BioSpace25 - Biodiversity insight from Space
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Using synthetic controls to attribute biodiversity shifts to remotely sensed landscape modifications

Joaquim Estopinan[1], Sara Si-Moussi[1], Lori Giagnacovo[2], Vincent Mièle[1], Wilfried Thuiller[1]

[1]LECA, CNRS, France; [2]VITO, Belgium

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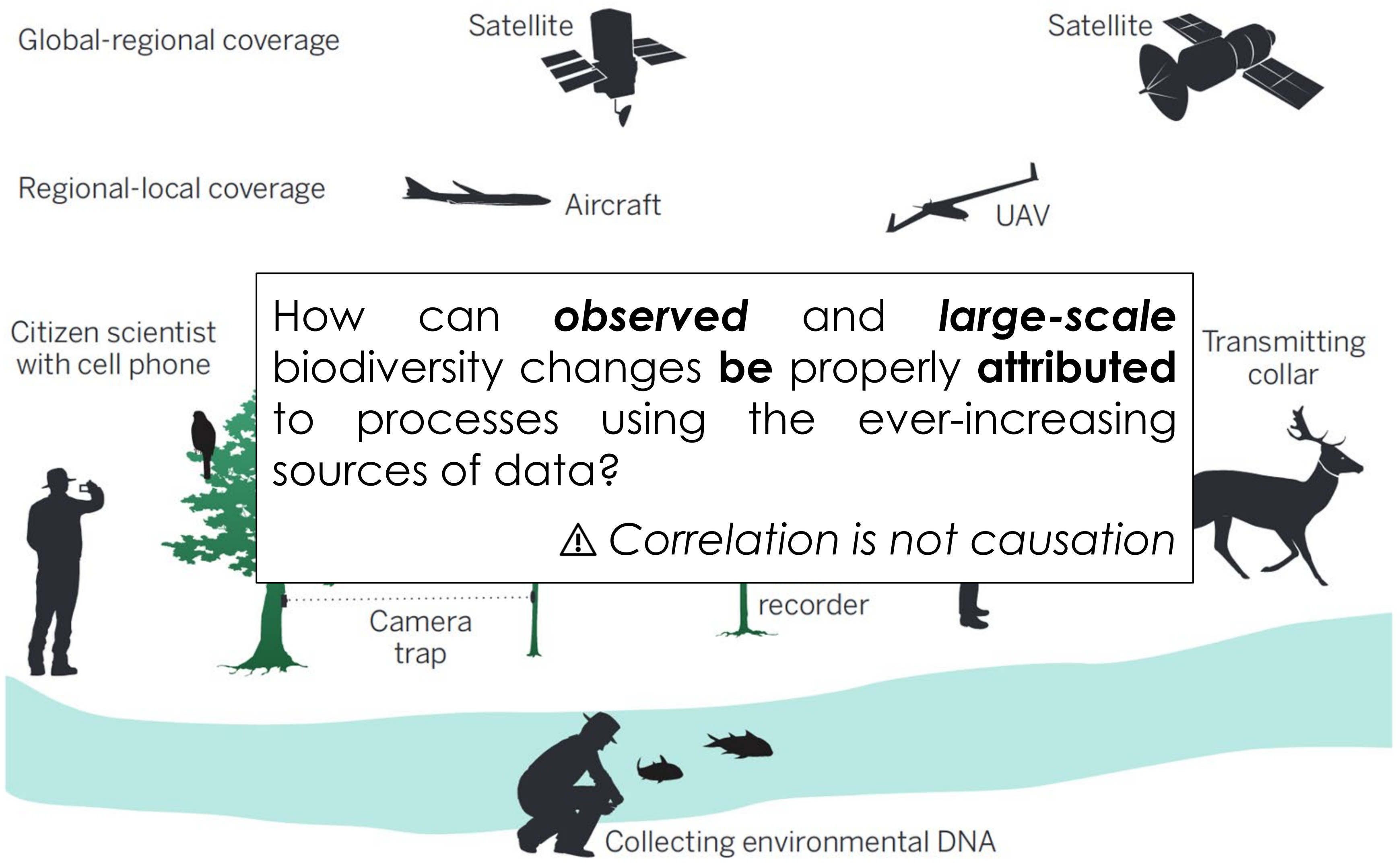
OBSGESSION
Observation of ecosystem changes for action

CESAB
CENTRE FOR THE SYNTHESIS AND ANALYSIS OF BIODIVERSITY

Biodiversity loss…

1. Monitored from increasing *observational* data sources
2. Resulting from blurry & entangled anthropogenic processes



How can ***observed*** and ***large-scale*** biodiversity changes **be** properly **attributed** to processes using the ever-increasing sources of data?

⚠ *Correlation is not causation*

Turner, Woody. "Sensing biodiversity." (2014)

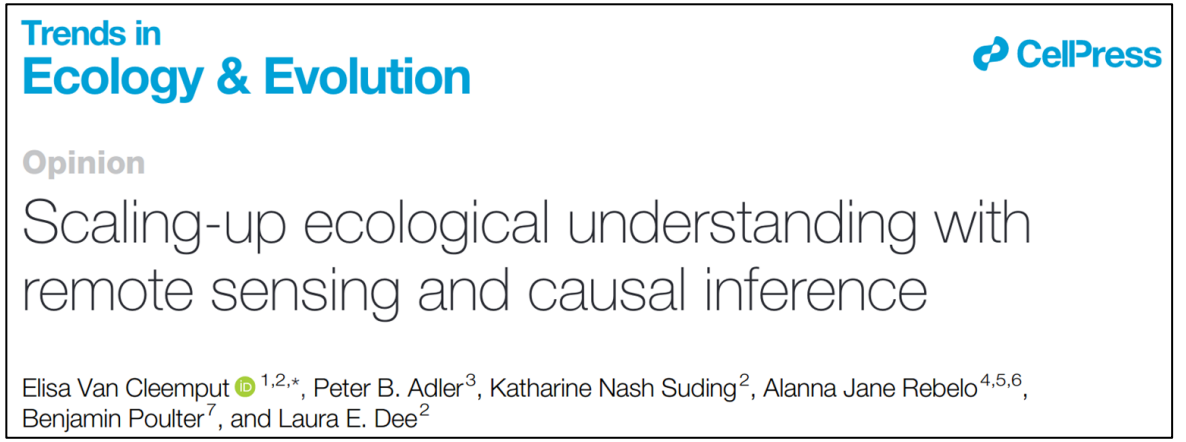
Díaz, Sandra, et al. "Pervasive human-driven decline of life on Earth points to the need for transformative change." (2019)

RS-driven causal inference needed to disentangle biodiversity pressures across scale

→ **Small-scale experiments** and observations have considerably raised understanding in biodiversity processes and functions

⚠ **However**, relationships **do not necessarily hold across scale** because of **confounding effects** that are:

- **Controlled for** at **small-scale**
- **Numerous** and **heterogenous** at **large scale**

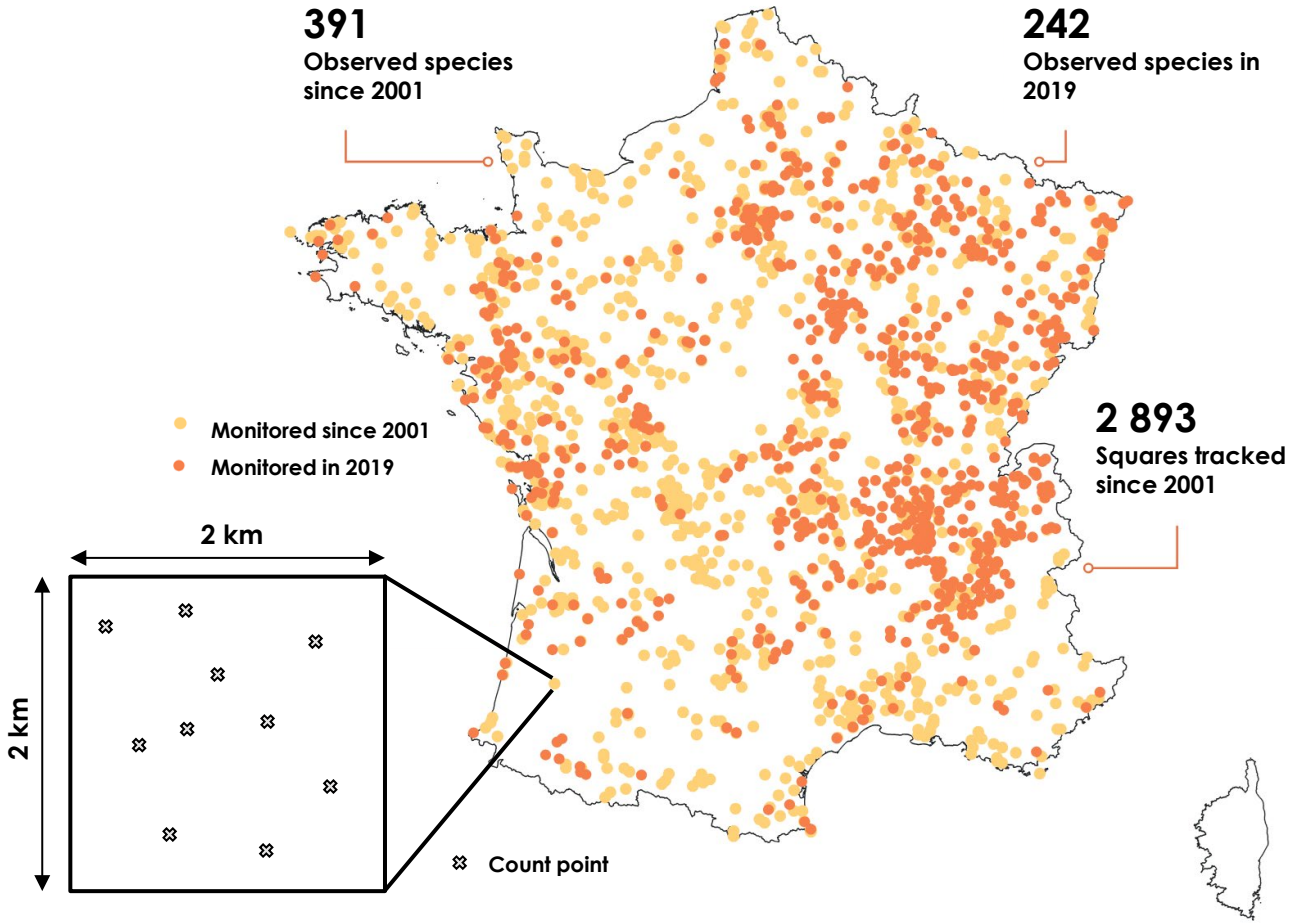


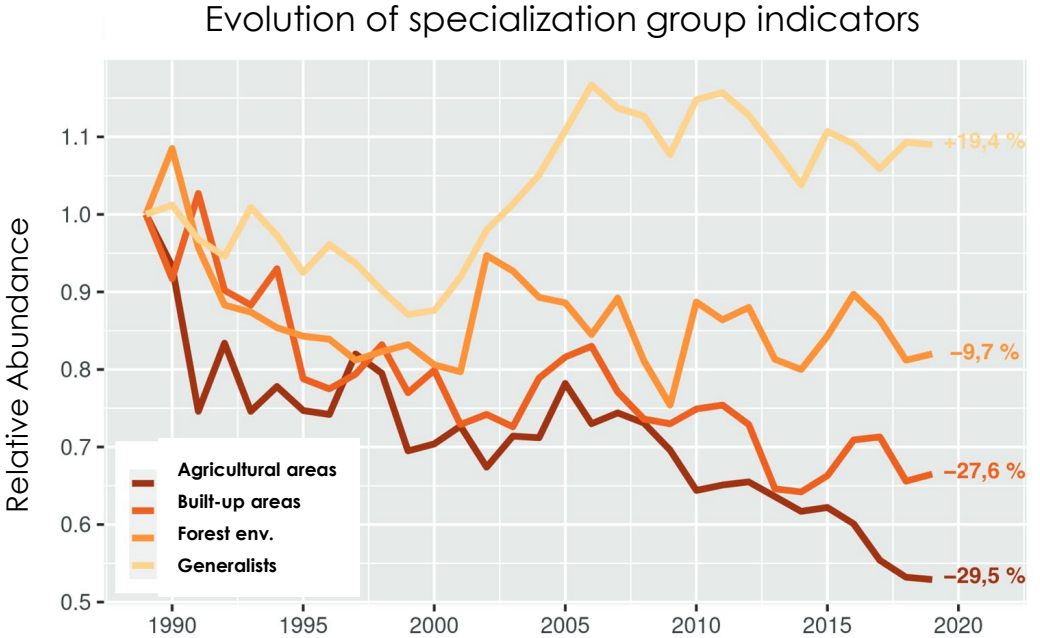
NEEDED

Remote sensing ∩ **Causal inference**

STOC | Temporal Monitoring of Common Birds

- Standardized count protocol of common birds in France
  - Study period = **2001 - 2019**
- **4 km²** square plots are monitored according to an annual random draw

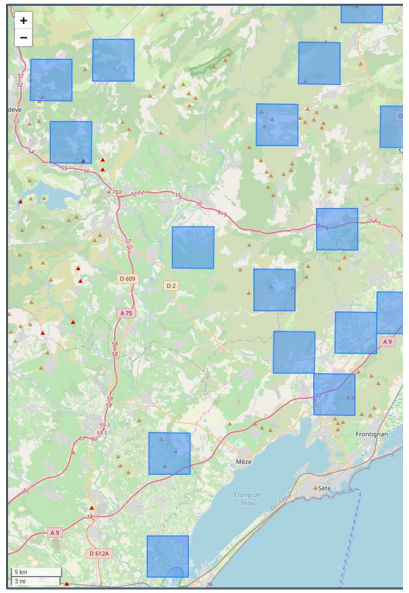


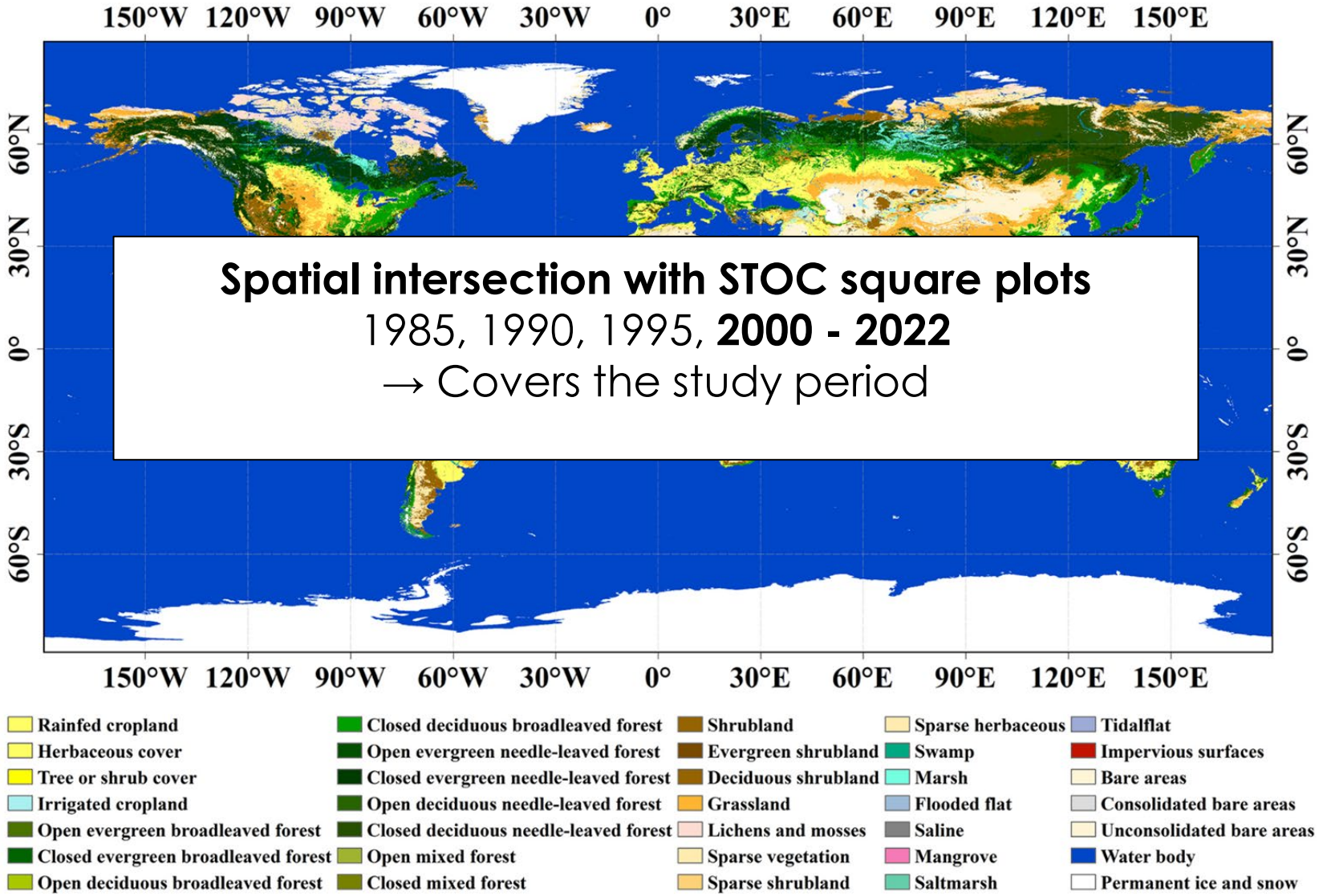


Fontaine, Benoît, et al. "Suivi des oiseaux communs en France 1989-2019: 30 ans de suivis participatifs." (2021)

Land cover | GLC_FCS30D (Zhang et al. 2024)

STOC plots **[2001 -**



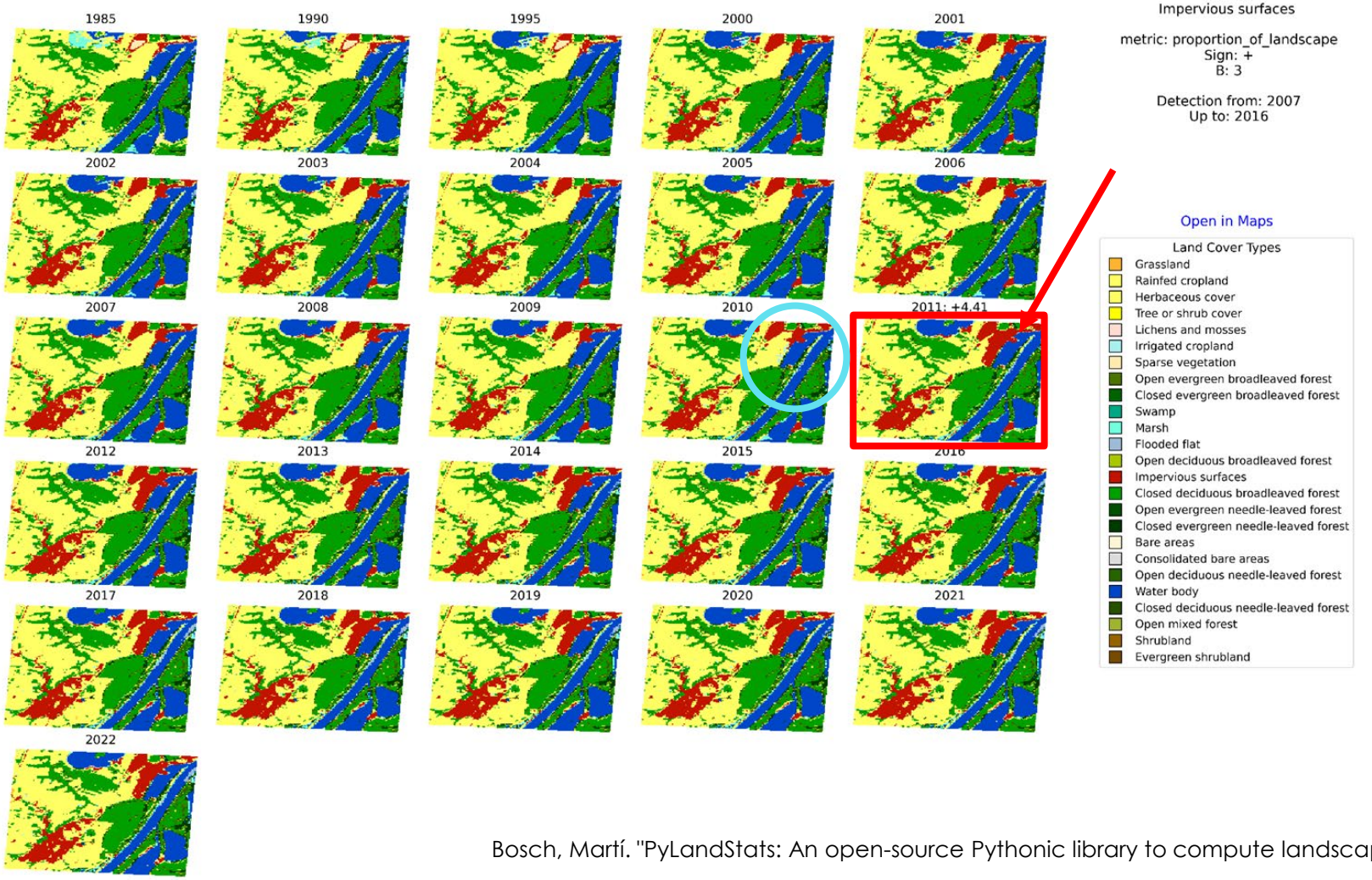


Spatial intersection with STOC square plots
1985, 1990, 1995, **2000 - 2022**
→ Covers the study period

LC change detection | Urbanization

From the annual class metric differences computed with PyLandStats (Bosch, 2019)

Assumption:
Urbanization will disturb bird resources and habitats



Bosch, Martí. "PyLandStats: An open-source Pythonic library to compute landscape metrics." (2019)

Question | Do the detected LC changes impact bird diversity metrics?

How do we test it ?

→ **Synthetic control** & variants, emerging from the field of econometrics

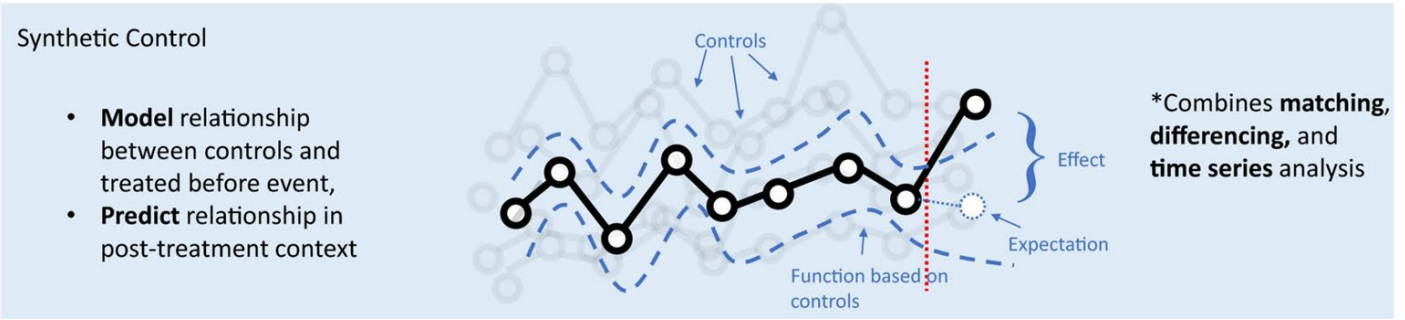
ECOLOGICAL APPLICATIONS
ECOLOGICAL SOCIETY OF AMERICA

Article | Full Access

Evaluating natural experiments in ecology: using synthetic controls in assessments of remotely sensed land treatments

Stephen E. Fick, Travis W. Nauman, Colby C. Brungard, Michael C. Duniway

First published: 21 November 2020 |



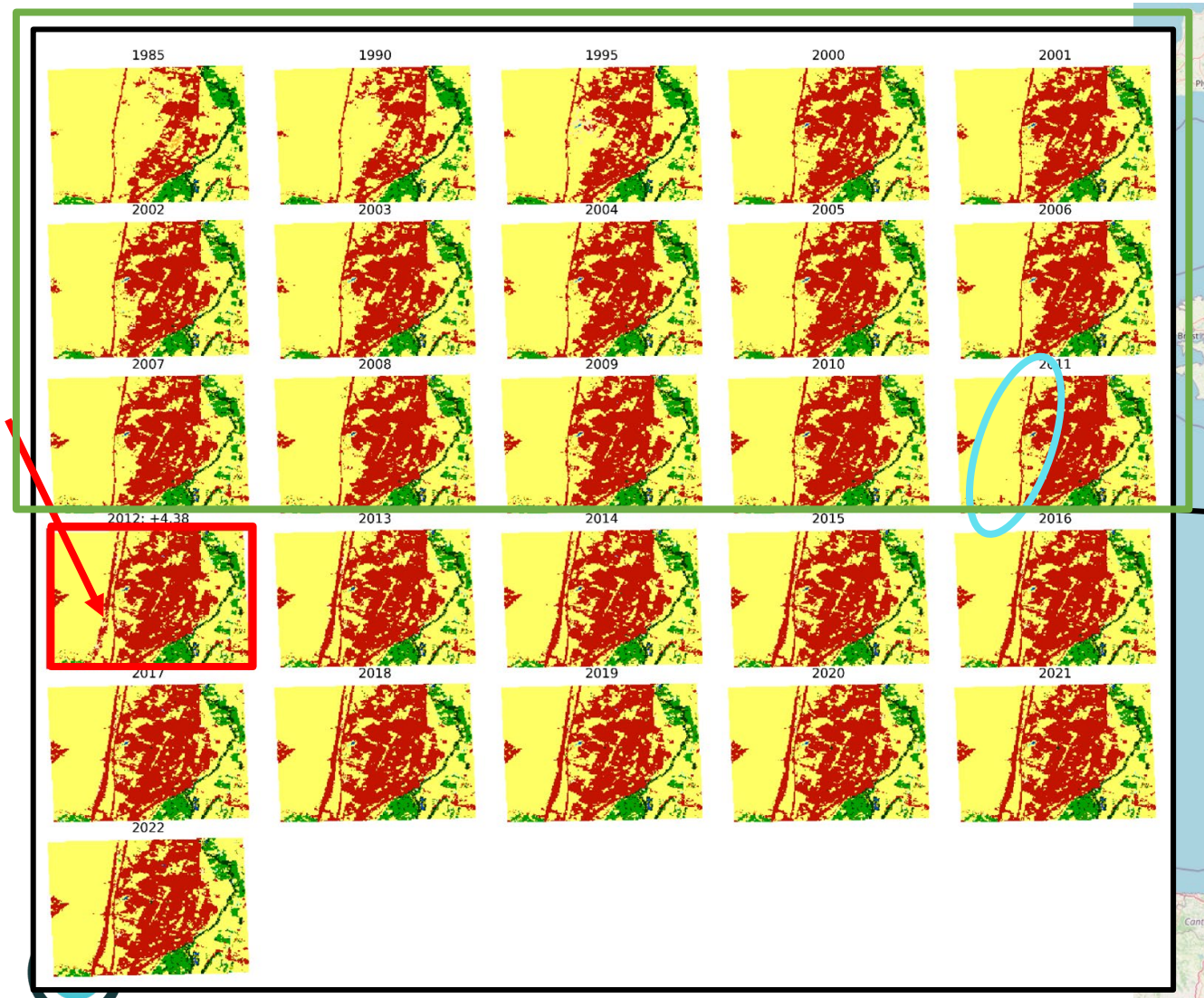
+ Allows to **isolate** and **test** the effect of an **abrupt change [**LC change**]** on an outcome variable **[**Bird abundance**]**
+ Reconstructs *what would have happened if a treatment had not occurred*, i.e. *the counterfactual*, based on **the *pre-intervention* relationship between the impacted units and a group of unaffected units**

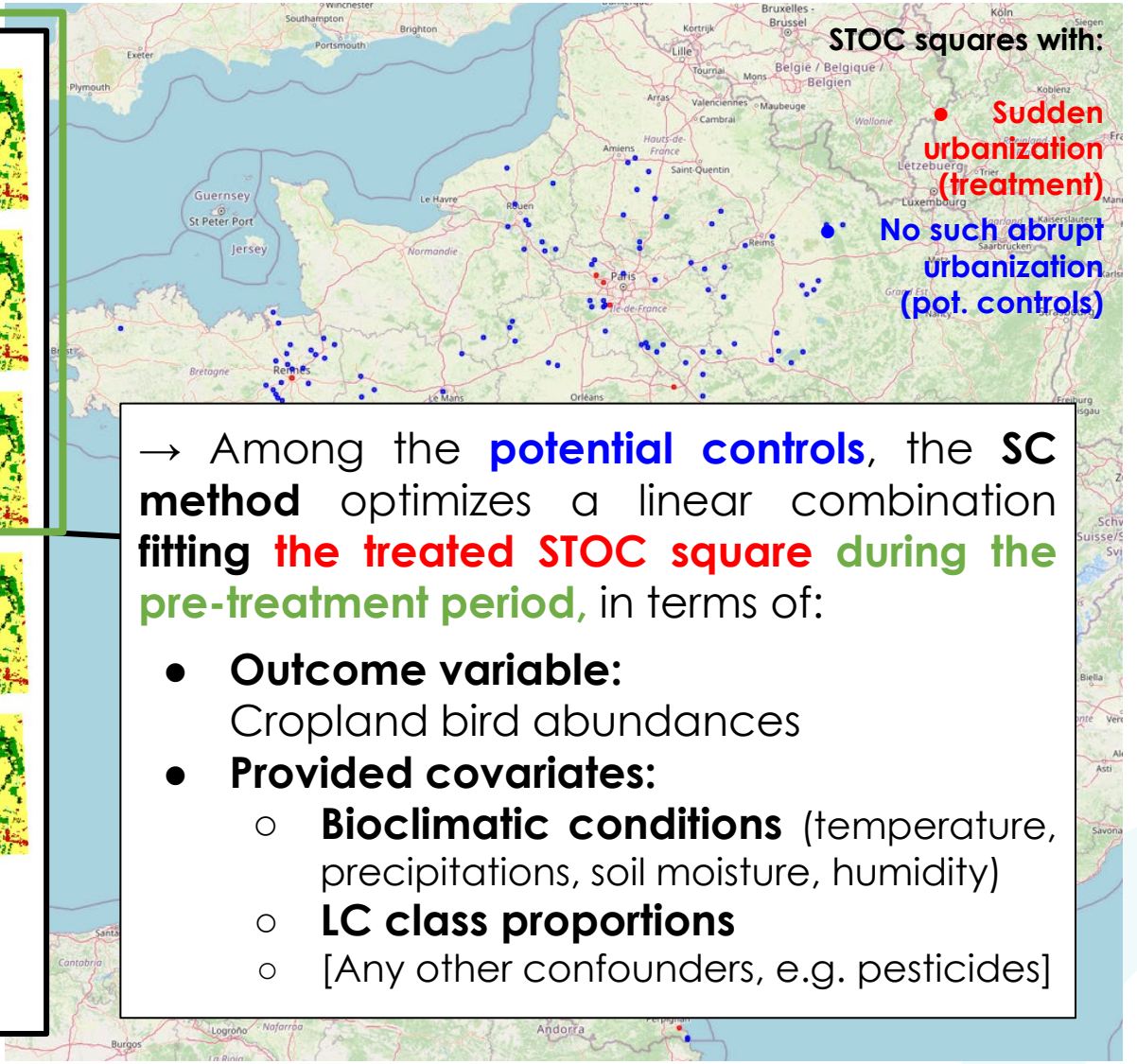
Abadie, Alberto, and Javier Gardeazabal. "The economic costs of conflict: A case study of the Basque Country." (2003)
Abadie, Alberto. "Using synthetic controls: Feasibility, data requirements, and methodological aspects." (2021)

Sudden urbanization effect

Case study

Sudden urbanization (Detected on RS products squares) → **Cropland bird A.** (STOC)





→ Among the **potential controls**, the **SC method** optimizes a linear combination **fitting the treated STOC square during the pre-treatment period,** in terms of:

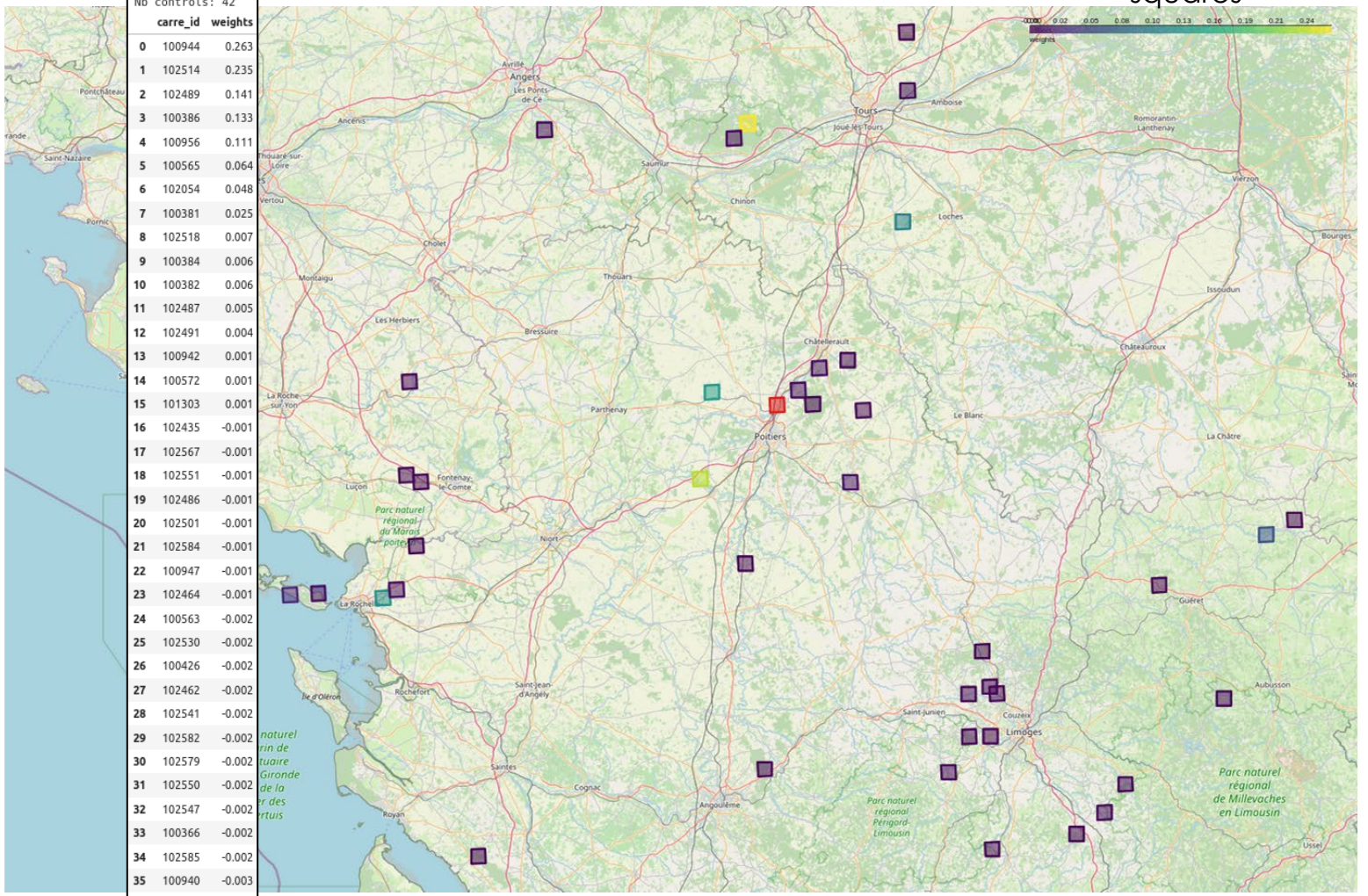
- **Outcome variable:**
  Cropland bird abundances
- **Provided covariates:**
  - **Bioclimatic conditions** (temperature, precipitations, soil moisture, humidity)
  - **LC class proportions**
  - [Any other confounders, e.g. pesticides]

Sudden urbanization ?→ **Cropland bird A.**
Detected on RS products — STOC
squares

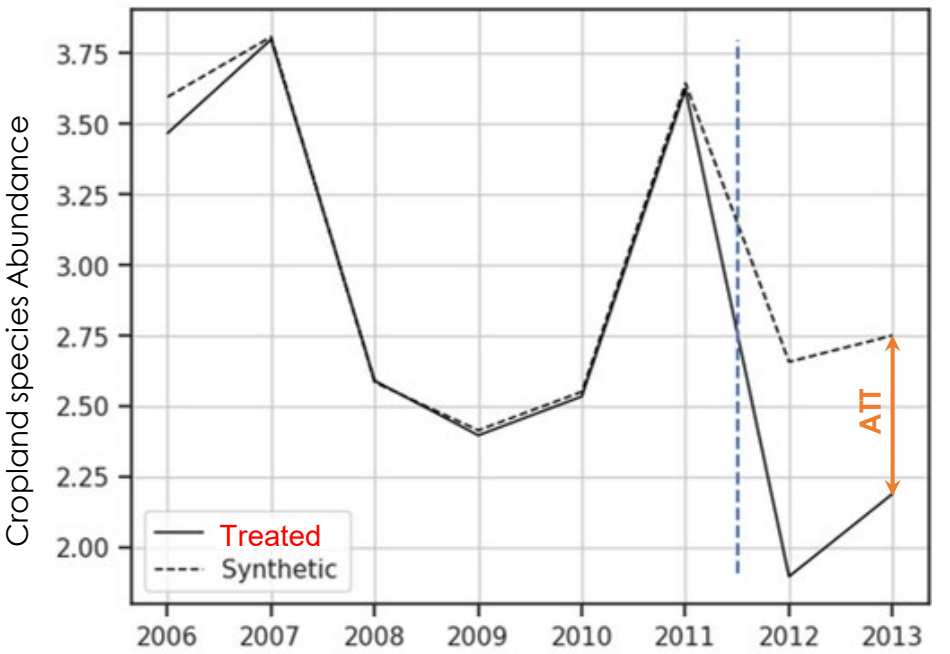
Results | Augmented SC

Nb controls: 42

	carre_id	weights
0	100944	0.263
1	102514	0.235
2	102489	0.141
3	100386	0.133
4	100956	0.111
5	100565	0.064
6	102054	0.048
7	100381	0.025
8	102518	0.007
9	100384	0.006
10	100382	0.006
11	102487	0.005
12	102491	0.004
13	100942	0.001
14	100572	0.001
15	101303	0.001
16	102435	-0.001
17	102567	-0.001
18	102551	-0.001
19	102486	-0.001
20	102501	-0.001
21	102584	-0.001
22	100947	-0.001
23	102464	-0.001
24	100563	-0.002
25	102530	-0.002
26	100426	-0.002
27	102462	-0.002
28	102541	-0.002
29	102582	-0.002
30	102579	-0.002
31	102550	-0.002
32	102547	-0.002
33	100366	-0.002
34	102585	-0.002
35	100940	-0.003
36	102573	-0.003
37	102055	-0.003
38	102566	-0.003
39	100372	-0.003
40	102497	-0.003
41	100587	-0.004



Positions and weights of selected controls
Lots of small negative weights



Very **good** pre-treatment fit …

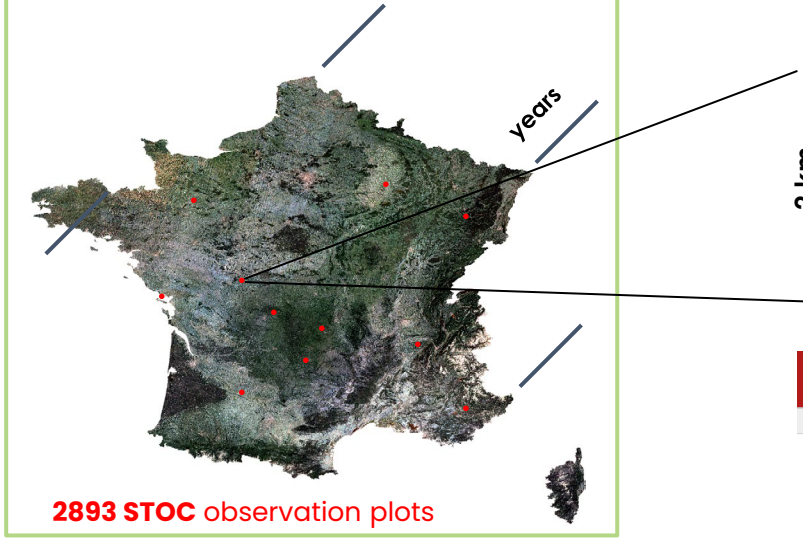
… But can we still trust this complex control combination?

→ **Placebo tests** allow testing the robustness and significance of the identified effect
p-value = 0.14

Ben-Michael et al. "The Augmented Synthetic Control Method." (2020)

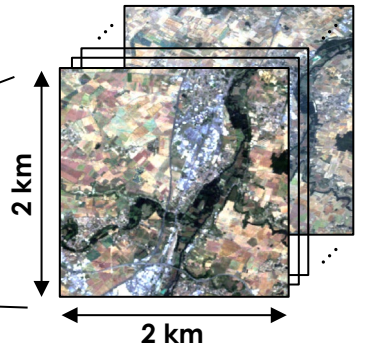
Back to change detection | What about embeddings from RS Foundation Models? (RSFM)

LANDSAT
Annual mosaics 2000-2023, 30 m
RGB, NIR, SWIR 1 & 2



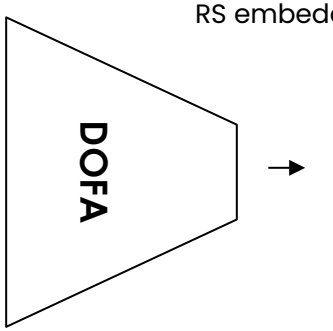
2893 STOC observation plots

Time-series extraction



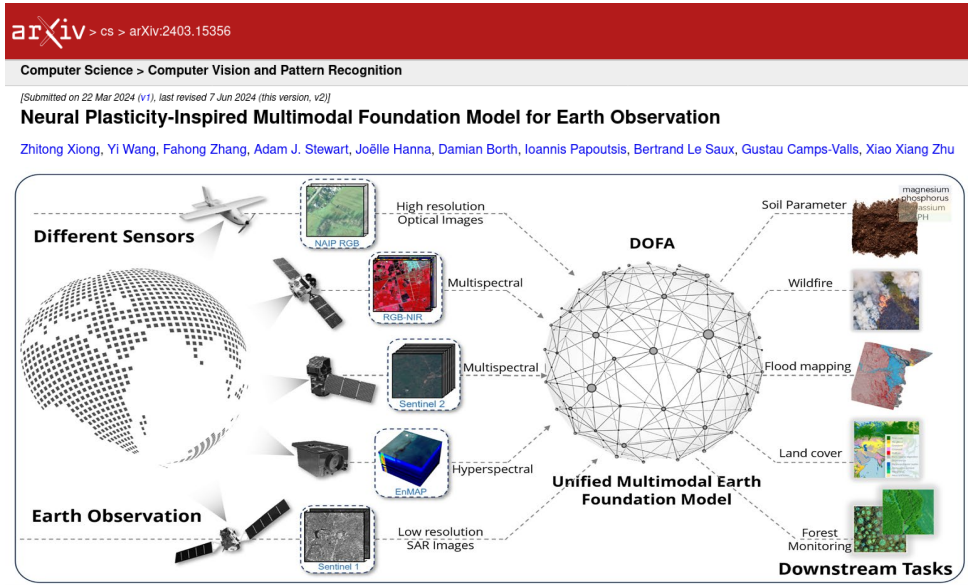
RSFM inference

RS embeddings (**768 x 1**)



Dimension reduction [UMAP]
+
Clustering [HDBSCAN]

Do we recover the same abrupt changes than with land cover metrics computation?



[Preliminary results]

Recovery rates - Annual embedding clusters aligned with abrupt land cover changes

- Urbanization : **80.95%** (68/84)

Leland McInnes et al. "Umap: Uniform manifold approximation and projection for dimension reduction." (2018)
Campello et al. "Density-based clustering based on hierarchical density estimates." (2013)

Conclusion

- **Landscape changes** at the STOC square level **can be detected** both from **LC products** and from clustering **RSFM embeddings** of multispectral imagery

- **Base SC requires long TS** and ~stable outcome variables
  - ➔ *Future work:* Continue testing **variants** between **matching** & **SC** methods to **accommodate shorter TS**

- Working at the bird **specialisation group** level, **no significant effects** could be **detected** across STOC plots
  - ➔ *Future work:* **Species-level** analyses open a new perspective to **disentangle species dynamics**

Three key recommendations for the conference organisers to consider in their future R&D and policy-related activities

- *Evaluate policy implementation with counterfactual modelling*
- *Encourage interdisciplinary research within project calls*
- *Facilitate data sharing across scales but also disciplines*

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joaquim.estopinan@univ-grenoble-alpes.fr

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