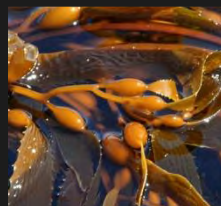





Using multi-species food-web and assessment models to evaluate climate change impacts on fisheries

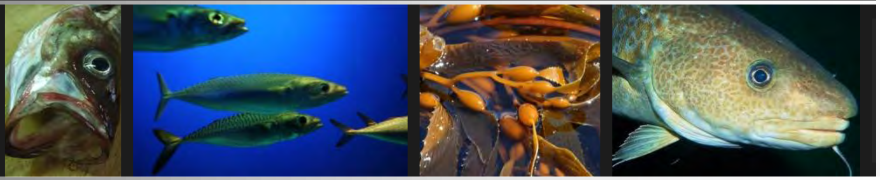
Kirstin Holsman
Kirstin.holsman@noaa.gov
UW JISAO / NOAA AFSC

Collaborators:

Jim Ianelli	Kerim Aydin
Ivonne Ortiz	Al Hermann
Liz Moffitt	André Punt

www.bsierp.nprb.org

Climate Change



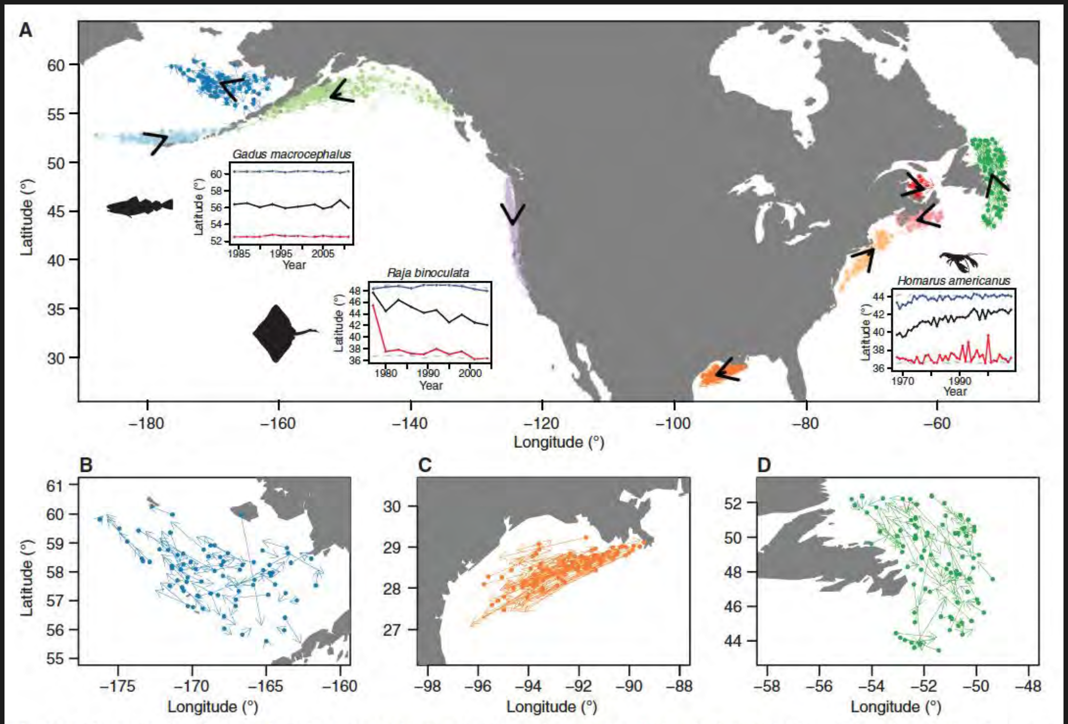
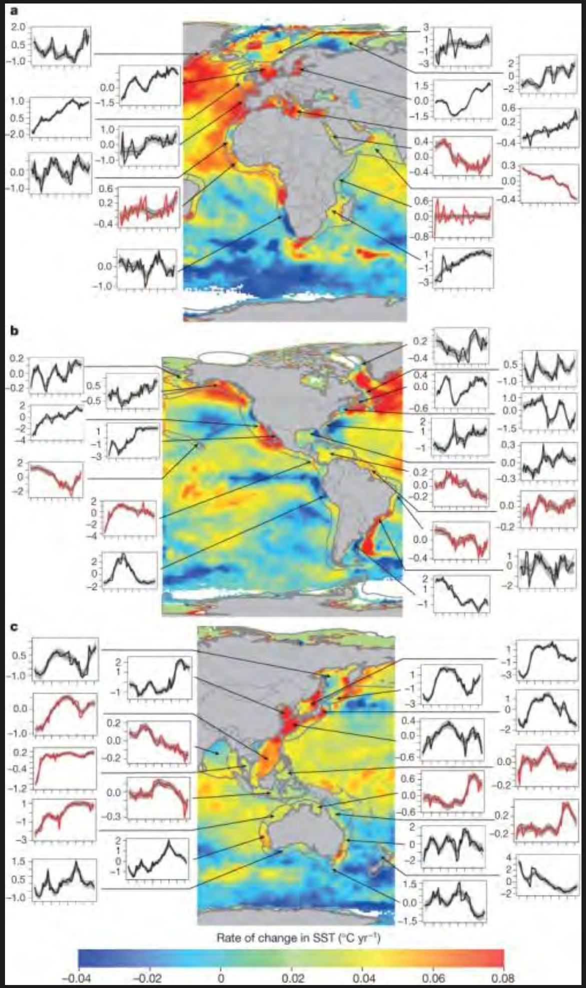


Fig. 1. Shifts in the distribution of marine taxa. (**A**) Vectors show the average shift in latitude and longitude for each taxon (colors) and the mean shift in each region (black). Insets show the mean (black), maximum (blue), and minimum (red) latitude of detection for Pacific cod (*Gadus macrocephalus*) in the Gulf of Alaska, big skate (*Raja binoculata*) on the U.S. West Coast, and American lobster (*Homarus americanus*) in the Northeast. Gray dashed lines in insets indicate the range of surveyed latitudes. Detailed views are also shown of (**B**) the Eastern Bering Sea, (**C**) the Gulf of Mexico, and (**D**) Newfoundland.

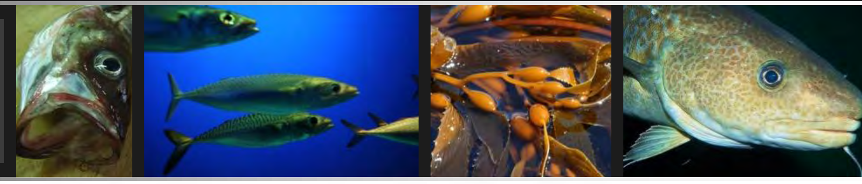


ML Pinsky et al. **Marine Taxa Track Local Climate Velocities**. *Science*, 13 September 2013: 1239-1242 DOI:10.1126/science.1239352

WWL Cheung *et al. Nature* **497**, 365-368 (2013) doi:10.1038/nature12156

kirstin.holsman@noaa.gov

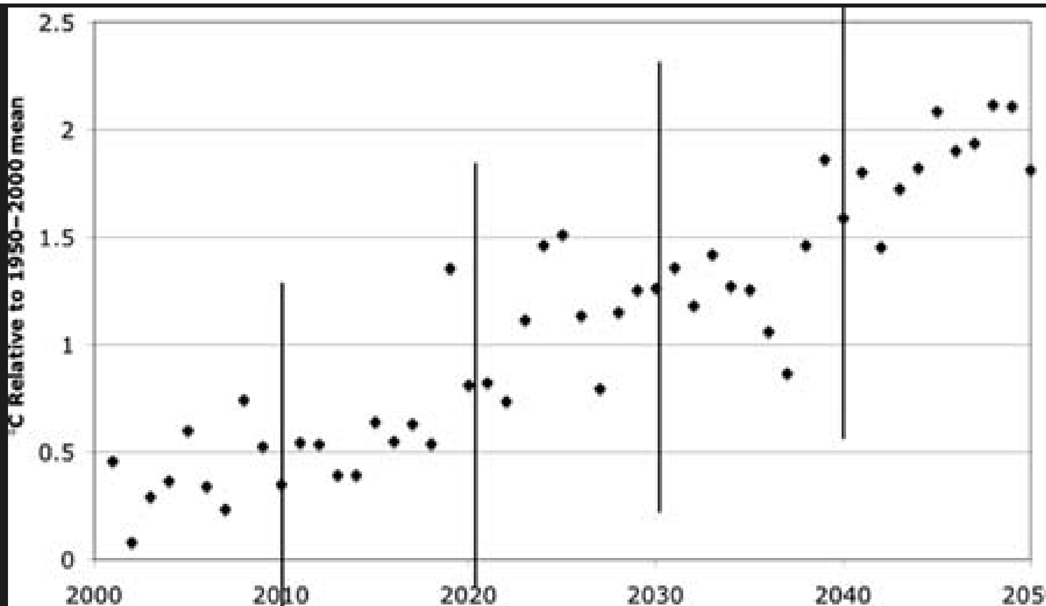
Climate Change



A framework for modelling fish and shellfish responses to future climate change

Anne Babcock Hollowed, Nicholas A. Bond, Thomas K. Wilderbuer, William T. Stockhausen, Z. Teresa A'mar, Richard J. Beamish, James E. Overland, and Michael J. Schirripa

(2009) ICES Journal of Marine Science, 66: 1584–1594.



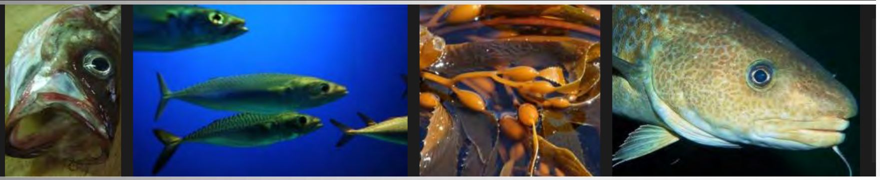
Weighted ensemble mean of IPCC forecasts of SST under A1B emissions scenario.

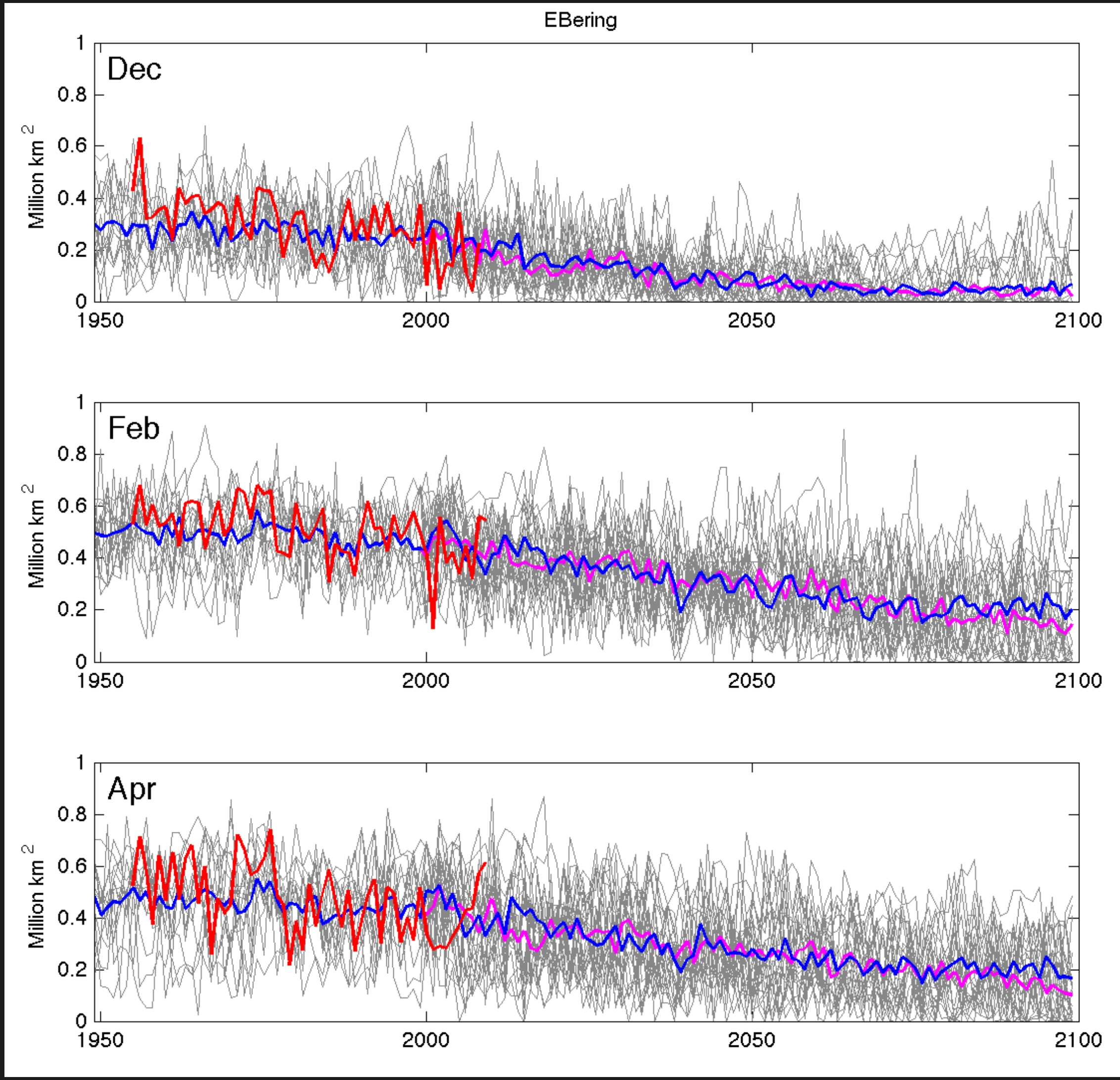
2 °C increase by 2050

4 °C increase by 2099

kirstin.holsman@noaa.gov

Climate Change





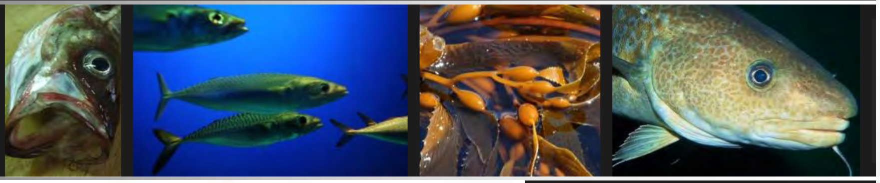
Projected Seasonal – Sea Ice Extent Over Bering Sea

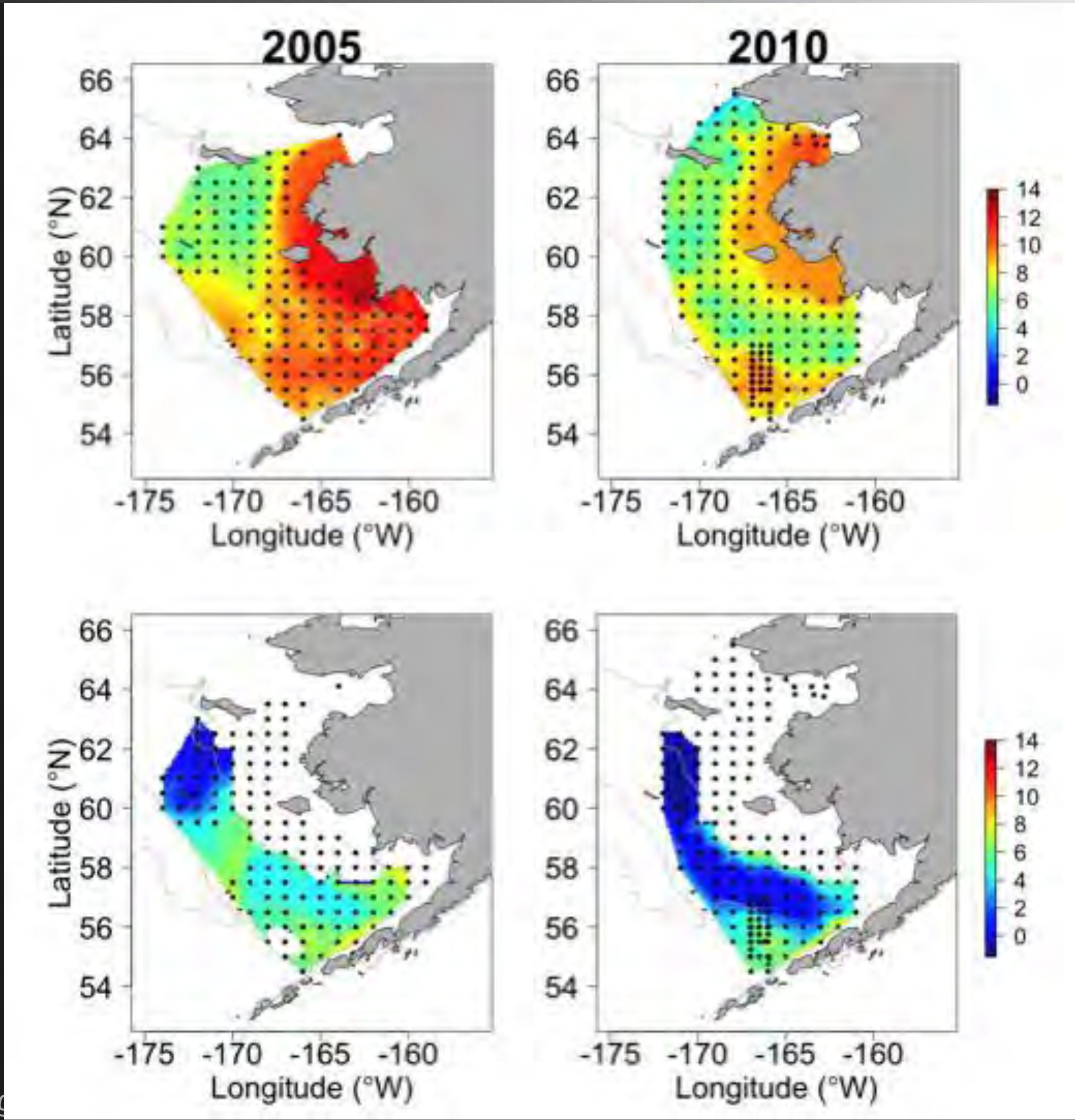
Red – Observed
Black – Ensemble means under A1B scenario
Pink – Ensemble mean under A2 scenario
Gray curvy – one realization of one model

Wang, Overland and Stabeno 2012 DSR II 65-70: 46-57

kirstin.holsman@noaa.gov

Climate Change



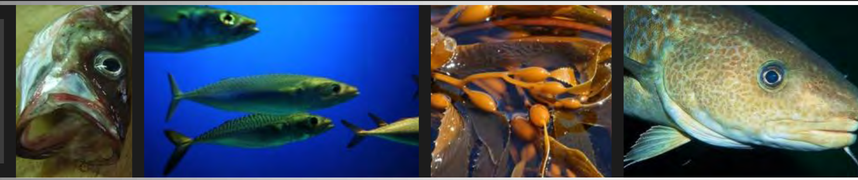


SST

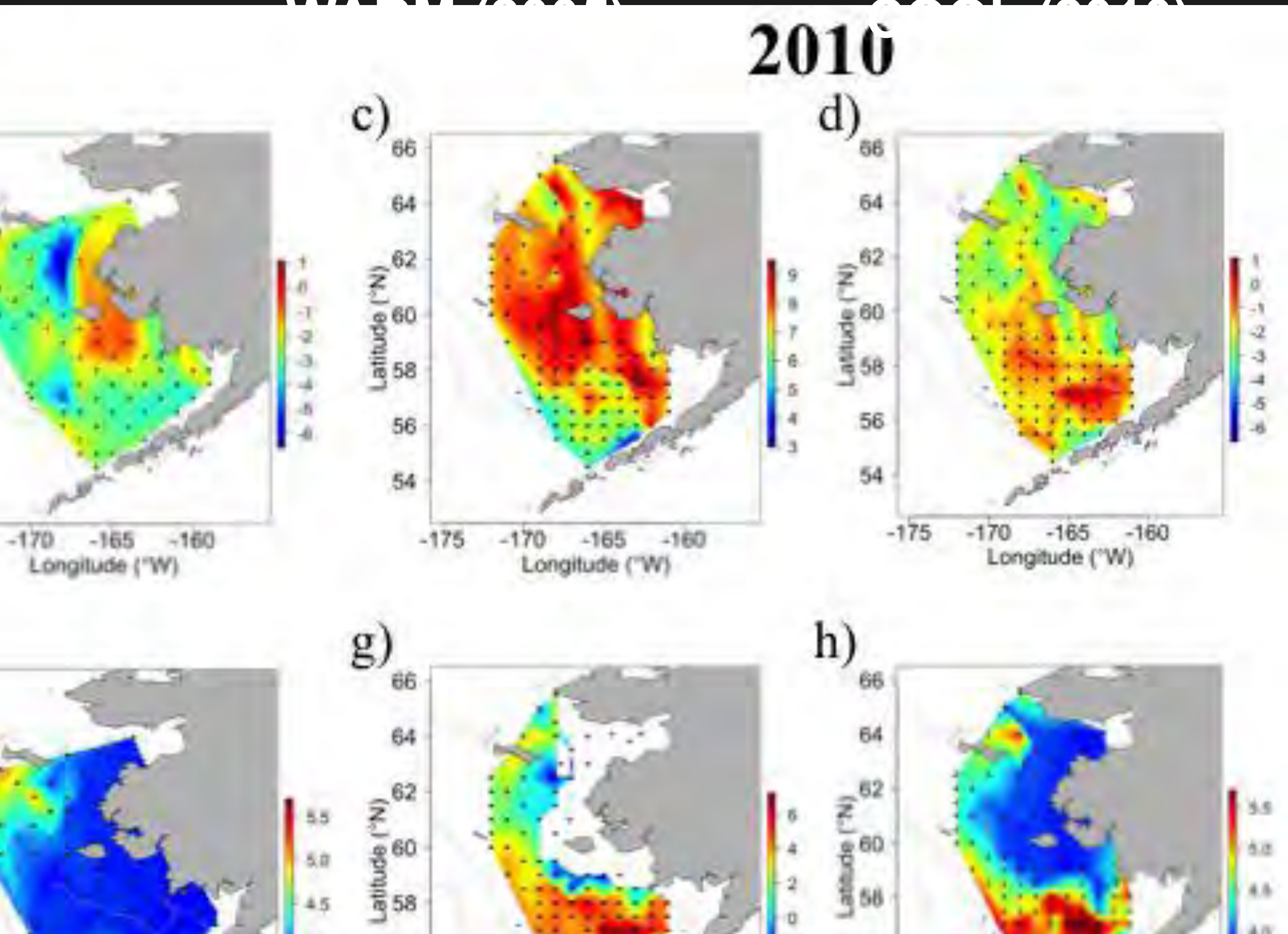
Bottom T

kirstin.holsman@noaa.g

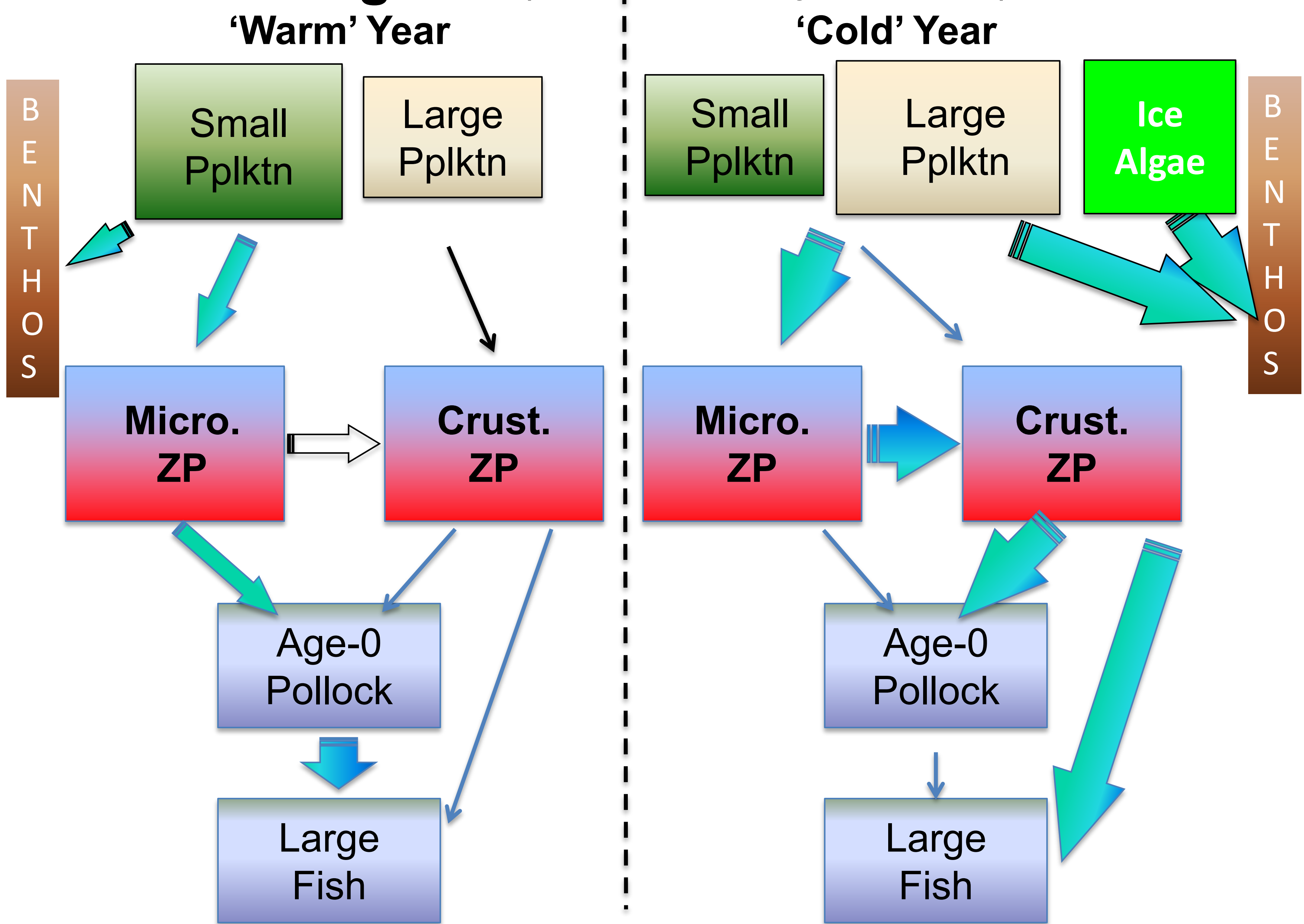
Climate Change



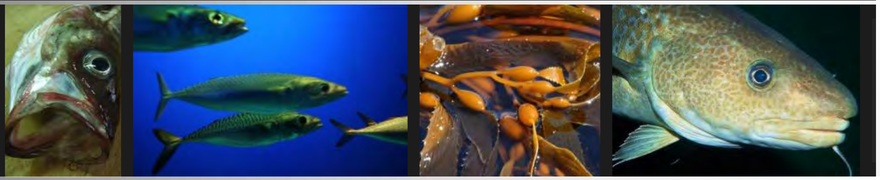
Log Available Zooplankton Biomass (g WW)



Conceptual Model of Carbon/Energy flow in the eastern Bering Sea (modified from Coyle et al. 2011)



Climate Change



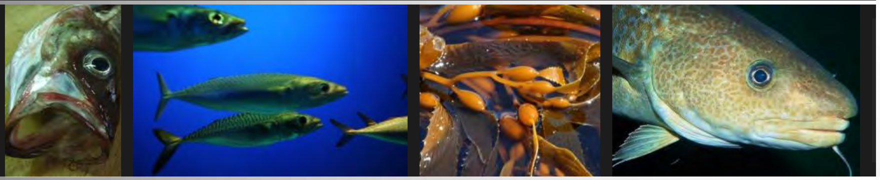
What is the range of effects of climate change on biomass, production, & recommended harvest rates?

Are current assessment models robust to climate driven changes? (if not, why not)?

Corey Arnold

kirstin.holsman@noaa.gov

Climate Change



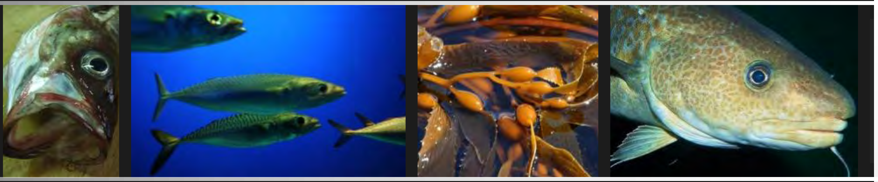
What is the range of effects of climate change on biomass, production, & recommended harvest rates?

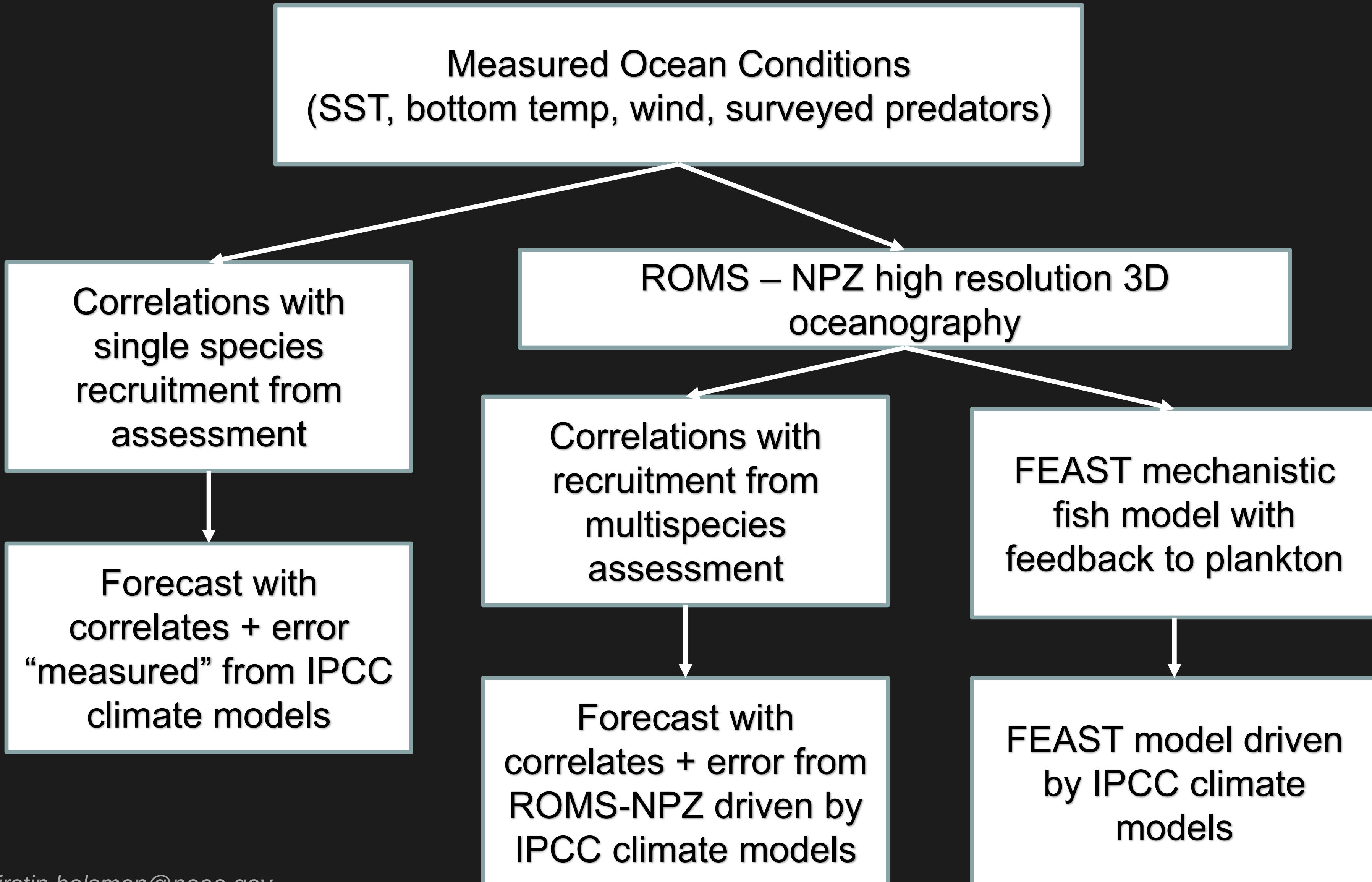
Are current assessment models robust to climate driven changes? (if not, why not)?

kirstin.holsman@noaa.gov

Corey Arnold

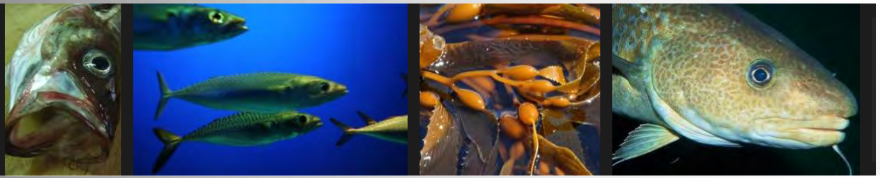
Approaches





kirstin.holsman@noaa.gov

Approaches



Measured Ocean Conditions
(SST, bottom temp, wind, surveyed predators)

Correlations with single species recruitment from assessment

Forecast with correlates + error “measured” from IPCC climate models

ROMS – NPZ high resolution 3D oceanography

Correlations with recruitment from multispecies assessment

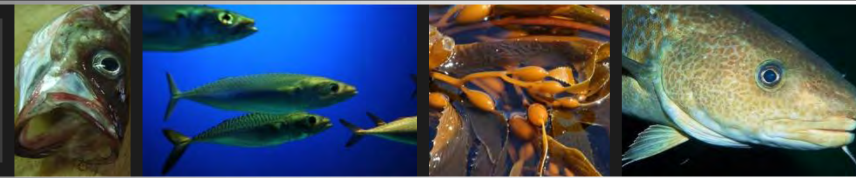
Forecast with correlates + error from ROMS-NPZ driven by IPCC climate models

FEAST mechanistic fish model with feedback to plankton

FEAST model driven by IPCC climate models

kirstin.holsman@noaa.gov

Approaches



Measured Ocean Conditions
(SST, bottom temp, wind, surveyed predators)

Correlations with single species recruitment from assessment

Forecast with correlates + error "measured" from IPCC climate models

ROMS – NPZ high resolution 3D oceanography

Correlations with recruitment from multispecies assessment

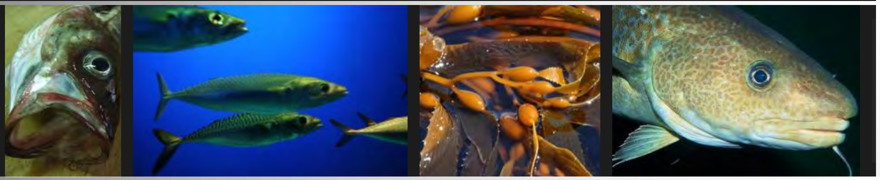
Forecast with correlates + error from ROMS-NPZ driven by IPCC climate models

FEAST mechanistic fish model with feedback to plankton

FEAST model driven by IPCC climate models

kirstin.holsman@noaa.gov

Approaches



Measured Ocean Conditions
(SST, bottom temp, wind, surveyed predators)

Correlations with single species recruitment from assessment

Forecast with correlates + error "measured" from IPCC climate models

ROMS – NPZ high resolution 3D oceanography

Correlations with recruitment from multispecies assessment

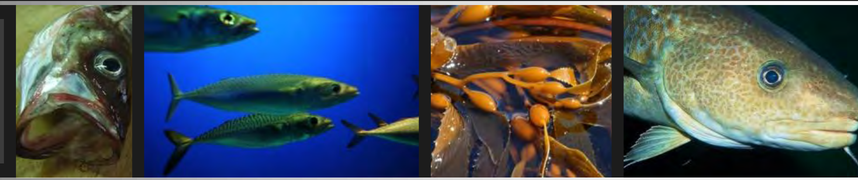
Forecast with correlates + error from ROMS-NPZ driven by IPCC climate models

FEAST mechanistic fish model with feedback to plankton

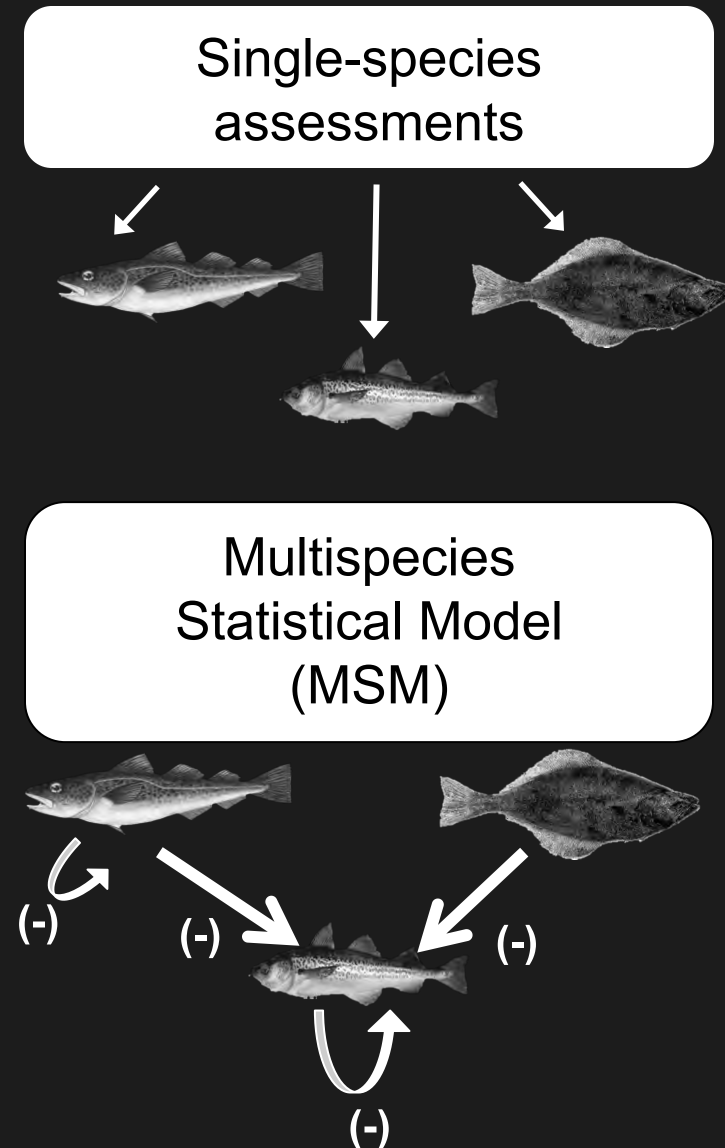
FEAST model driven by IPCC climate models

kirstin.holsman@noaa.gov

MSM Approach

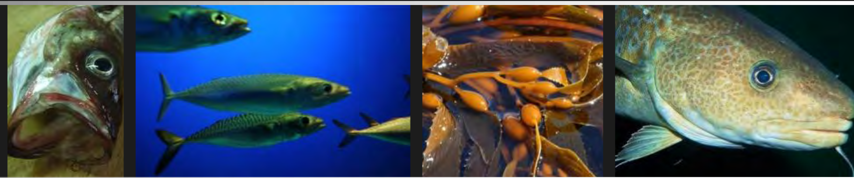


1. HINDCAST
   - Fit to data from 1979-2012
2. REGRESSION
   - GAMs for W_{age}, R, foraging, etc.~f(zoop, tempC, cold pool)
3. PROJECTION
   - Downscale IPCC / Run NPZ model
   - Project MSMo forward using ROMS/NPZ drivers with & without stochastic error
   - Harvest with current ABC / OFL from assessment models



kirstin.holsman@noaa.gov

MSM



Description	Equations		
Recruitment	$N_{y,1} = R_t = R_0 e^{\tau_y}$		
Catch	$C_{y,a} = \frac{F_{y,a}}{Z_{y,a}} \left(1 - e^{-Z_{y,a}}\right) N_{y,a} w_{y,a}$	$1 \leq y \leq Y$	$1 \leq a \leq A$
Numbers at age	$N_{y+1,a+1} = N_{y,a} e^{-Z_{y,a}}$	$1 < y \leq Y$	$1 \leq a < A$
	$N_{y+1,A} = N_{y,A-1} e^{-Z_{y,A-1}} + N_{y,A} e^{-Z_{y,A}}$	$1 \leq y \leq Y$	$a \geq A$
Spawning biomass	$S_t = \sum_{a=1}^{A} w_{y,a} \phi_a N_{y,a}$	$1 \leq y \leq Y$	
Total catch (yeild)	$C_t = \sum_{a=1}^{A} w_{y,a} C_{y,a}$		
Fishery age selectivity	$s_{f,a} =$		
Fishing mortality	$F_{y,a} =$		
Natural mortality	$M_{y,a} = M1_a + M2_{y,a}$		
Total mortality	$Z_{y,a} = M_{y,a} + F_{y,a}$		

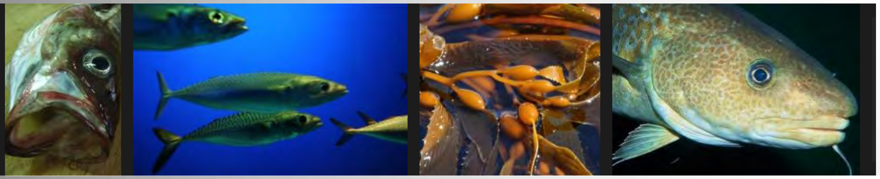
$$M_{y,a} = M1_a + M2_{y,a}$$

Residual Natural Mortality

Predation Natural Mortality

kirstin.holsman@noaa.gov

MSM



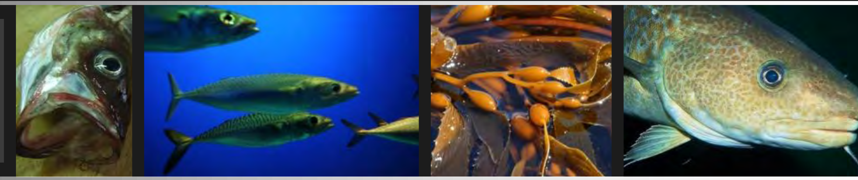
Size-specific predation mortality	$M2_{y,k_i} = \frac{E_{yk_i}}{B_{yk_i}}$
Biomass consumed $(g \cdot yr^{-1})$	$E_{y,k_i} = \sum_{p=1} \sum_{j=1} (\psi_{y,p_jk_i} \cdot N_{y,p_j} \cdot U_{y,p_jk_i})$
Annual ration $(g \cdot pred^{-1} \cdot yr^{-1})$	$\psi_{y,p_j} = \delta_p \cdot f(T_y)_p \cdot Cmax_{p_j} \cdot D_p$
Maximum consumption $(g \cdot pred^{-1} \cdot d^{-1})$	$Cmax_{p_j} = \alpha_p^c \cdot w_{p_j}^{(1+\beta_p^c)}$
Temperature scaling function	$f(T_y)_p = V^x \cdot e^{(X \cdot (1-V))}$
	$V = (T_p^{cm} - T_y)/(T_p^{cm} - T_p^{co})$
	$X = (Z^2 \cdot (1 + (1 + 40/Y)^{0.5})^2)/400$
	$Z = ln(Q_p^c) \cdot (T_p^{cm} - T_p^{co})$
	$Y = ln(Q_p^c) \cdot (T_p^{cm} - T_p^{co} + 2)$
Size specific prey selectivity	$U_{y,p_jk_i} = K_{p_jk} \cdot \frac{\alpha_{pk}^U \cdot \left(\frac{\eta_{p_jk_i}}{\sum \eta_{p_jk_i}}\right)^{\beta_{pk}^U}}{1+\alpha_{pk}^U \cdot \left(\frac{\eta_{p_jk_i}}{\sum \eta_{p_jk_i}}\right)^{\beta_{pk}^U}}$
Vulnerable prey	$\eta_{p_jk_i} = \frac{N_{k_i}}{\sum N_{k_i}} \cdot e^{\phi_{p_jk_i}}$
Prey vulnerability swtich	$\phi_{p_jk_i} = max\left\{0, \left(\frac{l_{k_i} - \ell\ell_{pk} \cdot H_{p_j}}{\ell_{pk}}\right)\right\}$
Predator gape limit (mm)	$H_{p_j} = \alpha_p^H + \beta_p^H \cdot l_{p_j}$

PREDATION MORTALITY

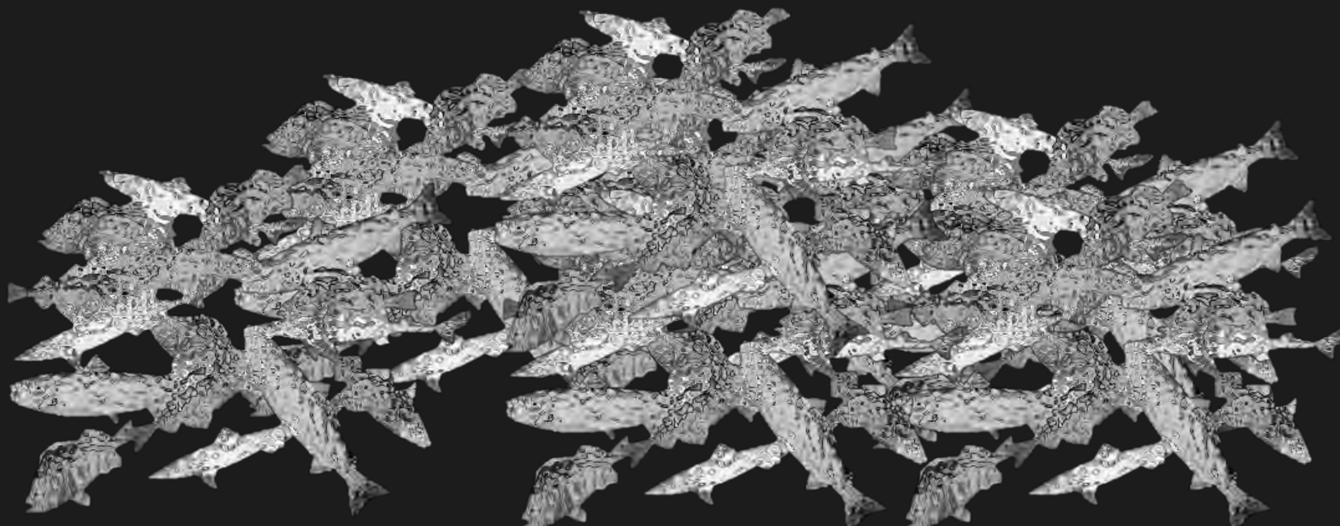
BIOENERGETICS MODEL

FORAGING MODEL

kirstin.holsman@noaa.gov

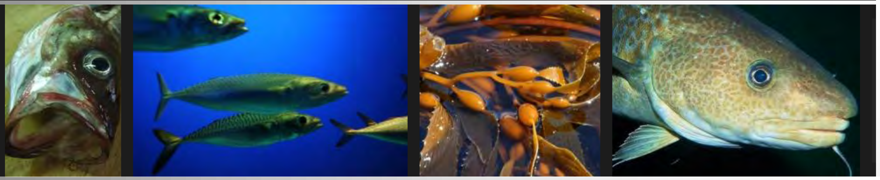


Bioenergetics models



How much is eaten?

kirstin.holsman@noaa.gov

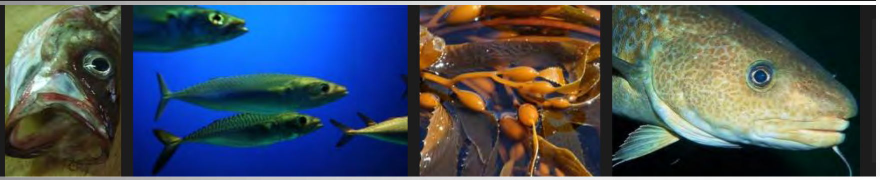


Foraging models

What is eaten?

kirstin.holsman@noaa.gov

MSM



Size-specific predation mortality	$M2_{y,k_i} = \frac{E_{yk_i}}{B_{yk_i}}$
Biomass co...	$E_{y,k_i} = \sum_{p=1}^{N_{sp}} \sum_{j=1}^{L_p} (\psi_{y,p_jk_i} \cdot N_{y,p_j} \cdot U_{y,p_jk_i})$
Annual ration $(g \cdot pred^{-1} \cdot yr^{-1})$	$\psi_{y,p_j} = \delta_p \cdot f(T_y)_p \cdot Cmax_{p_j} \cdot D_p$
Maximum consumption $(g \cdot pred^{-1} \cdot d^{-1})$	$Cmax_{p_j} = \alpha_p^c \cdot w_{p_j}^{(1+\beta_p^c)}$
Temperature scaling function	$f(T_y)_p = V^x \cdot e^{(X \cdot (1-V))}$ $V = (T_p^{cm} - T_y)/(T_p^{cm} - T_p^{co})$ $X = (Z^2 \cdot (1 + (1 + 40/Y)^{0.5})^2)/400$ $Z = ln(Q_p^c) \cdot (T_p^{cm} - T_p^{co})$ $Y = ln(Q_p^c) \cdot (T_p^{cm} - T_p^{co} + 2)$
Size specific prey selectivity	$U_{y,p_jk_i} = K_{p_jk} \cdot \frac{\alpha_{pk}^U \cdot \left(\frac{\eta_{p_jk_i}}{\sum \eta_{p_jk_i}}\right)^{\beta_{pk}^U}}{\ldots}$
Vulnera...	
Prey vulnerability swtich	$\phi_{p_jk_i} = max\left\{0, \left(\frac{l_{k_i} - \ell\ell_{pk} \cdot H_{p_j}}{\ell_{pk}}\right)\right\}$
Predator gape limit (mm)	$H_{p_j} = \alpha_p^H + \beta_p^H \cdot l_{p_j}$

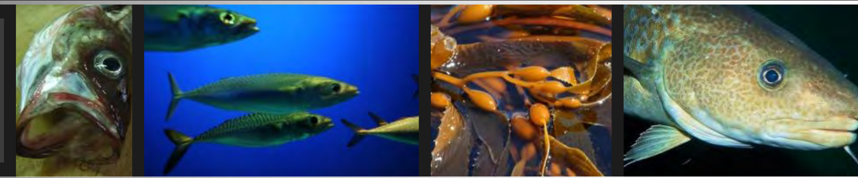
Annual ration

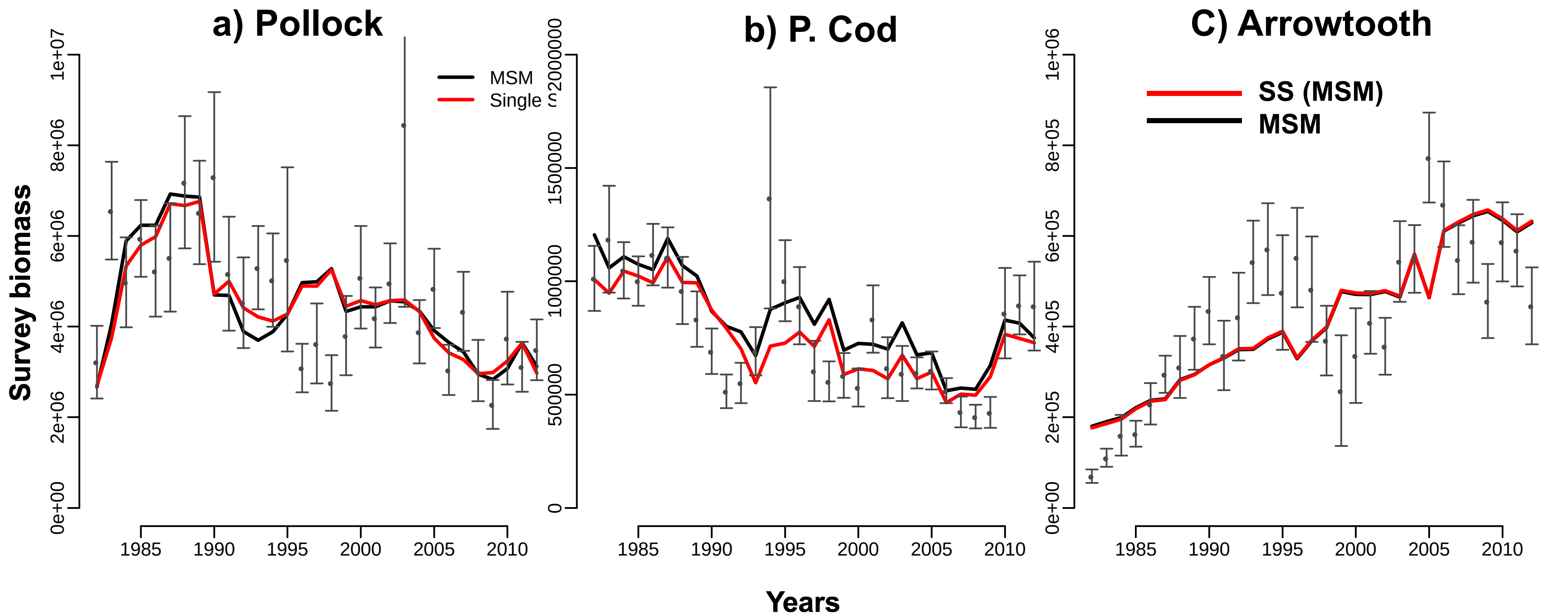
Temperature

Size specific prey selectivity

kirstin.holsman@noaa.gov

MSM HINDCAST

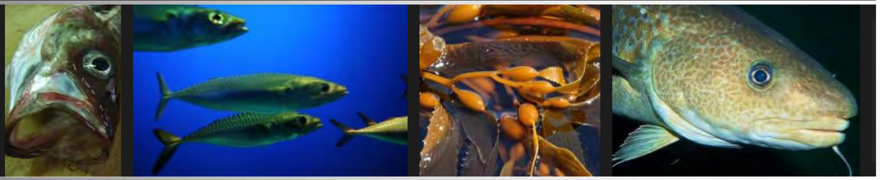


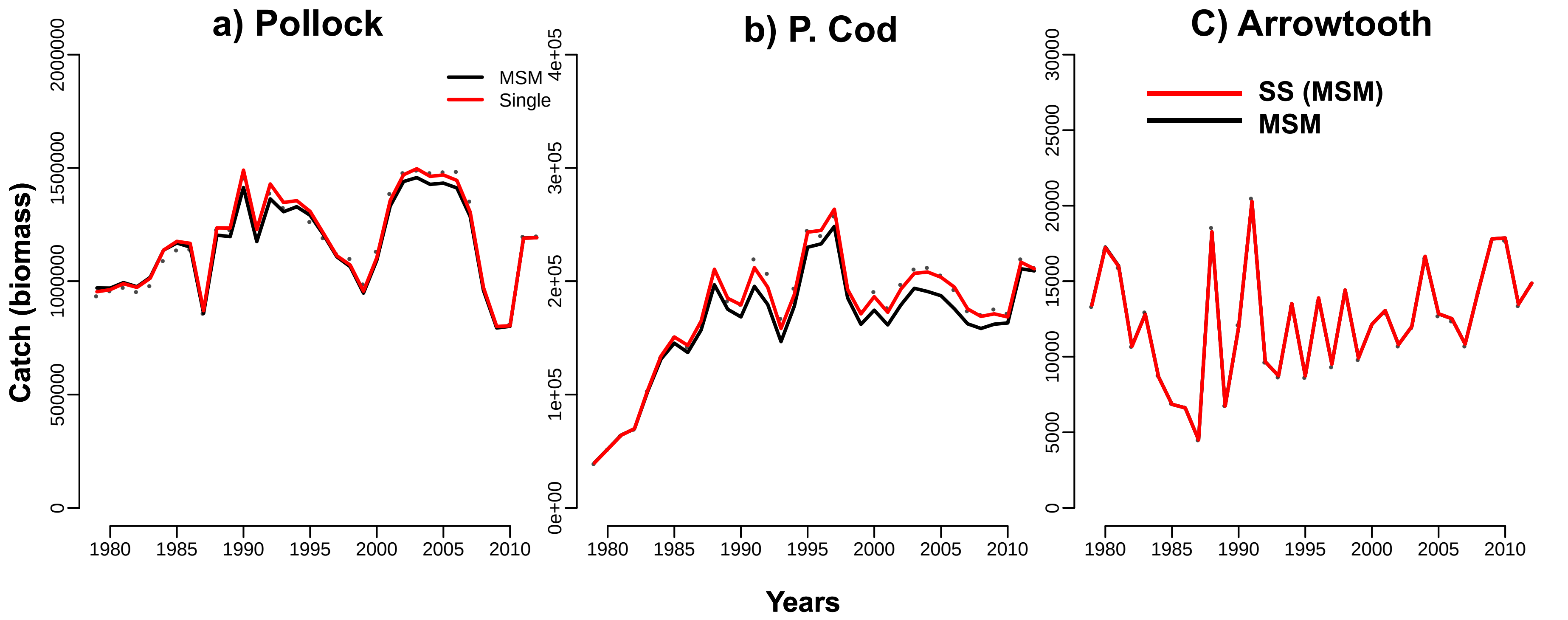


Fits to survey biomass

kirstin.holsman@noaa.gov

MSM HINDCAST

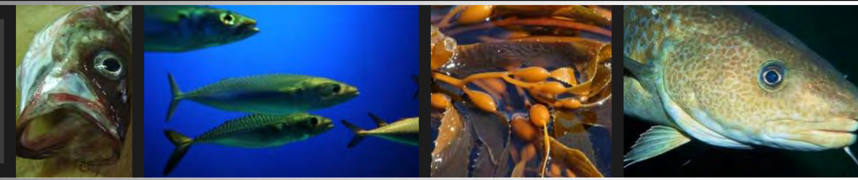


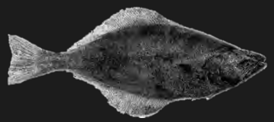


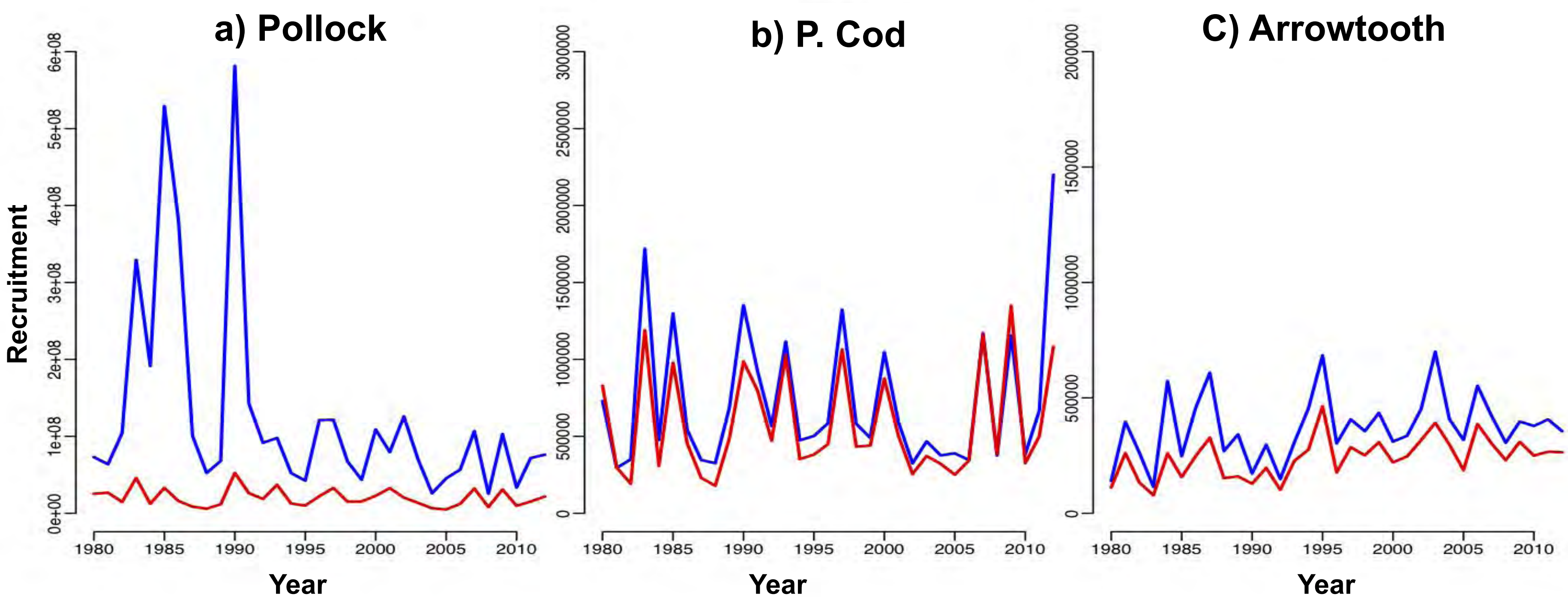
Fits to catch biomass

kirstin.holsman@noaa.gov

MSM HINDCAST

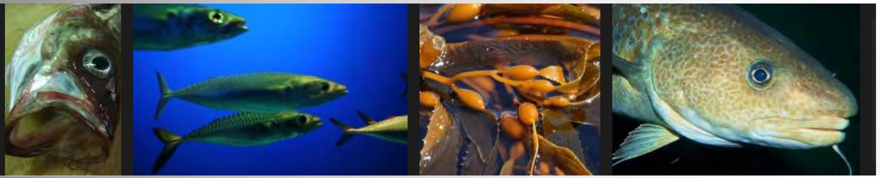






kirstin.holsman@noaa.gov

Projections



Description	Equations		
Recruitment	$N_{y,1} = R_t = R_0 e^{\tau_y}$		
Catch	$C_{y,a} = \frac{F_{y,a}}{Z_{y,a}}\left(1 - e^{-Z_{y,a}}\right) N_{y,a} w_{y,a}$	$1 \le y \le Y$	$1 \le a \le A$
Numbers at age	$N_{y+1,a+1} = N_{y,a} e^{-Z_{y,a}}$	$1 < y \le Y$	$1 \le a < A$
	$N_{y+1,A} = N_{y,A-1} e^{-Z_{y,A-1}} + N_{y,A} e^{-Z_{y,A}}$	$1 \le y \le Y$	$a \ge A$
Spawning biomass	$S_t = \sum_{a=1}^{A} w_{y,a} \phi_a N_{y,a}$	$1 \le y \le Y$	
Total catch (yeild)	$C_t = \sum_{a=1}^{A} w_{y,a} C_{y,a}$		
Fishery age selectivity	$s_{f,a} = e^{\eta_{f,a}}$	$\eta_{f,a} \sim N\left(0, \sigma^2_{f,a}\right)$	
Fishing mortality	$F_{y,a} = \mu_F e^{\varepsilon_{f,y}} s_{f,a}$	$\varepsilon_{f,y} \sim N\left(0, \sigma^2_F\right)$	
Natural mortality	$M_{y,a} = M1_a + M2_{y,a}$		
Total mortality	$Z_{y,a} = M_{y,a} + F_{y,a}$		

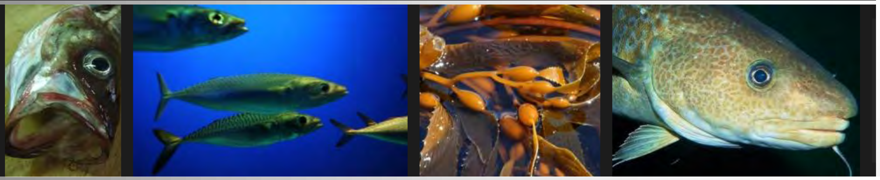
f **(Climate)**

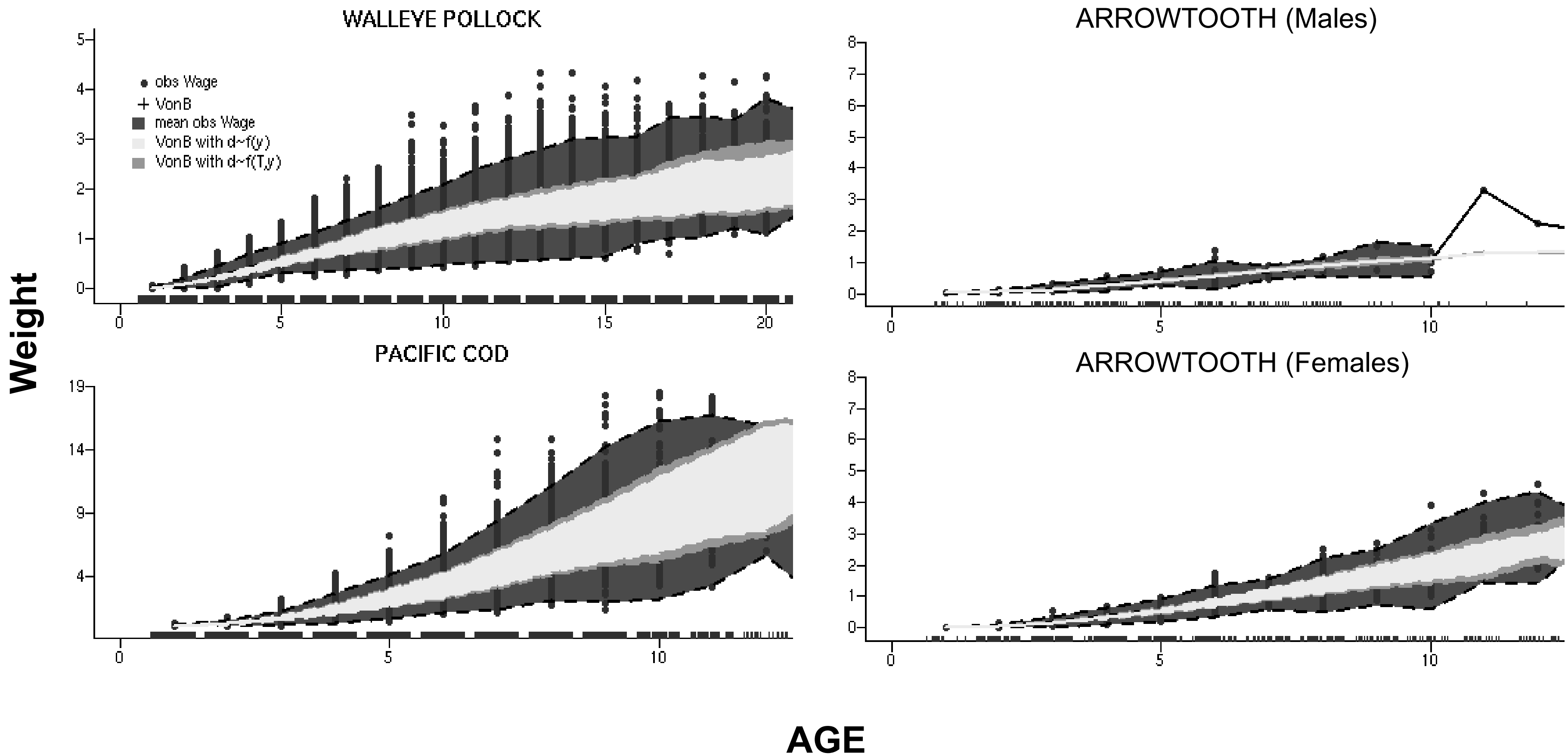
$$log\left(R^{fut}_{p,v}\right) = \log\left(\alpha_{R,p} \cdot SSB_{p,v-1}\right) - \beta_{R,p} \cdot SSB_{p,v-1} + \beta^{spr}_{Z,p} \cdot Z^{spr}_{v} - \beta^{fall}_{Z,p} \cdot \left(\delta^{fut}_{p1,v} \Big/ Z^{fall}_{v}\right)$$

Future recruitment

kirstin.holsman@noaa.gov

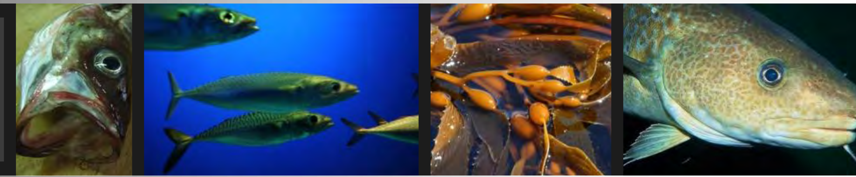
Projections

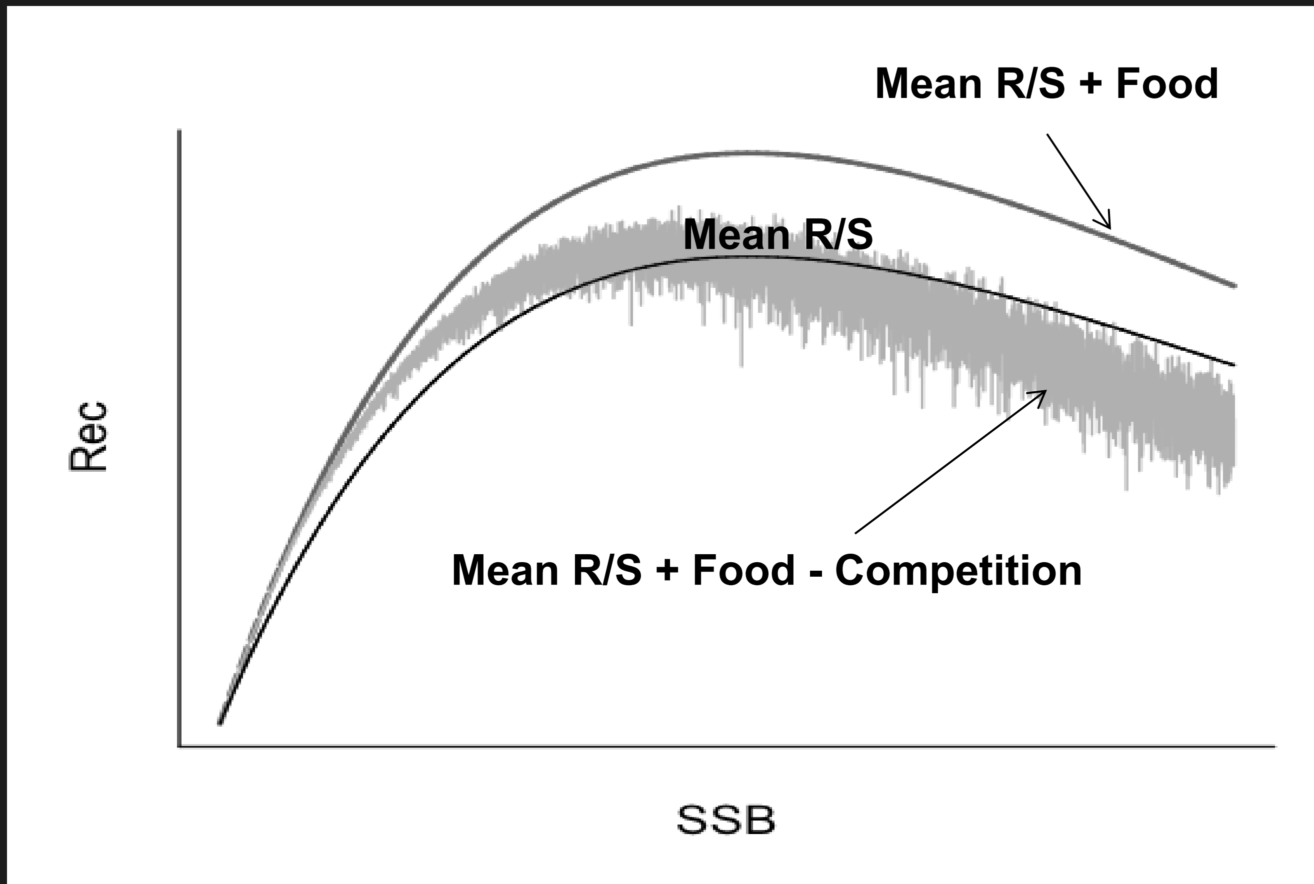




kirstin.holsman@noaa.gov

Projections



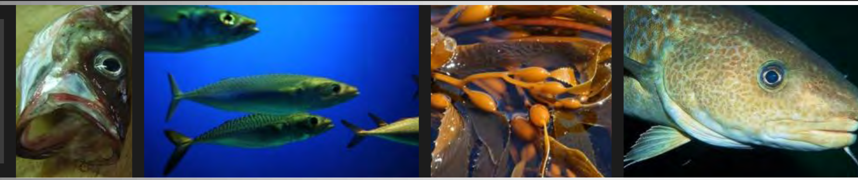


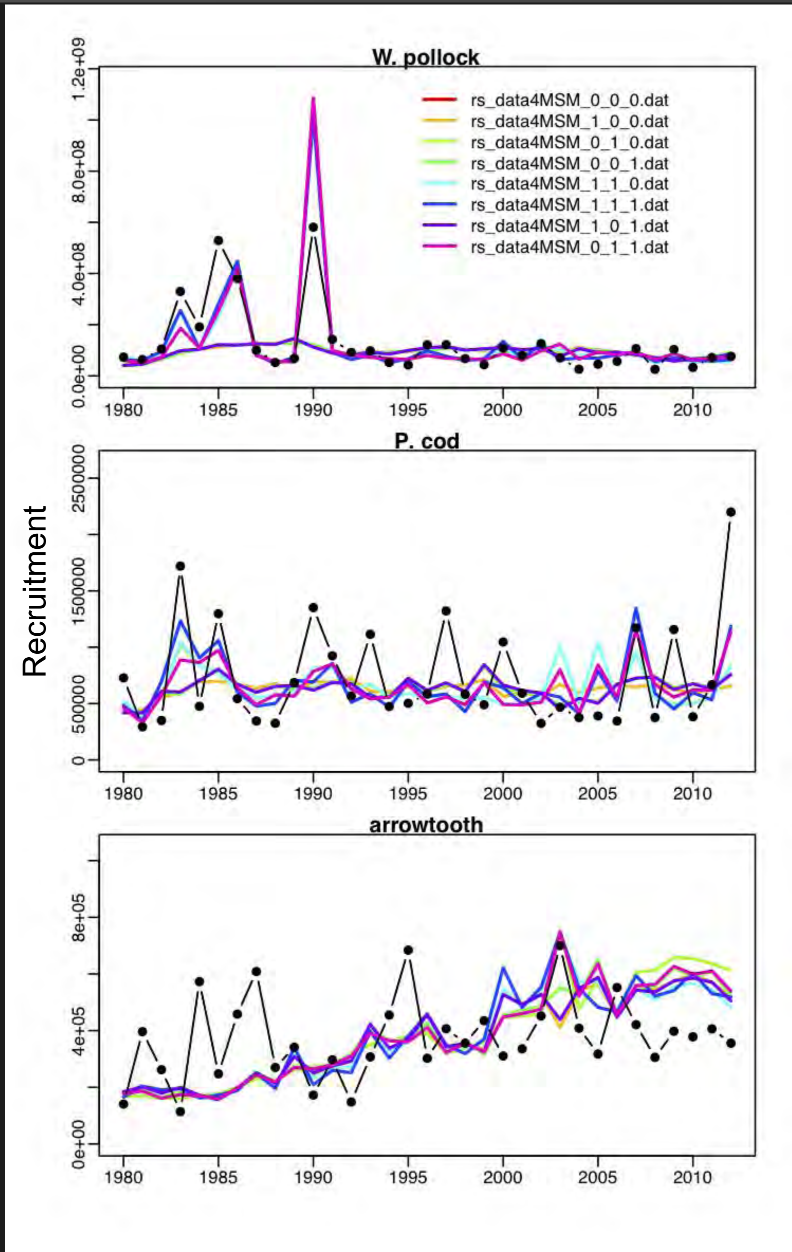
$$log\left(R_{p,v}^{fut}\right) = \log\left(\alpha_{R,p} \cdot SSB_{p,v-1}\right) - \beta_{R,p} \cdot SSB_{p,v-1} + \beta_{Z,p}^{spr} \cdot Z_v^{spr} - \beta_{Z,p}^{fall} \cdot \left({\delta_{p1,v}^{fut}} \middle/ {Z_v^{fall}} \right)$$

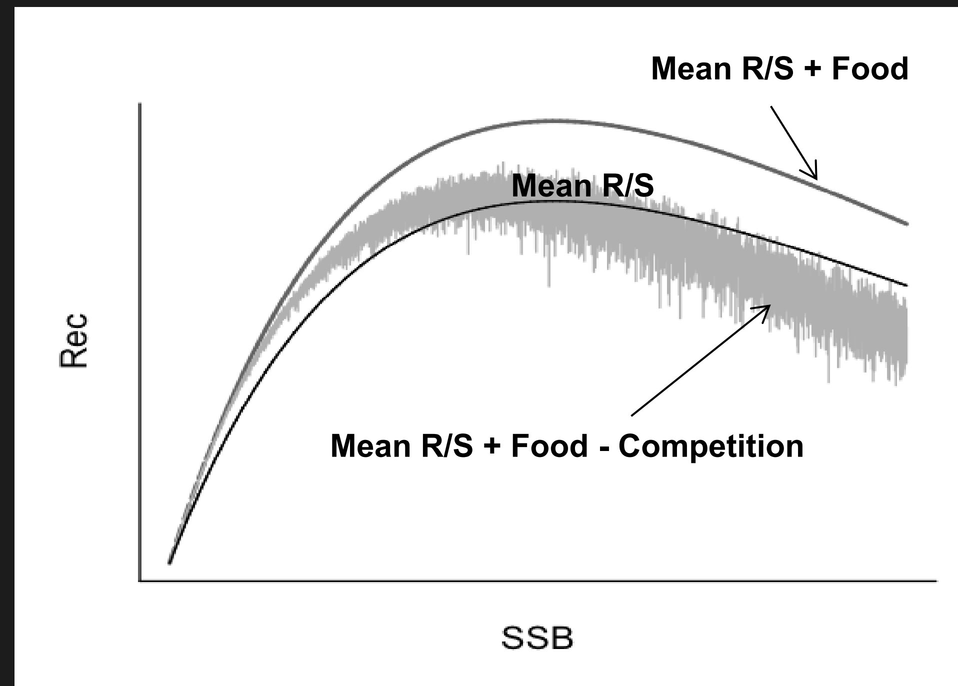
Future recruitment

kirstin.holsman@noaa.gov

Projections



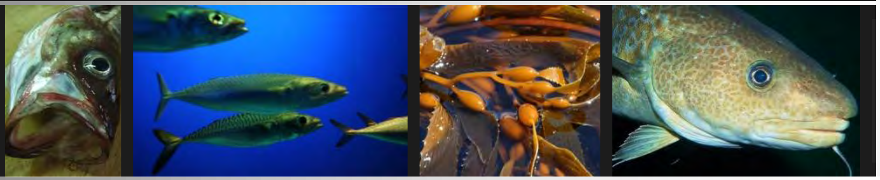


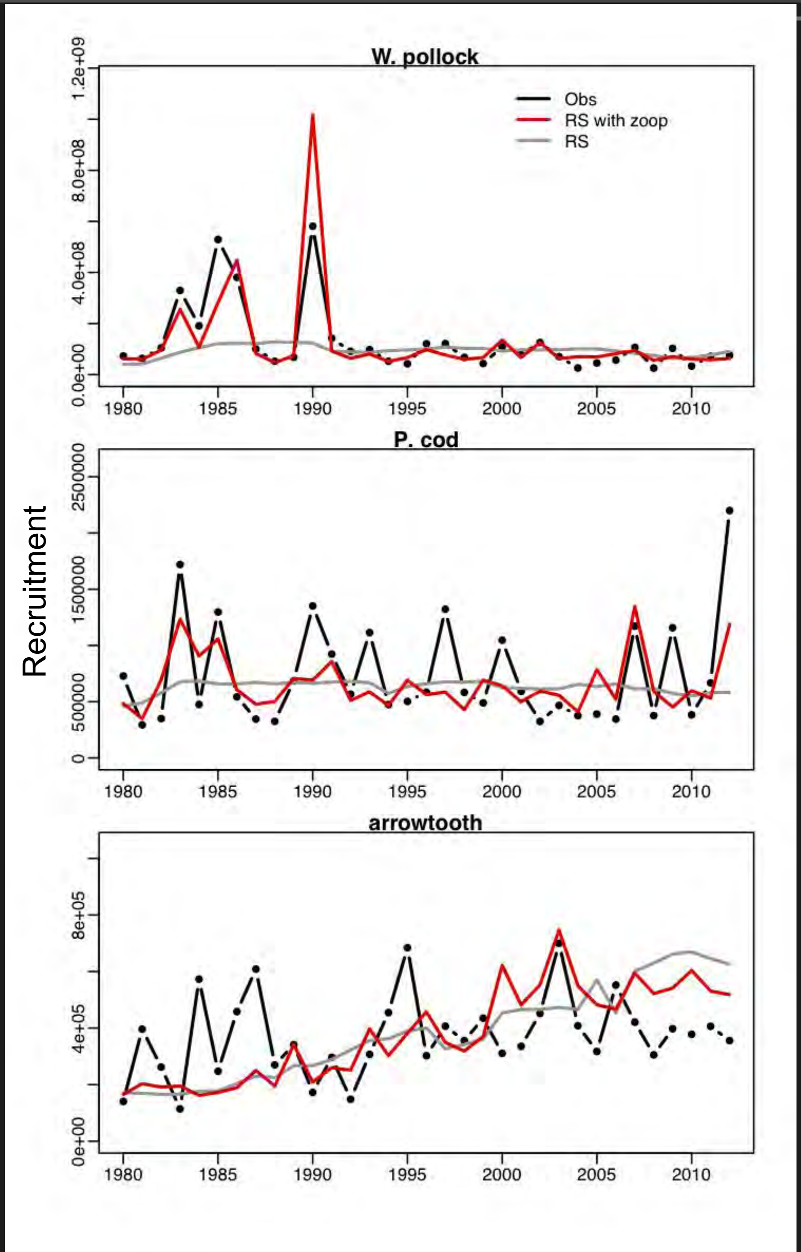


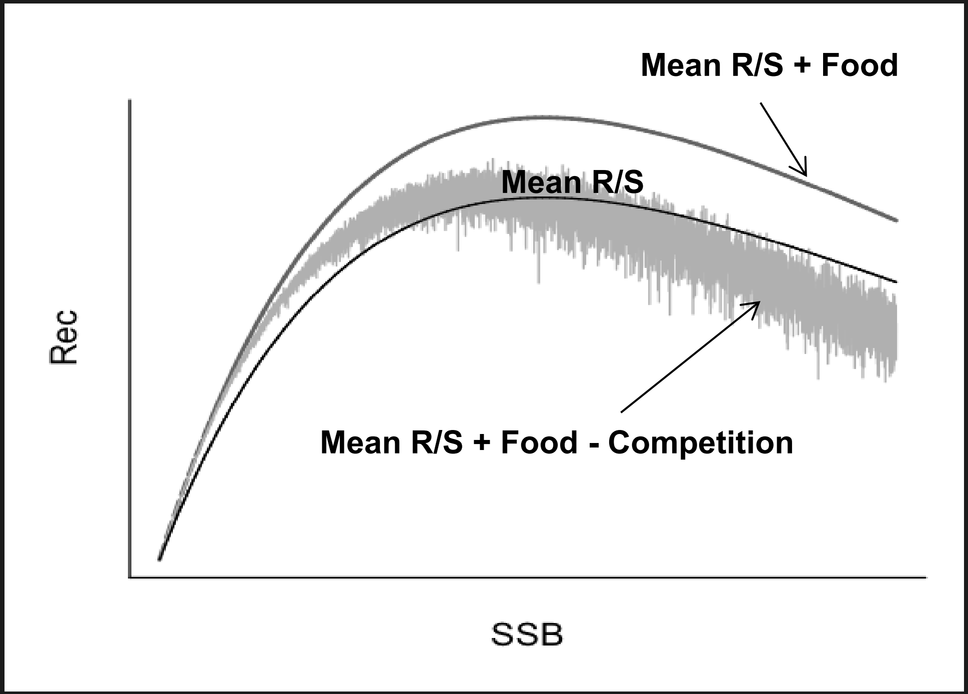
$$log\left(R_{p,v}^{fut}\right) = \log\left(\alpha_{R,p} \cdot SSB_{p,v-1}\right) - \beta_{R,p} \cdot SSB_{p,v-1} + \beta_{Z,p}^{spr} \cdot Z_v^{spr} - \beta_{Z,p}^{fall} \cdot \left(\delta_{p1,v}^{fut} \middle/ Z_v^{fall}\right)$$

Future recruitment

Projections



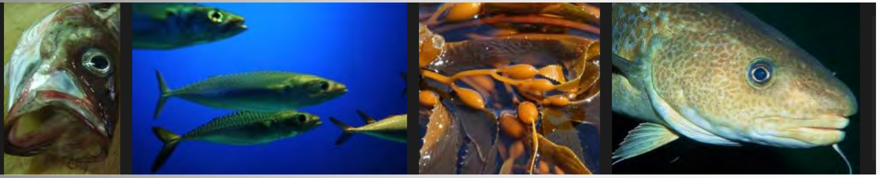


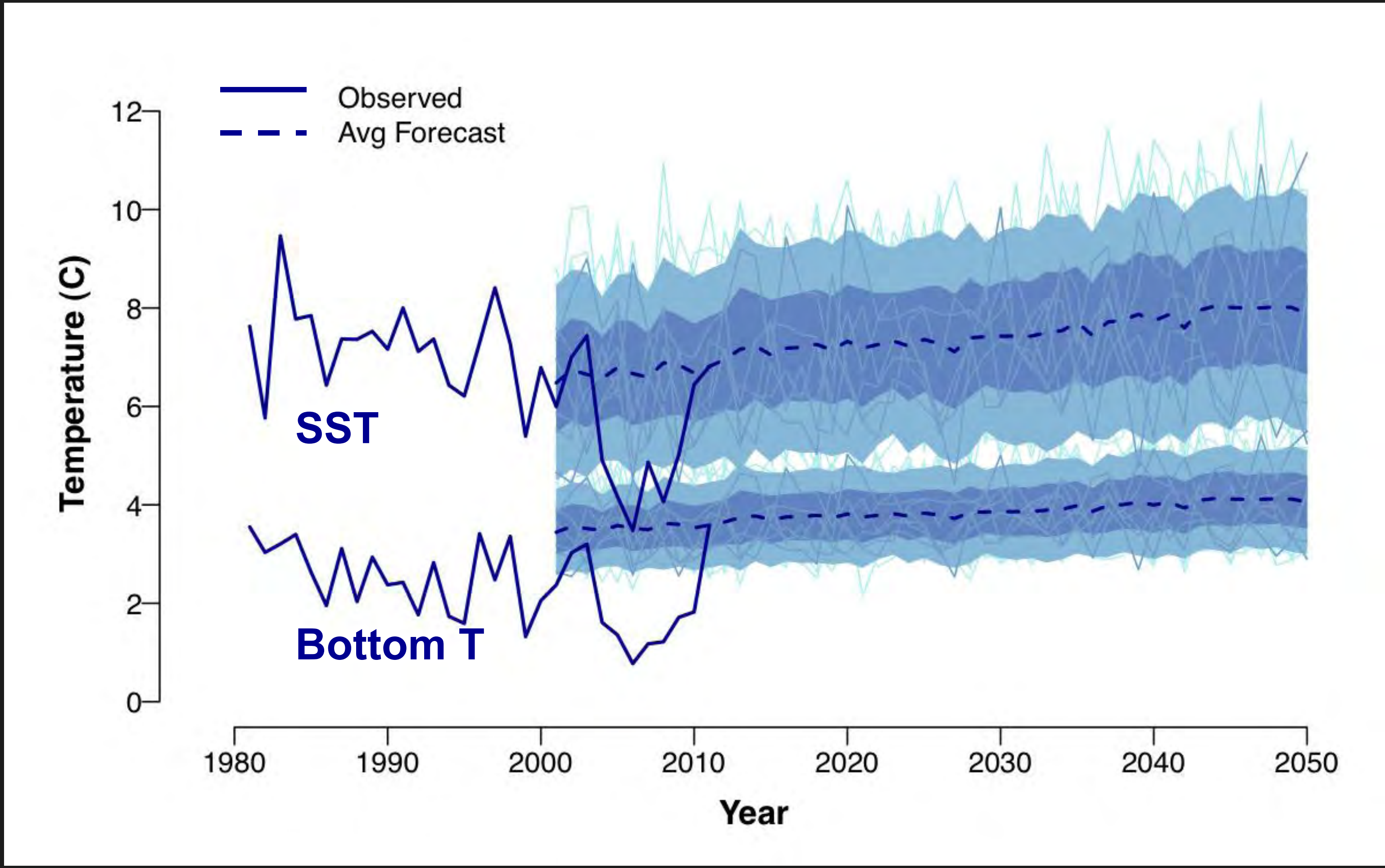


$$log\left(R_{p,v}^{fut}\right) = \log\left(\alpha_{R,p} \cdot SSB_{p,v-1}\right) - \beta_{R,p} \cdot SSB_{p,v-1} + \beta_{Z,p}^{spr} \cdot Z_v^{spr} - \beta_{Z,p}^{fall} \cdot \left(\delta_{p1,v}^{fut} / Z_v^{fall}\right)$$

Future recruitment

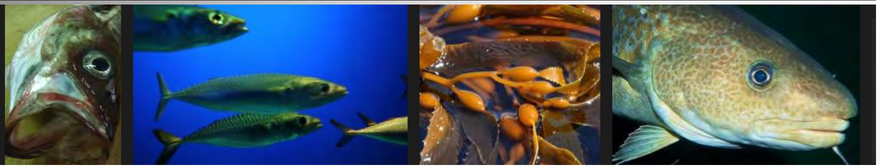
Projections

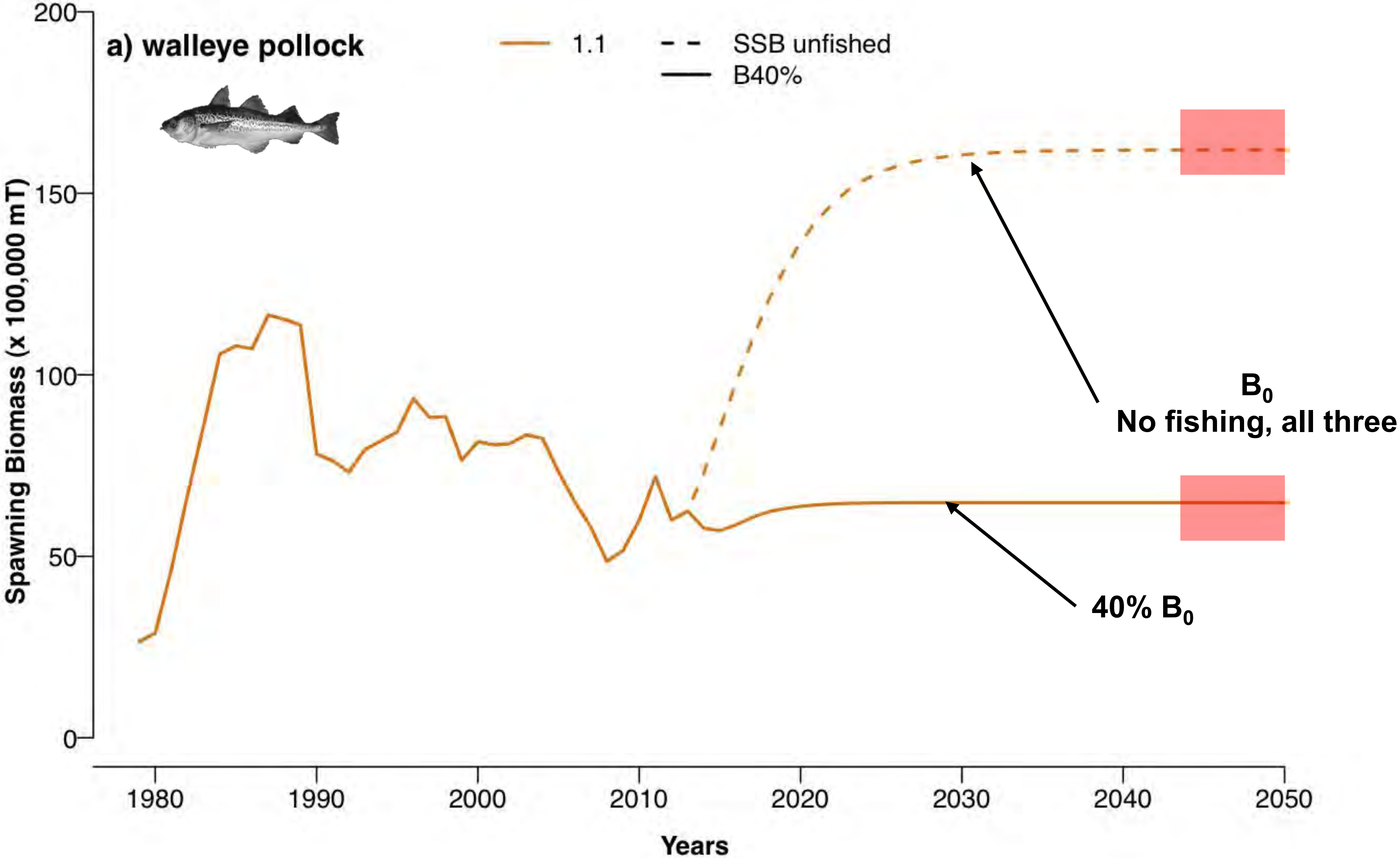




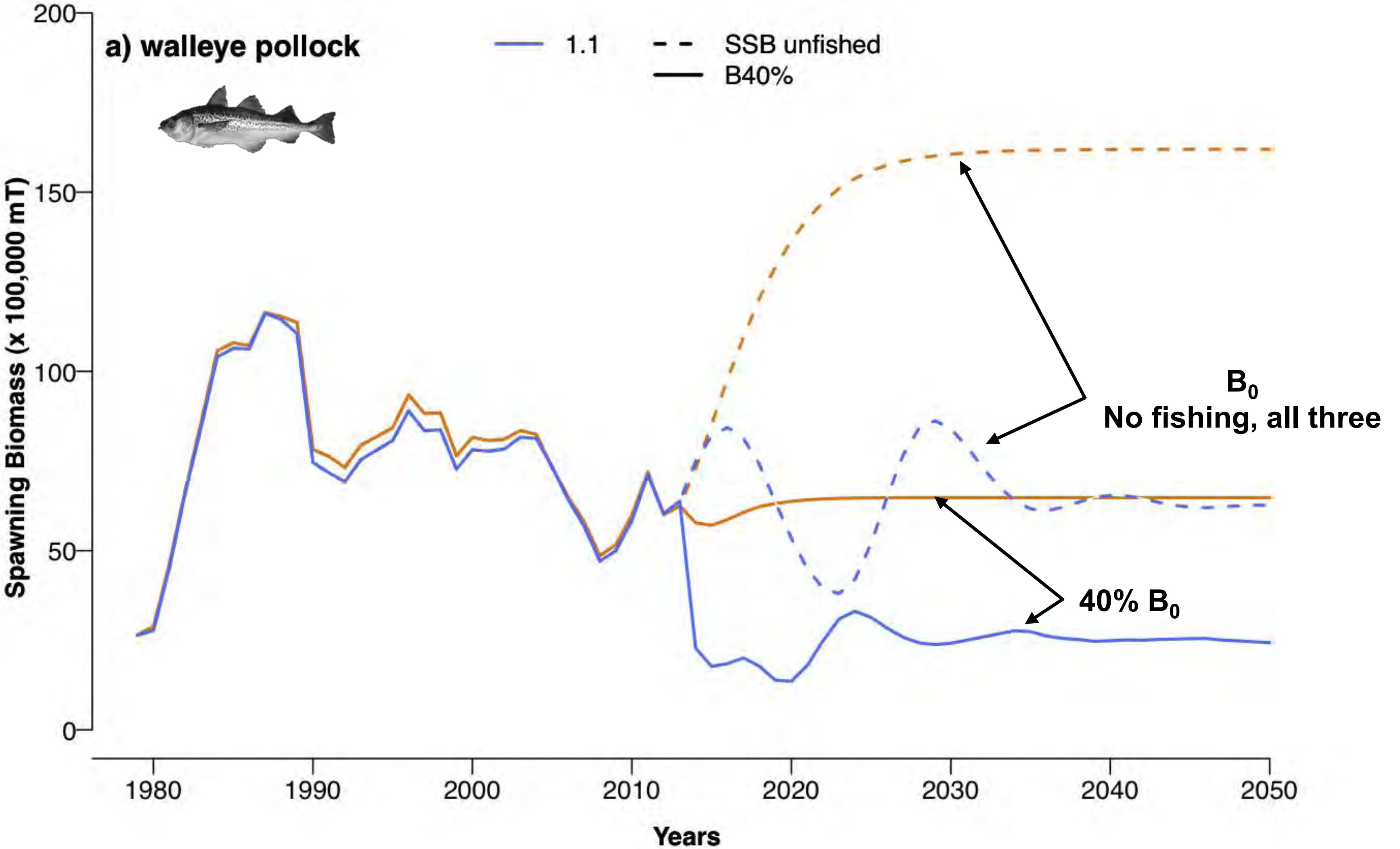
kirstin.holsman@noaa.gov

SPAWNING BIOMASS

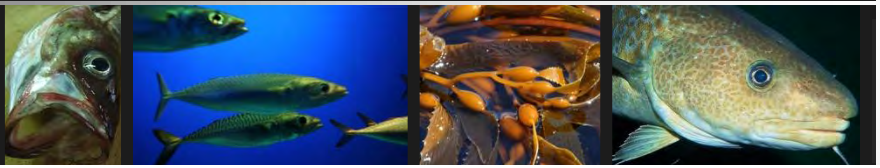


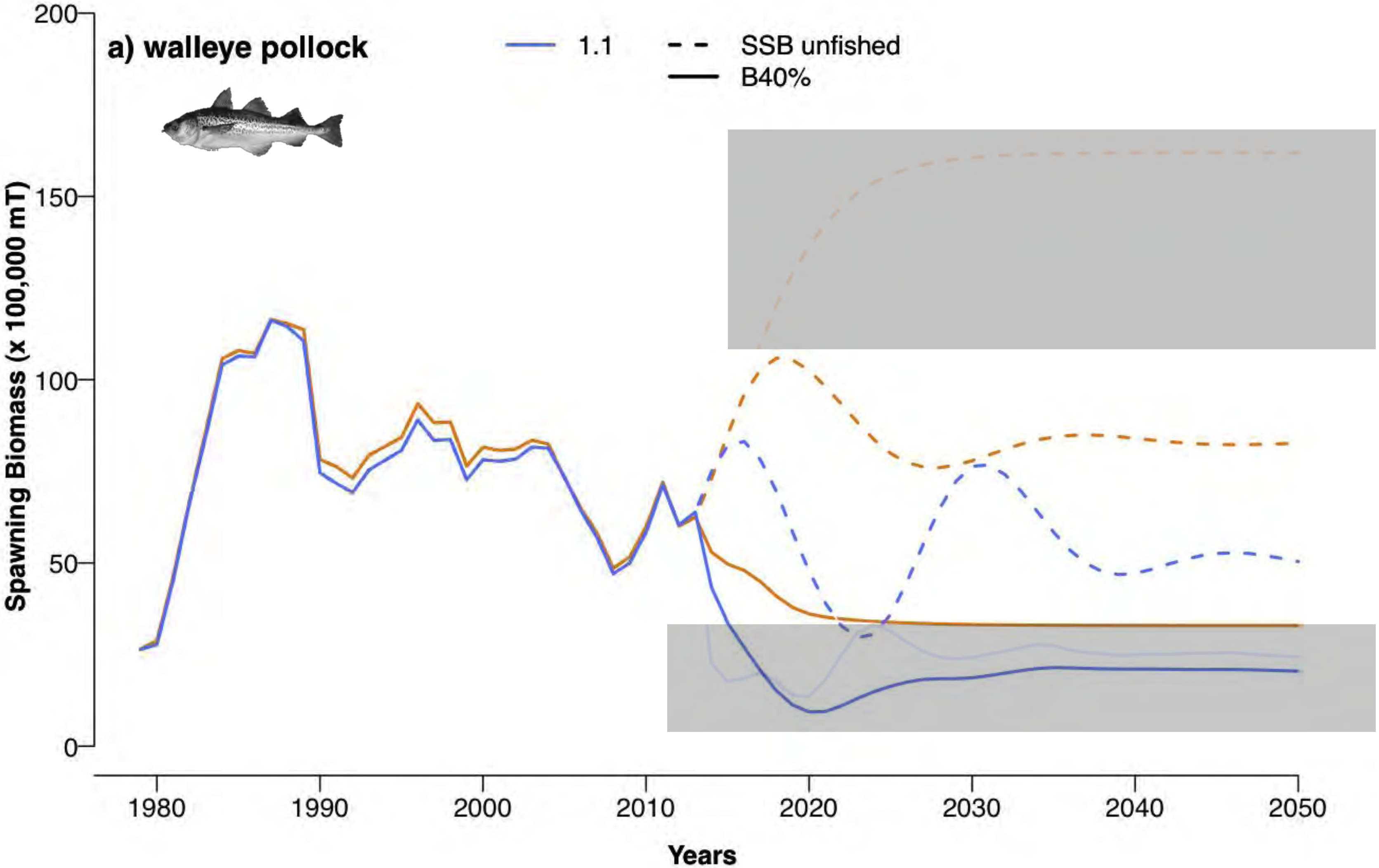


SPAWNING BIOMASS

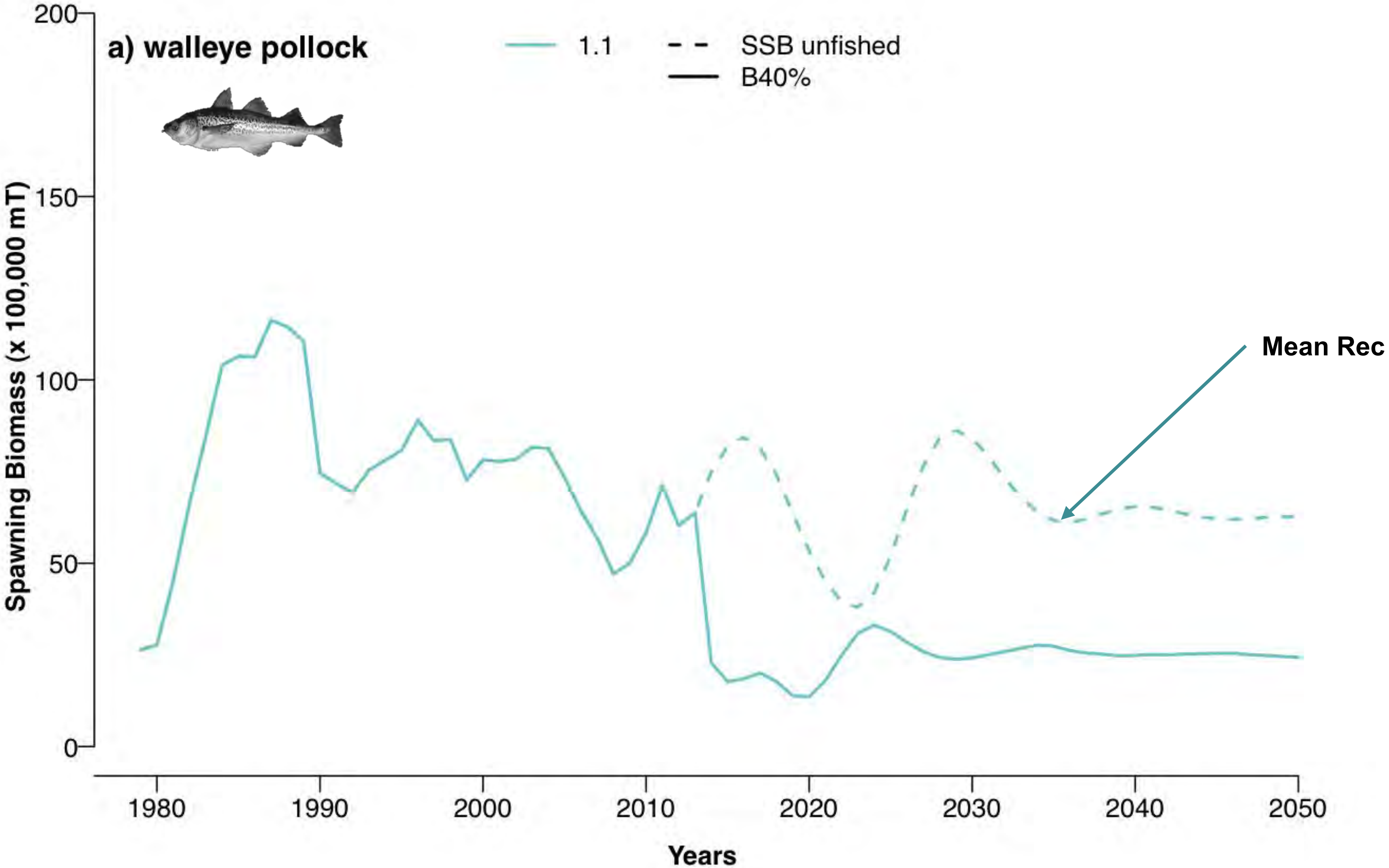


SPAWNING BIOMASS

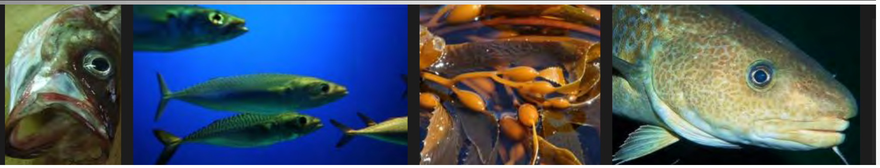


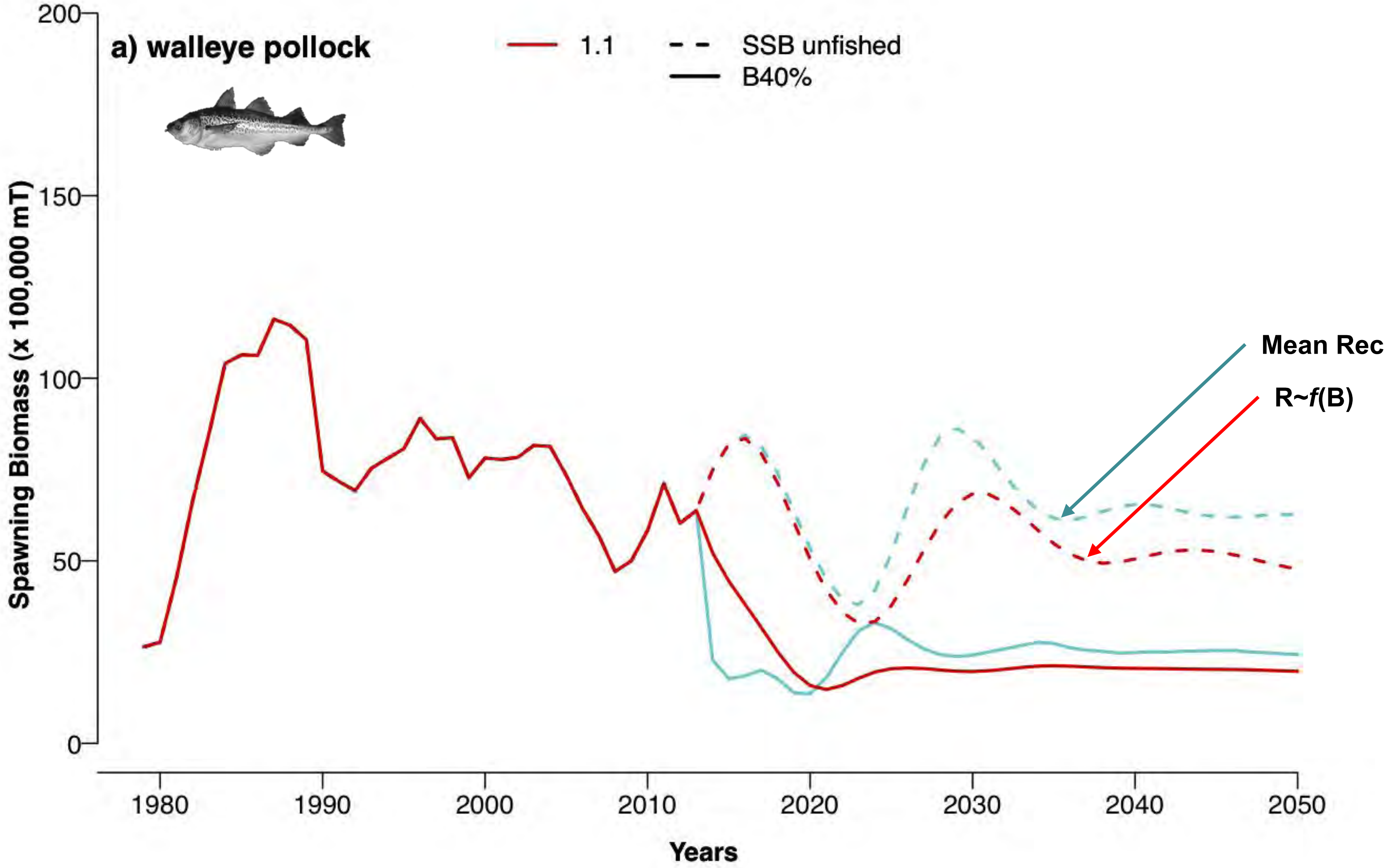


SPAWNING BIOMASS

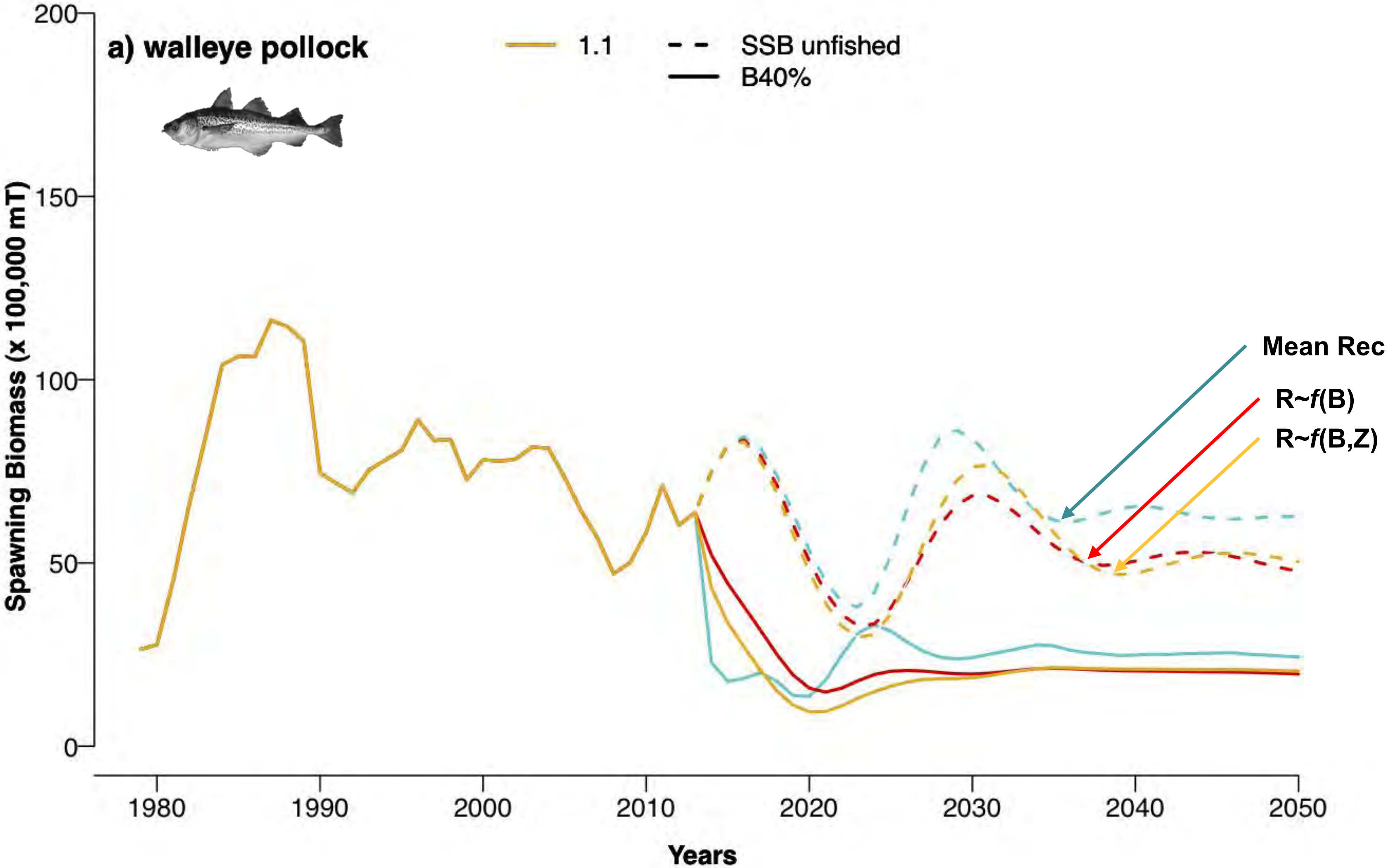


SPAWNING BIOMASS

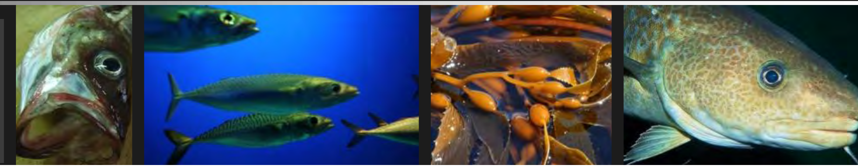


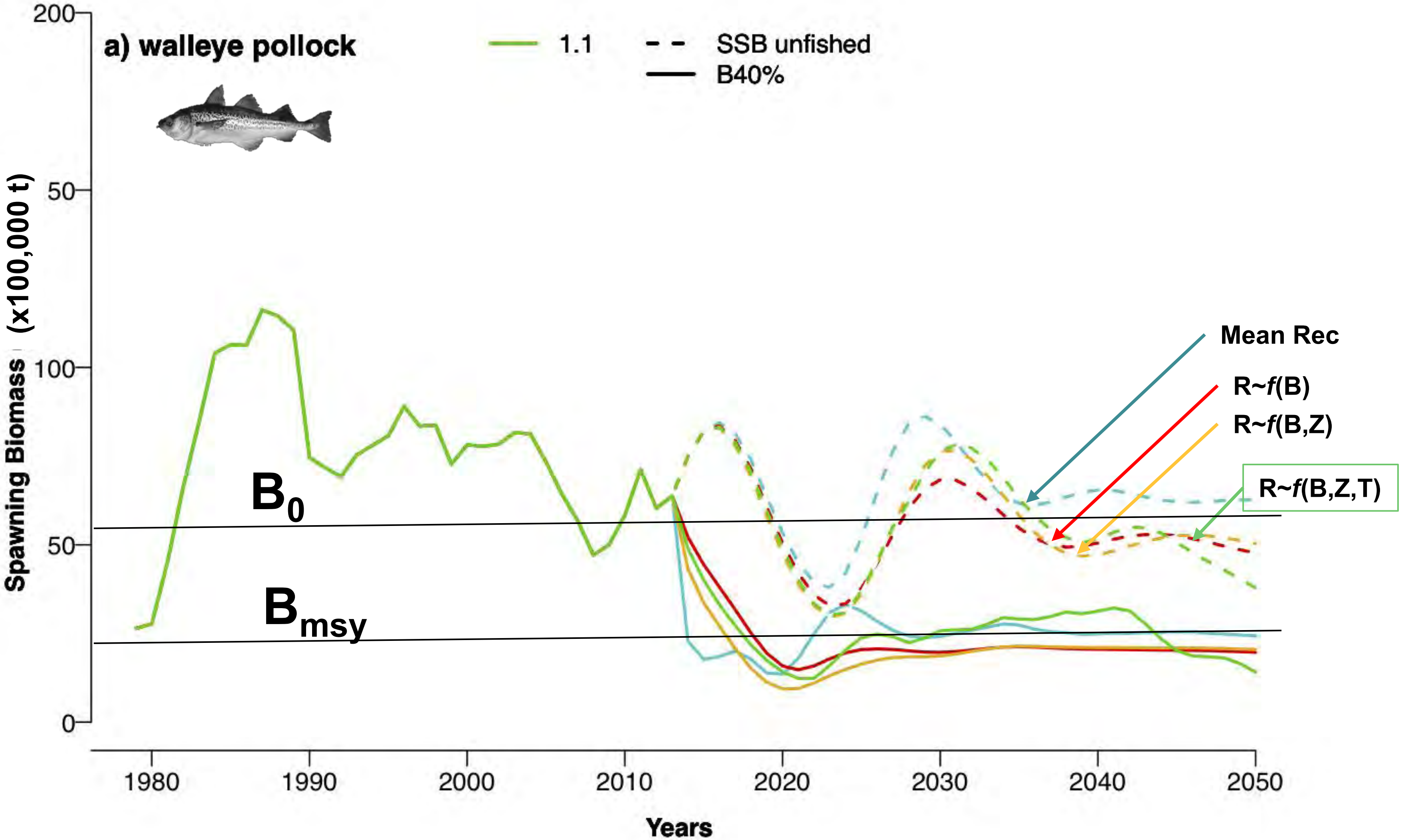


SPAWNING BIOMASS

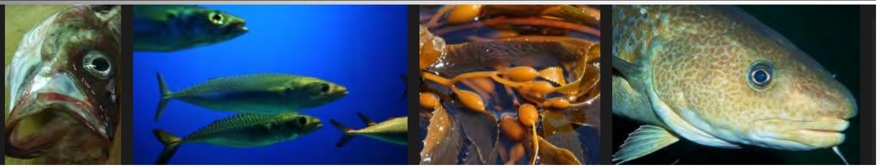


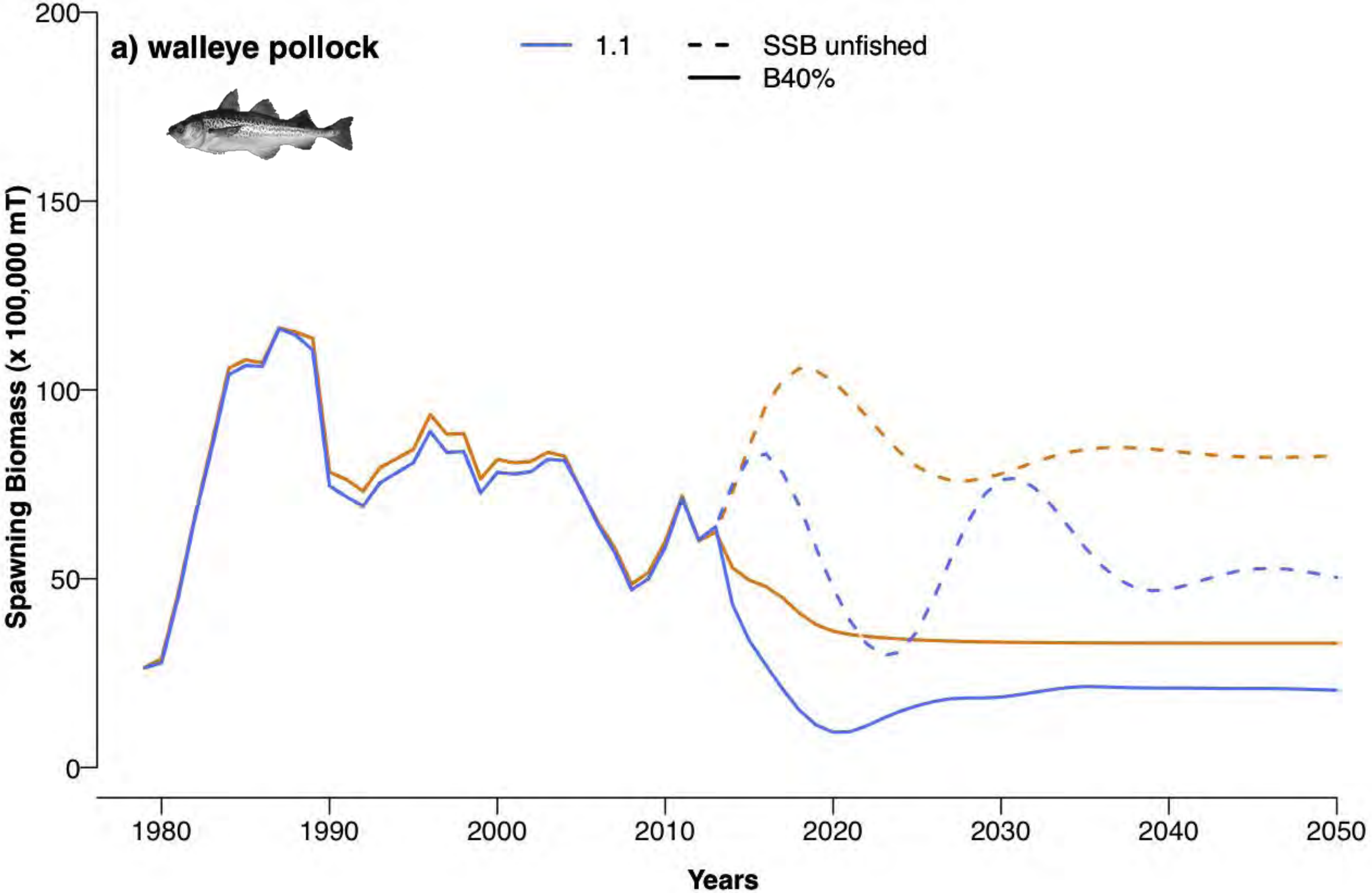
SPAWNING BIOMASS



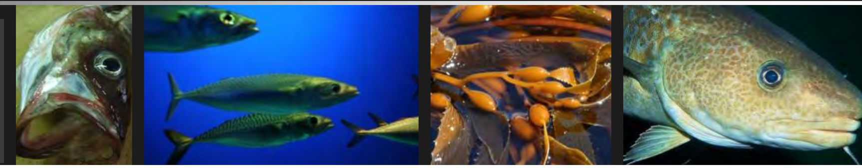


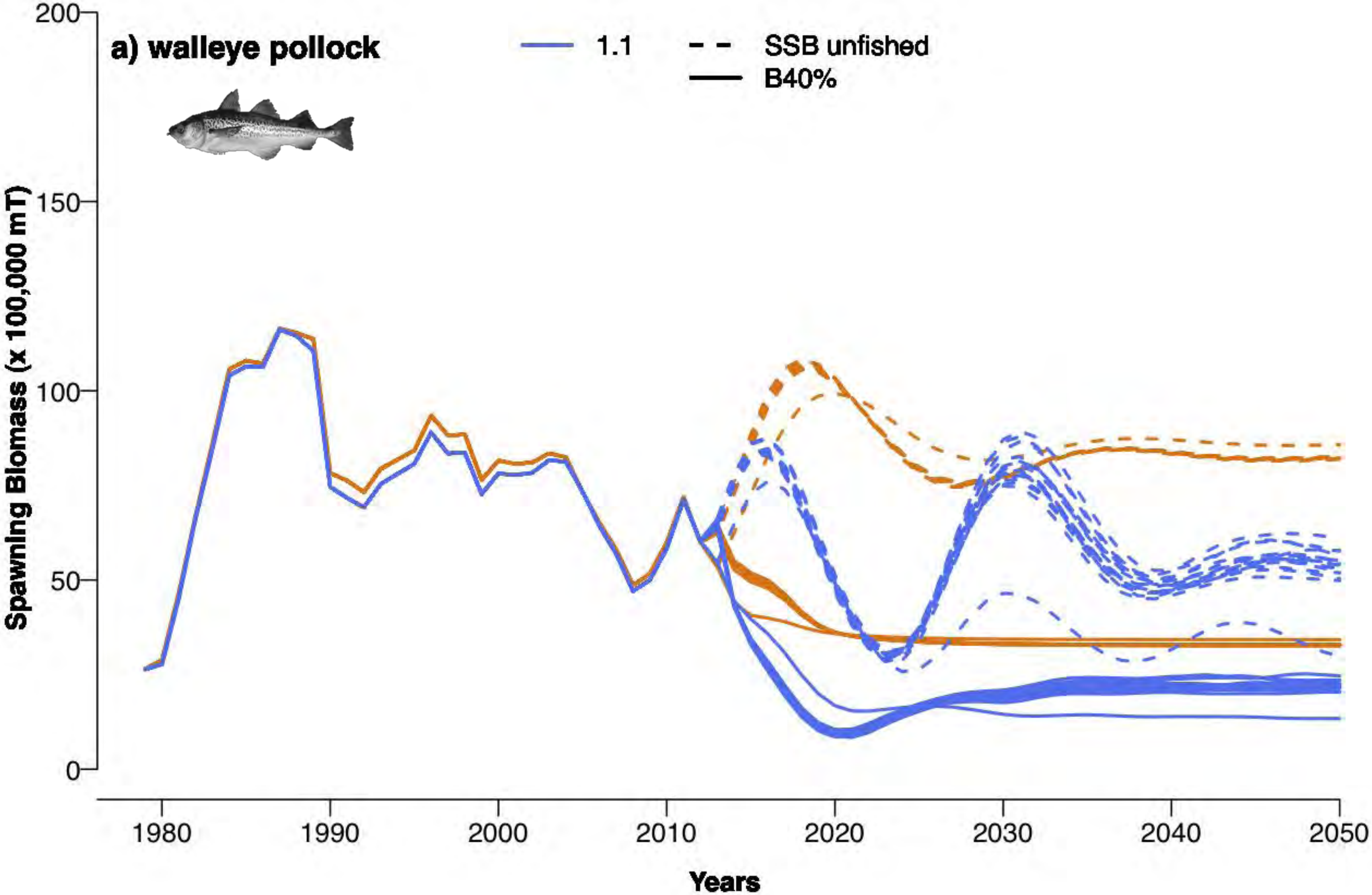
SPAWNING BIOMASS



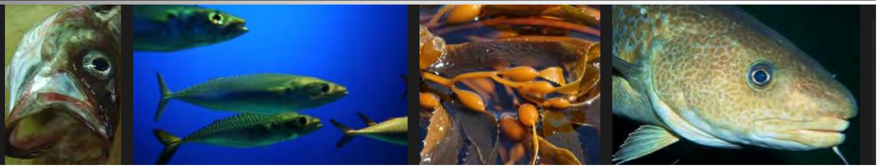


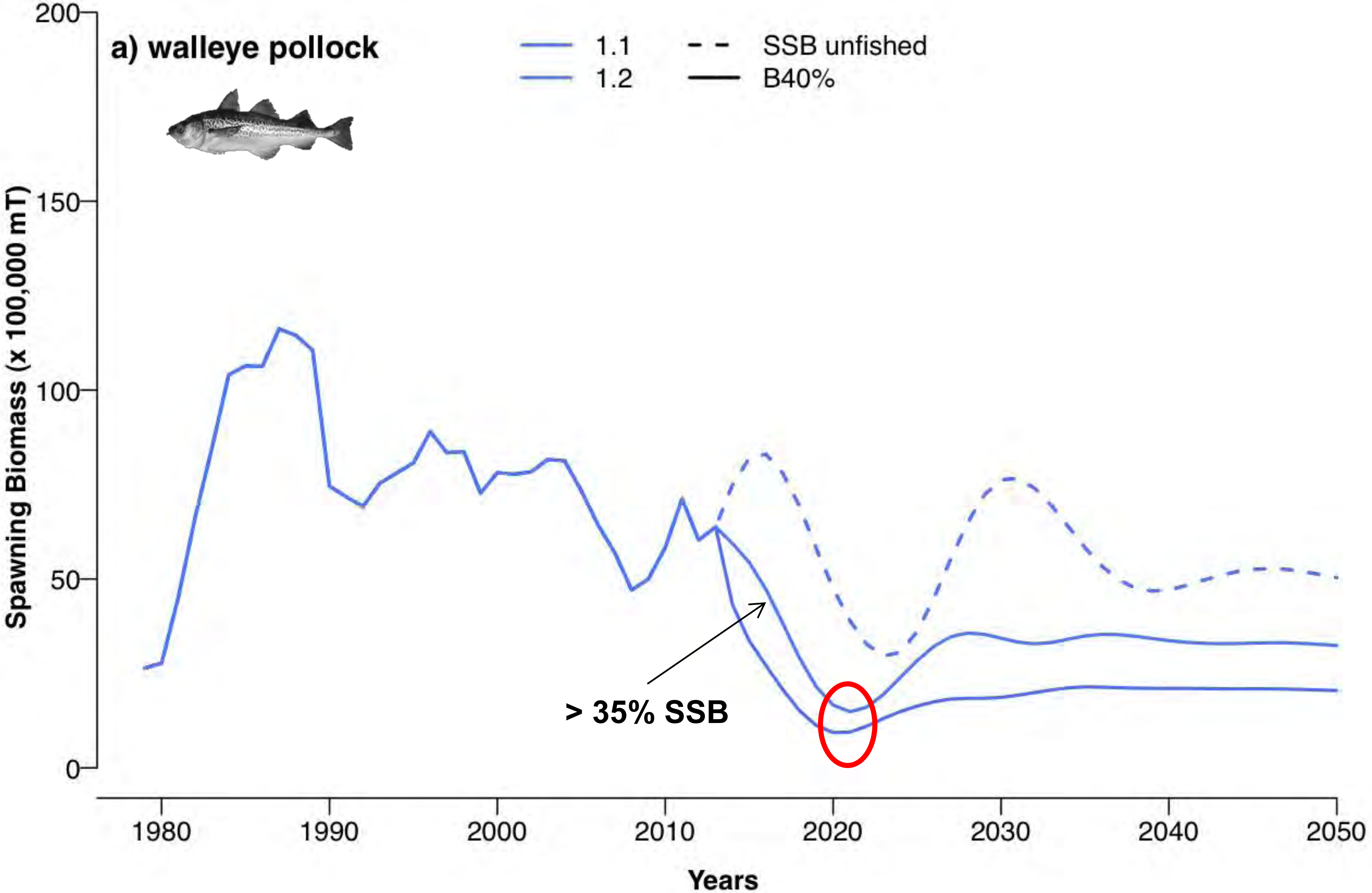
SPAWNING BIOMASS



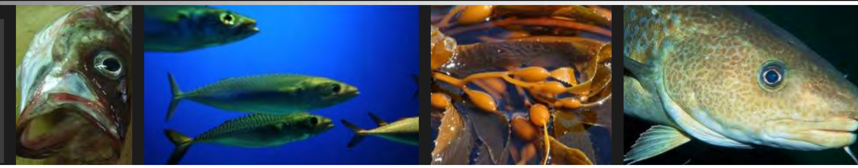


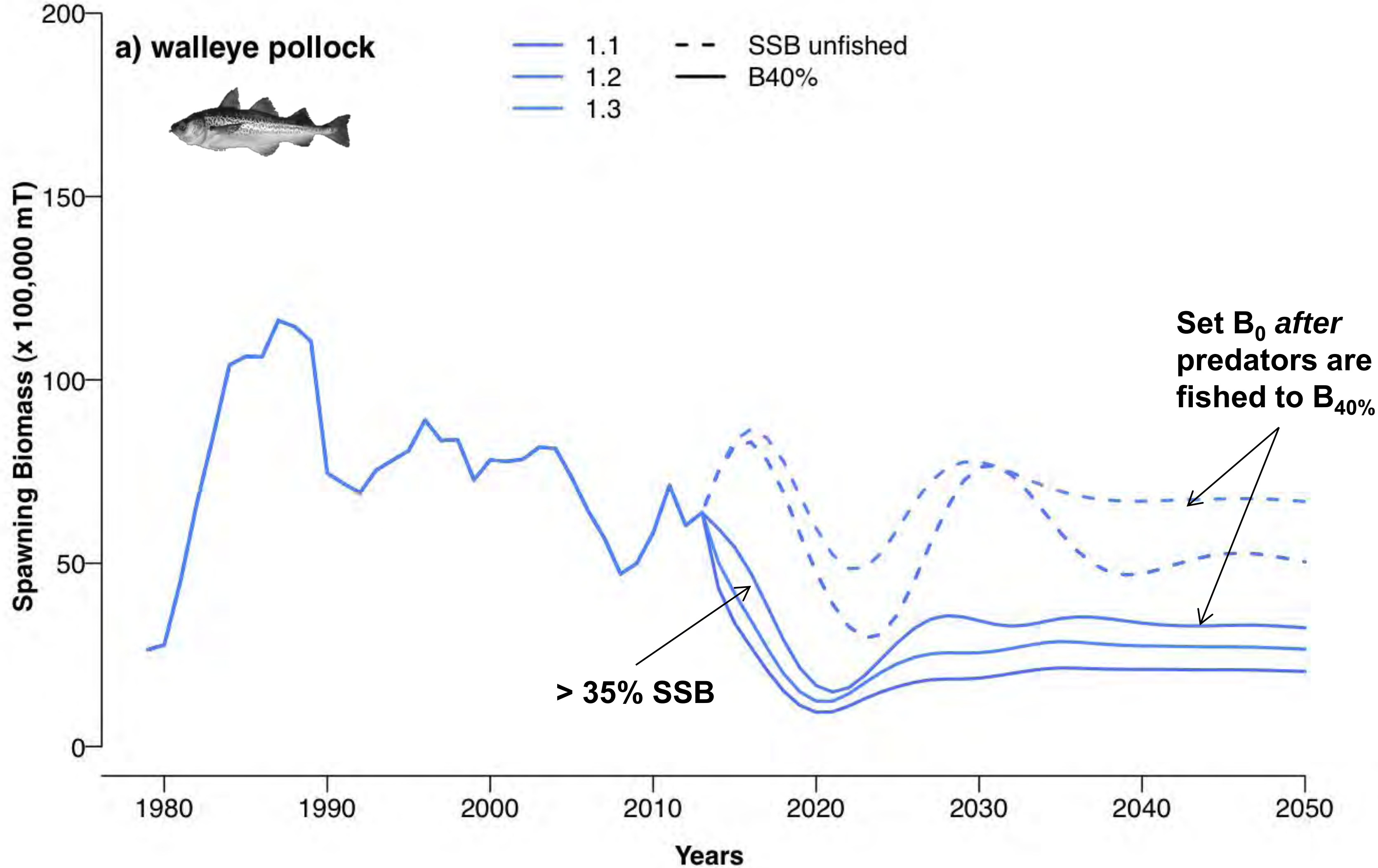
SPAWNING BIOMASS



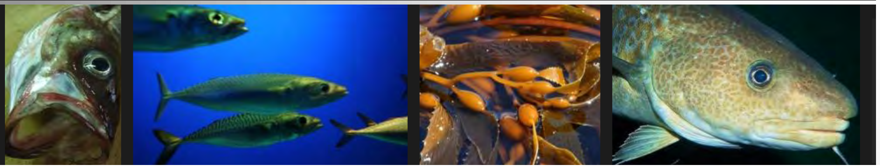


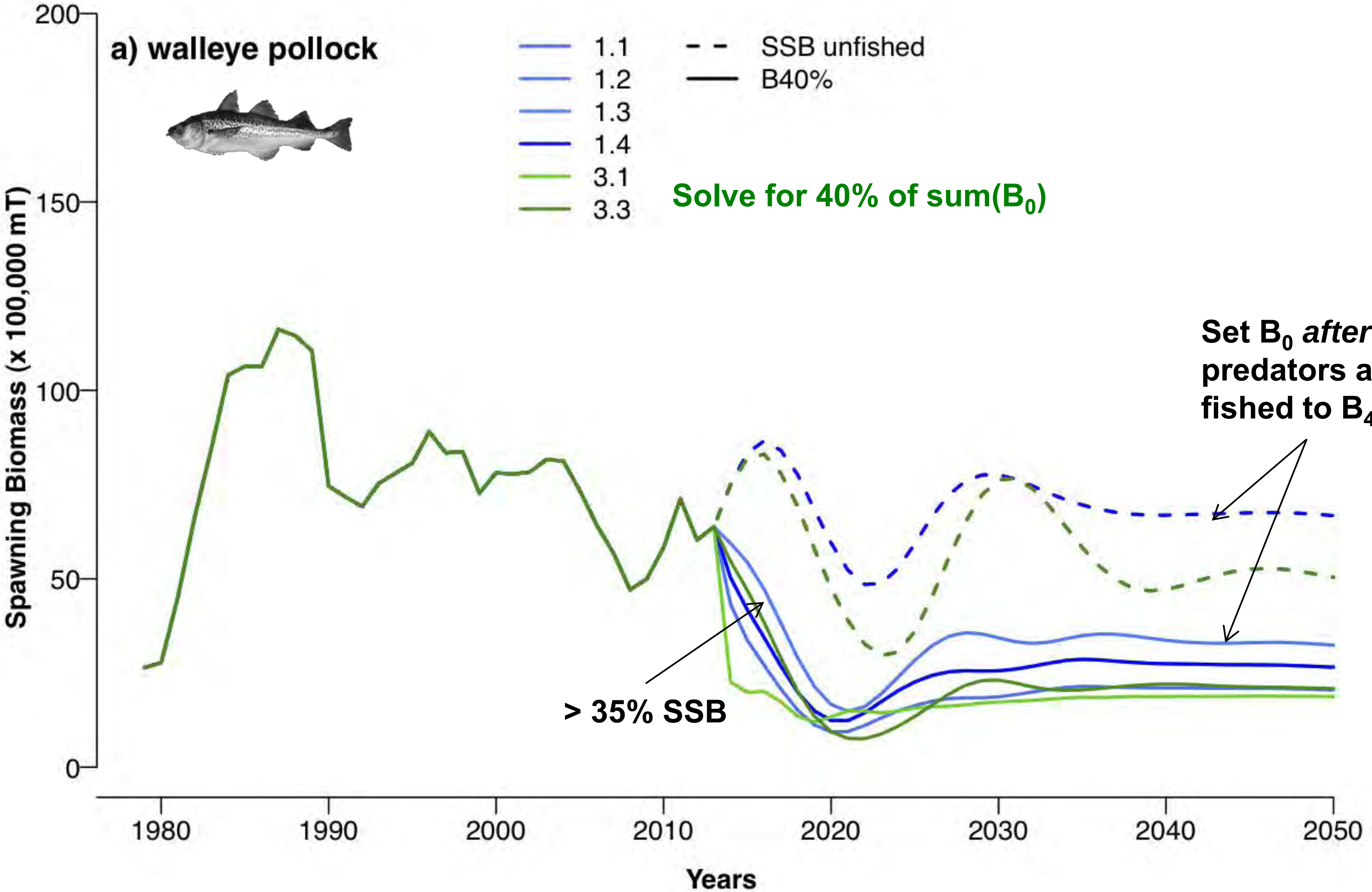
SPAWNING BIOMASS

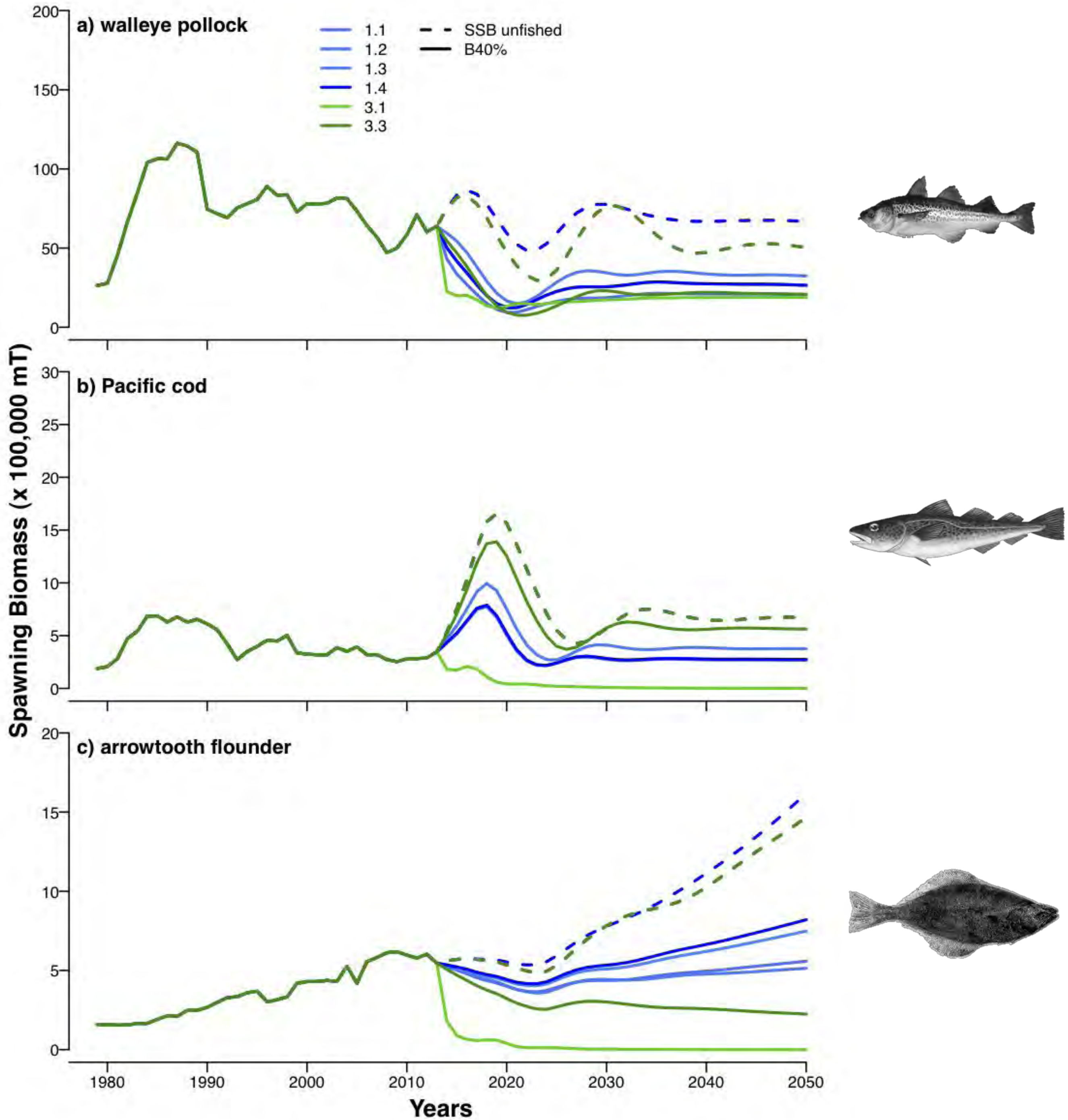




SPAWNING BIOMASS

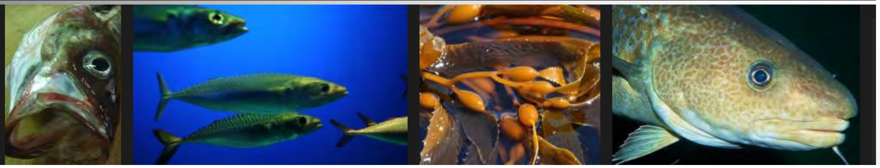


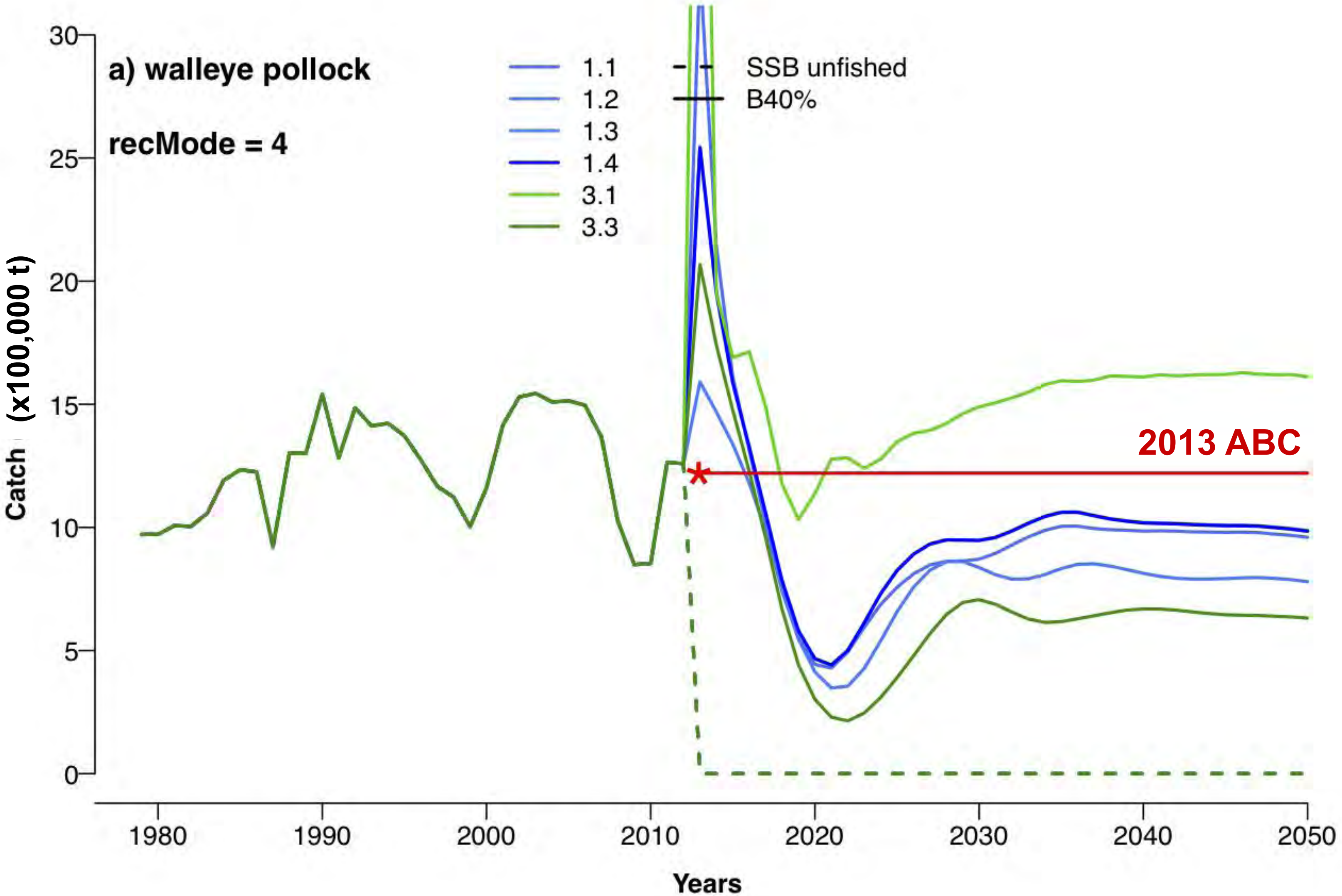




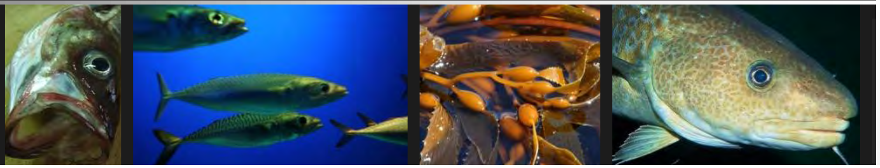
a) walleye pollock
b) Pacific cod
c) arrowtooth flounder
1.1
1.2
1.3
1.4
3.1
3.3
SSB unfished
B40%
Spawning Biomass (x 100,000 mT)
Years
0
50
100
150
200
0
5
10
15
20
25
30
0
5
10
15
20
1980
1990
2000
2010
2020
2030
2040
2050

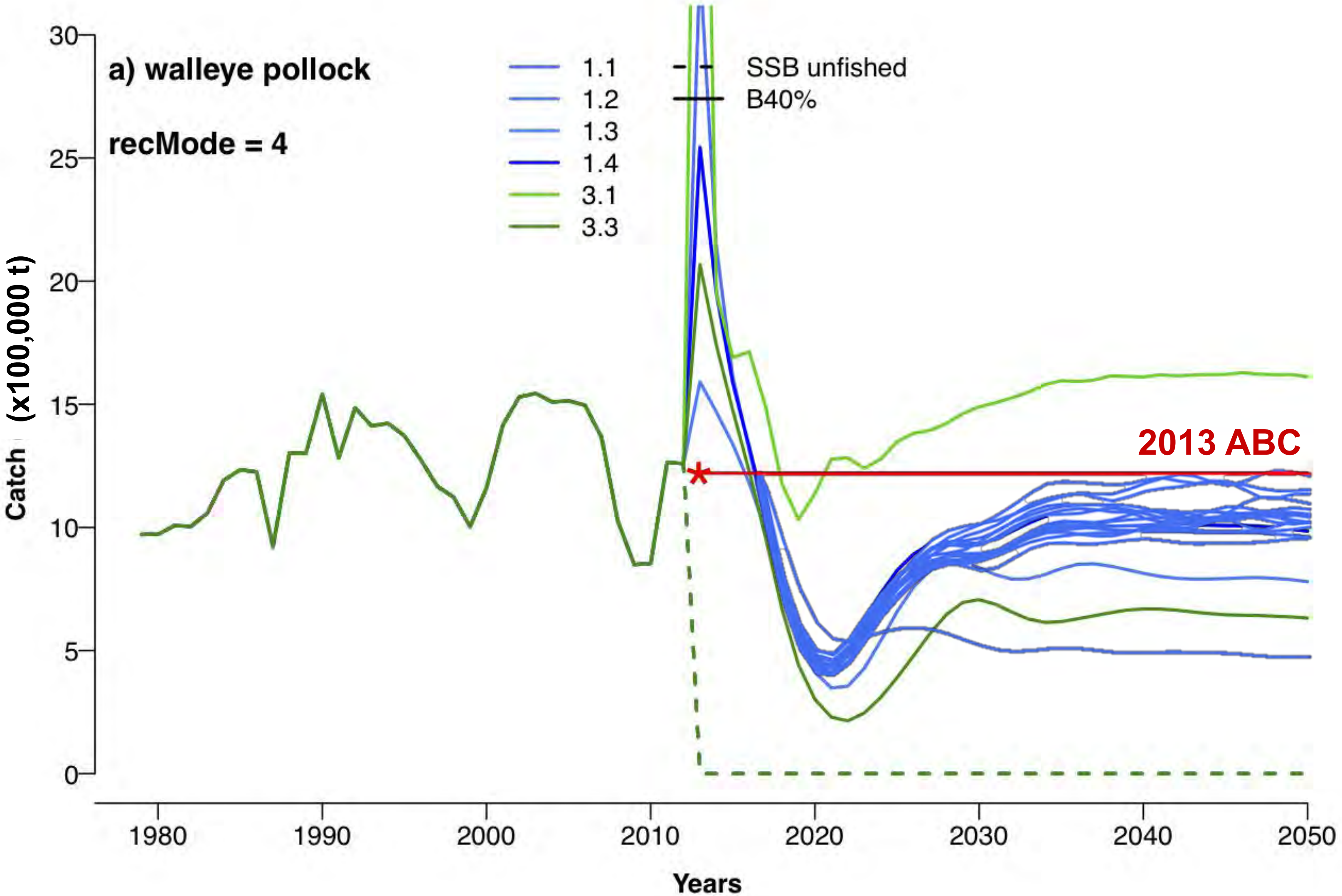
SPAWNING BIOMASS



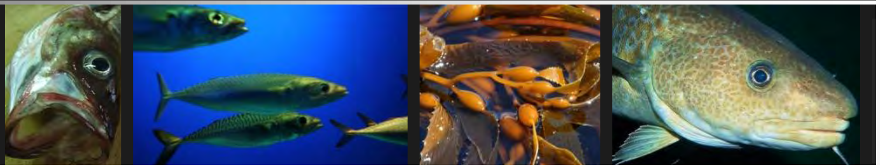


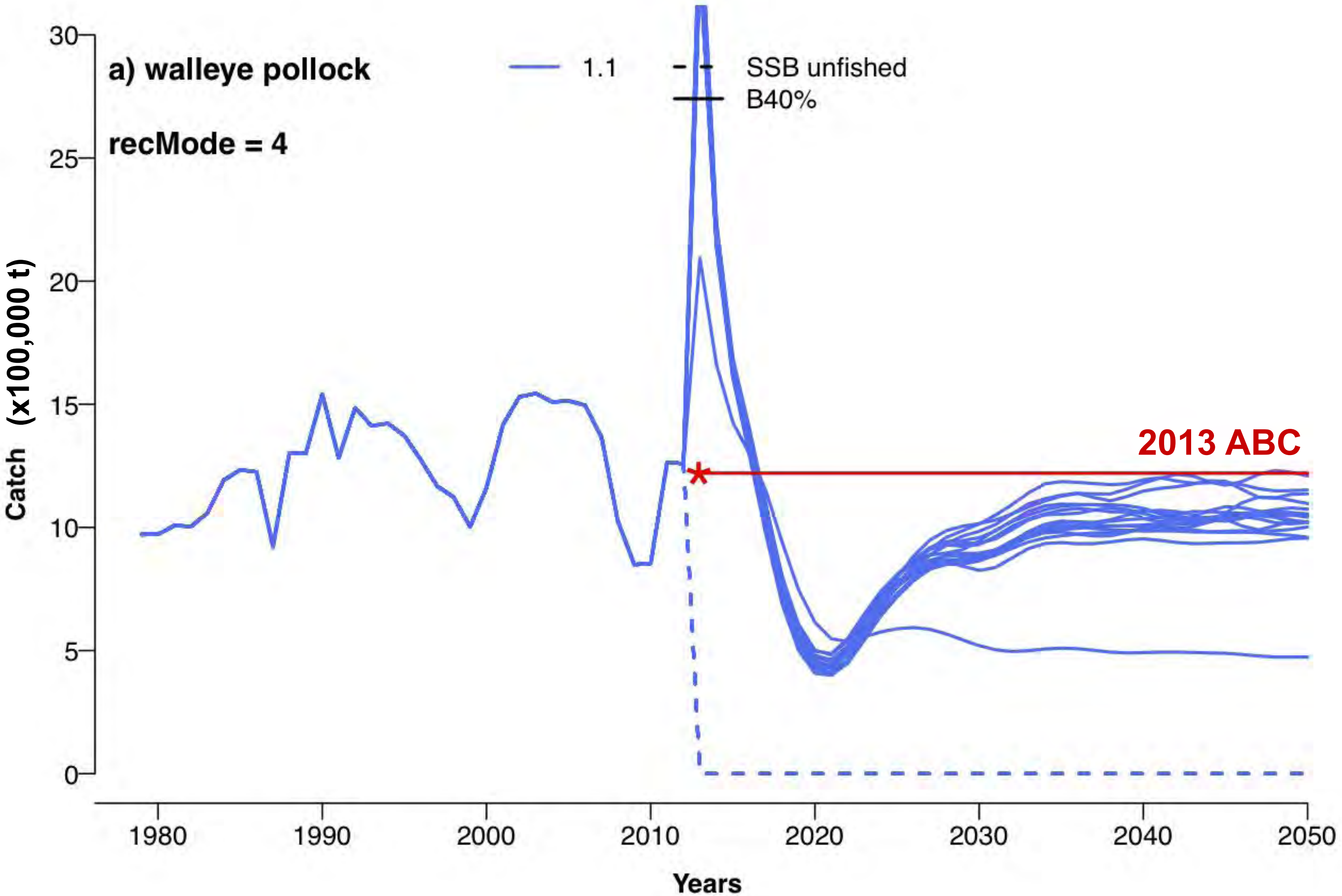
SPAWNING BIOMASS



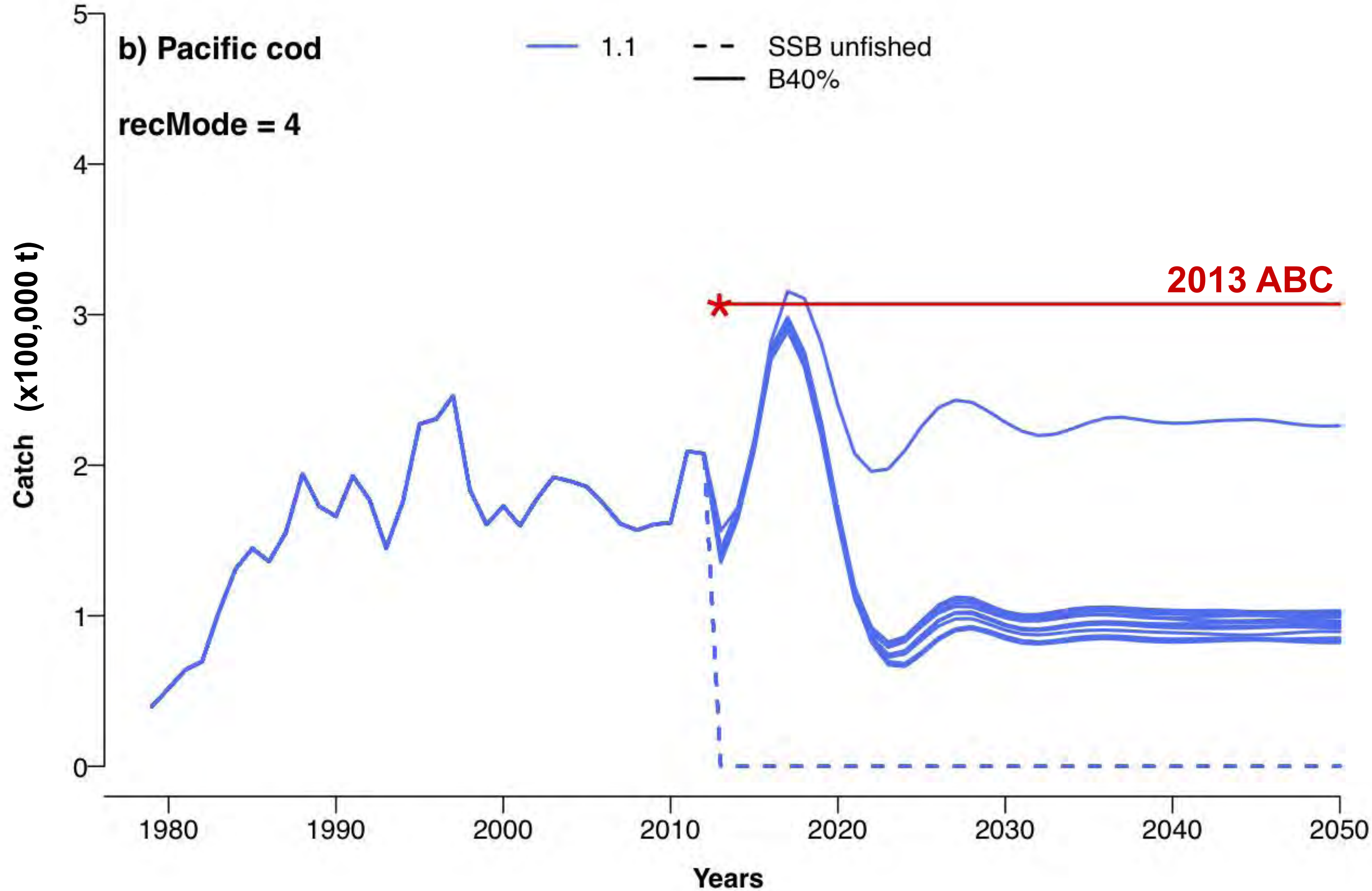


SPAWNING BIOMASS

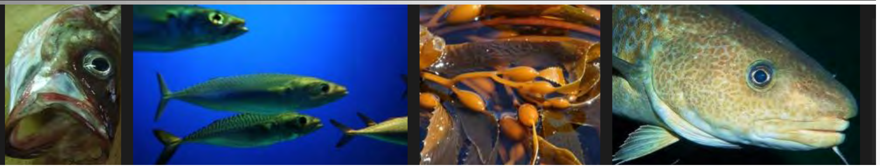




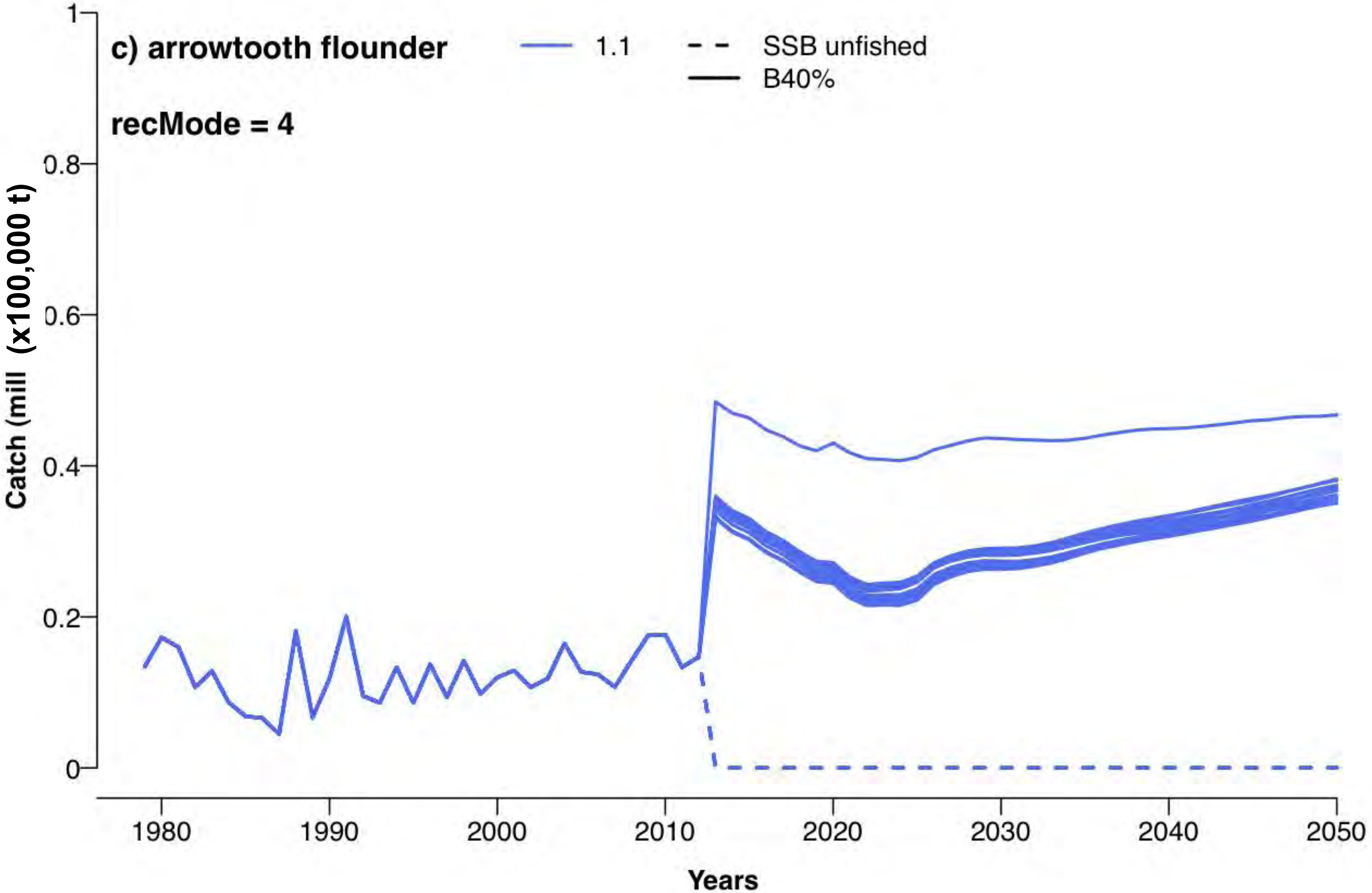
SPAWNING BIOMASS



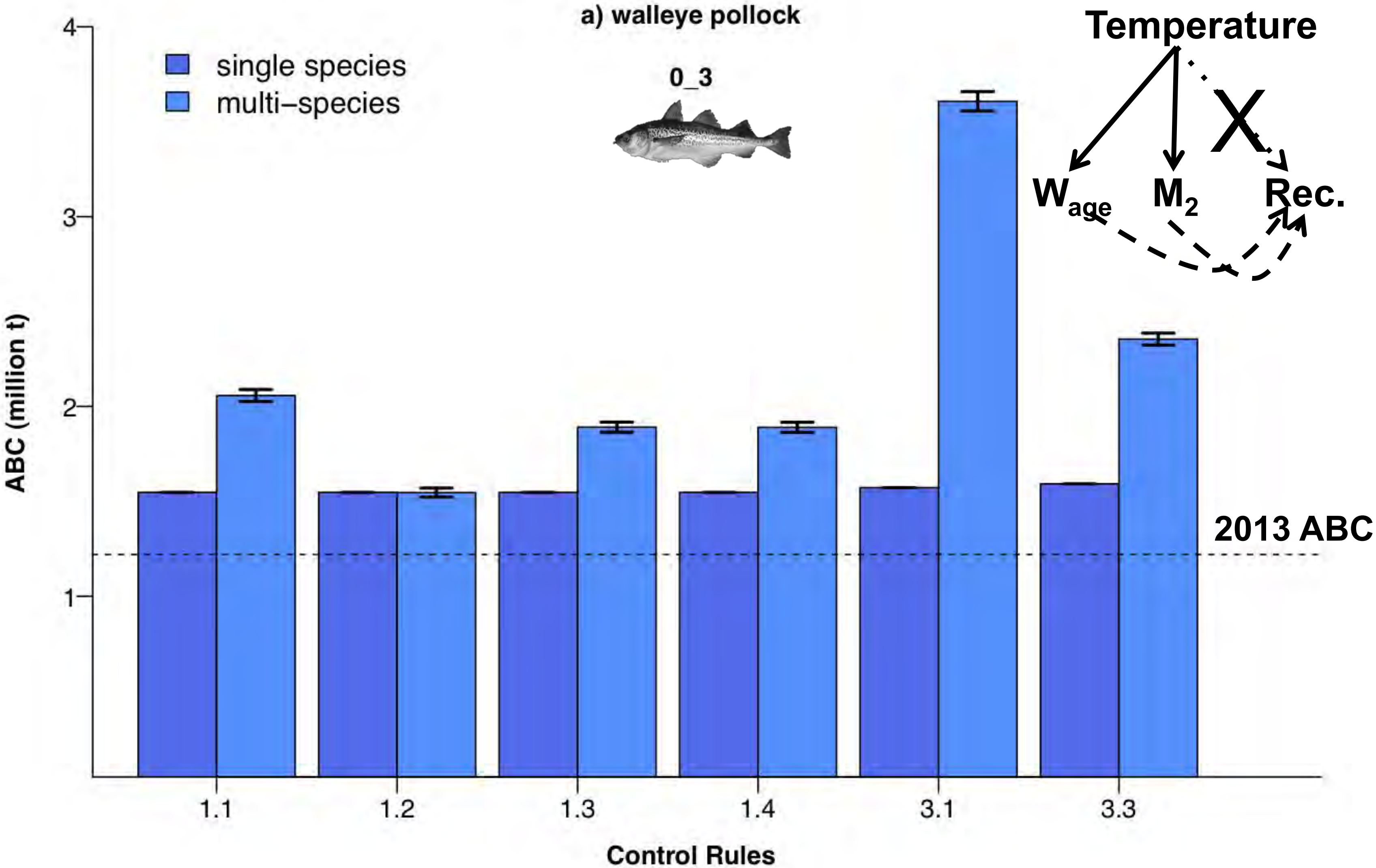
SPAWNING BIOMASS



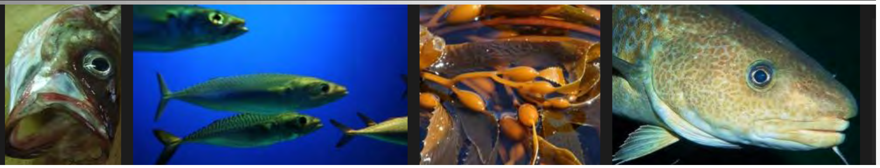
2013 ABC

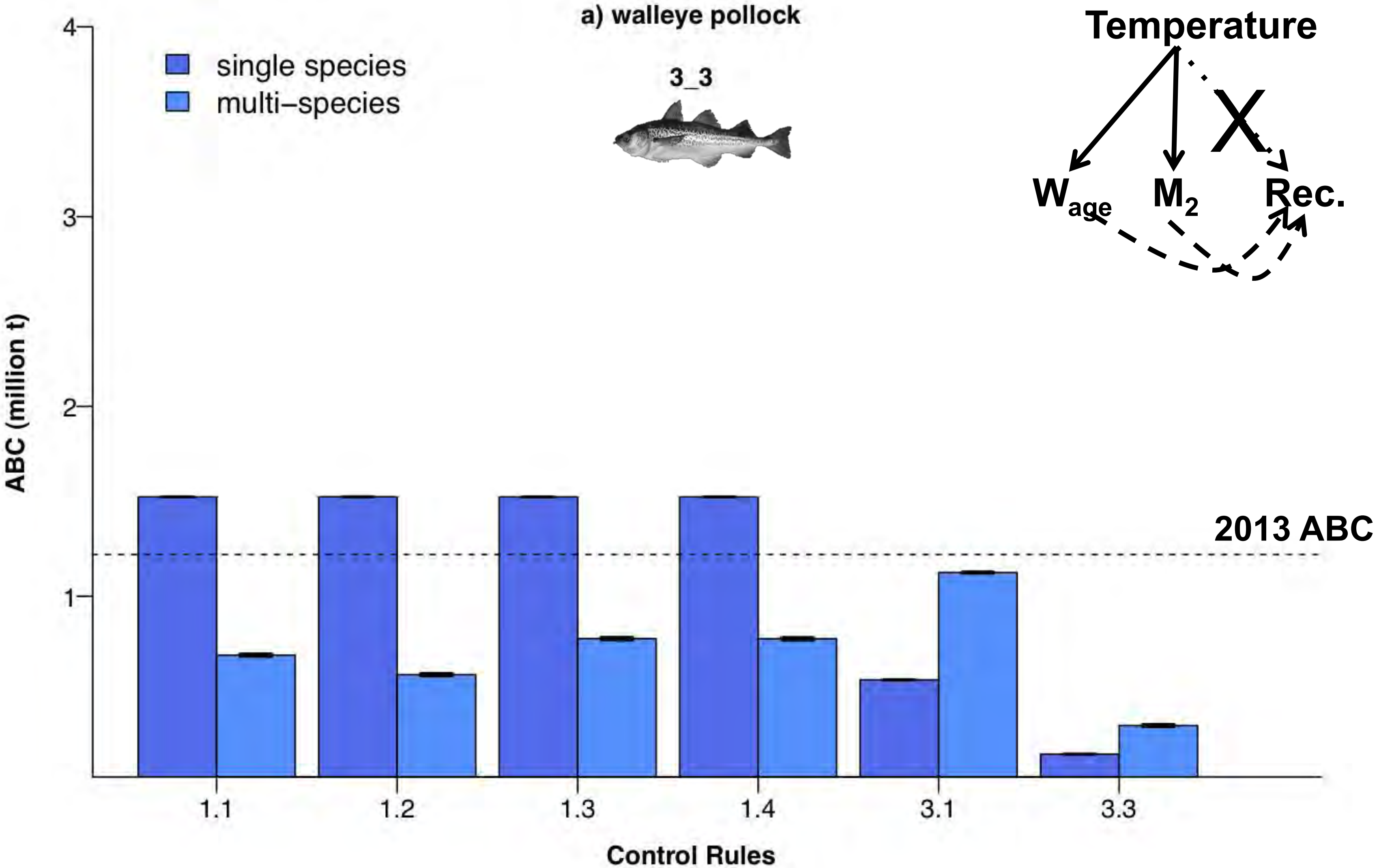


SPAWNING BIOMASS

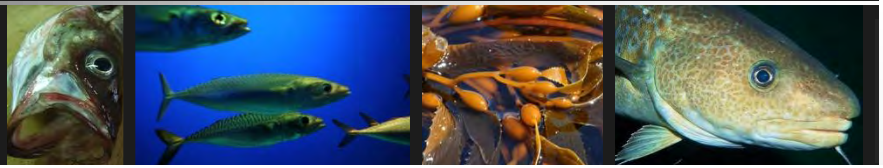


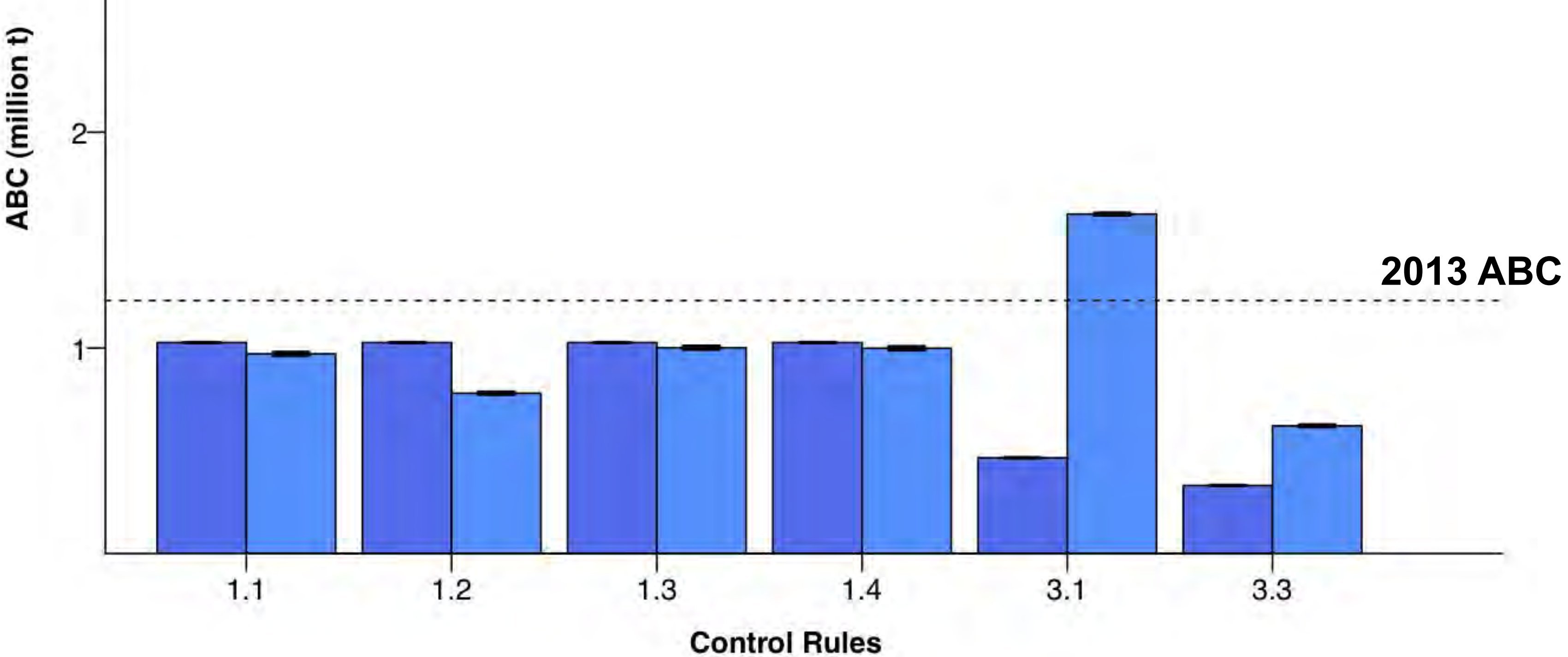
SPAWNING BIOMASS

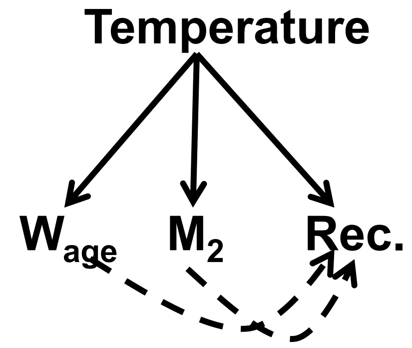




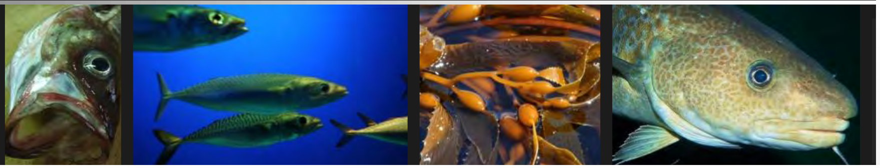
SPAWNING BIOMASS

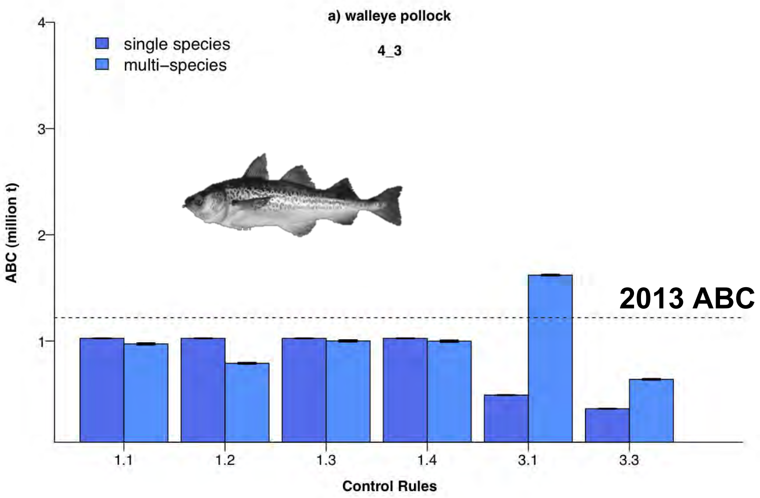


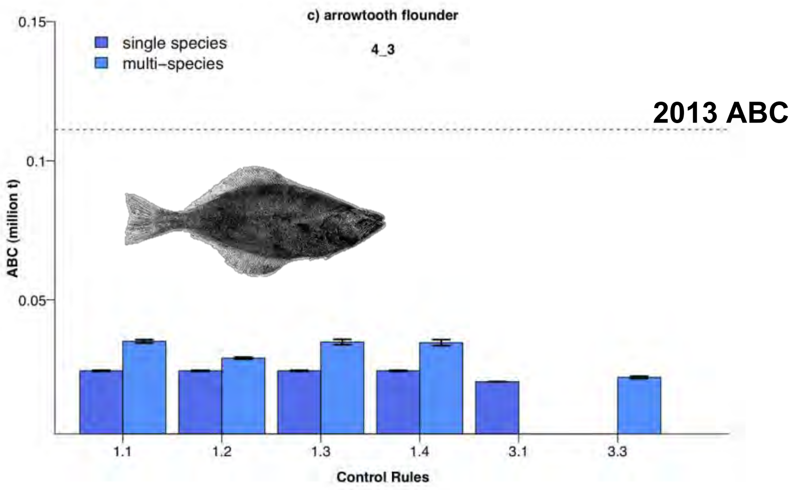


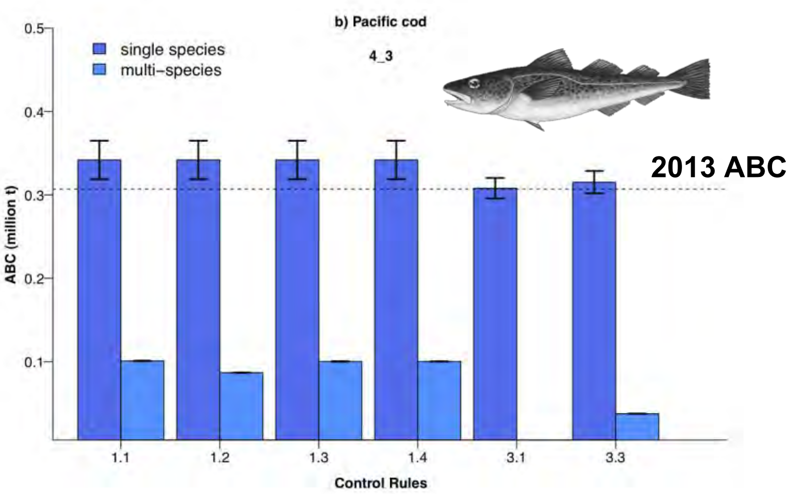


SPAWNING BIOMASS

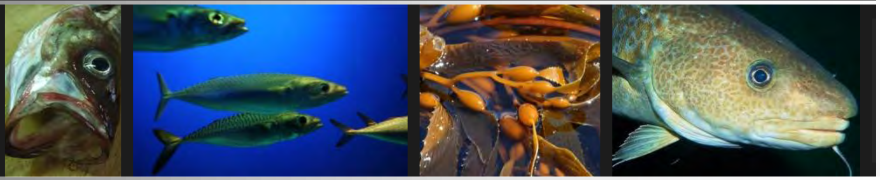








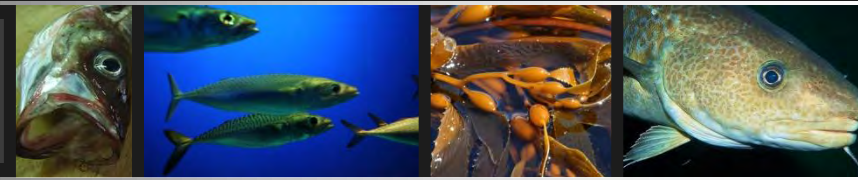
CONCLUSIONS



- MSM provides annual estimates of natural mortality
- Can project MSM models to derive multi-species BRPs
- BRPs are highly variable & depend on control rules
- Climatic variability introduces some differences but they are less than that introduced by control rules (4 pollock)
- For species with low predation – MSM ~ SS models

kirstin.holsman@noaa.gov

THANKS!

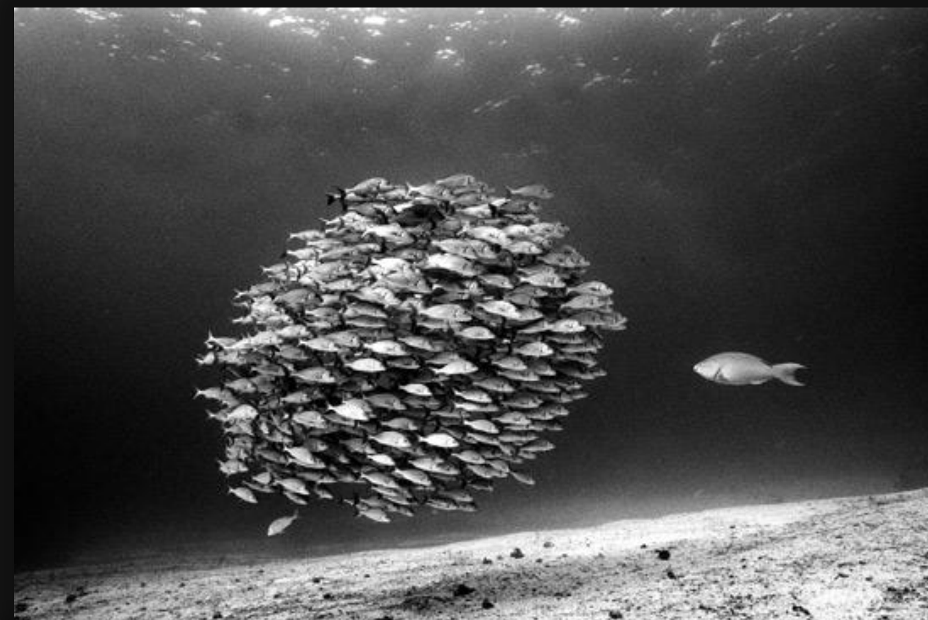


Collaborators

Kerim Aydin, Bruce Miller, Elizabeth Moffitt

Colleagues

Brain Knoth, Troy Buckley, Matt Baker, William Stockhausen, Sarah Gaichas, P.Sean McDonald, Ivonne Ortiz, Stephanie Zador



David Doubilet

kirstin.holsman@noaa.gov

bsierp.nprb.org

BEST-BSIERP Bering Sea Project