Incorporating ecosystem information & ecological interactions in management

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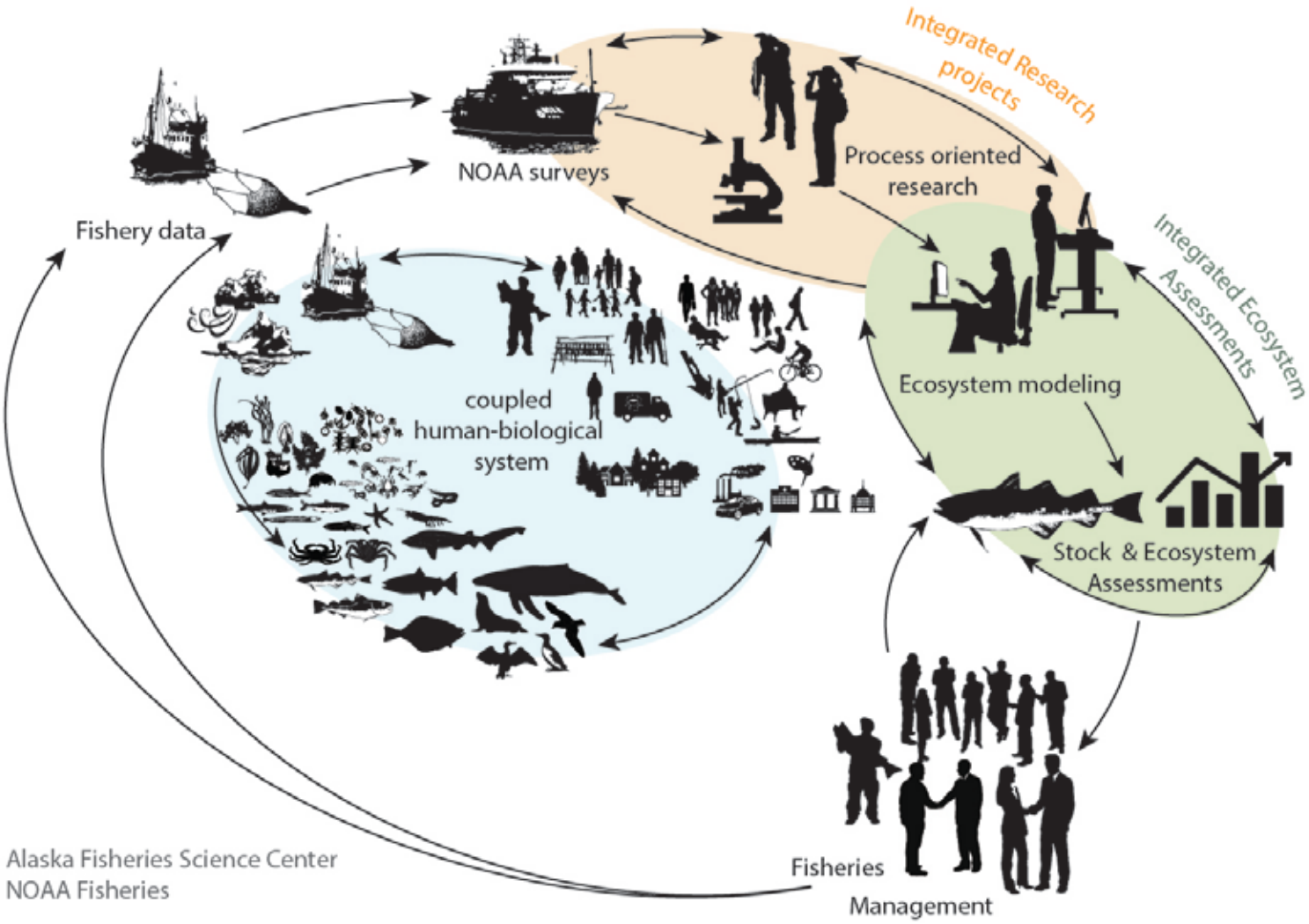
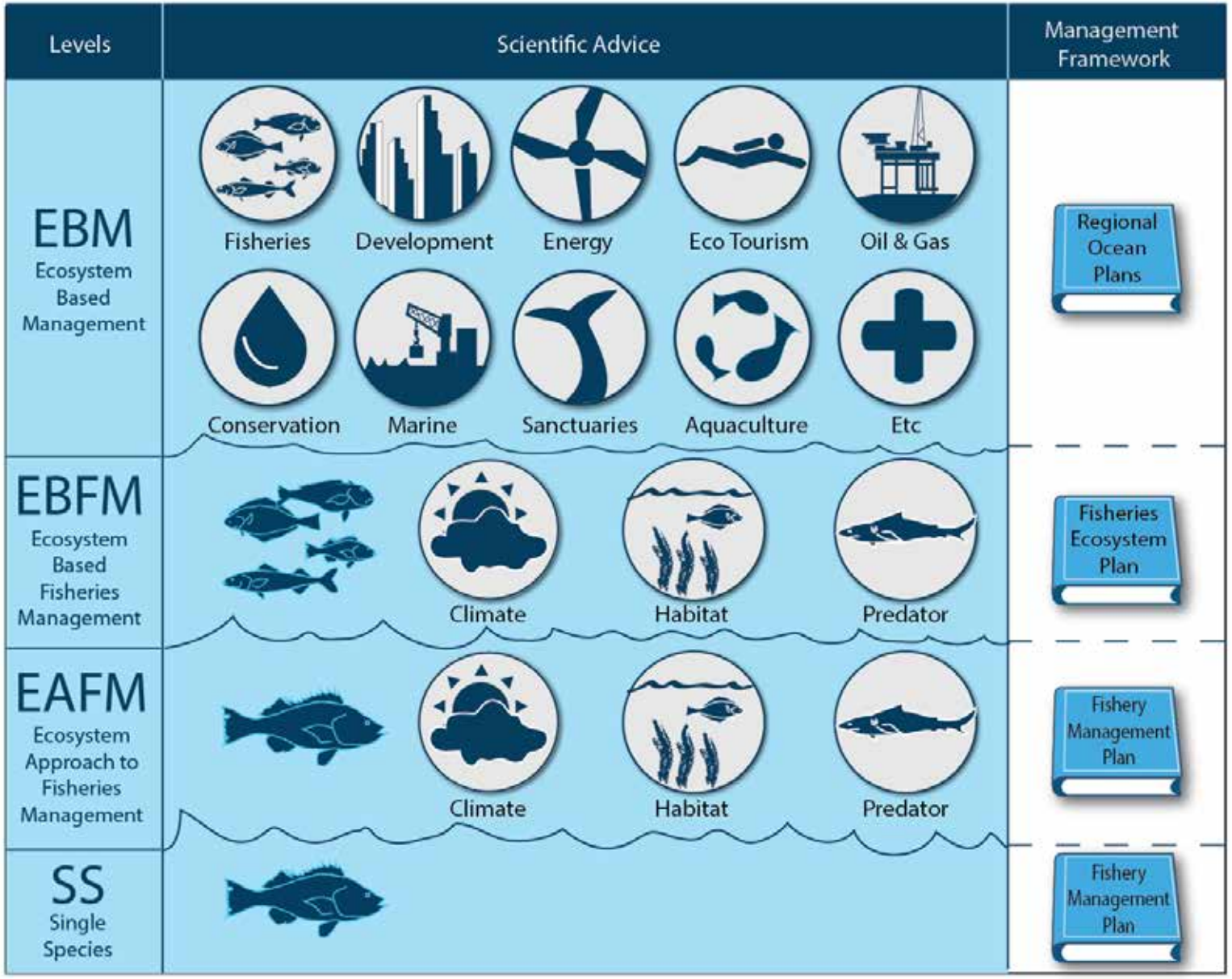
Photo: Mark Holsman

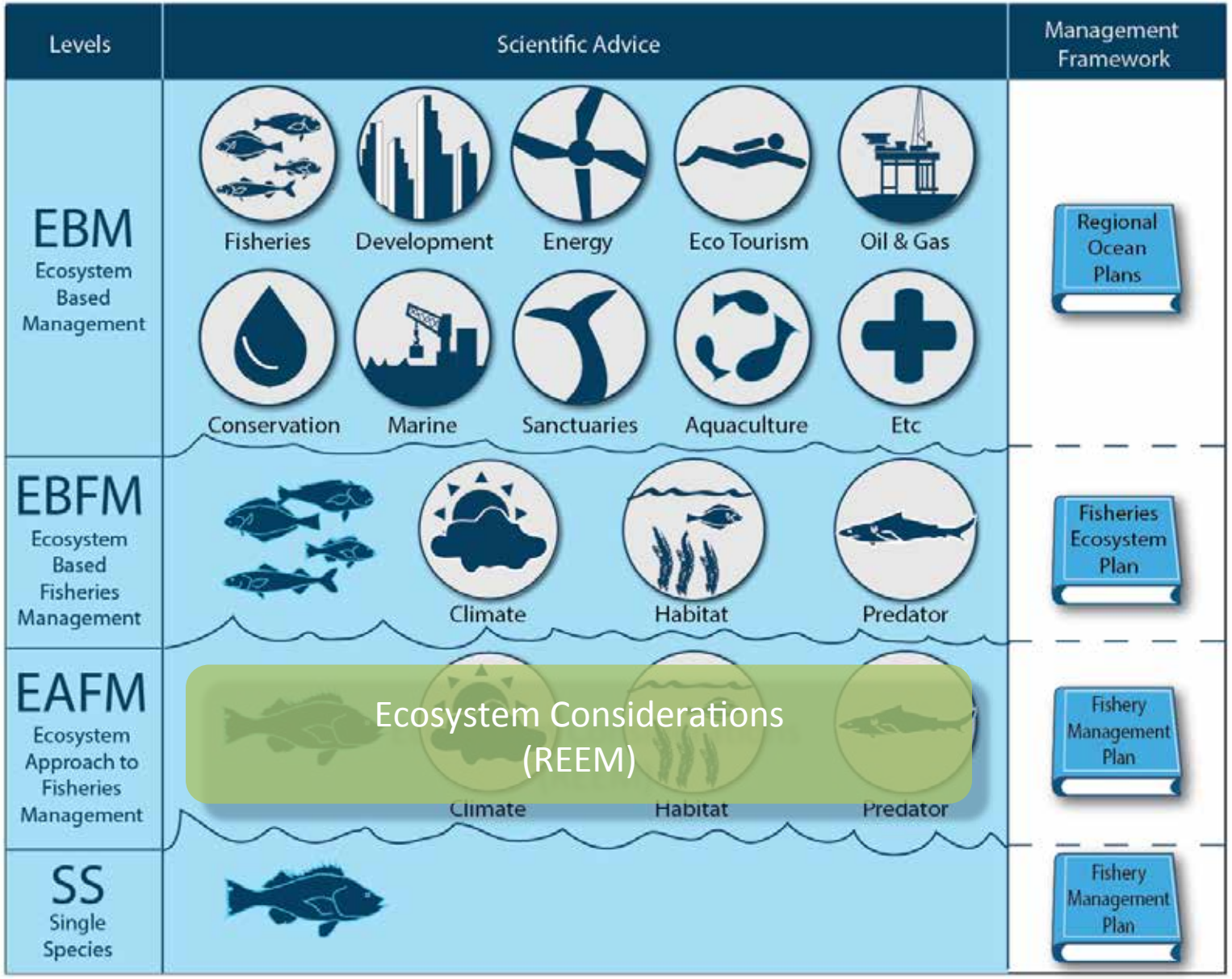
Ecosystem-Based Management Cycle





Slide courtesy of Jason Link

NOAA FISHERIES



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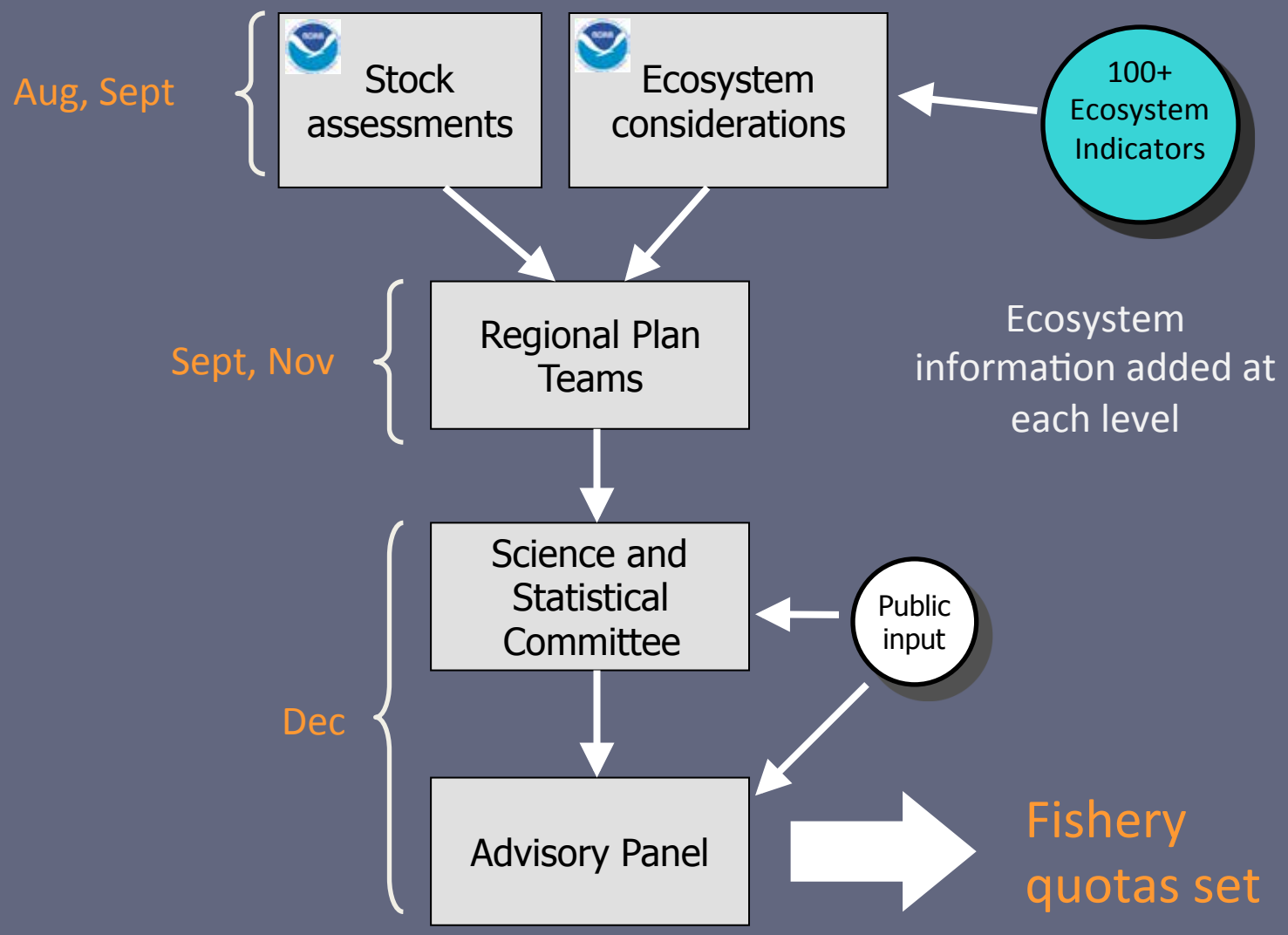
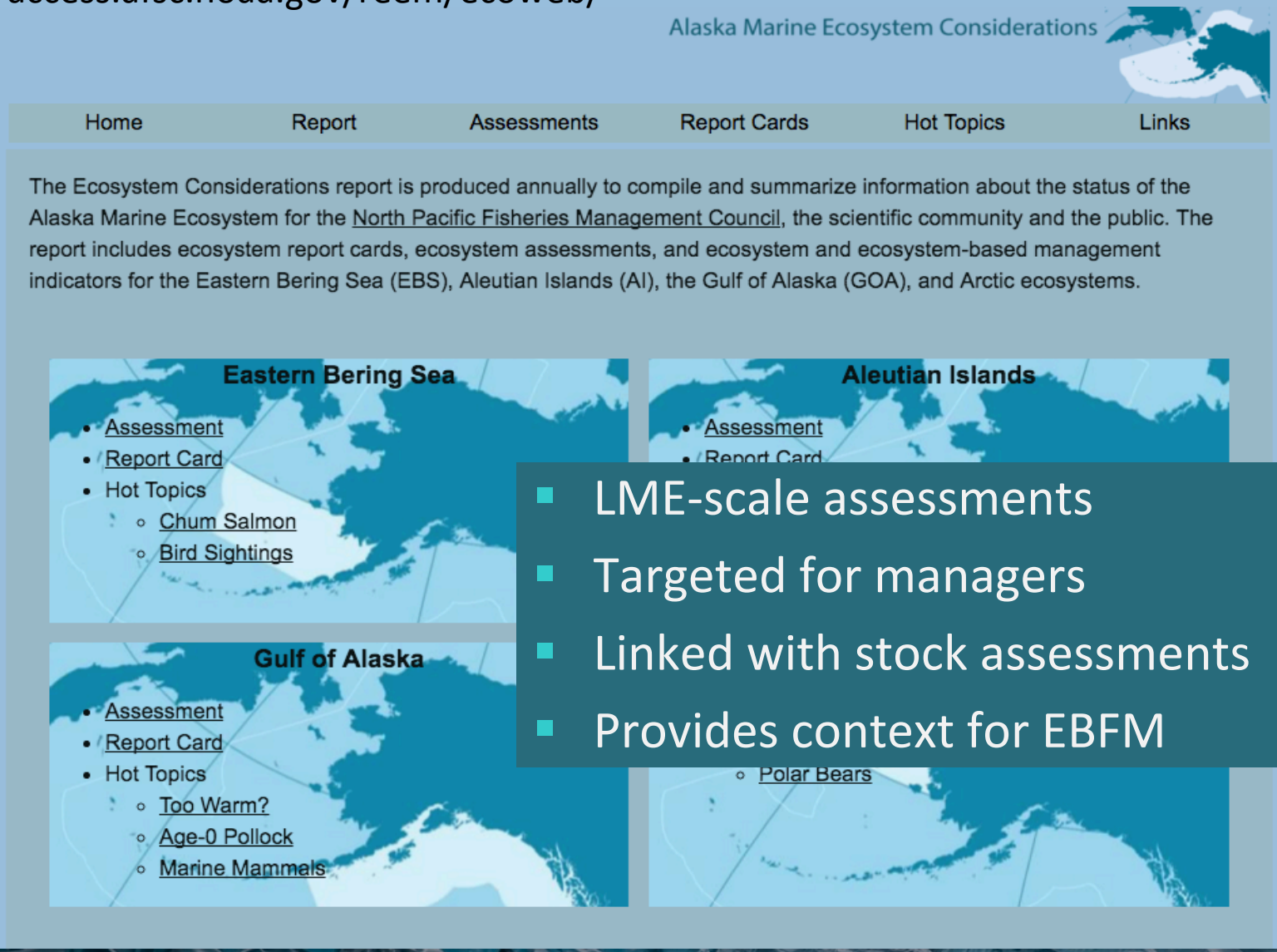
The Annual Council Process



Ecosystem Considerations Report

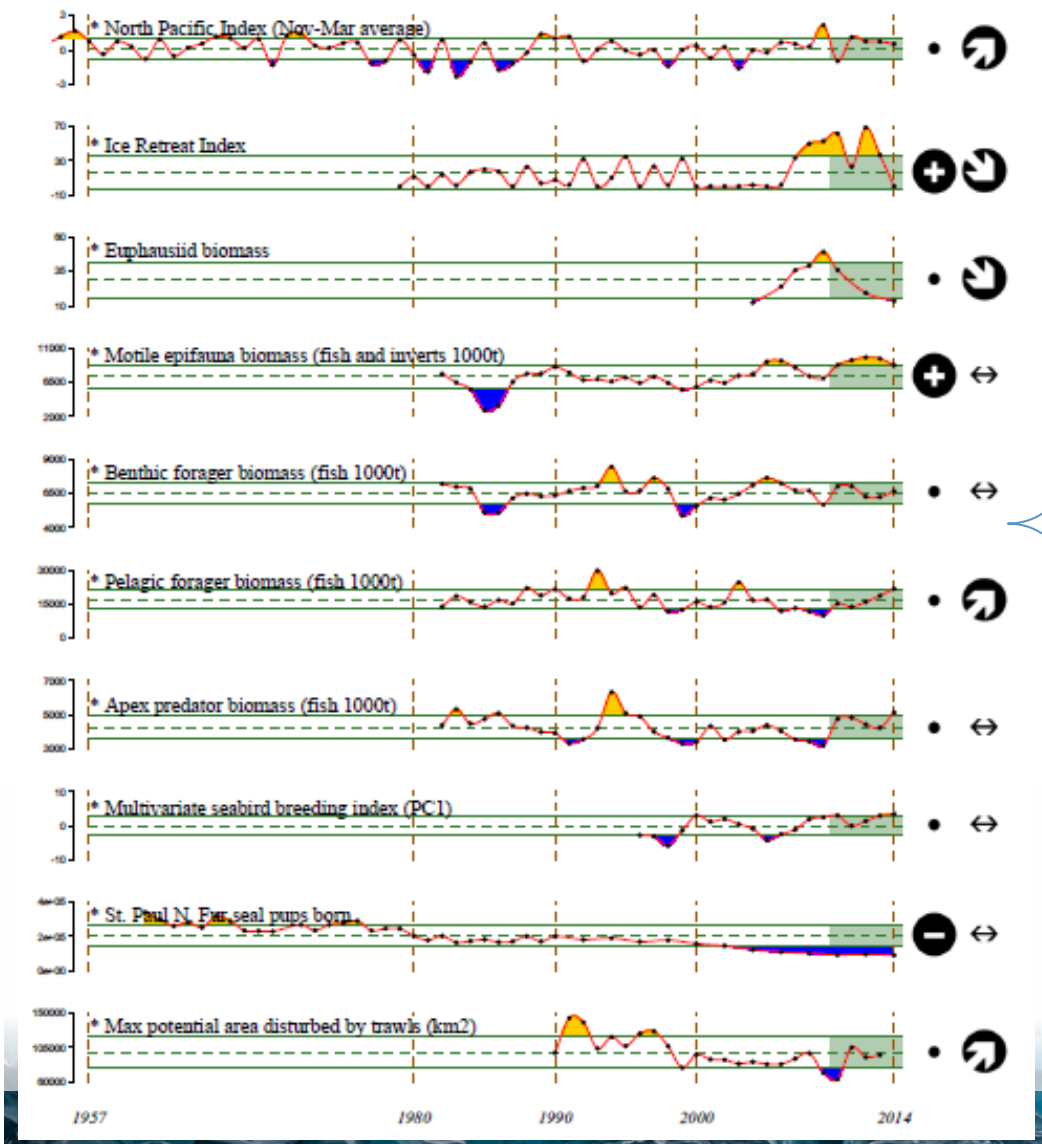
http://access.afsc.noaa.gov/reem/ecoweb/

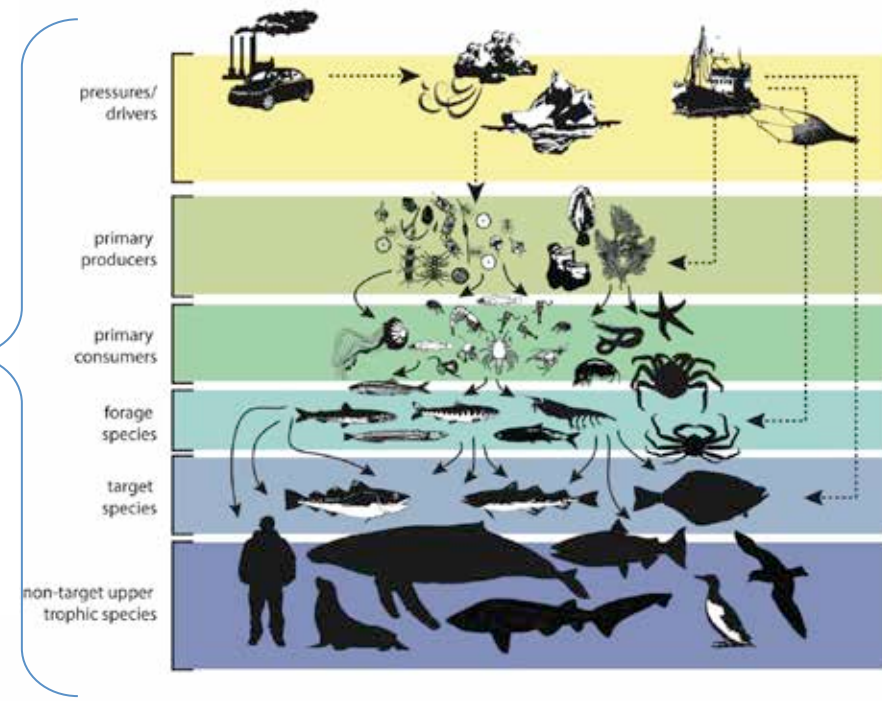


- LME-scale assessments
- Targeted for managers
- Linked with stock assessments
- Provides context for EBFM

Report Cards

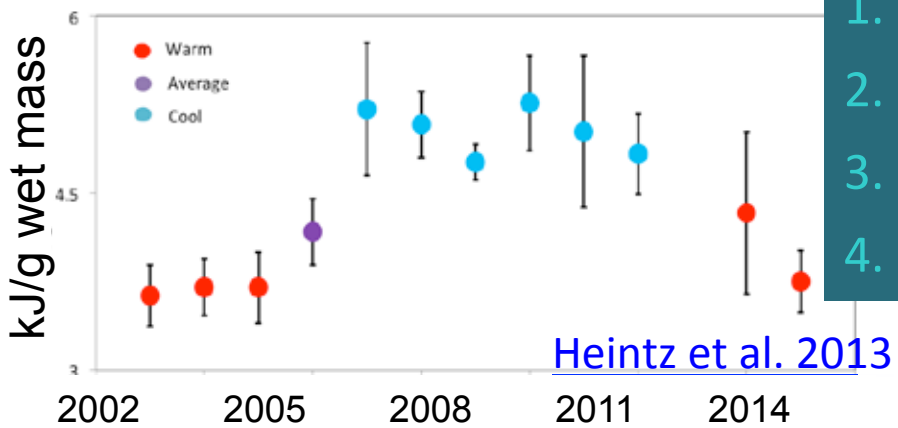
Indicators for each trophic level





EC Report: Indicator contributions

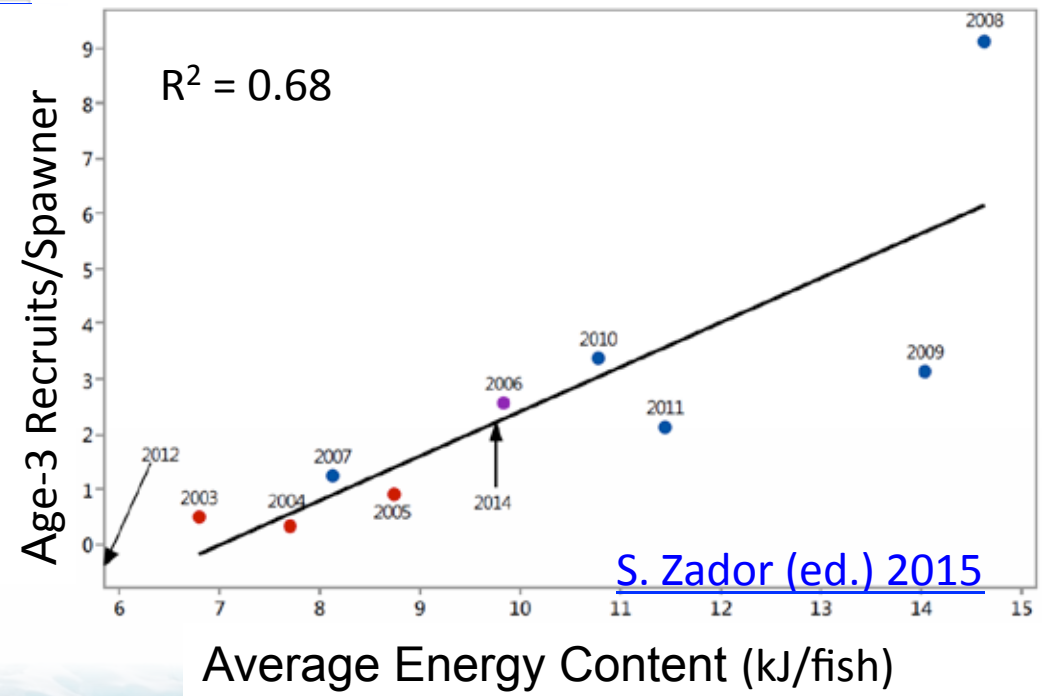
Energy density of age-0s



Heintz et al. 2013

1. Description of indicator
2. Status and Trends
3. Factors Influencing Trends
4. Implications for Fisheries Management

Fall condition of age-0 walleye pollock predicts recruitment of age-3 pollock



S. Zador (ed.) 2015

2006 example

From Council minutes, December 2006:

"The [eastern Bering Sea walleye pollock] stock remains above the MSY level, having declined … at a rate of about 19% per year….

Result from stock assessment

Other issues raised … suggest a need for further caution.

- a northward shift … with some portion of the population into Russian waters.

Assessment + ecosystem indicators

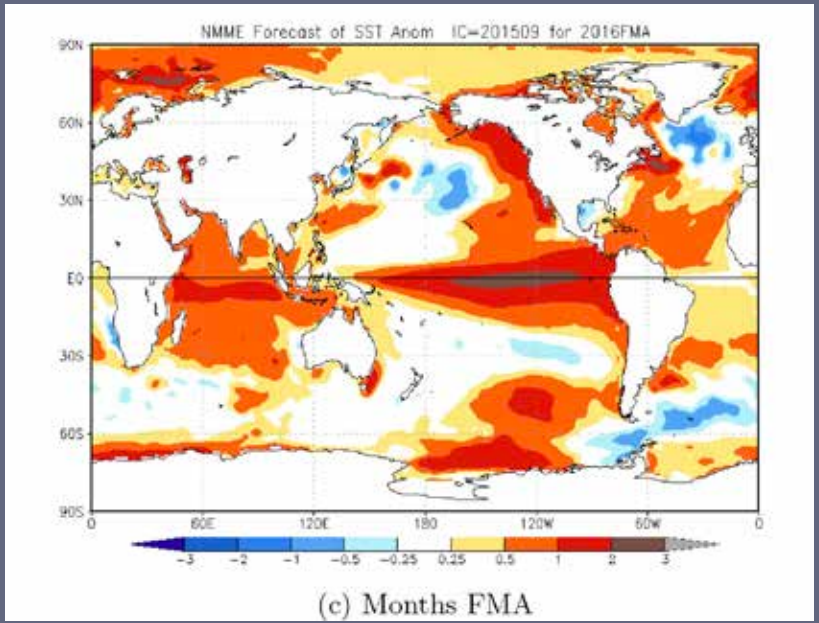
- a large decline in zooplankton, which is important in providing forage for juvenile pollock.

Ecosystem indicators

- increasing predation by arrowtooth flounder on juvenile pollock.

Multispecies model

Consequently, … <u>a reduction in … catch … is justified</u>."



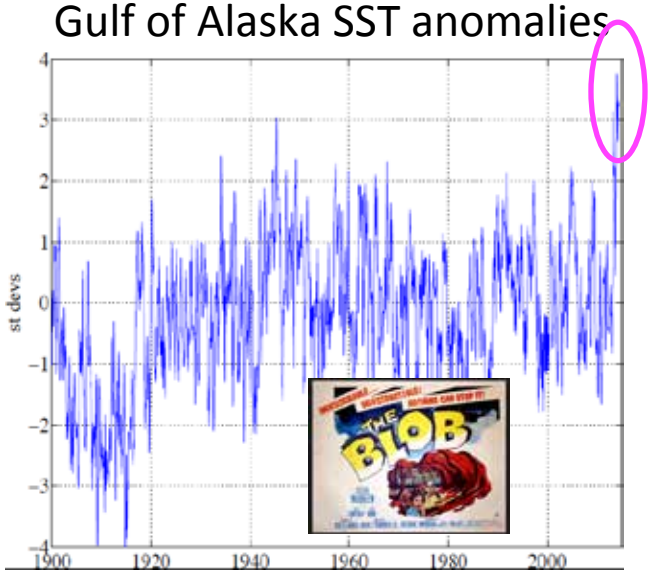
(c) Months FMA

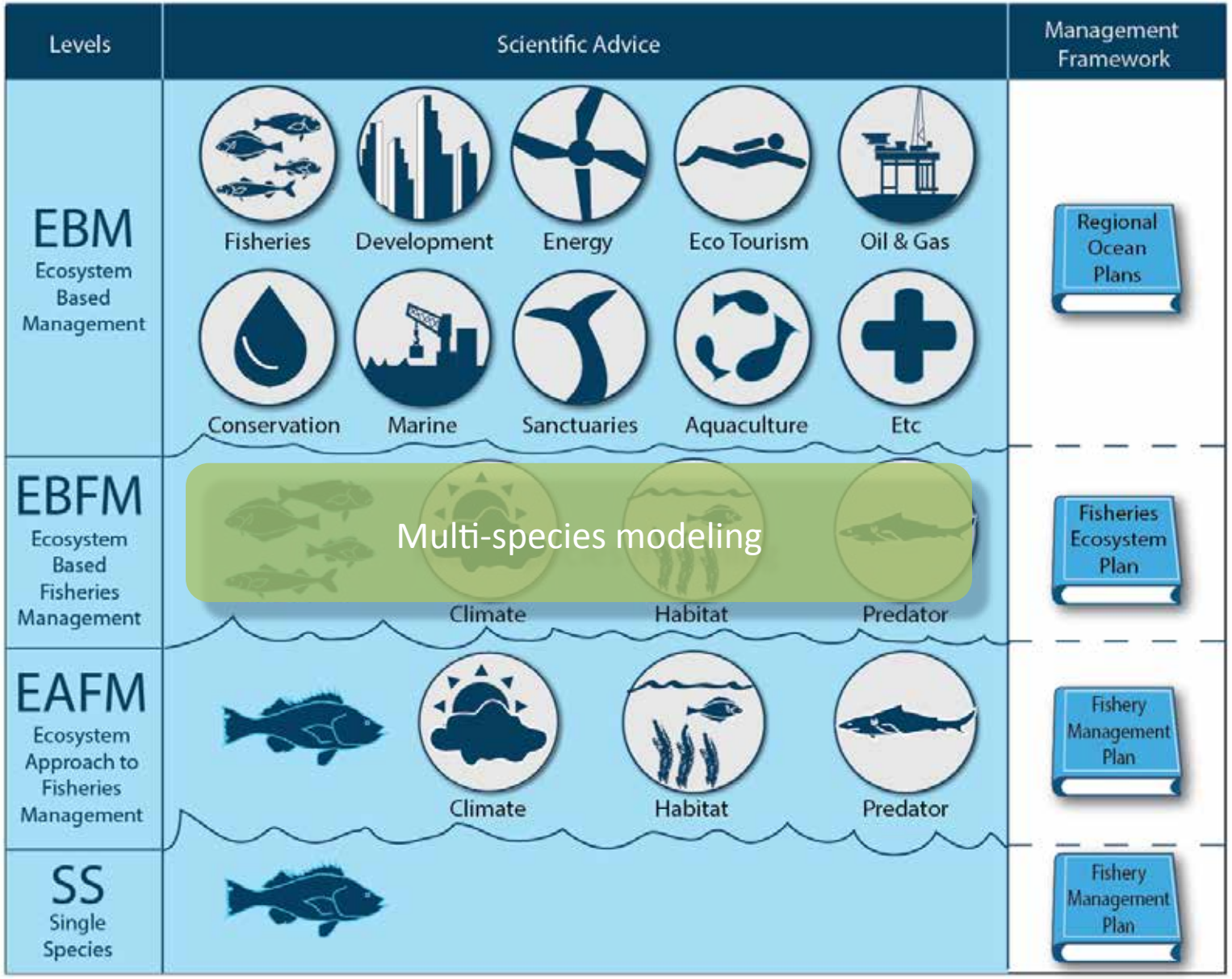
- Focus on predictive capacity
- Develop species-specific report cards
- Move indicators directly into stock assessments
- Develop ecosystem thresholds

Future Directions for Indicators

As we build modeling and predictive capacity, we will still need qualitative synthesis to capture events outside the bounds of current models and to detect impacts of the unexpected

Gulf of Alaska SST anomalies





Slide courtesy of Jason Link

NOAA FISHERIES

Ecosystem-Based Fisheries Management (EBFM)

"…a place-based, rather than species-based, management approach (Fogarty, 2014) that can account for fishery effects on food web structure and function, balance biodiversity and yield objectives, and improve management in systems characterized by large seasonal, decadal, and long-term climate variability (Pikitch et al., 2004; Arkema et al., 2006; Link, 2010; Agardy et al., 2011; Levin et al., 2013; Link and Browman, 2014)."

Holsman et al. in press. Deep Sea Res II

Multi-species models for EBFM

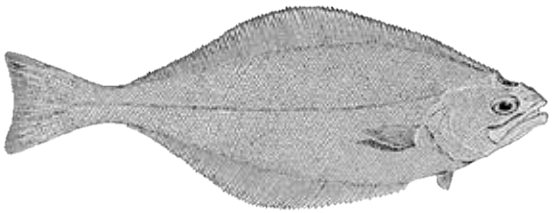
- Quantify relative effects of climate variability, trophic interactions, and fisheries on species productivity
- Non-stationary mortality, B0, and MSY
- Can identify indirect effects on other species and fisheries
- Quantify trade-offs among fisheries

Holsman et al. in press. Deep Sea Res II

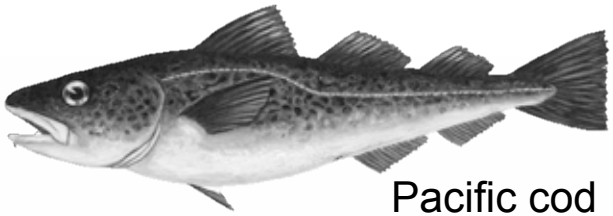
Photo: Mark Holsman

CEATTLE Multi-species stock assessment

Walleye pollock
(*Gadus chalcogrammus*)

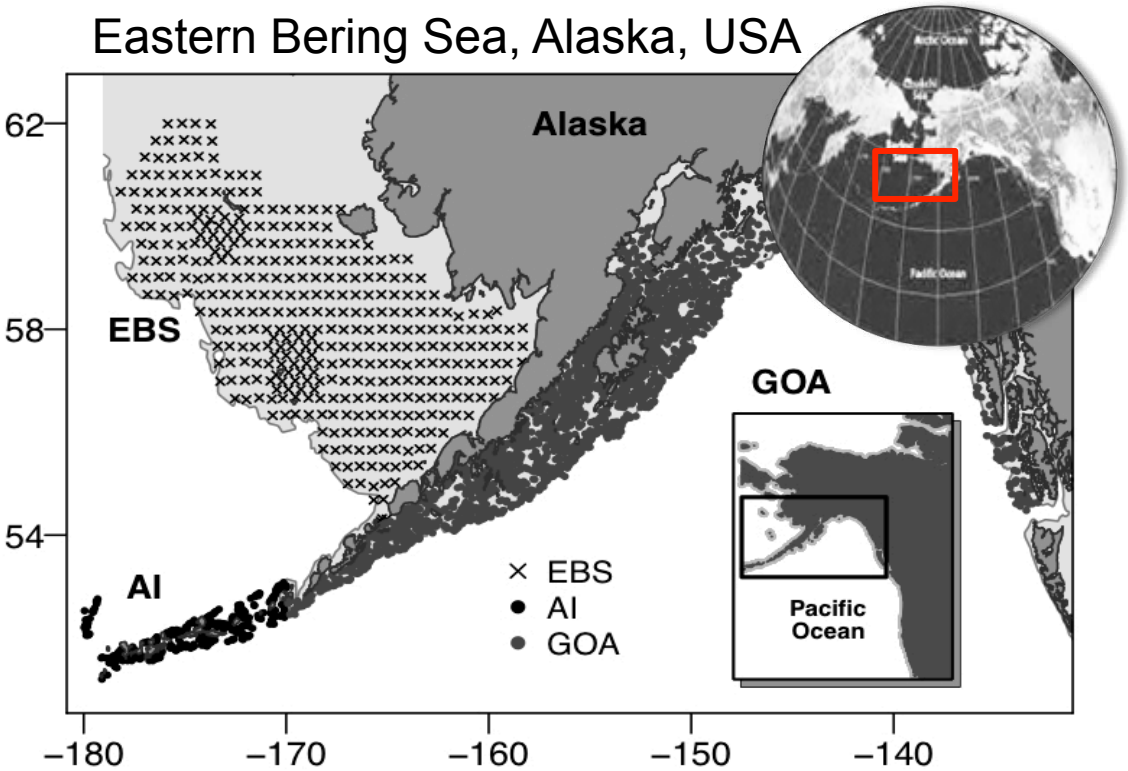


Arrowtooth flounder
(*Atheresthes stomias)*



Pacific cod
(*Gadus macrocephalus*)

Eastern Bering Sea, Alaska, USA



W@Age~*f*(Temperature)
Pred/prey~*f*(Temperature)

Climate-Enhanced, Age-based model with Temperature-specific Trophic Linkages and Energetics

Pred. Mortality (M2)

Definition	Equation		
Recruitment	$N_{i1,y} = R_{i,y} = R_{0,i}e^{\tau_{i,y}}$	$\tau_{i,y} \sim N(0,\sigma^2)$	T1.1
Initial abundance	$N_{ij,1} = \begin{cases} R_{0,i}e^{(-j\,M1_{ij})}N_{0,ij} & y=1 \quad 1<j\le A_i \\ R_{0,i}e^{(-j\,M1_{iA_i})}N_{0,iA_i}/\left(1-e^{(-j\,M1_{iA_i})}\right) & y=1 \quad j>A_i \end{cases}$		T1.2
Numbers at age	$N_{i,j+1,y+1} = N_{ij,y}e^{-Z_{ij,y}} \quad 1\le y\le n_y \quad 1\le j<A_i$ $N_{iA_i,y+1} = N_{iA_i-1,y}e^{-Z_{iA_i-1,y}} + N_{iA_i,y}e^{-Z_{iA_i,y}} \quad 1\le y\le n_y \quad j>A_i$		T1.3
Catch	$C_{ij,y} = \frac{F_{ij,y}}{Z_{ij,y}}(1-e^{-Z_{ij,y}})N_{ij,y}$		T1.4
Total yield (kg)	$Y_{i,y} = \sum_j^{A_i}\left(\frac{F_{ij,y}}{Z_{ij,y}}(1-e^{-Z_{ij,y}})N_{ij,y}W_{ij,y}\right)$		T1.5
	$B_{ij,y} = N_{ij,y}W_{ij,y}$		
	$Z_{ij,y} = M1_{ij} + M2_{ij,y} + F_{ij,y}$		
	$F_{ij,y} = F_{0,i}e^{\varepsilon_{i,y}}s^f_{ij}$	$\varepsilon_{i,y} \sim N(0,\sigma^2_{F,i})$	
	$W_{ij,y} = W_{\infty,iy}\left(1-e^{(-K_i(1-d_{i,y})(j-t_{0,i}))}\right)^{\frac{1}{1-d_{i,y}}}$		
	$d_{i,y} = e^{(\alpha_{d,i,y} + \alpha O_{d,i} + \beta_{d,i}T_y)}$		T1.10b
	$W_{\infty,iy} = \left(\frac{H_i}{K_i}\right)^{1/(1-d_{i,y})}$		T1.10c
BT survey biomass (kg)	$\hat{\beta}^s_{i,y} = \sum_j^{A_i}\left(N_{ij,y}e^{-0.5\,Z_{ij,y}}W_{ij,y}s^s_{ij}\right)$		T1.11
EIT surv			T1.12
Fishery			T1.13
BT surv			T1.14
EIT surv			T1.15
BT selectivity	$s^s_{ij} = \frac{1}{1+e^{(-\delta^s_i(j-\sigma^s_i))}}$		T1.16
Fishery selectivity	$s^f_{ij} = \begin{cases} e^{\eta_{ij}} & j\le A_{\eta,i} \\ e^{\eta_{iA_{\eta,i}}} & j>A_{\eta,i} \end{cases}$	$\eta_{ij} \sim N(0,\sigma^2_{f,i})$	T1.17
Proportion females	$\omega_{ij} = \frac{e^{-j\,M_{fem}}}{e^{-j\,M_{fem}}+e^{-j\,M_{male}}}$		T1.18
Proportion of mature females	$\rho_{ij} = \omega_{ij}\phi_{ij}$		T1.19
Weight at age (kg)	$W_{ij,y} = W^{fem}_{ij,y}\omega_{ij} + (1-\omega_{ij})W^{male}_{ij,y}$		T1.20
Residual natural mortality	$M1_{ij} = M^{fem}_{ij}\omega_{ij} + (1-\omega_{ij})M^{male}_{ij}$		T1.21

Residual Natural Mortality

Predation Natural Mortality

$$Z_{ij,y} = \mathrm{M1}_{ij} + \mathrm{M2}_{ij,y} + F_{ij,y}$$

Pred. Mortality (M2)

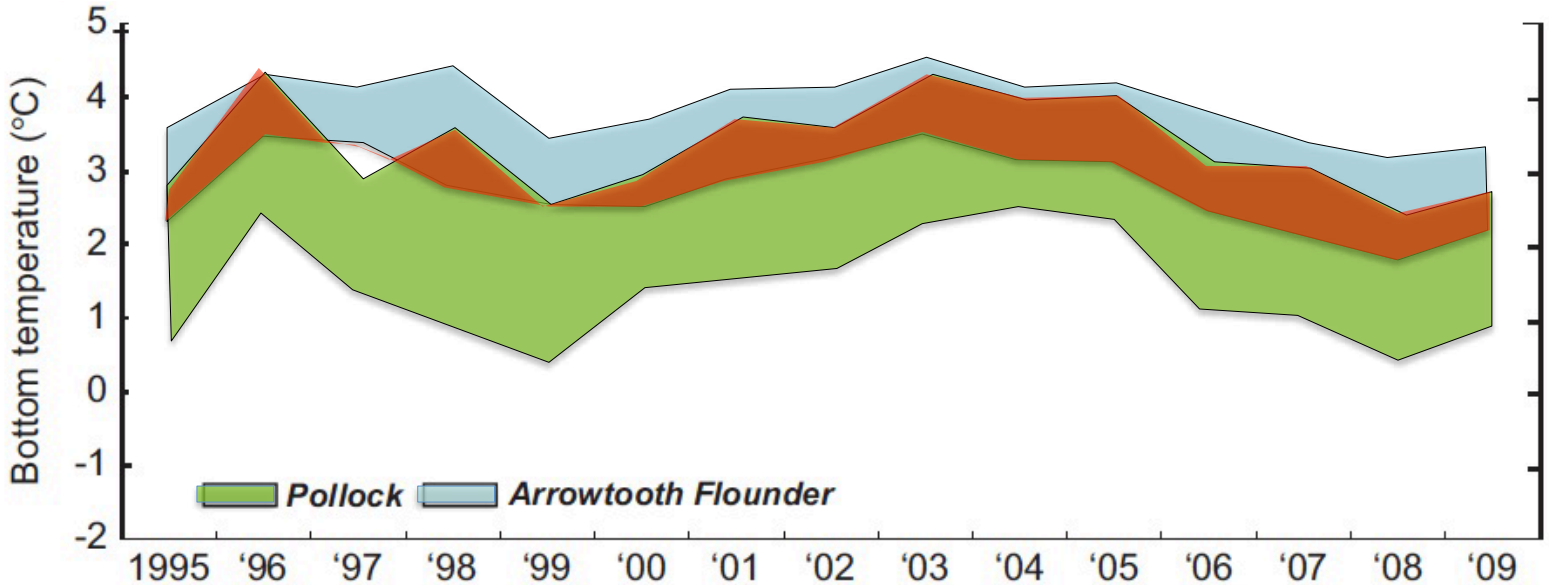
Definition	Equation	
Predation mortality	$M2_{ij,y} = \sum_{pa} \left(\frac{N_{pa,y}\delta_{pa,y}\bar{S}_{paij}}{\sum_{ij}\left(\bar{S}_{paij}B_{ij,y}\right) + B_p^{other}\left(1 - \sum_{ij}\left(\bar{S}_{paij}\right)\right)} \right)$	T2.1
Predator-prey suitabilit		
Mean gravimetric diet proportion		T2.3
Individual specific ratio (kg kg^{-1} yr^{-1})		
Temperature scaling algorithm	$f(T_p) = V^X e^{(X(1-V))}$	T2.5
	$X = \left(Z^2\left(1+(1+40/Y)^{0.5}\right)^2\right)/400$	T2.5b
	$Z = ln\left(Q_p^c\right)\left(T_p^{cm} - T_p^{co}\right)$	T2.5c
	$Y = ln\left(Q_p^c\right)\left(T_p^{cm} - T_p^{co} + 2\right)$	T2.5d

Age-specific prey selectivity

Size-specific annual ration

Temperature specific

Predator- Prey Overlap



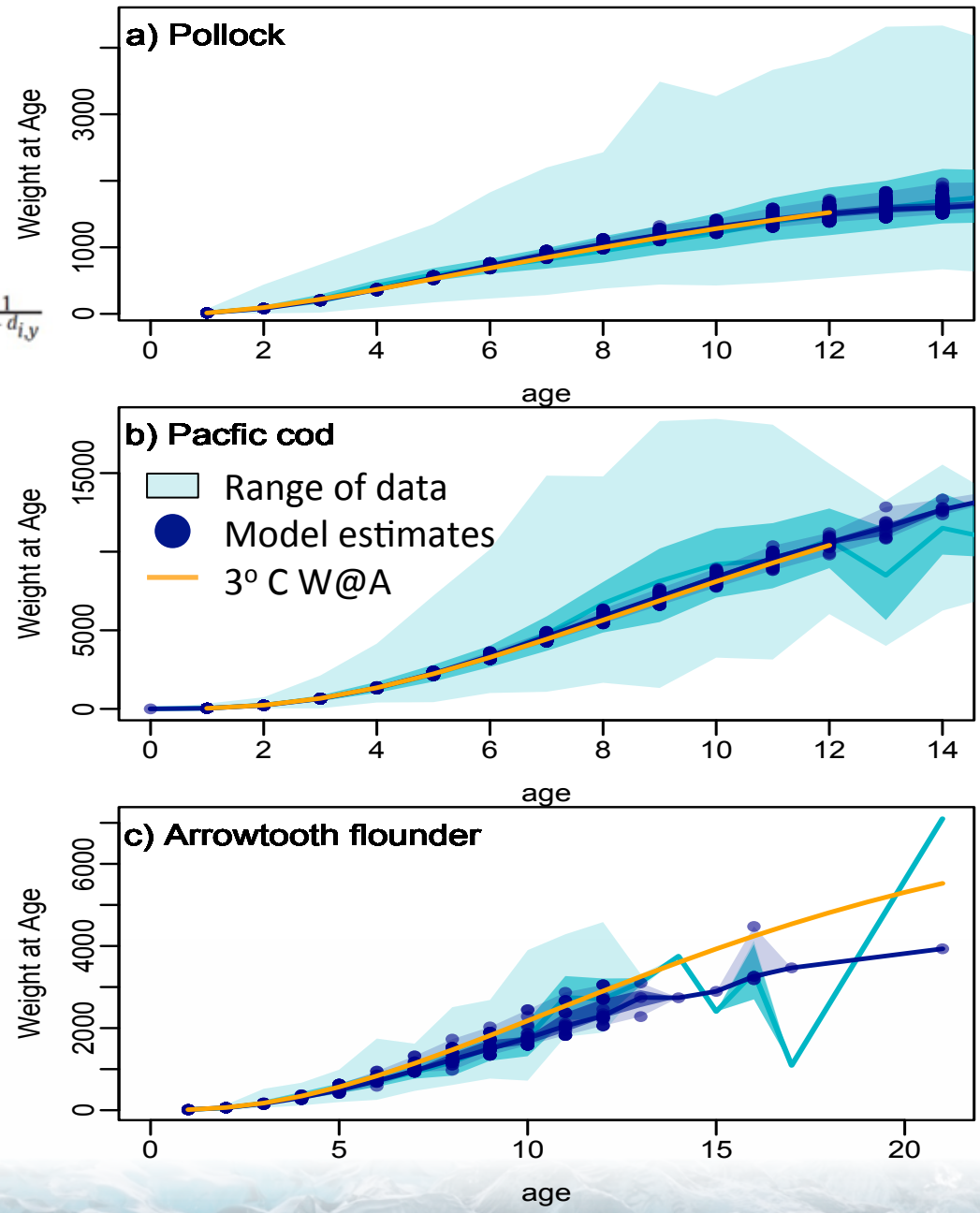
Stabeno et al. (2013) A comparison of the physics of the northern and southern shelves of the eastern Bering Sea and some implications for the ecosystem. Deep-Sea Res II 65-7014-30.

Temperature specific VonB

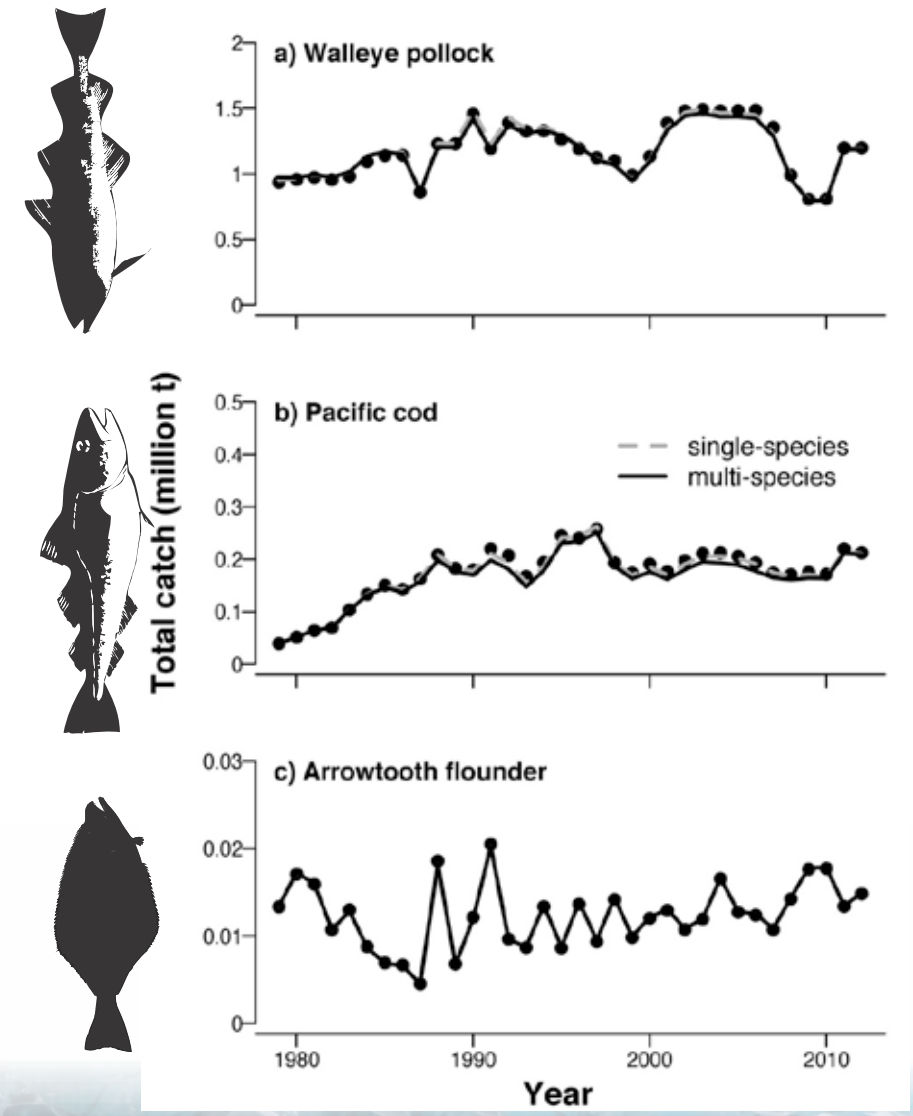
$$W_{ij,y} = W_{\infty,iy}\left(1 - e^{(-K_i(1-d_{i,y})(j-t_{0,i}))}\right)^{\frac{1}{1-d_{i,y}}}$$

$$d_{i,y} = e^{(\alpha_{d,i,y} + \alpha 0_{d,i} + \beta_{d,i} T_y)}$$

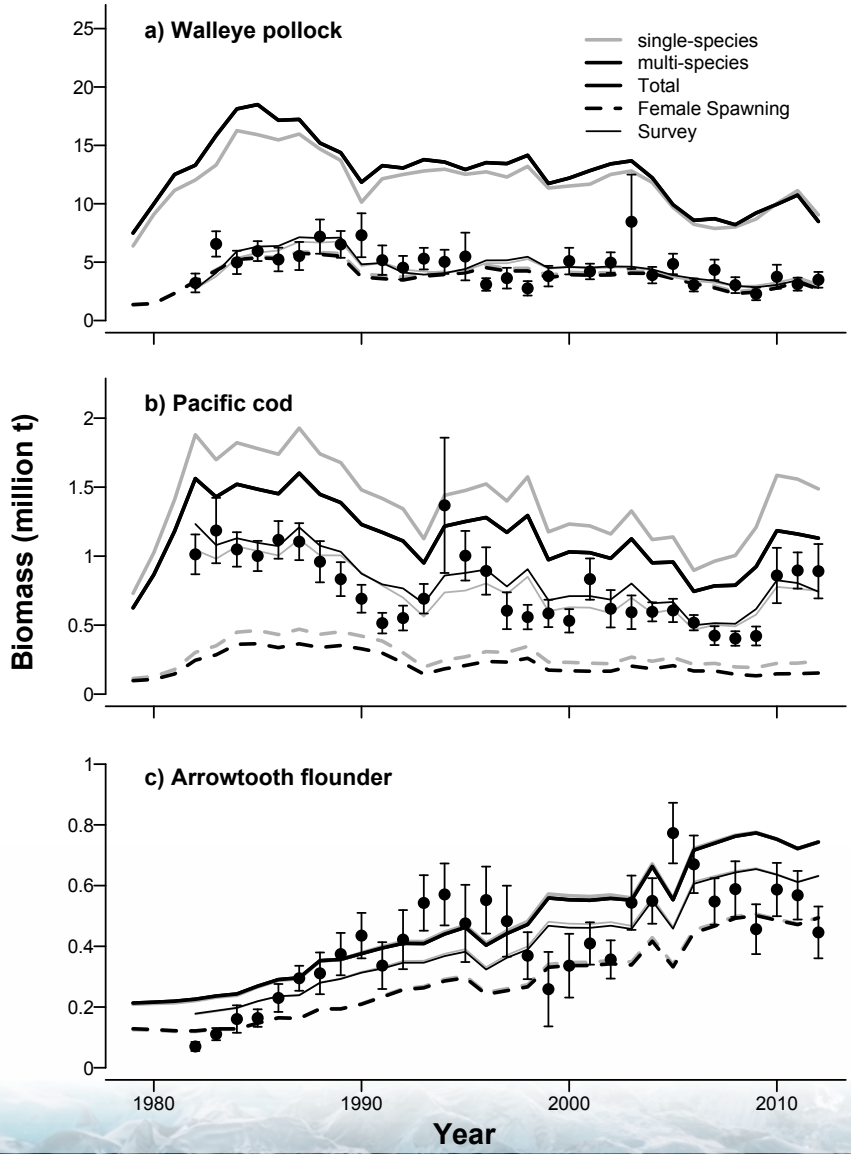
$$W_{\infty,iy} = \left(\frac{H_i}{K_i}\right)^{1/(1-d_{i,y})}$$



Catch

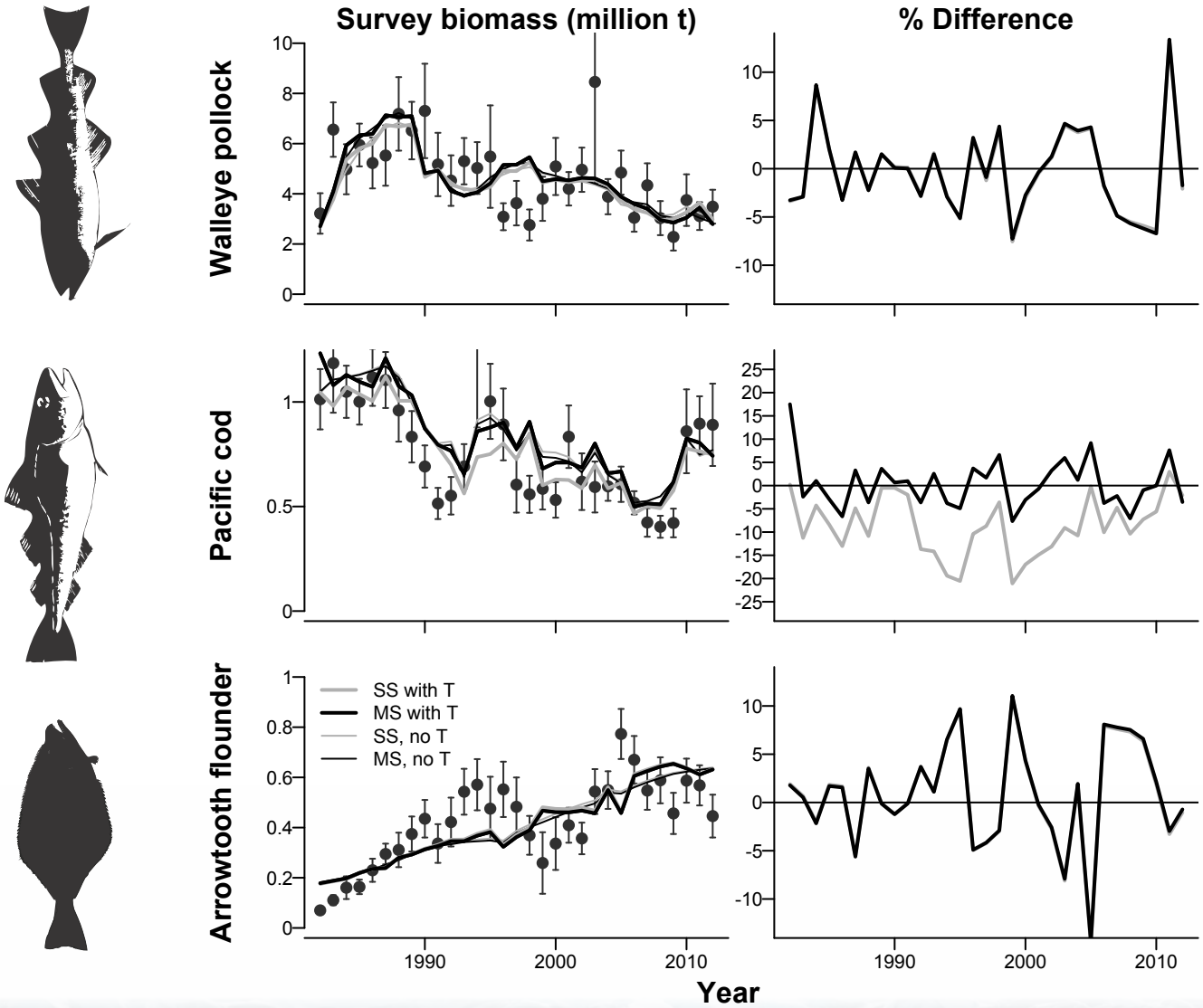


Biomass

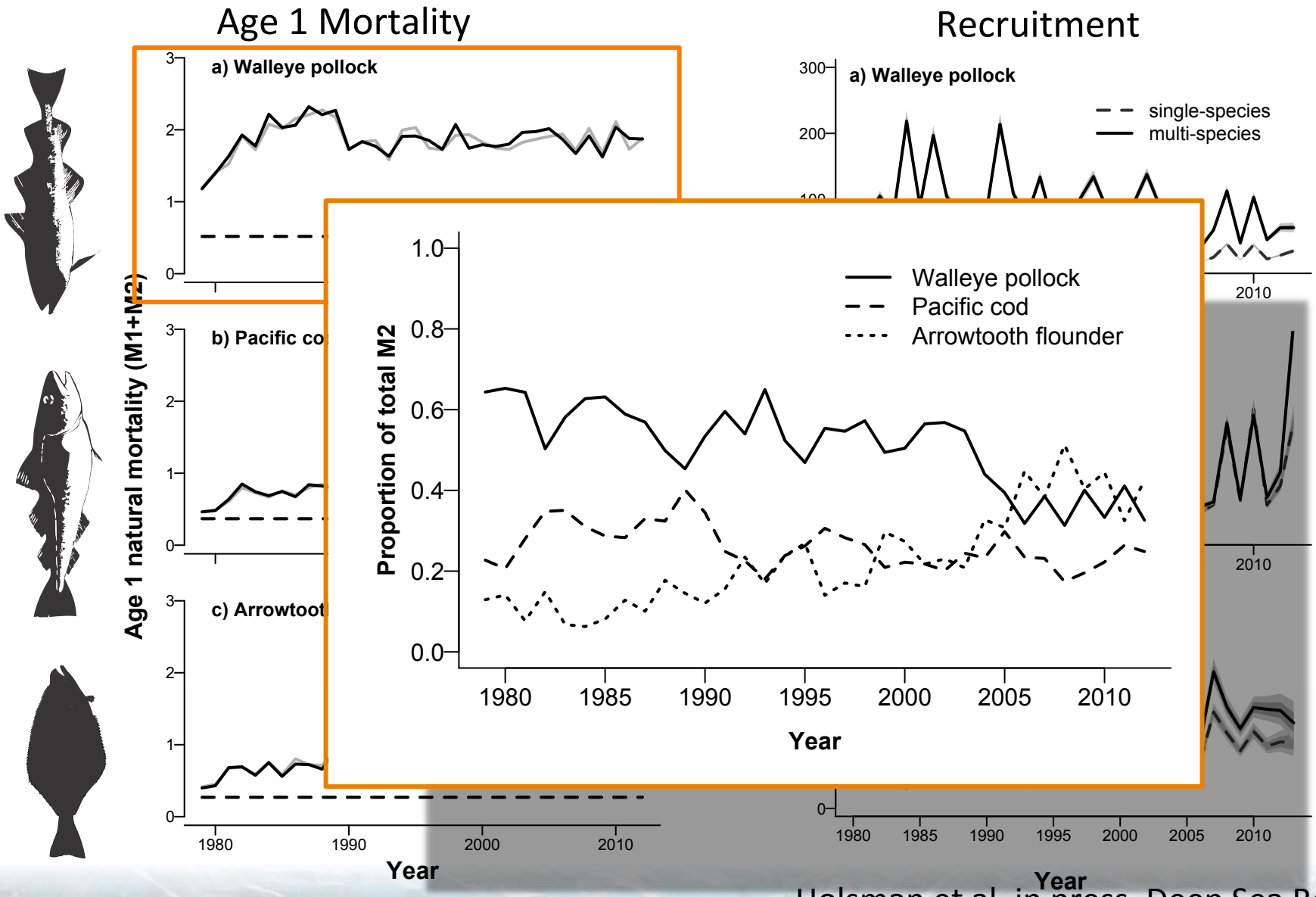


Temperature effects

Models with & without Temperature



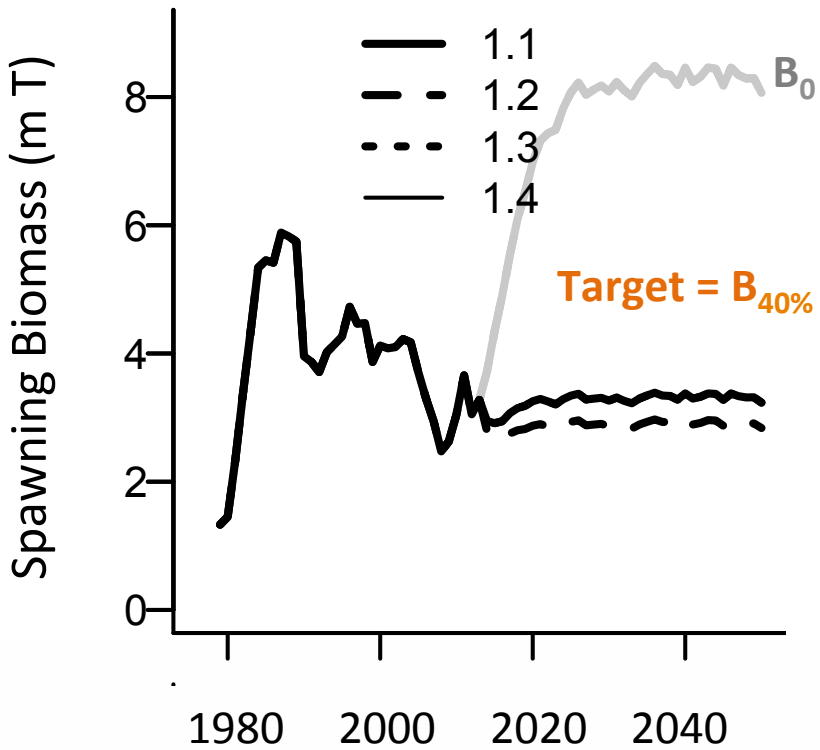
Understand mechanisms of change



Holsman et al. in press. Deep Sea Res II

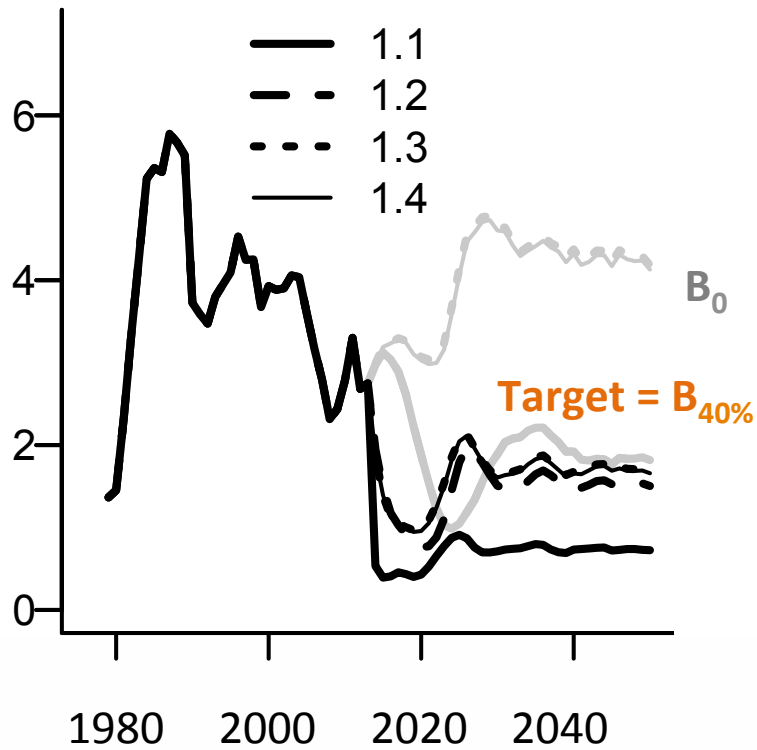
Single-species

Harvest scenario 1

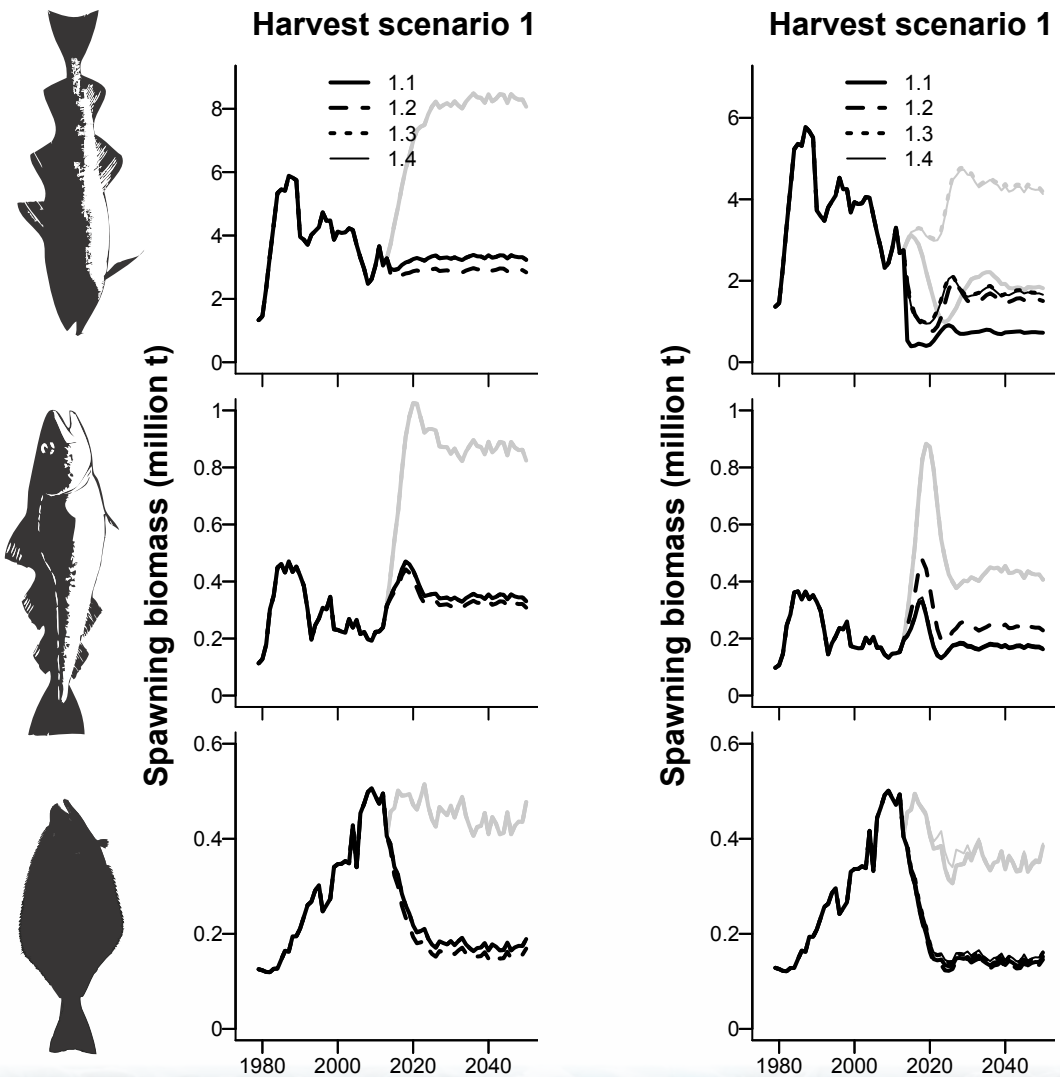


Multi-species

Harvest scenario 1



Single-species Multi-species



Differences between
Harvest Scenarios
Is greatest for prey spp

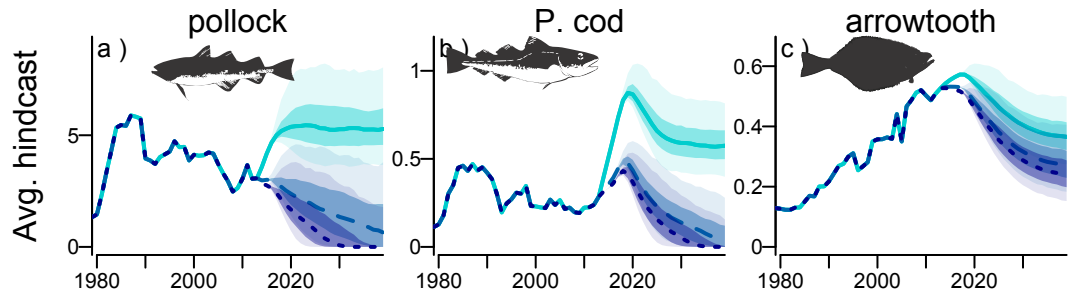
CEATTLE applications:

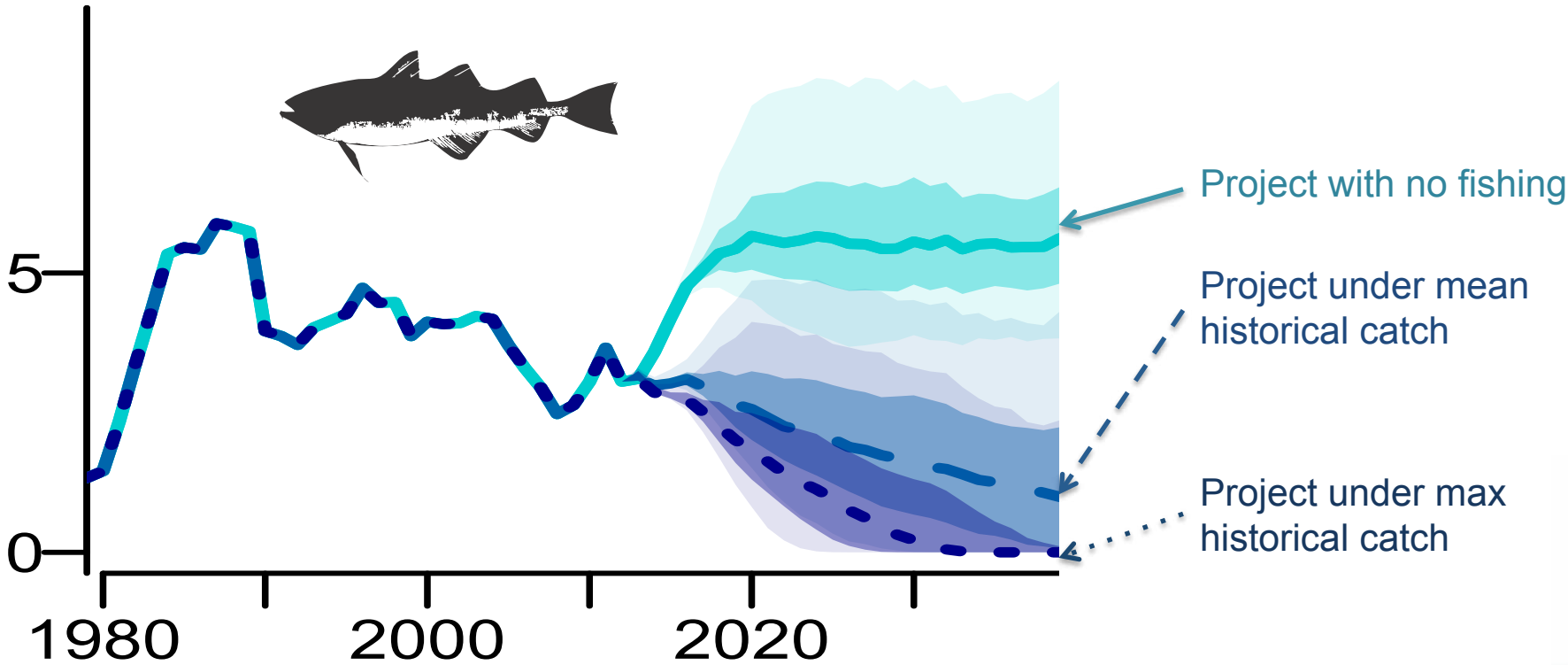
blended forecasts

CEATTLE: Single-species

Mean R

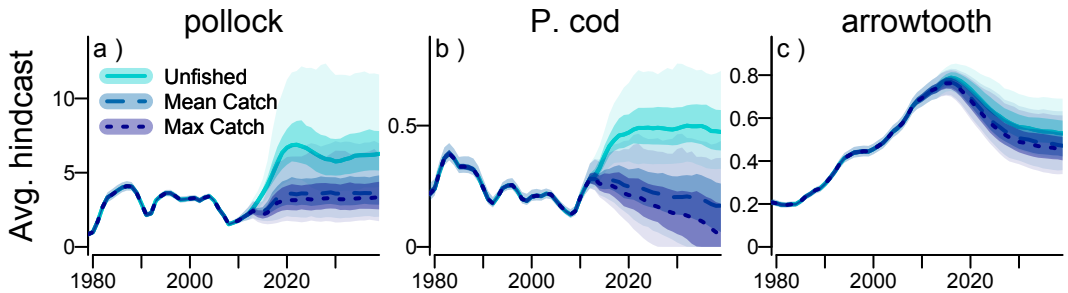
Temp→W@A

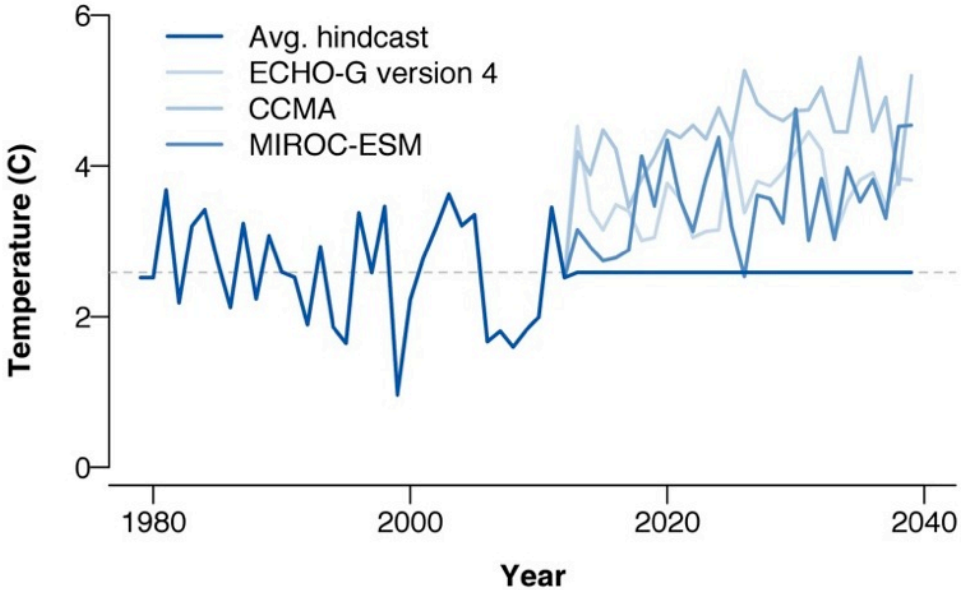




From Ianelli et al. *in press*

Blended results (all three models)





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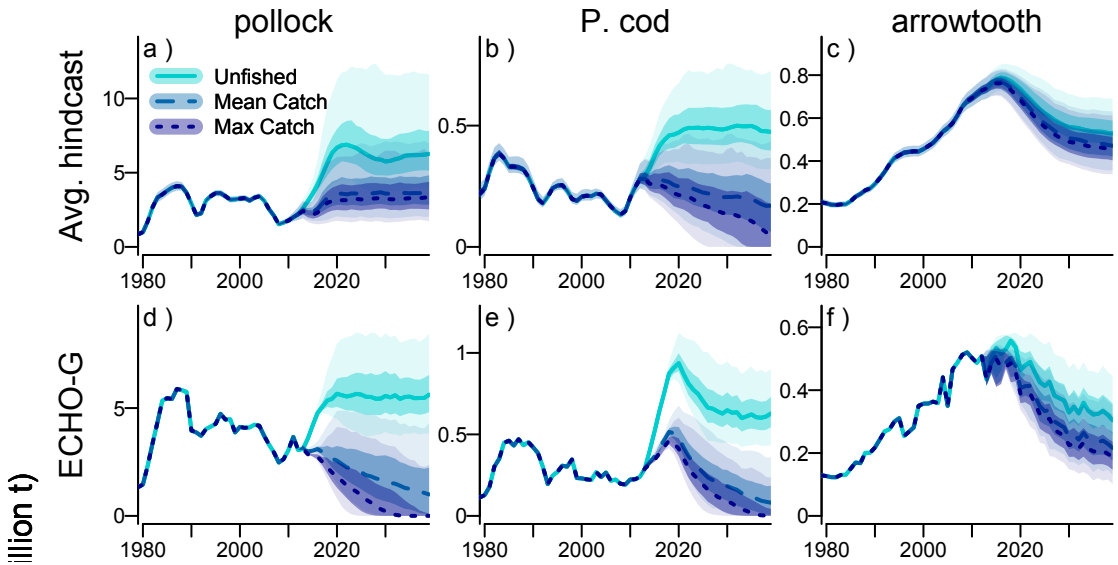

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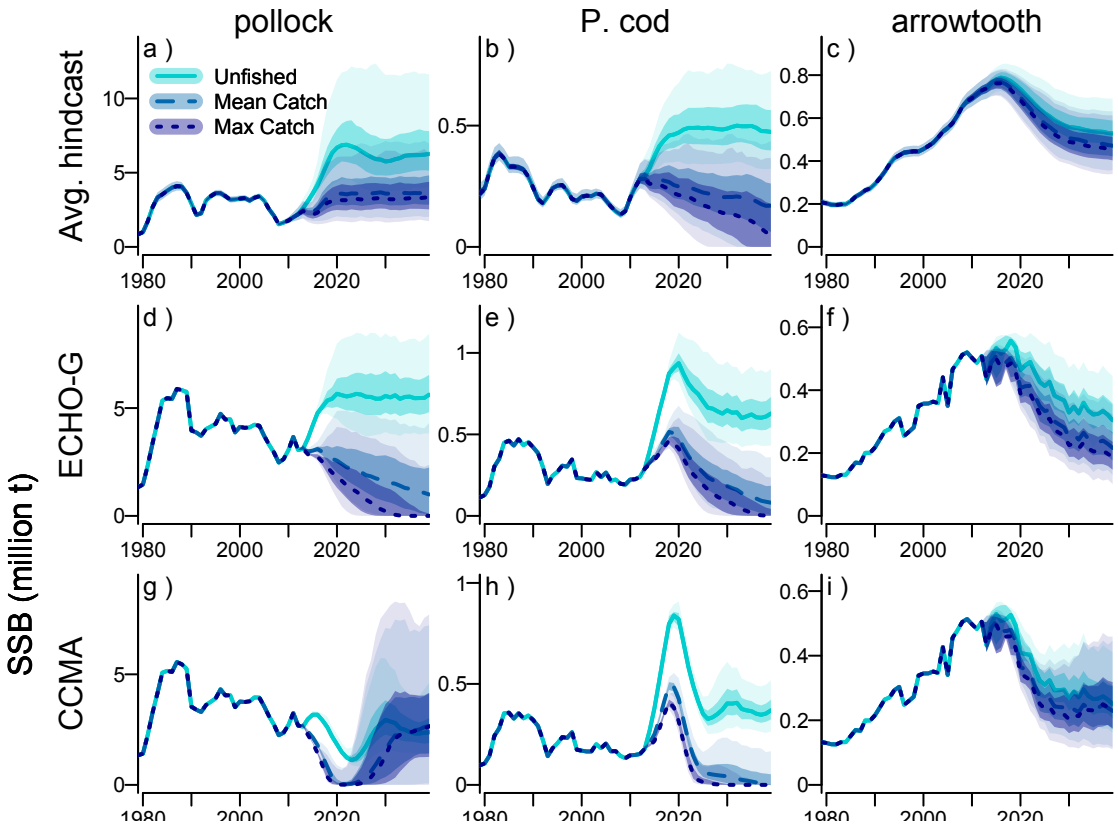

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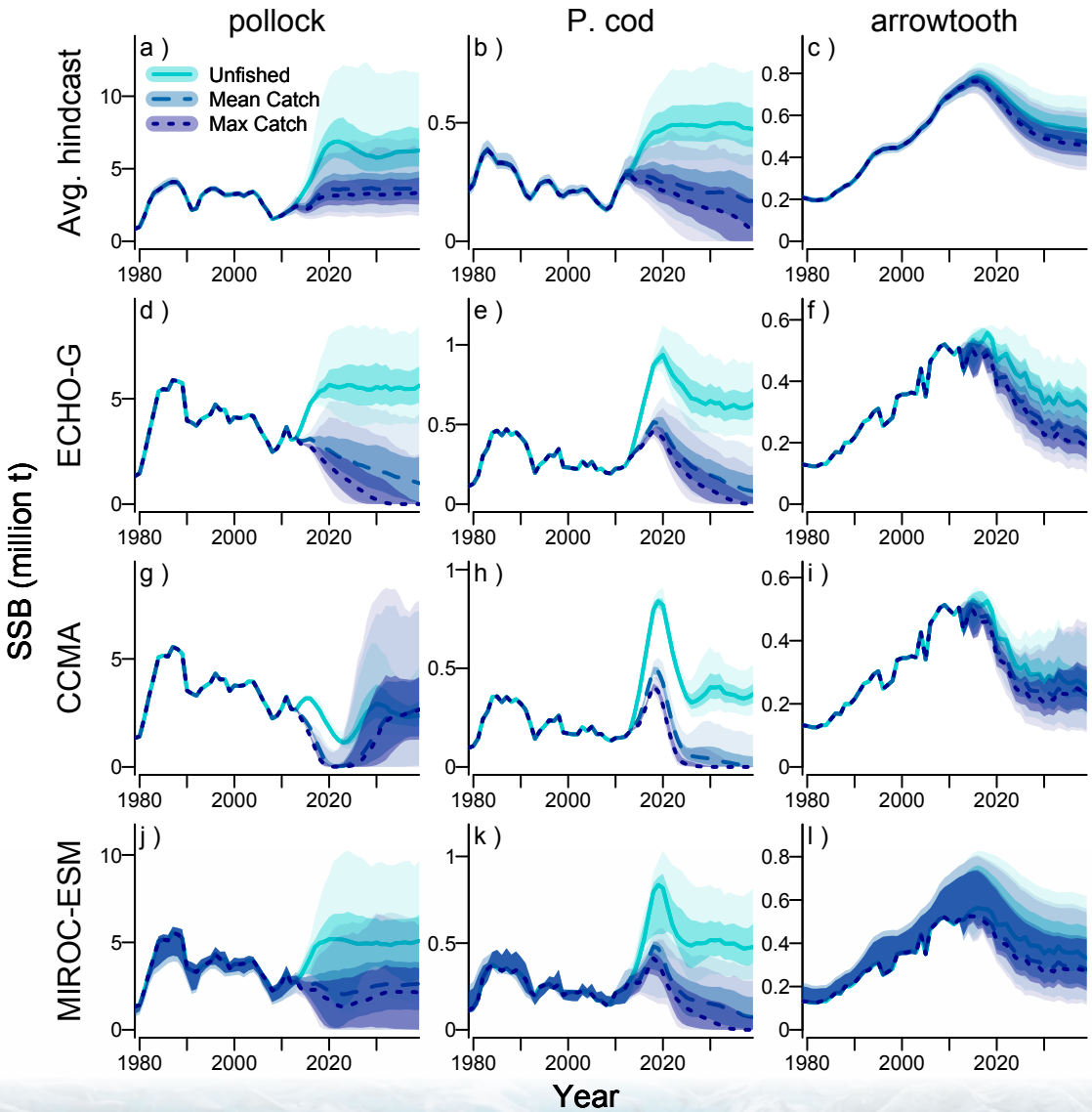


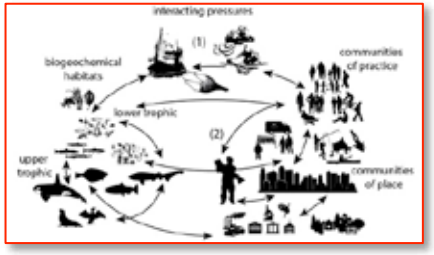
From Ianelli et al. *in press*

CEATTLE applications:

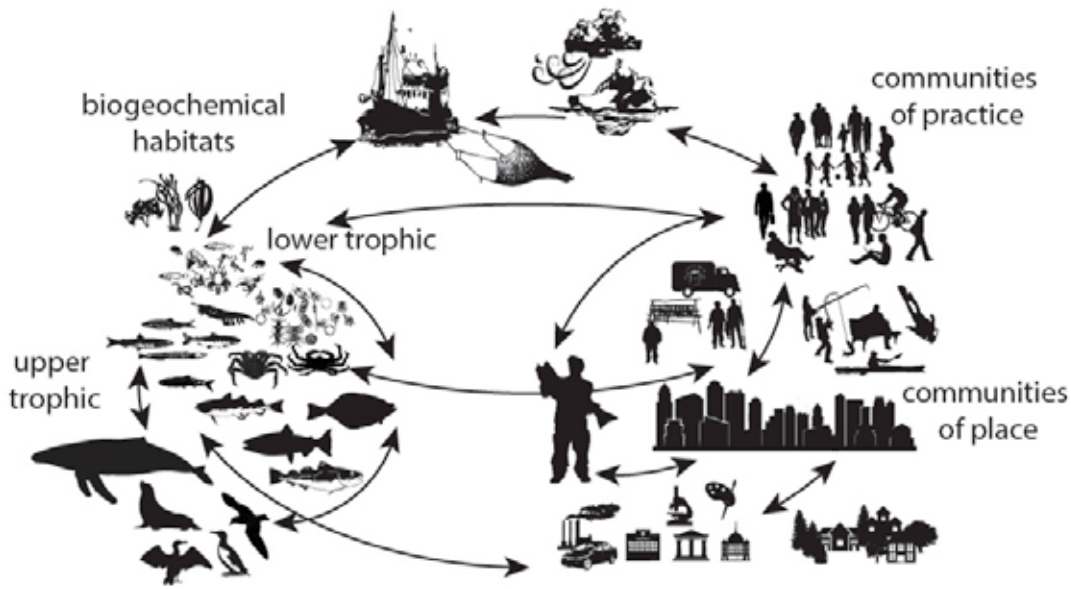
management strategy evaluations

Management Strategy Evaluation

Operating Model
more complex than assessment method

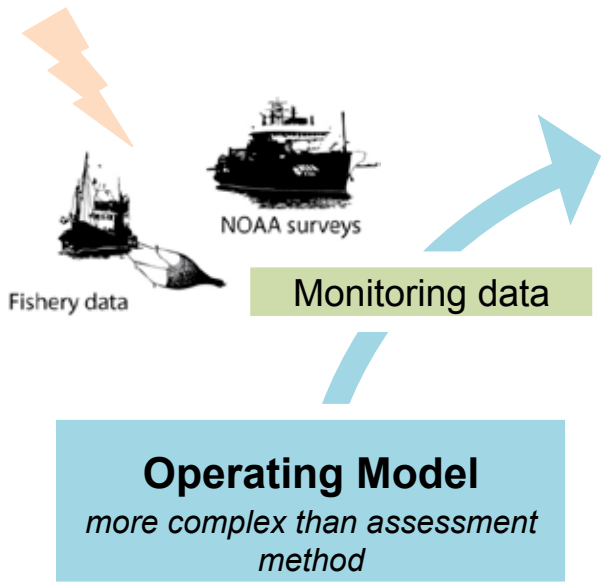


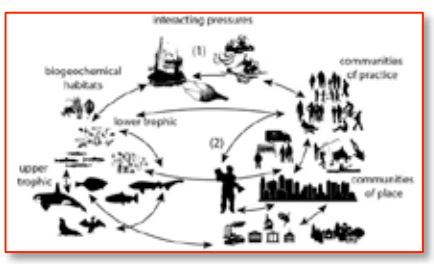
FEAST , CEATTLE, Ecosim
Size-spectrum Model



Management Strategy Evaluation

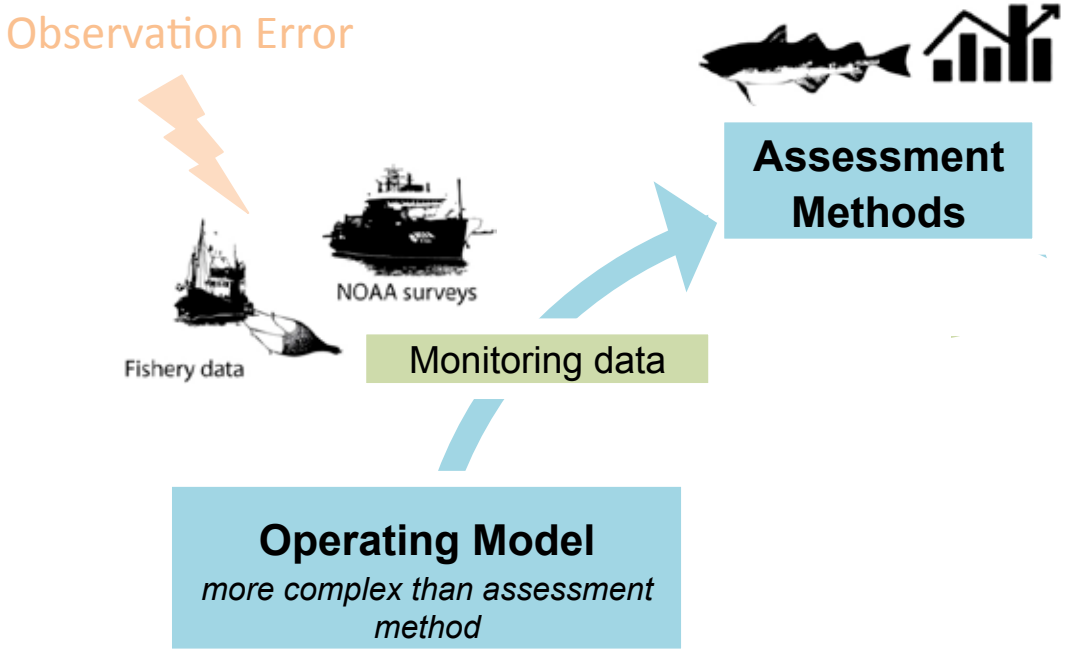
Observation Error

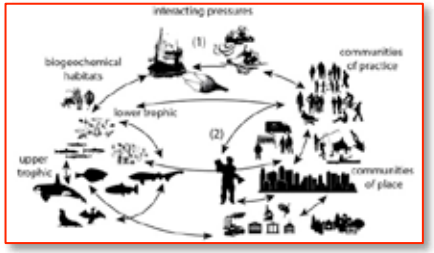




FEAST , CEATTLE, Ecosim
Size-spectrum Model

Management Strategy Evaluation





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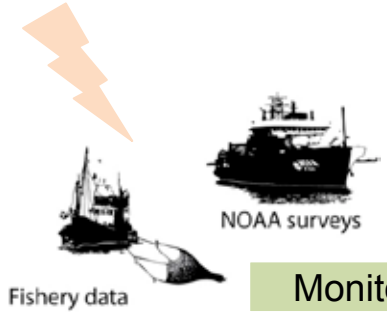
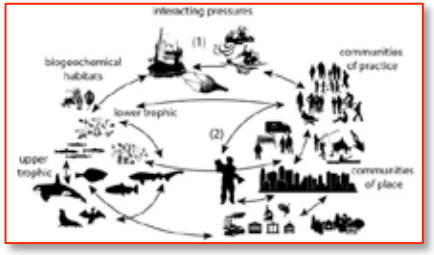


Monitoring data

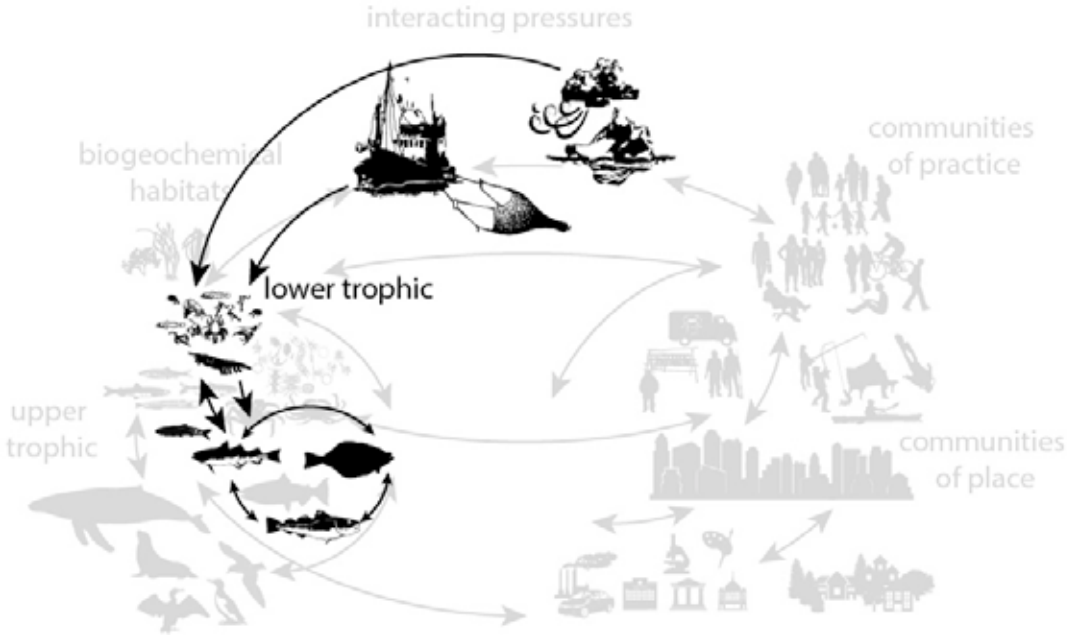
Assessment Methods

CE-SSM
CEATTLE
Ecosim

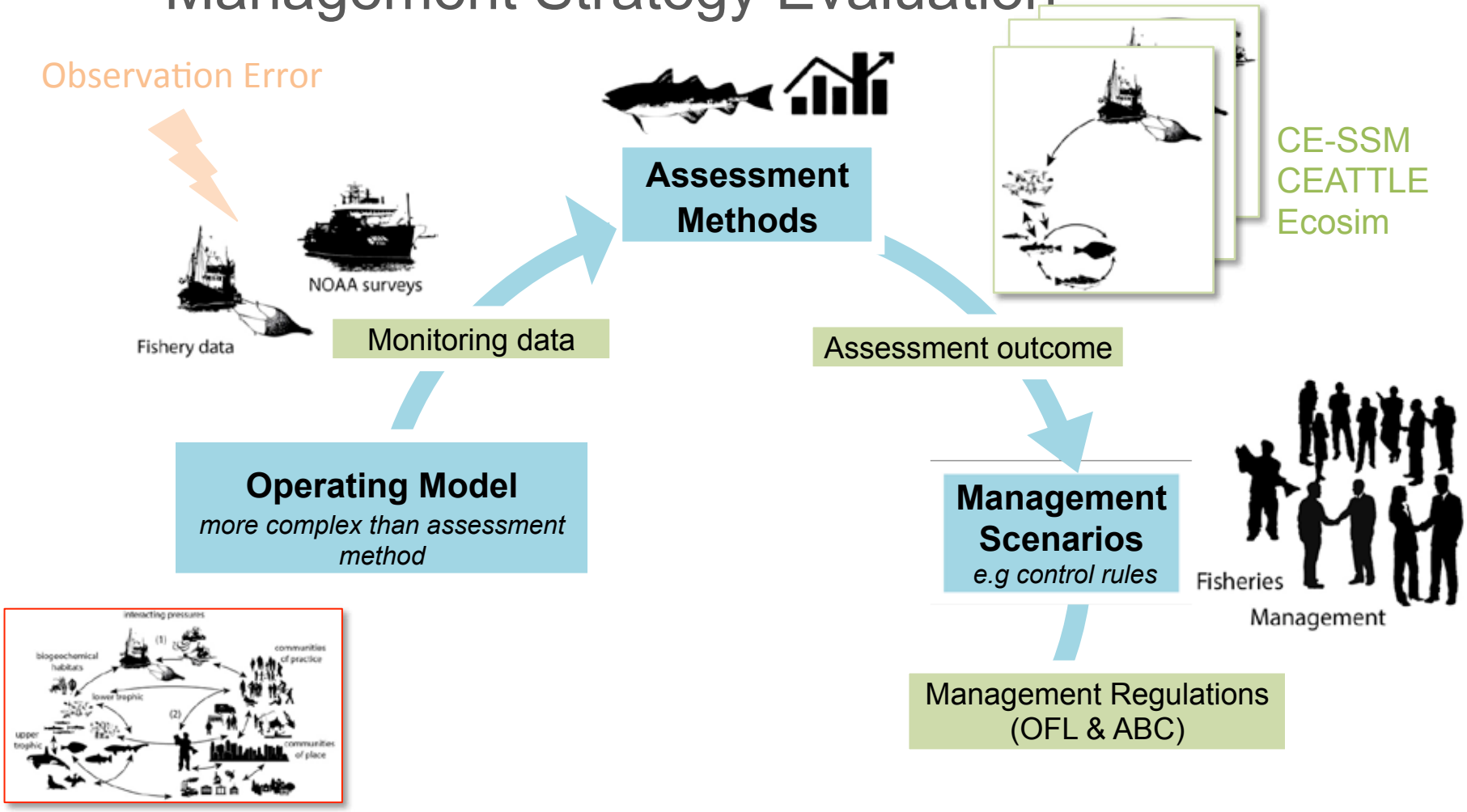
Operating Model
more complex than assessmen method



FEAST , CEATTLE, Ecosim
Size-spectrum Model

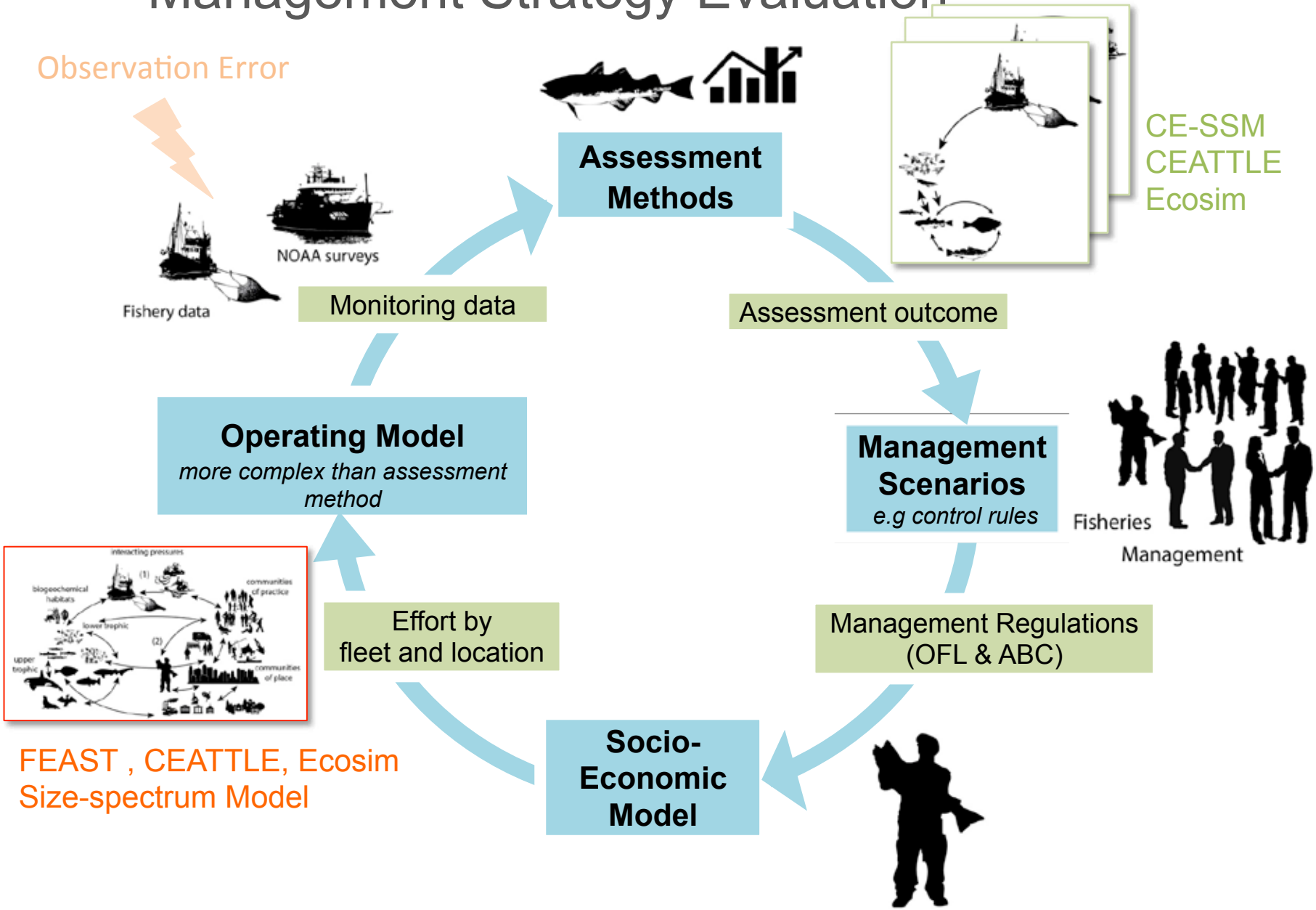


Management Strategy Evaluation

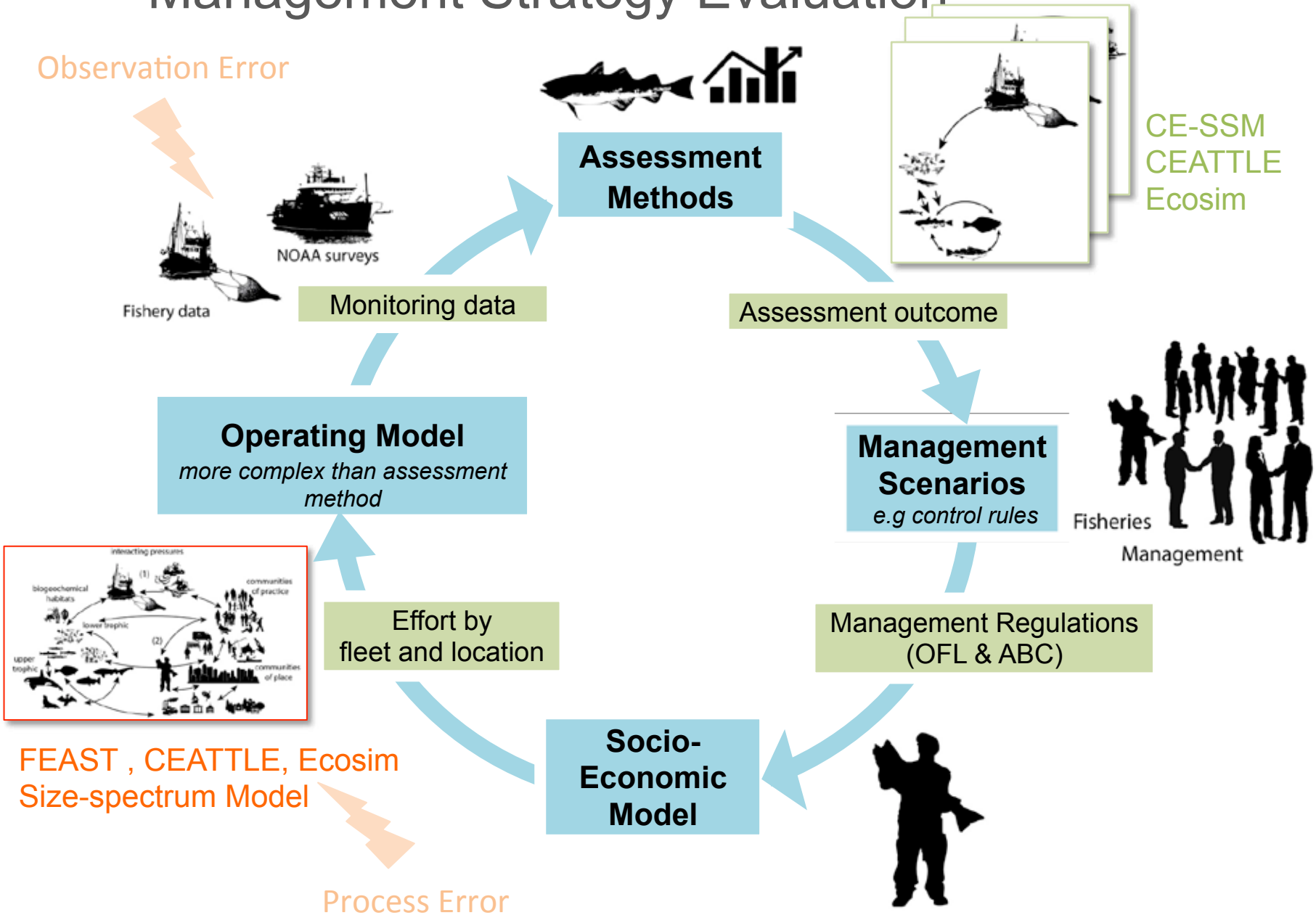


FEAST , CEATTLE, Ecosim
Size-spectrum Model

Management Strategy Evaluation

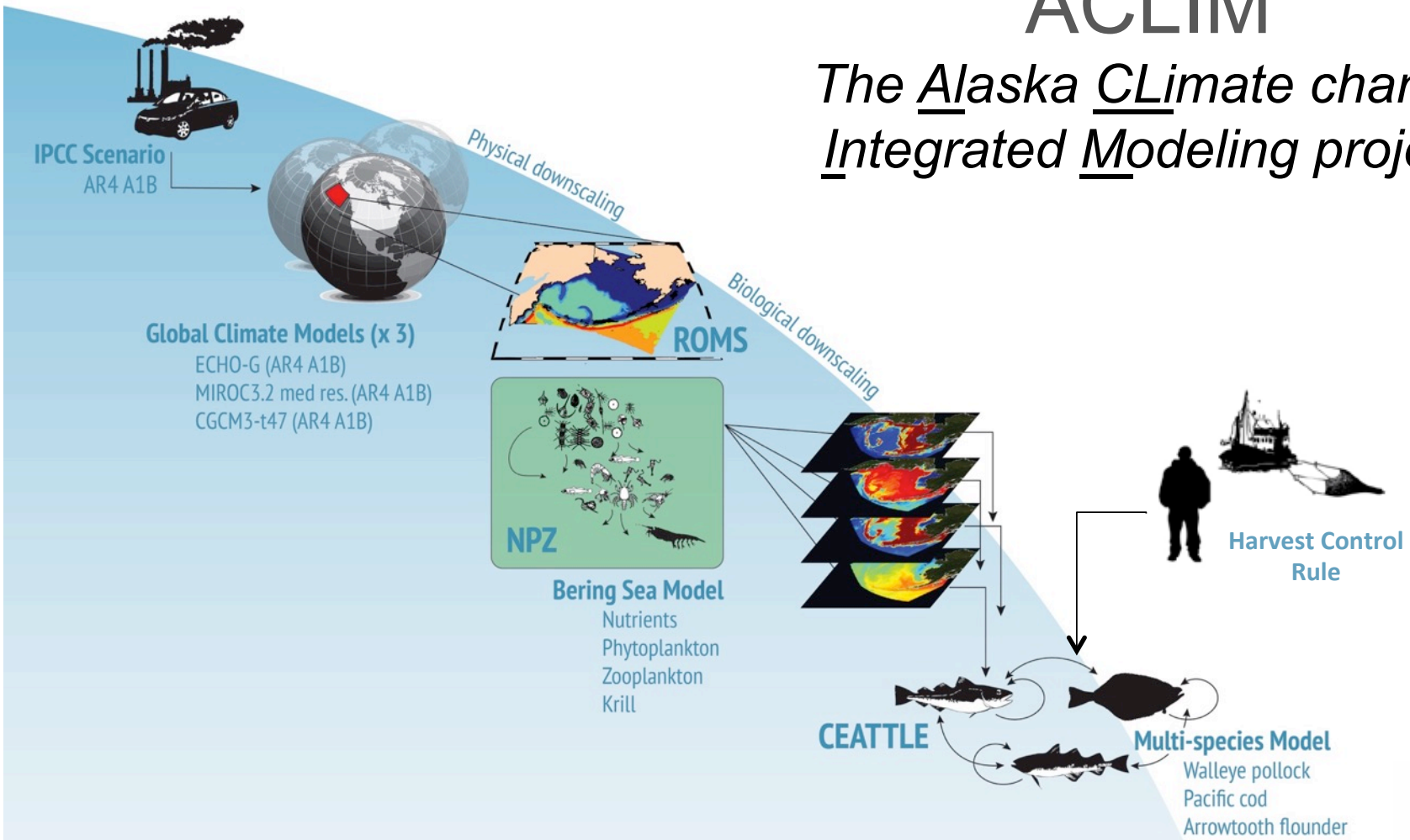


Management Strategy Evaluation



ACLIM

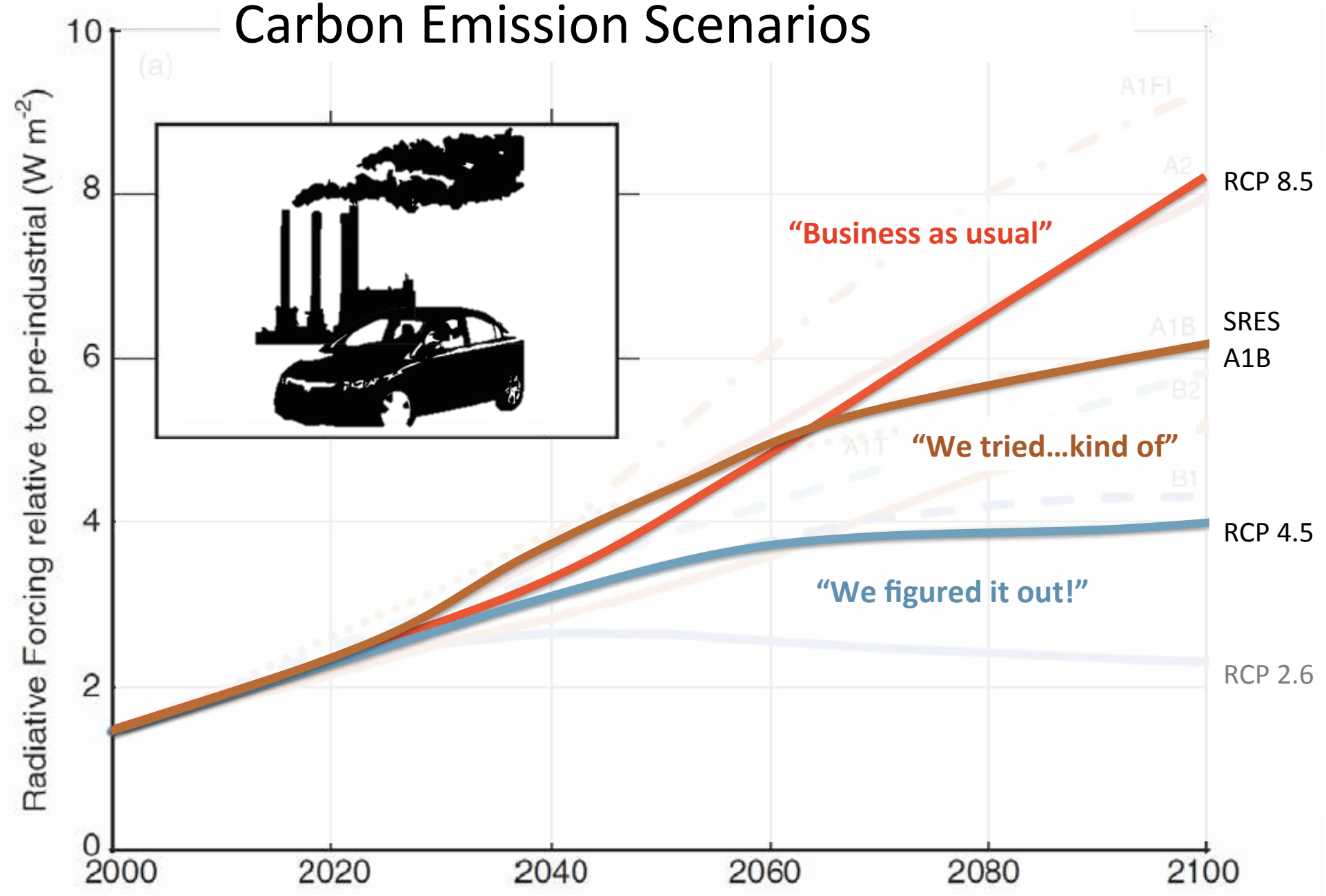
The Alaska CLimate change Integrated Modeling project

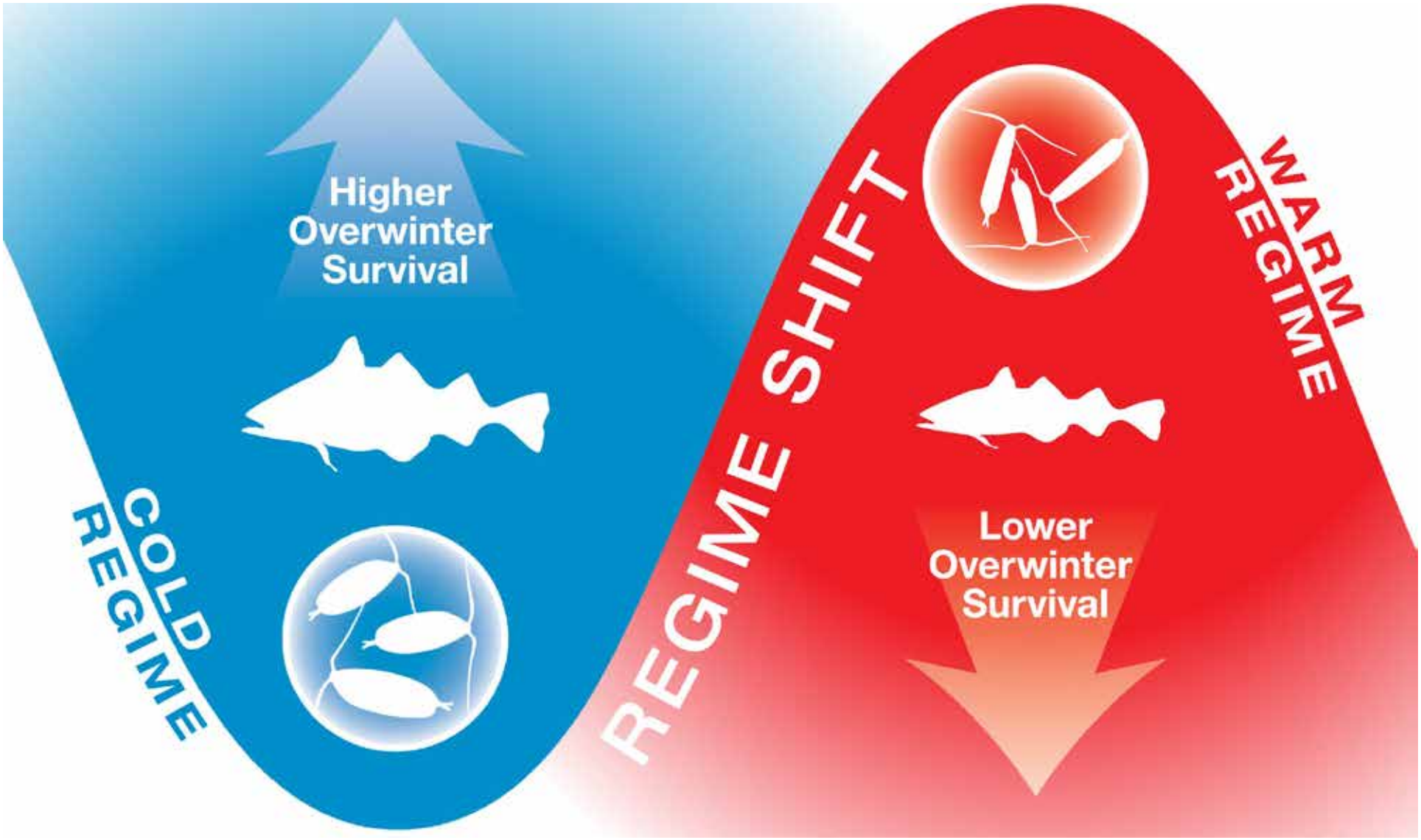


Holsman et al. in prep

Climate-specific Harvest & Population Projections

Carbon Emission Scenarios

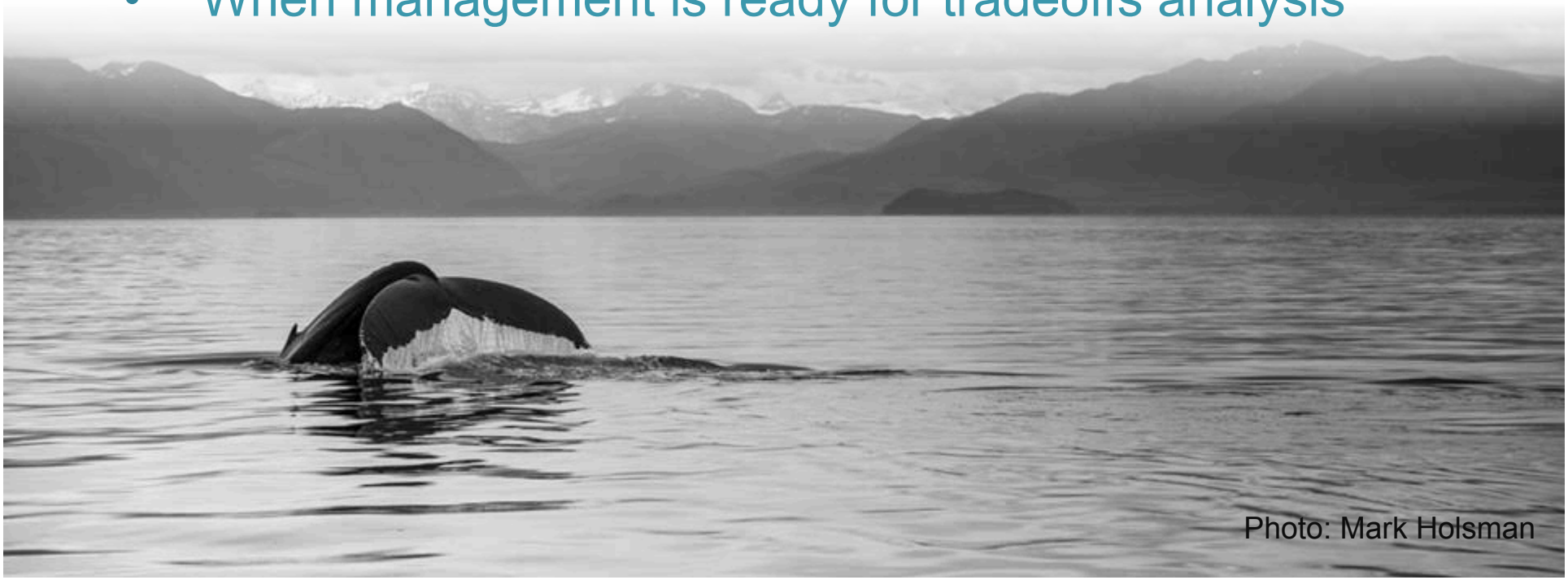




Slide courtesy of J. Duffy-Anderson

When to use multi-species models:

- When there is sufficient data/information
- When expert advice is not enough
- Relationships are non-linear and complex
- Species are fully exploited
- Pressures/impacts are high, efficiency is needed
- Scope for fishery response to management is high
- When management is ready for tradeoffs analysis



Thanks!

NOAA IEA program
FATE 13-07
SAAM 02

"Behind these numbers lies, of course, an infinity of movements and of destinies."

– von Bertalanffy 1938

…and of people!

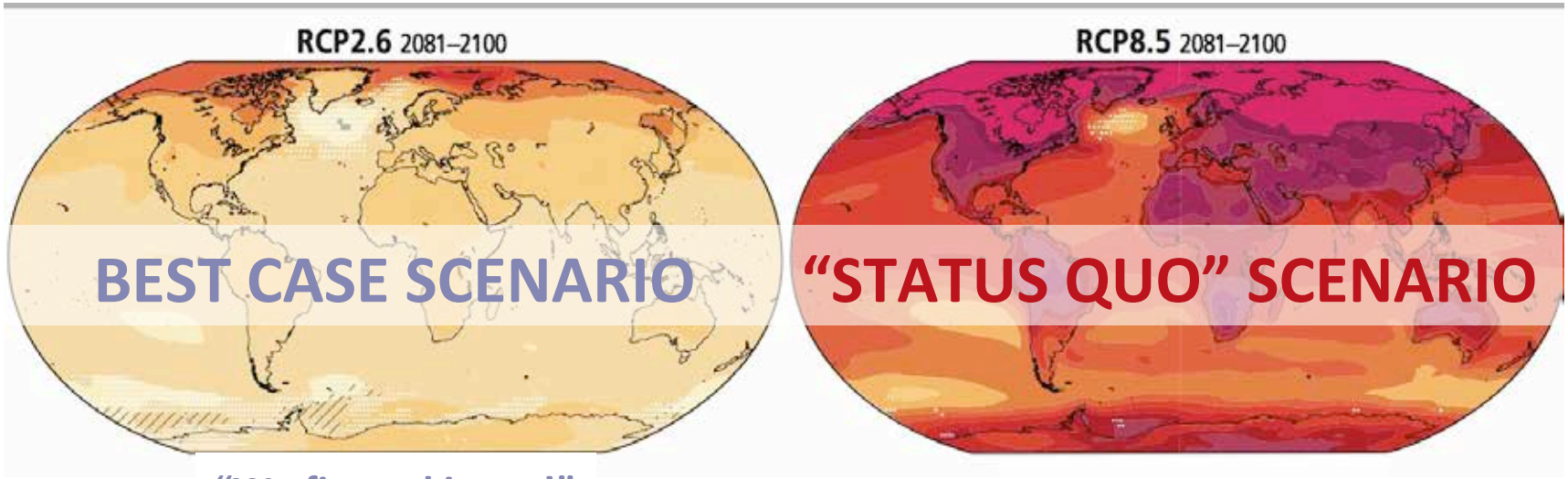
INTEGRATED ECOSYSTEM ASSESSMENT

Mark Holsman (Brother; all photos)

A. Hobday, A. Hollowed, K. Aydin, Isaac Kaplan, Troy Buckley, Matt Baker, Buck Stockhausen, P. Sean McDonald, Stephanie Zador, Paul Spencer, Ingrid Spies

END

Intergovernmental Panel on Climate Change (IPCC)
5th Assessment Report



"We figured it out!"

"Business as usual"

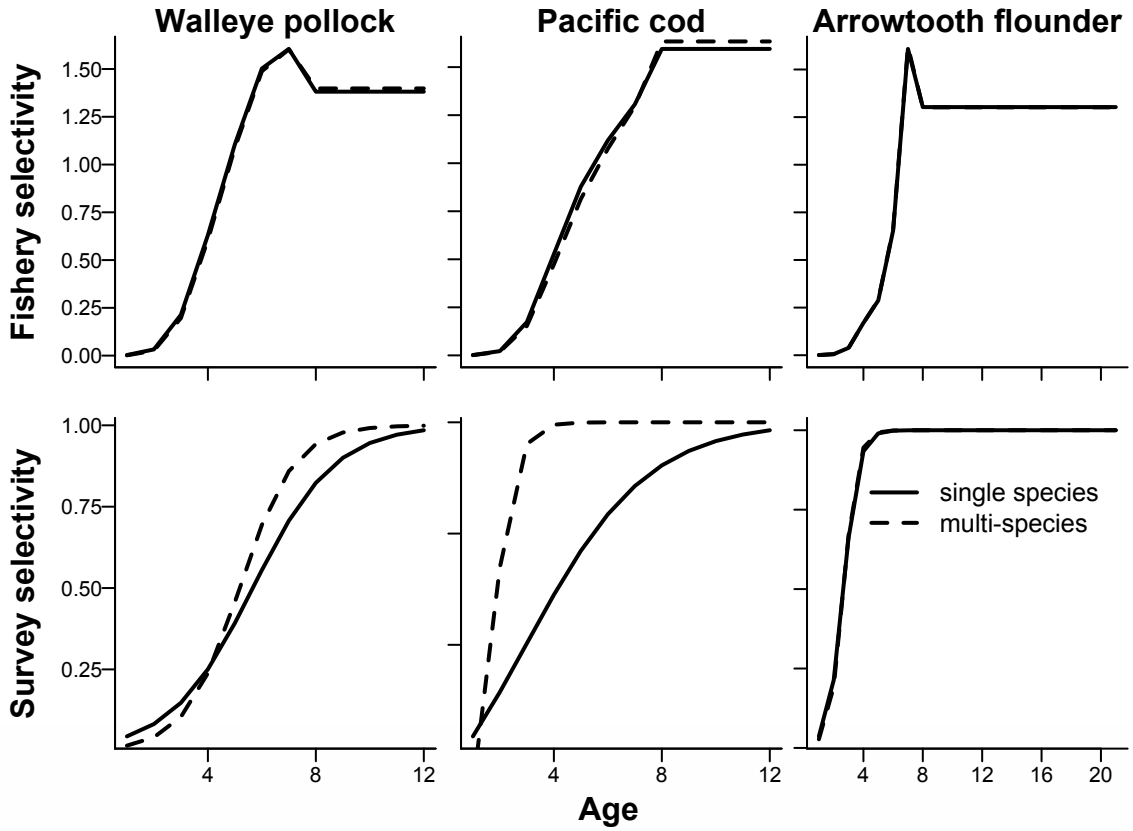
+ 1.8 °C

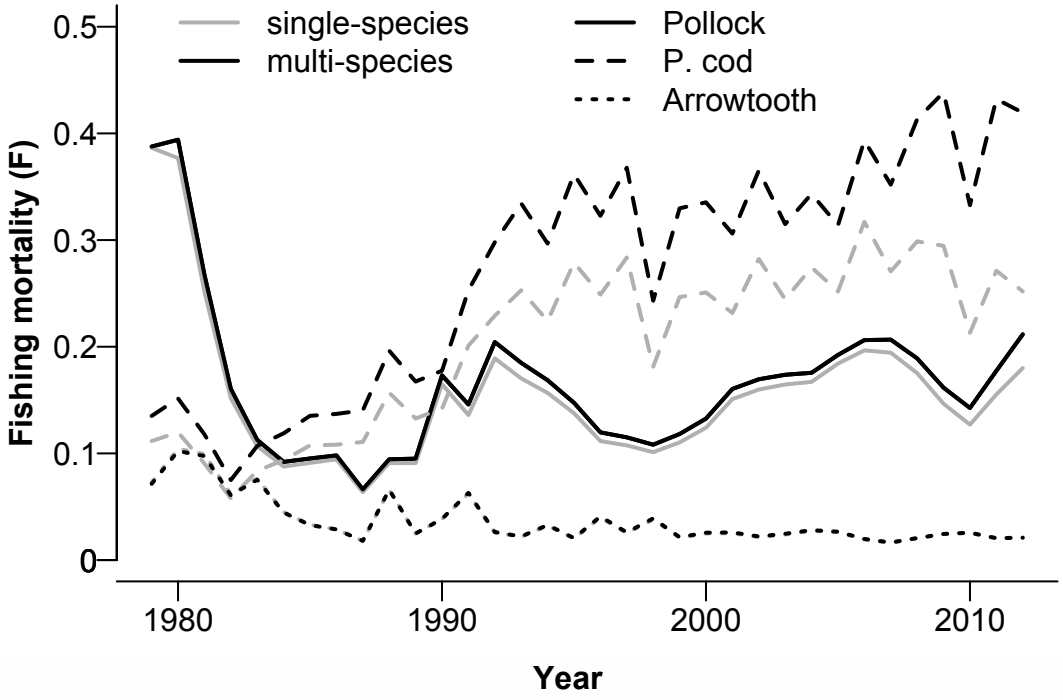
+4 °C

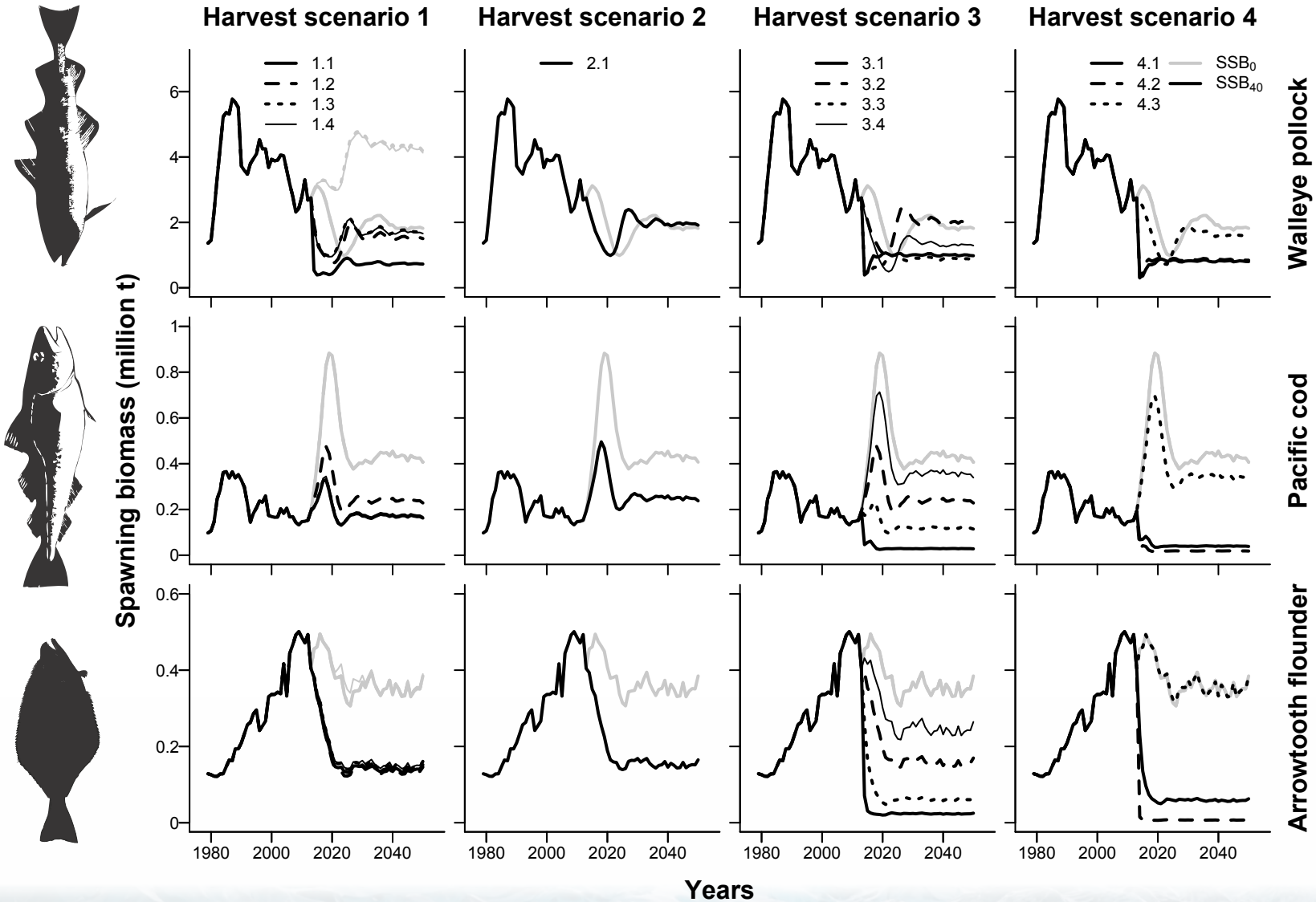
Table 4
Components of the likelihood fusnction for each species i of age j in year y. EBS: Eastern Bering Sea. See Tables 2–4 for parameter definitions.

Description	Equation	Data source	
Data components			
BT survey biomass	$\sum_i \sum_y \frac{\left[\ln\left(\beta^s_{i,y}\right)-\ln\left(\hat{\beta}^s_{i,y}\right)\right]^2}{2\sigma^2_{s,i}}$	NFMS annual EBS BT survey (1979–2012)	T4.1
BT survey age composition	$-\sum_i n_i \sum_y \sum_j \left(O^s_{ij,y}+v\right)\ln\left(\hat{O}^s_{ij,y}+v\right)$	NFMS annual EBS BT survey (1979–2012)	T4.2
EIT survey biomass	$\sum_y \frac{\left[\ln\left(\beta^{eit}_y\right)-\ln\left(\hat{\beta}^{eit}_y\right)\right]^2}{2\sigma^2_{eit}}$, $\sigma_{eit}=0.2$	Pollock acoustic trawl survey (1979–2012)	T4.3
EIT age composition	$-n\sum_y \sum_j \left(O^{eit}_{1j,y}+v\right)\ln\left(\hat{O}^{eit}_{1j,y}+v\right)$	Pollock acoustic trawl survey (1979–2012)	T.4.4
Total catch	$\sum_i \sum_y \frac{\left[\ln\left(C^*_{i,y}\right)-\ln\left(\hat{C}^*_{i,y}\right)\right]^2}{2\sigma^2_C}$, $\sigma_C=0.05$	Fishery observer data (1979–2012)	T.4.5
Fishery age composition	$-\sum_i n_i \sum_y \sum_j \left(O^f_{ij,y}+v\right)\ln\left(\hat{O}^f_{ij,y}+v\right)$	Fishery observer data (1979–2012)	T4.6
Penalties			
Fishery selectivity	$\sum_i \sum_j^{A_i-1} \chi \cdot \left[\ln\left(\frac{\eta^f_{ij}}{\eta^f_{ij+1}}\right)-\ln\left(\frac{\eta^f_{ij+1}}{\eta^f_{ij+2}}\right)\right]^2$, $\chi=\begin{cases} 20, & if \quad \eta^f_{ij}>\eta^f_{ji+1} \\ 0, & if \quad \eta^f_{ij}\le\eta^f_{ij+1} \end{cases}$		T4.7
Priors			
	$\sum_i \sum_y (\tau_{i,y})^2$		T4.8
	$\sum_i \sum_y (N_{0,ij})^2$		T4.9
	$\sum_i \sum_y (\varepsilon_{i,y})^2$		T4.10

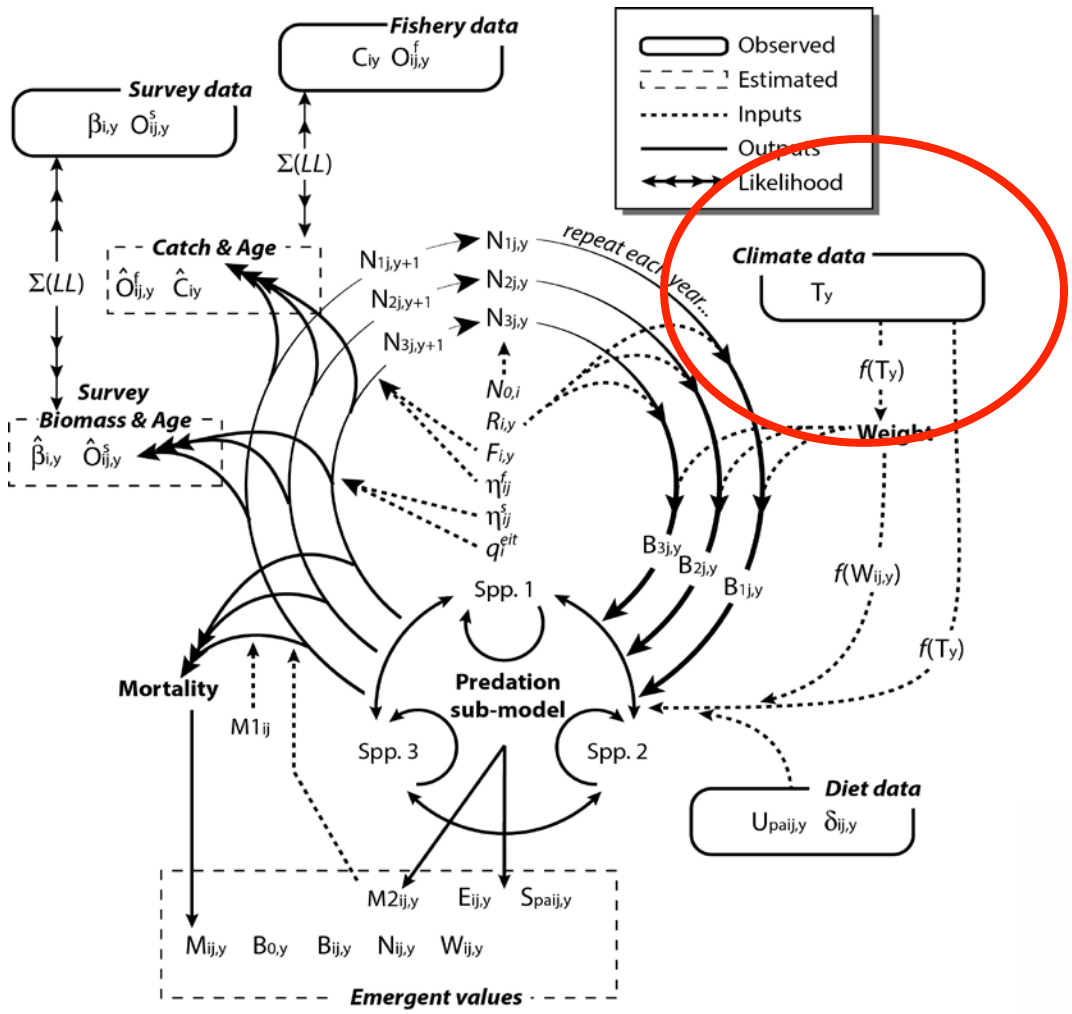
$v=0.001$.


Walleye pollock
Pacific cod
Arrowtooth flounder
Fishery selectivity
1.50
1.25
1.00
0.75
0.50
0.25
0.00
Survey selectivity
1.00
0.75
0.50
0.25
4
8
12
16
20
Age
single species
multi-species


single-species
multi-species
Pollock
P. cod
Arrowtooth
Fishing mortality (F)
0.5
0.4
0.3
0.2
0.1
0
1980
1990
2000
2010
Year

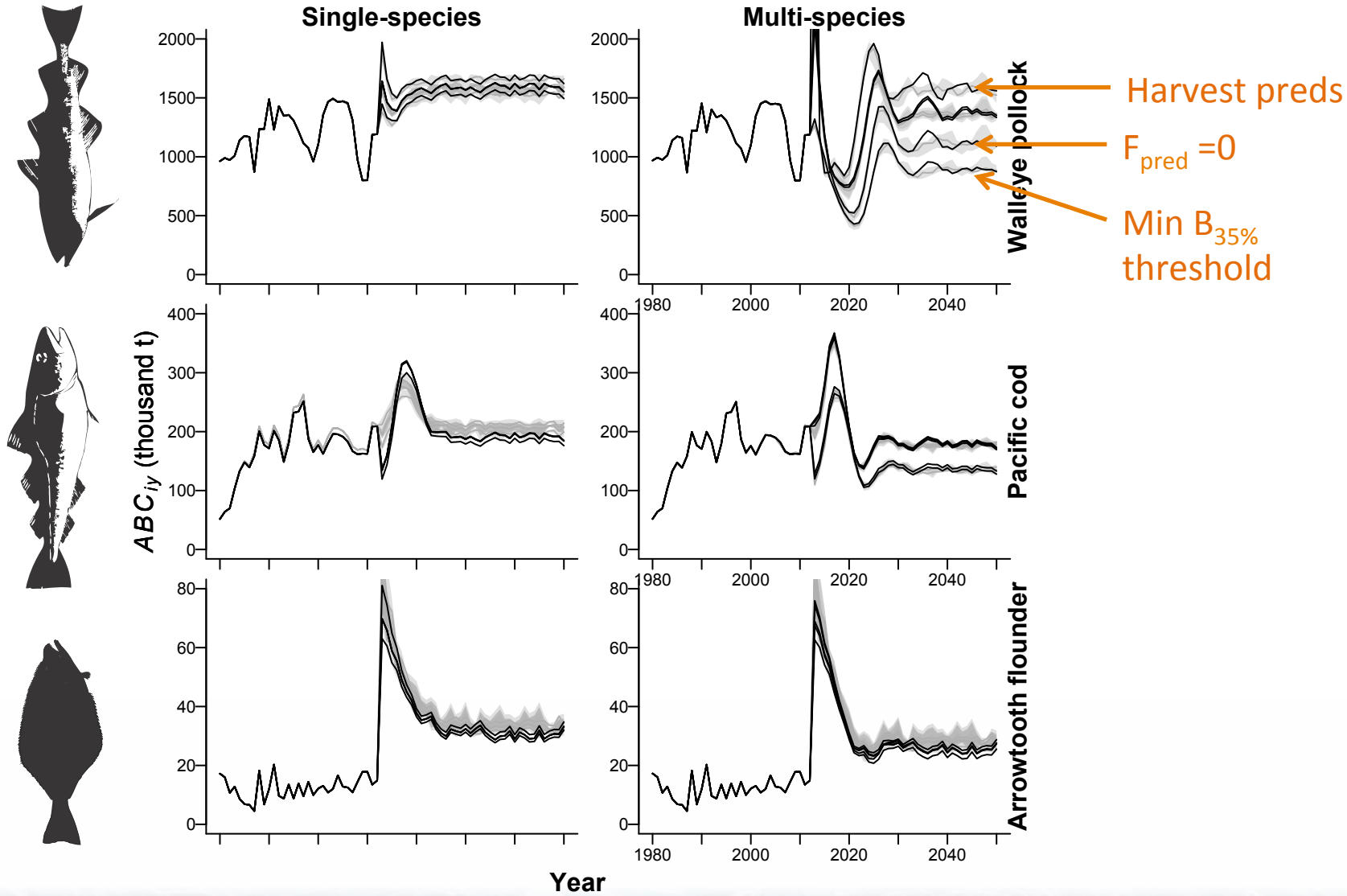

Harvest scenario 1
Harvest scenario 2
Harvest scenario 3
Harvest scenario 4
1.1
1.2
1.3
1.4
2.1
3.1
3.2
3.3
3.4
4.1
4.2
4.3
SSB0
SSB40
Walleye pollock
Pacific cod
Arrowtooth flounder
Spawning biomass (million t)
Years
1980
2000
2020
2040

Weight at Age



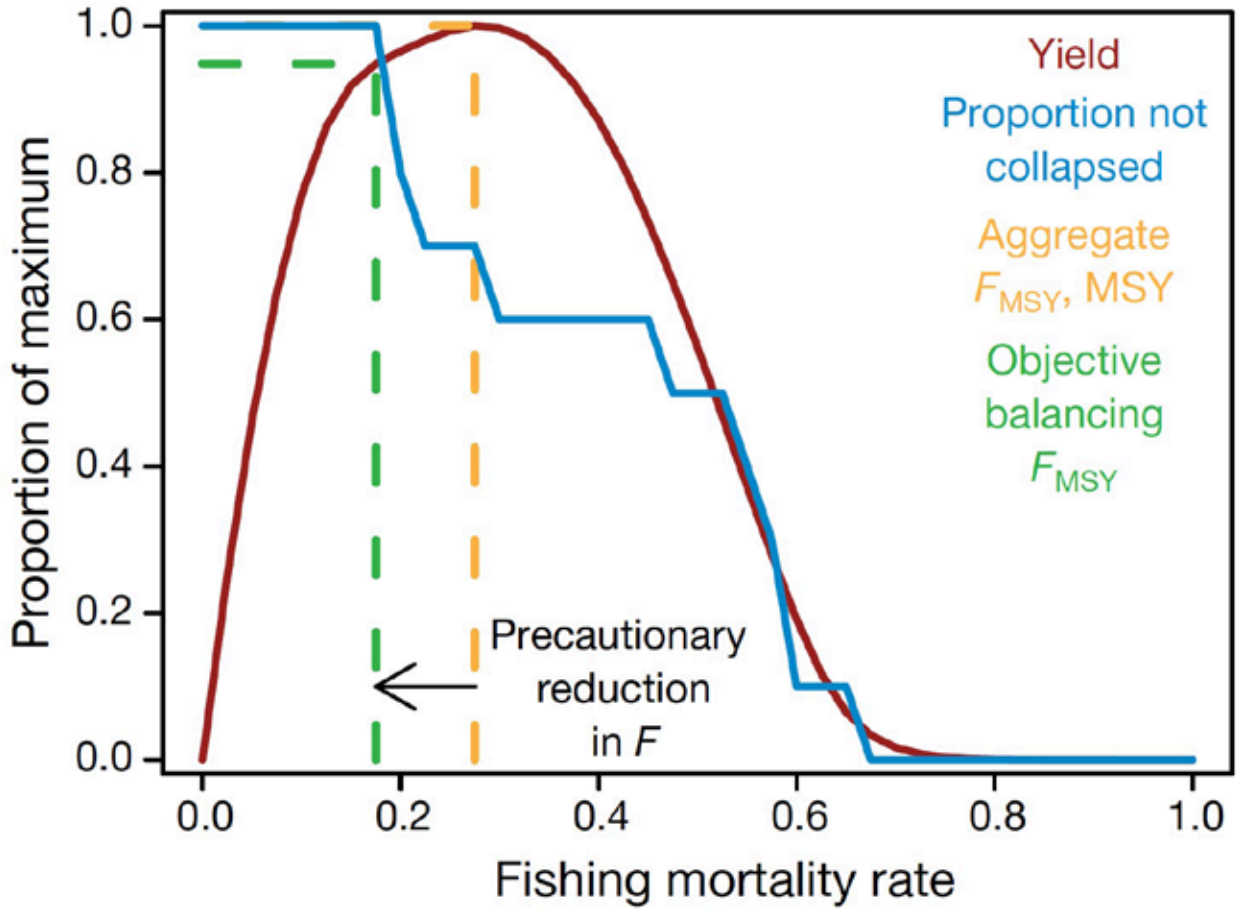
Evaluate projection sensitivity

Temp effect << F effect



Holsman et al. in press. Deep Sea Res II

Balance multiple objectives

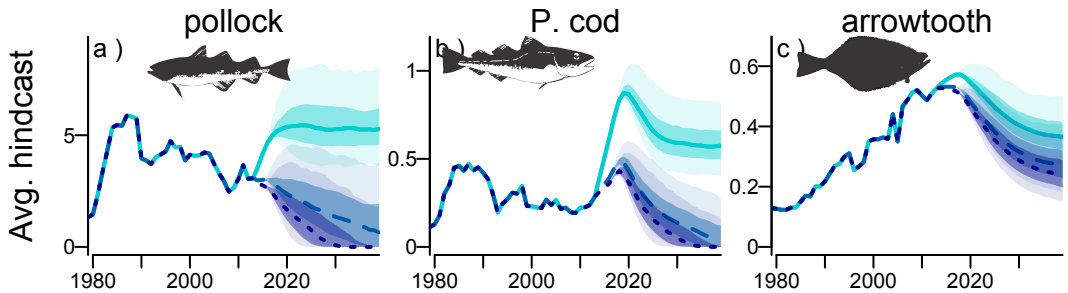


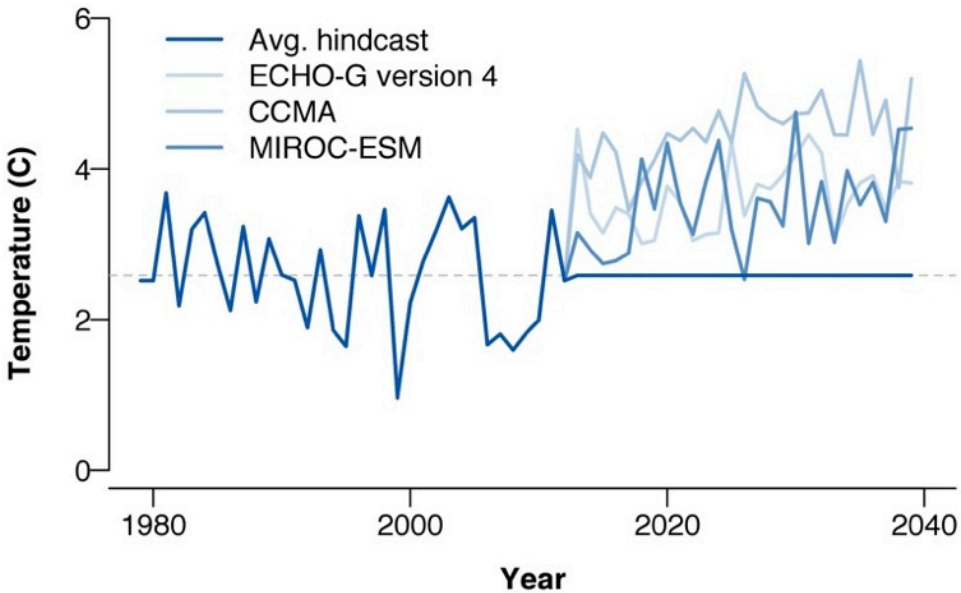
Gaichas et al. 2012. Mar Ecol Prog Ser 459: 275–292

CEATTLE: Single-species

Mean R

Temp→W@A



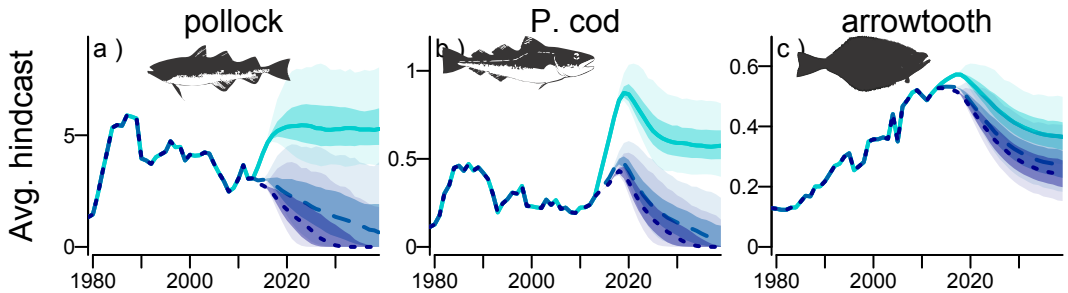


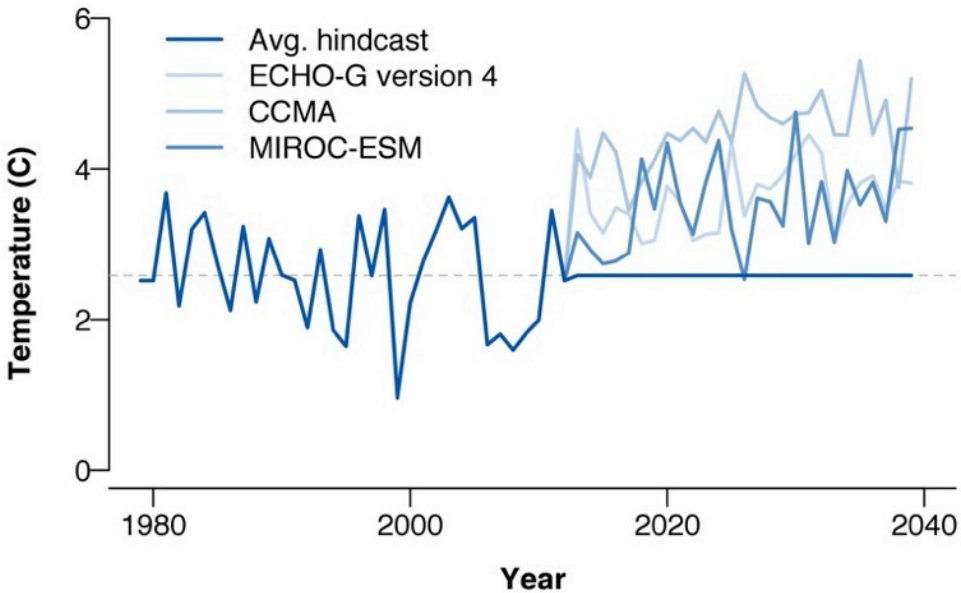
From Ianelli et al. *in press*

CEATTLE: Single-species

Mean R

Temp→W@A



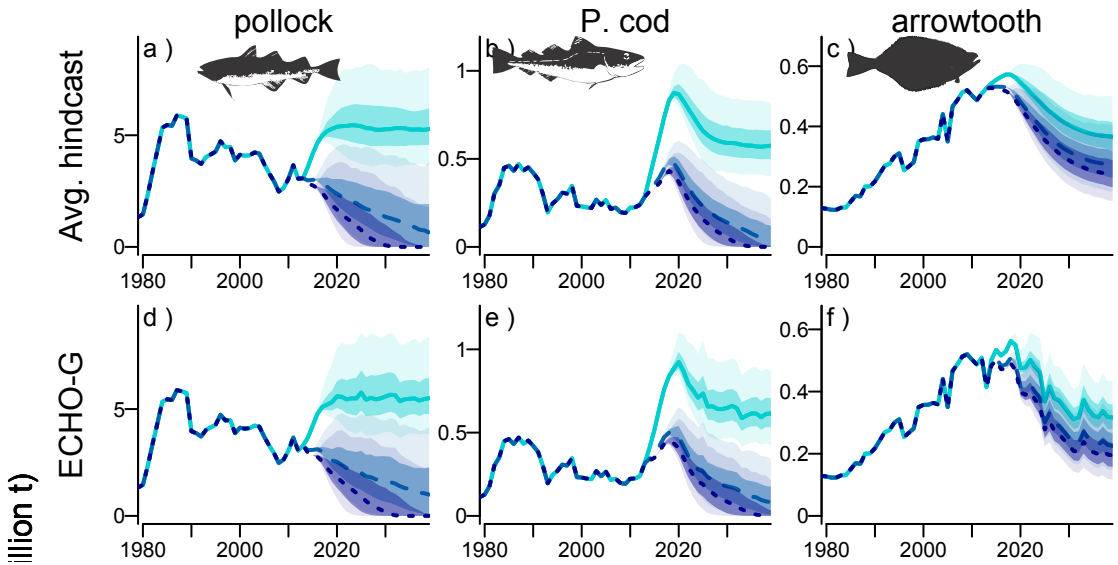


From Ianelli et al. *in press*

CEATTLE: Single-species

Mean R

Temp→W@A

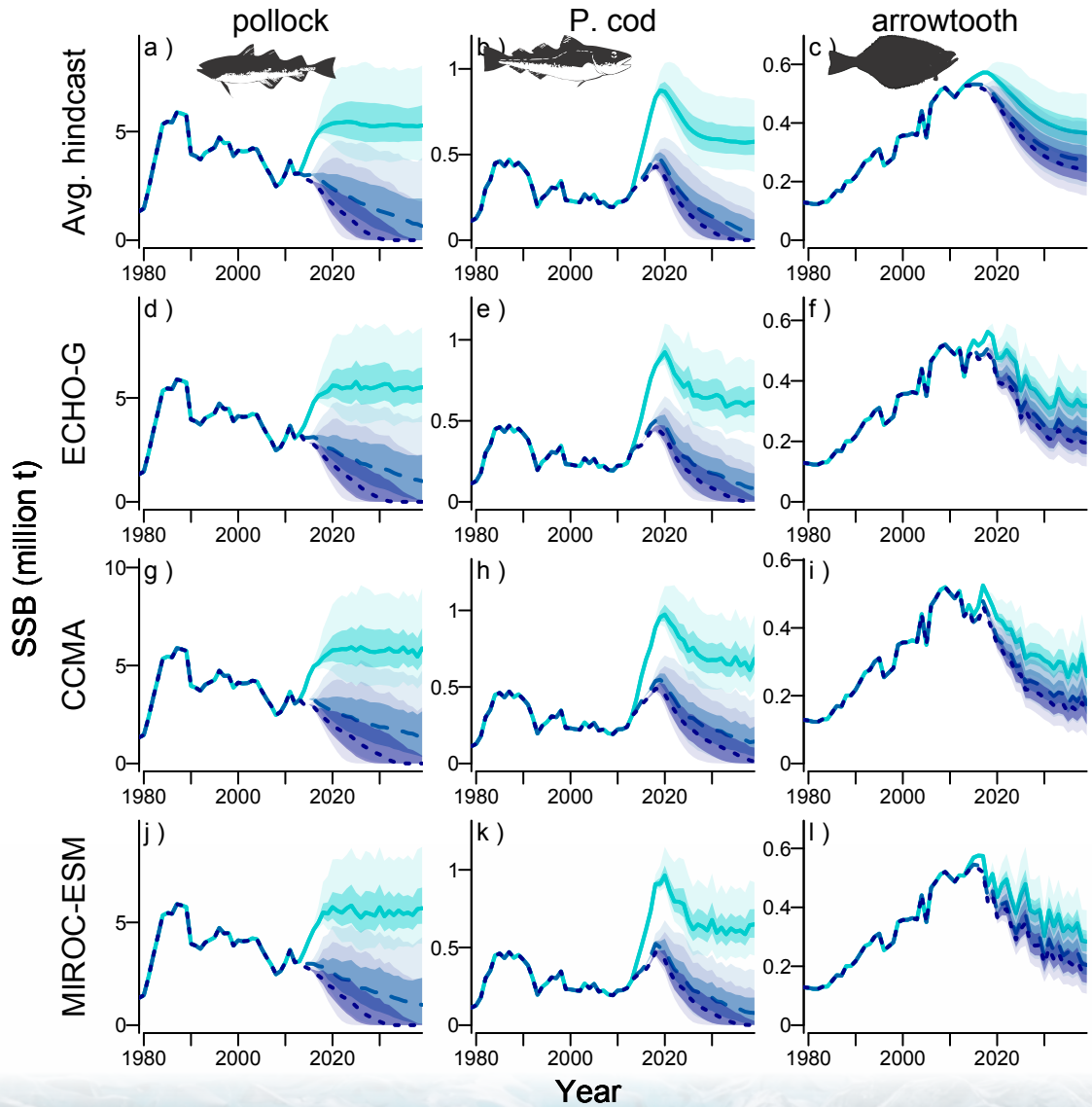


From Ianelli et al. *in press*

CEATTLE: Single-species

Mean R

Temp→W@A



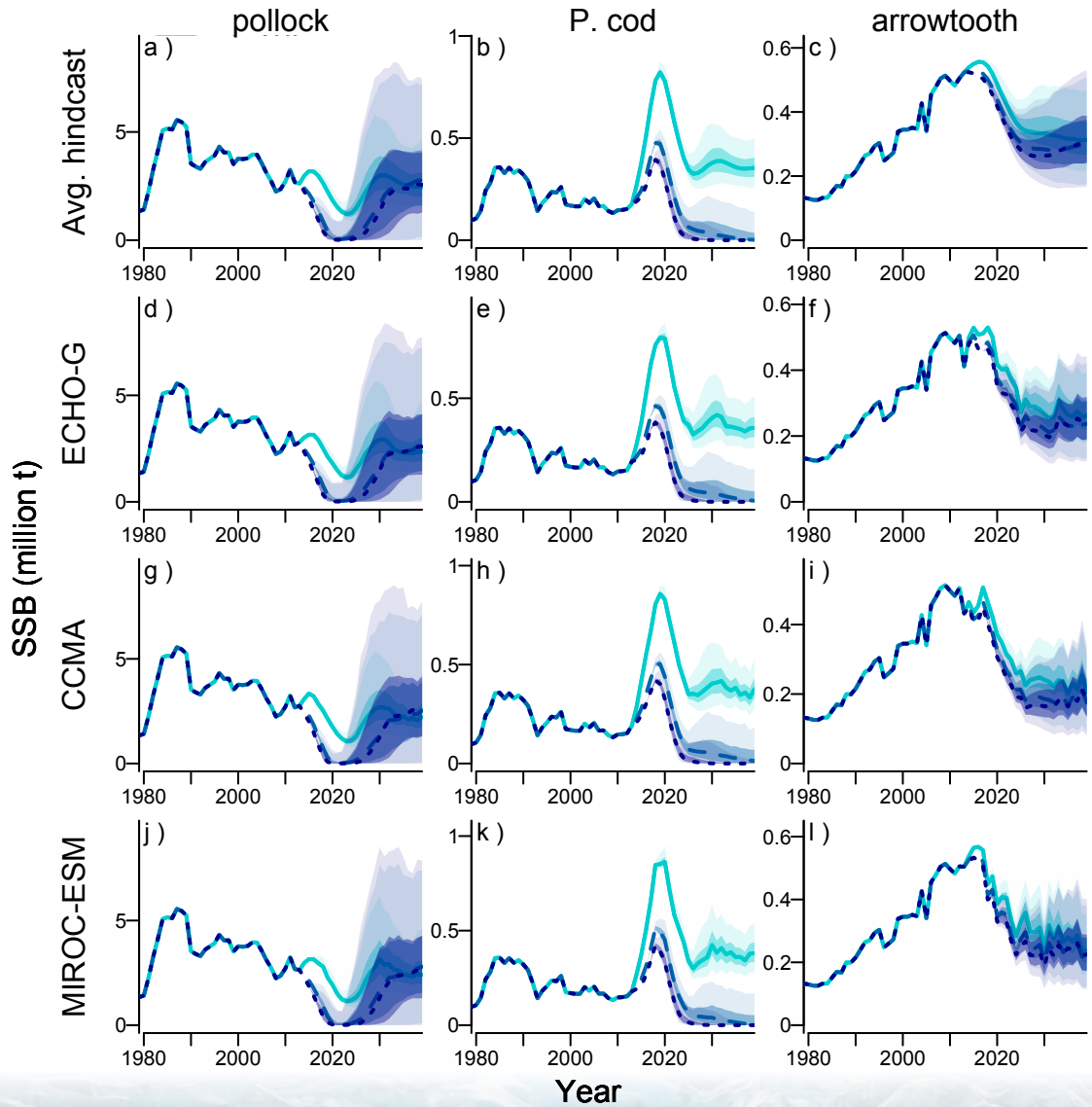
From Ianelli et al. *in press*

CEATTLE Multi-Species

Mean R

Temp→W@A

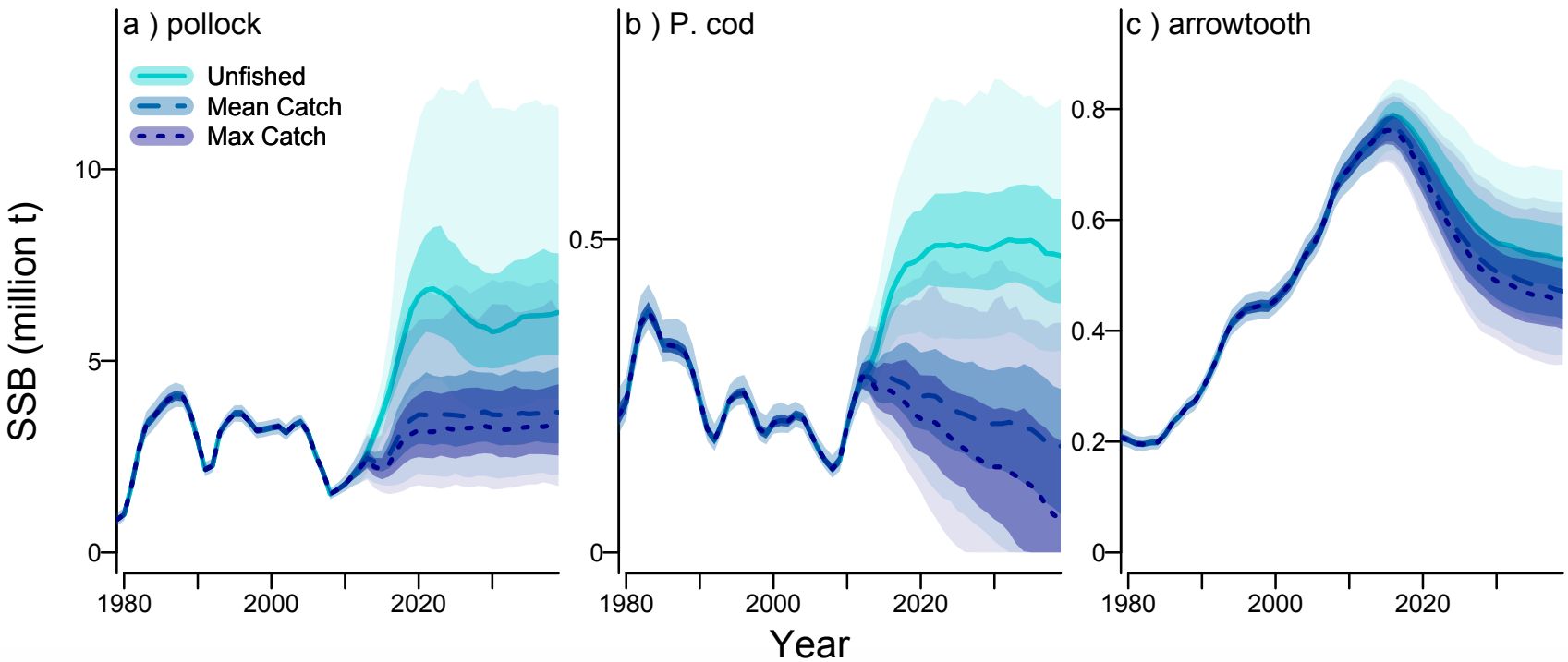
Temp→ Mort



From Ianelli et al. *in press*

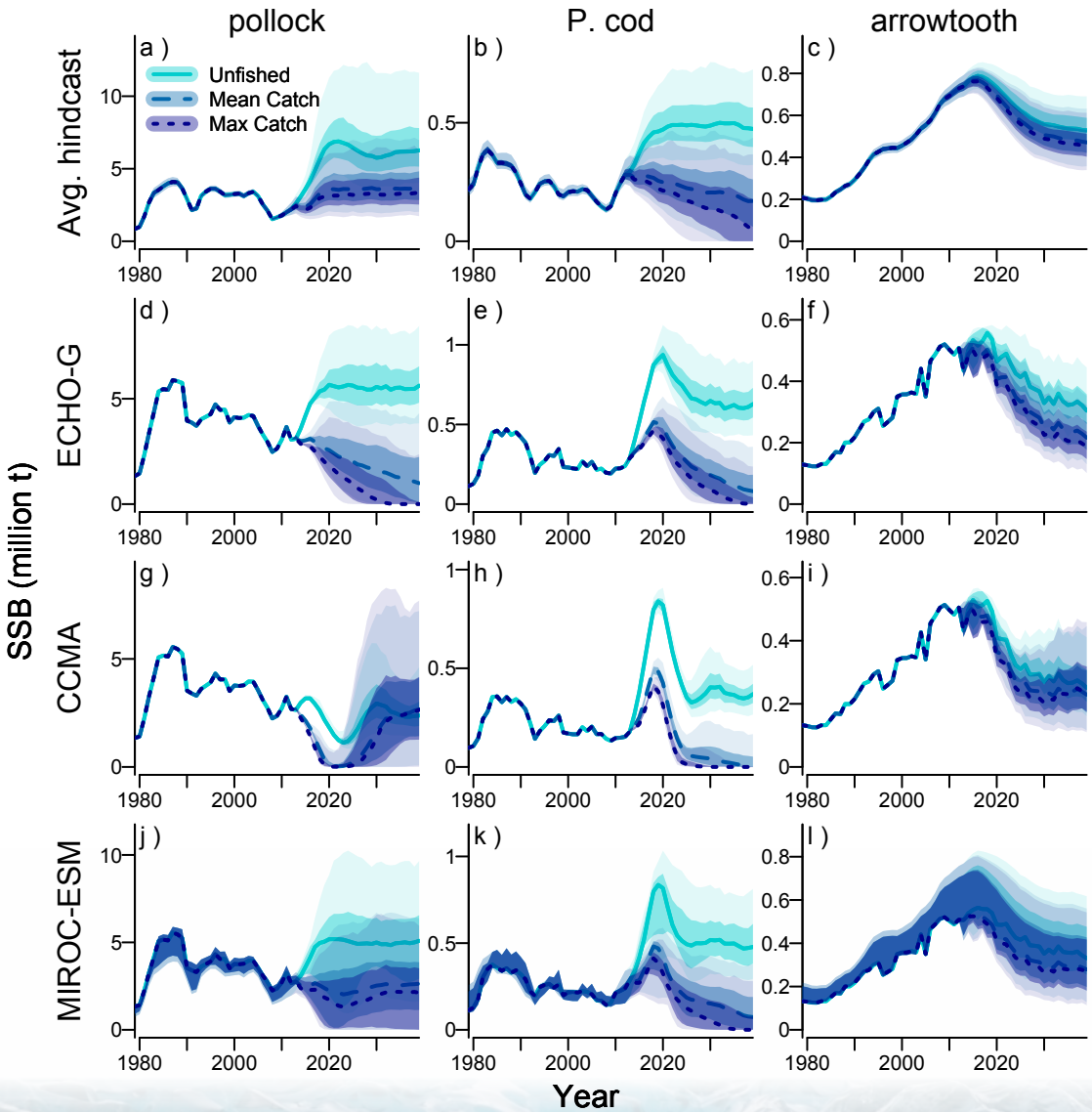
Single species models

Mean R; no Temp. effects



From Ianelli et al. *in press*

Blended results (all three models)



From Ianelli et al. *in press*