Marine ecosystem modelling

Using an end-to-end model to test ecosystem models

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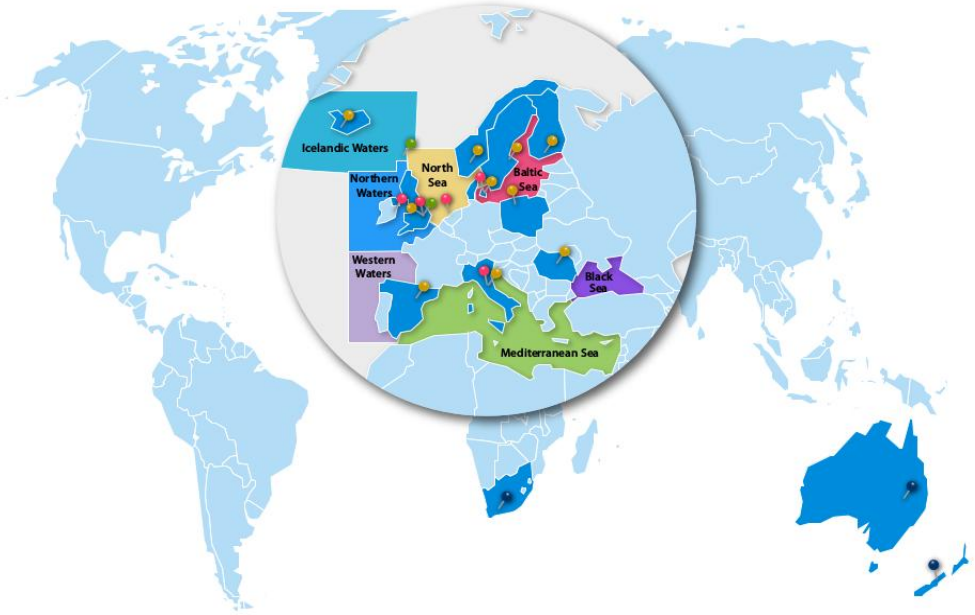
MareFrame

MINOUW

Ecosystem Approach to Fisheries Management

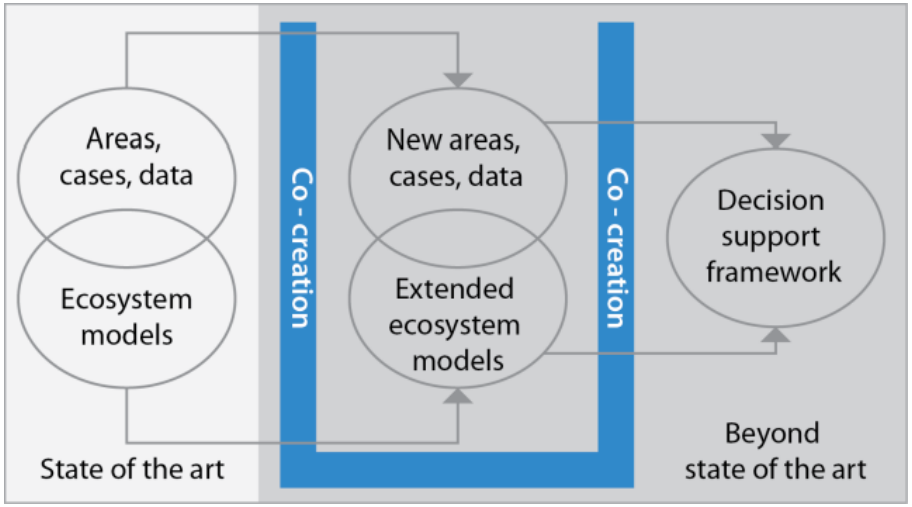
- **Fisheries management today**
  - Single species stock assessment
  - Effect of fishing on target species
- **EAFM**
  - Effect of fishing on the ecosystem
  - Multi-species or ecosystem models
  - Socio-economic factors

The MareFrame Project



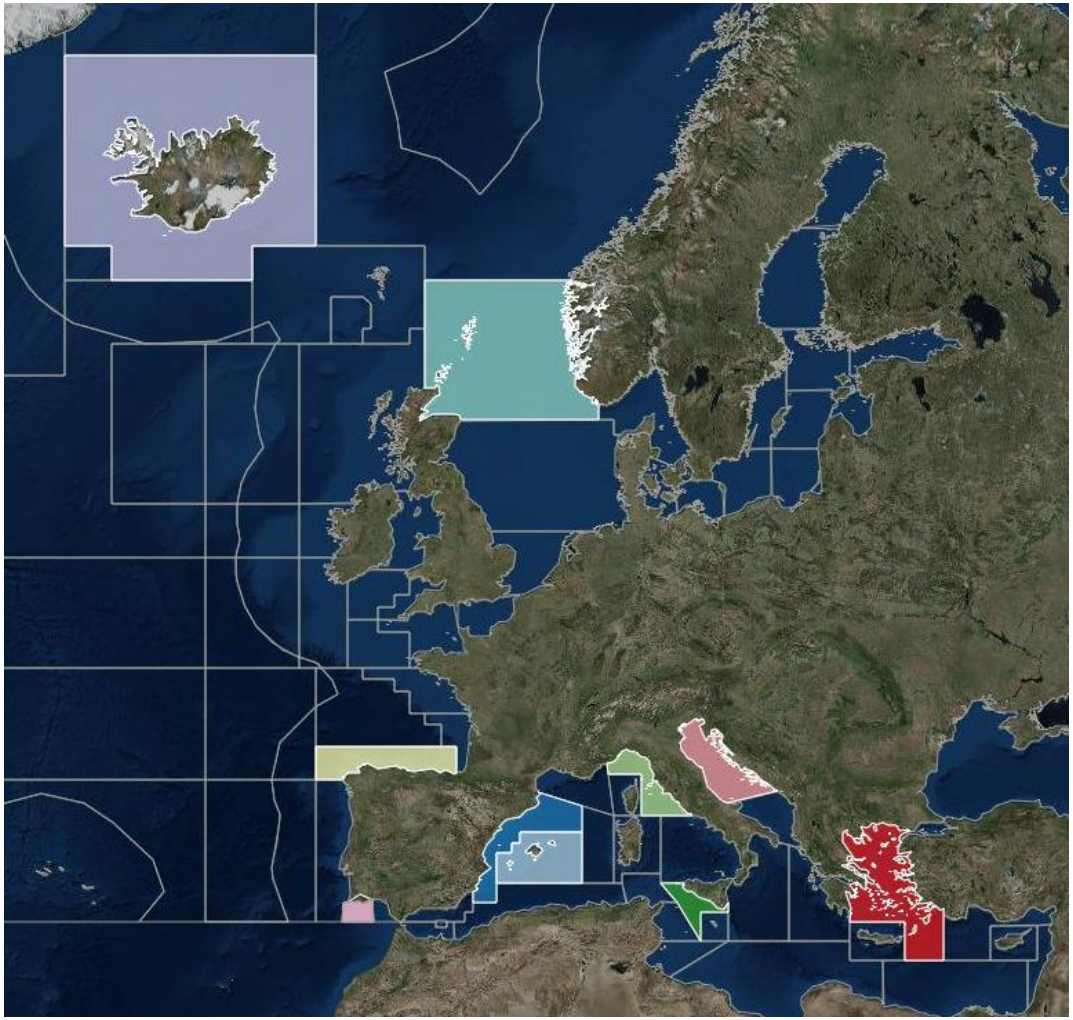
- **28 partners in 14 countries on 3 continents**

- **Aim: improve the science that supports EAFM**

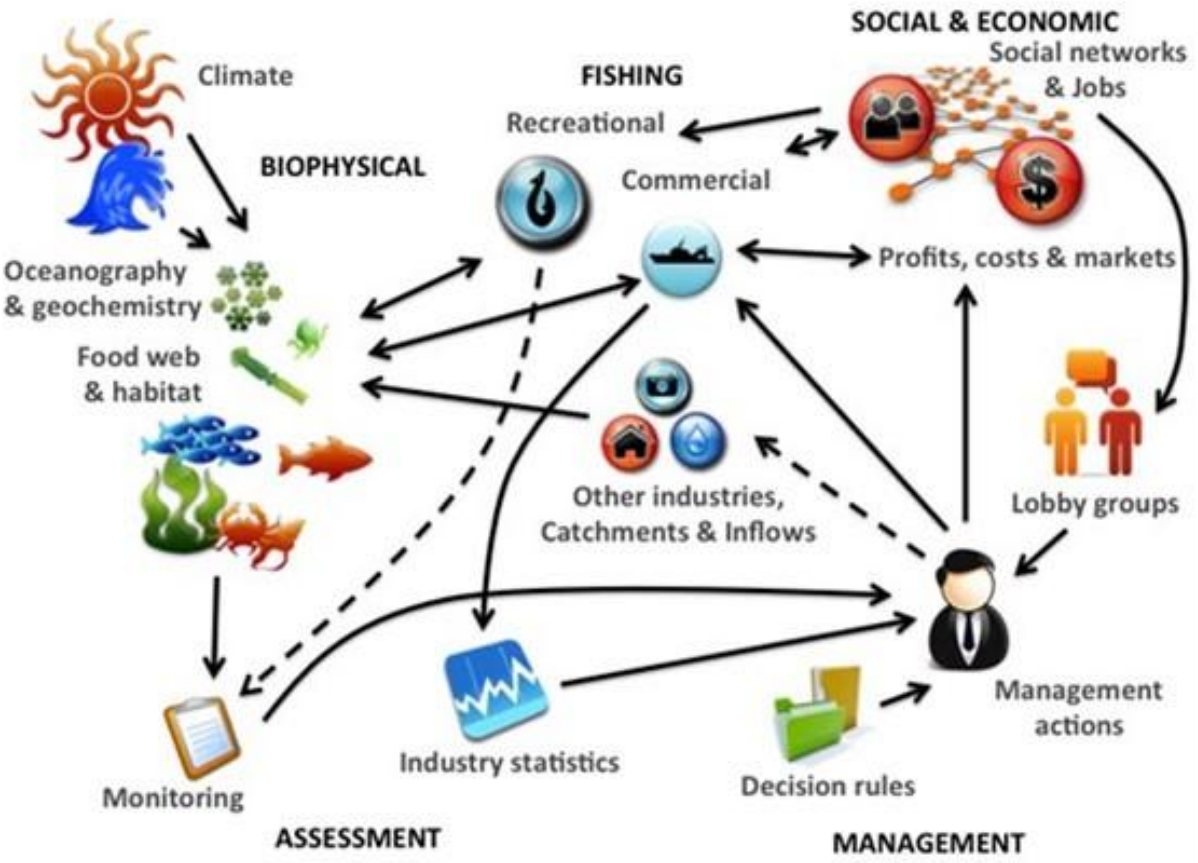


The Minouw Project

- 15 partners in 10 countries.
- Aim: minimize unwanted catches and discards



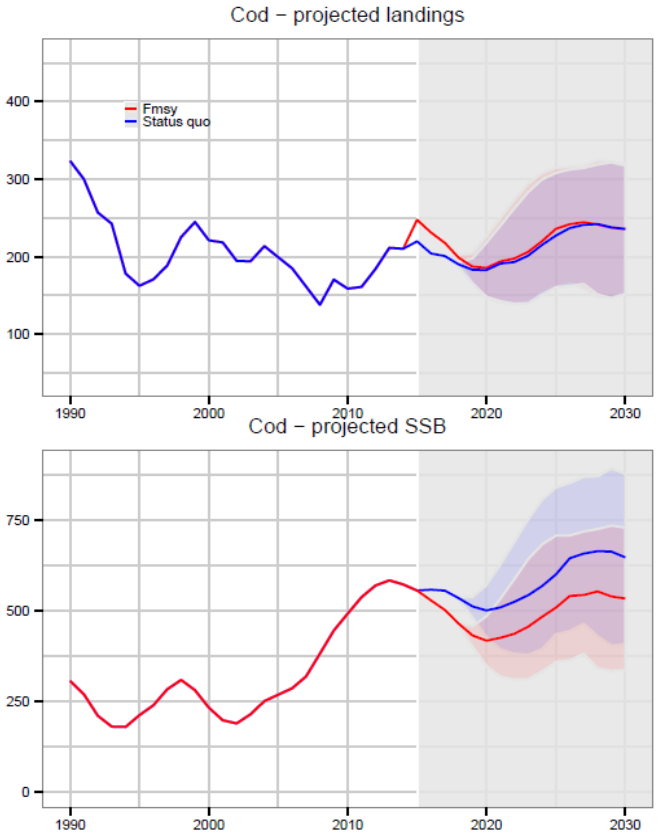
Marine Ecosystem Modelling



From Beth Fulton, CSIRO, Australia

How can ecosystem models be used in EAFM?

- **Improve understanding**
- **Forecasting scenarios**
  - Change in fishing pressure
  - Increased nutrient load
  - Change in water temperature
- **Quantify trade-offs**
- **Decision and policy making**



The modelling frameworks

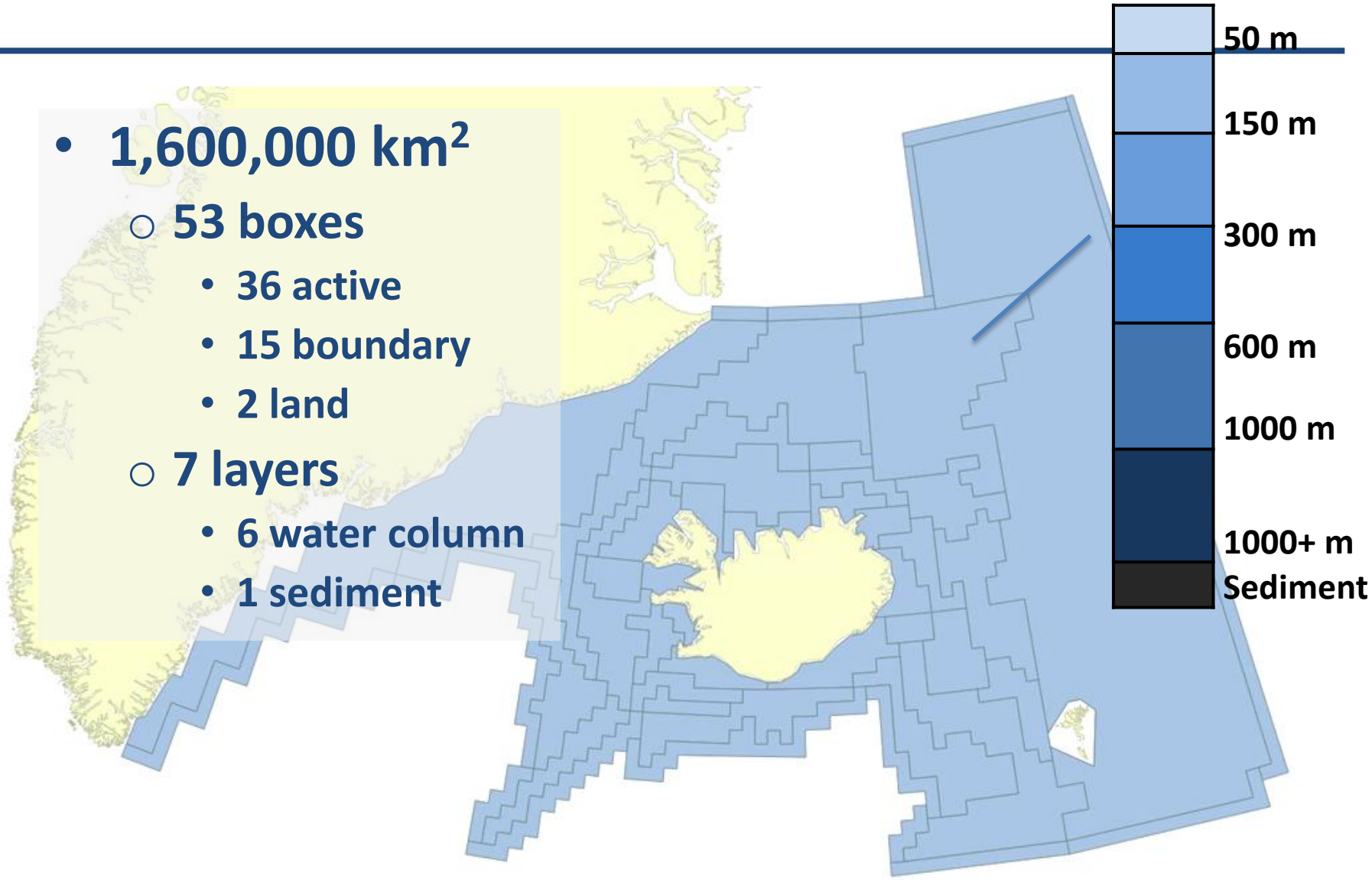
- **Atlantis: end-to-end model**
- **Ecopath with Ecosim (EwE): food web model**
- **Globally applicable Area Disaggregated General Ecosystem Toolbox (Gadget): multi-species model**

Atlantis

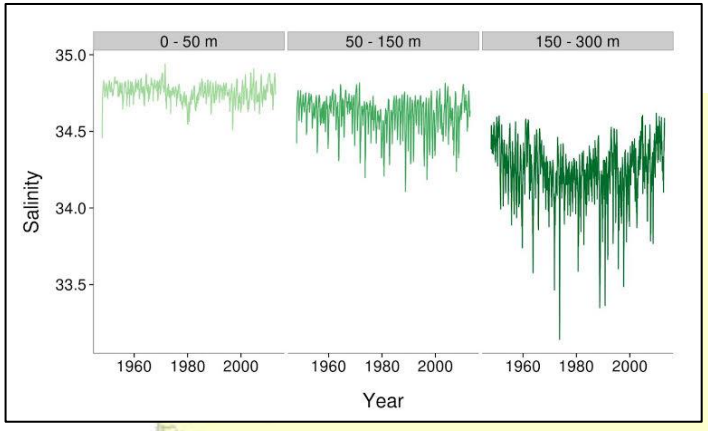
- Simulates the entire ecosystem
- Ecosystem model
- Fisheries model
- Sampling and assessment model
- Management model
- Socio-economic model

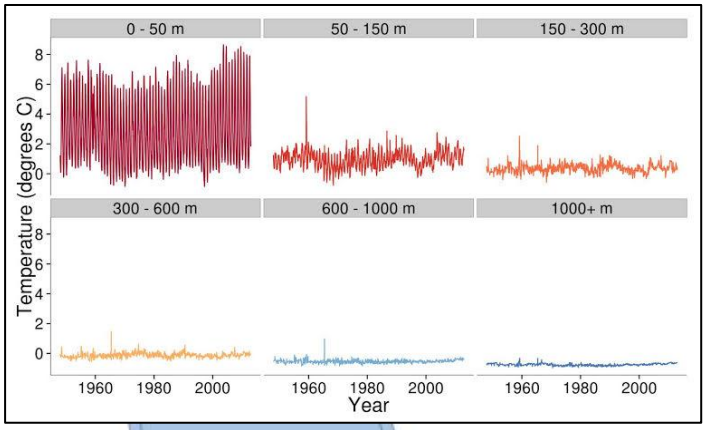
The Icelandic Atlantis model

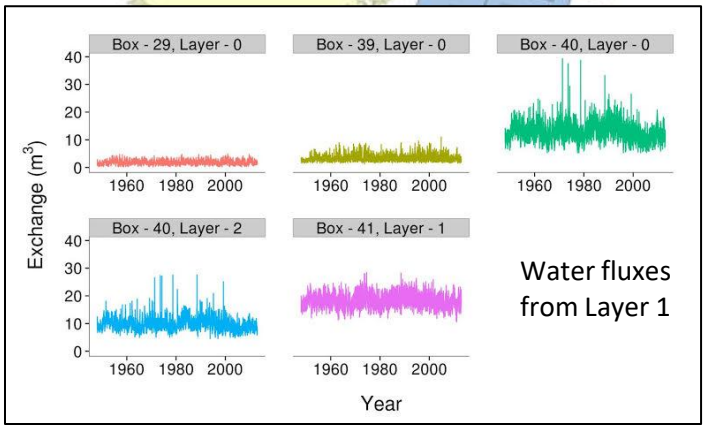
- 1,600,000 km^2
  - 53 boxes
    - 36 active
    - 15 boundary
    - 2 land
  - 7 layers
    - 6 water column
    - 1 sediment



The oceanography model





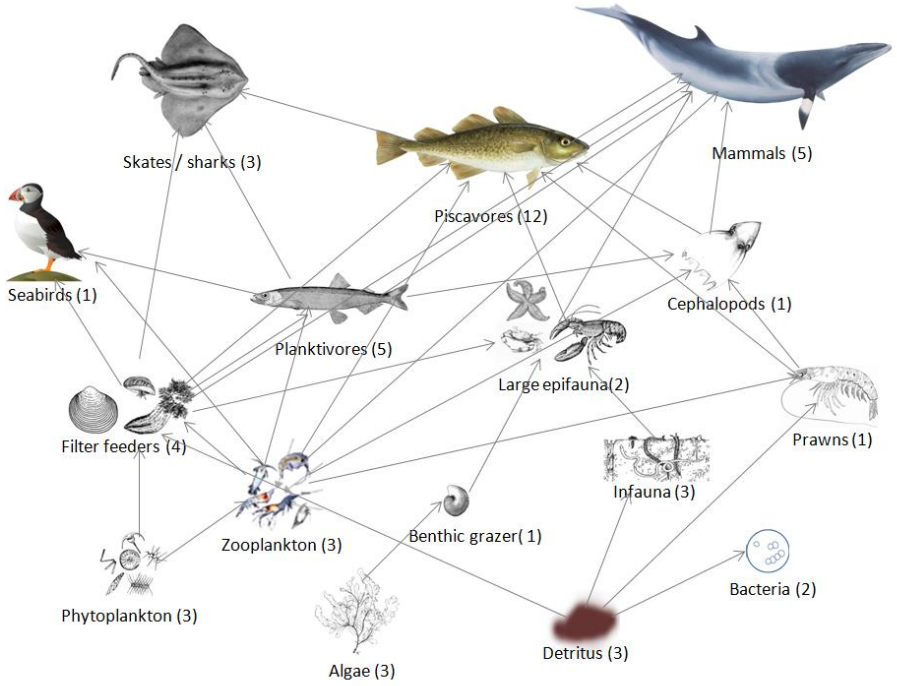


The biology model

- Functional groups
- Consumption
- Predation
- Growth
- Reproduction
- Movement
- Migration

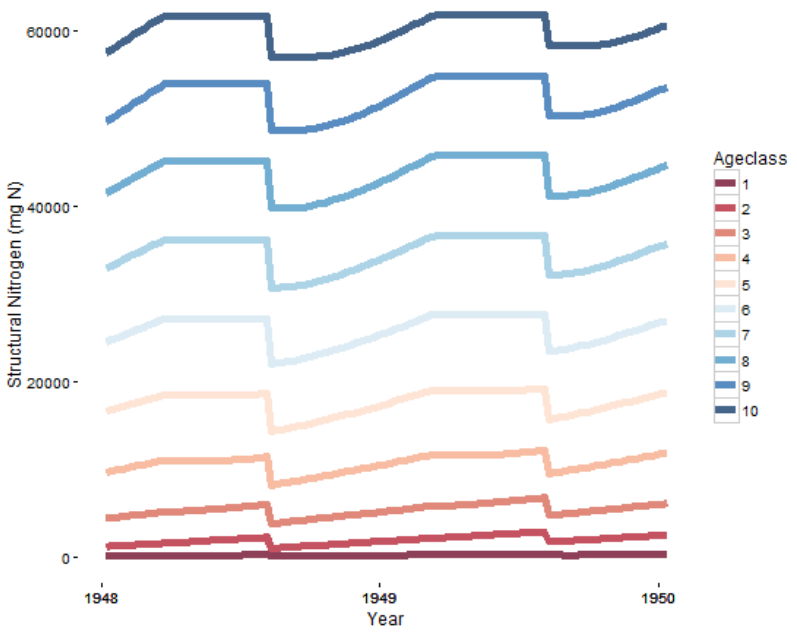
The functional groups

- 52 functional group
  - 25 vertebrates
    - 16 fish
    - 3 shark/skates
    - 5 mammal
    - 1 seabird
  - 16 invertebrate groups
  - 6 primary producers
  - 2 bacteria
  - 3 detritus



The biology model

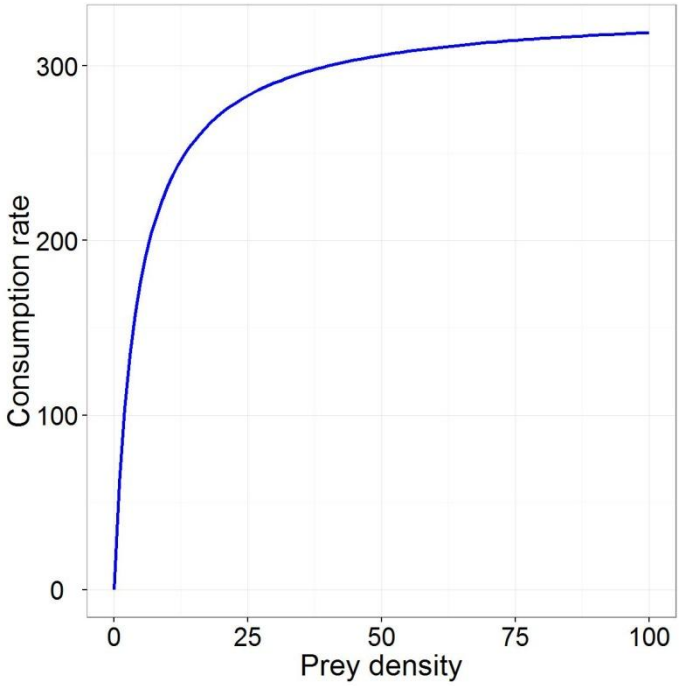
- Vertebrates
  - 10 age classes
    - Numbers per age within ageclass
  - Weight in mg N per individual
    - Reserved weight
    - Structural weight
- Invertebrates
  - 2 ageclasses
  - Biomass pools mg N m^{-3}



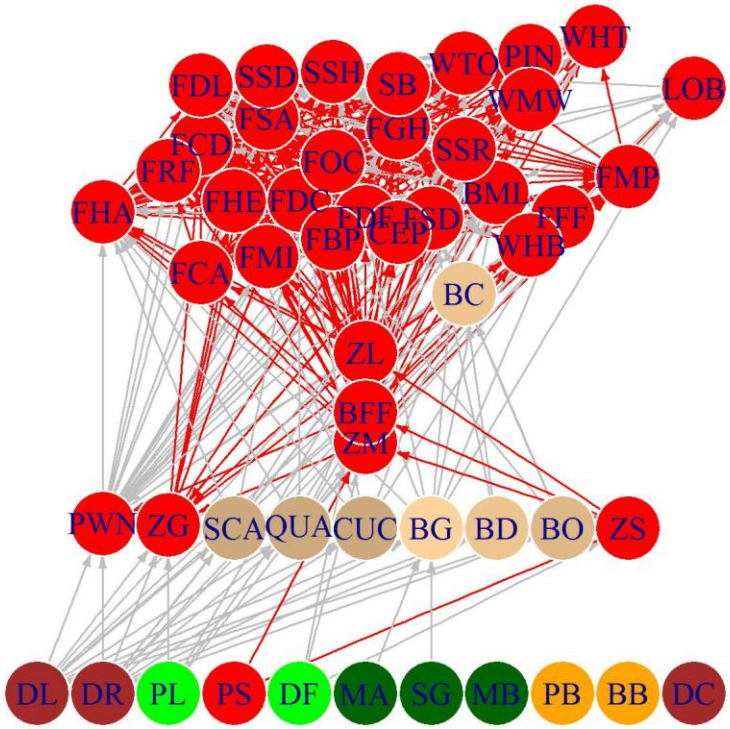
Consumption

- Holling type II
- Gape limitation
- Spatial overlap
- Prey availability

$$Q_{ij} = \frac{a_{ij} \cdot Prey_i \cdot C_j}{1 + \frac{C_j}{\mu_j} \sum_k Prey_k \cdot \epsilon_{ij} \cdot a_{ij}}$$



Food web from the Atlantis model

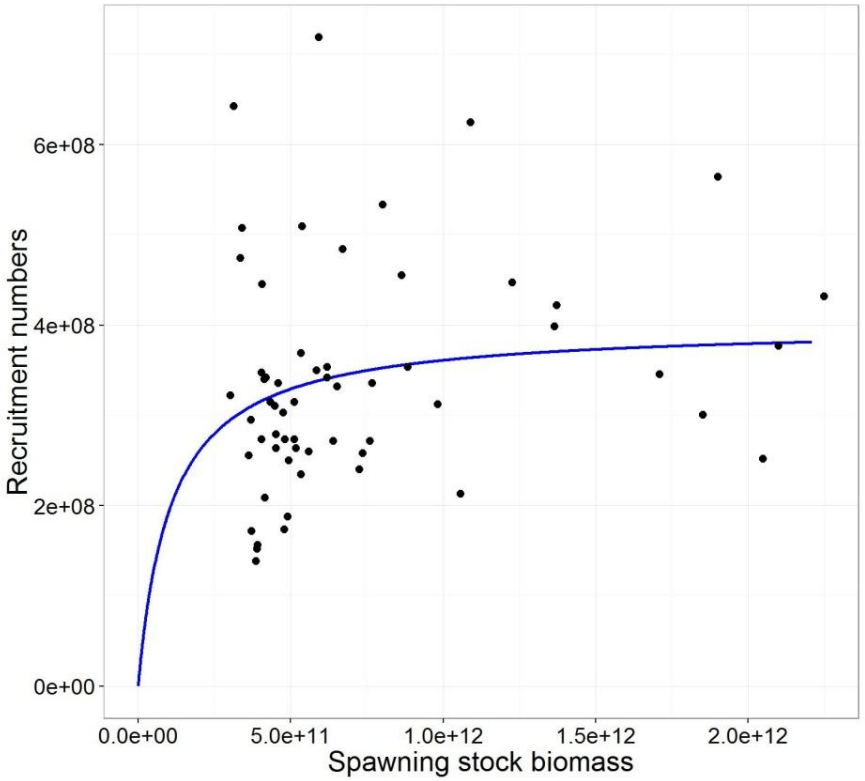


- Fish
- Seabird
- Mammals
- Shark/Skates
- Detritus
- Phytoplankton
- Algae
- Bacteria
- Cephalopods
- Prawns
- Zooplankton
- Large benthos
- Benthos

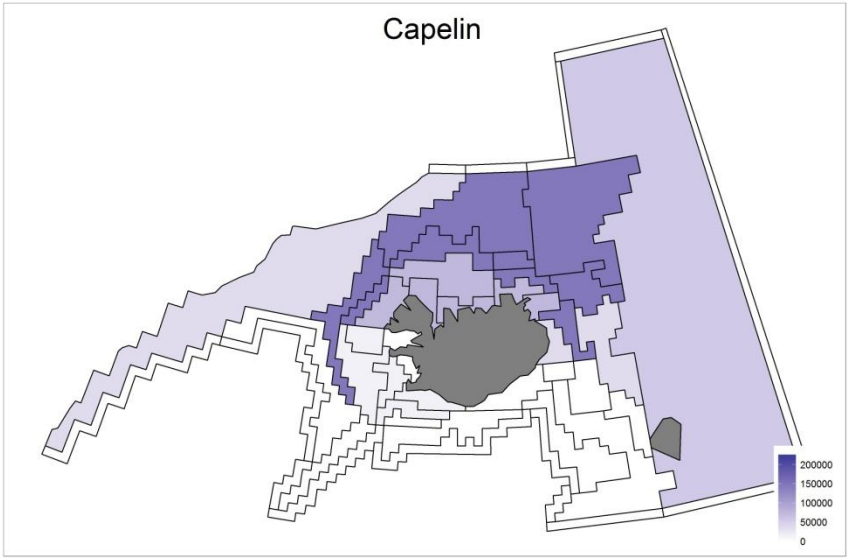
Reproduction

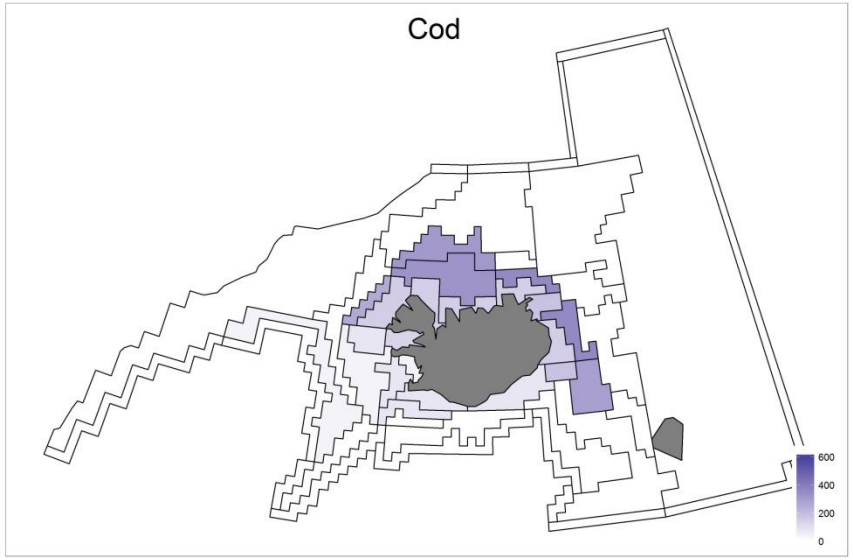
- **Fixed number per adult**
- **Beverton – Holt**

$$N_{\mathrm{Rec}} = \frac{SSB \cdot \alpha}{\beta + SSB}$$



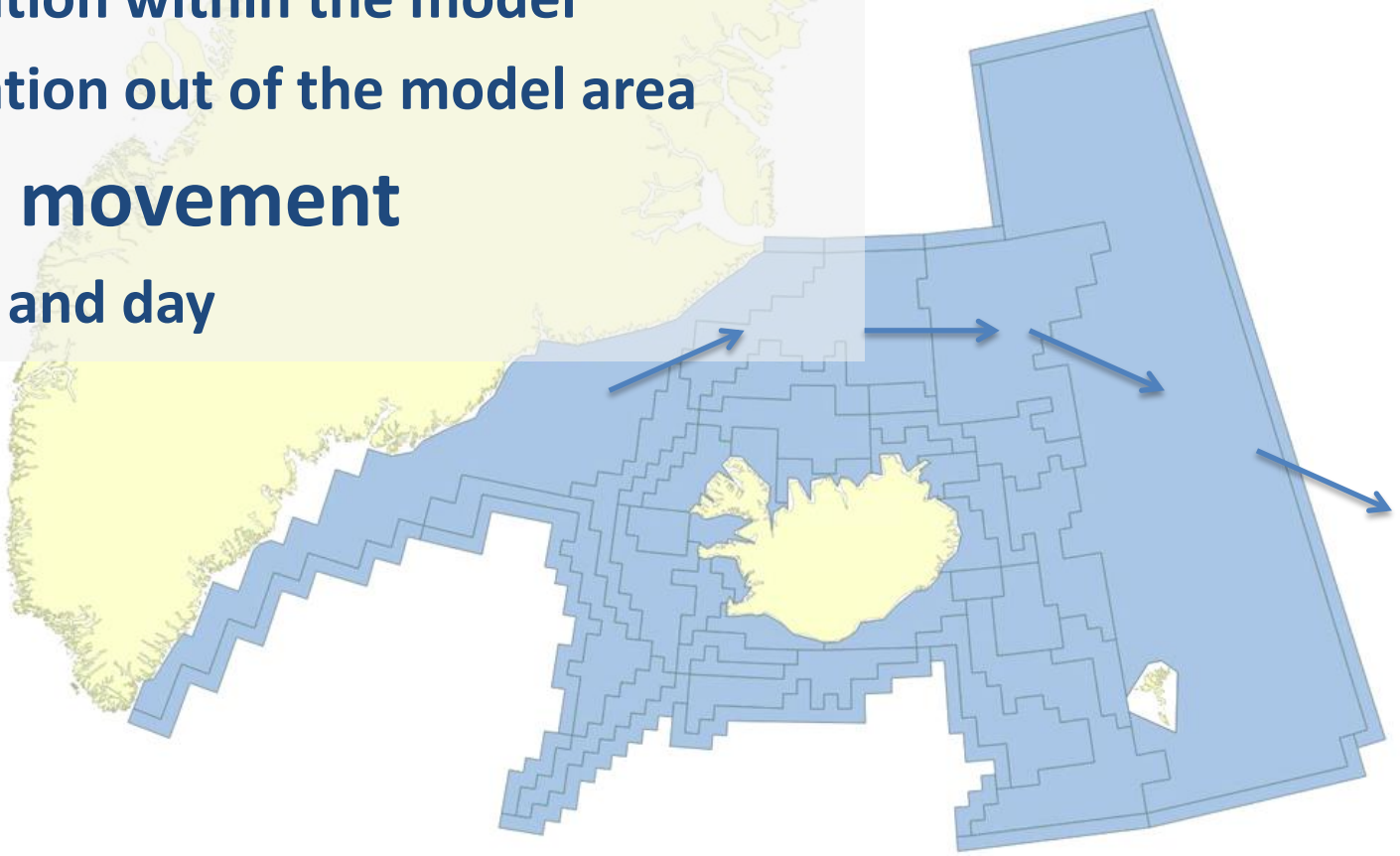
Spatial distribution



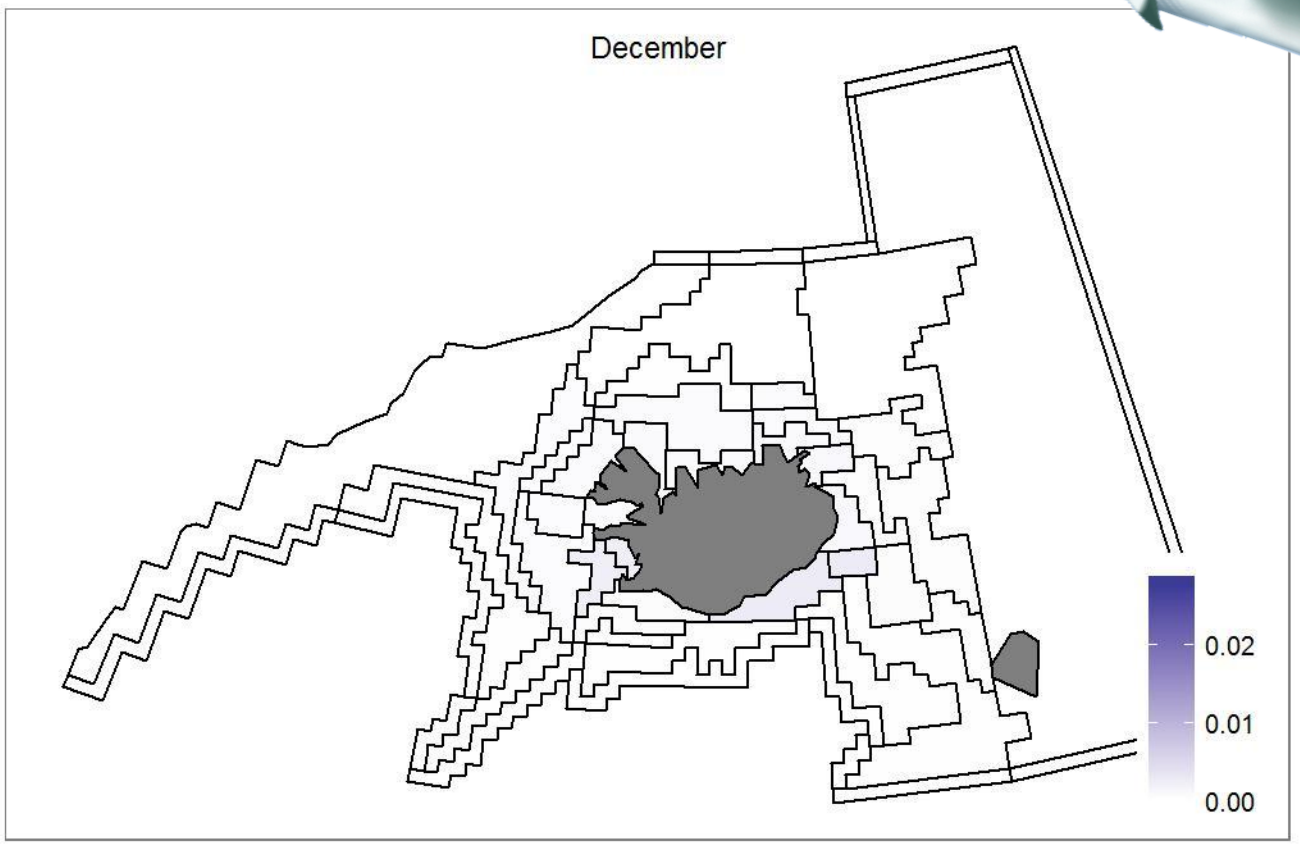


Migration and movement

- Horizontal movement
  - Migration within the model
  - Migration out of the model area
- Vertical movement
  - Night and day



Migration of Minke Whale



The fisheries model

- **Fisheries**
  - **Multiple fleets**
    - **Gear**
    - **Target**
    - **Selectivity**


Photo: Sigurður Bergþórsson


Photo: Magnús Jónsson

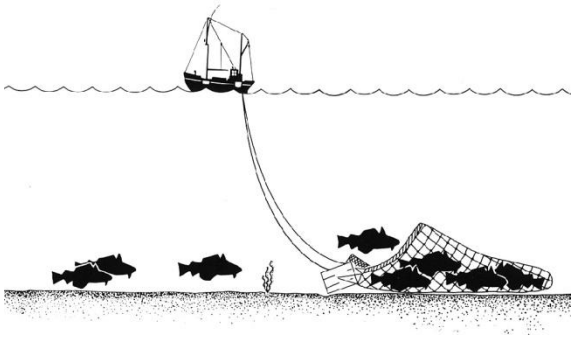

Photo Vinnslustöðin

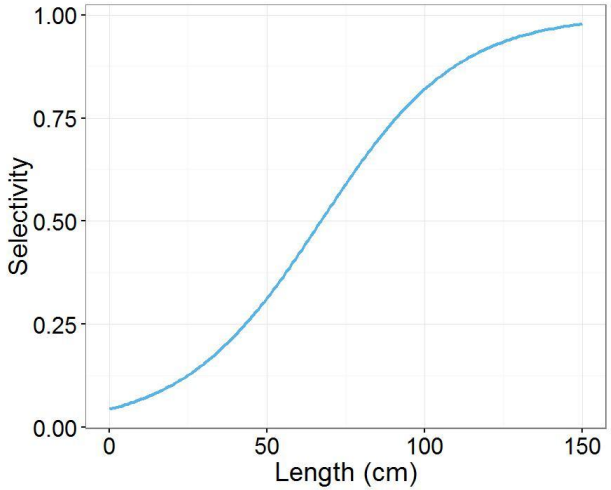
Fishing fleets

- Longline
- Gillnet
- Handline
- Purse seine
- Danish seine
- Midwater trawl
- Bottom trawl
- Shrimp trawl
- Lobster traps
- Dredge
- Whaling

Fishing

Fishing gear → Selectivity → Harvest rate → Catch biomass

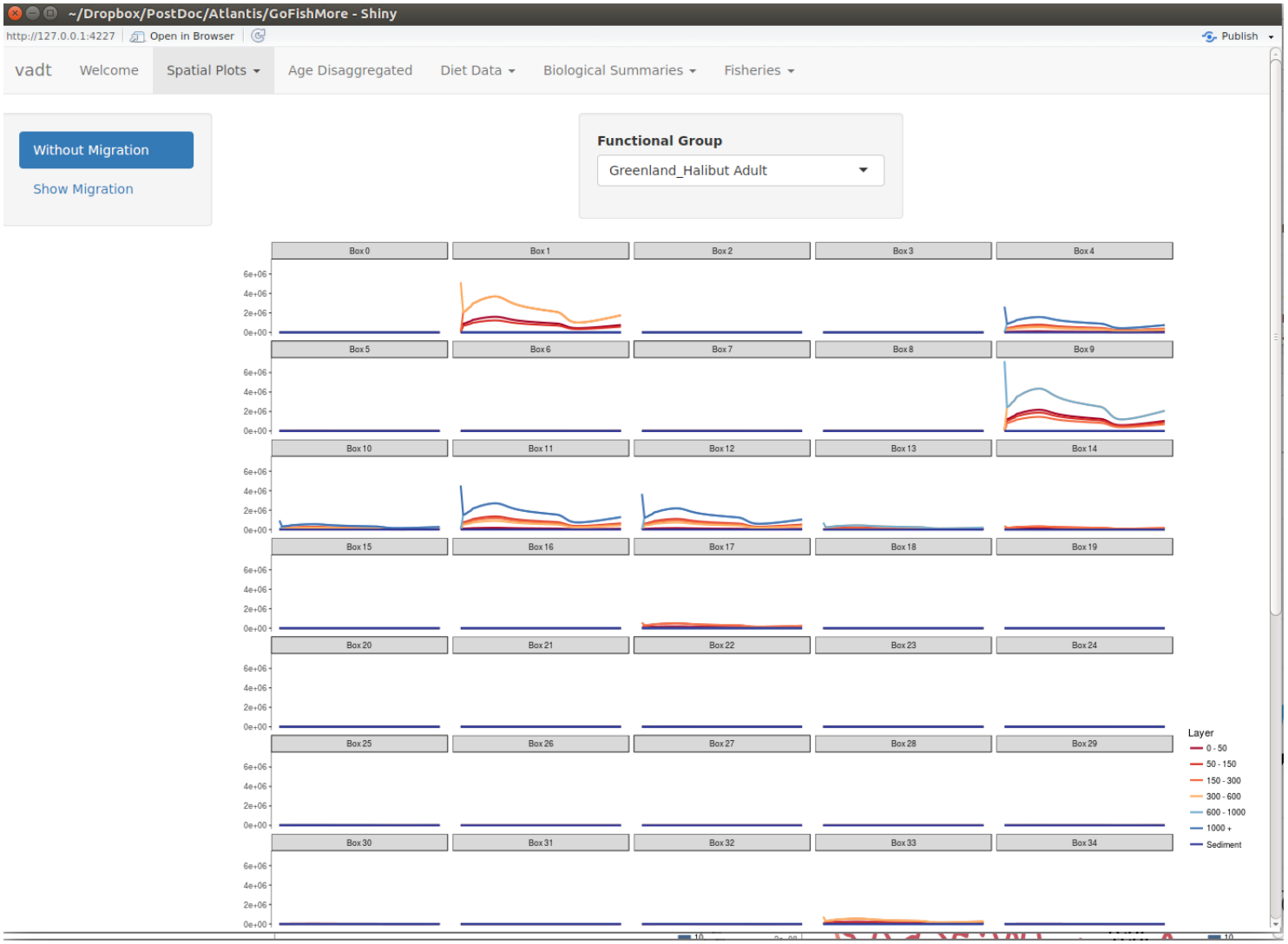




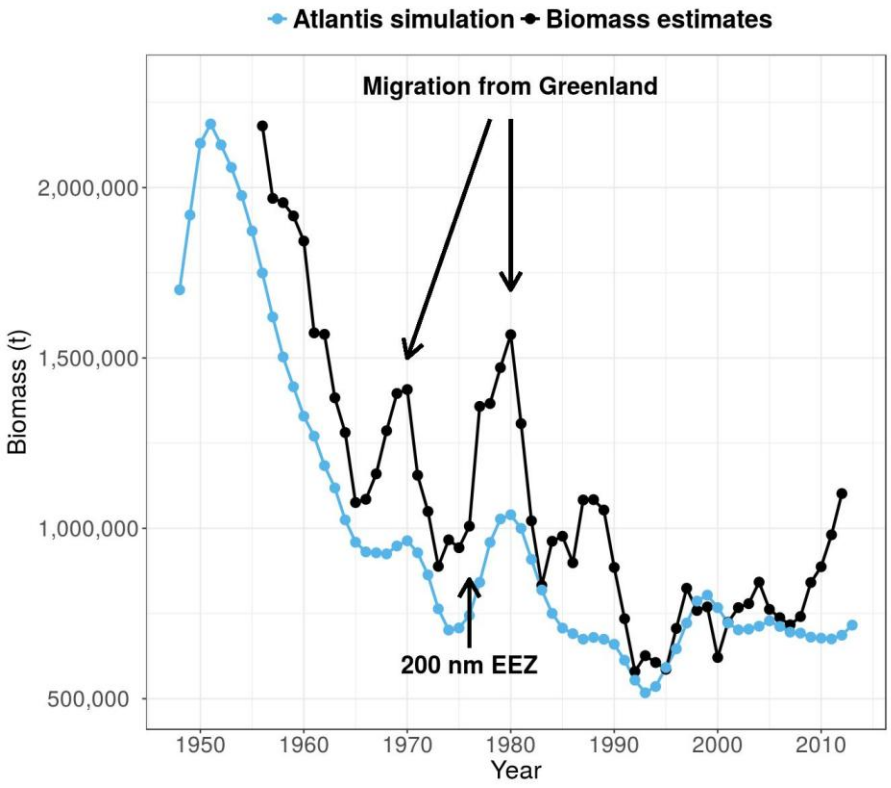
Building the model

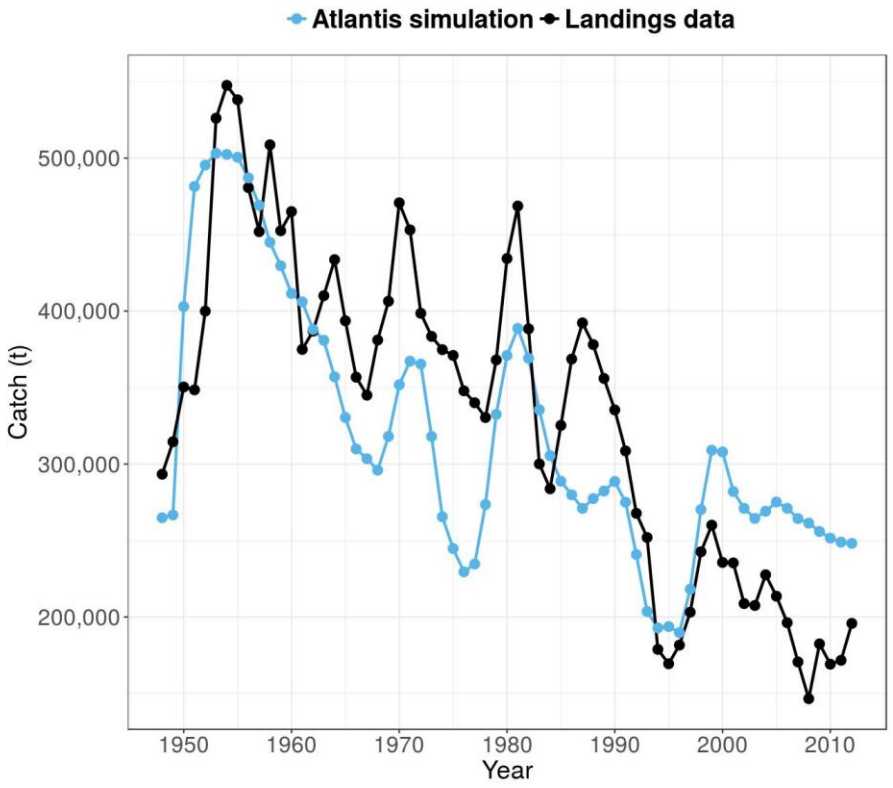
- **Survey data from MRI used**
  - Only available for the commercial species
  - Biomass estimates from single stock assessments
- **Logbooks**
  - Information about each tow
- **Parameters estimted outside of the model**
  - Recruitment curve
  - Growth curve
  - Length-weight relationship
  - Selectivity
- **A lot of tuning and debugging!**

Visualizing the output with Shiny app in R

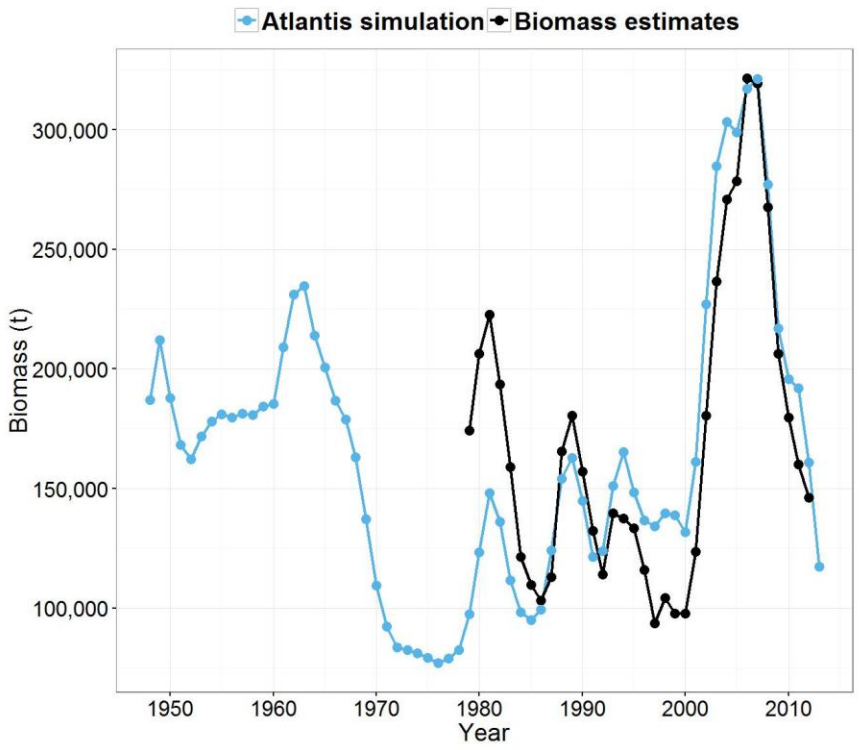


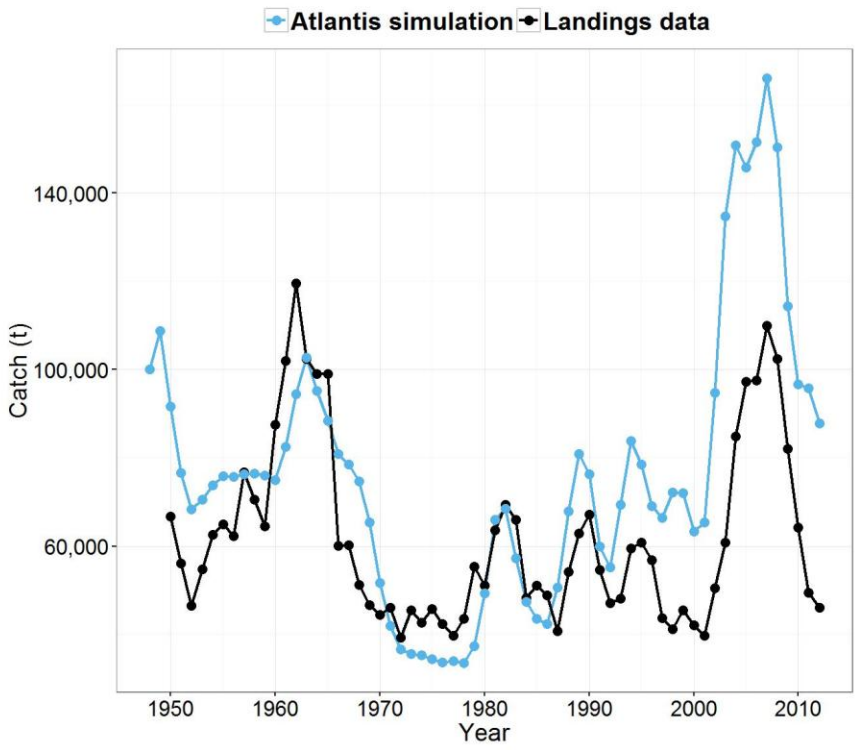
Cod


Atlantis simulation
Biomass estimates
Migration from Greenland
200 nm EEZ
Biomass (t)
2,000,000
1,500,000
1,000,000
500,000
1950
1960
1970
1980
1990
2000
2010
Year

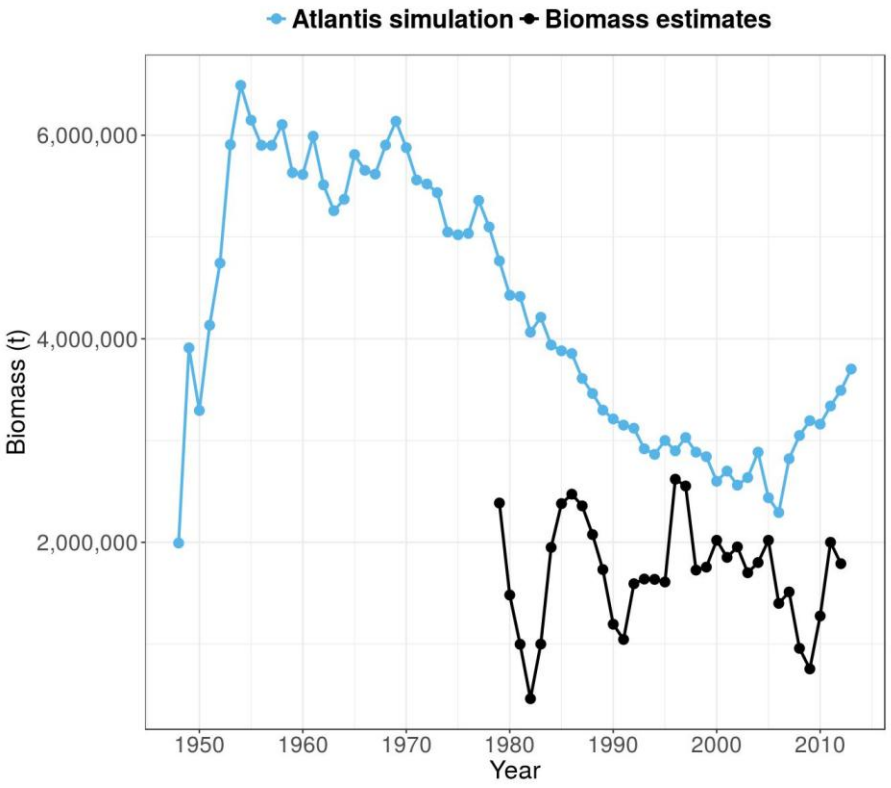

Atlantis simulation
Landings data
Catch (t)
500,000
400,000
300,000
200,000
1950
1960
1970
1980
1990
2000
2010
Year

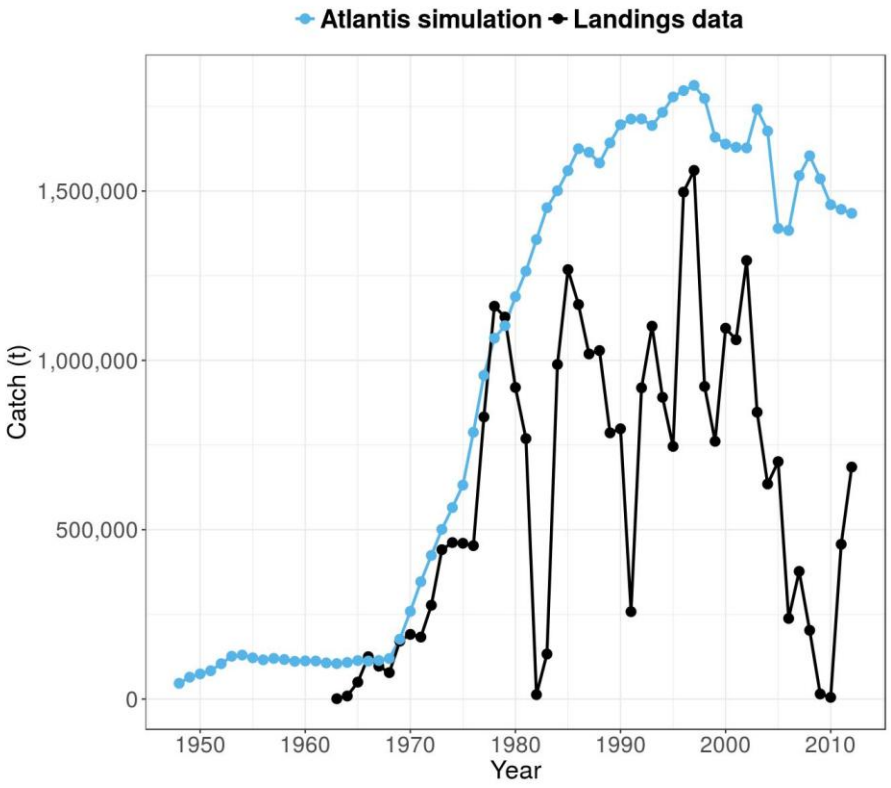
Haddock


Atlantis simulation
Biomass estimates
Biomass (t)
300,000
250,000
200,000
150,000
100,000
1950
1960
1970
1980
1990
2000
2010
Year


Atlantis simulation
Landings data
Catch (t)
140,000
100,000
60,000
1950
1960
1970
1980
1990
2000
2010
Year

Capelin


Atlantis simulation
Biomass estimates
Biomass (t)
6,000,000
4,000,000
2,000,000
1950
1960
1970
1980
1990
2000
2010
Year

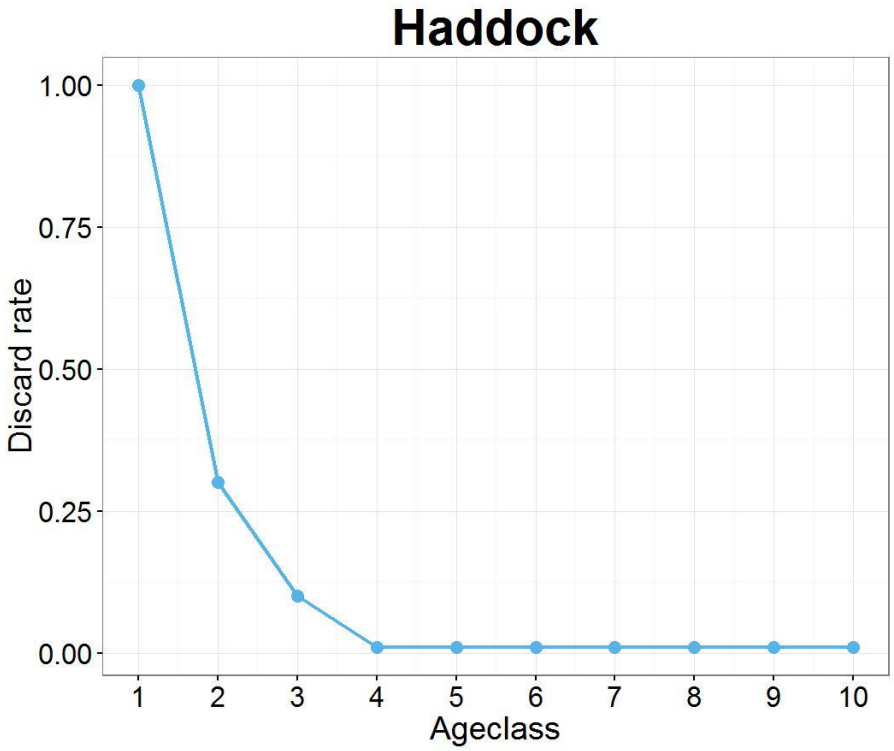

Atlantis simulation
Landings data
Catch (t)
1,500,000
1,000,000
500,000
0
1950
1960
1970
1980
1990
2000
2010
Year

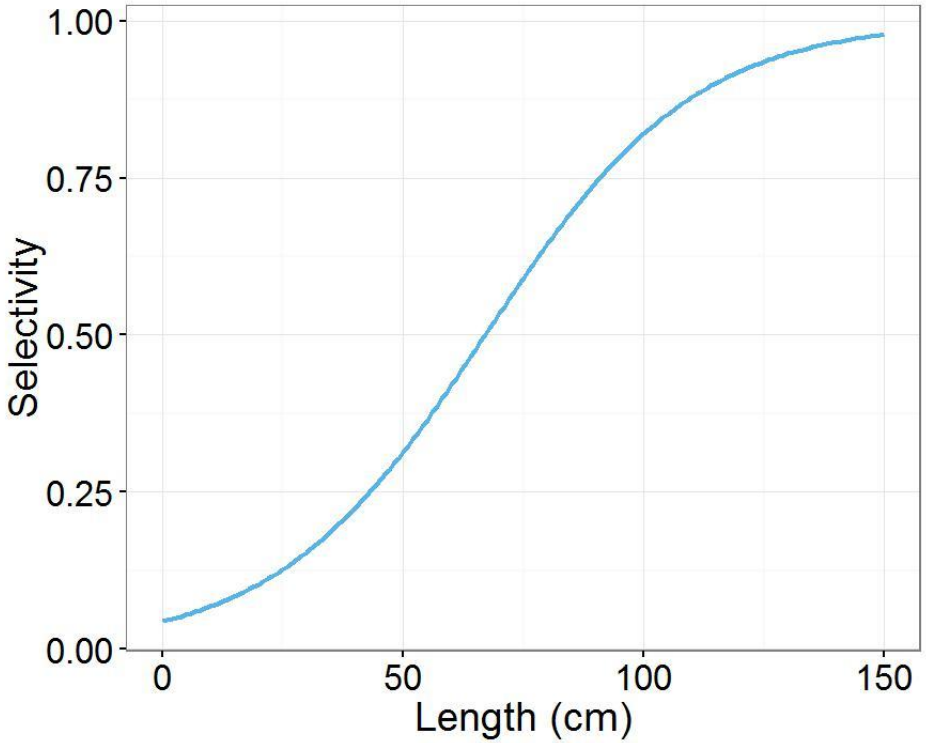
Discards

- Constant
- Constant per age class
- Size based
- Discard survival
- Discarded waste

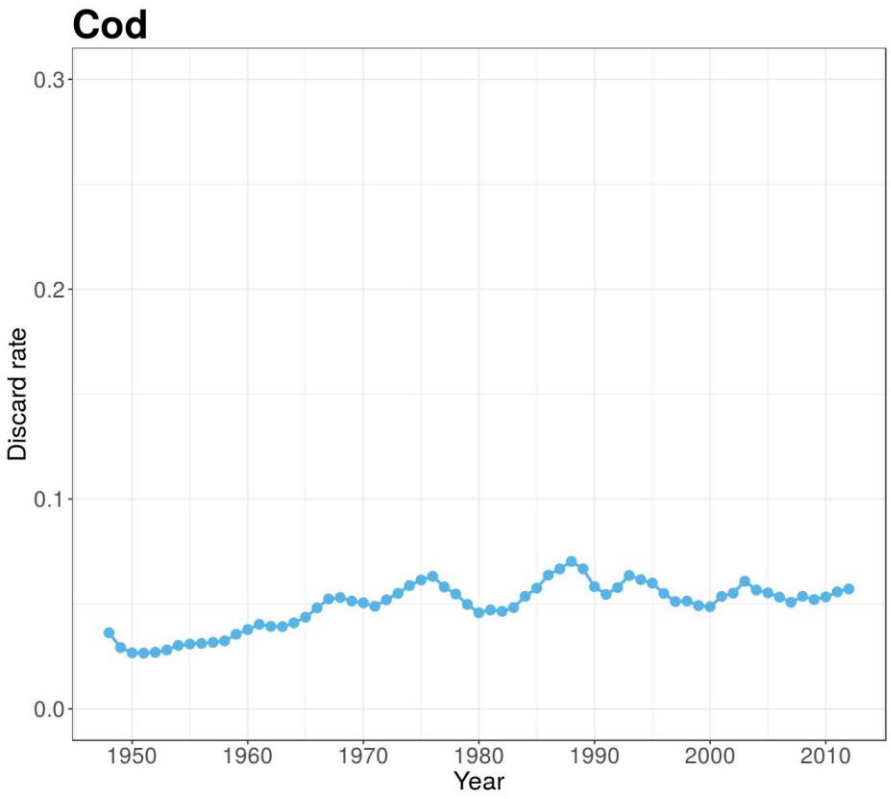
Discards

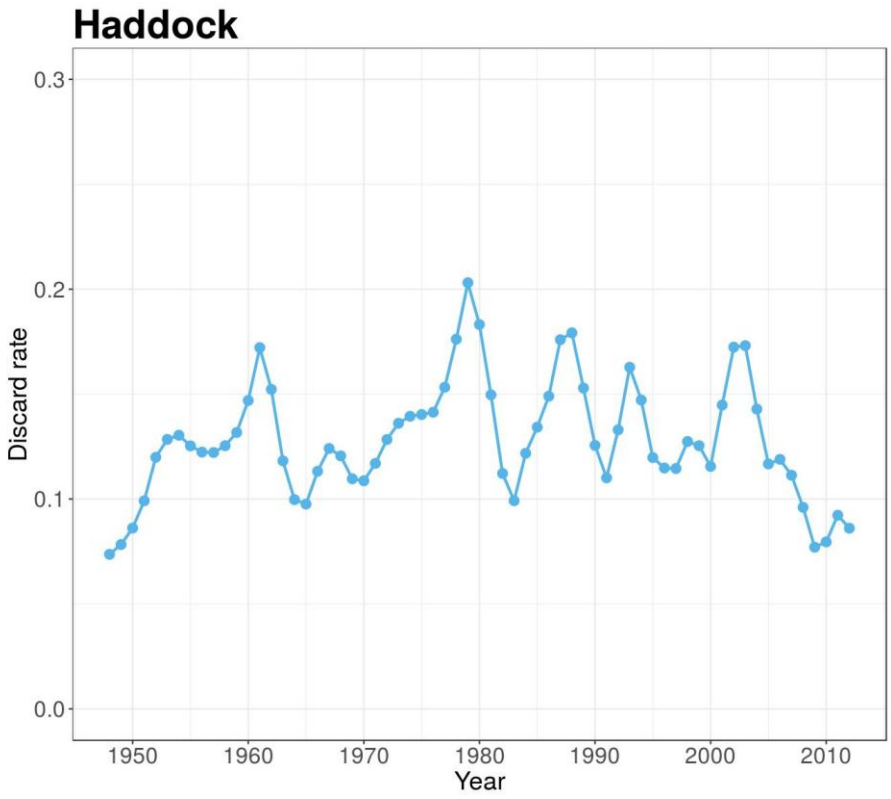
- **Constant per age-class**





Simulated Discards





Use of Atlantis

- **Operating model**
- **Scenarios**
  - Fishing pressure
  - Effect of discards
- **Management strategy evaluation**

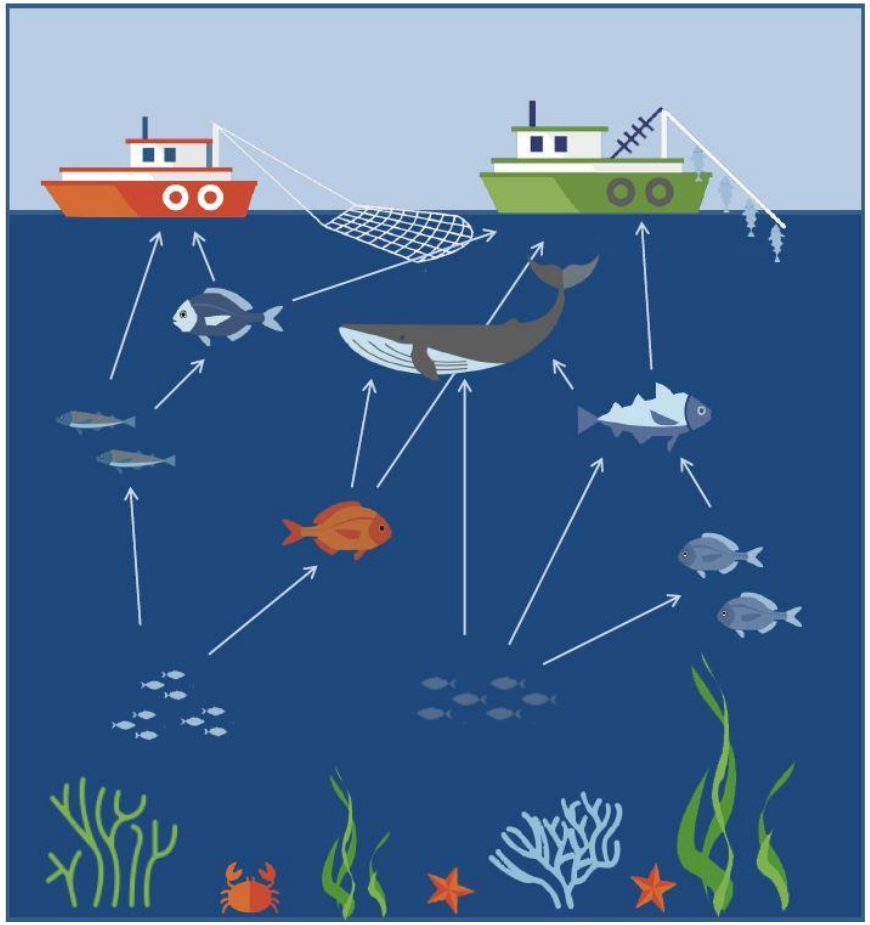
Performance of Ecosystem Models

- Atlantis used as an operating model
- Data from Atlantis imported into EwE and Gadget
- Can EwE and Gadget mimic the Atlantis ecosystem?

Ecopath with Ecosim (EwE)

- **Ecopath: a static, mass-balanced snapshot of the system.**

- **Ecosim: a time dynamic simulation module.**



The Ecopath part

- **The Ecopath equations**

$$P_i = Y_i + M2 + E_i + BA_i + MO_i$$

$$M2_i = \sum_{j=1}^{n} Q_j * DC_{ij} \qquad M0_i = P_i(1 - EE_i)$$

- **Parameters in Ecopath: B, P/B, Q/B, EE and DC**

The Ecosim part

- **Balanced Ecopath model is the start**

- **The growth rate in Ecosim is defined as:**

$$\frac{\partial B_i}{\partial t} = g_i \sum_j^n c_{ji} - \sum_j^n c_{ij} + E_i - (M0_i + F_i)B_i$$

$$c_{ij} = Q_{ij} * \frac{V_{ij} * Y_j}{V_{ij} - 1 + Y_j} * \frac{D_{ij} * Y_i}{D_{ij} - 1 + Y_i}$$

Scenarios tested

- **Scenario 1: Best possible knowlegde**
- **Scenario 2: Error added to the data**
- **Scenario 3: Missing data**

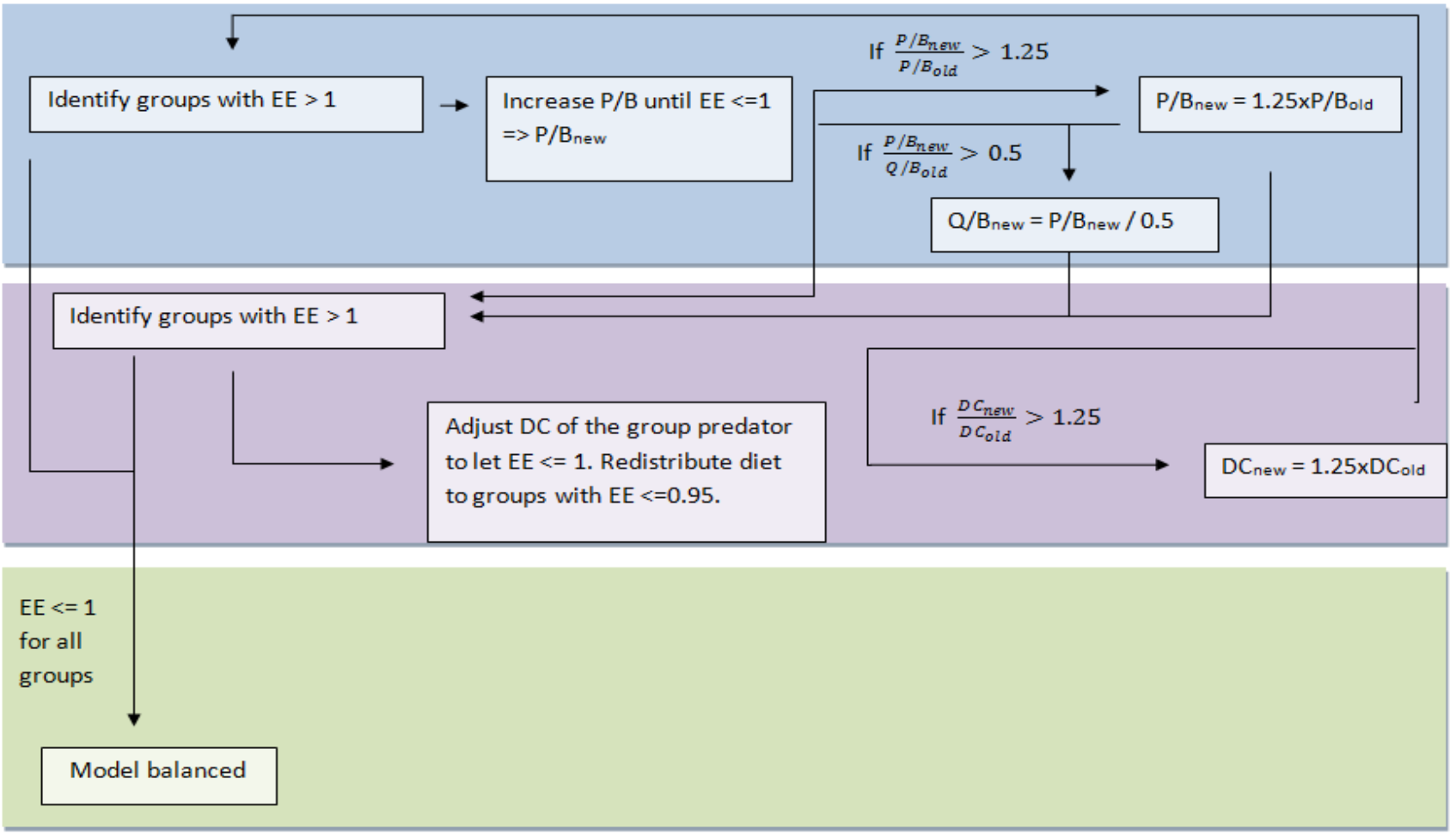
Building an Ecopath model

- The value of parameters calculated from Atlantis
- Balancing needed before moving to the Ecosim part
- No estimation of parameters
- Usually done manually => subjective
- Not obvious what parameters to change
- Here done automatically with iterations

Unbalanced model

Group	type	TL	Biomass	PB	QB	EE	GE	Removals
Cod 0-4	0	4.07	366493	0.37	4.44	0.59	0.08	6537
Cod 4+	0	4.28	1523327	0.49	2.01	0.61	0.25	448843
Haddock 0-4	0	3.38	107812	0.58	3.33	0.51	0.18	8672
Haddock 4+	0	3.35	80137	0.92	1.93	0.74	0.48	50415
Saithejuv 0-4	0	4.17	82634	0.38	3.11	0.74	0.12	1361
Saithe 4+	0	4.26	371033	0.37	1.49	0.78	0.25	53280
Redfish	0	3.91	1836558	0.09	0.97	2.15	0.10	0
Greenland Halibut	0	4.27	571364	0.16	1.89	1.47	0.09	6105
Flatfish	0	2.88	225305	0.30	1.74	0.22	0.17	19981
Herring 0-4	0	3.69	417900	0.51	1.30	1.42	0.40	4749
Herring 4+	0	3.69	471015	0.39	0.87	1.53	0.45	29929
Capelin	0	3.50	5899716	1.17	3.03	0.61	0.39	121793
Migratory pelagic	0	3.53	1253964	0.51	1.71	0.56	0.30	0
Other Codfish	0	3.89	115588	0.47	1.88	0.94	0.25	19333
Demersal Commerical	0	3.72	255543	0.31	1.90	1.40	0.16	19572
Other Demersal Fish	0	3.46	534144	0.58	1.79	0.32	0.32	0
Sandeel Fish	0	3.47	1273289	0.58	3.22	0.55	0.18	0
Long Lived Demersal	0	4.42	115273	0.15	1.31	0.85	0.12	0
Large Pelagic Fish	0	3.95	87526	0.15	1.33	1.54	0.12	0
Small Pelagic Fish	0	3.61	106630	0.51	2.39	2.05	0.21	0
Small Sharks	0	4.50	117525	0.09	1.06	1.29	0.08	0
Skates	0	4.06	61269	0.15	1.12	0.53	0.14	0
Large Sharks	0	4.60	111533	0.05	0.95	3.34	0.05	0
Seabird	0	4.30	29786	0.11	1.38	-0.03	0.08	0
Pinniped	0	4.67	1835	0.13	1.48	2.61	0.09	0
Minke Whale	0	4.09	69106	0.10	1.58	0.11	0.06	0
Whale Baleen	0	3.64	389033	0.08	0.82	0.29	0.10	15025
Whale Tooth	0	4.82	408143	0.06	1.85	0.17	0.03	1414
Whale Tooth Other	0	4.69	11323	0.16	0.45	0.15	0.35	0

Automatic balancing process



Changes when balancing

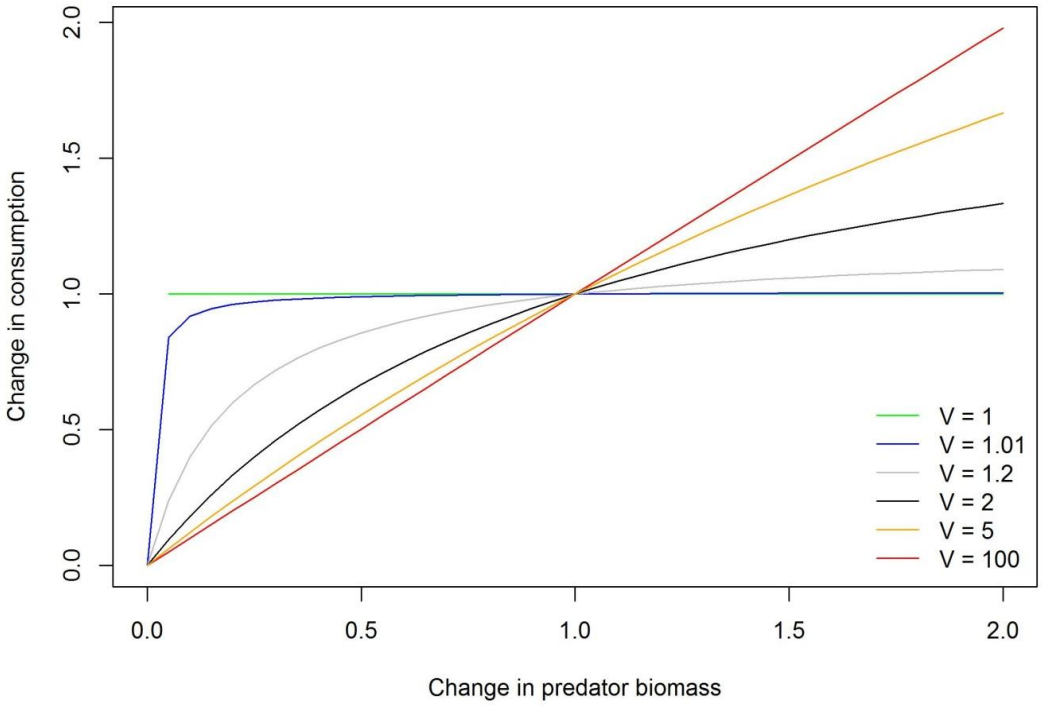
Group	Predation mortality change (%)	PB change (%)	QB change (%)
Cod 0-4	8	0	0
Cod 4+	12	0	0
Haddock 0-4	4	0	0
Haddock 4+	6	0	0
Saithejuv 0-4	8	0	0
Saithe 4+	12	0	0
Redfish	-33	56	0
Greenland Halibut	-22	25	0
Flatfish	2	0	0
Herring 0-4	3	25	16
Herring 4+	-19	25	13
Capelin	2	0	0
Migratory pelagic	2	0	0
Other Codfish	3	0	0

Fitting the Ecosim model

- Fitted to time-series of biomass and catches.
- Vulnerability parameters in predator-prey interactions estimated
- 671 parameters!

$$c_{ij} = Q_{ij} * \frac{V_{ij} * Y_j}{V_{ij} - 1 + Y_j} * \frac{D_{ij} * Y_i}{D_{ij} - 1 + Y_i}$$

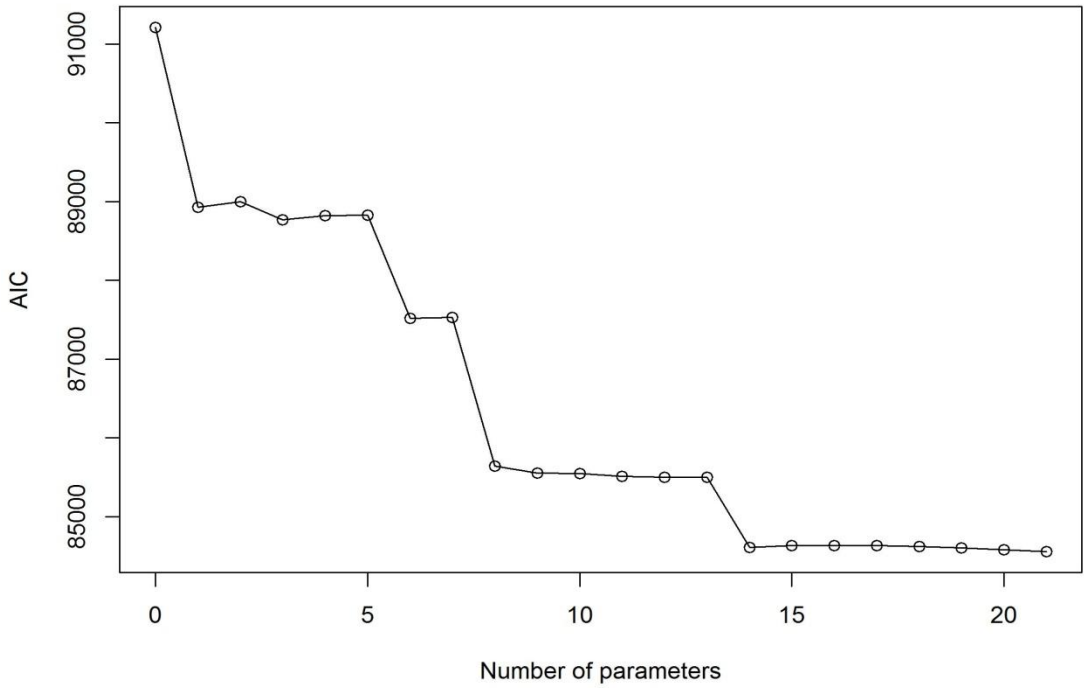
Predator-prey interactions



The fitting

- Not possible to do simultaneously
- Done iteratively
- Minimizing SS

$$SS = \sum_{i=1}^{2} \sum_{g=1}^{G} \sum_{t=1}^{T} \left(y_{gti} - \hat{y}_{gti}\right)^2$$



Biomass before and after fitting

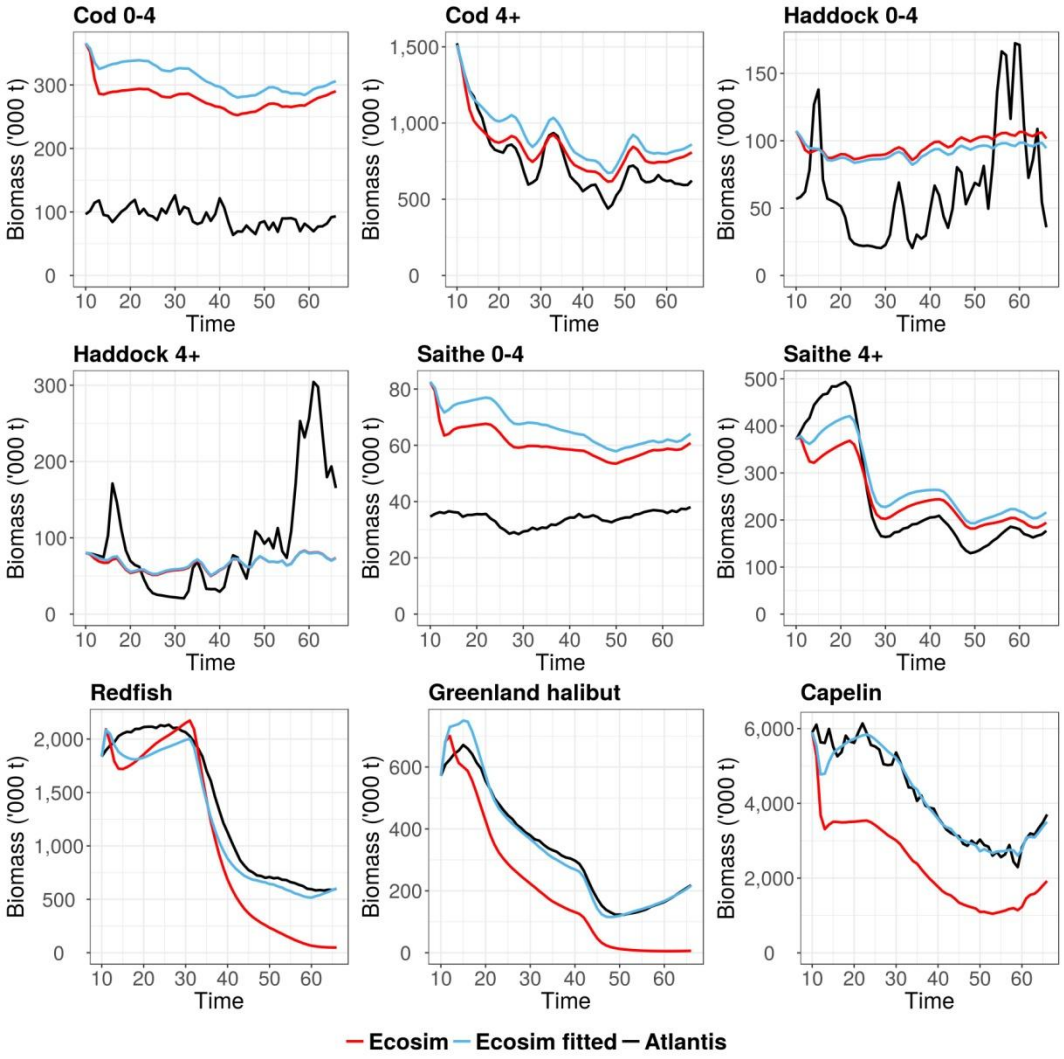
Cod 4+

$$r = \frac{\sum_{i=1}^{n}(O_i - \bar{O})(P_i - \bar{P})}{\sqrt{\sum_{i=1}^{n}(O_i - \bar{O})^2 \sum_{i=1}^{n}(P_i - \bar{P})^2}}$$

$$RI = exp\sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(\log\frac{O_i}{P_i}\right)^2}$$

$$MEF = \frac{\sum_{i=1}^{n}(O_i - \bar{O})^2 - \sum_{i=1}^{n}(P_i - O_i)^2}{\sum_{i=1}^{n}(O_i - \bar{O})^2}$$

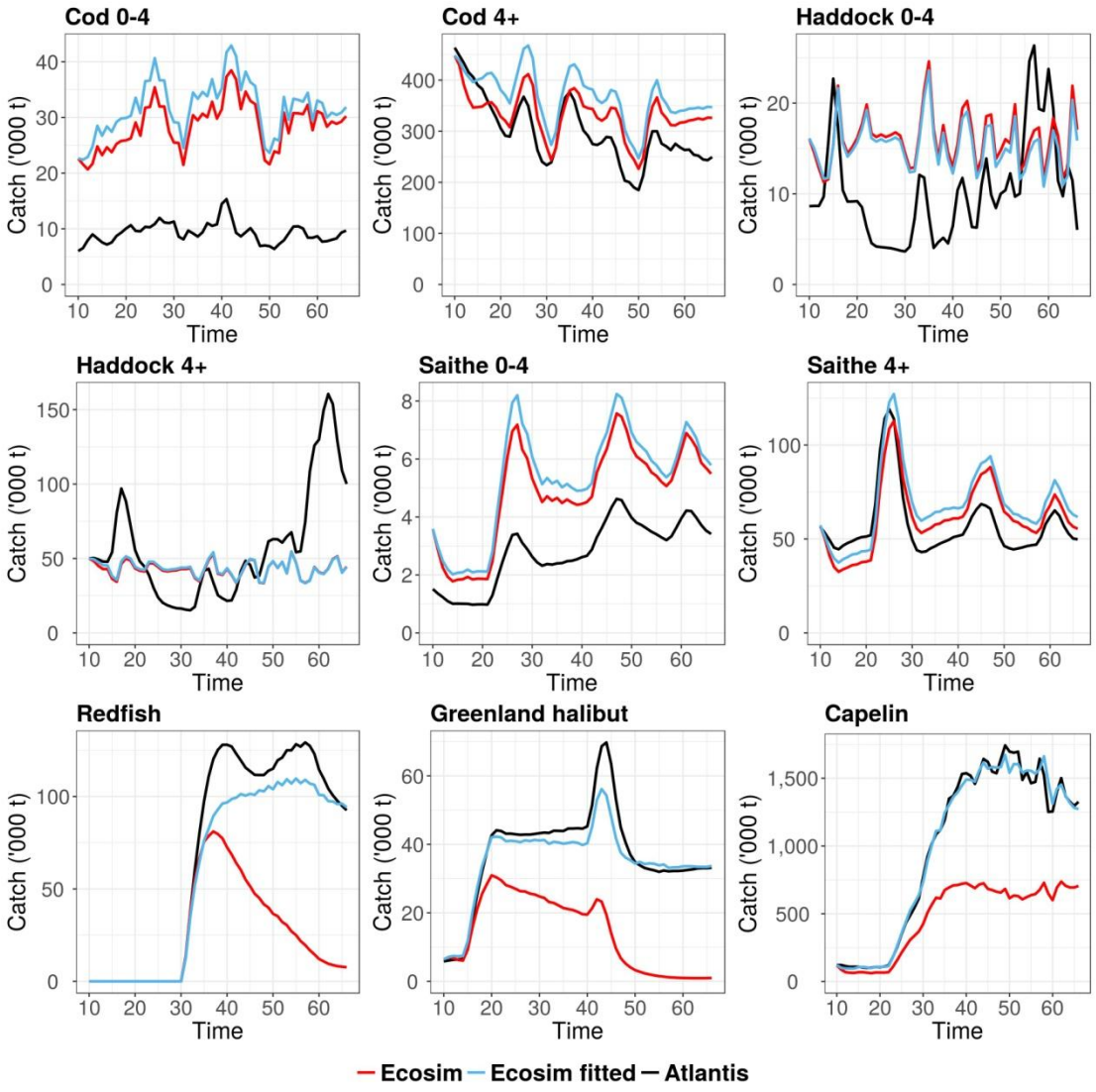
0.95 → 0.97	1.96 → 1.06	-1.29 -> 0.95



Catch before and after fitting

Cod 4+		
r	RI	MEF
0.83 → 0.85	1.19 → 1.27	0.38 → -0.4

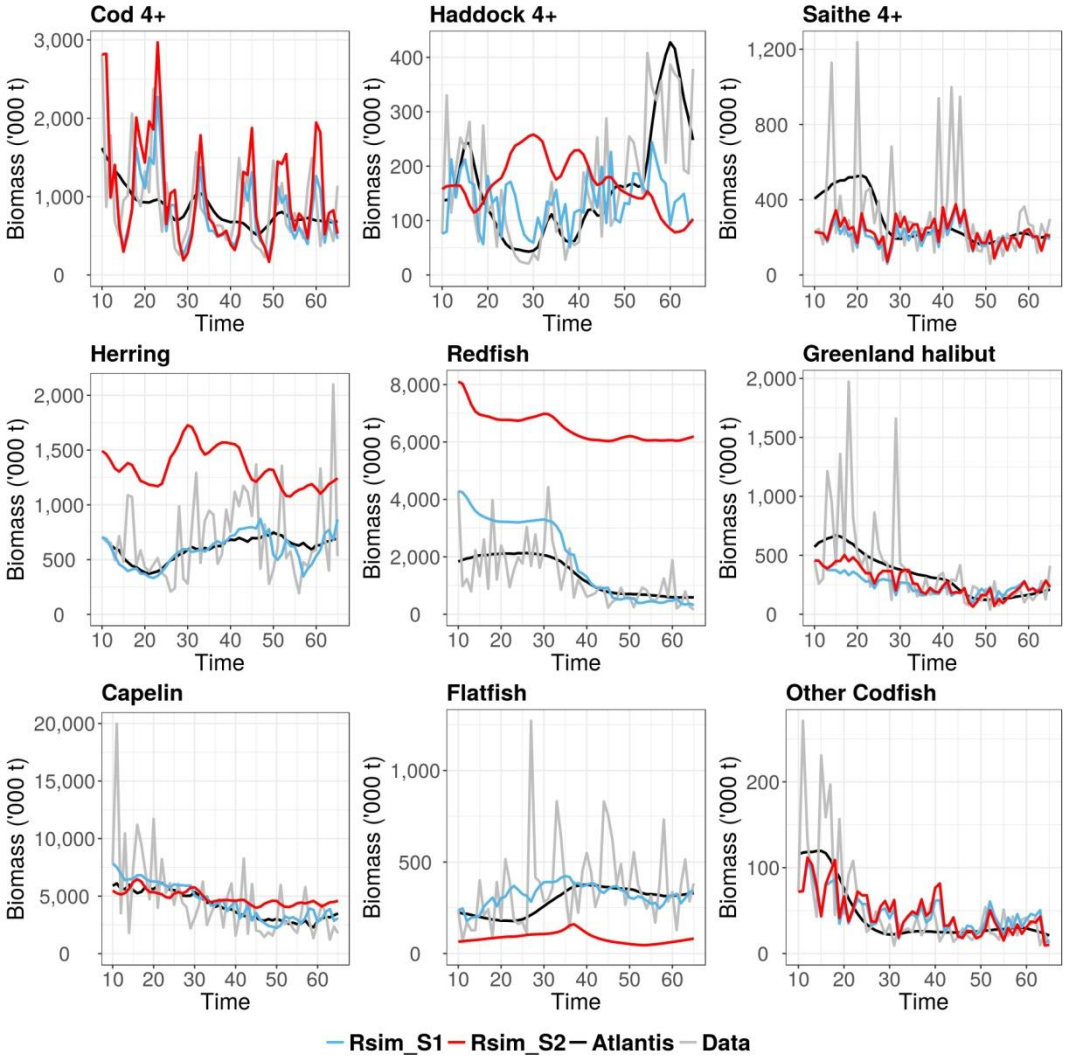
Capelin		
r	RI	MEF
0.97 → 1	1.97 → 1.06	-0.08 -> 0.99



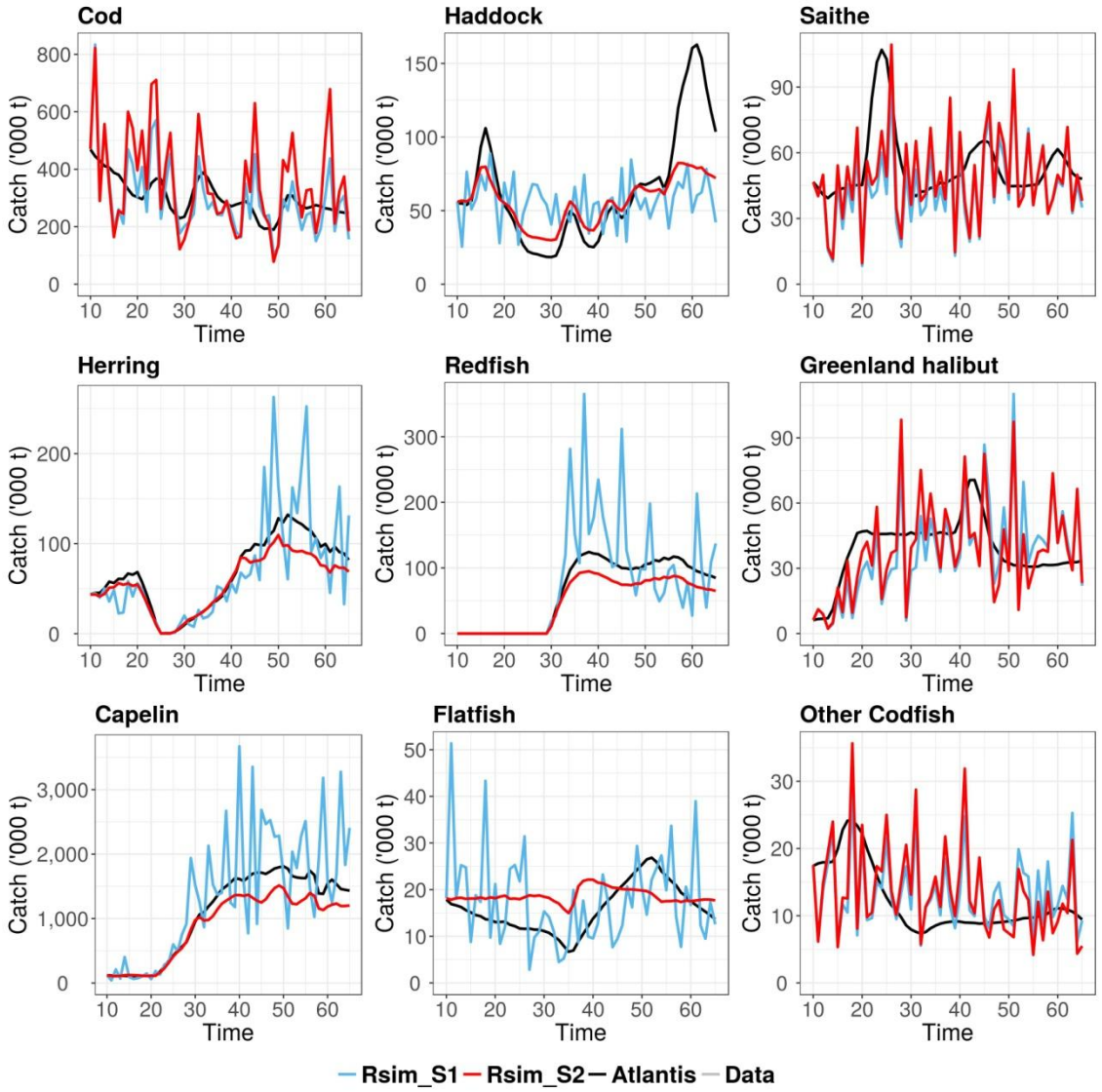
The data poor scenarios

- **Log-normal error added, CV = 0.5**
- **Missing biomass for 13 groups:** haddock, redfish, flafish, herring, capelin, migratory pelagics, other demersal fish, sandeel, small and large pelagics, small shark, skates and long lived demersals
- **EE = 0.95 or EE = 0.80**

Biomass from data poor scenarios



Catch from data poor scenarios



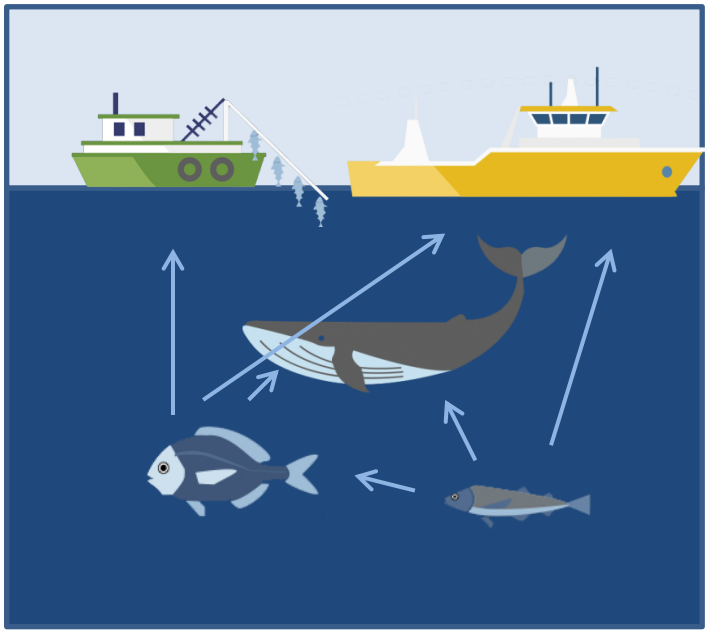
EwE conclusion

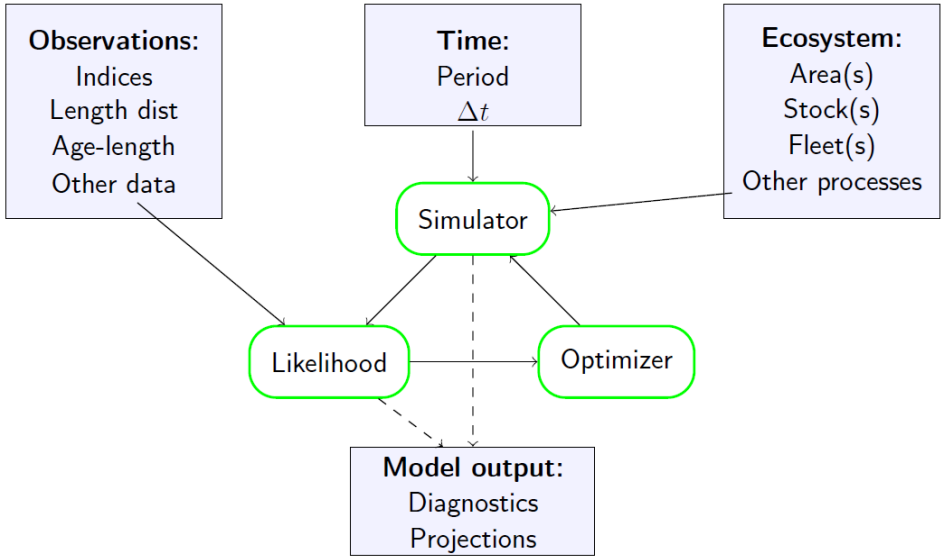
- **EwE was able to mimic the Atlantis ecosystem in the best possible information scenario.**

Scenario	r	# r > 0.8	RI	# RI < 2
S1	0.60	11	1.25	25
S2	0.54	8	1.41	25
S3	0.35	9	2.87	15

Gadget

- Statistical multi-species model
- Estimates and simulates population size
- Based on length, weight and age data from survey and catches





- Species interactions
- Technical interactions
- Up to 12 likelihood components

Scenarios tested

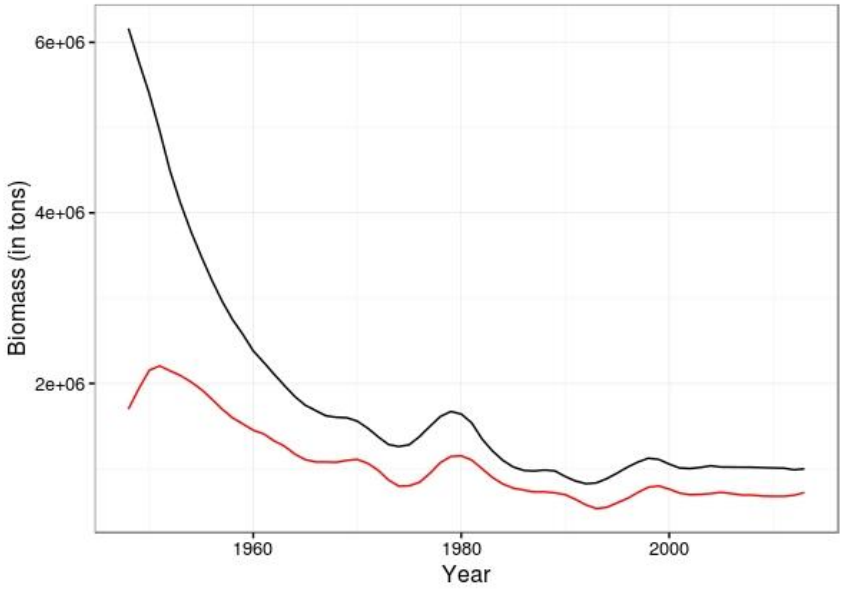
- **Scenario 1: Large sample size**
- **Scenario 2: Reduced age data (10%)**
- **Scenario 3: Age data every 5 years**
- **Scenario 4: Missing age data**

Building the Gadget model

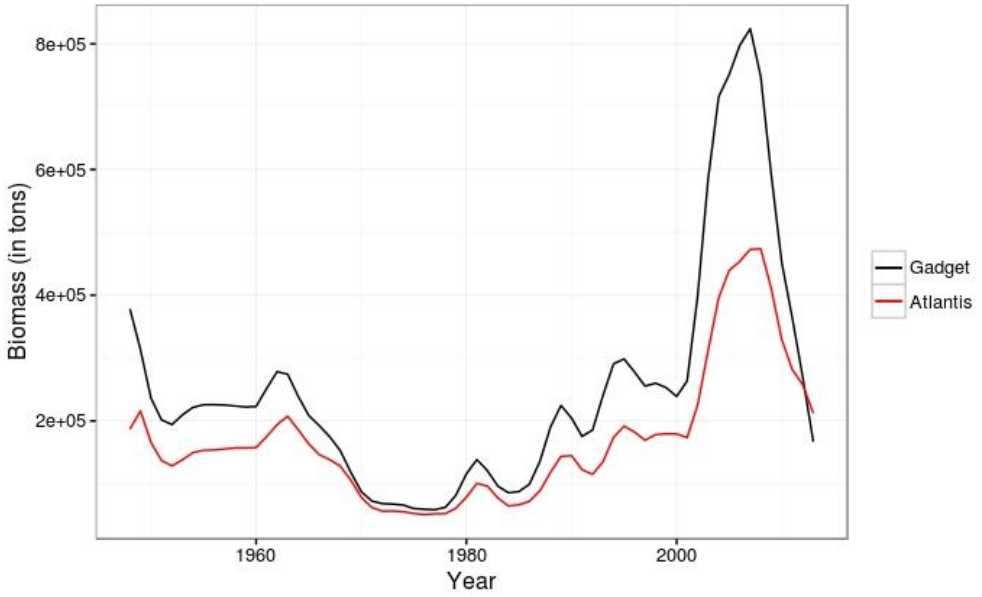
- **Single-species model**
  - **Cod**
  - **Haddock**
- **Data sampled from Atlantis**
- **Problems:**
  - Age-classes in Atlantis
  - All fish in an age-class has the same weight

Scenario 1: Large sample size

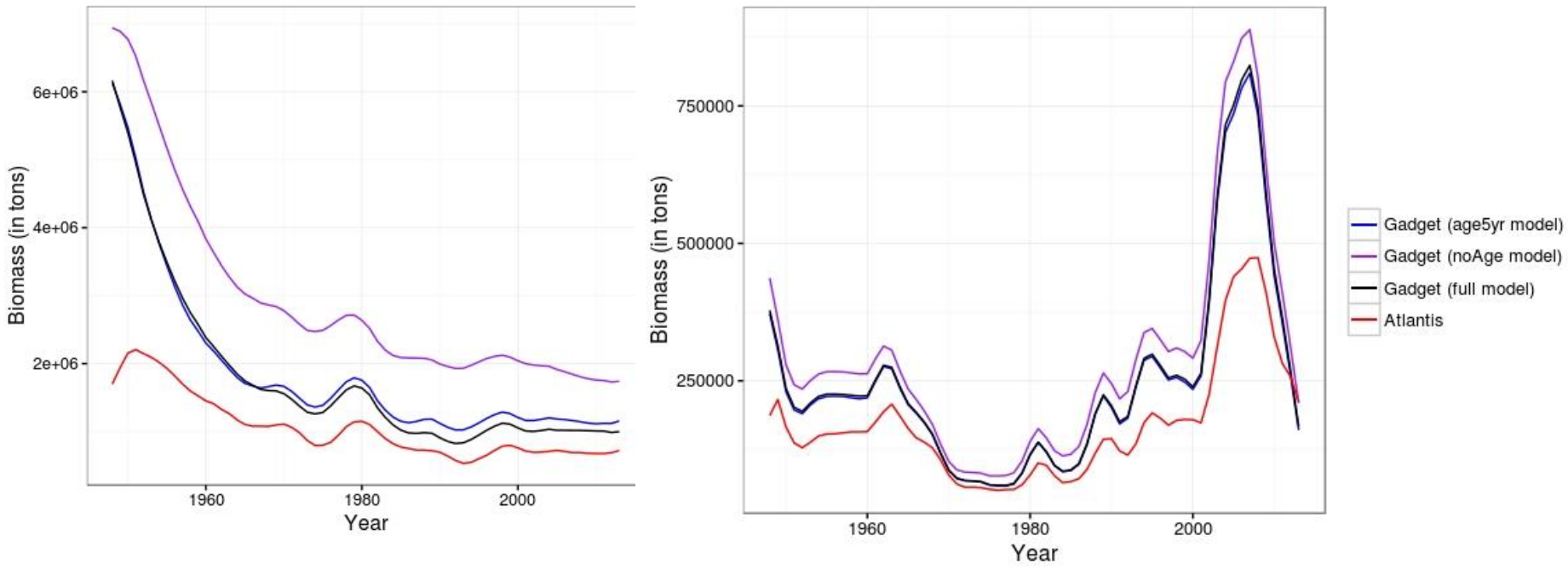
Cod



Haddock

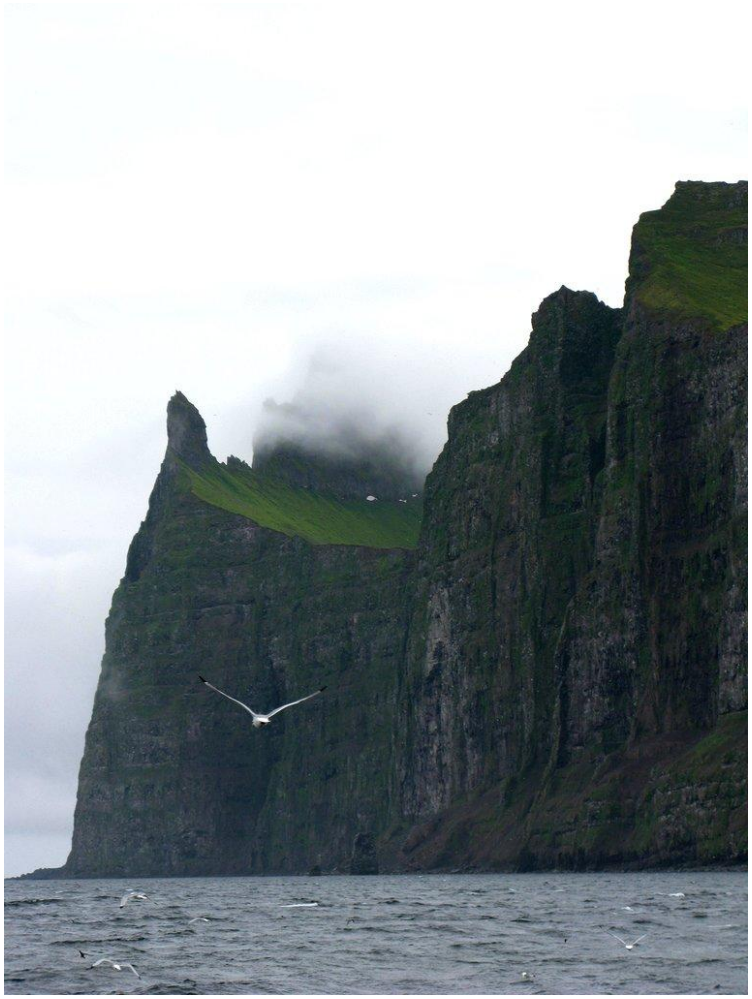


Biomass from data poor scenarios



Future work

- Advanced fisheries model
- Economic model
- Connecting Atlantis and Gadget
- Estimating parameters in Atlantis
- Estimation and uncertainty in EwE



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