The effects of past and future climate change on desert locust population dynamics

Fanny Herbillon

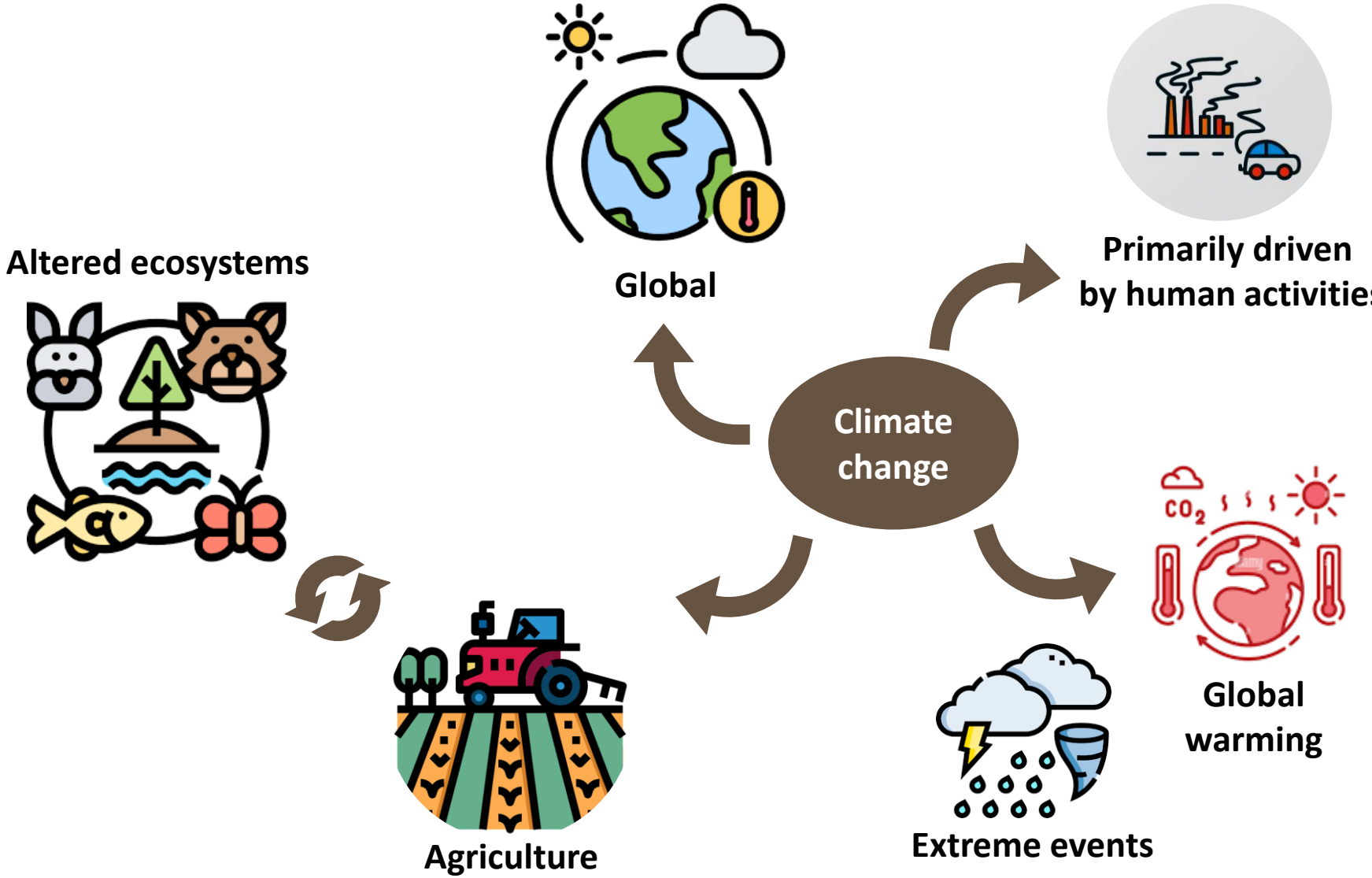
PhD defense to obtain the Degree of Doctor

January 21, 2025

Doctoral Examination Commitee

Arianne J. CEASE, Arizona State University	Rapporteur
Uta BERGER, Dresden University of Technology	Rapporteur
Olivier GIMENEZ, CNRS, CEFE	Examiner
Karine BERTHIER, INRAE	Examiner
Christine MEYNARD, INRAE, UMR CBGP	Supervisor
Cyril PIOU, FAO	Supervisor
Mohamed L. HAMOUNY, CLCPRO – FAO	Guest

Climate change



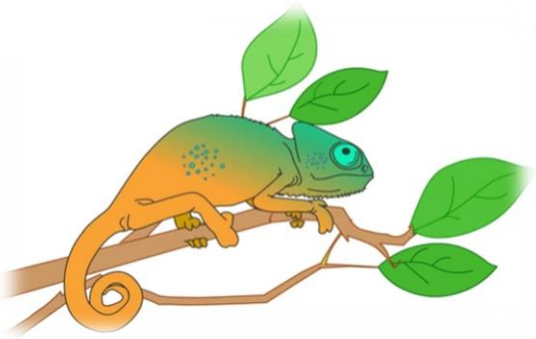
Climate change & biodiversity

Altered ecosystems

Response

Resilience
To cope with immediate stressors

Adaptation
Long-term evolutionary responses



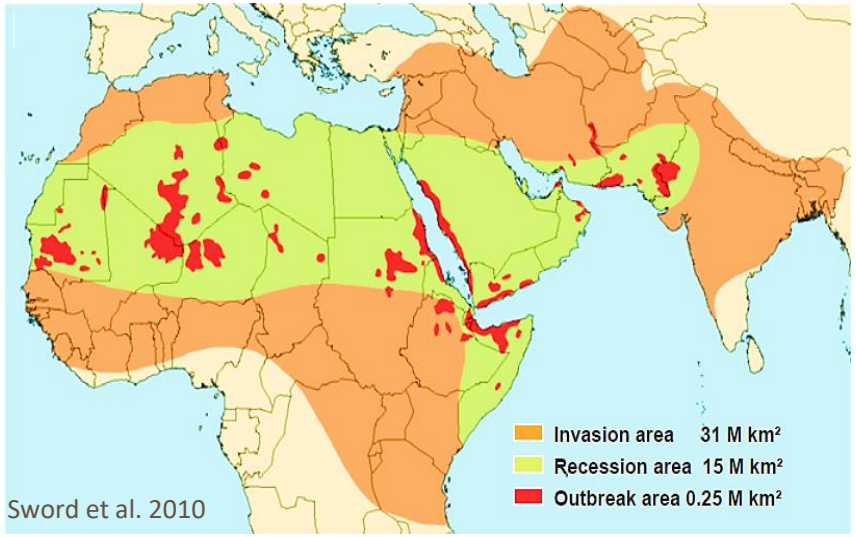
Native/endangered species ≠ **Invasive/agricultural pest species**

Relative advantage

The problematic of desert locust

Schistocerca gregaria

1km² swarm ≈ 80 million adults



Sword et al. 2010

2003–2005 crisis in West Africa:

20 countries treated (~130,000 km²)

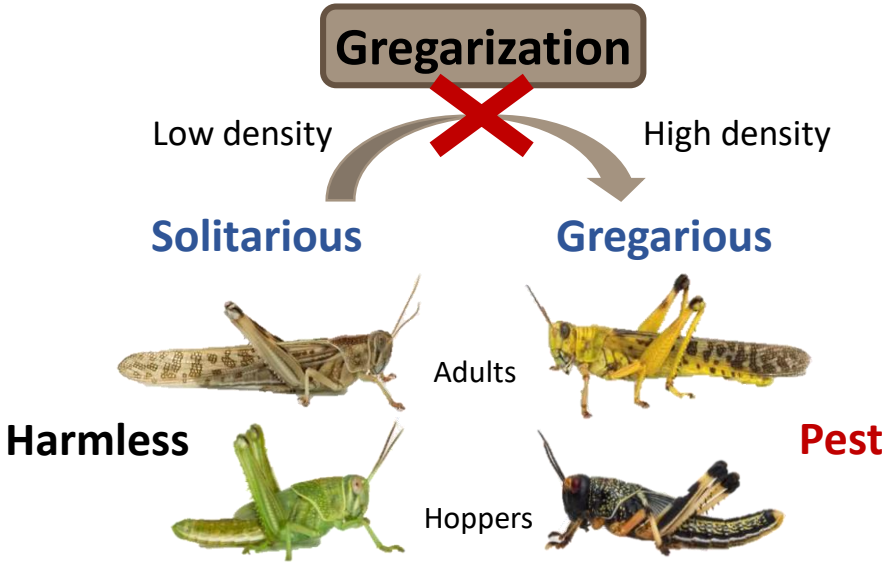
The costs of fighting > US$400 million

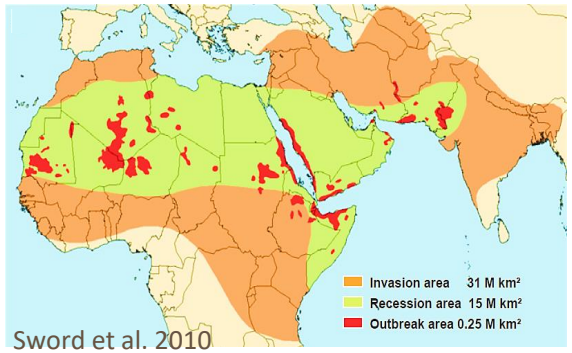
Harvest losses valued up to US$2.5 billion

(FAO, Associated Press)

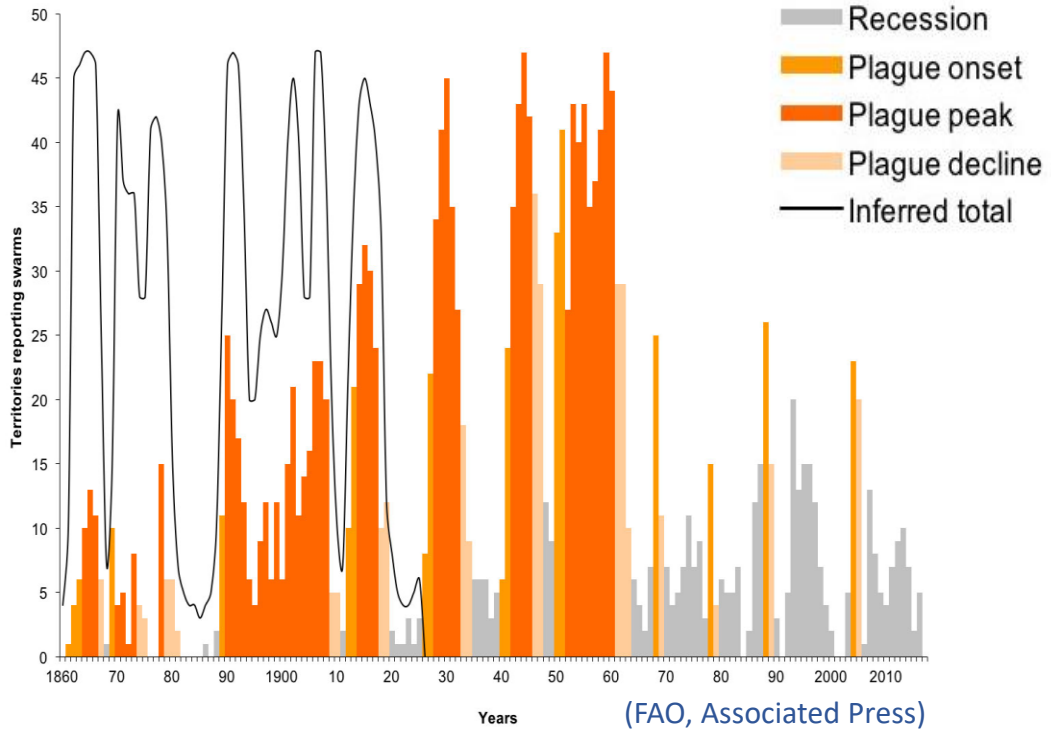
Gregarization & Preventive management

Locusts = grasshopper (Acrididae, Orthoptera) able to form hopper bands and swarms and exhibit **phase polyphenism**.





Sword et al. 2010

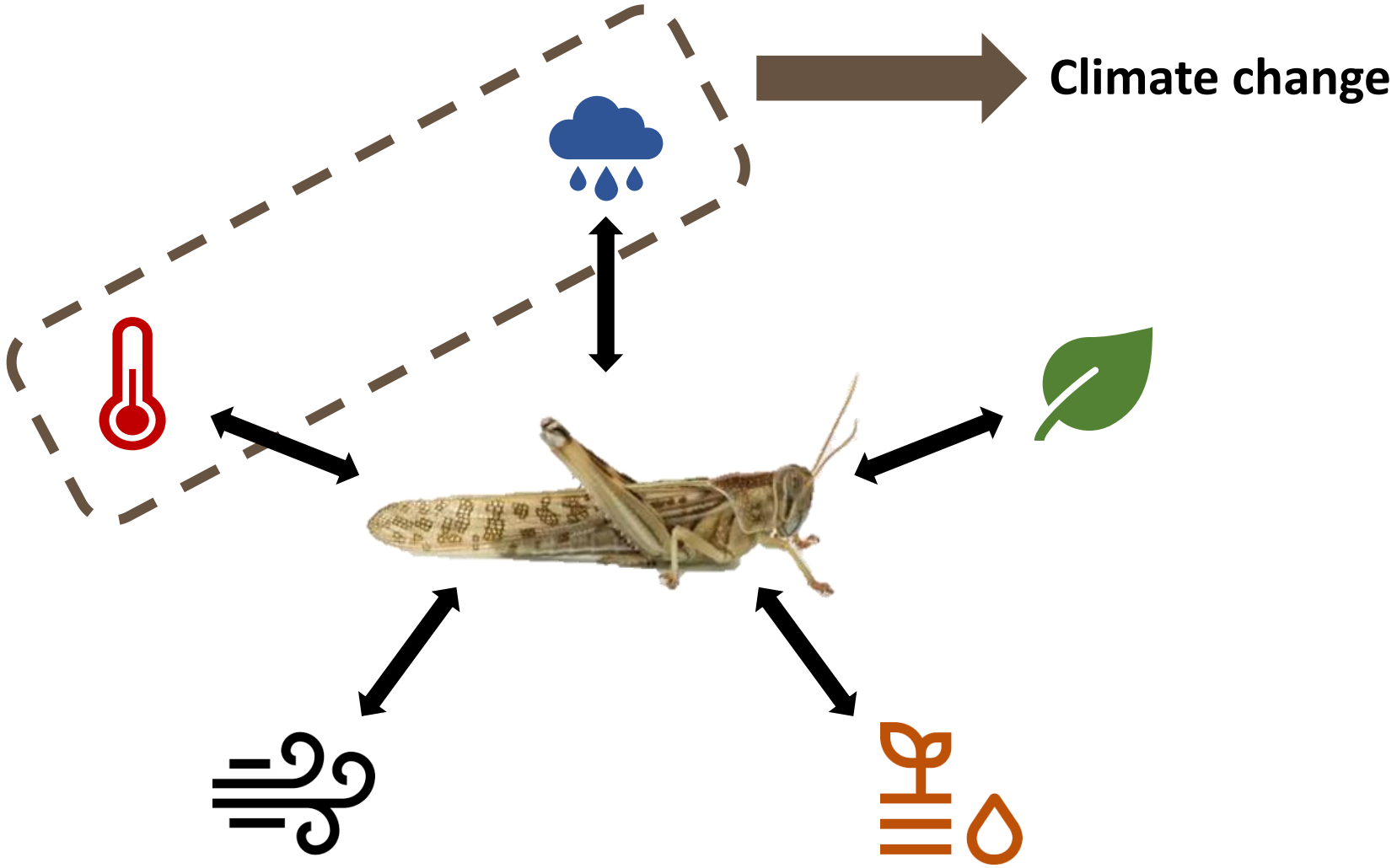


(FAO, Associated Press)

To help manage the desert locust :

Is there a risk of outbreaks ?
Where ?
When ?
Evolution in the future
(short-term & long-term)

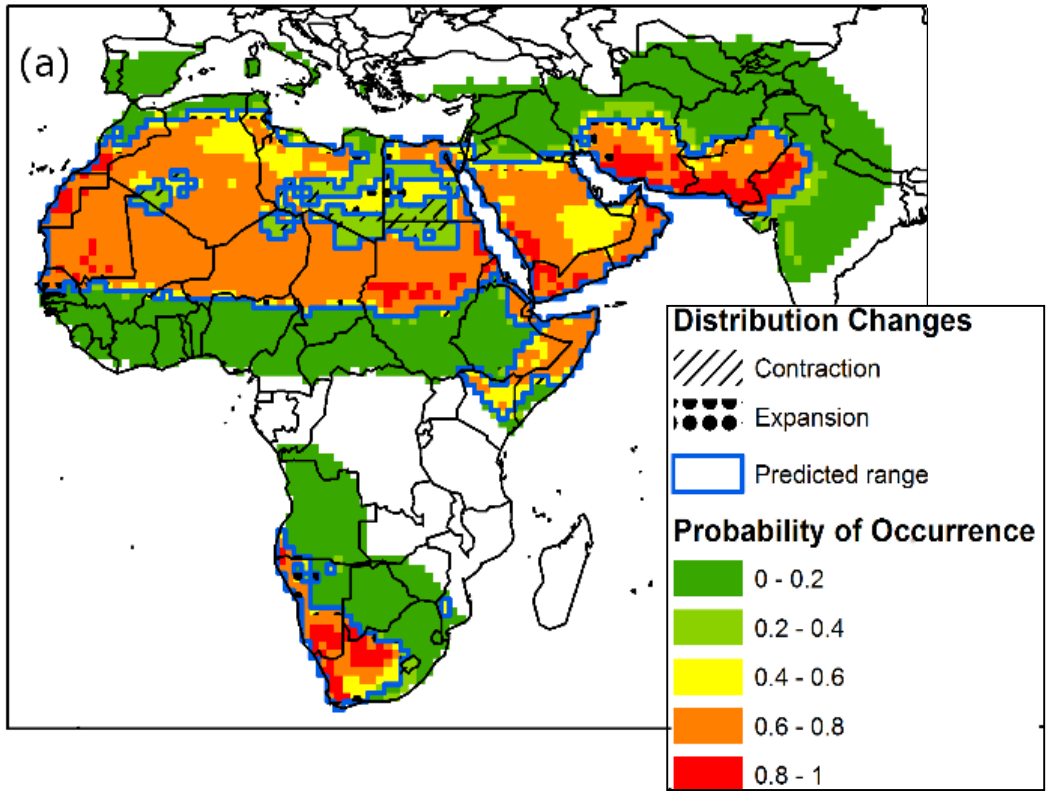
Desert locust & Climate change



Past studies - Correlative

Meynard et al. 2017

Climate change effects on species distribution ranges



Saha, Rahman, et Alam 2021
Guan et al. 2021

} **Reduction of solitarious survival areas**

Correlative studies

→ No mechanism / no dynamics

Focus on solitarious only or no distinction

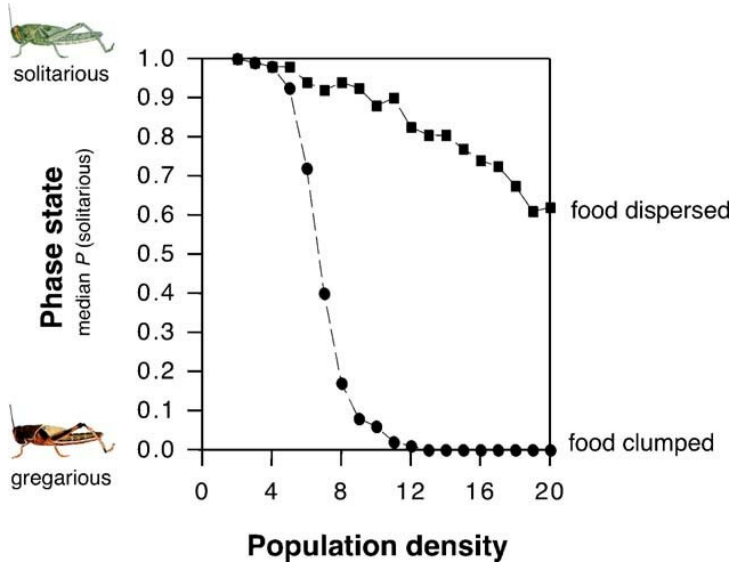
→ Gregarization phenomena ?

→ Past effects ?

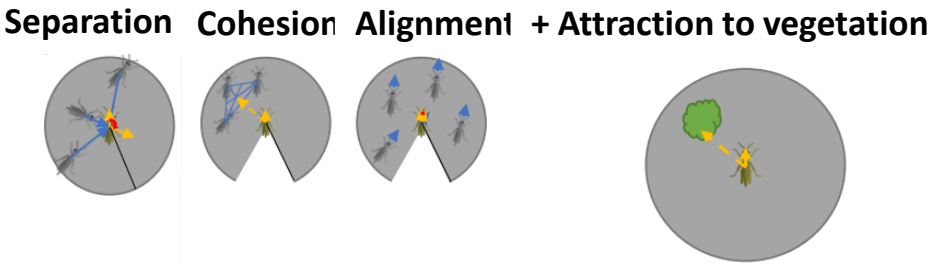
→ Effect of management ? (Tratalos et al, 2010)

Past studies - Mechanistic

Resource distribution on gregarization
Collett et al. 1998



Hopper movement - Vegetation
Dkhili et al. 2017

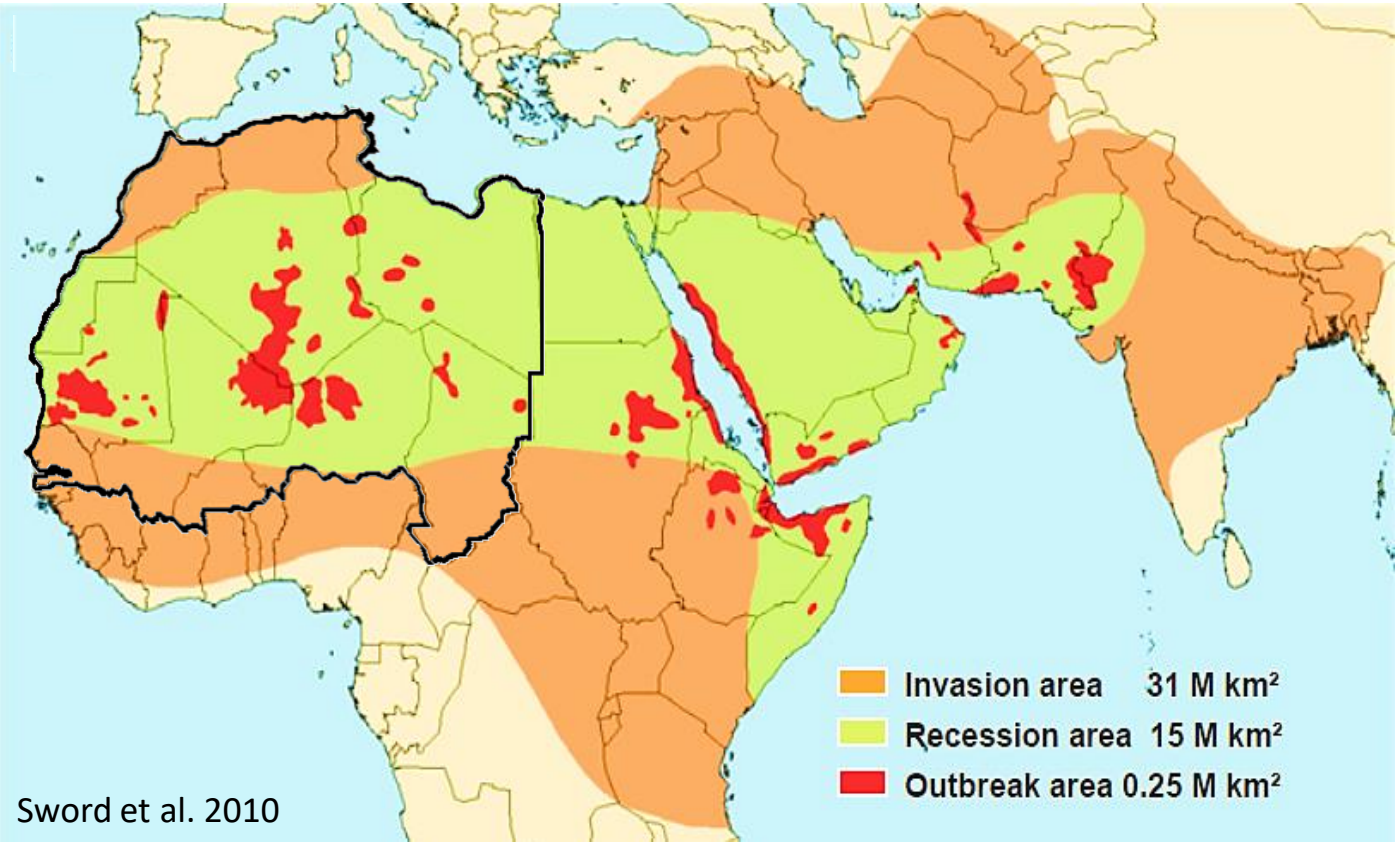


Collective movement - Polyphenism
Vernier et al. 2023

→ **Theory confirmation vs Prediction**

→ **No large scale**

Study area



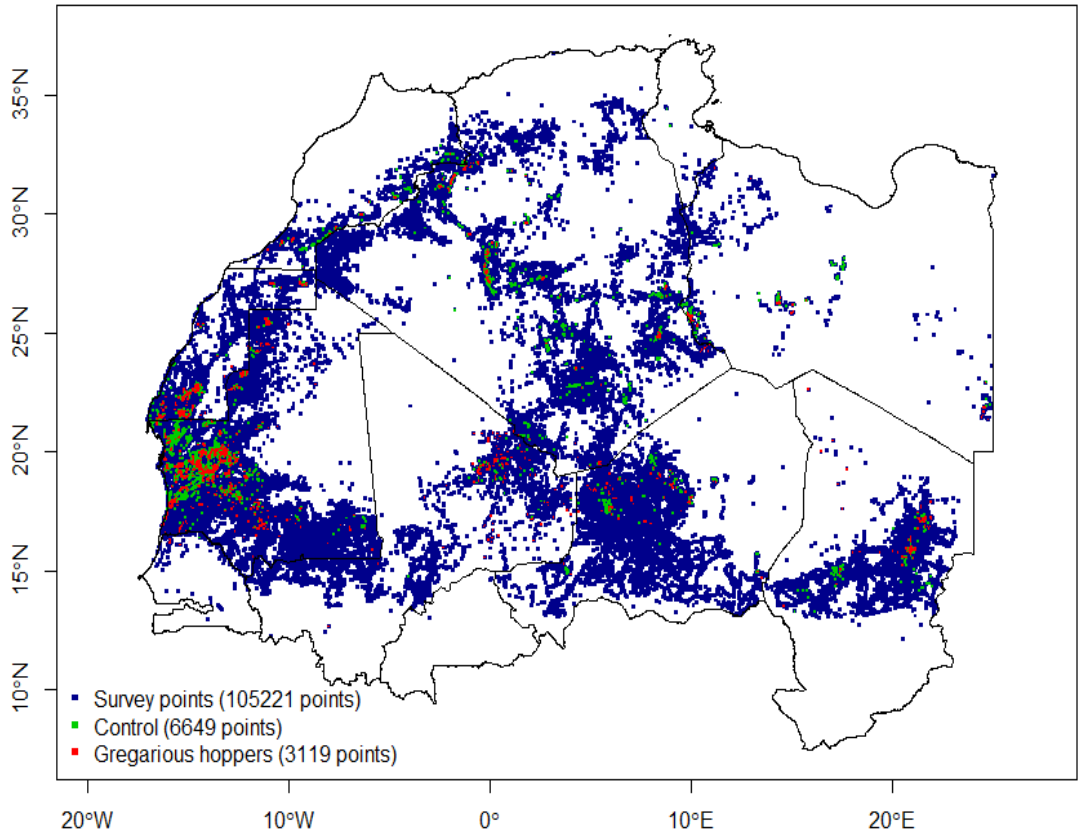
Sword et al. 2010

CLCPRO region ~ 10,5 million km²

CLCPRO = Commission for the Control of the Desert Locust in the Western Region

Data available

1985 - 2018



Context

Date, coordinates

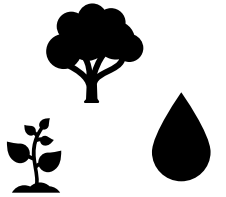
Management actions

Date, pesticide, volume

Population structure

Density, stage, appearance

Environment



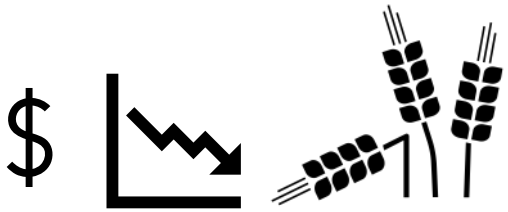
Vegetation, humidity

Summary

Pest – Relative advantage w/ CC

Multiples studies
≠ temporal/spatial scale

Buts GAPS → CC x Management
Mechanism



Large economic impacts

Gregarization

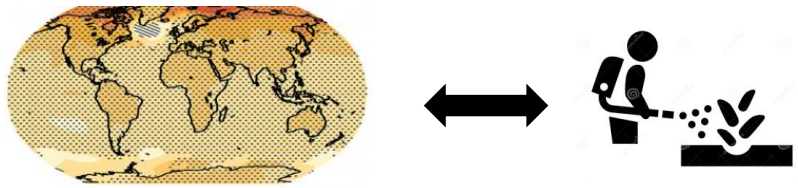
Data
Long term – Large scale

Preventive management

Solitarious
Gregarious
} ≠ dynamics

Objectives of the thesis

PAST



Can variations in gregarization be explained by the interaction of climate and management?

Statistical analysis of historical data

Chapter 1

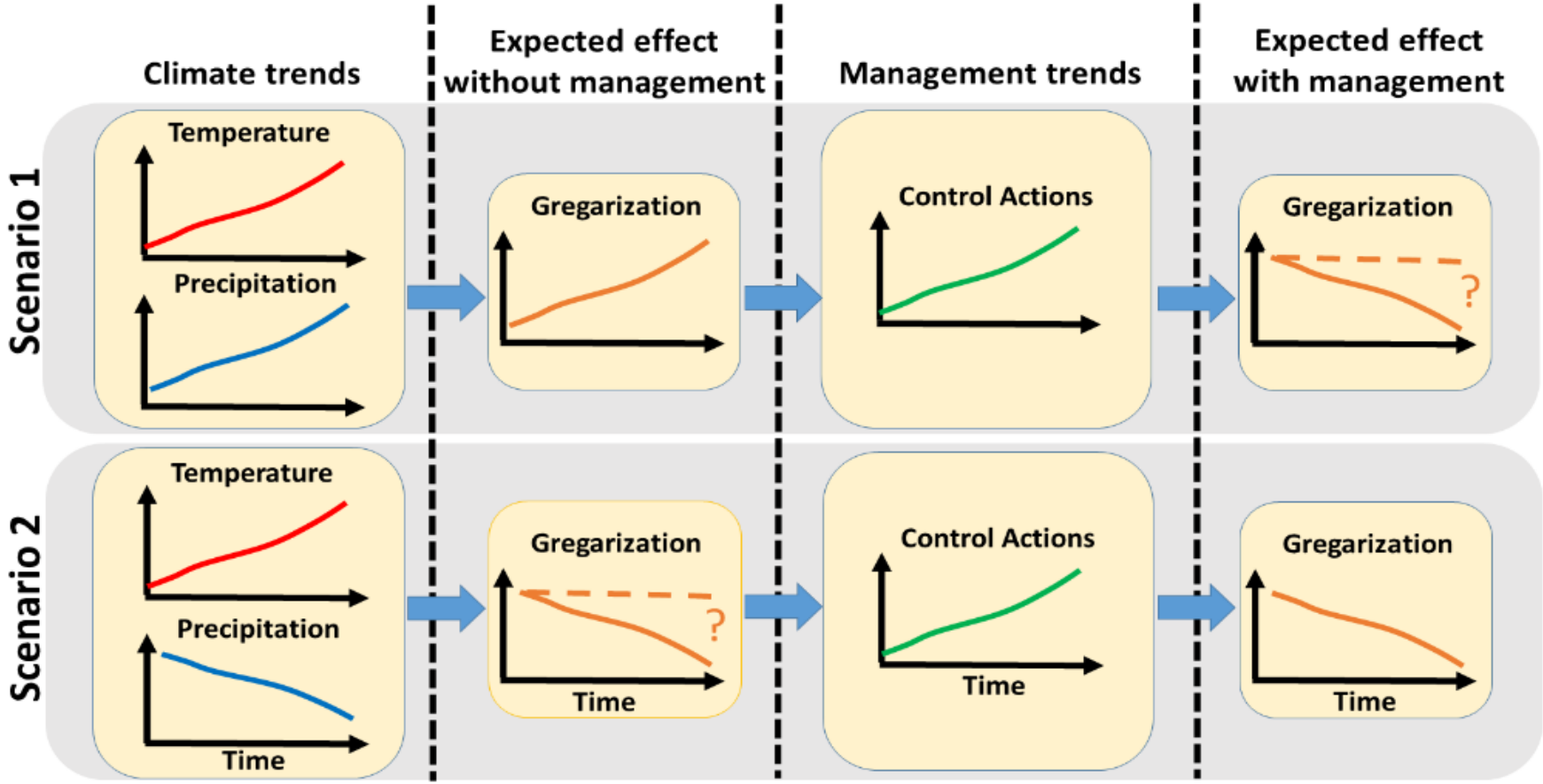
FUTURE

How might desert locust populations respond to future climate changes?

Development of a **mechanistic** model → Simulation of climate change scenarios

Chapter 2 & Chapter 3

Expectations



Climate x Management ?

Material & Methods

Multi-scale analysis

Trend determination with **GLM**

3 types of response variables :

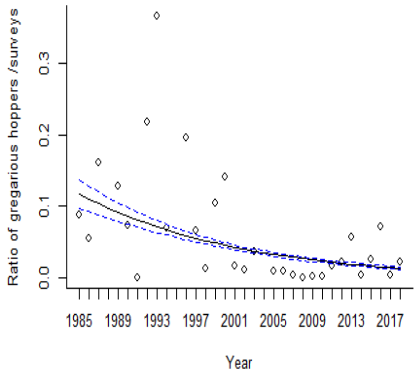
Gregarization $\frac{number\ of\ surveys\ with\ gregarious\ hoppers}{number\ of\ total\ surveys}$

Management $number\ of\ pesticide\ applications$

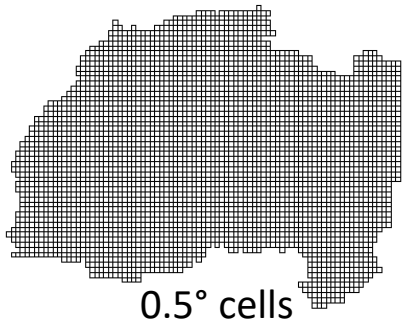
Climate $monthly\ precipitations\ (mm)$, $monthly\ temperatures\ (°C)$

with **year** as main predictor

Region

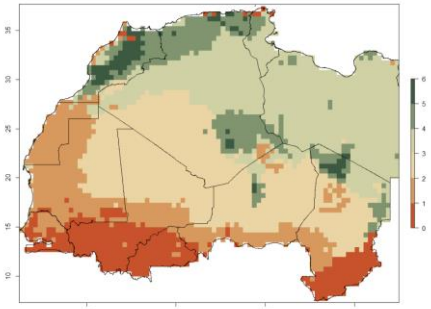


Grid

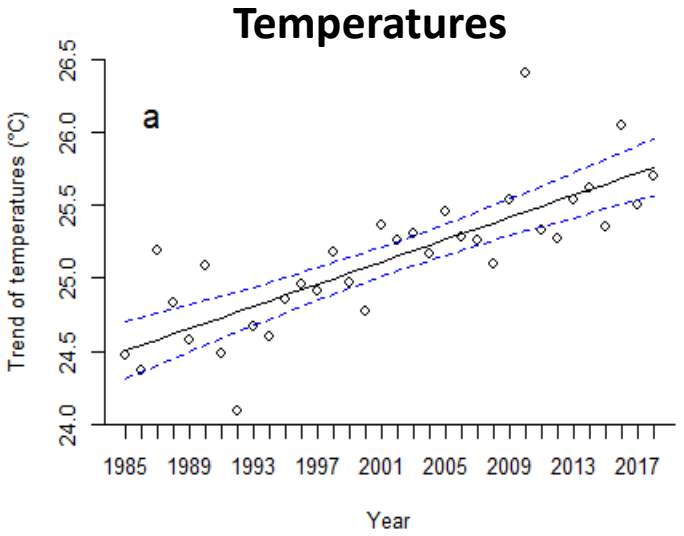


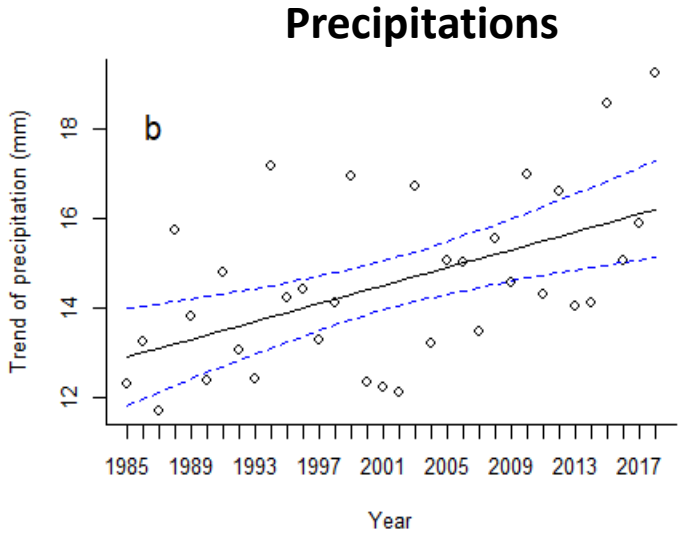
0.5° cells
(3532 total)

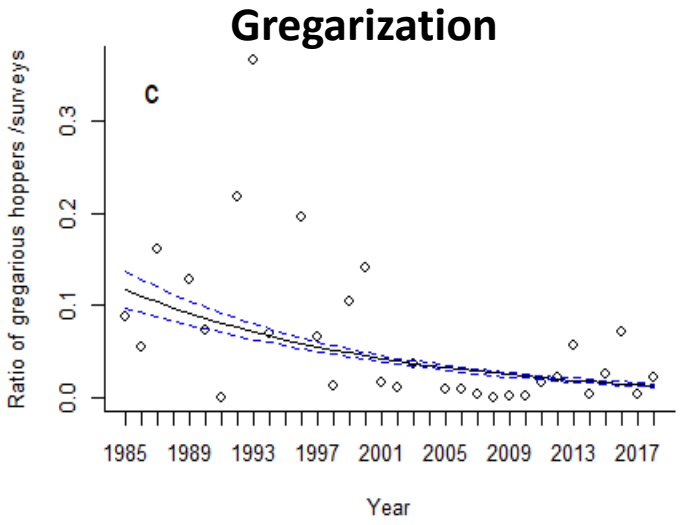
Climatic clusters

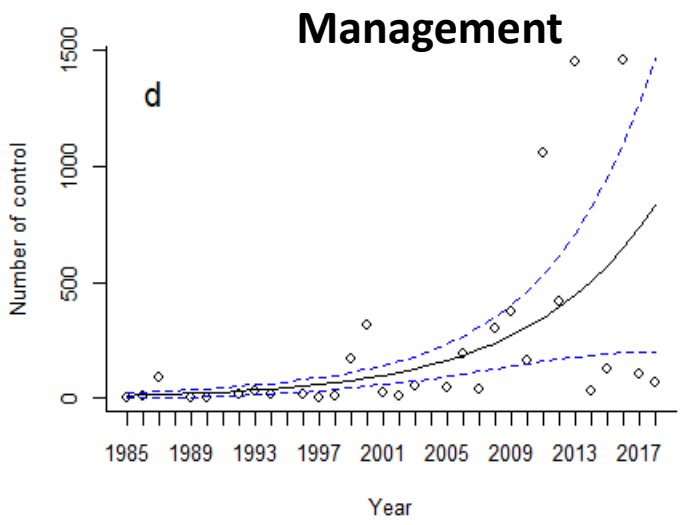


Results









Gregarization

Management

→ **No spatial information**

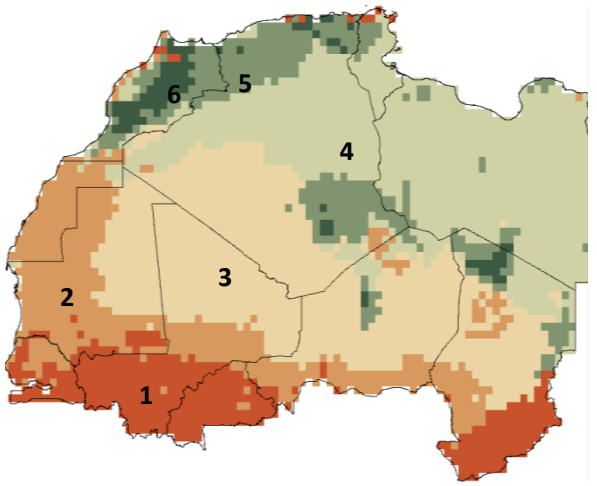
Causes of the decline of gregarization ?

Results

Gregarization trend		Precipitations		
		+	~	-
Temperatures	+	↗	~	↘

	Management		
	+	~	-
Gregarization trend	↘	~	↗

Climate x Management ?



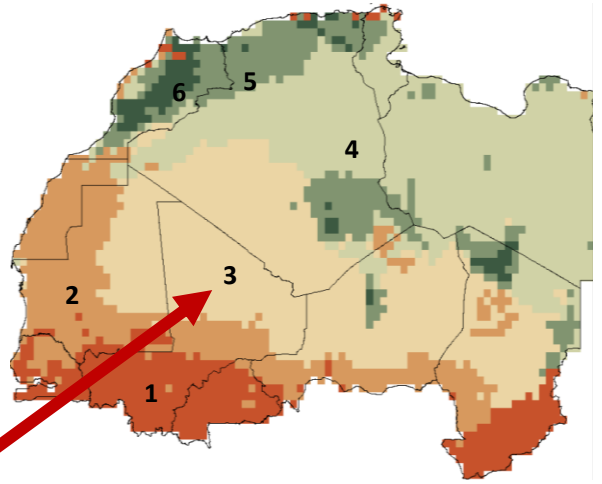
Cluster	Temperatures		Precipitations		Management	Gregarization
	Mean	Trend	Mean	Trend		
1	++	(***)	+++	(***)	~	-
2	++	(***)	+	(*)	++	+
3	++	(***)	~	~	+	-
4	+	(***)	~	~	++	+
5	+	(***)	+	(*)	+	~
6	+	(***)	++	~	NA	NA

Results

Gregarization trend		Precipitations		
		+	~	-
Temperatures	+	↗	~	↘

	Management		
	+	~	-
Gregarization trend	↘	~	↗

Climate x Management ?



Cluster	Temperatures		Precipitations		Management	Gregarization
	Mean	Trend	Mean	Trend		
1	++	(***)	+++	(***)	~	-
2	++	(***)	+	(*)	++	+
3	**++**	**(***)**	**~**	**~**	**+**	**-**
4	+	(***)	~	~	++	+
5	+	(***)	+	(*)	+	~
6	+	(***)	++	~	NA	NA

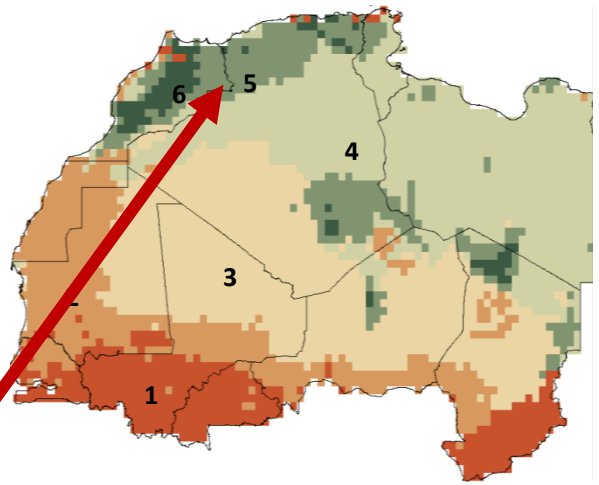
→ **Effective management**

Results

Gregarization trend	Precipitations +	Precipitations ~	Precipitations -
Temperatures +	↗	~	↘

	Management +	Management ~	Management -
Gregarization trend	↘	~	↗

Climate x Management ?



Cluster	Temperatures		Precipitations		Management	Gregarization
	Mean	Trend	Mean	Trend		
1	++	(***)	+++	(***)	~	-
2	++	(***)	+	(*)	++	+
3	++	(***)	~	~	+	-
4	+	(***)	~	~	++	+
5	**+**	**(***)**	**+**	**(*)**	**+**	**~**
6	+	(***)	++	~	NA	NA

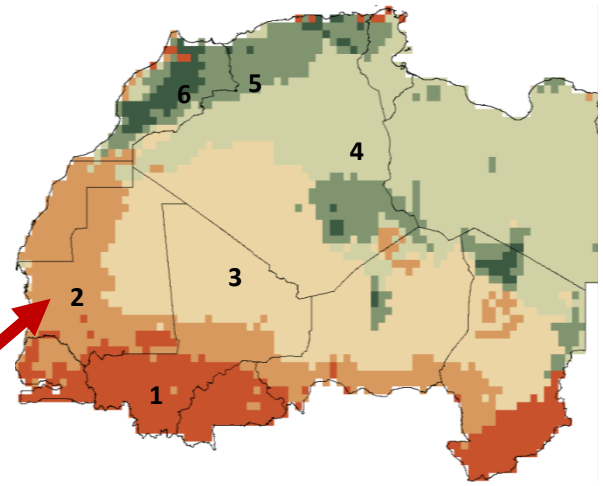
→ **Compensatory effect**

Results

Gregarization trend	Precipitations +	Precipitations ~	Precipitations -
Temperatures +	↗	~	↘

	Management +	Management ~	Management -
Gregarization trend	↘	~	↗

Climate x Management ?



Cluster	Temperatures		Precipitations		Management	Gregarization
	Mean	Trend	Mean	Trend		
1	++	(***)	+++	(***)	~	-
2	**++**	**(***)**	**+**	**(*)**	**++**	**+**
3	++	(***)	~	~	+	-
4	+	(***)	~	~	++	+
5	+	(***)	+	(*)	+	~
6	+	(***)	++	~	NA	NA

→ **Damage control**

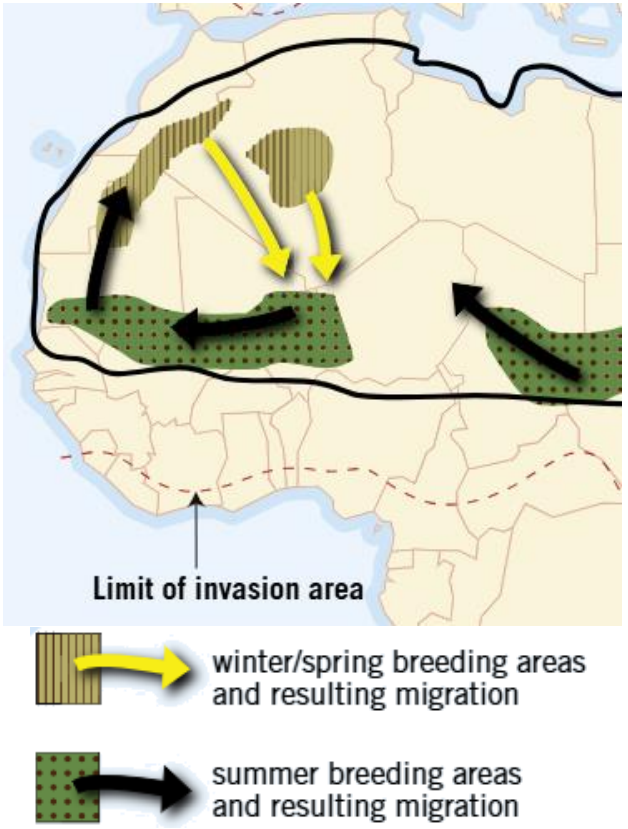
Summary

Spatial and temporal trends are highly heterogeneous

Favorable climate conditions ↘ Gregarization ↗ Management

→ **The effects of climate change have been countered by increased management efforts!**

Importance of interaction between climate and management at large scales



Objectives

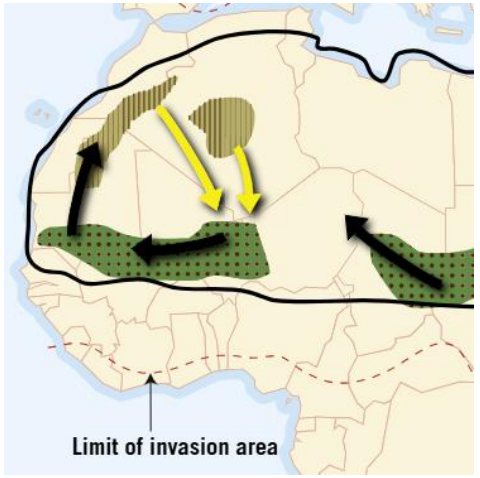
→ Develop a **mechanistic model** capable of reproducing desert locust **population dynamics**

Realist cartography** of **CLCPRO

→ **Large-scale** model

*Population dynamics **simulations***

→ **Gregarization** phenomenon



→ Seasonal **migration** cycle

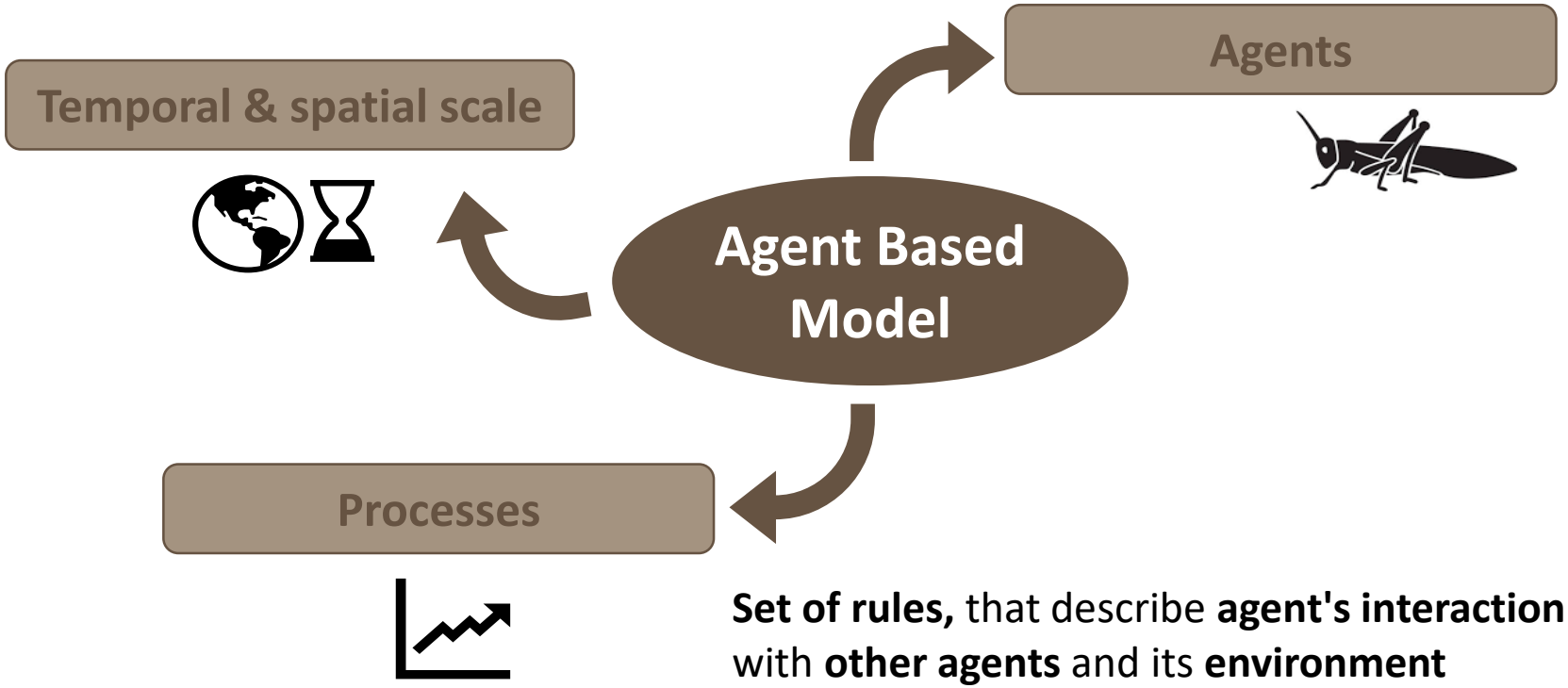
Chap 3

Climate change scenarios projection

→ ***Climatic variables only***
(temperature & precipitation)

Material & Methods

What is an ABM?



Unique and autonomous entities
Defined by **state variables**

Set of rules, that describe **agent's interaction** with **other agents** and its **environment**

Development of the ABM

(1) Definition of model

Purpose, variables, scales, scheduling

(2) First parameters set

From literature review

(3)Parametrization phase

Use of historical data to establish correlations with model parameters and climatic data

(4) Calibration phase

Use of 4 types of errors, for temporal and spatial criteria, to find optimal values for parameters

(5) Validation phase

Use data independent of the one in calibration to confirm set of parameter selected for the final model

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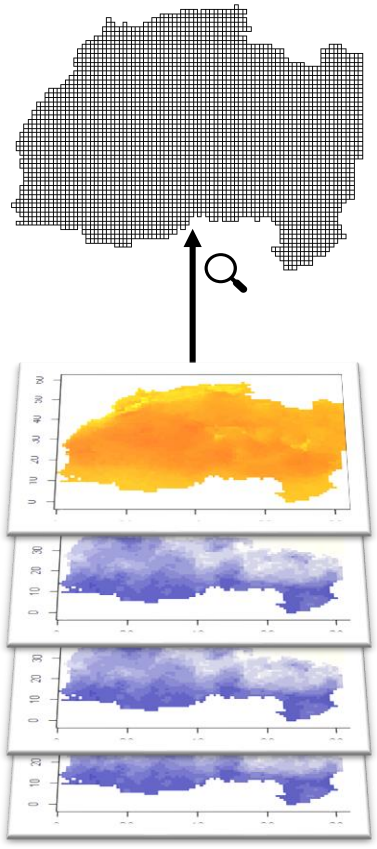
Environment

Spatially explicit

CLCPRO map

Cells 50x50km



Temperature (t)

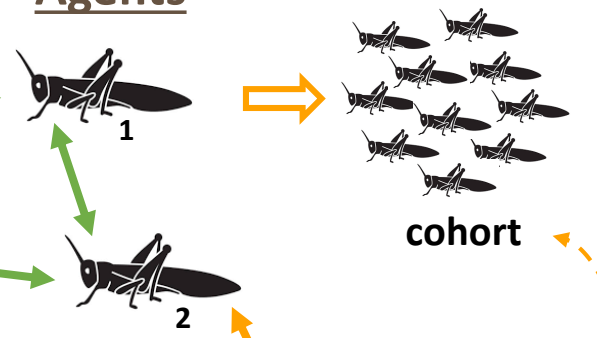
Precipitations (t)

Precipitations (t-1)

Precipitations (t-2)

Monthly

Agents



Interactions

Processes

Eat
Grow
Survive
Move
Reproduce
Regroup
Gregarize

State variables

- Age
- Stage
- Phase
- …

Historic
- Nb of days without food
- Nb of reproduction
- Nb of days until next repro
- …

Daily → *For 731 days*

Setting parameter values

(1) Definition of model

Purpose, variables, scales, scheduling

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From literature review

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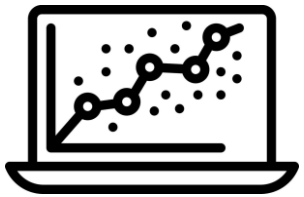
Literature review 18 parameters / 38 total



Correlative analysis 11 parameters / 38 total

Calibration

(1) Definition of model

Purpose, variables, scales, scheduling

(2) First parameters set

From literature review

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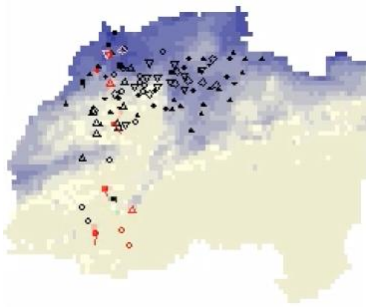
Objective : Find the parameter values that give the most realistic model output possible

Output

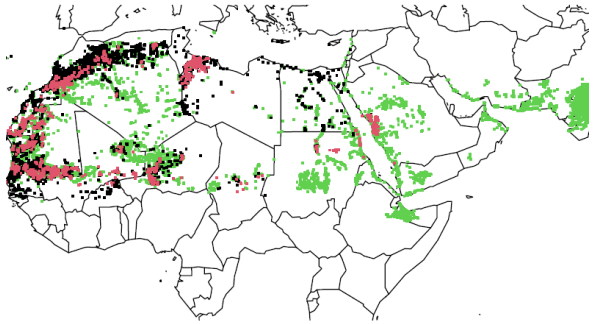


Dates
Coordinates
Population structure
Gregarization events

Comparison

Error measures

FAO data



Calibration

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From literature review

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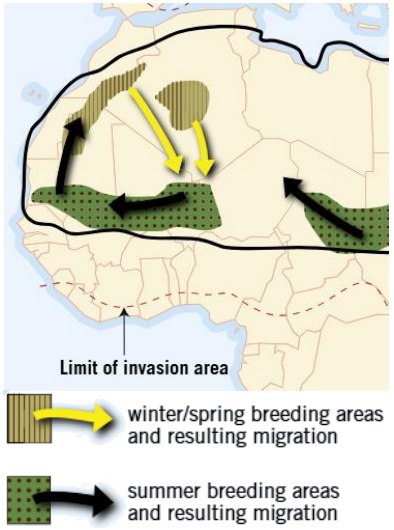
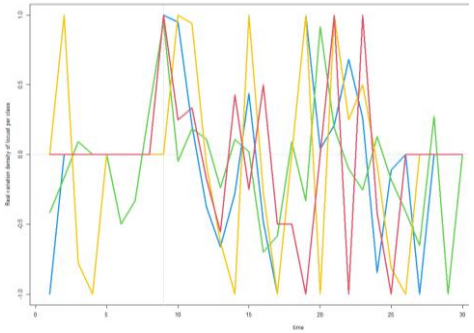
Error measures

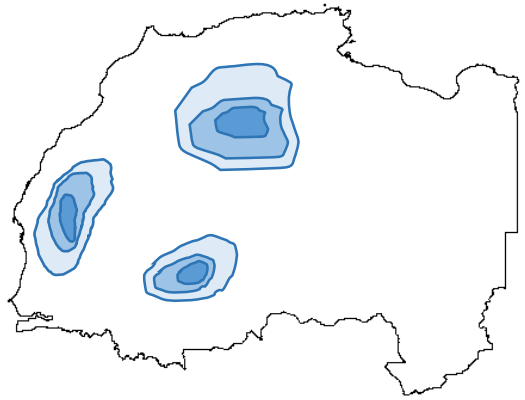
Spatial



Dynamic



Gregarization



Period type?

recession

invasion

Reference error thresholds

Validation

(1) Definition of model

Purpose, variables, scales, scheduling

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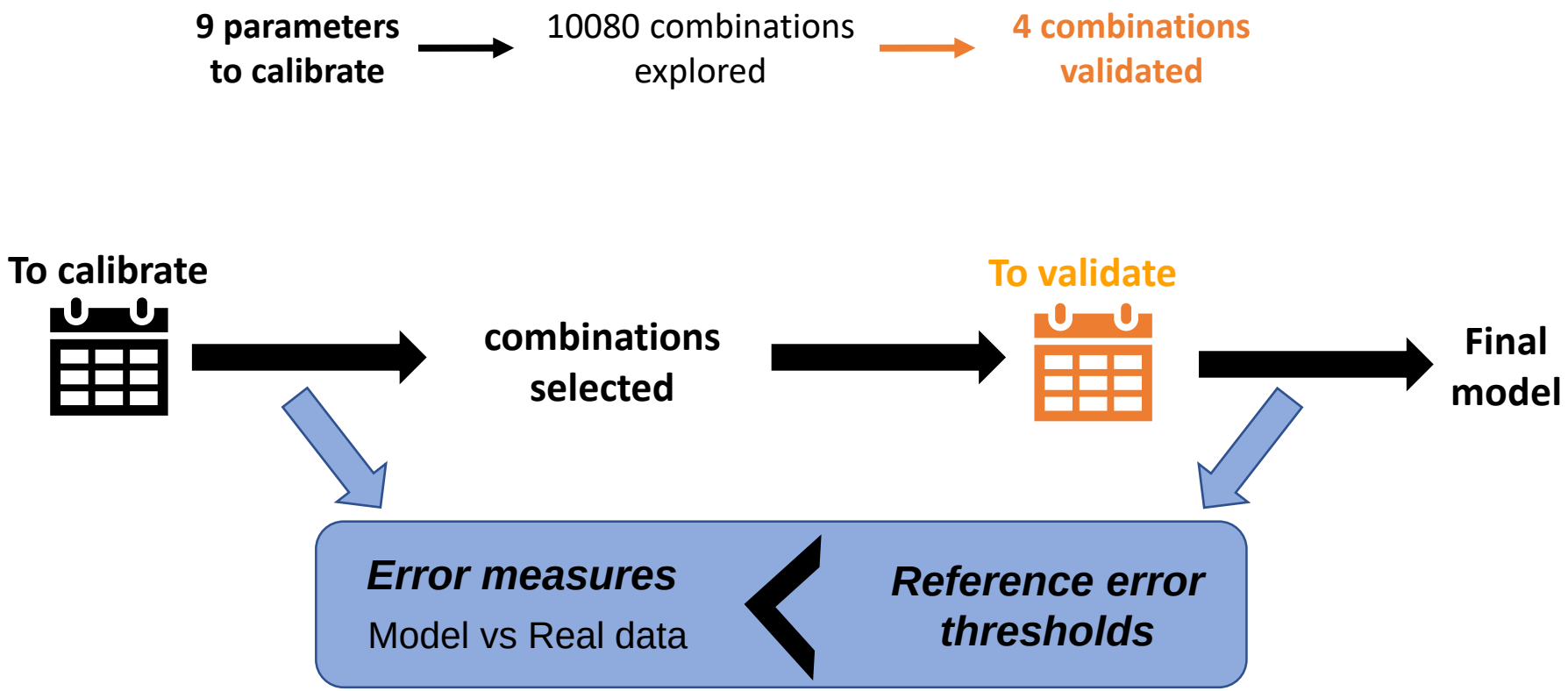
(5) Validation phase

Use data independent of the one in calibration to confirm set of parameter selected for the final model



Result – Temporal accuracy

(1) Definition of model

Purpose, variables, scales, scheduling

(2) First parameters set

From literature review

(3)Parametrization phase

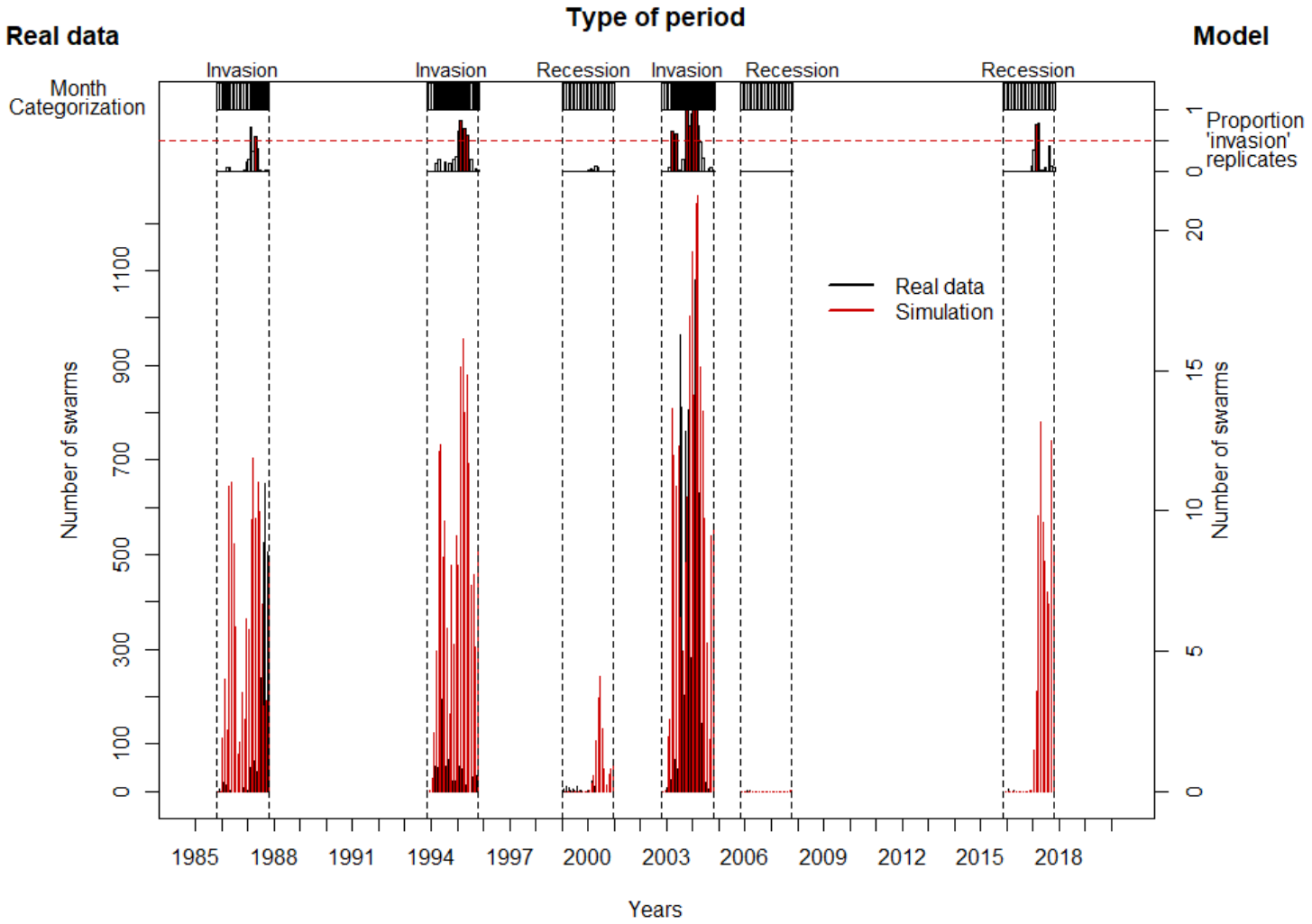
Use of historical data to establish correlations with model parameters and climatic data

(4) Calibration phase

Use of 4 types of errors, for temporal and spatial criteria, to find optimal values for parameters

(5) Validation phase

Use data independent of the one in calibration to confirm set of parameter selected for the final model



Result – Spatial accuracy

(1) Definition of model

Purpose, variables, scales, scheduling

(2) First parameters set

From literature review

(3)Parametrization phase

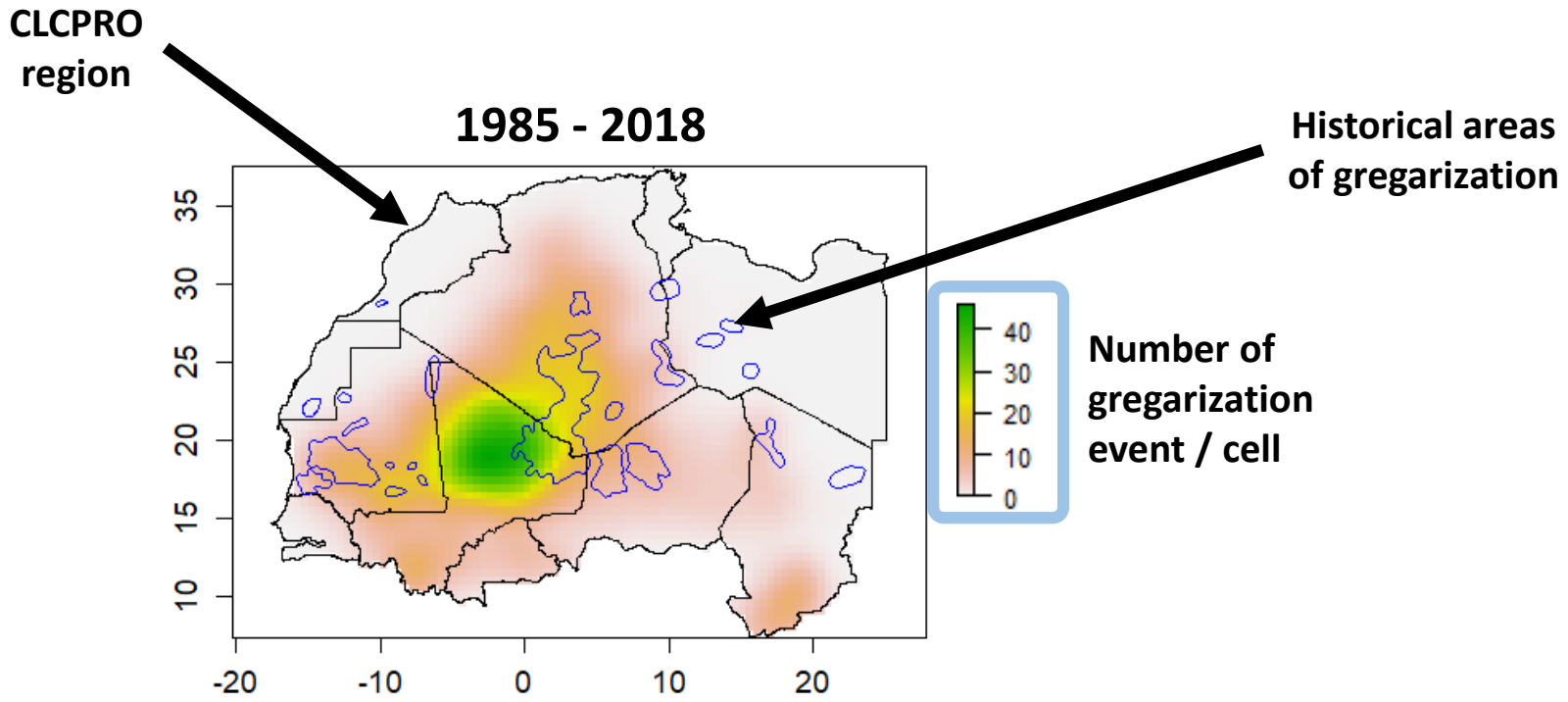
Use of historical data to establish correlations with model parameters and climatic data

(4) Calibration phase

Use of 4 types of errors, for temporal and spatial criteria, to find optimal values for parameters

(5) Validation phase

Use data independent of the one in calibration to confirm set of parameter selected for the final model



Summary

Successfully developed a ABM able to simulate population dynamics depending on climate variables only

Temporal dynamics > Spatial dynamics

Latitude of gregarization ✓

Spatial errors may be due to other ecological elements (wind, vegetation, topology,) management,…

Predictions of future dynamics

(1) Definition of model

Purpose, variables, scales, scheduling

(2) First parameters set

From literature review

(3)Parametrization phase

Use of historical data to establish correlations with model parameters and climatic data

(4) Calibration phase

Use of 4 types of errors, for temporal and spatial criteria, to find optimal values for parameters

(5) Validation phase

Use data independent of the one in calibration to confirm set of parameter selected for the final model

Chapter 3

(6) Predictions

Simulations under climate change scenarios

Climate data

Environment

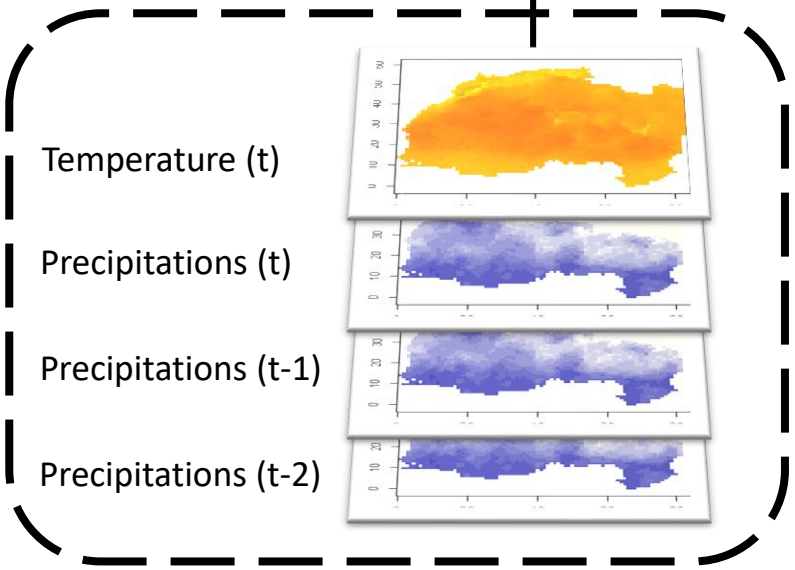
Spatially explicit

CLCPRO map

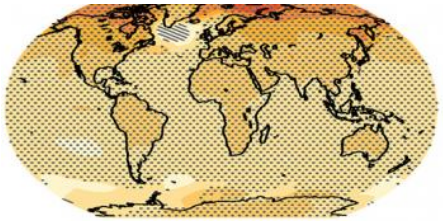
Cells 50x50km

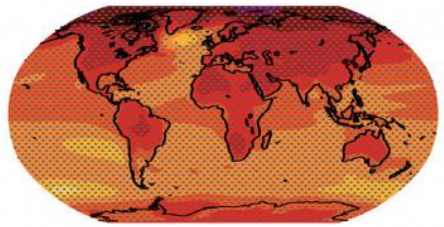
Agents

Interactions



Past climate data ⟷ **Future climate projection**



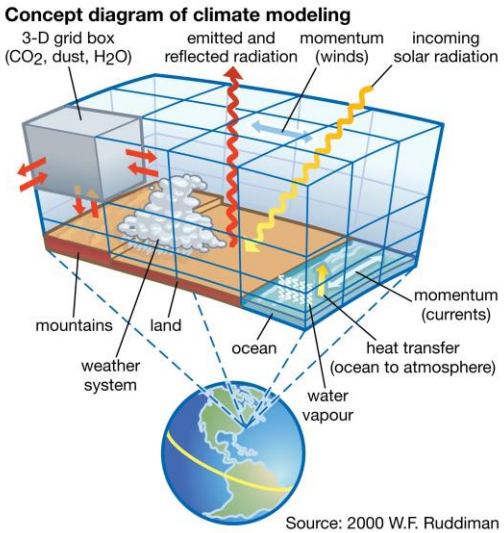


Climate change projections

Projected climate data

GCM = General Circulation Models

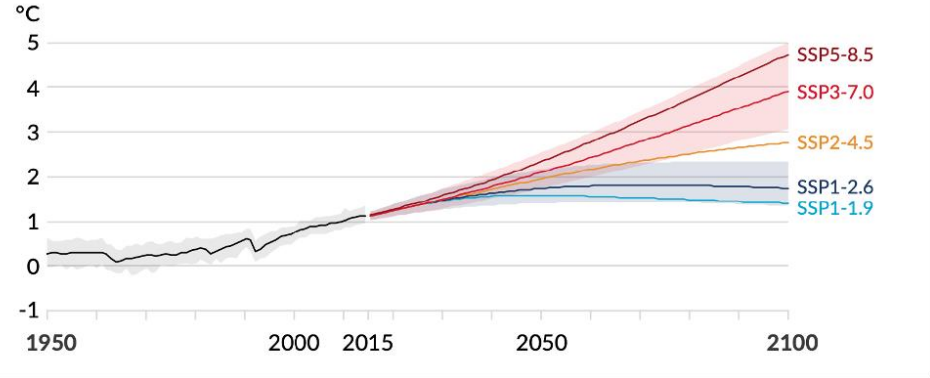
Models simulating global climate dynamics



CSIRO (Australia)
MPI (Germany)

SSP= Shared Socioeconomic Pathways

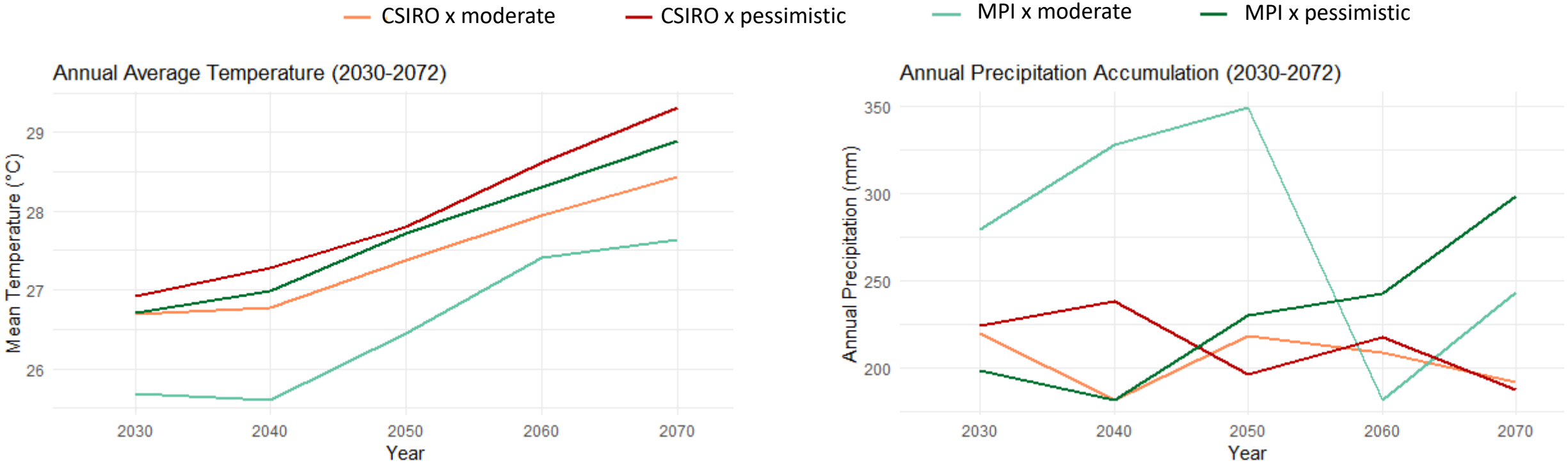
Scenarios predicting future emissions based on societal choices



SSP3.7.0 = moderate
SSP5.8.5 = pessimistic

Projection = GCM x SSP

Scenarios



moderate < pessimistic

MPI < CSIRO

Difference between GCM

moderate ? pessimistic

MPI > CSIRO

Results – Gregarization areas

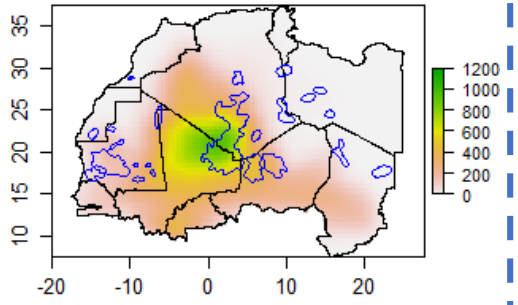
CSIRO

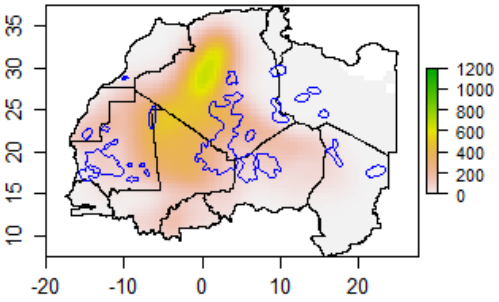
Scenarios

Moderate **Pessimistic**

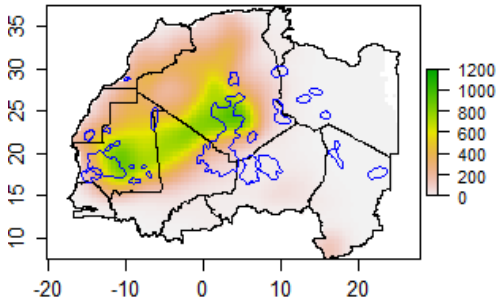
Year

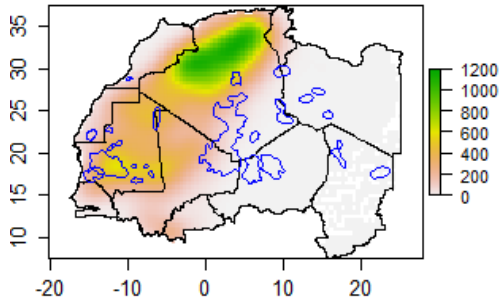
2030





2070





Results – Gregarization areas

CSIRO

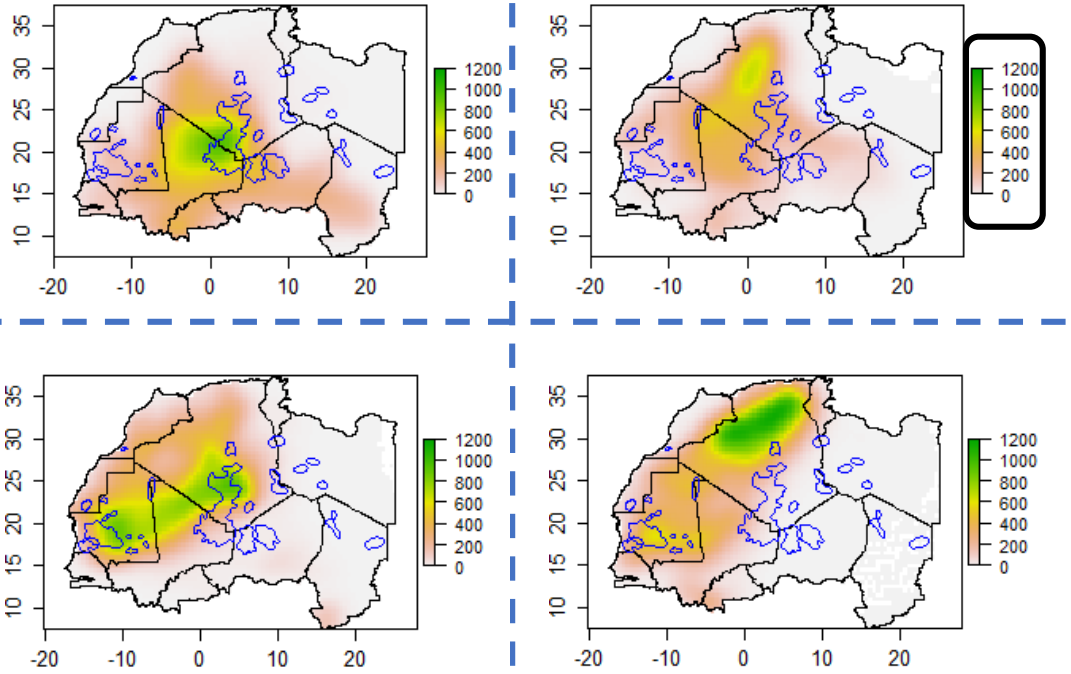
Scenarios

Moderate **Pessimistic**

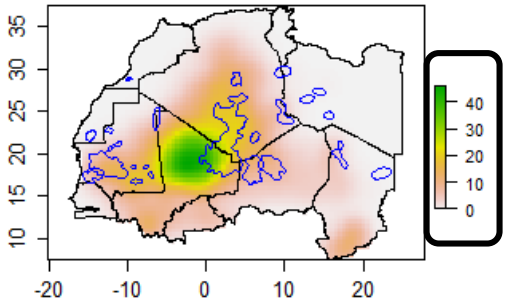
Year

2030

2070



1985 - 2018



Gregarization events

2030 **2070**

moderate **pessimistic**

Results – Gregarization areas

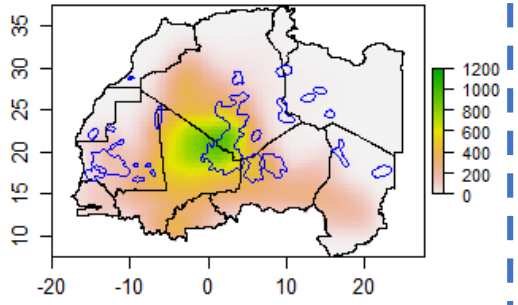
CSIRO

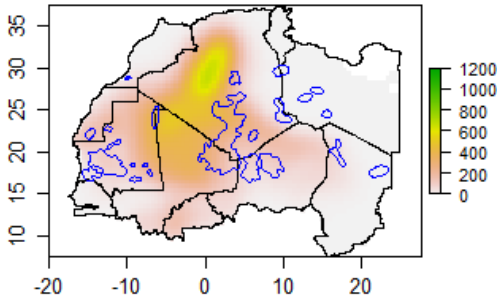
Scenarios

Moderate | **Pessimistic**

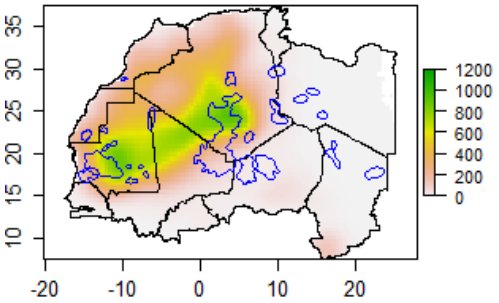
Year

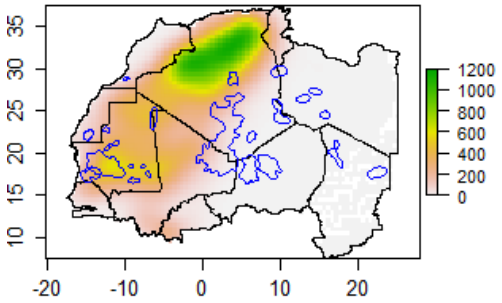
2030



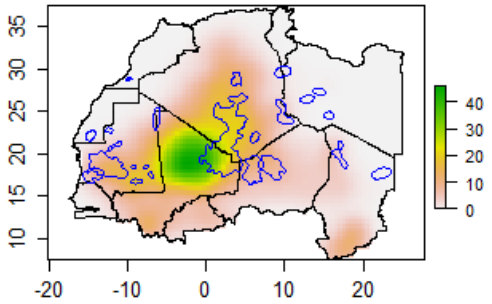


2070

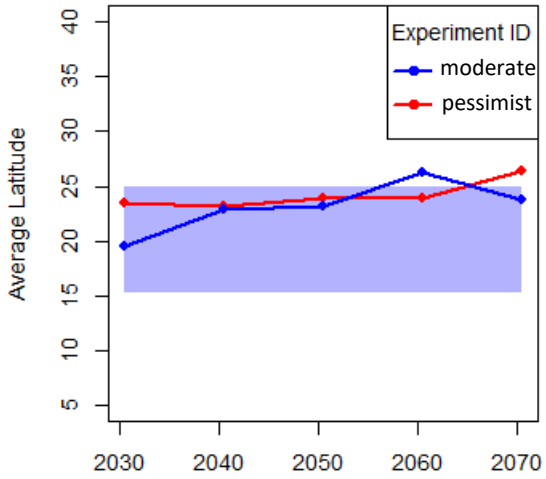




1985 - 2018



Average latitude



Gregarization events

2030 → **2070**

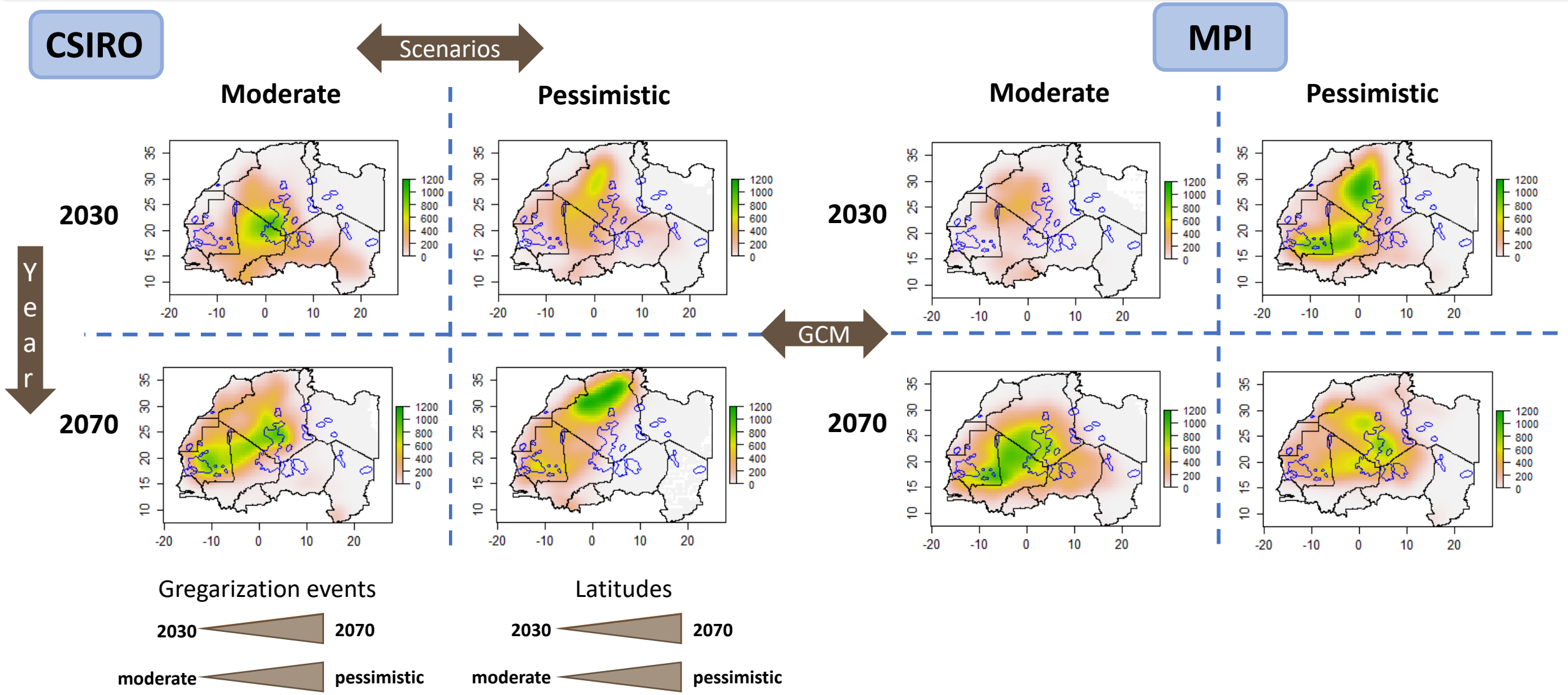
moderate → **pessimistic**

Latitudes

2030 → **2070**

moderate → **pessimistic**

Results – Gregarization areas



Results – Gregarization areas

CSIRO — Scenarios — **MPI**

	Moderate	Pessimistic	Moderate	Pessimistic
	pr - 2070 - CSIRO - ssp370	pr - 2070 - CSIRO - ssp585	pr - 2070 - MPI-M - ssp370	pr - 2070 - MPI-M - ssp585
2070				

GCM

Gregarization events

2030 — 2070

moderate — pessimistic

Latitudes

2030 — 2070

moderate — pessimistic

Summary

Assess how populations might respond to climate change in the future

3 key changes :

- Increase in gregarization frequencies
- Northward shift in gregarization areas
- Historical & New gregarization areas

Can help guide monitoring and preventive management

Overview

Chapter 1

PAST

FUTURE

Chapter 2 & 3

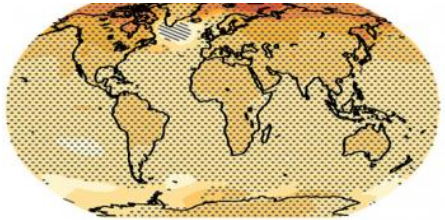
Overview

Chapter 1

PAST

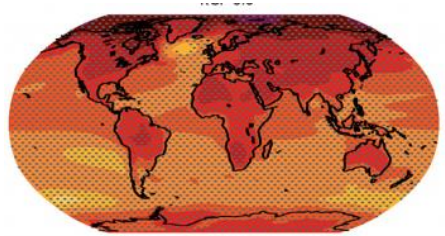
FUTURE

Chapter 2 & 3



Gregarization

Climate change



Gregarization

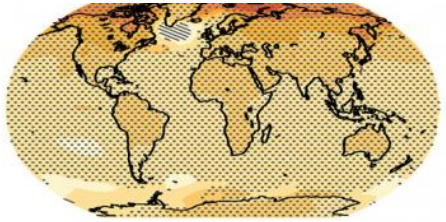
Overview

Chapter 1

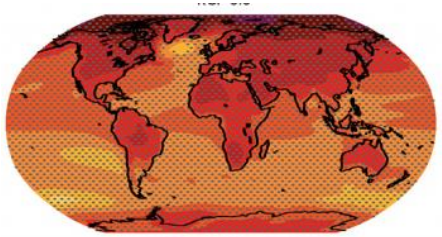
PAST

FUTURE

Chapter 2 & 3



Climate change



Gregarization

Gregarization

+ Shift of areas

Preventive management

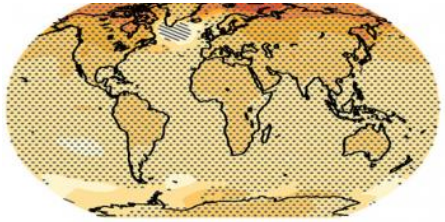
Overview

Chapter 1

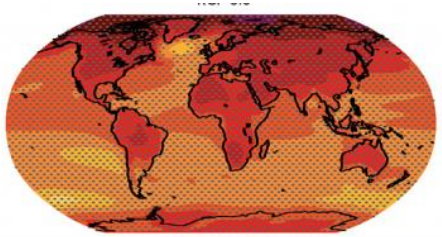
PAST

FUTURE

Chapter 2 & 3



Climate change



Gregarization

Gregarization

+ Shift of areas

Preventive management

Will agricultural pest species be favored by climate change?

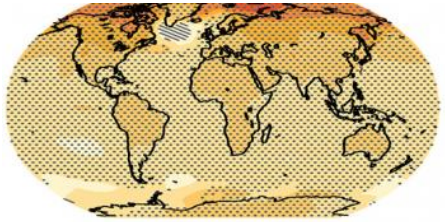
Overview

Chapter 1

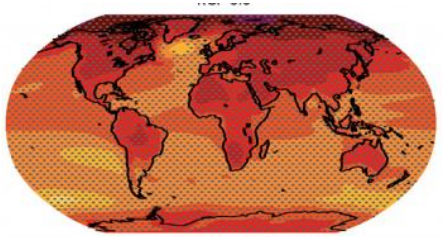
PAST

FUTURE

Chapter 2 & 3



Climate change



Gregarization

Gregarization

+ Shift of areas

Easy to implement Management

No mechanisms

Preventive management

Mechanisms

Spatial error

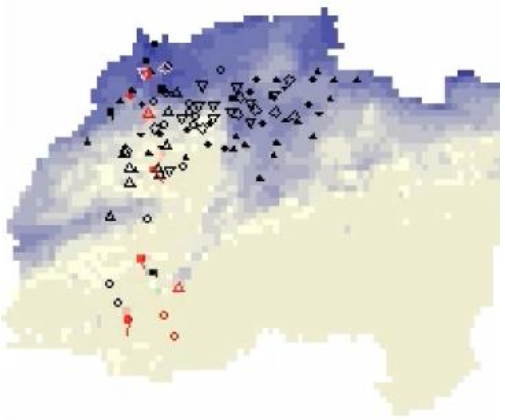
Will agricultural pest species be favored by climate change?

Perspectives

Management in the model

Chapter 1 → important effects of management
→ CC x management interaction

Model



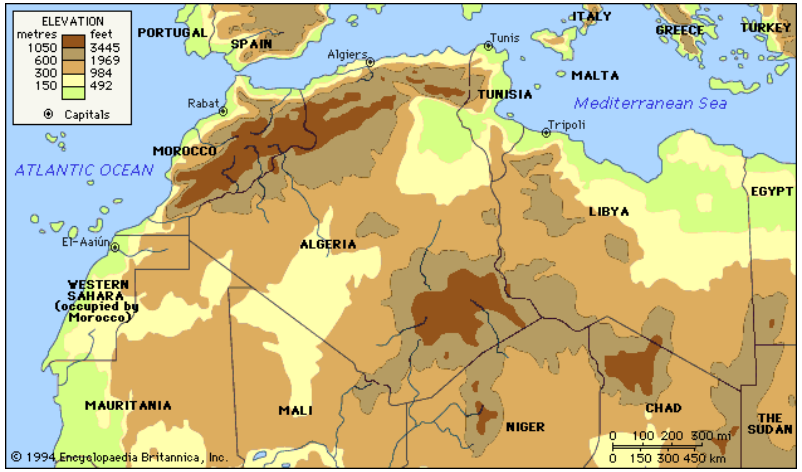
Calibrate with data from a period without management

Simulated control action ?

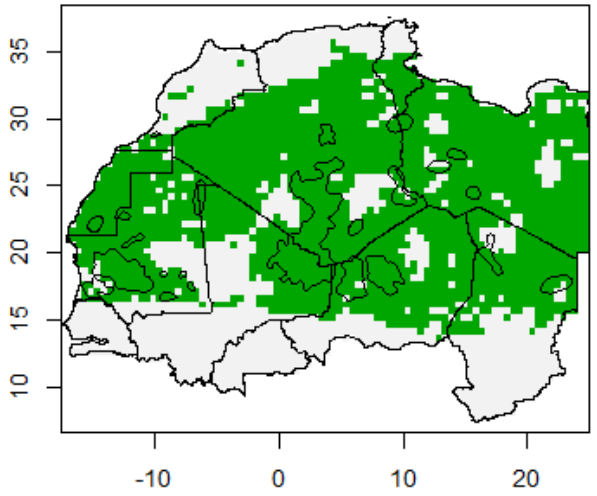
Constant mortality rate 

Treatment/month/area parameter 

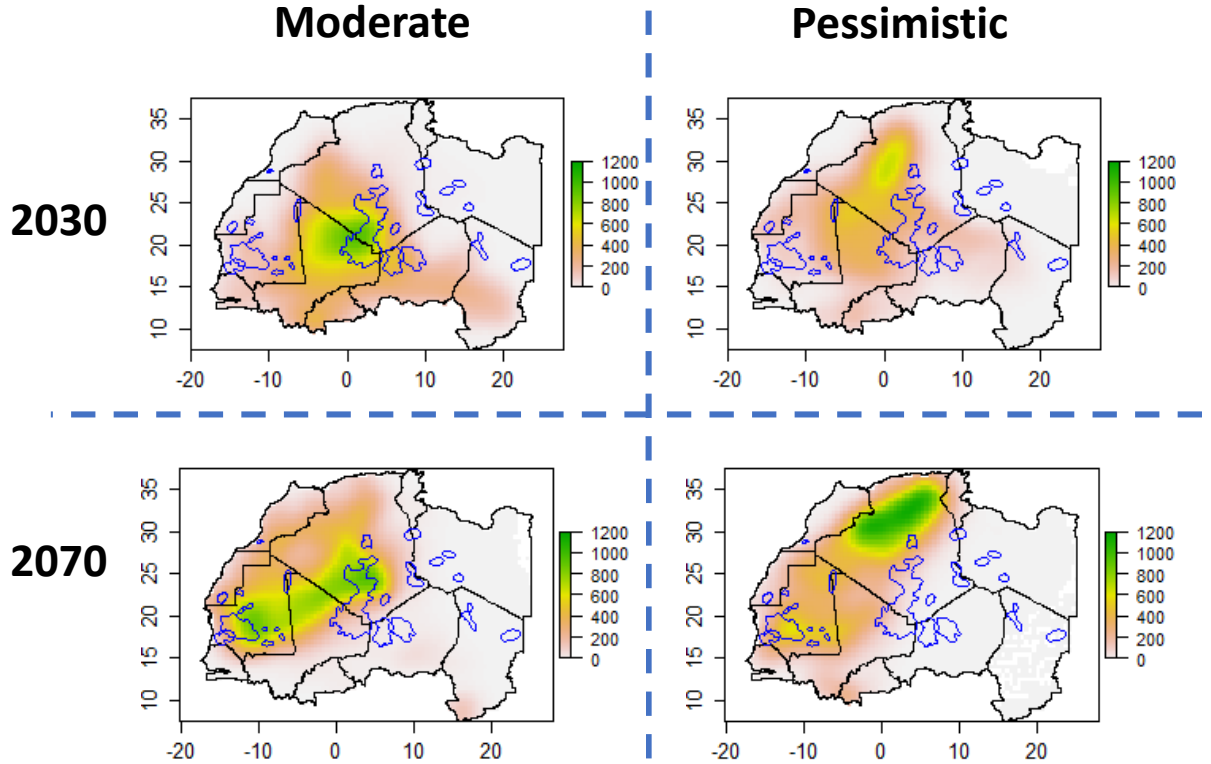
Perspectives



Topography



Mathias Kayalto : geomorphic variability →gregarization



Acknowledgements