Evaluation de la dynamique des reseaux trophiques avec RCaN

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The historical team behind RCaN

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Benjamin Planque   Ulf Lindstrøm   Elliot Sivel

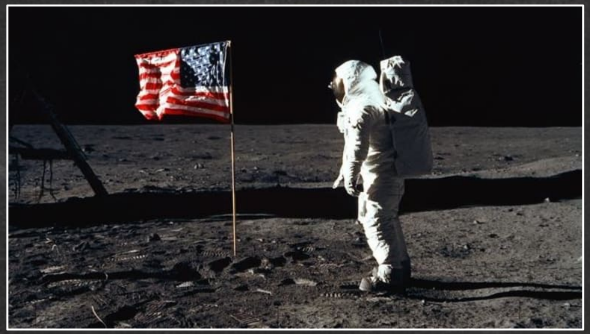
Food-web assessment using RCaN

I. Chance and necessity
II. Making sense of different sources of data
III. Principles of CaN modelling
IV. A one species example
V. A food-web example
VI. RCaN and RCaN Constructor

I
Chance and necessity

Rocket science is easy for modellers

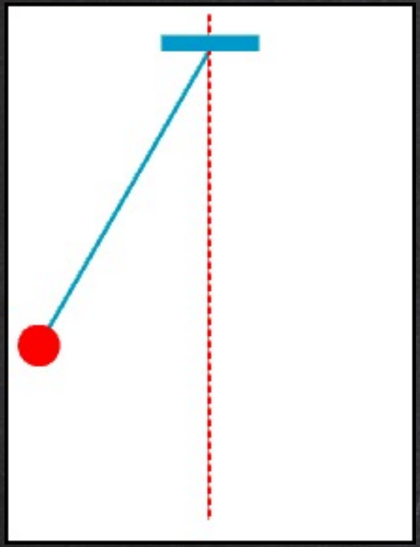
Newton



Apollo 11 - 1969

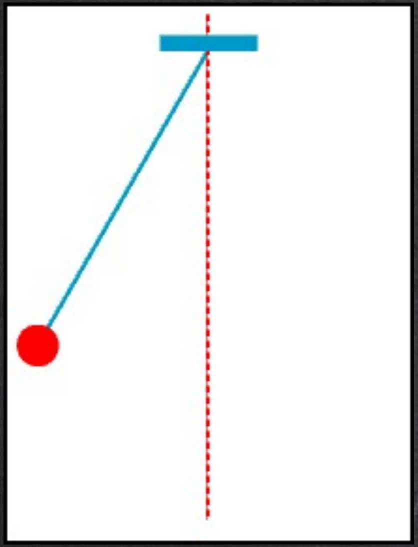
Simple physics is generally …simple

pendulum



Simple physics can sometimes be complex

pendulum



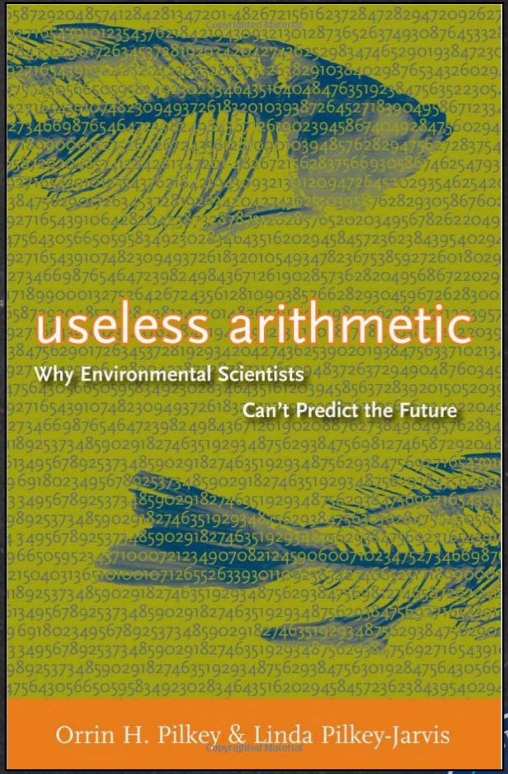
Double pendulum

Deterministic chaos
=
We know the equations
but
we cannot predict

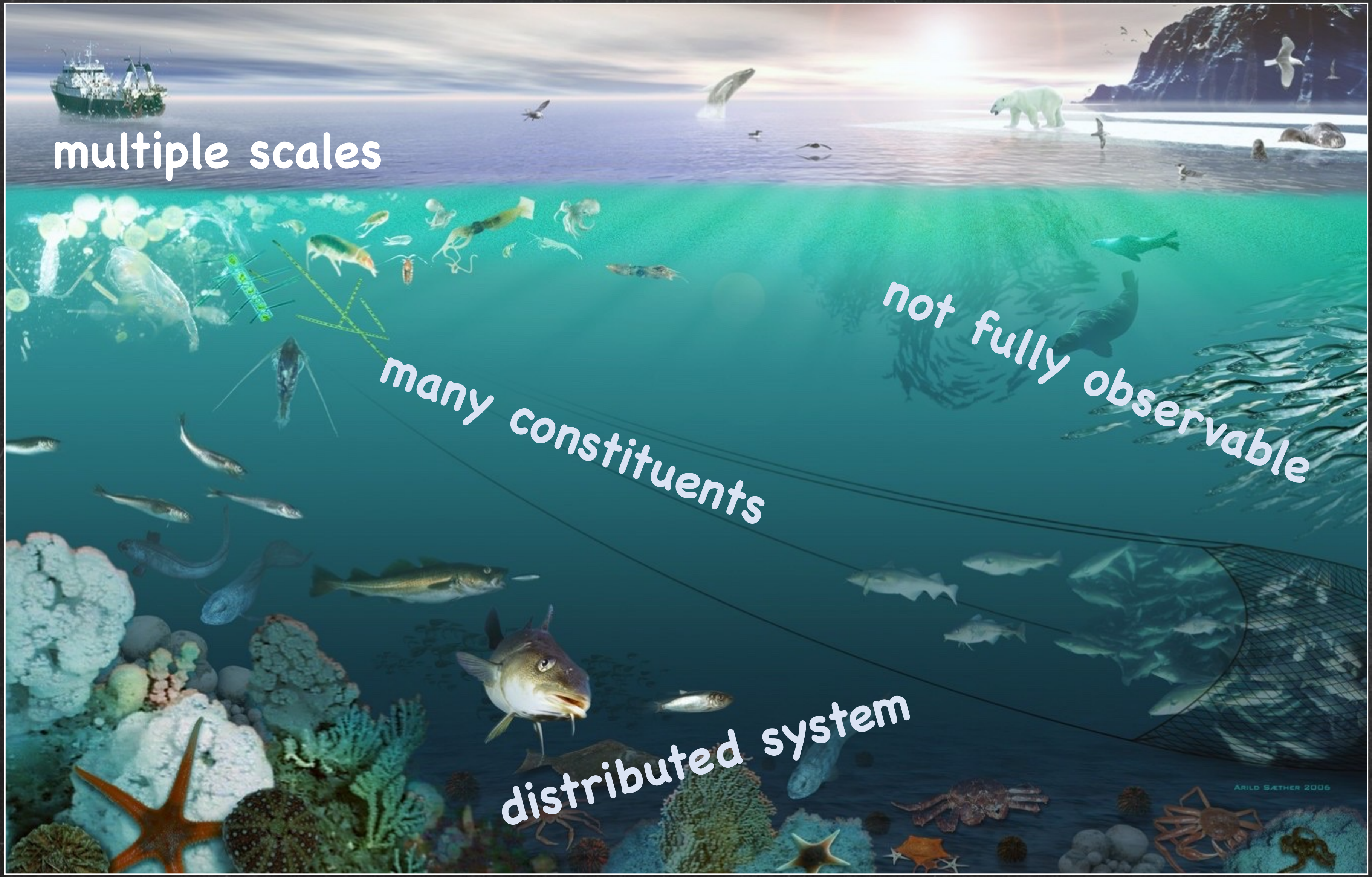
A Knight i fuzzy armour

University of Chicago Centennial Exhibition Catalogues

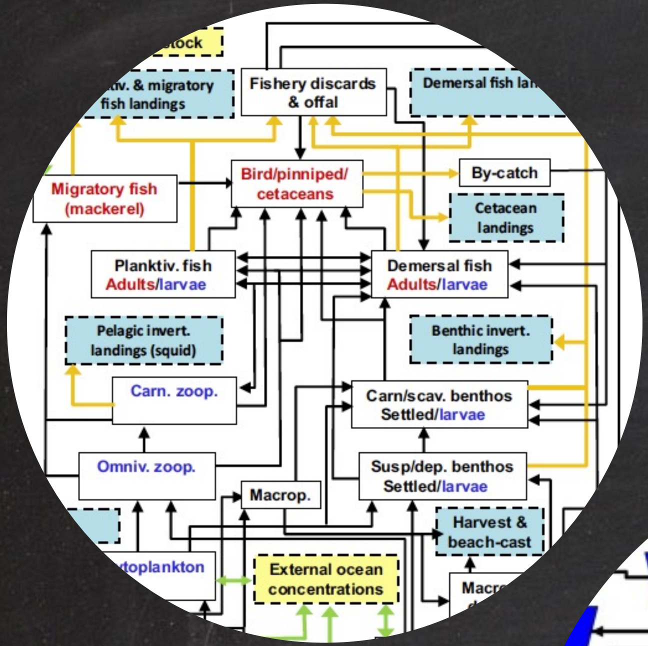
Knightian uncertainty
=
Unquantifiable risk

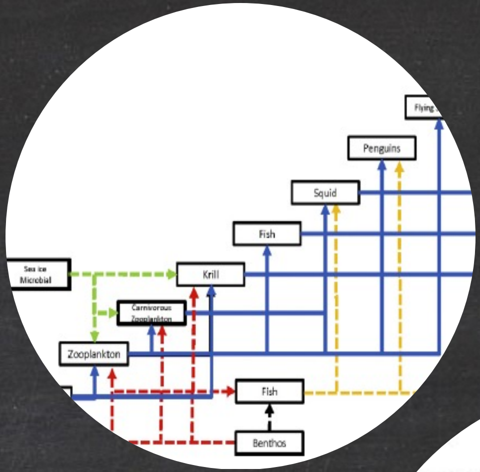


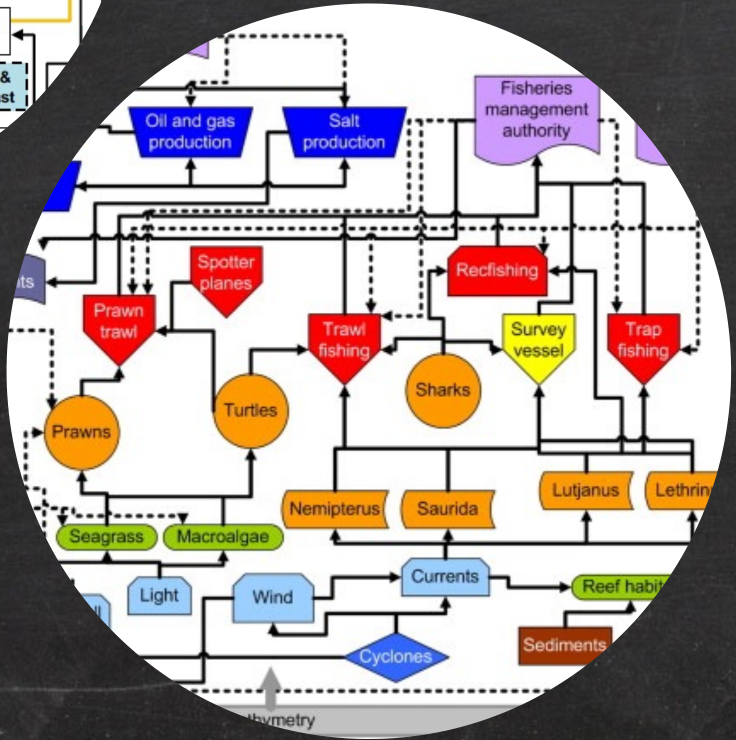
Ecosystems are complicated and complex

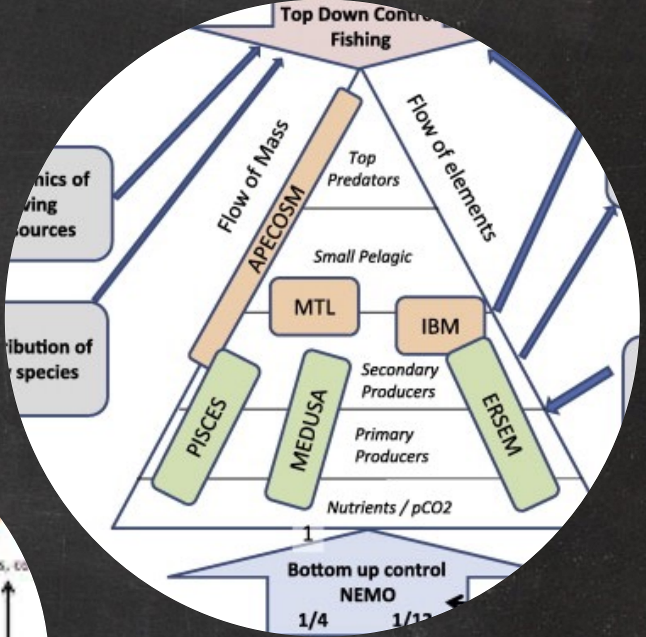


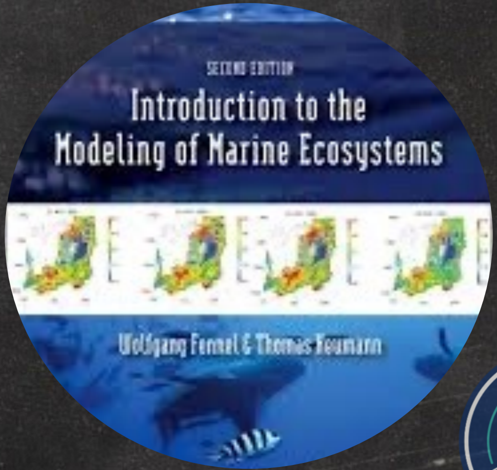
Modellers can model ecosystems











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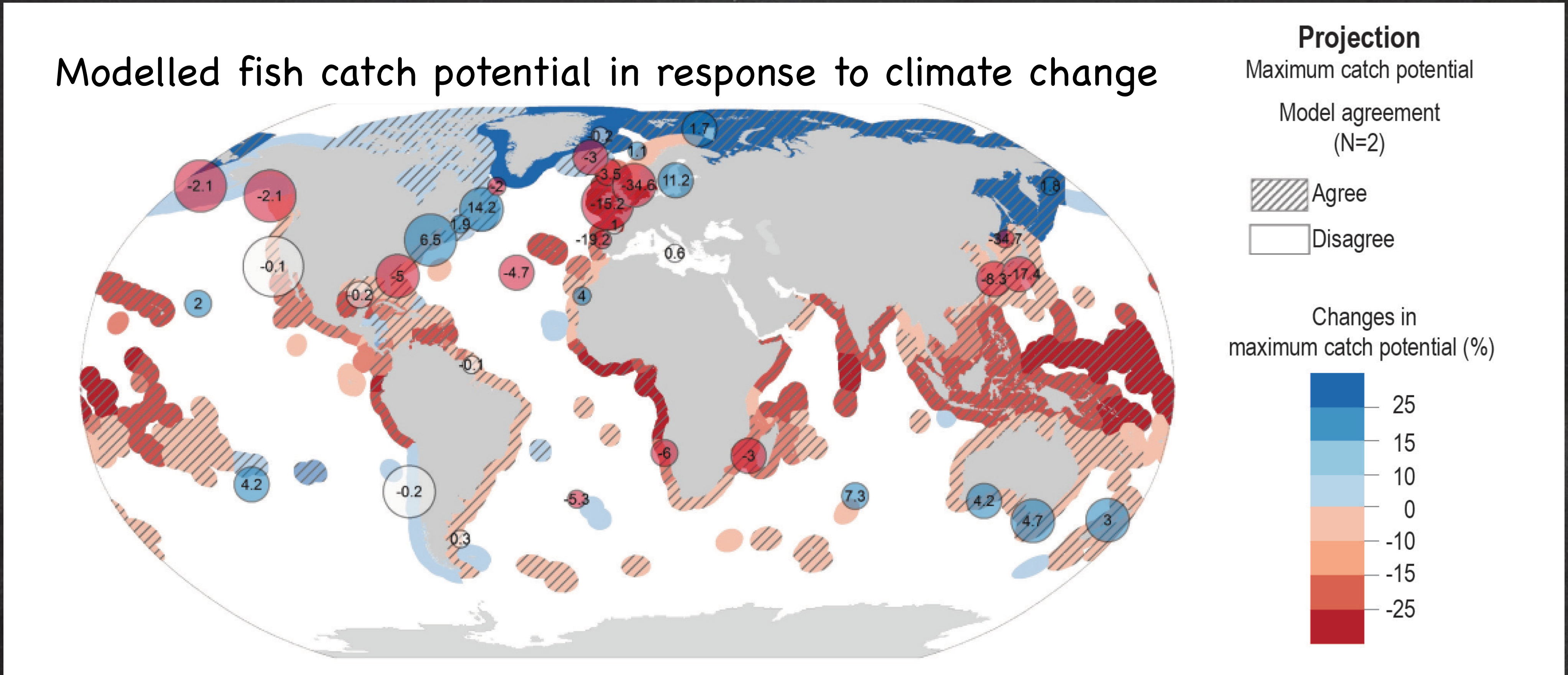
Modellers can model ecosystems



IPCC, 2019: Summary for Policymakers. In: IPCC Special Report on the Ocean and Cryosphere in a Changing Climate

Why should one trust ecosystem models?

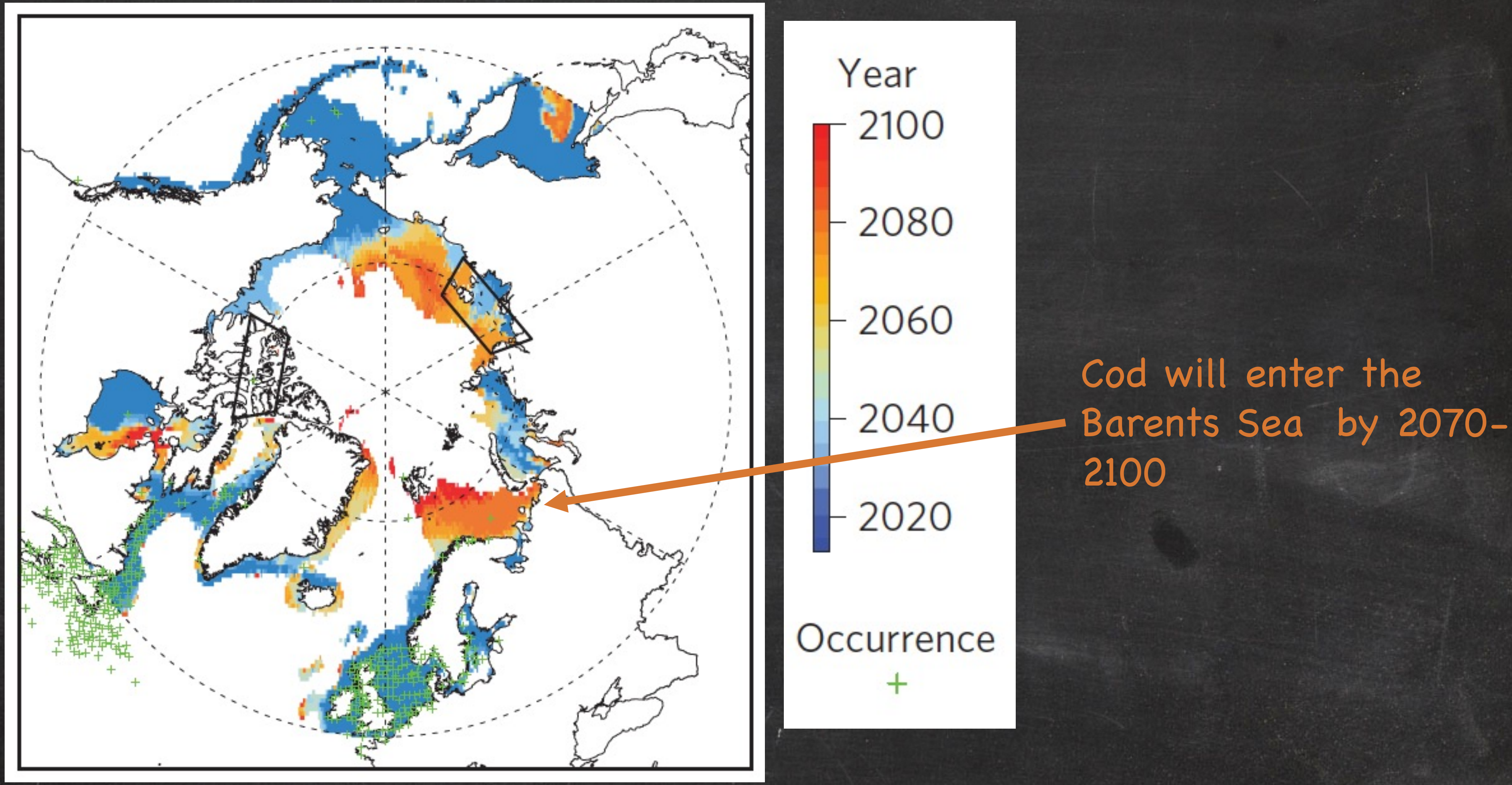
Ecosystems are too complex to be modelled

No theory

Many assumptions

Different models give different results

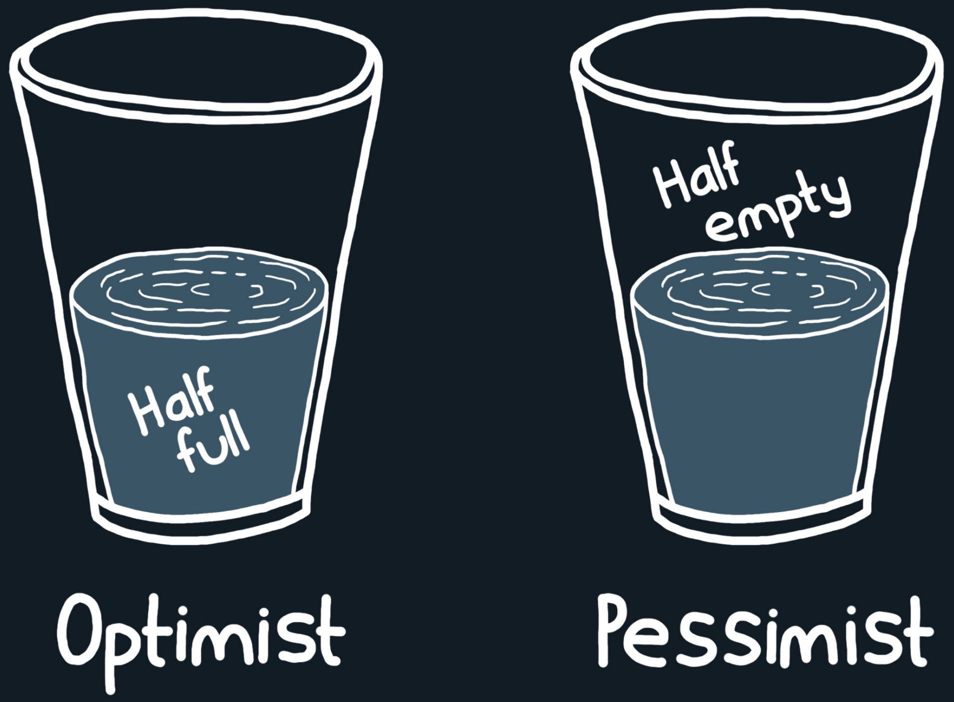
Why should one trust ecosystem models?



predicted year in which the conditions become suitable for Atlantic cod (*Gadus morhua*). Wisz et al. 2015

Reconciling models and practitioners

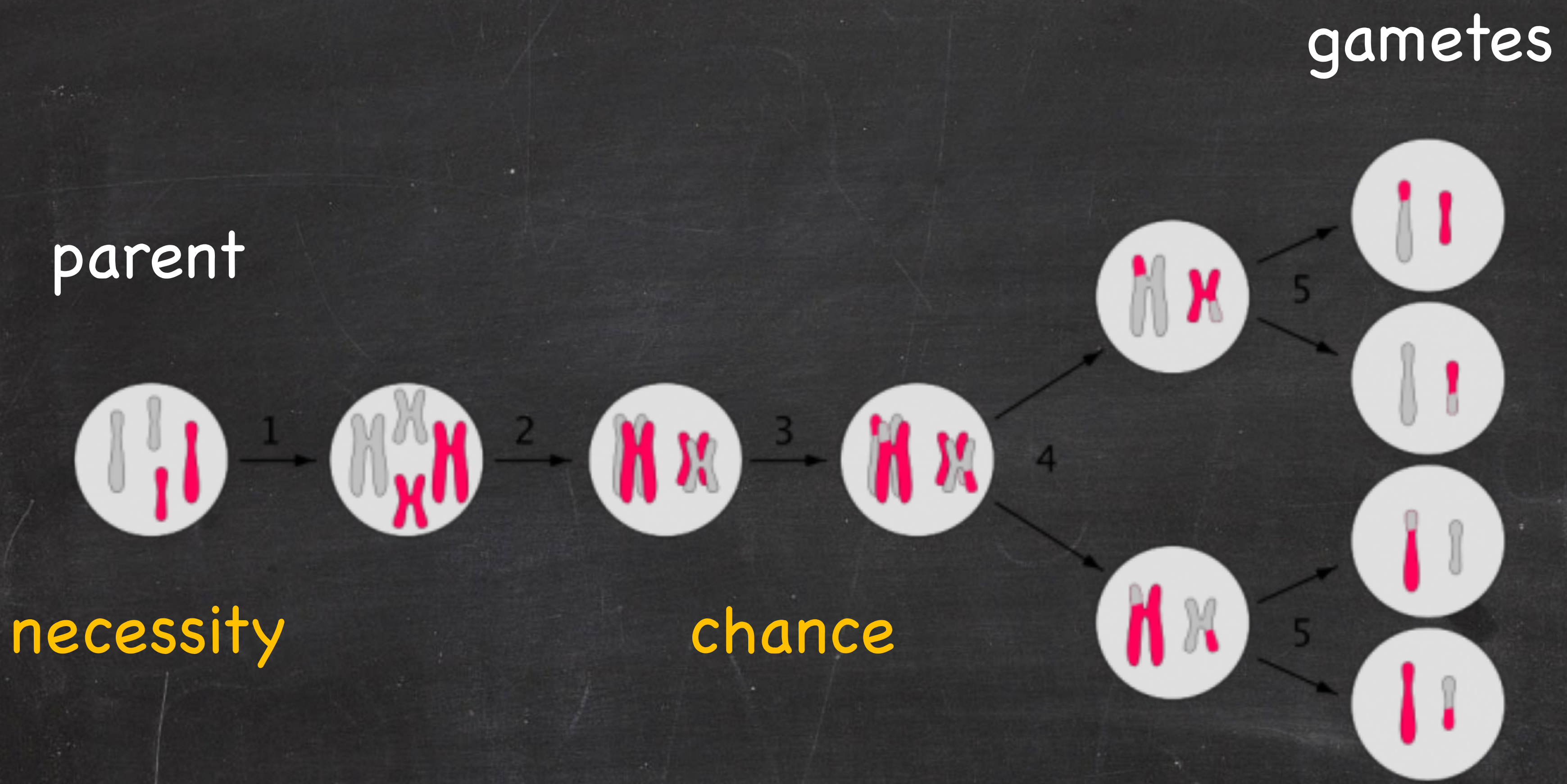
There's enough we know to tell something about the natural system



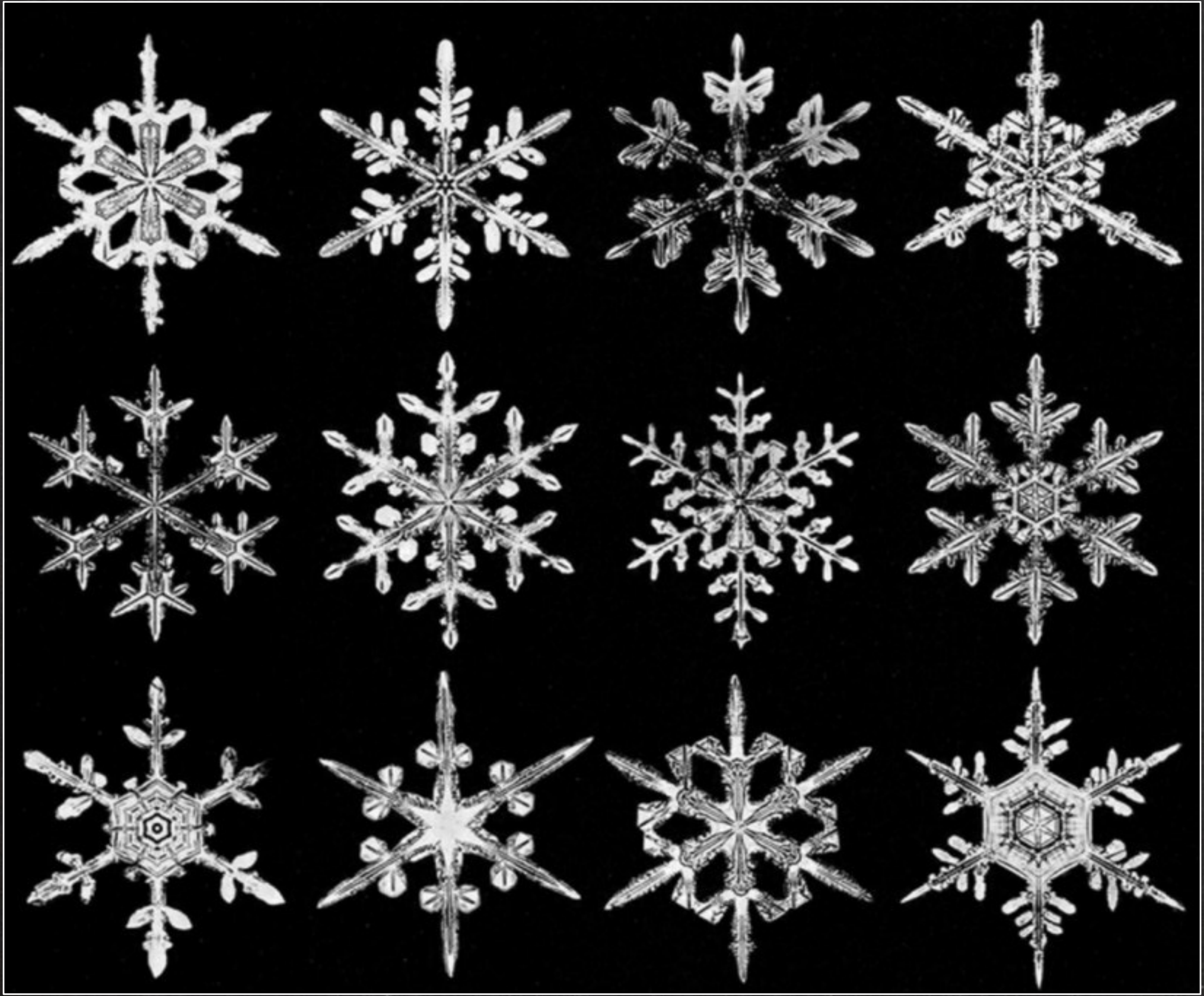
There's not enough we know to tell something about the system

Chance and necessity modelling (CaN):
Model what we know and leave the rest to chance

Chance and Necessity: sexual reproduction



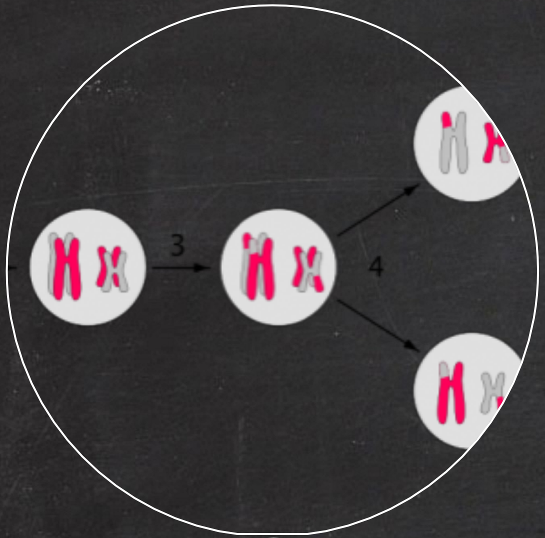
Chance and Necessity: snow flakes

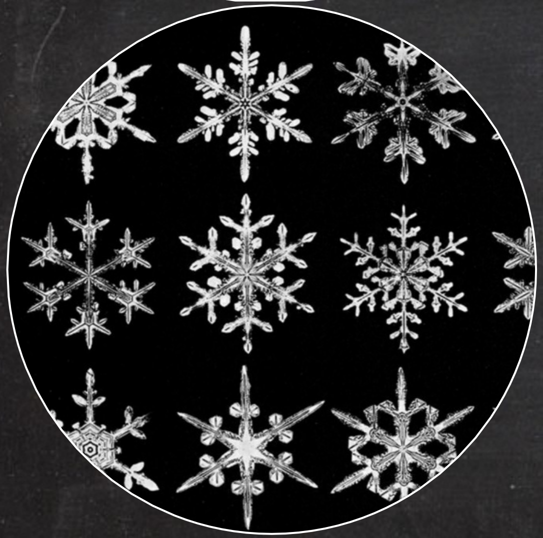


Wilson Bentley 1865-1931

Necessity: humidity & cold
Chance…gives the shape

There is no 'most likely' outcome





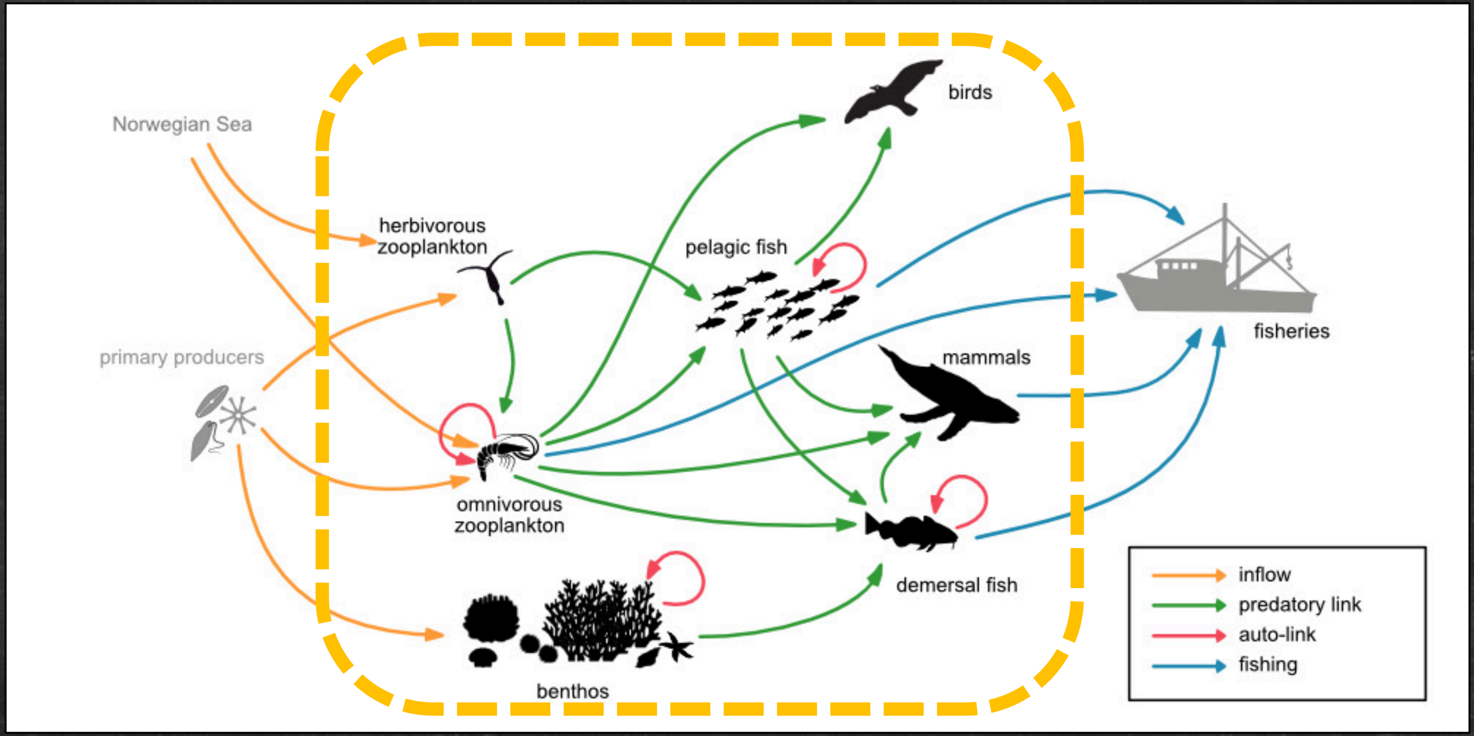
Contribution to the Themed Section: 'Science in support of a nonlinear non-equilibrium world'

Food for Thought

Modelling chance and necessity in natural systems

Benjamin Planque [1*] and Christian Mullon [2]

Explore the diversity of the Barents Sea food web dynamics



II
Making sense of different sources of data


Information
CaN
IEA
Chance and Necessity
modelling
Surveys
Single stock
assessments
Food-web &
Trophic
interactions
Ecological/biological
knowledge
hypotheses
uncertainties
& unknowns
Drouineau - Mullon - Planque
Anyone CAN
Model
Data
RCaN
Participatory
modelling
Are the assumptions,
information and data consistent?
Historical
reconstructions
Short term forecasts
Scenario
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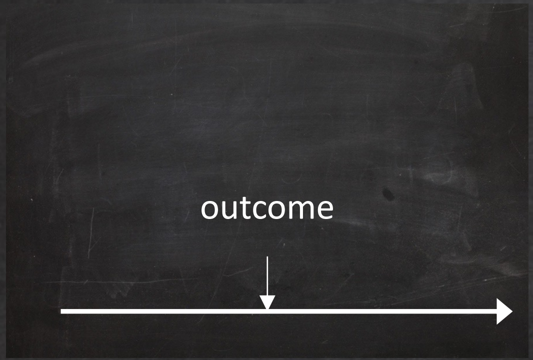
III
Principles of CaN modelling

CaN modelling is about sampling “possible” outcomes

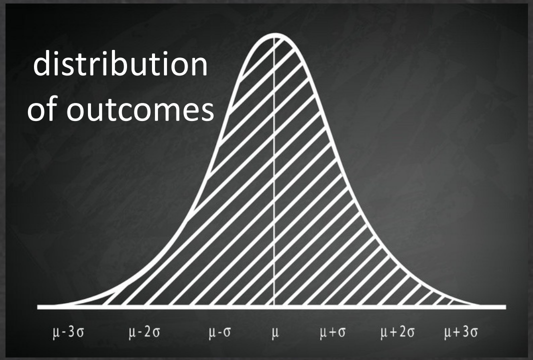
Causes
&
Mechanisms

Mathematical model



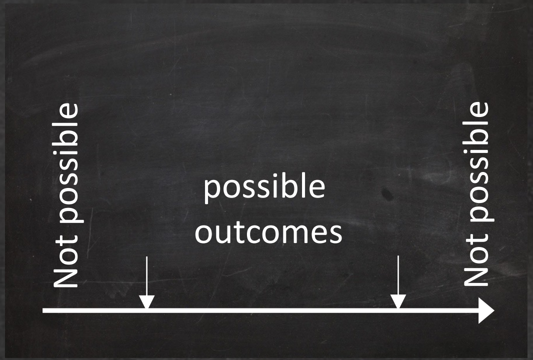
Point estimate

Statistical model



Probability distribution
(but we often focus on the point estimate)

CaN model

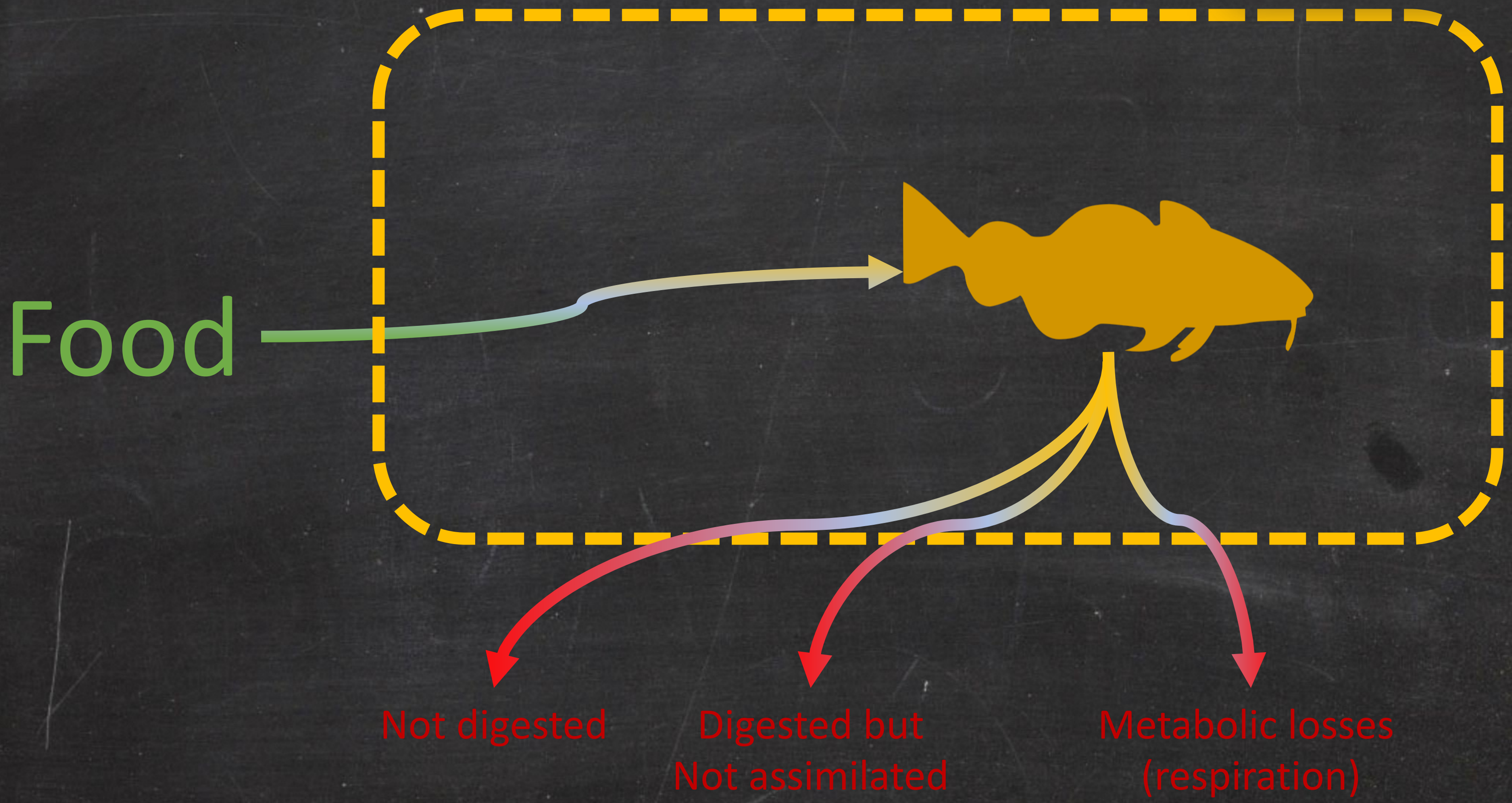


Range of possibilities
(point estimate is not the point)

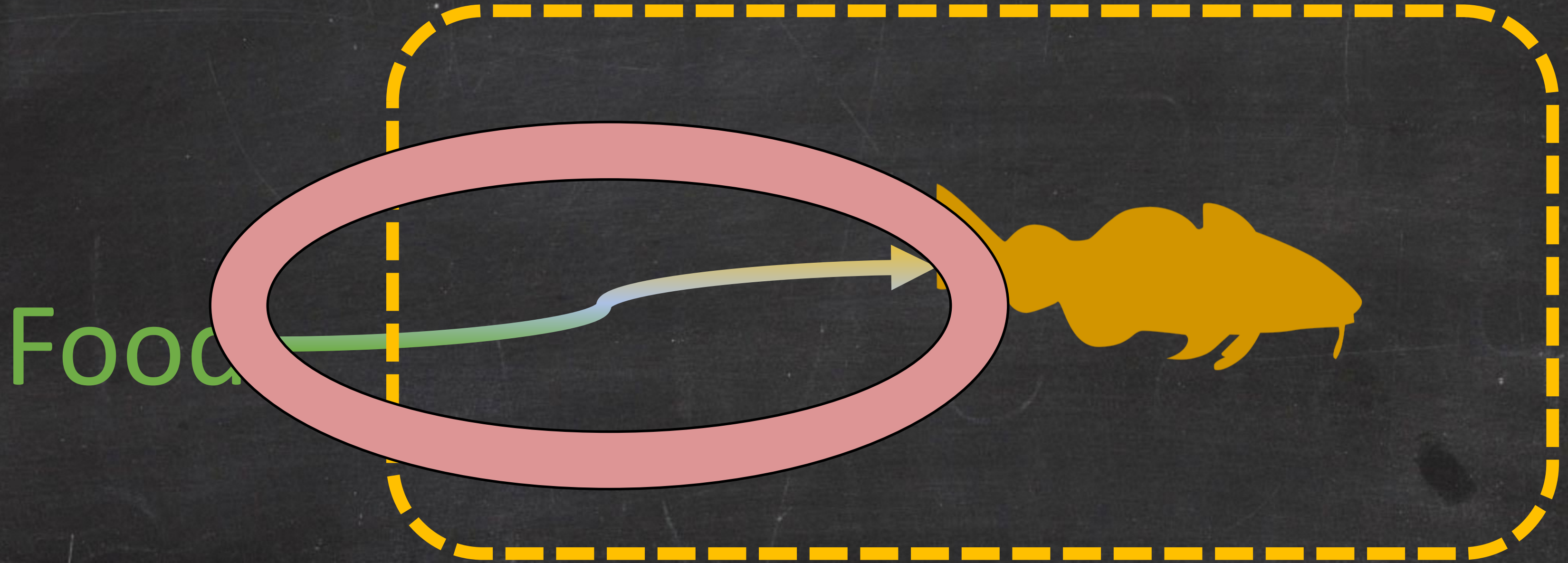
IV
A one species example

Part of the ingested food is ‘lost’ and the rest contributes to population growth

$$B_{t+1} = (1-H)B_t + \sum_f N_f F_f$$



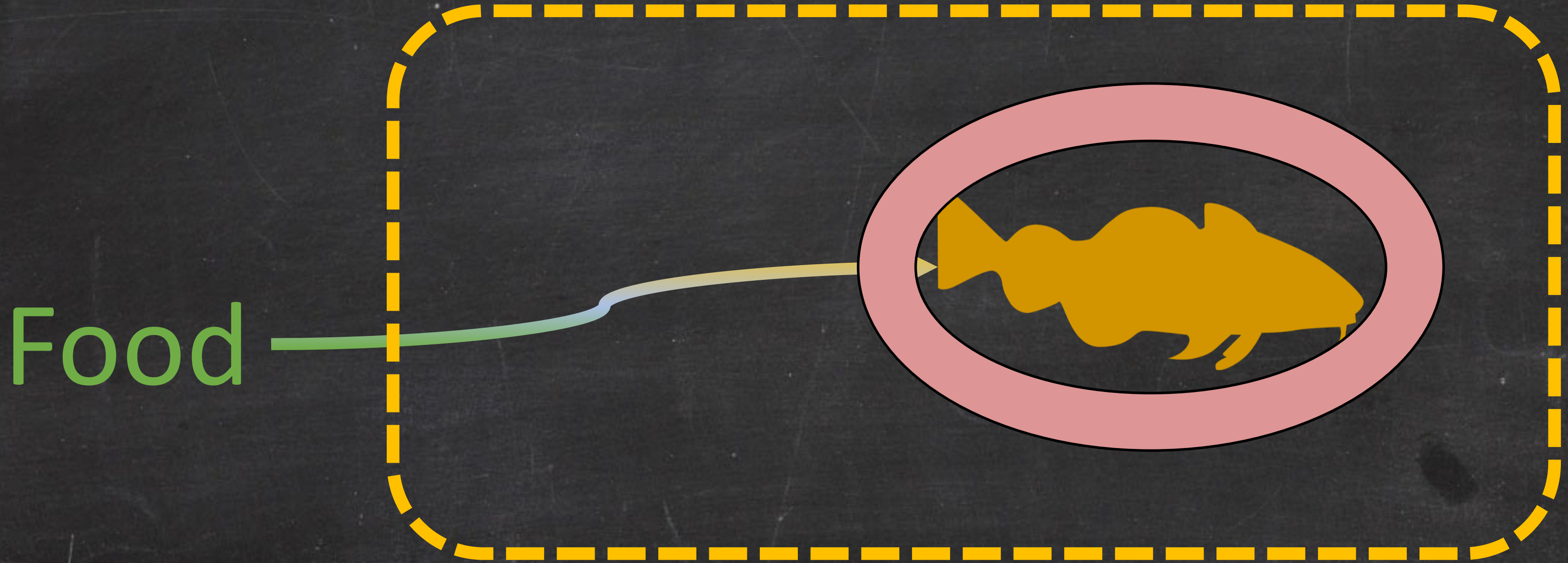
The quantity ingested is indeterminate (chance) but constrained (necessity)



Flow (food -> fish) ≤ Biomass.of.fish x satiation

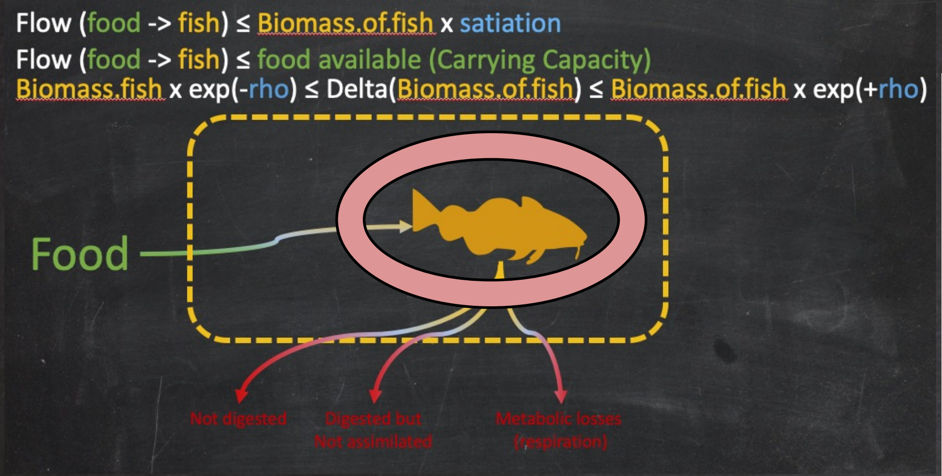
Flow (food -> fish) ≤ food available

The change in biomass from one year to the next is indeterminate (chance) but constrained (necessity)



Biomass.fish x exp(-rho) ≤ Delta(Biomass.of.fish) ≤ Biomass.of.fish x exp(+rho)

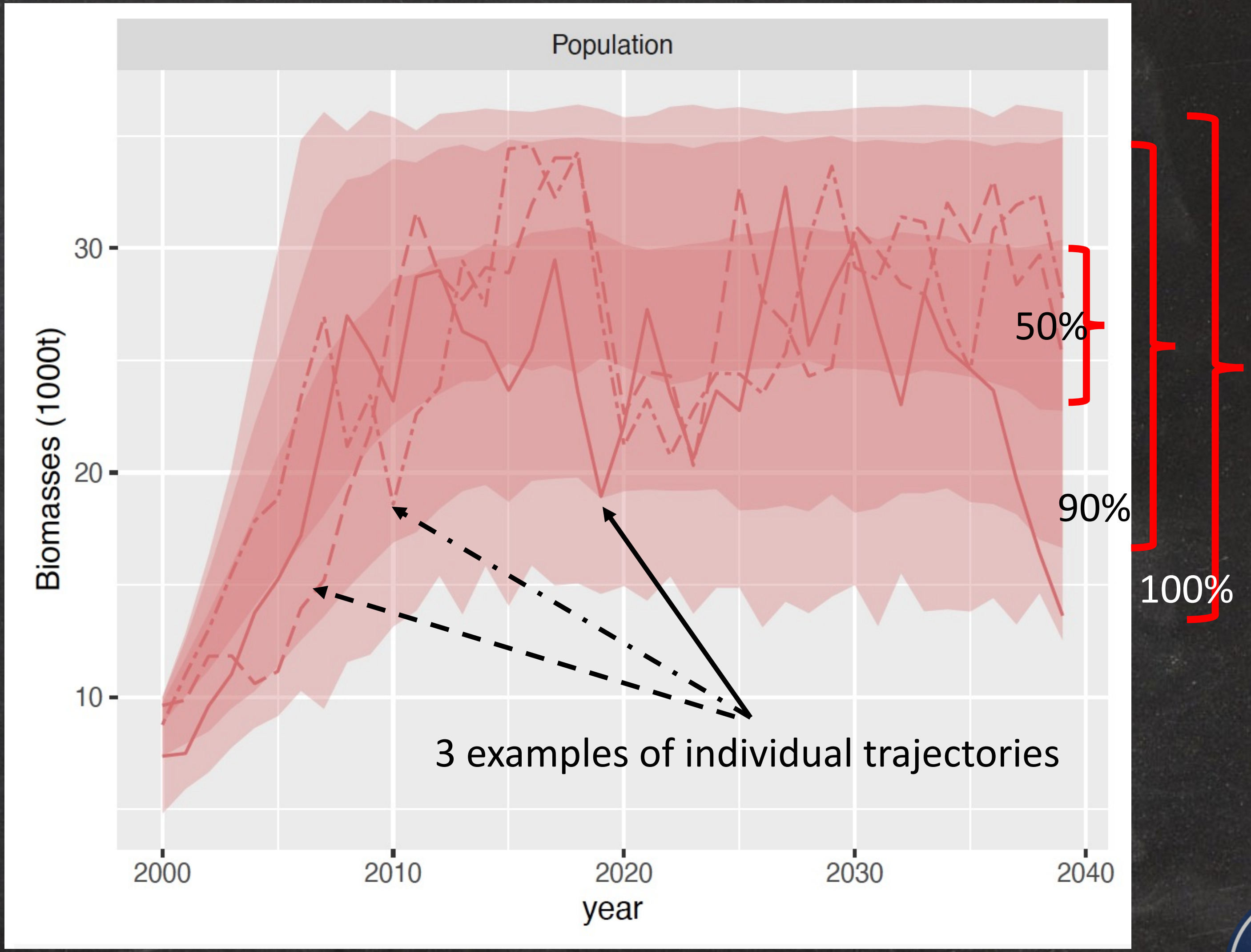
Sampling model solutions



Model input parameters
Satiation = 5.5
Inertia = 0.25
Metabolic losses = 1.65
Digestibility (food) = 0.65
Assimilation Efficiency = 0.93
Refuge Biomass = 0.01

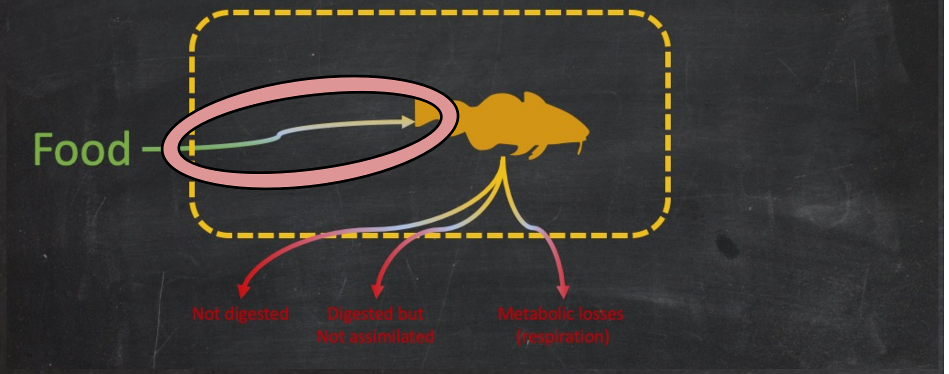
Constraints
Satiation
Inertia
Max consumption (<100)
Starting value (<10)

Biomass



Sampling model solutions

Flow (food -> fish) ≤ Biomass.of.fish x satiation
Flow (food -> fish) ≤ food available (Carrying Capacity)
Biomass.fish x exp(-rho) ≤ Delta(Biomass.of.fish) ≤ Biomass.of.fish x exp(+rho)



Model input parameters
Satiation = 5.5
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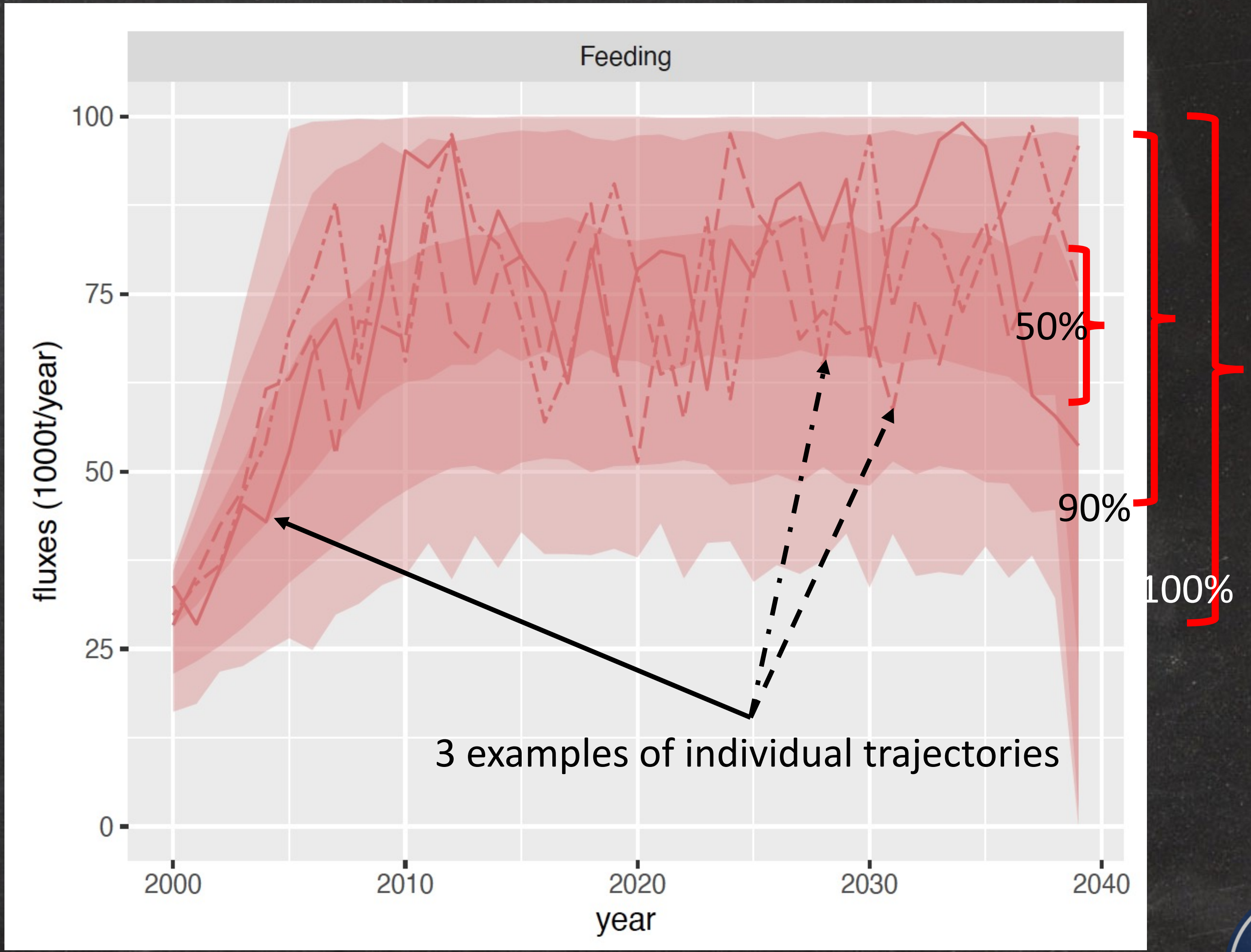
Metabolic losses = 1.65
Digestibility (food) = 0.65
Assimilation Efficiency = 0.93
Refuge Biomass = 0.01

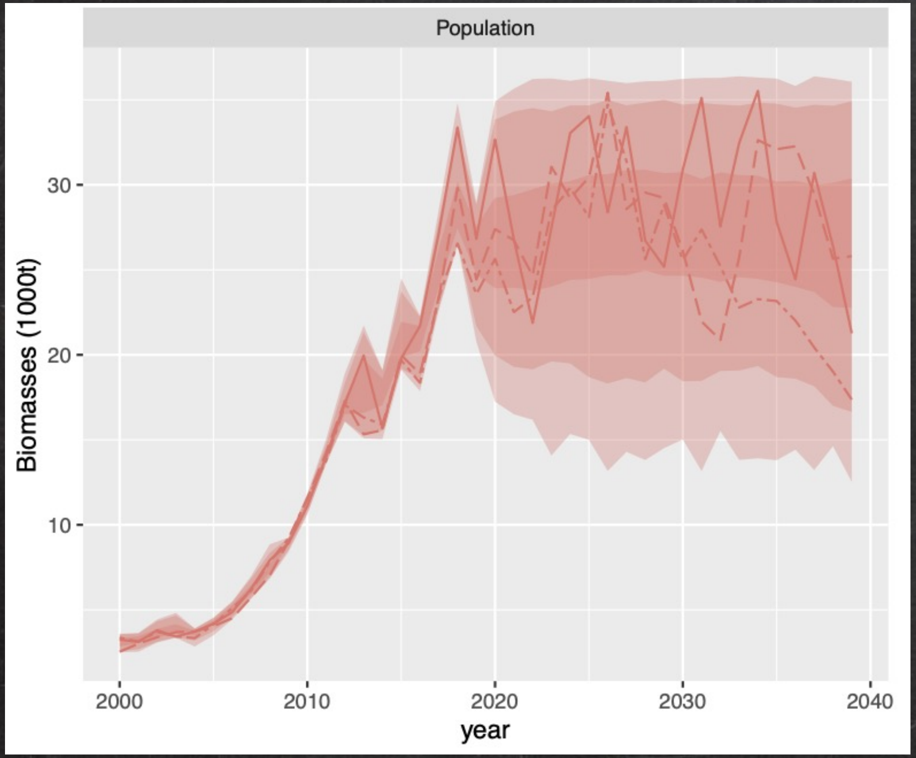
Constraints
Satiation
Inertia
Carrying capacity (<100)
Starting value (<10)

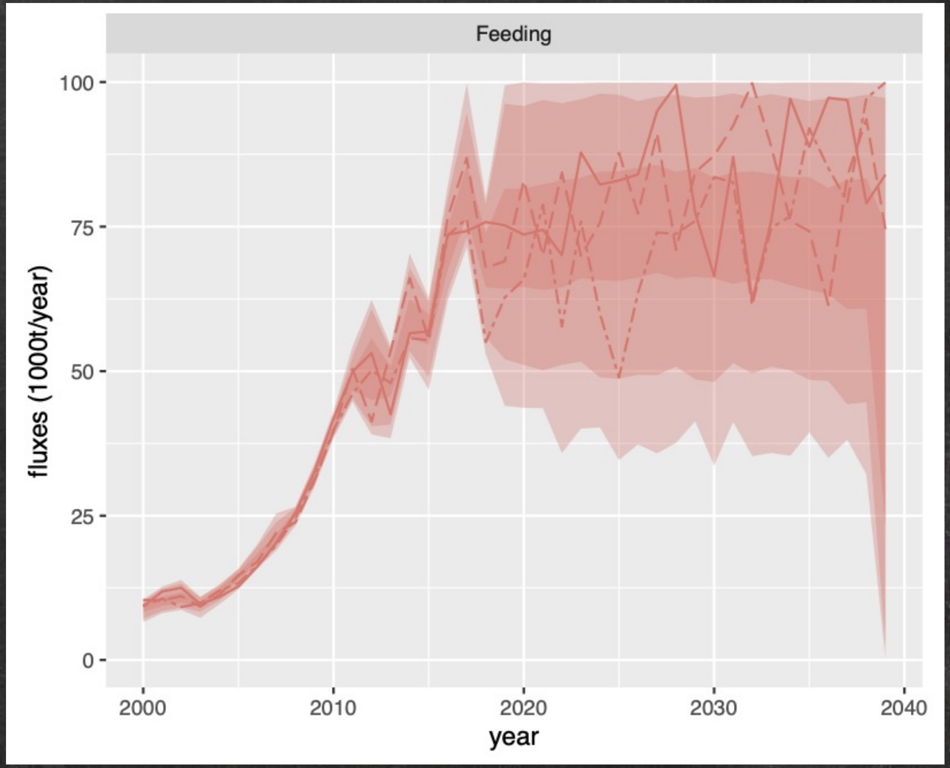
Trophic flow



What if we have observations about the population?

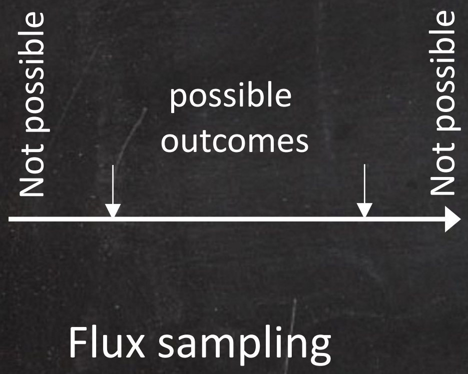
- 1. We already had one observation: the starting max value
- 2. We add biomass estimates, with uncertainties, for the period 2000-2019



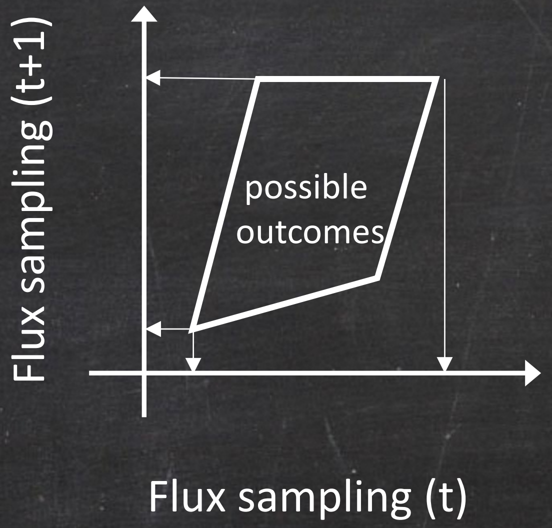


A short digression on polytope sampling

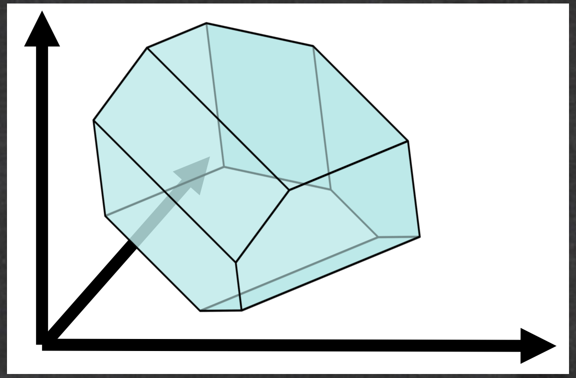
One flux , one year



One flux, two years



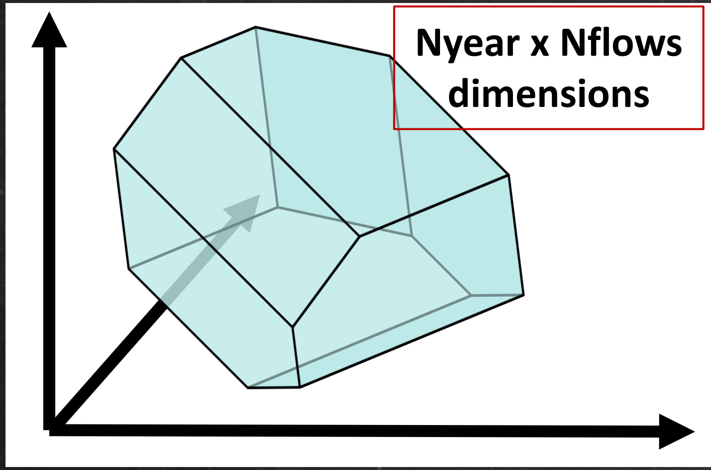
One flux, three years

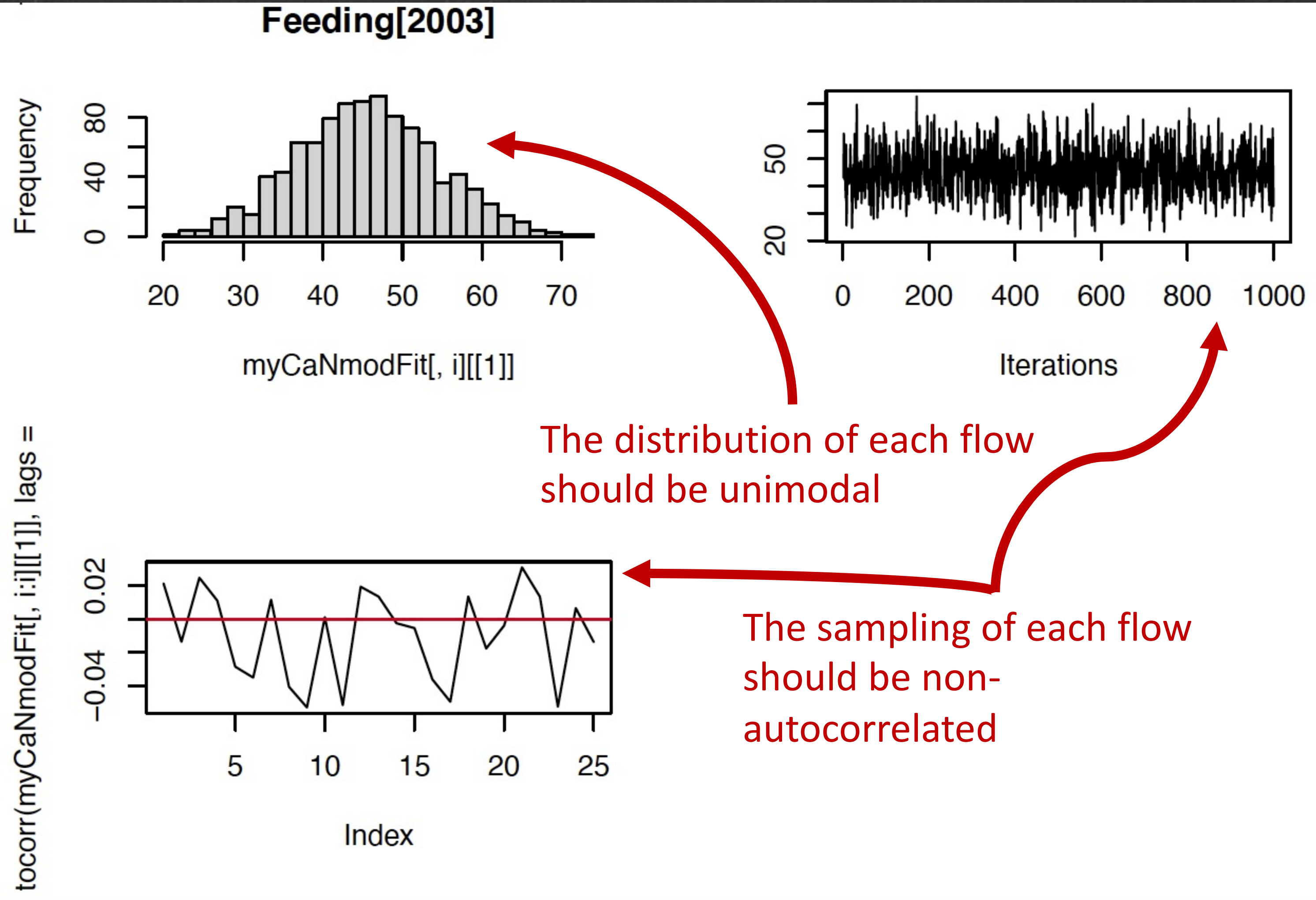


Many flux, many years

Many dimensions
-
complex polytope

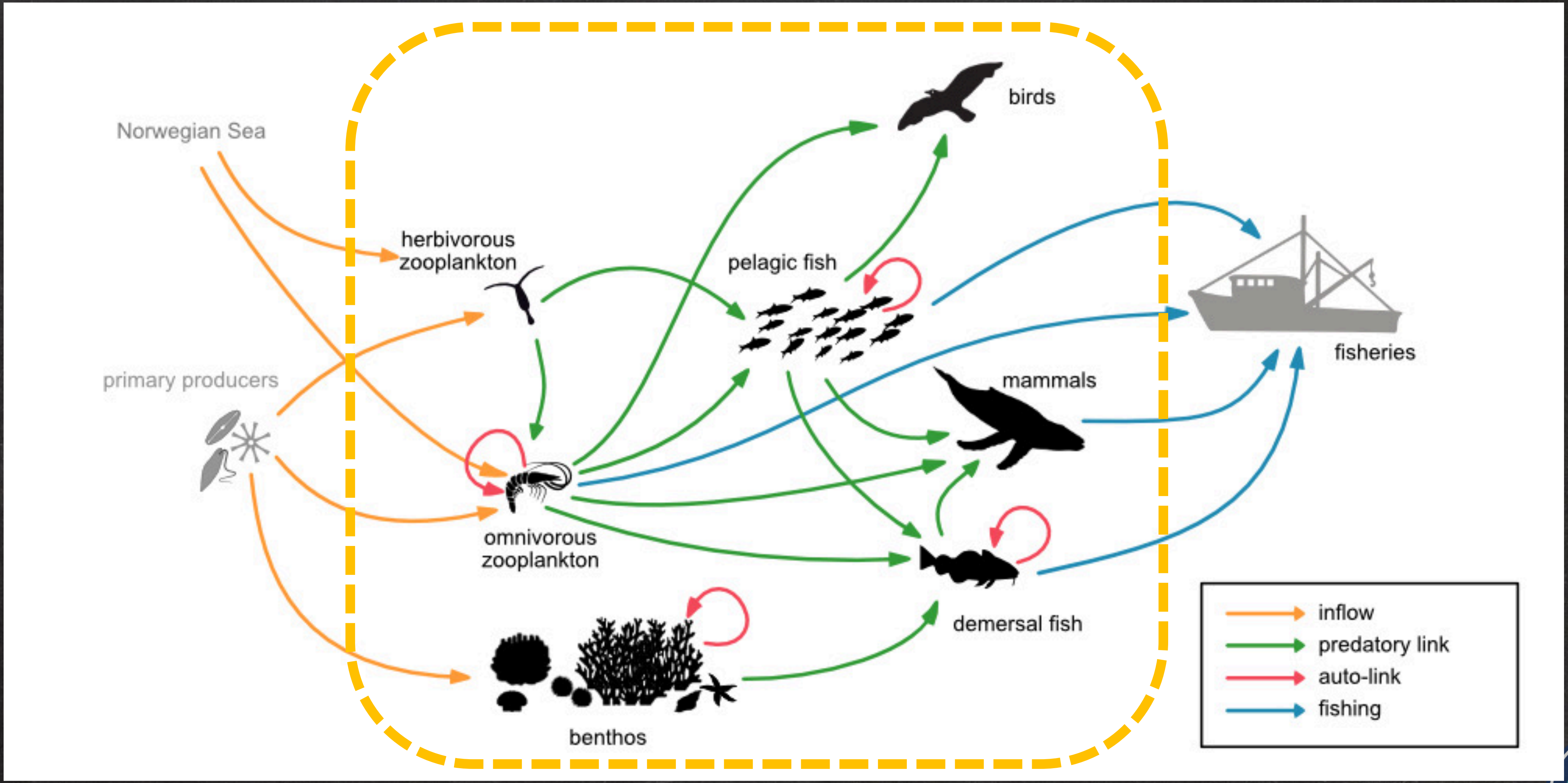
A short digression on polytope sampling



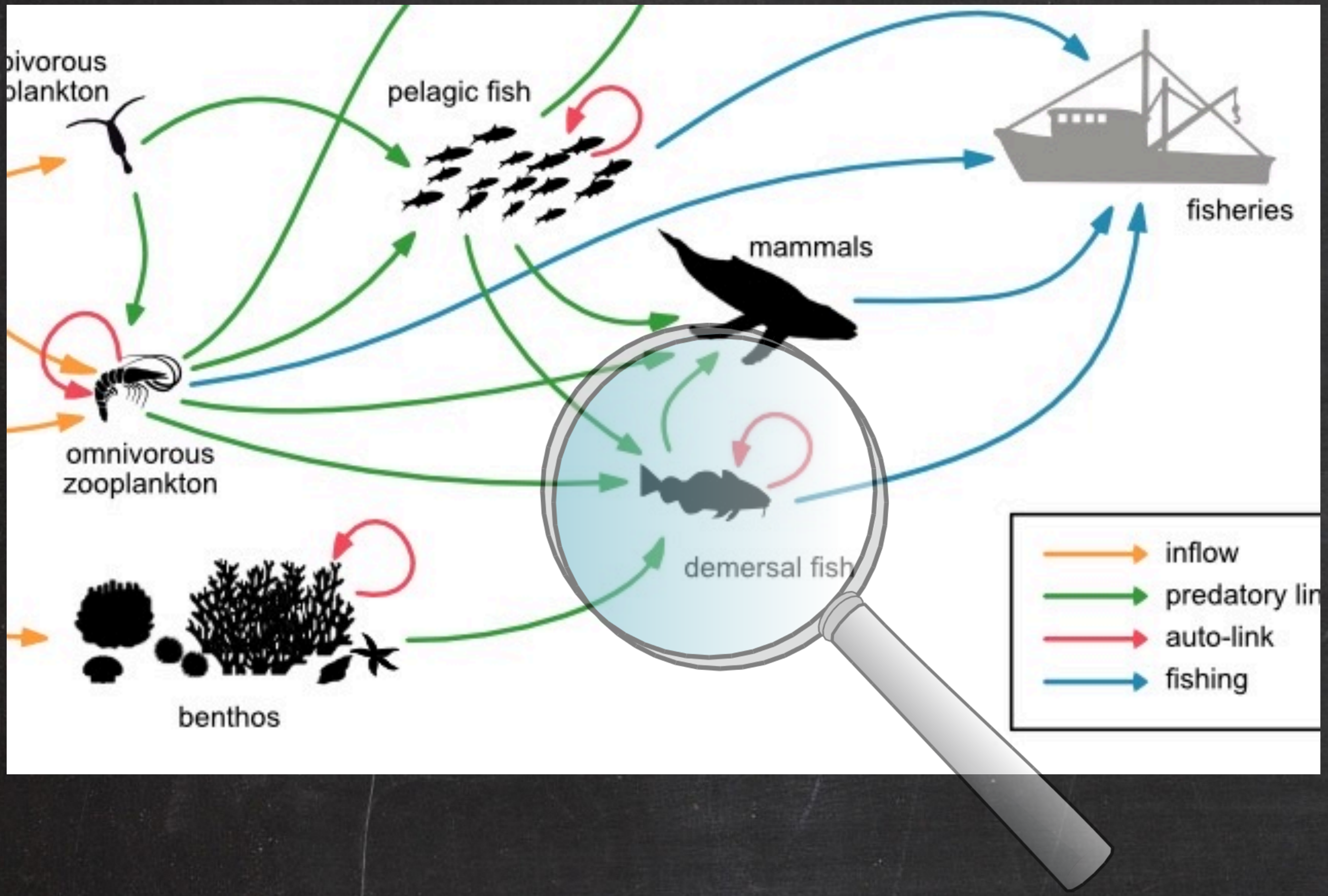


V
A food-web example

Simplified food-web for the Barents Sea



Simplified food-web for the Barents Sea: focus on demersals



General processes:
Variation in demerals biomass is the result of gains (feeding) minus losses (predation, fishing, non-assimilates/digested fraction and metabolic losses)

'General' constraints:
Satiation: max feeding by demerals depends on their total biomass

Inertia: the change in biomass of demersals from one year to the next is limited

Refuge Biomass: the biomass of demersals cannot go below a minimal level.

'Observational' constraints:
Biomass variations follow observations
Trophic flows follow observations
Fisheries catch follow observations

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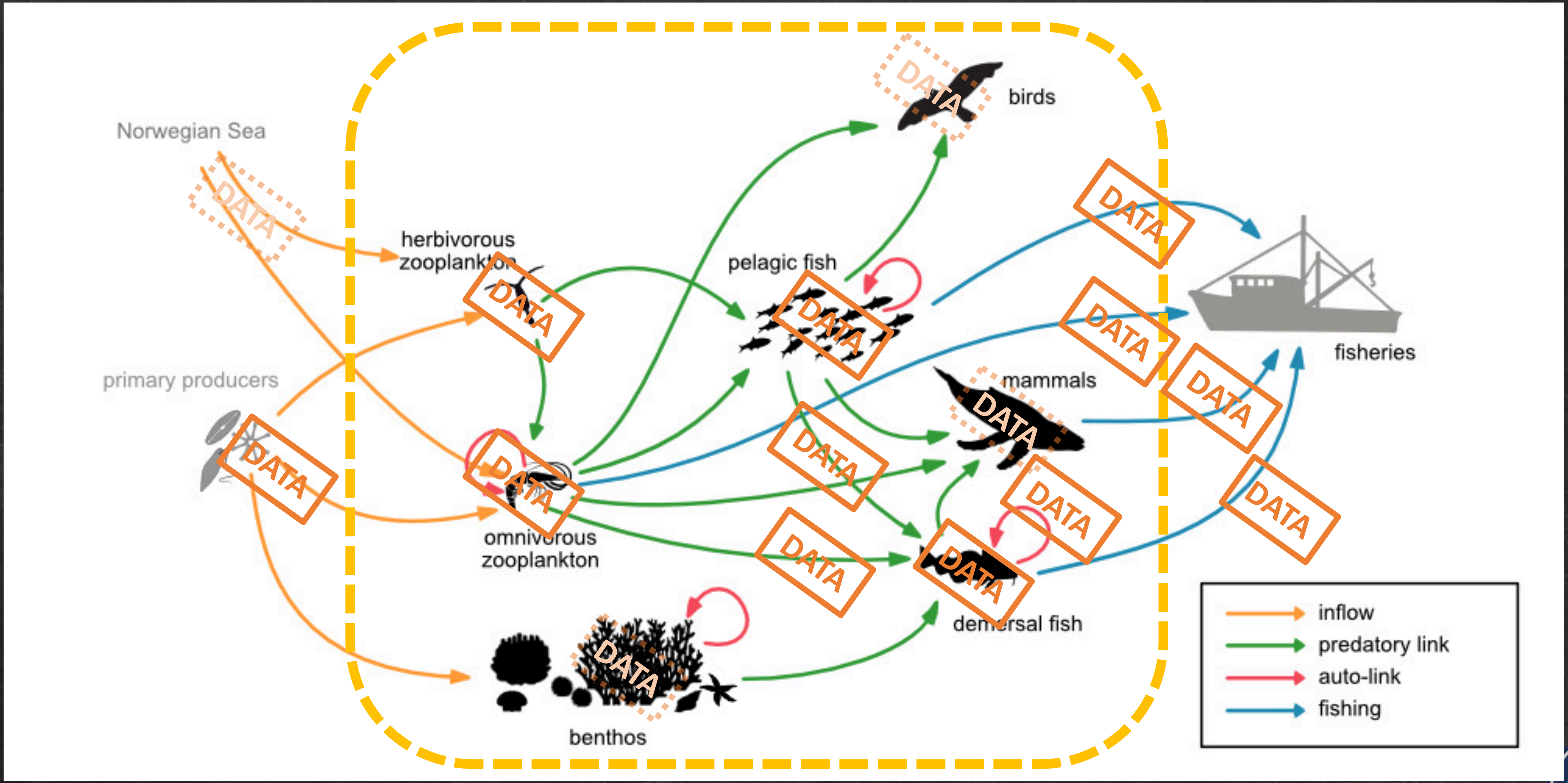
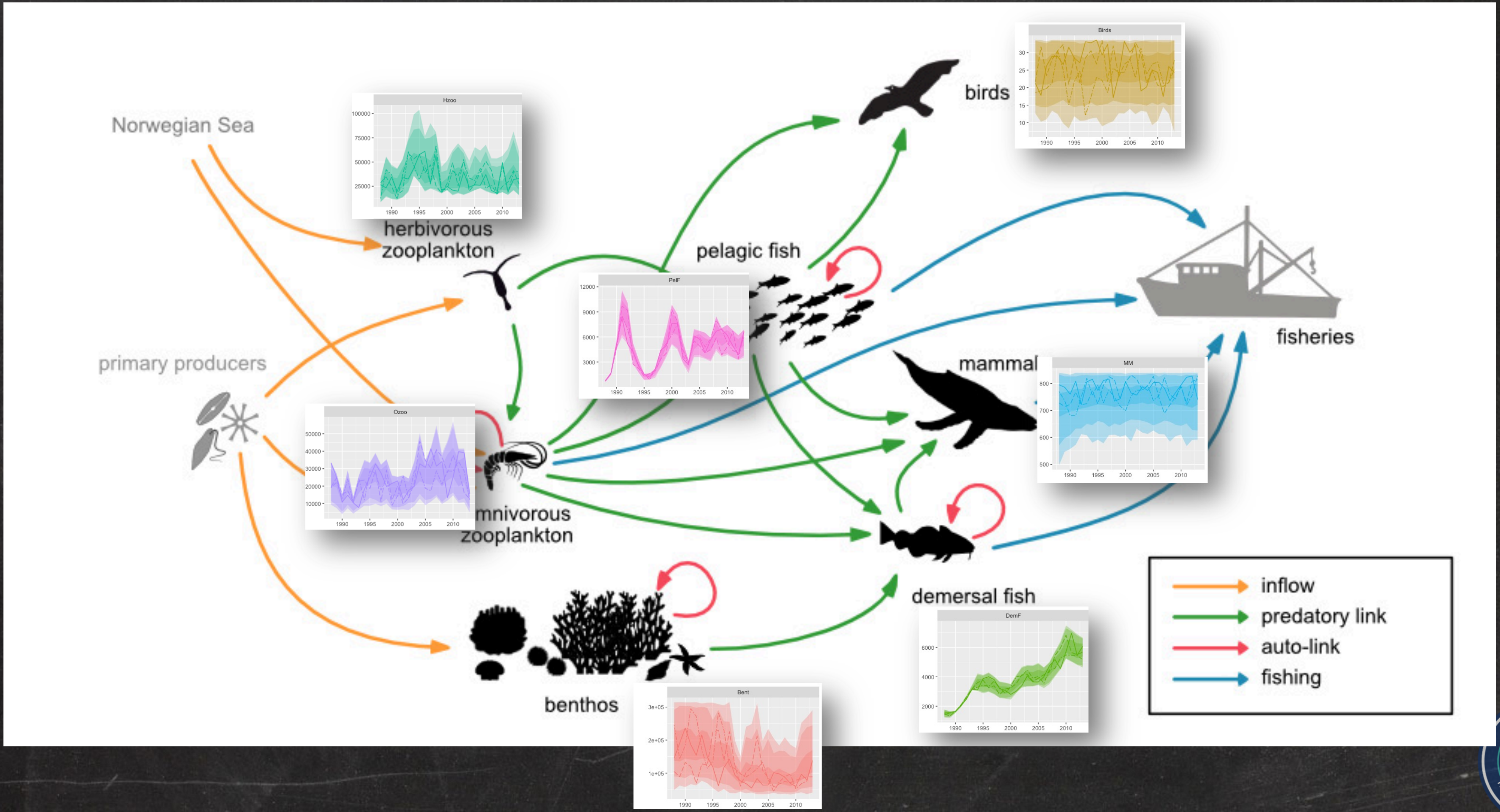
A lot of data…but not everywhere and not of equal quality

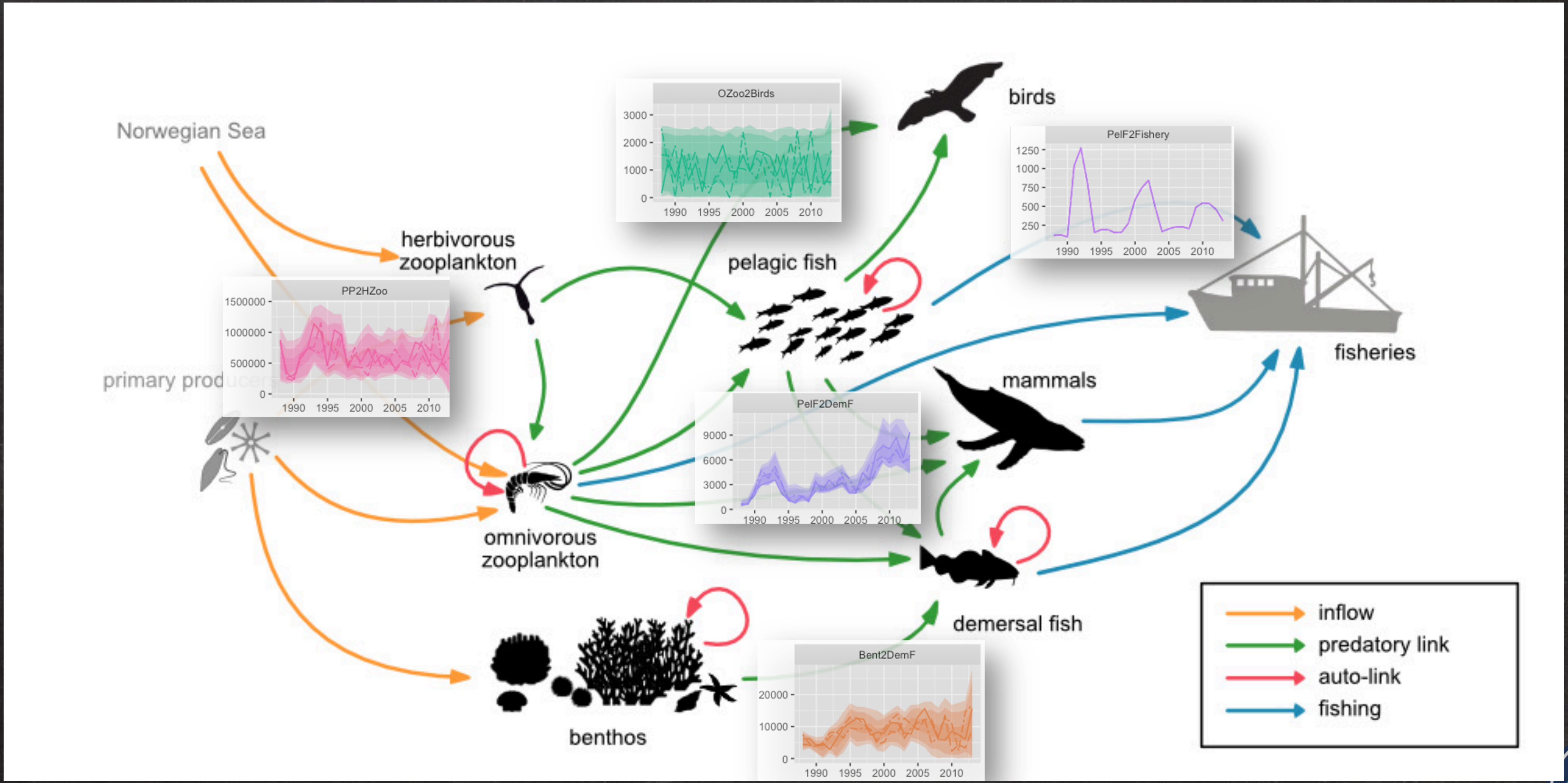


Multiple data types: absolute estimates, relative indices, ranges of values, diet fractions, …

Reconstructed biomasses



Reconstructed flows (trophic and non-trophic)



Information

CaN

Chance and Necessity modelling

IEA

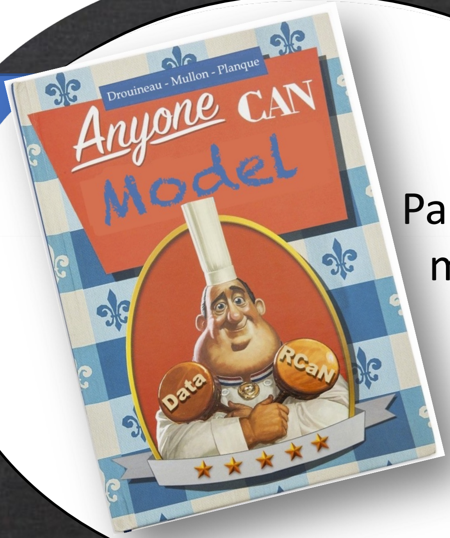
Surveys

Single stock assessments

Food-web & Trophic interactions

Ecological/biological knowledge

Integrate uncertainties & unknowns



Participatory modelling

Historical reconstructions

Short term forecasts

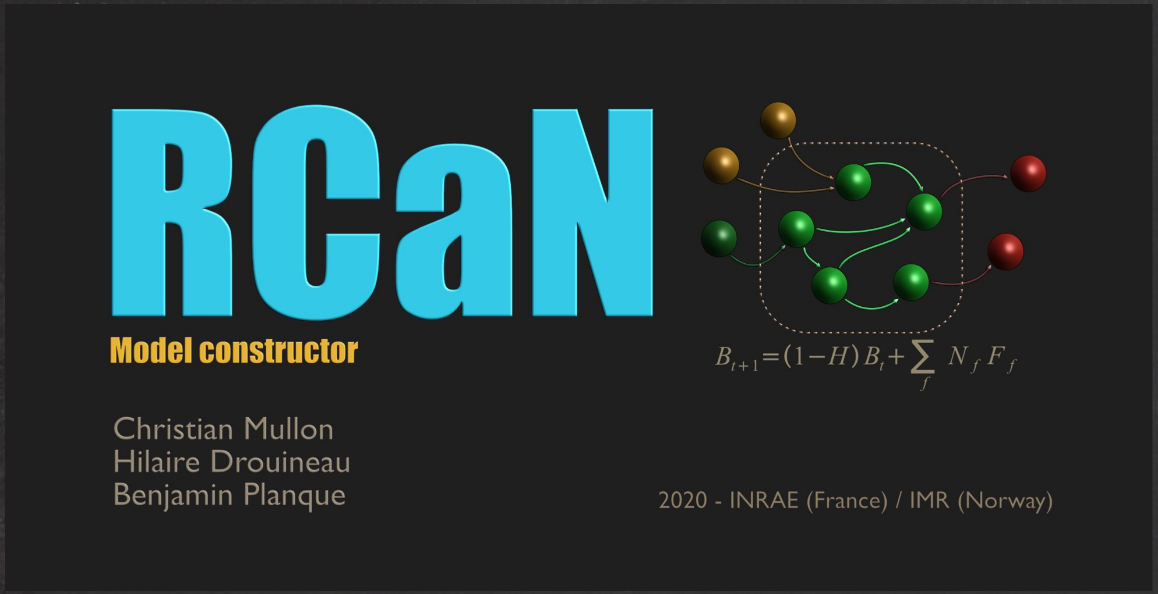
Scenario

A summary of all the ‘ingredients’ of an RCaN model

1. Components: trophospecies, fishing fleets, food sources
2. Input biological parameters: Assimilation efficiency, digestibility, other losses, inertia, satiation
3. Fluxes: trophic, import/export, fishing
4. Observational series
5. Constraints

VI
RCaN and RCaN-Constructor

Excel template, RCaN & RCaN constructor



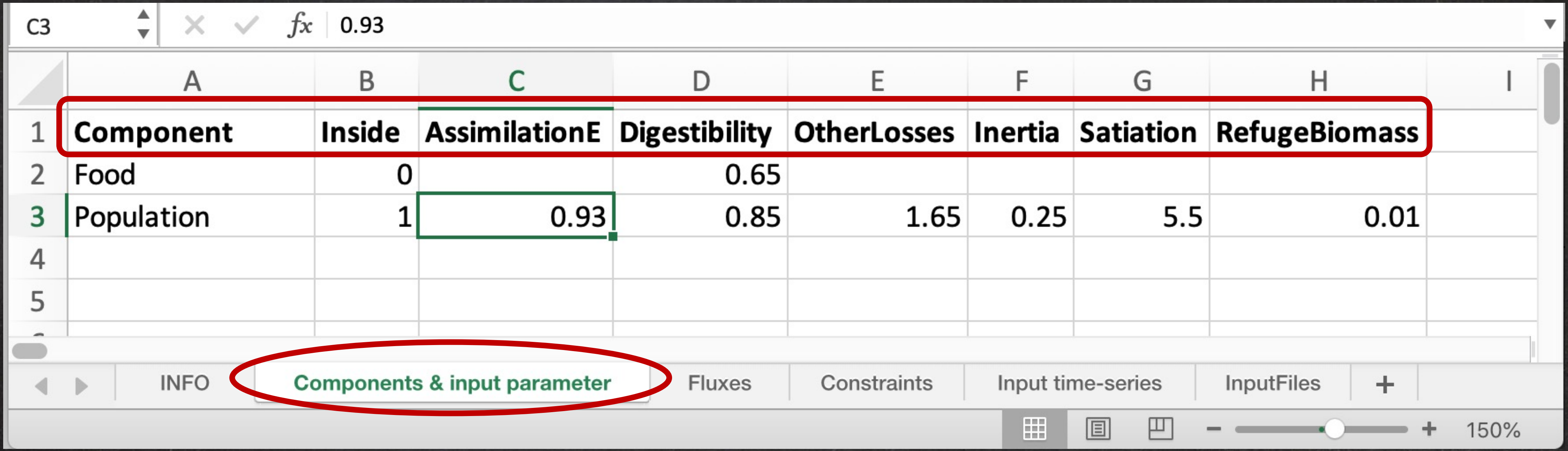
RCaN
Excel template

The RCaN template

RCaN
Excel template

- Document in xlsx format
- Compulsory worksheets:
    1. Components & 2. Input parameters
    3. Fluxes
    4. Input time-series
    5. Constraints
- Additional worksheets:
    6. INFO
    7. InputFiles

Worksheet #1. Components & input parameters



Component	Inside	AssimilationE	Digestibility	OtherLosses	Inertia	Satiation	RefugeBiomass
Food	0		0.65				
Population	1	0.93	0.85	1.65	0.25	5.5	0.01

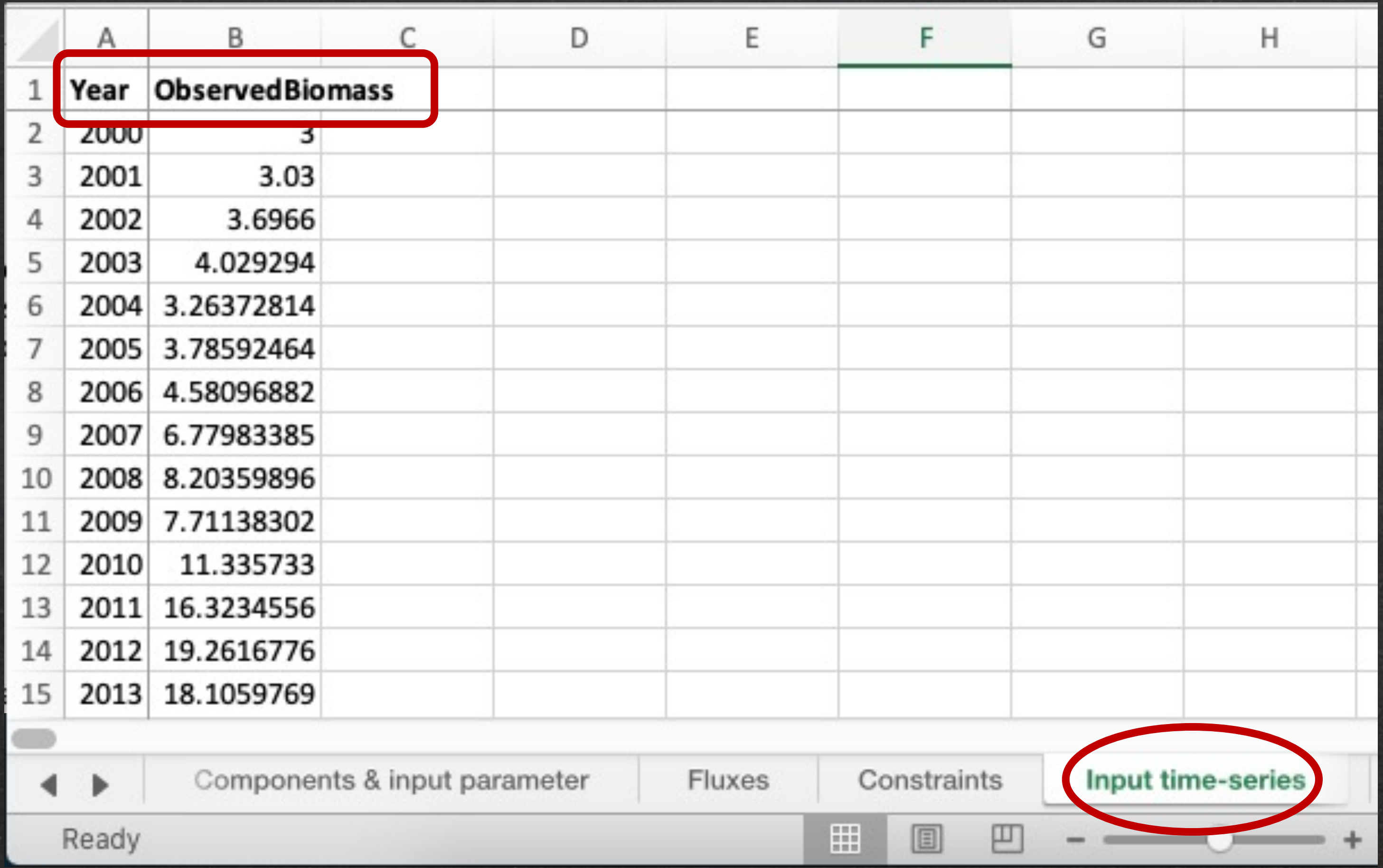
Worksheet #2. Fluxes

Flux	From	To	Trophic
Feeding	Food	Population	1

INFO | Components & input paramete | Fluxes | Constraints | Input time-series | InputFiles | +

Ready 176%

Worksheet #4. Input time-series



	A	B
1	Year	ObservedBiomass
2	2000	3
3	2001	3.03
4	2002	3.6966
5	2003	4.029294
6	2004	3.26372814
7	2005	3.78592464
8	2006	4.58096882
9	2007	6.77983385
10	2008	8.20359896
11	2009	7.71138302
12	2010	11.335733
13	2011	16.3234556
14	2012	19.2616776
15	2013	18.1059769

Worksheet #3. Constraints

	B	C	D	E
1	**Constraint**	**Time-range**	**Active**	**Information**
2	Population<=10	2000	1	Constraint on biomass
3	Feeding<=100	2000:2039	1	Constraint on flux. Carying Capacity
4	Population<=ObservedBiomass*1.2	2000:2019	0	Constraint biomass on observations (upper bound)
5	Population>=ObservedBiomass/1.2	2000:2019	0	Constraint biomass on observations (lower bound)
6				

INFO | Components & input parameter | Fluxes | Constraints | Input time-series | InputFiles

Ready 162%

Worksheet #1, #2, #3, #4: Connections

Components

Component	in_out	AssimilationE	Digestibility	OtherLosses	Inertia	Satiation	RefugeBiomass
Food	Out		0.65				
Population	In	0.93	0.85	1.65	0.25	5.5	0.01

Fluxes

Flux	From	To	Trophic
Feeding	Food	Population	1

Constraints

Constraint	Time-range	Active	Information
Population<10	2000	1	Constraint on biomass
Feeding<=100	2000:2039	1	Constraint on flux. Carying Capacity
Population<ObservedBiomass*1.2	2000:2019	0	Constraint biomass on observations (upper bound)
Population>ObservedBiomass/1.2	2000:2019	0	Constraint biomass on observations (lower bound)

Data

Year	ObservedBiomass
2000	3
2001	3.03
2002	3.6966
2003	4.029294
2004	3.26372814
2005	3.78592464
2006	4.58096882
2007	6.77983385
2008	8.20359896

Worksheet #5. INFO

- This contains all the metadata about the model
  - Authors, date-time, objectives, data sources, parameter calculations, literature, working group, etc…

Worksheet #6. InputFiles

- The list of CSV data files from which observations are taken
- …this is only produced when building the template with RCaN constructor

More on constraints:

Default constraints

- *Satiation, inertia, refuge biomass, positive flows*

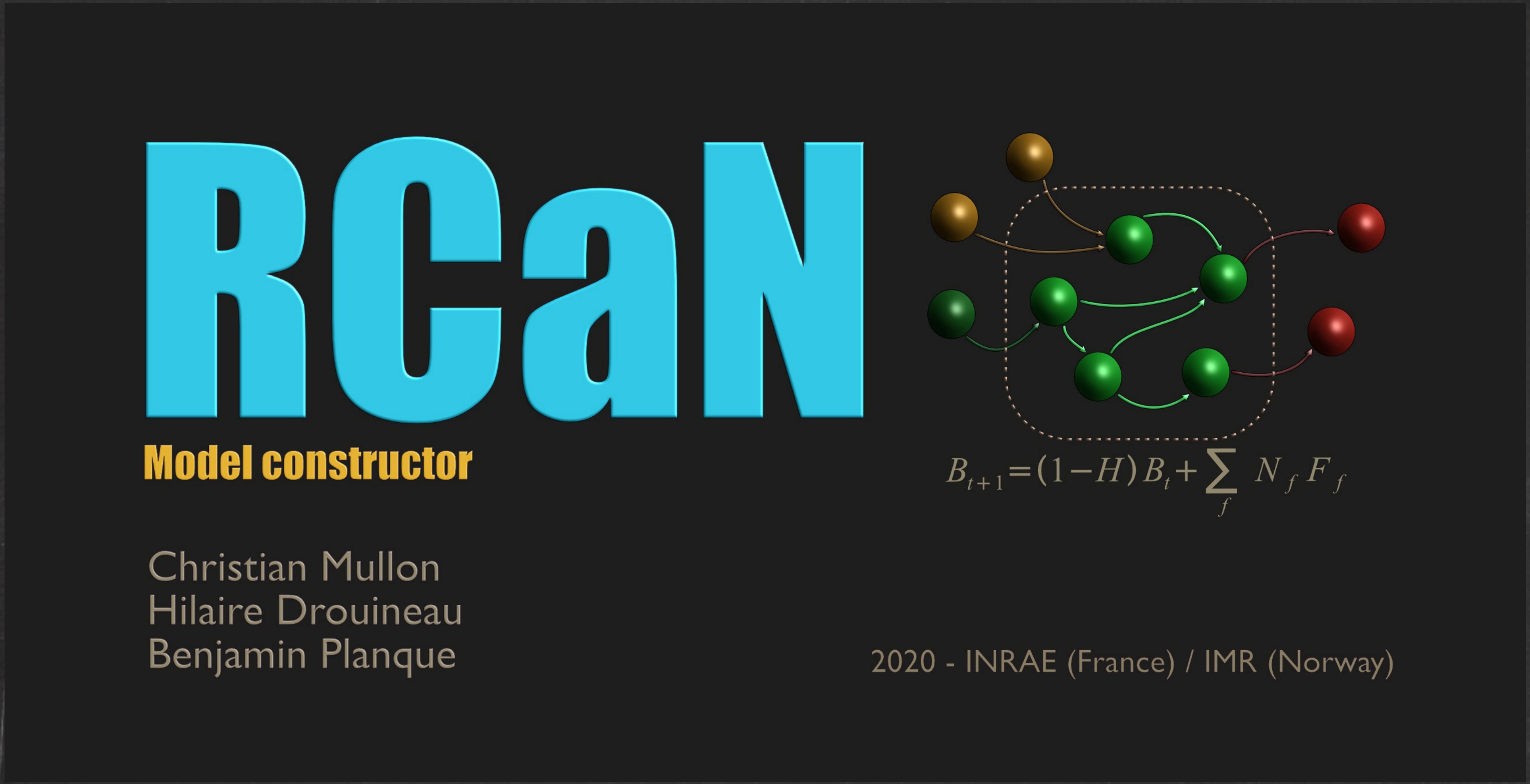
  !!! These apply to all years

Model specific constraints

- Constant absolute limits (e.g. max PP)
- Varying absolute limits (e.g. time series on biomass, flows, catches)
- Varying relative limits (e.g. time series on survey indices)
- Ratios (e.g. diet ratios, biomass ratios)
- Inequalities & equalities can be used

  !!! These can apply to selected years

RCaN constructor



A graphical user interface (GUI) to support the construction of RCaN templates

PAUSE

Questions?

Derivation of biological parameters

Lindstrøm et al., 2017 Ecosystems

https://doi.org/10.1007/s10021-016-0022-y

Satation

- Satiation (sigma): the maximum consumption rate per unit biomass of the predator. The coefficient is strictly positive. A coefficient of 10 indicates that a species group can eat up to 10 times it body weight in the course of 1 time unit (a year, this is equivalent to a maximum daily consumption rate of 2.7%).

$$\sigma = \frac{1}{\gamma\kappa} f_J a_J M^{-0.25}$$

Based on body size and species specific physiology

(Q/B)

Borrowed from an existing Ecopath model

Inertia

- Inertia (rho): a parameter that bounds biomass variations between a maximum growth rate and a maximum mortality rate. The coefficient is strictly positive. The upper bound of biomass variation is given by exp(rho) and the minimum bound rate is given by exp(-rho). A value of 0.25 indicates that over 1 time unit (a year) the biomass of a species can reach at most exp(0.25) ≈ 128% and at least exp(-0.25) ≈ 78% of the original biomass.

$$r_{max} = e^{a_s} e^{-\frac{b_s}{kT}} M^{-0.25}$$

$$\rho = r_{max} \cdot d$$

Based on body size and temperature (metabolic theory of ecology)

$$\rho = e^{a_l} age^{b_l} \lambda$$

Based on longevity (life history correlates)

$$(\ \rho' = \bar{\rho} / \sqrt{NS}\ ).$$

Correction for multiple species in a trophospecies group

Metabolic losses

- Other losses (mu): a coefficient that account for losses, i.e. metabolic losses and other mortality not explicitly accounted for in the model. The losses are expressed in the form exp(-mu). The coefficient is strictly positive. A value of 2 indicates that over 1 time unit (a year) metabolic losses and other mortality losses will represent 1-exp(-2) ≈ 86% of the original biomass (equivalent to 1-exp(2/365) = 0.55% daily losses).

$$\mu_{Gillooy} = 3\left(\underbrace{e^{a_{bmr}} e^{-\frac{b_{bmr}}{T}1000} M^{0.75}}_{BMR_{Gillooy}}\right)$$

$$\mu_{Yodzis} = a_T M^{-0.25}$$

$$\mu_{BS} = 3\left(BMR_{Mak.}\, 2^{(T_{BS}-T_M)/10}\right)$$

Based on body size and temperature (metabolic theory of ecology, experimental results)

Digestibility

- Digestibility correction factor (kappa): a correction factor that accounts for variations in energy content of a prey. The value of the parameter is between zero (no energy content) and one. The product of the potential assimilation efficiency by the digestibility correction factor is the absorption efficiency (the proportion of prey biomass digested and absorbed).

Assimilation Efficiency

- Potential assimilation efficiency (gamma): the proportion of the biomass ingested by a predator that is effectively assimilated. The value of the parameter is between zero (no assimilation) and one (complete assimilation). The product of the potential assimilation efficiency by the digestibility correction factor is the absorption efficiency (the proportion of prey biomass digested and absorbed).

Relevant papers

2009

FISH and FISHERIES

FISH and FISHERIES, 2009, **10**, 115–131

A minimal model of the variability of marine ecosystems

Christian Mullon[1], Pierre Fréon[1], Philippe Cury[1], Lynne Shannon[2] & Claude Roy[3]

2014

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Non-Deterministic Modelling of Food-Web Dynamics

Benjamin Planque[1]*, Ulf Lindstrøm[1], Sam Subbey[2]

1 Institute of Marine Research, Tromsø, Norway, 2 Institute of Marine Research, Bergen, Norway

2016

J. Math. Biol. (2016) 73:575–595
DOI 10.1007/s00285-015-0959-z

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Sam Subbey[1,2] · Benjamin Planque[2,3] · Ulf Lindstrøm[3]

2017

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Ulf Lindstrøm,[1] Benjamin Planque,[1,2]* and Sam Subbey[2,3]

2020

ICES Journal of Marine Science

ICES CIEM International Council for the Exploration of the Sea Conseil International pour l'Exploration de la Mer

ICES Journal of Marine Science (2020), 77(4), 1573–1588. doi:10.1093/icesjms/fsz173

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Benjamin Planque [1]* and Christian Mullon [2]

New Results

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Hilaire Drouineau, Benjamin Planque, Christian Mullon

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Benjamin Planque; Aurélien Favreau; Bérengère Husson; Erik Mousing; Cecilie Hansen; Cecilie Broms; Ulf Lindstrøm; Elliot Sivel

INSTITUTE OF MARINE RESEARCH

https://github.com/inrae/RCaN

+packages:
symengine, ggplot2, ggraph, coda, DT, tidyverse

https://doi.org/10.1101/2021.06.09.447734


New Results

RCaN : a software for Chance and Necessity modelling

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