The Madingley Model and sustainable fisheries management

Philip J. Underwood

University of British Colombia, 28/05/2015

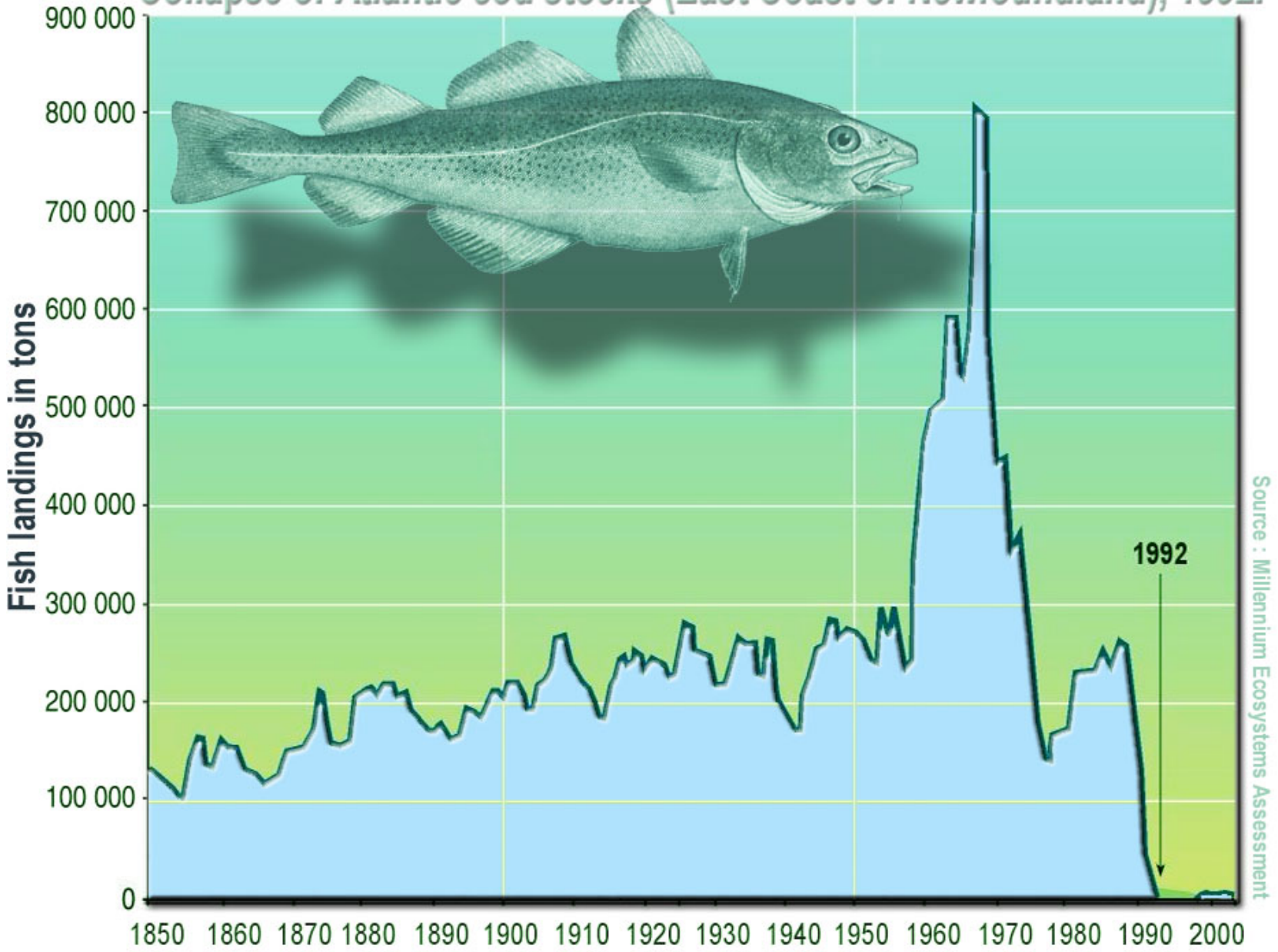
Fisheries Model Project Aims

- Integrate past fisheries catch data.
- Integrate multi-year input data.
- Improve oceanic ecological realism.
- Experiment with alternative management scenarios.
- Produce policy-relevant outputs.

Motivation

Guam Division of Aquatic and Wildlife Resources, Department of Agriculture

Collapse of Atlantic cod stocks (East Coast of Newfoundland), 1992.



Food Chain Catastrophe: Emergency Shut Down Of West Coast Fisheries: “Populations Have Crashed 91 Percent”

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In Mackerel's Plunder, Hints of Epic Fish Collapse

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A school of jack mackerel in the Southern Pacific. Stocks of the fish, rich in oily protein, have declined from 30 million metric tons to less than a tenth of that in two decades. Eduardo Sorensen/Oceana

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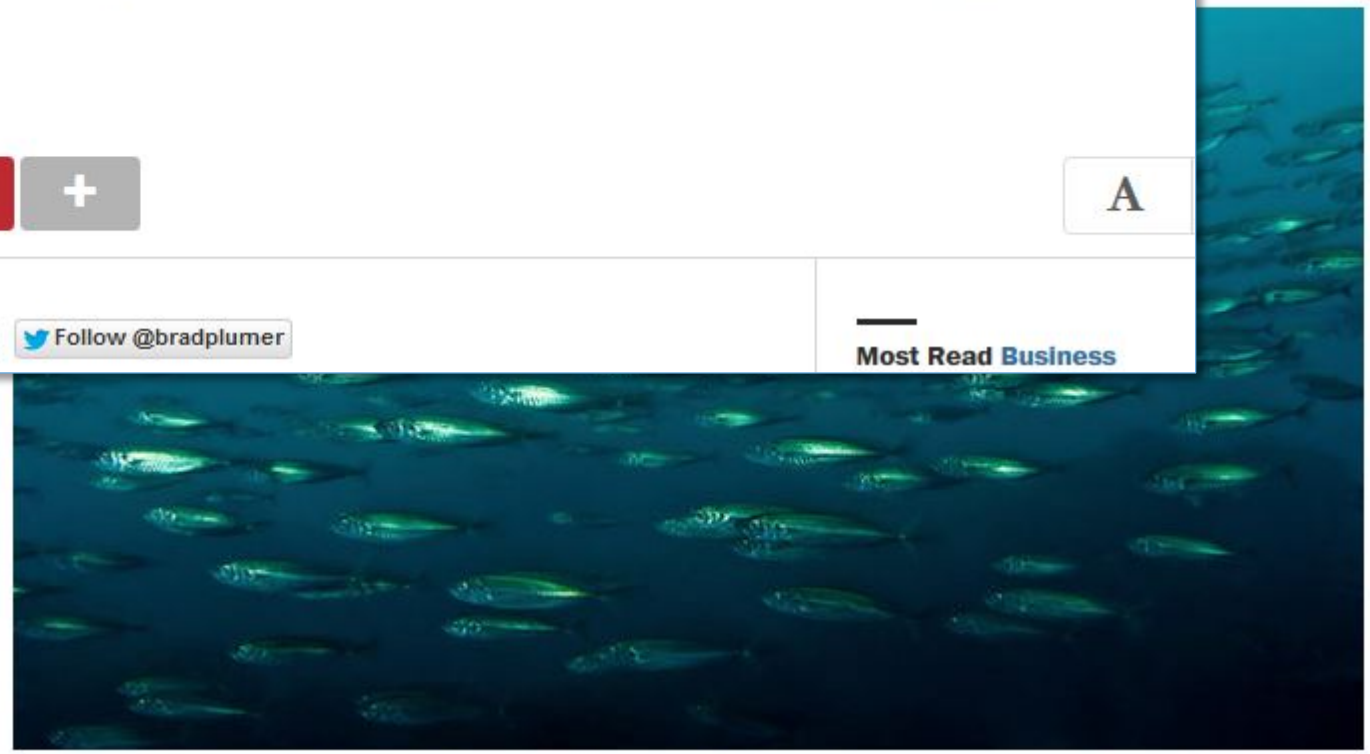

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By Janet Thomson and Manmeet Ahluwalia, CBC News Posted: Jun 29, 2012 5:41 PM ET | Last Updated: Jun 29, 2012 5:40 PM ET

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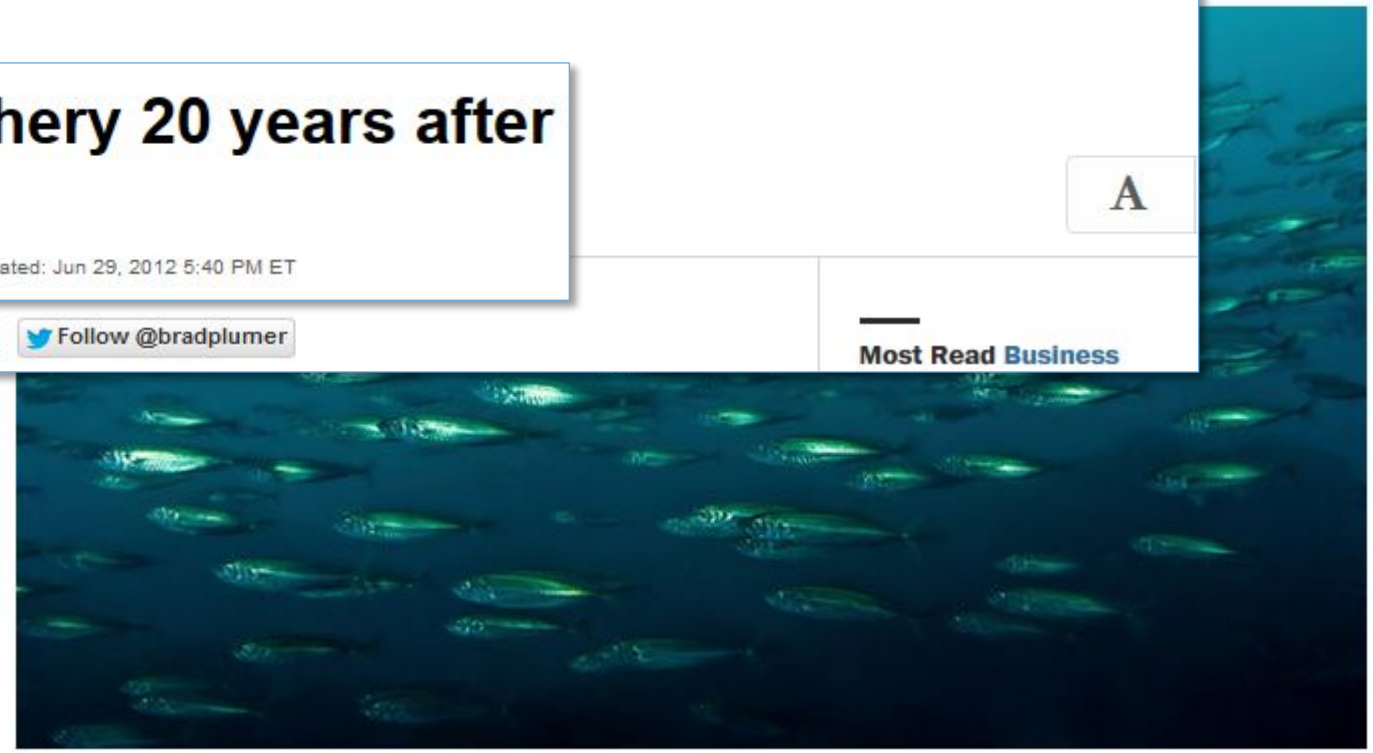

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West Coast sardine collapse leads to fishing closure

Story Comments Print Font Size:

Posted: Monday, April 13, 2015 5:13 pm | *Updated: 7:30 pm, Mon Apr 13, 2015.*

Associated Press |

Fisheries managers have decided to call off the West Coast sardine fishing season that starts in July because of rapidly dwindling numbers, hoping to save an iconic industry from the kind of collapse that hit in the 1940s and lasted 50 years.

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Science News *from research organizations*

Did The North Atlantic Fisheries Collapse Due To Fisheries-induced Evolution?

Date: May 26, 2009

Source: Public Library of Science

Summary: The Atlantic cod has, for many centuries, sustained major fisheries on both sides of the Atlantic. However, the North American fisheries have now largely collapsed. A new article provides insights into possible mechanisms of the collapse of fisheries, due to fisheries-induced evolution.

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The Historical Collapse of Southern California Fisheries and the Rocky Future of Seafood

By Jim Haw | July 1, 2013 | 1

By Katie Lee

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Consumers want more than fisheries can supply, and certification standards are falling.

BY BRIAN PALMER | @PALMERBRIAN | *1 week ago*

PHOTO: DAVID LINKIE/MARINE STEWARDSHIP COUNCIL

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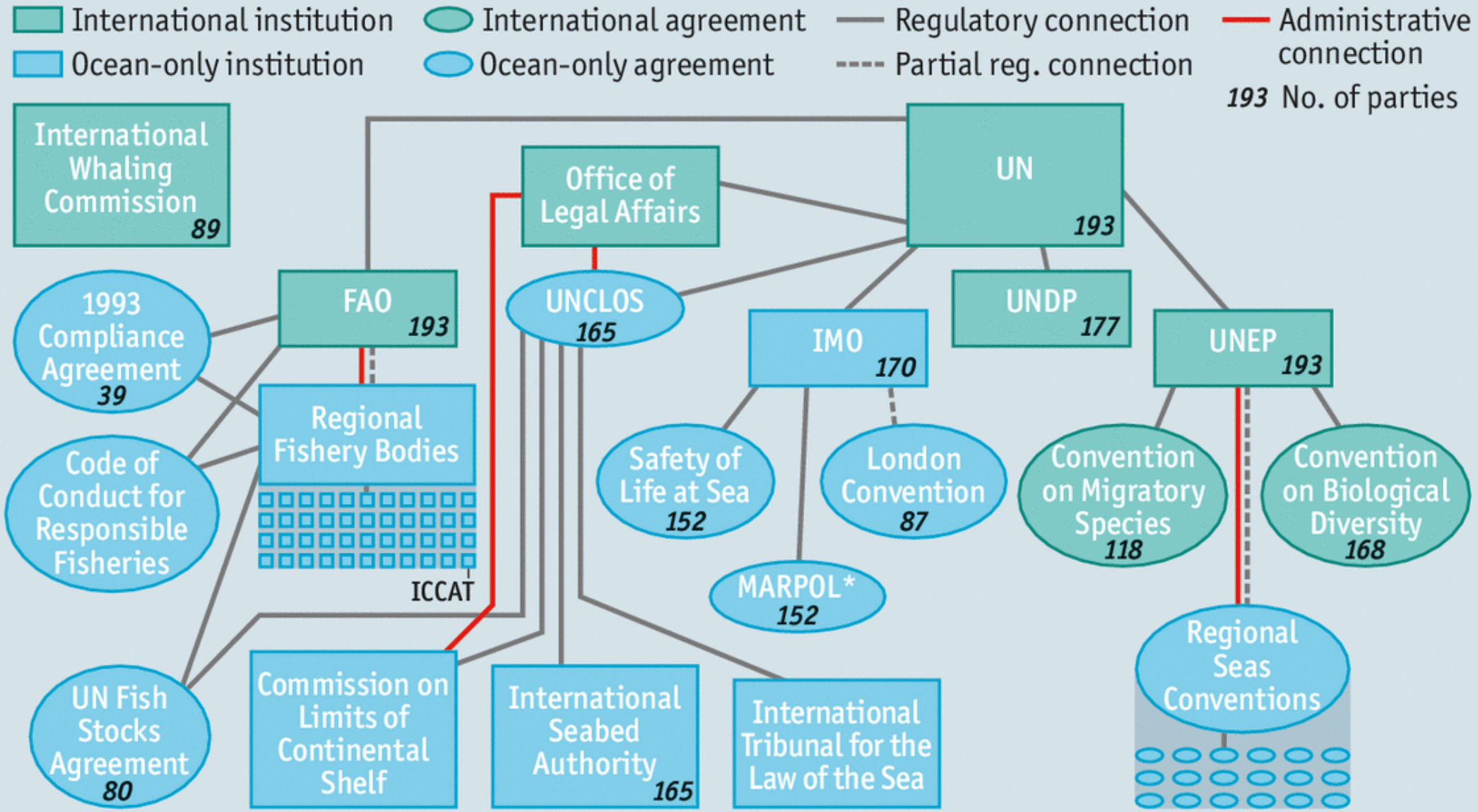
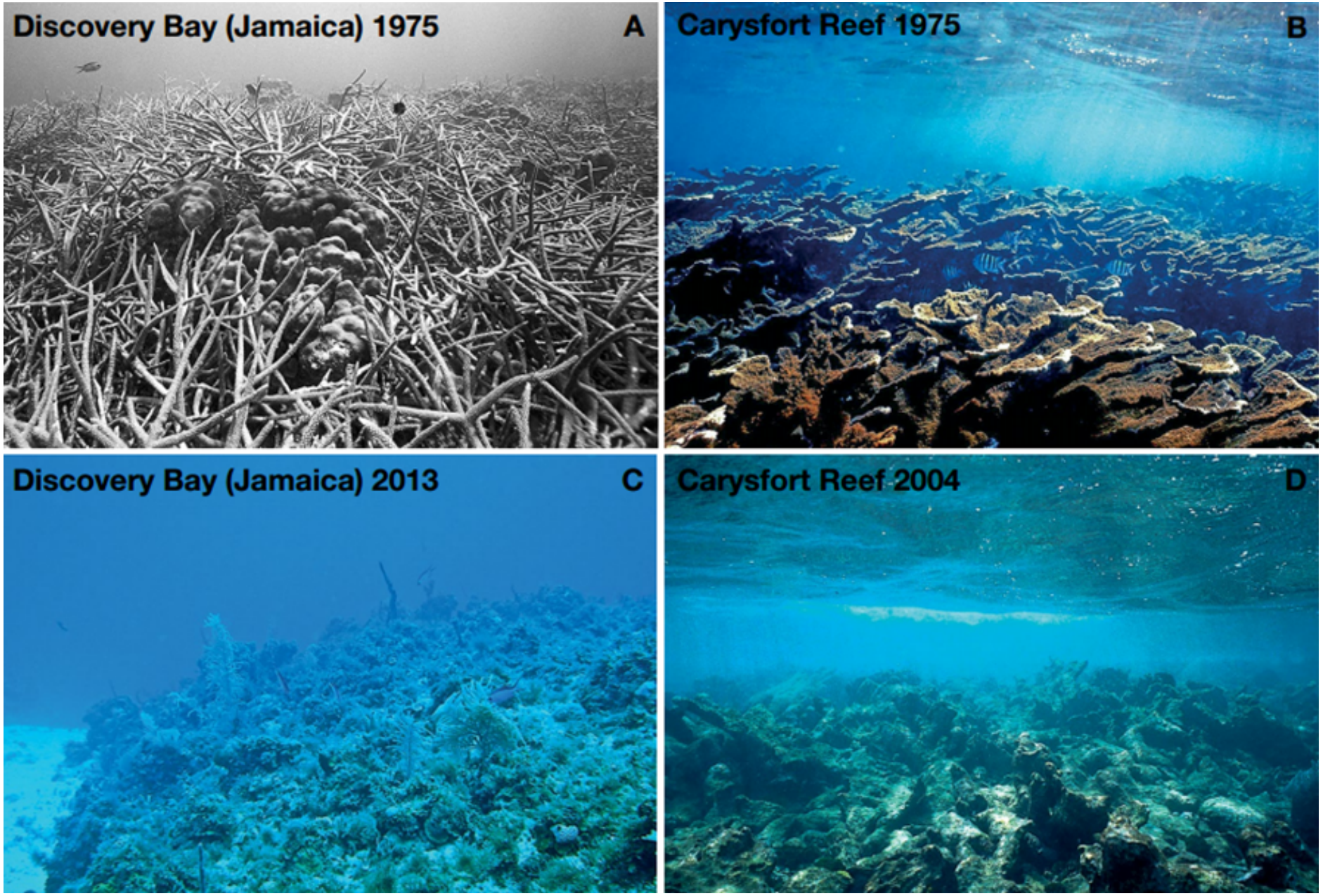
Trouble at sea

International management of the high seas, simplified, 2014



Sources: Global Oceans Commission; *The Economist*

*International Convention for the Prevention of Pollution from Ships



http://www.iucn.org/?16056/From-despair-to-repair-Dramatic-decline-of-Caribbean-corals-can-be-reversedStory

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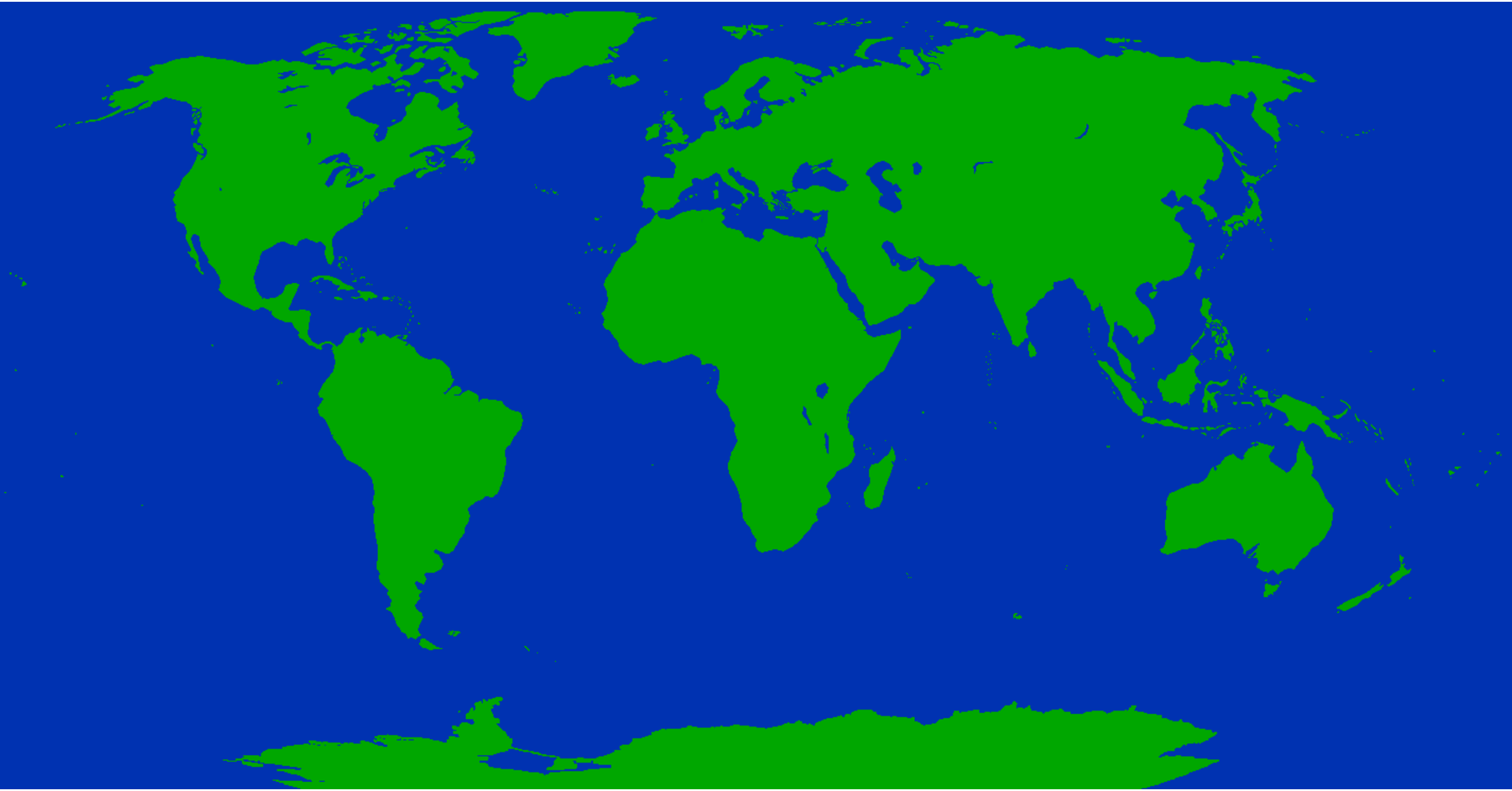
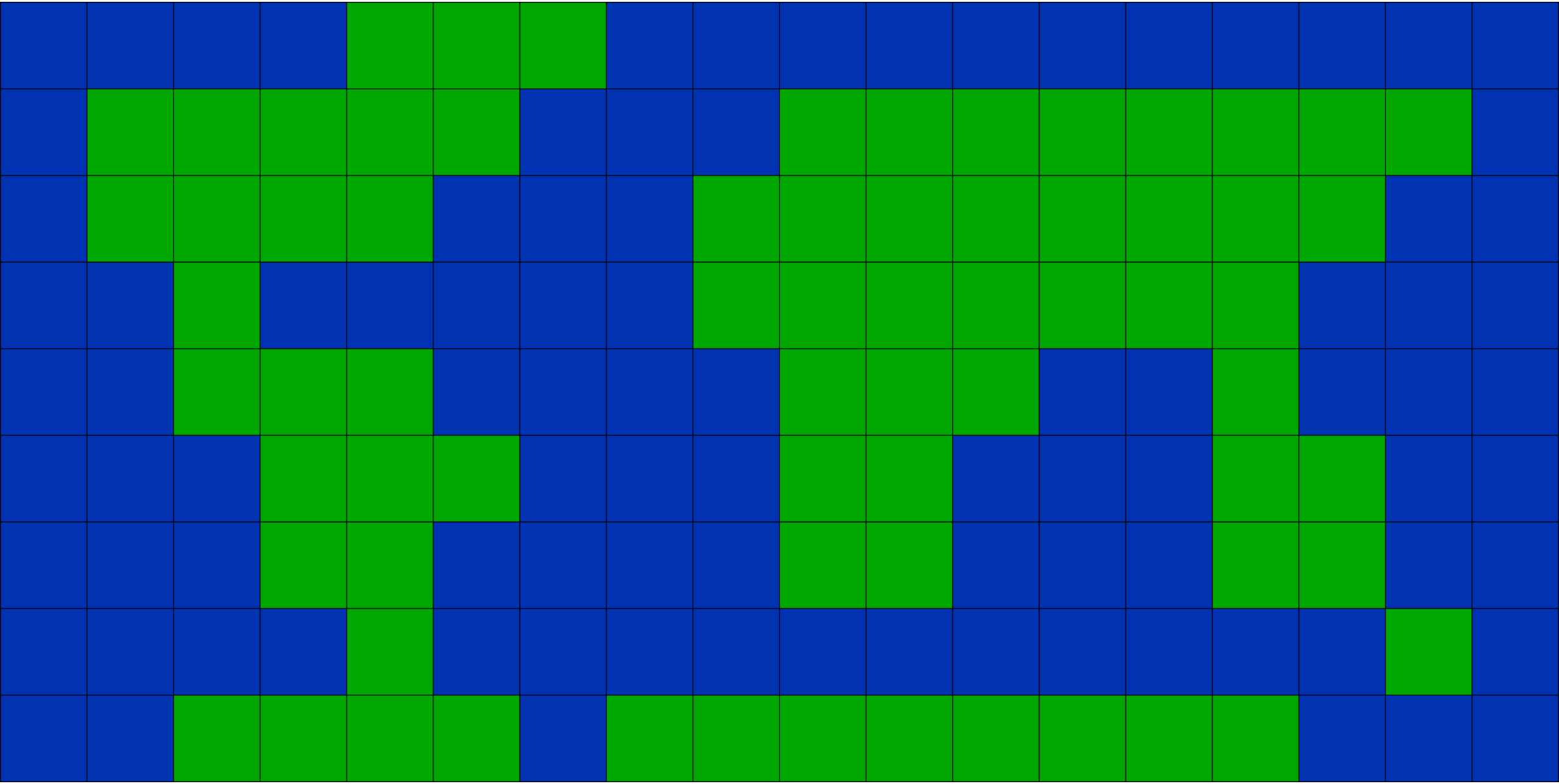
The Madingley Model

A Model of All Life

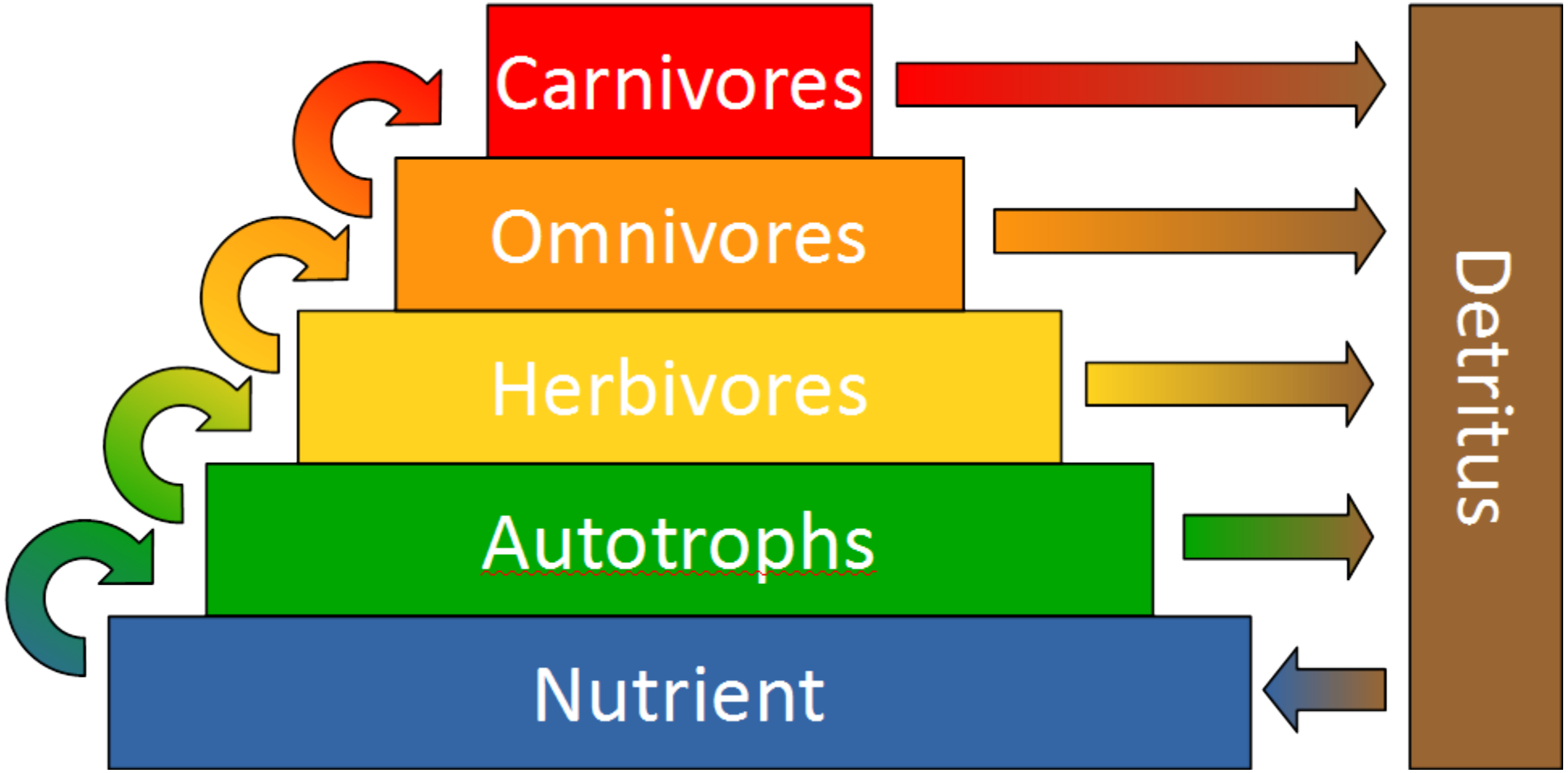
- Global
- Individual-based
- Data and theory driven
- Exhibits emergent behaviours
- Potential for exploring:
  - Evolution
  - Adaptation
  - Regime shifts
  - Tipping points

Harfoot et al. (2014). PLoS Biology, 12(4).





Trophic System



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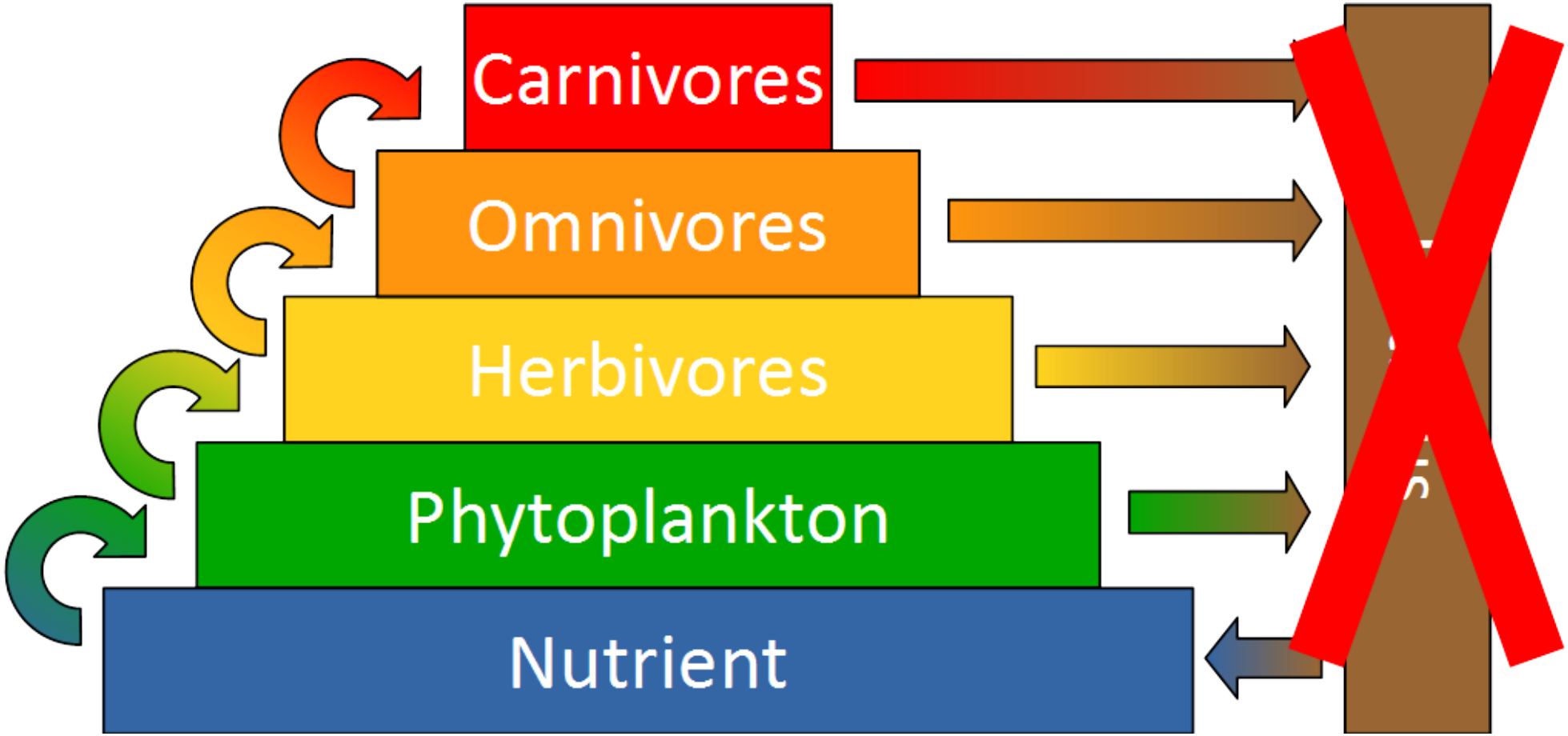

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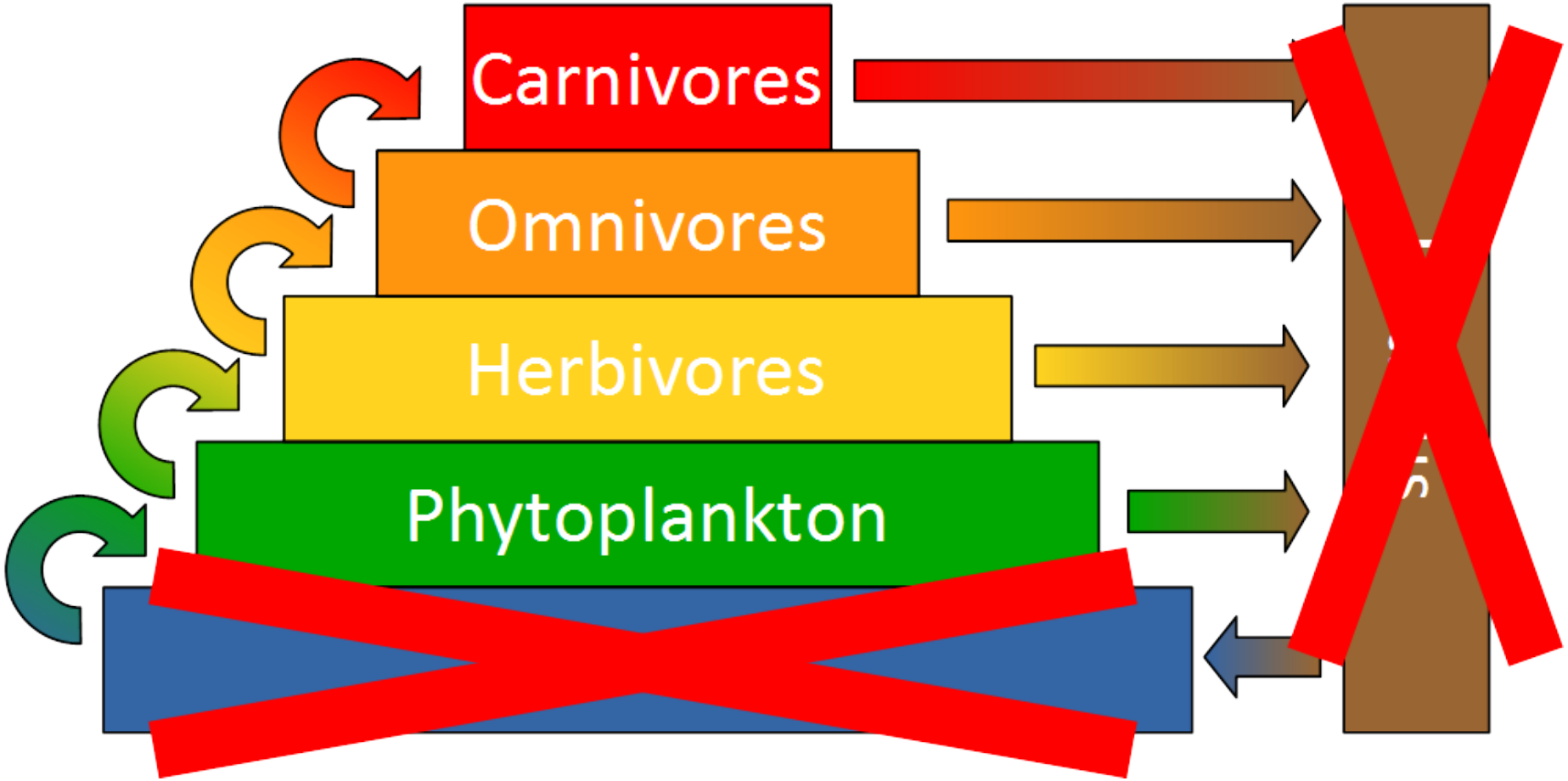

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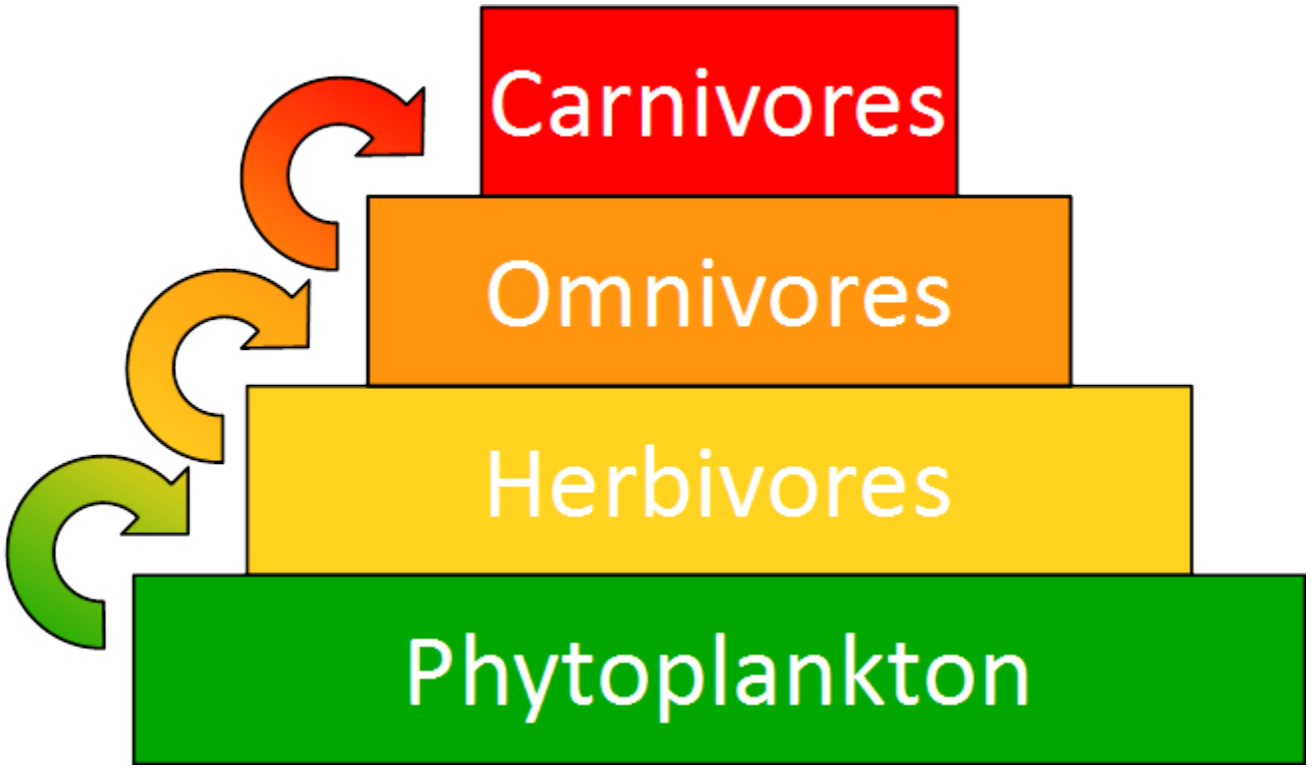
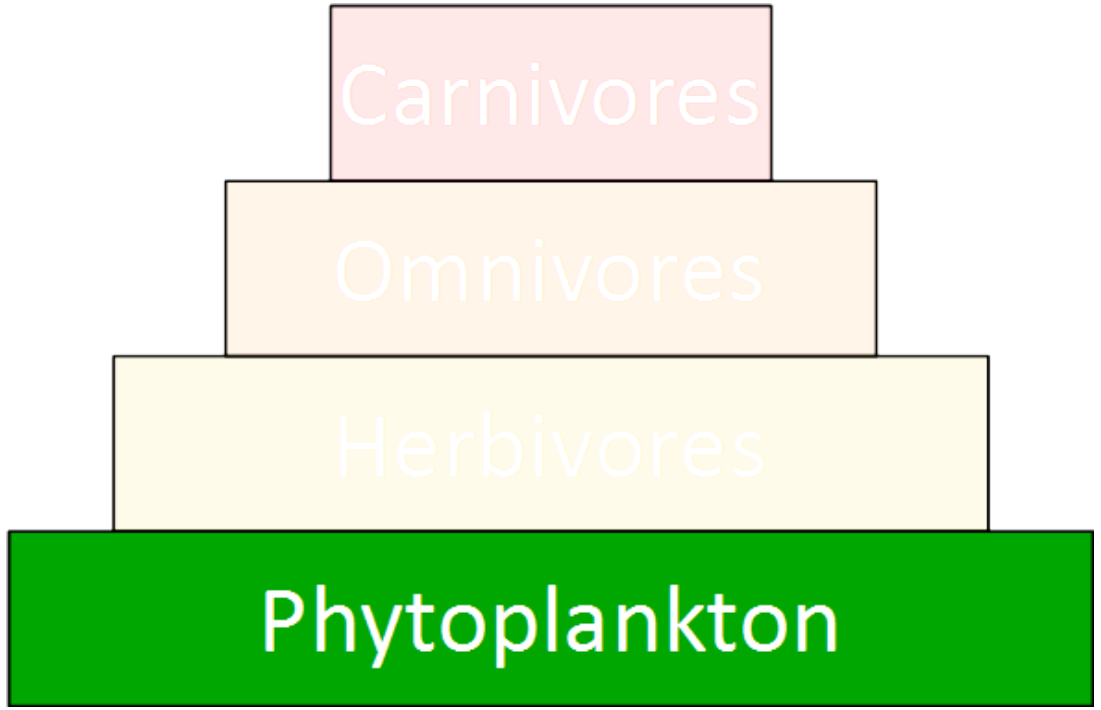


Autotrophy: Phytoplankton

- Single state variable

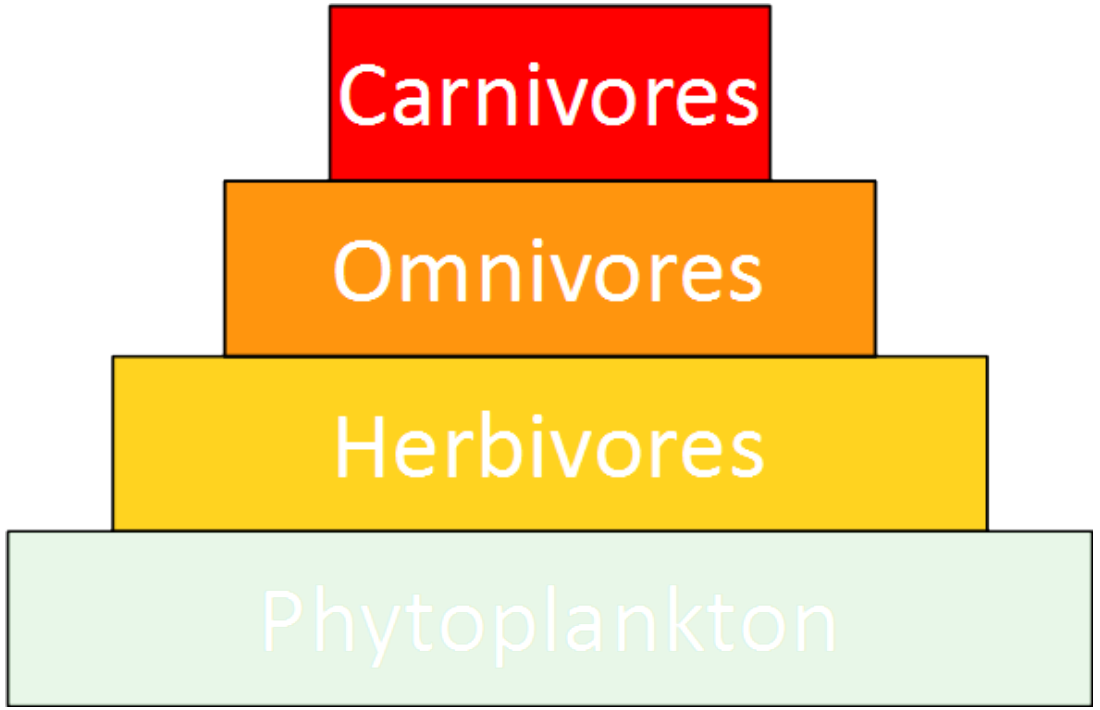
- Growth driven by data on oceanic NPP
  - Circular model
  - Room for improvement



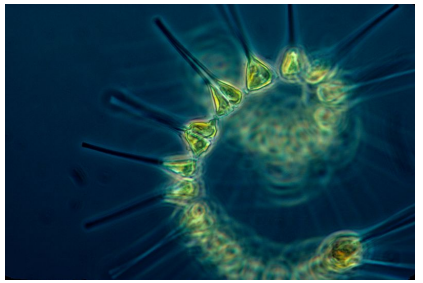
Heterotrophy

- Modelled as populations of individuals

- How?



Model All Species?

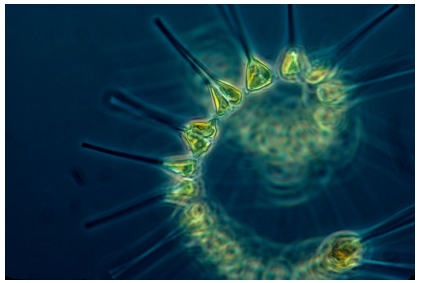


No! Approximate Species by Function

- **Food:** *Autotroph, Herbivore, Omnivore, or Carnivore?*
- **Thermoregulation:** *Endotherm, or Ecotherm?*
- **Reproduction:** *Iteroparous, or Semelparous?*
- **Mobility:** *Sessile, Planktonic, or Mobile?*
- **Metabolism:** *Assimilation efficiency?*
- **Habitat:** *Marine or Terrestrial?*
- **Mass:** *Minimum, Maximum?*

Model Functional Types

Herbivores



Autotrophs

Ectotherm

Semelparous

Carnivores

Sessile

Endotherm

Mobile

Iteroparous

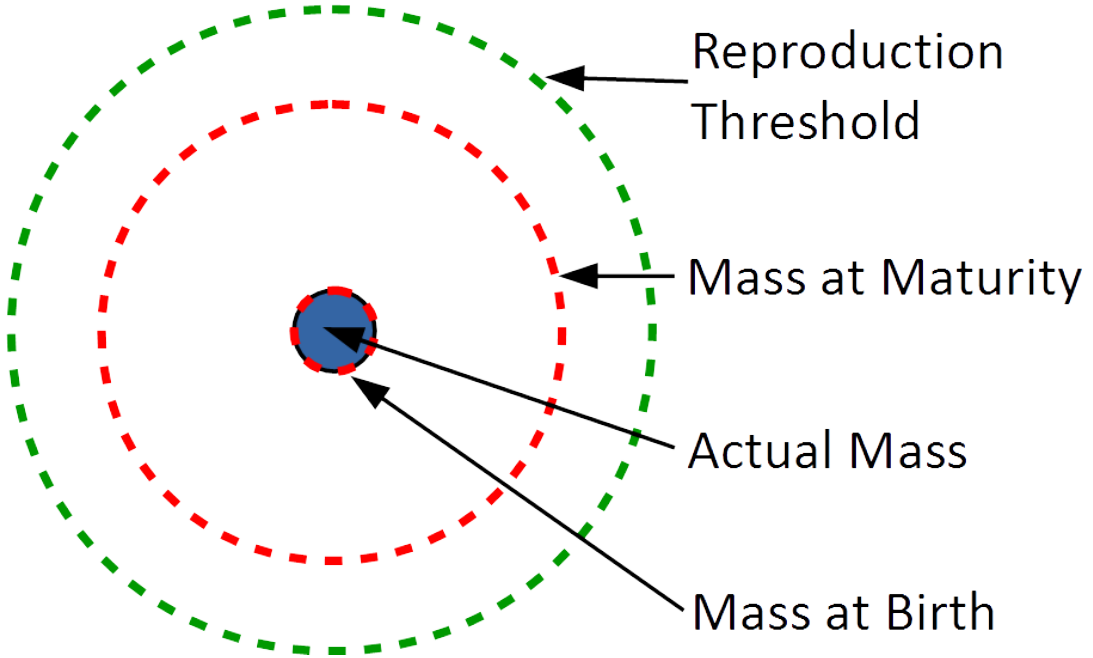
Omnivores

Individuals

They all have mass

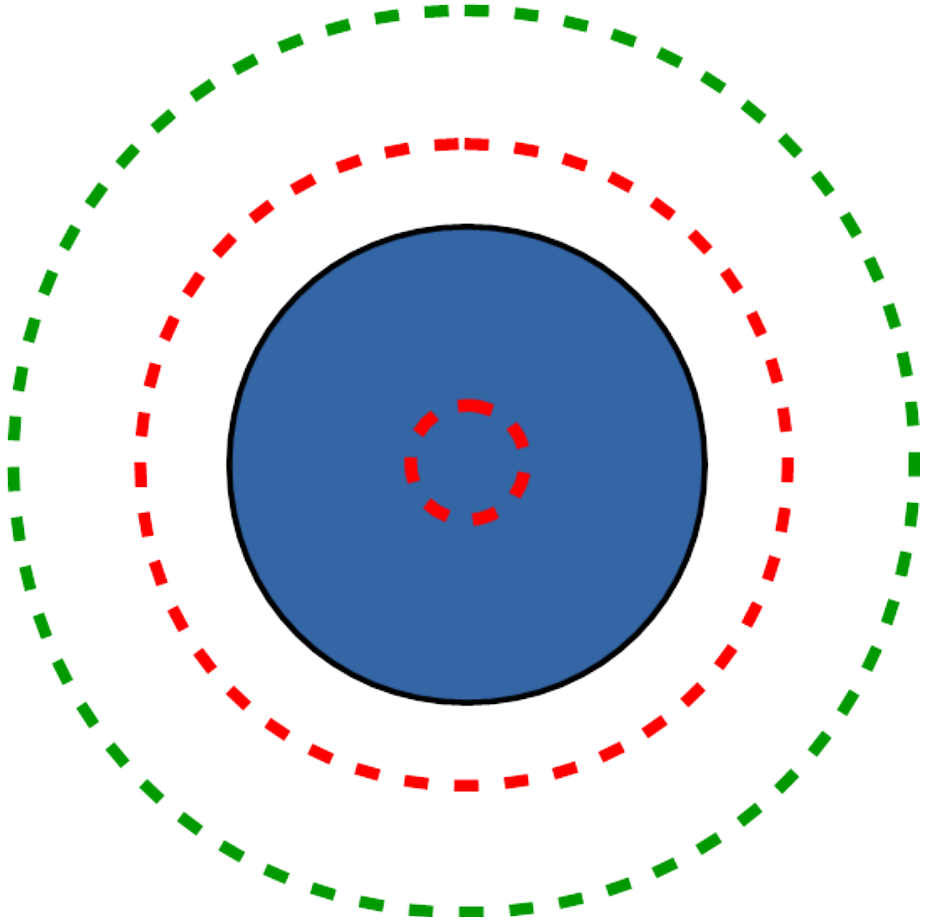
Individuals

In addition to functional classification they have <u>continuous attributes</u>



Individuals

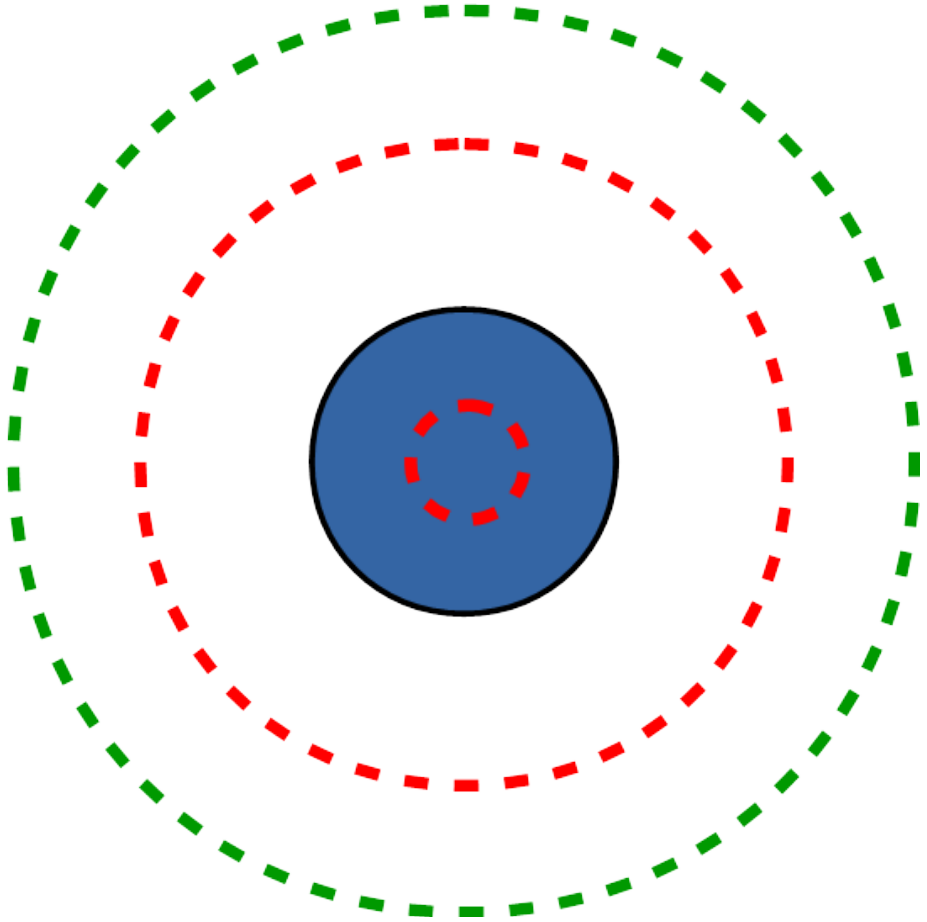
They can assimilate and grow



Individuals

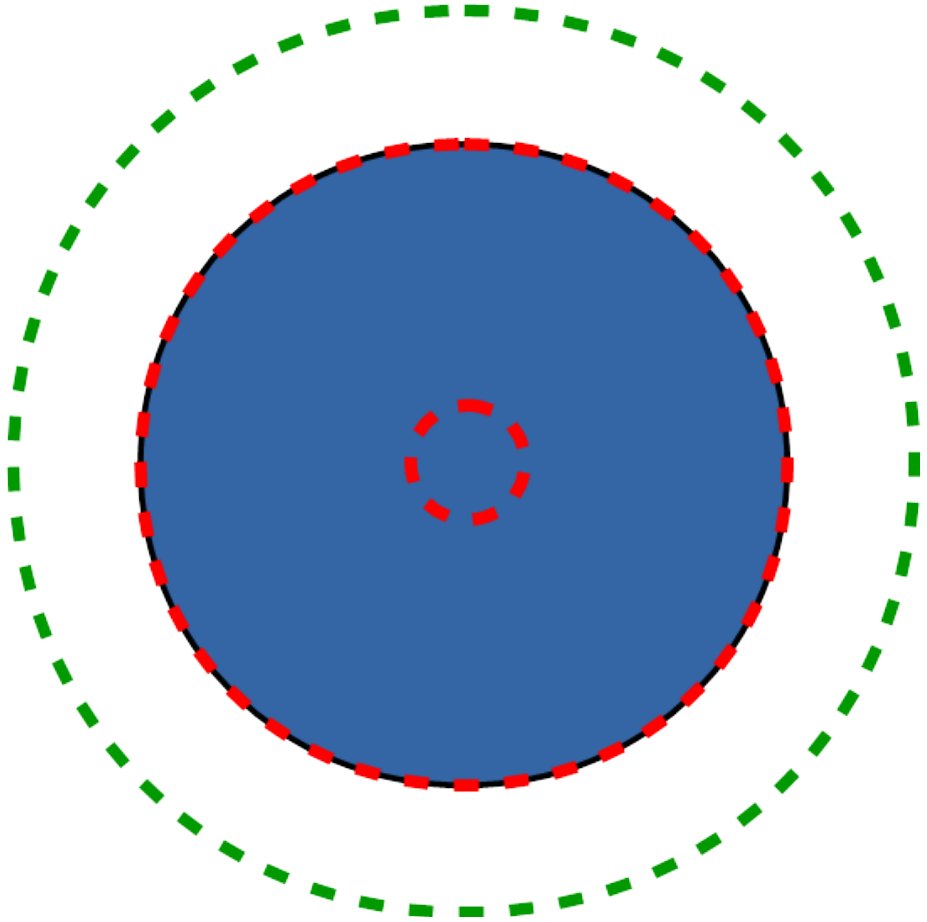
They metabolise and can shrink

- This may lead to starvation mortality



Individuals

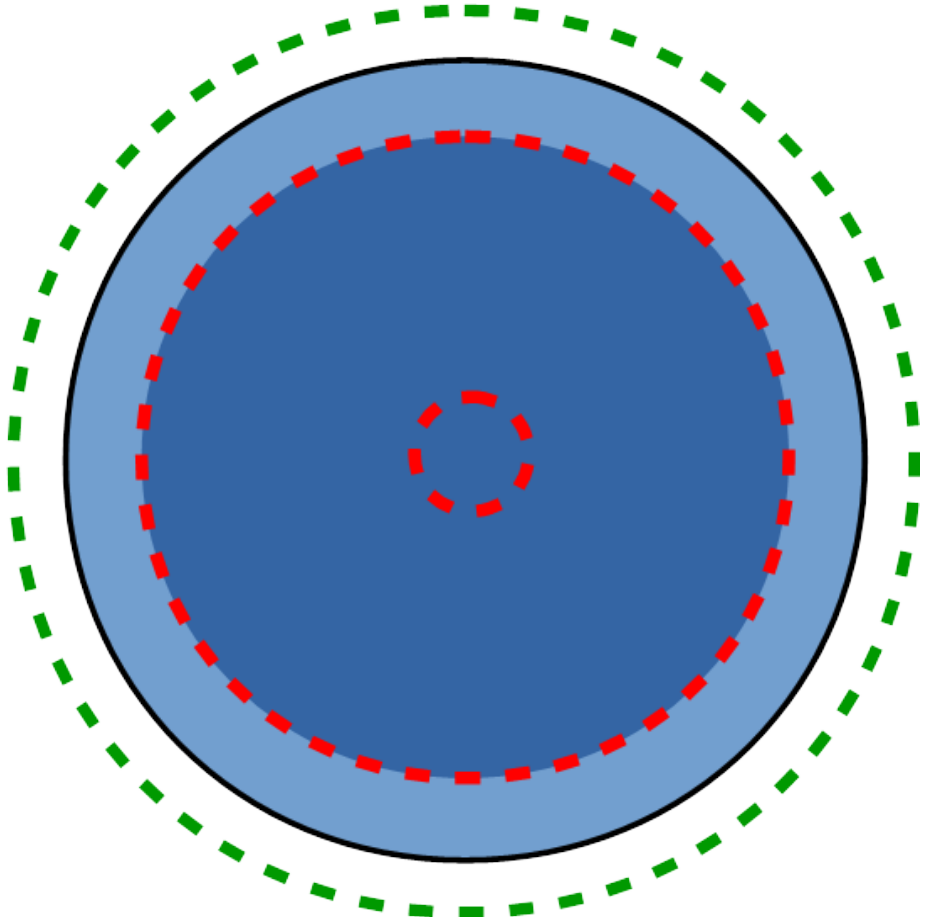
They can grow to maturity



Individuals

They can continue to grow beyond maturity

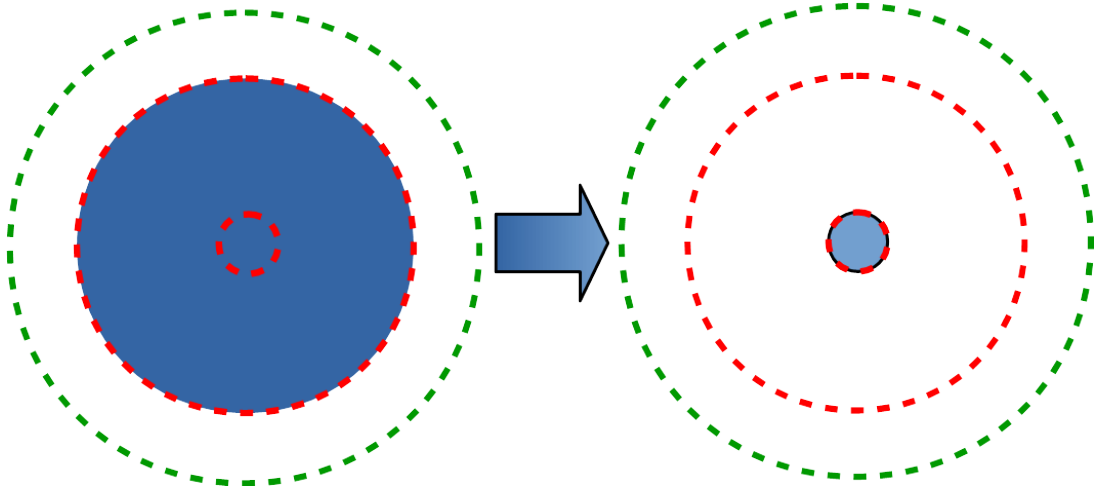
- The additional mass can be used for reproduction



Individuals

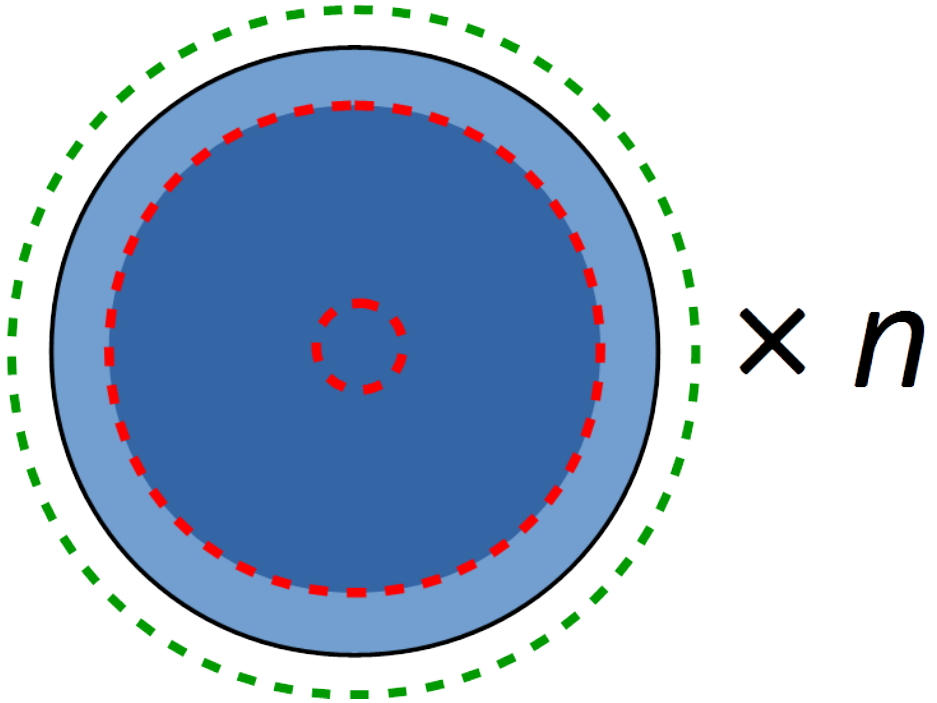
They can reproduce

- Subject to potential mutation of the continuous traits



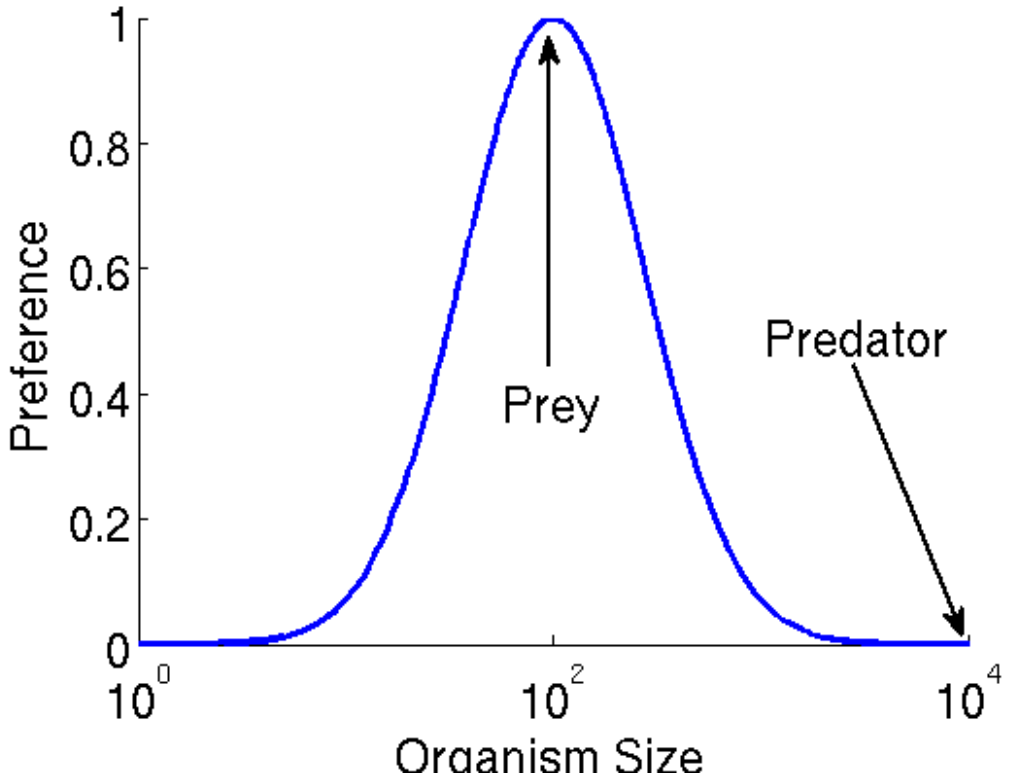
Individuals

- Representing all individuals is computationally intractable
- Model cohorts instead
  - Additional trait represents number of individuals in cohort



Prey Selection

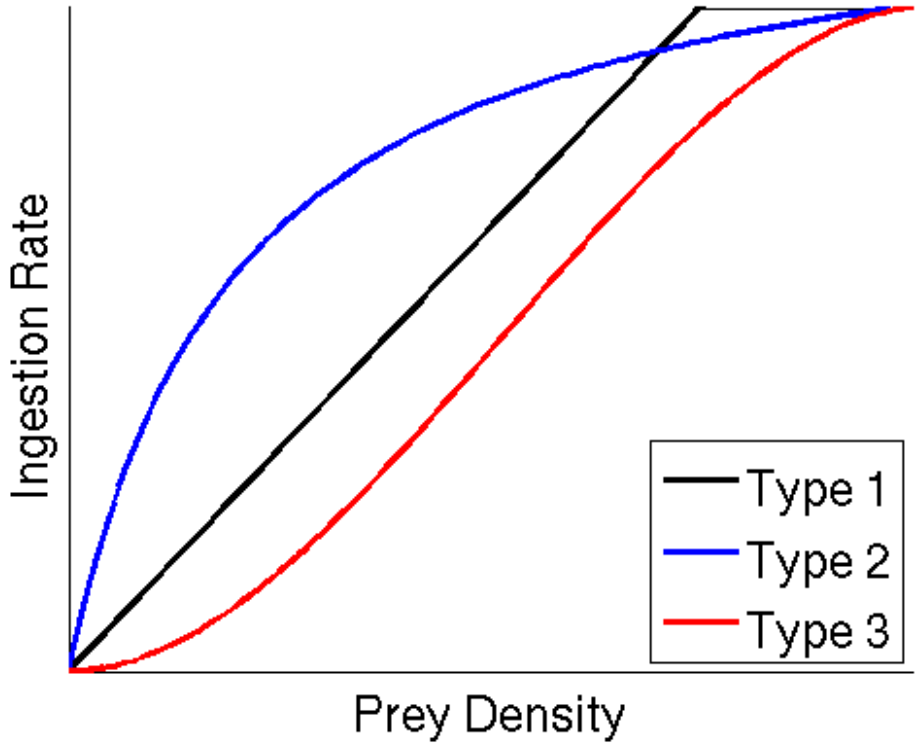
Determined by predator and prey size (and functional group)



Andersen, K. H. & Beyer, J. E. (2006). The American Naturalist, 168, 1, pp 54-61.

Assimilation

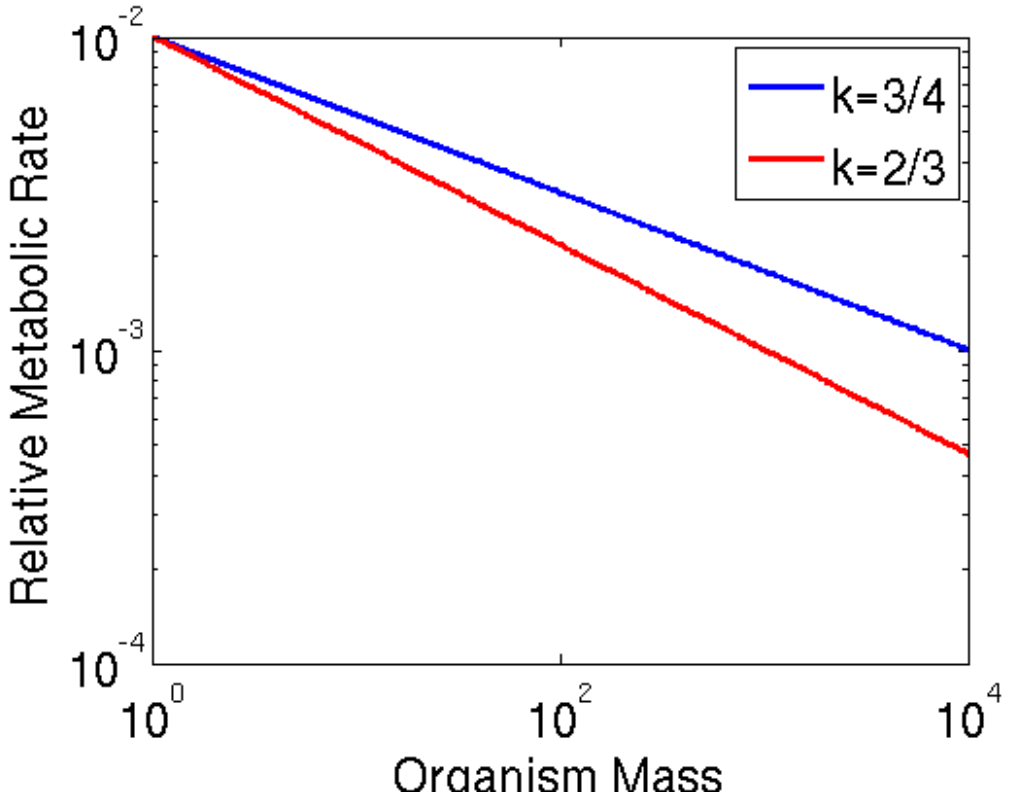
- Ingestion rate is a function of prey density
- Ingested mass is subject to assimilatory losses



Holling, C. S. (1959). The Canadian Entomologist, 91,7, pp 385-398.

Metabolism

- Allometrically-scaled metabolic rate



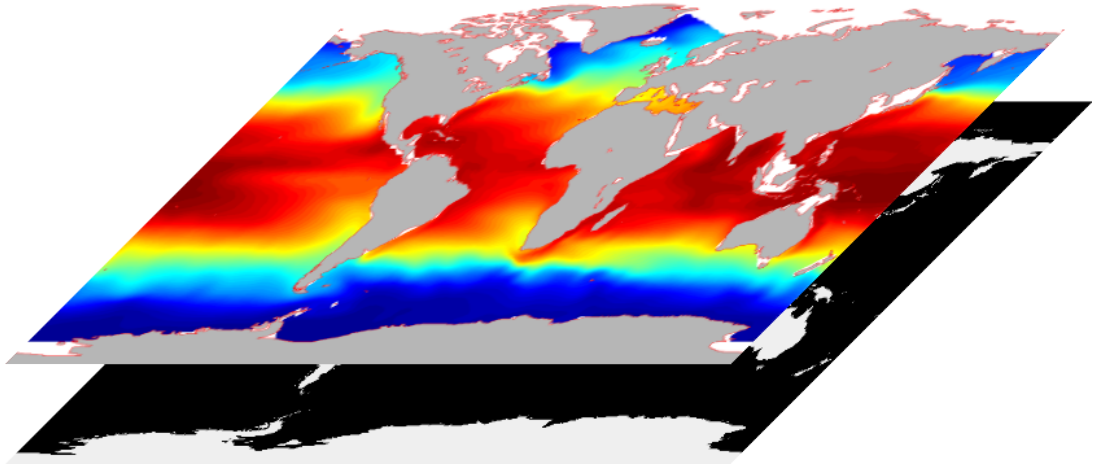
Kleiber, M. (1947). Physiological Reviews, 27, 4, pp 511-541.

Input Data

- Land-sea Mask

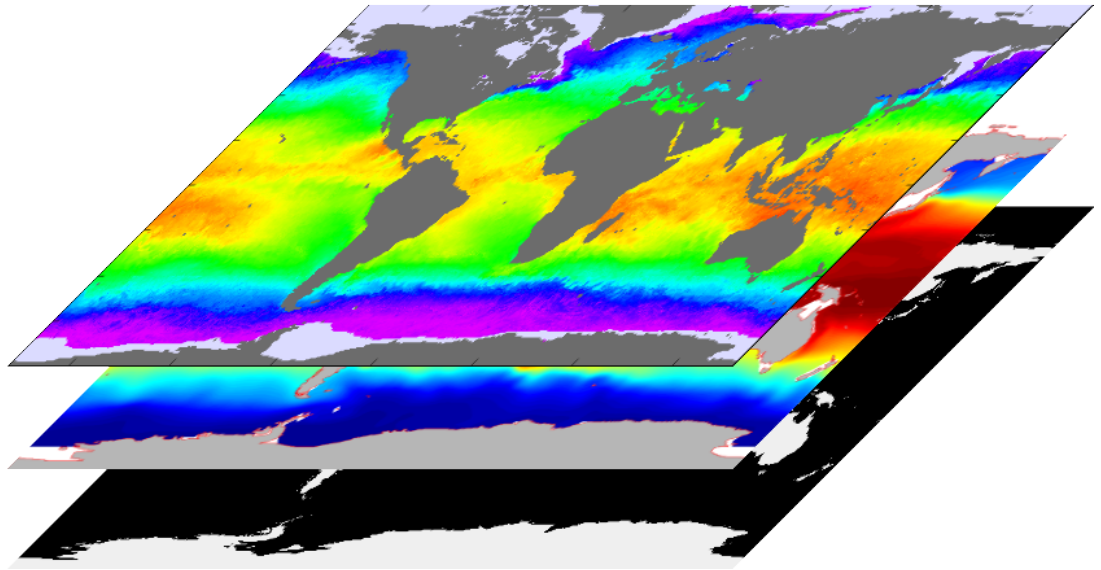
Input Data

- Land-sea Mask
- Near surface ocean temperature*



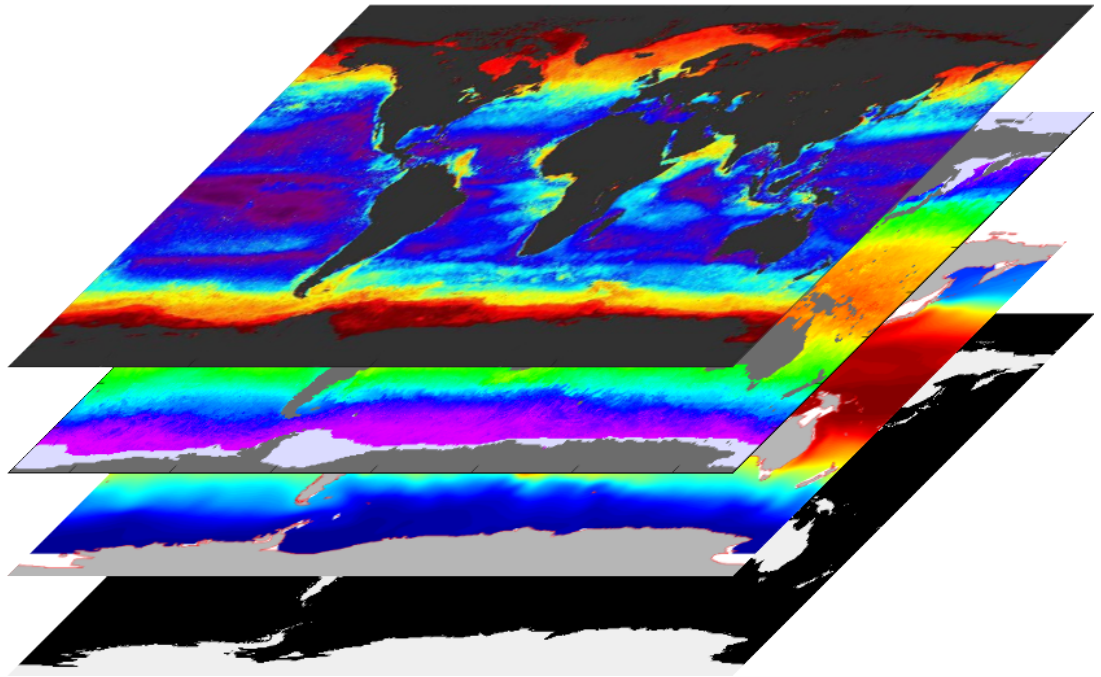
Input Data

- Land-sea Mask
- Near surface ocean temperature*
- Sea Surface Temperature*



Input Data

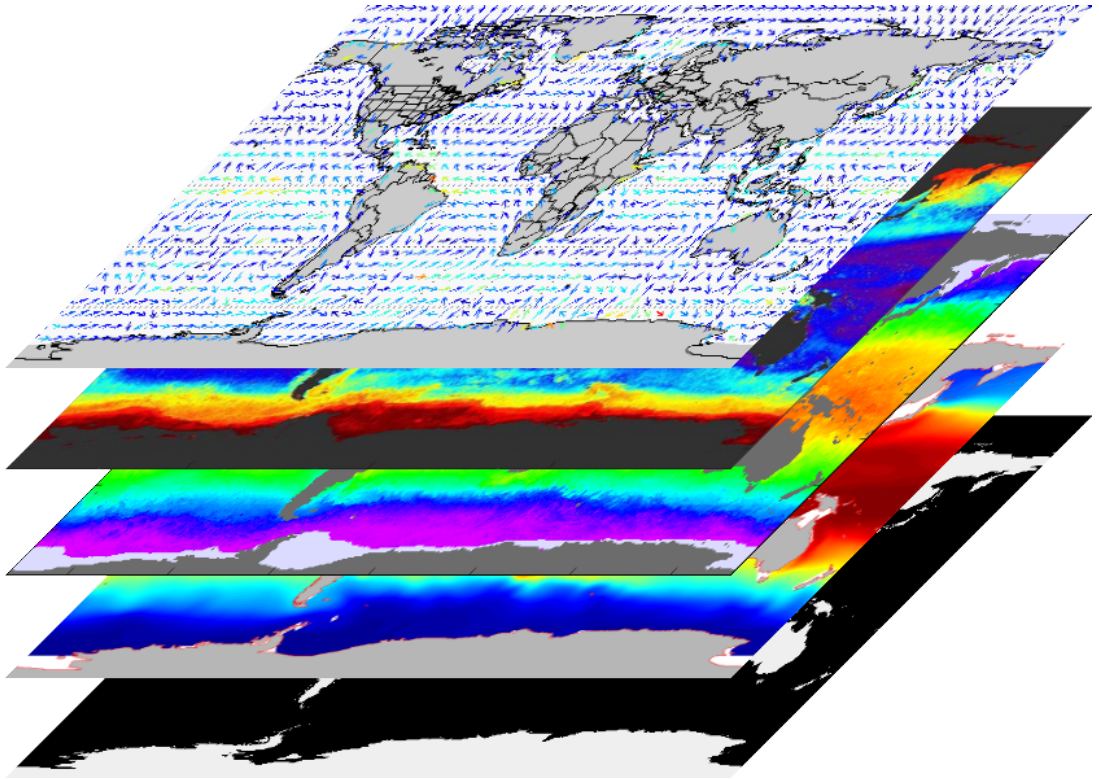
- Land-sea Mask
- Near surface ocean temperature*
- Sea Surface Temperature*
- Ocean Net Primary Productivity*



Input Data

- Land-sea Mask
- Near surface ocean temperature*
- Sea Surface Temperature*
- Ocean Net Primary Productivity*
- Ocean Current Velocity*

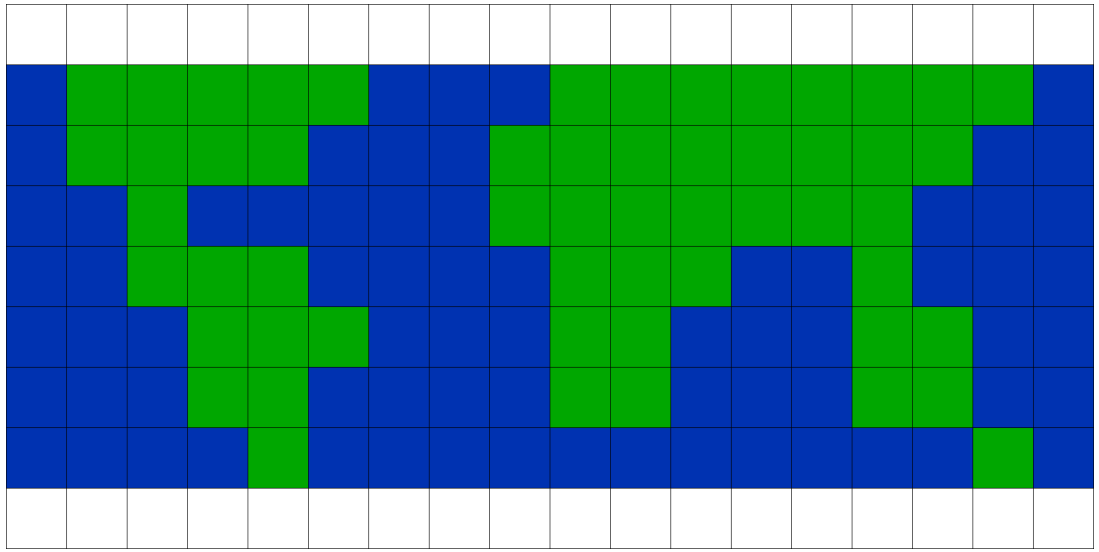
* Monthly mean values



Configuration

High latitudes (>65°) not included due to missing NPP data

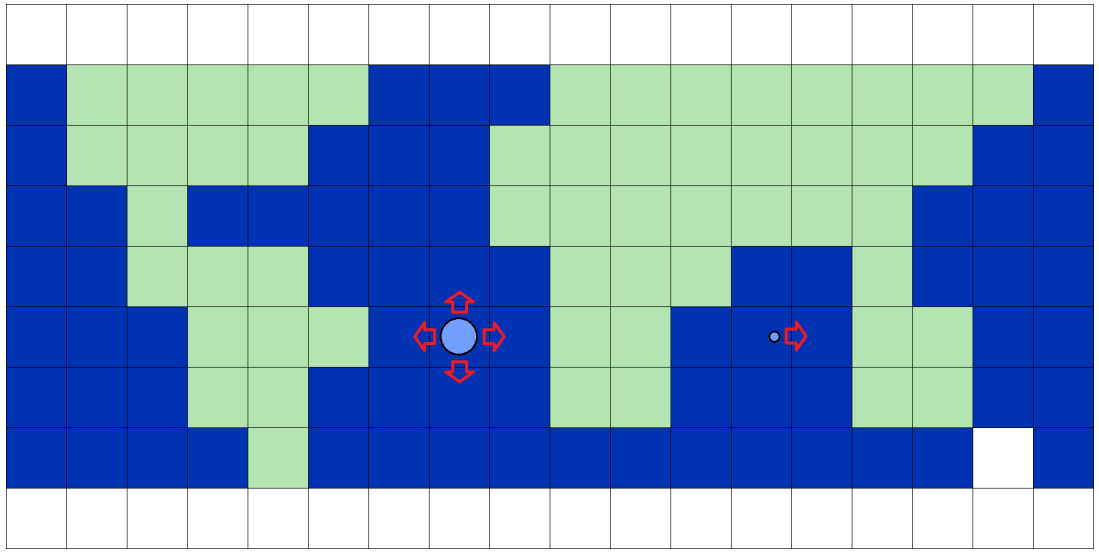
- Satellite chlorophyll



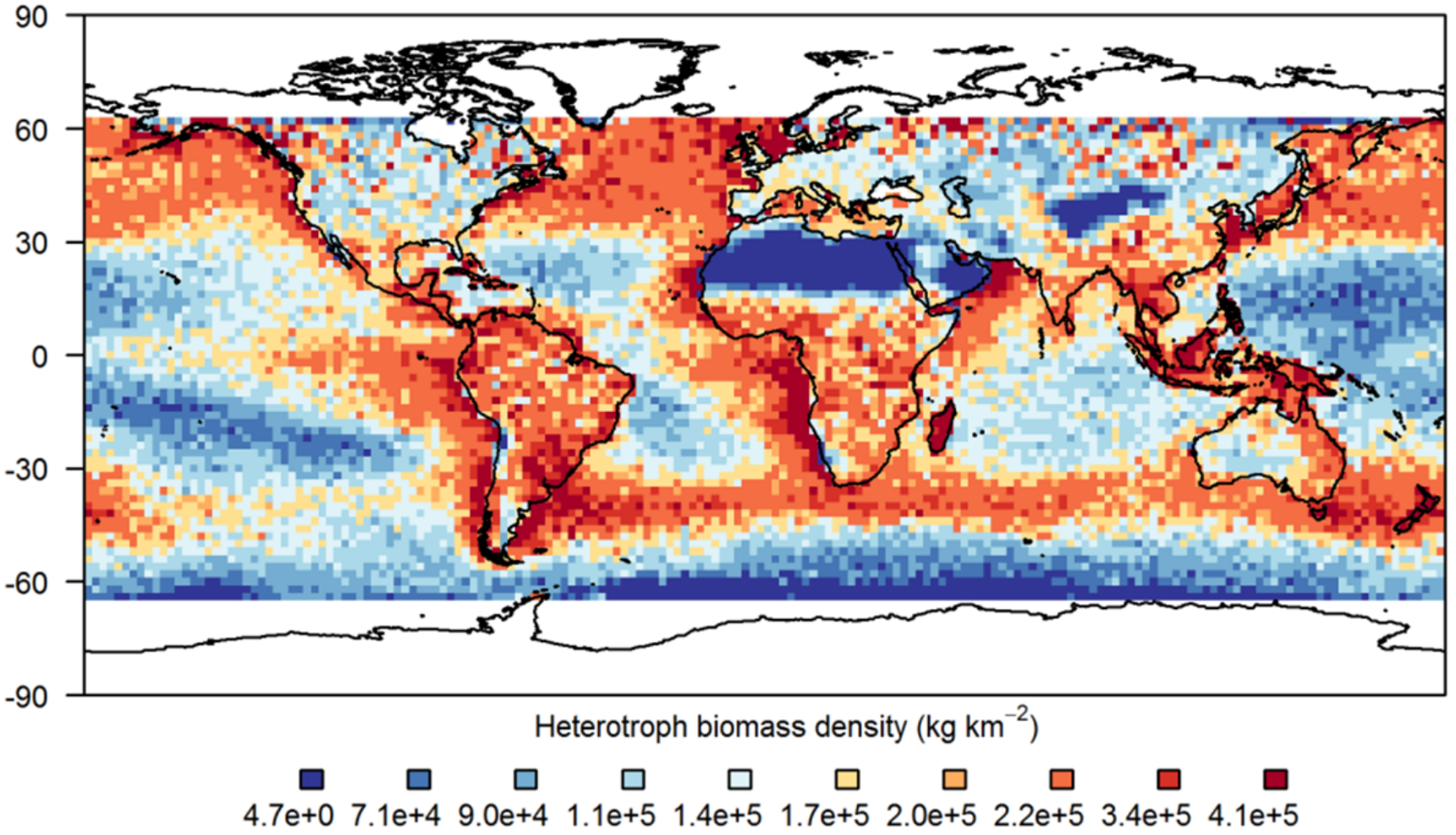
Dispersal

Individuals can disperse to neighbouring cells of the same domain

- Allometrically-scaled probability
- Large individuals move actively
- Small individuals are moved by physical currents



Global Ecosystem Result

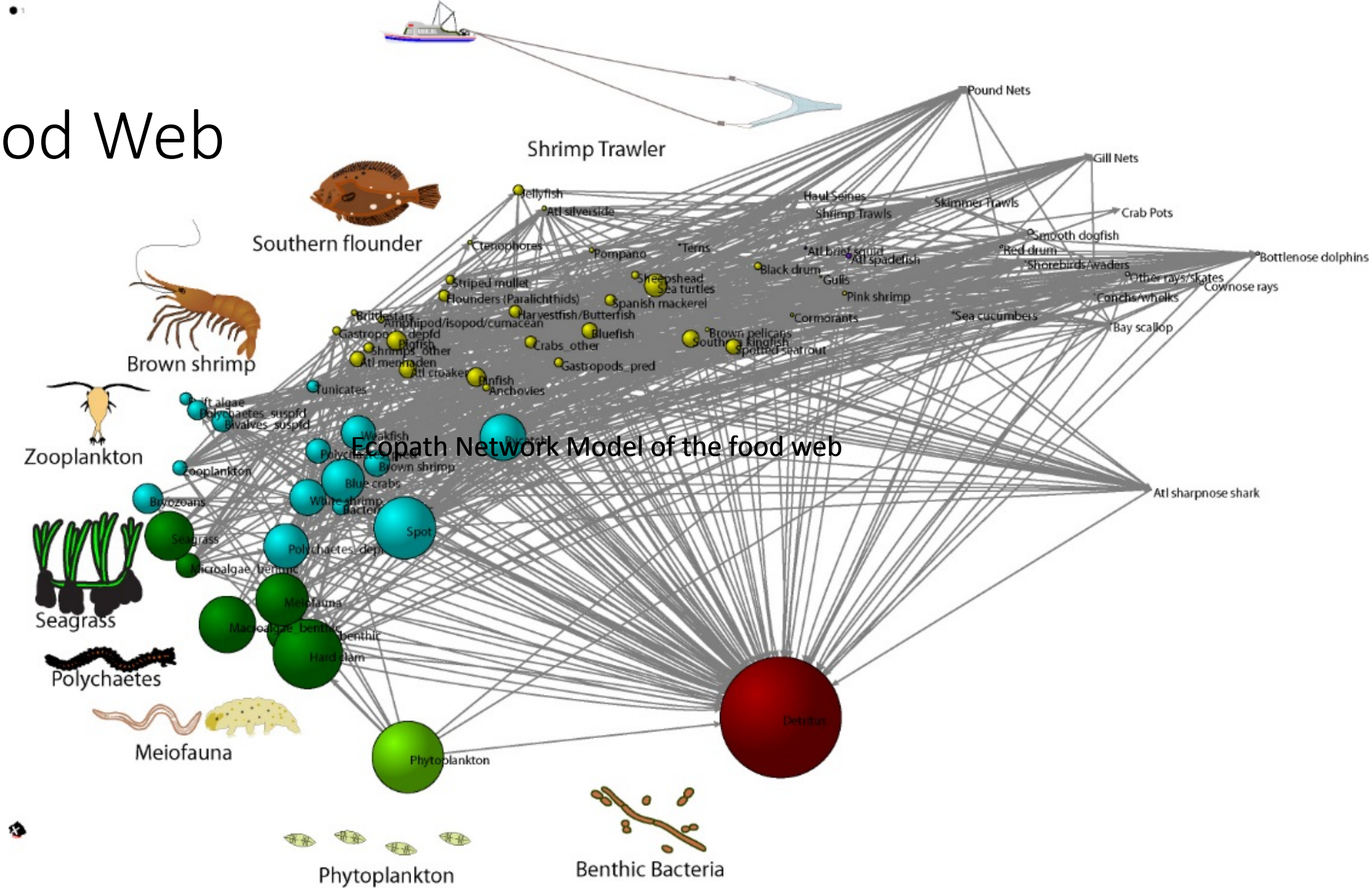


Harfoot et al. (2014). PLoS Biology, 12(4).

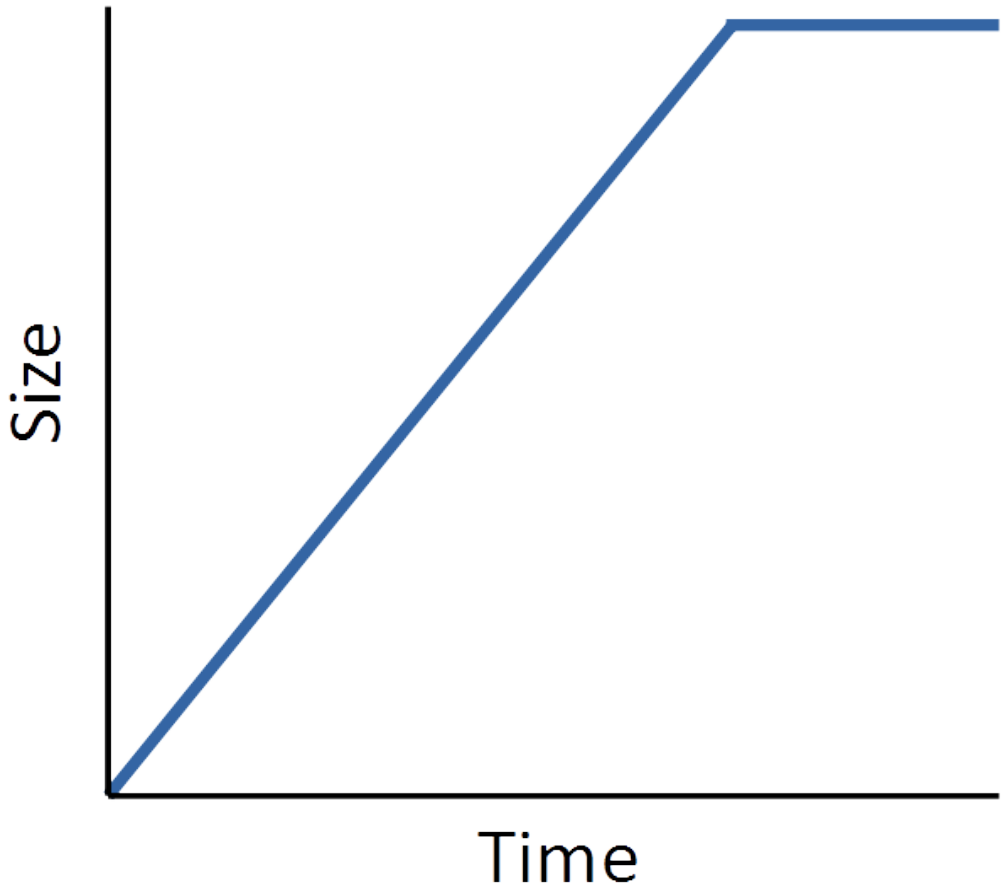
Why Madingley?

Why not a more mature model?

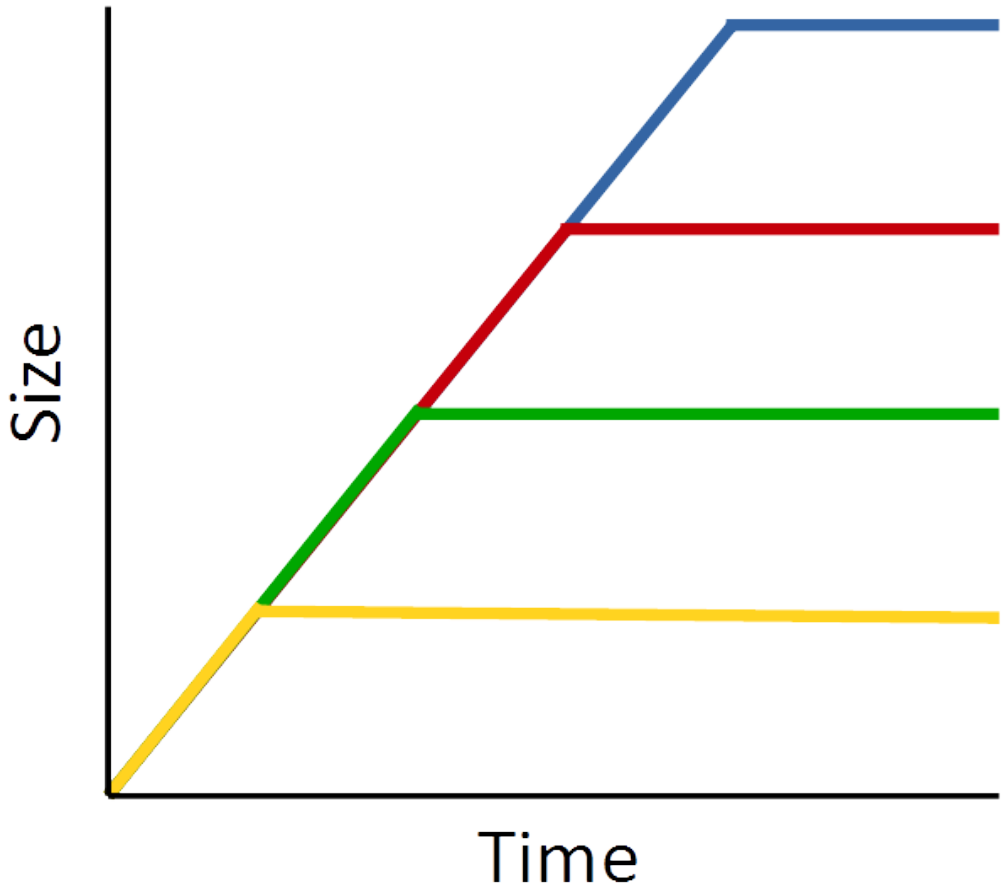
Food Web


Shrimp Trawler
Pound Nets
Gill Nets
Crab Pots
Haul Seines
Shrimp Trawls
Skimmer Trawls
Smooth dogfish
Red drum
Shorebirds/waders
Bottlenose dolphins
Other rays/skates
Cownose rays
Conchs/whelks
Bay scallop
Sea cucumbers
Cormorants
Pink shrimp
Gulls
Black drum
Atl spadefish
Atl brief squid
Terns
Pompano
Ctenophores
Atl silverside
Jellyfish
Southern flounder
Striped mullet
Flounders (Paralichthids)
Sheepshead
Sea turtles
Spanish mackerel
Harvestfish/Butterfish
Bluefish
Crabs_other
Gastropods_pred
Anchovies
Menhaden
Croaker
Shrimps_other
Pigfish
Gastropods_depfd
Amphipod/isopod/cumacean
Brittlestars
Brown pelicans
Kingfish
Spotted seatrout
Brown shrimp
Zooplankton
Tunicates
Polychaetes_suspfd
Bivalves_suspfd
Weakfish
Blue crabs
Bryozoans
Seagrass
Spot
Microalgae_benthic
Meiofauna
Hard clam
Polychaetes
Meiofauna
Phytoplankton
Benthic Bacteria
Detritus
Atl sharpnose shark
Ecopath Network Model of the food web

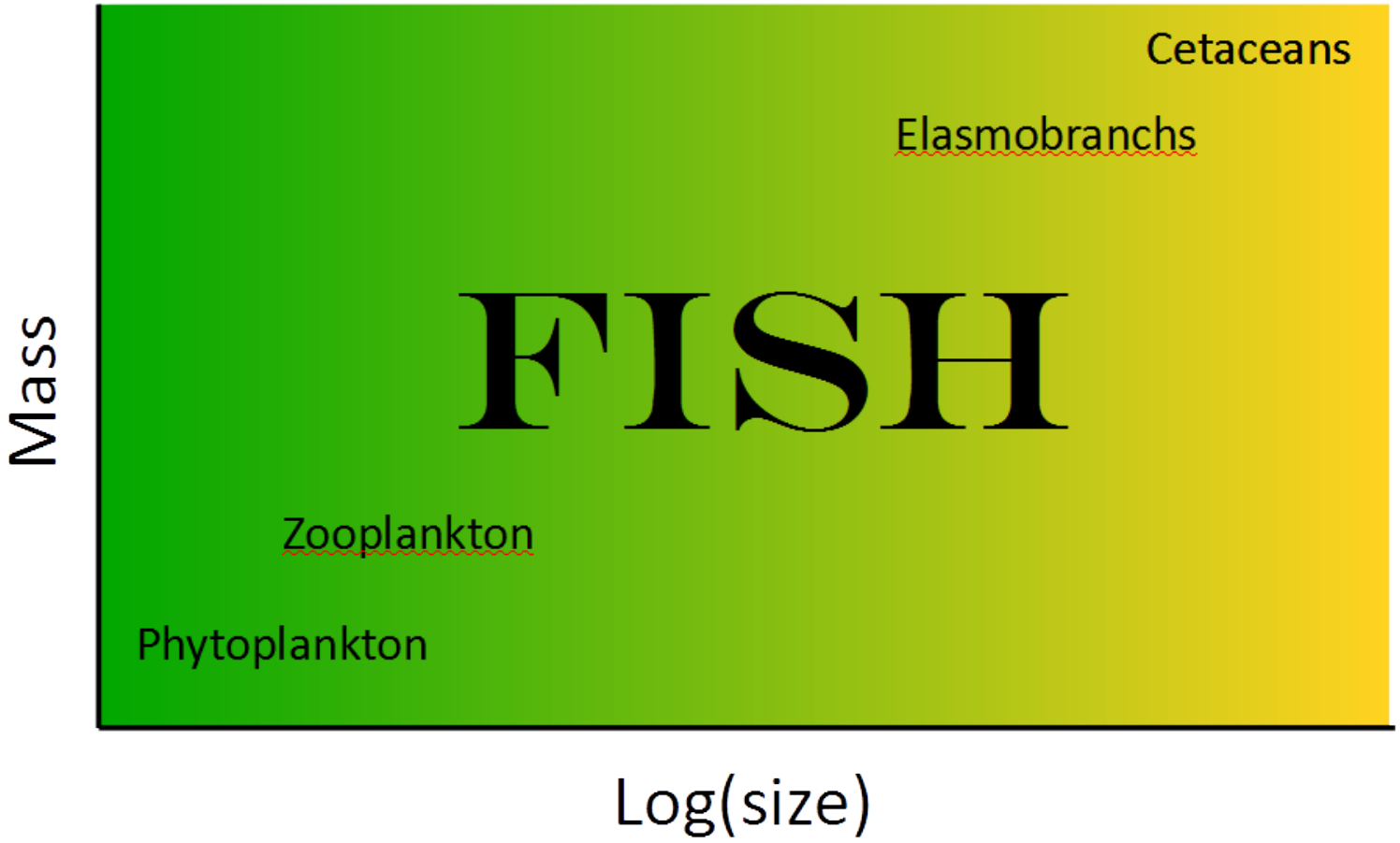
Life History



Size Structured Model

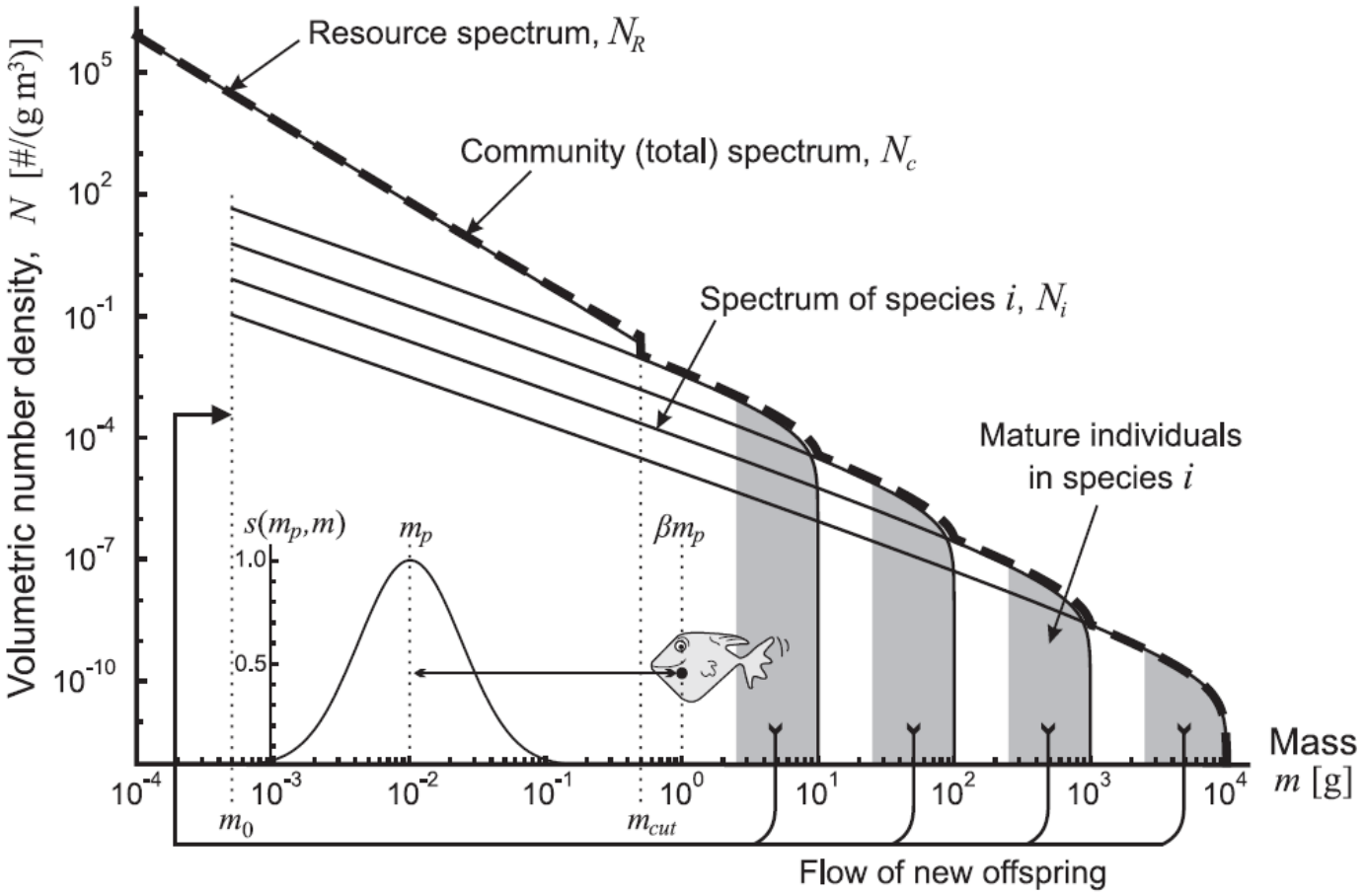


Sheldon Spectrum



Adapted from Andersen (2010). Sheldon et al. (1973). Limnology & Oceanography, 18(5), pp 719-733

Size Spectrum Model

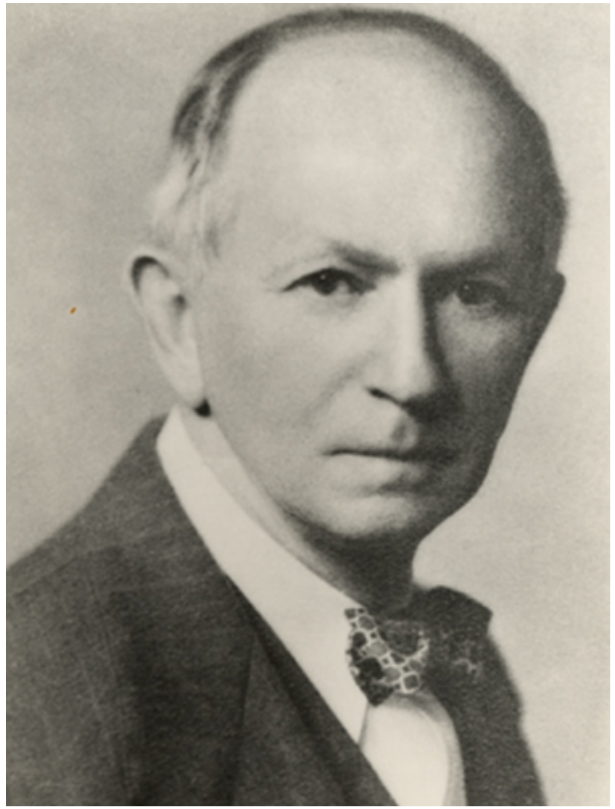


Hartvig et al. (2011). Journal of Theoretical Biology. 272(1), pp 113-122

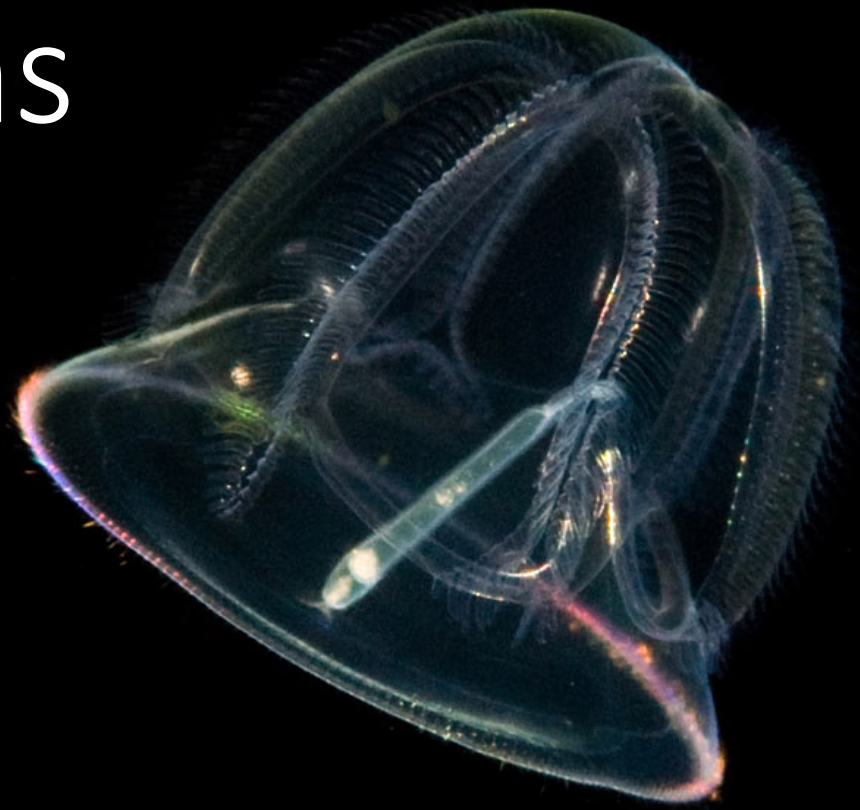
It’s All About Context

“The physical laws governing evolution in all probability take on a simpler form when referred to the system as a whole than to any portion thereof. It is not so much the organism or the species that evolves, but the entire system, species and environment. The two are inseparable.”

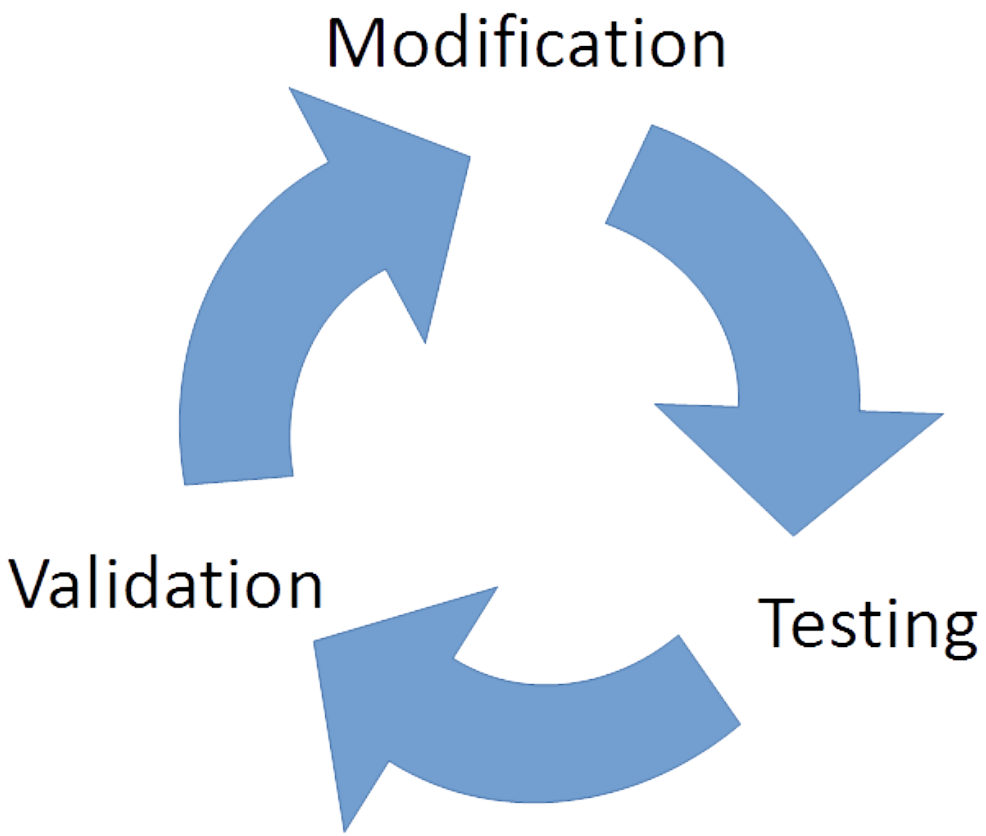
- Alfred J. Lotka (1925)



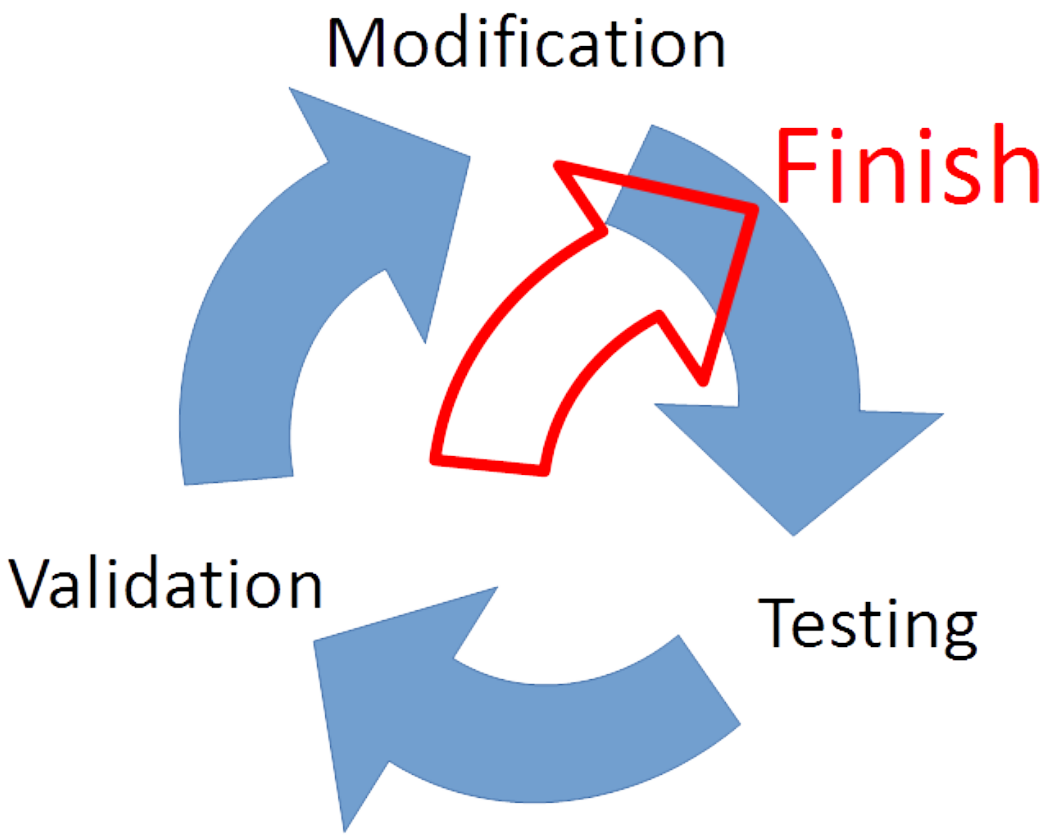
Project Plans



Developmental Cycle

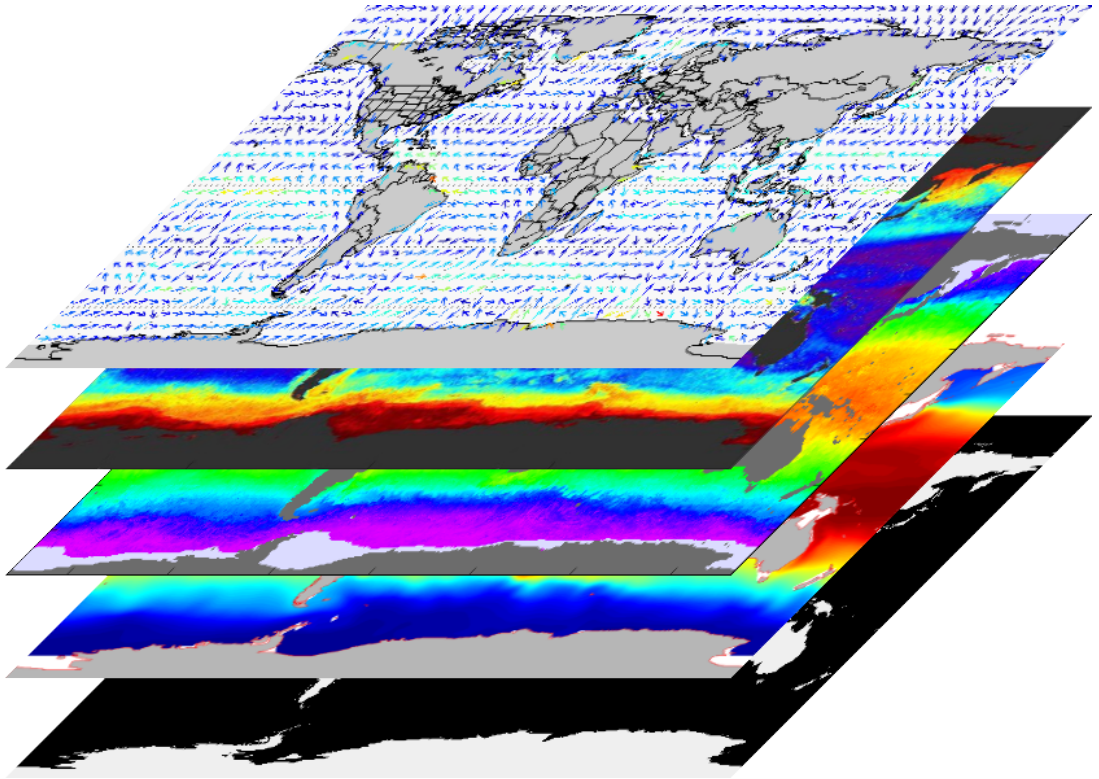


Developmental Cycle



Multi-Year Input Data

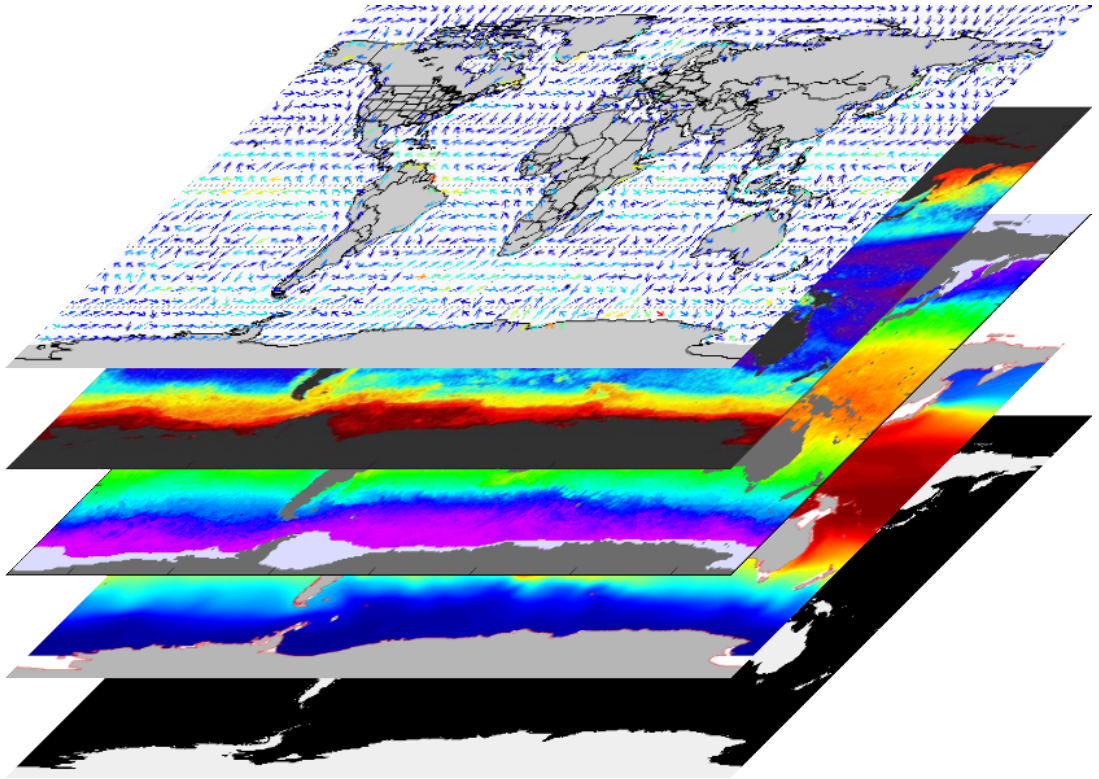
- Near surface ocean temperature
- Sea Surface Temperature
- Ocean Current Velocity
- Ocean Net Primary Productivity



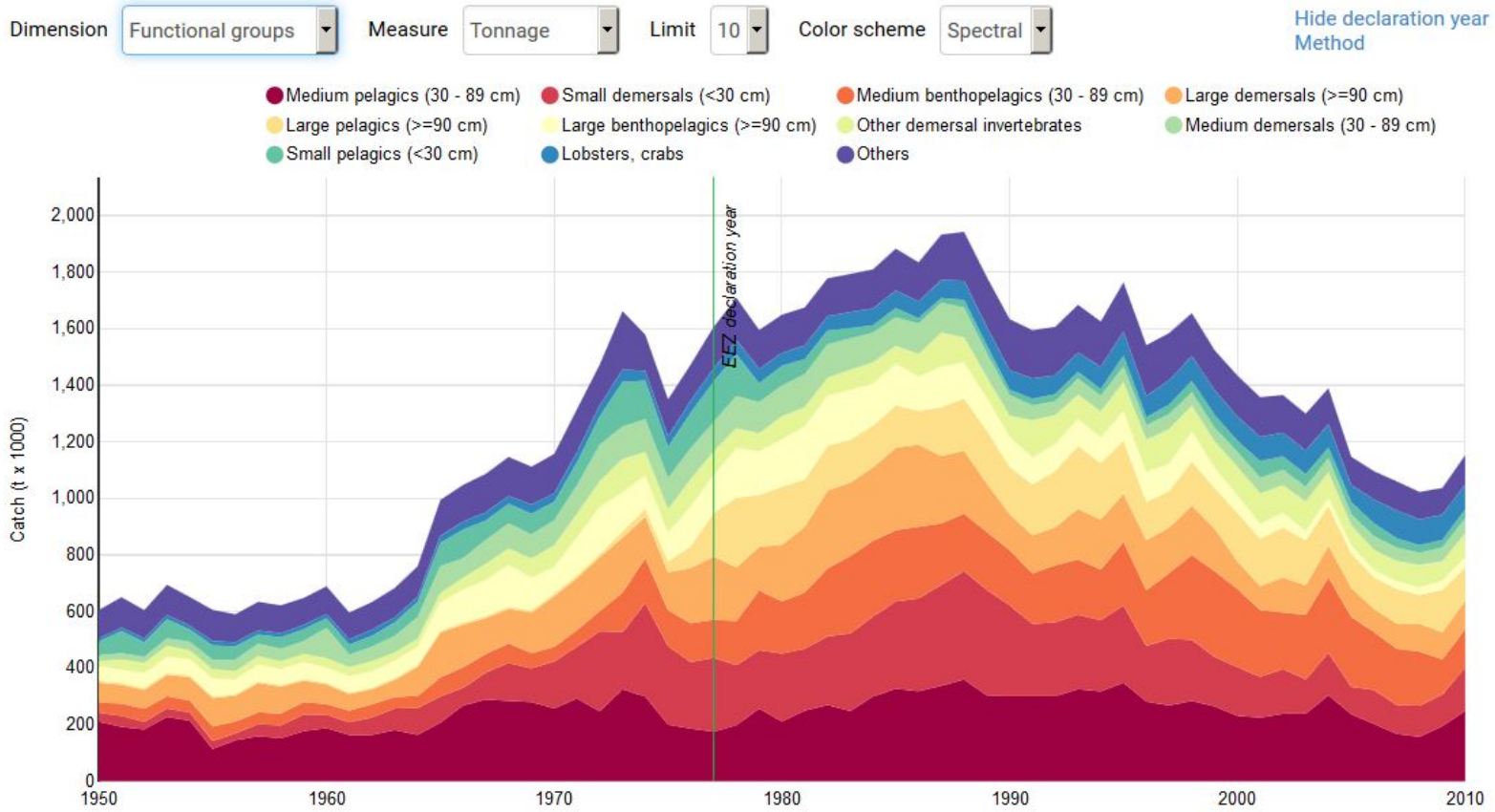
Multi-Year Input Data

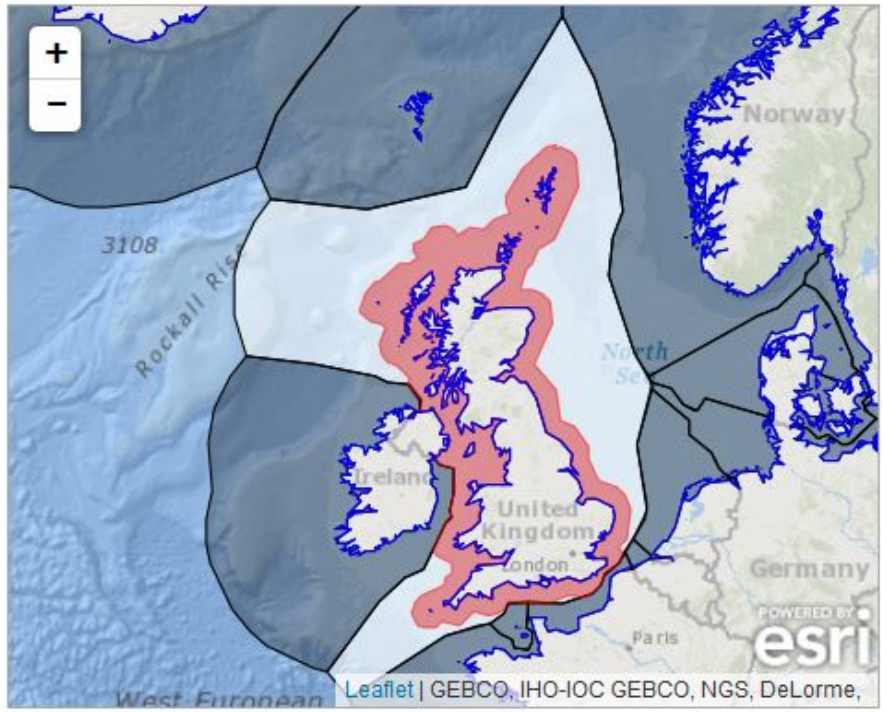
- Near surface ocean temperature
- Sea Surface Temperature
- Ocean Current Velocity
- ~~Ocean Net Primary Productivity~~
- Ocean Chemistry

- Same period as SAUD



Sea Around Us Data





Select FAO area boundaries

All | NE Atlantic

Legend

EEZ | Disputed/shared | Other EEZ

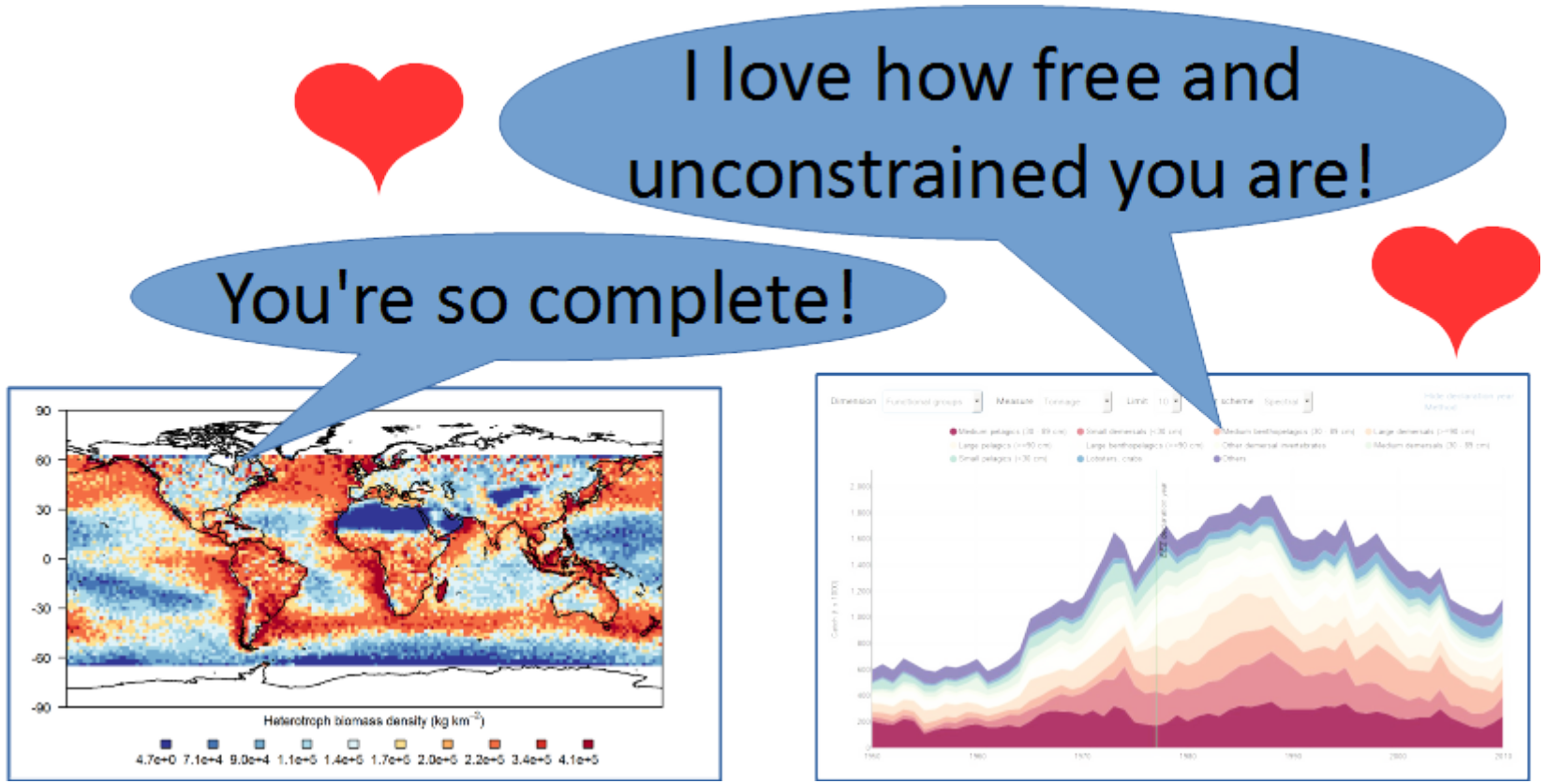
FAO boundary | High seas | IFA area

Disclaimer: The maritime limits and boundaries shown on this map are not to be considered as an authority on the delimitation of the international maritime boundaries.

FAO Areas EEZ Boundary explanation

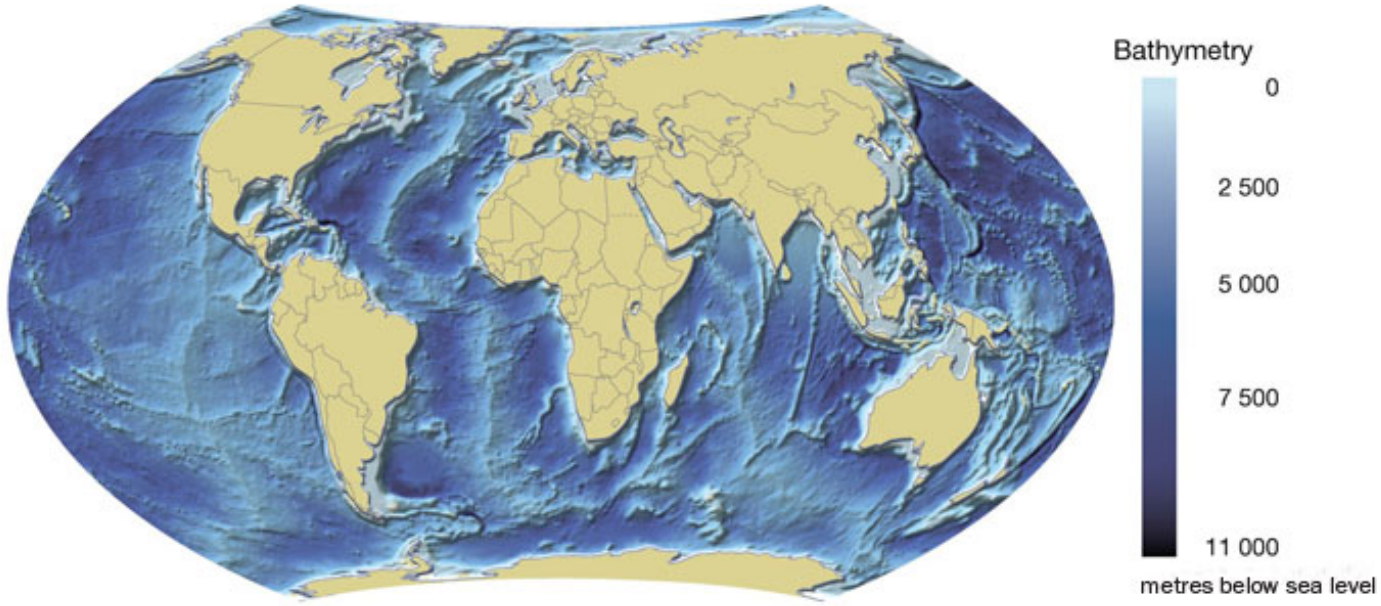
http://www.seaaroundus.org

Fish Translation Layer



Habitat Representation

- Madingley is currently two-dimensional.
- Introduce heterogeneity from bathymetry
- Approximate depth via habitat affinity
- Coupled benthic and pelagic



Testing

- Sensitivity analysis:
  - Feeding rate
  - Metabolic rate
  - Mortality rate
  - Migratory behaviours

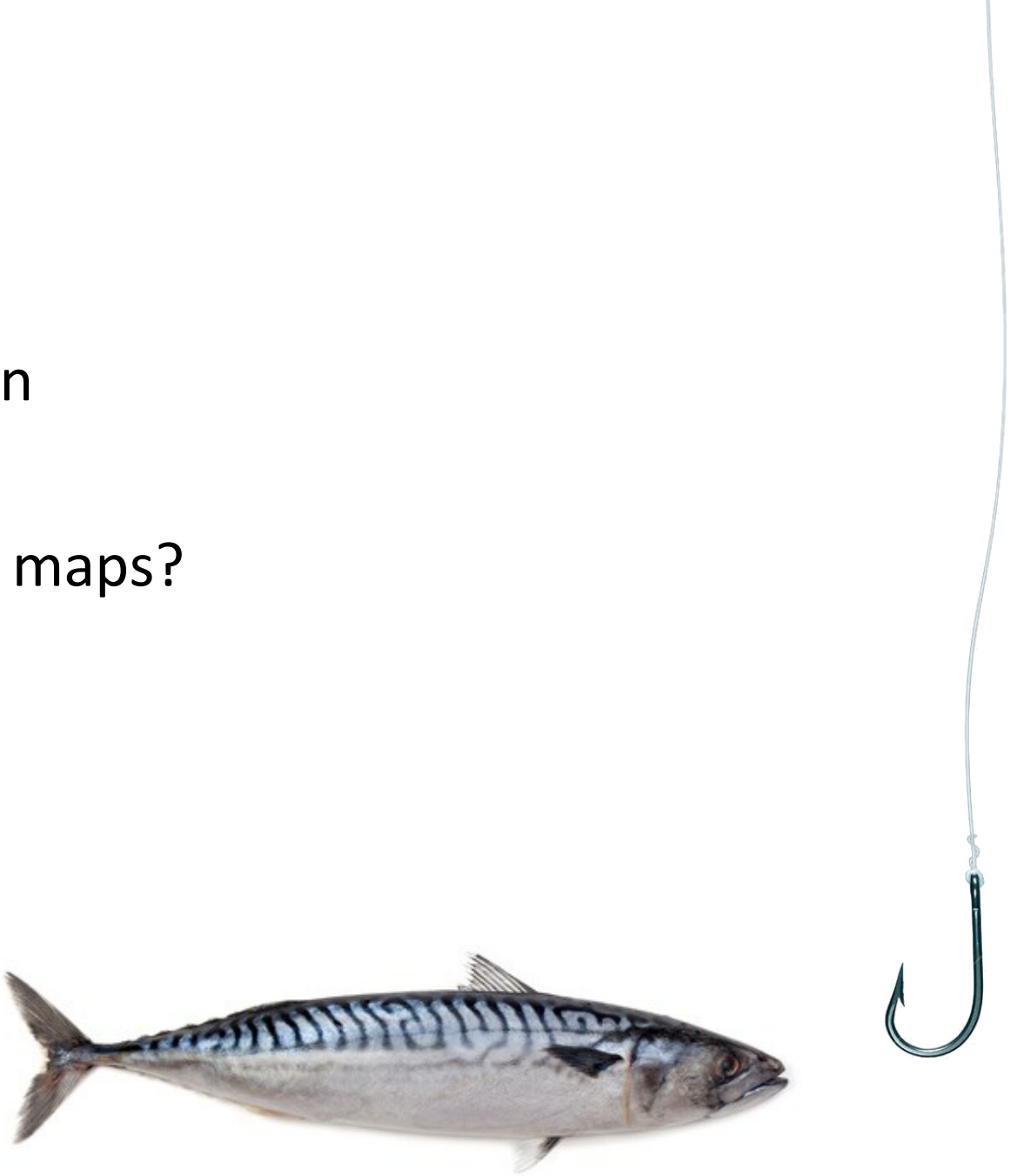
- Agree a set of diagnostics
  - Compare with other models (EcoOcean)?
  - Use Fish-MIP as a guide?

Validation

Use real species data for validation

- Is OBIS the best source for this?
- What about species distribution maps?

- Quantify uncertainty

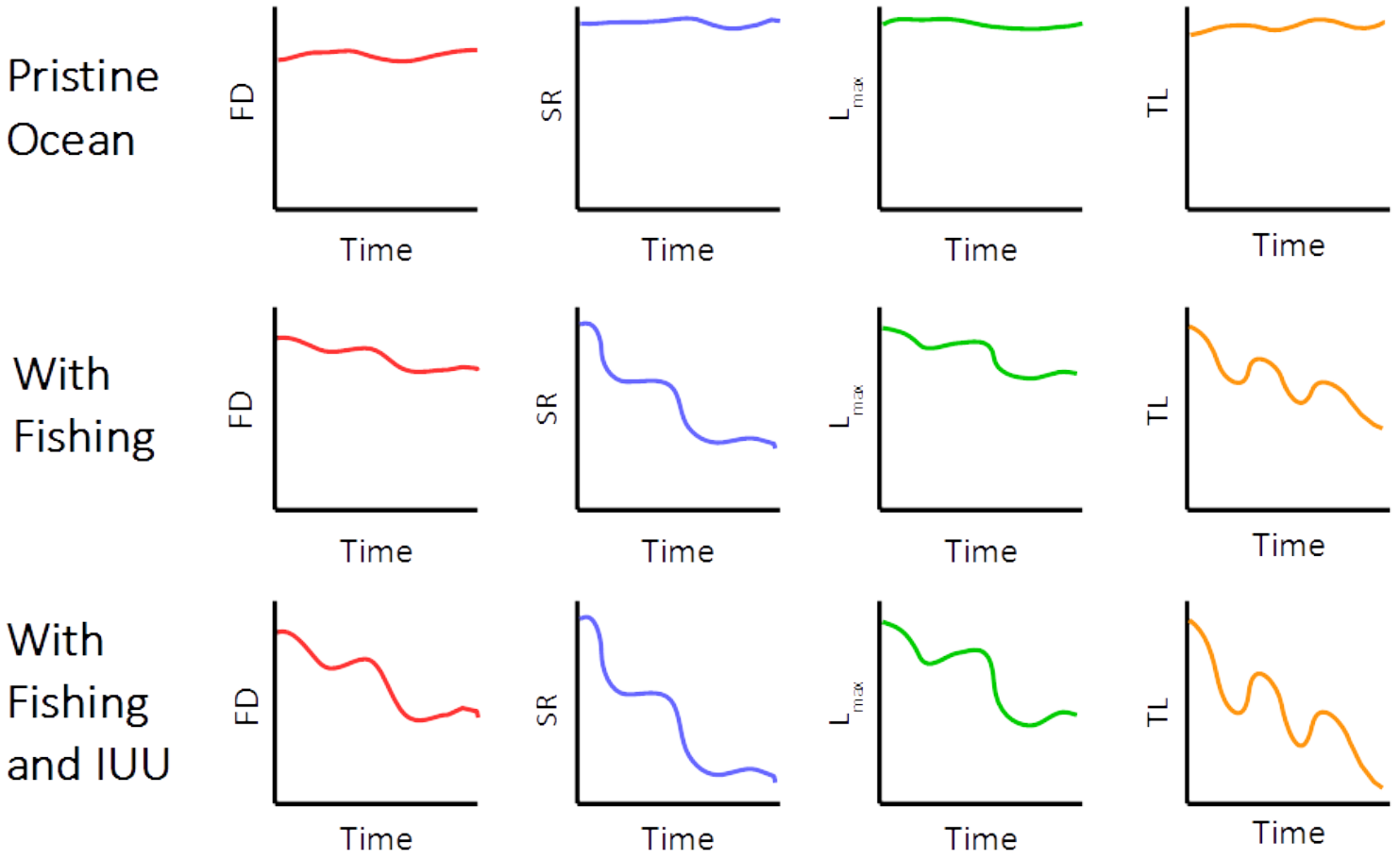


Testing & Validation

- Sensitivity analysis:
  - Feeding rate
  - Metabolic rate
  - Mortality rate
  - Migratory behaviours

- Enter Madingley into Fish-MIP
  - Run standard fisheries model protocol
  - Compare with other models

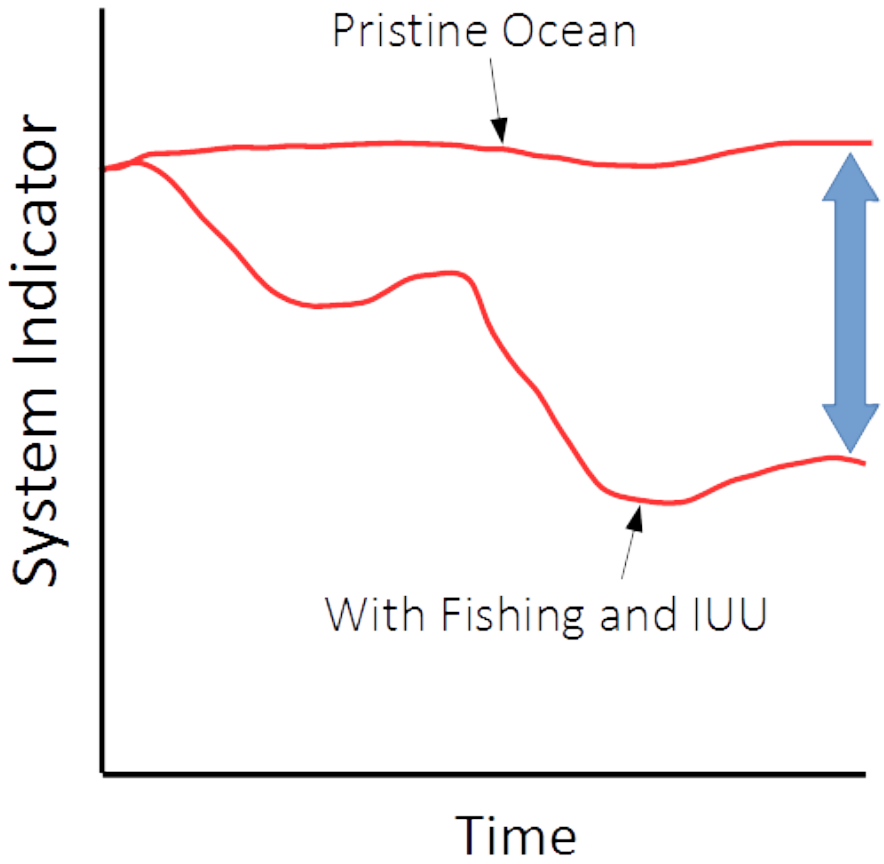
Develop Ecosystem Indicators



Fulton et al. (2005), ICES Journal of Marine Science, 62: 540-551.

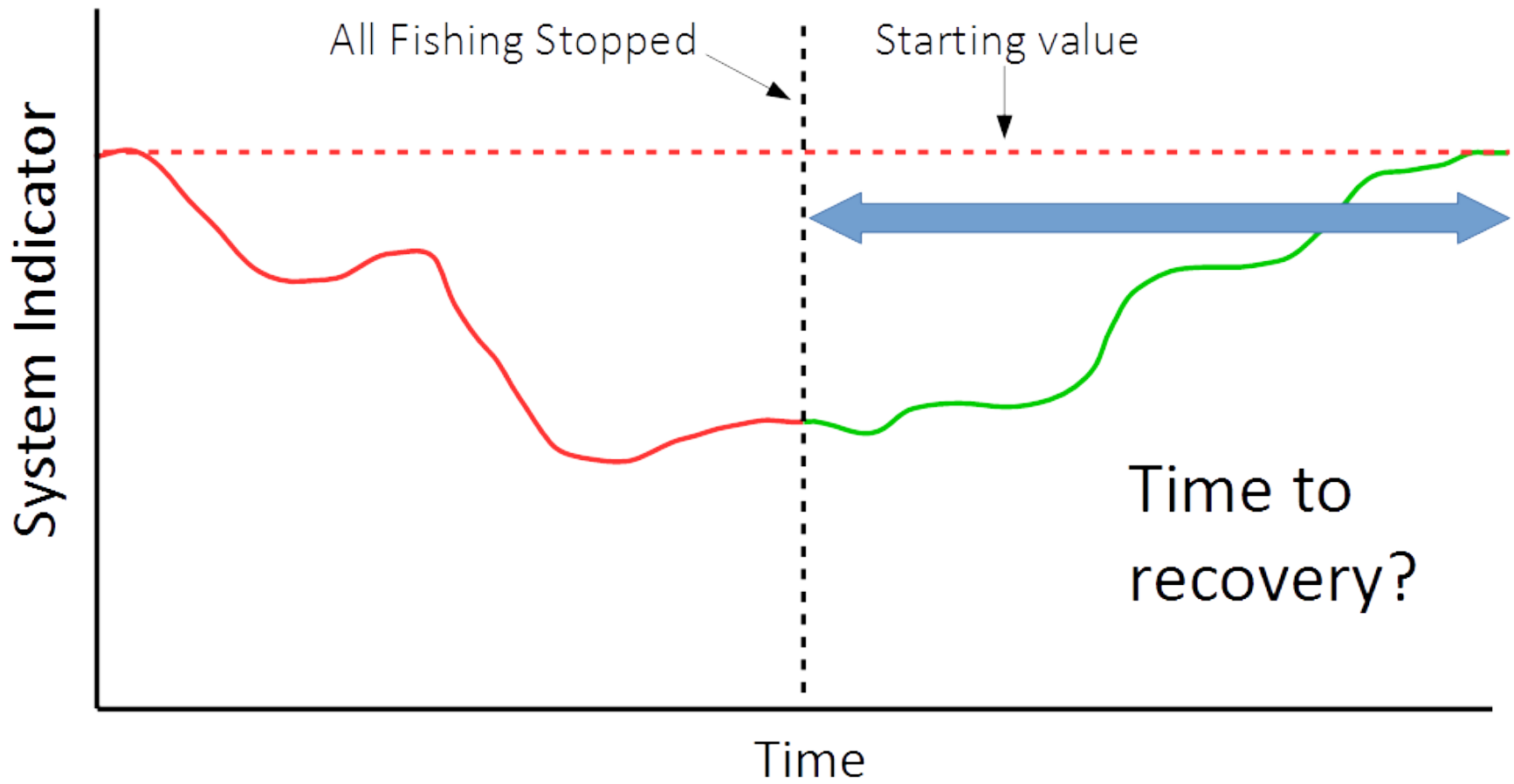
Outputs

Recovery Rate

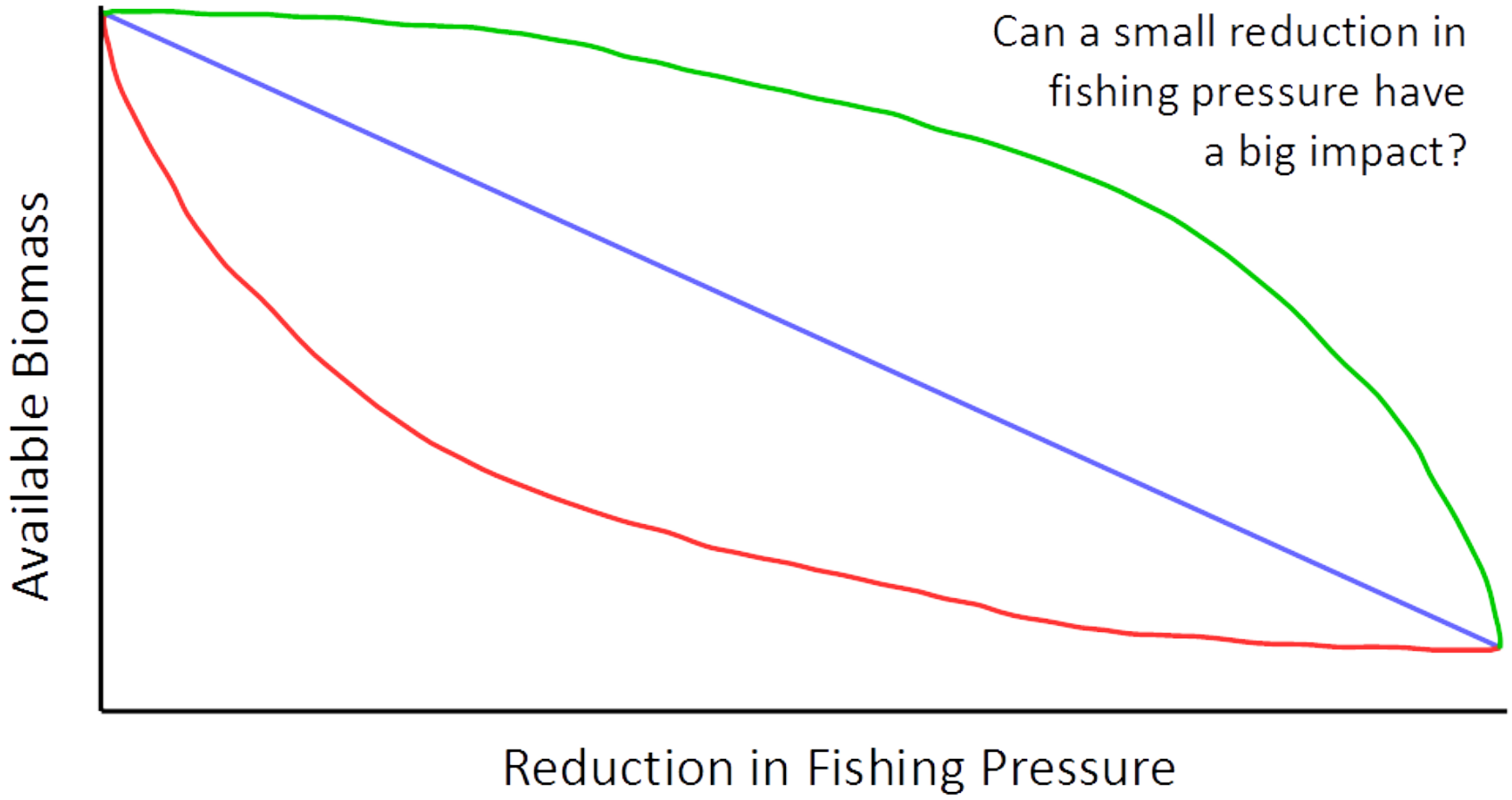


Distance to recovery?

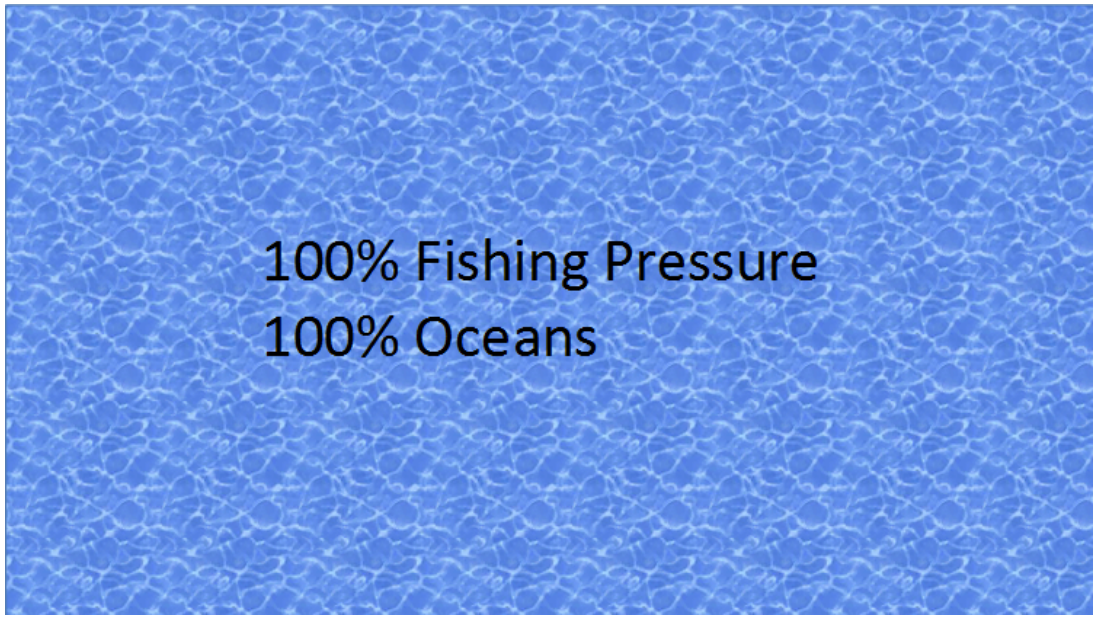
Recovery Rate

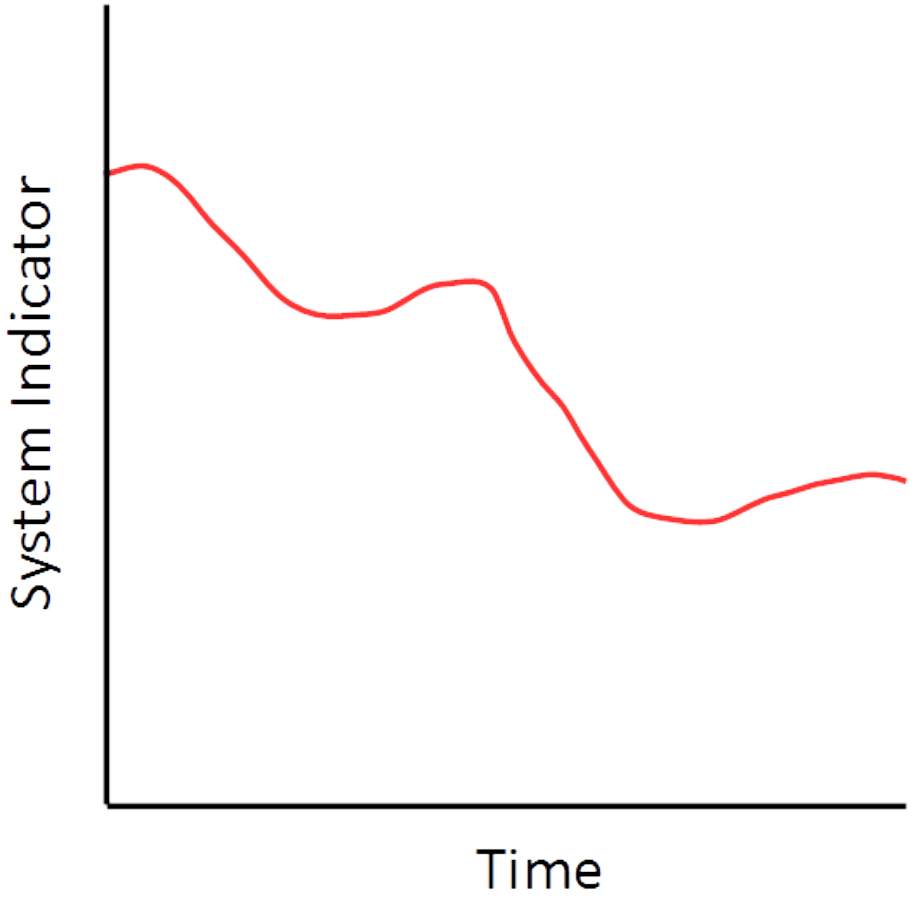


The Fishing Pressure-Recovery Relationship

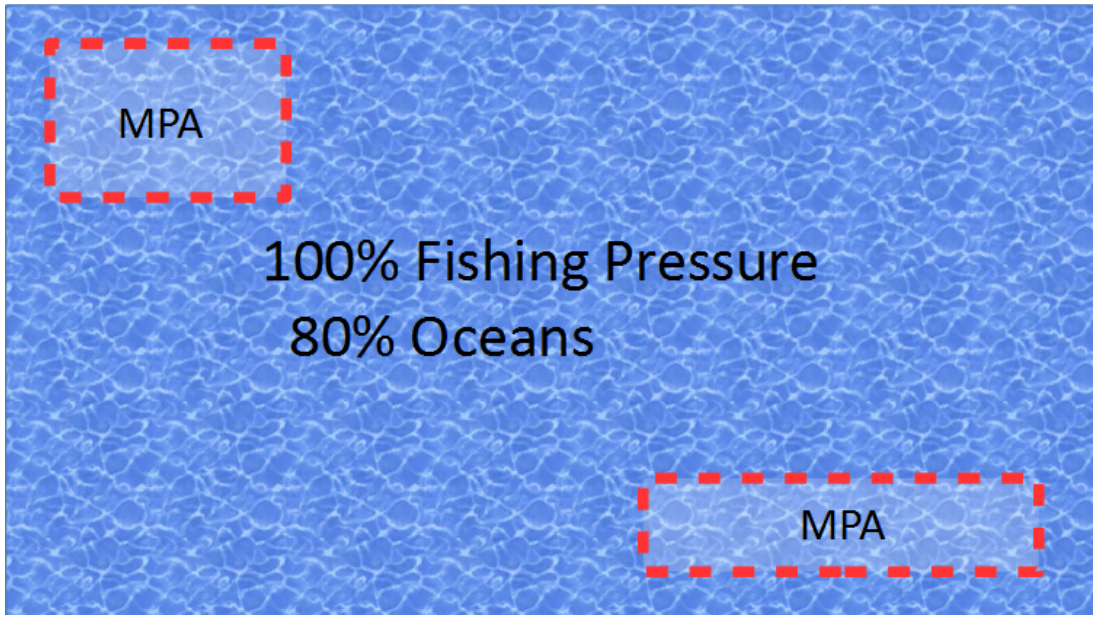


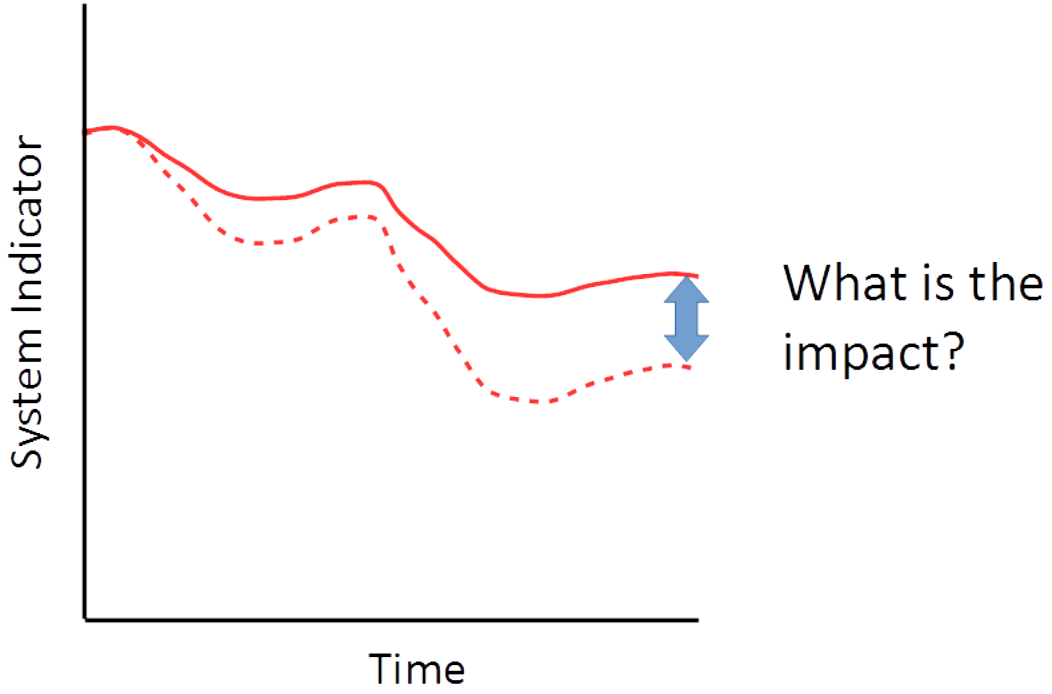
Marine Protected Areas



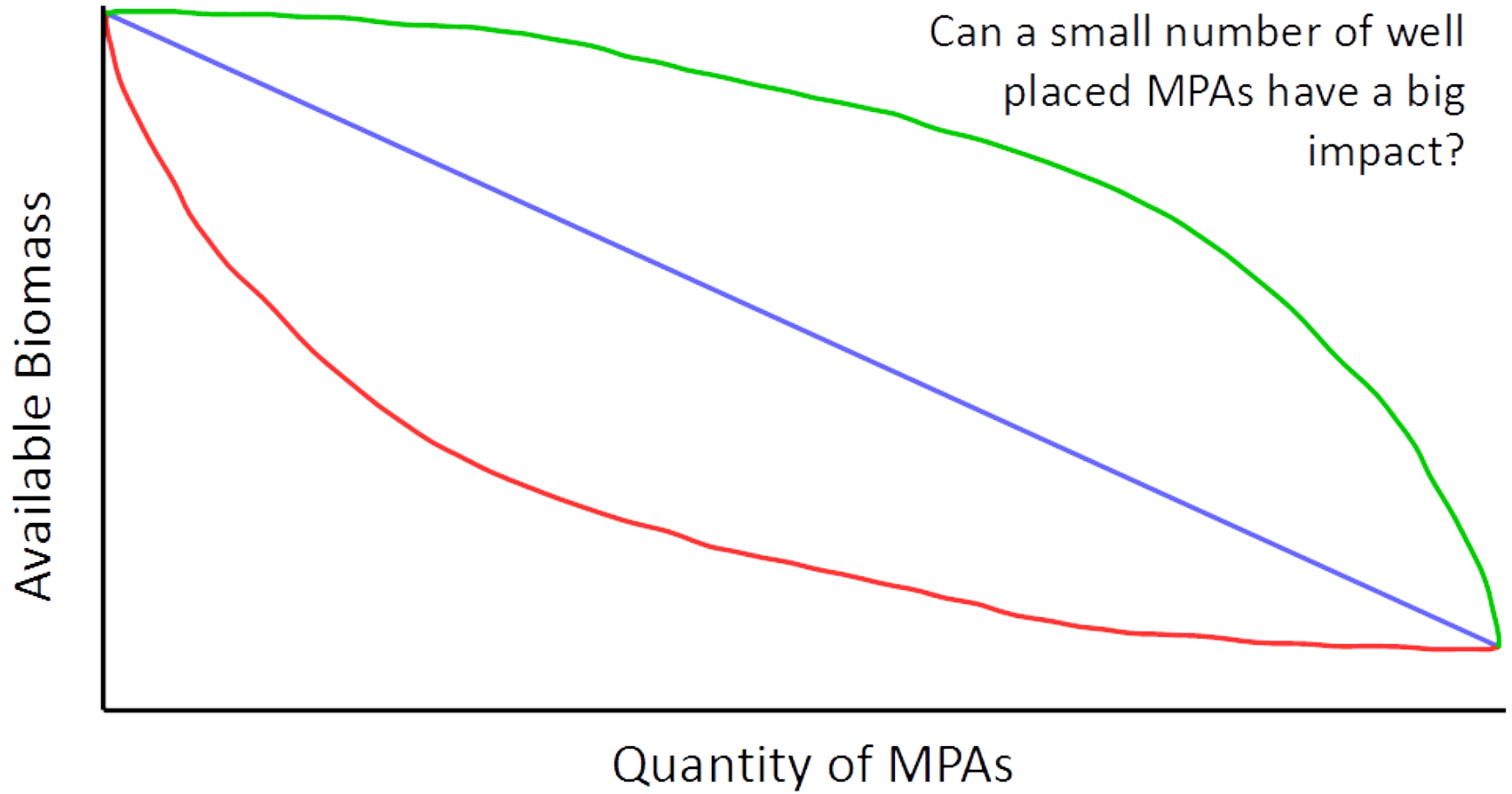


Marine Protected Areas

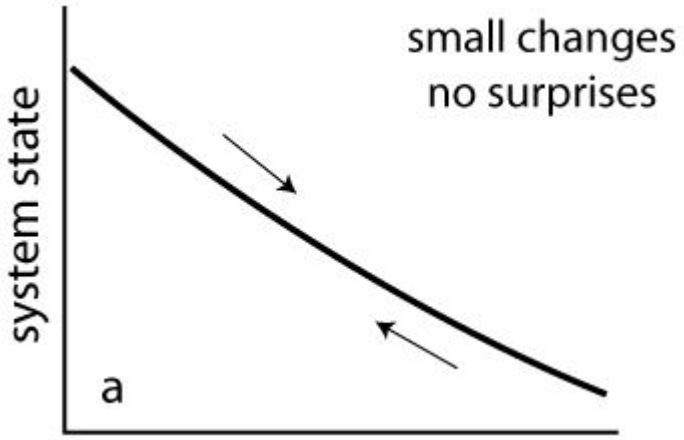


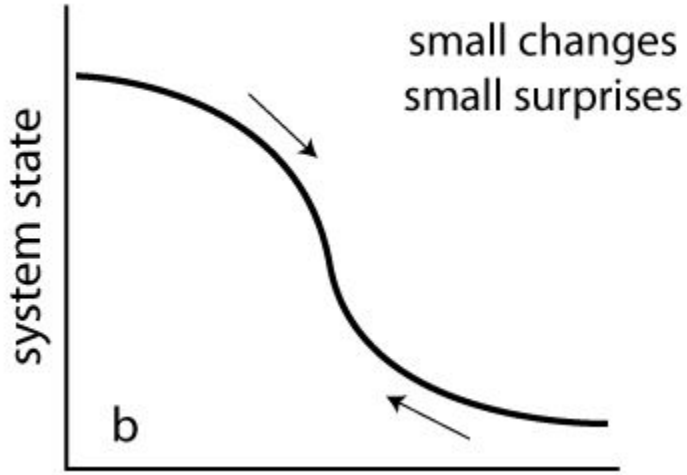


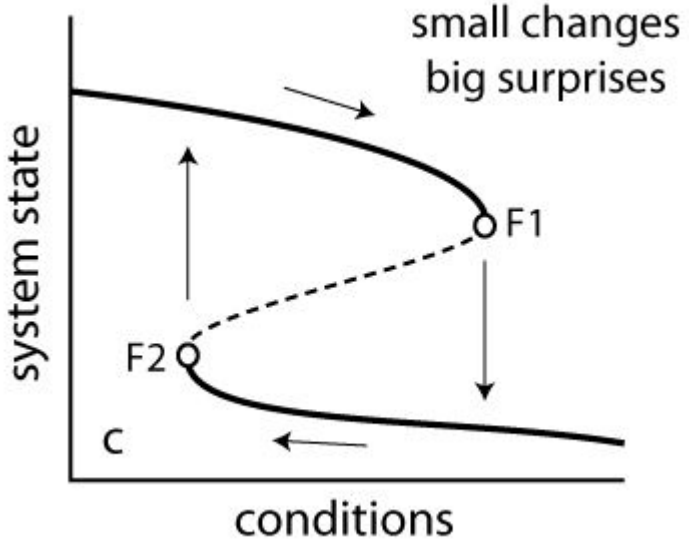
The MPA-Impact Relationship



Early Warning Signals



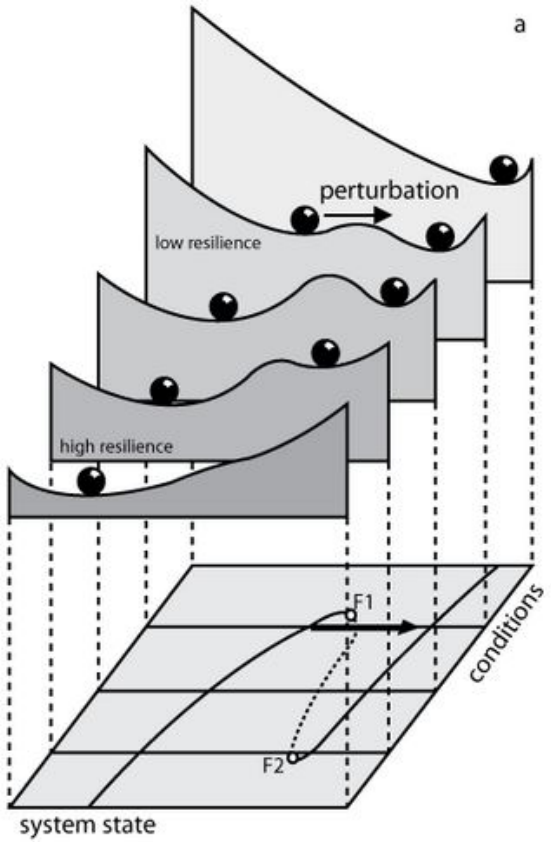


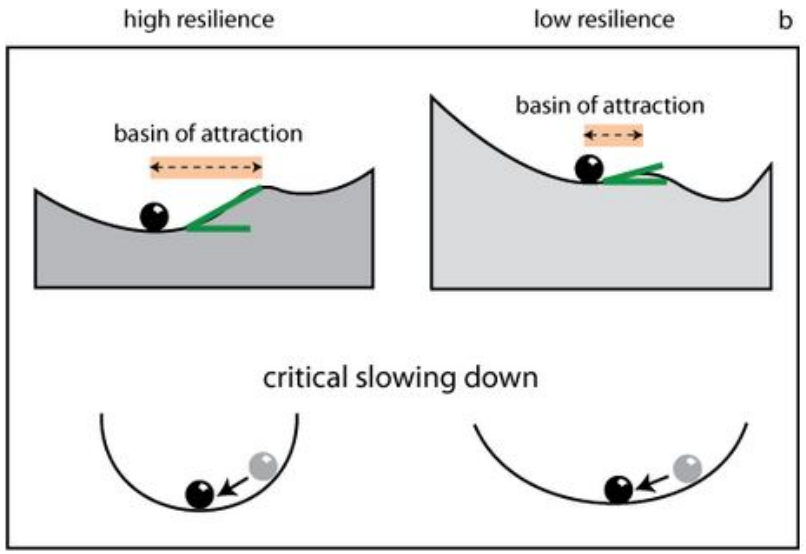


http://www.early-warning-signals.org

Early Warning Signals

A longer time to recovery is a sign of a **critical slowing down**; an Early Warning Signal that the system is approaching a **catastrophic bifurcation**.





http://www.early-warning-signals.org

Future Madingley Developments

- **It's a component-based model!**

- **UNEP-WCMC**
- **Microsoft Research**
- **Soon to be three PhD students**
- **Plus a growing community**
- **Would you like to join us?**

http://www.madingleymodel.org/

Thank you! Questions, or suggestions?

Acknowledgements:

The Nippon Foundation and The Nereus Program

Chris Mcowen, Mike Harfoot, Derek Tittensor, and Tim Newbold

Mike Bithell, and Tom Spencer

Drew Purves

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UNEP WCMC

UNIVERSITY OF CAMBRIDGE

Microsoft