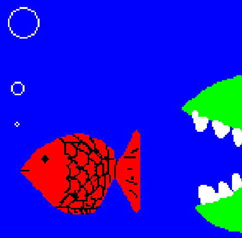
End-to-End Models of the Georges Bank Ecosystem: Implications for Ecosystem Based Management



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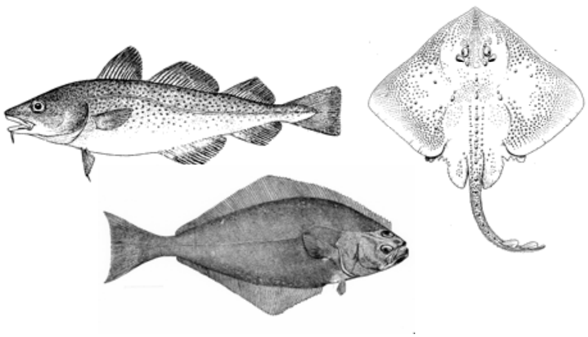
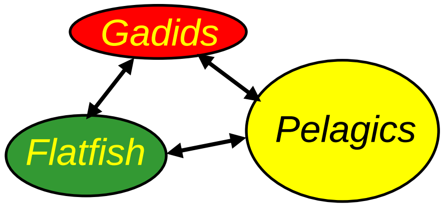
Outline: Gradient of Model Complexity

Single-species | Multi-species | Aggregate Ecosystem | Whole Ecosystem

Parameter estimation





Messy Picture Here

Simulation

2. Age structured multispecies assessments

1. Food-web or network models

3. What do we learn that will advance the Ecosystem Approach to Fisheries?

Modified from Link (2002) Fisheries 27:18-21

Example: Georges Bank Ecosystem

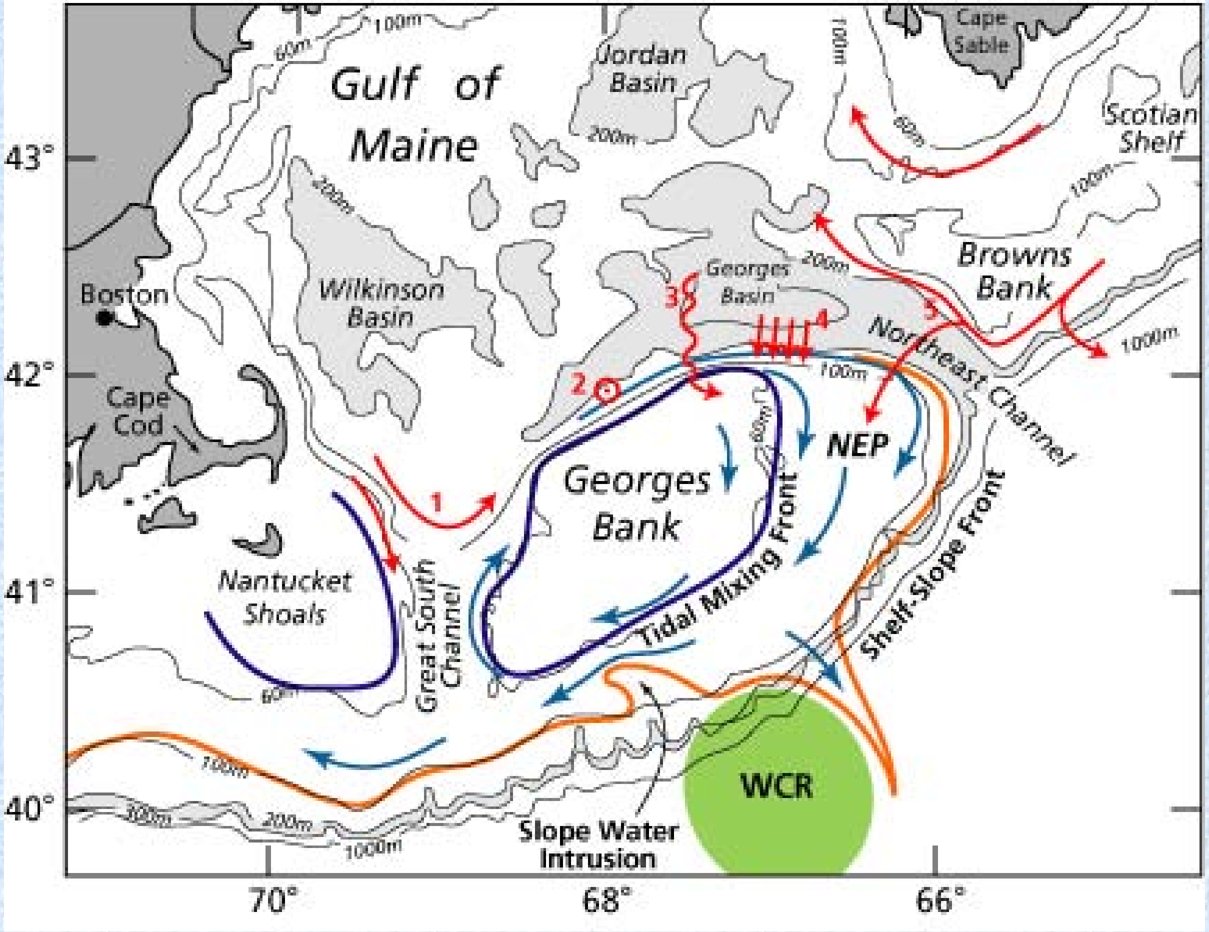
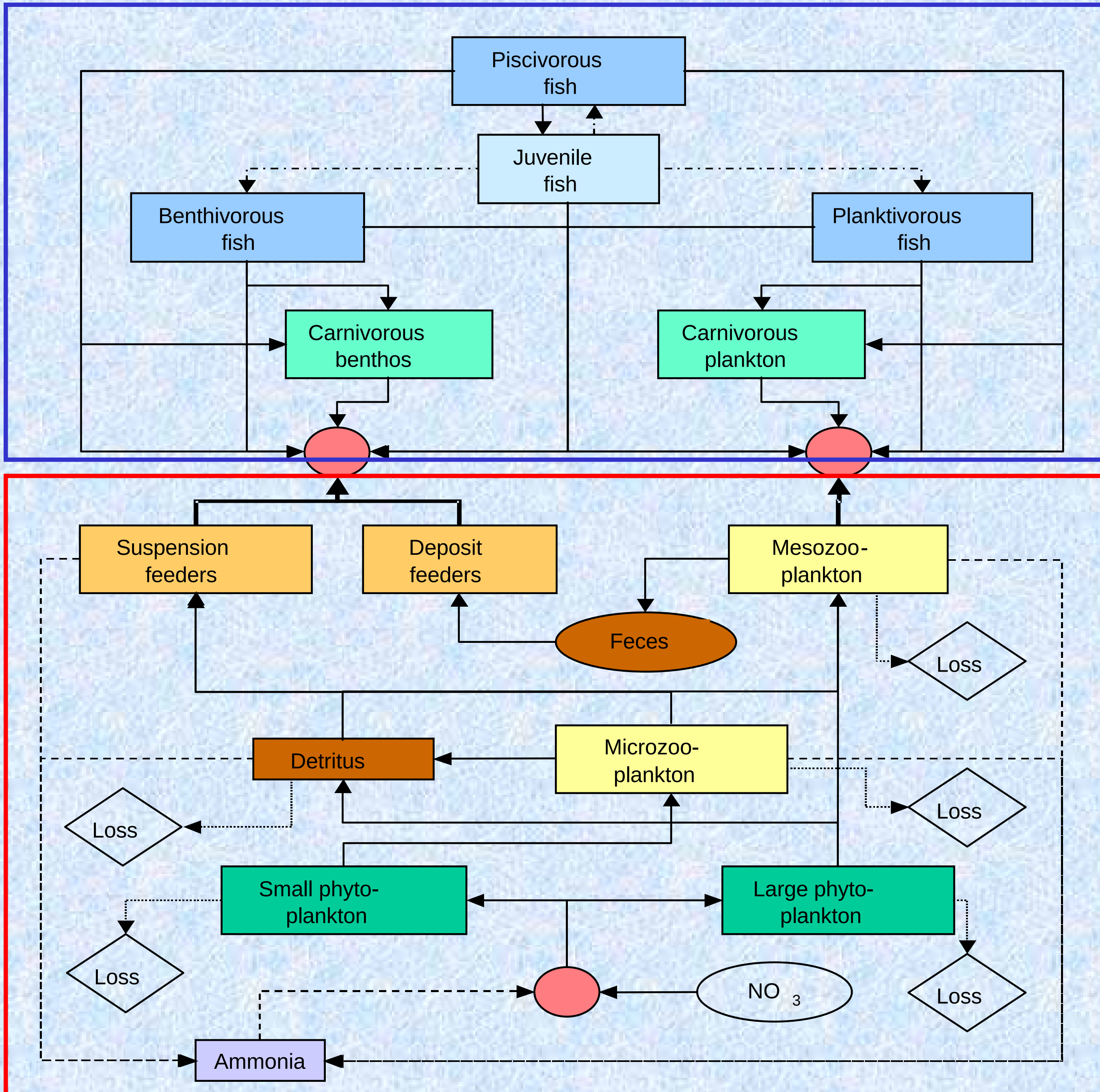
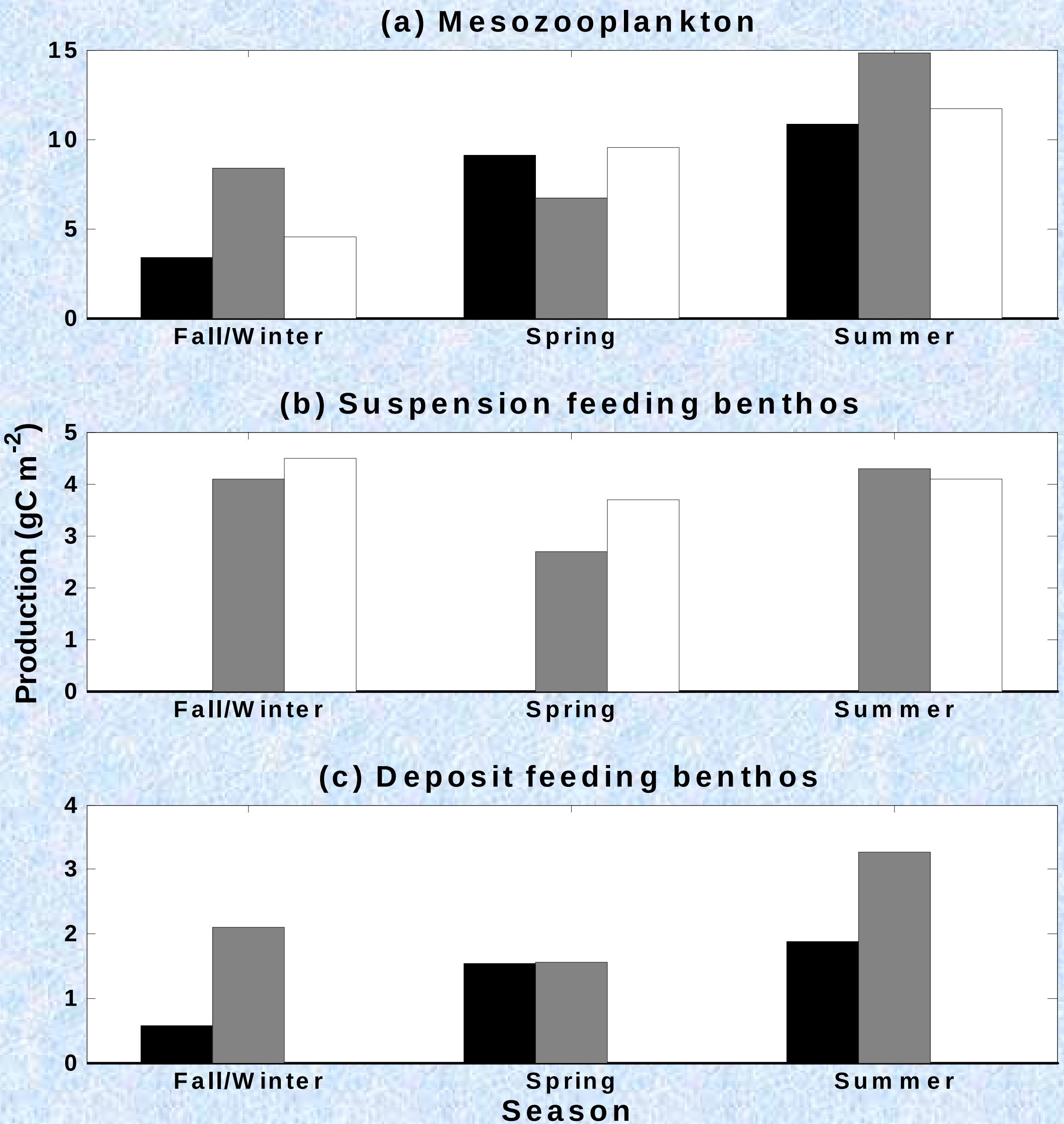


Image from Peter Wiebe (2002) *Oceanography* 15:14.


Piscivorous fish
Juvenile fish
Benthivorous fish
Planktivorous fish
Carnivorous benthos
Carnivorous plankton
Suspension feeders
Deposit feeders
Mesozoo-plankton
Feces
Loss
Detritus
Microzoo-plankton
Loss
Loss
Small phyto-plankton
Large phyto-plankton
Loss
NO 3
Loss
Ammonia



Spatial zones

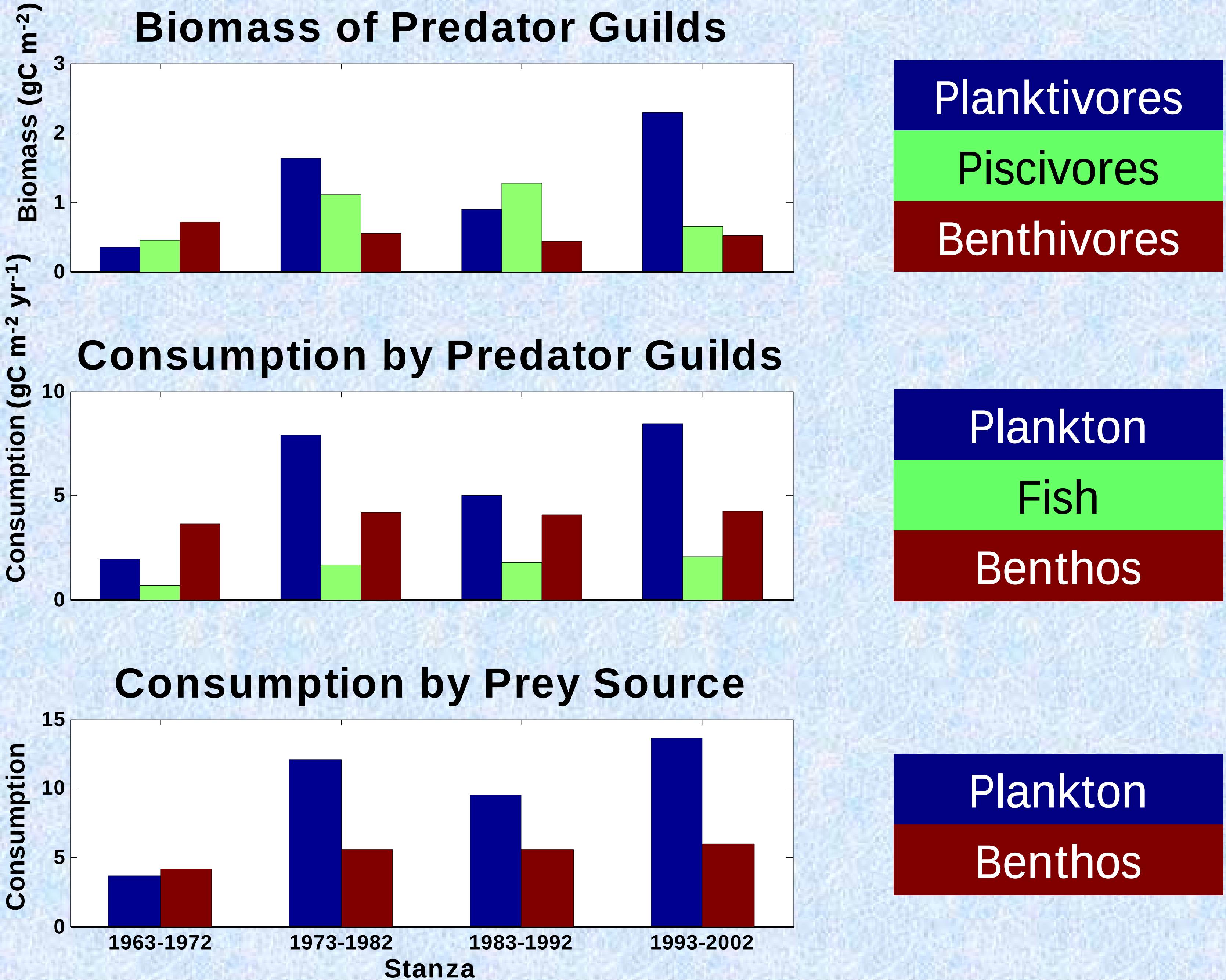
Stratified

Transition

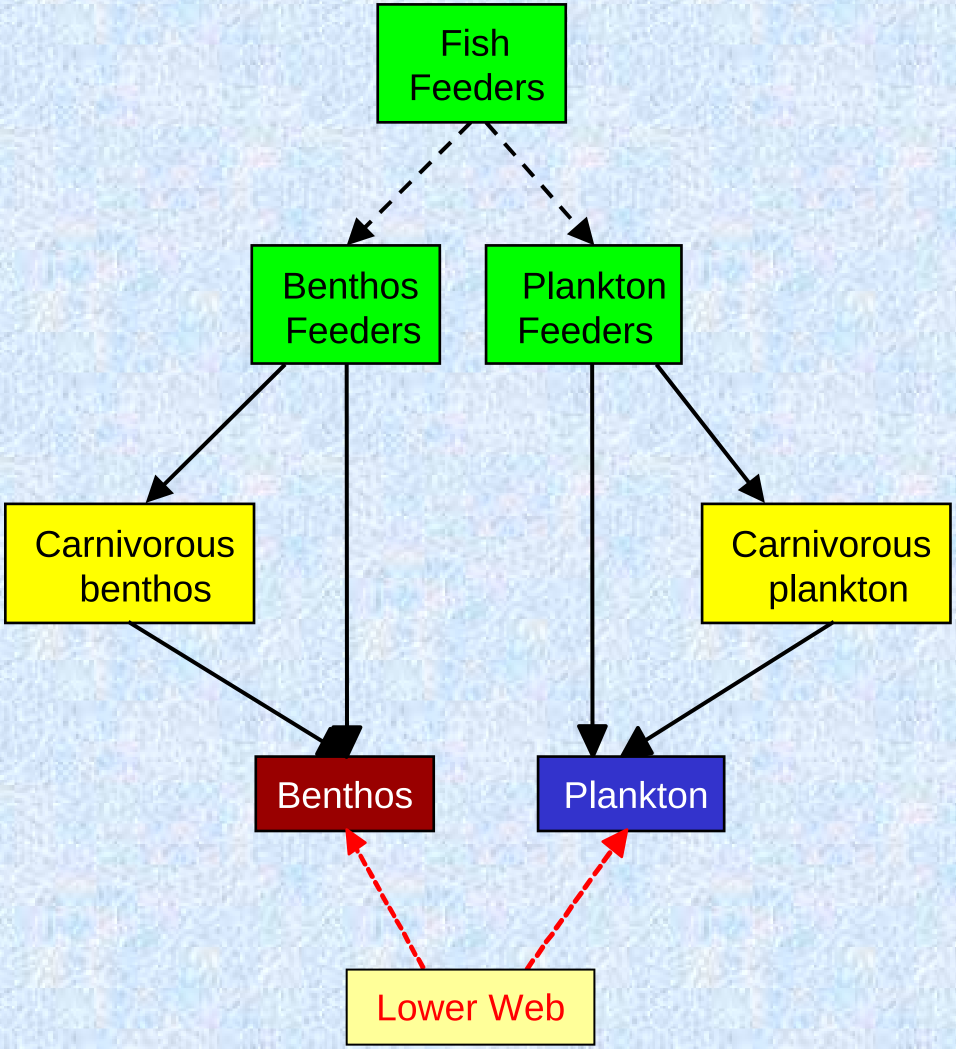
Mixed

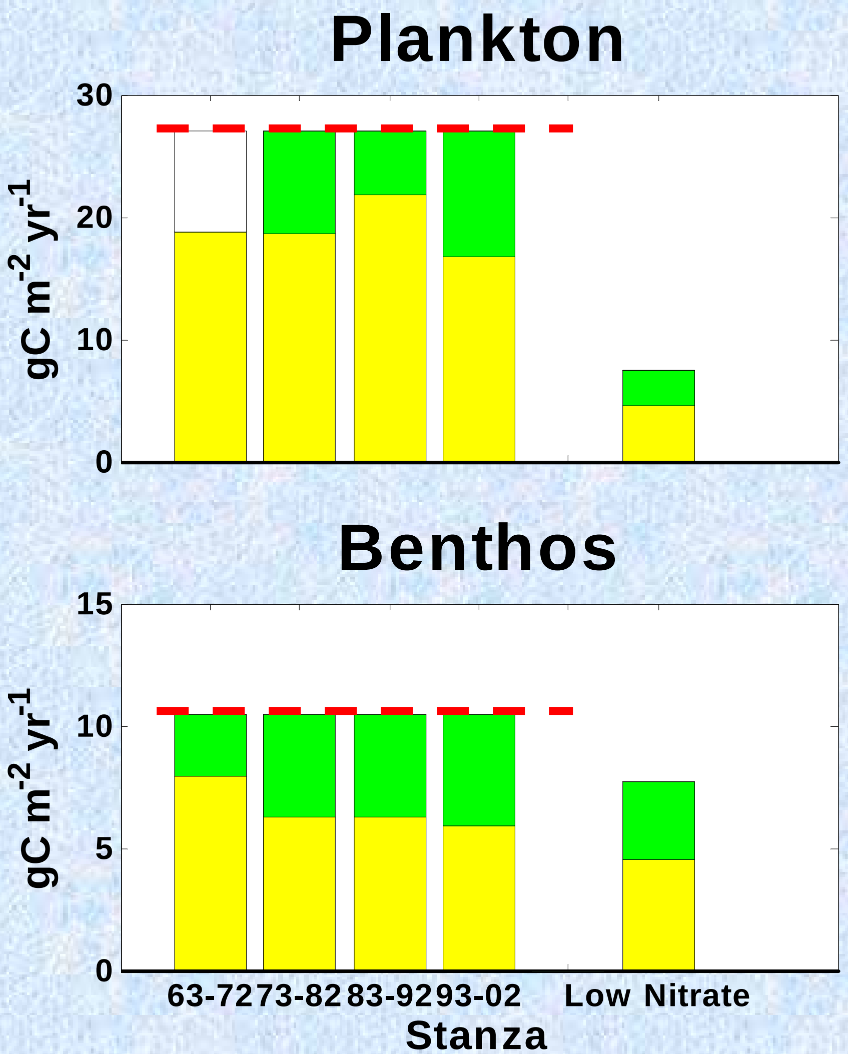
Integrated production ($gC\ m^{-2}\ yr^{-1}$)

Zooplankton	27.0
Benthos	10.5


Biomass of Predator Guilds
Biomass (gC m-2)
0
1
2
3
Planktivores
Piscivores
Benthivores
Consumption by Predator Guilds
Consumption (gC m-2 yr-1)
0
5
10
Plankton
Fish
Benthos
Consumption by Prey Source
Consumption
0
5
10
15
1963-1972
1973-1982
1983-1992
1993-2002
Stanza
Plankton
Benthos

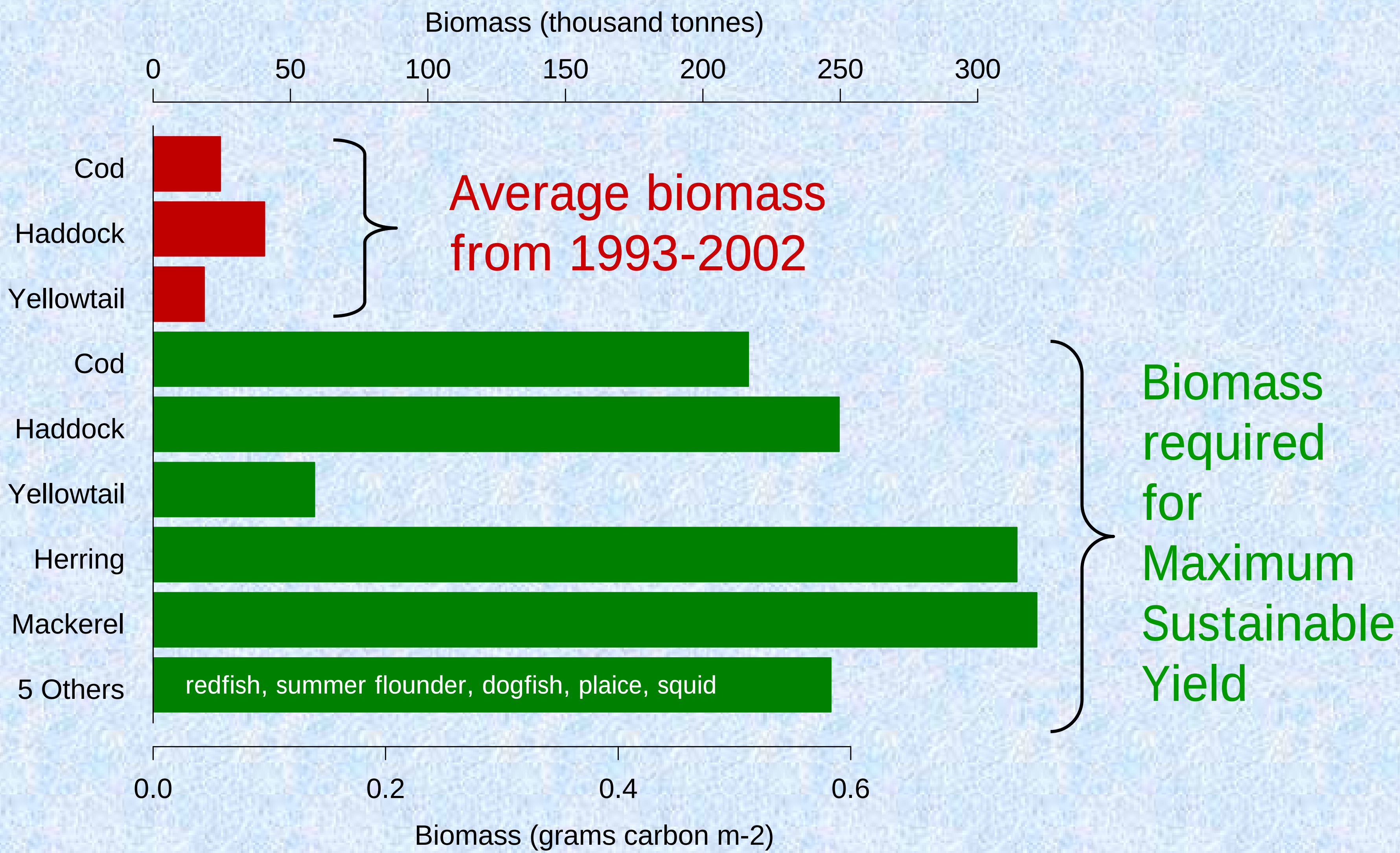
Fish consumption accounts for all the production from the lower food web



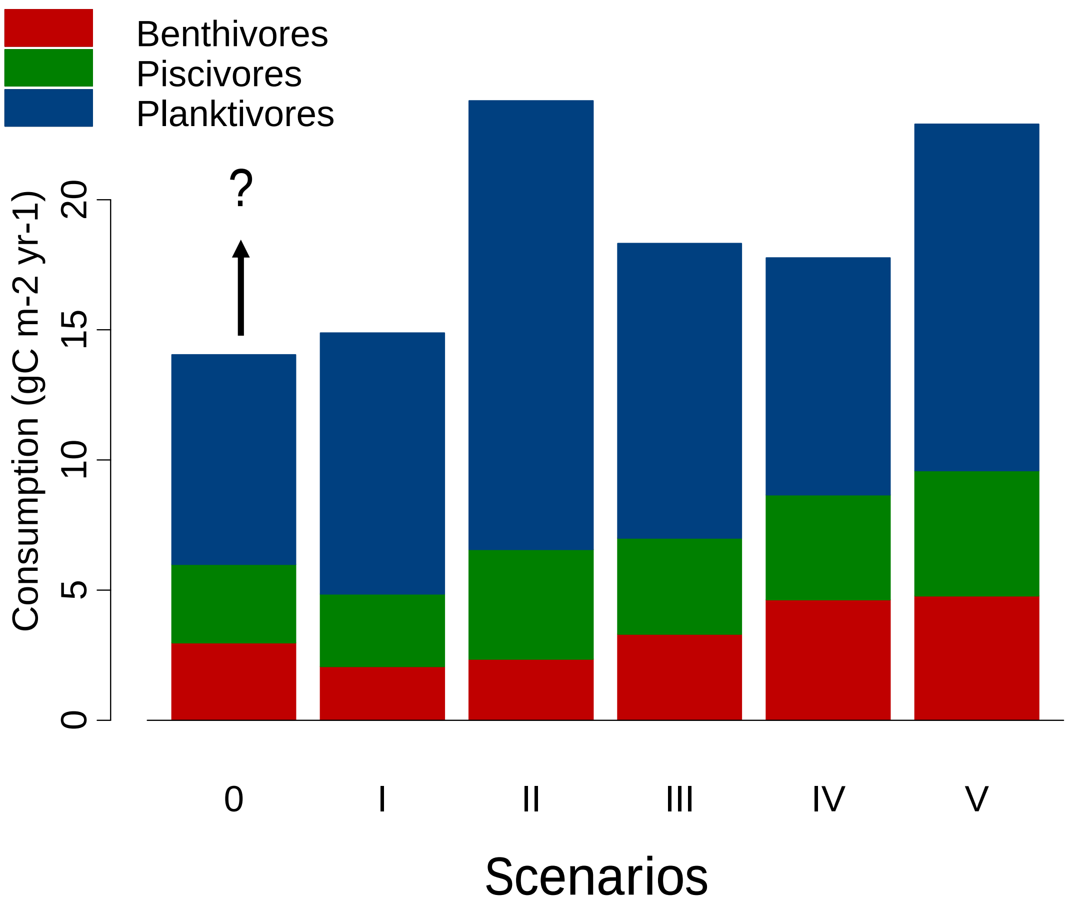


Steele, Collie, Gifford, Link, et al. (2007)

Is there enough food for recovered fish stocks?



Food-web modifications



Scenarios:

0. Biomass of 10 (out of 35) species at MSY;

I. 1993-2002 baseline;

II. Eliminate planktonic invertebrate carnivores (e.g. jellyfish);

III. Eliminate benthic invertebrate carnivores (e.g. crabs, lobsters);

IV. Increase suspension-feeding benthos;

V. Eliminate jellyfish and increase benthos (II+IV).

Conclusions from the food webs

- The lower food web accounts for recycling, spatial and seasonal differences, and advective losses;
- Commercially-important species have been replaced with non-commercial species;
- Plankton consumption has increased relative to benthos;
- There is some evidence of bottom-up control of fish production in the 1960s;
- Outputs from the lower food web limit fish production;
- Recovery of the commercial fish species to B_{msy} levels requires reductions in non-commercial species.

Age-structured Multispecies Model

A statistical implementation of Multispecies Virtual Population Analysis.

Key attributes:

- Forward progressing age-structured model;
- Fit to catch-at-age, survey-at-age, and diet composition data measured with error;
- Objective function used for parameter estimation.
- Parameters estimated in the model include:
  - Initial abundances of each cohort (X_a, Y_a, Z_a);
  - Fishing mortality (F) and selectivity (α, β);
  - Catchability (q) and predation parameters (η, σ, ρ).

Modeling predation

Predation mortality is a function of predator ingestion, predator size preference, prey vulnerability and available food

$$g_{i,a,j,b} = \exp\left[\frac{1}{2\sigma_j^2}\left(\ln\frac{w_{j,b}}{w_{i,a}} - \eta_{i.j}\right)^2\right]$$

variance

preferred ratio of pred:prey weight

$$\nu_{i,a,j,b} = \rho_{i,j}\, g_{i,a,j,b}$$

prey vulnerability

$$\phi_{i,a,j,b,t} = \tilde{\nu}_{i,a,j,b} N_{i,a,t} w_{i,a}$$

available food

prey biomass

$$M2_{i,a,t} = \frac{1}{N_{i,a,t} W_{i,a}} \sum_j \sum_b I_{j,b} N_{j,b,t} \frac{\phi_{i,a,j,b,t}}{\phi_{j,b,t}}$$

i = prey species

j = predator species

a = prey age

b = predator age

Anderson and Ursin 1977, Lewy and Vinther 2004

Parameter estimation

- Objective function is minimized to find best fit
- Three likelihood components of objective function:

Catch
(lognormal)

$$LL_{catch} = 50 \cdot \sum_{t,sp,a} \left[\ln\left(C + 0.001\right) - \ln\left(\hat{C} + 0.001\right)\right]^2$$

Survey N
(lognormal)

$$LL_{survey} = 50 \cdot \sum_{t,sp,a} \left[\ln\left(N + 0.001\right) - \ln\left(\hat{N} + 0.001\right)\right]^2$$

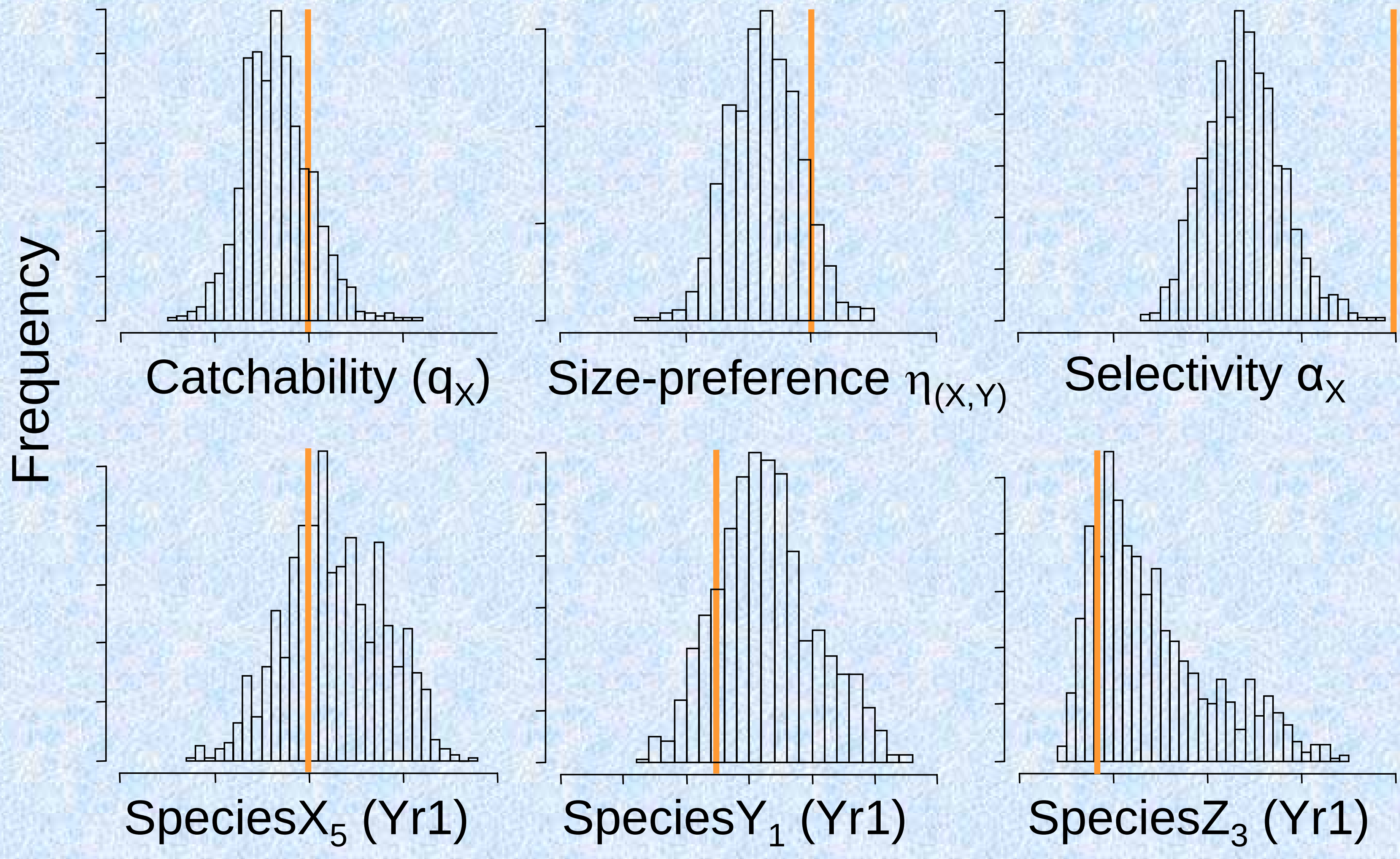
Stomach Contents
(multinomial)

$$LL_S = \sum_{t,sp,a} 50 \cdot \left(S + 0.001\right) \cdot \ln\left(\hat{S} + 0.001\right)$$

Simulations – can we estimate the parameters?

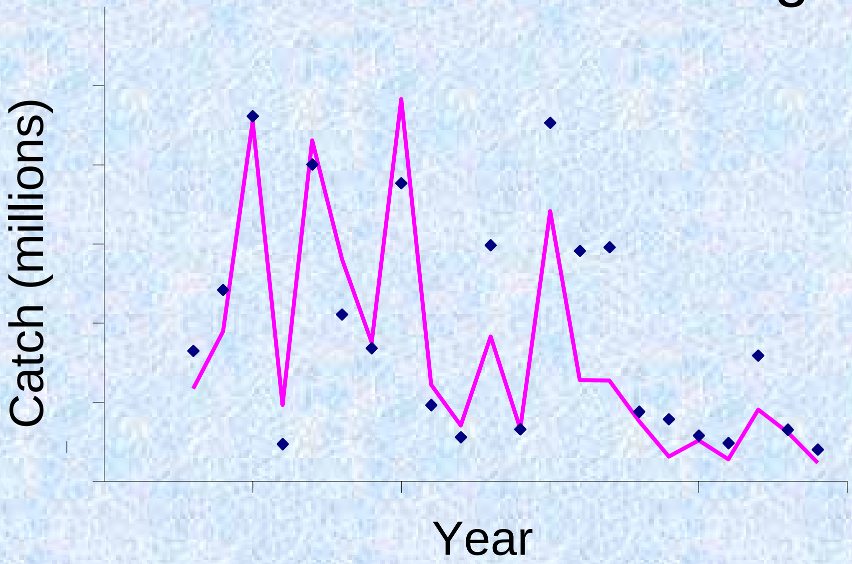
- Given a known fish community, can we estimate the desired parameters?
- Population data were simulated in R; parameters were estimated with AD Model Builder.
- Measurement error was added to the commercial catch and survey relative abundance data.
- Markov Chain Monte Carlo (MCMC) simulations were used to explore parameter distributions in the face of observation error.

MCMC: Posterior distribution

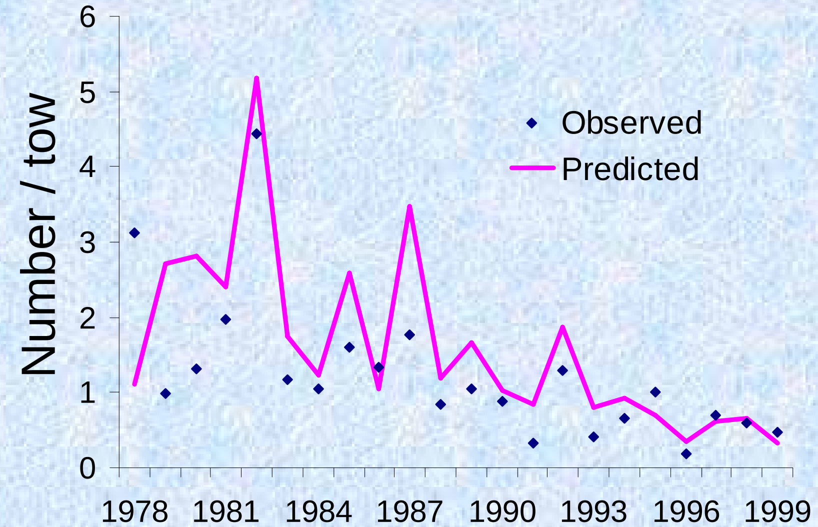


Stdev = 0.2

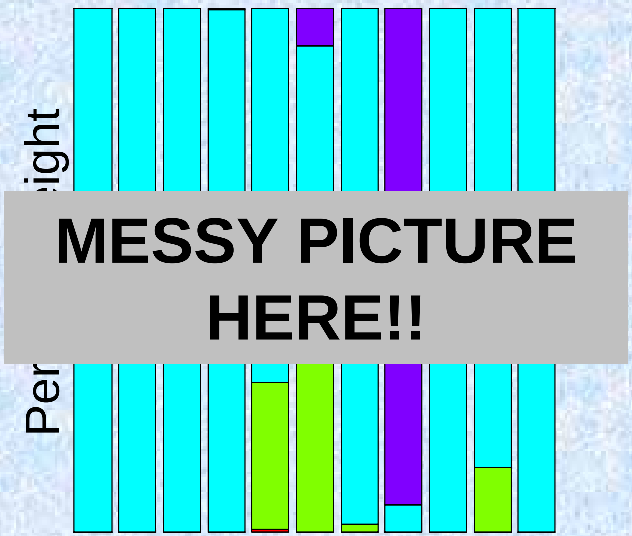
Commercial Catch: Cod Age 5



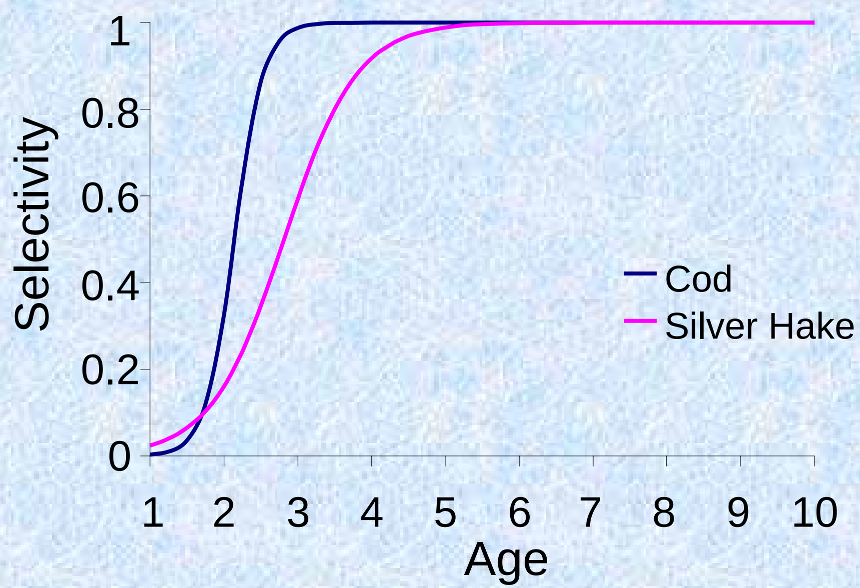
Survey Catch: Cod Age 2



Food Habits



Fishery Selectivity



General Conclusions

- Bottom-up forcing of marine food webs alters the partitioning of energy among different guilds of fishes;
- Rebuilding targets for single species may be constrained by available food;
- Dynamic models are needed to understand the interactions of species within the guilds;
- Predation mortality rates are high and variable (Tsou & Collie 2001);
- Multispecies models need a statistical foundation to be accepted as tools for fisheries management.

Acknowledgements

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