Understanding the drivers of changes in agro-ecosystems

Roxanne S. Lorilla, Georgios Giannarakis
Vassilis Sitokonstantinou, Charalampos Kontoes

Outline

- Introduction
- Preliminary Ecosystem Services assessment
- Assessing Impacts
- Achievements
- The way forward and next steps

Introduction

Concept and Objectives

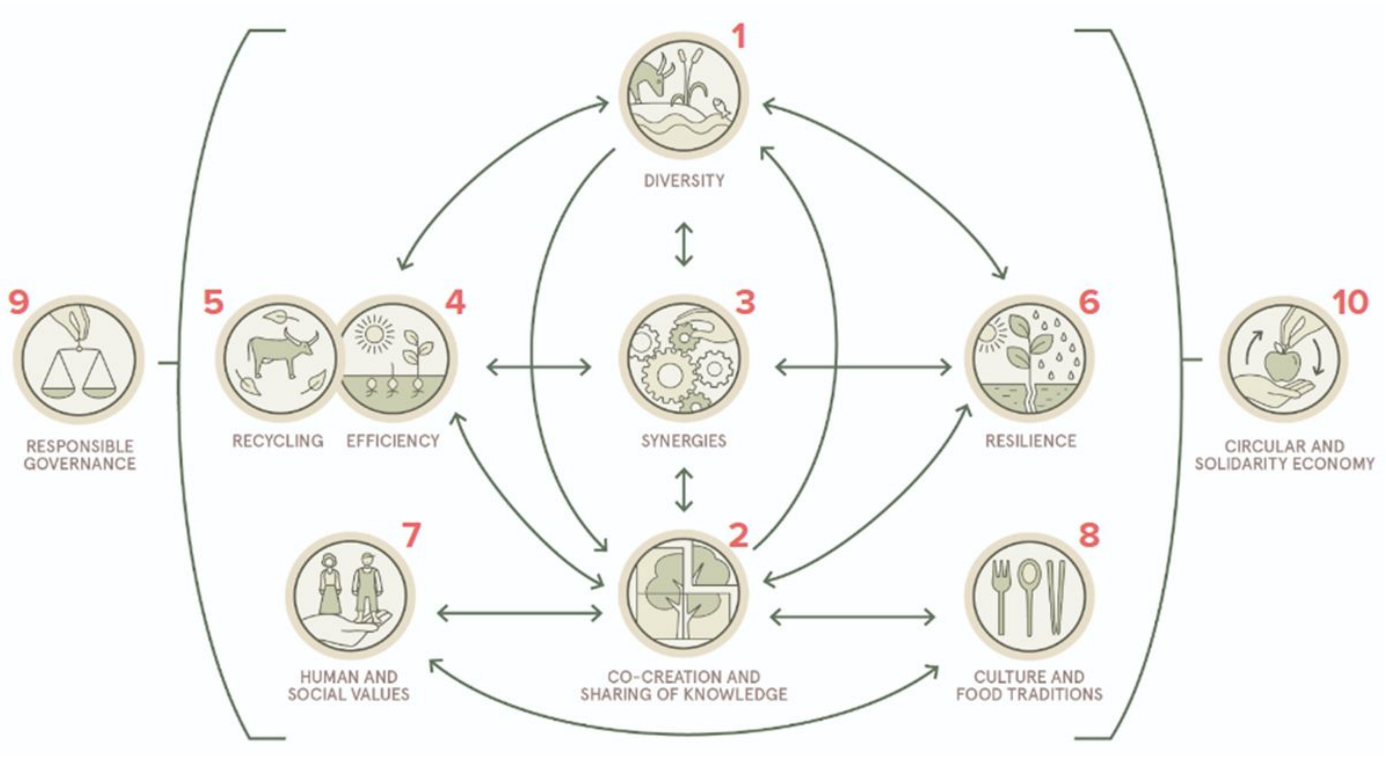
Common Agricultural Policy (CAP)

- National and farm-level flexibility in choices of greening measures resulted in the **horizontal implementation of management rules** (lack of spatial targeting of environmental measures)
- The **increase of production efficiency** has lead to landscape homogenization.
- Criticized for their **cost** and environmental **effectiveness** [1,2]
- The **post 2020 CAP** brings to the table key elements for the environment and climate, aiming to increase efficiency

[1] *European Court of Auditors, Special Report n°21/2017*

[2] *Evaluation of the CAP Greening measures, European Economic Interest Grouping*

Introduction - Agroecosystem resilience

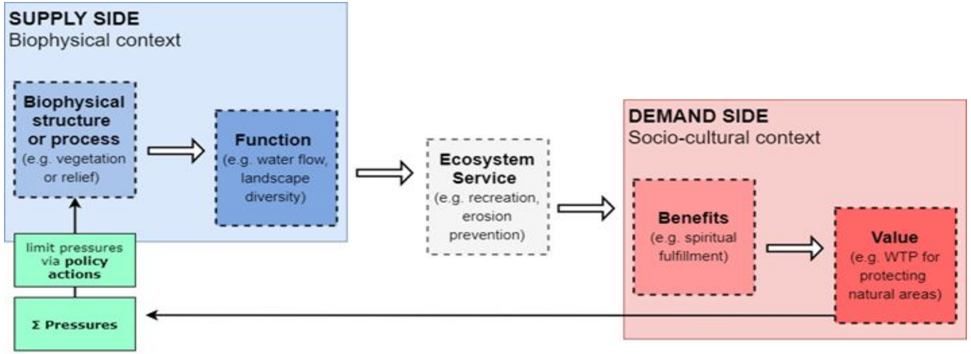


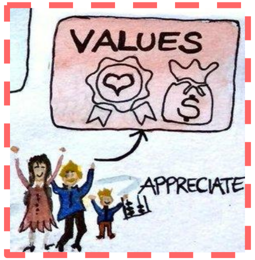
The 10 elements of agroecology (FAO, 2018) https://www.fao.org/documents/card/en/c/I9037EN/

Introduction - Ecosystem Services (ES) Concept

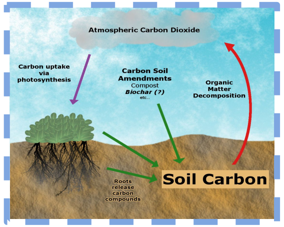
The Cascade Model

Biophysical Characteristics





Function

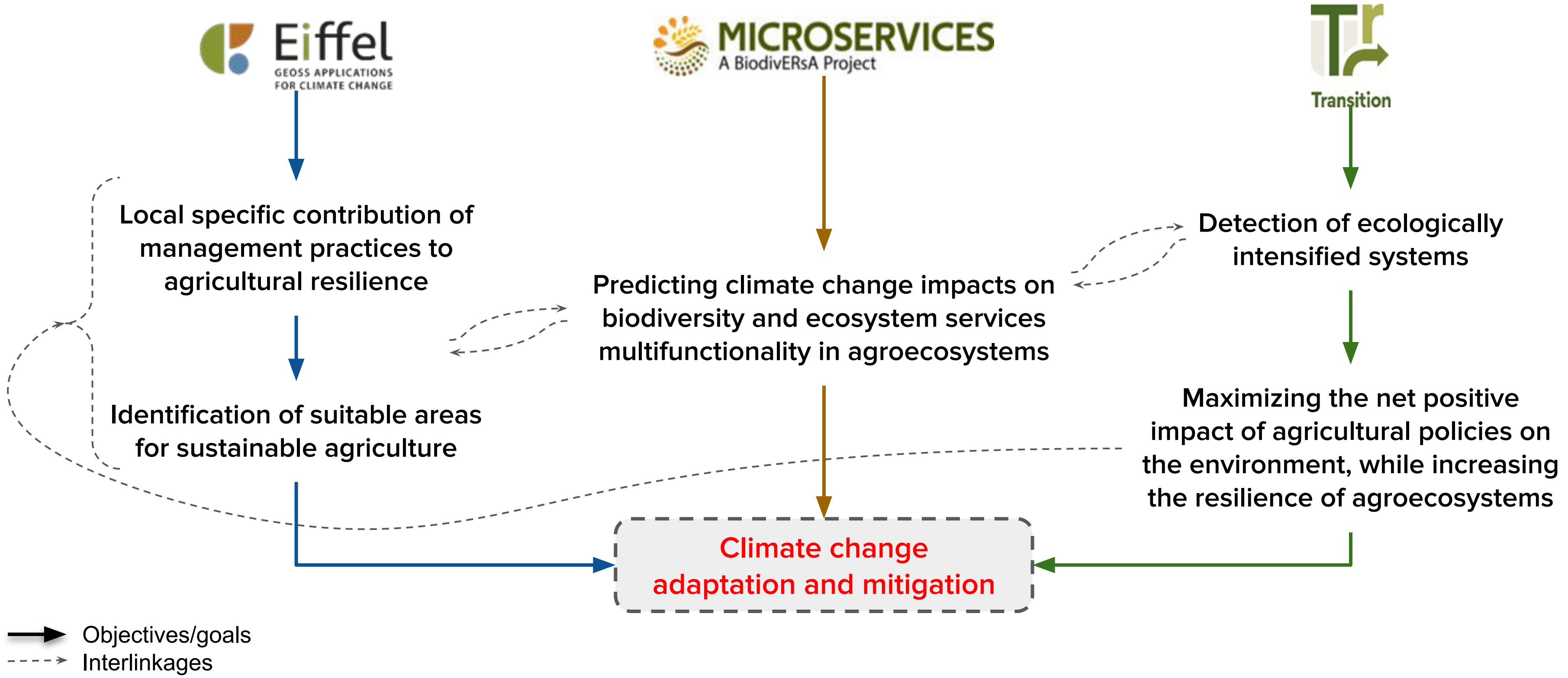


Service

Climate Regulation

Benefit

Ecosystems' Projects

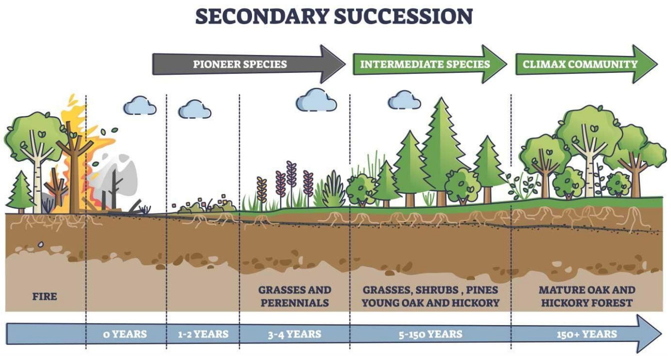


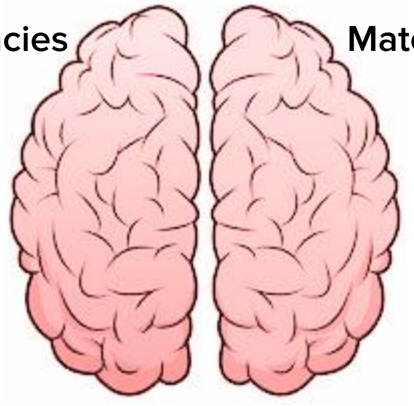
Ecological memory

how ecosystems respond to disturbance/interventions?

Information legacies

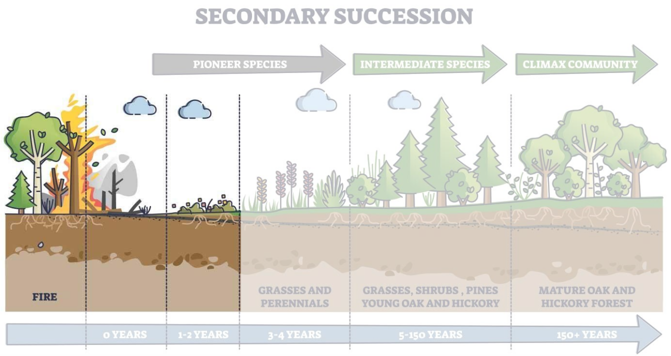
Responses (adaptations) to historical disturbance/ interventions cycles, described by the presence, frequency, and distribution of ecosystem traits





Material legacies

Matter/traits (state of ecosystems) present in an ecosystem after a disturbance event/ an intervention

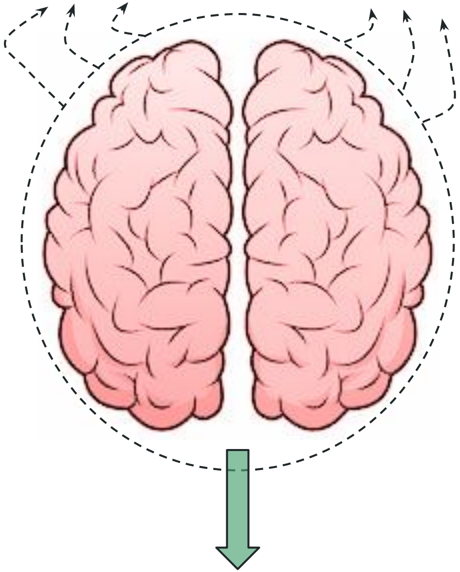


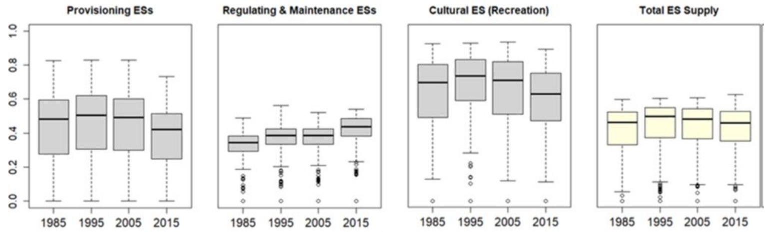
Encoding of past environmental conditions in the current ecosystem state that affects its future trajectory

Ecological memory

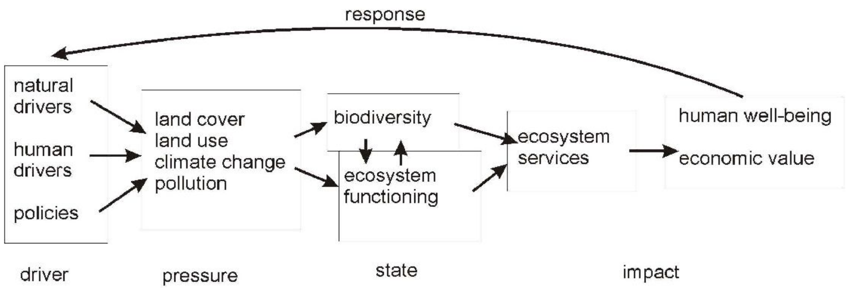
Past and current status/trends

Disturbance/Intervention characteristics





Future trajectories



Enhance **ecological resilience**

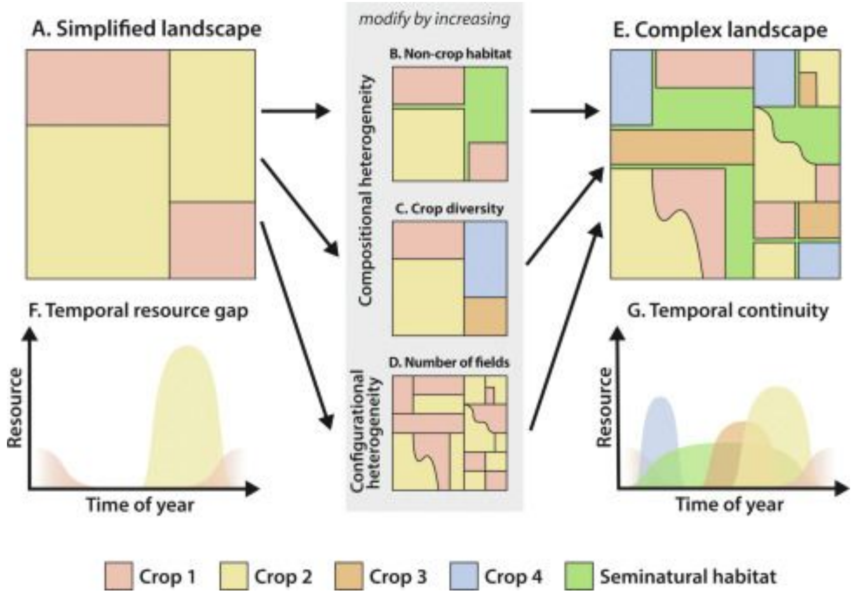
Maintain a **Safe Operating Space** for ecosystem recovery

Preliminary ES assessment

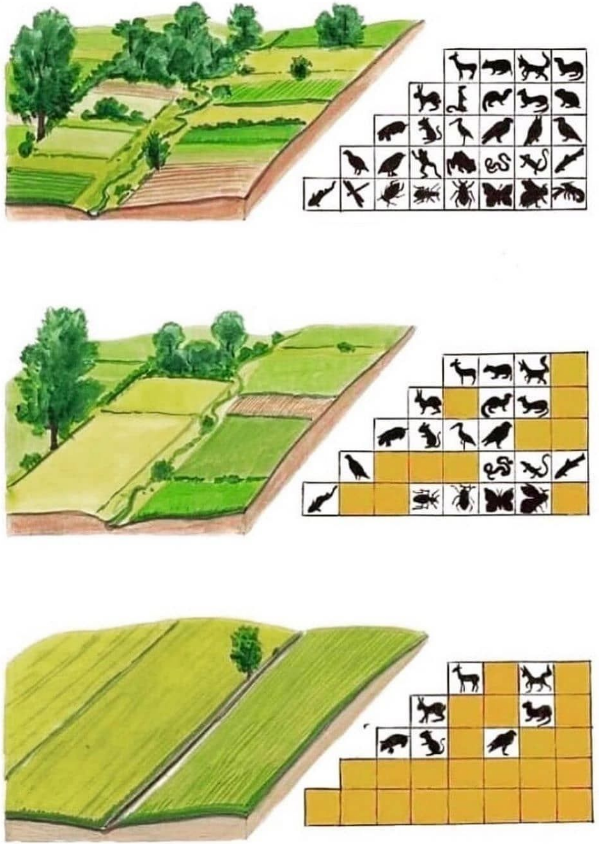
Multi-functionality, ecosystem resilience

Agricultural landscapes

Increased demand led to **agricultural intensification** and **homogeneous landscapes**, causing **loss of biodiversity** and **degradation of ecological processes**



Source: Haan et al. (2021) https://doi.org/10.1016/bs.aecr.2021.01.003



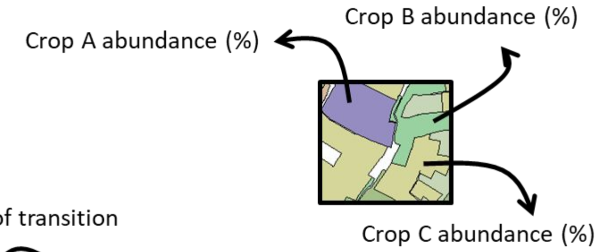
Methodology - ES quantification

Ecosystem services	Indicators	Method	Related literature
Nutrition biomass	Nutrition value of crops	Quantification of per hectare caloric value for different crop types using harvest yield and nutritive factors	Haase et al. (2012); Kroll et al. (2012); Maes et al. (2016)
Erosion control	Actual soil erosion prevention	Assessment of the provision of soil erosion prevention using the RUSLE model	Guerra et al. (2016)
Climate regulation	Carbon sequestration	Calculation of the difference of annual net primary production using the CASA model	Braun et al. (2018); Raich et al. (2002)
Lifecycle maintenance	Functional diversity	Measuring Rao's Q (quadratic entropy) diversity index using remotely sensed vegetation indices as a biodiversity proxy	Rocchini et al. (2017; 2018; 2019)
Pollination	Relative pollination potential	ESTIMAP Pollination model	Lonsdorf et al. (2009); Stange et al. (2017); Zulian et al. (2013)

Methodology - Agricultural management practices

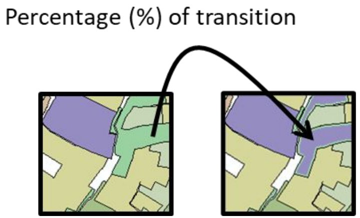
Crop Abundance (7 variables)

- Forage, Fruit, Maize, Potato, Sugarbeet, Tuber_Roots, Winter Wheat



Crop Transition (6 variables)

- Maize to Potato, Maize to Winter Wheat
- Potato to Maize, Potato to Winter Wheat
- Sugarbeet to Winter Wheat
- Winter Wheat to Maize

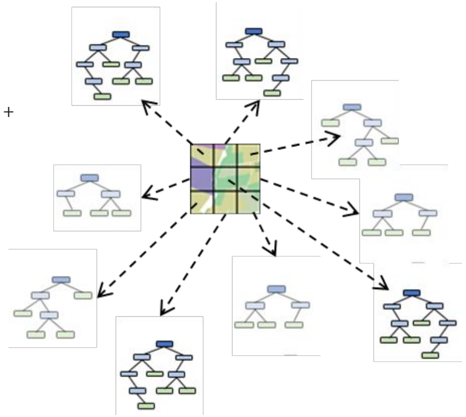


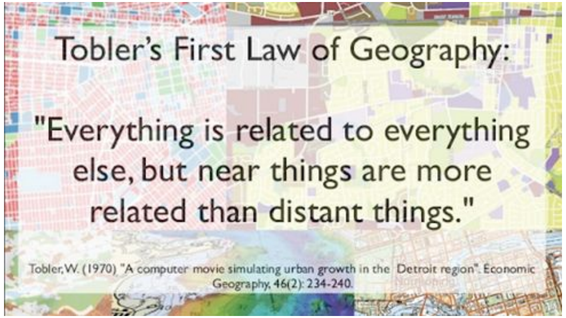
Spatial Diversification

- Shannon's diversity index

Methodology - Geographical Random Forest

```
# library(GWmodel)

# Define bandwidth value
bw.a <- bw.gwr(ES~Forage + Fruit + Maize + Potato + Sugarbeet + Tuber_Roots + Winter_Wheat + Maize_to_Potato + Maize_to_Winter Wheat +
        Potato_to_Maize + Potato_to_Winter_Wheat + Sugarbeet_to_Winter_Wheat +  Winter_Wheat_to_Maize + DIVERSIF,
        data=rf.trainset, approach = "AICc", kernel = "gaussian", adaptive = TRUE)

# library(SpatialML)
Coords <- rf.trainset@data[,2:3]

# run model
grf.model <- grf(formula, dataframe, bandwidth=bw.a, kernel, cords=Coords, ntree=ntree, mtry=mtry,
       importance=TRUE, forests = TRUE) # *formula = ES~all_features

# predict
pred.grf <- predict.grf(grf.model , test.df, x.var.name="X", y.var.name="Y")
```

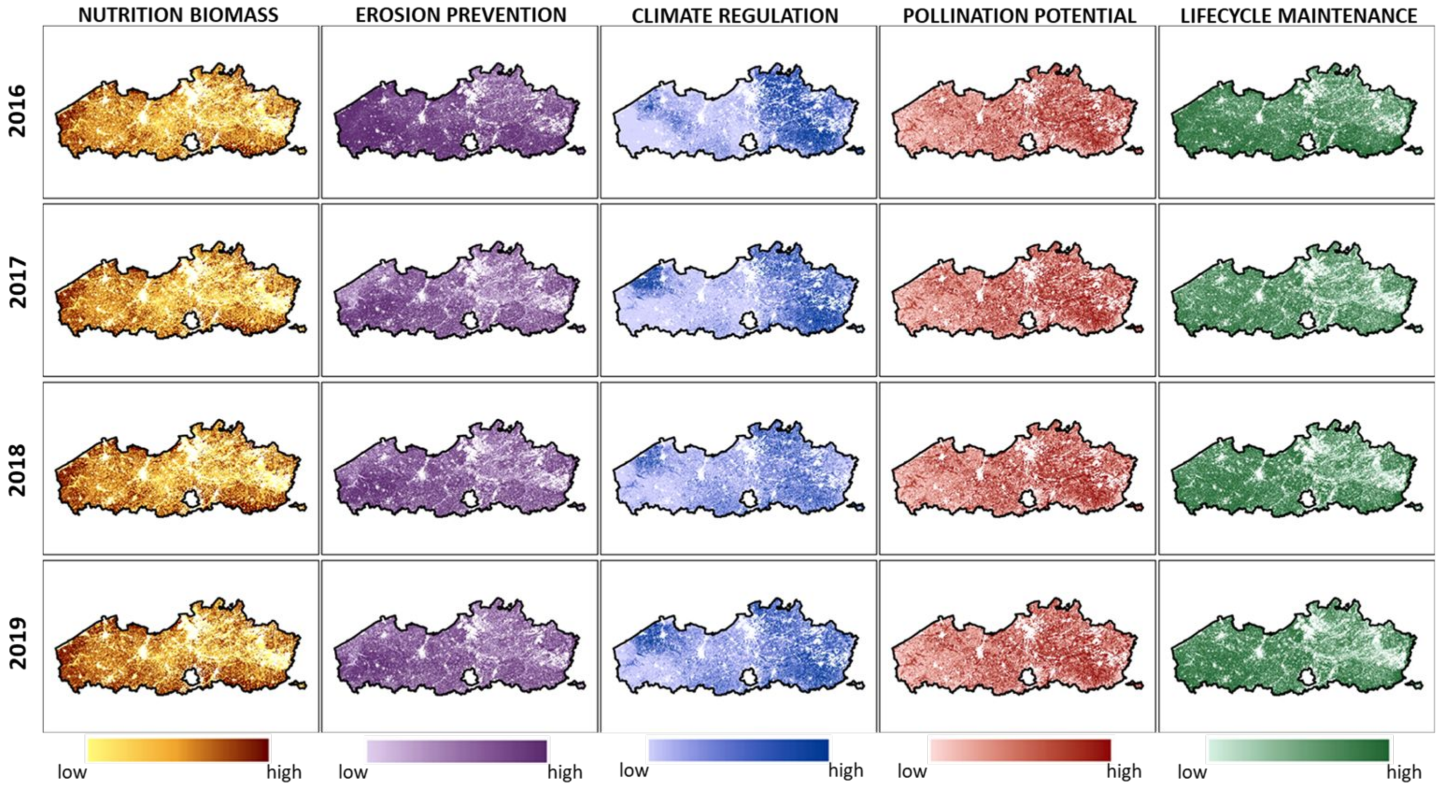




Output of geographical random forest model

Locations	a numeric matrix or data frame of two columns giving the X,Y coordinates of the observations
Local.Pc.IncMSE	a numeric data frame with the local feature importance (IncMSE) for each predictor in each local random forest model
Local.IncNodePurity	a numeric data frame with the local IncNodePurity for each predictor in each local random forest model
LGofFit	a numeric data frame with residuals and local goodness of fit statistics (training and OOB).
Forests	all local forests.
lModelSummary	Local Model Summary and goodness of fit statistics (training and OOB).

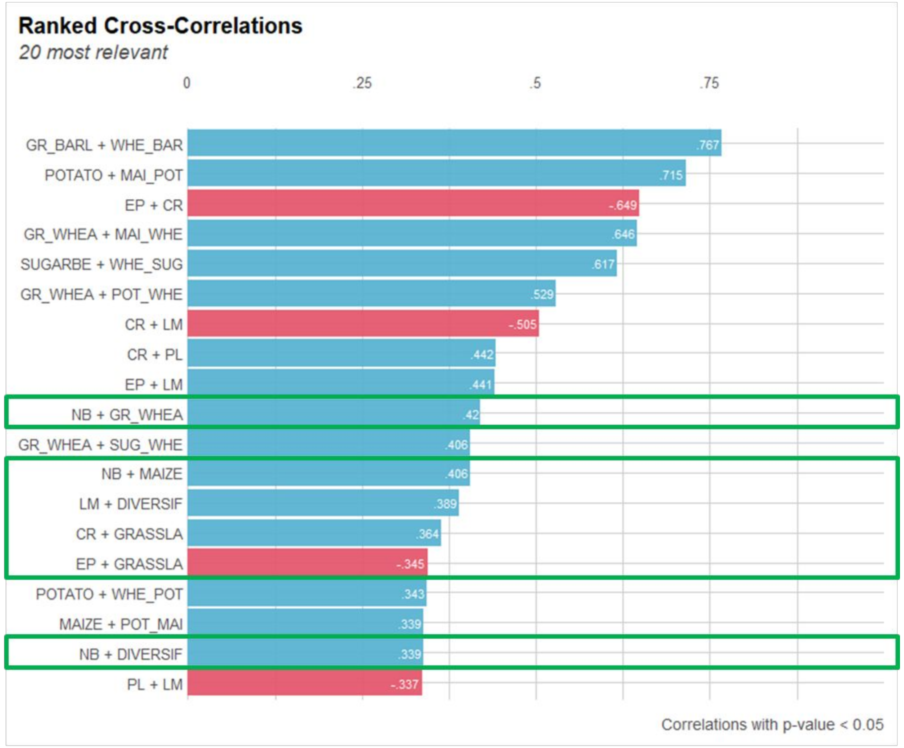
Results - ES distribution



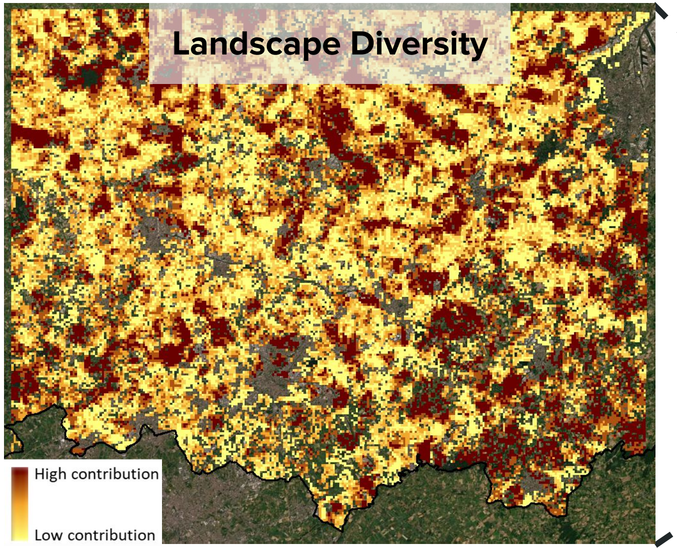
Results - ES synergies and trade-offs

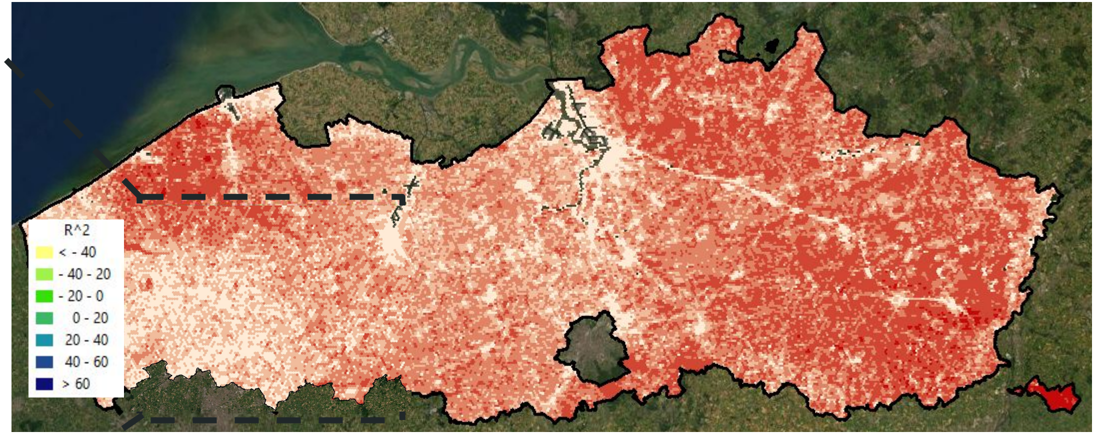
Table 1. Pairwise correlations between ES and potential agricultural management practices through time; all listed correlations are significant with p-value < 0.05.

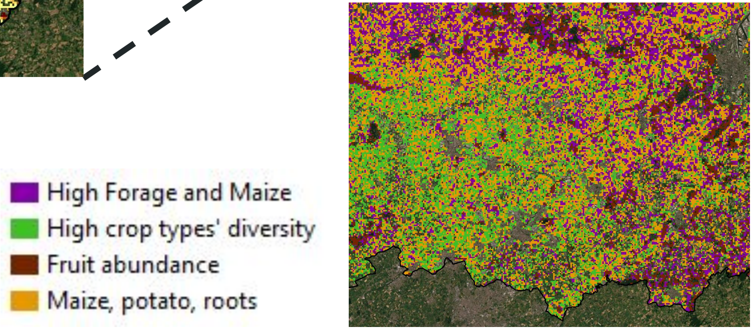
	2016	2017	2018	2019
Among ES (all possible pairs)				
NB - EP	0.000	0.280	0.280	0.150
NB - CR	-0.100	-0.270	-0.270	-0.160
NB - PL	-0.424	-0.361	-0.346	-0.350
NB - LM	0.050	0.260	0.310	0.300
EP - CR	-0.580	-0.603	-0.733	-0.711
EP - PL	-0.170	-0.370	-0.390	-0.330
EP - LM	0.631	0.419	0.592	0.528
CR - LM	-0.476	-0.393	-0.584	-0.543
CR - PL	0.340	0.497	0.524	0.472
LM - PL	-0.200	-0.220	-0.310	-0.330
Between ES and explanatory variables (selected pairs)				
NB - Grassland	-0.240	-0.200	-0.190	-0.150
EP - Grassland	-0.230	-0.330	-0.330	-0.369
CR - Grassland	0.280	0.290	0.310	0.330
PL - Grassland	0.270	0.300	0.290	0.290
NB - Maize	0.586	0.571	0.577	0.575
EP - Maize	-0.240	0.351	0.280	0.140
PL - Maize	-0.386	-0.260	-0.290	-0.280
NB - Potato	0.324	0.320	0.330	0.310
NB - Wheat	0.320	0.351	0.384	0.466
NB - Diversity	0.450	0.459	0.430	0.515
PL - Diversity	-0.348	-0.240	-0.230	-0.240
LM - Diversity	0.320	0.360	0.357	0.389
Among explanatory variables (selected pairs)				
Barley - Wheat to Barley	0.792	0.795	0.764	0.736
Maize - Diversity	0.422	0.420	0.430	0.439
Potato - Diversity	0.391	0.386	0.381	0.385
Wheat - Diversity	0.400	0.370	0.370	0.385
Potato - Maize to Potato	0.752	0.718	0.725	0.738
Potato - Wheat to Potato	0.400	0.401	0.370	0.354
Wheat - Maize to Wheat	0.733	0.701	0.703	0.723
Wheat - Potato to Wheat	0.468	0.506	0.515	0.504
Wheat - Sugar beet to Wheat	0.336	0.390	0.387	0.366
Sugar beet - Wheat to Sugar beet	0.654	0.651	0.620	0.620

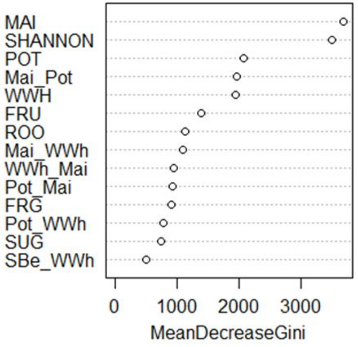


Results - Local-specific contributions









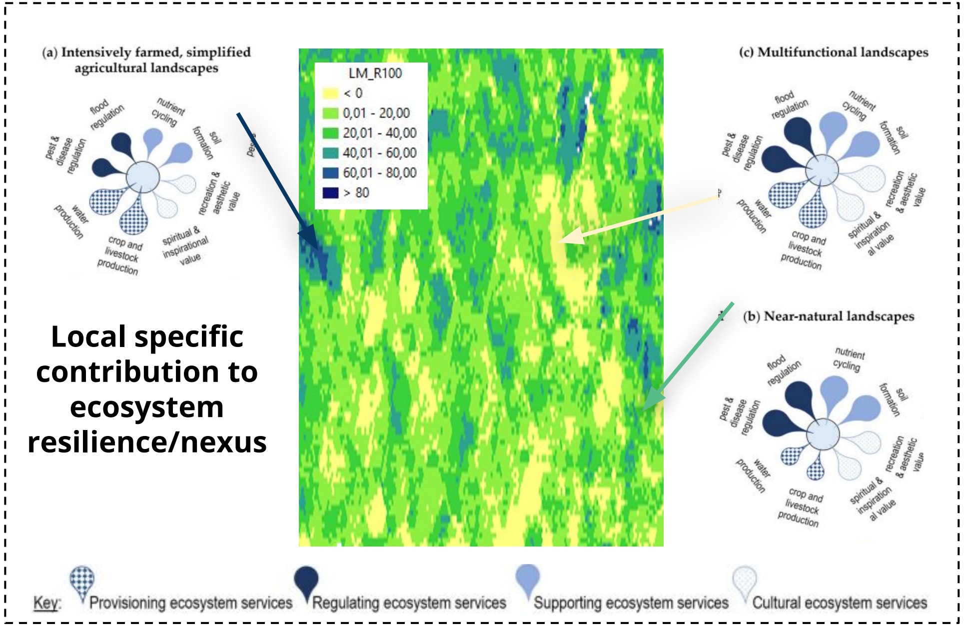
The plan

Identification of **multifunctional areas** to support **resilient** and **healthy ecosystems** while ensuring societal and economic (**human**) **well-being**

Ecosystem resilience (or nexus?)

Management regime/practices

Local specific contribution to ecosystem resilience/nexus



Assessing Impacts

CAP, Sustainability & Land Suitability

The big picture

Understanding the **local impact** of agricultural practices on agroecosystems

e.g. crop diversification, grassland maintenance

Eiffel
GEOSS APPLICATIONS FOR CLIMATE CHANGE

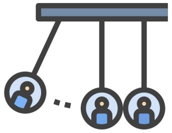
Local specific contribution of management practices to agricultural resilience

Identification of suitable areas for sustainable agriculture

Climate change adaptation and mitigation

Causal Machine Learning: Overview

A family of machine learning methods specialized for causal inference



The mathematical study of cause and effect

Use historical large scale data to learn the impact of interventions

What is the effect of a new drug on blood pressure?

Highly relevant to **decision making, policy evaluation, personalization**

Causal Machine Learning: Personalization

What is the average impact of an intervention on the whole population?

(Non-personalized insight, aka “Average treatment effect”)

What is the impact of an intervention **for a unit with particular characteristics?**

(Personalized insight, aka “Heterogeneous treatment effect”)

Why care?

BEYOND Centre of EO Research and Satellite Remote Sensing

IAASARS

The new common agricultural policy: 2023-27

The new common agricultural policy will be key to securing the future of agriculture and forestry, as well as achieving the objectives of the European Green Deal.

On 2 December, 2021, the agreement on reform of the common agricultural policy (CAP) was formally adopted. The new legislation, which is due to begin in 2023, paves the way for a fairer, greener and more performance-based CAP.

It will seek to ensure a sustainable future for European farmers, provide more targeted support to smaller farms, and allow greater flexibility for EU countries to adapt measures to local conditions.

Targeted support

Flexibility to adapt measures to local conditions

Geospatial “personalization”

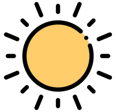
The new CAP: a personalization problem

What is the impact of an intervention for a unit with particular characteristics?

Agricultural Practice

Parcel

Agro-environmental info



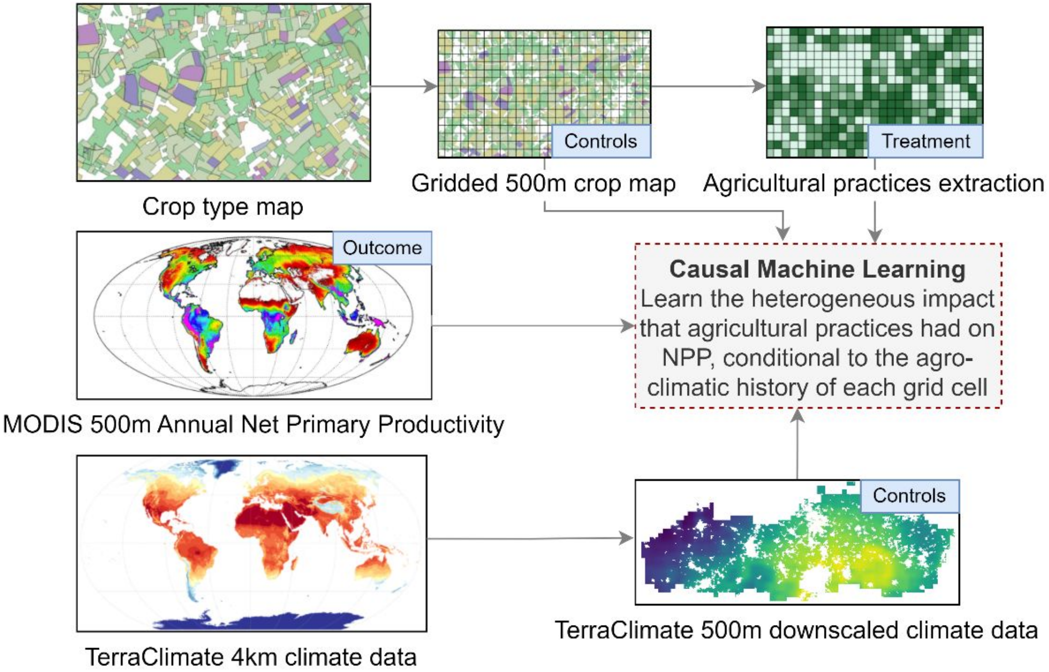
The estimated practice impact is proposed as a **land suitability score**

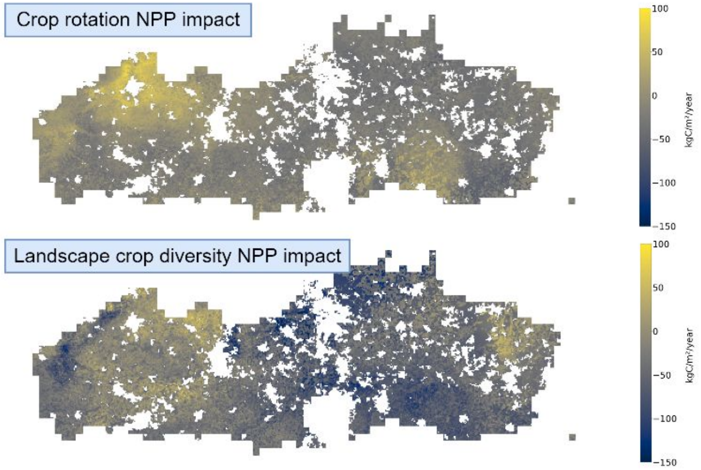
Eiffel
GEOSS APPLICATIONS FOR CLIMATE CHANGE

Crop rotation
Crop diversity...

Ecosystem Services
Yield
Soil Organic Carbon
Net Primary Productivity...

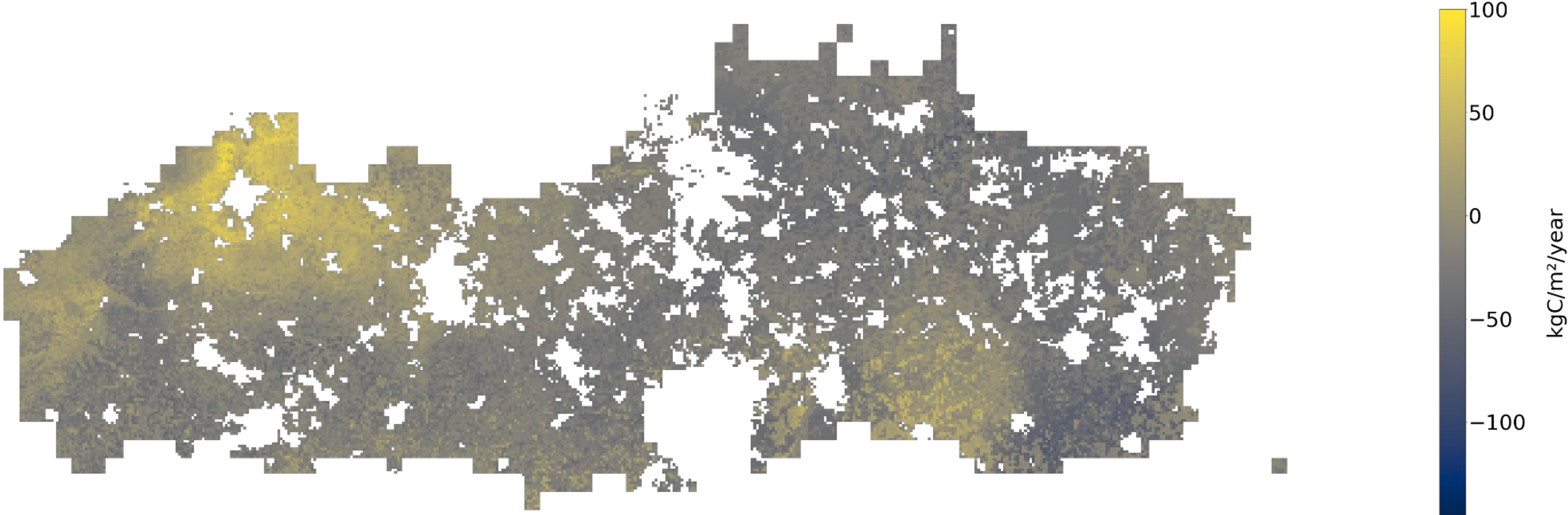
Proof of Concept (Flanders, Belgium, 2010-2020)





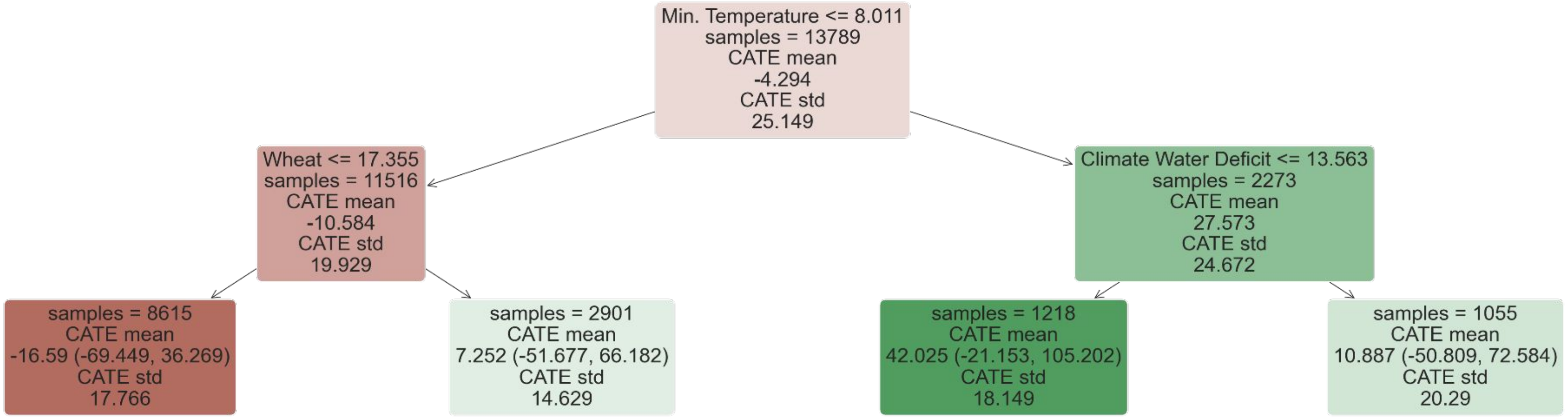
- The learned impact as a Land Suitability Score
- Understand agro-climatic conditions driving impact variability

Estimated impact for “crop rotation” practice*



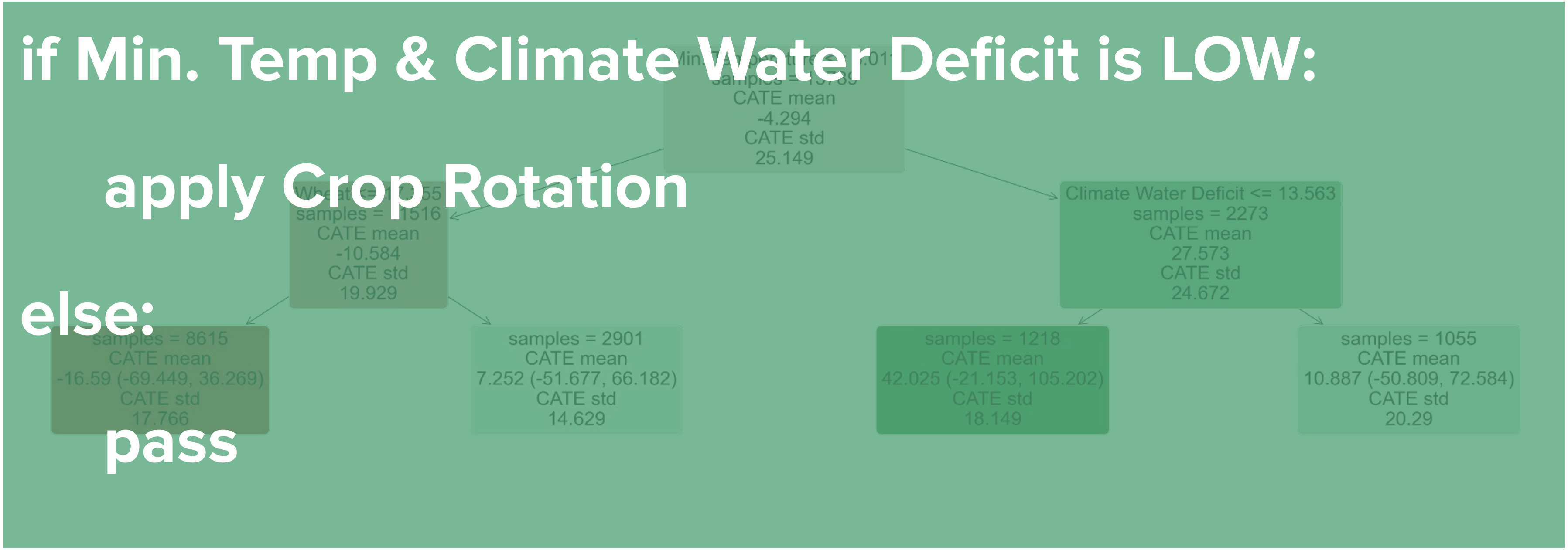
*Impact on ecosystem Net Primary Productivity (MODIS NPP)

Environmental conditions favoring practices



*Environmental conditions driving impact of crop rotations

Data-informed agro-ecological rules



if Min. Temp & Climate Water Deficit is LOW:

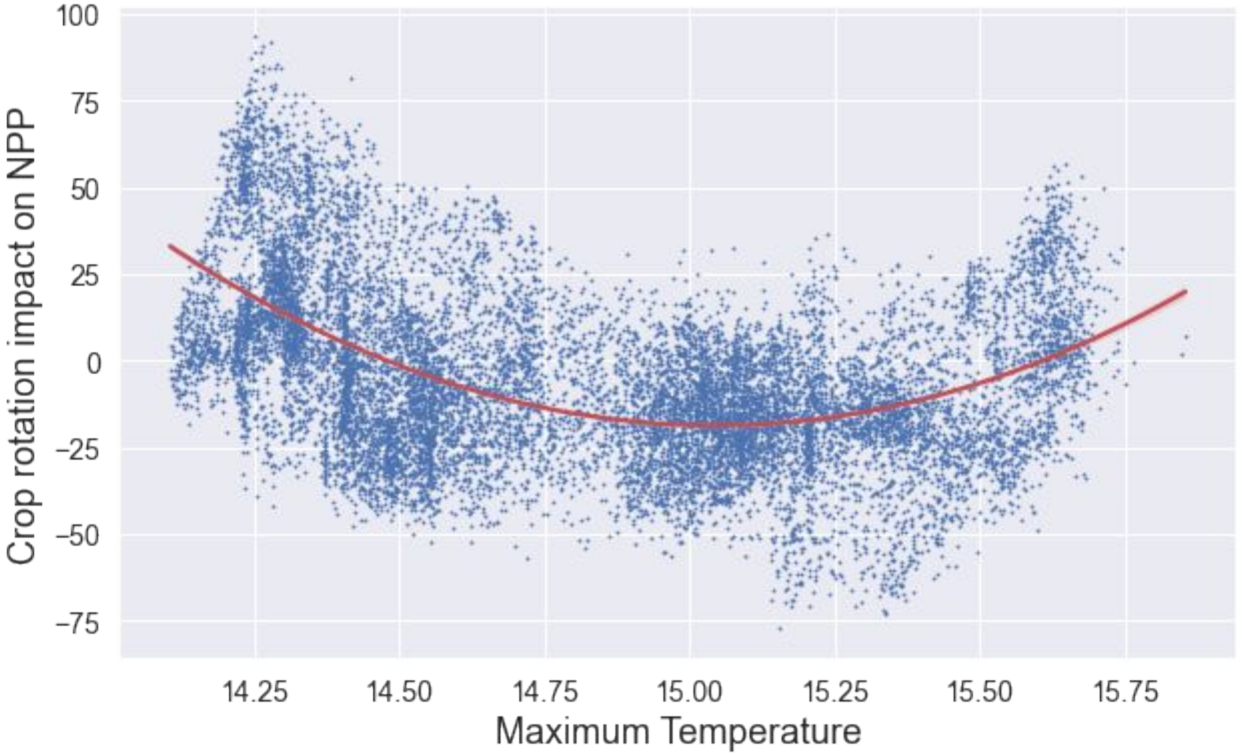
apply Crop Rotation

else:

pass

*Environmental conditions driving impact of crop rotations

Towards climate smart agriculture



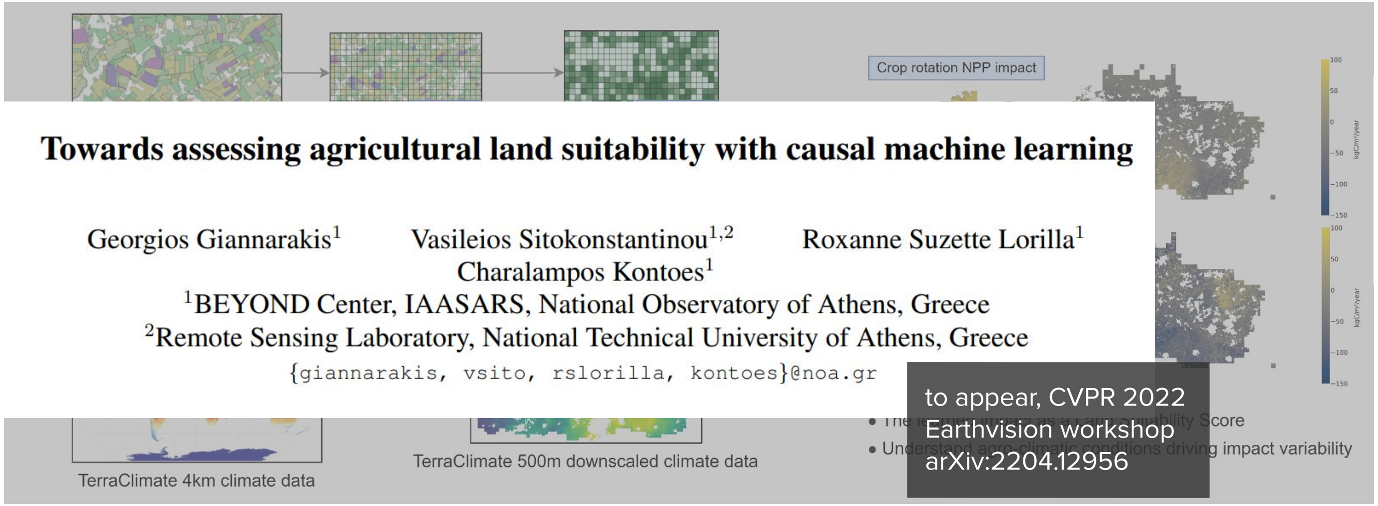
*In a warmer planet, crop rotation might be more beneficial for productivity

*Using future climate projections, how do impact results change?

Achievements

Paper Writing, Visibility & Network

Paper Writing



Towards assessing agricultural land suitability with causal machine learning

Georgios Giannarakis[1] Vasileios Sitokonstantinou[1,2] Roxanne Suzette Lorilla[1]
Charalampos Kontoes[1]
[1]BEYOND Center, IAASARS, National Observatory of Athens, Greece
[2]Remote Sensing Laboratory, National Technical University of Athens, Greece
{giannarakis, vsito, rslorilla, kontoes}@noa.gr

to appear, CVPR 2022
Earthvision workshop
arXiv:2204.12956

EARTHVISION 2022

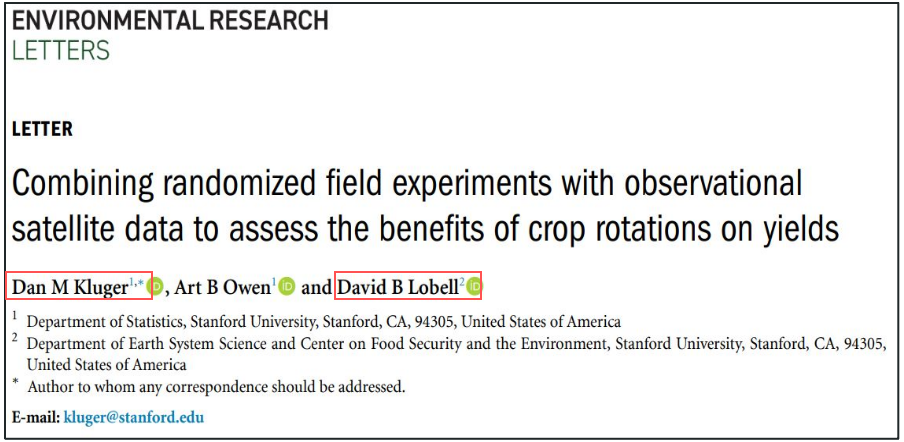
June 19th, New Orleans, Louisiana - hybrid/virtual

in conjuction with the Computer Vision and Pattern Recognition (CVPR) 2022 Conference

CVPR JUNE 19-24 2022 NEW ORLEANS LOUISIANA

- Targeted workshop for AI4EO community
- In its 3rd year, frequently featuring top names and institutions
- Carries the CVPR seal (main track IF : 45)
- “Emerging applications in Remote Sensing” (IEEE Xplore, presenting June 19th)

Visibility


ENVIRONMENTAL RESEARCH
LETTERS

LETTER

Combining randomized field experiments with observational satellite data to assess the benefits of crop rotations on yields

Dan M Kluger[1,*], Art B Owen[1] and David B Lobell[2]

[1] Department of Statistics, Stanford University, Stanford, CA, 94305, United States of America
[2] Department of Earth System Science and Center on Food Security and the Environment, Stanford University, Stanford, CA, 94305, United States of America
[*] Author to whom any correspondence should be addressed.

E-mail: kluger@stanford.edu

- Presented our work in a community workshop organized by Microsoft Research
- Correspondence and feedback from Stanford researchers

Network

ESP
Ecosystem Services Partnership

Thematic Working Groups: TWG 3 – ES Indicators

Lead Team & Members

- Roxanne Lorilla, National Observatory of Athens (NOA), Greece
- Ute Schwaibold, University of the Witwatersrand, South Africa
- Lyndre Nel, Hungarian University of Agricultural & Life Sciences, Hungary
- Alexander van Oudenhoven, Leiden University, The Netherlands

Session Co-hosts in the upcoming ESP Europe Conference 2022
T3a - The operationalization of ecosystem services indicators: a matter of scale, data, purpose and end-users
https://www.espconference.org/europe22/wiki/754946/session-overview

ipbes

150 leading international experts, over 50 countries around the world are contributing to the Nexus assessment.

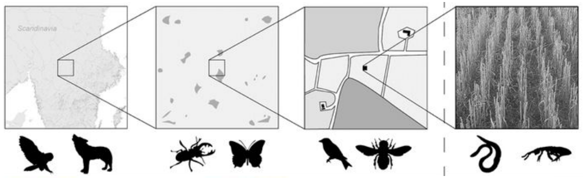
The way forward

Next steps & Conclusions

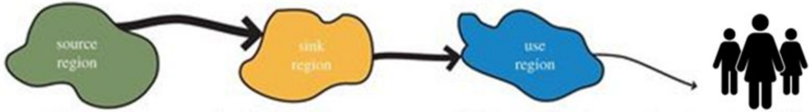
The operationalization of Ecosystem Services

The journey to monitoring ecosystem services

1. **Identify key ES indicators**
2. **Combining observations and data across scales**



3. **Monitor teleconnections among ES**



4. **Identifying essential social metrics of ES and improve socio-ecological link**

5. **Interdisciplinary collaboration to guide applications**

A DSS for sustainable agriculture: Roadmap

LPIS, EO, Climate, ES historical data sources

Land suitability score

If I do practice T, what is the impact on a land plot with features X?

Climate change awareness

How are practice impacts expected to change because of CC?

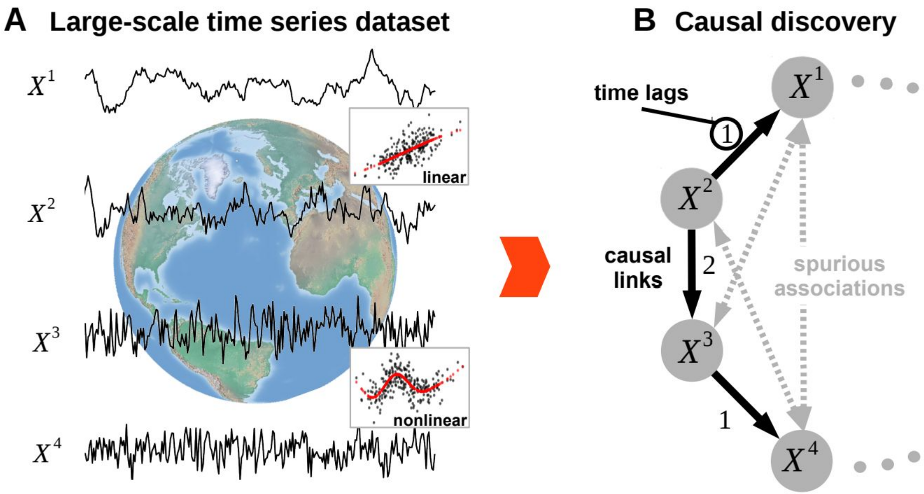
Data → Causal ML → Assess Suitability → Derive Policy → CC-aware Future

Model the heterogeneous effect of a practice T on a metric Y

Based on the characteristics of my land, what practice is most effective?

Assign most effective practice to each plot

Outlook



Agricultural policy making as a geospatial **impact assessment** problem

Data-hungry methods meet ever-increasing volumes of EO data

Other exciting directions have yet to be pursued (discovery of causal drivers in ecosystems, natural experiments)

Modern, not “black-box” science - inherently explainable and transparent

Hard to evaluate: more domain knowledge & robustness checks needed

Thanks! Questions?