Integrating Catch Data into Madingley

```
if( hunger > fear )
    SeekFood( );
else
    SeekRefuge( );
```

Phil Underwood

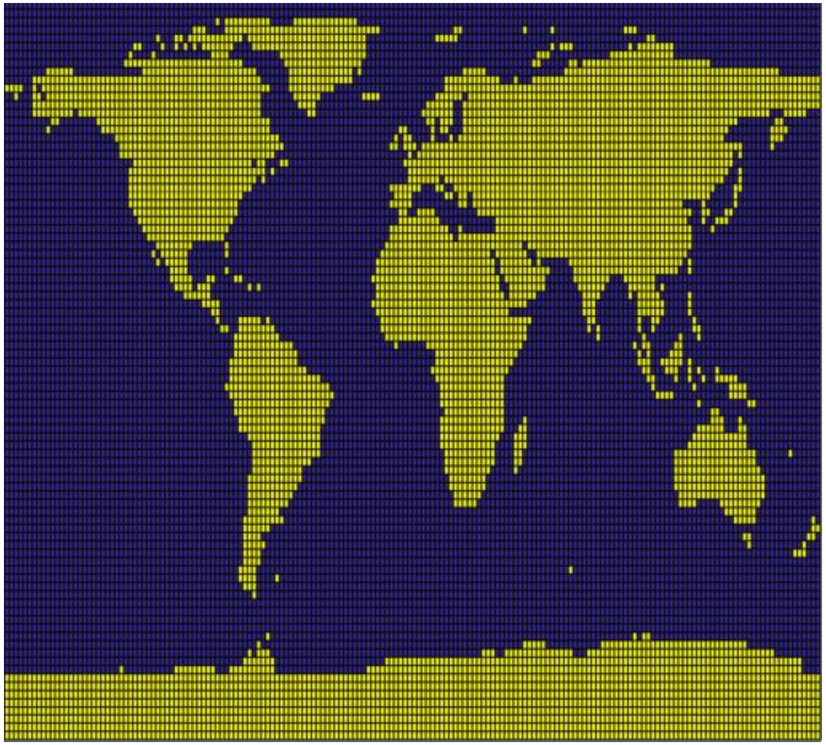
University of British Columbia, June 1st 2016

A Model of All Life

- Global
- Individual-based
- Mechanistic
- Exhibits emergent behaviours
- Potential for exploring:
  - Evolution
  - Adaptation
  - Regime shifts
  - Tipping points

Purves et al. (2013). Nature, 493.

Model Grid



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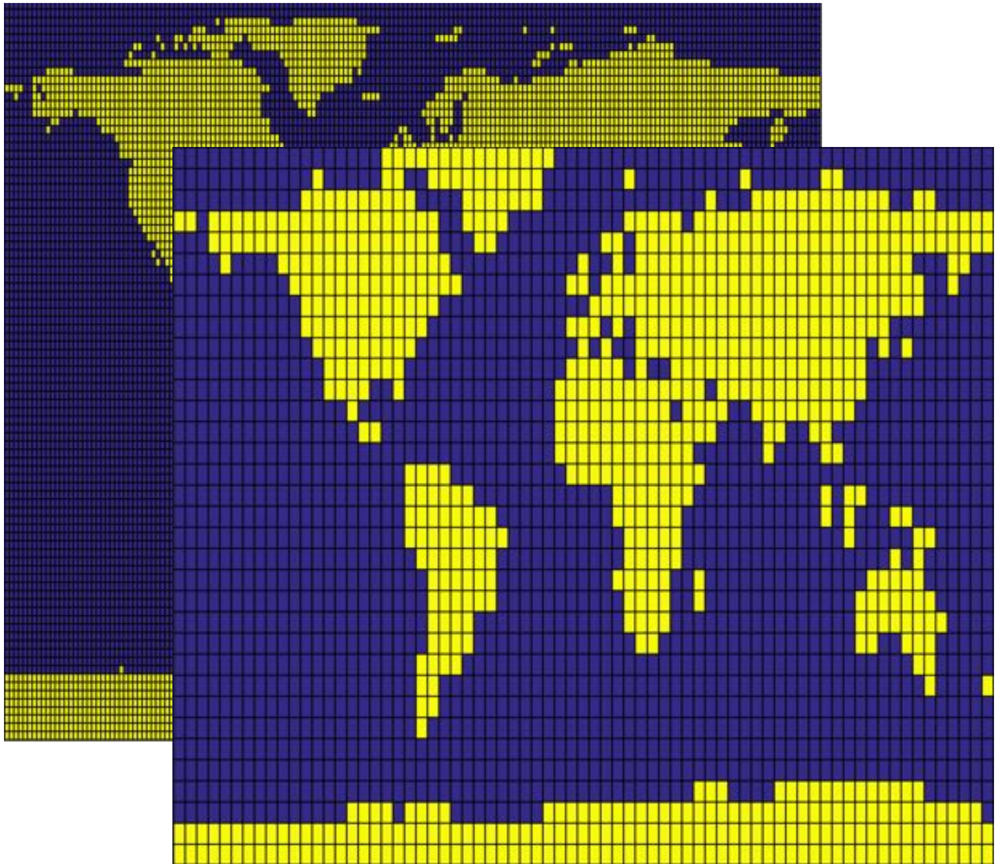

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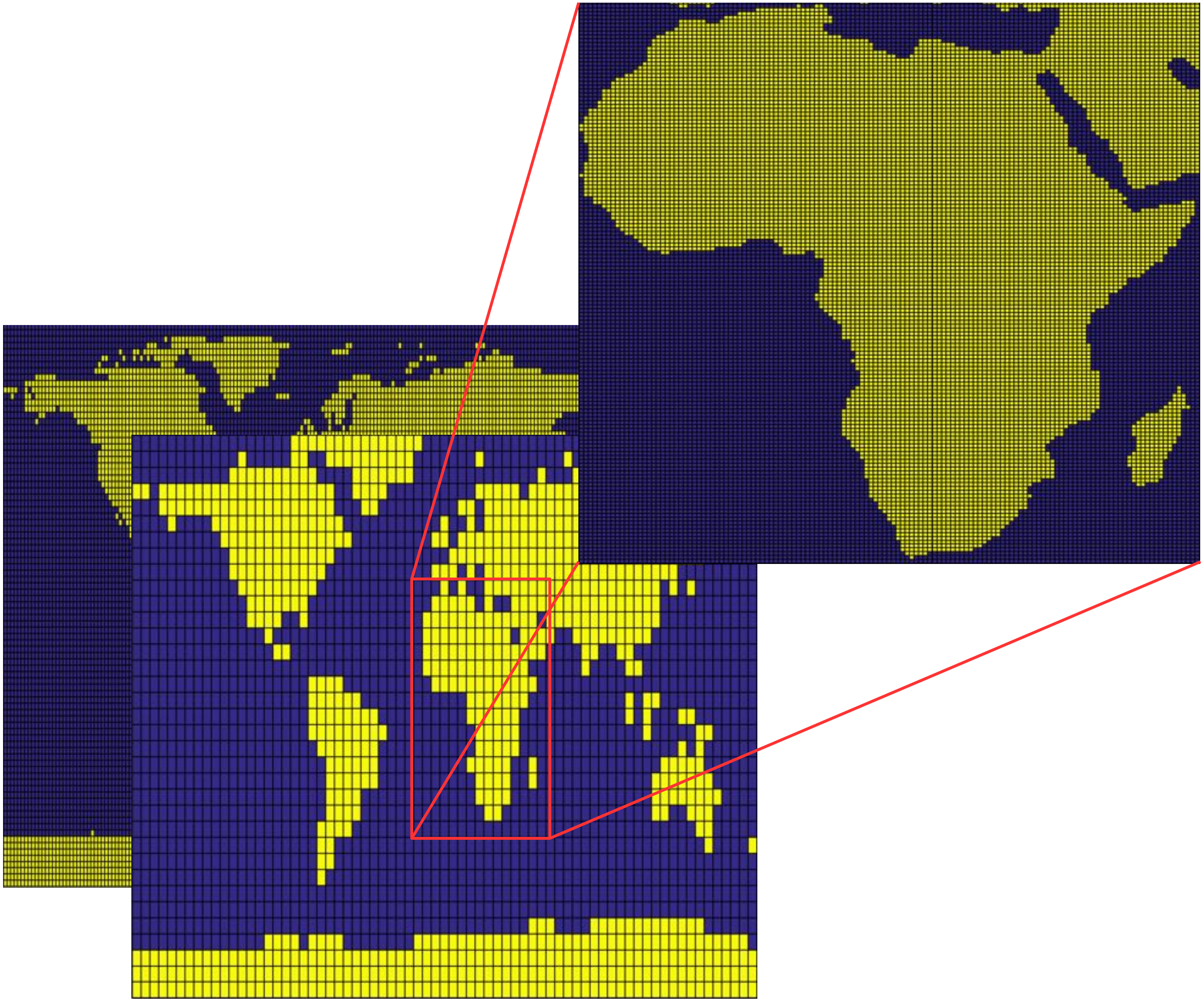

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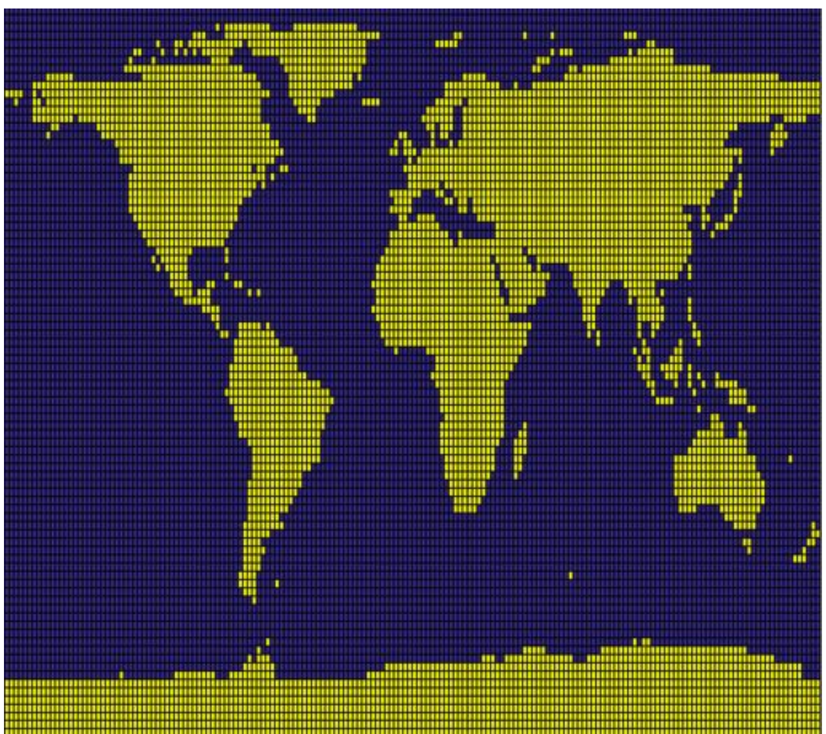
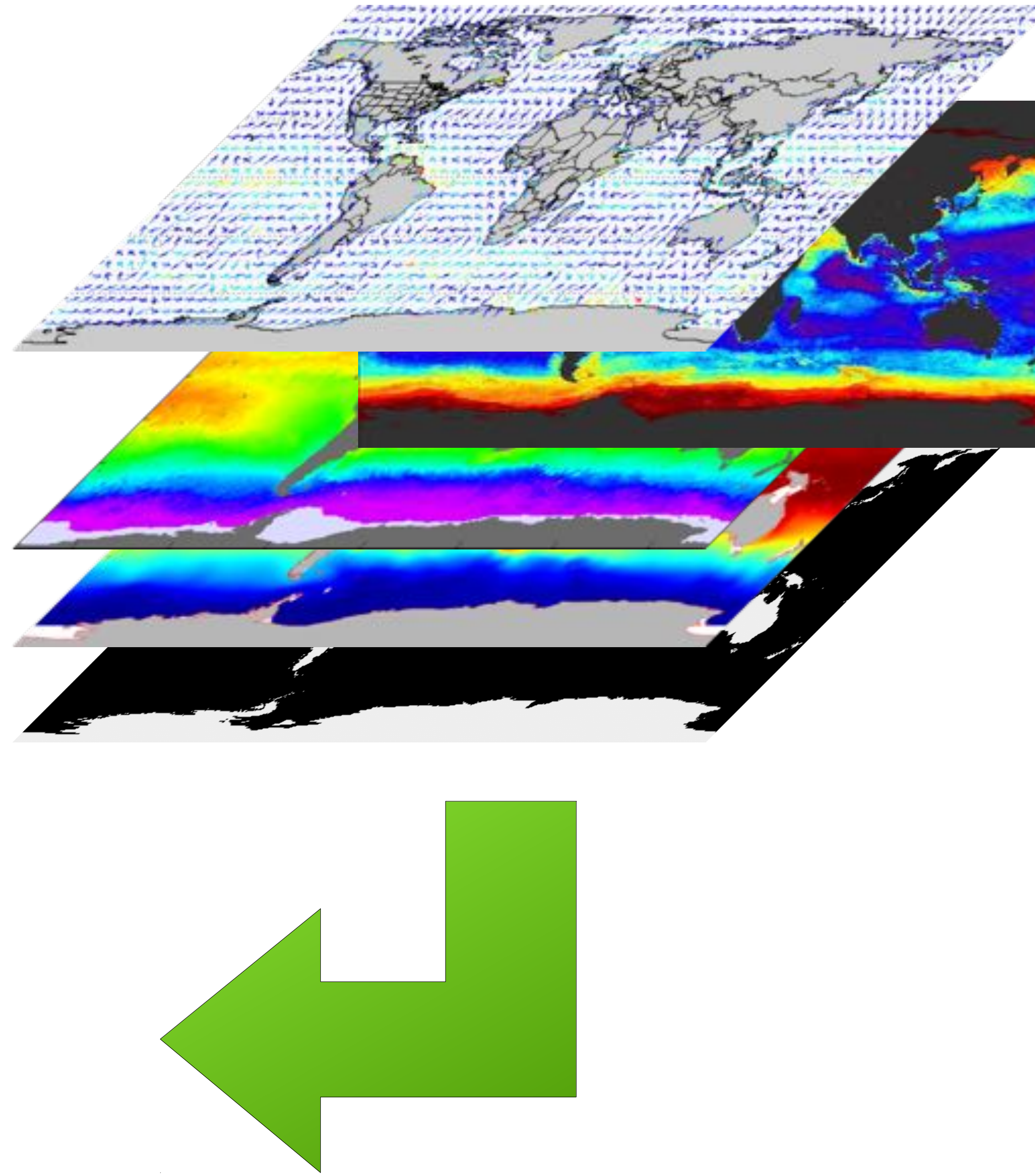
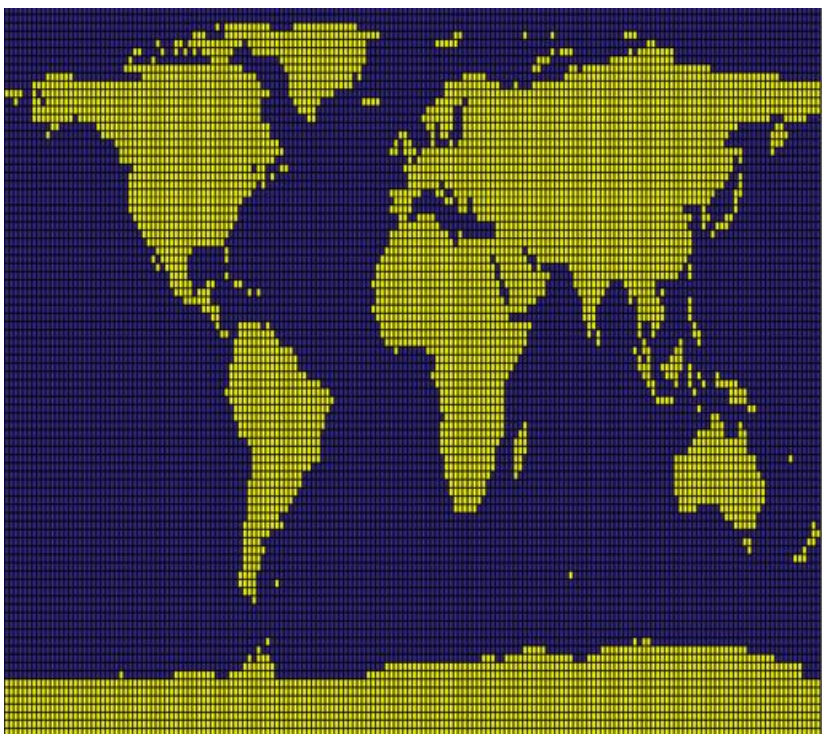
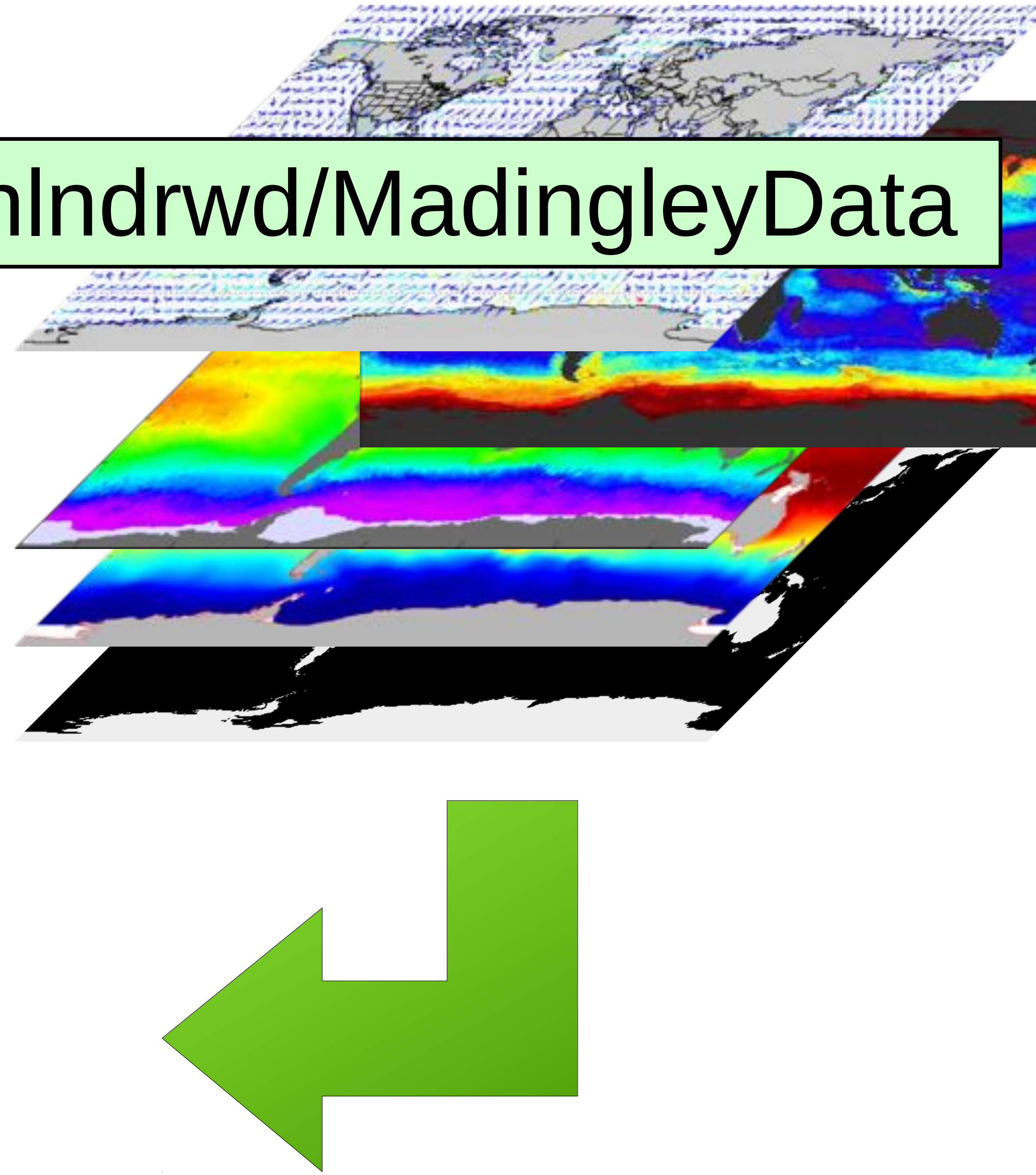




Model Grid

https://github.com/phlndrwd/MadingleyData





Functional Types

Herbivore

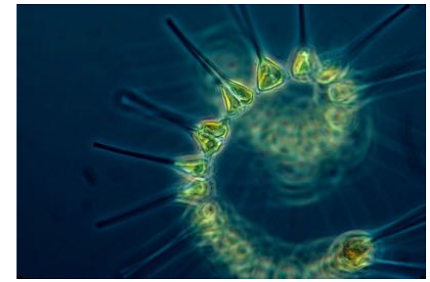
Carnivore

Omnivore

Ectotherm

Endotherm

Autotrophic



Sessile

Mobile

Semelparous

Iteroparous

How do they acquire energy?

Herbivore

Carnivore

Omnivore

Ectotherm

Endotherm

Autotrophic

Sessile

Mobile

Semelparous

Iteroparous

What type of thermoregulation?

Herbivore

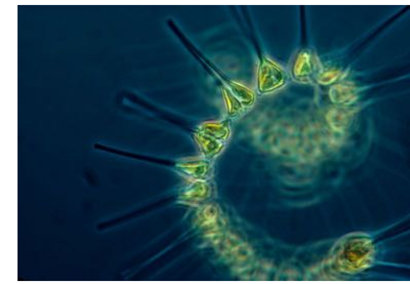
Carnivore

Omnivore

Ectotherm

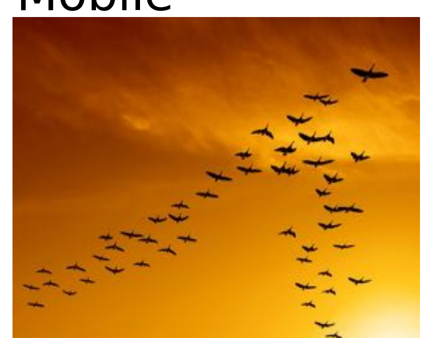
Endotherm

Autotrophic



Sessile

Mobile



Semelparous

Iteroparous

Are they mobile?

Herbivore

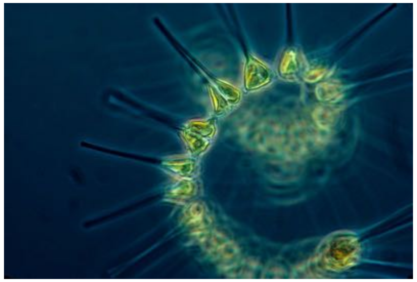
Carnivore

Omnivore

Ectotherm

Endotherm

Autotrophic



Sessile

Mobile

Semelparous

Iteroparous

Method of reproduction?

Herbivore

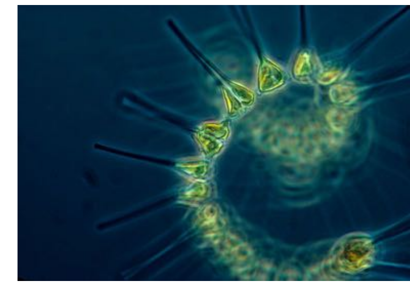
Carnivore

Omnivore

Ectotherm

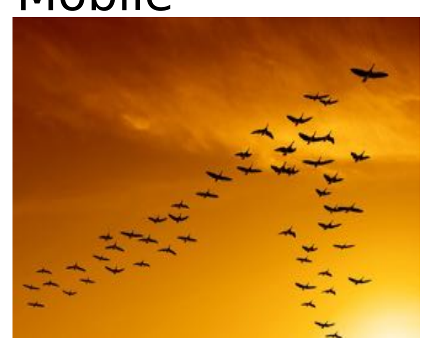
Endotherm

Autotrophic



Sessile

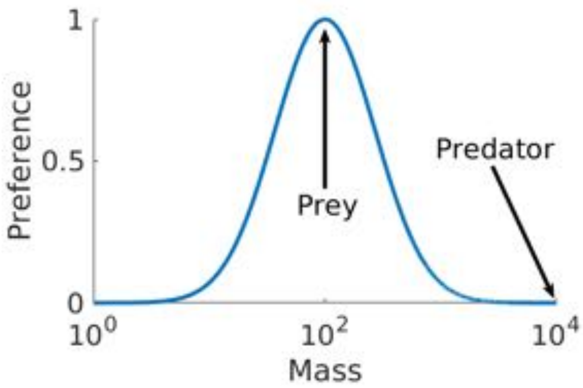
Mobile



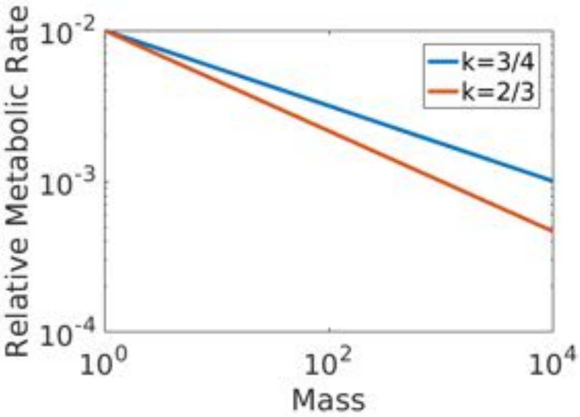
Semelparous

Iteroparous

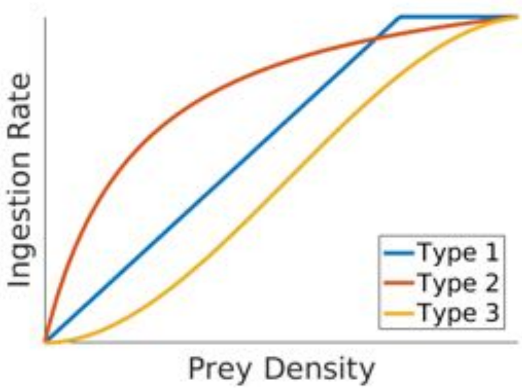
Mechanistic Principles



Functional response determines rate at which predators strike



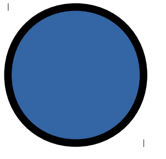
Feeding kernel determines prey for predator



Allometrically scaled metabolic and other rates

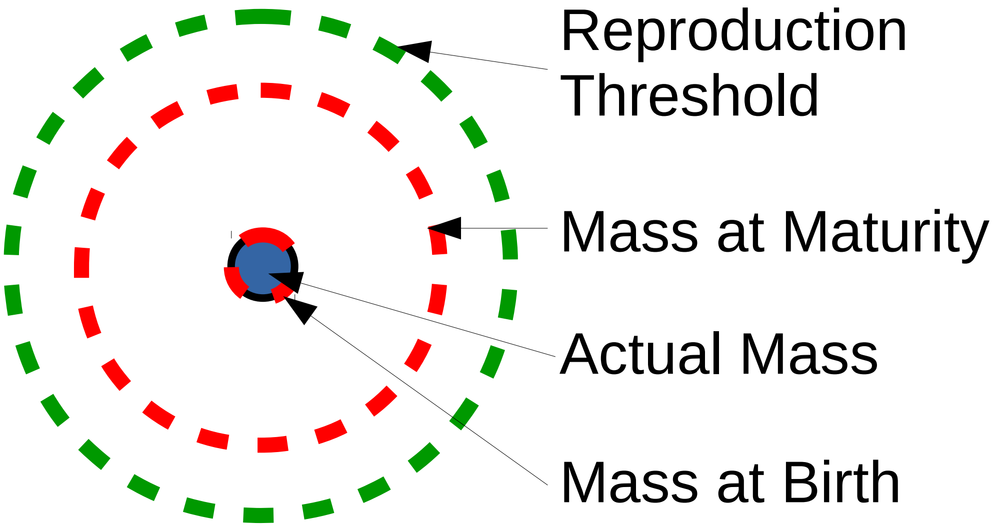
Individuals

- Have mass



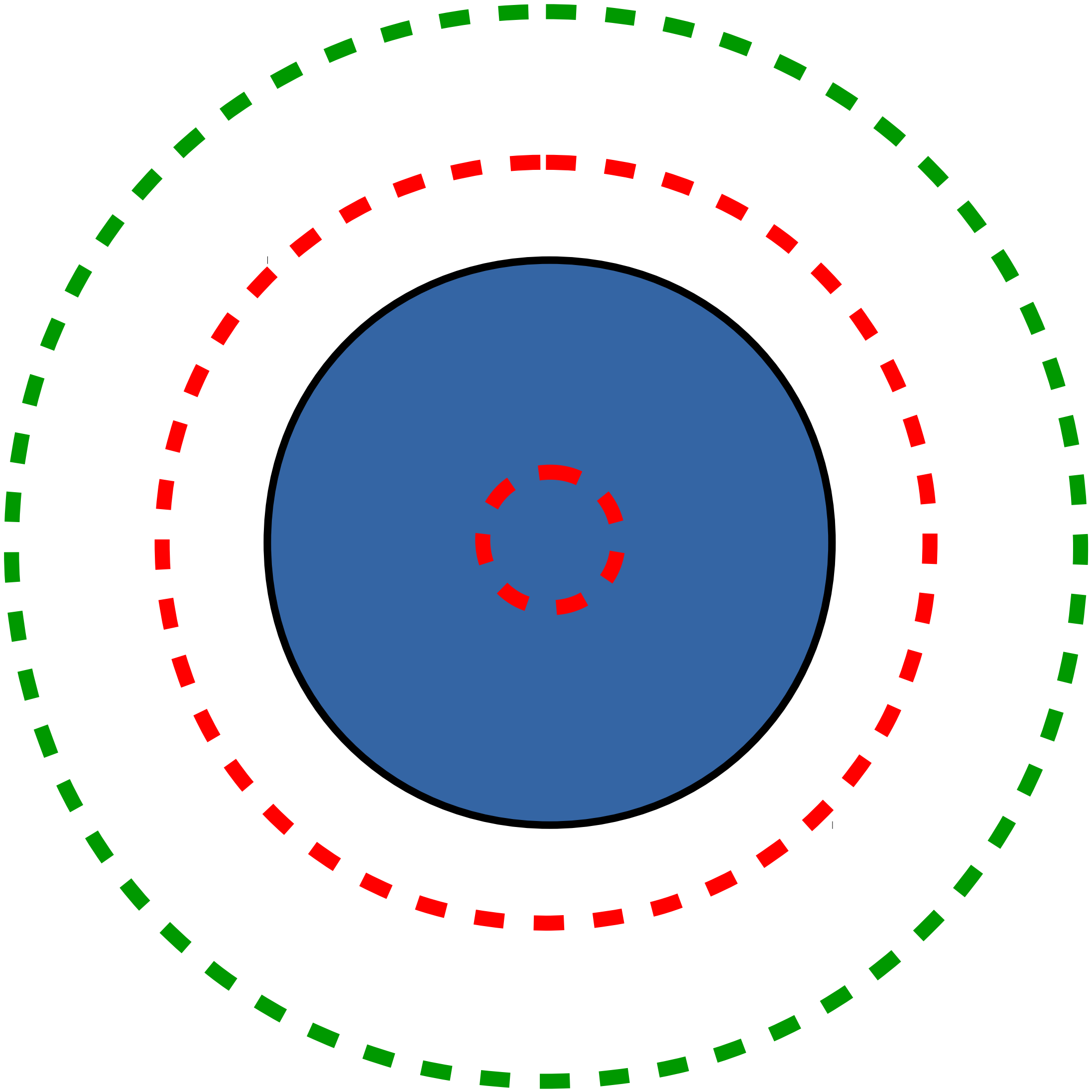
Individuals

- Have mass
- Continuous attributes



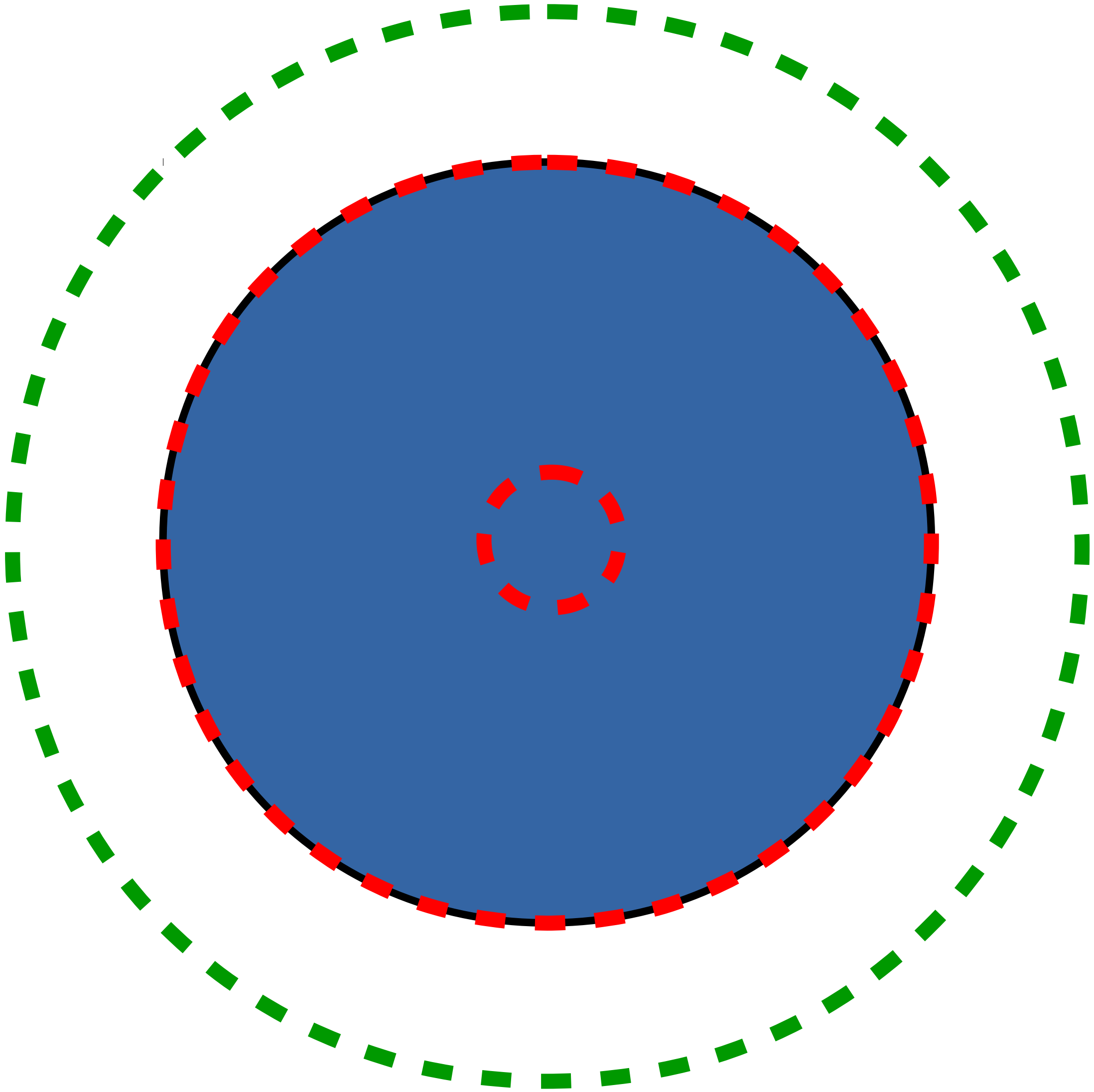
Individuals

- Have mass
- Continuous attributes
- Can assimilate and grow



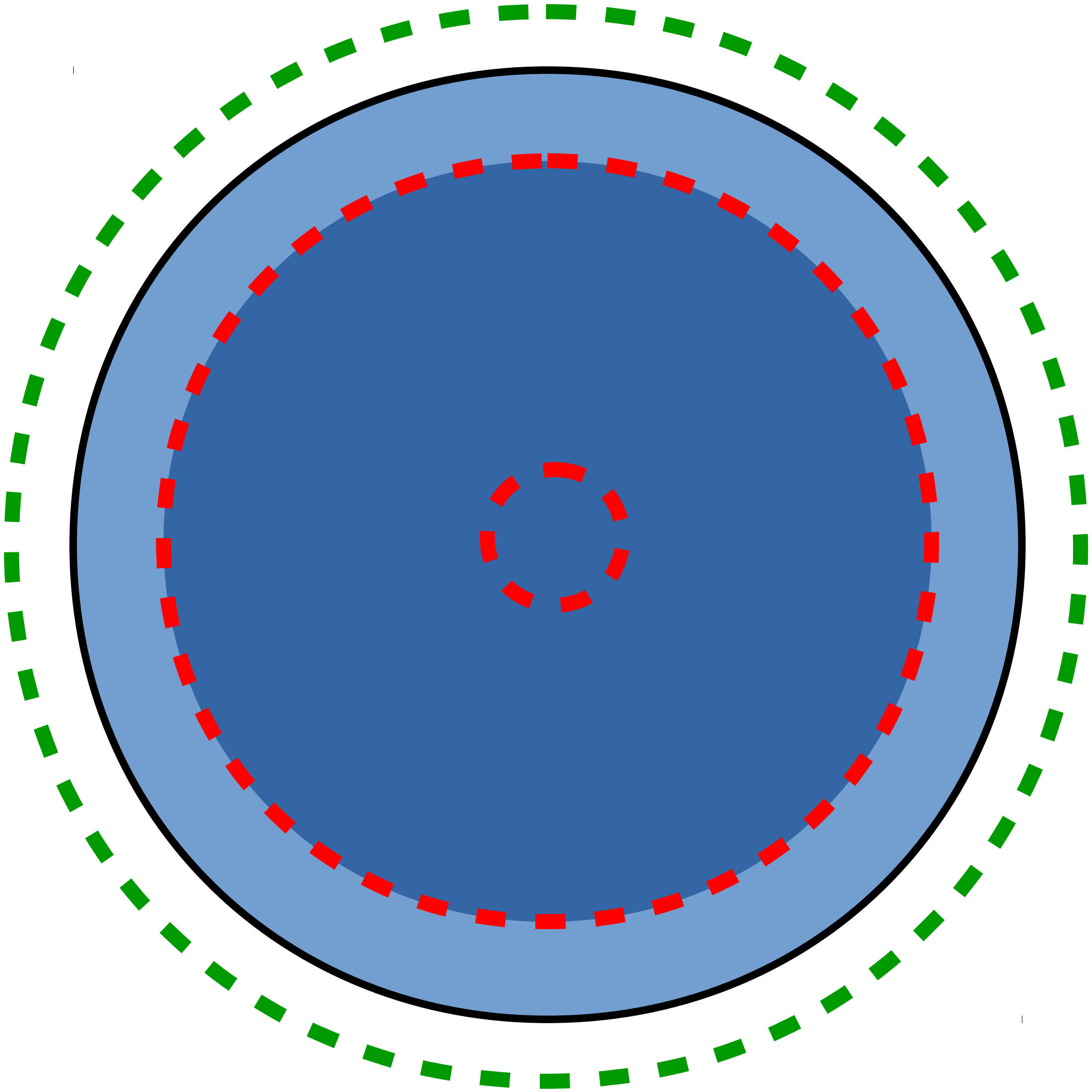
Individuals

- Have mass
- Continuous attributes
- Can assimilate and grow
  - To maturity



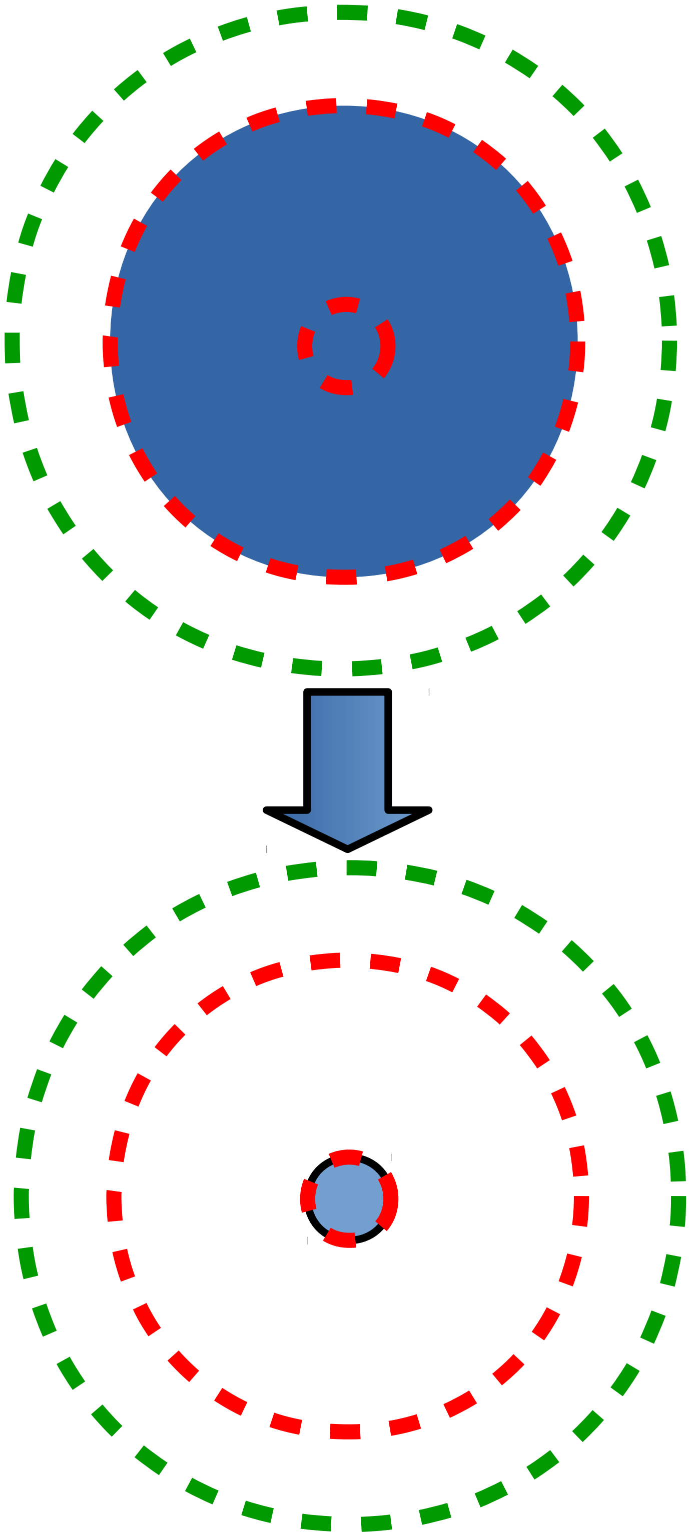
Individuals

- Have mass
- Continuous attributes
- Can assimilate and grow
  - To maturity
  - Beyond maturity



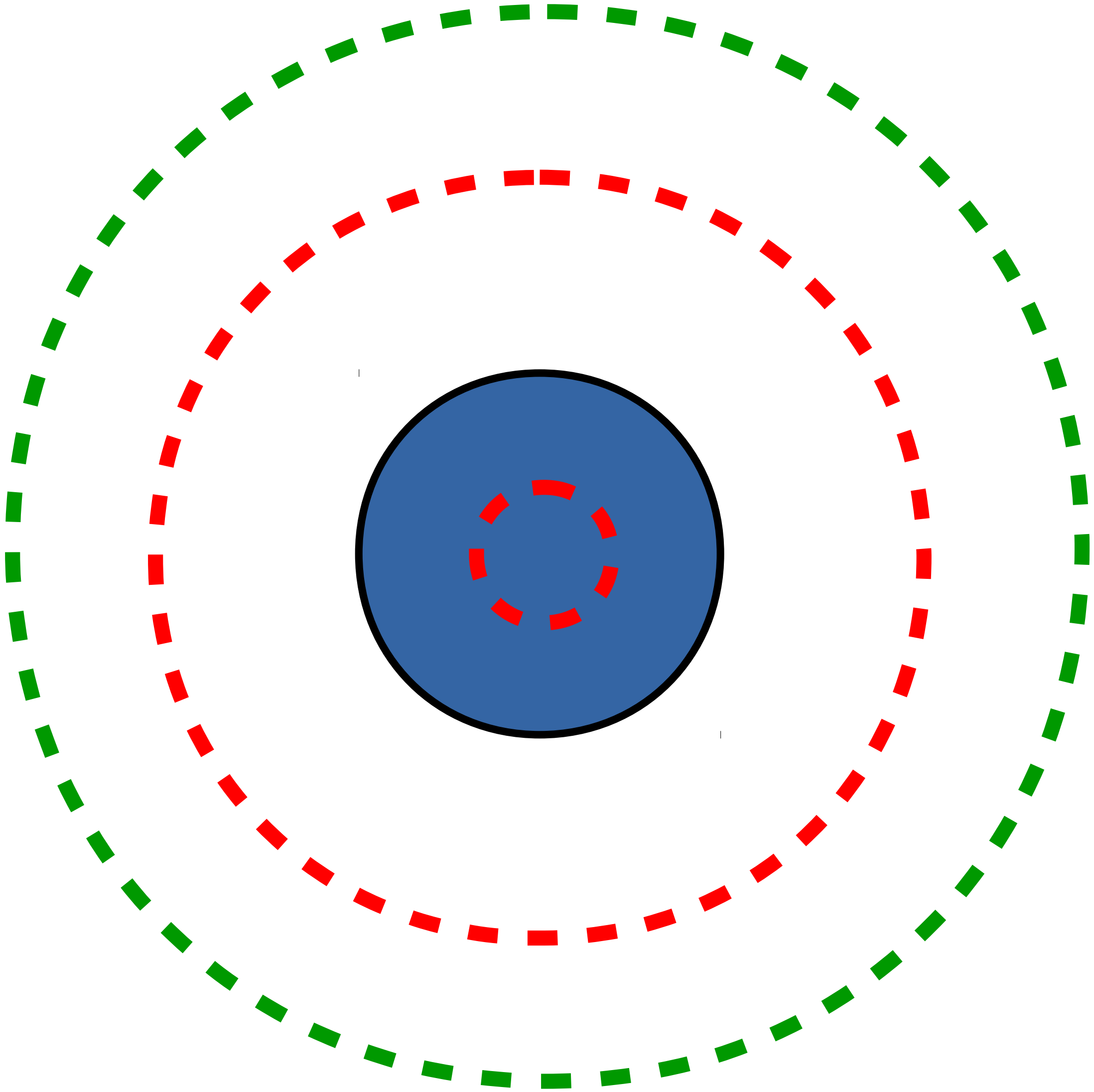
Individuals

- Have mass
- Continuous attributes
- Can assimilate and grow
  - To maturity
  - Beyond maturity
  - To reproduce



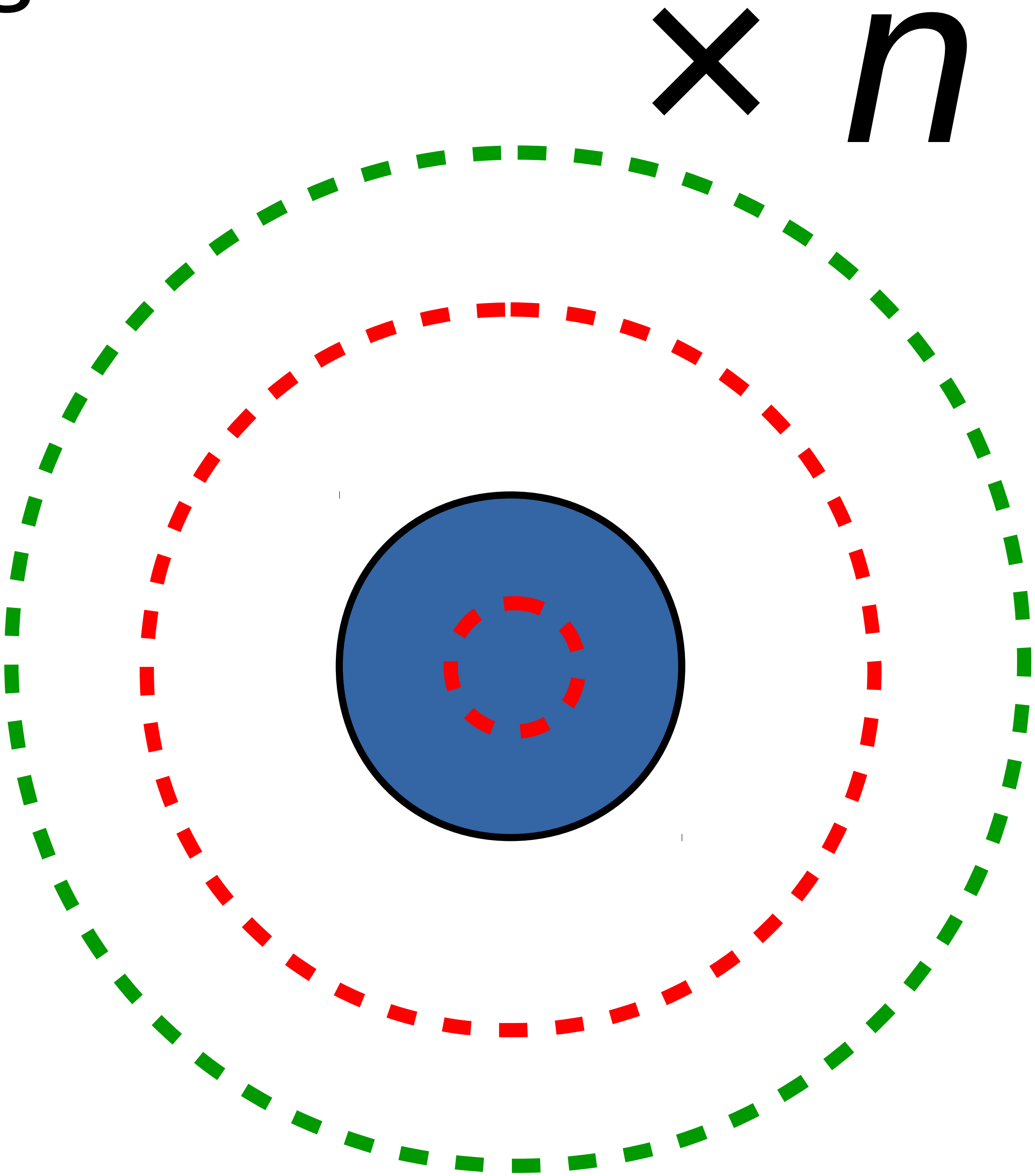
Individuals

- Have mass
- Continuous attributes
- Can assimilate and grow
  - To maturity
  - Beyond maturity
  - To reproduce
- Metabolise and shrink
  - May starve

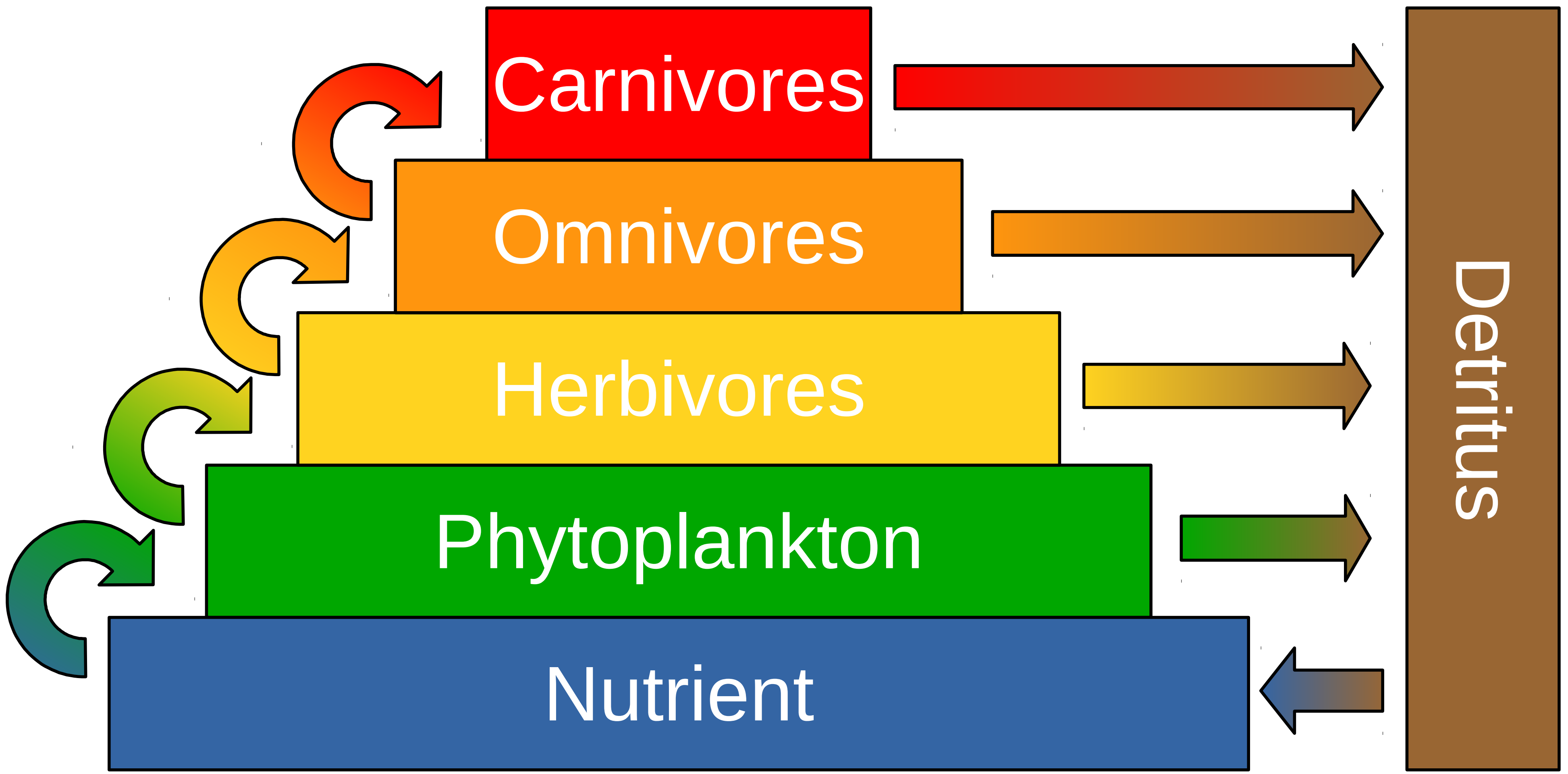


Individual Cohorts

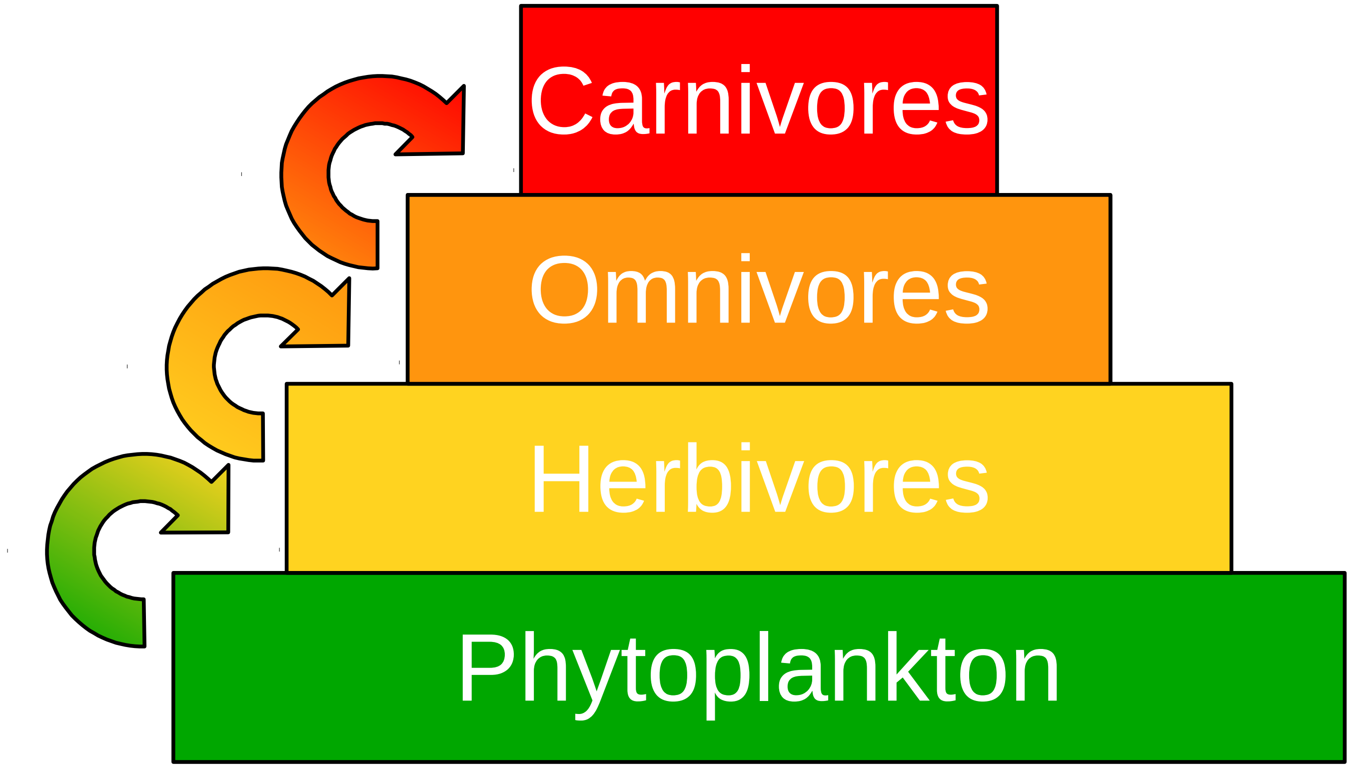
- Have mass
- Continuous attributes
- Can assimilate and grow
  - To maturity
  - Beyond maturity
  - To reproduce
- Metabolise and shrink
  - May starve
- Abundance attribute



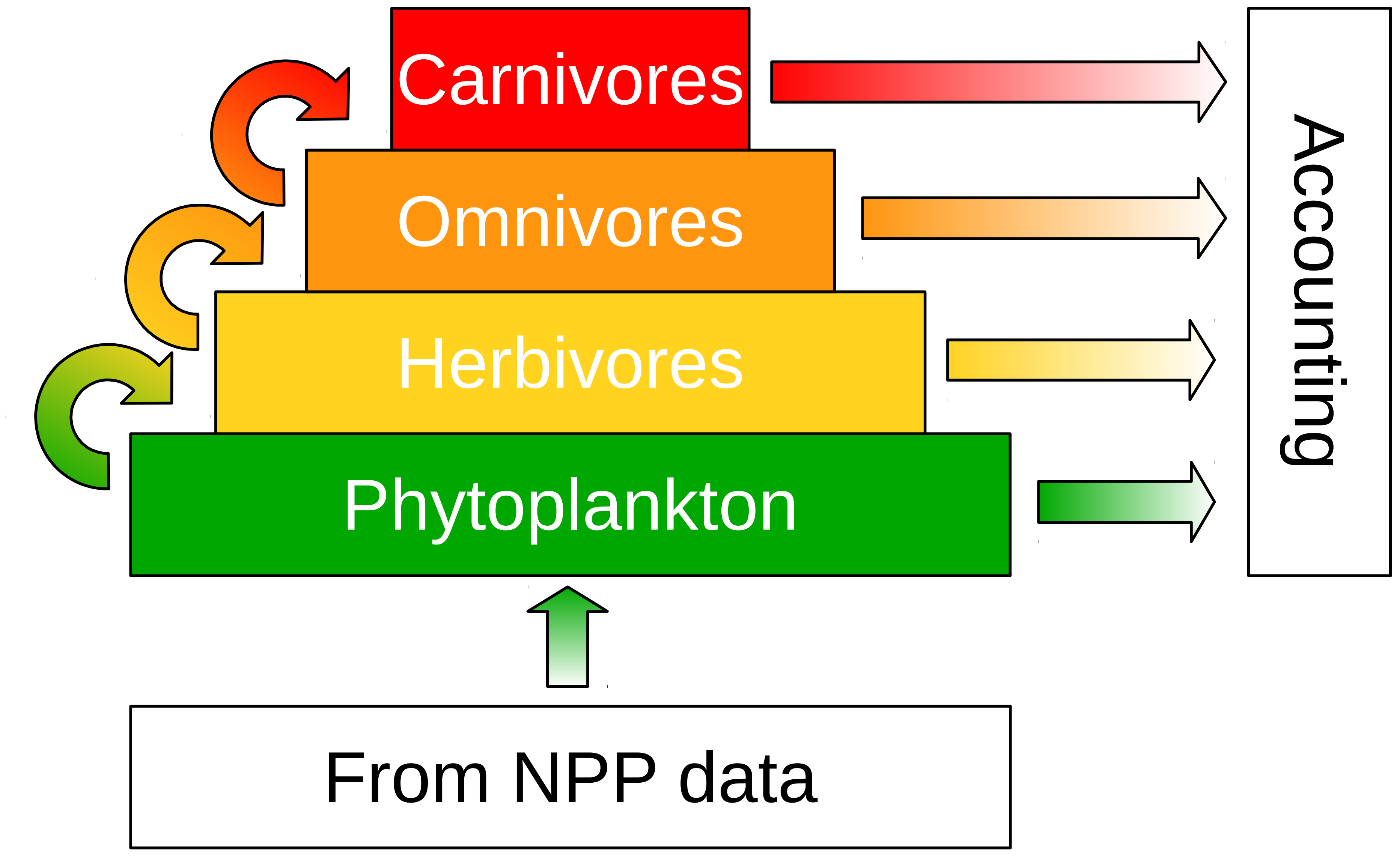
Ideal Trophic System



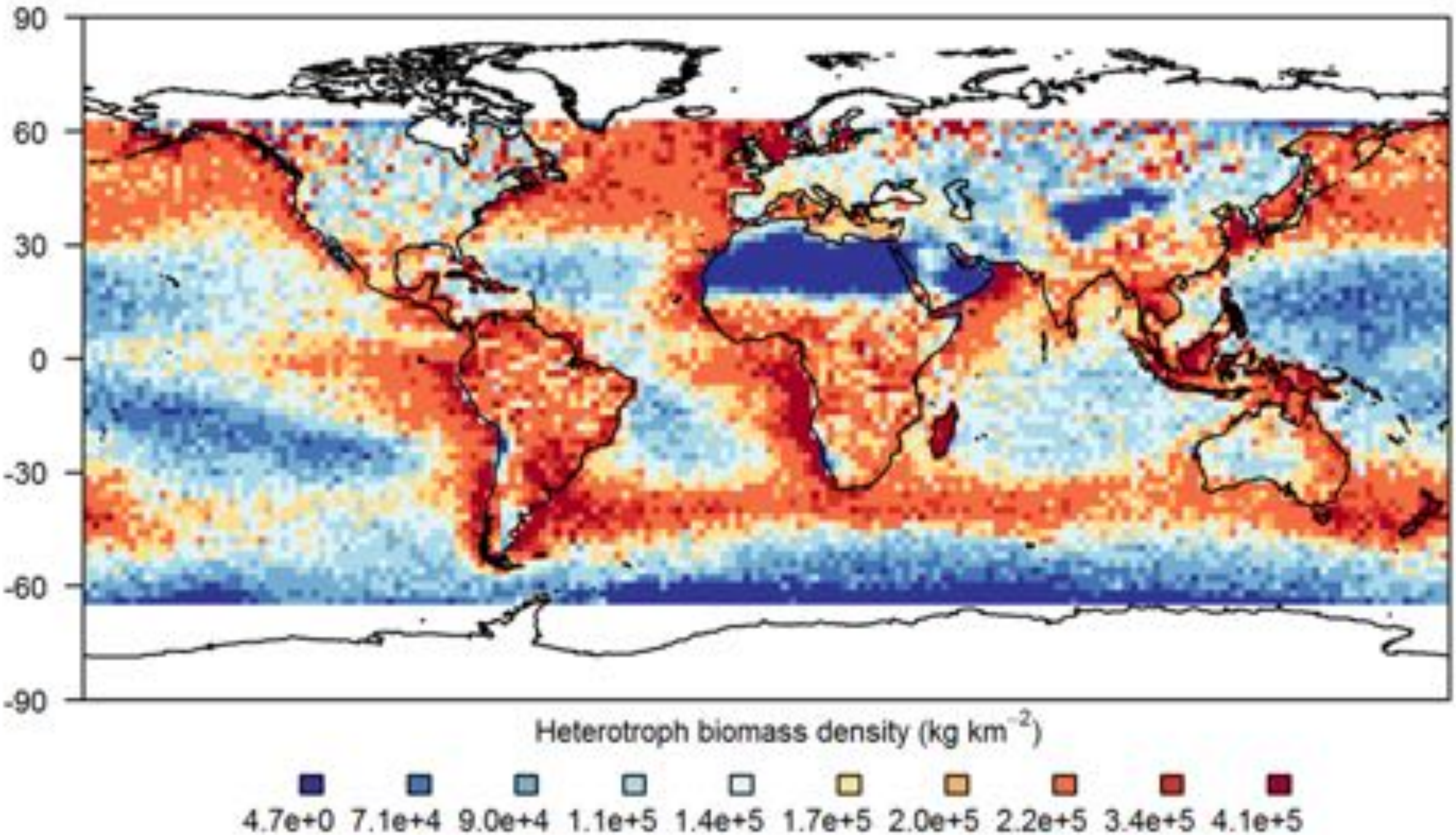
Madingley Trophic System



Trophic System I/O



Emergent Global Result



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

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.

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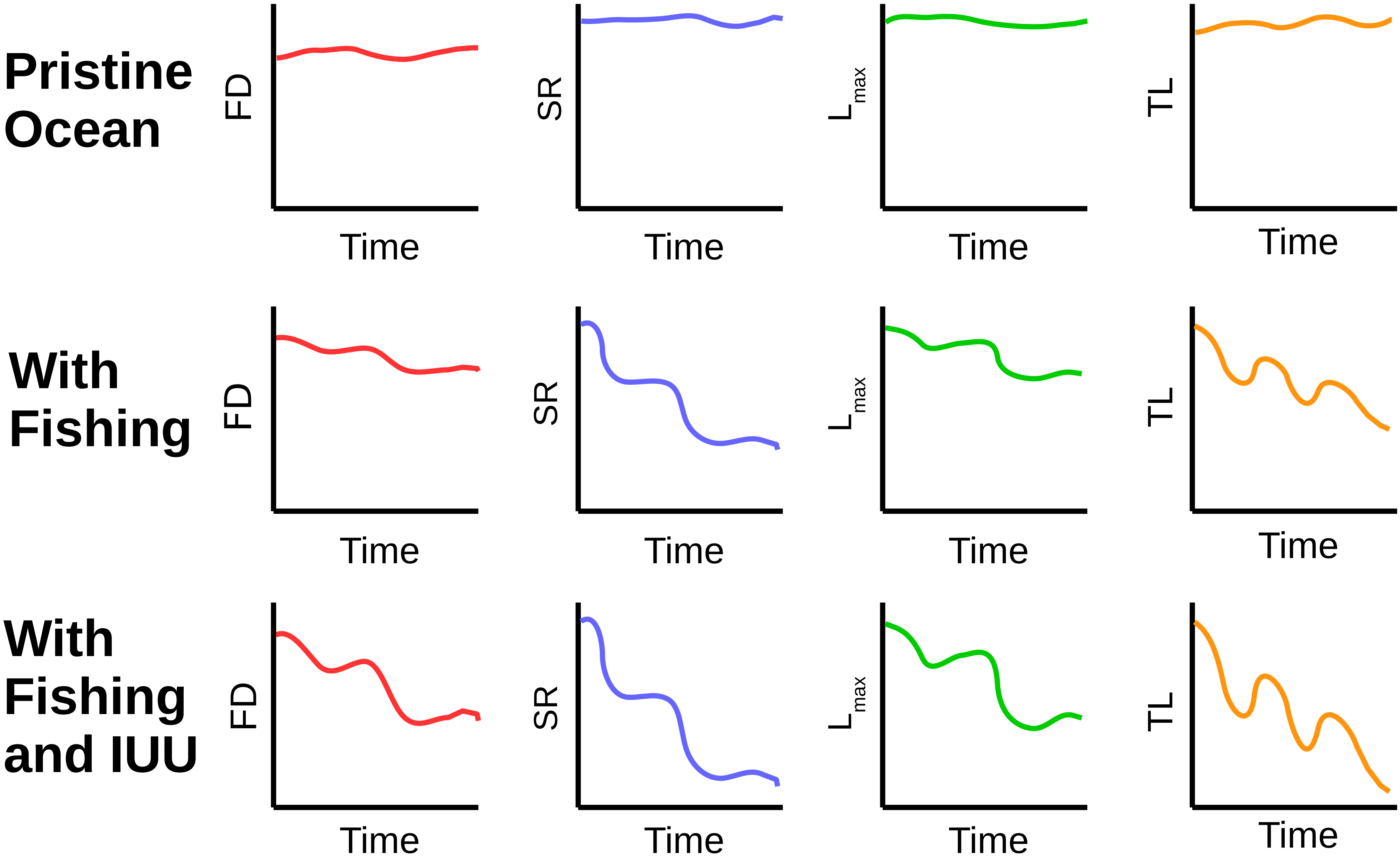
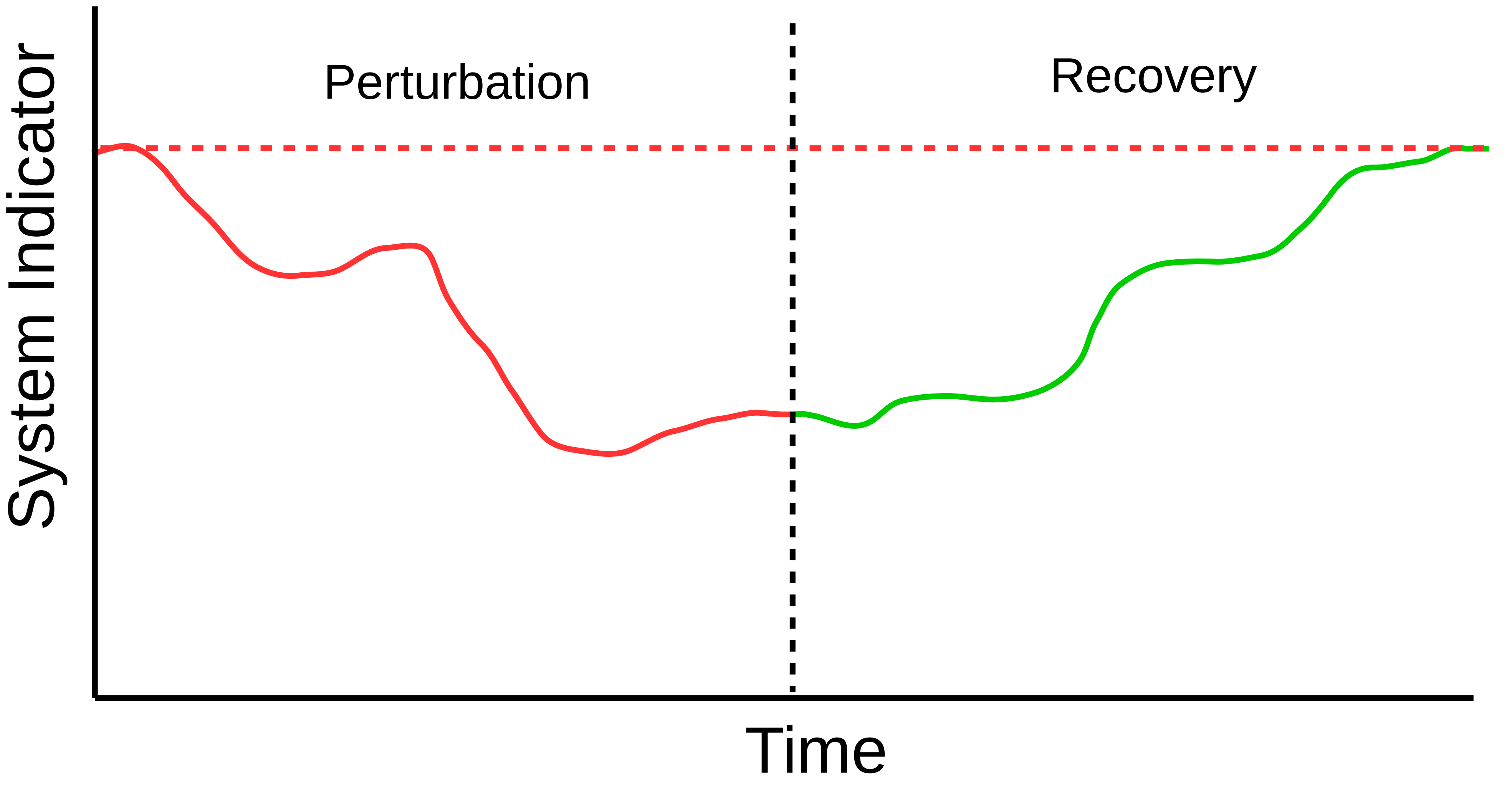
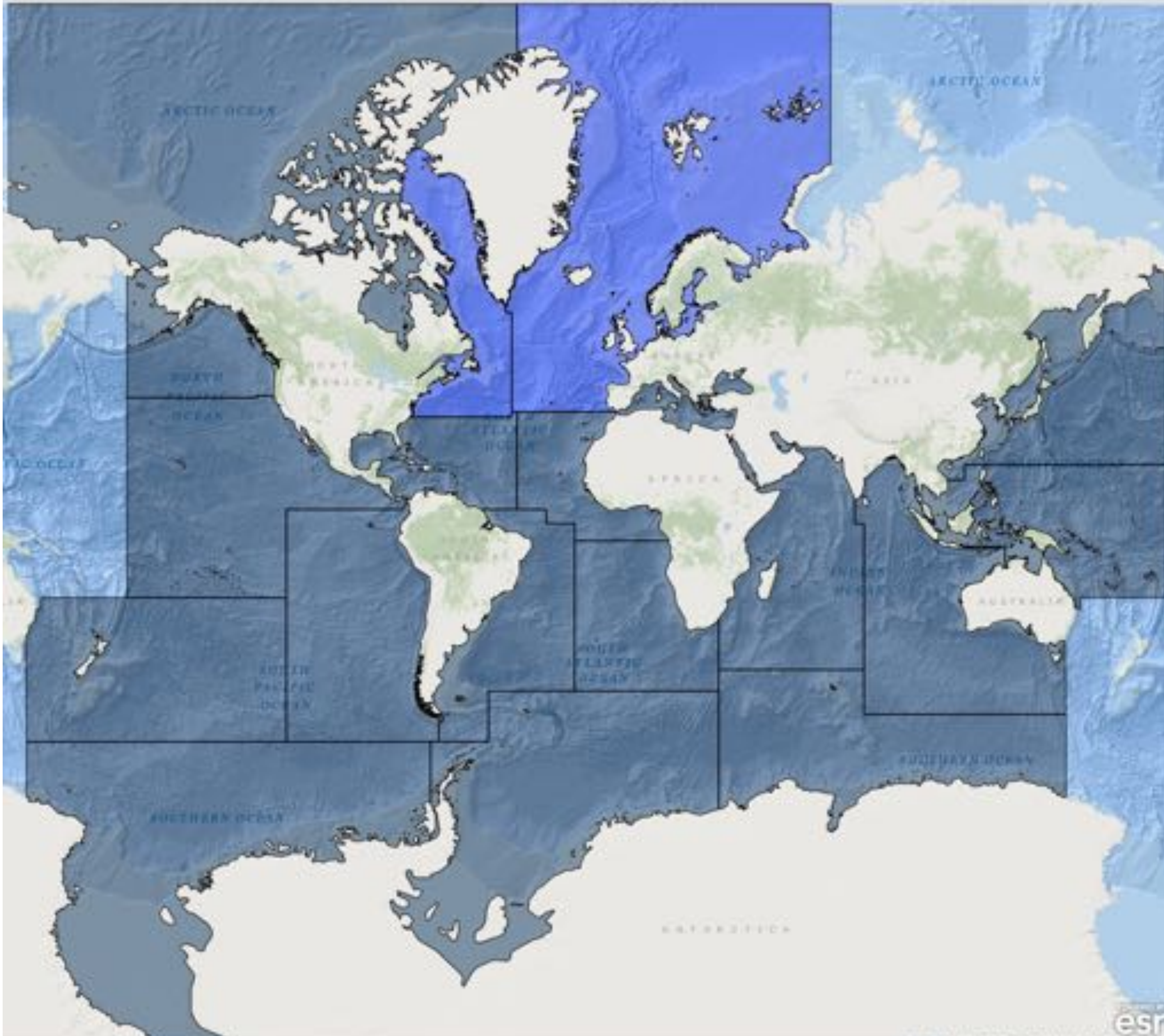
Develop System Indicators



Marine Madingley




ARCTIC OCEAN
SOUTHERN OCEAN

Sea Around Us Data

32465315x10 table

	1 Year	2 CellID	3 TaxonName	4 CommonName	5 FunctionalGroupID	6 SLMax	7 MinDepth	8 MaxDepth	9 catchtypeID	10 SumCatch
1	1959	53632	'Marine fishes ...	'Marine fishes'	4	50	10	9999	1	27.7925
2	1951	63595	'Rajidae'	'Skates'	21	98	1	4156	1	0.0848
3	1953	54366	'Rostroraja alba'	'white skate'	22	189	30	600	3	0.0806
4	1968	45713	'Sharks rays a...	'Cartilaginous fish...	21	150	10	9999	1	0.0022
5	1975	65052	'Rachycentrid...	'Cobia'	3	178	1	1200	1	8.9944e-04
6	1976	27078	'Lamna nasus'	'Porbeagle'	20	287	1	9999	1	0.0155
7	1978	58673	'Loligo'	'Common squids'	25	46	1	500	1	1.9290
8	1984	23262	'Reinhardtius ...	'Greenland halibut'	23	72	1	2000	1	1.2427
9	1996	45706	'Eutrigla gurn...	'Grey gurnard'	5	53	10	340	2	1.5018
10	1998	46426	'Marine fishes ...	'Marine fishes'	4	50	10	9999	2	3.1154
11	1997	57138	'Salmo'	'Salmons and tro...	2	119	1	500	1	0.0011
12	1987	62175	'Strongylocen...	'Green sea urchin'	29	8	1	300	2	2.3926
13	1962	75881	'Marine fishes ...	'Pelagic fishes'	1	50	10	9999	1	6.5493e-04
14	1984	76530	'Crustacea'	'Crustaceans'	27	25	1	3700	2	1.2863
15	1999	70870	'Sarda sarda'	'Atlantic bonito'	3	84	80	200	1	5.7999e-04
16	1961	47877	'Zeus faber'	'john dory'	15	79	5	400	3	0.0893
17	1965	39913	'Rajiformes'	'Skates and rays'	21	135	1	3000	1	0.1114
18	1968	26168	'Pandalus bor...	'Northern prawn'	26	14	9	1450	1	25.8548
19	1993	36315	'Cyclopterus l...	'Lumpfish'	14	52	1	868	2	0.7315
20	2005	50067	'Salmo salar'	'Atlantic salmon'	15	135	1	210	2	0.4655
21	1985	29965	'Raja'	'Skates'	21	78	1	732	2	2.4289
22	1957	72971	'Xiphias gladius'	'Swordfish'	3	449	1	800	1	0.0354
23	2005	54364	'Platichthys fle...	'European flounder'	23	50	1	100	1	6.5698
24	1989	20364	'Flounders or ...	'Flounders/halibut...	23	197	20	500	3	0.0034
25	1994	73706	'Thunnus alba...	'Yellowfin tuna'	3	231	1	9999	1	0.1659
26	1992	78017	'Perciformes'	'Perch-likes'	4	58	1	9999	1	4.0859
27	2004	49344	'Salmo'	'Salmons and tro...	2	119	1	500	1	3.3543e-04

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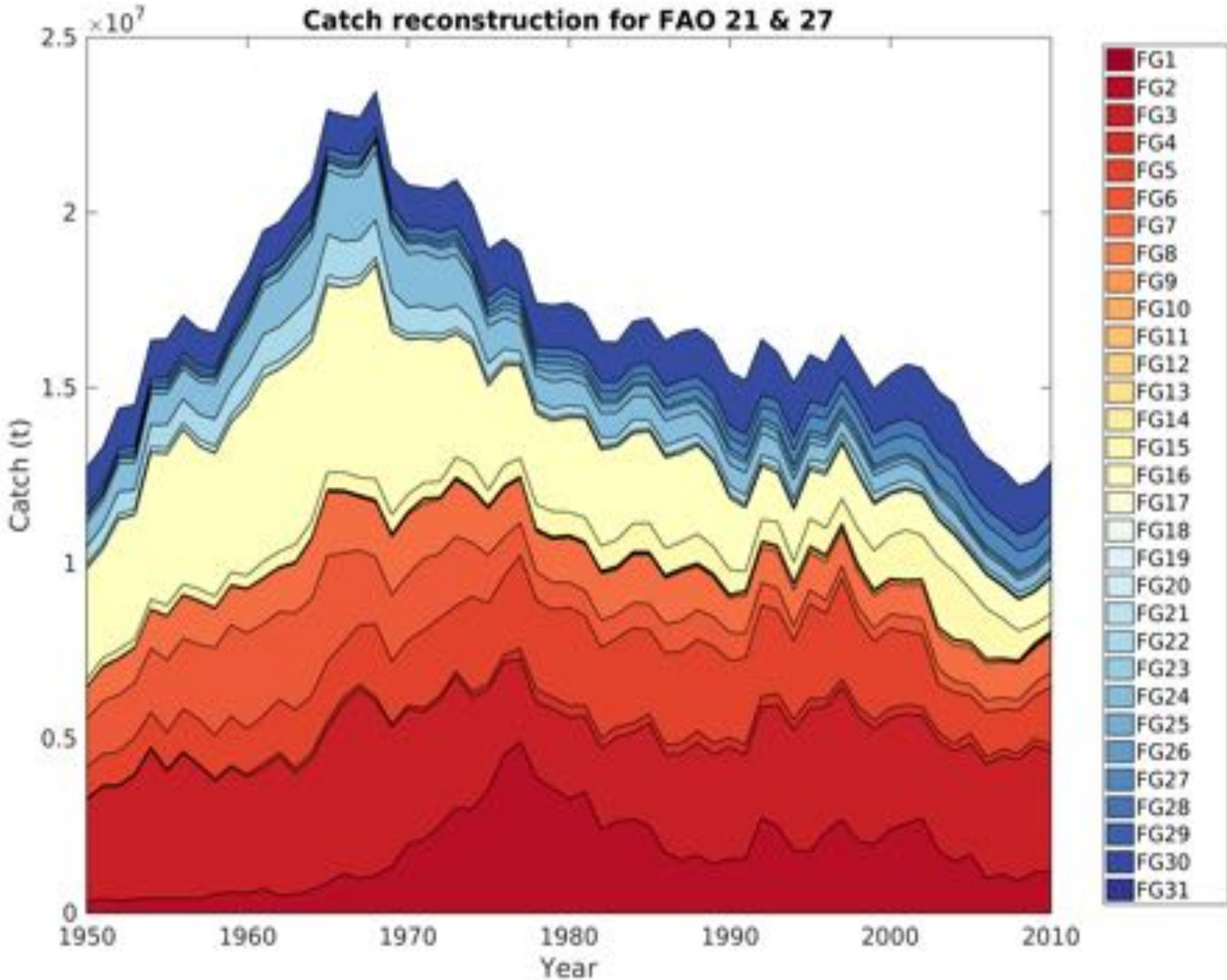
26	1992	78017	'Perciformes'	'Perch-likes'	4	58	1	9999	1	4.0859
27	2004	49344	'Salmo'	'Salmons and tro...	2	119	1	500	1	3.3543e-04

Name	Description	Size (cm)
FG0	Other	-
FG1	Small Pelagics	<30
FG2	Medium Pelagics	30-90
FG3	Large Pelagics	>=90
FG4	Small Demersals	<30
FG5	Medium Demersals	30-90
FG6	Large Demersals	>=90
FG7	Small Bathypelagics	<30
FG8	Medium Bathypelagics	30-90
FG9	Large Bathypelagics	>=90
FG10	Small Bathydemersals	<30
FG11	Medium Bathydemersals	30-90
FG12	Large Bathydemersals	>=90
FG13	Small Benthopelagics	<30
FG14	Medium Benthopelagics	30-90
FG15	Large Benthopelagics	>=90
FG16	Small Reef associated fish	<30
FG17	Medium Reef associated fish	30-90
FG18	Large Reef associated fish	>=90
FG19	Small to Medium Sharks	<90
FG20	Large Sharks	>=90
FG21	Small to Medium Rays	<90
FG22	Large Rays	>=90
FG23	Small to Medium Flatfishes	<90
FG24	Large Flatfishes	>=90
FG25	Cephalopods	-
FG26	Shrimps	-
FG27	Lobsters, Crabs	-
FG28	Jellyfish	-
FG29	Other Demersal Invertebrates	-
FG30	Krill	-


Catch reconstruction for FAO 21 & 27
×10^7
2.5
2
1.5
1
0.5
0
Catch (t)
1950
1960
1970
1980
1990
2000
2010
Year
FG1
FG2
FG3
FG4
FG5
FG6
FG7
FG8
FG9
FG10
FG11
FG12
FG13
FG14
FG15
FG16
FG17
FG18
FG19
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FG21
FG22
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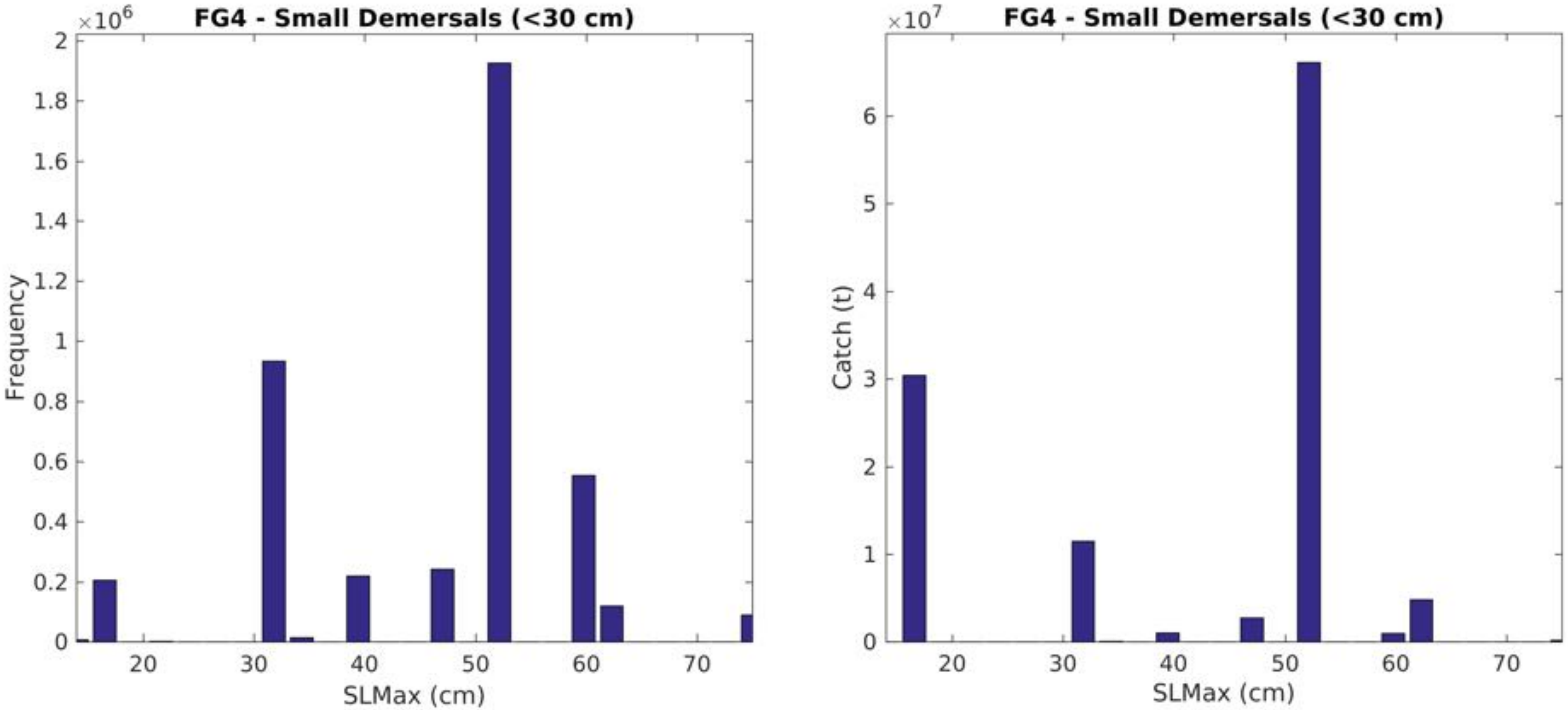
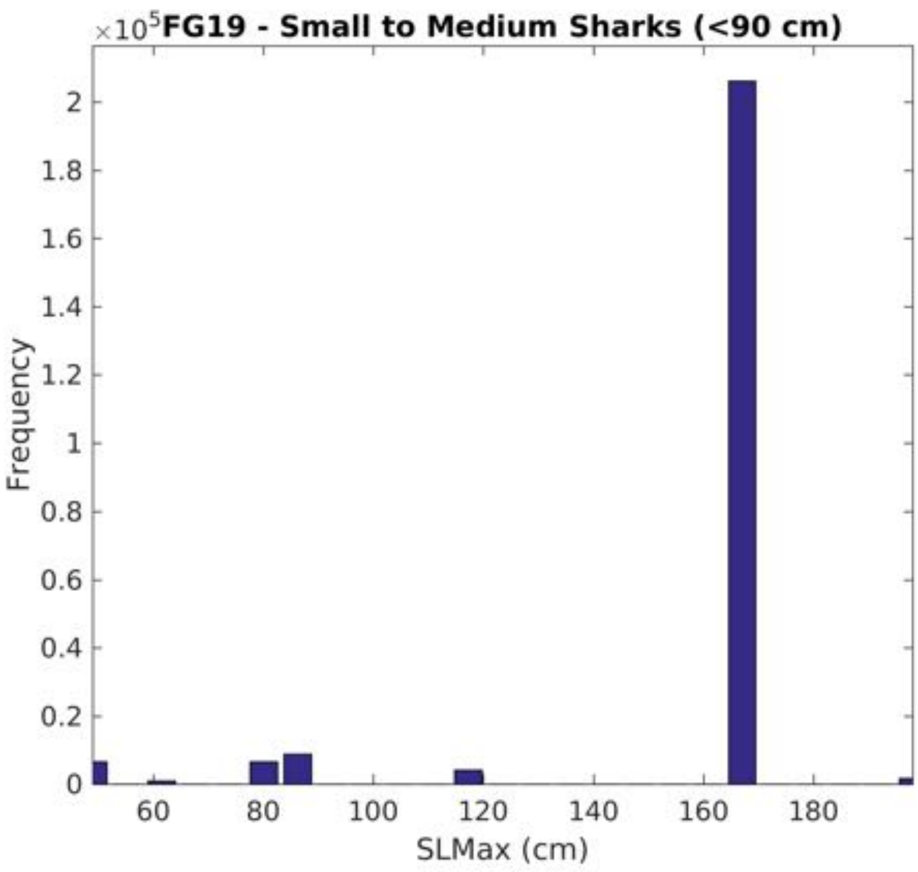
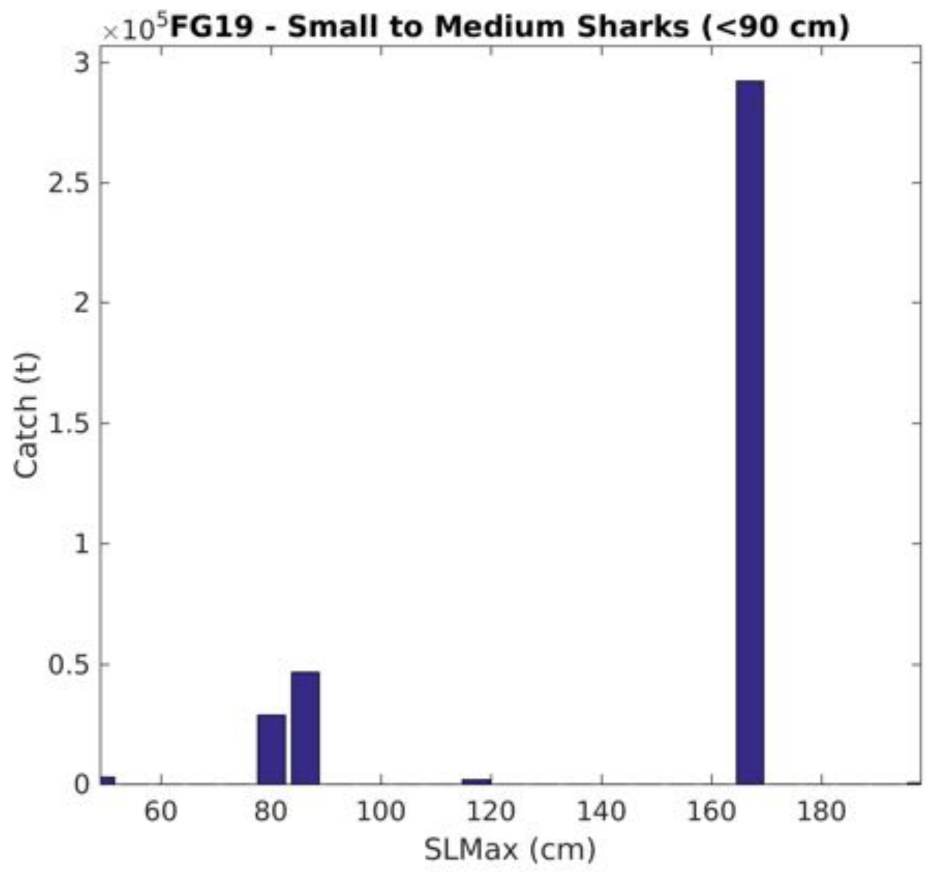
FG24
FG25
FG26
FG27
FG28
FG29
FG30
FG31

Catch Distributions

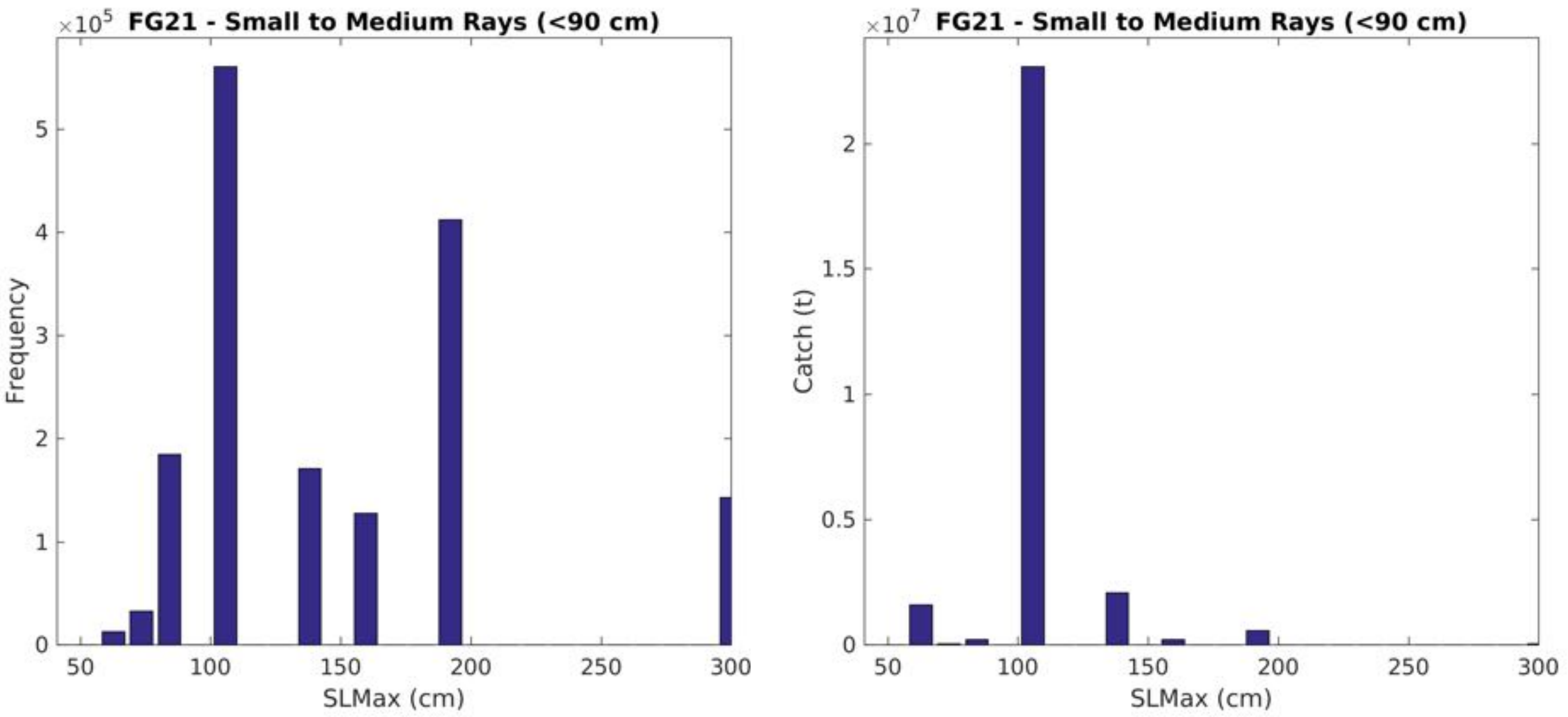


Catch Distributions





Catch Distributions



Taxon Growth Table

von Bertalanffy Growth Function:

$$L_t = \boxed{L_\infty}\left(1 - e^{-\boxed{K}(t - \boxed{t_0})}\right)$$

Length to mass conversion:

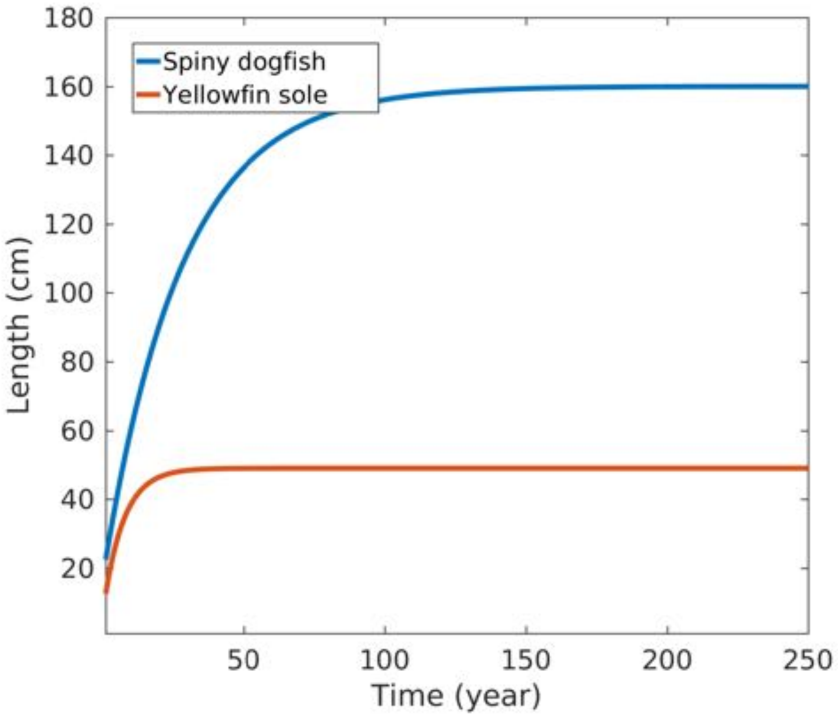
$$W = \boxed{a}L^{\boxed{b}}$$

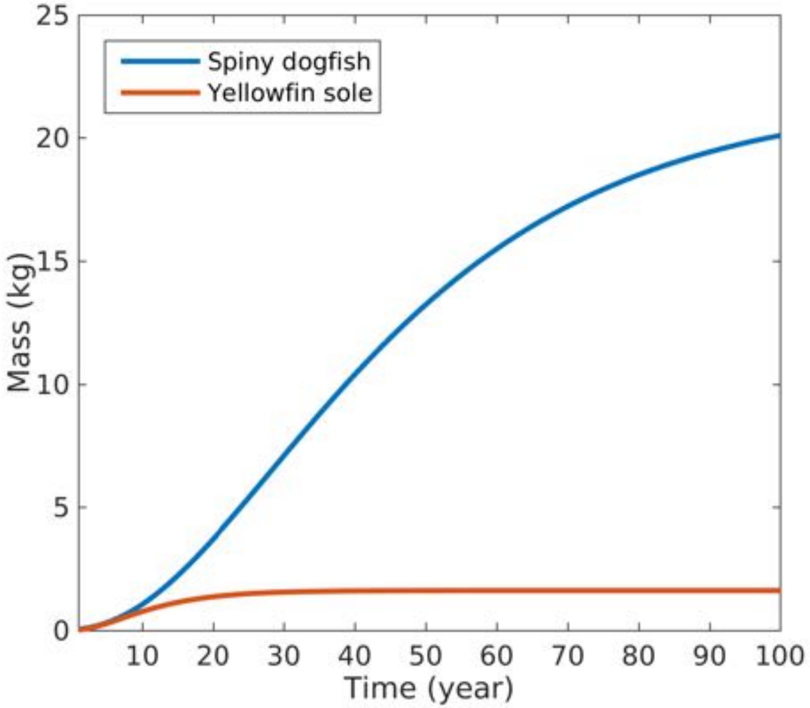
TaxonKey	TaxonName	Linf	VBonK	t0	lwA	lwB
600120	Scomberomorus cavalla	184	0.28	-0.43202	0.00831	2.973
600121	Scomberomorus commerson	240	0.38	-0.27718	0.0099	2.95
600123	Scomberomorus guttatus	78.5	0.34	-0.37	0.0096	3.002
600125	Scomberomorus lineolatus	82.6	0.33	-0.33	0.00417	3.044
600126	Scomberomorus maculatus	91	0.27	-0.47638	0.00884	2.982
600131	Scomberomorus niphonius	100	0.91	-0.13366	0.01	3
600134	Scomberomorus regalis	186.4	0.17	-0.61	0.0202	2.8
600136	Scomberomorus sierra	101.8	0.27	-0.44	0.01	3
600138	Somniosus microcephalus	730			0.01	3
600139	Squalus acanthias	160	0.036	-3.19986	0.0031	3.1056
600140	Rhinobatos percellens	102.8	0.31	-0.38	0.00811	2.81
600141	Scomberomorus tritor	100	0.311	-0.38363	0.018	2.93
600142	Thunnus alalunga	159.201	0.13	-0.83474	0.0272	2.8
600143	Thunnus albacares	239	0.37	-0.26754	0.0216	2.981
600144	Thunnus atlanticus	107.95	0.33	-0.38626	0.0184	3.024
600145	Thunnus maccoyii	245	0.151	-0.65371	0.0167	3.06
600146	Thunnus obesus	250	0.125	-0.78016	0.0178	2.902
600147	Thunnus thynnus	458	0.067	-1.29891	0.0231	2.934
600148	Thunnus tonggol	144.983	0.324	-0.35815	0.01	3
600149	Rhinobatos planiceps	78.8	0.41	-0.31	0.01	3
600509	Ophiodon elongatus	152	0.18	-0.66948	0.01	3
600510	Pleurogrammus azonus	64.3	0.34	-0.34	0.01	3
600512	Anoplopoma fimbria	120	0.29	-0.46306	0.0058	3.14
600513	Psettodes erumei	64	0.558	-0.26279	0.0039	3.214
600514	Hippoglossus stenolepis	258	0.06	-1.78659	0.00314	3.24
600516	Reinhardtius hippoglossoides	116.3	0.07	-1.73038	0.00303	3.2578
600517	Atheresthes stomias	86.6	0.11	-1.02	0.01981	2.7913
600518	Reinhardtius evermanni	100	0.13	-1.0074	0.00372	3.2532
600519	Hippoglossoides elassodon	54	0.35	-0.35	0.01018	3.0076
600520	Limanda aspera	49	0.14	-1.10391	0.0076	3.1531
600521	Limanda ferruginea	64	0.335	-0.42978	0.01	3
600524	Pseudopleuronectes americanus	64	0.384	-0.39717	0.01	3
600525	Solea solea	70	0.264	-0.56861	0.00622	3.04
600526	Dicologlossa cuneata	30	0.47	-0.36719	0.00845	2.968
600527	Austroglossus microlepis	77.5	0.14	-0.94	0.01	3
600528	Austroglossus pectoralis	60	0.375	-0.39774	0.00178	3.335
600529	Scophthalmus rhombus	75	0.5	-0.30497	0.0143	2.93
600530	Scophthalmus aquosus	45.7	0.242	-0.63615	0.01	3
600531	Stephanolepis cirrhifer	31.5	0.26	-0.63	0.01	3

Growth Parameters

Spiny dogfish (*Squalus acanthias*)

Yellowfin sole (*Limanda aspera*)





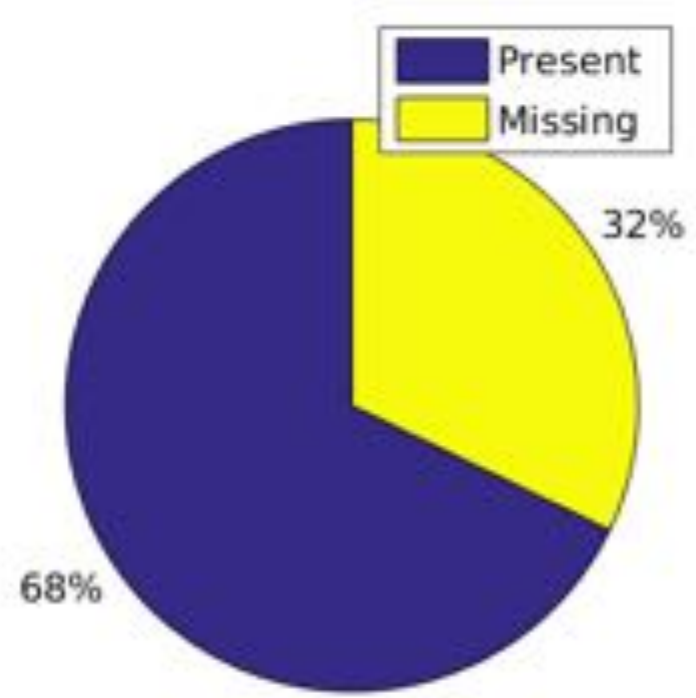
Functional Group Growth Table

- Average five parameters in taxon growth table
- Calculate weighted averages
- Catch that doesn't weight calculation:
  - Missing taxon
  - Incomplete set of parameters

$$\bar{x} = \frac{\sum_{i=1}^{d} x_i C_i}{\sum_{i=1}^{d} C_i}$$

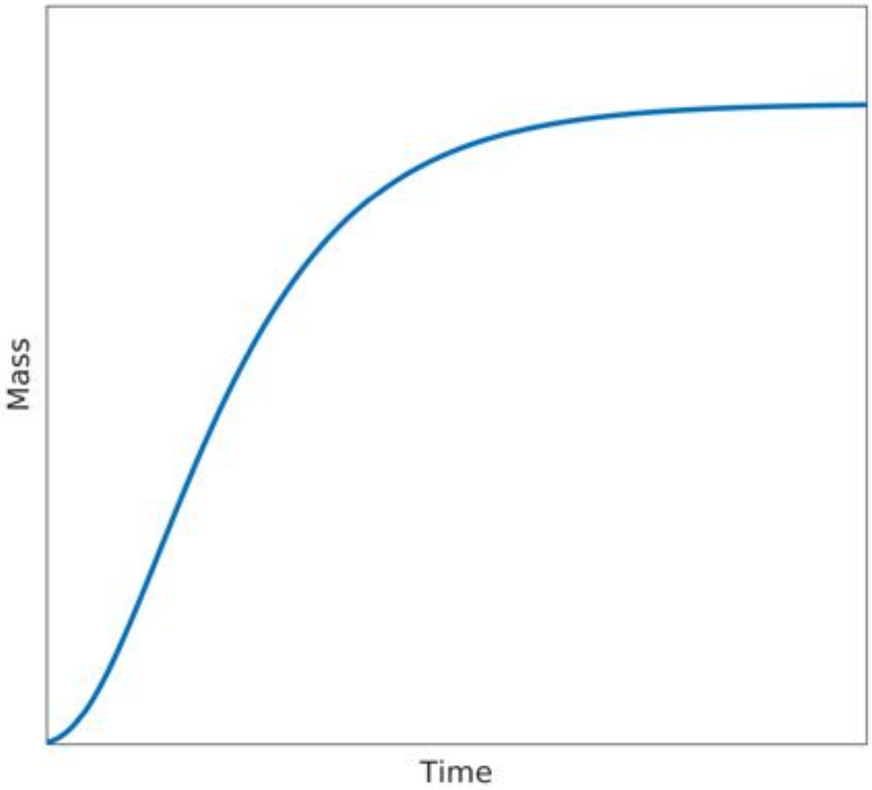
Name	Description	Size (cm)
FG0	Other	-
FG1	Small Pelagics	<30
FG2	Medium Pelagics	30-90
FG3	Large Pelagics	>=90
FG4	Small Demersals	<30
FG5	Medium Demersals	30-90
FG6	Large Demersals	>=90
FG7	Small Bathypelagics	<30
FG8	Medium Bathypelagics	30-90
FG9	Large Bathypelagics	>=90
FG10	Small Bathydemersals	<30
FG11	Medium Bathydemersals	30-90
FG12	Large Bathydemersals	>=90
FG13	Small Benthopelagics	<30
FG14	Medium Benthopelagics	30-90
FG15	Large Benthopelagics	>=90
FG16	Small Reef associated fish	<30
FG17	Medium Reef associated fish	30-90
FG18	Large Reef associated fish	>=90
FG19	Small to Medium Sharks	<90
FG20	Large Sharks	>=90
FG21	Small to Medium Rays	<90
FG22	Large Rays	>=90
FG23	Small to Medium Flatfishes	<90
FG24	Large Flatfishes	>=90
FG25	Cephalopods	-
FG26	Shrimps	-
FG27	Lobsters, Crabs	-
FG28	Jellyfish	-
FG29	Other Demersal Invertebrates	-
FG30	Krill	-

Missing Data

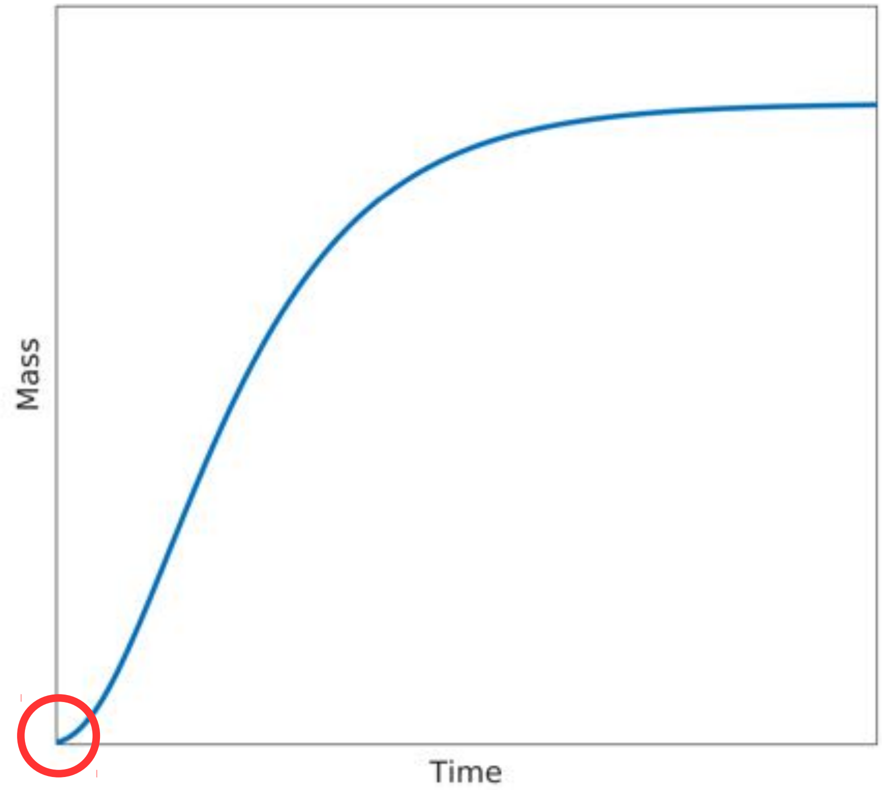


Of 1,039,675,097.2687 tonnes

Size Classes

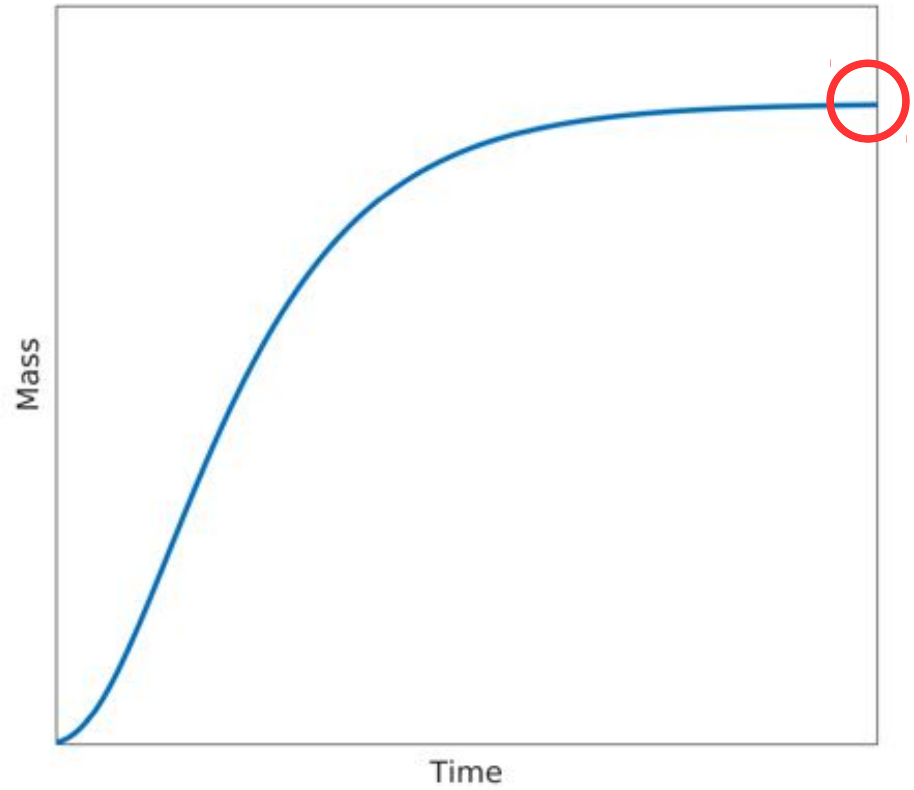


Size Classes



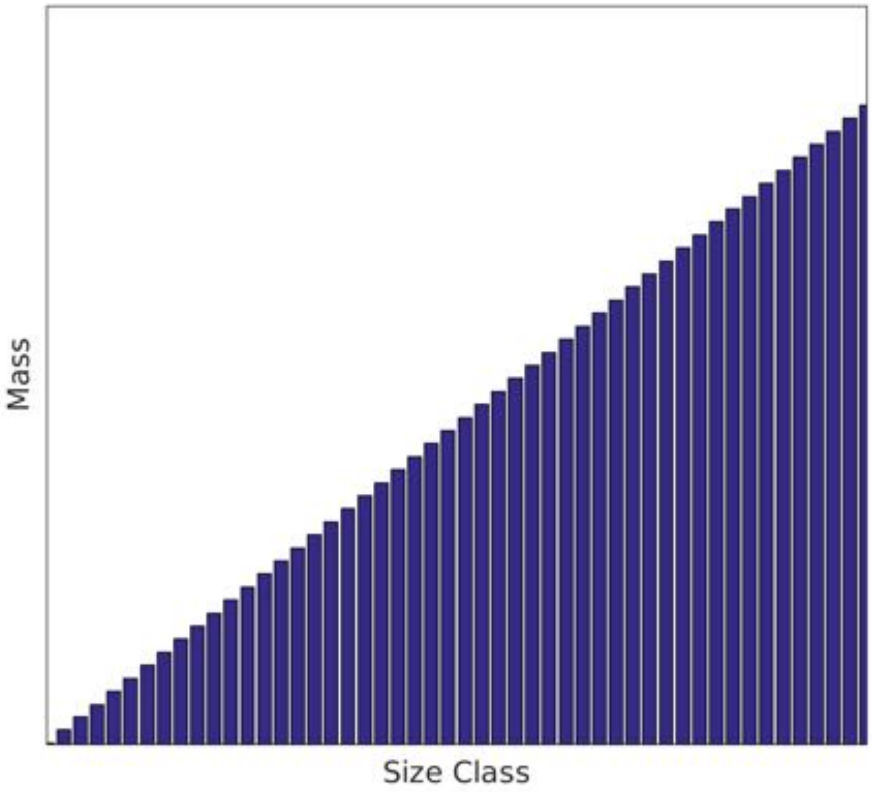
$$W = a\left(L_\infty\left(1 - e^{-K(t - t_0)}\right)\right)^b$$

Size Classes

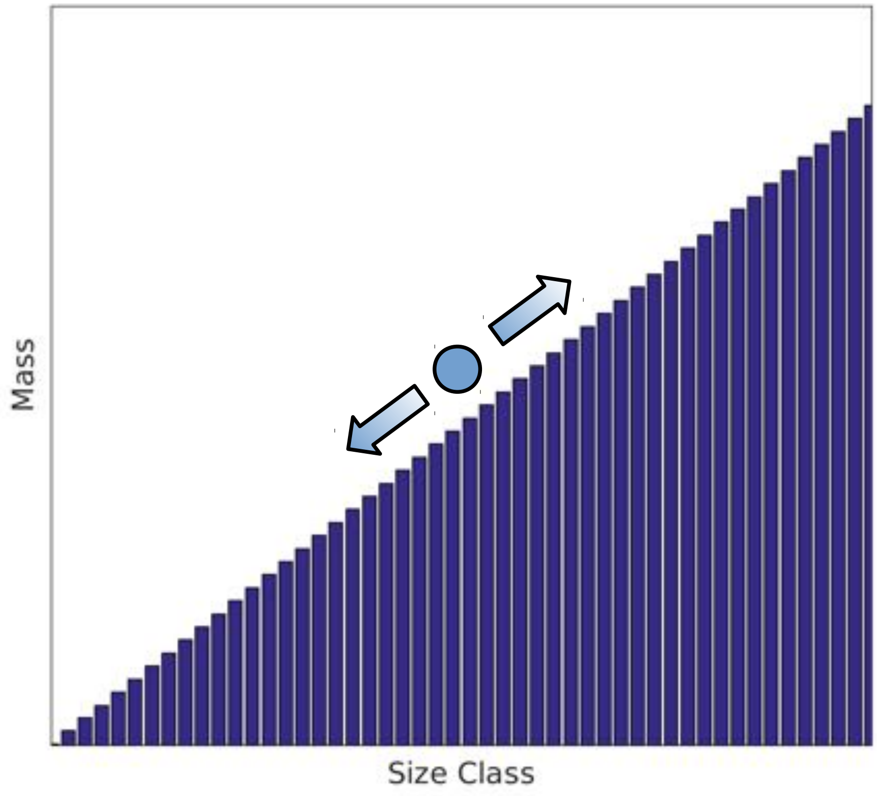


$$W = a L_{\infty}^{b}$$

Size Classes



Size Classes

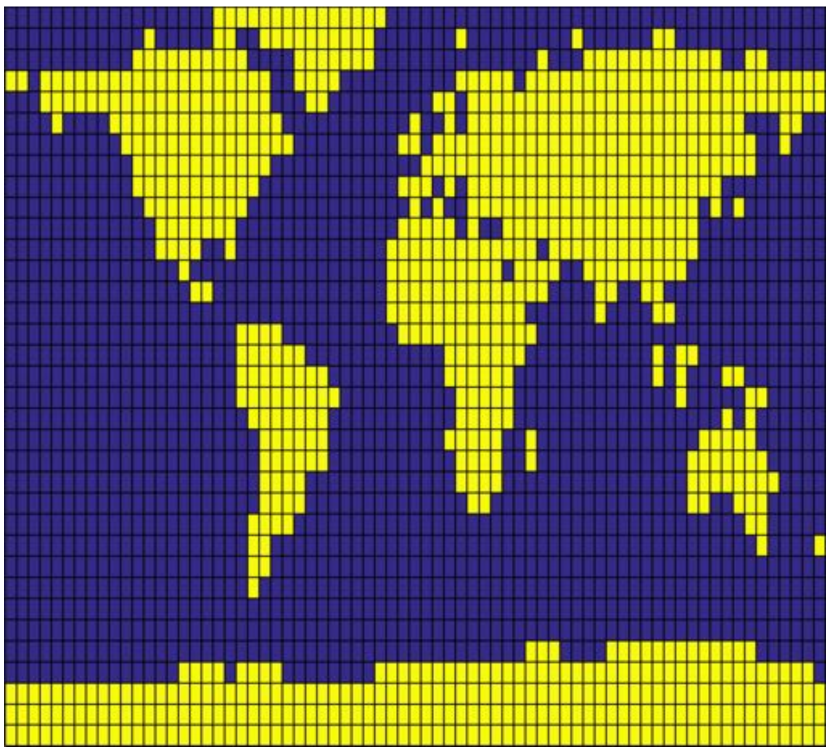


Dummy Model

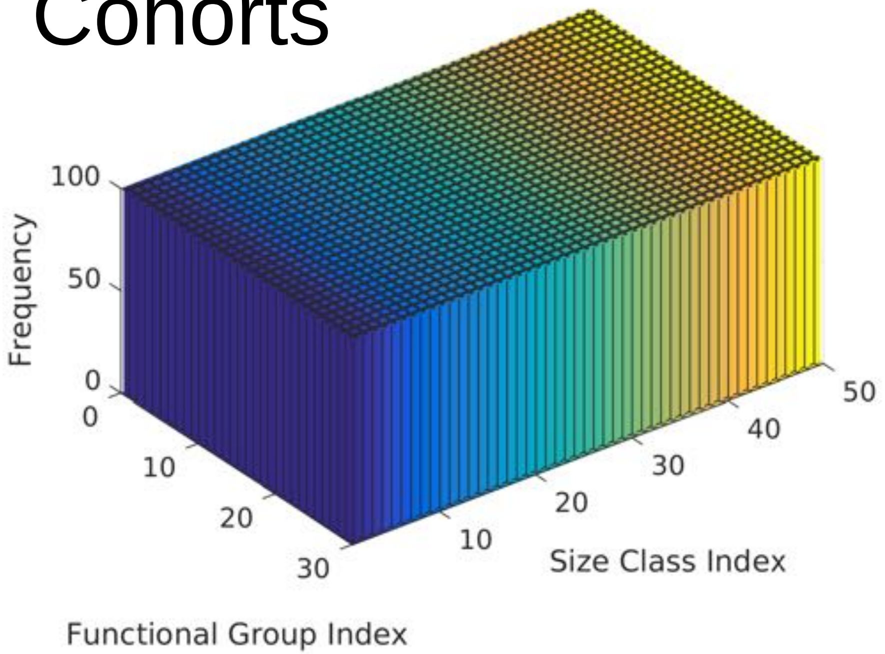
- Reads and makes input data available
- Instantiates model grid
- Populates grid cells with cohorts
  - No ecological processes
  - Fished cohorts remain in place
- Writes output data to file

Dummy Model

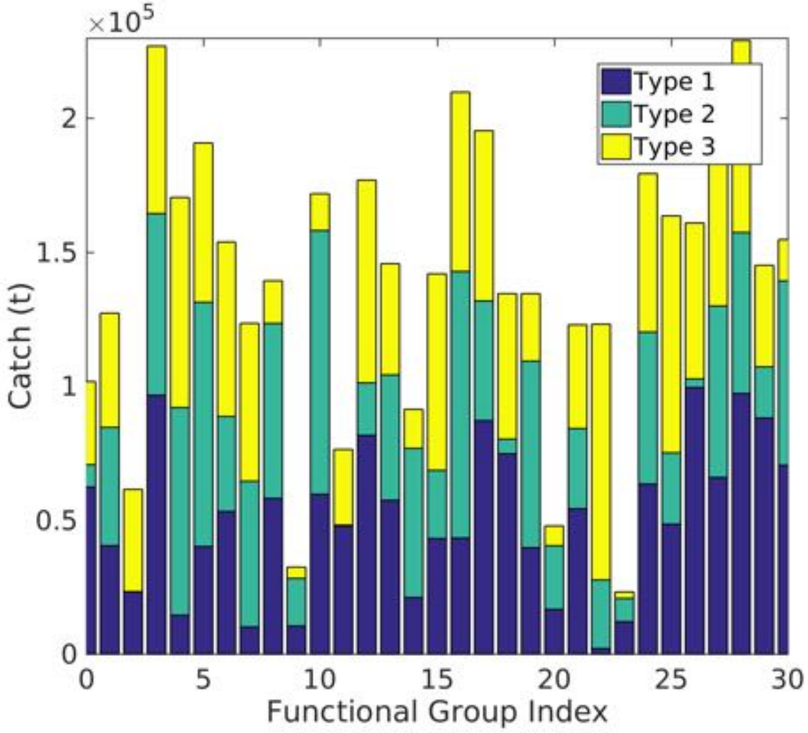
Model Grid

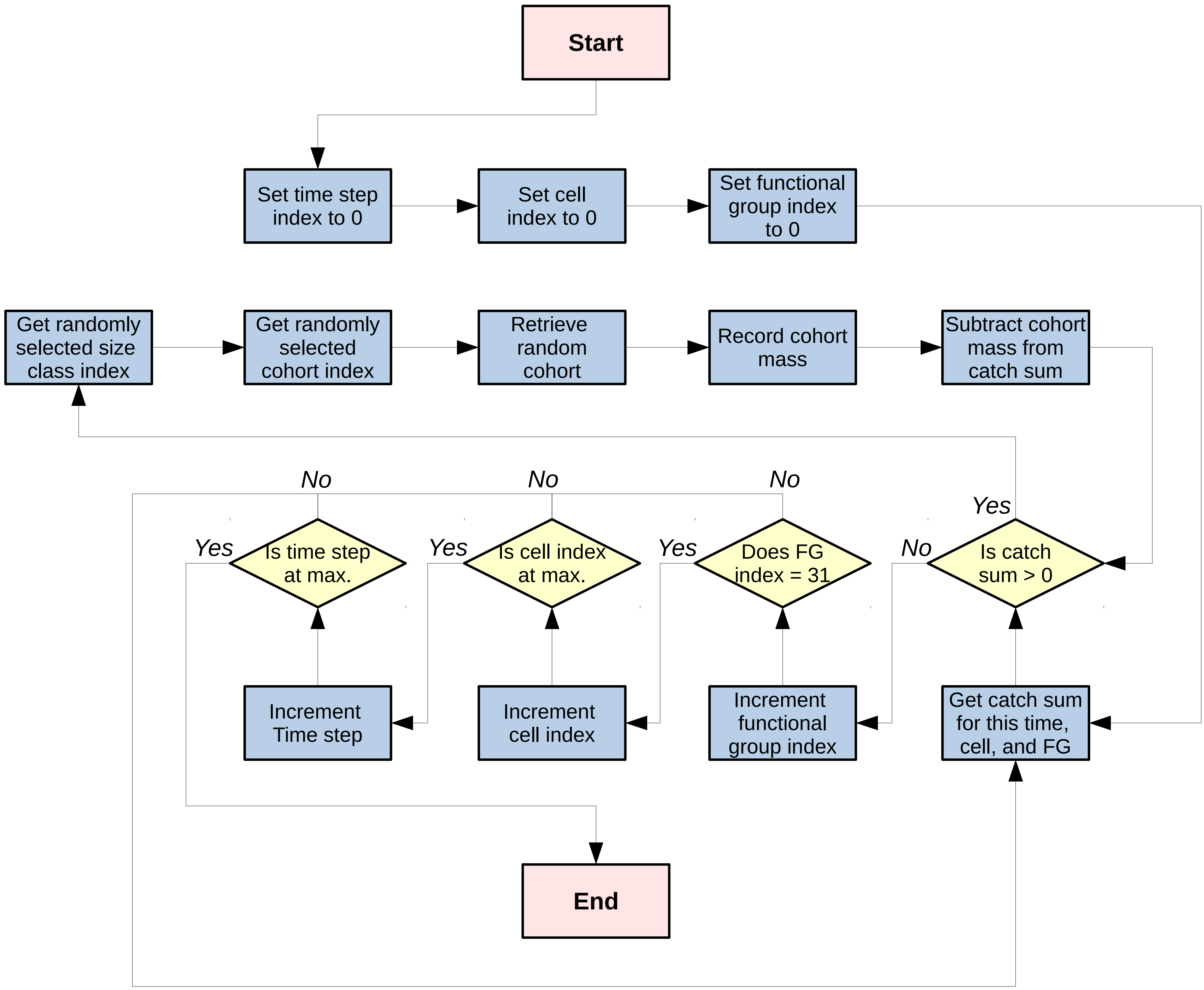


Cohorts

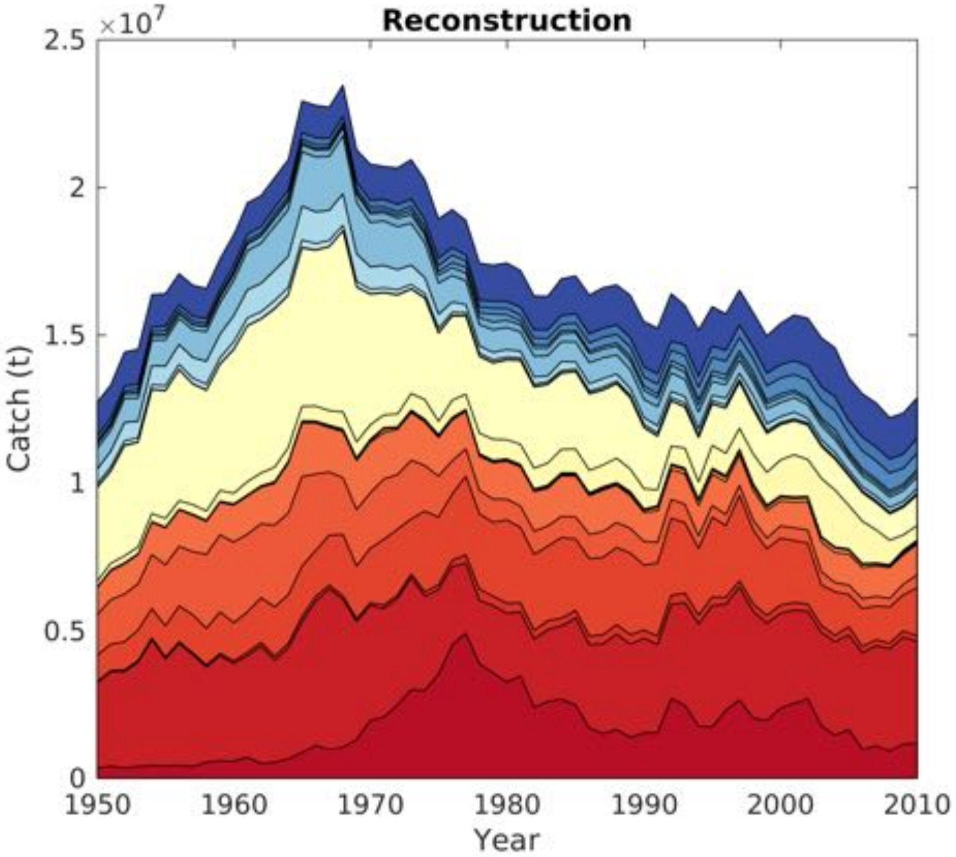


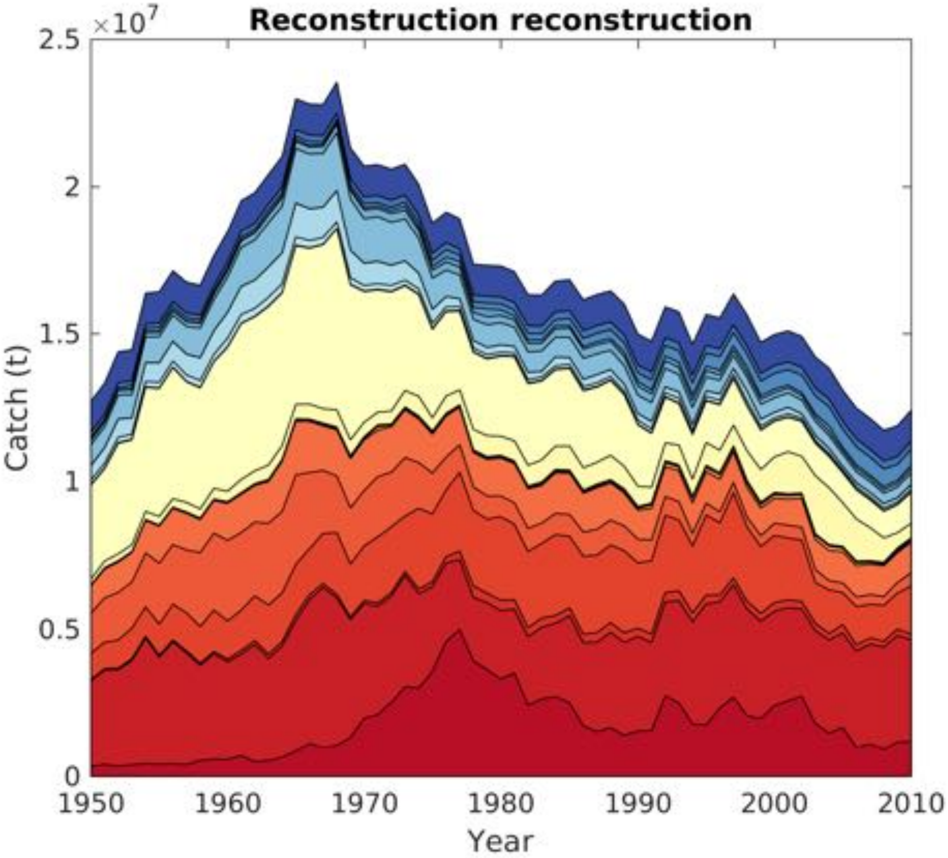
Catch Data



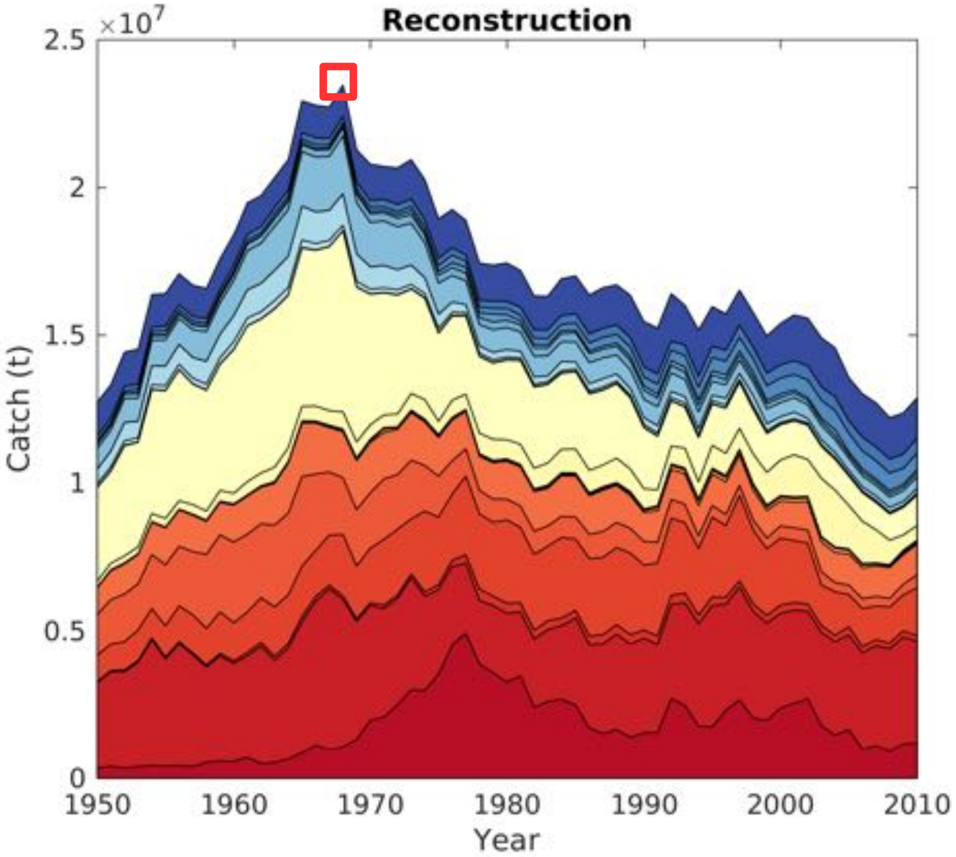

Start
Set time step index to 0
Set cell index to 0
Set functional group index to 0
Get randomly selected size class index
Get randomly selected cohort index
Retrieve random cohort
Record cohort mass
Subtract cohort mass from catch sum
No
No
No
Yes
Yes
Is time step at max.
Yes
Is cell index at max.
Yes
Does FG index = 31
No
Is catch sum > 0
Increment Time step
Increment cell index
Increment functional group index
Get catch sum for this time, cell, and FG
End

Results

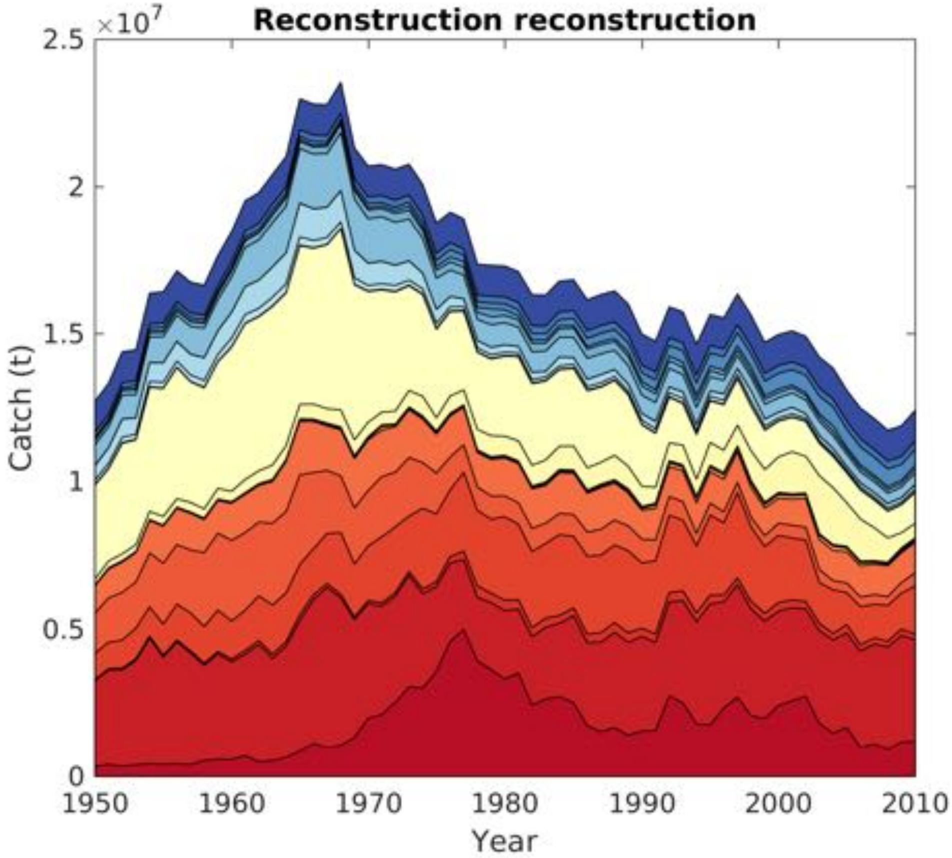

Reconstruction
×10^7
2.5
2
1.5
1
0.5
0
Catch (t)
1950
1960
1970
1980
1990
2000
2010
Year


Reconstruction reconstruction
×10^7
2.5
2
1.5
1
0.5
0
Catch (t)
1950
1960
1970
1980
1990
2000
2010
Year

Results

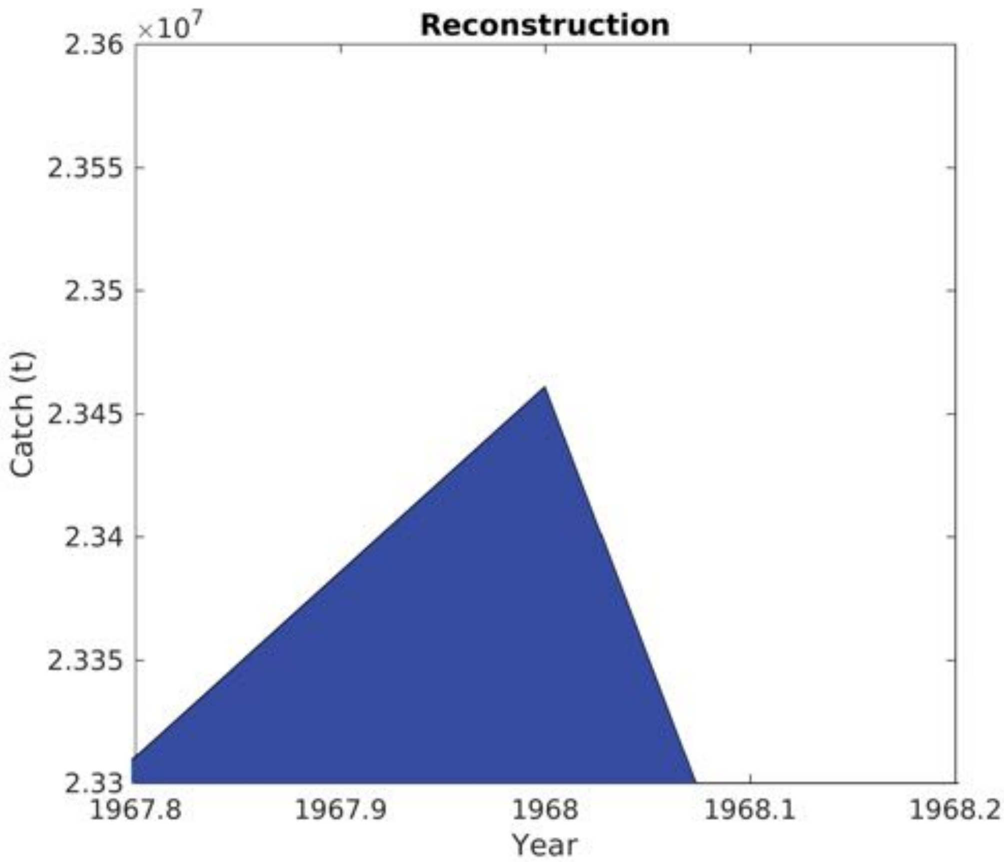


Reconstruction
$\times10^7$
2.5
2
1.5
1
0.5
0
Catch (t)
1950
1960
1970
1980
1990
2000
2010
Year

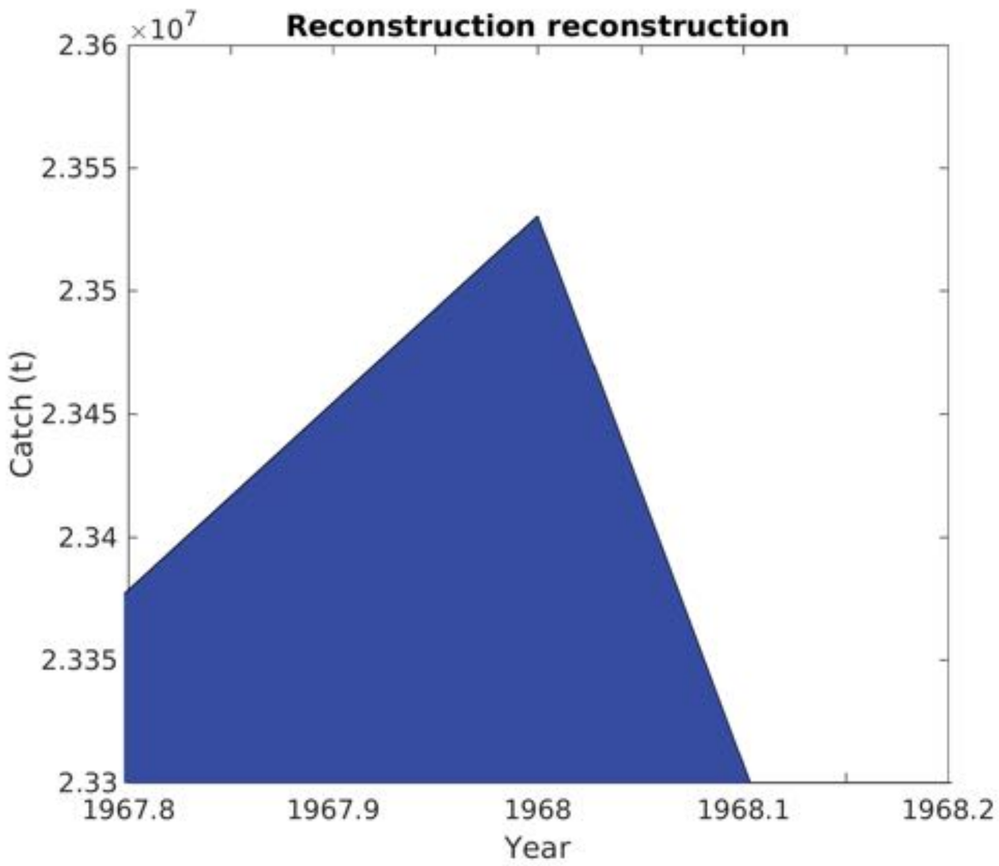


Reconstruction reconstruction
$\times10^7$
2.5
2
1.5
1
0.5
0
Catch (t)
1950
1960
1970
1980
1990
2000
2010
Year

Results



Reconstruction
$\times 10^7$
2.36
2.355
2.35
2.345
2.34
2.335
2.33
Catch (t)
1967.8
1967.9
1968
1968.1
1968.2
Year



Reconstruction reconstruction
$\times 10^7$
2.36
2.355
2.35
2.345
2.34
2.335
2.33
Catch (t)
1967.8
1967.9
1968
1968.1
1968.2
Year

Areas For Development

- Fished size-class based on technology
- Bathymetry and habitat affinity attribute
- Division between commercially and non-commercially exploited species
  - 2.2 million marine species*
  - 2.55 thousand species in SAUP taxon table
  - Critical to stability of modelled system

*Mora et al. (2011). PLoS Biology, 9(8).

Thank You!

Acknowledgements

- The Nippon Foundation and the Nereus Program
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- Rebecca Asch and Charlie Stock
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