Digital twins of ecosystems

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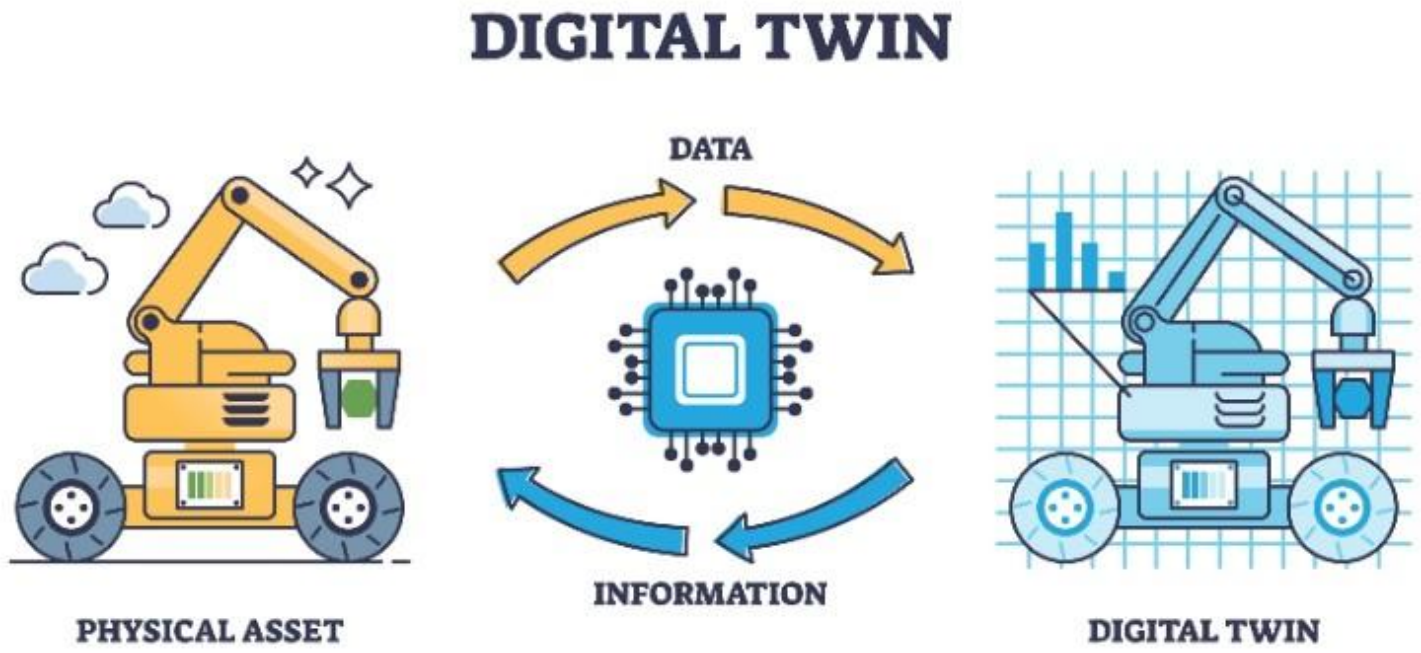
What are digital twins?



A digital twin is a digital model of an intended or actual real-world physical product, system, or process (a physical twin) that serves as a digital counterpart of it for purposes such as simulation, integration, testing, monitoring, and maintenance (*Wikipedia*)

What are digital twins?

Digital twin prototype (DTP): exists before there is a physical product. The DTP consists of the designs, analyses, and processes that realize a physical product.

Digital twin instance (DTI): the digital twin of each individual instance of the product once it is manufactured. The DTI is linked with its physical counterpart for the remainder of the physical counterpart's life.

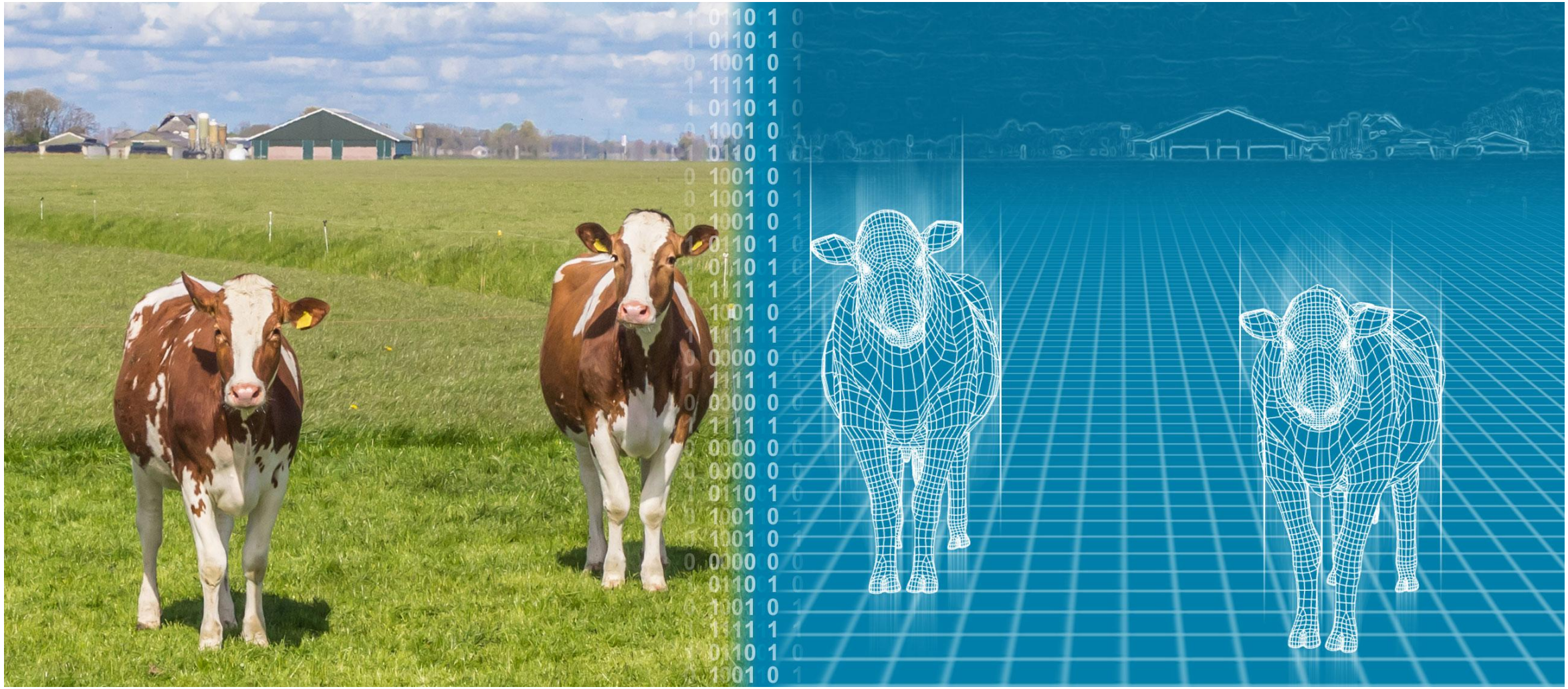
What are digital twins?

1991: The idea of digital twin technology was coined in *Mirror Worlds* (a book by David Gelernter)

2002: Michael Grieves was the first to apply the concept to manufacturing

2010: John Vickers at NASA introduced the new term—"digital twin"—formally

Digital twins in the life sciences



Digital twins in the life sciences

Important difference with engineering: the ‘physical entity’ already exists and functions (so the physical twin is there before the digital twin)

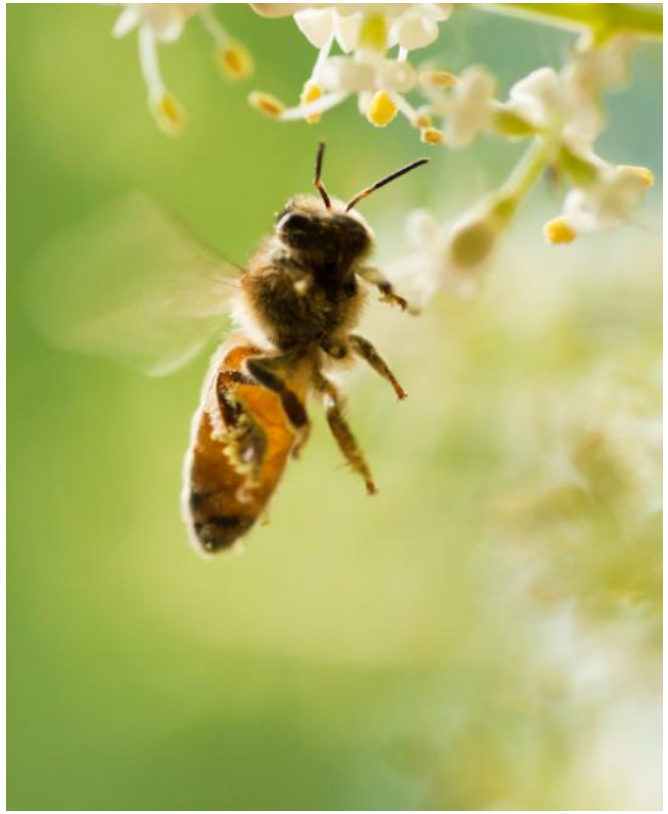
Digital twin prototype (DTP): exists before there is a physical product. The DTP consists of the designs, analyses, and processes that realize a physical product.

Digital twin instance (DTI): the digital twin of each individual instance of the product once it is manufactured. The DTI is linked with its physical counterpart for the remainder of the physical counterpart's life.

Posterior digital twin: a digital twin that is constructed as a digital counterpart of an already functioning physical entity

Digital twins in the life sciences

- three examples -



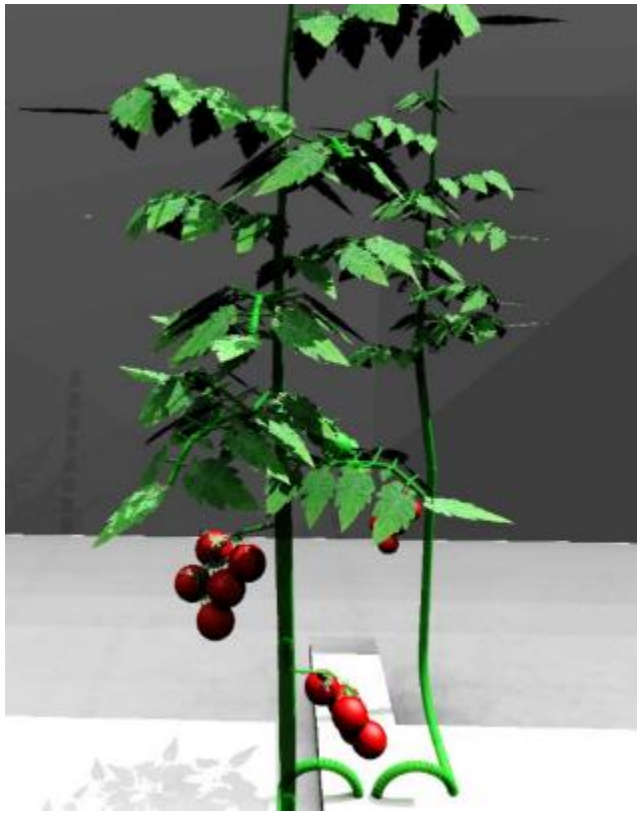
Digital twins in the life sciences
- Tomato plant -

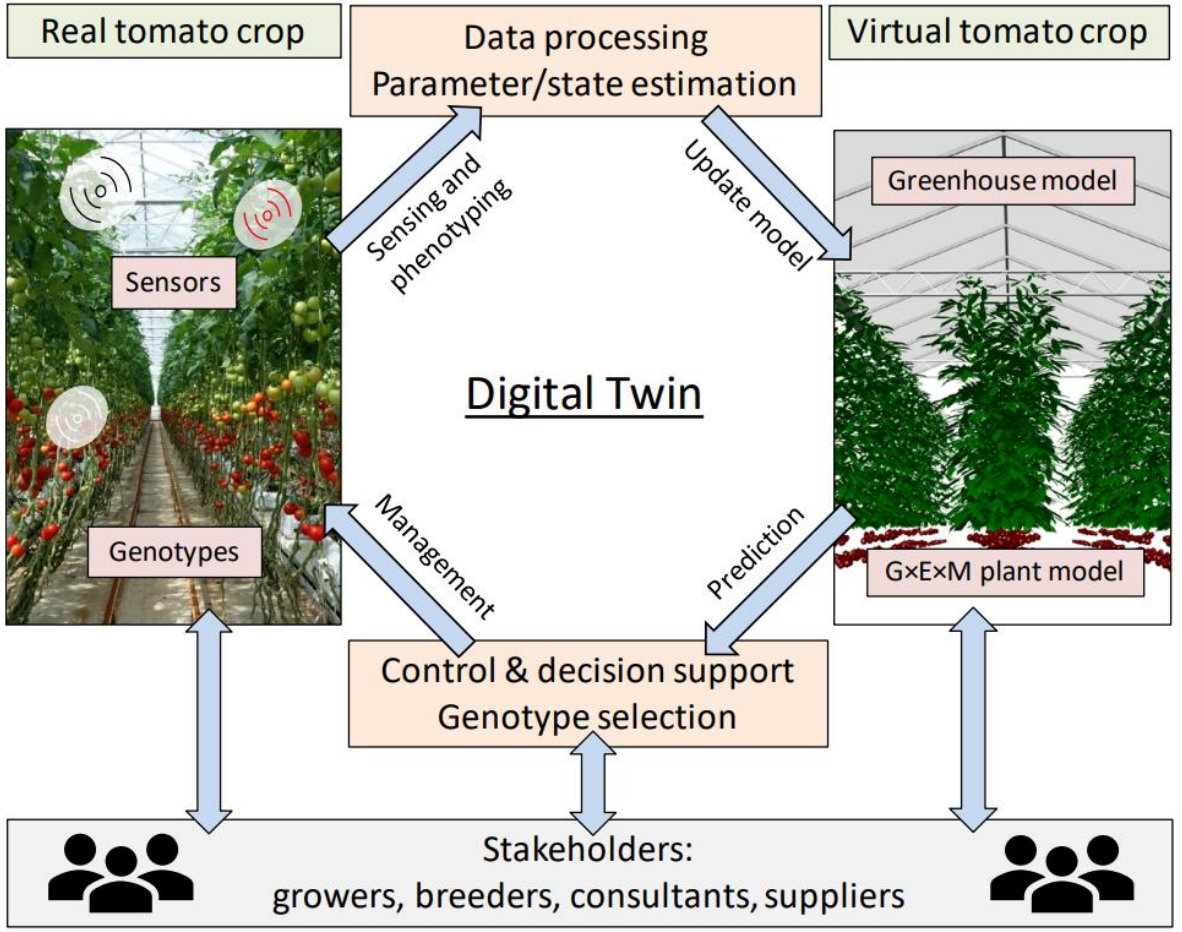
A digital twin of a tomato crop in a greenhouse: a 3D simulation model that is fed in real-time with sensor information from a real greenhouse.

The interactions between crop characteristics, environmental factors and crop management are all simulated.

Growers will be able to use it as a decision-support tool for growing tomatoes.

Digital twins in the life sciences
- Tomato plant -



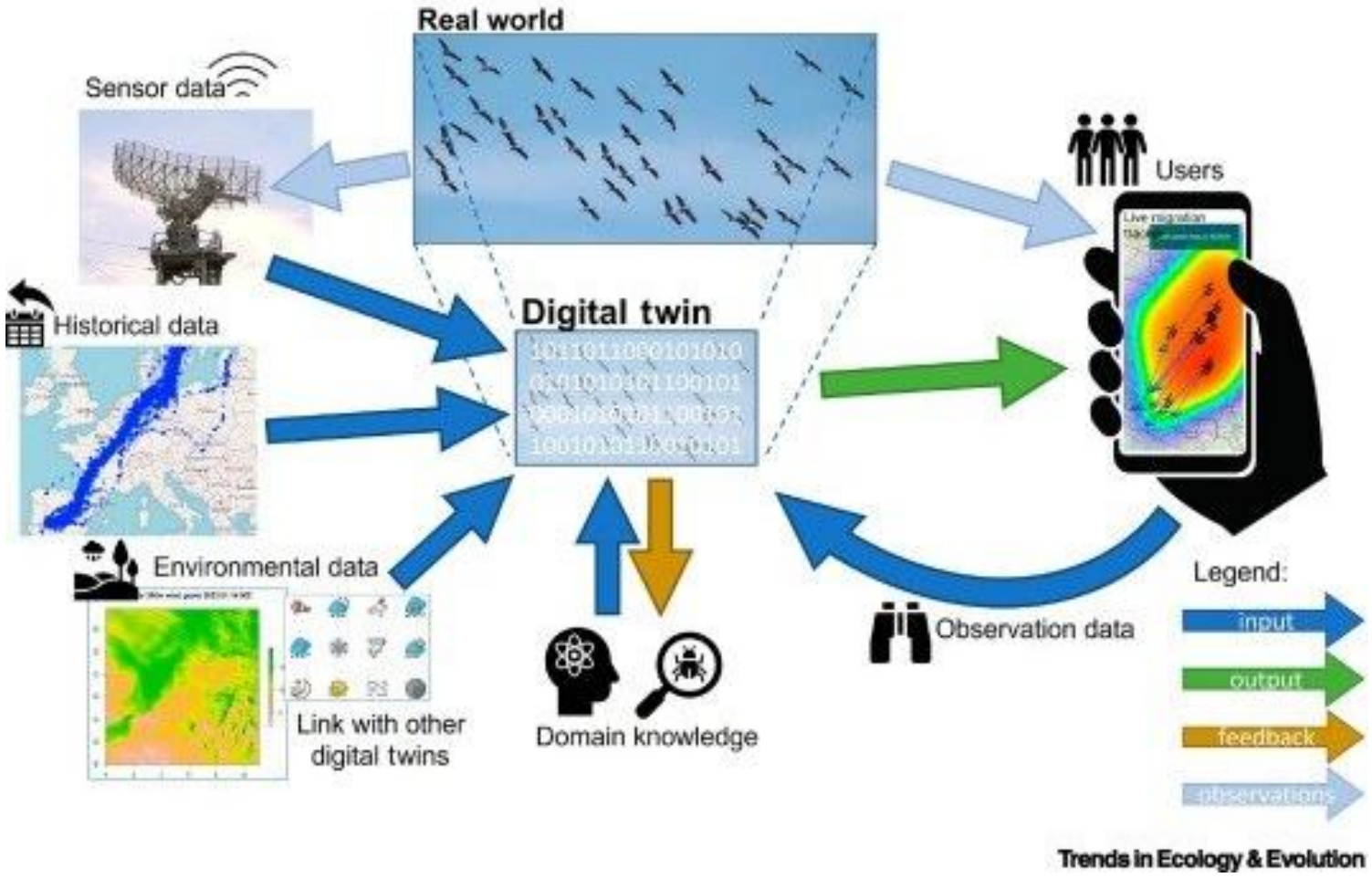


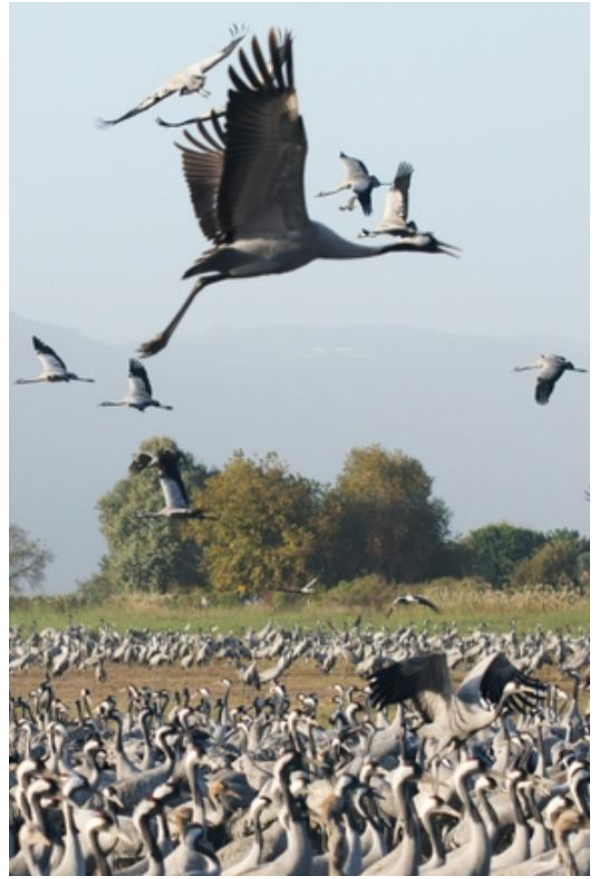
Concept map of the Virtual Tomato Crops digital twin. (G×E×M = interaction between genotype, environment and management)

https://magazines.wur.nl/ko-magazine-2021-en/digital-twins/

Digital twins in the life sciences

- Crane radar -

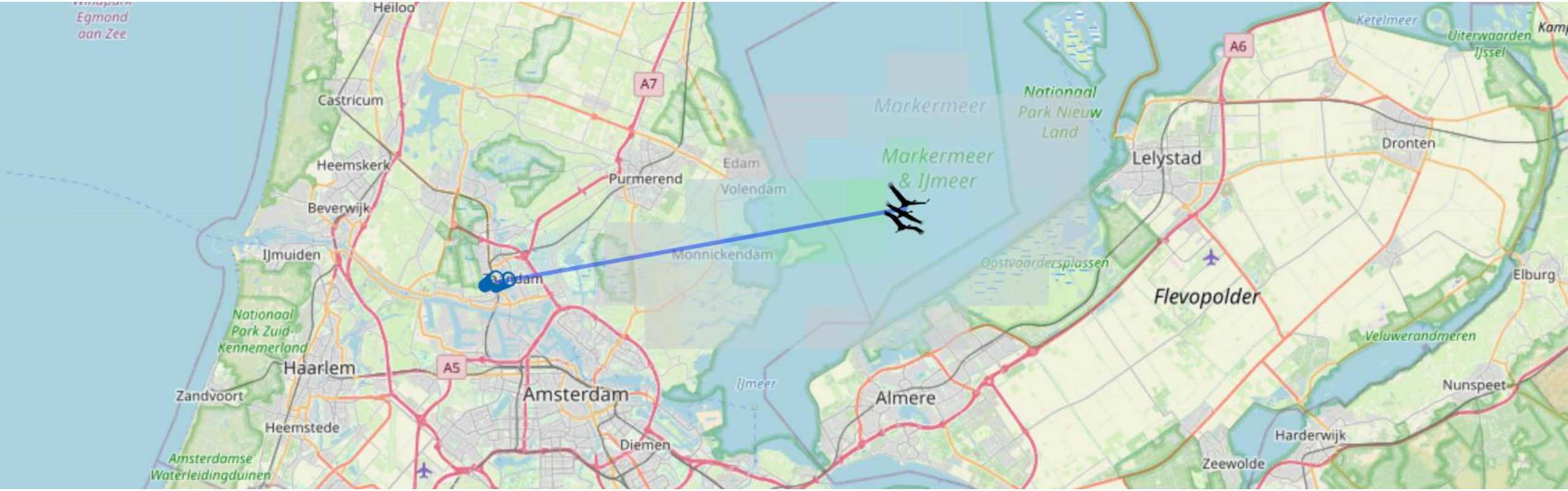




De Koning et al. (2023) TREE

Digital twins in the life sciences

- Crane radar -



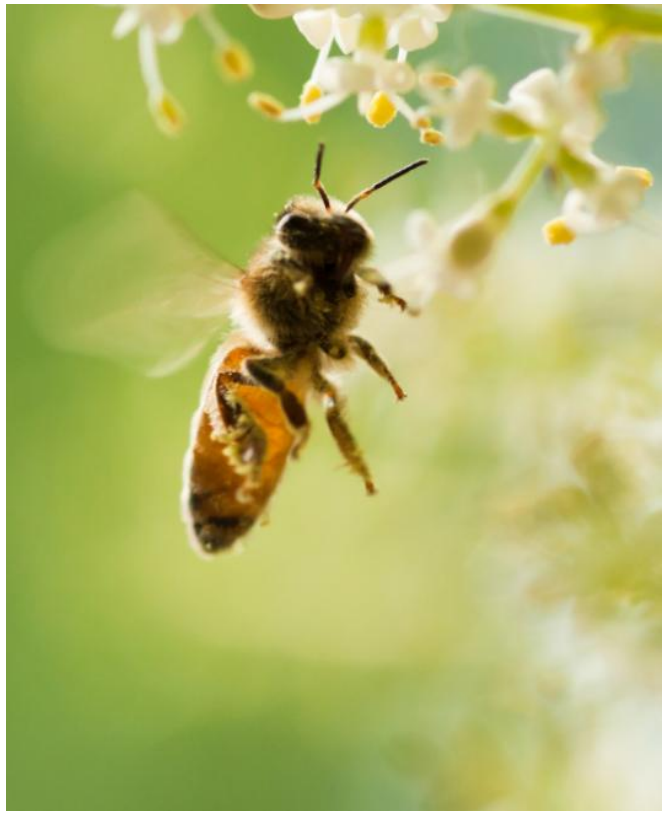
Go to: https://analytical.sensingclues.org/cranes/ to use this digital twin

Digital twins in the life sciences
- Bee hives -

A proto-DT to assess the viability and productivity of honey bee colonies in different landscapes and under different management and climate-change scenarios.

The proto-DT simulates foraging, population dynamics and Varroa mite infestation of a single honey bee colony.

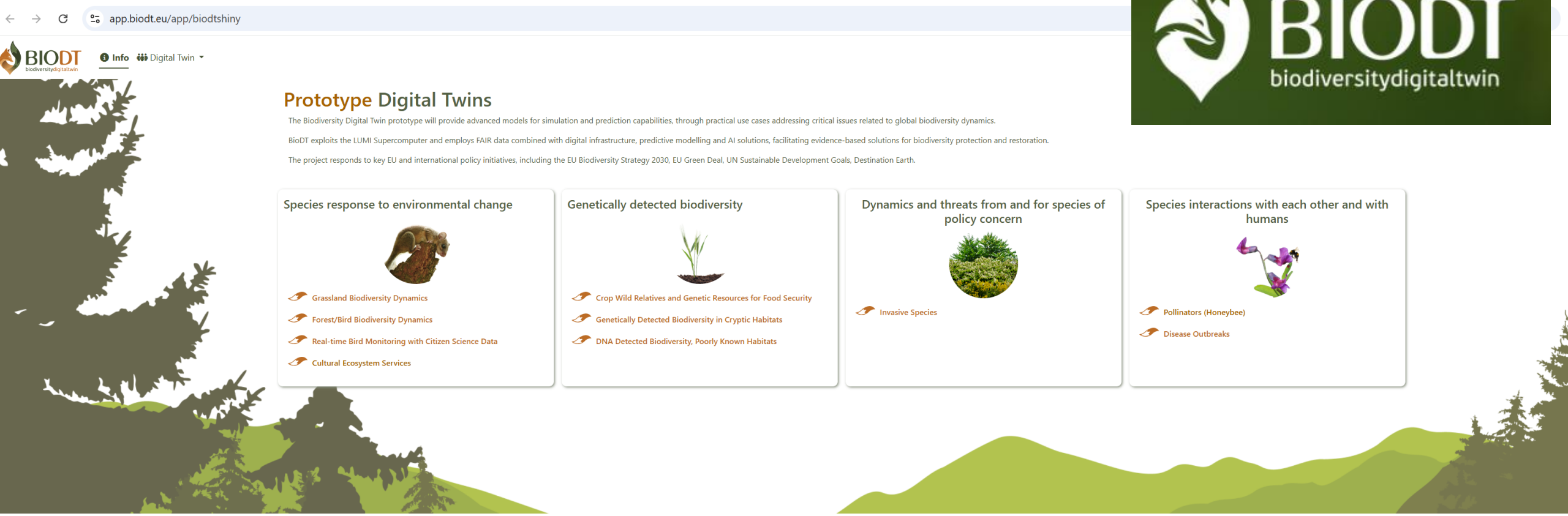
The main input data are land-cover maps and daily weather data.



Groenenveld et al. (2024) RIO

Digital twins in the life sciences

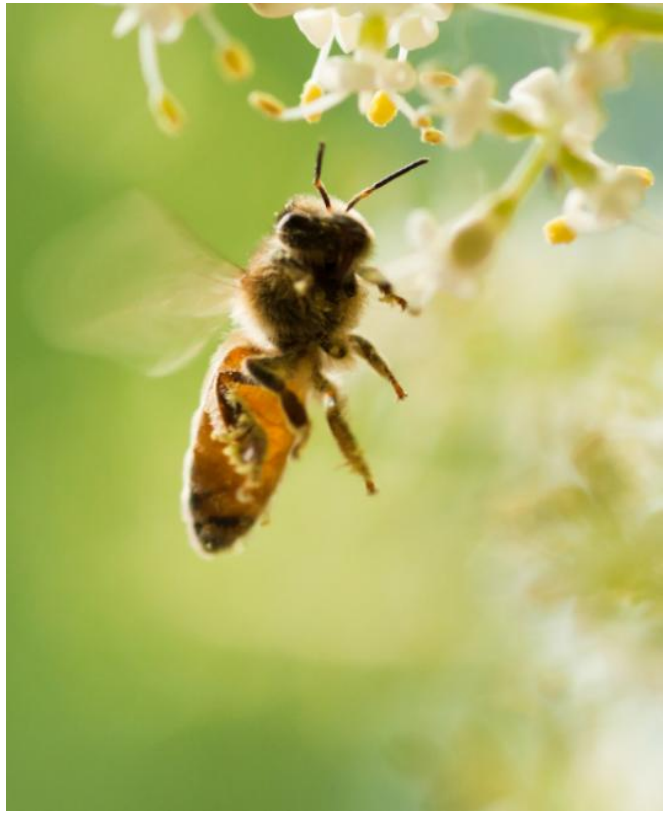
- Bee hives -



Go to: https://app.biodt.eu/app/biodtshiny to test out this prototype digital twin

Digital twins in the life sciences

- Are these ‘real’ digital twins? -



Digital twins in the life sciences
- Characteristics-

i) Continuous updated with real-time data

ii) Include historic data for training the prediction models, and environmental data that drive the dynamics of the system

iii) Automated data retrieval

iv) Based on mechanistic models in order to mimic the behaviour of the physical system with high fidelity

v) End-user interactions by including an operational environment where decisions are made

De Koning (2025) Ecological Informatics

Digital twins in the life sciences
- Considerations part 1-

An important difference is that while engineering a digital twin is constructed based on physical knowledge this is not necessarily the case in the life sciences

There it can be based on

- a biophysical approach (as in medical sciences)
- a data-driven approach (as in ecology)
  - *using statistical modelling* – which does contain some process insights
  - *using AI* – which may be hard to relate back to processes

Digital twins in the life sciences
- Considerations part 2-

In engineering once both the physical and digital twin exist there is digital thread: the digital twin is real time updated based on input from the physical twin.

In life sciences such real time update is not really needed as

- digital twins are not always used as a real time decision tool (the aim is to predict the “climate” rather than the “weather”)
- some processes are annual rather than at a much shorter time scale (like reproduction of animals)

Digital twins in ecosystem research

Understanding ecosystems

Scenario studies

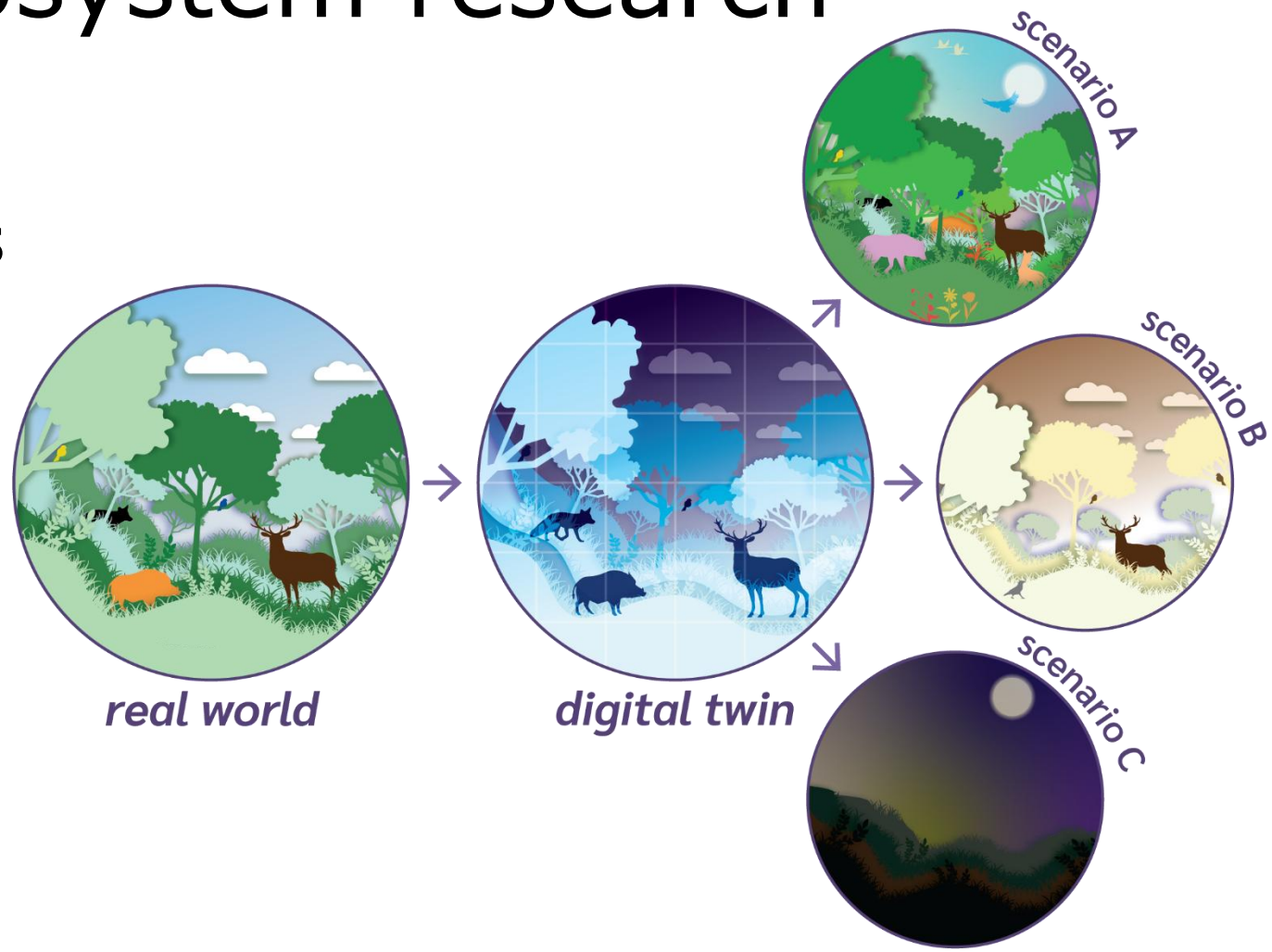
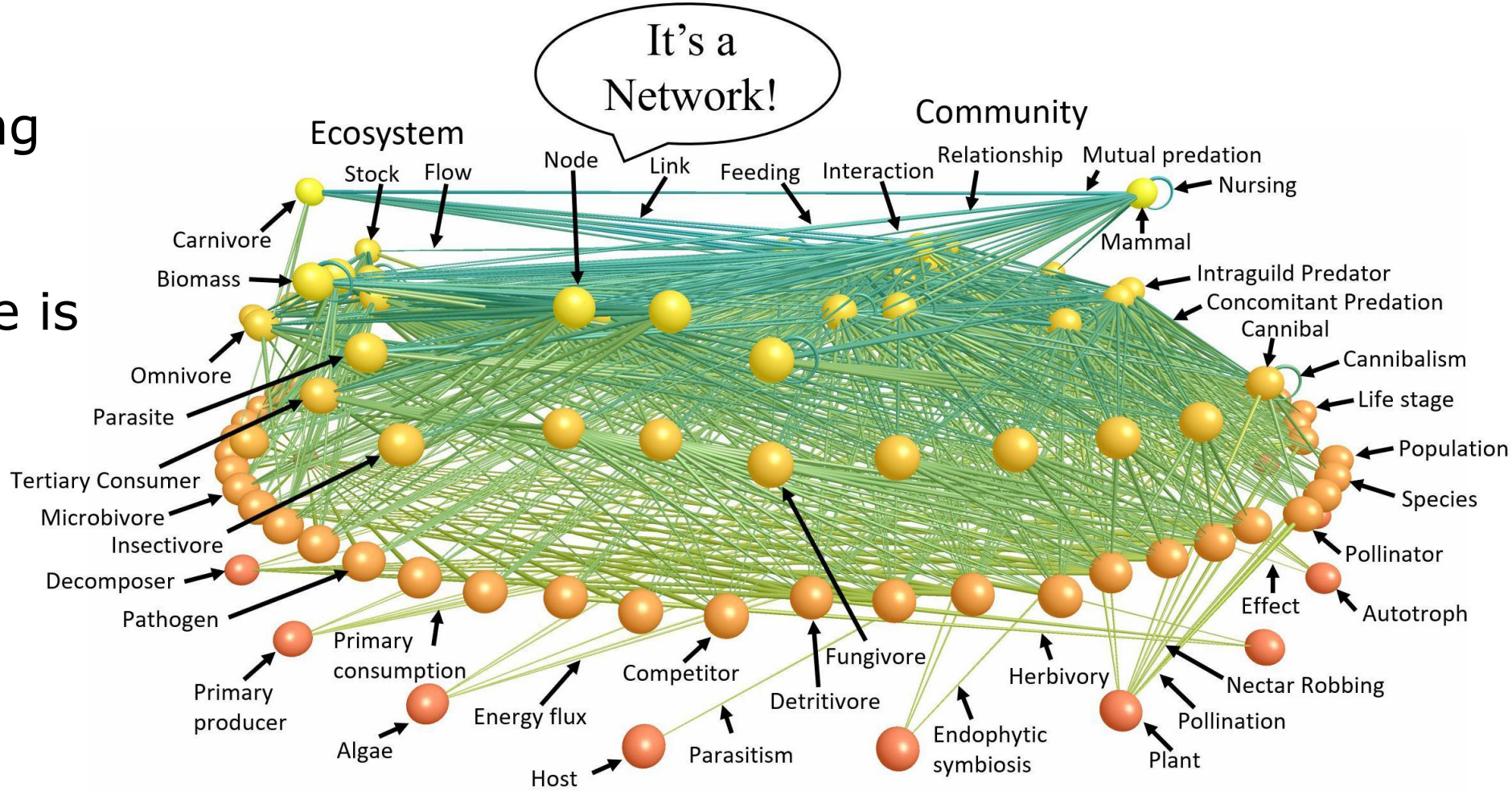


Illustration: Stefan Vriend

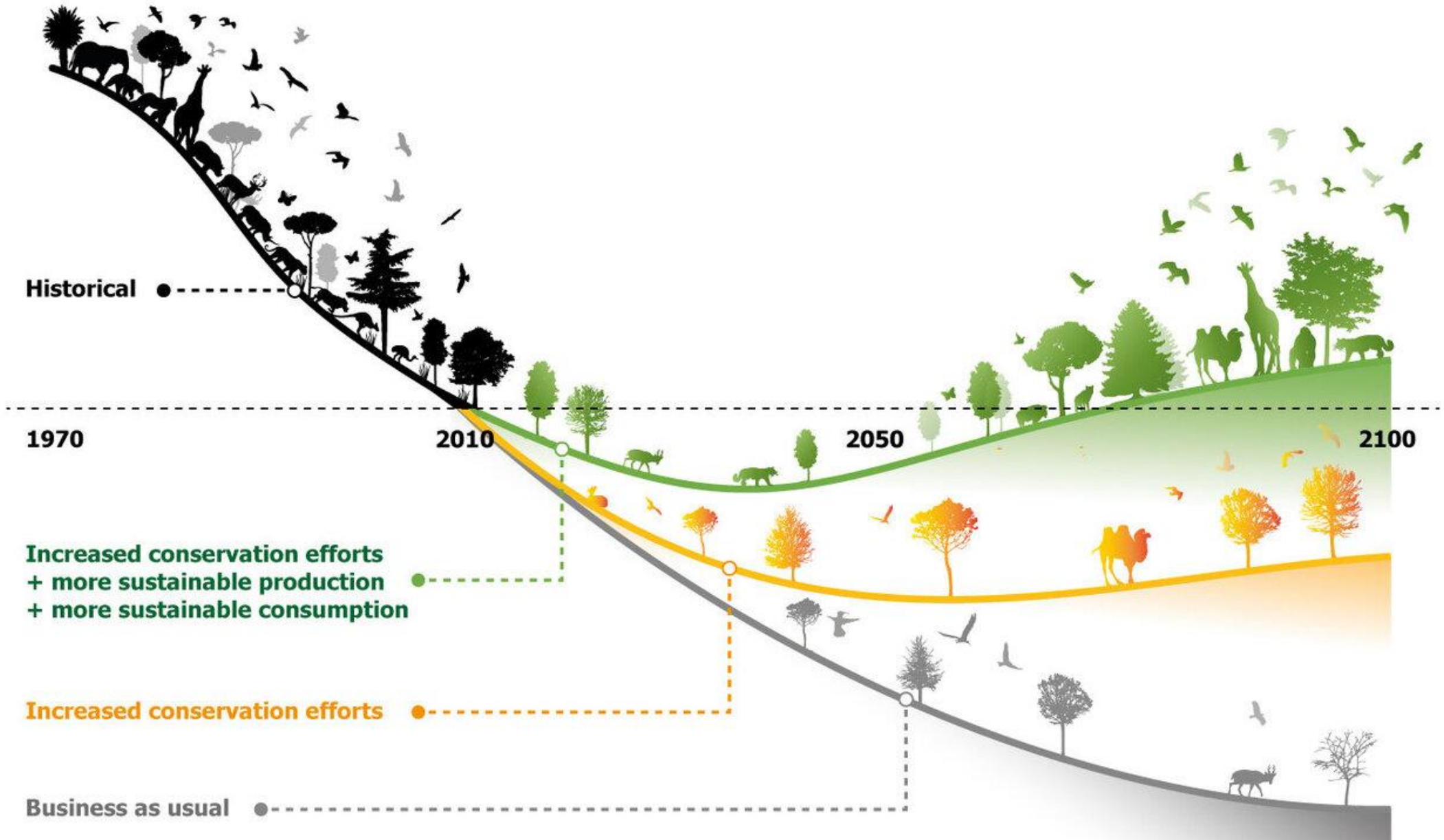
Digital twins to help understand ecosystems

Digital twins to help understand ecosystems

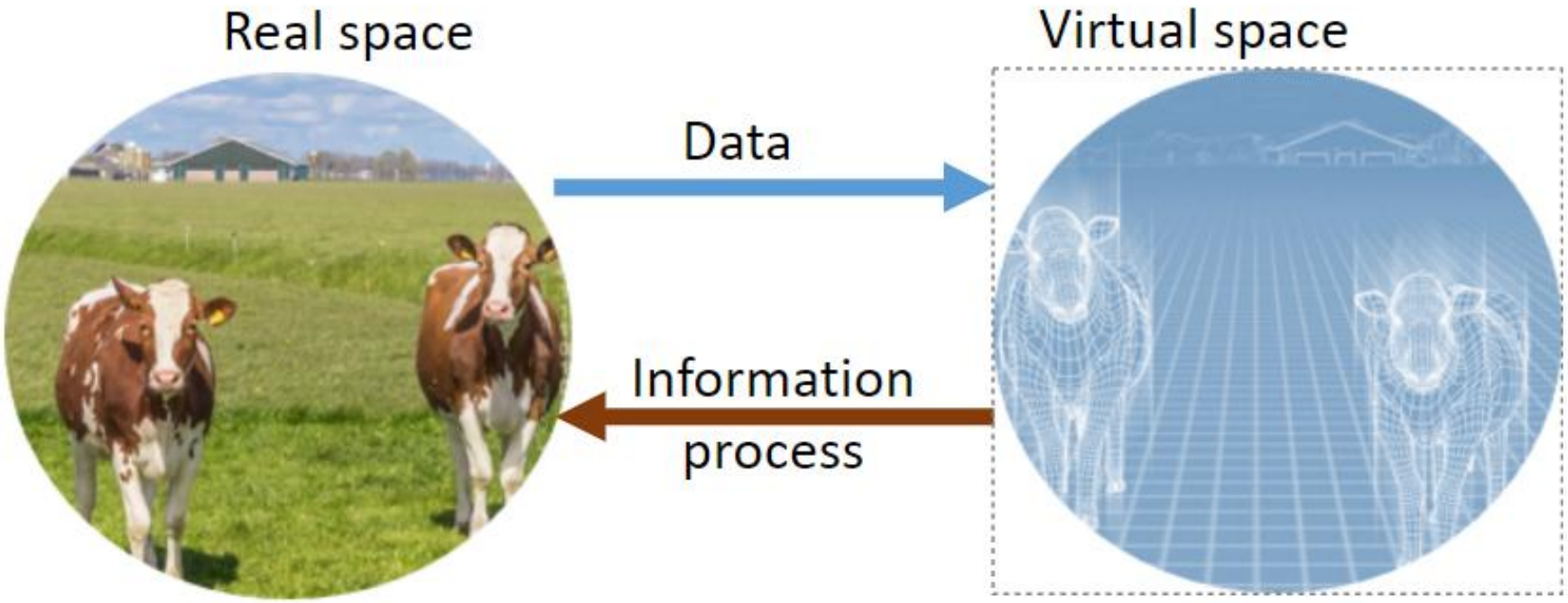
Understanding ecosystems using DT and ecology informed deep learning – where is the ‘dark knowledge’?



Digital twins to do scenario studies



Digital twins in the ecosystem research



A digital twin “only” needs to behave as the physical twin

A research infrastructure to develop **Digital Twins** of ecosystems in a changing world

See www.lter-life.nl for more info

The LTER-LIFE infra-structure

LTER-LIFE is a research infrastructure that enables researchers to build digital twins of ecosystems.

We are in year 2 of a 10-year project to develop the infrastructure

It is a collaboration of:

NIOO

NIOZ Sea Research

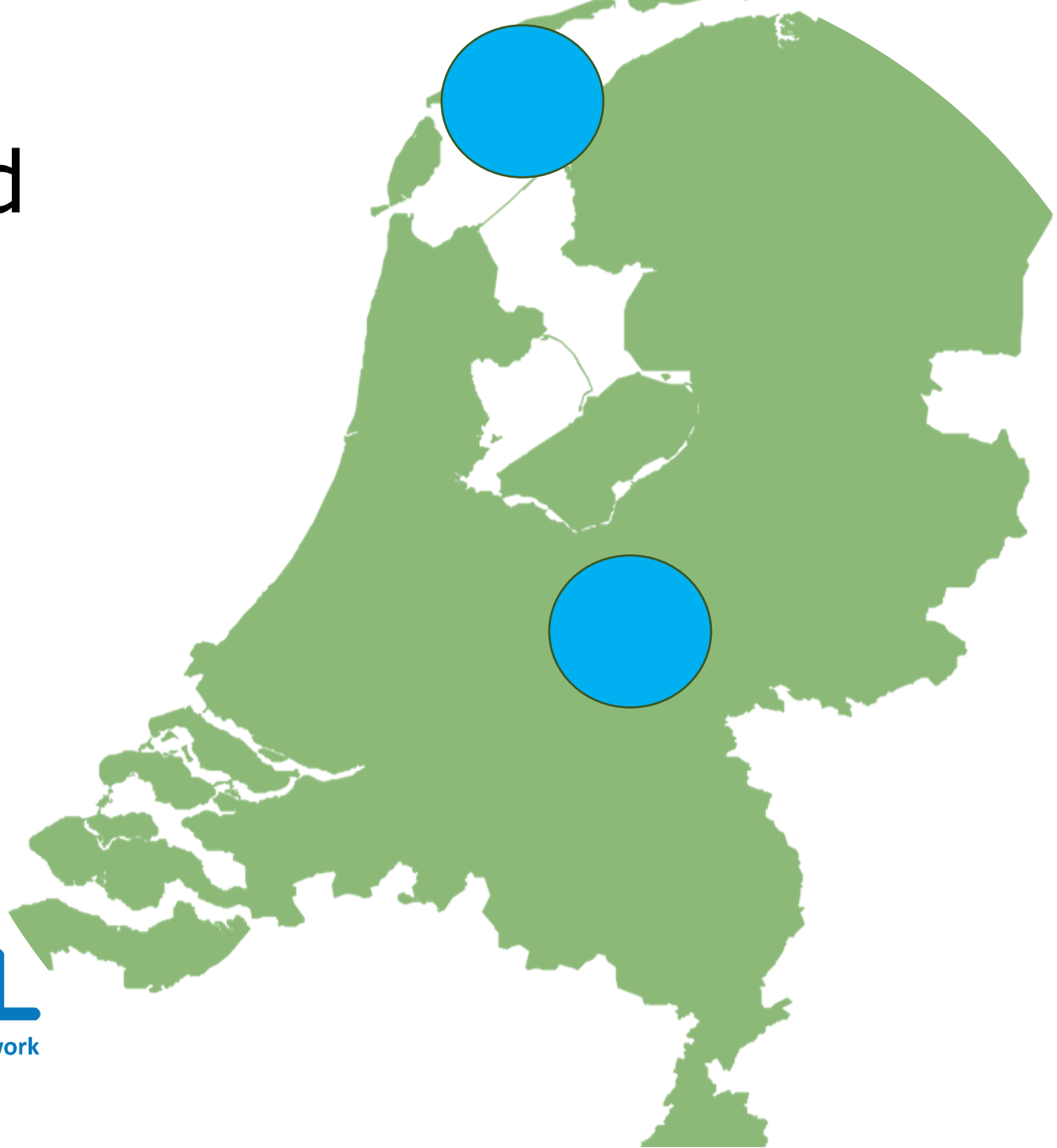
National Institute for Public Health and the Environment
Ministry of Health, Welfare and Sport

Universiteit van Amsterdam

WAGENINGEN UNIVERSITY & RESEARCH

Ecosystem-oriented approach

- LTSER Dutch Wadden Sea
- LTSER Veluwe



LTER LIFE

LTER-NL
Netherlands Long-term Ecosystem Research Network

FAIR Data & Models

Community

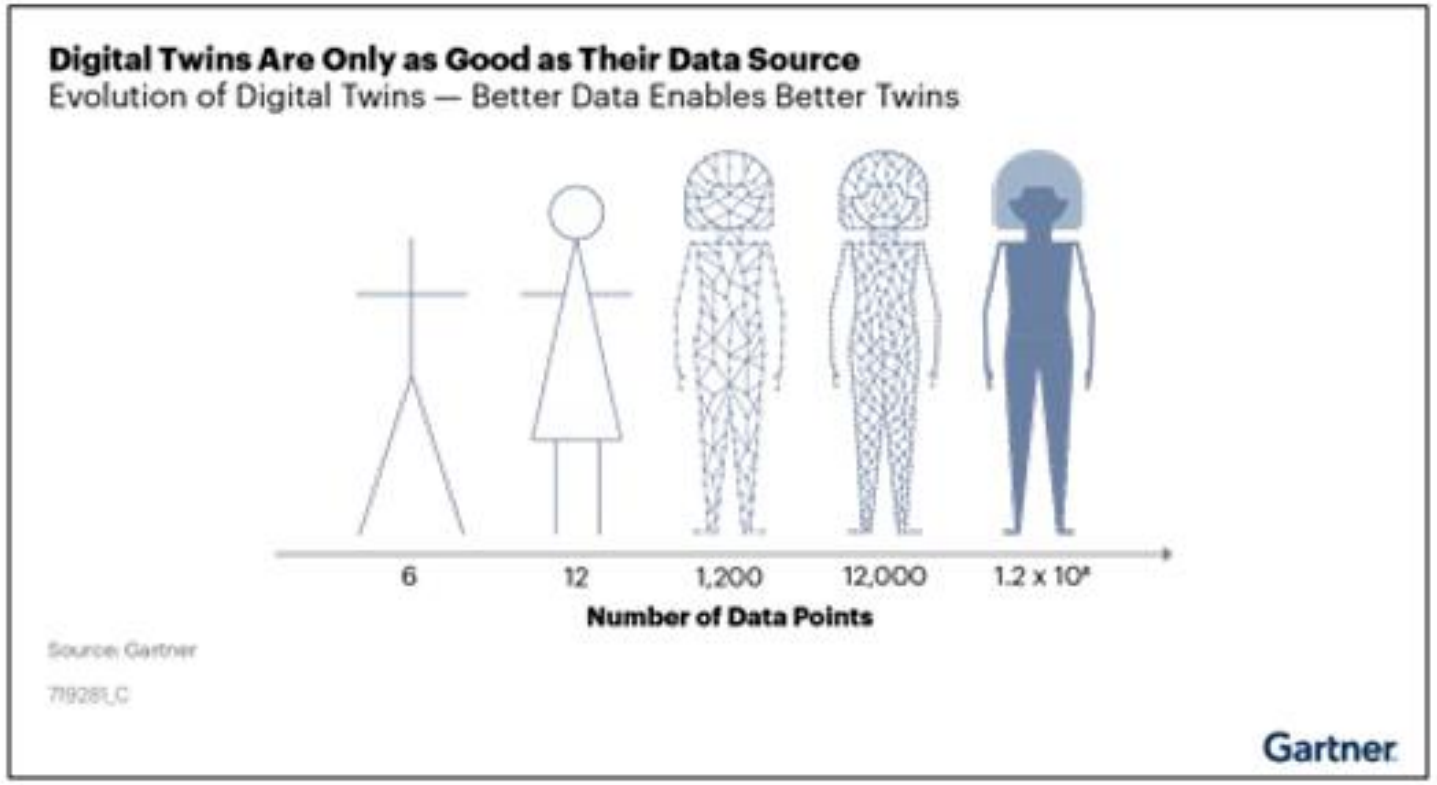
Virtual Lab

Digital twins in the ecosystem research

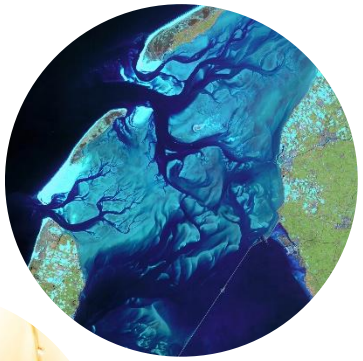
Data is needed is build digital twins

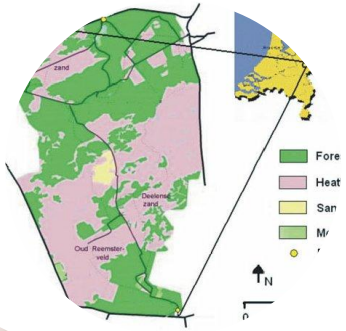
"Better data enables better twins"

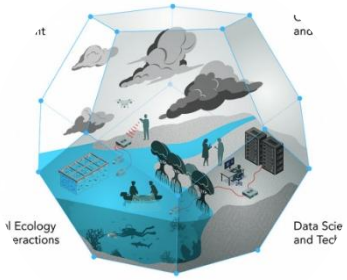
- Long-term data
- Biotic and abiotic data
- FAIR data

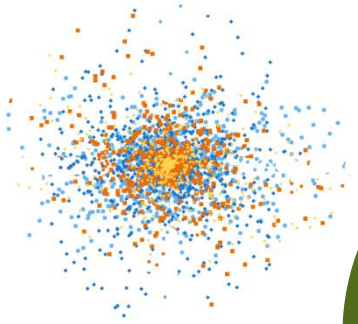


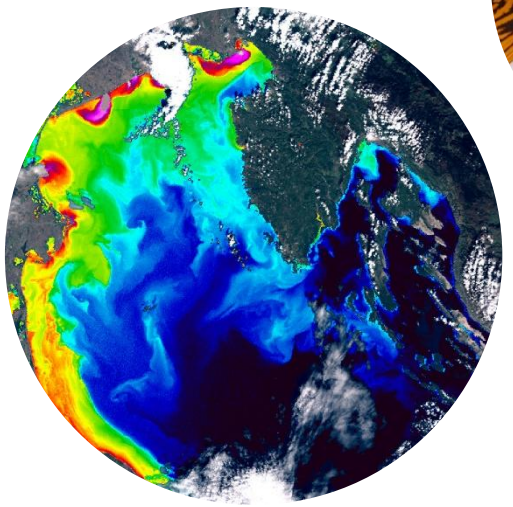
Scattered “unFAIR” data and models

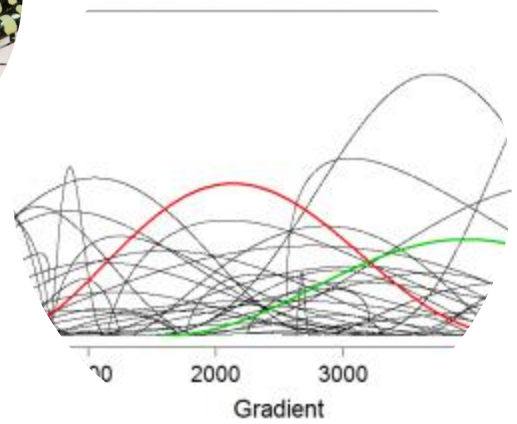






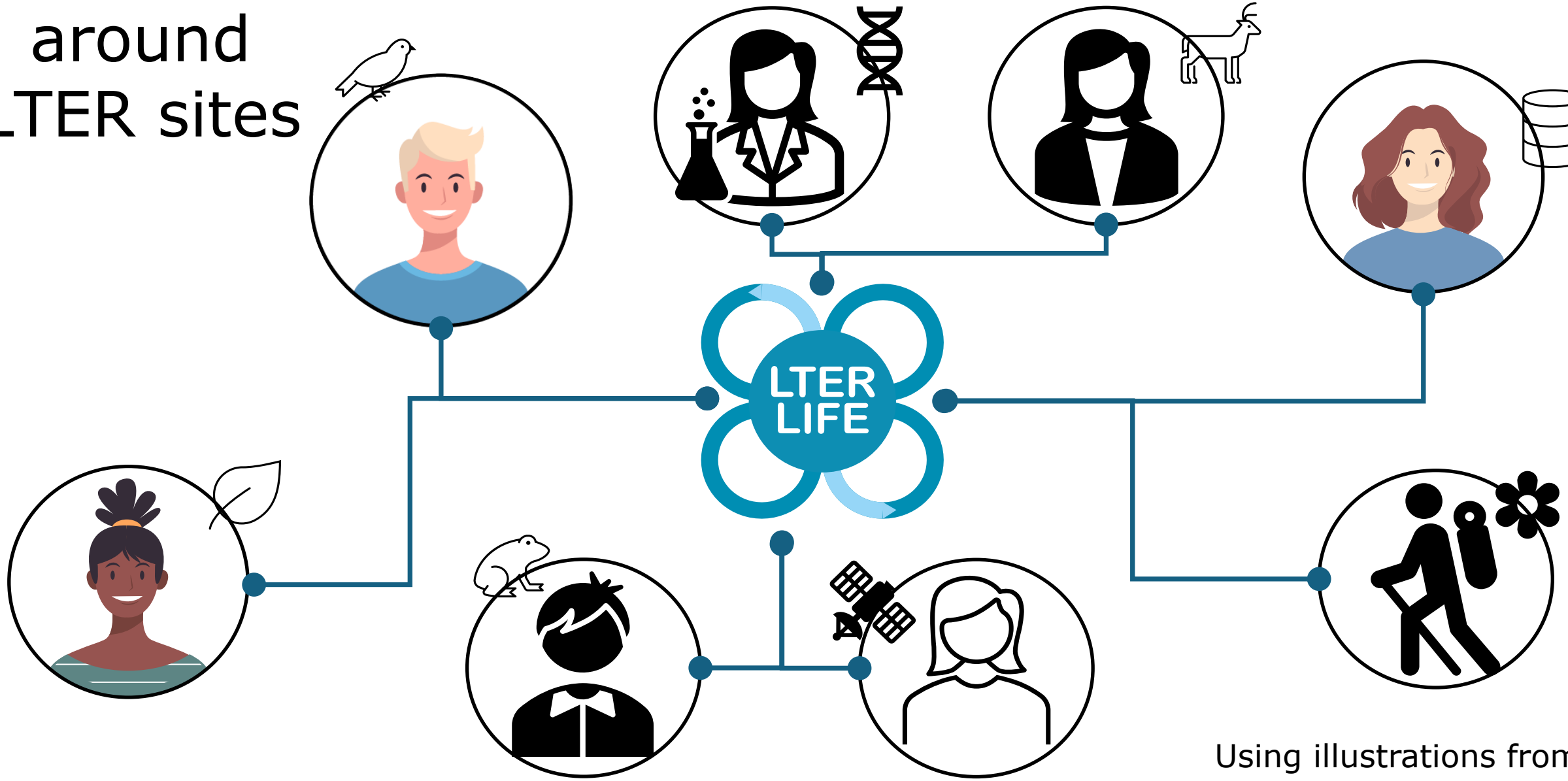






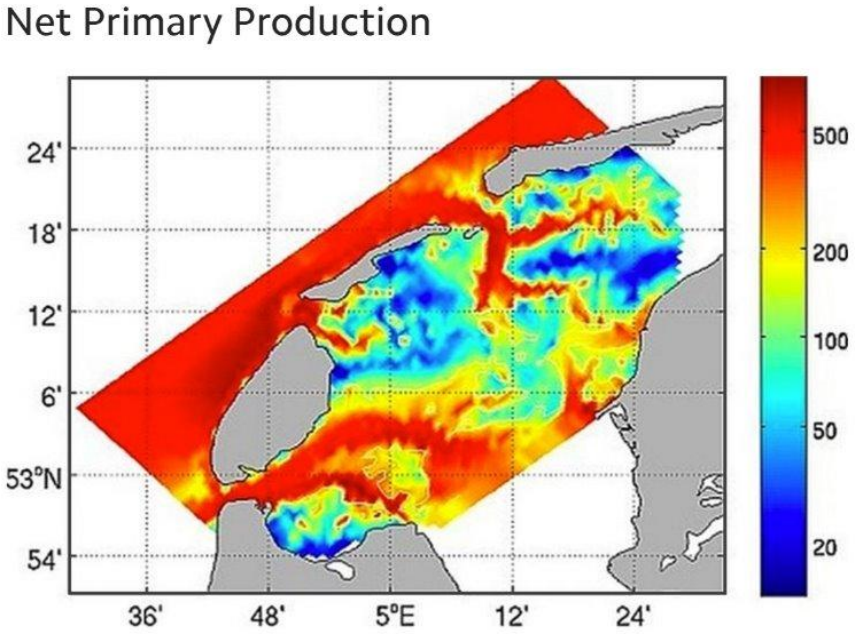
Further the FAIRification of ecological data by applying meta-data standards, controlled vocabularies, ontologies, and persistent identifiers

Community around LTER sites



Using illustrations from
Storyset, Freepik, Flaticon

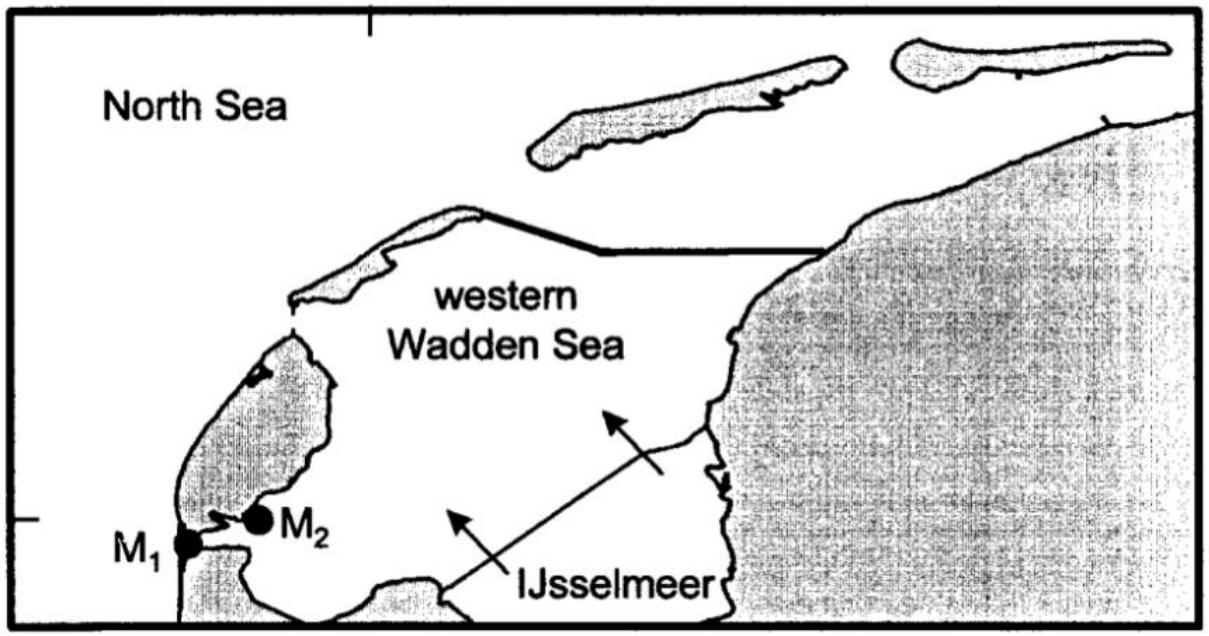
LTER-LIFE: two examples



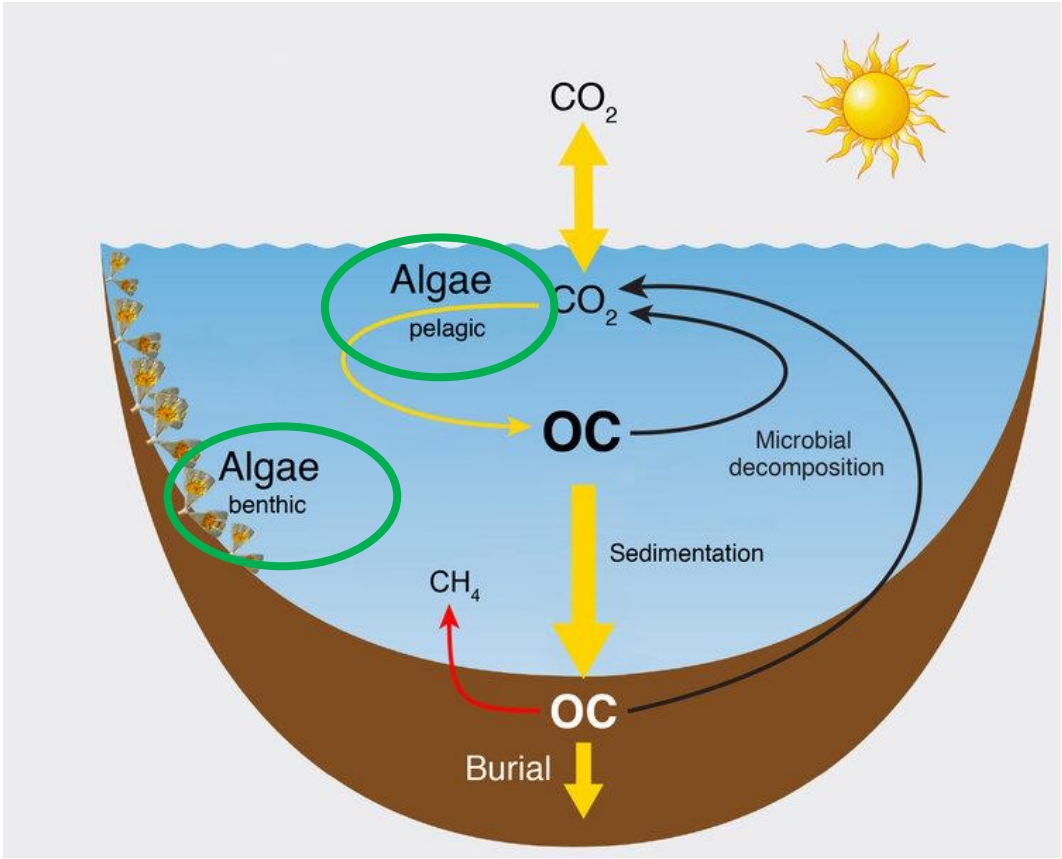
Primary production Wadden

Beech crop Veluwe

LTER-LIFE: primary production Wadden Sea



N-loading from Lake IJsselmeer in the Wadden Sea



OC – Organic Carbon

Helgol Mar Res (2000) 54:55–62

ORIGINAL ARTICLE

Catharina J.M. Philippart · Gerhard C. Cadée

Was total primary production in the western Wadden Sea stimulated by nitrogen loading?

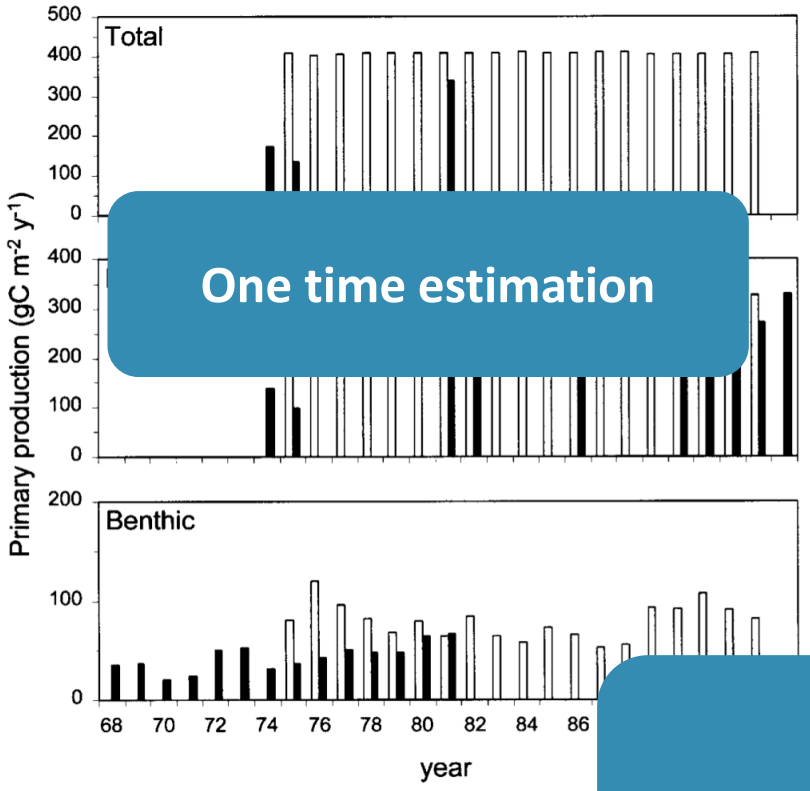
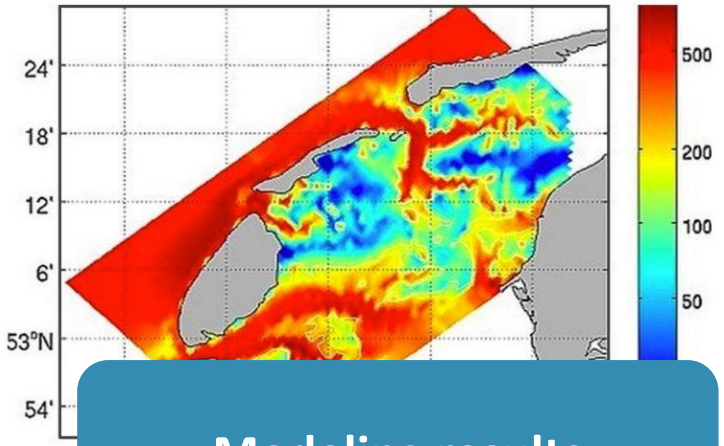


Fig. 3 Total (**A**; *upper panel*), pelagic (**B**; *middle*
hic (**C**; *lower panel*) primary production in the
Sea between 1968 and 1994. *White bars* indica
estimates as derived from N loadings from the
IJsselmeer according to empirical relationships for
coastal areas supplied by Borum and Sand-Jensen (1996); *solid bars* show actual production values as measured in the study area

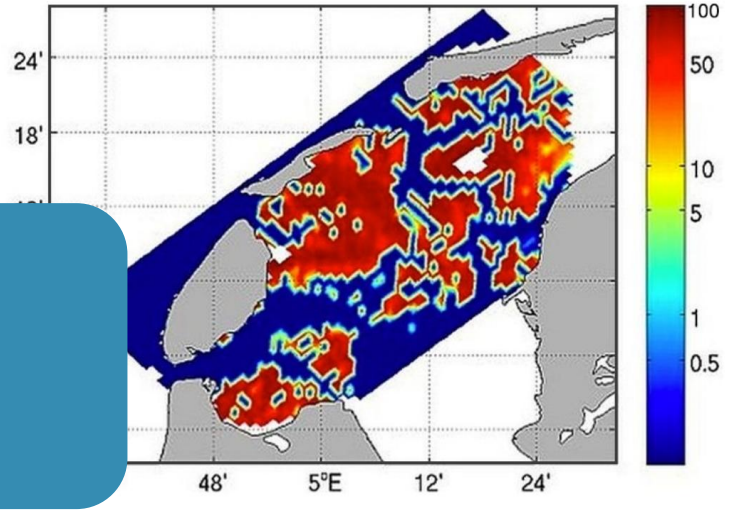
One time estimation

Pelagic algae primary production



Modeling results

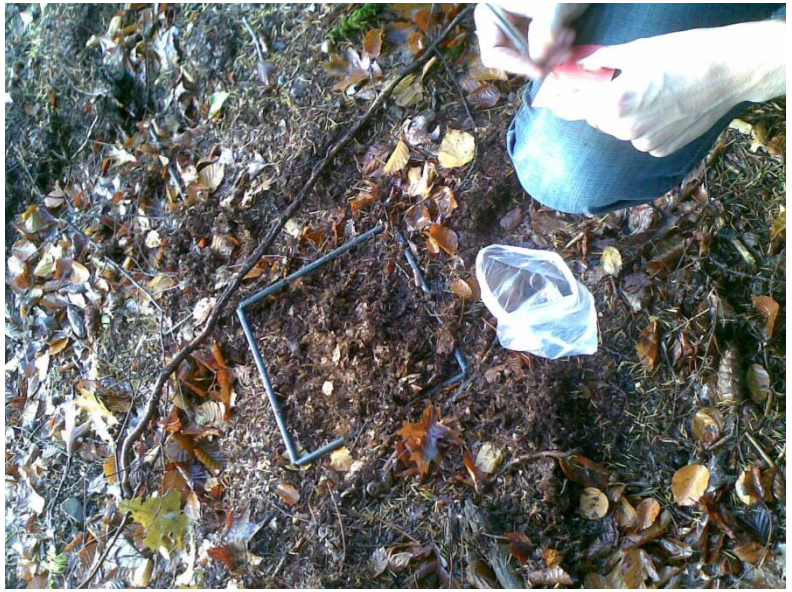
Benthic algae primary production



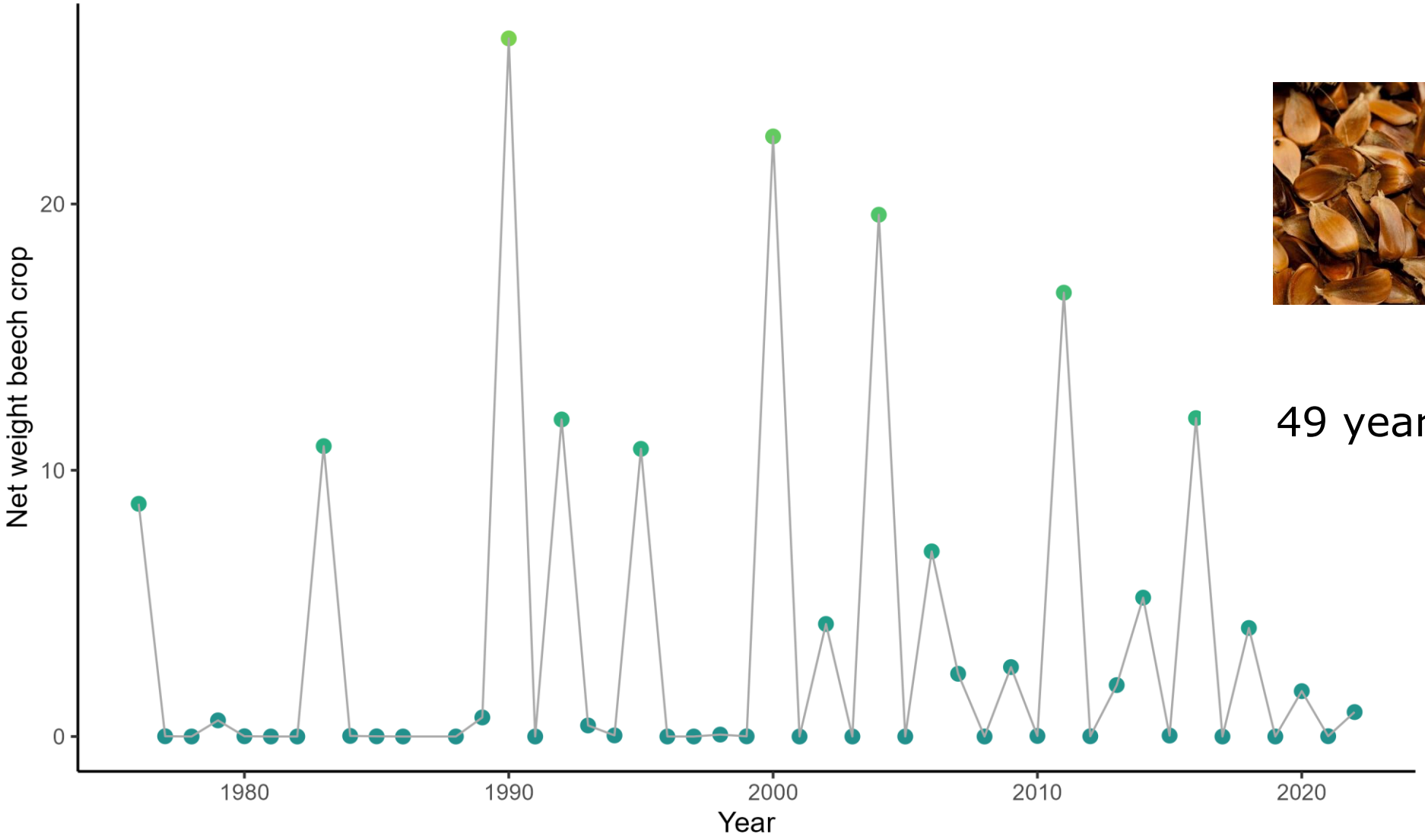
HOW about:
Continuous &
Data-based estimation

van Leeuwen, GETM-ERSEM-BMF model

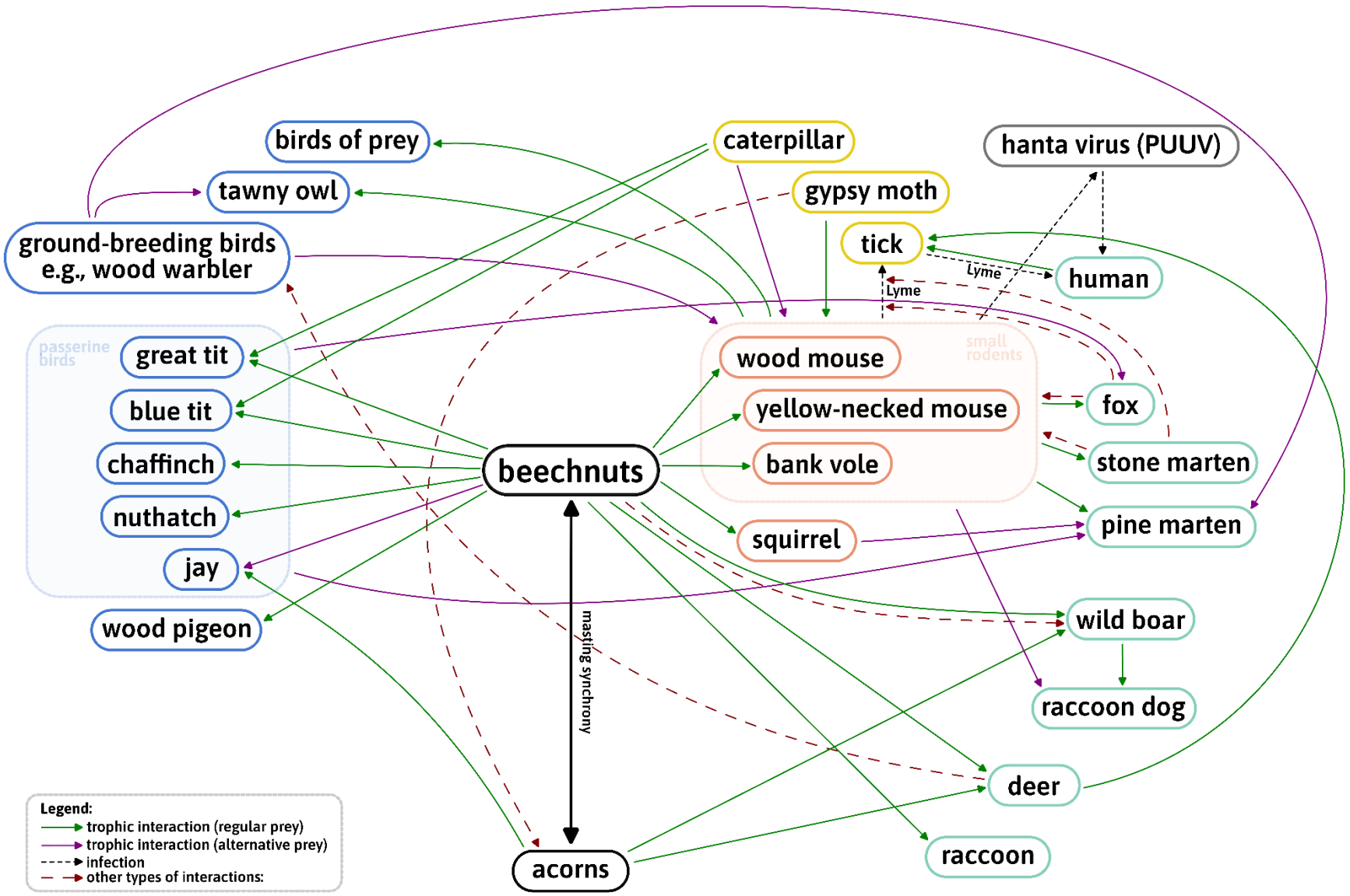
LTER-LIFE: beech crop Veluwe



LTER-LIFE: beech crop Veluwe

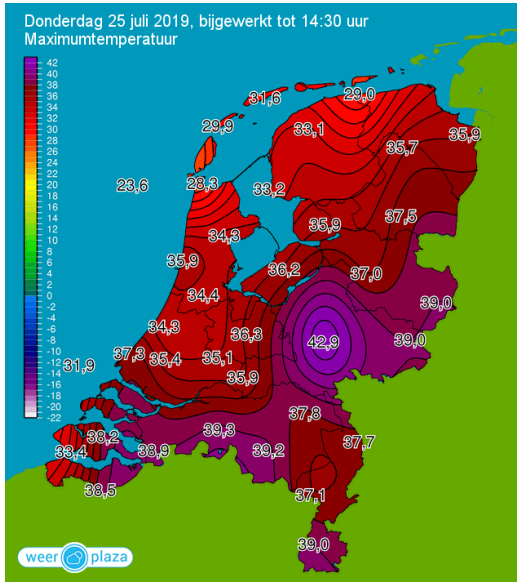


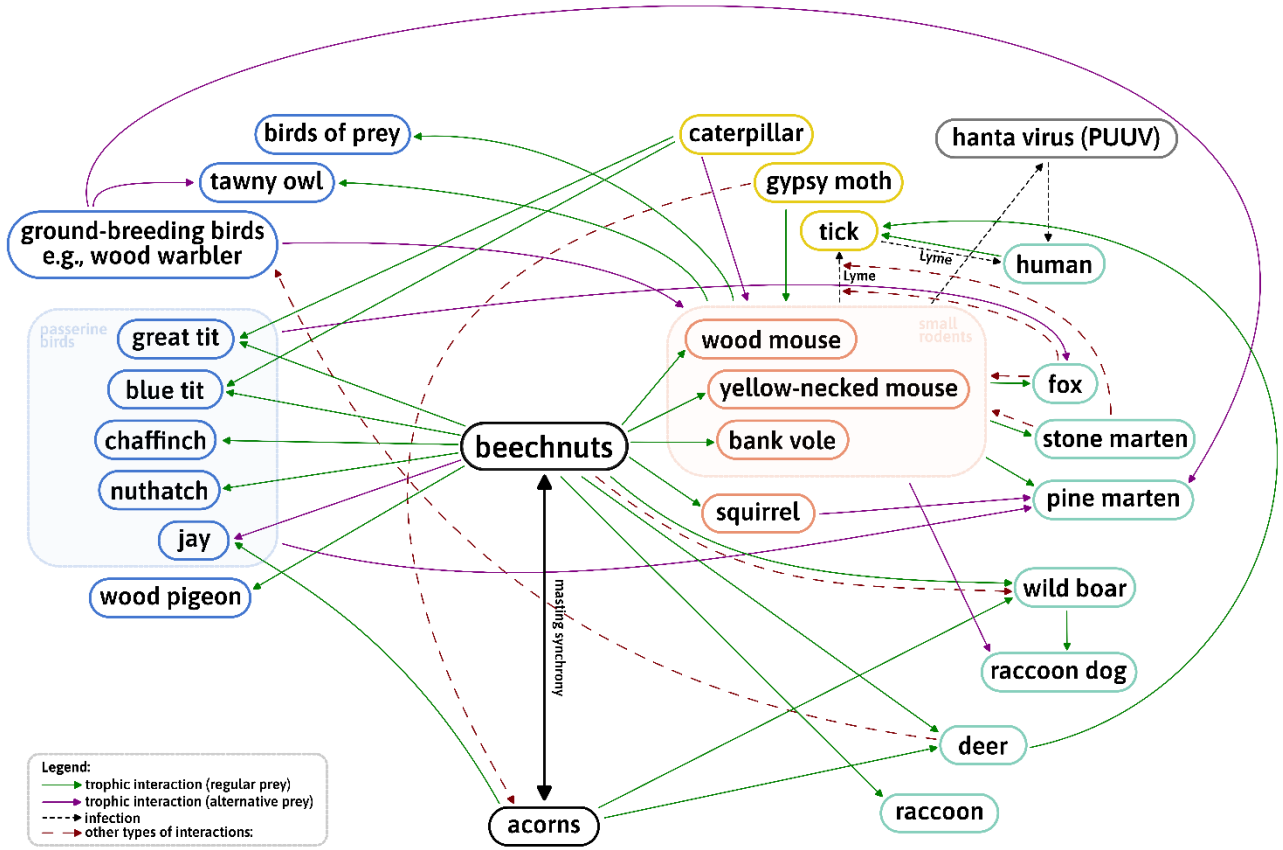
49 years of data



PhD project of Cherine Jantzen

LTER-LIFE: beech crop Veluwe



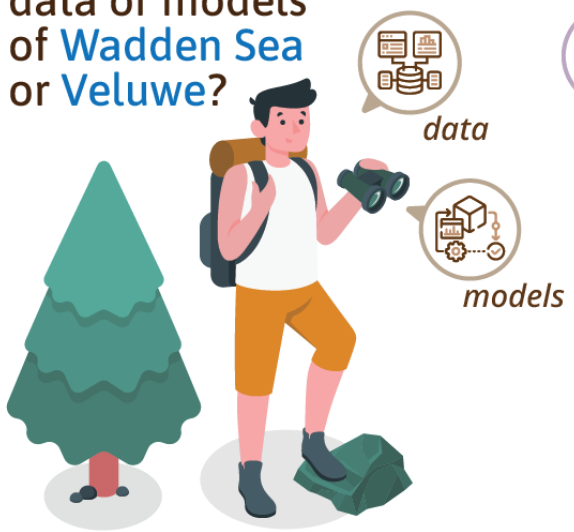


Destination Earth

Analyse the past, monitor the present, predict the future

Join the community!

Do you have data or models of Wadden Sea or Veluwe?



Do you want to build a Digital Twin?

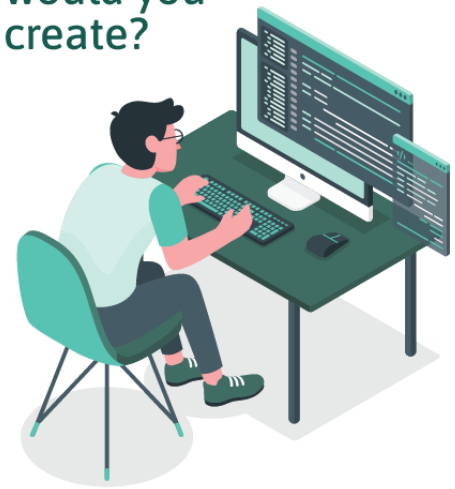
SCAN ME

https://lter-life.nl/en

lter-life@nioo.knaw.nl

You can help!

What digital twin would you create?



What should the virtual lab look like?

Drawings by Geerten Hengeveld
Design by Stefan Vriend, Geerten Hengeveld
using illustrations from Storyset, Freepik, Flaticon

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