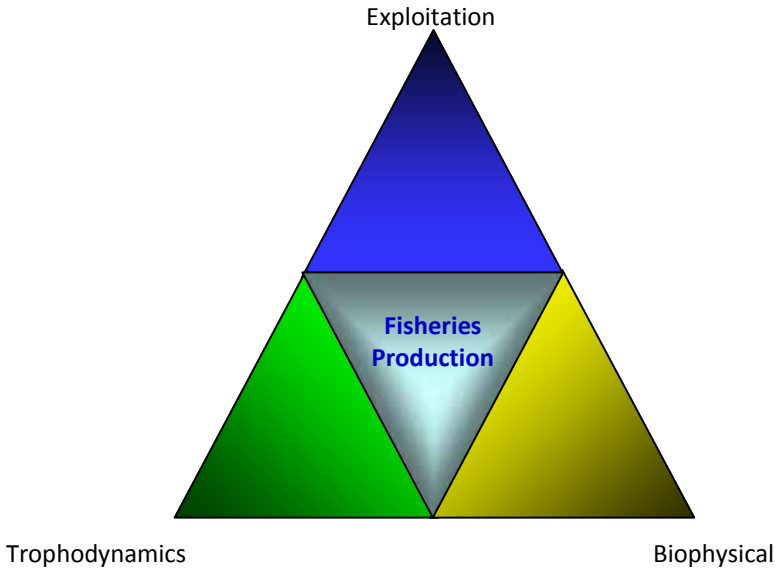
Using production models as tools to examine factors that influence productivity of marine systems: Contrasts across levels of aggregation, ecosystems and drivers

Sarah Gaichas, Jason S. Link, Thomas J. Miller, Tim Essington, R. Ian Perry, Alida Bundy, Jennifer Boldt, Ken F. Drinkwater, Erlend Moksness,

and all workshop participants!



International Stock Production Modeling Workshop 2

Workshop to Compare Canadian Norwegian and US Ecosystems

May 2-6, 2011
Woods Hole, MA, USA

CAMEO
Comparative Analysis of Marine Ecosystem Organization

Fisheries and Oceans Canada | Pêches et Océans Canada

INSTITUTE OF MARINE RESEARCH

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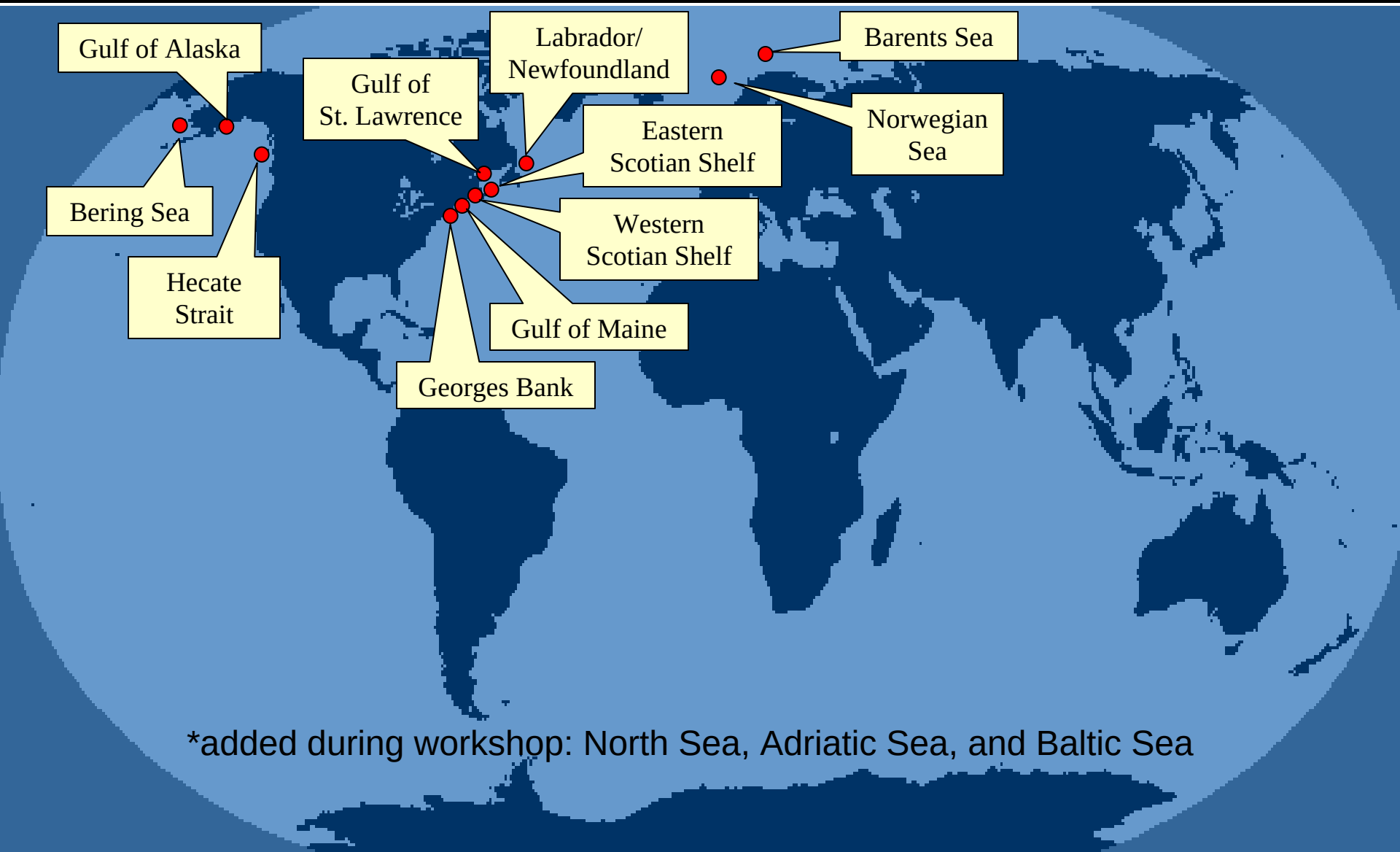
Ecosystem Studies of Sub-Arctic Seas
ESSAS

NOAA Fisheries

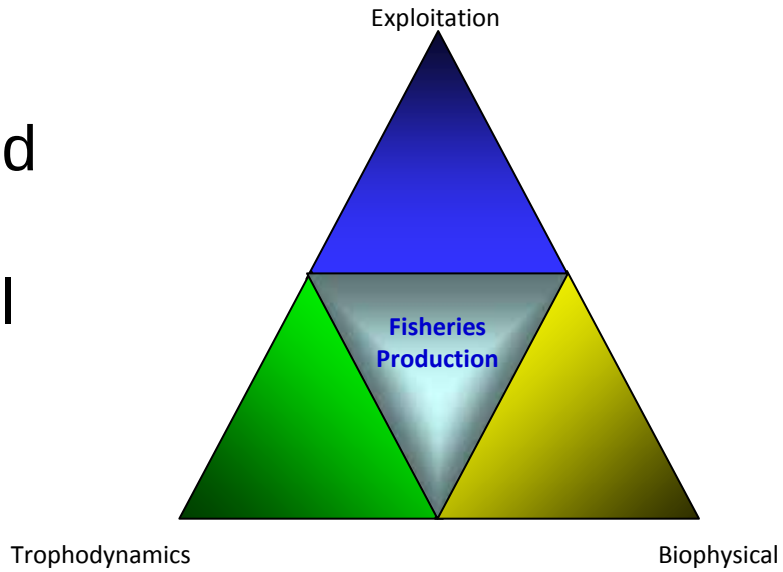
Marine Ecosystems Examined at this Workshop*



*added during workshop: North Sea, Adriatic Sea, and Baltic Sea

Objectives

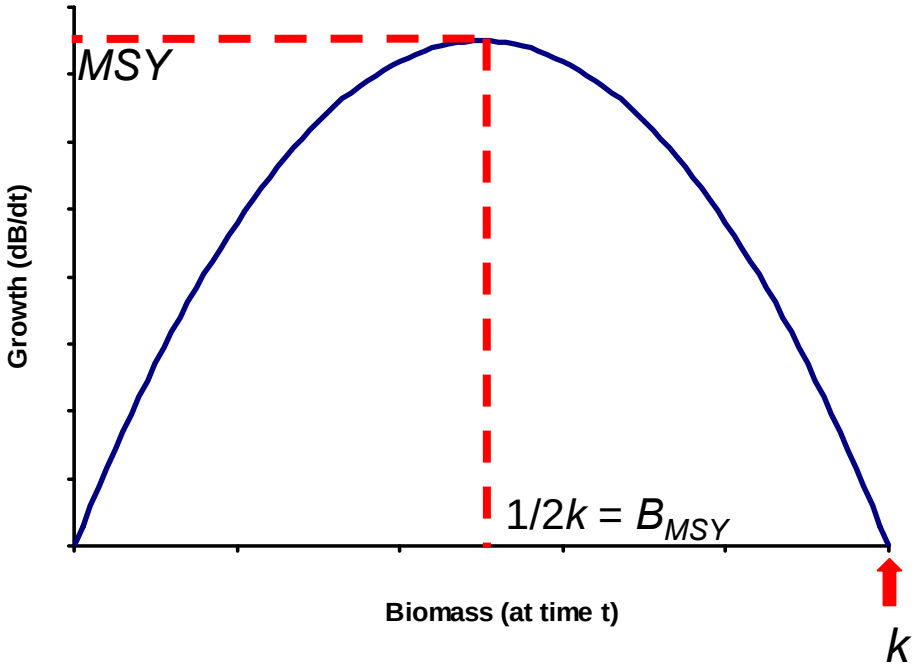
- Compare ecosystems of Canada, Norway and the US (many of the systems are ESSAS regions)
- Use production modeling, applied across several species and communities, as the unifying tool to serve as a comparative framework
- Identify the relative effects of physical forcing, trophodynamics, and fisheries exploitation drivers on fish production

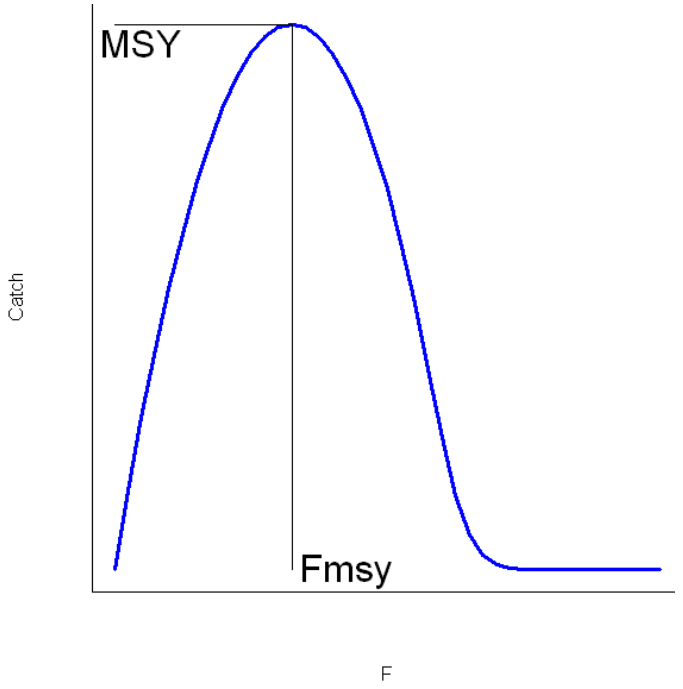


Why production models?
Simple, but with management implications

$$\frac{dB}{dt} = rB\left(1 - \frac{B}{k}\right) - C$$

$$MSY = \frac{r}{4}k \qquad F_{MSY} = \frac{r}{2}$$





B = biomass *C* = catch *r* = intrinsic population growth rate

k = unfished population biomass

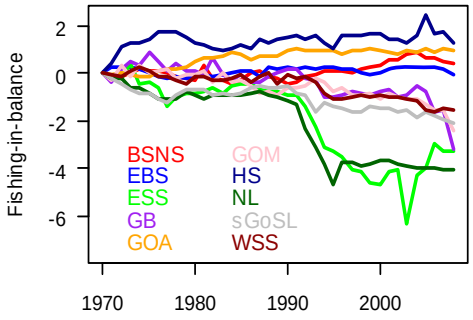
(*i.e.* equilibrium carrying capacity with no harvest)

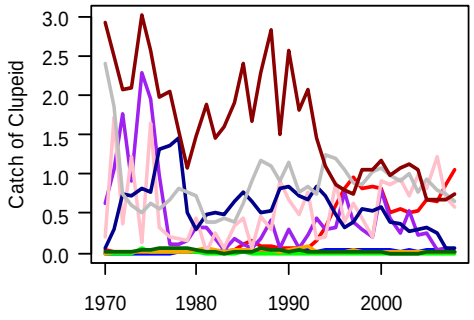
Approach

- Assembled comprehensive database of catch, biomass and research survey time series on multiple exploited species for 11+ ecosystems, including
  - Environmental time series
  - Trophic interactions data
  - Consistent aggregation rules

- Parallel working groups comparing systems with
  - Empirical statistical analysis
  - Full system aggregate production models
  - Functional (e.g. habitat, size) aggregate production models
  - Single species production models
  - Simulation modeling exploring management tradeoffs

Empirical results: catch





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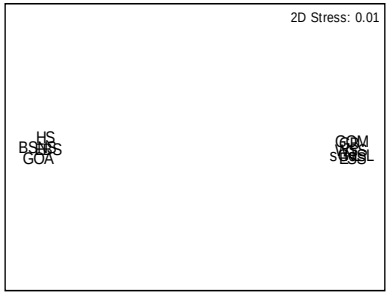

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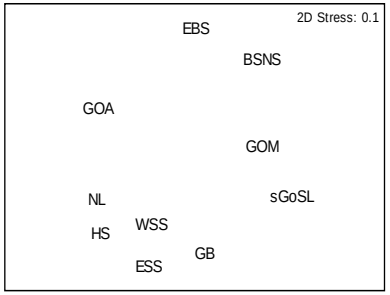

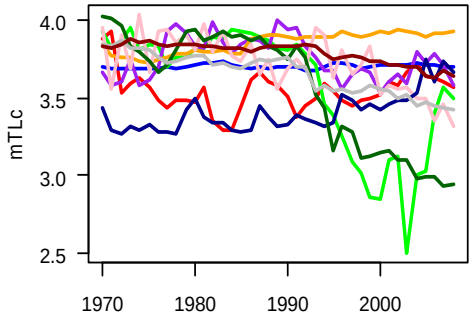

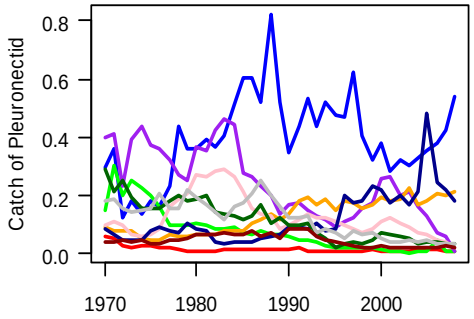

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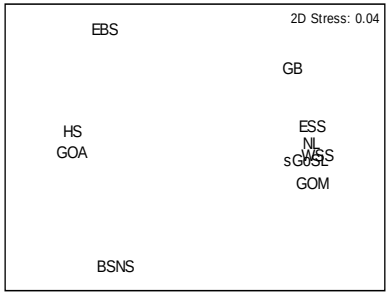

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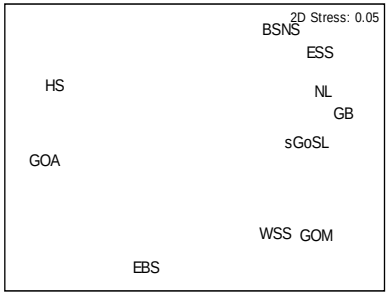

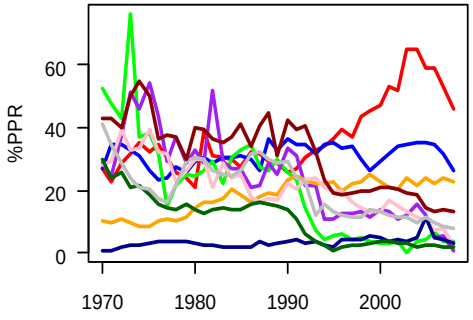

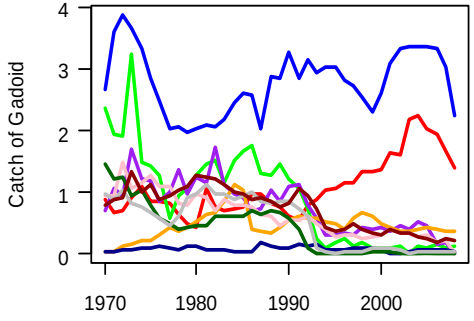

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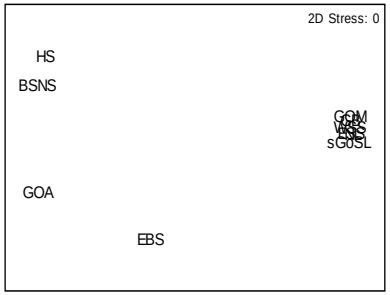

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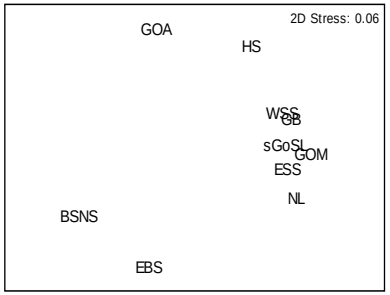
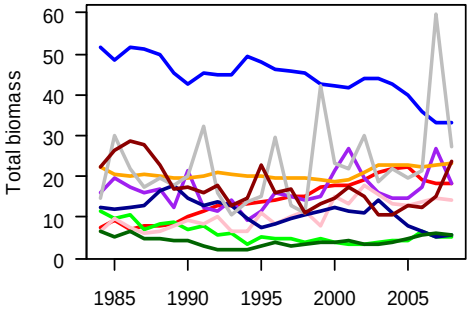
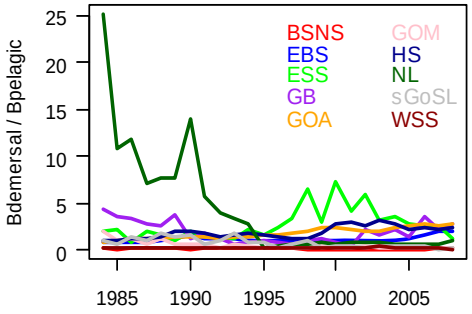
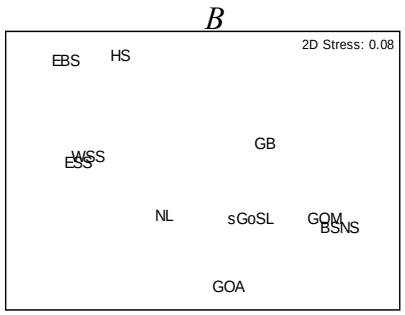
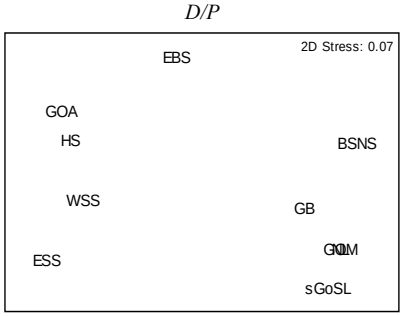


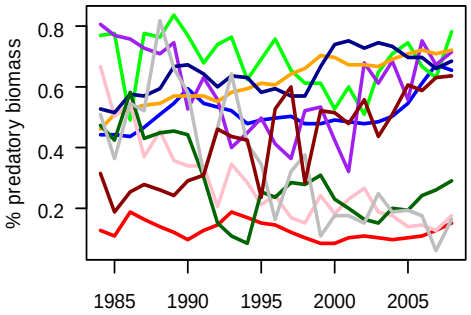
Empirical results: biomass

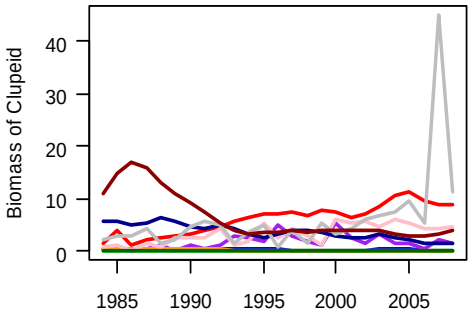


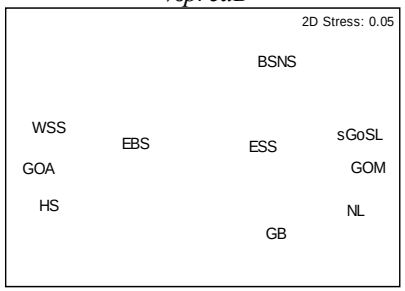


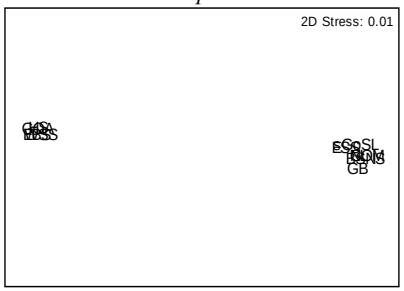


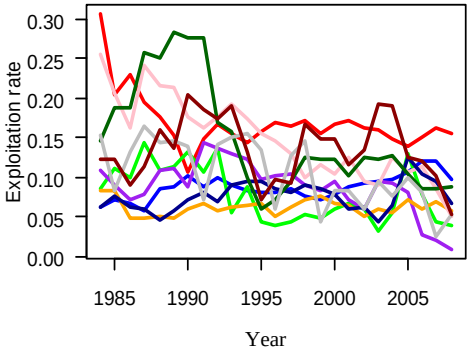


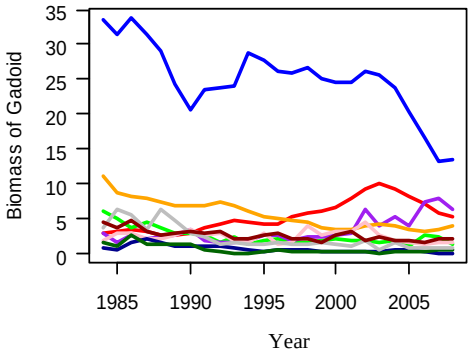


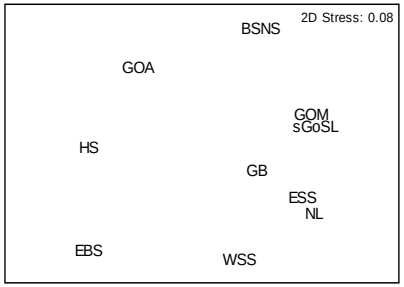


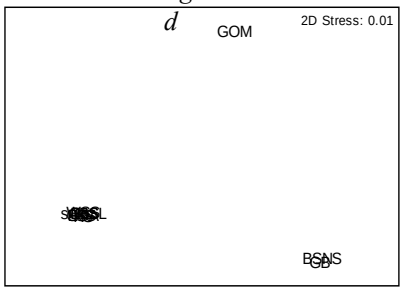






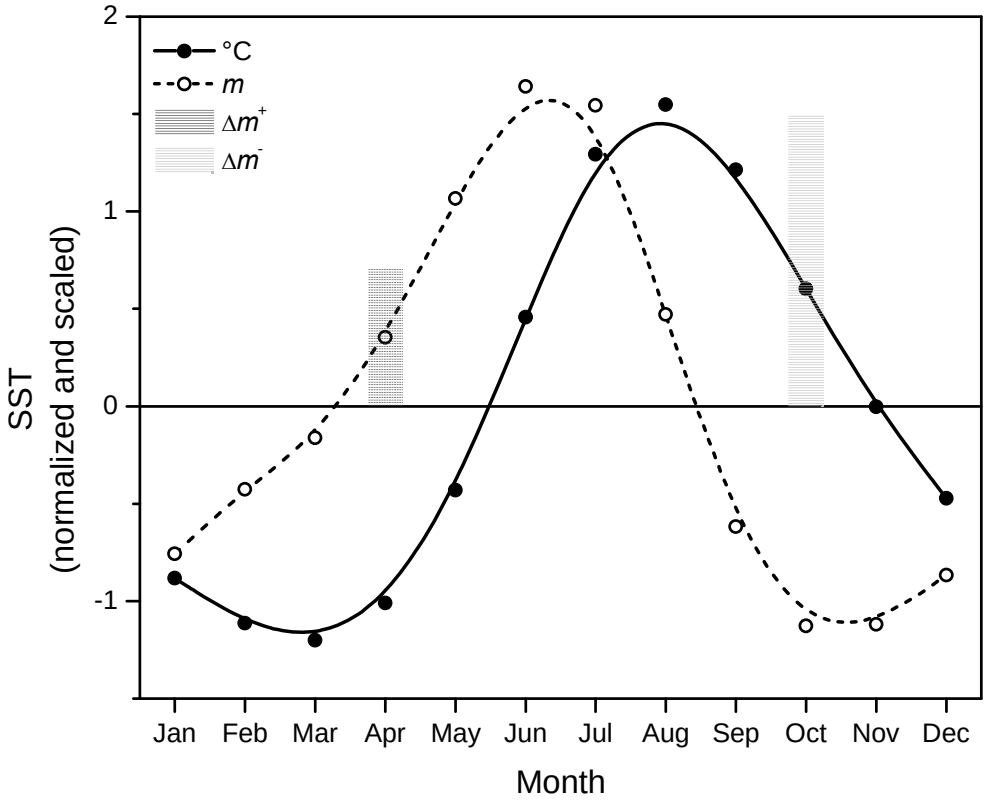


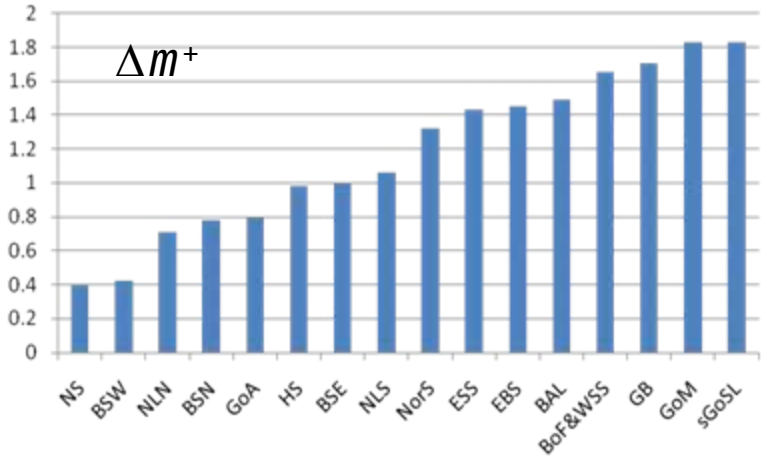


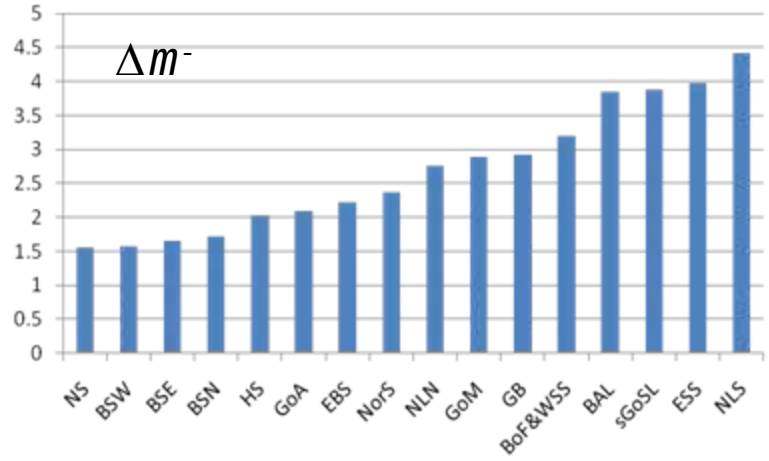


Empirical results: environment

Δm^+ Absolute value of the change in slopes going from a positive to negative slope
Δm^- Absolute value of the change in slopes going from a negative to positive slope
$\Delta m^{\pm}$ Sum of Δm^+ and Δm^-







Modeling Methods

Data: -Biomass (B) and catch (C) for commercial species, summed by year
-Environmental indices, standardized to mean = 0
standard deviation = 1

Annual Surplus Production Models:

$$ASP_t = B_{t+1} - B_t + C_t$$

$$ASP_t = \alpha B_t + \beta B_t^2 + \delta X_{t-\ell} + \varepsilon_t$$

$$\varepsilon_t = \phi \cdot \varepsilon_{t-1} + \nu_t$$

$$\nu_t \sim N(0, \sigma_\nu^2)$$

Dynamic Surplus Production Models:

$$\hat{B}_{t+1} = \hat{B}_t + r_t \hat{B}_t \left(1 - \frac{\hat{B}_t}{k}\right) - C_t \times \varepsilon_t$$

$$r_t = r_m e^{\gamma X_{t-\ell}}$$

$$\varepsilon \sim LnN(0, \sigma_\nu^2)$$

$\alpha, \beta, \delta, \gamma$ = parameterized quantities
k = density dependence parameter
φ = first-order autoregressive coefficient
r = population growth
l = time lag
^ = predicted
$\boldsymbol{B}_{(t=0)}$ = parameterized quantity in dynamic surplus production models

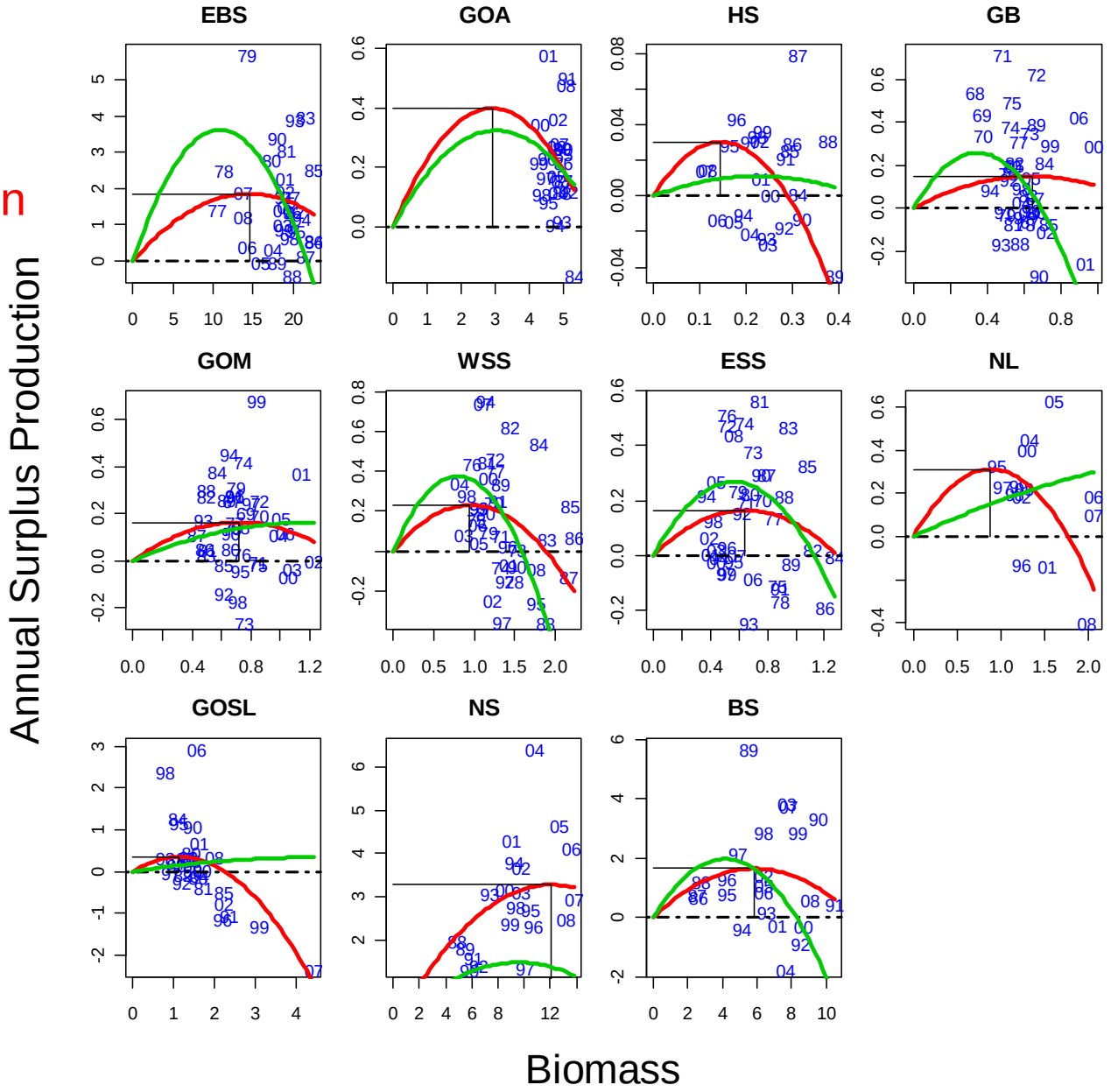
Model Fitting:

Annual Surplus Production (R), Dynamic Surplus Production (ADMB)

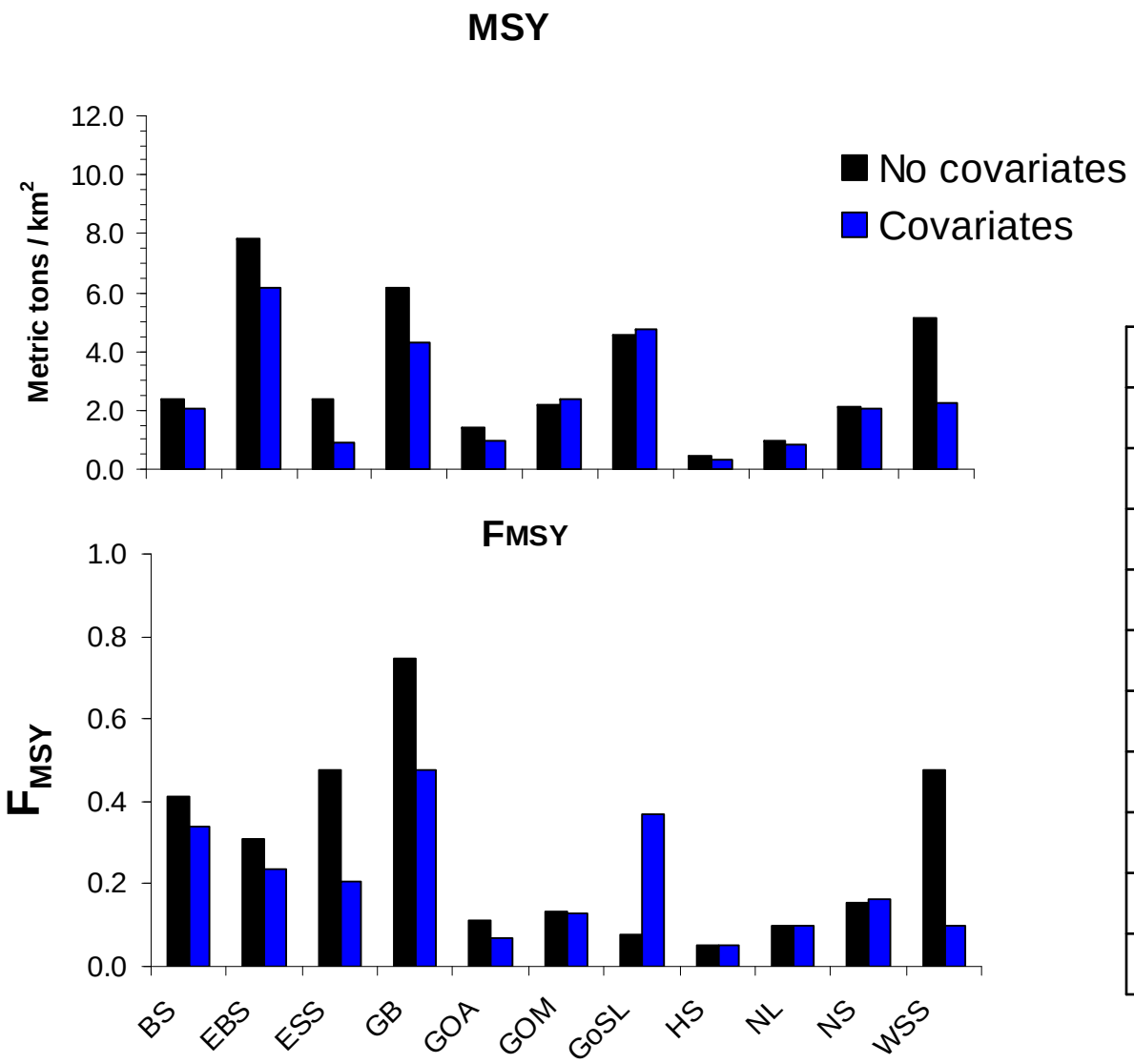
Full system aggregate results

Annual surplus production regression

Dynamic surplus production model



Full system aggregate results



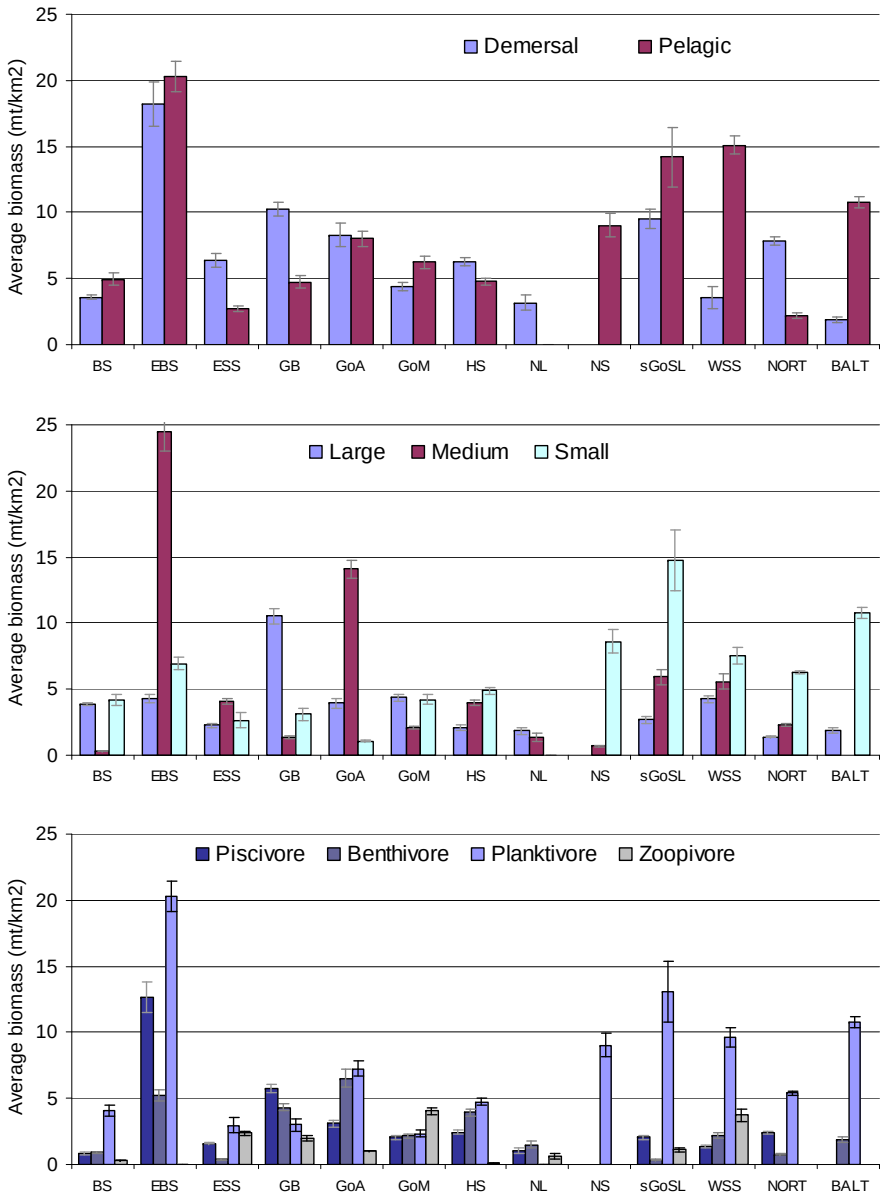
Covariates:

BS	sea_ice	6
EBS	sSST	1
ESS	grayseal	0
GB	NAO	5
GOA	sSST	5
GOM	aveSST	3
GoSL	SST	1
HS	pAFL	4
NL	composite	0, 1
NS	aveSST	4
WSS	grayseal	0

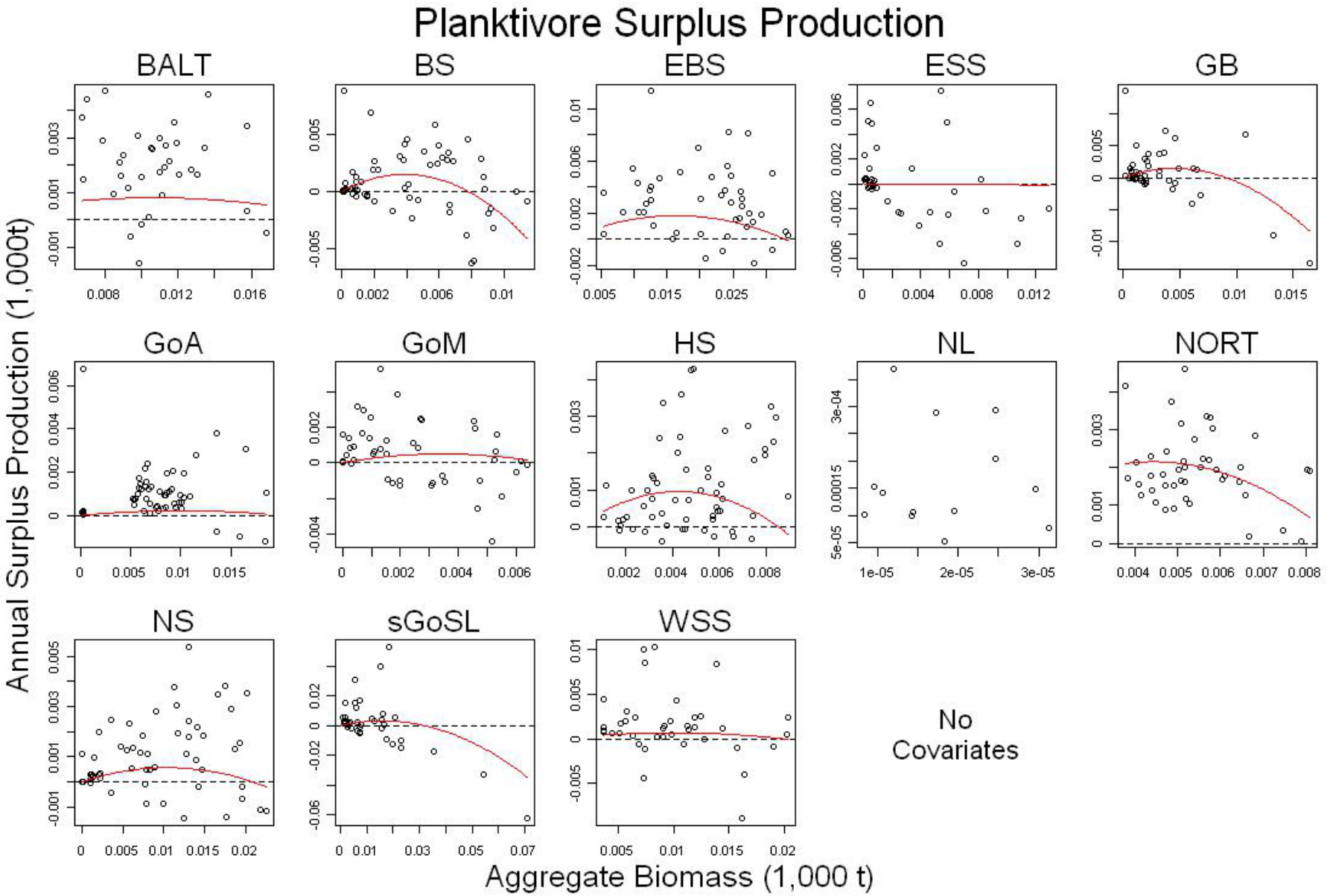
Functional aggregate results

- Habitat
  - Demersal
  - Pelagic
- Size
  - Large
  - Medium
  - small
- Feeding guild
  - Piscivore
  - Benthivore
  - Planktivore
  - Zoopivore

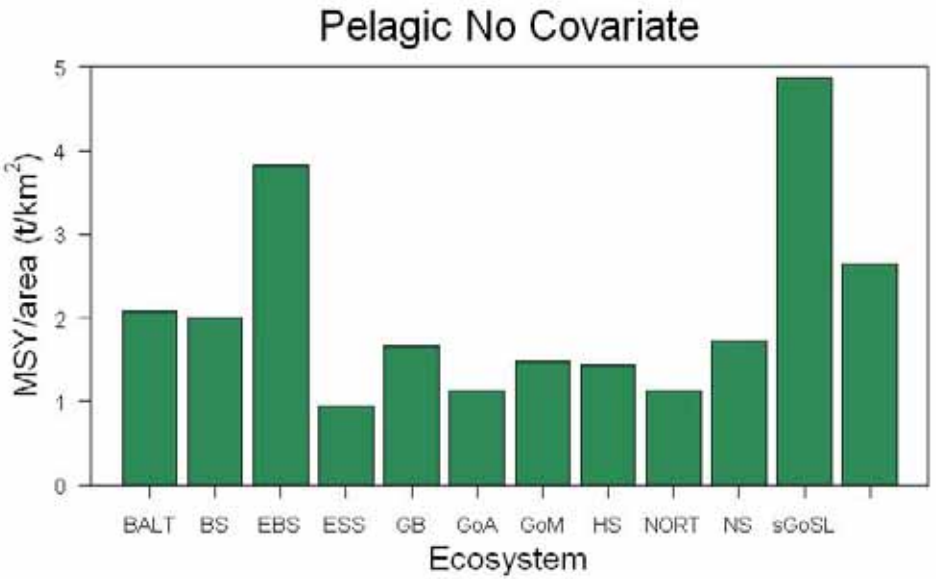
Biomass t/km^2

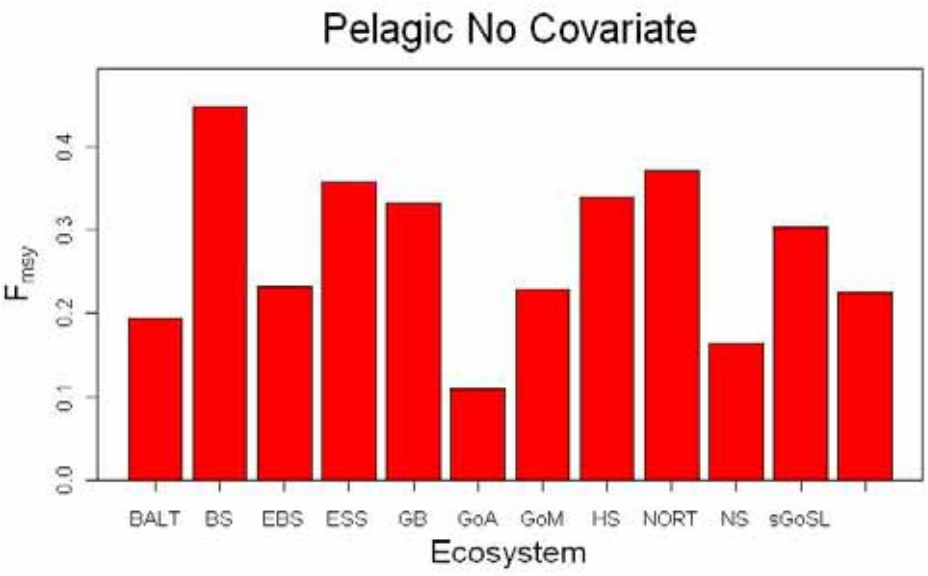


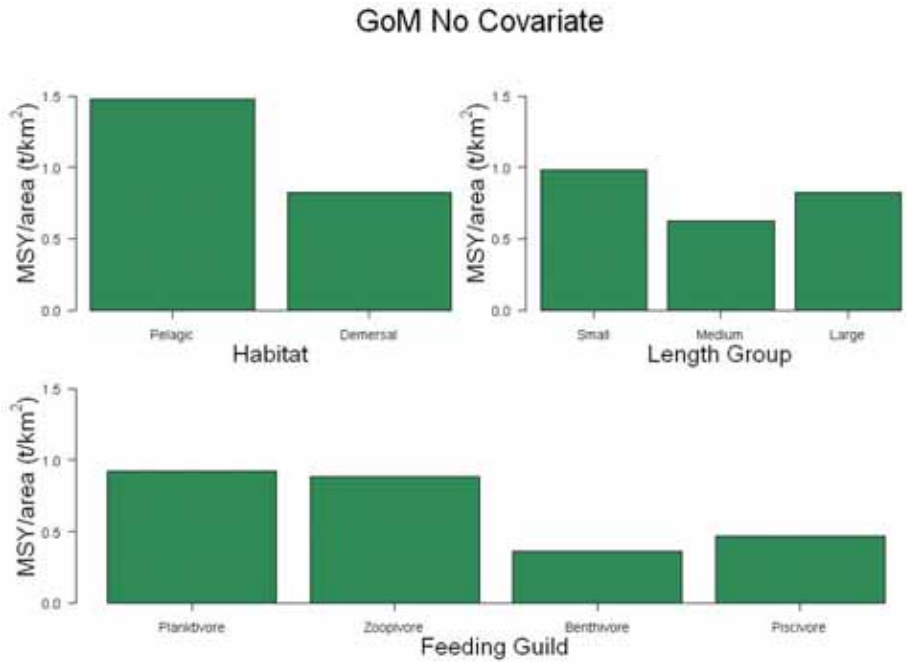
Functional aggregate results



Functional aggregate results

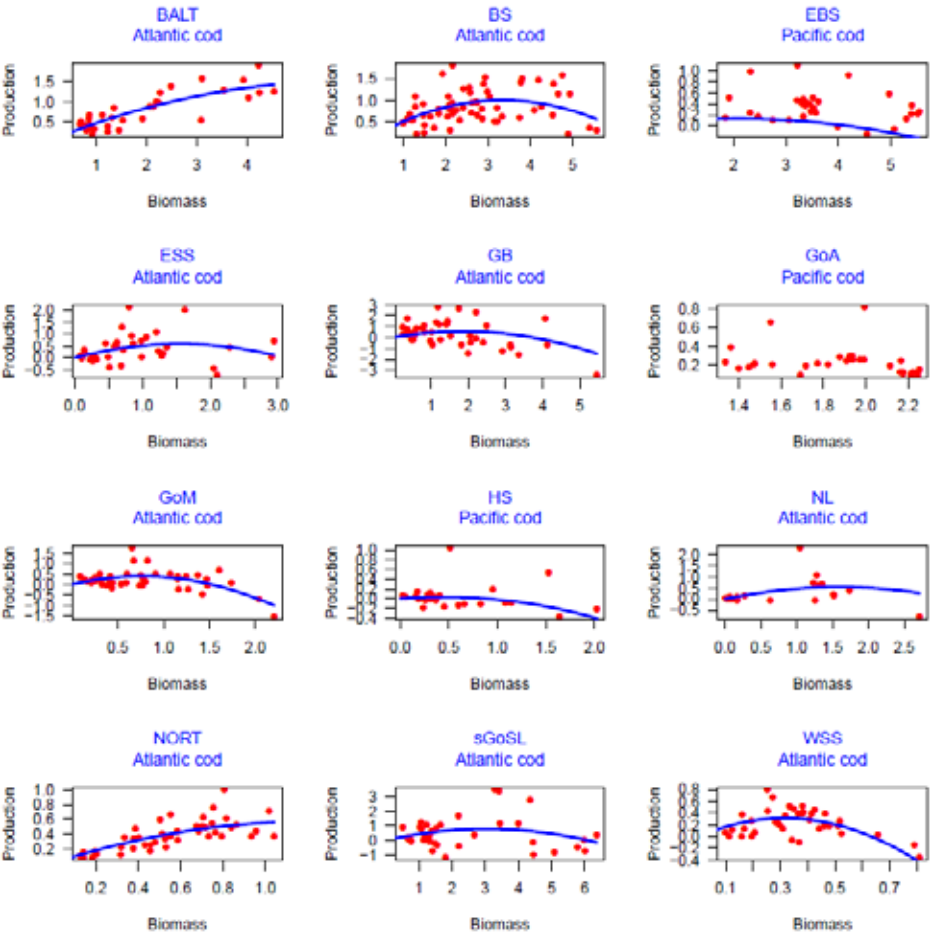


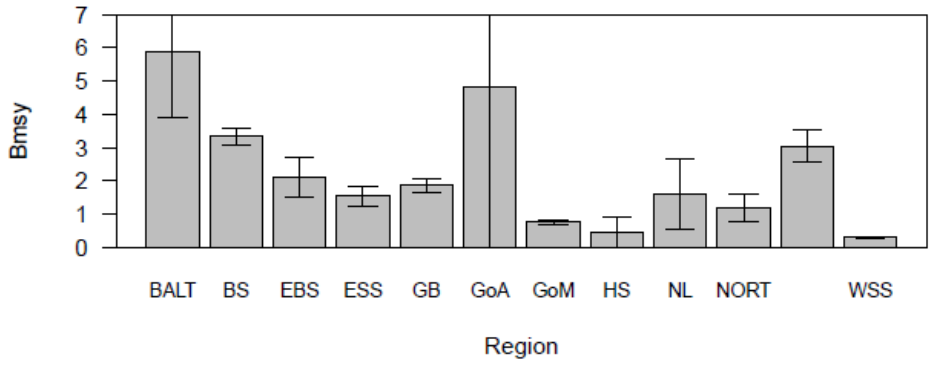


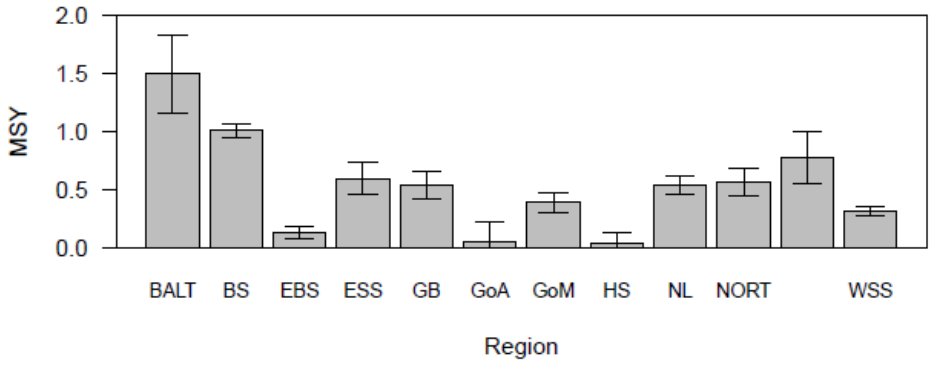


Single species results

Cod

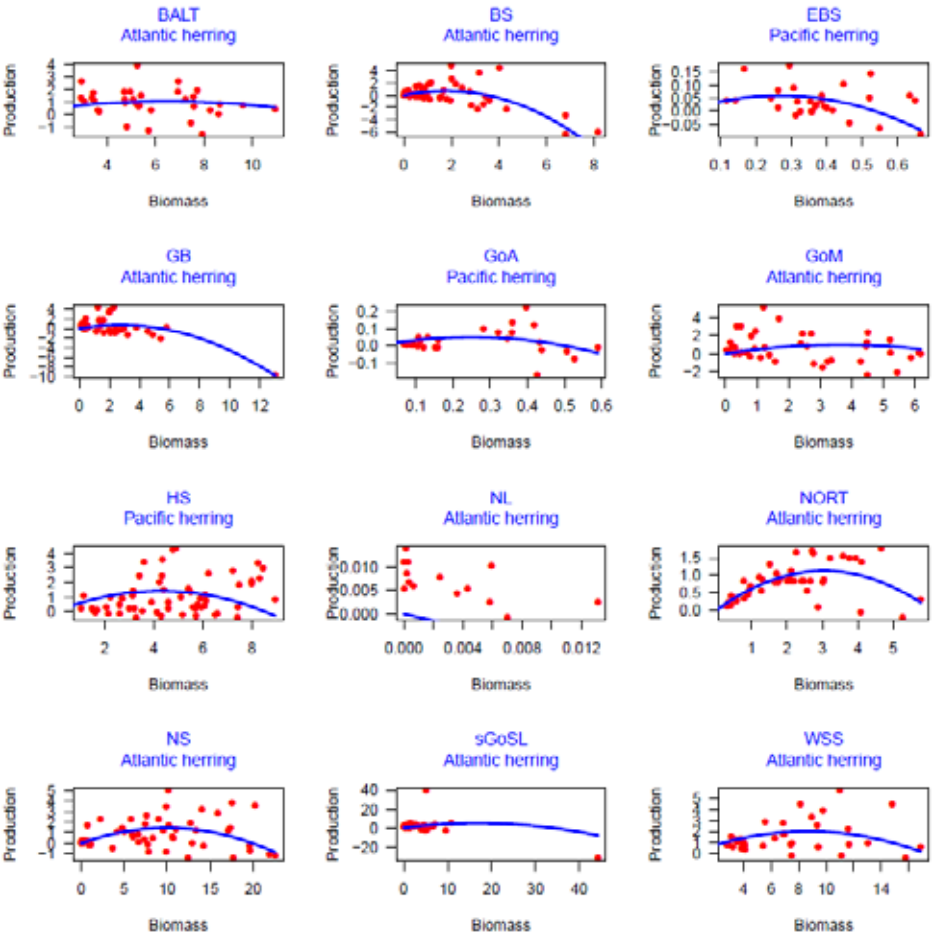


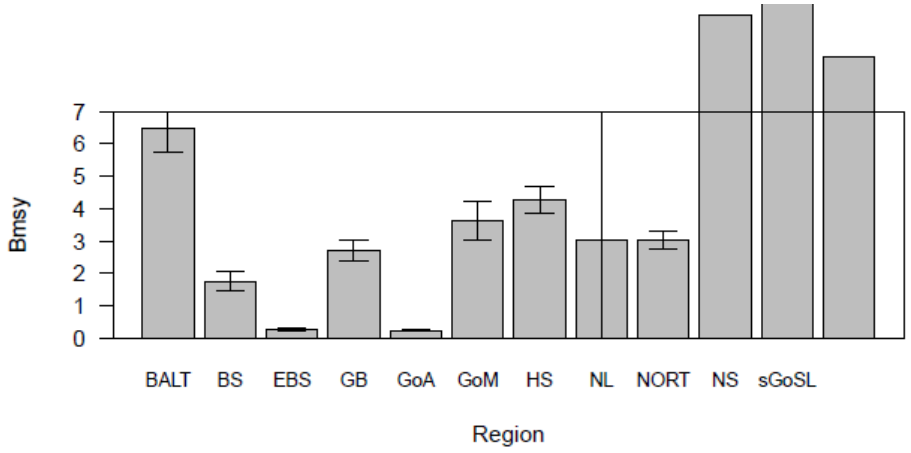


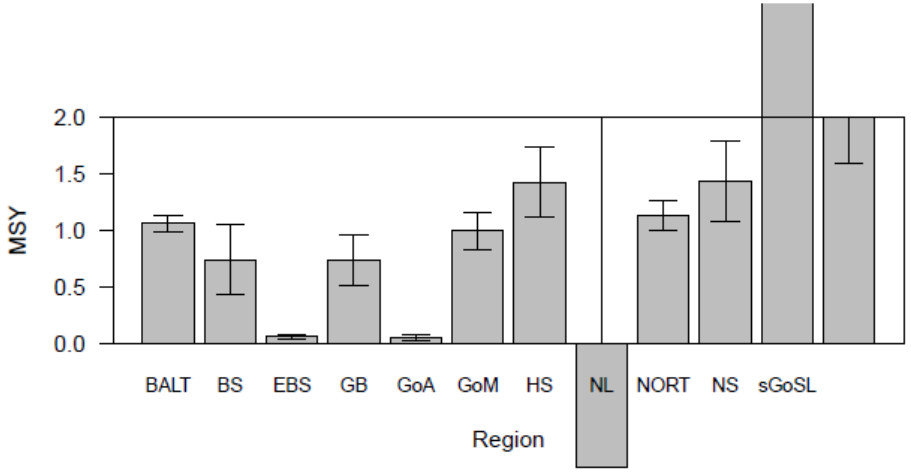


Single species results

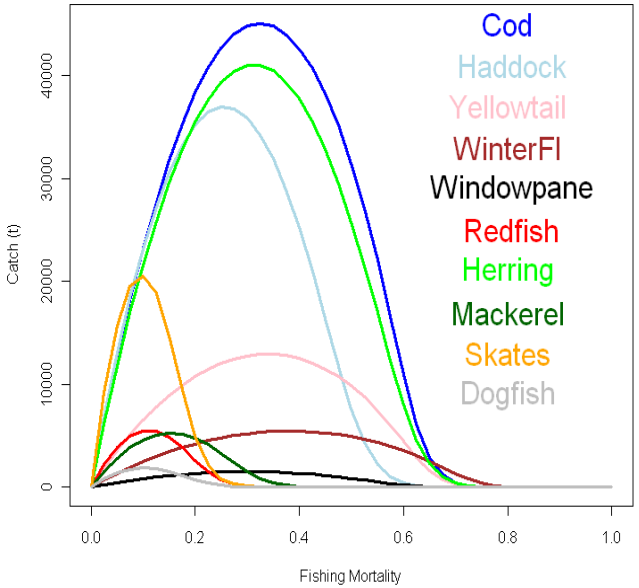
Herring



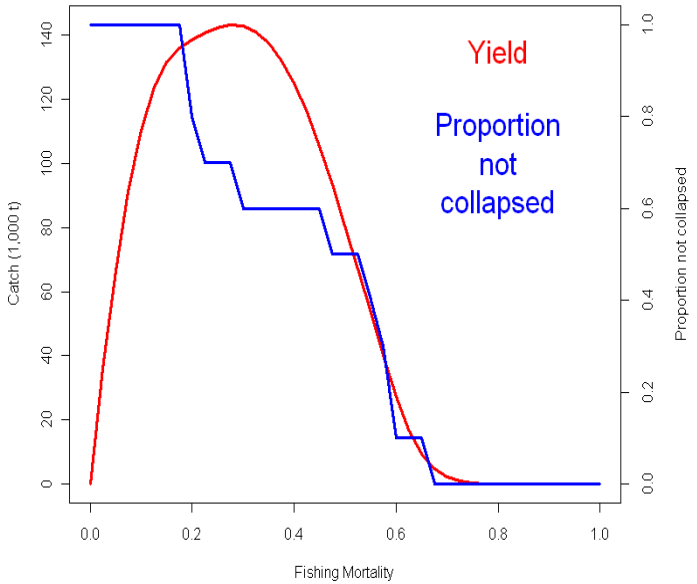


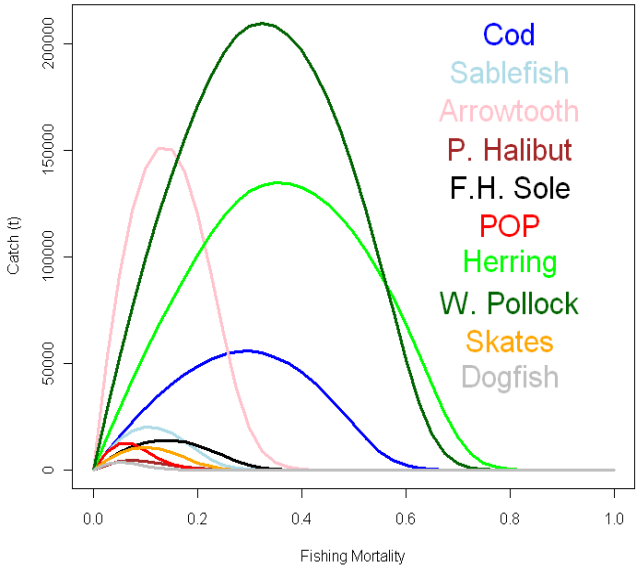


Simulation results

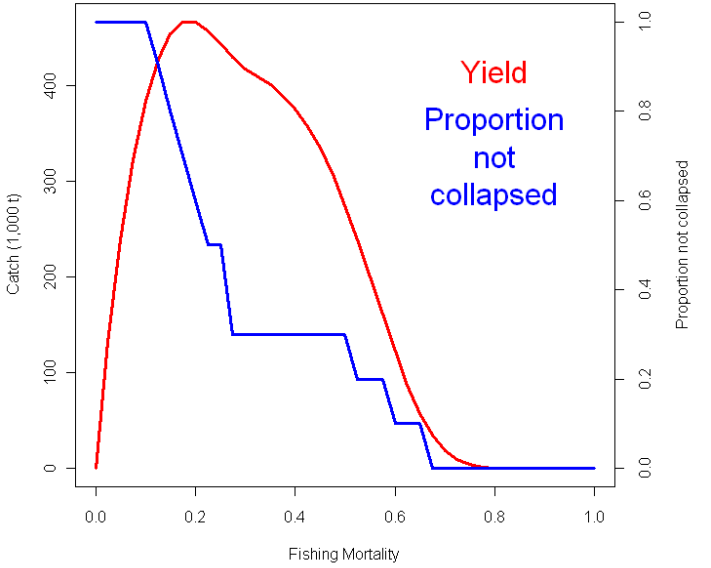


Georges Bank
(competition)

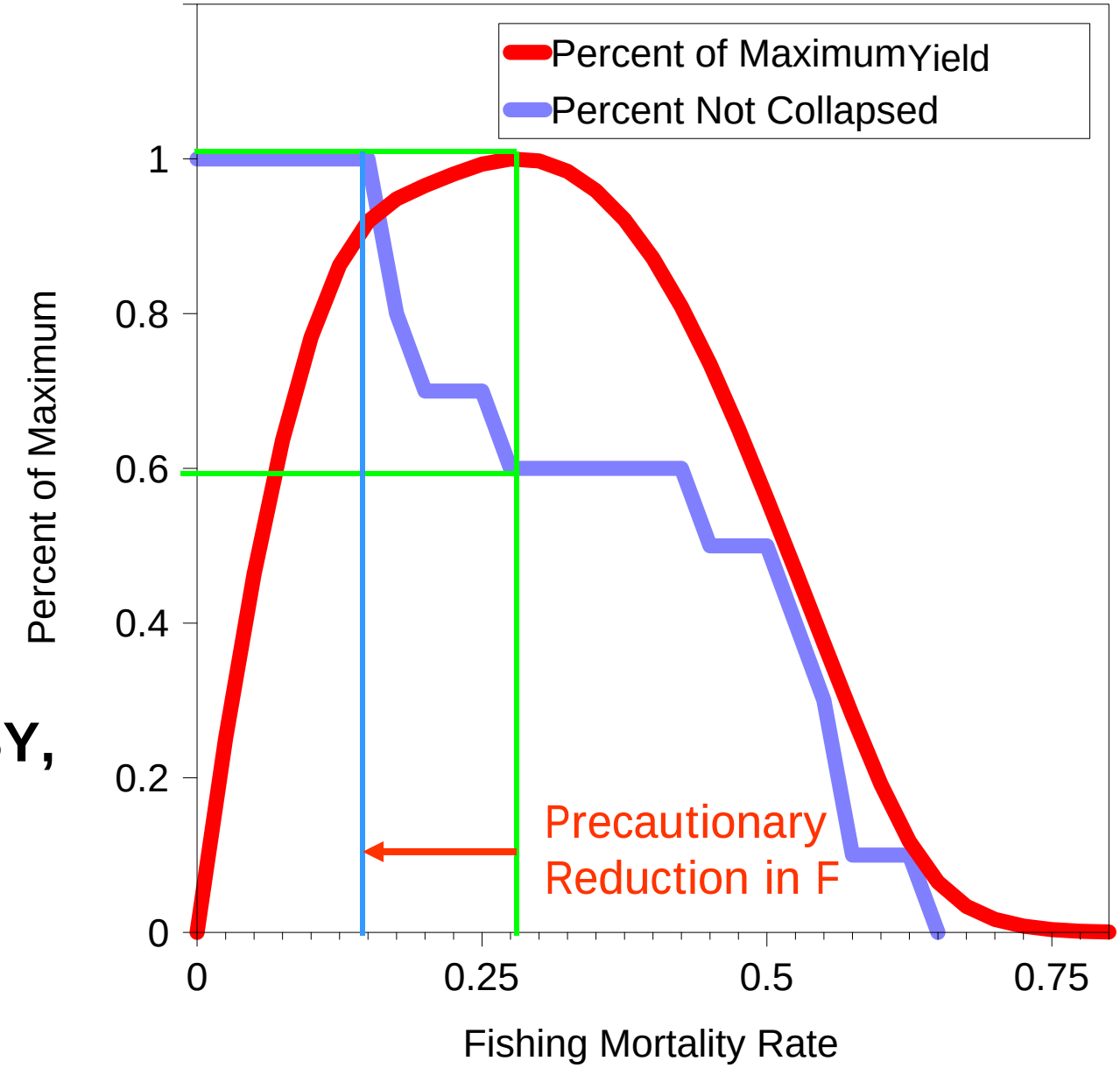




Gulf of Alaska
(predation)



Simulation results

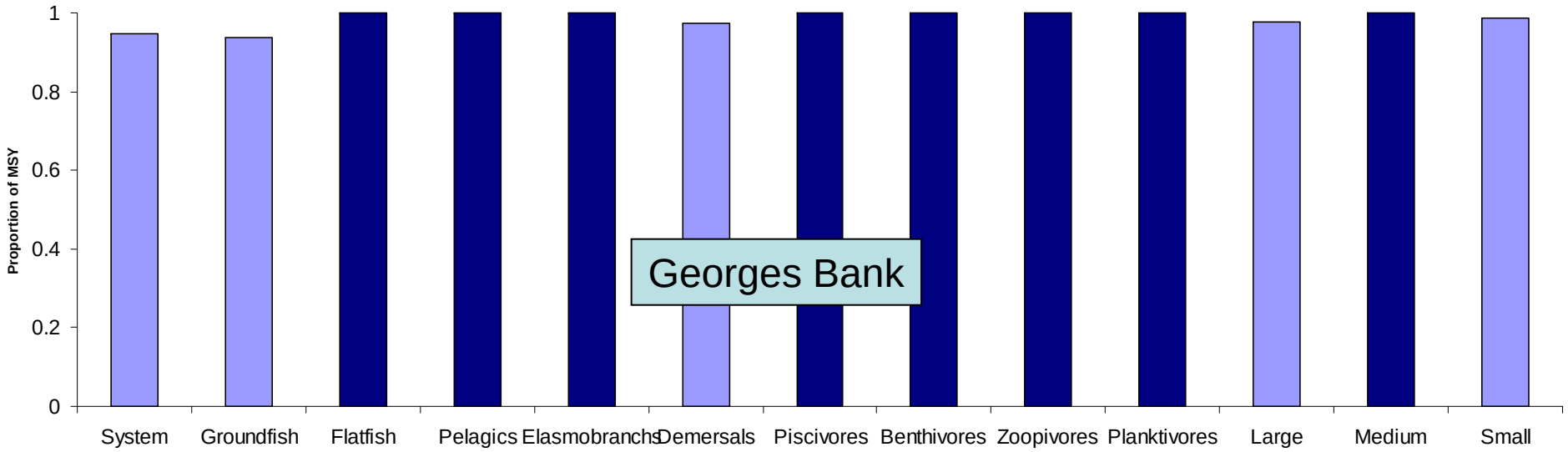


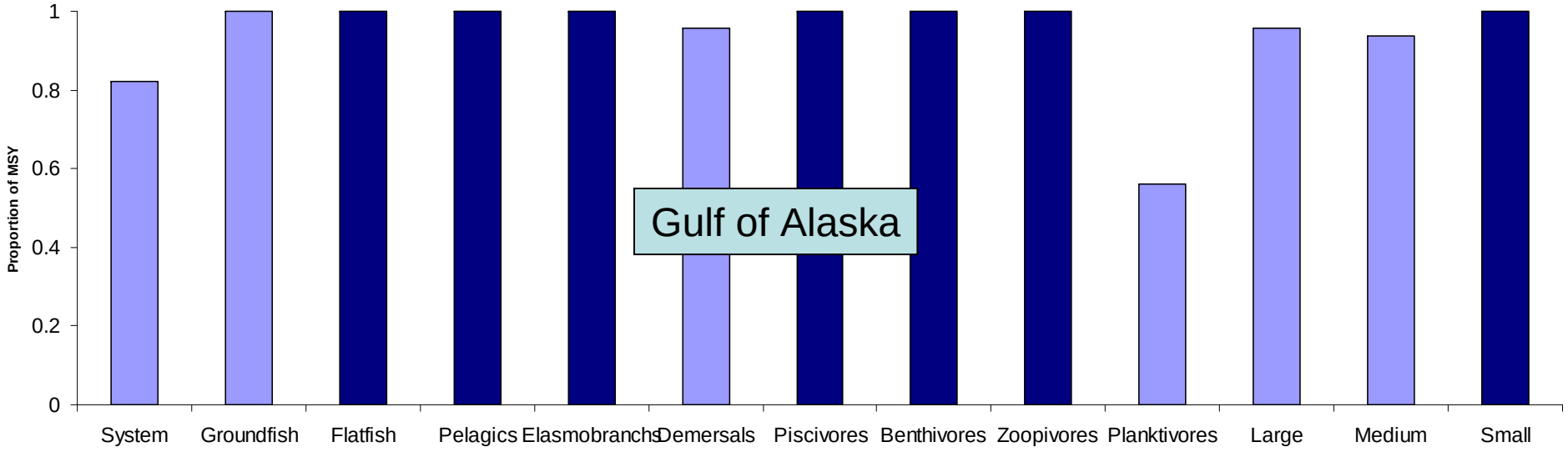
Get ~95% of MSY, no collapsed species with reduced F

Simulation results

proportion of MSY obtainable with no species below 10%

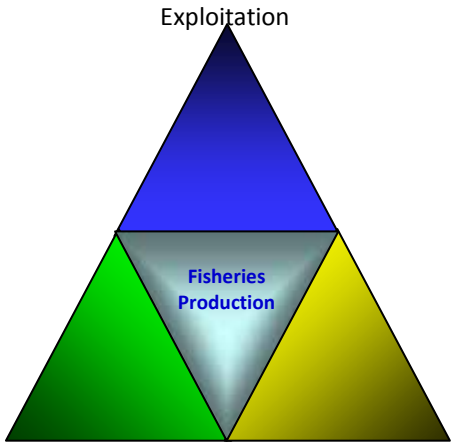
Dark bars are 1.0





Preliminary Synthesis

- Across these marine ecosystems, total yield has a fairly consistent range of 1-5 t km^{-2}
- MSY (and associated BRPs) calculated at increasing levels of aggregation is lower than sum of single species MSYs
- Covariates can improve fits, do affect MSY
- Relationship between fishery yield and PP is not as straightforward as was once thought
- Tradeoff between MSY and biodiversity can be minimized with thoughtful aggregation



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