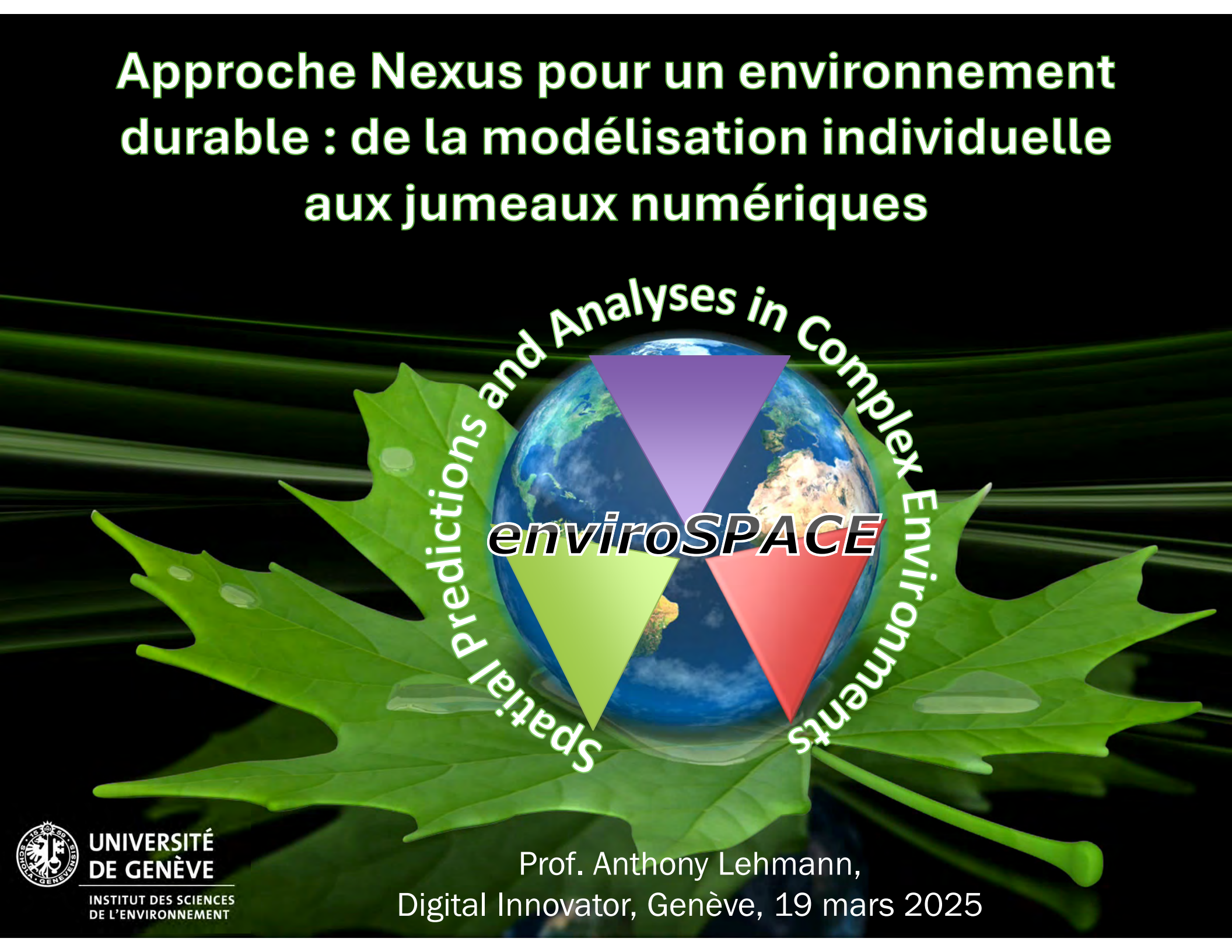
Approche Nexus pour un environnement durable : de la modélisation individuelle aux jumeaux numériques



UNIVERSITÉ DE GENÈVE
INSTITUT DES SCIENCES DE L'ENVIRONNEMENT

Prof. Anthony Lehmann,
Digital Innovator, Genève, 19 mars 2025

Talk plan

1. Introduction
2. Essential variables and workflows
3. Individual models approach
4. Models integration into Ecological Infrastructures
5. Need for a Nexus approach
6. Towards Digital Twins

An attempt to summarize my personal journey from from individual modeling approaches to nexus and digital twins approaches

1

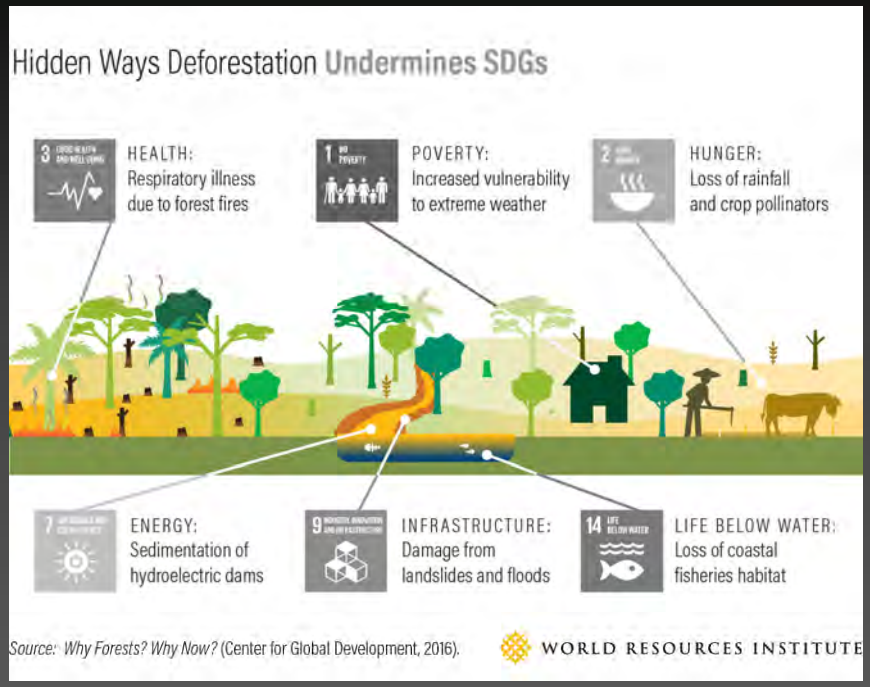
INTRODUCTION

Ecosystem Services (ES)

Ecosystem services are the benefits that humans derive from the environment and ecosystems.

Metro Vancouver Regional Planning 2018

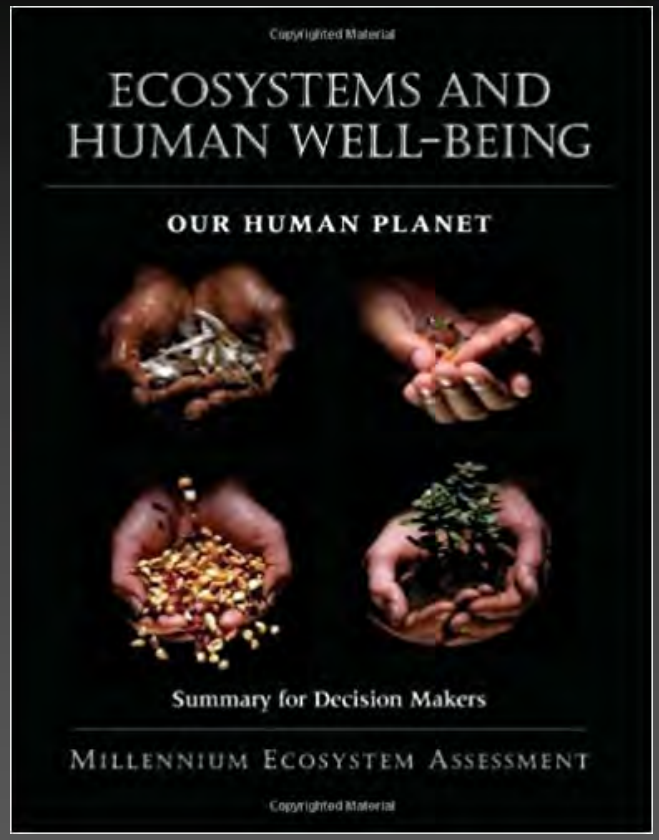
Healthy Ecosystems Provide ES to SDGs like in forests



https://www.cgdev.org/sites/default/files/Seymour-Busch-why-forests-why-now-full-book.PDF

https://wri-indonesia.org/en/blog/forests-and-sdgs-taking-second-look

Millenium Ecosystem Assemment

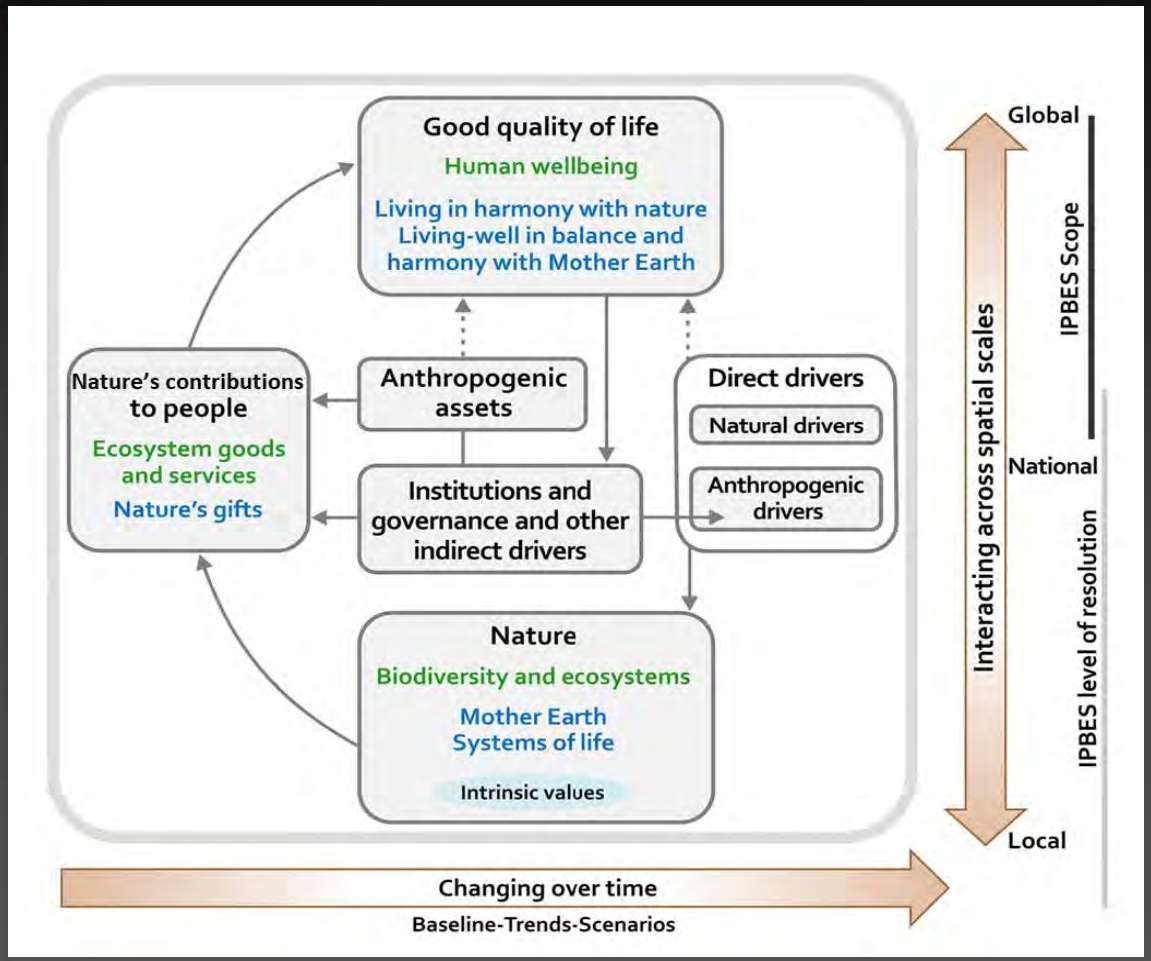


This report widely disseminated the concept of ES with its classification as:

- Support
- Supply
- Regulation
- Cultural

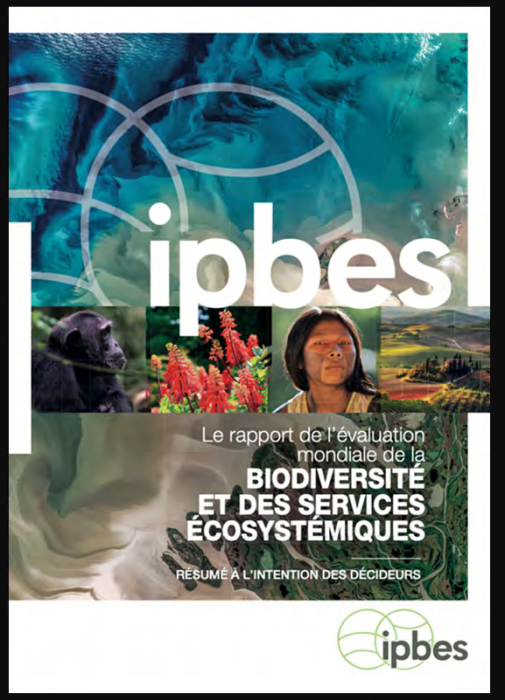
UN, MEA 2005

IBPES Conceptual Framework



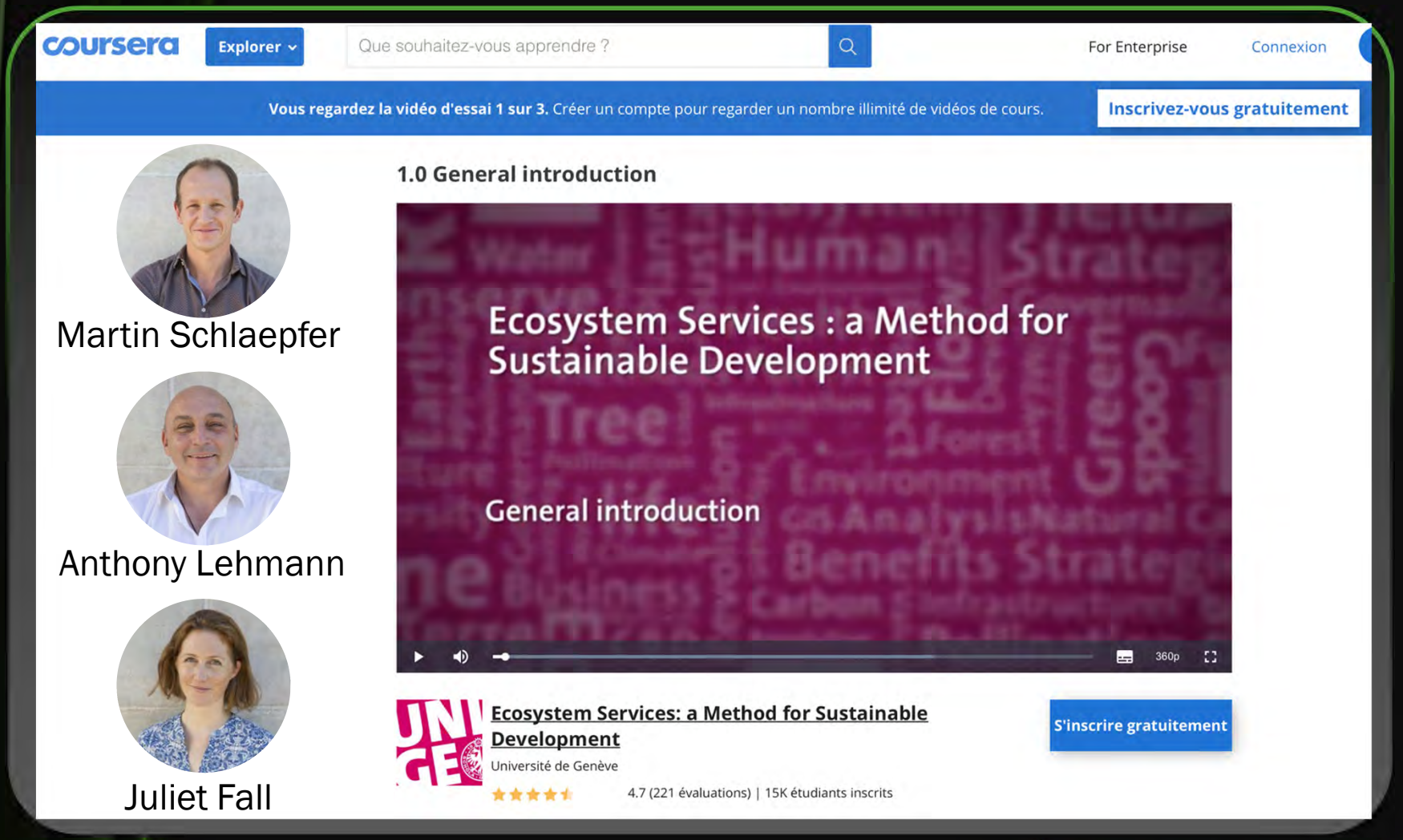
Concepts of occidental science

Other forms of knowledge



- "Nature," "nature's contributions to people" and "good quality of life" are inclusive categories that have been identified in a participatory process.
- This includes other knowledge systems, such as those of indigenous peoples and local communities.

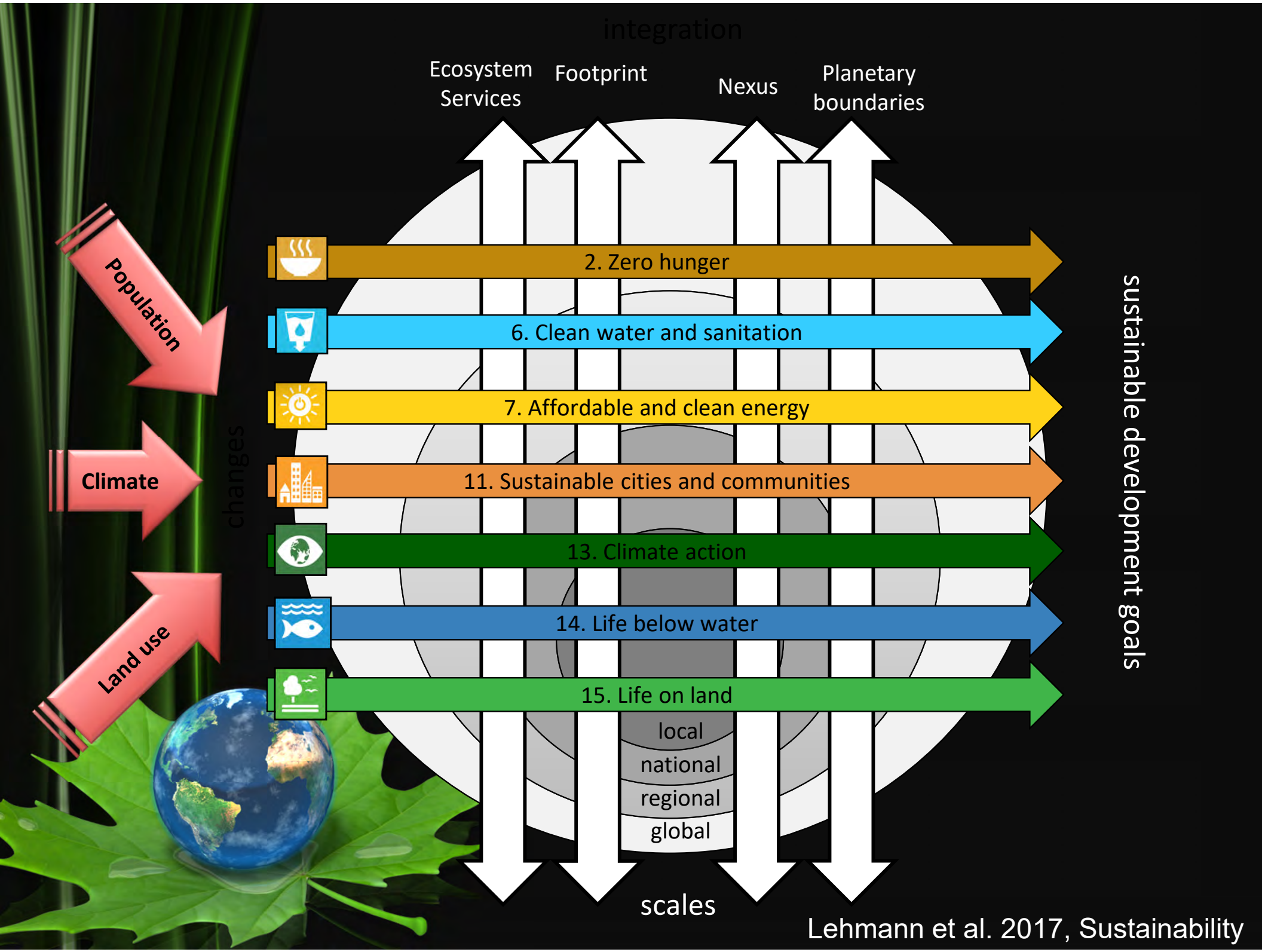
https://ipbes.net/global-assessment



MOOC sur les Services Ecosystémiques

An online course developed at the University of Geneva that critically presents Ecosystemic Services, their economic, biophysical and spatial assessments, as well as their political implementation.

https://www.coursera.org/learn/ecosystem-services

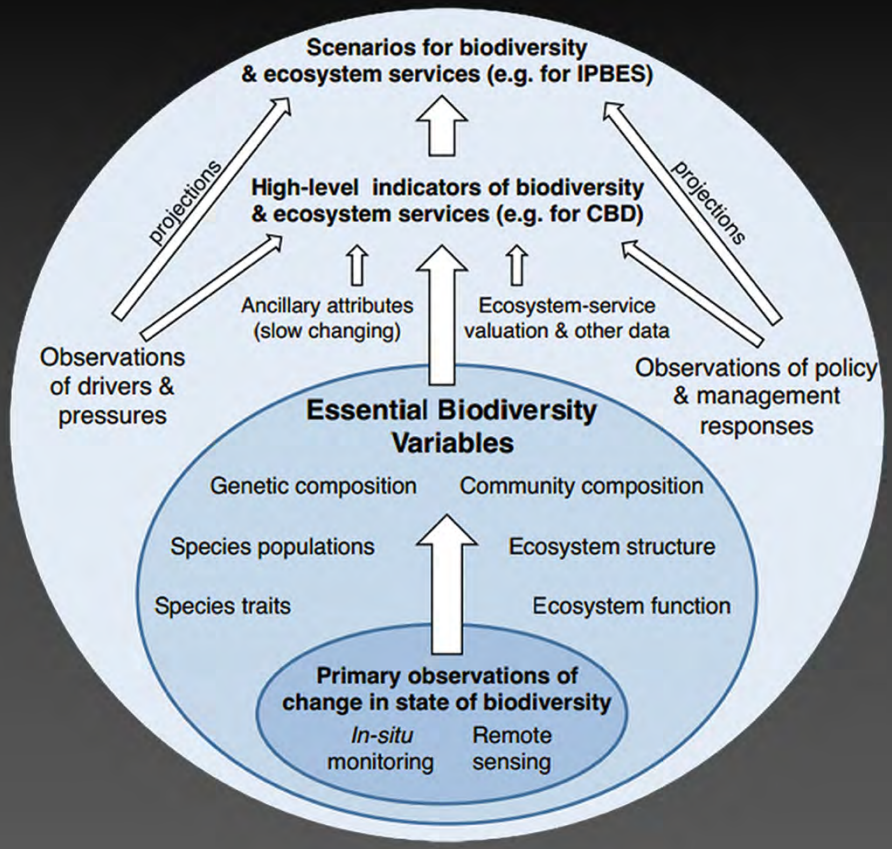

integration
Ecosystem Services
Footprint
Nexus
Planetary boundaries
Population
Climate
Land use
changes
2. Zero hunger
6. Clean water and sanitation
7. Affordable and clean energy
11. Sustainable cities and communities
13. Climate action
14. Life below water
15. Life on land
local
national
regional
global
scales
sustainable development goals
Lehmann et al. 2017, Sustainability

2

ESSENTIAL VARIABLES AND WORKFLOWS

Essential Biodiversity Variables (EBVs)

EBV classes	Candidates
Genetic composition	Co-ancenstry Allelic diversity Population genetic differentiation Breed and variety diversity
Species populations	Species distribution Population abundance Population structure
Species traits	Phenology Body mass Natal dispersion distance Migratory behavior Demographic traits Physiological traits
Community composition	Species richness Species interactions
Ecosystem function	Net primary productivity Secondary productivity Nutrient retention Disturbance regime
Ecosystem structure	Habitat structure Ecosystem extent and fragmentation Ecosystem composition by functional type

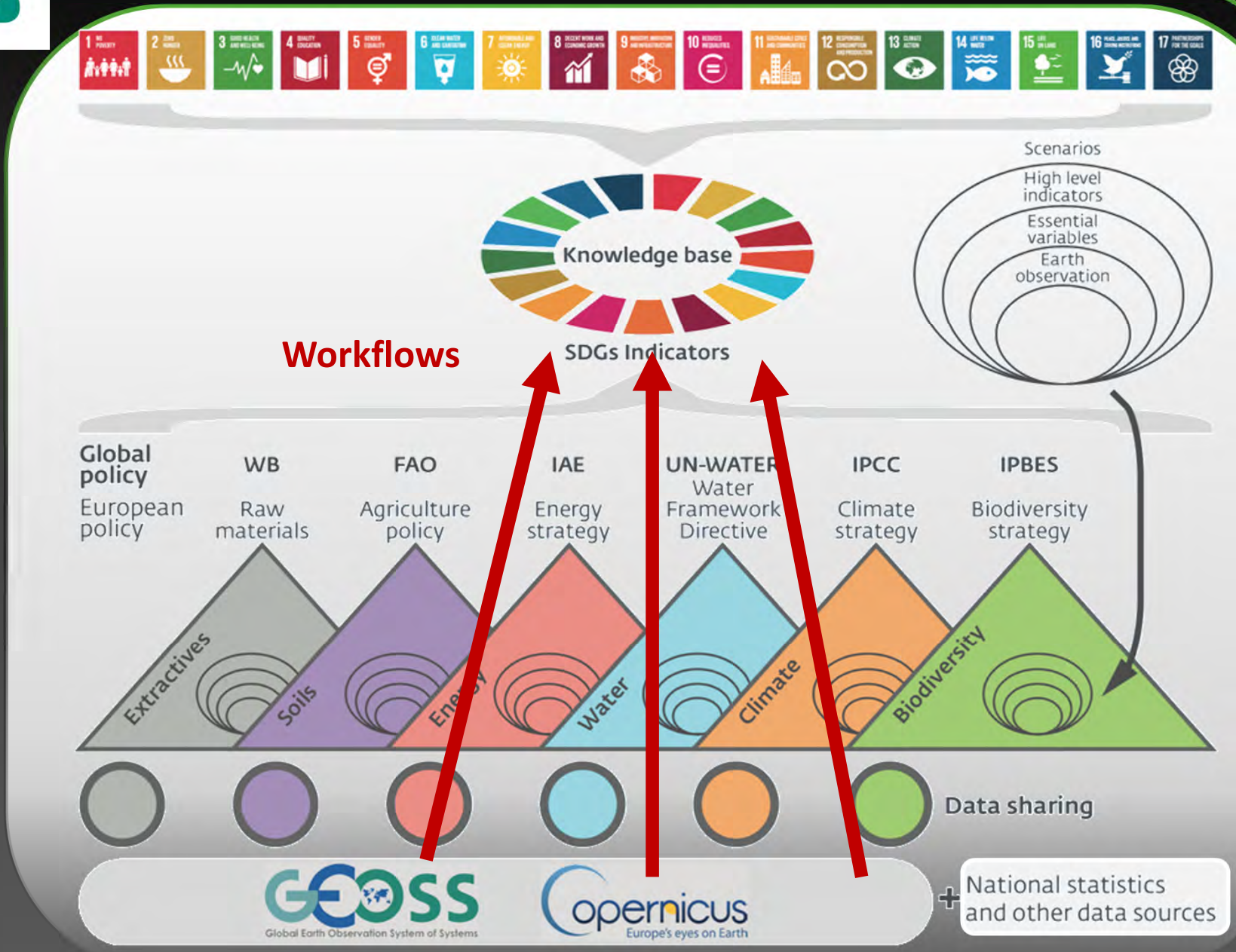


Essential variables of biodiversity are defined as the derived measures needed to study, report and manage changes in biodiversity, focusing on the state and trend of biodiversity elements. They provide the first level of abstraction between low-level primary observations and high-level biodiversity indicators.

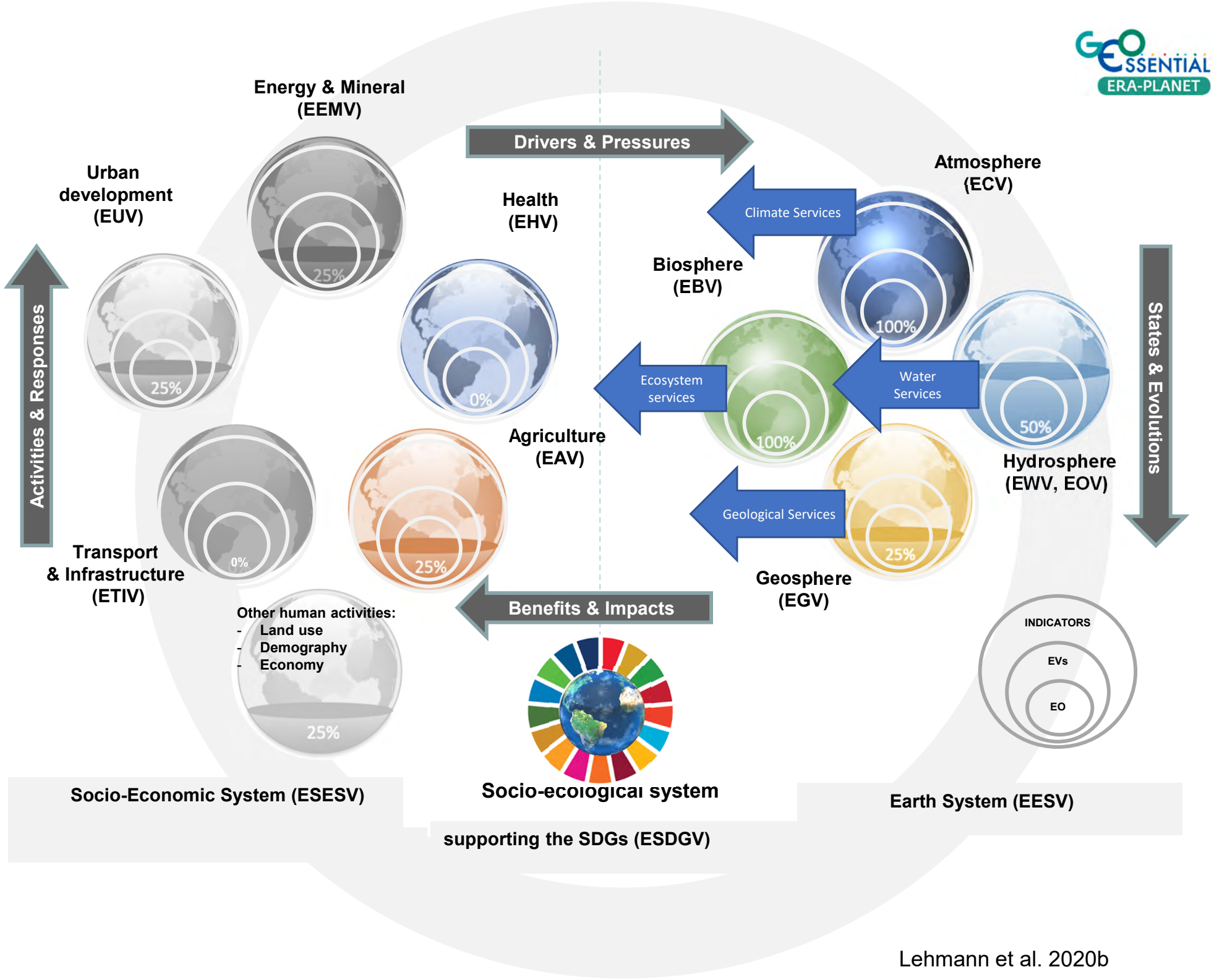
https://geobon.org/ebvs/what-are-ebvs/

GEOEssential project

GEOEssential general framework linking data sources to policy indicators through Essential Variables

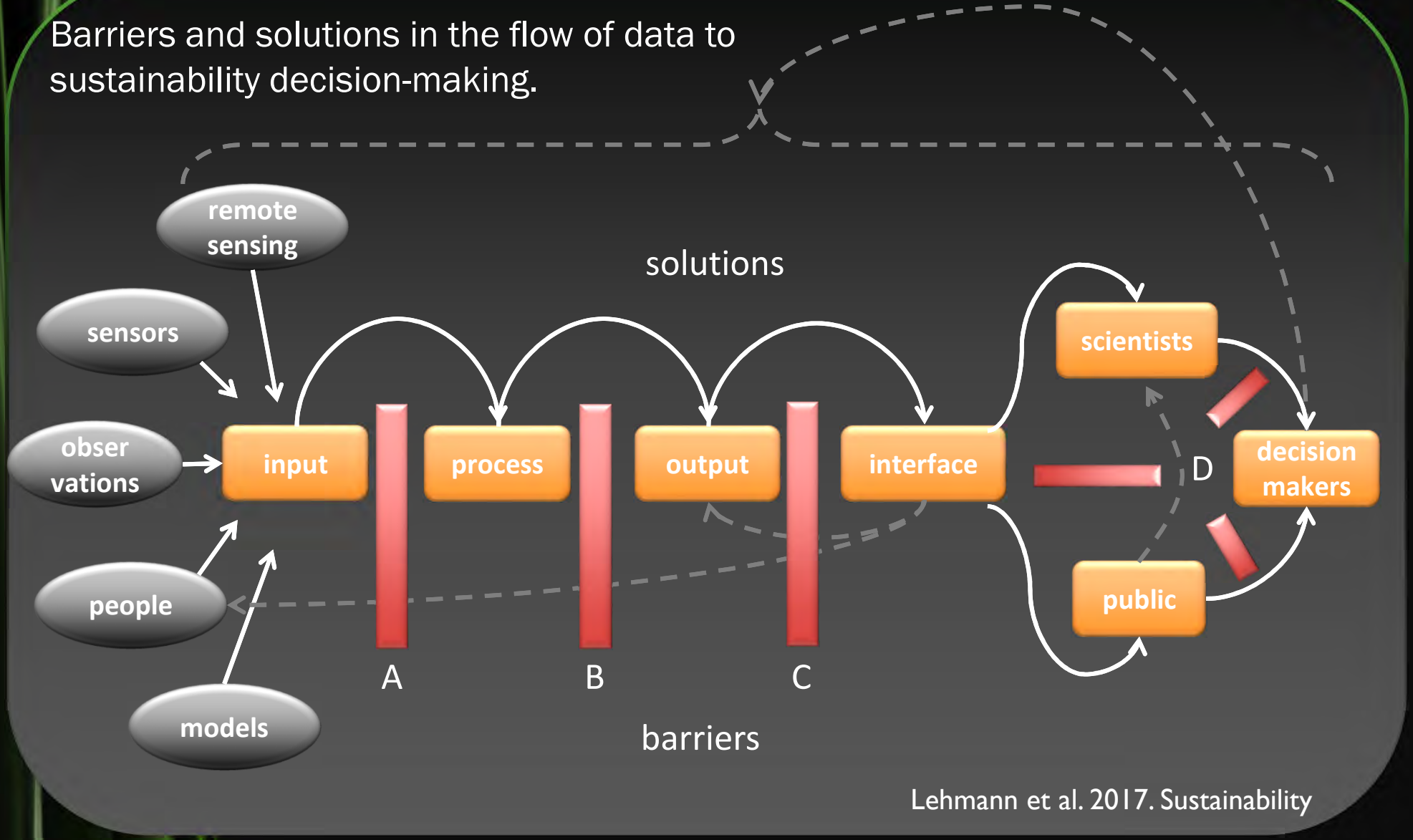


Lehmann et al. 2019. IJDE



Lehmann et al. 2020b

Barriers and solutions in the flow of data to sustainability decision-making.



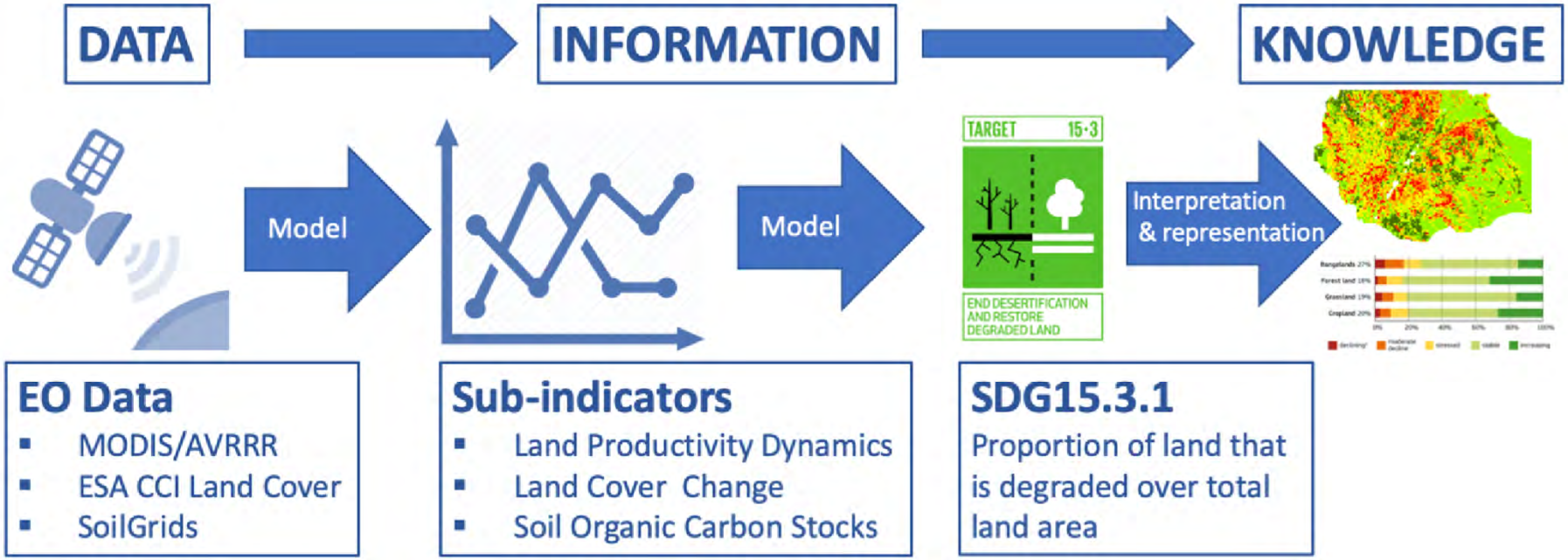
(A) access to data; (B) data size; (C) the ability to develop and iterate existing software; and (D) knowledge transmission. Simple arrows are solutions for removing obstacles, and dotted arrows represent an active feedback in the workflow.

Lehmann et al. 2017

GEOEssential workflow

SDG 15.3.1 Land Degradation…

… is undermining the well-being of 3.2 billion people (IPBES)



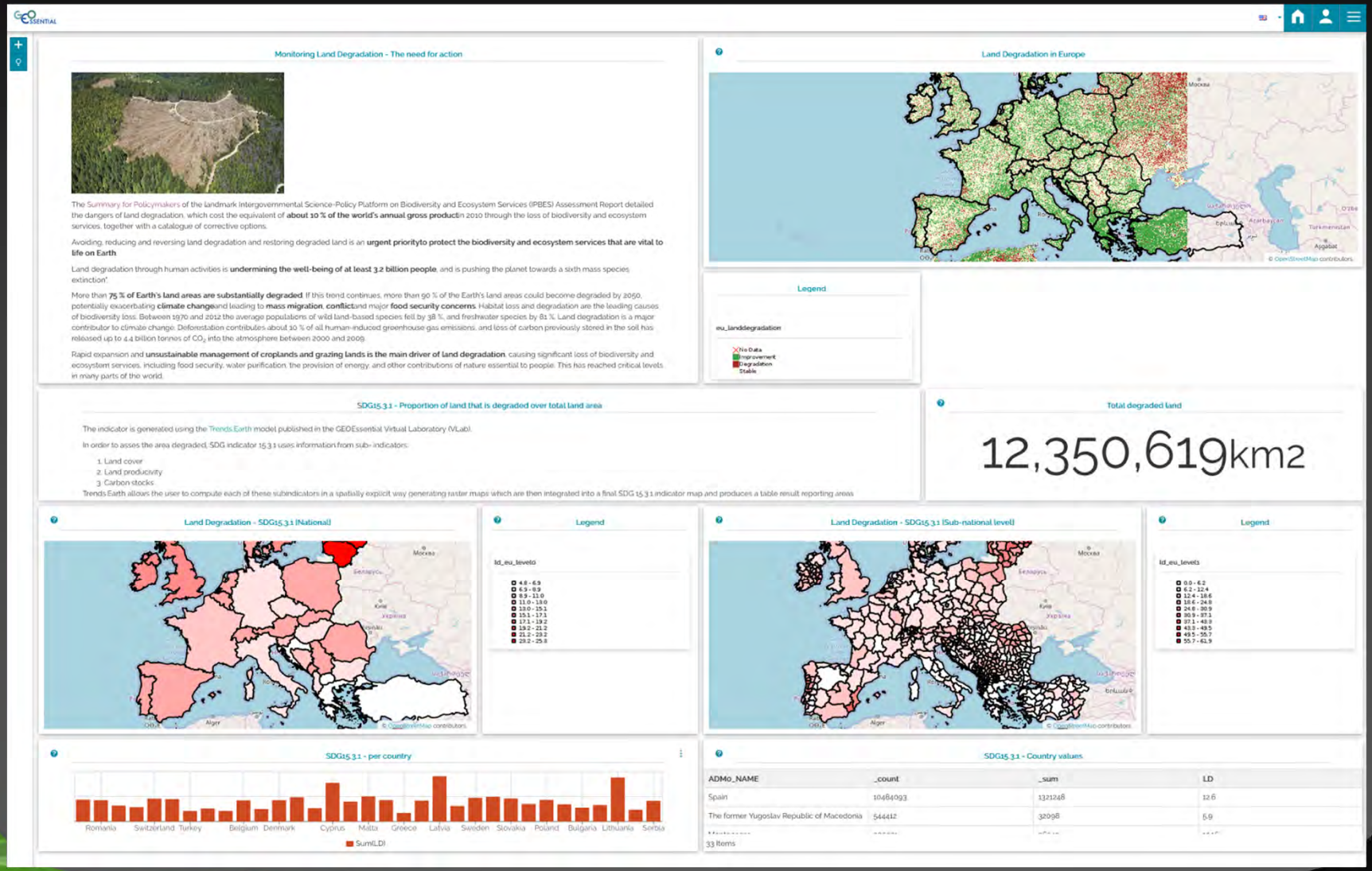
Giuliani et al., submitted

Collaboration: University of Geneva; GEO; ESA, CNR, JRC; UN Environment

http://www.geoessential.eu

GEOEssential Dashboard…

…using GeoServer, GeoNetwork, MapStore



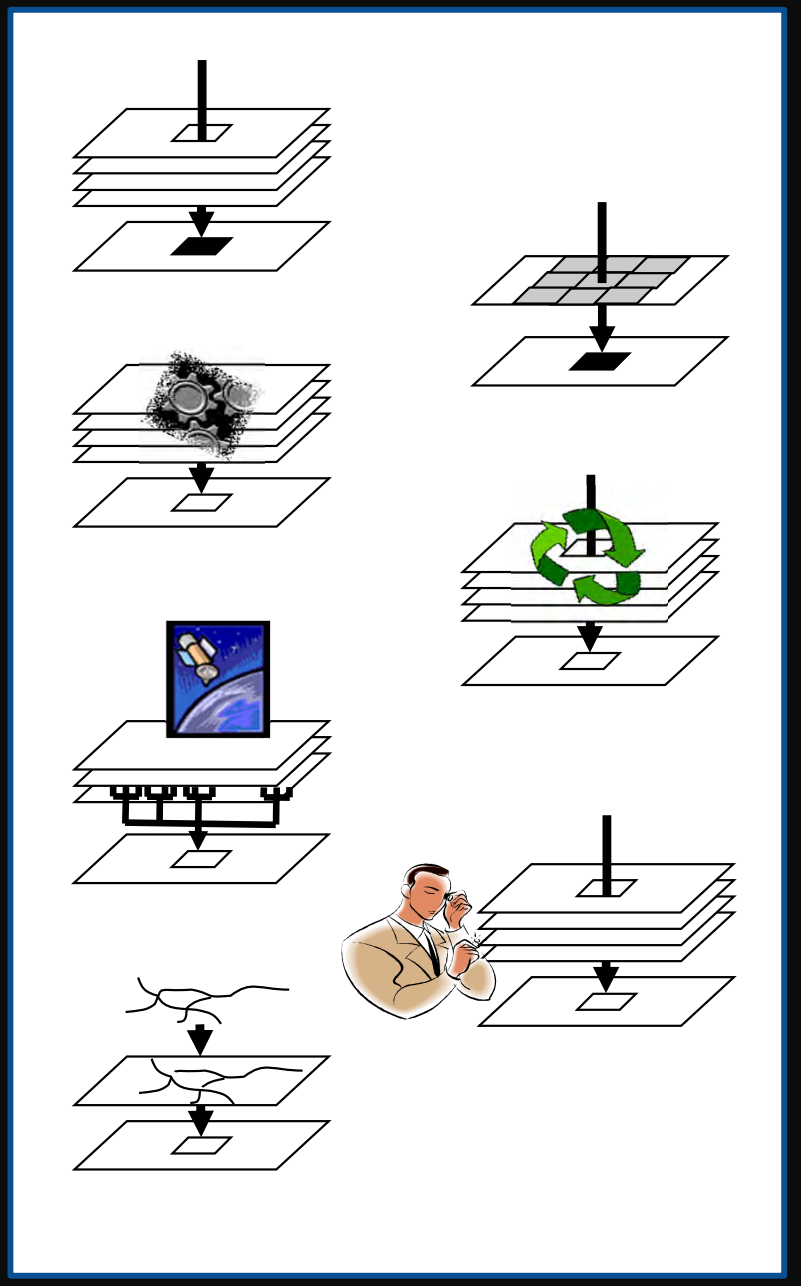
https://geoessential.unepgrid.ch/mapstore/#/dashboard/4

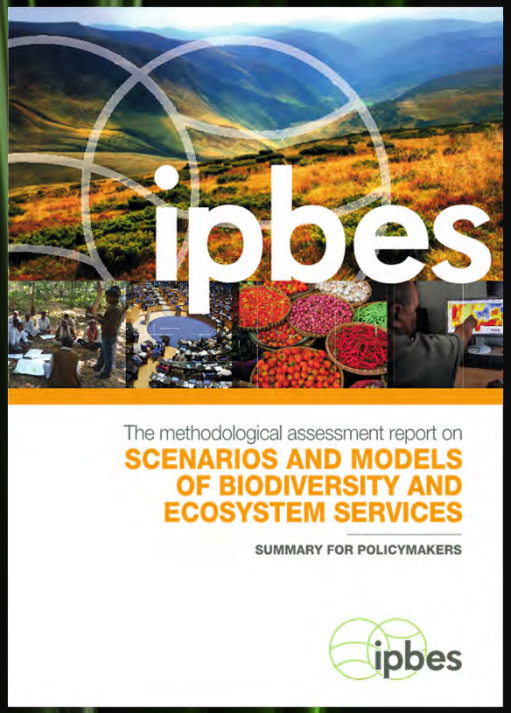
3

INDIVIDUAL MODELS

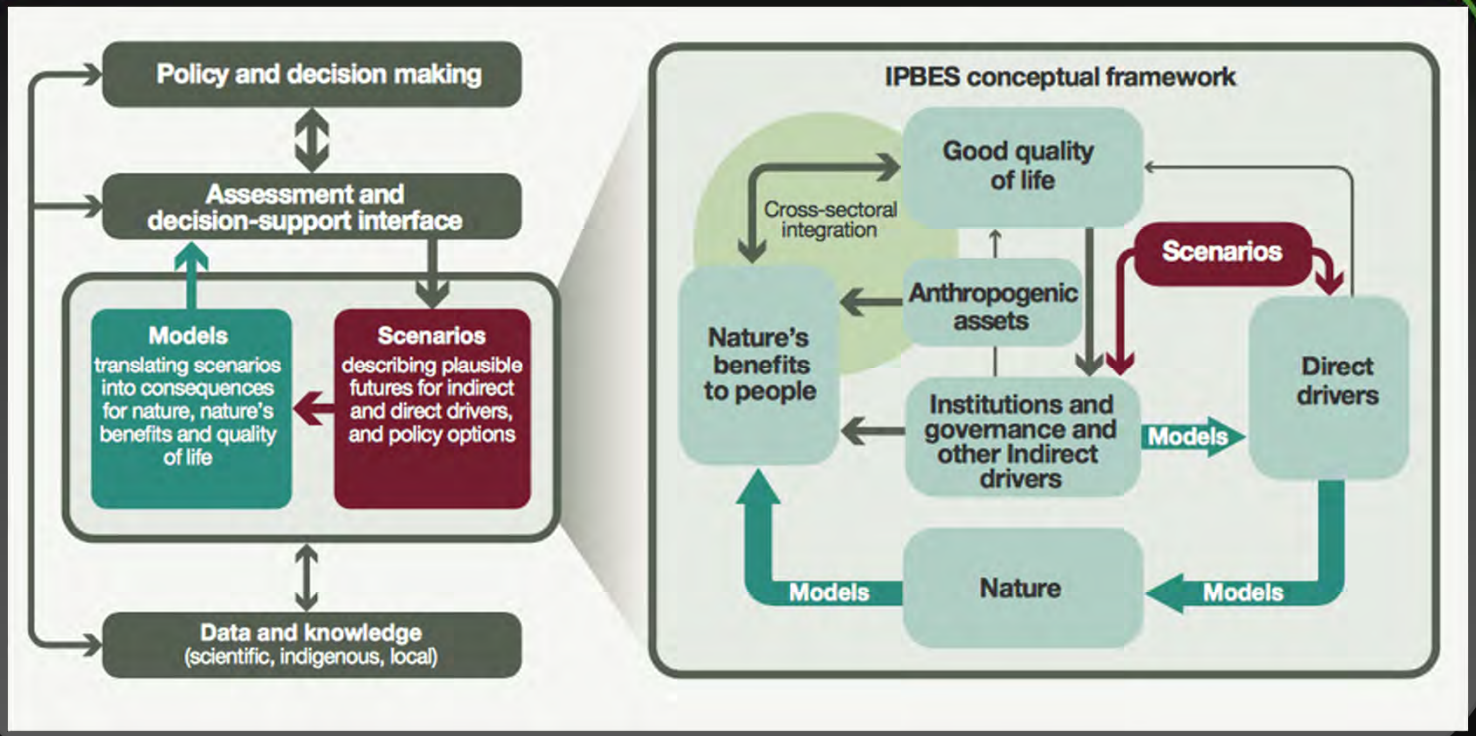
The tools available for spatial analyses

- Statistics: GIS layer combination through a statistical model established on observation points: Regression...
- Geostatistics: Spatialization of point information using spatial self-correction by interpolation: Krigeage, Neural Networks...
- Dynamics: Integration of space-time dynamism in the model: cellular automatons...
- Experts: Replaces the statistical model when data is missing.
- Process: GIS layer combination via a conceptual model of the relationship between parameters and the search for their coefficients.
- Remote sensing: Satellite or airborne, allows you to obtain a continuous description of space at different wavelengths.
- Digitalization: Digitalization of existing maps remains a precise and effective way to capture spatial information.
-





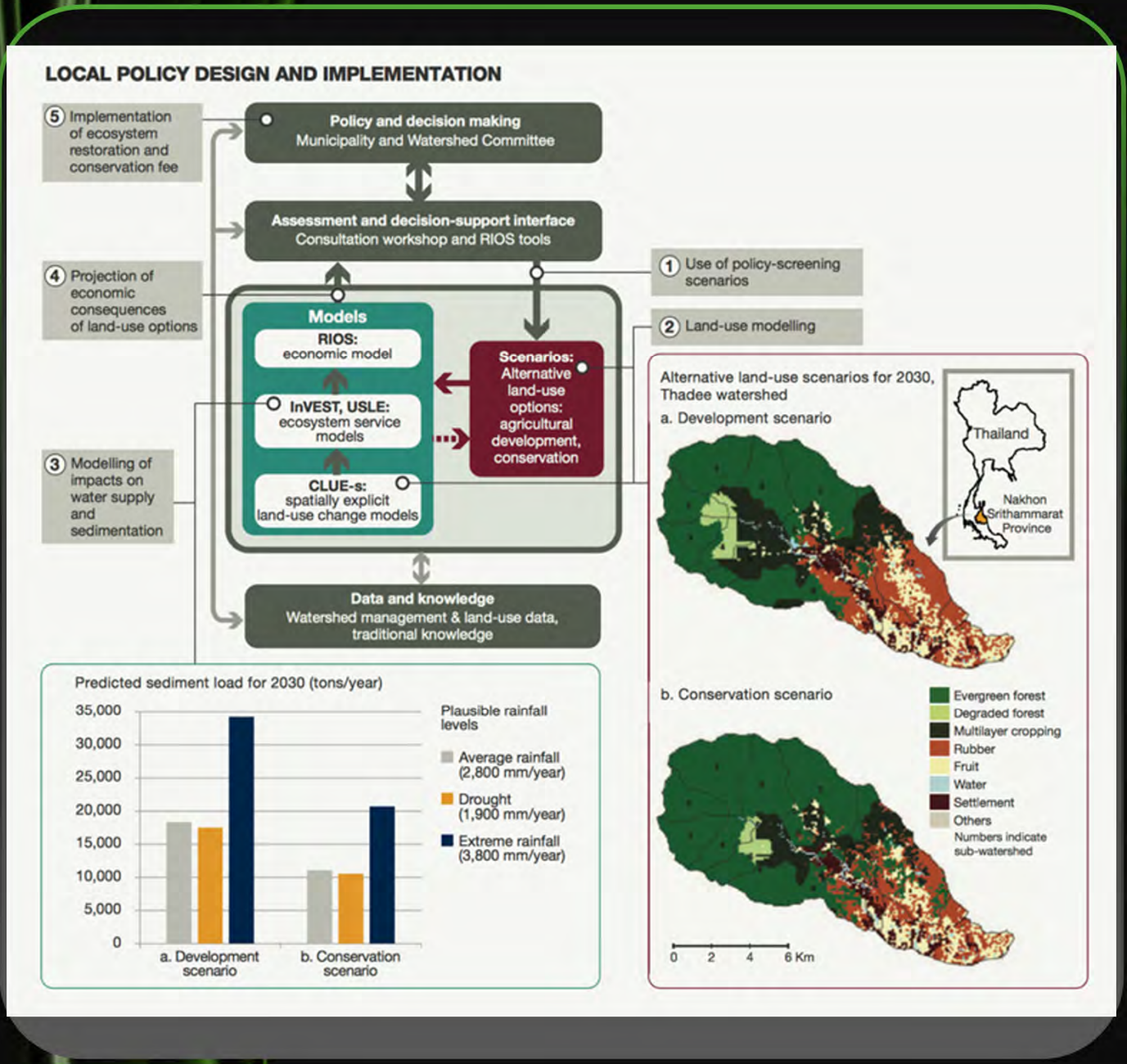
Scenarios and models



The panel on the left points out that scenarios and models are directly dependent on data and knowledge for their construction and testing and add value by synthesizing and organizing knowledge.
The right panel provides a detailed view of the relationships between scenarios, models and key elements of the platform's conceptual framework

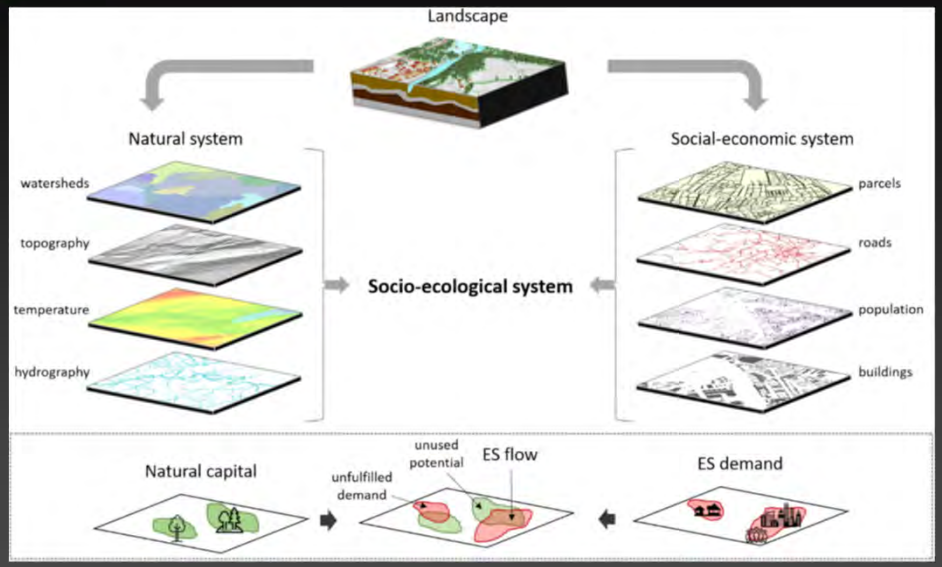
https://www.ipbes.net/document-library-categories/assessment-reports-and-outputs

Scenarios and models



Thadee watershed, Thailand, where farmers' water supply and household consumption have been degraded by the conversion of natural forests to rubber plantations.

Ecosystem Services

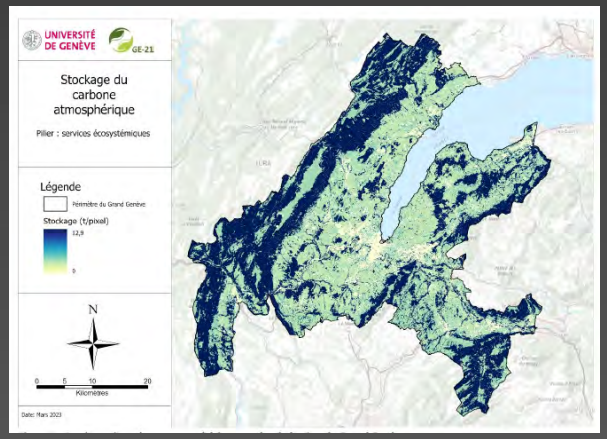


InVEST

integrated valuation of ecosystem services and tradeoffs

- Pollinator-friendly areas
- Carbon storage
- Water quality regulation
- Erosion control & sediment retention
- Local climate regulation and air quality

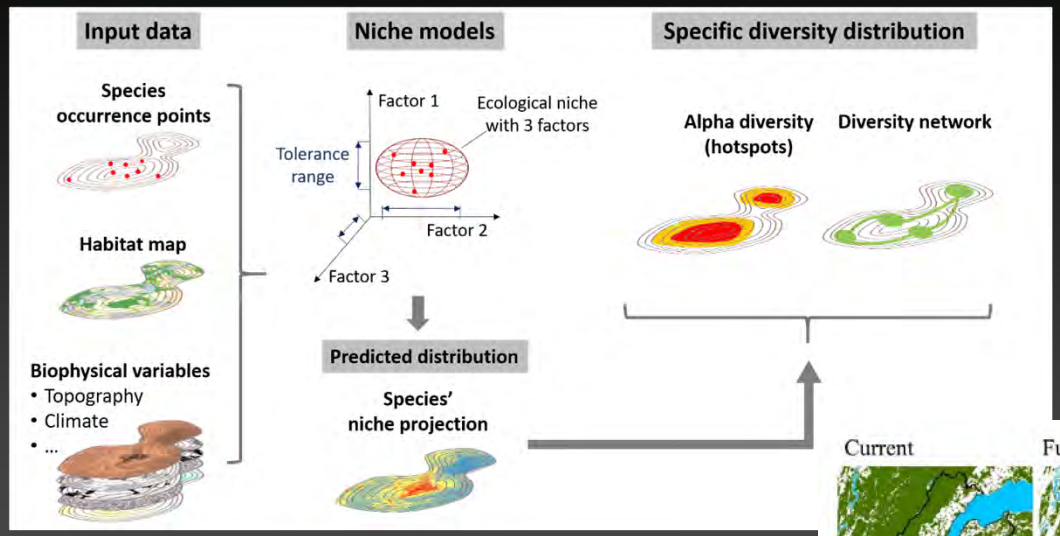
Carbon storage

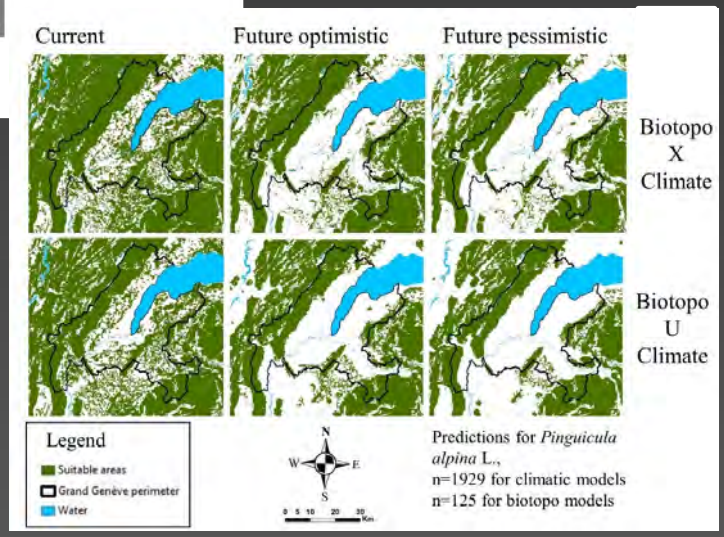


UNIVERSITÉ DE GENÈVE

Honeck et al. 2020, Sanguet et al. 2023

Composition Pillar: Species and Ecosystems





This pillar is composed of:

1816 maps of the distribution of plant species, 336 of which are threatened on the Swiss Red List.

585 distribution maps for animal species, 135 of which are threatened on the Swiss Red List.

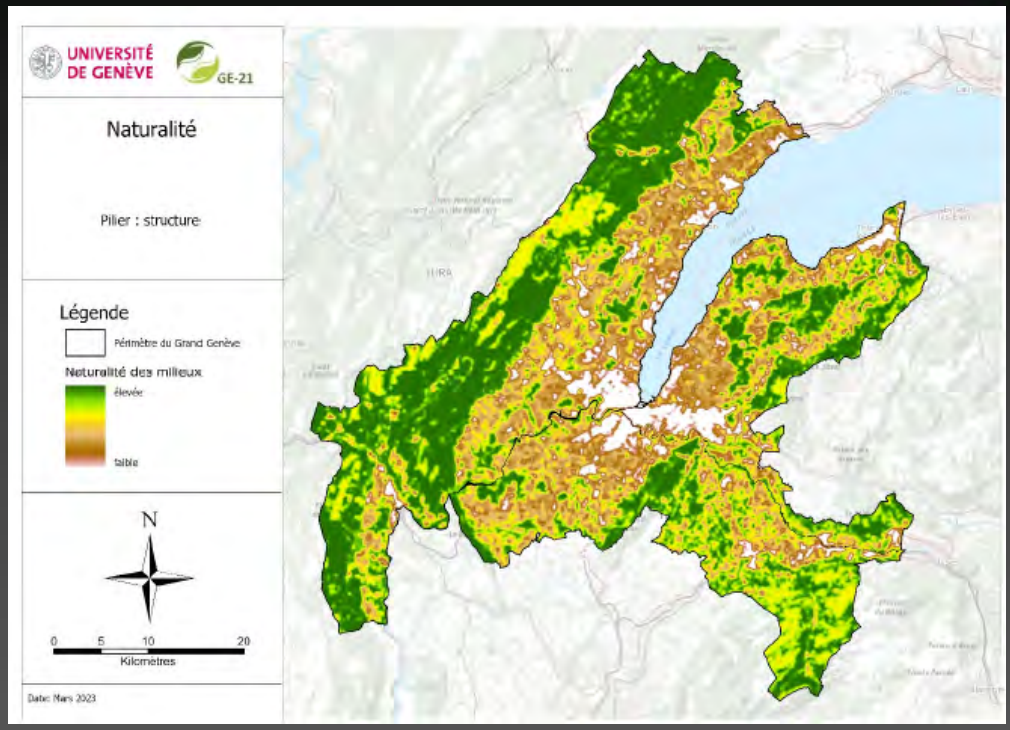
Natural Habitats

Honeck et al., 2020, Sanguet et al. 2022

Landscape structure

- Fragmentation (or continuity) index of natural habitats
- Permeability of land use classes
- Naturalness of the territory
- Diversity of green environments (Shannon index)
- Central zone indicator

FragStats

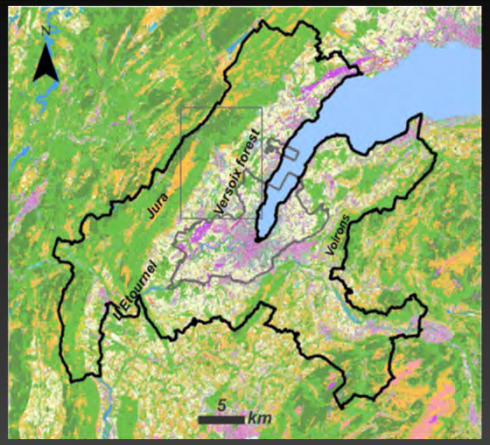


Conservatoire et Jardin botaniques Genève

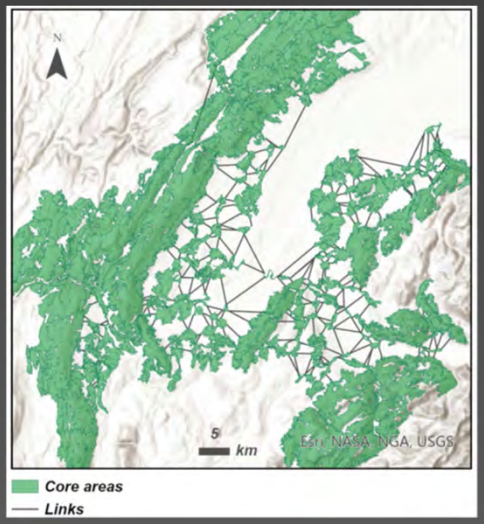
Sanguet et al. 2023

Connectivity for Deer

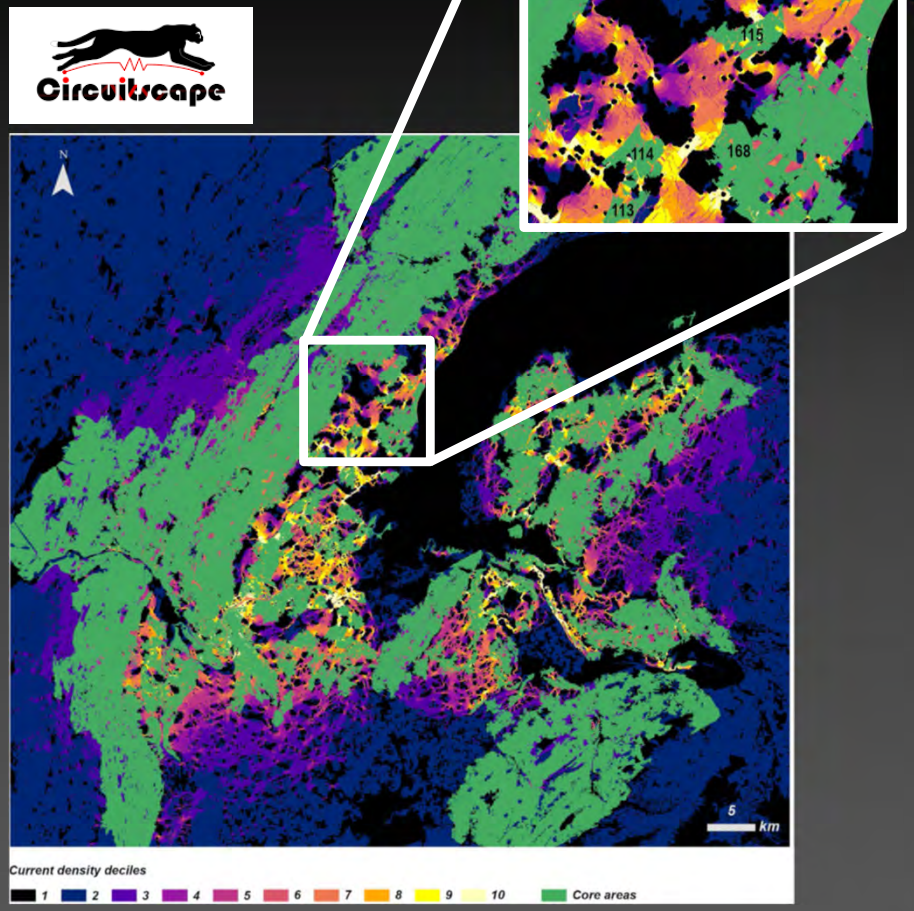
Natural Habitats



Connections



"Current"



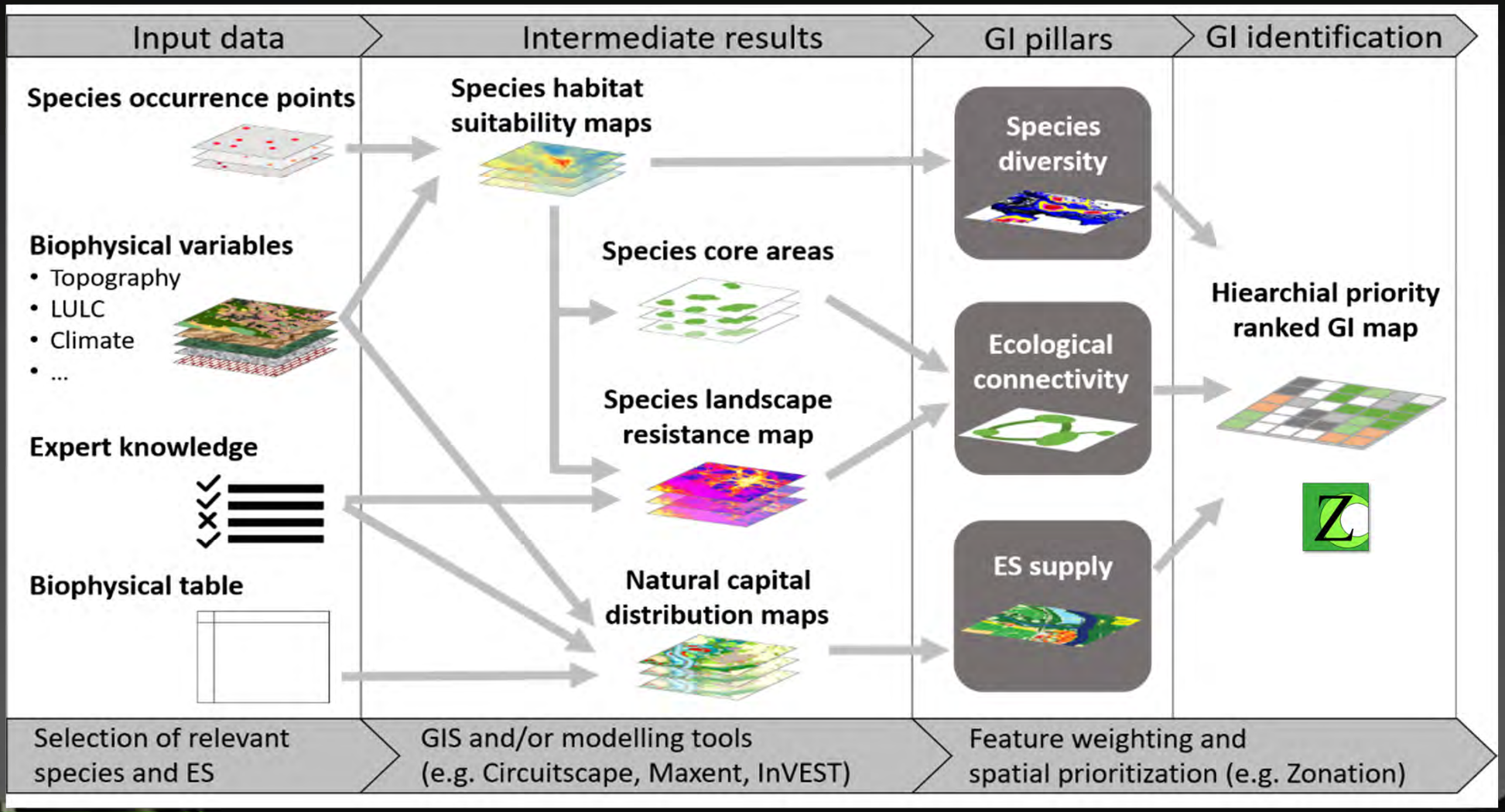
h e p i a
Haute école du paysage, d'ingénierie et d'architecture de Genève

Loreto et al. 2023; Loreto et al. 2024

4

ECOLOGICAL INFRASTRUCTURES

Proposed Methods for Identifying EI

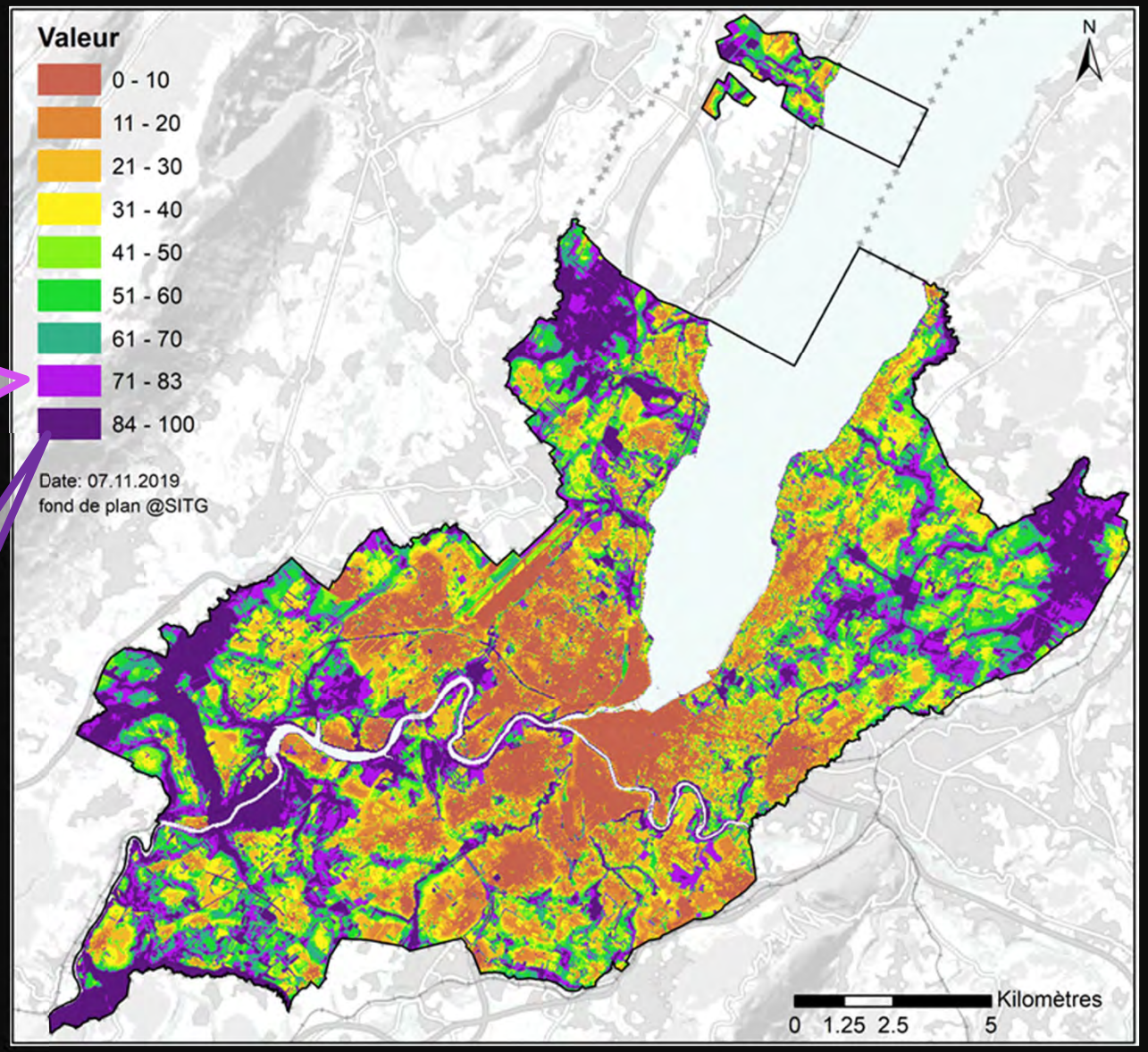


Honeck et al. 2020a

Infrastructure Ecologique de Genève >> PDCn

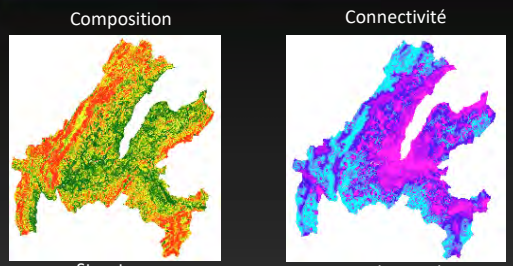
13% additional networking of main habitats

17% of the most interesting areas including existing protected areas. This correpsond to the main habitats and the CBD Aichi Object

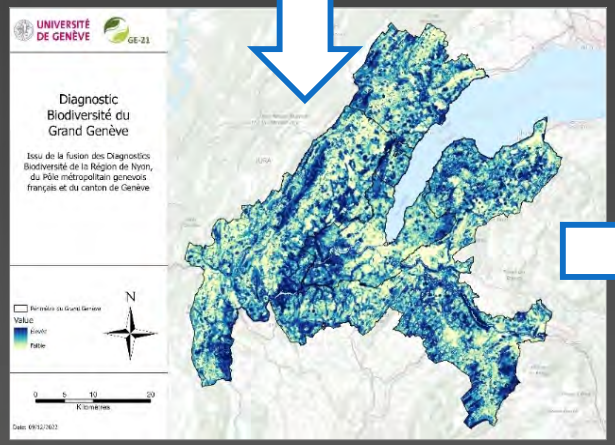


Honeck et al. 2020: doi:10.3390/su12041387

Ecological infrastructure of Greater Geneva >> VTT

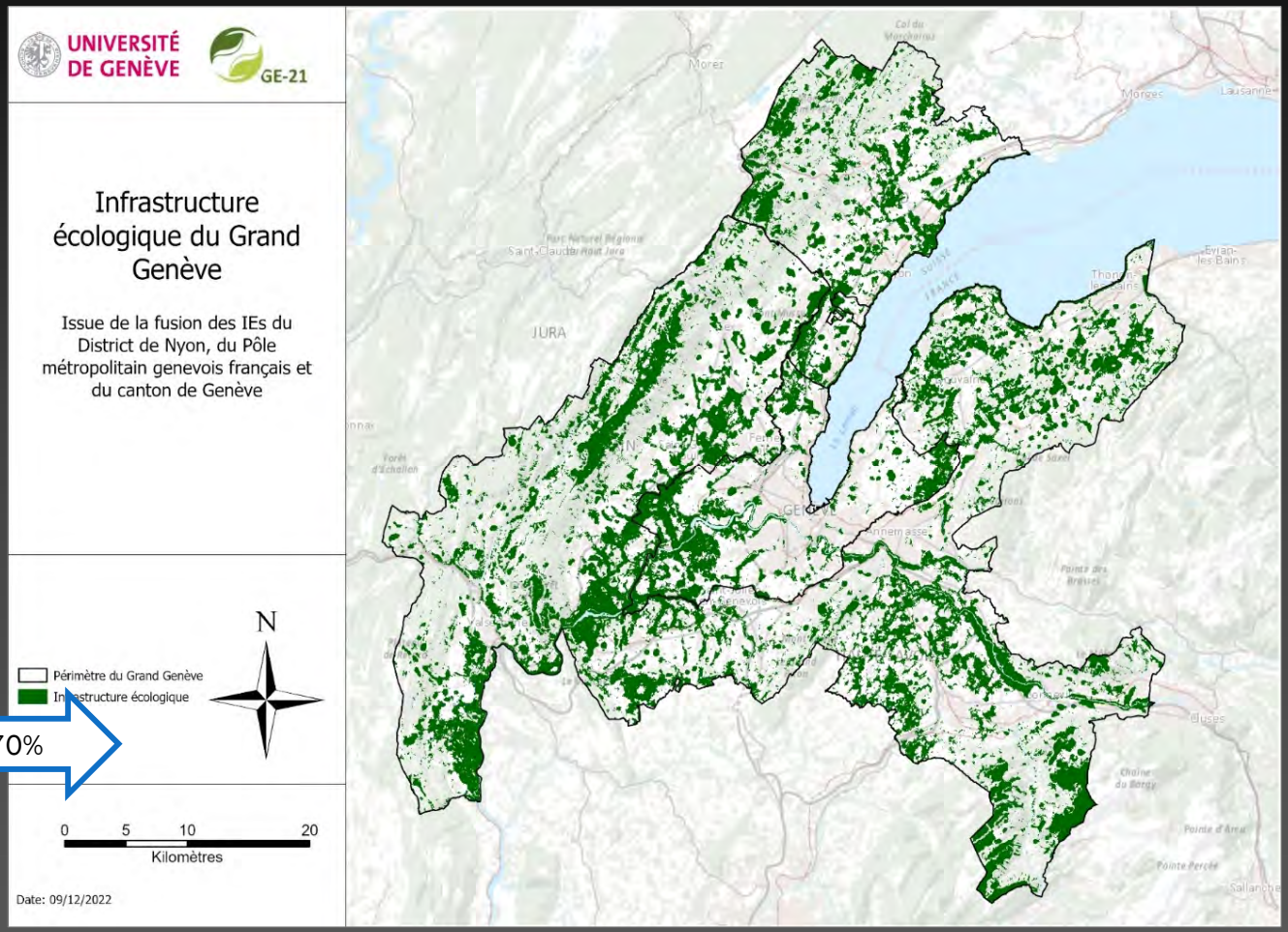


ZONATION



Diagnostic: 0 -> 100

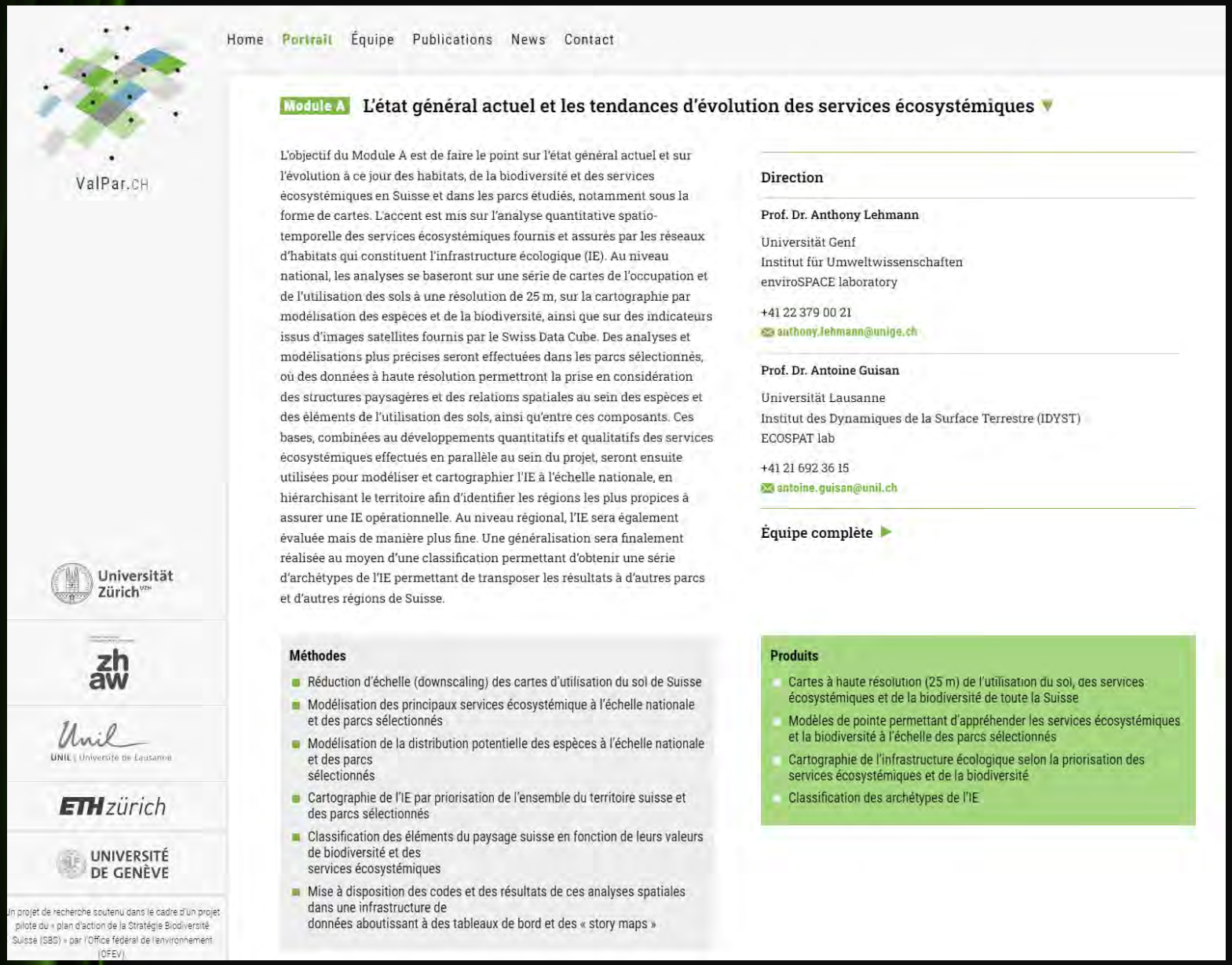
>=70%



Infrastructure: 0 / 1

Sanguet et al. 2023

ValPar.CH: Added value of EI



ValPar.CH

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Module A **L'état général actuel et les tendances d'évolution des services écosystémiques**

L'objectif du Module A est de faire le point sur l'état général actuel et sur l'évolution à ce jour des habitats, de la biodiversité et des services écosystémiques en Suisse et dans les parcs étudiés, notamment sous la forme de cartes. L'accent est mis sur l'analyse quantitative spatio-temporelle des services écosystémiques fournis et assurés par les réseaux d'habitats qui constituent l'infrastructure écologique (IE). Au niveau national, les analyses se baseront sur une série de cartes de l'occupation et de l'utilisation des sols à une résolution de 25 m, sur la cartographie par modélisation des espèces et de la biodiversité, ainsi que sur des indicateurs issus d'images satellites fournis par le Swiss Data Cube. Des analyses et modélisations plus précises seront effectuées dans les parcs sélectionnés, où des données à haute résolution permettront la prise en considération des structures paysagères et des relations spatiales au sein des espèces et des éléments de l'utilisation des sols, ainsi qu'entre ces composants. Ces bases, combinées au développements quantitatifs et qualitatifs des services écosystémiques effectués en parallèle au sein du projet, seront ensuite utilisées pour modéliser et cartographier l'IE à l'échelle nationale, en hiérarchisant le territoire afin d'identifier les régions les plus propices à assurer une IE opérationnelle. Au niveau régional, l'IE sera également évaluée mais de manière plus fine. Une généralisation sera finalement réalisée au moyen d'une classification permettant d'obtenir une série d'archétypes de l'IE permettant de transposer les résultats à d'autres parcs et d'autres régions de Suisse.

Direction

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Équipe complète

Méthodes

- Réduction d'échelle (downscaling) des cartes d'utilisation du sol de Suisse
- Modélisation des principaux services écosystémique à l'échelle nationale et des parcs sélectionnés
- Modélisation de la distribution potentielle des espèces à l'échelle nationale et des parcs sélectionnés
- Cartographie de l'IE par priorisation de l'ensemble du territoire suisse et des parcs sélectionnés
- Classification des éléments du paysage suisse en fonction de leurs valeurs de biodiversité et des services écosystémiques
- Mise à disposition des codes et des résultats de ces analyses spatiales dans une infrastructure de données aboutissant à des tableaux de bord et des « story maps »

Produits

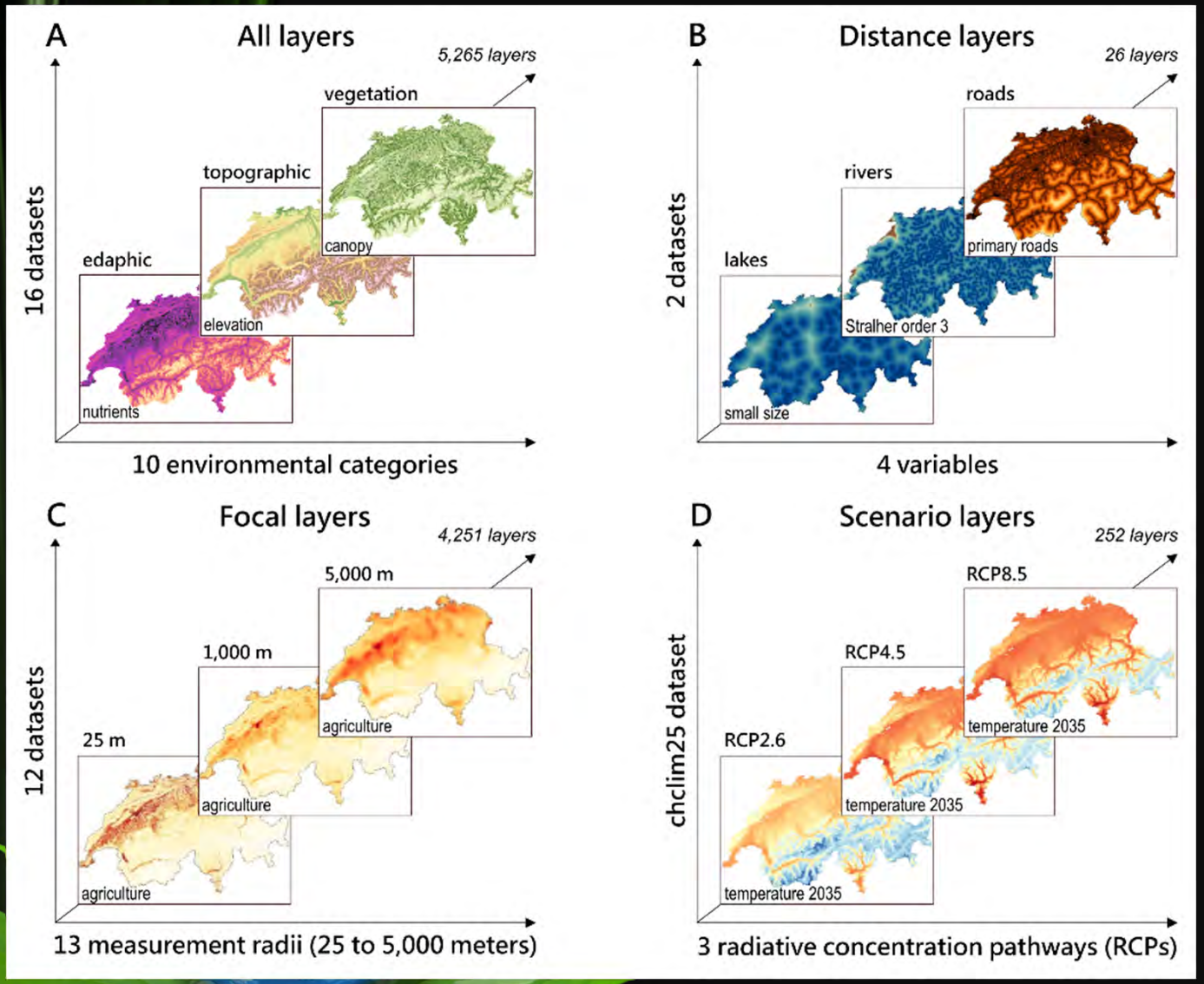
- Cartes à haute résolution (25 m) de l'utilisation du sol, des services écosystémiques et de la biodiversité de toute la Suisse
- Modèles de pointe permettant d'appréhender les services écosystémiques et la biodiversité à l'échelle des parcs sélectionnés
- Cartographie de l'infrastructure écologique selon la priorisation des services écosystémiques et de la biodiversité
- Classification des archétypes de l'IE

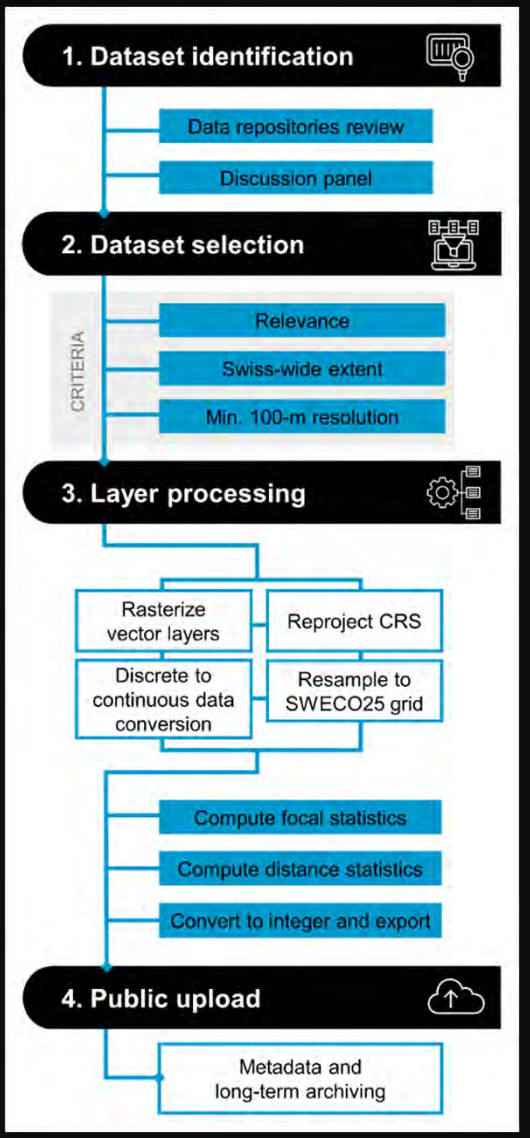
Universität Zürich[UZH]
zh aw
UNIL | Université de Lausanne
ETH zürich
UNIVERSITÉ DE GENÈVE

Un projet de recherche soutenu dans le cadre d'un projet pilote du « plan d'action de la Stratégie Biodiversité Suisse (SBS) » par l'Office fédéral de l'environnement (OFEV)

www.valpar.ch

SWECO25: a raster database for ecological research in Switzerland





5 265 couches en 10 catégories: géologique, topographique, bioclimatique, hydrologique, édaphique, utilisation et couverture des sols, population, transport, végétation et télédétection

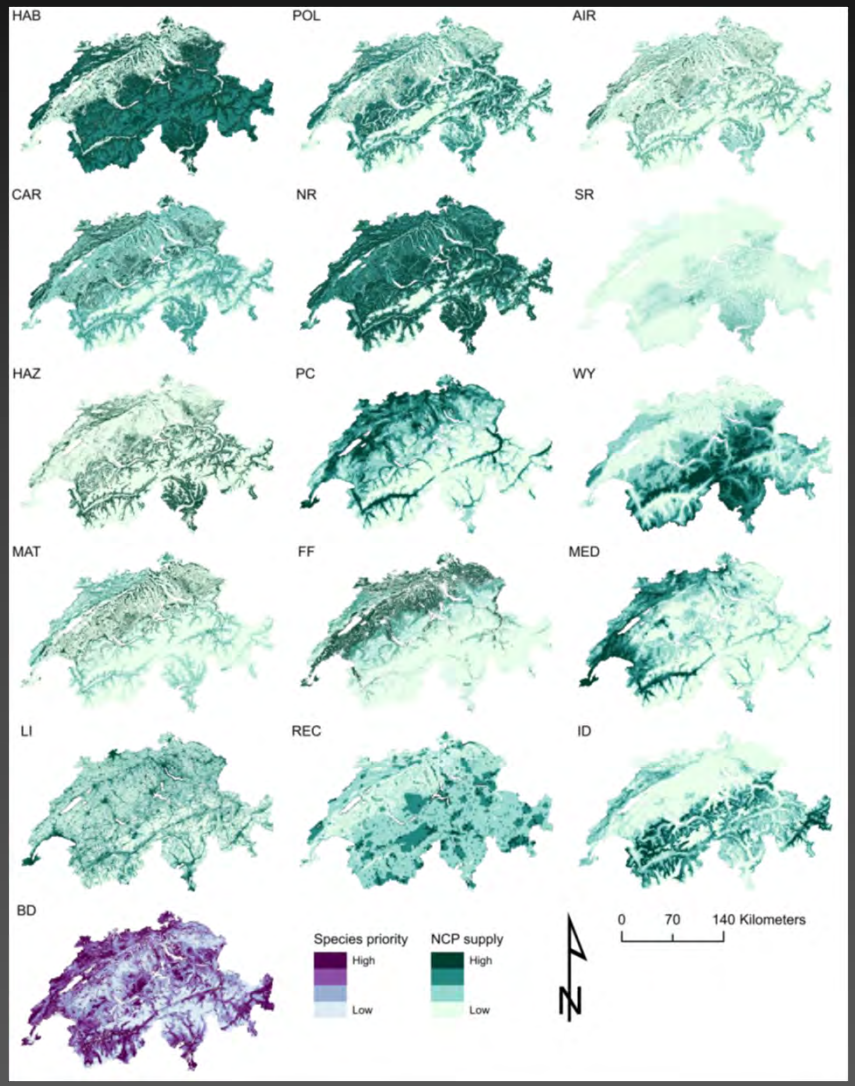
Külling, Adde et al, 2024

Choix des indicateurs des SE base sur la liste des categories de l'IPBES

N°	Category	Name (IPBES)	IPBES reference	Indicator used
1	Nature/non anthropocentric	Individual organisms	N1	
2	Nature/non anthropocentric	Biophysical assemblages	N2	
3	Nature/non anthropocentric	Biophysical processes	N3	Landscape connectivity for target species
4	Nature/non anthropocentric	Biodiversity	N4	
5	Regulation	Habitat creation and maintenance	C2.1	Habitat quality index
6	Regulation	Pollination and dispersal of seeds	C2.2	Habitat abundance for pollinators
7	Regulation	Regulation of air quality	C2.3	Annual removal of PM10 by vegetation
8	Regulation	Regulation of climate	C2.4	Carbon stored in biomass and soil
9	Regulation	Regulation of freshwater quantity, location and timing	C2.6	Annual water yield
10	Regulation	Regulation of freshwater quality	C2.7	Annual nutrient retention by vegetation
11	Regulation	Formation, protection and decontamination of soils	C2.8	Erosion control by sediment retention
12	Regulation	Regulation of hazards and extreme events	C2.9	Landscape protection from natural hazards (forests + floodp
13	Regulation	Regulation of organisms detrimental to humans	C2.10	Distribution of main predators to main pests
14	Material	Energy	C3.11	Wood-derived energy production
15	Material	Food and feed	C3.12	Crop production
16	Material	Materials and assistance	C3.13	Wood (timber) production
17	Material	Medicinal, biochemical and genetic resources	C3.14	Distribution of medicinal plant species
18	Non-Material	Learning and inspiration	C4.15	Picture-taking probability
19	Non-Material	Physical and psychological experiences	C4.16	Accessibility to recreation areas
20	Non-Material	Supporting identities	C4.17	Index of species richness for "supporting identities" [1-0]
21	Options value for NCPs	Maintenance of options	C1.18	Genetic diversity distribution of selected species

Külling et al., 2024.

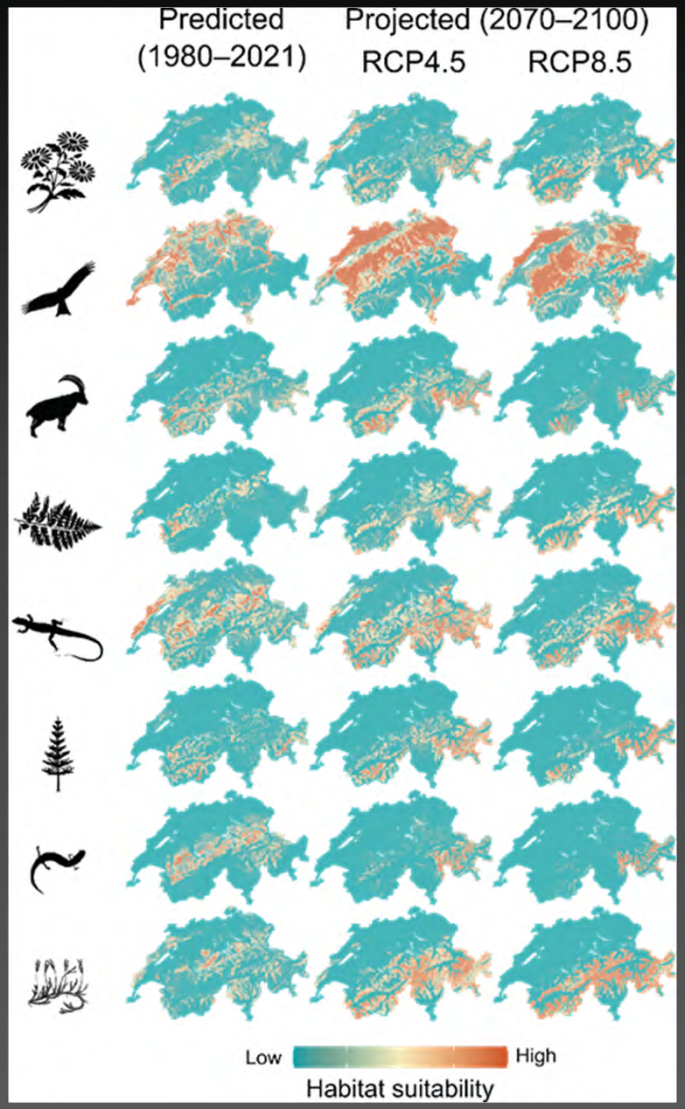
15 mapped ES and Biodiversity



Normalized distribution of indicators maps. Color schemes defined by Jenks natural breaks. **BD** - Red list species, **HAB** - Habitat quality, **POL** - Pollinator abundance, **AIR** - Removal of PM10 by vegetation, **CAR** - Carbon stored in biomass, **NR** - Nutrient retention by landscape, **SR** - Sediment retention by landscape, **HAZ** - Protective forests and floodplains, **PC** - Pest control species, **WY** - Annual water yield, **MAT** - Wood provision potential, **FF** - Landscape suitability for agriculture, **MED** - Medicinal plants, **LI** - Landscape suitability for picture-taking, **REC** - Recreation potential, and **ID** - Emblematic species.

New distribution maps of the 7,000 species for Switzerland

- Using N-SDM, we produced maps for ~7,000 individual species (native and invasive) and aggregate biodiversity indices
- These maps cover the whole of Switzerland with a spatial resolution of 25 metres
- They are made available for current and future periods (up to 2100), according to several climate change scenarios



Cartographie des aires de répartition potentielles actuelles et futures de huit espèces savantes

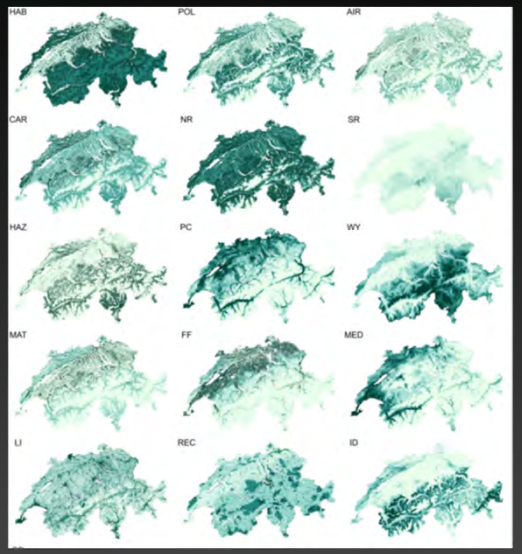
Adde e C

ValPar.CH

UNIL | Université de Lausanne

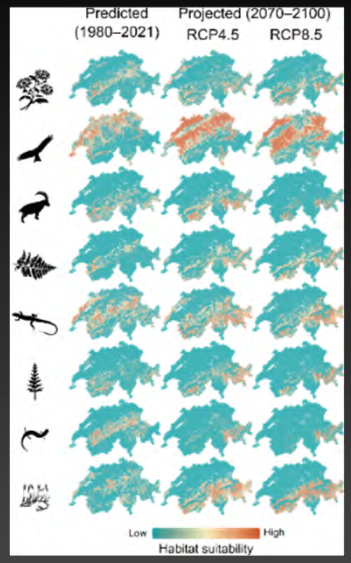
National Ecological Infrastructure

UNIVERSITÉ DE GENÈVE

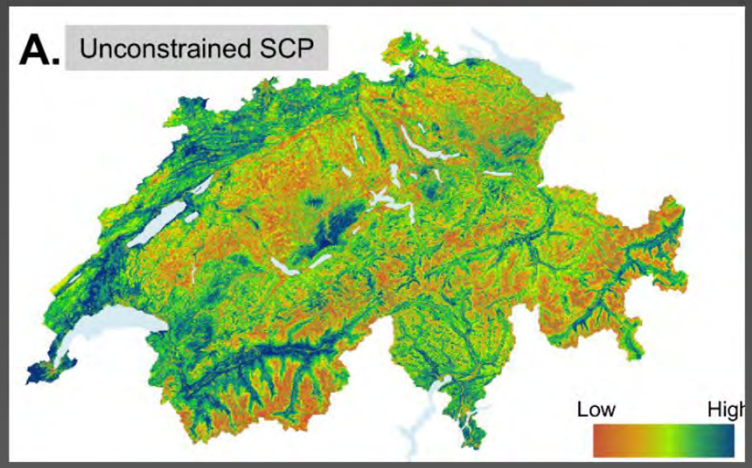


Ecosystem Services

ZONATION



SDMs



- Regional parcs
- Cantons
- Communes

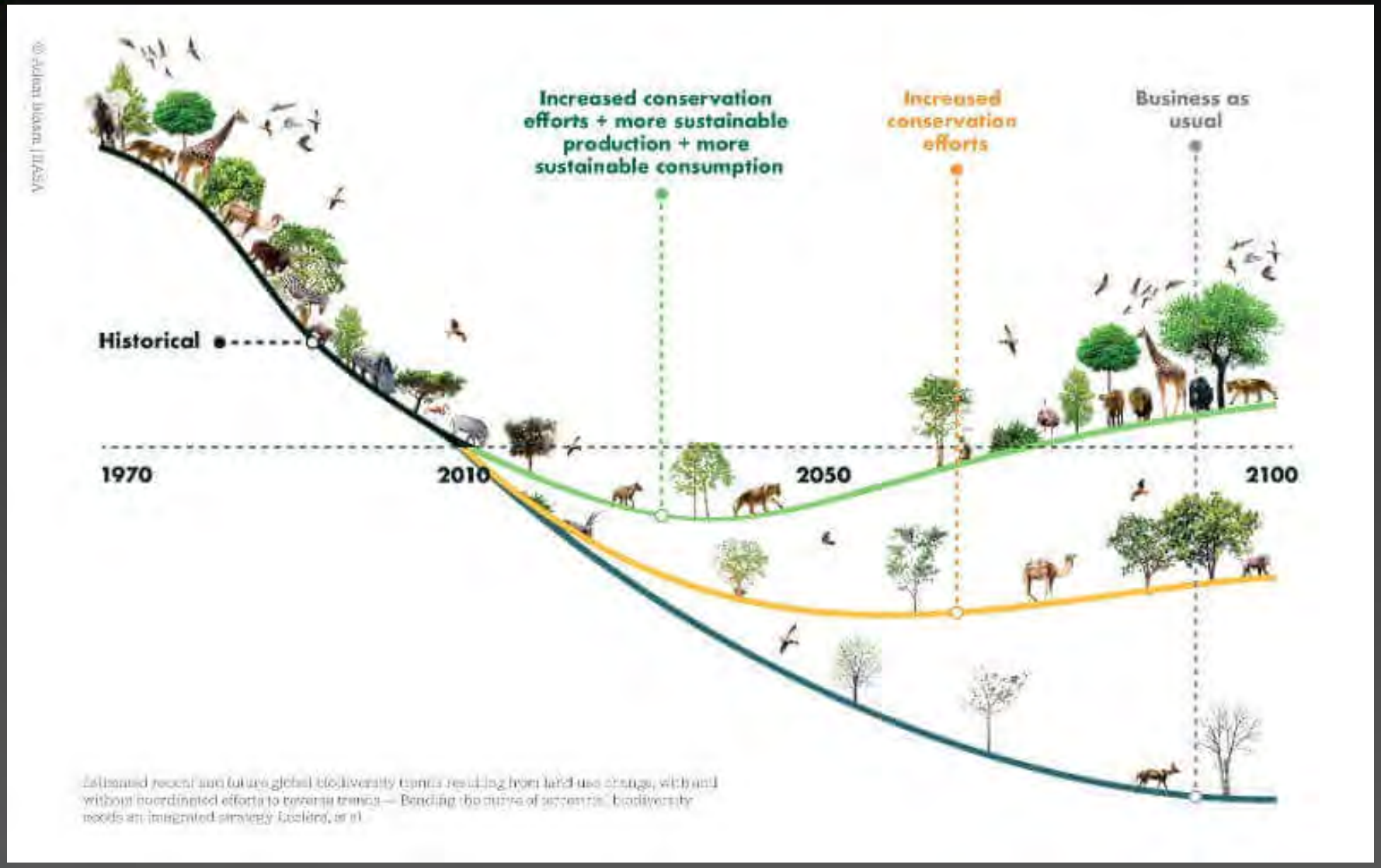
ValPar.CH

Külling et al, submitted.

5

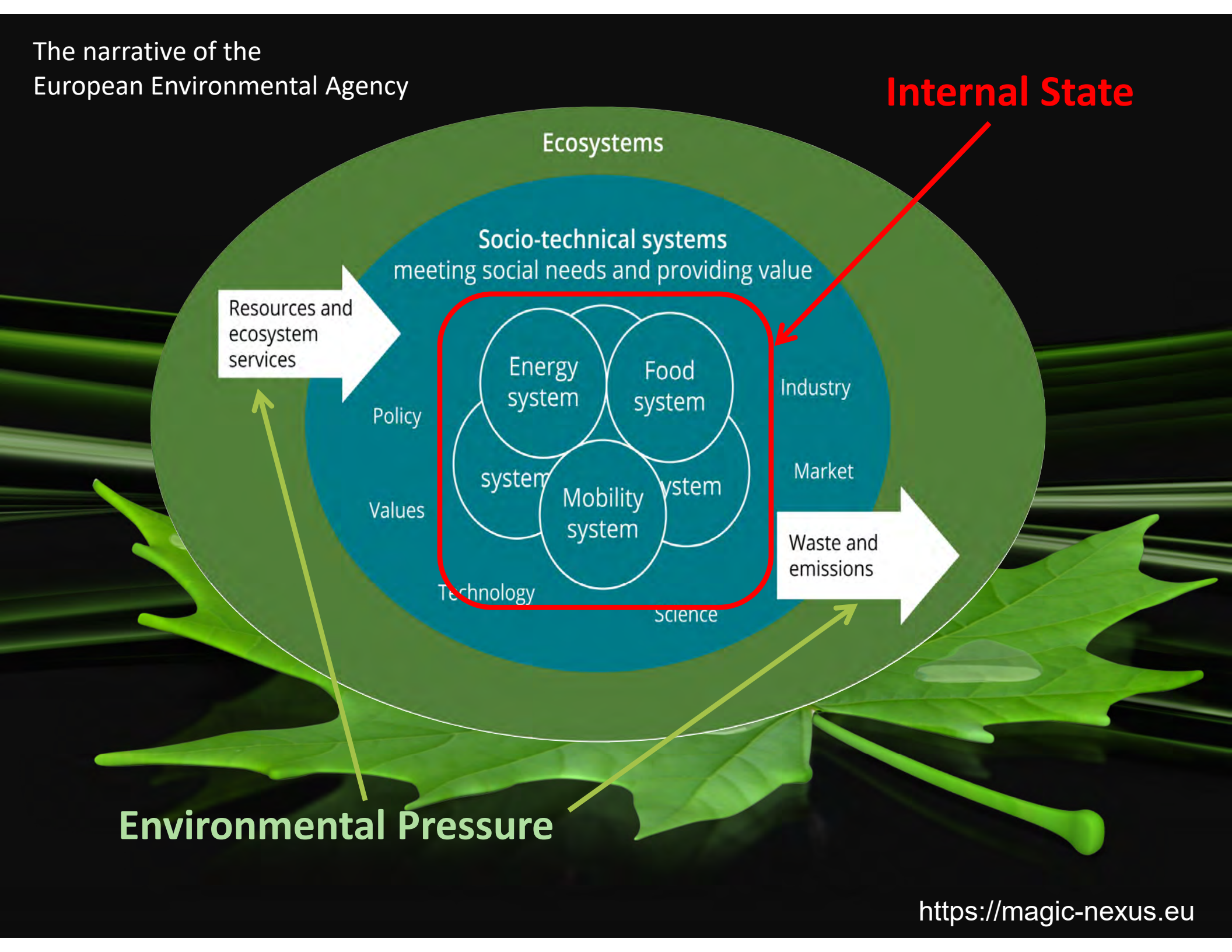
THE NEED FOR A NEXUS APPROACH

Nature positive initiative



Leclère et al. 2020. Nature 585

The narrative of the
European Environmental Agency



https://magic-nexus.eu

Characterizing the Security of Food Systems for a selected region: the case of Greater Geneva agglomeration

Alexander Folz

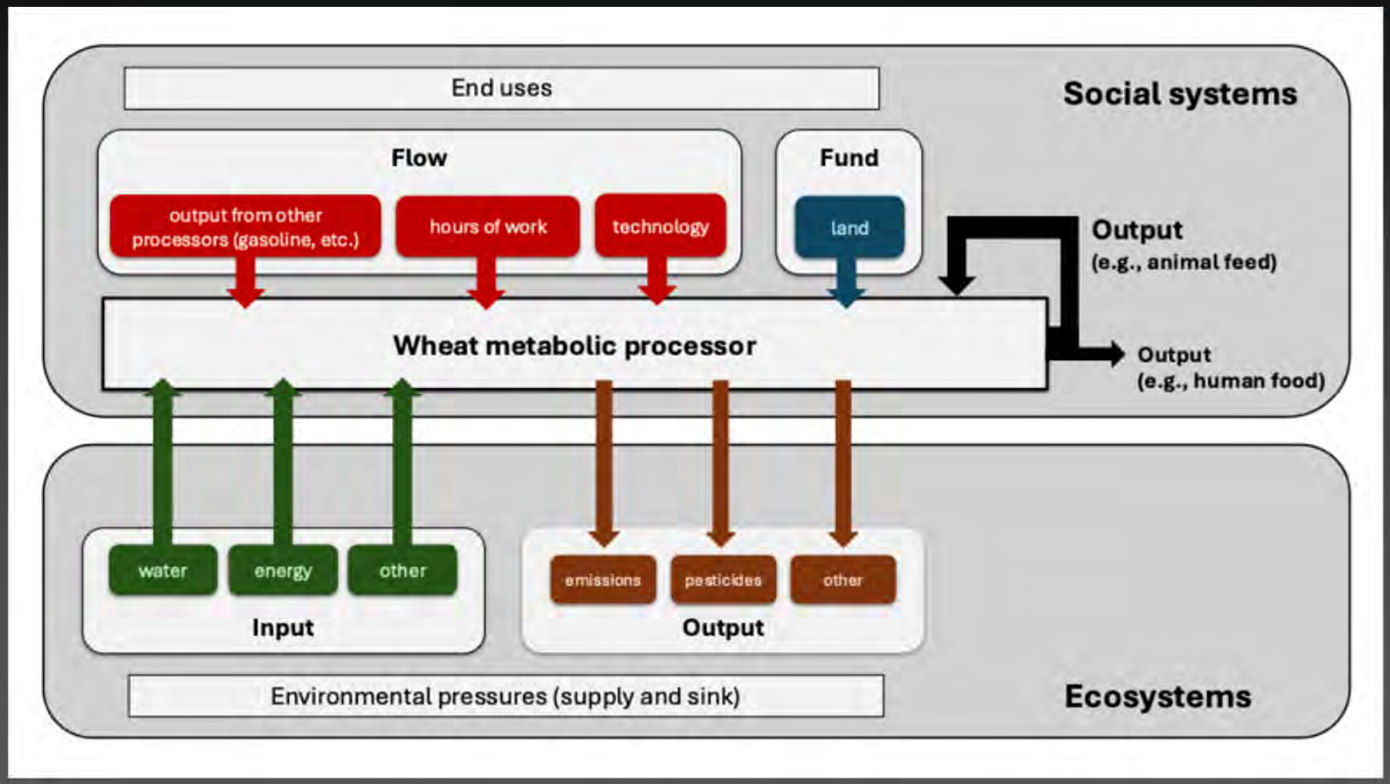
Phd student, UNIGE and Liphe4

- 209 transboundary communes on ~ 2000 km2 [3]
- ~ 946 000 inhab. (2014) [3], ~ +30 % in 2040 [4]
- Climatic projection in 2035 (1980-2010; RCP8.5) [5]
  - Temperature ~ +1.4°C (winter) & +1.3°C (summer)
  - Precipitation ~ +13.3% (winter) & -3.4% (summer)
  - Increase in evapotranspiration
  - Negative glacier balance

NEXUS avec MuSIASEM

Multi-Scale Integrated Analysis of
Societal and Ecosystem Metabolism

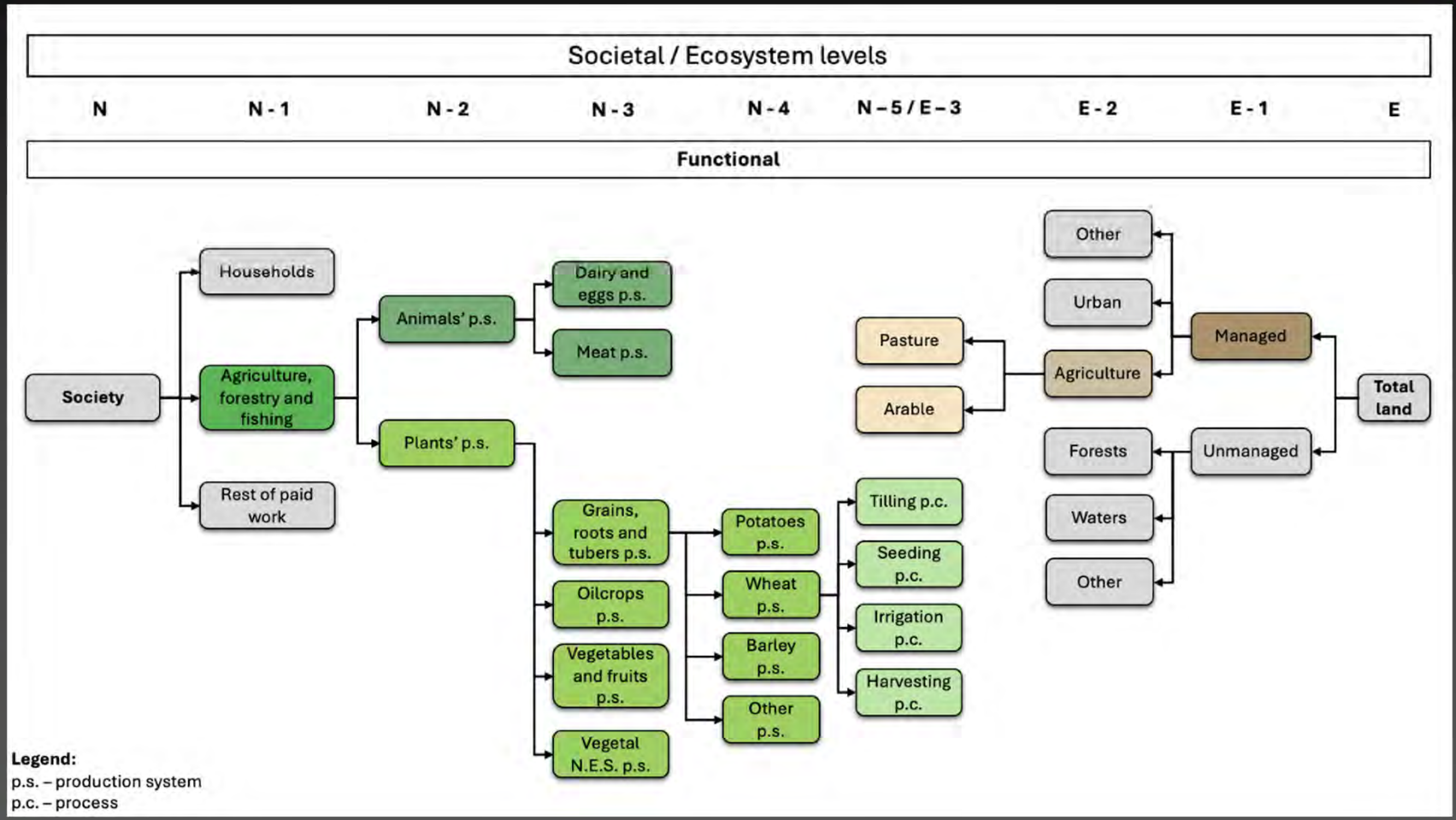
Example of a wheat metabolic processor



Folz et al. submitted

https://en.wikipedia.org/wiki/MuSIASEM

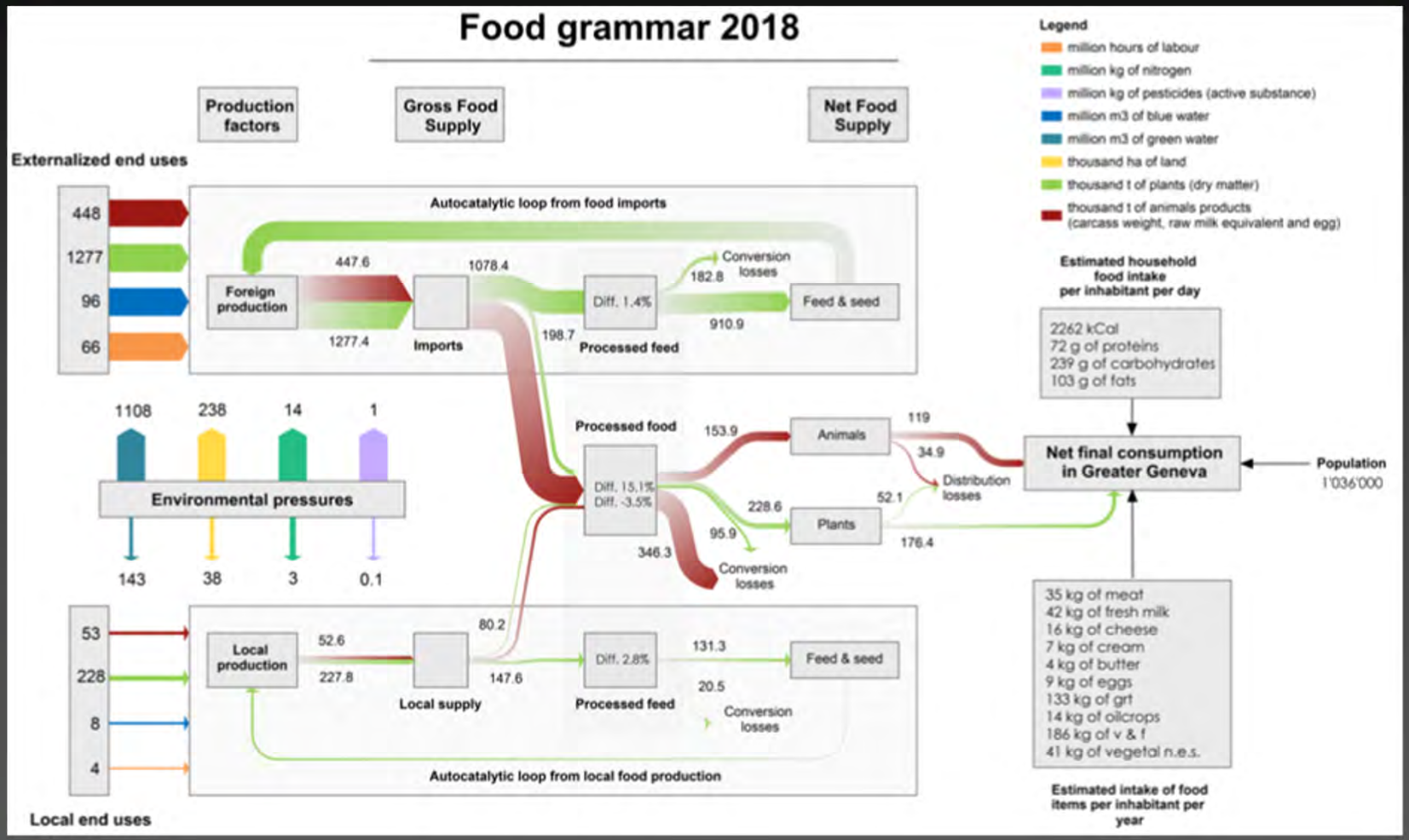
Hierarchical levels of Greater Geneva's food metabolic pattern



Folz et al. submitted

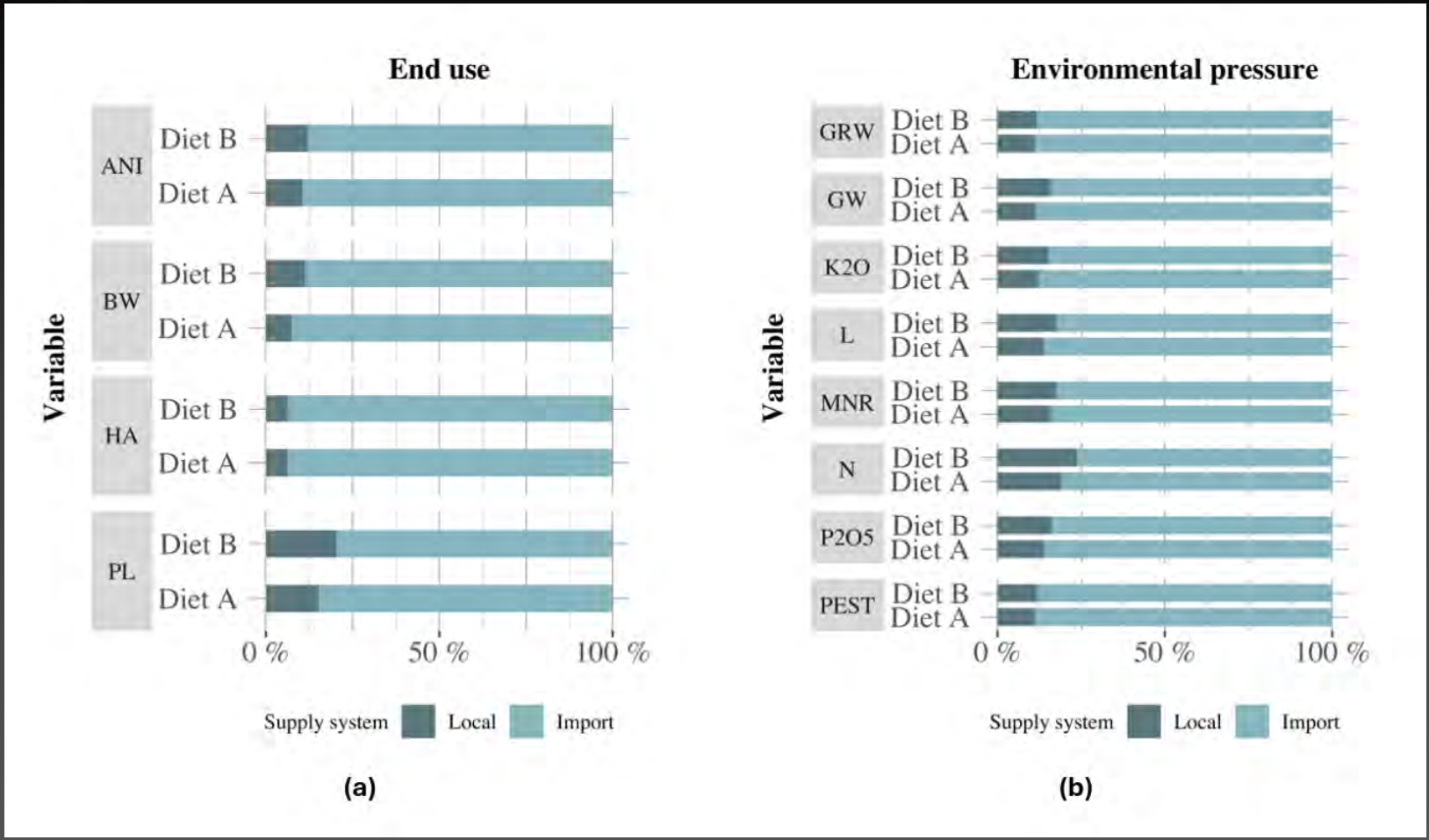
Characterizing the security of Food systems for a selected region?

Greater Geneva's food grammar



Folz et al. submitted

End use (a) and environmental pressure (b) of Greater Geneva's agricultural system with diet A and B respectively.

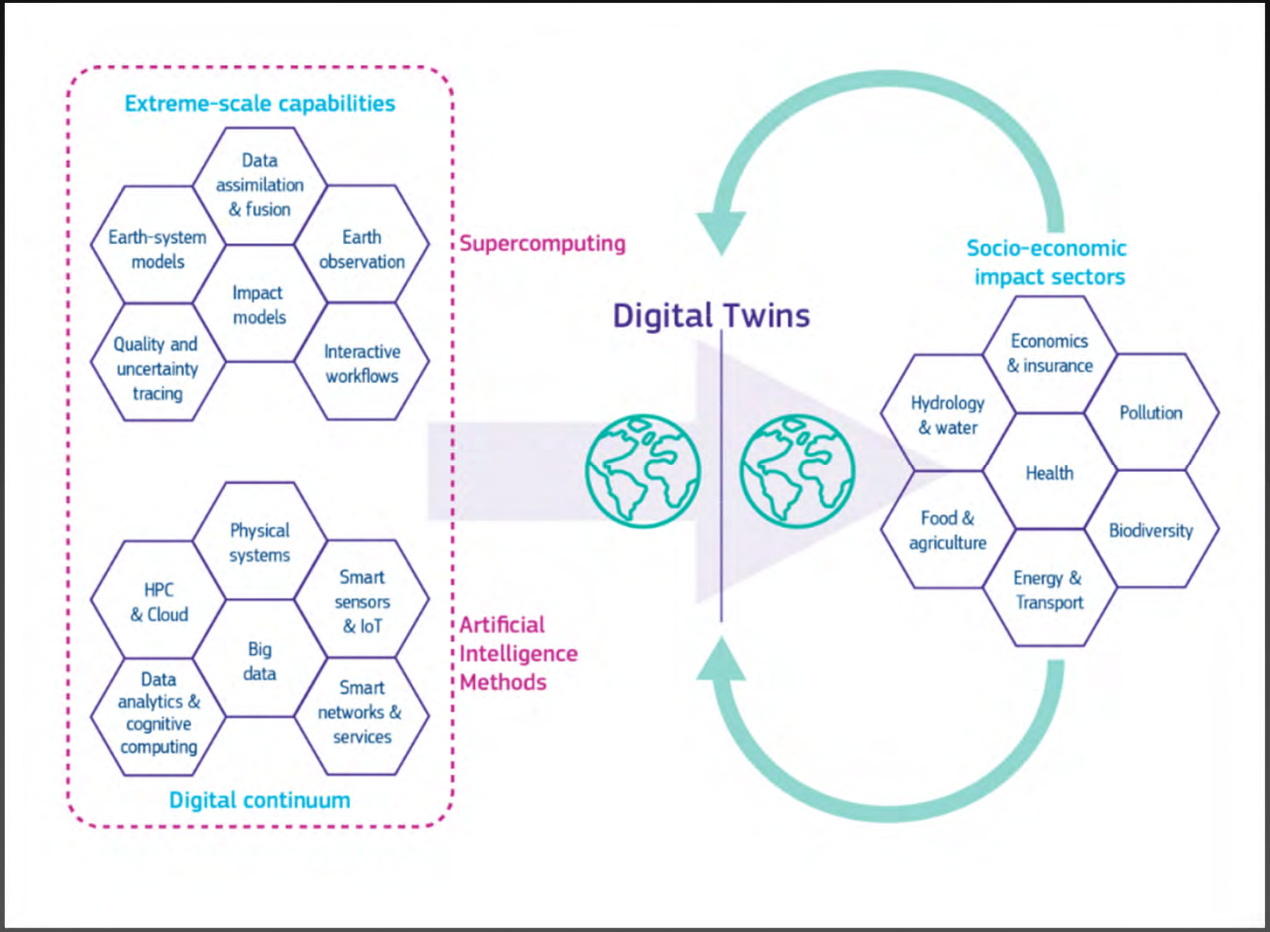


PL – Plants; ANI – Animals; BW – Blue water; HA – Human activity;
GW – Green water; GRW – Grey water; L – Land; N/P2O5/K2O – Fertilizer ; PEST – Pesticides; MNR – Manure.

Folz et al. submitted


6
DIGITAL TWINS

Destination Earth digital twins

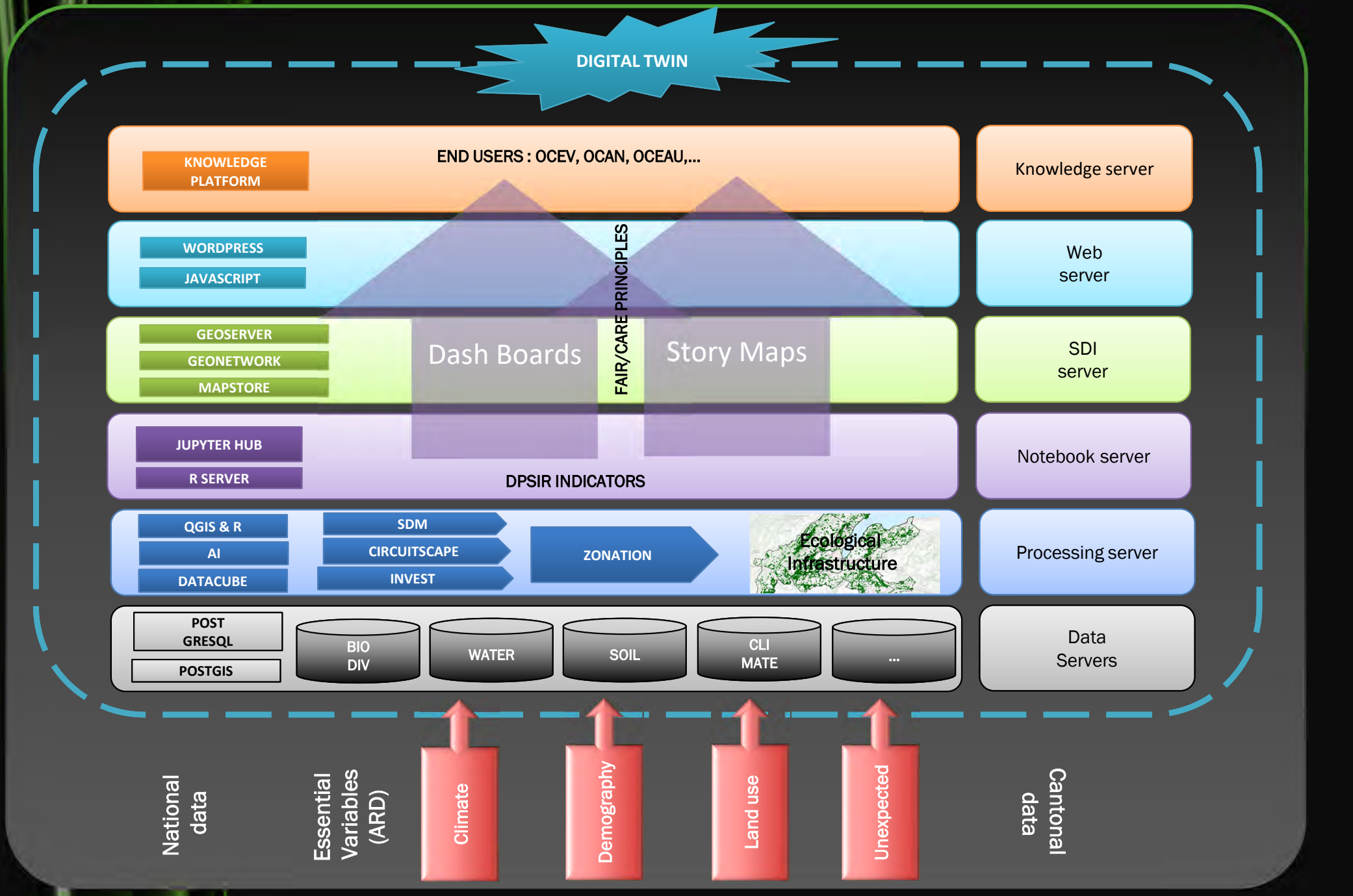


"Digital twins are interactive systems where you can change things in the digital world, which in turn helps you plan, define and operate assets in the real world such as dykes, wind farms, or flood dams," Peter Bauer, ECMWF.

Destination Earth digital twins are digital replicas of the Earth system. The ultimate aim is to integrate these digital replicas to form a comprehensive digital twin of the complete Earth system. Source: EC Europa.

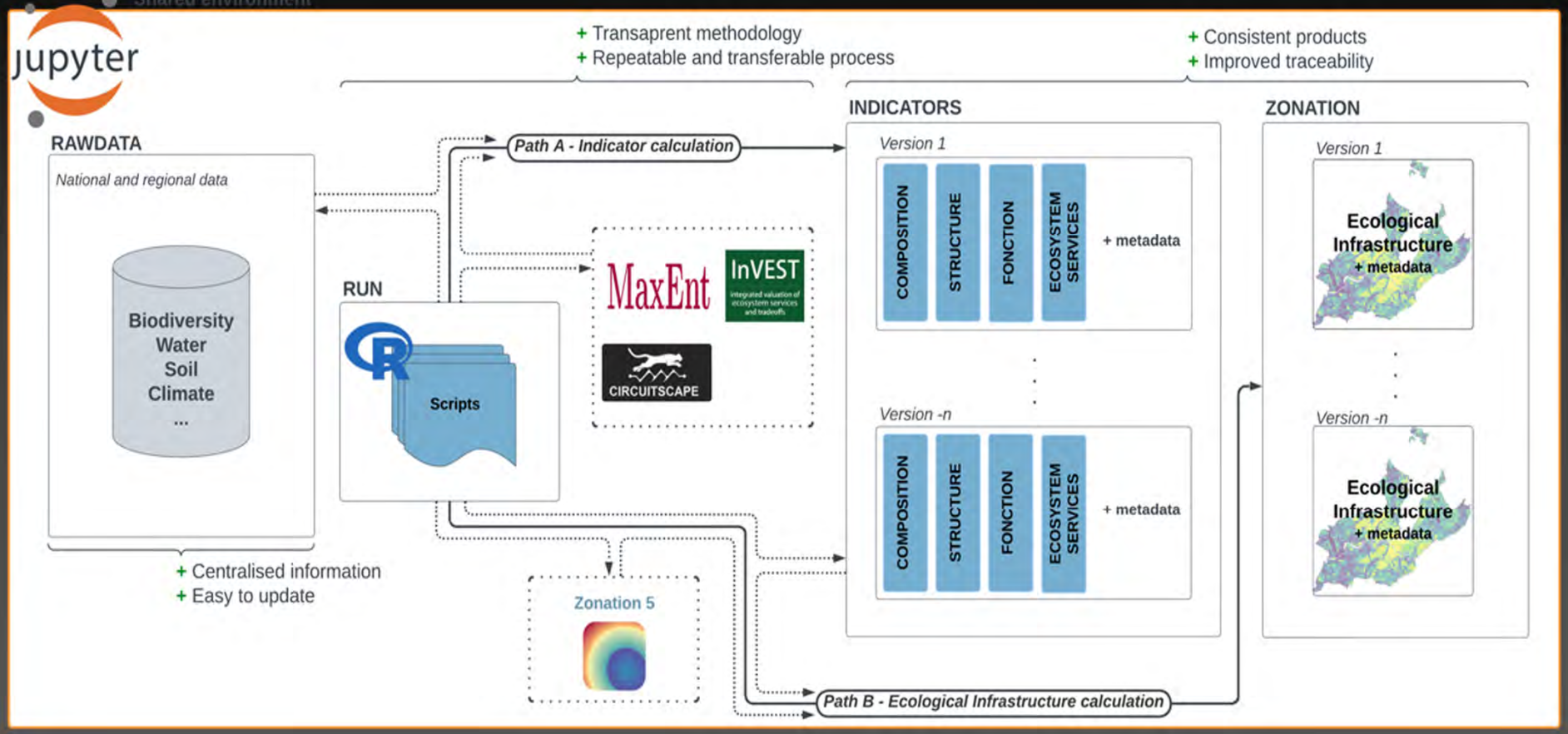
https://www.climateforesight.eu/seeds/digital-twin

Integration of the JupyterHub solution into the general objective of developing a digital twin for the environment in Geneva



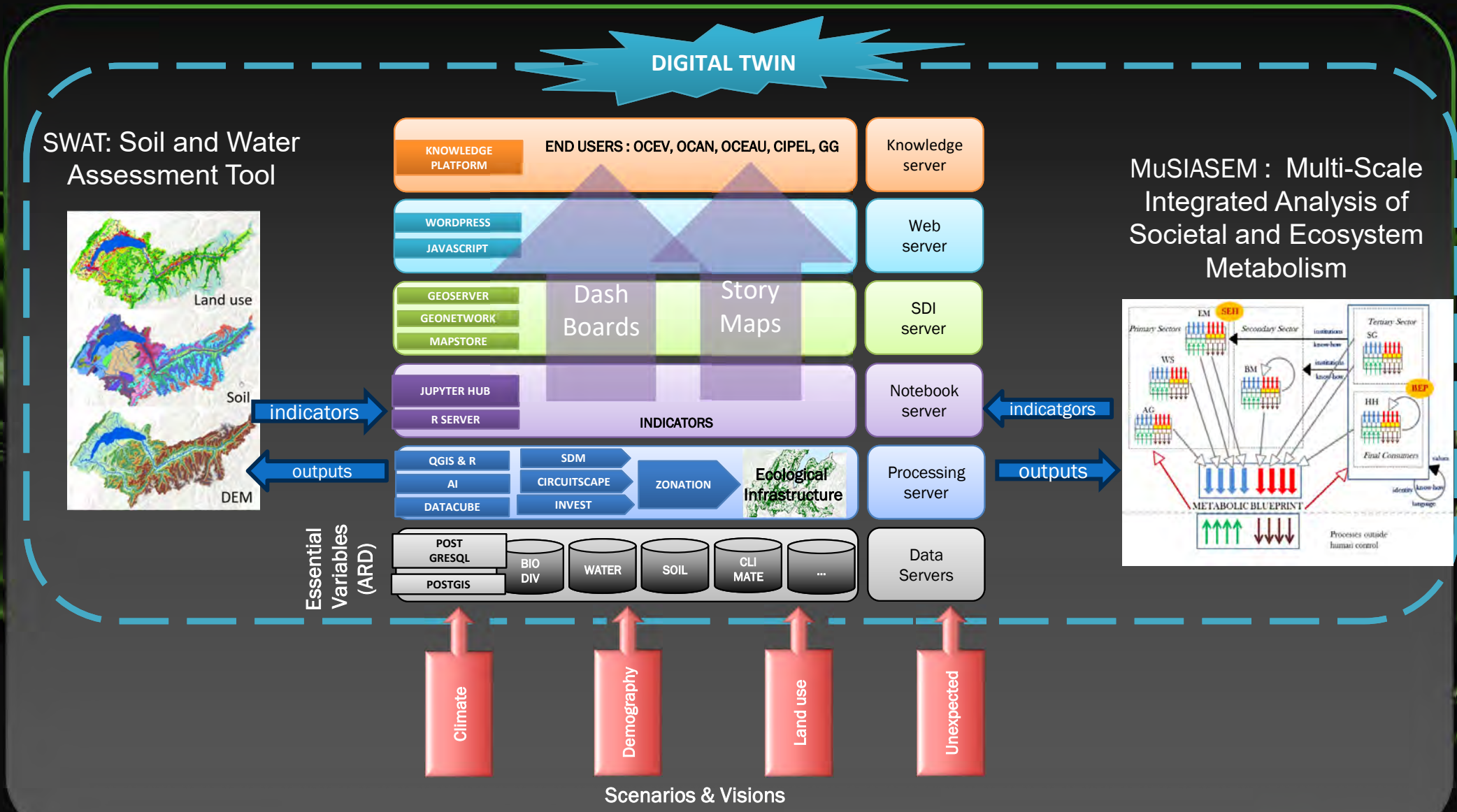
Lambiel et al. in prep.

Architecture of the Shared JupyterLab Environment and the Automation Process for Ecological Infrastructure (EI) Calculation and Its Indicators



Lambiel et al. in prep.

Integration of different modeling approaches into the JupyterHub solution




CONCLUSIONS

Is there a pilot on the plane?

The current level of control around sustainable development issues

Giampietros' slides

Is there a pilot on the plane?

The level of control we'd like to see everywhere

Giampietros' slides

Is there a pilot on the plane?

The level of control we'd like to see everywhere

Giampietros' slides

https://www.naturebasedsolutionsinitiative.org

Conclusions

We have the data and individual models to assess different dimensions of the environment

We have methods such as ecological infrastructure to integrate indivual models into land use planning

Digital Twins and Nexus approach bring new opportunities to monitor and model socio-ecological systems in order to better inform decision making for a more sustainable world

Selected publications from enviroSPACE

Adde, A., et al. 2023. N-SDM: a high-performance computing pipeline for Nested Species Distribution Modelling. Ecography.

Folz et al. Reconciling urban food metabolic pattern with its environment – a “mission impossible”? (Submitted).

Giuliani, G. et al. Knowledge generation using satellite earth observations to support sustainable development goals (SDG): A use case on Land degradation: Int. Journal of Applied Earth Observation and Geoinformation (2020).

Honeck, E.C., et al., 2021, Integrating ecosystem services into policymaking – A case study on the use of boundary organizations: Ecosystem Services, v. 49, no. 101286.

Honeck, E.C., et al., 2020, Implementing Green Infrastructure for the Spatial Planning of Peri-Urban Areas in Geneva, Switzerland: Sustainability, v. 12, no. 4, p. 1387.

Honeck, E.C. Sanguet, A., et al., 2020, Methods for identifying green infrastructure: SN Applied Sciences, v. 2, no. 1916.

Kuelling, N., Adde, A., et al., soumis. SWECO25: a cross-thematic raster database for ecological research in Switzerland.

Kuelling, N., et al., in prep. What is the driver? Ecosystem services and biodiversity patterns of Switzerland

Lehmann, A. et al. Lifting the Information Barriers to Address Sustainability Challenges with Data from Physical Geography and Earth Observation. Sustainability 9 (2017).

Lehmann, A. et al. GEOEssential – mainstreaming workflows from data sources to environment policy indicators with essential variables: International Journal of Digital Earth (2019).

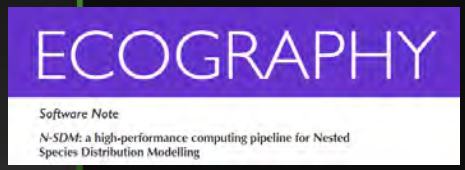
Lehmann, A., et al. Towards integrated essential variables for sustainability. International Journal of Digital Earth (2020).

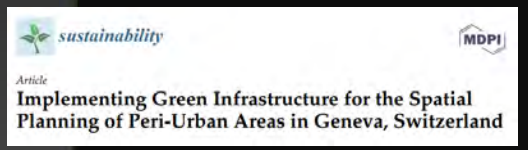
Sanguet, A., et al. 2022. Beyond topo-climatic predictors: Does habitats distribution and remote sensing information improve predictions of species distribution models? Global Ecology and Conservation, 39.

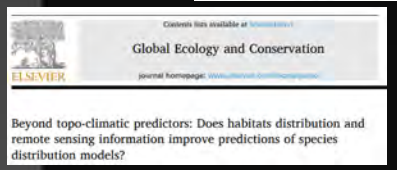
Sanguet, A., et al. 2023. Mapping Ecological Infrastructure in a Cross-Border Regional Context. Land 2023, 12, 2010.

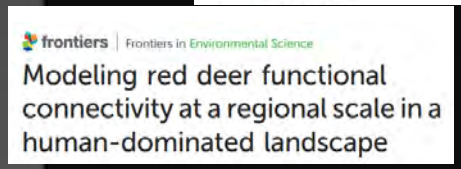
Urbina, L., et al. 2023. Modeling red deer functional connectivity at a regional scale in a human-dominated landscape. Frontiers in Environmental Science, 11: 1198168.

Urbina, L., et al. soumis. Combining multi-species connectivity modelling with expert knowledge to inform the green infrastructure design.

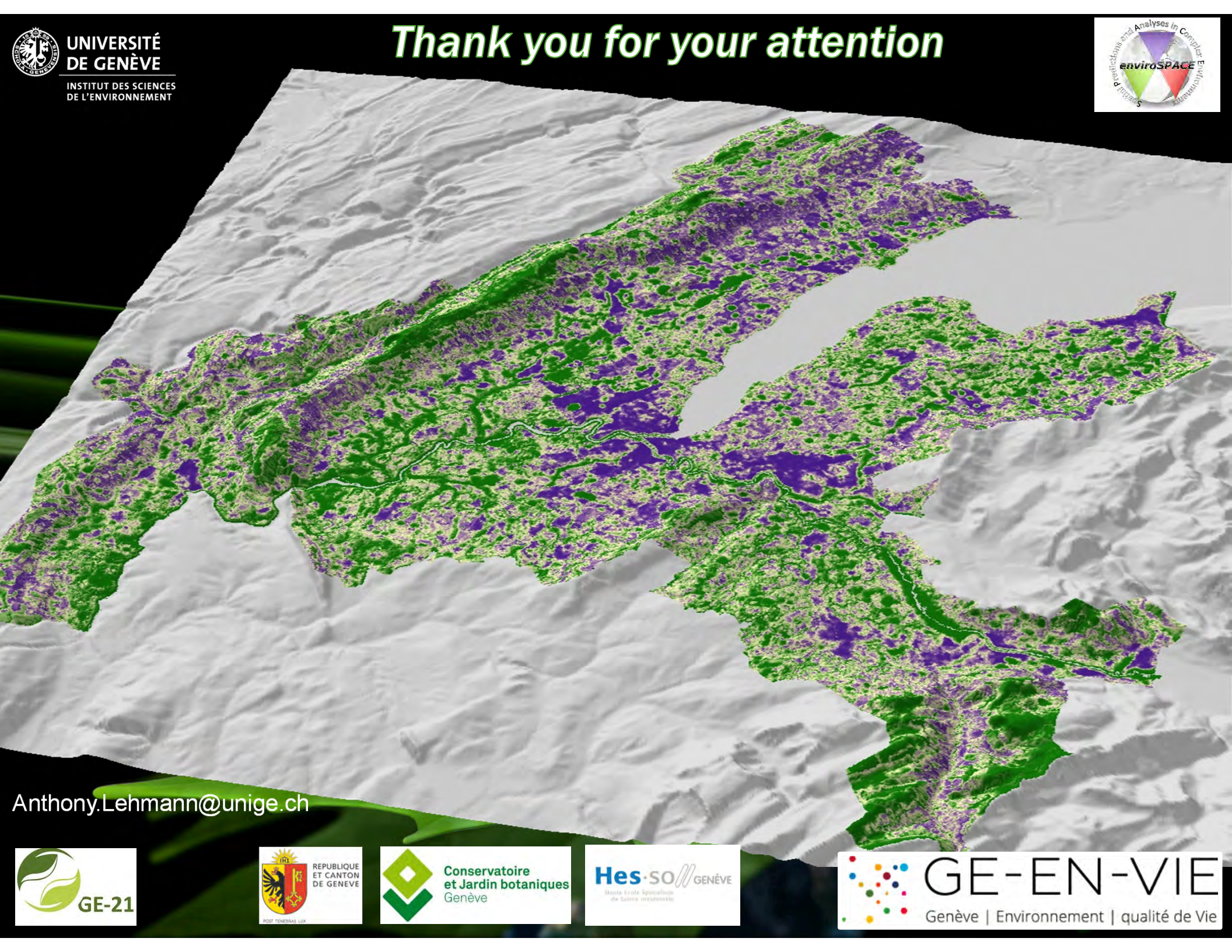








Thank you for your attention



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INSTITUT DES SCIENCES DE L'ENVIRONNEMENT

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GE-21

REPUBLIQUE ET CANTON DE GENEVE

Conservatoire et Jardin botaniques Genève

Hes·so GENÈVE

GE-EN-VIE
Genève | Environnement | qualité de Vie

GE-EN-VIE

Genève | Environnement | qualité de Vie

RENCONTRE 2025

« Changements globaux: s'adapter grâce au socle du vivant »

1. **Date: 24 Juin de 15h30 à 19h**
2. Lieu: Maison Internationale de l'Environnement 2, Châtelaine
3. **Keynote: 30' Mario Giampietro: Time to move to better sustainability discussions . . .**
4. Speakers: 10'
    1. ETAT: Socle du vivant GG (Walter Vetterli)
    2. HES: Projet substrat des toitures (Patrice Prunier, Philippe Royer)
    3. UNIGE: Consommation (Marlyne Sahakian)
5. Pause: 30'
6. Ateliers : 60'
    1. GE-NEXUS Agriculture (Alexander Folz, Mario Giampietro,…)
    2. GE-NEXUS Eau (Igor Chernov, Mostafa Jafari,…)
    3. Adaptation et socle du vivant pour PDCn (Walter Vetterli, Nathan Külling, Anthony Lehmann,…)
7. Wrapup et discussion : 30'
8. Apéro: 30'