Application and use of insect phenology modeling for regional and global pest risk assessments

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General overview

Introduction

- Development of the Insect Life Cycle Modeling (ILCYM) software: For which purpose
- Main features and advantages

ILCYM applications

- Pest Risk Analysis (PRA) on different scales
- Climate change and adaptation planning
- Regional assessments

Next steps

ILCYM: For which purpose

Analytical tools for predicting, evaluating and understanding the dynamics of insect populations in agroecosystems

1 Species distribution mapping (SDM) in support of pest risk assessment (PRA, IPPC)

2 Climate change / adaptation planning

3 Integrated Pest Management (Examples)

- Simulation of pest life-table parameters under prevailing weather conditions as decision support for pest management
- Identification of potential release sites for parasitoids (classical biocontrol)
- Simulation of field performance of biopesticides and application rates

Framework for Pest Risk Analysis

	A	B
	Likelihood of entry and establishment*	Consequences of establishment
1	Entry potential	Economic impact potential
2	Colonization potential Establishment potential	Environmental impact potential
3	Spread potential	Social impacts

*under current and future climates

Insect Life Cycle Modeling (ILCYM)

Software package for developing temperature-based insect phenology models with applications for regional and global pest risk assessments and mapping.

<u>Required input</u>: Life-table data collected under constant and fluctuating temperatures

<u>Model builder</u>

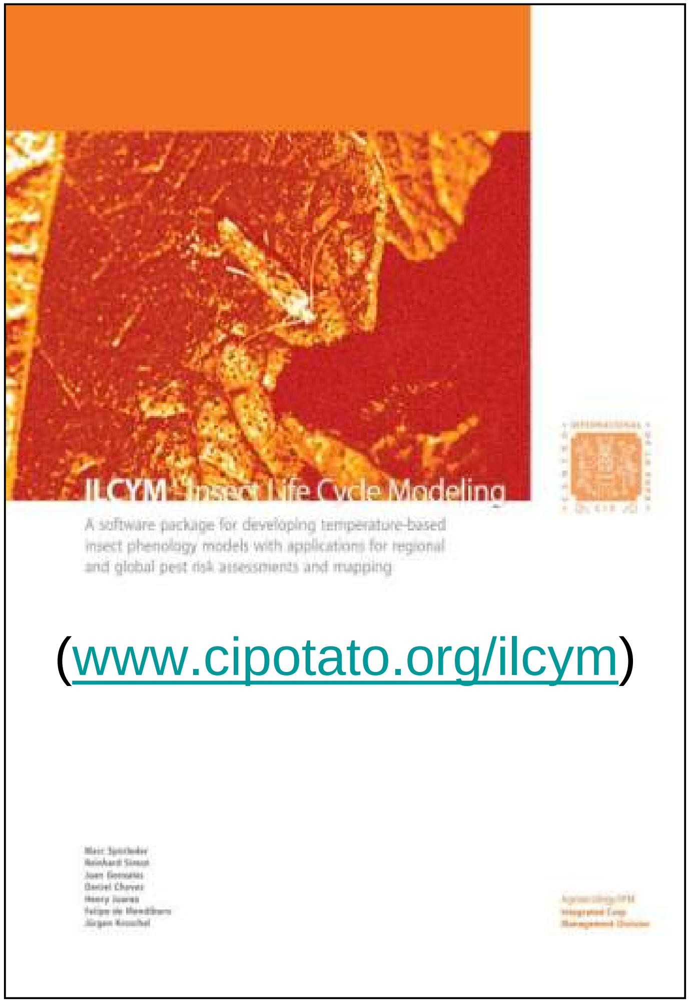
- Fitting functions for describing temperature-driven development processes under constant temperatures, i.e. development rate, mortality and reproduction

<u>Validation and simulation module</u>

- Uses life-table data established under fluctuating temperature; can be used for deterministic and stochastic simulations

<u>Potential population and risk mapping module</u>

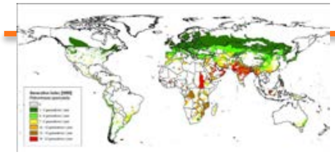
- Establishment index
- Generation index
- Activity index



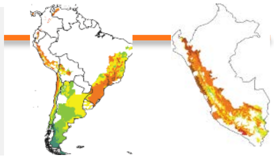
(www.cipotato.org/ilcym)

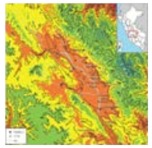
Pest risk mapping using ILCYM

Risk mapping



Potential distribution at global, regional and local level





Current climate: 2000

(1950-2000: www.worldclim.org/)

With and without crop shapes

Future climate: 2050

Down-scaled data SRES-A1B, IPCC (2007): http://gisweb.ciat.cgiar.org/GCMPage

ERI $= \dfrac{(\sum_{i=1}^{365} \widehat{Ro}_i)/365}{max(\widehat{Ro}_i)}$

GI $= \dfrac{(\sum_{i=1}^{365} 365\,/\widehat{GL}_i)}{365}$

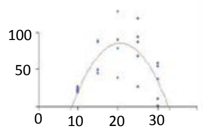
AI $= \log_{10}\left(\prod_{i=1}^{365} \hat{\lambda}_i\right)$

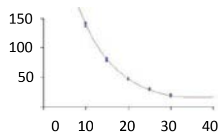
ERI | GI | AI

Risk indices

Model validation

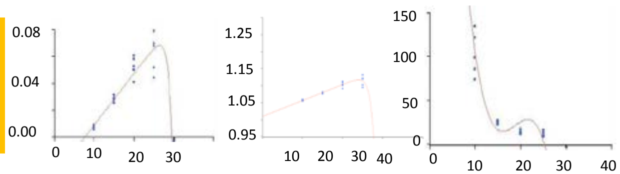
Model builder



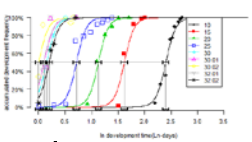


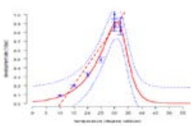
Net reproduction rate, generation time

Simulation of life-table parameters



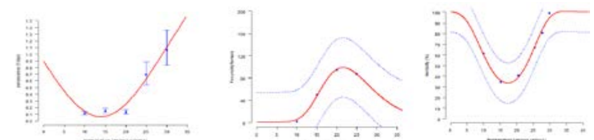
intrinsic and finite rate of increase, doubling time



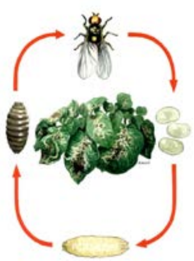


Development rate and time

Temperature-based phenology models

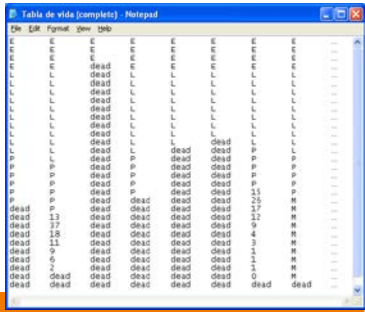


Survival rate, oviposition, mortality



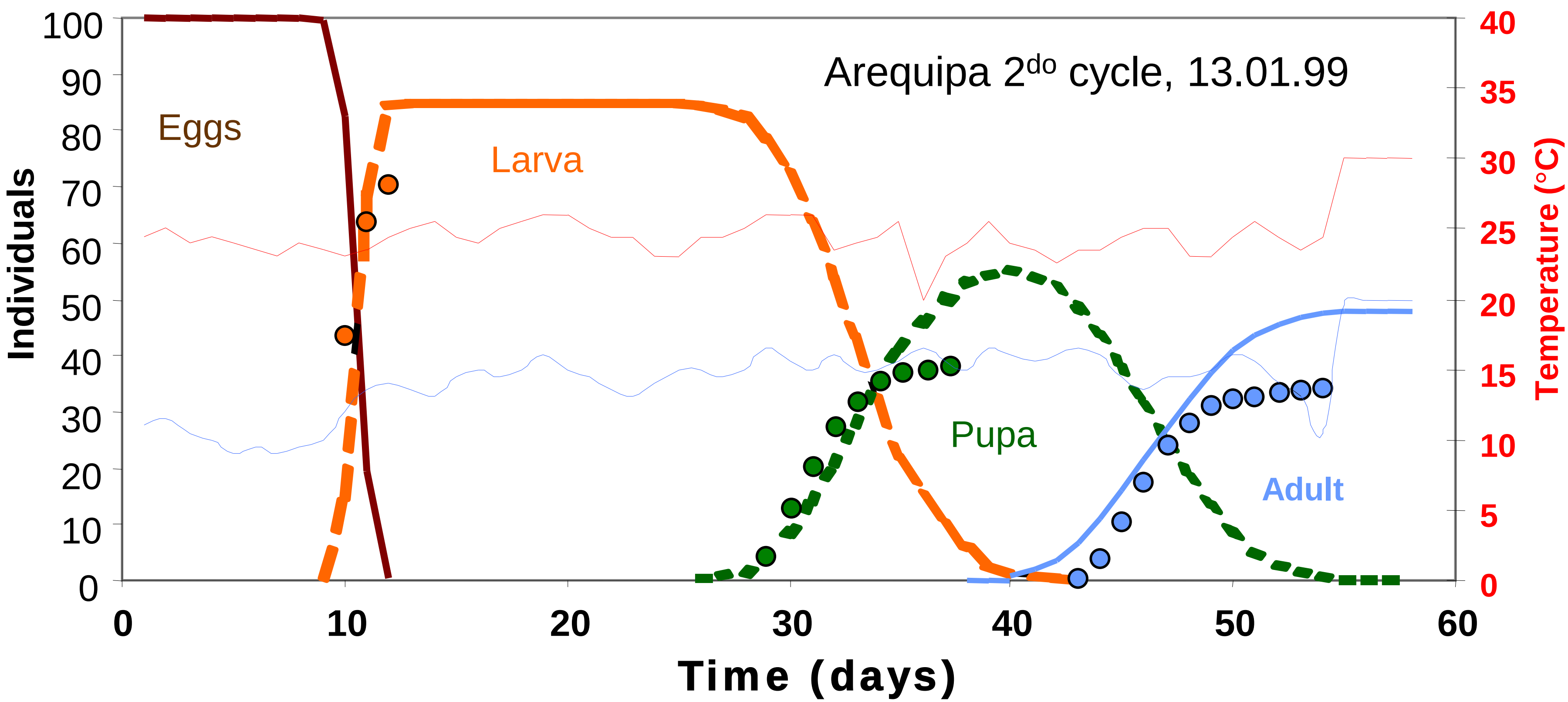
Life-table studies

At constant and fluctuating temperatures: oviposition, survival time, development time, mortality



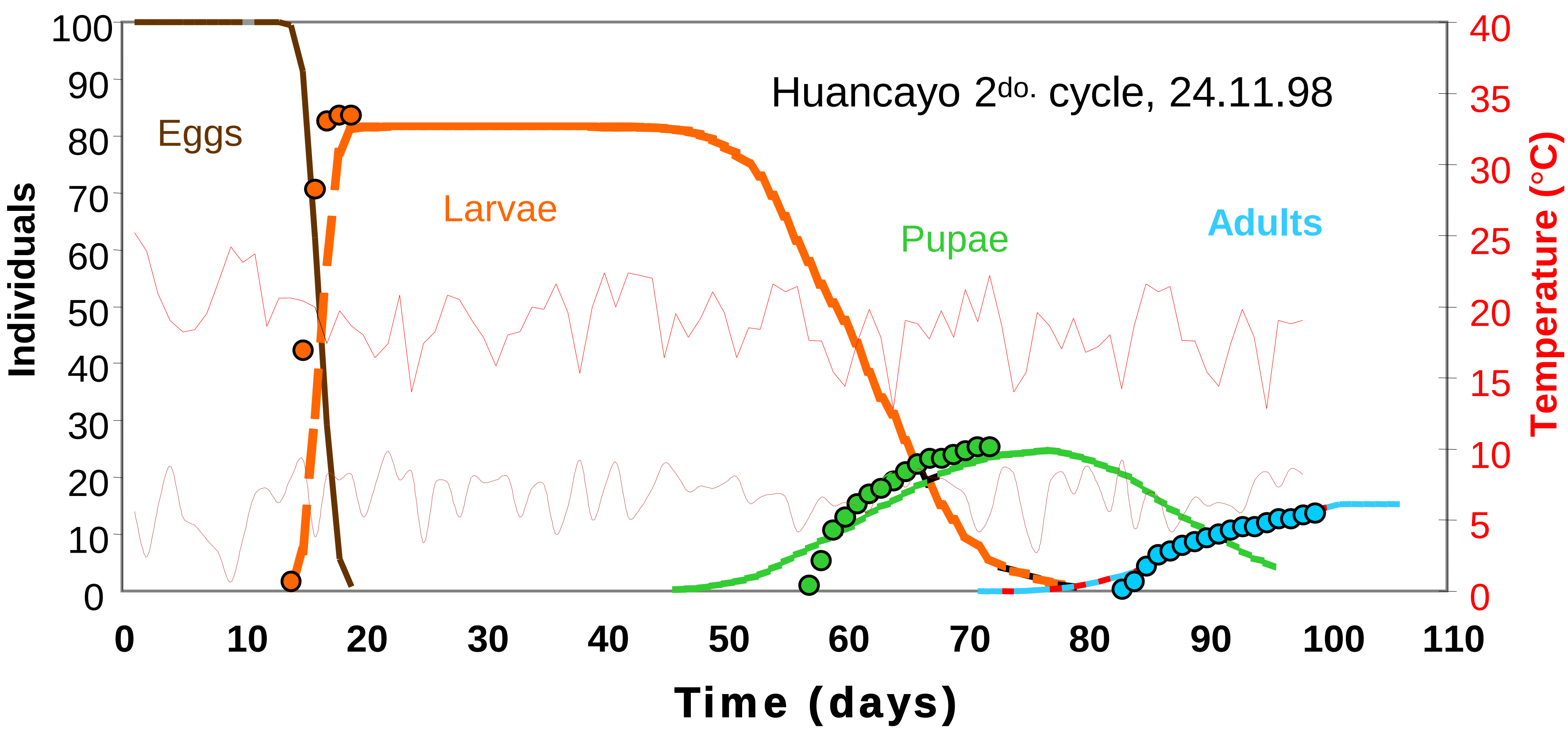
(www.cipotato.org/ilcym)

Model validation



(Keller 2003)

Model validation



(Keller 2003)

ILCYM's risk indices

Establishment risk index (Survival risk index): Indicates the capacity of invasive pest species to establish permanent populations

$$\text{Index} = \frac{\left(\sum_{i=1}^{365} \widehat{Ro}_i\right)/365}{max(\widehat{Ro}_i)}$$

The index is defined as the number of time intervals with a net reproduction rate, R_0, above 1 ($I_{i=1}$) divided by the total number of time intervals within a year (I_l).

Generation Index: Indicates the potential infestation of a crop

$$\text{Index} = \frac{\left(\sum_{i=1}^{12} 365 \,/\widehat{GL}_i\right)}{12}$$

The index is computed by averaging the sum of estimated generation lengths, $_{Ti}$, calculated for each Julian day, x, where 365 is the number of days per year and Ti is the predicted average generation lengths in days during the month, i (i = 1, 2, 3, …, 12).

Activity Index: Indicates pest potential population growth, spread and severity

$$\text{Index} = \log_{10}\left(\prod_{i=1}^{365} \hat{\lambda}_i\right)$$

where λ is the finite rate of increase at Julian day, x (x = 1, 2, 3, …365).

Main advantages of ILCYM modeling

- Complex simulation of an entire insect life system.
- It uses process-based functions that provide a mechanistically detailed representation of the insects life history, and hence population growth.
- Model functions are build based on statistical analysis of experimental data that allows determining errors in particular processes.
- Full live history (development, survival, reproduction) and the software compiles the overall model automatically is modeled
- Models have parameters with straightforward interpretation of the biological system.
- Individual functions of a model can be validated and improved.
- The information can be used in different modeling types; i.e. spatially (SDM through the use of specific risk indices), or in time (in a given area) for different inquiry (from basic ecological understanding to prediction, management and policy-making).
- Input data can be real or simulated temperature at variable intervals.
- The simulation is implemented in R-language, which is open source software.

ILCYM: Reference publications

Sporleder, M., J. Kroschel, M. R. Gutierrez Quispe & A. Lagnaoui (2004): A temperature-based simulation model for the potato tuber worm, *Phthorimaea operculella* Zeller (Lepidoptera; Gelechiidae). **Environmental Entomology** 33 (3): 477-486.

Kroschel, J., M. Sporleder, H.E.Z. Tonnang, H. Juarez, P. Carhuapoma, J.C. Gonzales & R. Simon (2013): Predicting climate change caused changes in global temperature on potato tuber moth *Phthorimaea operculella* (Zeller) distribution and abundance using phenology modeling and GIS mapping. **Journal of Agricultural and Forest Meteorology** 170: 228-241.

Tonnang, E.Z.H., P. Carhuapoma, H. Juarez, J.C. Gonzales, D. Mendoza, M. Sporleder, R. Simon, J. Kroschel (2013): ILCYM - Insect Life Cycle Modeling (version 3.). **User Guide**. A software package for developing temperature-based insect phenology models with applications for regional and global analysis of insect population and mapping. International Potato Center, Lima, Peru. pp 193.

Sporleder, M., H.E.Z. Tonnang, P. Carhuapoma, J. C. Gonzales, H. Juarez & J. Kroschel (2013): Insect Life Cycle Modeling (ILCYM) software – a new tool for Regional and Global Insect Pest Risk Assessments under Current and Future Climate Change Scenarios. **CABI Book publication**, 412-427.

ILCYM users

Number of ILCYM potential users that have visited the software webpage in the last 5 months

Applications of ILCYM: Pest Risk Analysis (PRA)

"The process of evaluating biological or other scientific and economic evidence to determine whether an organism is a pest, whether it should be regulated, and the strength of any phytosanitary measures to be taken against it"

Stage I: Initiation	Stage II: PR-Assessment	Stage III: PR-Management	Stage IV: Documentation
Pest identification Pathway Policy review PRA area Pest taxonomy etc.	Pest categorization Probability X Magnitude of econ./environ. Impact	React Test & evaluate efficacy of measures	Rational for phytosanitary requirements (by NPPO)

Pest Risk Mapping and new framework to assess climate change impacts!

Surveillance
Diagnostics

National and regional adaptation planning!

*(adopted from FAO-IPPC, 2007)

Pest Risk Mapping

Validation of risk maps by using geo-referenced distribution maps

Example: potato tuber moth

Green points: countries with reported pest establishment

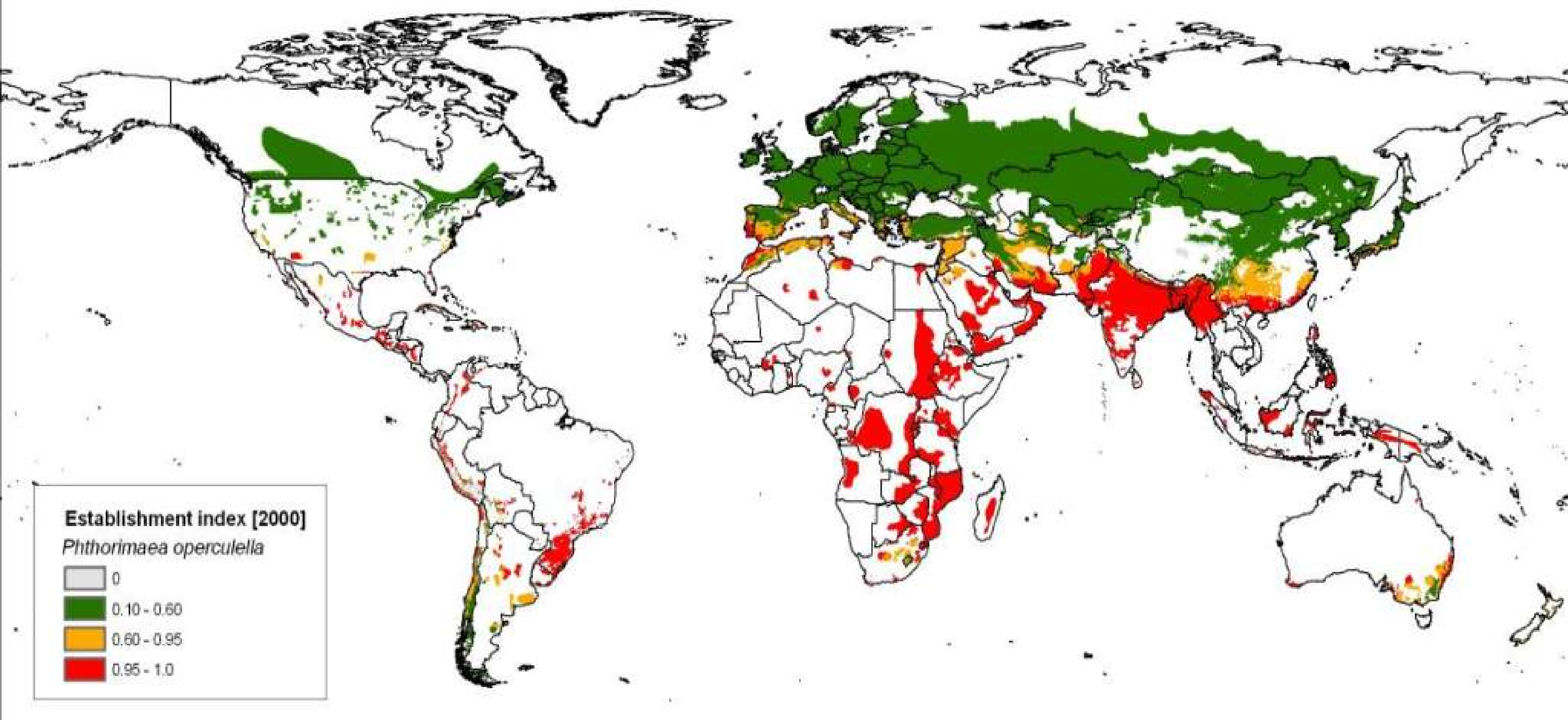
Red points: geo-referenced distribution data

Yellow points: permanent establishment not confirmed

Impact of climate change on *Phthorimaea operculella*

Establishment Risk Index: years 2000 and 2050

A range expansion into temperate regions of the northern hemisphere and in tropical mountainous regions



(Kroschel et al., J. Agric. Forest Meterol., 2013)

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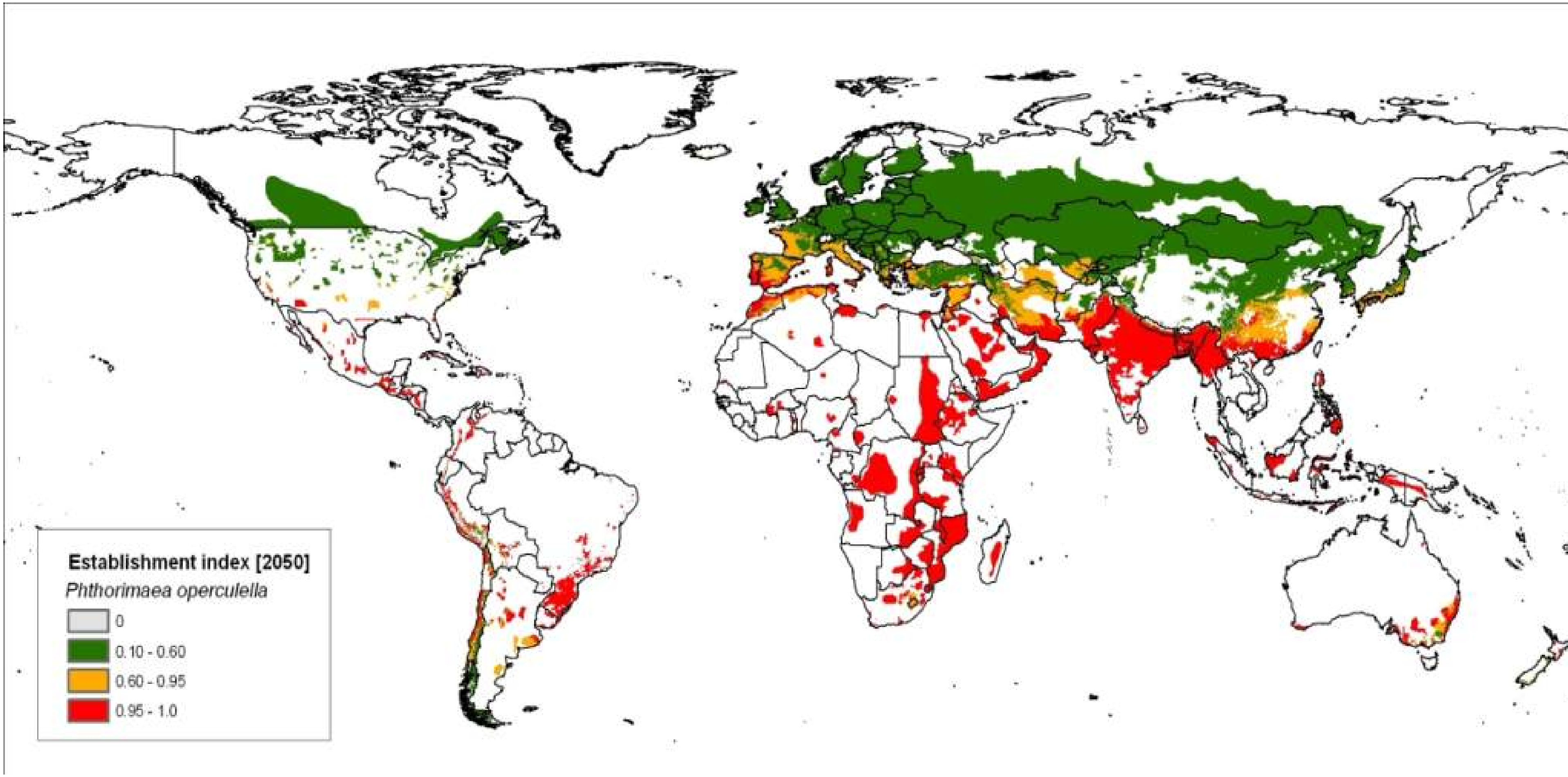

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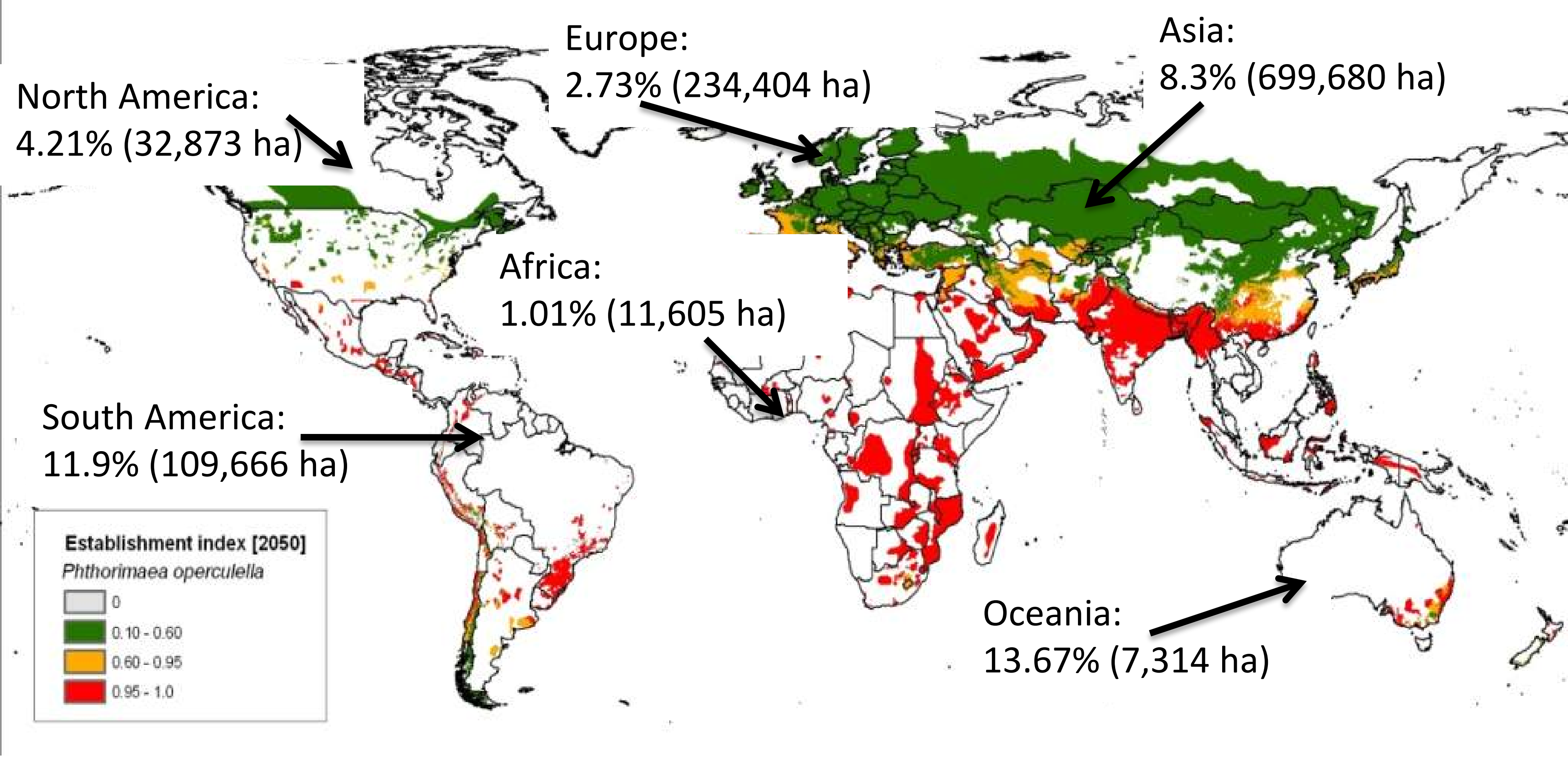
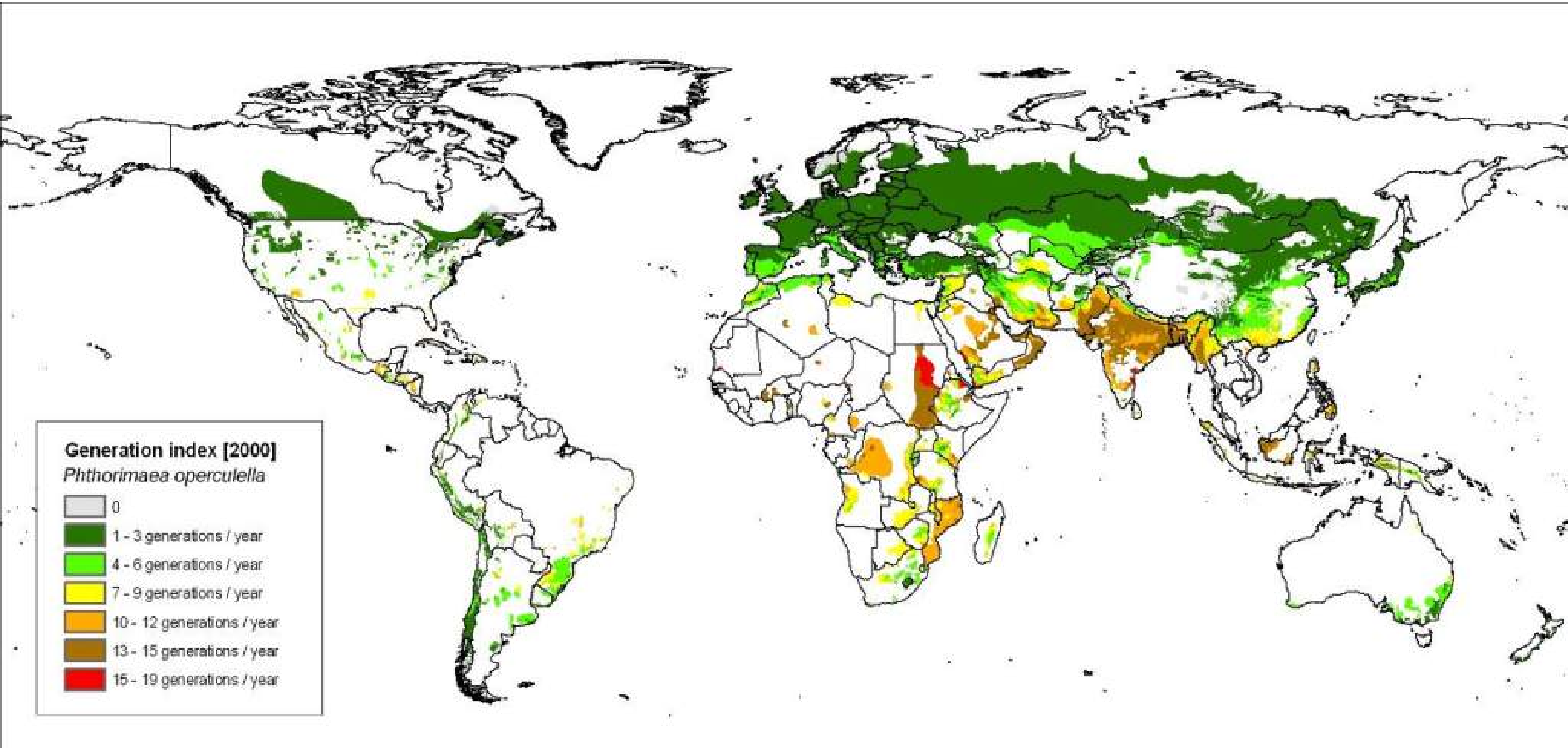


(Kroschel et al., J. Agric. Forest Meterol., 2013)

Impact of climate change on *Phthorimaea operculella*

Generation Index: year 2000

Abundance and damage potential will progressively increase in all regions where the pest already prevails today with an excessive increase in warmer cropping regions of the tropics and subtropics

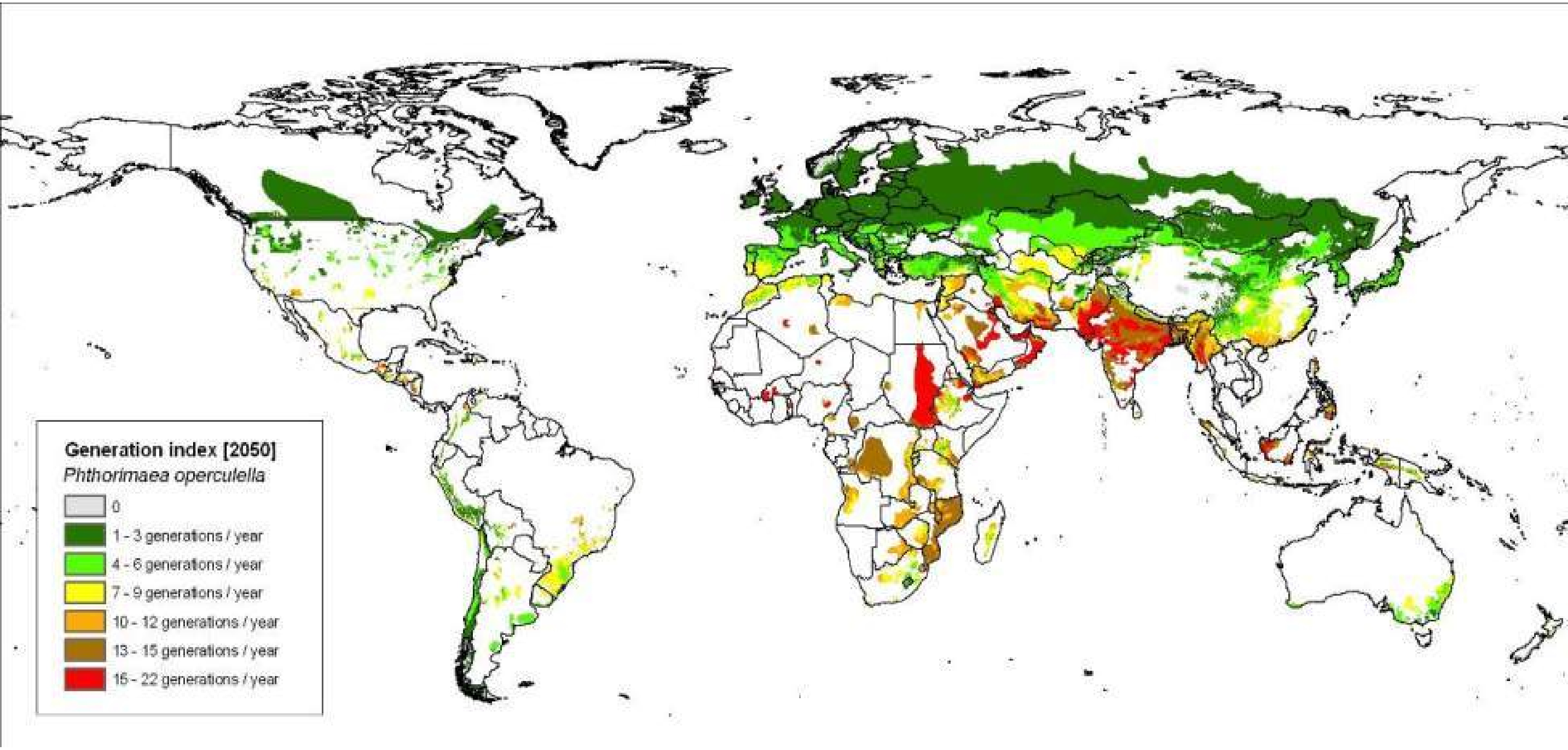


(Kroschel et al., J. Agric. Forest Meterol., 2013)

Impact of climate change on *Phthorimaea operculella*

Generation Index: year 2050

Abundance and damage potential will progressively increase in all regions where the pest already prevails today with an excessive increase in warmer cropping regions of the tropics and subtropics



(Kroschel et al., J. Agric. Forest Meterol., 2013)

ILCYM: Risk mapping under current and future climates

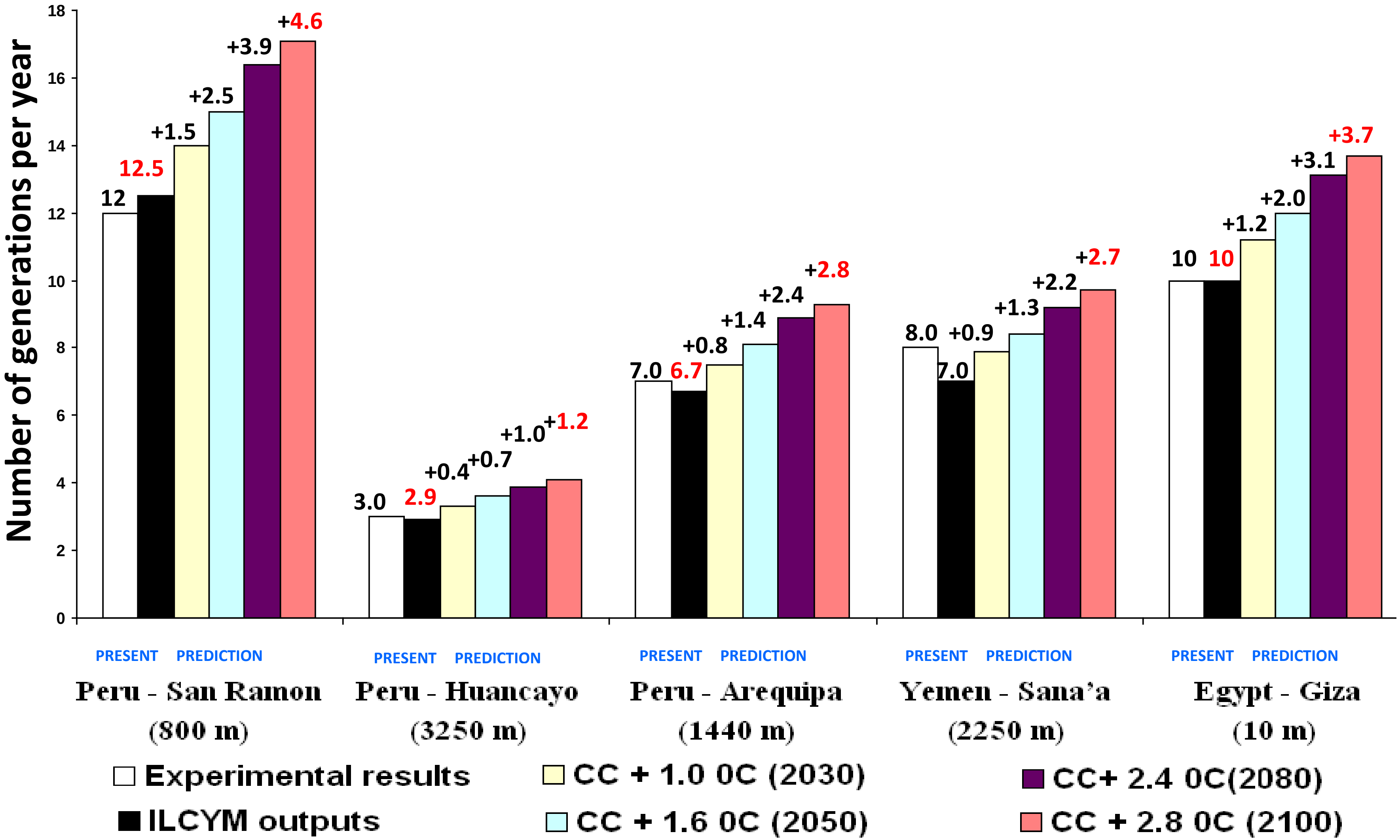
P. operculella **validation: observed and predicted numbers of generations at different locations using different climate input data**

Country/location	Life table studies under local natural conditions	ILCYM modeling results using local weather station data	ILCYM modeling results using WorldClim data Monthly records
Peru: San Ramon, 800 m a.s.l.	12	12	9.5
Peru: Arequipa, 1140 m a.s.l.	7[1]	6.7	7.2
Peru: Huancayo, 3250 m a.s.l.	3-4	3.1	2.3
Yemen: Sana’a, 2150 m a.s.l.	8[2]	7.1	5.4
Egypt: Giza, 10 m a.s.l.	10[3]	10	8.6

(Kroschel et al., J. Agric. Forest Meterol., 2013)

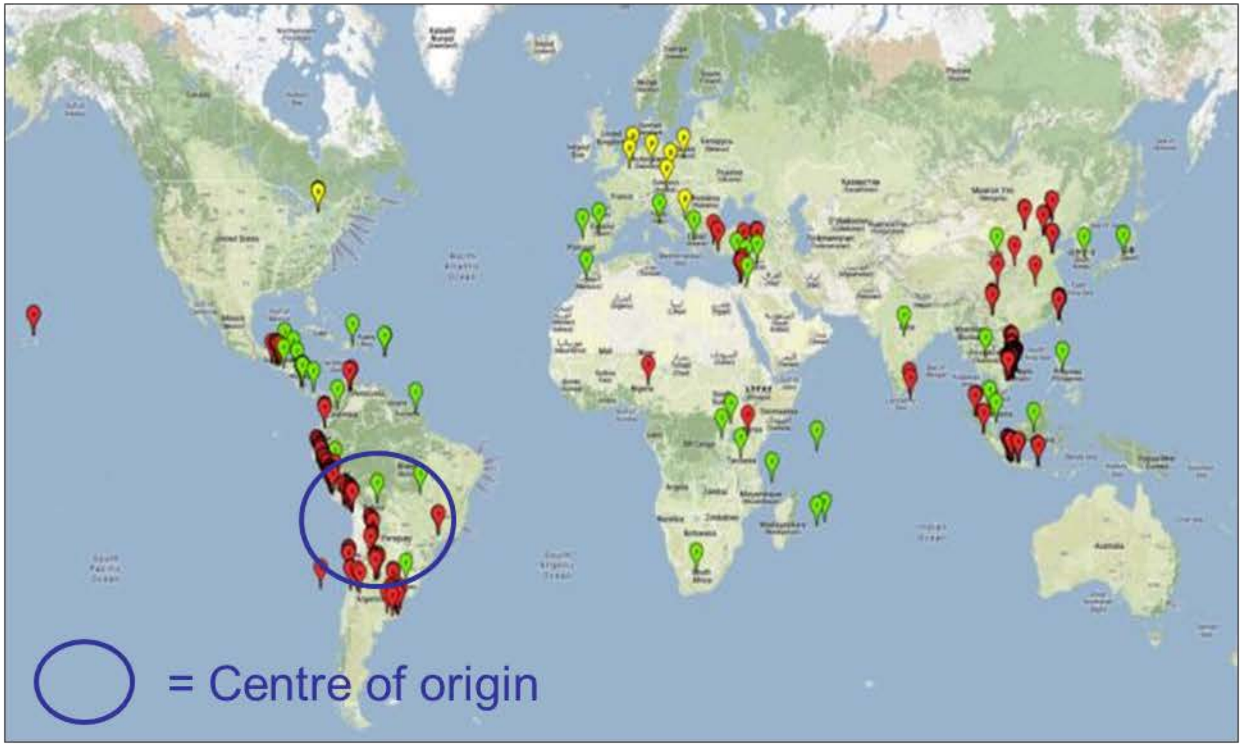
ILCYM: Risk mapping under current and future climates

Effect of climate change on the number of generations at different locations



Leafminer fly, *Liriomyza huidobrensis*

- Center of origin in the neotropics; reported from more than 66 countries
- Very polyphagous; in Peru pest in >27 horticultural crops
- Yield loss without management up to 70% in potato

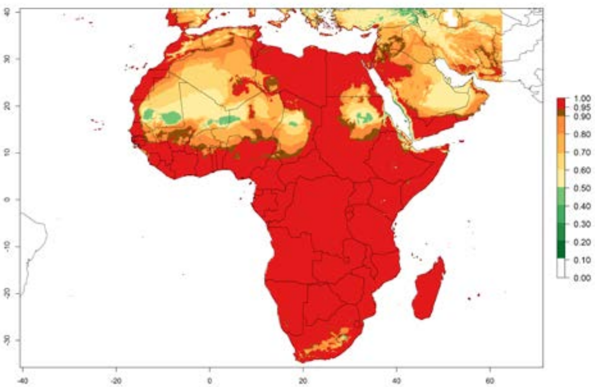


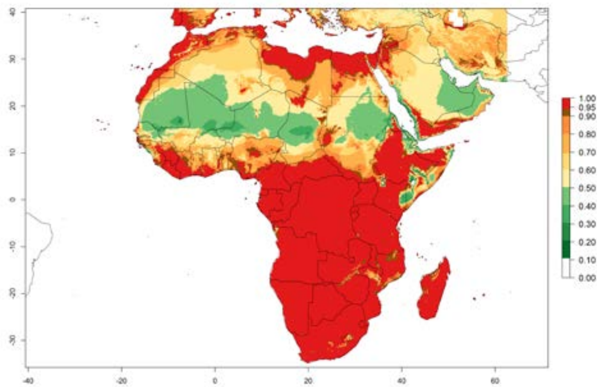
Green points: countries with reported pest establishment
Yellow points: reported in protected crops
Red points: geo-referenced distribution data

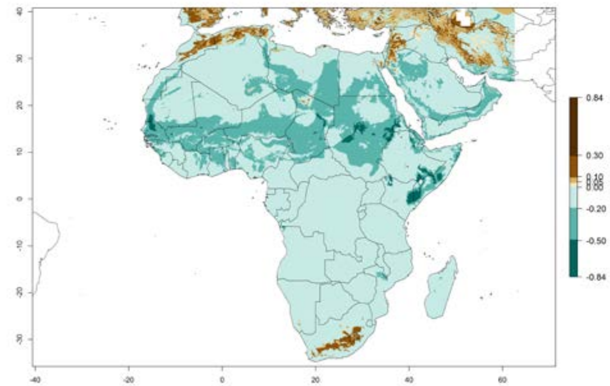
ILCYM: Risk mapping under current and future climates

Liriomyza huidobrensis: Regional maps

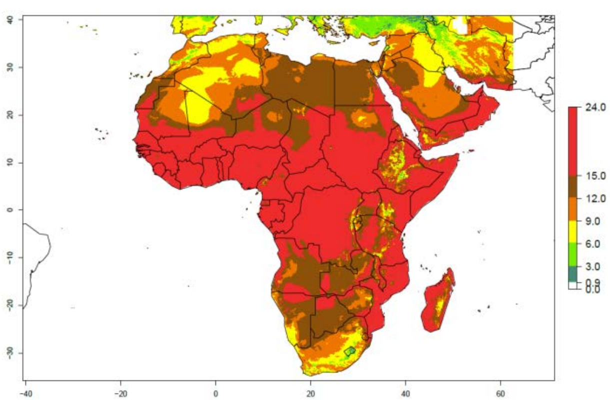
ERI | **2000** | **2050** | **Index change: 2000-2050**

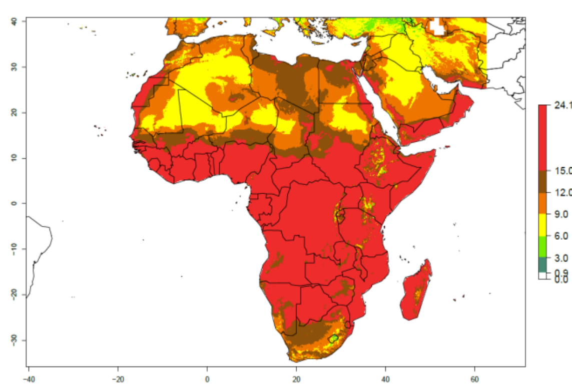


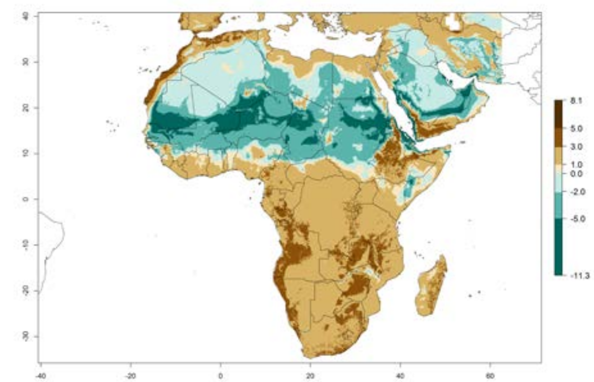




GI







(Mujica et al. 2016. In Pest Risk Atlas for Africa)

ILCYM: Risk mapping under current and future climates

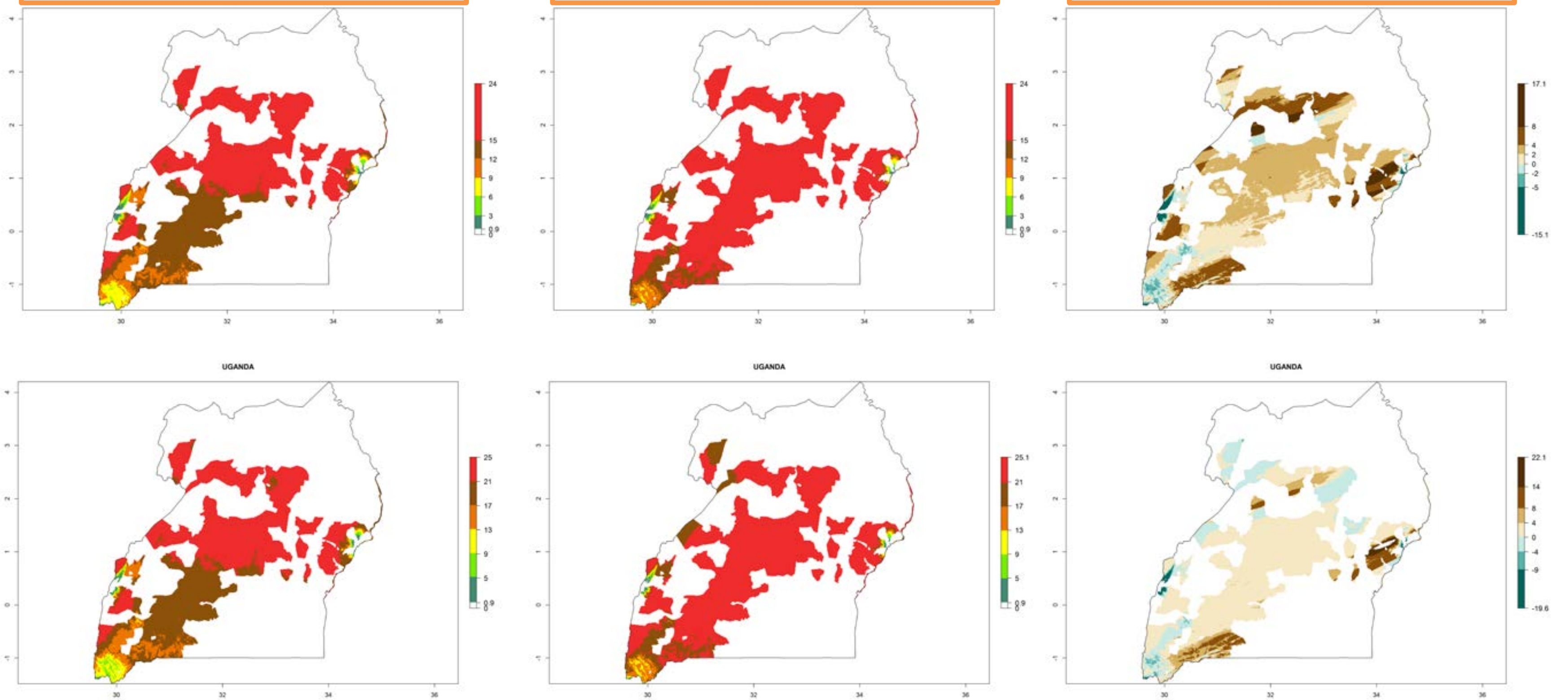
Liriomyza huidobrensis: country maps for Uganda

L. huidobrensis **will potentially increase its risks in the northern, eastern and southern provinces due the high values of GI>12 and AI>17**

2000 | 2050 | Change

Generation index

Activity index



(Mujica et al. 2016. In Pest Risk Atlas for Africa)

Climate change / adaptation planning

Reducing crop vulnerability by adaptation to new and emerging pests

Mitigation

Reduction of CO_2 emissions

Crop yields

Exposure

Temperature increase: 2 °C

Crop pests

Sensitivity

+

Adaptation (of IPM)

Pot. impacts on crop yields based on pest expansion/increased abundance: Higher infestations reduce yields by 20%

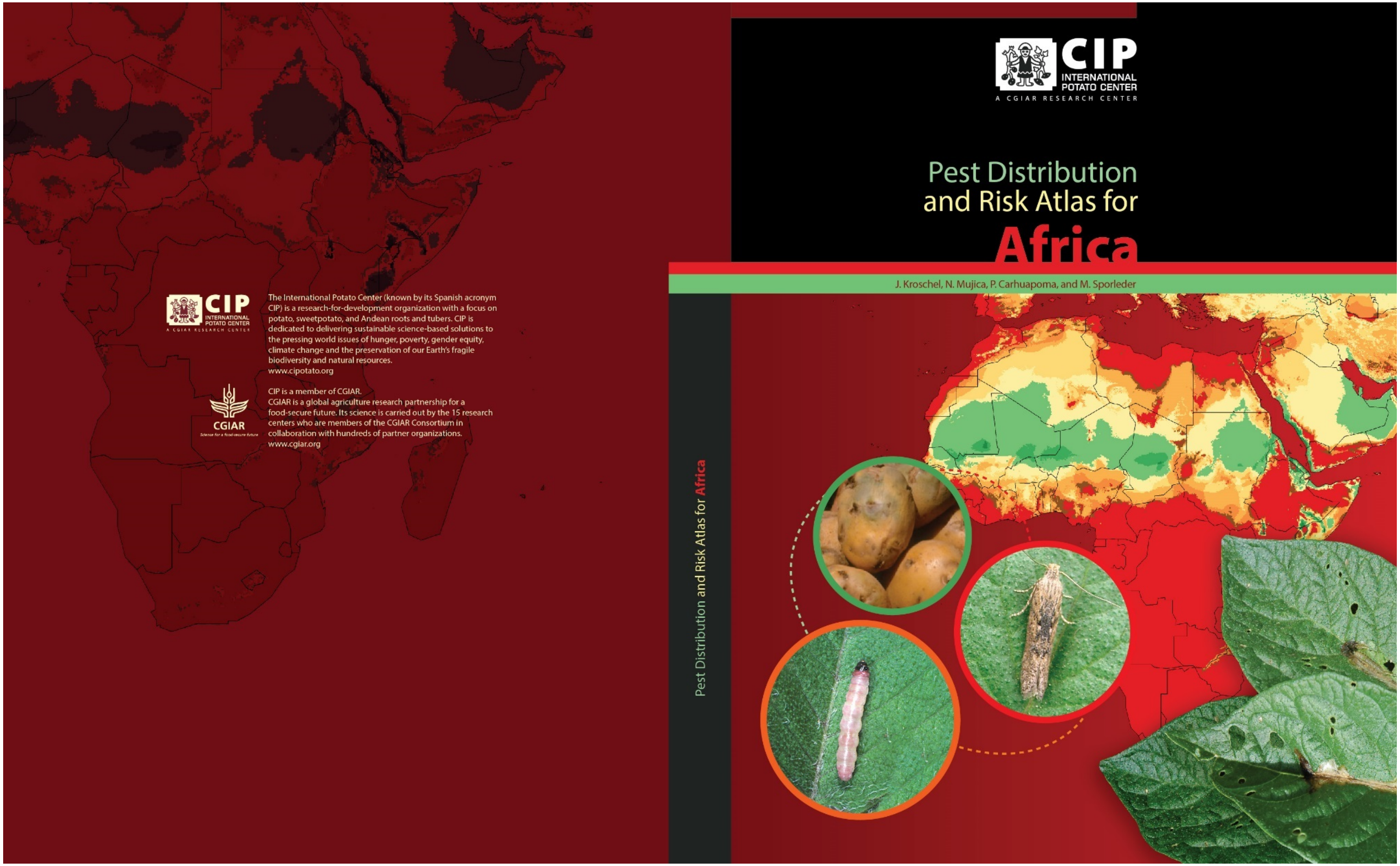
Resilient systems, new technologies, tolerant and resistant varieties reduce pest caused losses by 15%

Vulnerability

Actual impact on crop yields by pests increase by 5%

(Adapted from IPCC, 2001, 2007)

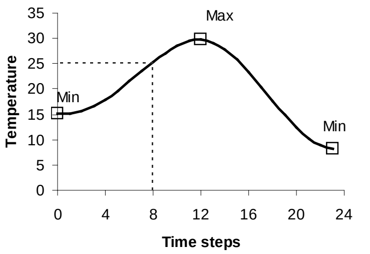
Pest Risk Atlas for Africa



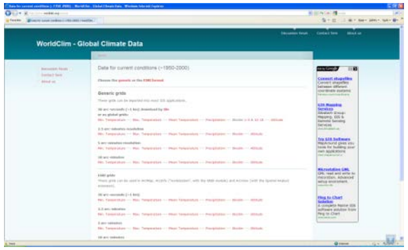
Kroschel, J.; Mujica, N.; Carhuapoma, P.; Sporleder, M. (eds.). 2016. Pest Distribution and Risk Atlas for Africa. Potential global and regional distribution and abundance of agricultural and horticultural pests and associated biocontrol agents under current and future climates. Lima (Peru). International Potato Center (CIP). ISBN 978-92-9060-476-1. 416 p.

ILCYM: regional assessments (1)

Climate data and map resolution

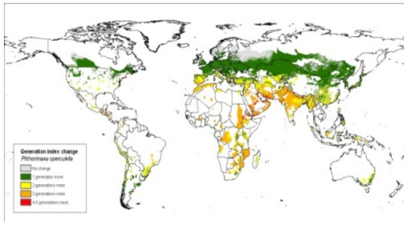


For estimating pest risk for specific locations, max. and min. temperature data in a 1 hr time step length are used to consider the within-day temperature variability that may affect insects.



For global and regional pest risk mapping, currently available temperature surfaces use monthly average aggregated climate data from 1960 to 2000 (www.worldclim.org).

Aggregation and interpolation of temperature data has its limitations especially in mountainous regions due to local temperature variability (topographic effects) over short distances.



Higher accuracy of risk maps and predictions of potential pest distribution could be achieved through locally collected daily weather data processed and interpolated in ILCYM.

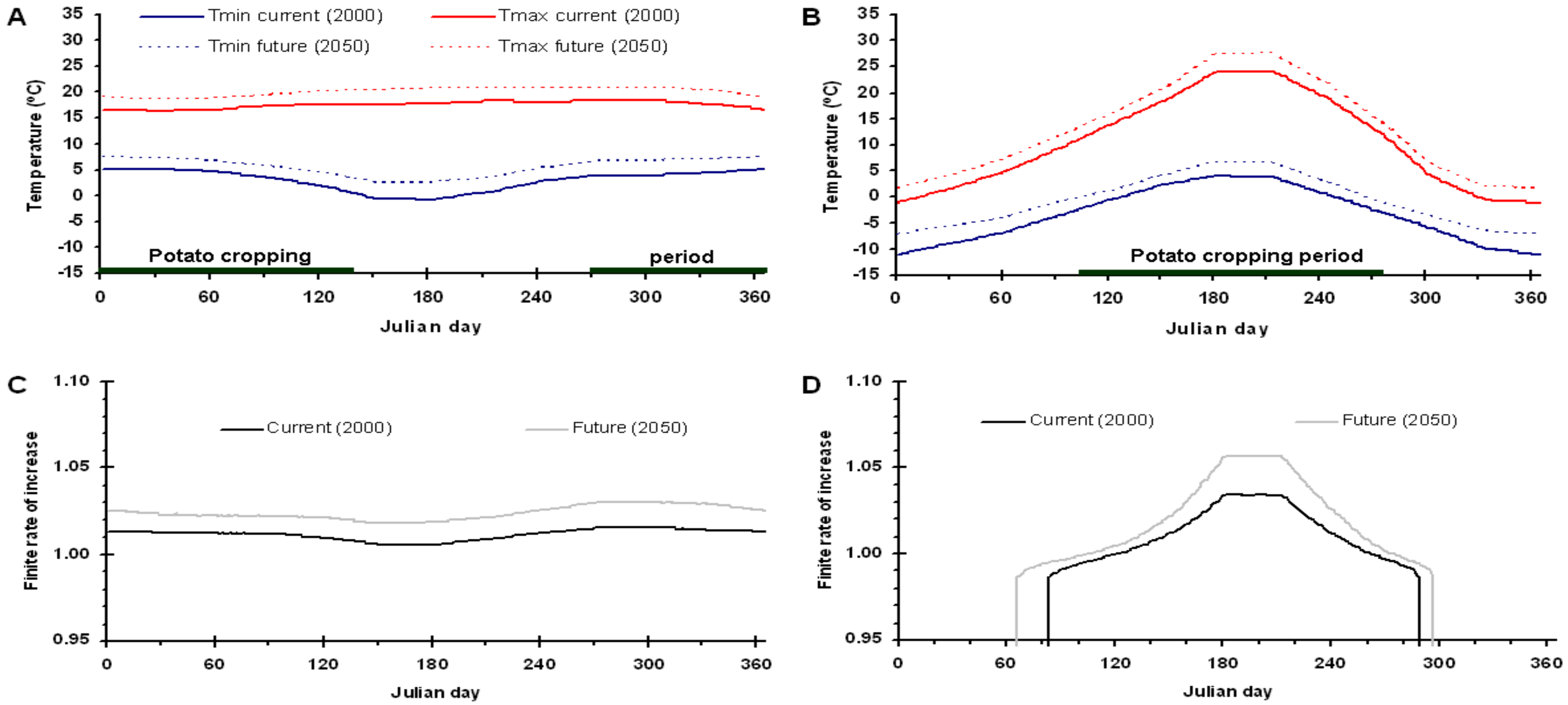
→ ILCYM's Index Interpolator – New tool for regional assessments of pest risks in mountainous regions at high resolution. (see poster)

ILCYM: regional assessments (2)

Potato tuber moth: Simulation of the rate of population increase within one year at two different locations

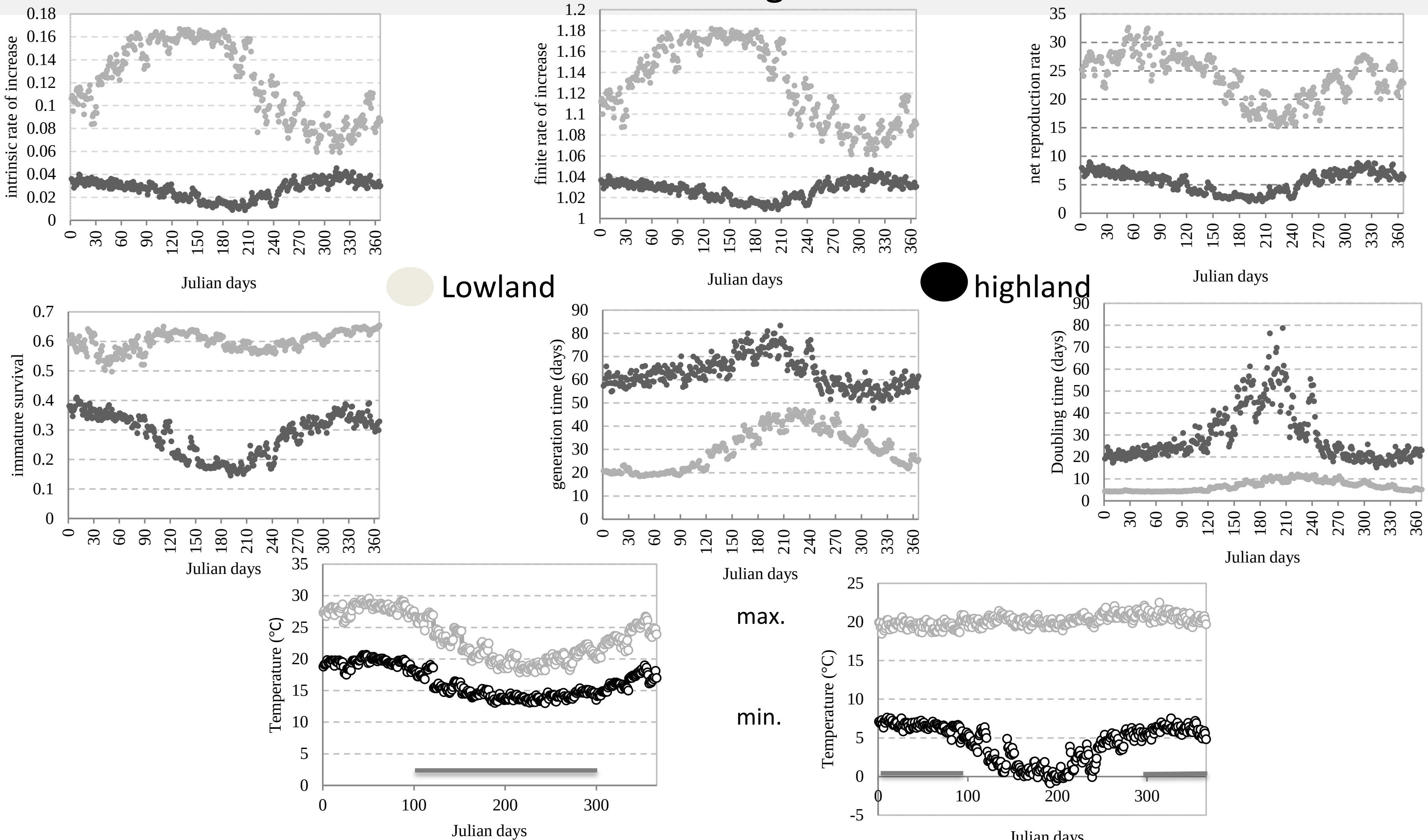
Huancayo, Peru (3250 masl)

Hermiston, Oregon, USA (144 masl)



ILCYM: regional assessments (3)

Simulation of life-table parameters of the leafminer fly, *Liriomyza huidobrensis,* under Peruvian lowland and highland conditions



Lowland agroecology (350 masl) Highland agroecology (3250 masl)

Next steps

ILCYM version 4 with a new interface fully in R-language (shiny-applications) to reduce required skills to maintain ILCYM software and to increase user-friendliness and flexibility to use the software.

The International Potato Center (known by its Spanish acronym CIP) is a research-for-development organization with a focus on potato, sweetpotato, and Andean roots and tubers. CIP is dedicated to delivering sustainable science-based solutions to the pressing world issues of hunger, poverty, gender equity, climate change and the preservation of our Earth's fragile biodiversity and natural resources.

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