CEATTLE multi-species model

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Photo: Mark Holsman

Multi-species models for EBFM

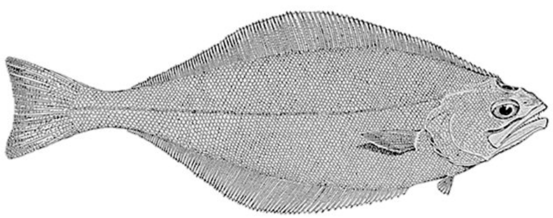
- Increase forecast accuracy (partition observation & process error)
- Quantify relative effects of climate variability, trophic interactions, and fisheries on species productivity
- Non-stationary mortality, B0, and MSY
- Can identify indirect effects on other species and fisheries
- Quantify trade-offs among fisheries
- Reduce risk of overharvest?

Holsman et al. in press. Deep Sea Res II

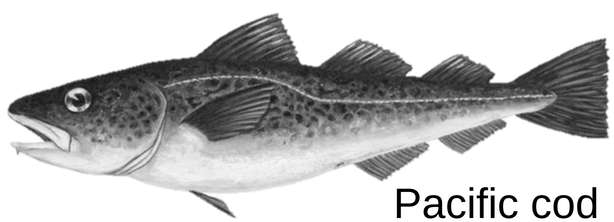
Photo: Mark Holsman

MSMt (Multi-species stock assessment model)

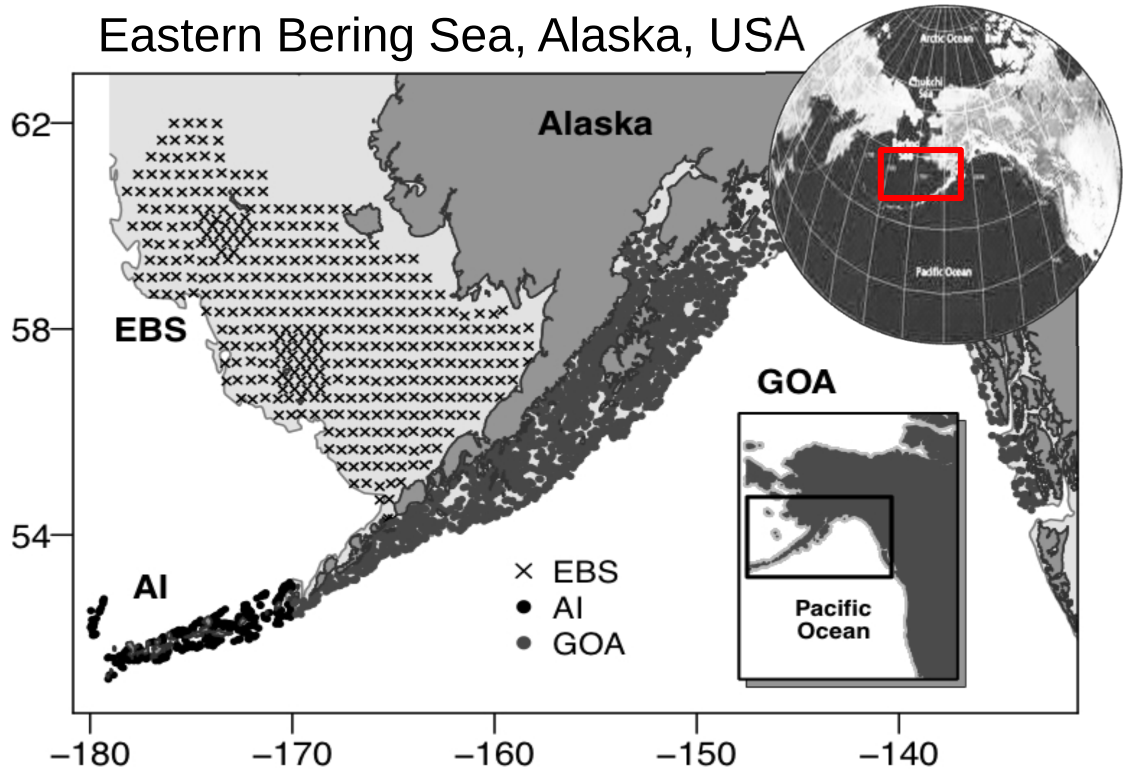
Walleye pollock
(*Gadus chalcogrammus*)



Arrowtooth flounder
(*Atheresthes stomias)*



Pacific cod
(*Gadus macrocephalus*)



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

CEATTLE 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	$N_{ij,1} = \begin{cases} R_{0,i}e^{(-j\,M1_{ij})}N_{0,ij} \\ R_{0,i}e^{(-j\,M1_{i,A_i})}N_{0,i,A_i}/(1-e^{(-j\,M1_{i,A_i})}) \end{cases}$	$y = 1 \quad 1 < j \le A_i$ $y = 1 \quad j > A_i$	T1.2
Numbers at age	$N_{i,j+1,y+1} = N_{ij,y}e^{-Z_{ij,y}}$ $N_{i,A_i,y+1} = N_{i,A_i-1,y}e^{-Z_{i,A_i-1,y}} + N_{i,A_i,y}e^{-Z_{i,A_i,y}}$	$1 \le y \le n_y \quad 1 \le j < A_i$ $1 \le y \le n_y \quad j > A_i$	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
Biomass at age (kg)	$B_{ij,y} = N_{ij,y}W_{ij,y}$		T.16
Spawning biomass at age (kg)	$SSB_{ij,y} = B_{ij,y}\rho_{ij}$		T1.7
Total mortality at age	$Z_{ij,y} = M1_{ij} + M2_{ij,y} + F_{ij,y}$		T1.8
Fishing mortality at age	$F_{ij,y} = F_{0,i}e^{\varepsilon_{i,y}}s_{ij}^{f}$	$\varepsilon_{i,y} \sim N(0, \sigma_{F,i}^2)$	T1.9
Weight at age (kg)	$W_{ij,y} = \log(W_{\infty,iy}) + \left(1/(1-d_{i,y})\right)\log\left(1-e^{(-K_i(1-d_{i,y})(j-t_{0,i}))}\right)$		T1.10a
Fishery age composition	$O_{ij,y}^{f} = \frac{C_{ij,y}}{\sum_j C_{ij,y}}$		T1.13
BT survey age composition	$O_{ij,y}^{s} = \frac{N_{ij,y}e^{0.5(-Z_{ij,y})}s_{ij}^{s}q_{ij}^{s}}{\sum_j\left(N_{ij,y}e^{0.5(-Z_{ij,y})}s_{ij}^{s}q_{ij}^{s}\right)}$		T1.14
EIT survey age composition	$O_{1j,y}^{eit} = \frac{N_{1j,y}e^{0.5(-Z_{1j,y})}s_{1j}^{eit}q_{1j}^{eit}}{\sum_j\left(N_{1j,y}e^{0.5(-Z_{1j,y})}s_{1j}^{eit}q_{1j}^{eit}\right)}$		T1.15

Residual Natural Mortality

Predation Natural Mortality

$$Z_{ij,y} = M1_{ij} + M2_{ij,y} + F_{ij,y}$$

CEATTLE Pred. Mortality (M2)

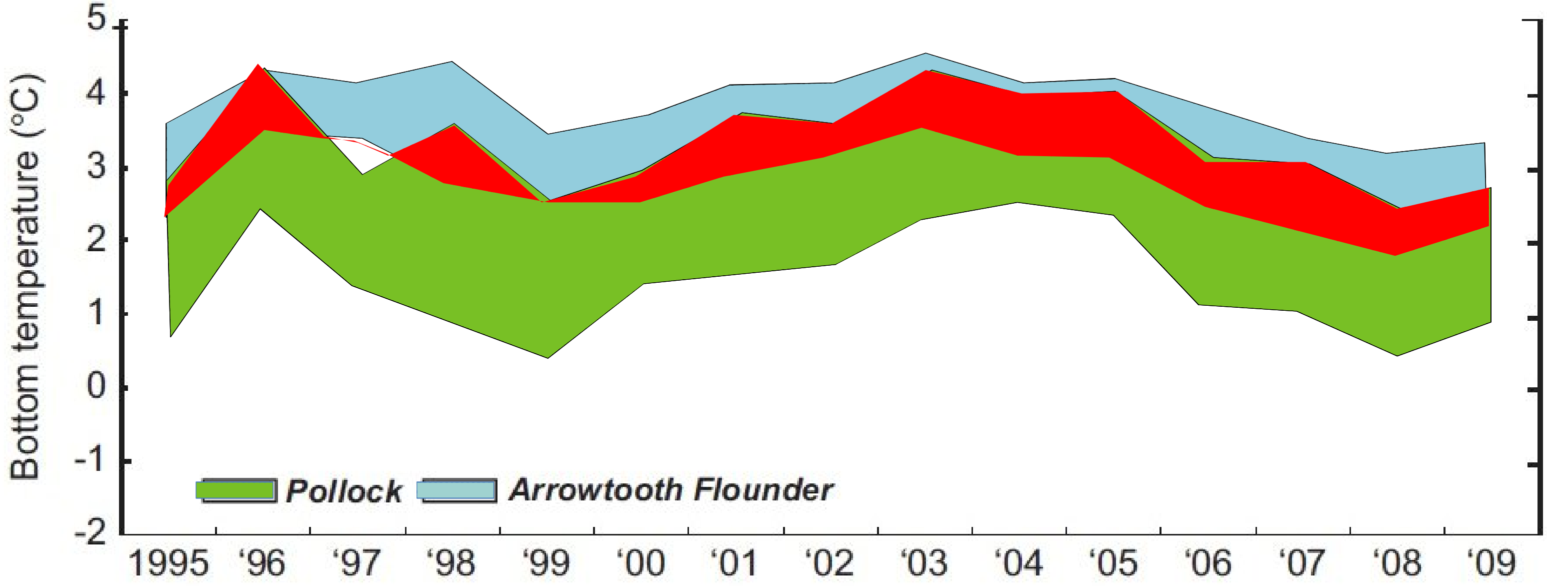
Definition	Equation	
Predation morality	$M2_{ij,y} = \sum_{pa}\left(\frac{N_{pa,y}\delta_{pa,y}\bar{S}_{paij}}{\sum_{ij}(\bar{S}_{paij}B_{ij,y}) + B_p^{other}(1-\sum_{ij}(\bar{S}_{paij}))}\right)$	T2.1
Predator-prey suitabilit	$n_y \sum_{y}\left(\sum_{ij}\left(\frac{U_{paij}}{B_{ij,y}}\right) + \frac{1+\sum_{ij}U_{paij}}{B_p^{other}}\right)$	T2.2
Mean gravimetric die proportion		T2.3
Individual specific ration (kg kg^{-1} yr^{-1})	$\delta_{pa,y} = \hat{\varphi}_{p,y}\alpha_{\delta}W_{pa,y}^{(1+\beta_{\delta})}f(T_y)_p$	T2.4
Temperature scaling algorithm	$f(T_y) = V^X e^{(X(1-V))}$	T2.5
		T2.5a
		T2.5b
	$Z = ln(Q_p^c)(T_p^{cm} - T_p^{co})$	T2.5c
	$Y = ln(Q_p^c)(T_p^{cm} - T_p^{co} + 2)$	T2.5d

Age-specific prey selectivity

Size-specific annual ration

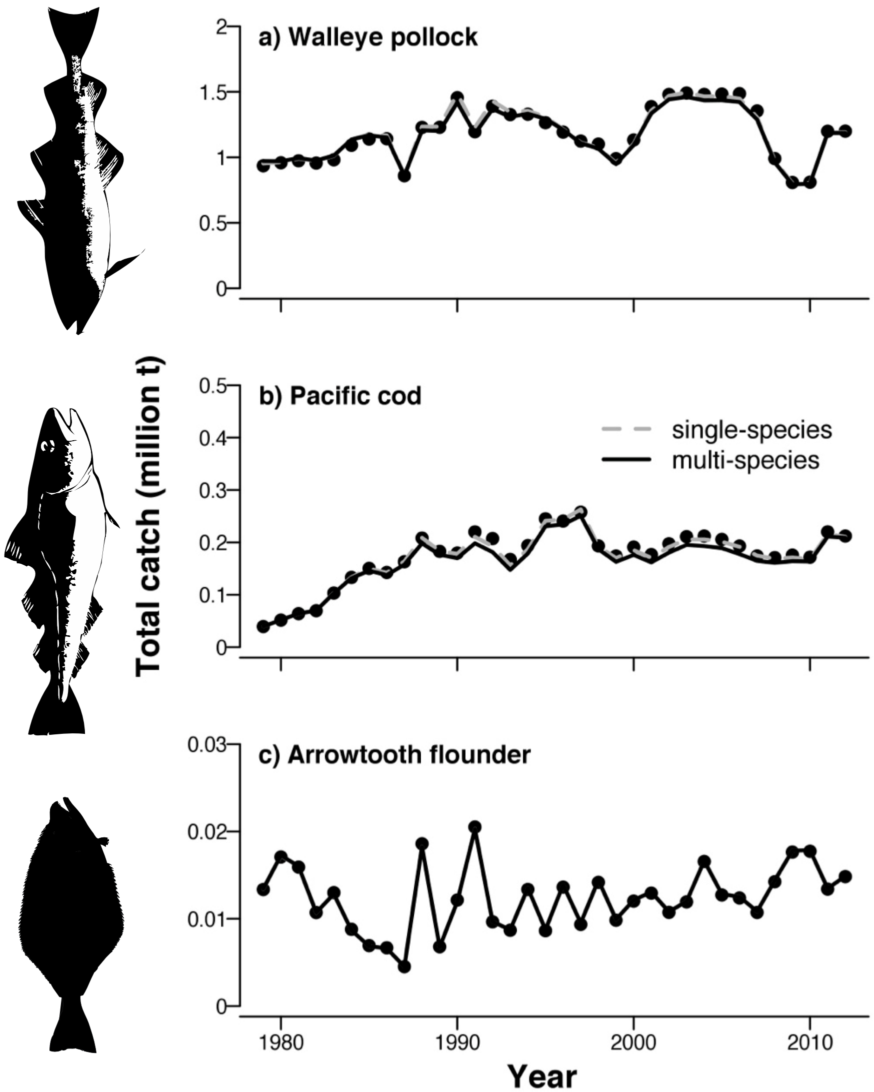
Temperature specific

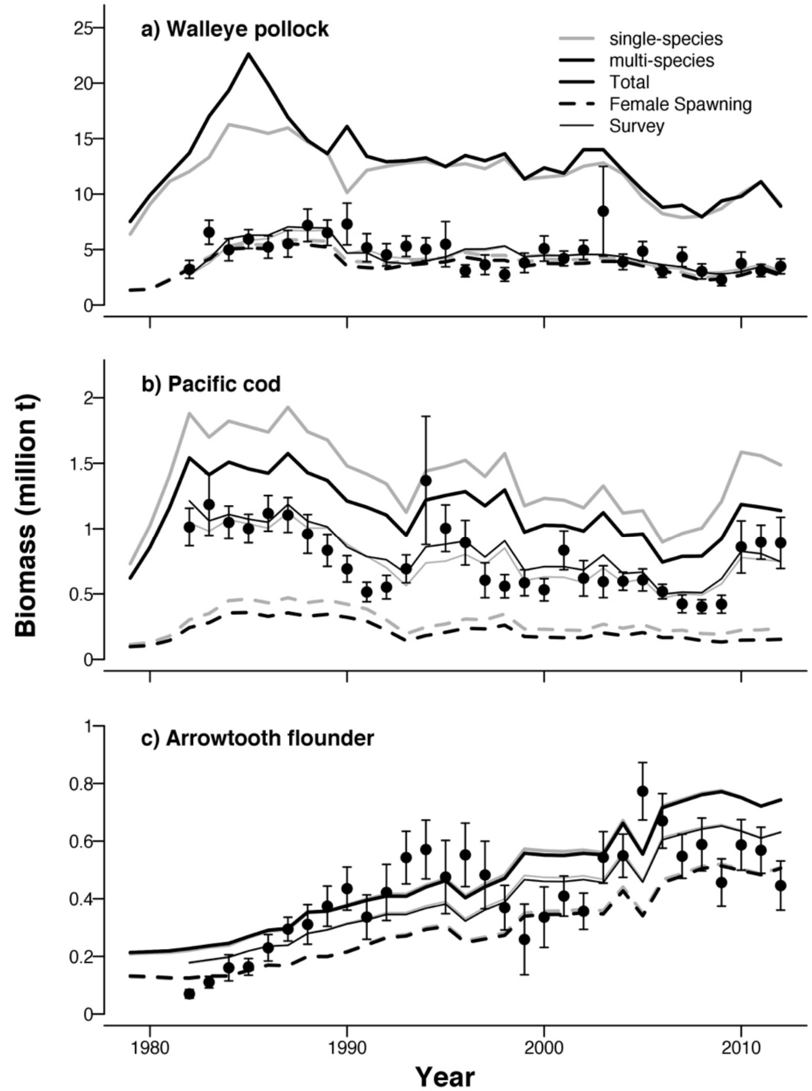
Pred-prey overlap based on thermal envelopes



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.

CEATTLE Estimation

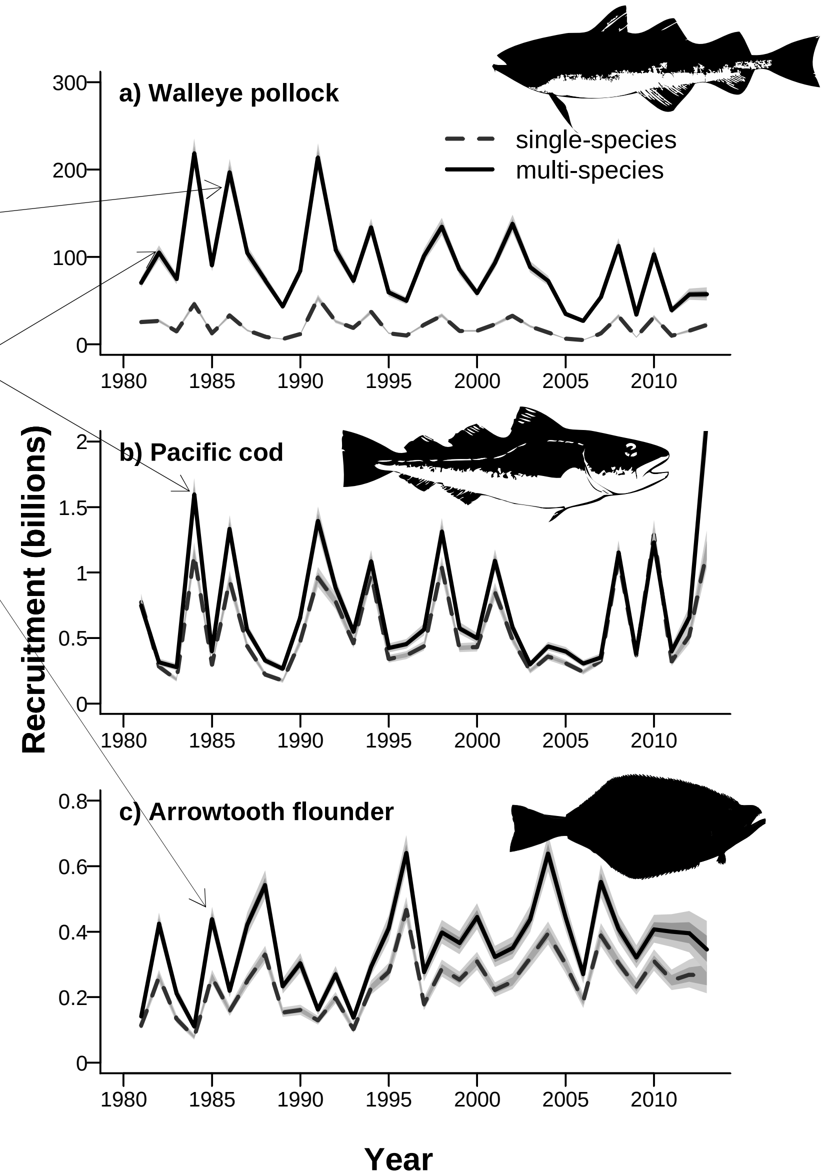




CEATTLE Recruitment

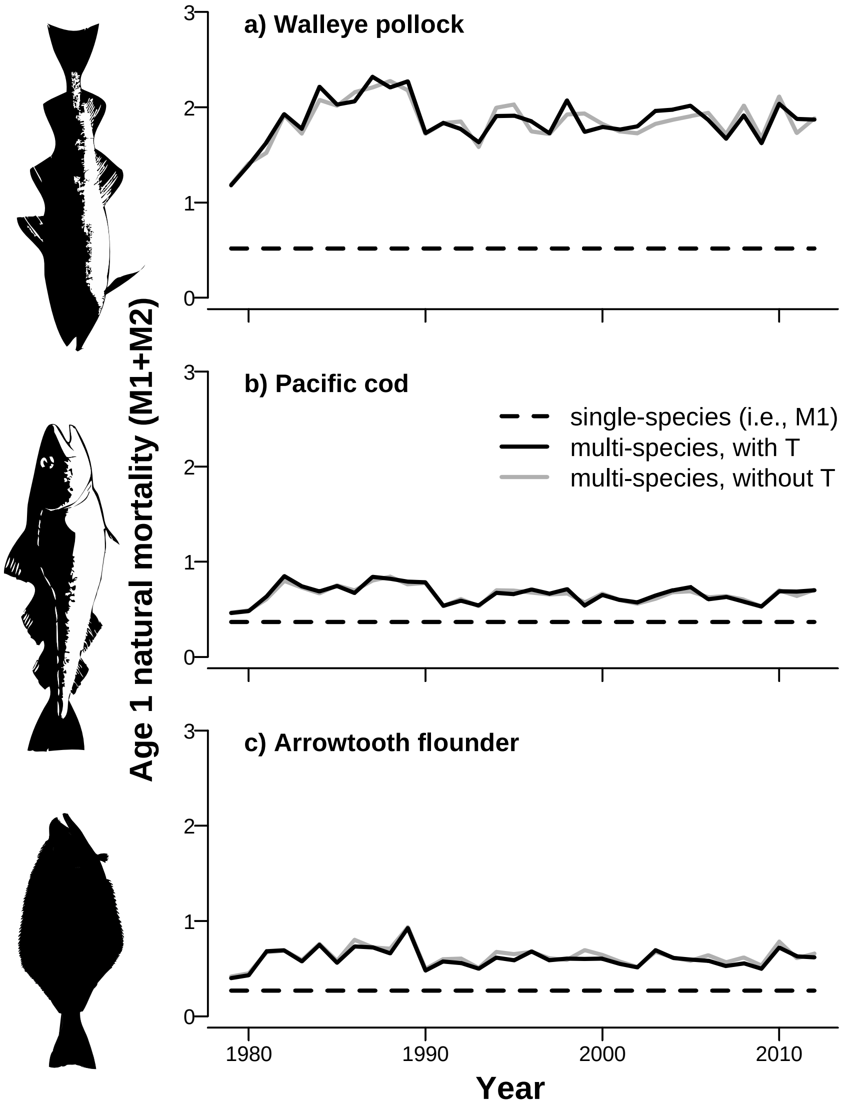
CEATTLE Recruitment ⬆
(M2 effect)

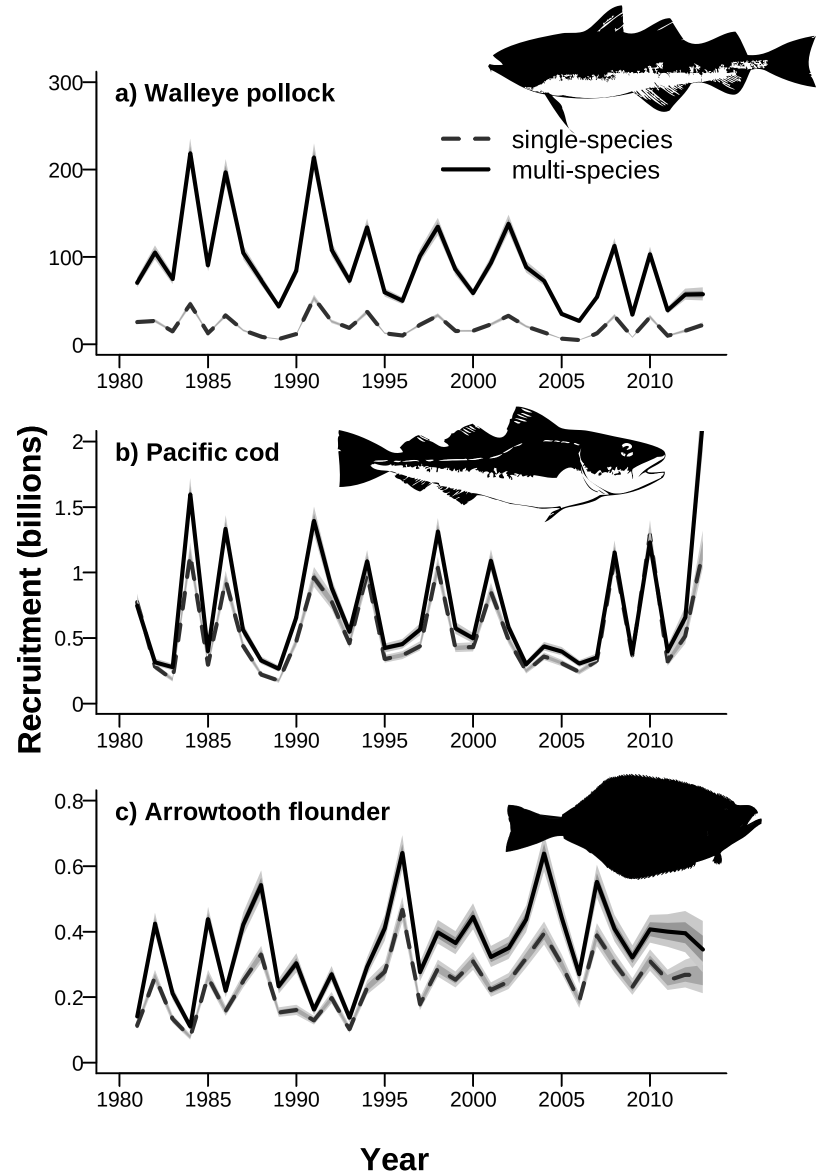
Peaks in recruitment
(Temp. effect)



Holsman et al. in press. Deep Sea Res II

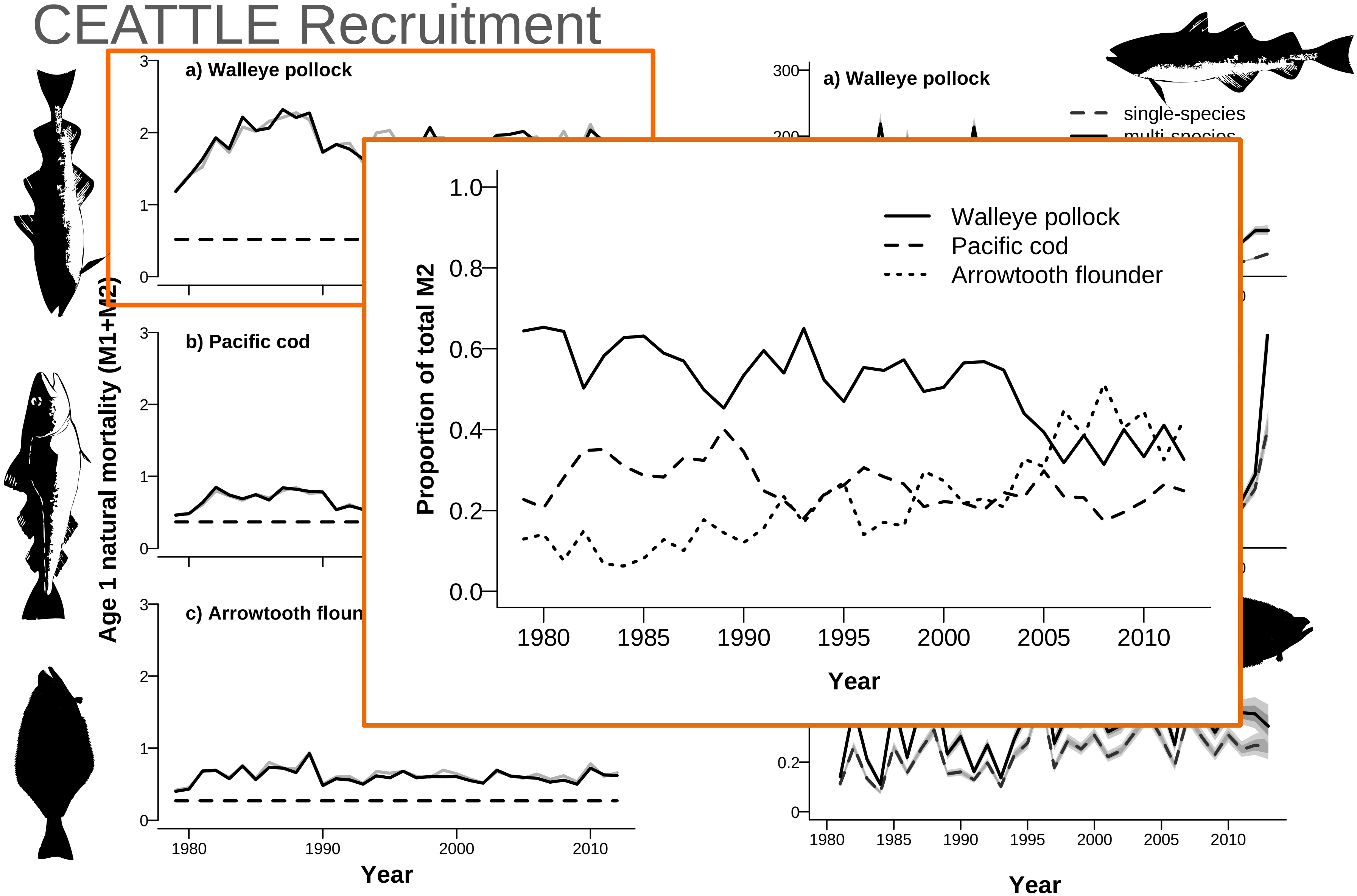
CEATTLE Recruitment





Holsman et al. in press. Deep Sea Res II

CEATTLE Recruitment



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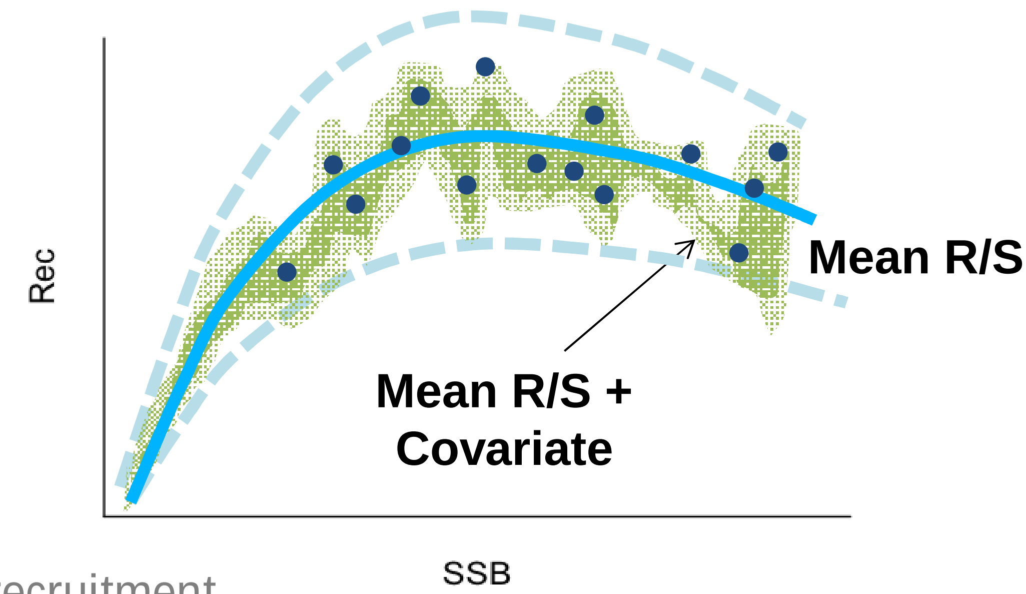
CEATTLE Recruitment



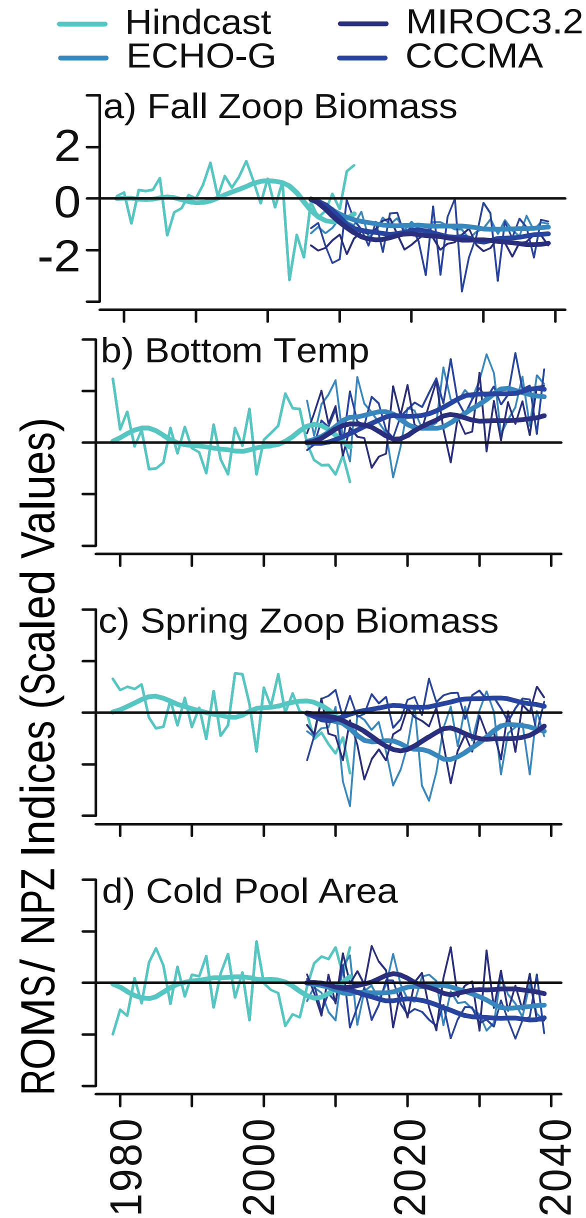
recruitment

$$\log(R_t) = \log(\alpha \cdot B_{t-1}) - \beta_1 \cdot B_{t-1} + \sum \beta_k \cdot X_{k,t} + \varepsilon,$$

productivity

carrying capacity

environmental effects on carrying capacity



Comparisons of reference points – management strategies (Moffitt et al. in press)