. distances from EI>0
- This dataset was **fitted into a ECDF** to derive PP_i for each Member State

$$PP_i = 1 - F(D_i)$$

where,

- D_i is the **country centroid's distance from** the area of permanent establishment (**EI>0**) for each Member State i
- $F(D_i) \in [0,1]$ is the **value of the ECDF for each $\boldsymbol{D_i}$**

- The **direct economic impact** $DEI_{i,s}$ is calculated as follows:

$$DEI_{i,s} = GM_i^{baseline} - GM_{i,s}^{FAW}$$

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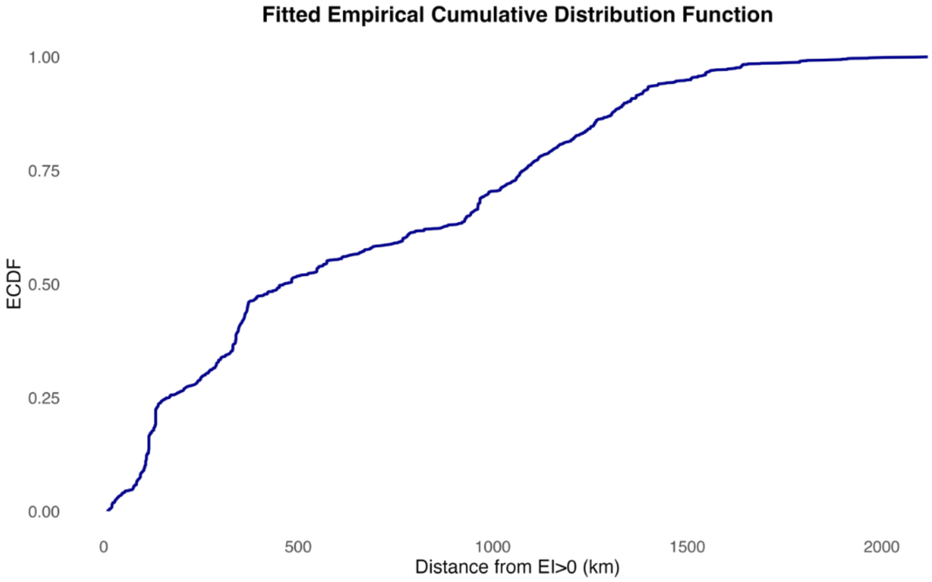
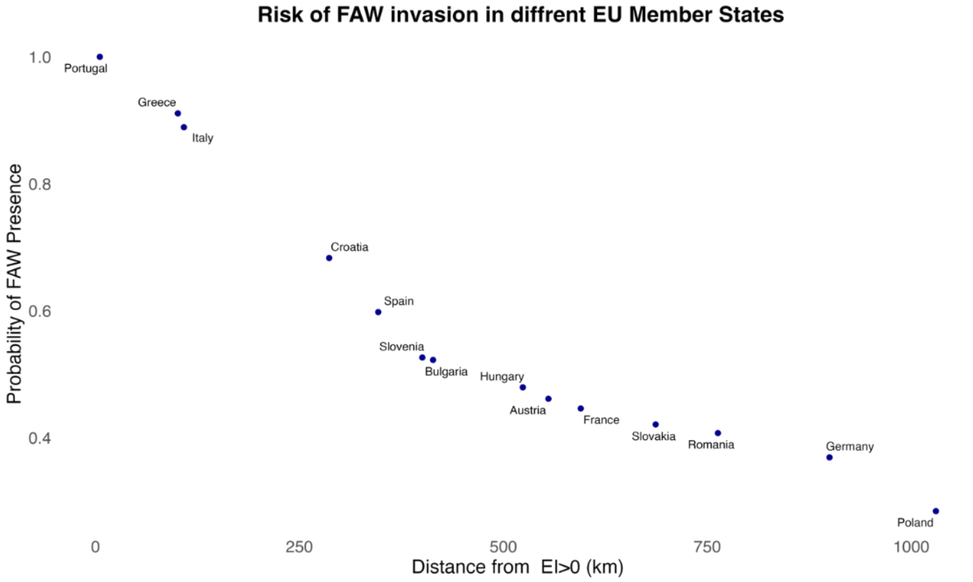
03 Assess the potential direct economic impact on European grain maize production





The fitted ECDF is based on *S. frugiperda* migration distances from the permanent establishment (EI>0) area in the USA and Canada. The curve illustrates the cumulative probability that the pest would fly a certain distance away from EI>0. (Kartakis, et al., 2025)

The probability of *S. frugiperda* annual presence in 13 EU Member States, based on the distance of the centroid of each MS to the closest projected area of permanent establishment (EI>0). (Kartakis, et al., 2025)

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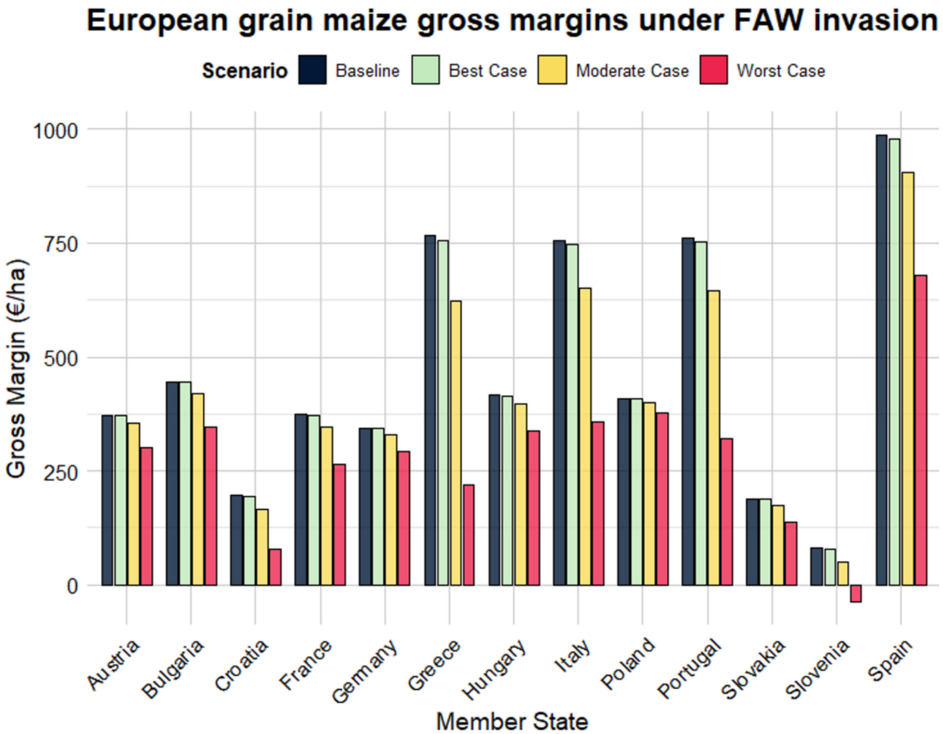
03 Assess the potential direct economic impact on European grain maize production



The potential annual impact of *S. frugiperda* on grain maize gross margins (€/ha) in different EU Member States, under three yield loss scenarios. (Kartakis, et al., 2025)

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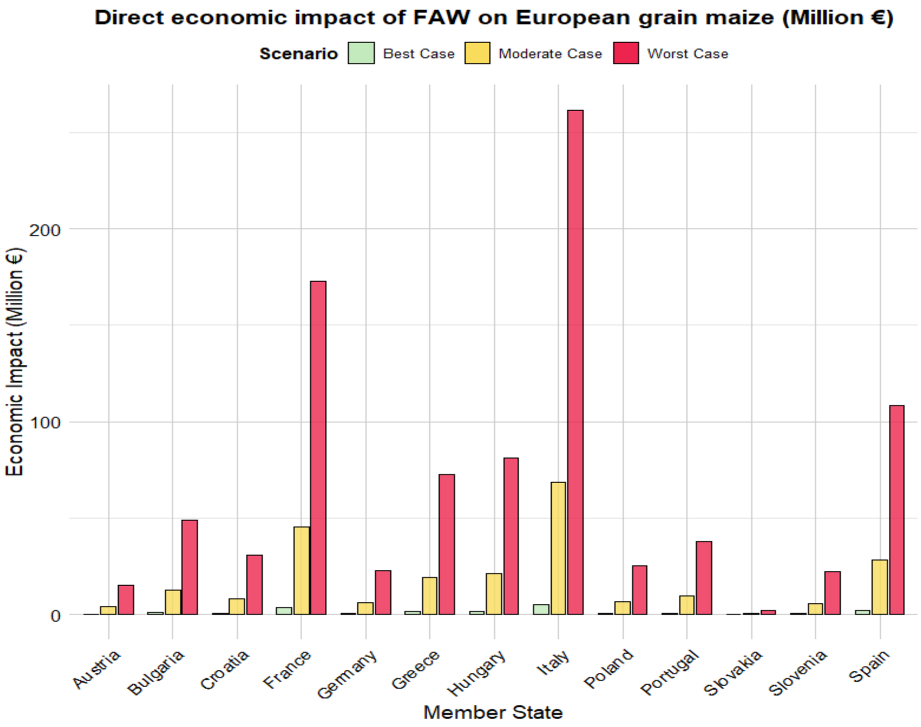

The potential annual direct economic impact (in million €) of *S. frugiperda* on grain maize production in different EU Member States, under three yield loss scenarios.
(Kartakis, et al., 2025)

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Conclusion

- **High risk for Europe:** Several **climatically suitable areas** for FAW permanent establishment **along the Mediterranean**.
- Grain maize gross margin losses could reach up to €900 million annually, with **southern Member States mostly affected**.
- A zone of ≈**1,000 km** into adjacent ephemeral climate suitability habitat ($EI=0$ and $GI_A>0$) would be **accessible and prone to FAW annual migration**.
- **Prevention alone is unlikely to be sufficient** – Europe needs early detection systems, IPM tools, and coordinated biosecurity measures, especially in high-risk zones.

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PurPest

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