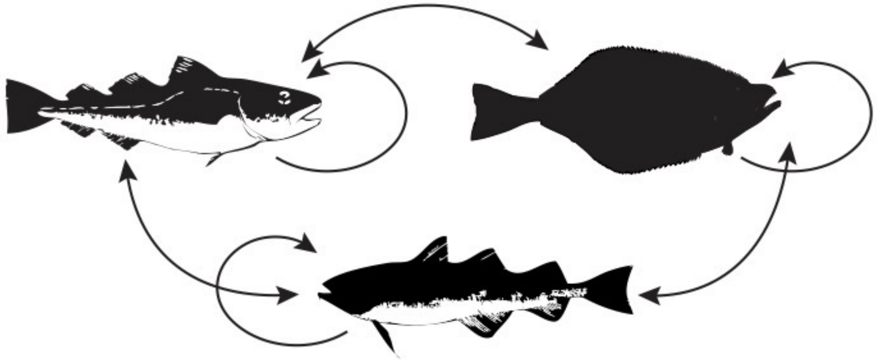
CEATTLE:

Climate enhanced Age-based model with Temperature specific Trophic linkages & Energetics



Kirstin Holsman & Grant Adams
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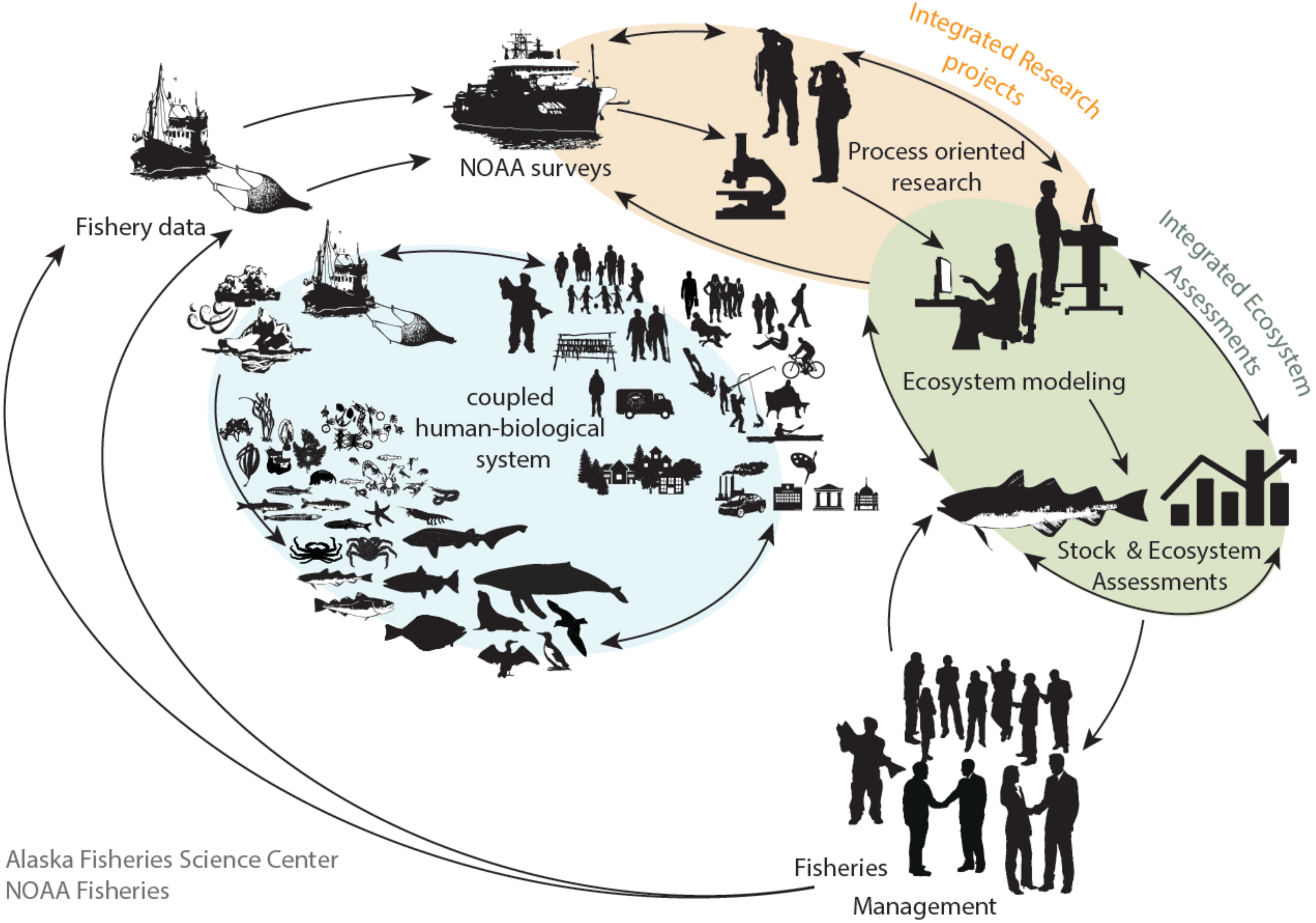
(alphabetical):

Kerim Aydin, Steve Barbeaux,

Martin Dorn, Jim Ianelli, André Punt,
Ingrid Spies, Grant Thompson

Photo: Mark Holsman

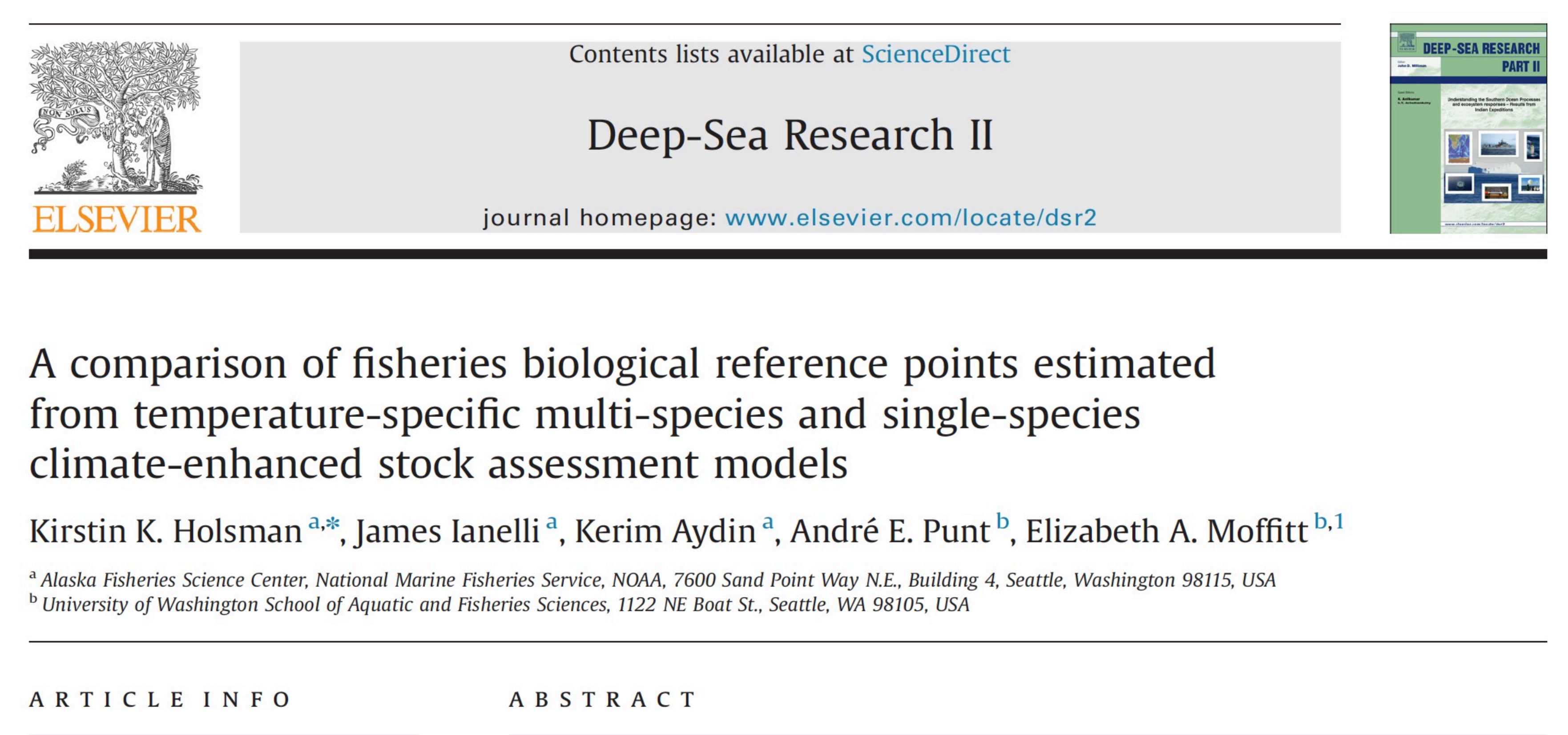
AFSC Ecosystem Based Fisheries Management



CEATTLE overview

Photo: Mark Holsman

CEATTLE methods references



Contents lists available at ScienceDirect

Deep-Sea Research II

journal homepage: www.elsevier.com/locate/dsr2

ELSEVIER

A comparison of fisheries biological reference points estimated from temperature-specific multi-species and single-species climate-enhanced stock assessment models

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ARTICLE INFO

ABSTRACT

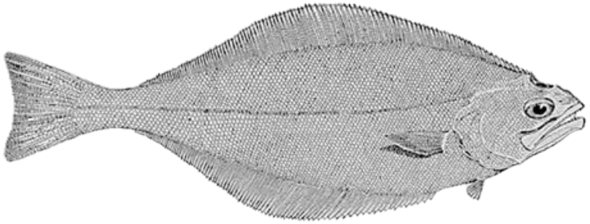
Multi-species statistical catch at age models (MSCAA) can quantify interacting effects of climate and

Holsman, KK, J Ianelli, K Aydin, AE Punt, EA Moffitt (2016). Comparative biological reference points estimated from temperature-specific multispecies and single species stock assessment models. Deep Sea Res II. doi:10.1016/j.dsr2.2015.08.001.

Moffitt, E, AE Punt, KK Holsman, KY Aydin, JN Ianelli, I Ortiz (2016). Moving towards Ecosystem Based Fisheries Management: options for parameterizing multi-species harvest control rules. Deep Sea Res II. doi:10.1016/j.dsr2.2015.08.002

CEATTLE Multi-species model

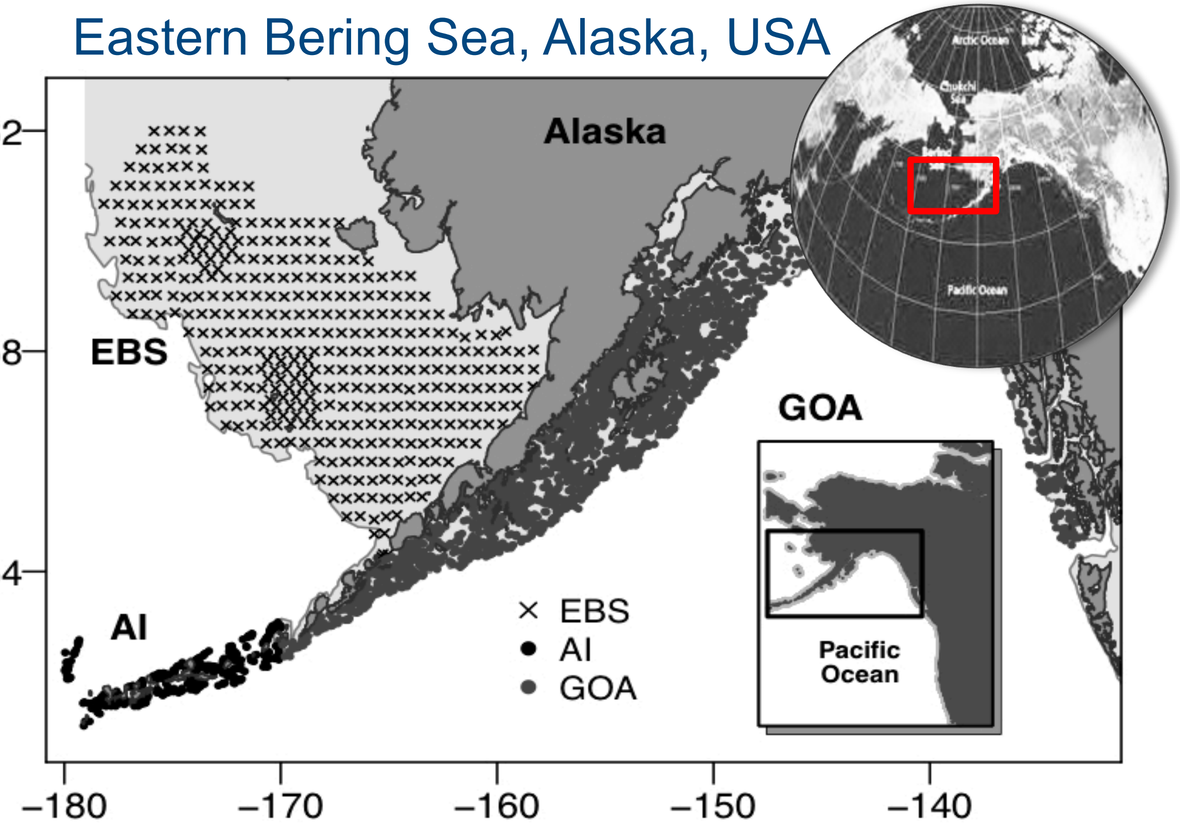
Walleye pollock
(*Gadus chalcogrammus*)



Arrowtooth flounder
(*Atheresthes stomias*)

Pacific cod
(*Gadus macrocephalus*)

Eastern Bering Sea, Alaska, USA

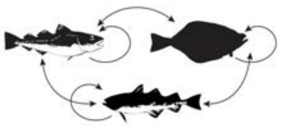


W@Age~*f*(Temperature)
Pred/prey~*f*(Temperature)

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

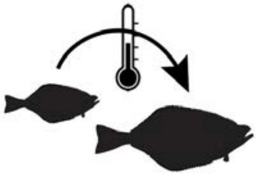
CEATTLE-EBS: Options

Mortality



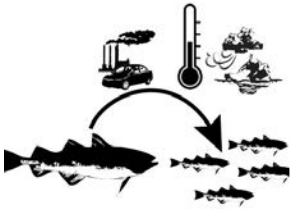
- Empirical diets
- Bioenergetics

Weight @ Age



- Empirical
- VonB with Temp

Rec

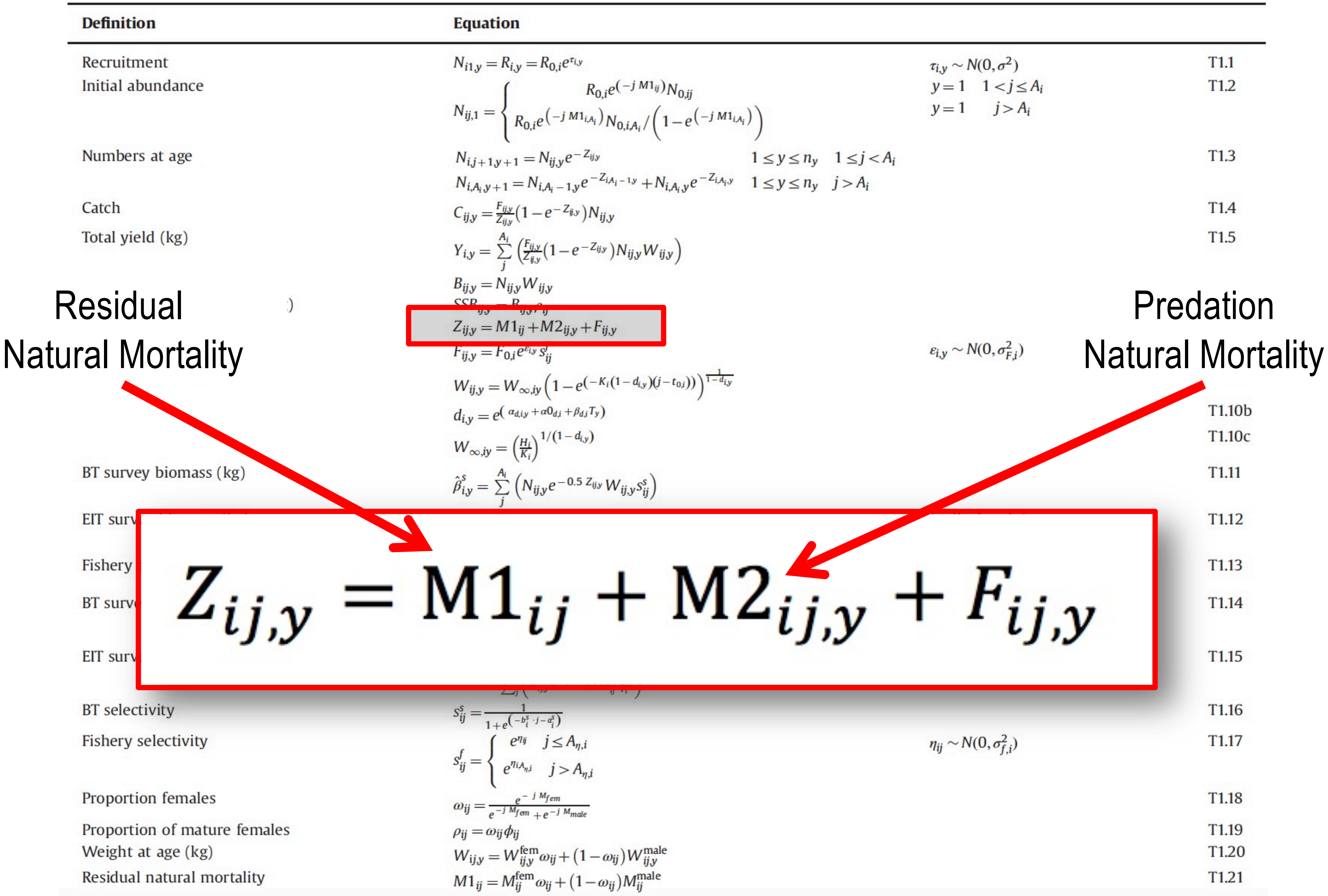


- Climate-S/R
- S/R
- mean R

HCRs

- Climate ABC
- MMSY
- MEY
- SPR
- Aggregate MSY

Table 1: Model equations



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	$N_{ij,1}=\begin{cases} R_{0,i}e^{(-j\,M1_{ij})}N_{0,ij} \\ R_{0,i}e^{(-j\,M1_{i,A_i})}N_{0,i,A_i}/\left(1-e^{(-j\,M1_{i,A_i})}\right)\end{cases}$	$y=1 \quad 1<j\le A_i$ $y=1 \quad j>A_i$	T1.2
Numbers at age	$N_{i,j+1,y+1}=N_{ij,y}e^{-Z_{ij,y}} \quad 1\le y\le n_y \quad 1\le j<A_i$ $N_{i,A_i,y+1}=N_{i,A_i-1,y}e^{-Z_{i,A_i-1,y}}+N_{i,A_i,y}e^{-Z_{i,A_i,y}} \quad 1\le y\le n_y \quad j>A_i$		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
	$B_{ij,y}=N_{ij,y}W_{ij,y}$		
	$Z_{ij,y}=M1_{ij}+M2_{ij,y}+F_{ij,y}$		
	$F_{ij,y}=F_{0,i}e^{\varepsilon_{i,y}}s^{f}_{ij}$	$\varepsilon_{i,y}\sim N(0,\sigma^2_{F,i})$	
	$W_{ij,y}=W_{\infty,iy}\left(1-e^{(-K_i(1-d_{i,y})(j-t_{0,i}))}\right)^{\frac{1}{1-d_{i,y}}}$		
	$d_{i,y}=e^{(\alpha_{d,i,y}+\alpha 0_{d,i}+\beta_{d,i}T_y)}$		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	$s^{s}_{ij}=\frac{1}{1+e^{(-b^{s}_{i}\cdot j-a^{s}_{i})}}$		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

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

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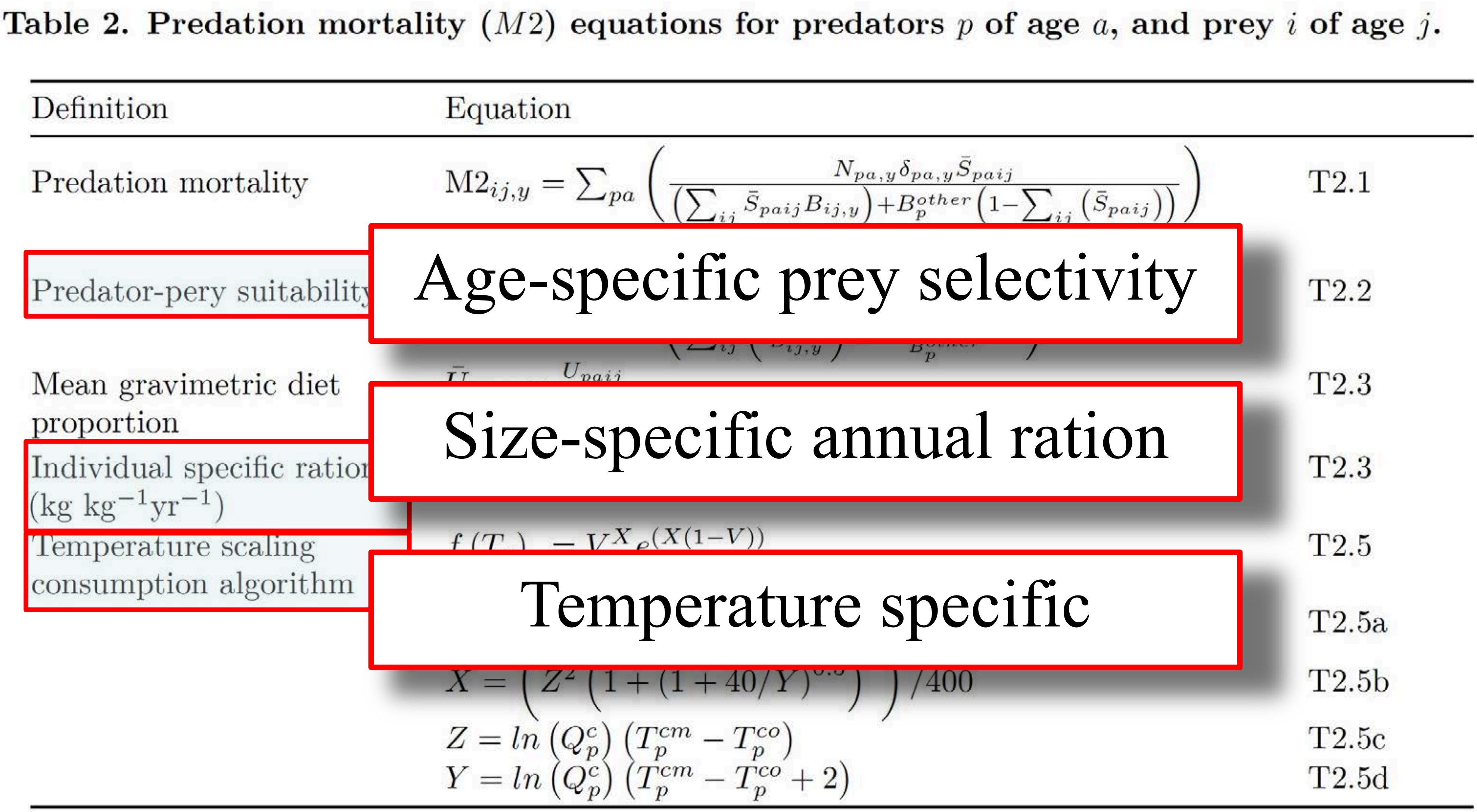

Table 2. Predation mortality ($M2$) equations for predators p of age a, and prey i of age j.

Definition	Equation	
Predation mortality	$\mathrm{M2}_{ij,y} = \sum_{pa}\left(\frac{N_{pa,y}\delta_{pa,y}\bar{S}_{paij}}{\left(\sum_{ij}\bar{S}_{paij}B_{ij,y}\right)+B_p^{other}\left(1-\sum_{ij}\left(\bar{S}_{paij}\right)\right)}\right)$	T2.1
Predator-pery suitability		T2.2
Mean gravimetric diet proportion		T2.3
Individual specific ration (kg kg^{-1}yr^{-1})		T2.3
Temperature scaling consumption algorithm	$f(T) = V^X e^{(X(1-V))}$	T2.5
		T2.5a
	$X = \left(Z^2\left(1+(1+40/Y)^{0.5}\right)\right)/400$	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

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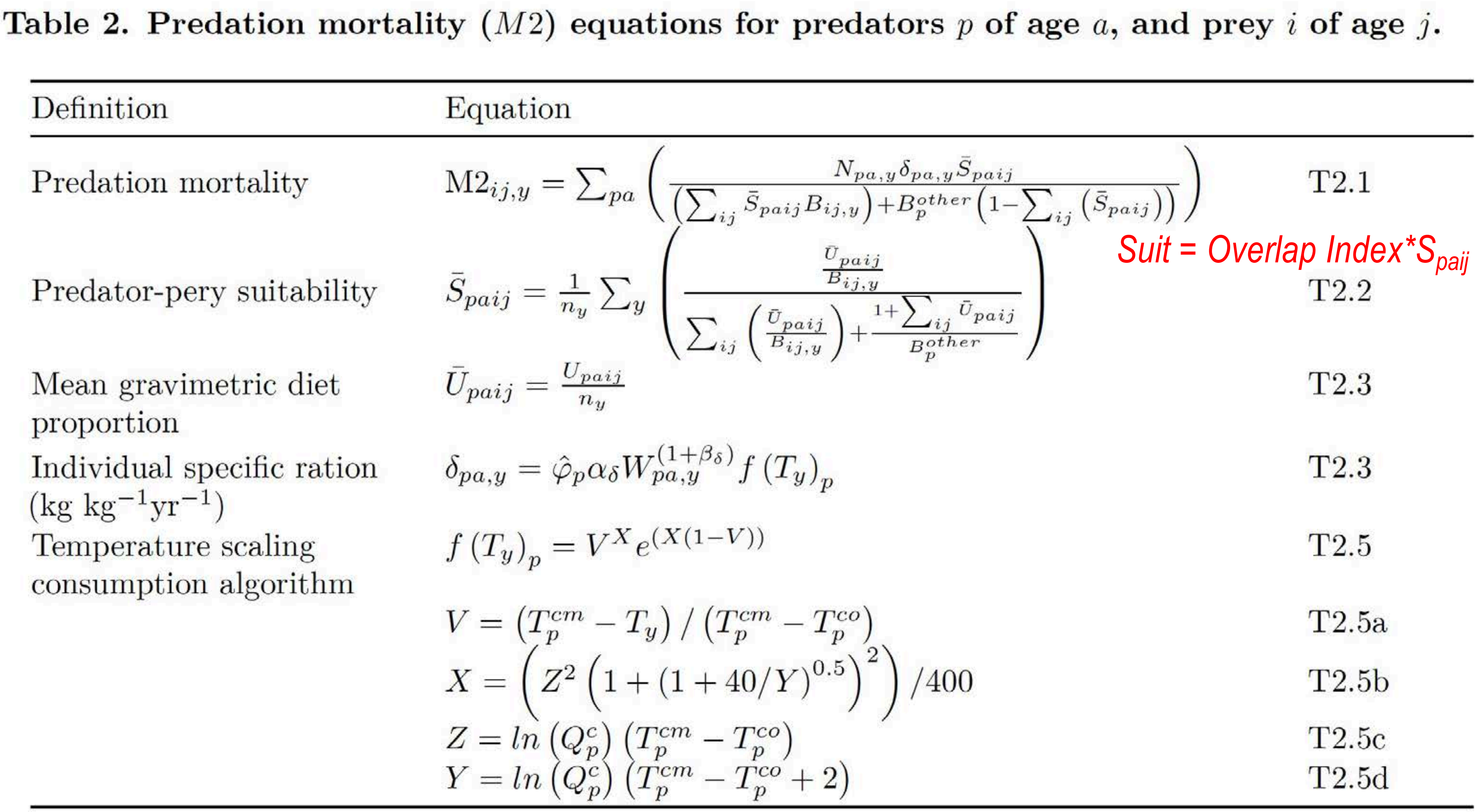

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Definition	Equation	
Predation mortality	$\mathrm{M2}_{ij,y} = \sum_{pa} \left(\frac{N_{pa,y} \delta_{pa,y} \bar{S}_{paij}}{\left(\sum_{ij} \bar{S}_{paij} B_{ij,y}\right) + B_p^{other} \left(1 - \sum_{ij} \left(\bar{S}_{paij}\right)\right)} \right)$	T2.1
Predator-pery suitability	$\bar{S}_{paij} = \frac{1}{n_y} \sum_y \left(\frac{\frac{\bar{U}_{paij}}{B_{ij,y}}}{\sum_{ij} \left(\frac{\bar{U}_{paij}}{B_{ij,y}}\right) + \frac{1 + \sum_{ij} \bar{U}_{paij}}{B_p^{other}}} \right)$	T2.2
Mean gravimetric diet proportion	$\bar{U}_{paij} = \frac{U_{paij}}{n_y}$	T2.3
Individual specific ration (kg $\mathrm{kg}^{-1}\mathrm{yr}^{-1}$)	$\delta_{pa,y} = \hat{\varphi}_p \alpha_\delta W_{pa,y}^{(1+\beta_\delta)} f\left(T_y\right)_p$	T2.3
Temperature scaling consumption algorithm	$f\left(T_y\right)_p = V^X e^{(X(1-V))}$	T2.5
	$V = \left(T_p^{cm} - T_y\right) / \left(T_p^{cm} - T_p^{co}\right)$	T2.5a
	$X = \left(Z^2 \left(1 + \left(1 + 40/Y\right)^{0.5}\right)^2\right) / 400$	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

Suit = Overlap IndexS_{paij}*

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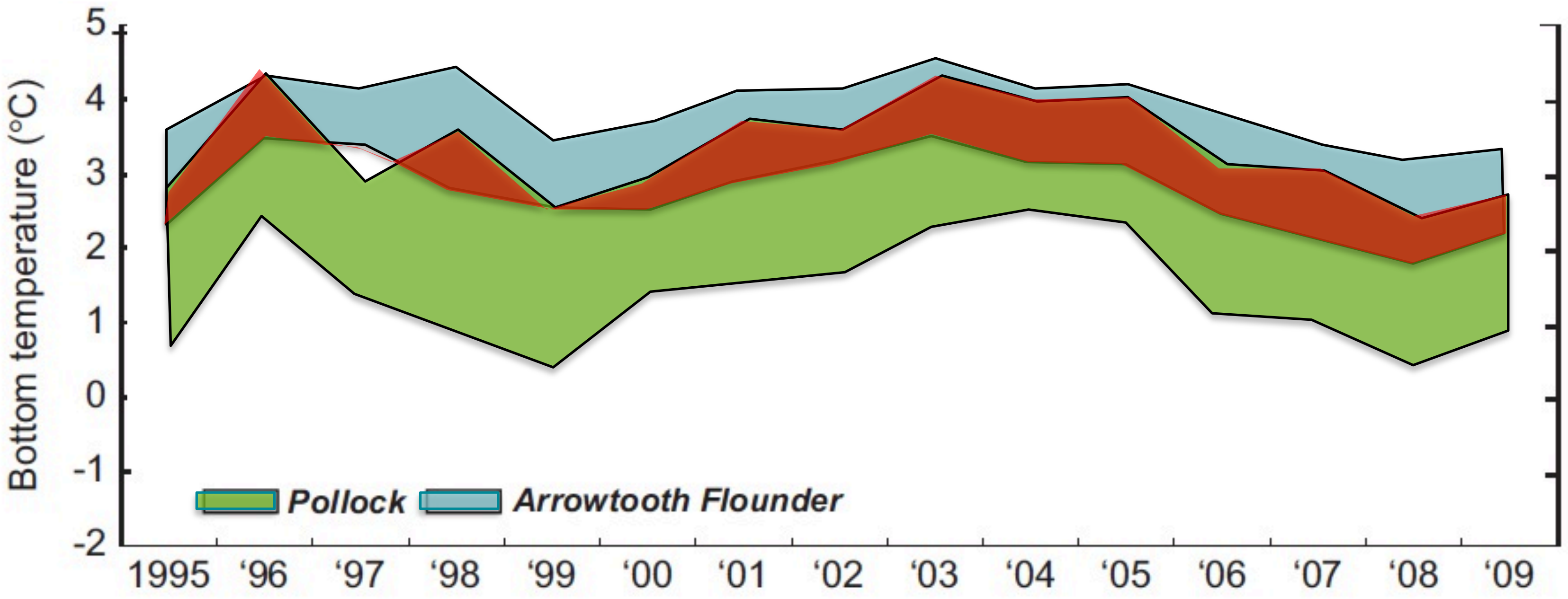
Predator- Prey Overlap

Set to 1.0 in this assessment



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.

Van kirk 2010

Table 4. Objective function components.

Description	Equation
Annual catch	$\sum_i \sum_t \left[\ln(C_{\mathrm{tot}_{i,t}} + 0.001) - \ln(\widehat{C}_{\mathrm{tot}_{i,t}} + 0.001)\right]^2$
Annual survey abundance	$\sum_i \sum_t \left[\ln(S_{\mathrm{tot}_{i,t}} + 0.001) - \ln(\widehat{S}_{\mathrm{tot}_{i,t}} + 0.001)\right]^2$
Catch at age	$-\sum_i \sum_a \sum_t \left[\left(\frac{C_{i,a,t}}{C_{\mathrm{tot}_{i,t}}} + 0.0001\right) \cdot \ln\left(\frac{\widehat{C}_{i,a,t}}{\widehat{C}_{\mathrm{tot}_{i,t}}} + 0.0001\right)\right]$
Survey abundance at age	$-\sum_i \sum_a \sum_t \left[\left(\frac{S_{i,a,t}}{S_{\mathrm{tot}_{i,t}}} + 0.0001\right) \cdot \ln\left(\frac{\widehat{S}_{i,a,t}}{\widehat{S}_{\mathrm{tot}_{i,t}}} + 0.0001\right)\right]$
Stomach contents	$\sum_i \sum_a \sum_j \sum_b \sum_t \left[\left(\frac{\varphi_{i,a,j,b,t}}{\varphi_{j,b,t}} + 0.0001\right) - \left(\frac{\widehat{\varphi}_{i,a,j,b,t}}{\widehat{\varphi}_{j,b,t}} + 0.0001\right)\right]^2$

Note: A caret denotes a quantity estimated by the model.

biomass of prey species i,a in year t. [This is analogous to the Baranov catch equation $C = F\overline{N}$.] The definition of P in eq. 1, however, is recursive in that predation mortality, as an element of total mortality Z, is also present in the calculation of $\overline{B}_{i,a,t}$. Without Z, mean prey abundance $\overline{N}_{i,a,t}$ and mean prey biomass $\overline{B}_{i,a,t}$ cannot be calculated. Following Lewy and Vinther (2004), we therefore approximate the true instantaneous rate of predation mortality as

$$(2) \qquad P_{i,a,t} = \frac{1}{B_{i,a,t}} \sum_j \sum_b I_{j,b}\, N_{j,b,t}\, \frac{\varphi_{i,a,j,b,t}}{\varphi_{j,b,t}}$$

using abundance and biomass of predators and prey at the beginning of each year.

The ratio $\varphi_{i,a,j,b,t}/\varphi_{j,b,t}$ is the proportion of prey i,a in all food available to predator j,b in year t, which is assumed equal to the proportion of food within the stomach of predator j,b in year t composed of prey i,a. Availability is the product of a suitability coefficient ν and prey biomass:

size-preference coefficient for all prey of a given size regardless of species, but g carries the subscript for both species and age as different prey species differ in size at age.

The total food available to a given predator j,b in the GOA includes many species beyond those explicitly defined in the model. To ensure that the stomach quotient (eq. 2) above correctly reflects this diet diversity, the divisor contains a nonmodeled prey component in addition to modeled prey as

$$(6) \qquad \varphi_{j,b,t} = B_{\mathrm{oth}} + \sum_i \sum_a \nu_{i,a,j,b,t}\, B_{i,a,t}$$

in which B_{oth} refers to the biomass of the nonmodeled prey, constant over time and across species and age. As this biomass is constant (set to e^{15} through trial and error), its suitability coefficient is fixed at 1, allowing size- and species-preference parameters for modeled species to be estimated relative to other prey.

AD Model Builder (ADMB, Otter Research Ltd. 2004)

Response name	Type	Number of estimable parameters	$\phi_{k,a,y}^{r,u}$ (from equation 7)
Linear	I	1	$\theta^{r,u}\, v_k^r$
Asymptotic (Holling Type II)	II	2	$\dfrac{v_k^r \theta^{r,u}\, [1 + \tilde{v}_k^r]}{1 + \tilde{v}_k^r\, \Phi_y^{r,u}}$
Sigmoid (Holling Type III)	III	3	$\dfrac{v_k^r \theta^{r,u}\, (1 + \tilde{v}_k^r) \left(\Phi_y^{r,u}\right)^{\tilde{\tilde{v}}_k^r - 1}}{1 + \tilde{v}_k^r\, (\Phi_y^{r,u})^{\tilde{\tilde{v}}_k^r}}$
Interference	IV	3	$\dfrac{v_k^r \theta^{r,u}\, [1 + \tilde{v}_k^r]}{1 + \tilde{v}_k^r \Phi_y^{r,u} + \tilde{\tilde{v}}_k^r (\Psi_y^{k,a} - 1)}$
Pre-emption	V	3	$\dfrac{v_k^r \theta^{r,u}\, [1 + \tilde{v}_k^r]}{(1 + \tilde{v}_k^r\, \Phi_y^{r,u})\, [1 + \tilde{\tilde{v}}_k^r (\Psi_y^{k,a} - 1)]}$
Hassell–Varley	VI	3	$\dfrac{v_k^r \theta^{r,u}\, [1 + \tilde{v}_k^r]}{\tilde{v}_k^r \Phi_y^{r,u} + (\Phi_y^{r,u})^{\tilde{\tilde{v}}_k^r}}$
Ecosim	VII	2	$\dfrac{v_k^r \theta^{r,u}}{1 + \tilde{v}_k^r (\Psi_y^{k,a} - 1)}$

Kinzey & Punt 2009

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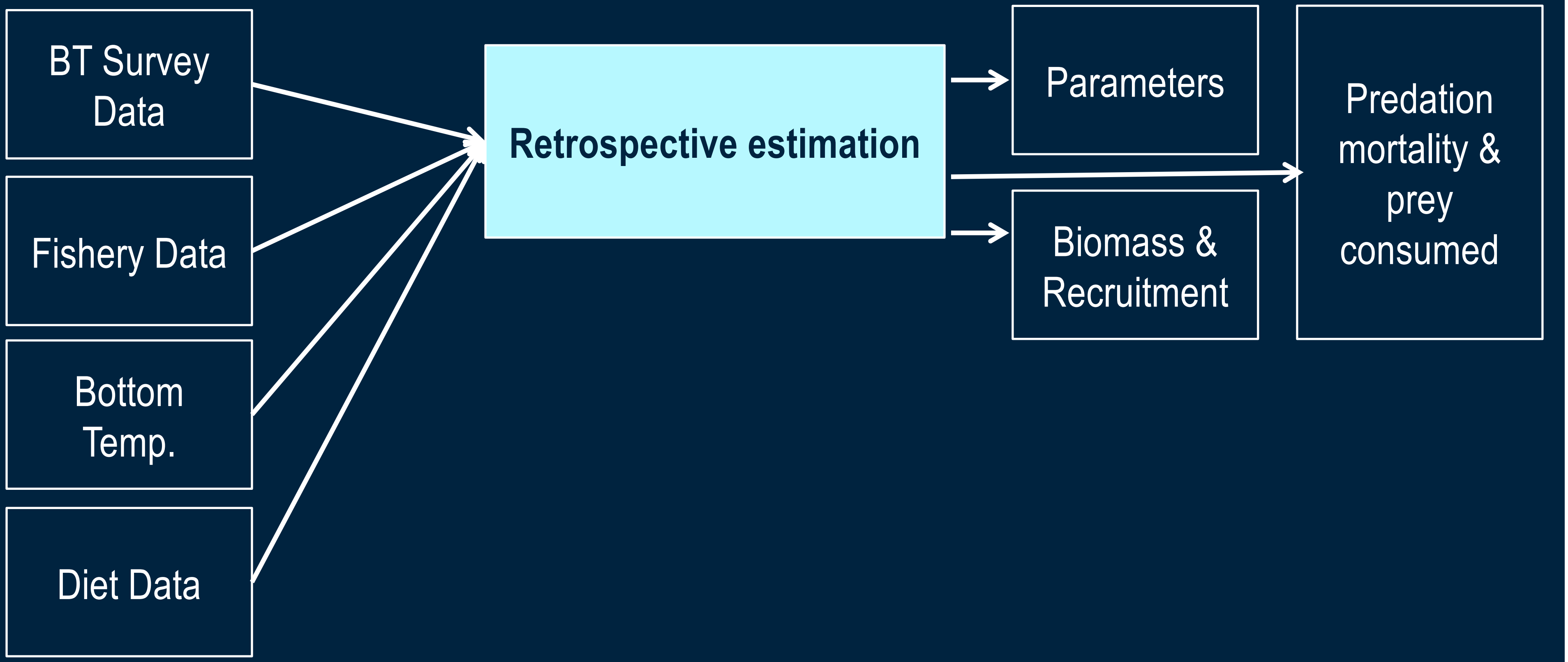

BT Survey Data

Fishery Data

Bottom Temp.

Diet Data

Retrospective estimation

Parameters

Biomass & Recruitment

Predation mortality & prey consumed

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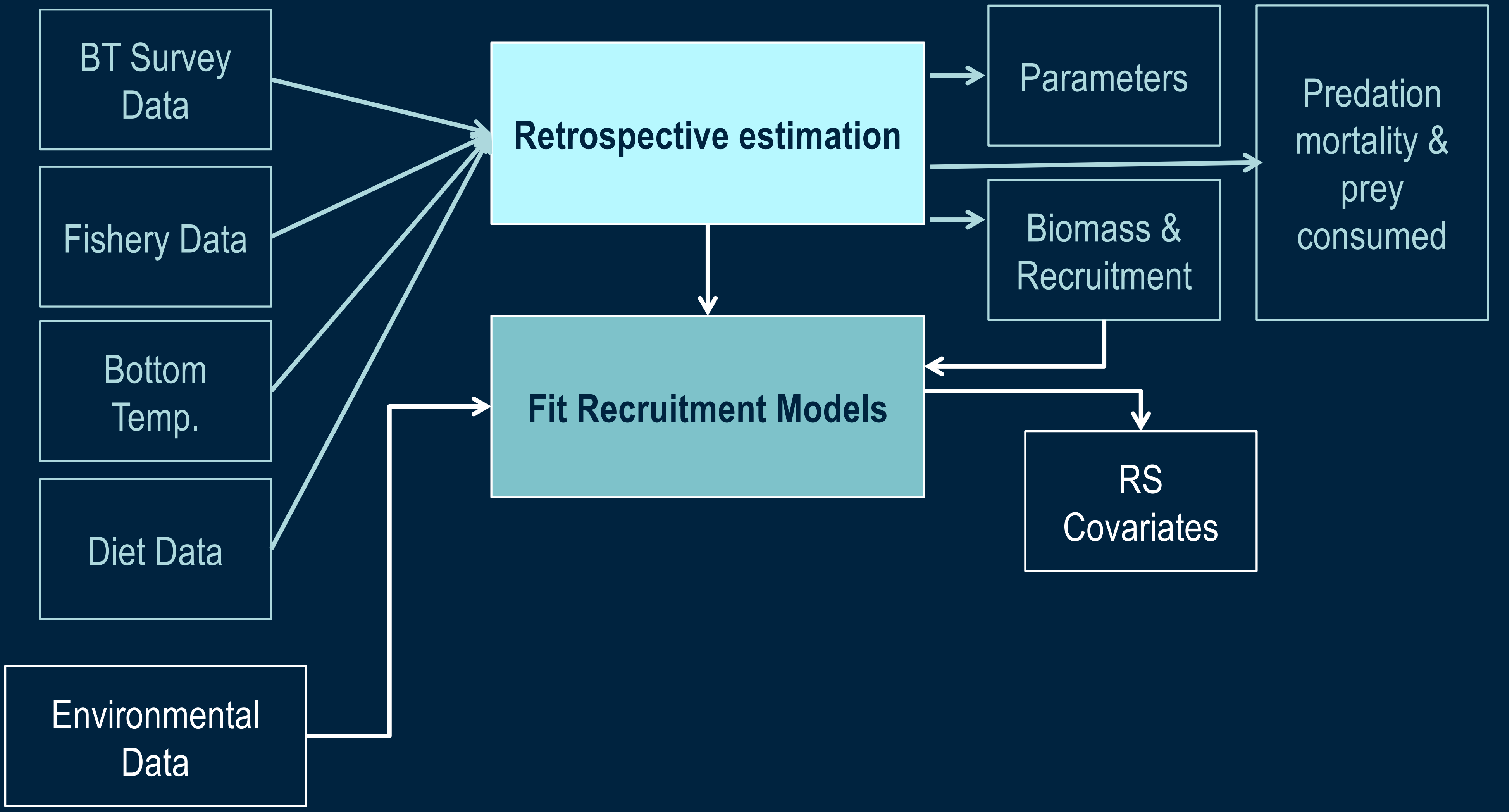

BT Survey Data

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Environmental Data

Retrospective estimation

Fit Recruitment Models

Parameters

Predation mortality & prey consumed

Biomass & Recruitment

RS Covariates

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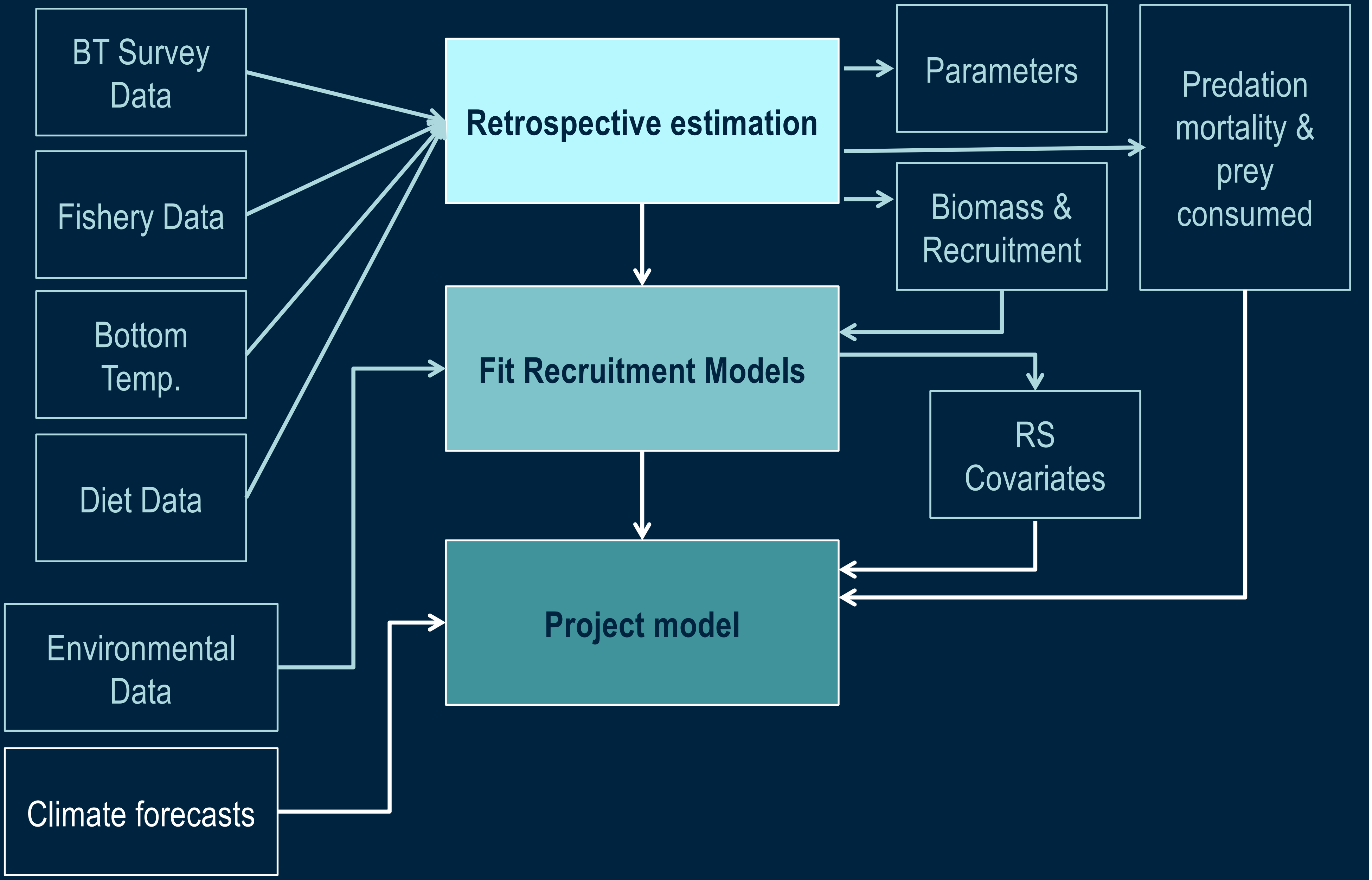
BT Survey Data

Fishery Data

Bottom Temp.

Diet Data

Environmental Data

Climate forecasts

Retrospective estimation

Fit Recruitment Models

Project model

Parameters

Biomass & Recruitment

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RS Covariates

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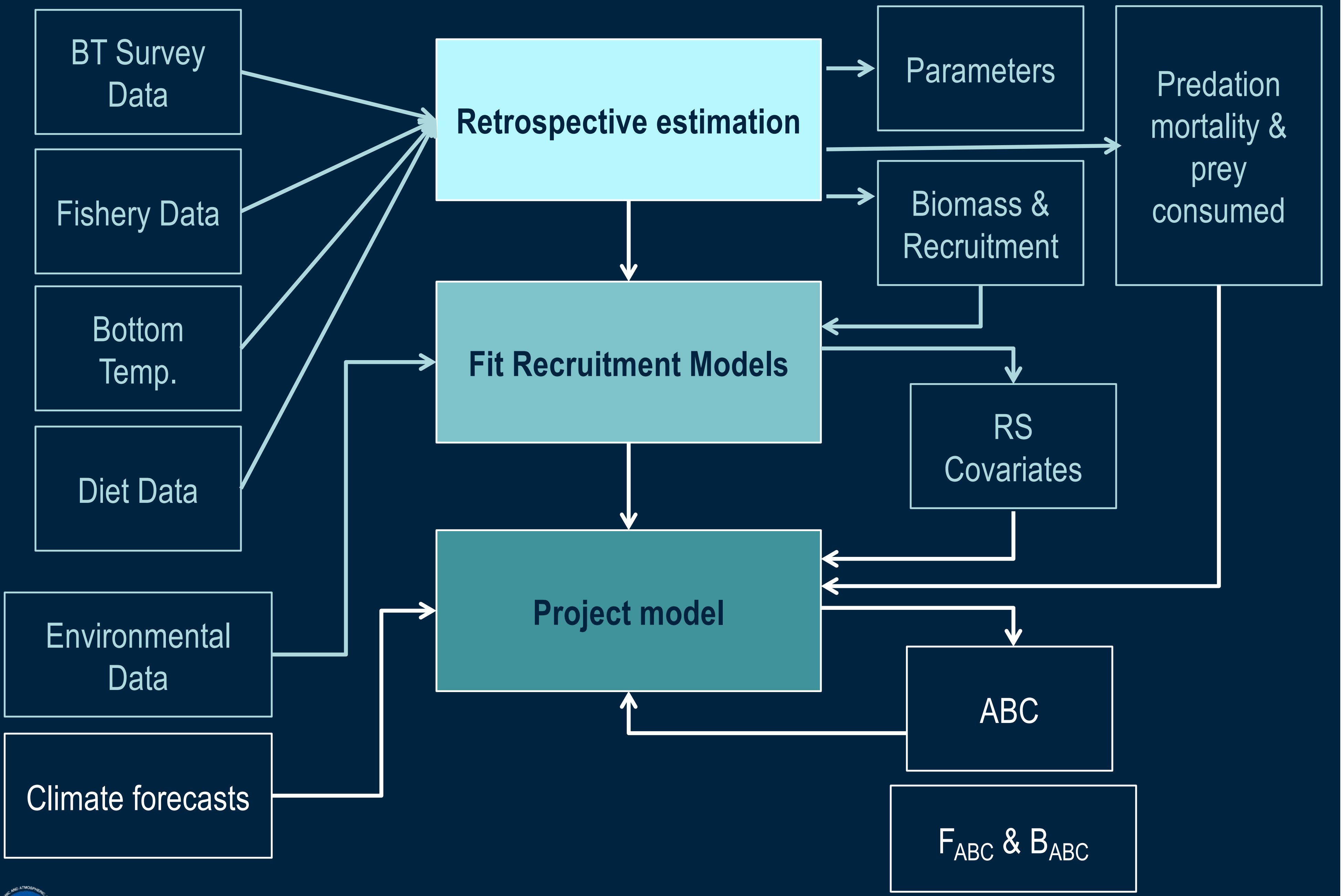

BT Survey Data

Fishery Data

Bottom Temp.

Diet Data

Environmental Data

Climate forecasts

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Parameters

Biomass & Recruitment

Predation mortality & prey consumed

RS Covariates

ABC

F_{ABC} & B_{ABC}

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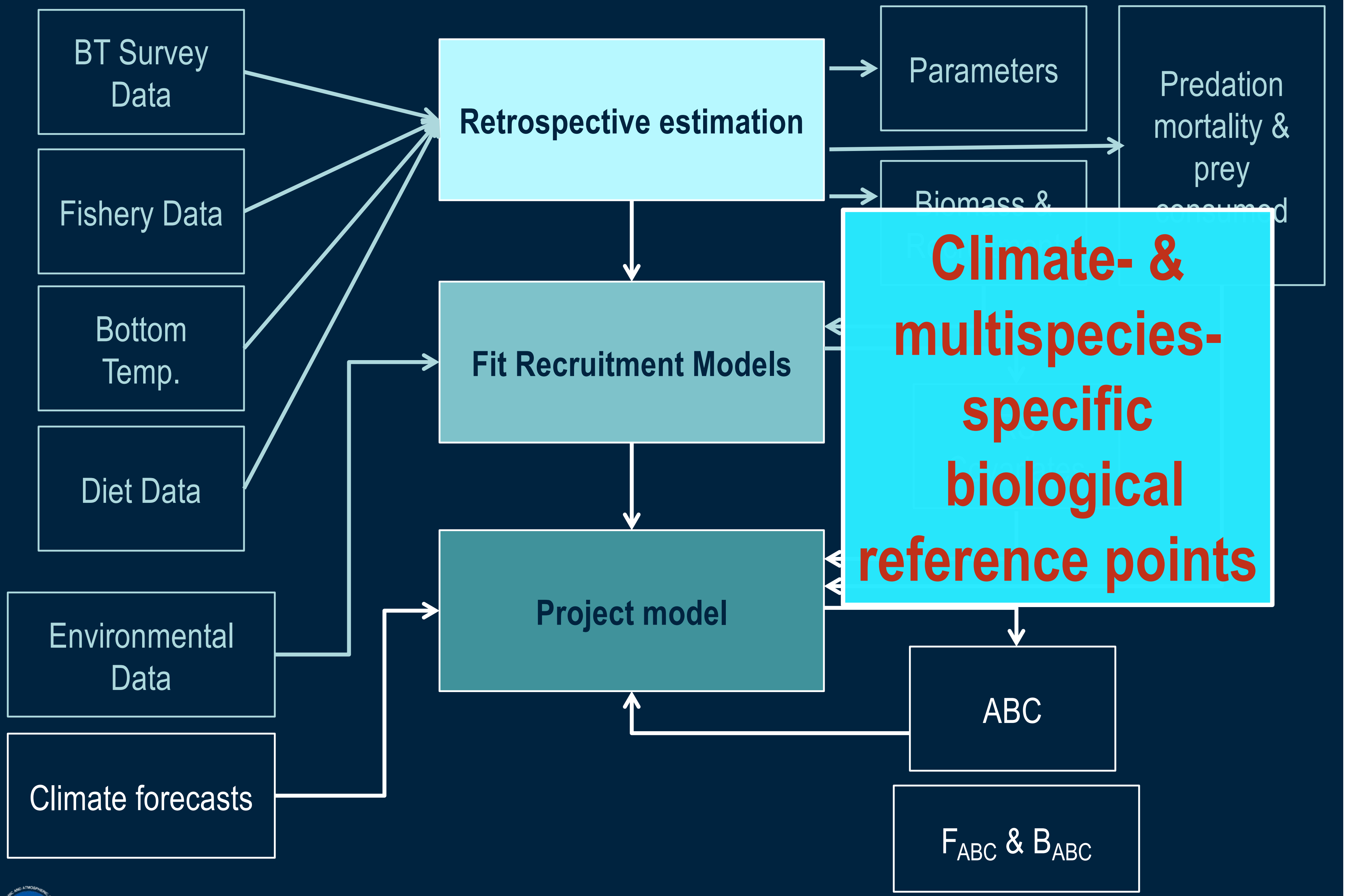


BT Survey Data

Fishery Data

Bottom Temp.

Diet Data

Environmental Data

Climate forecasts

Retrospective estimation

Fit Recruitment Models

Project model

Parameters

Biomass &

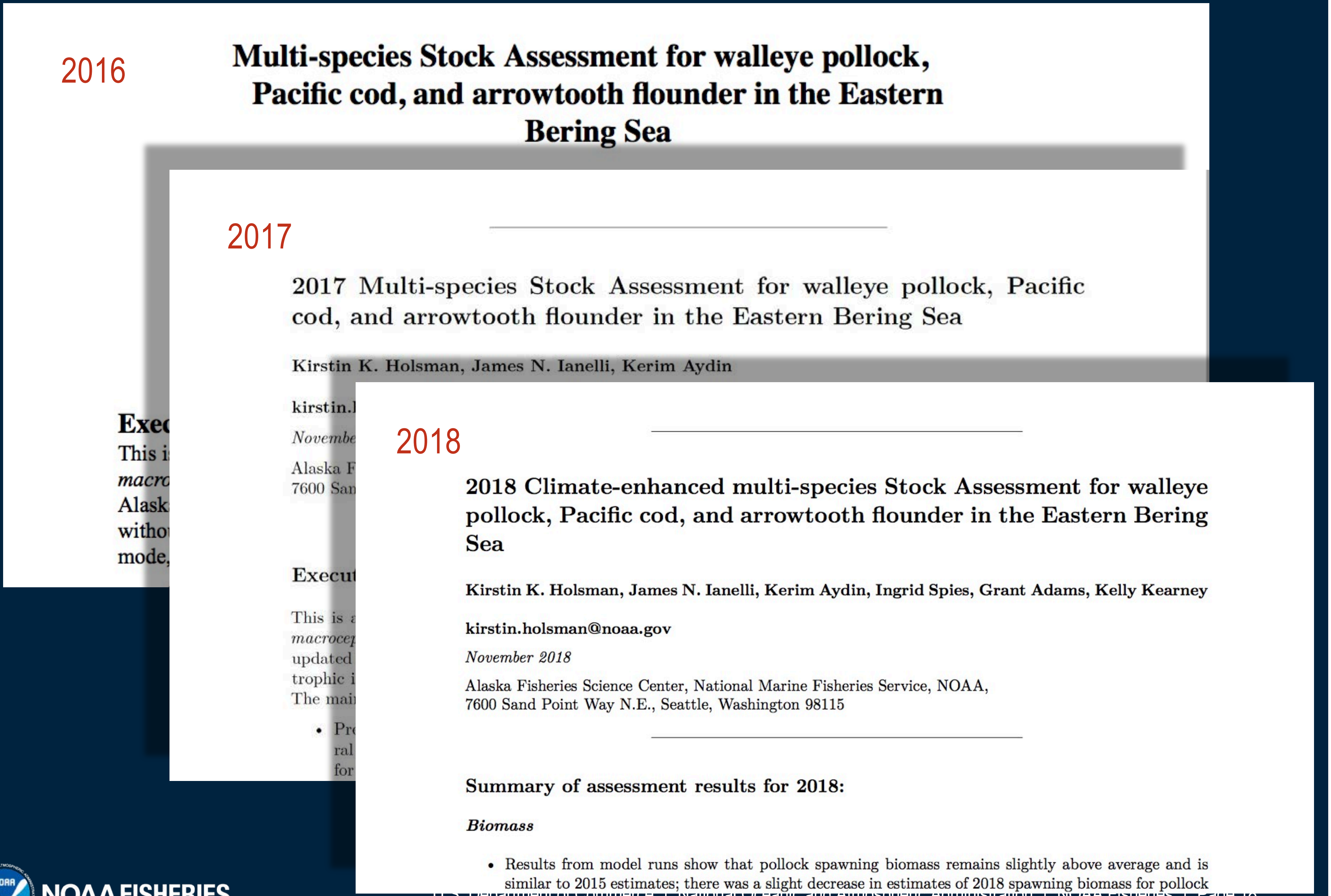
Predation mortality & prey consumed

ABC

F_{ABC} & B_{ABC}

Climate- & multispecies-specific biological reference points

"Shadow Assessment": Multispecies supplement to the BSAI pollock assessment



2016

Multi-species Stock Assessment for walleye pollock, Pacific cod, and arrowtooth flounder in the Eastern Bering Sea

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2017

2017 Multi-species Stock Assessment for walleye pollock, Pacific cod, and arrowtooth flounder in the Eastern Bering Sea

Kirstin K. Holsman, James N. Ianelli, Kerim Aydin

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2018

2018 Climate-enhanced multi-species Stock Assessment for walleye pollock, Pacific cod, and arrowtooth flounder in the Eastern Bering Sea

Kirstin K. Holsman, James N. Ianelli, Kerim Aydin, Ingrid Spies, Grant Adams, Kelly Kearney

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November 2018

Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA,
7600 Sand Point Way N.E., Seattle, Washington 98115

Summary of assessment results for 2018:

Biomass

- Results from model runs show that pollock spawning biomass remains slightly above average and is similar to 2015 estimates; there was a slight decrease in estimates of 2018 spawning biomass for pollock

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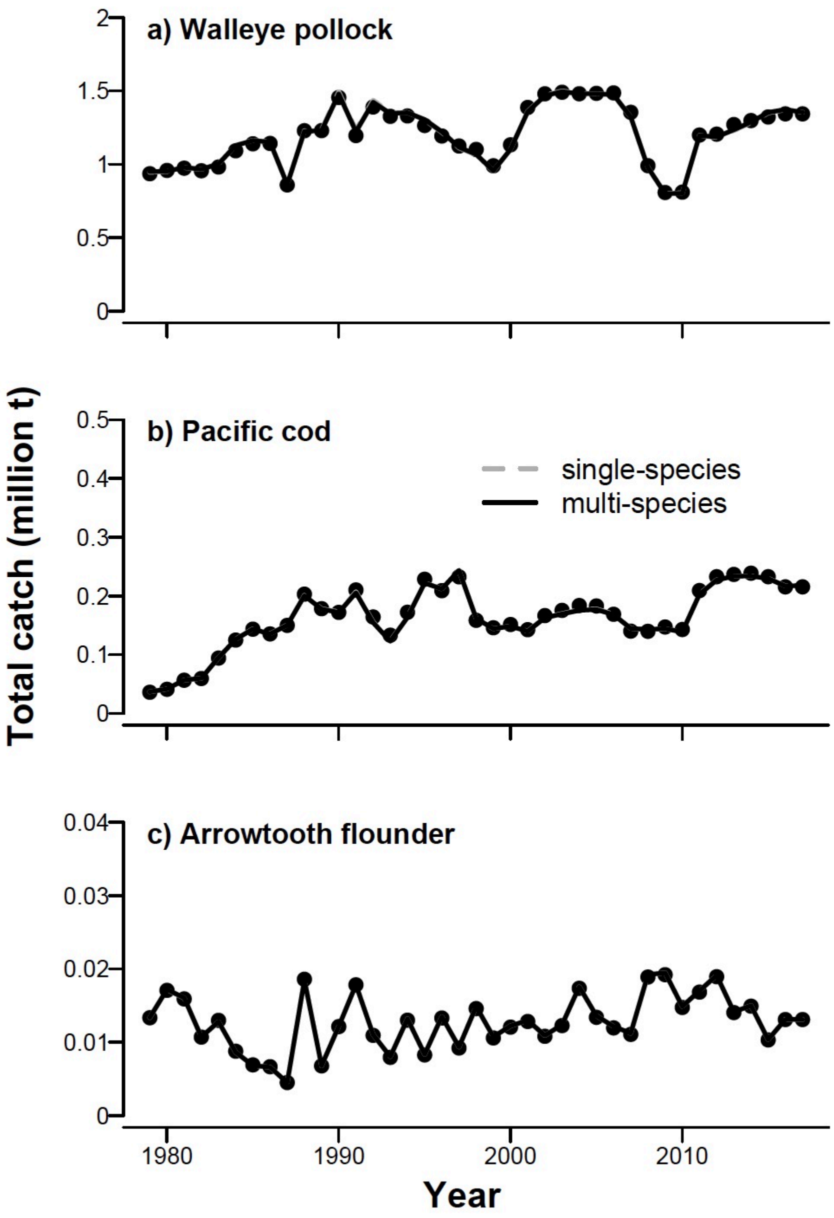
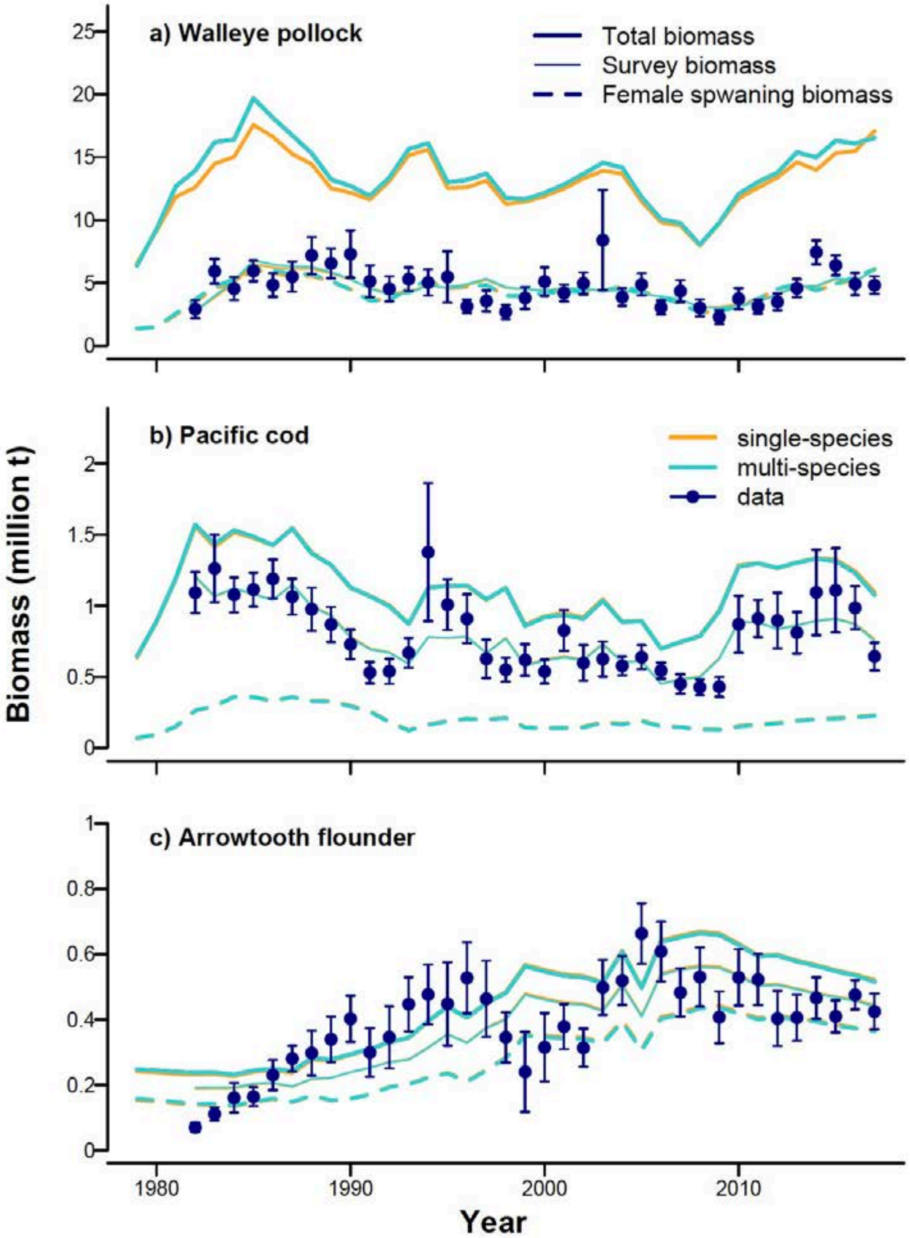
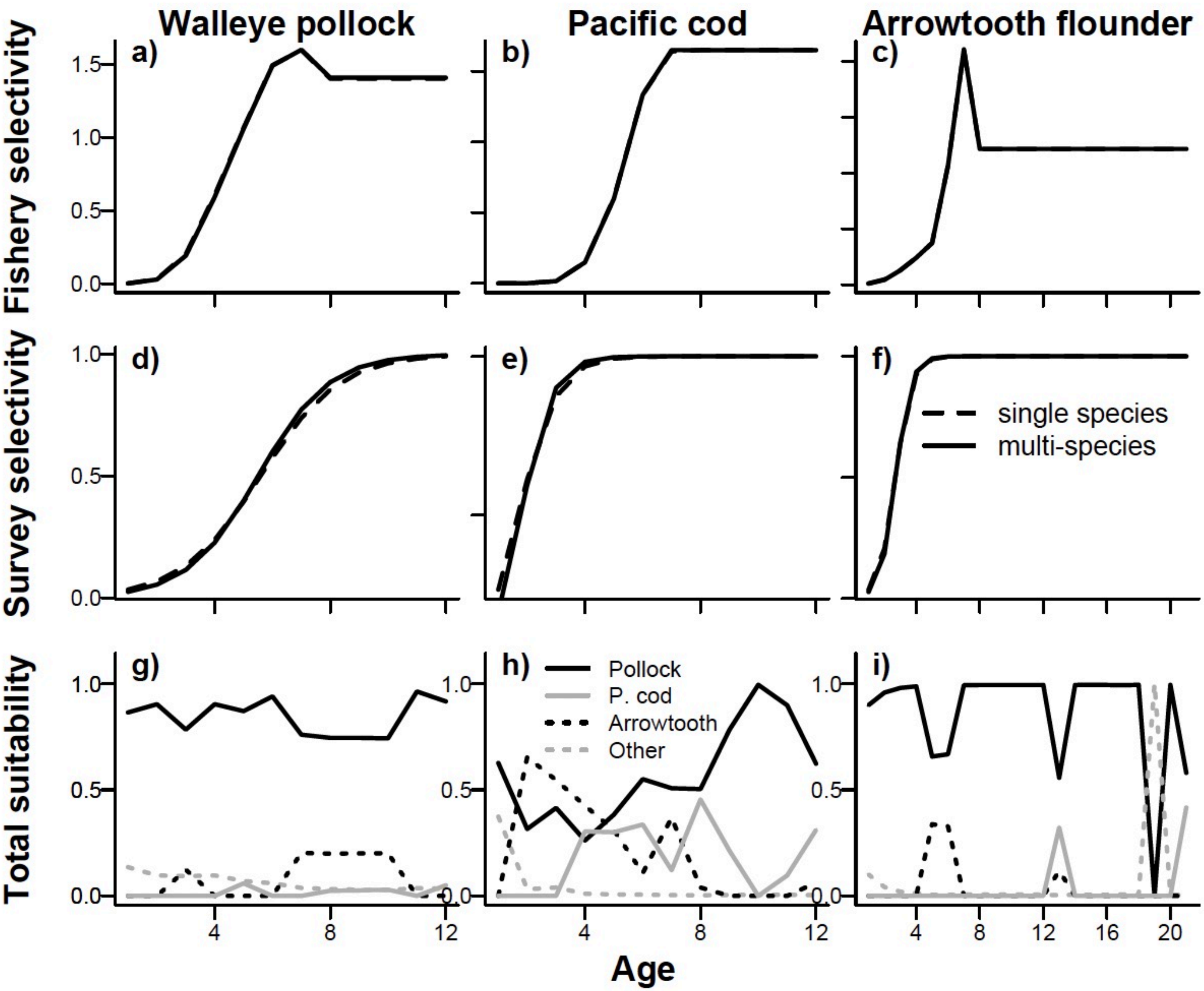
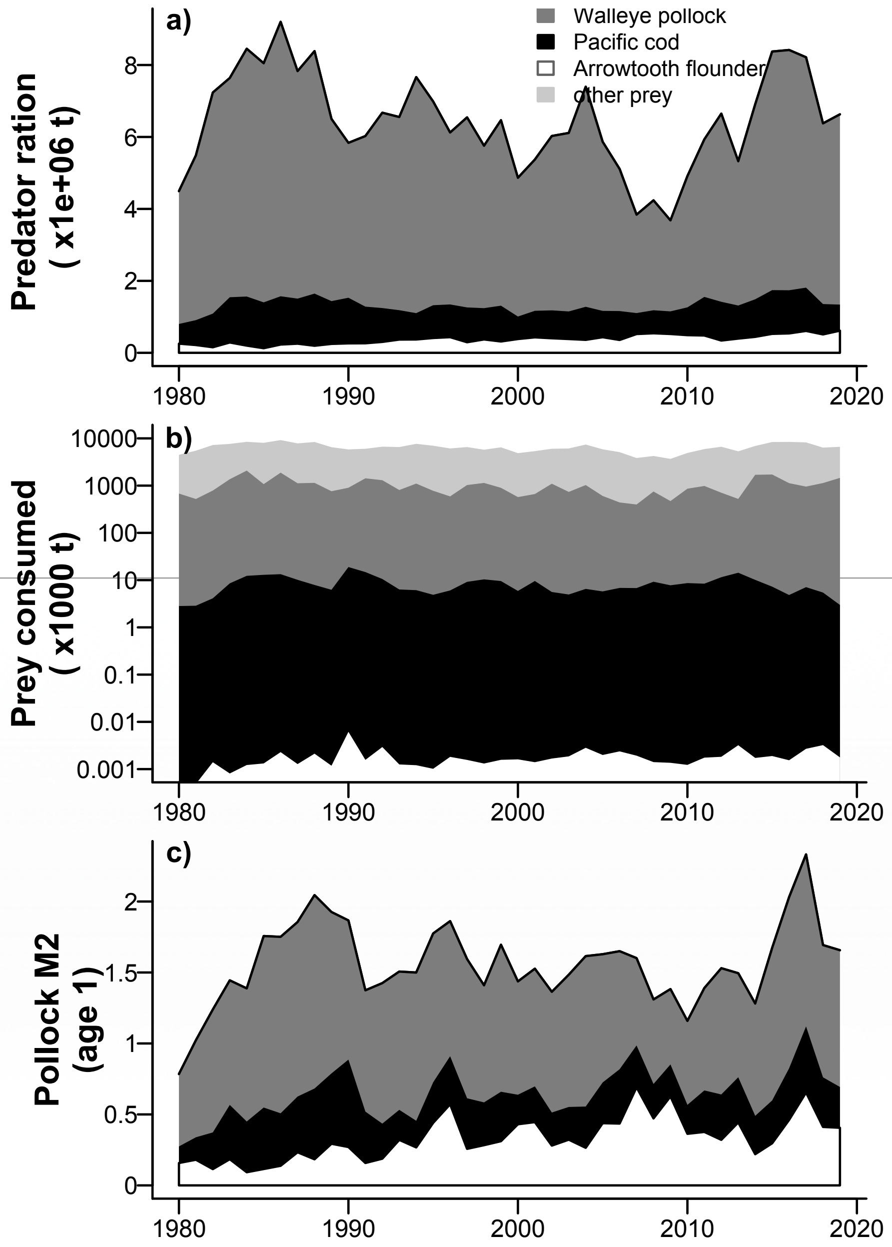
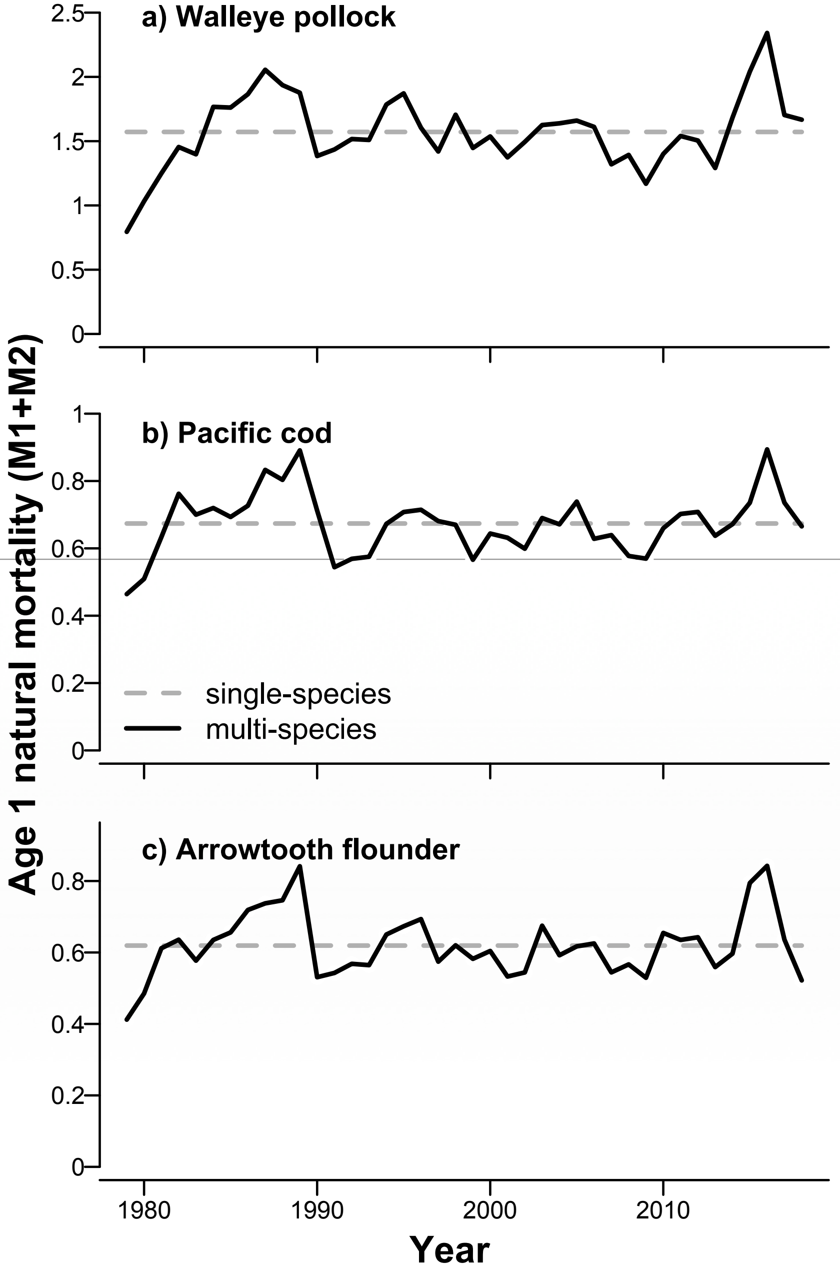

Total catch (million t)
a) Walleye pollock
2
1.5
1
0.5
0
b) Pacific cod
0.5
0.4
0.3
0.2
0.1
0
single-species
multi-species
c) Arrowtooth flounder
0.04
0.03
0.02
0.01
0
1980
1990
2000
2010
Year

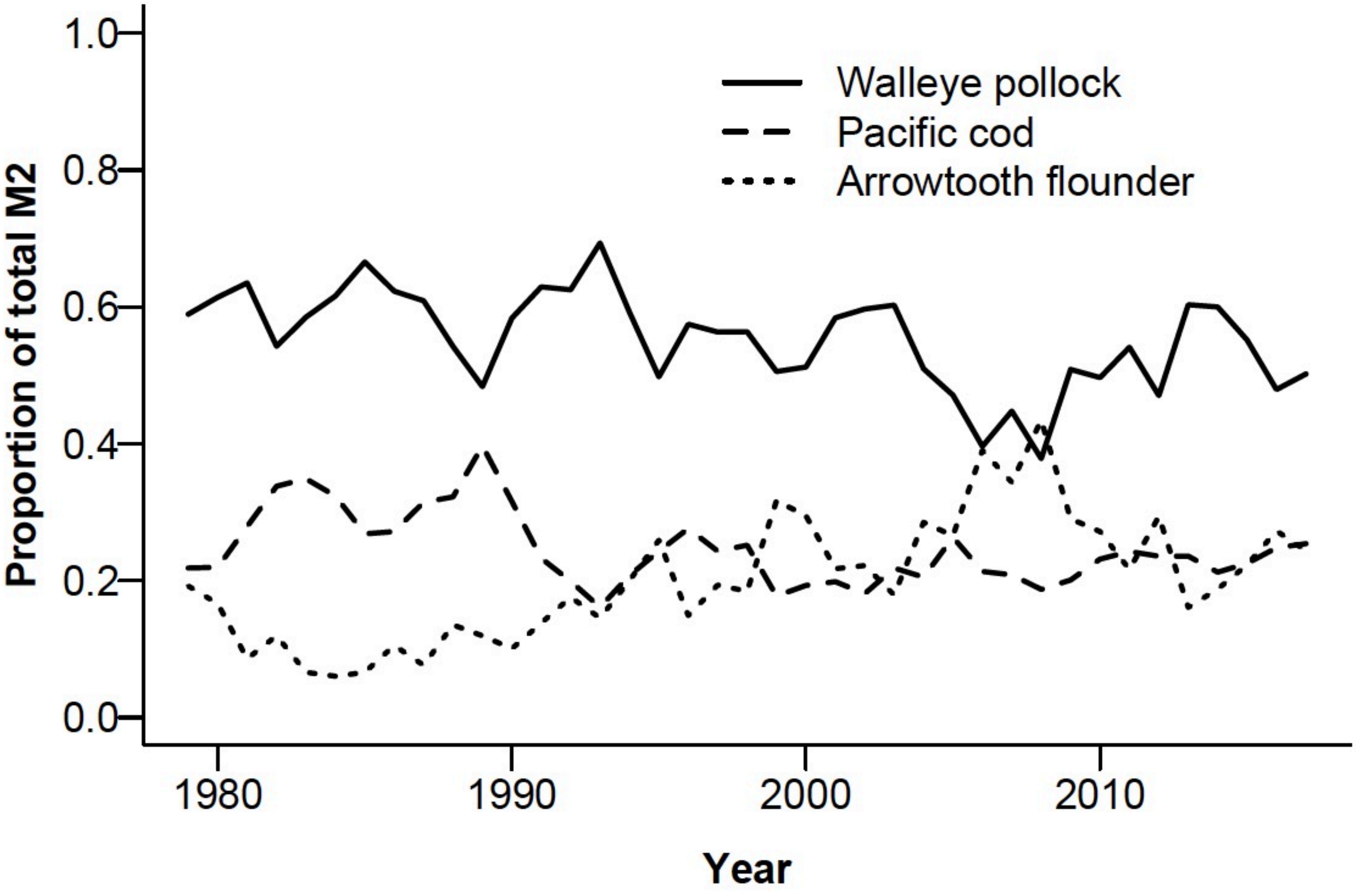

Biomass (million t)
a) Walleye pollock
Total biomass
Survey biomass
Female spwaning biomass
25
20
15
10
5
0
b) Pacific cod
single-species
multi-species
data
2
1.5
1
0.5
0
c) Arrowtooth flounder
1
0.8
0.6
0.4
0.2
0
1980
1990
2000
2010
Year


Walleye pollock
Pacific cod
Arrowtooth flounder
Fishery selectivity
Survey selectivity
Total suitability
a)
b)
c)
d)
e)
f)
g)
h)
i)
1.5
1.0
0.5
0.0
single species
multi-species
Pollock
P. cod
Arrowtooth
Other
4
8
12
16
20
Age


a)
Walleye pollock
Pacific cod
Arrowtooth flounder
other prey
Predator ration (x1e+06 t)
0
2
4
6
8
1980
1990
2000
2010
2020
b)
Prey consumed (x1000 t)
10000
1000
100
10
1
0.1
0.01
0.001
1980
1990
2000
2010
2020
c)
Pollock M2 (age 1)
0
0.5
1
1.5
2
1980
1990
2000
2010
2020

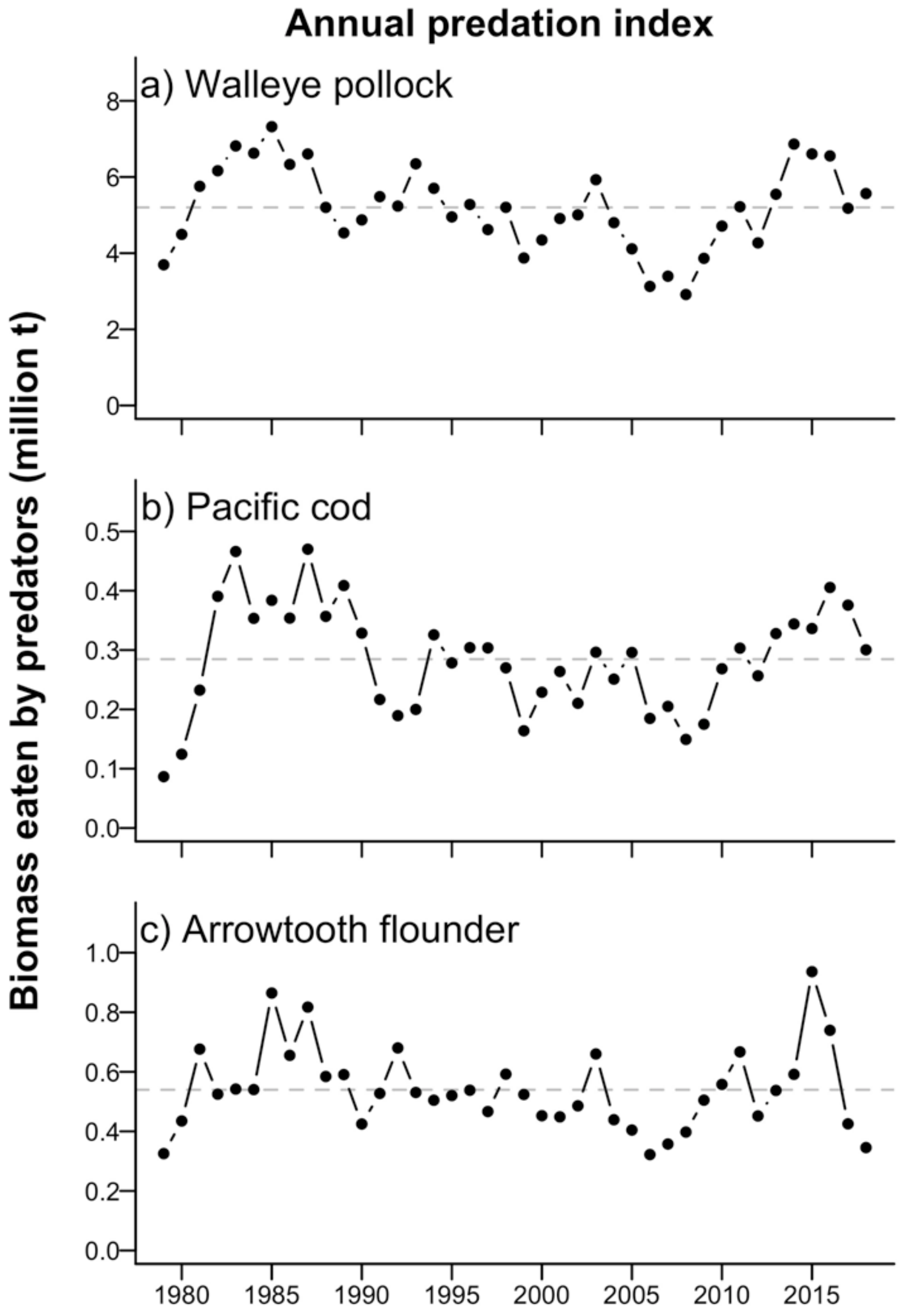

a) Walleye pollock
0
0.5
1
1.5
2
2.5
b) Pacific cod
0
0.2
0.4
0.6
0.8
1
single-species
multi-species
c) Arrowtooth flounder
0
0.2
0.4
0.6
0.8
Age 1 natural mortality (M1+M2)
1980
1990
2000
2010
Year

Pollock M2

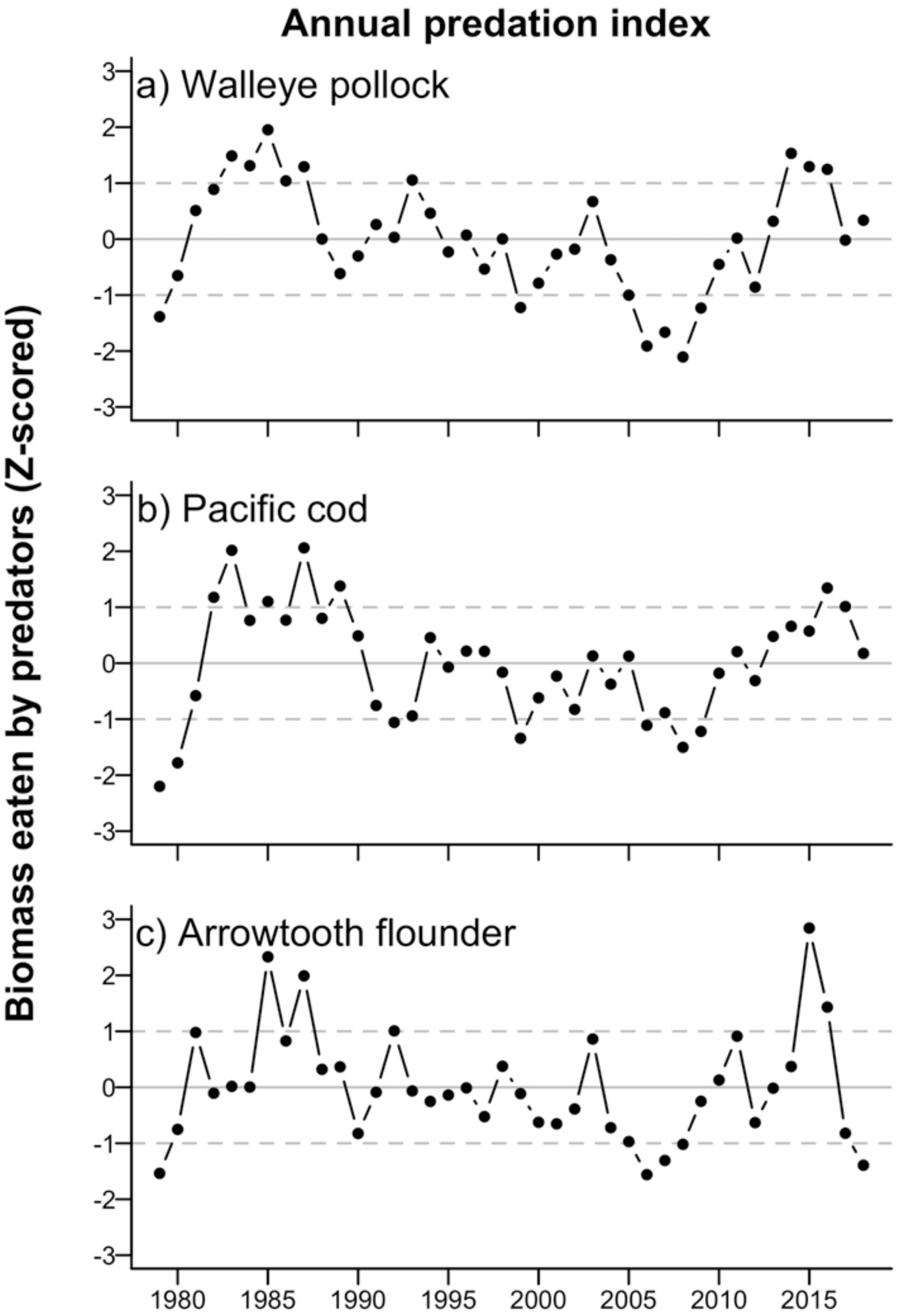


1.0
0.8
0.6
0.4
0.2
0.0
Proportion of total M2
1980
1990
2000
2010
Year
Walleye pollock
Pacific cod
Arrowtooth flounder

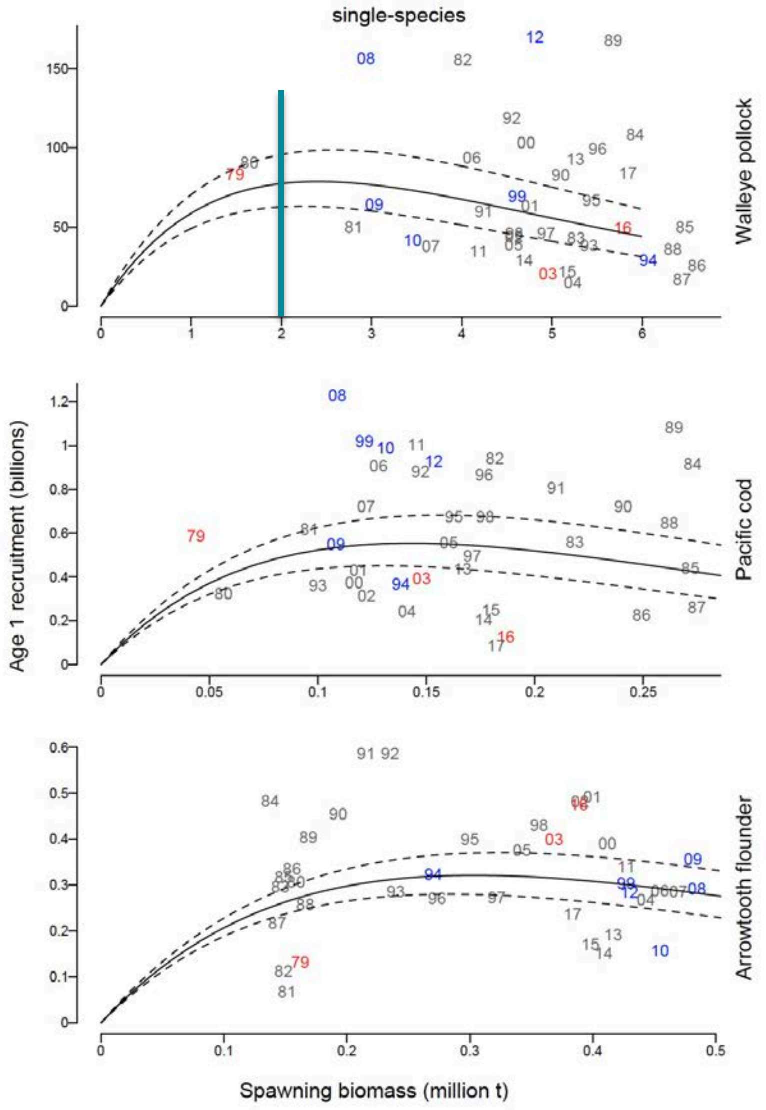
Predation Index



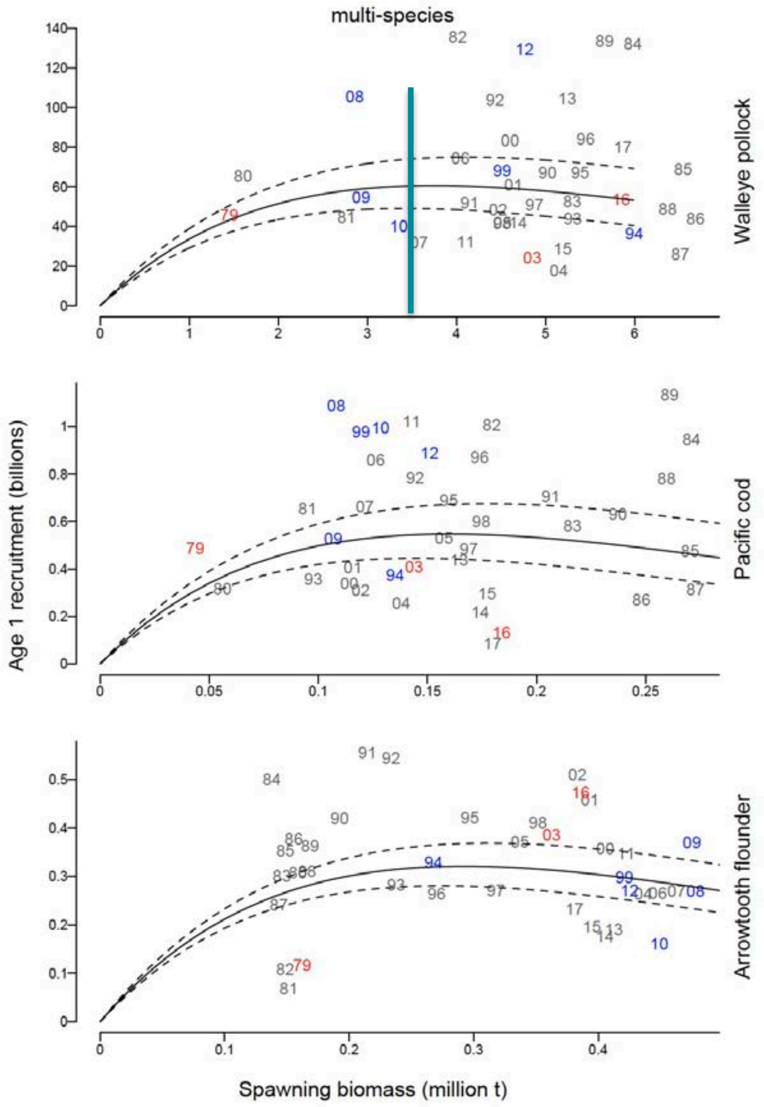
Predation Index



CEATTLE Recruitment: Arrowtooth

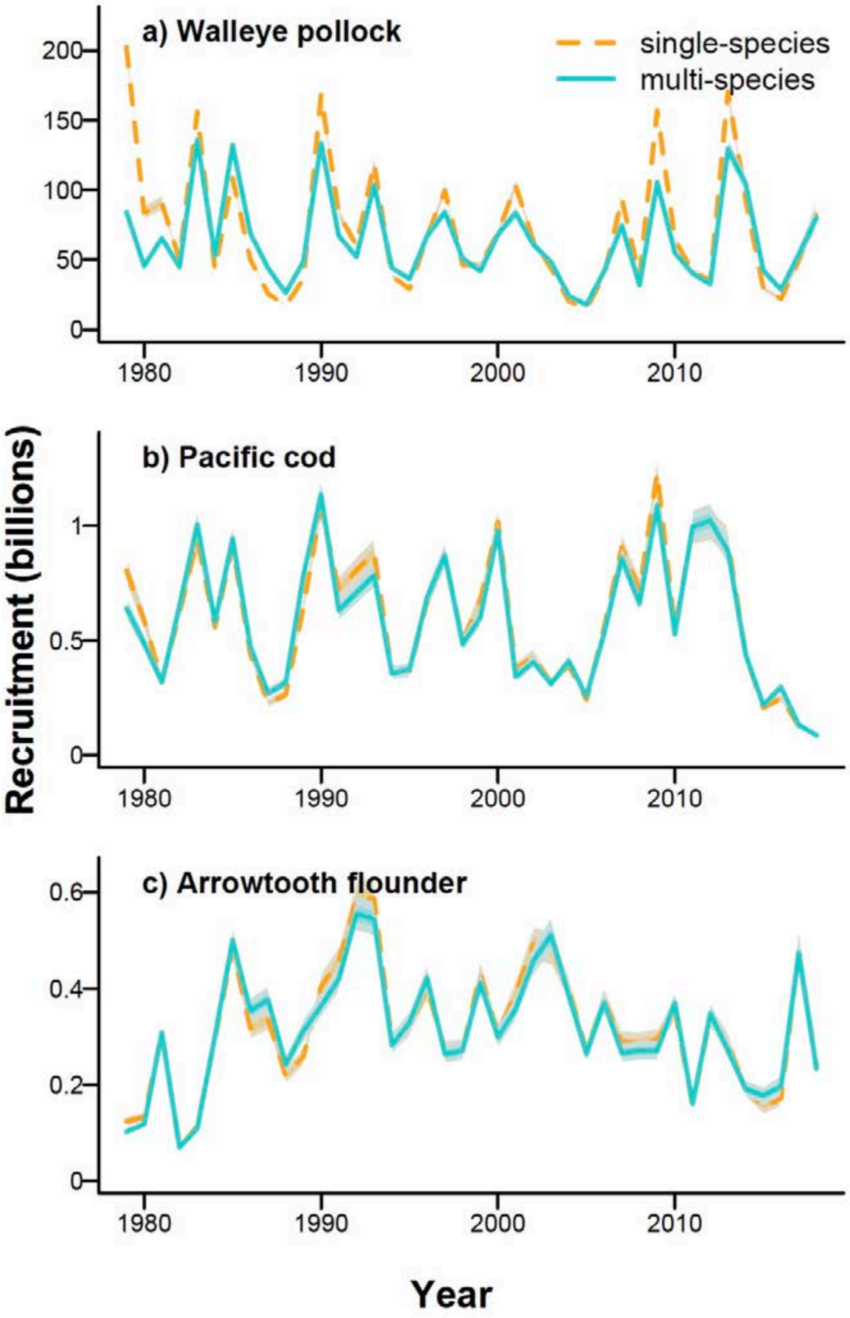


18: Stock-recruit curves for the single-species model. Red and blue text indicates years where bot
ature was + or ??? 1 standard deviation from the mean (respectively).

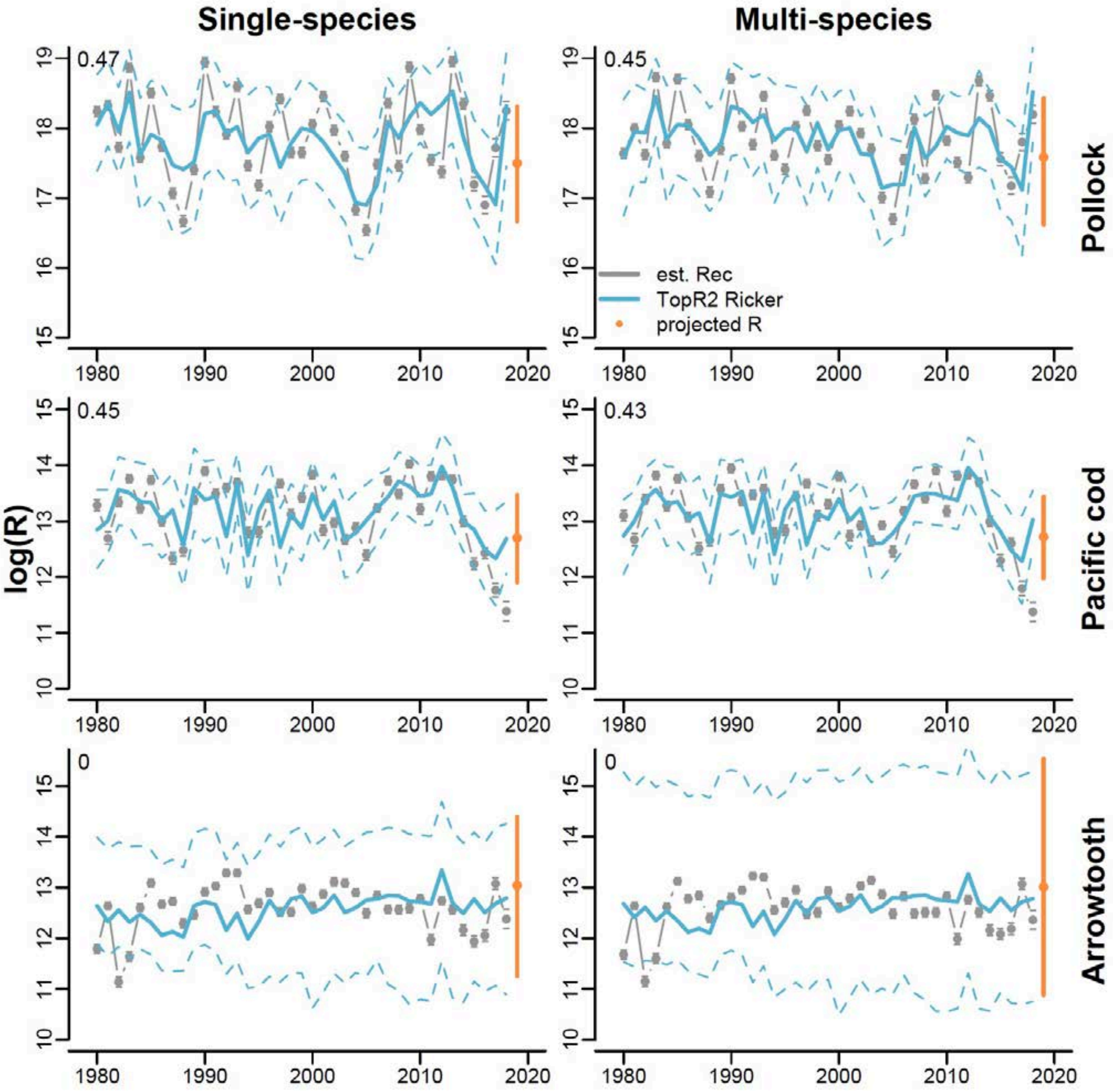


9: Stock-recruit curves for the multi-species model. Red and blue text indicates years where bot
ture was + or ??? 1 standard deviation from the mean (respectively).

Recruitment



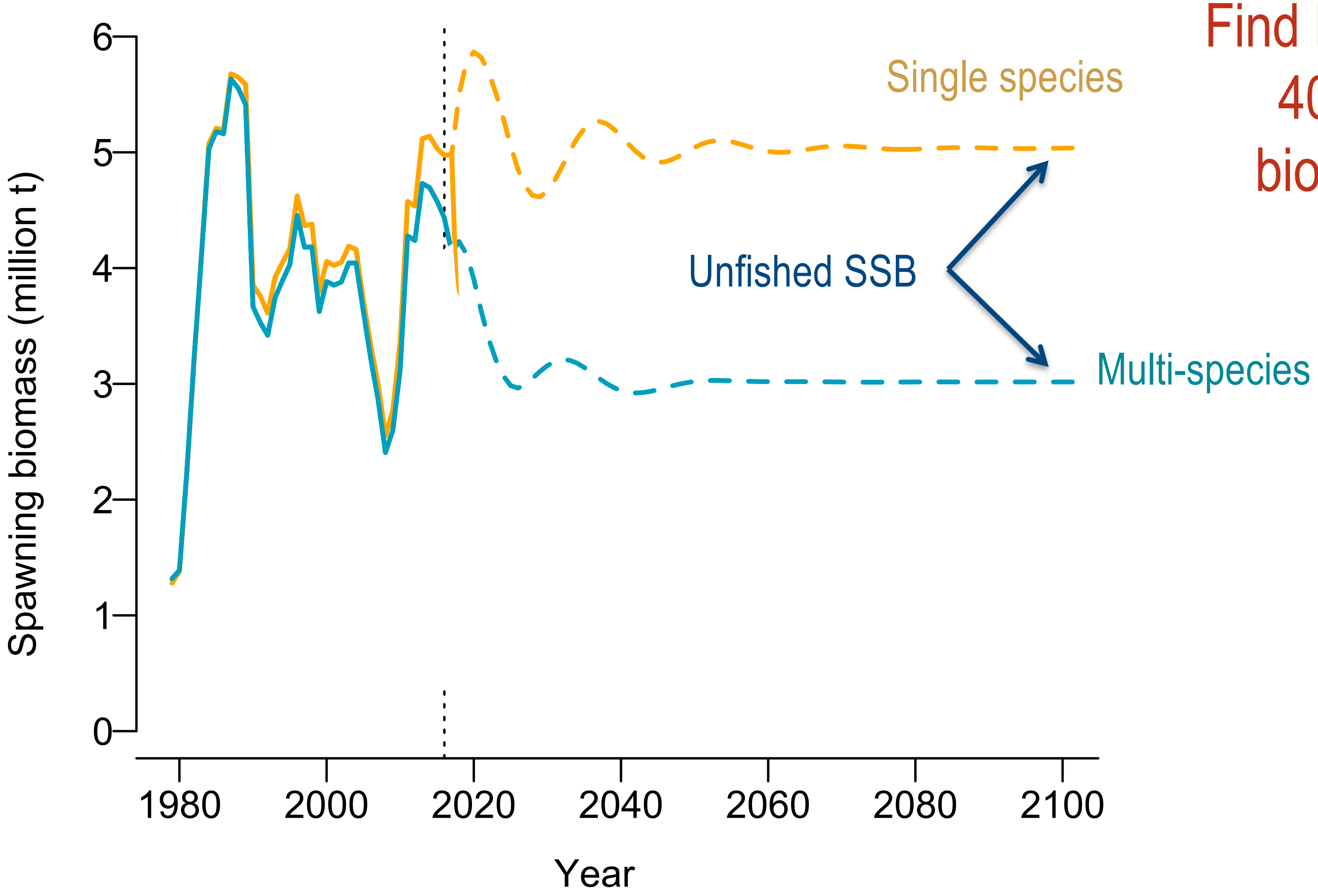
Recruitment



Projections for BRPs

Photo: Mark Holsman

ABC multi-species proxy approach (Moffitt et al. 2016)

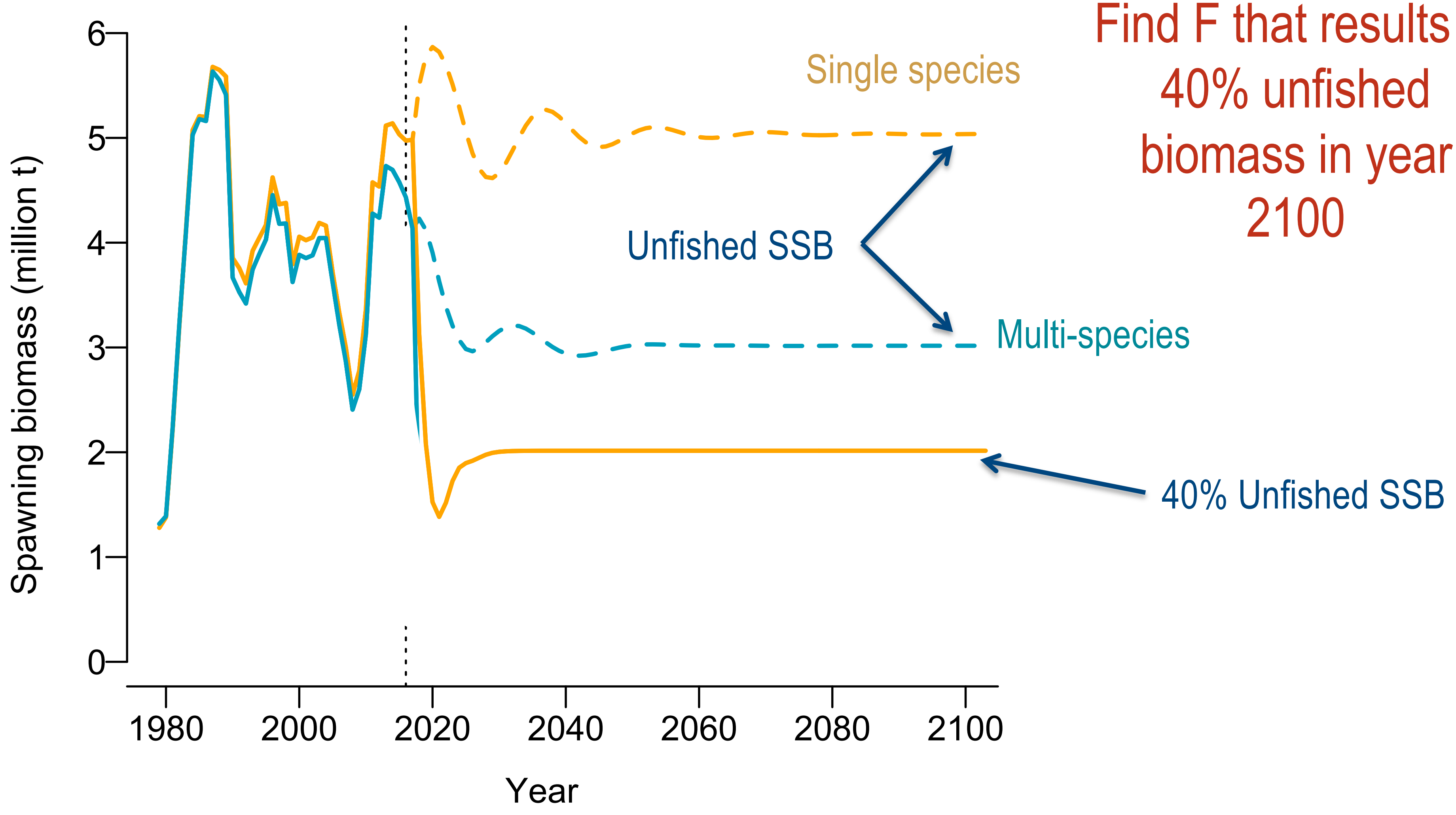


Find F that results in 40% unfished biomass in year 2100

$$\text{Eq. } 4 \qquad \mathrm{ABC}_{x,i,y} = \sum_j^{A_i}((F^*_{\mathrm{ABC},x,i} s^{\mathrm{f}}_{ij}/Z_{x,ij,y})(1-e^{-Z_{x,ij,y}})N_{x,ij,y}W_{ij,y})$$

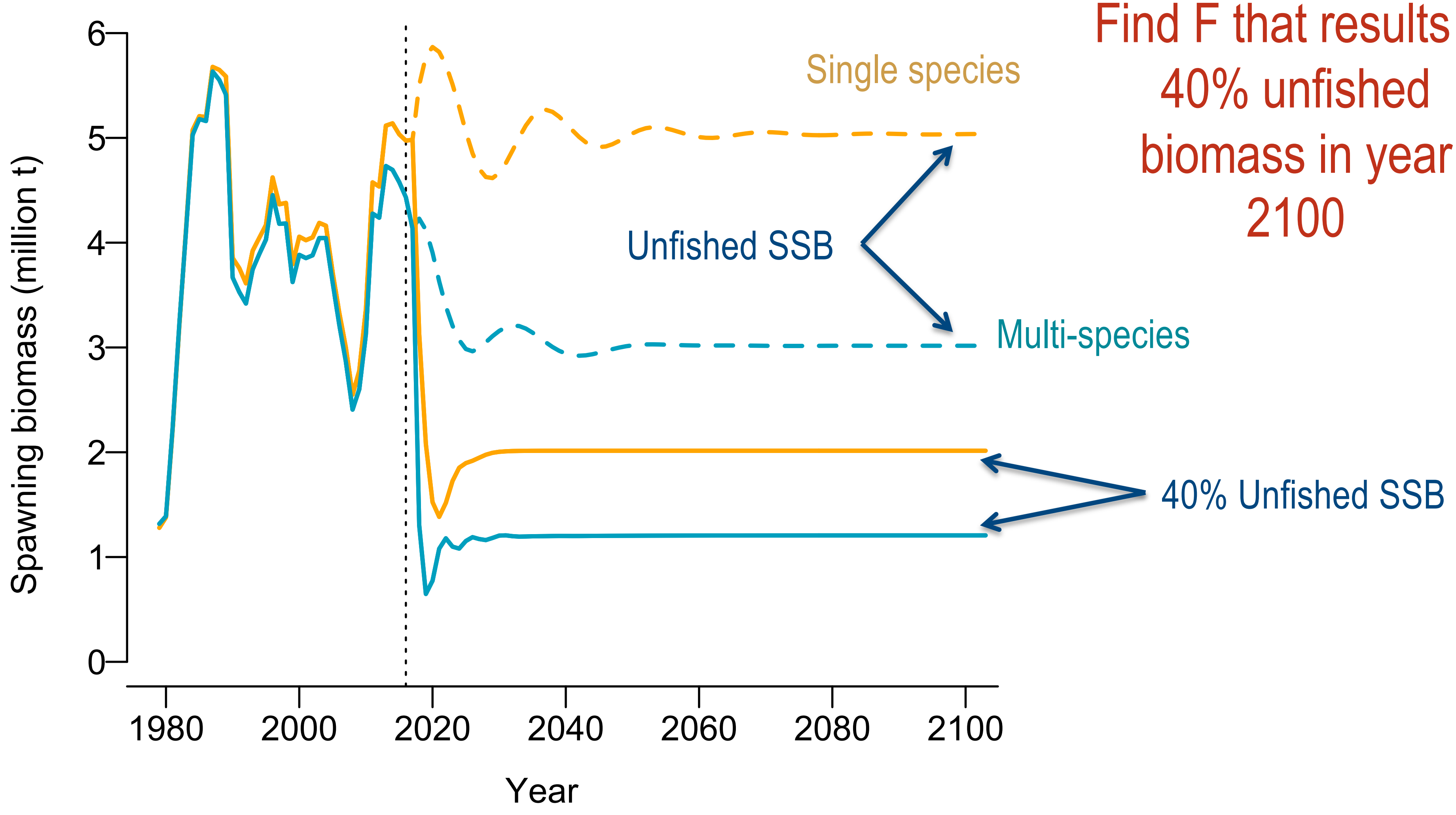
ABC multi-species proxy approach (Moffitt et al. in press)

Find F that results in 40% unfished biomass in year 2100



Eq. 4 $$\mathrm{ABC}_{x,i,y} = \sum_j^{A_i}((F^*_{\mathrm{ABC},x,i} s^{\mathrm{f}}_{ij}/Z_{x,ij,y})(1-e^{-Z_{x,ij,y}})N_{x,ij,y}W_{ij,y})$$

ABC multi-species proxy approach (Moffitt et al. in press)



Find F that results in 40% unfished biomass in year 2100

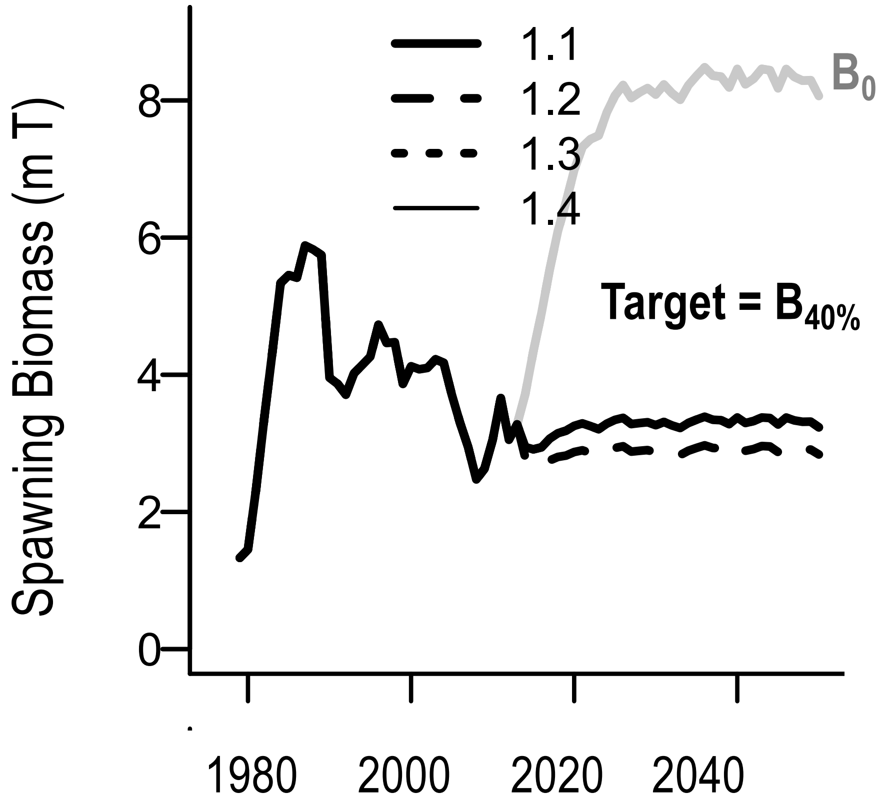
Eq. 4 $$\mathrm{ABC}_{x,i,y} = \sum_j^{A_i}((F^*_{\mathrm{ABC},x,i}s^{\mathrm{f}}_{ij}/Z_{x,ij,y})(1-e^{-Z_{x,ij,y}})N_{x,ij,y}W_{ij,y})$$

Harvest

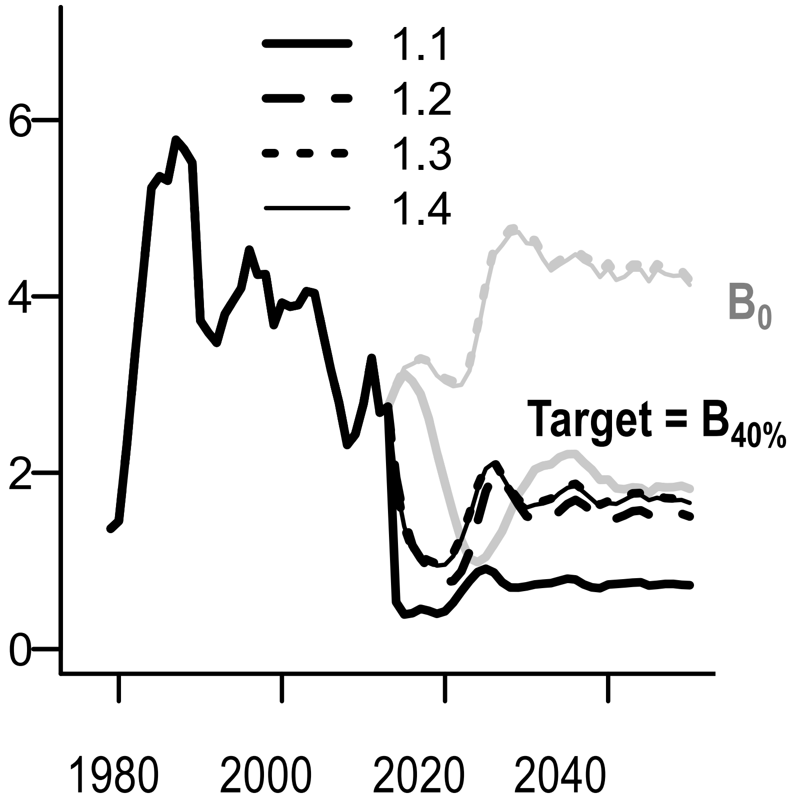
Single-species

Multi-species

Harvest scenario 1

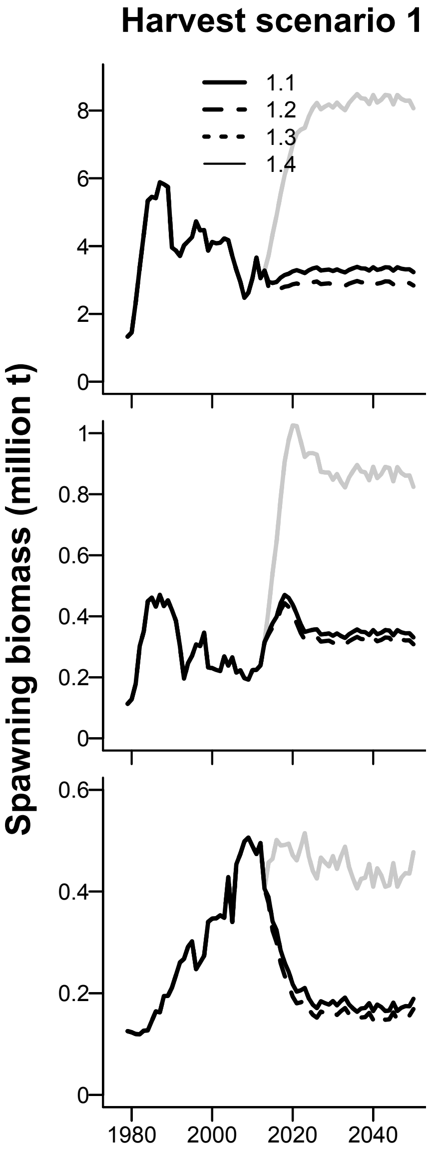


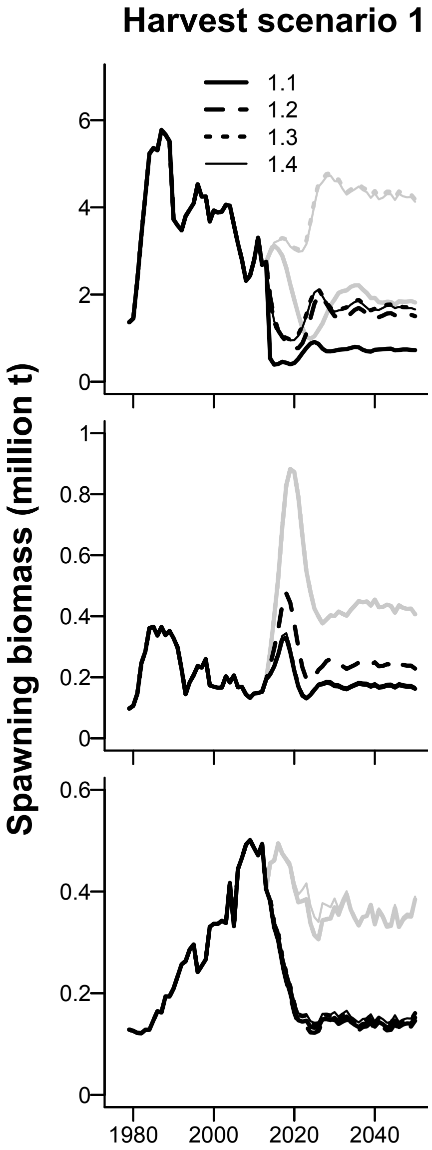
Harvest scenario 1



Holsman et al. *2016*

Single-species Multi-species

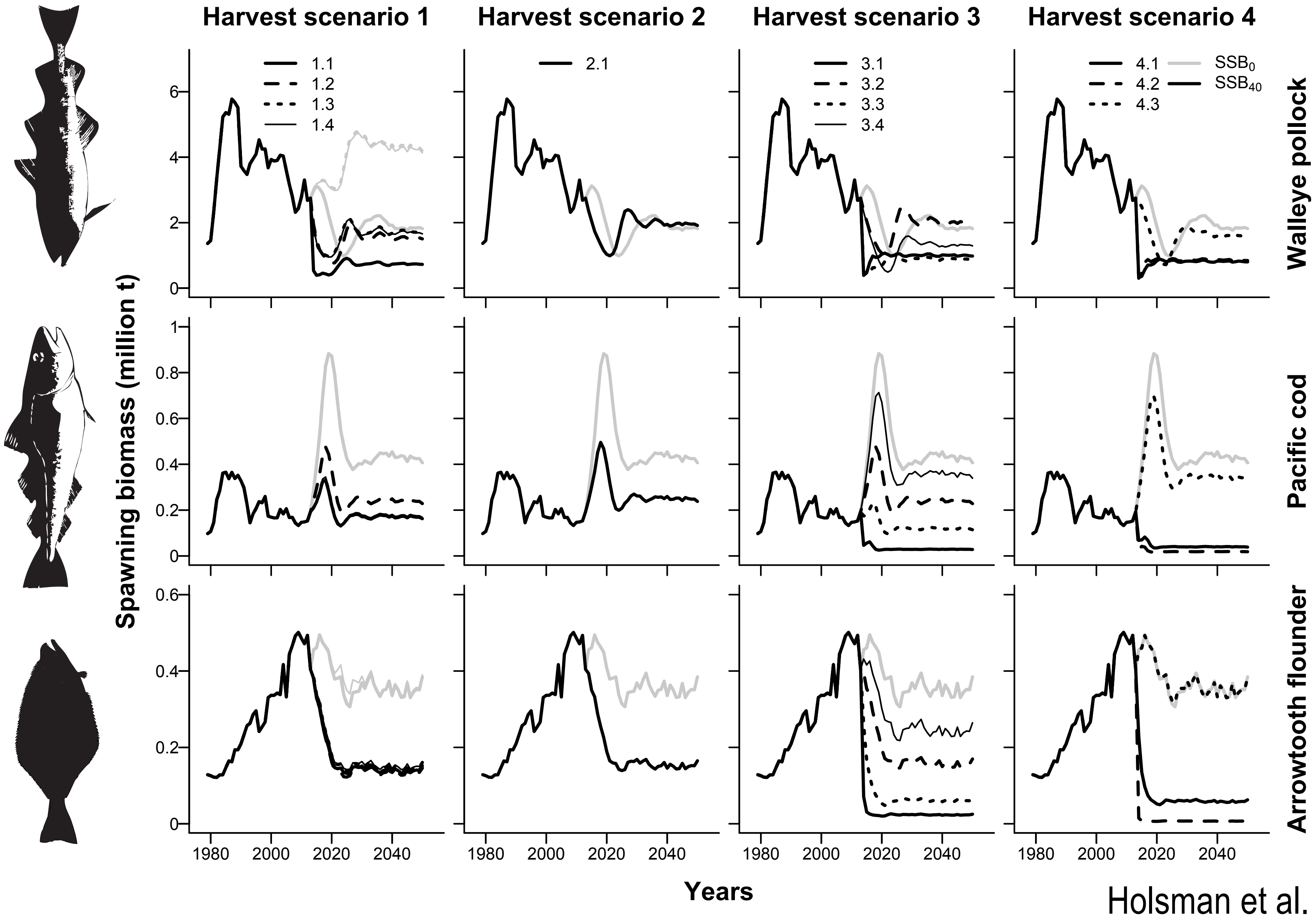




Differences between
Harvest Scenarios
Is greatest for prey spp

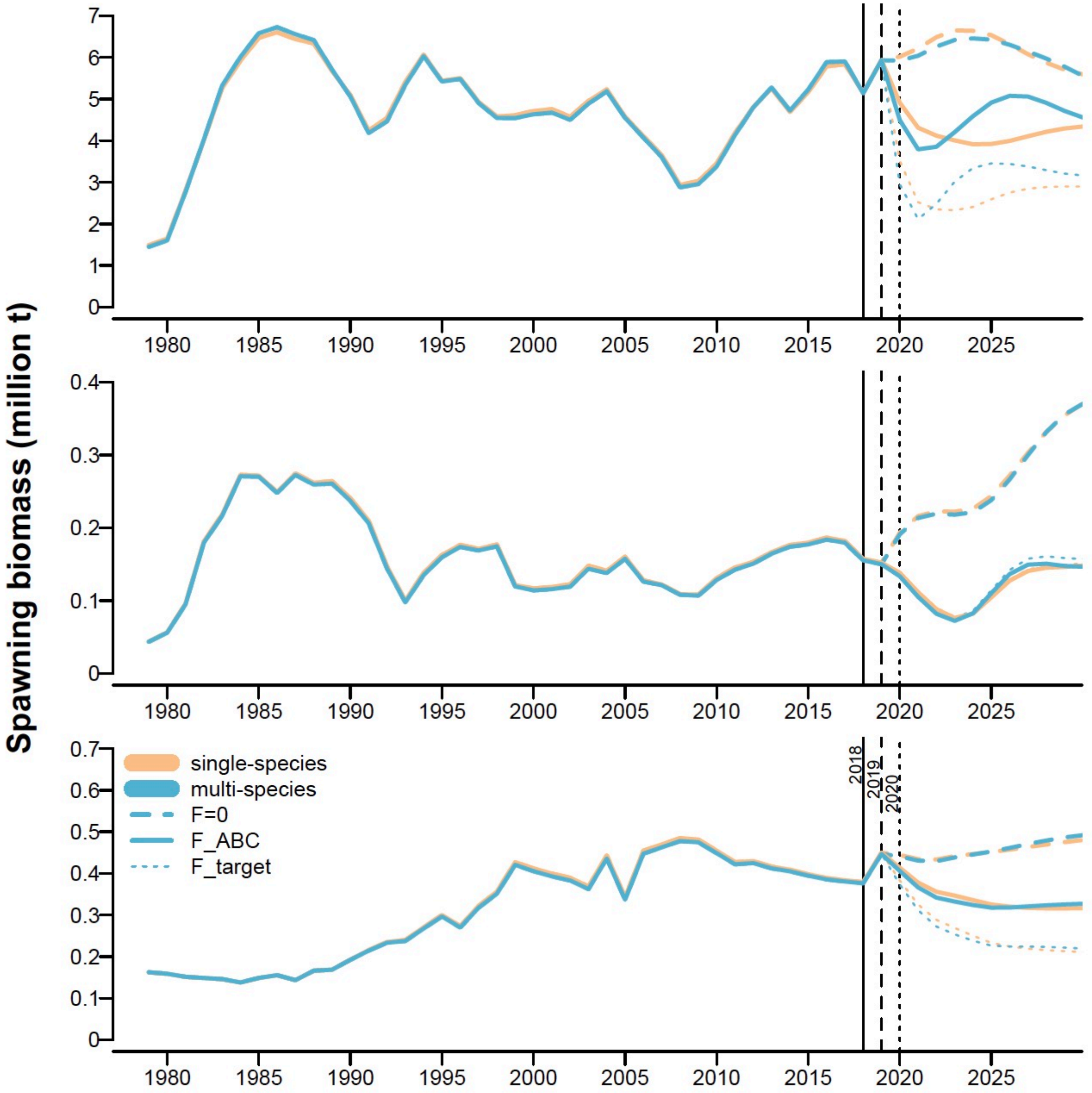
Holsman et al. *2016*

Multispecies control rules



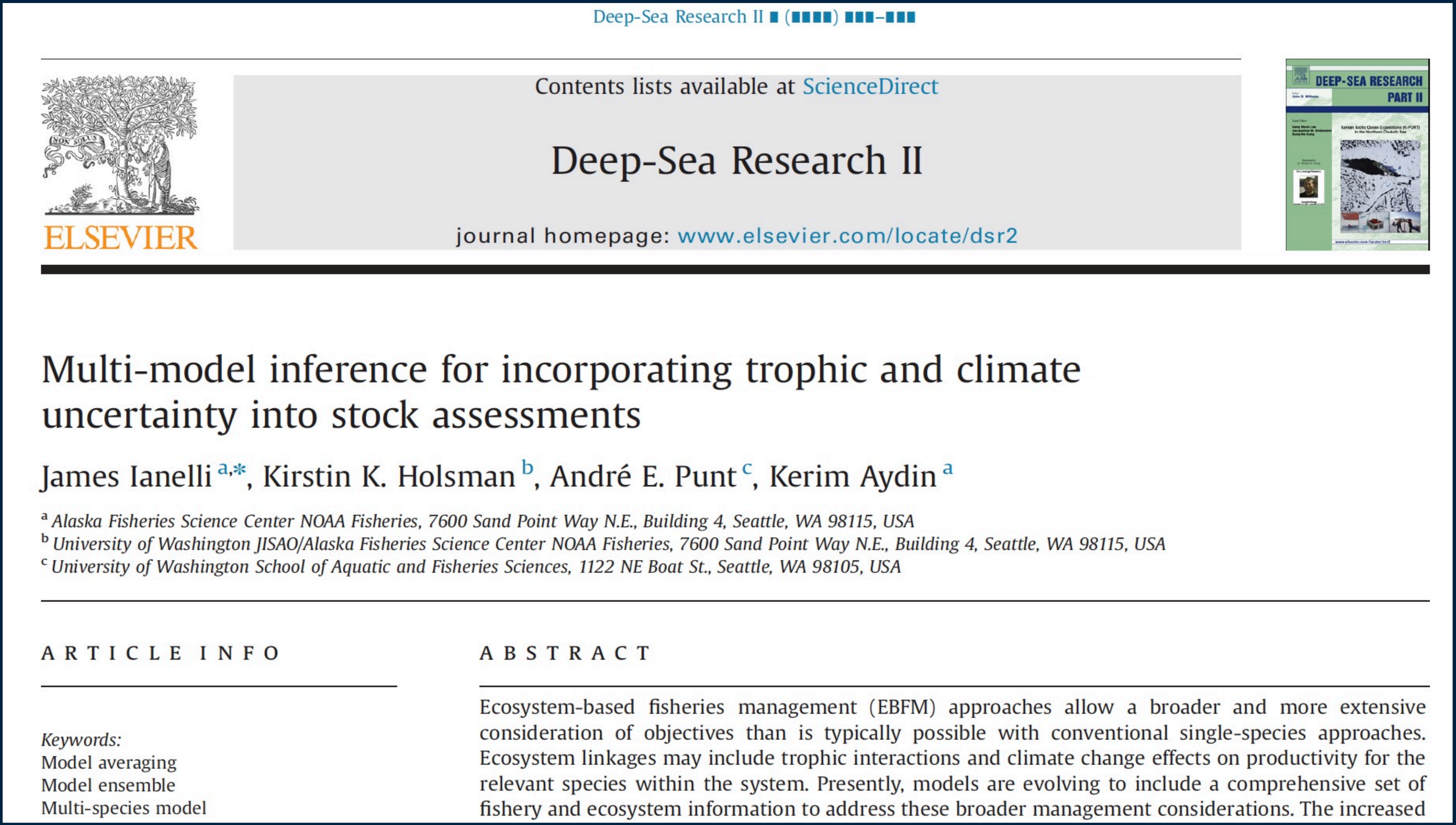
Holsman et al. *2016*

Multispecies control rules



Holsman et al. *2018*

Ianelli et al. in press: Blended Forecasts



Deep-Sea Research II ∎ (∎∎∎∎) ∎∎∎–∎∎∎

Contents lists available at ScienceDirect

Deep-Sea Research II

journal homepage: www.elsevier.com/locate/dsr2

Multi-model inference for incorporating trophic and climate uncertainty into stock assessments

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ARTICLE INFO

Keywords:
Model averaging
Model ensemble
Multi-species model

ABSTRACT

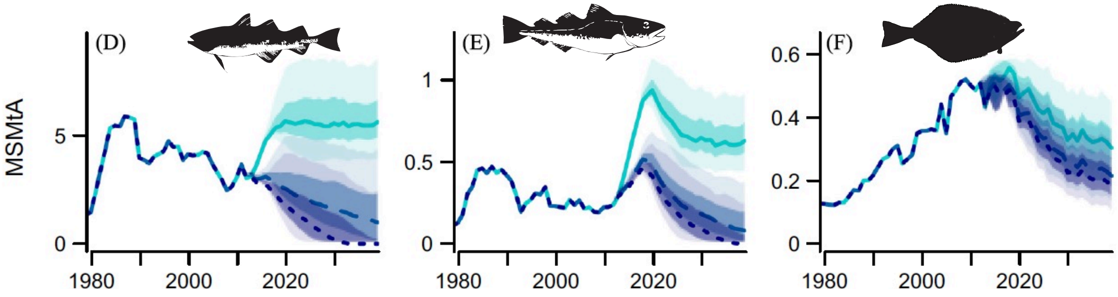
Ecosystem-based fisheries management (EBFM) approaches allow a broader and more extensive consideration of objectives than is typically possible with conventional single-species approaches. Ecosystem linkages may include trophic interactions and climate change effects on productivity for the relevant species within the system. Presently, models are evolving to include a comprehensive set of fishery and ecosystem information to address these broader management considerations. The increased

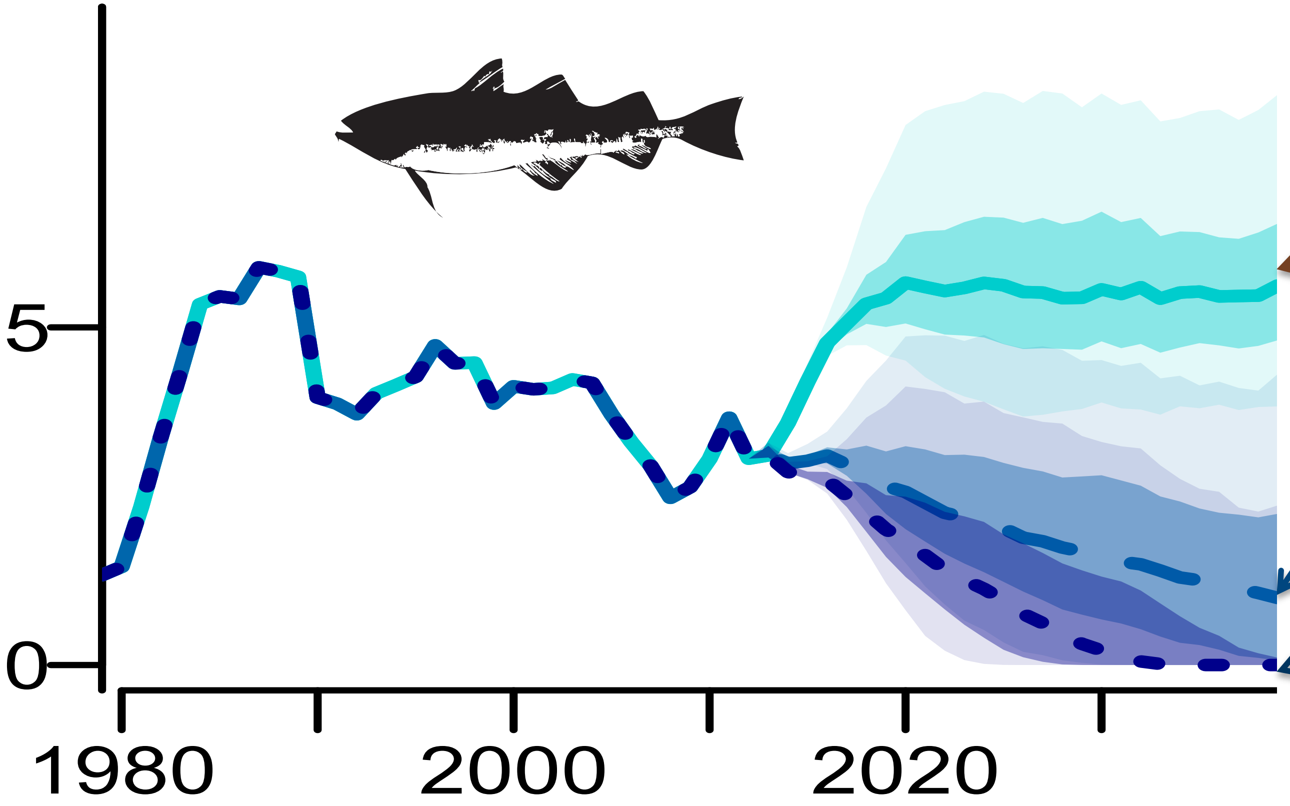
Ianelli, J KK Holsman, AE Punt, K Aydin (2015). Multi-model inference for incorporating trophic and climate uncertainty into stock assessment estimates of fishery biological reference points. Deep Sea Res II. DOI: 10.1016/j.dsr2.2015.04.002

CEATTLE: Single-species

Mean R

Temp→W@A



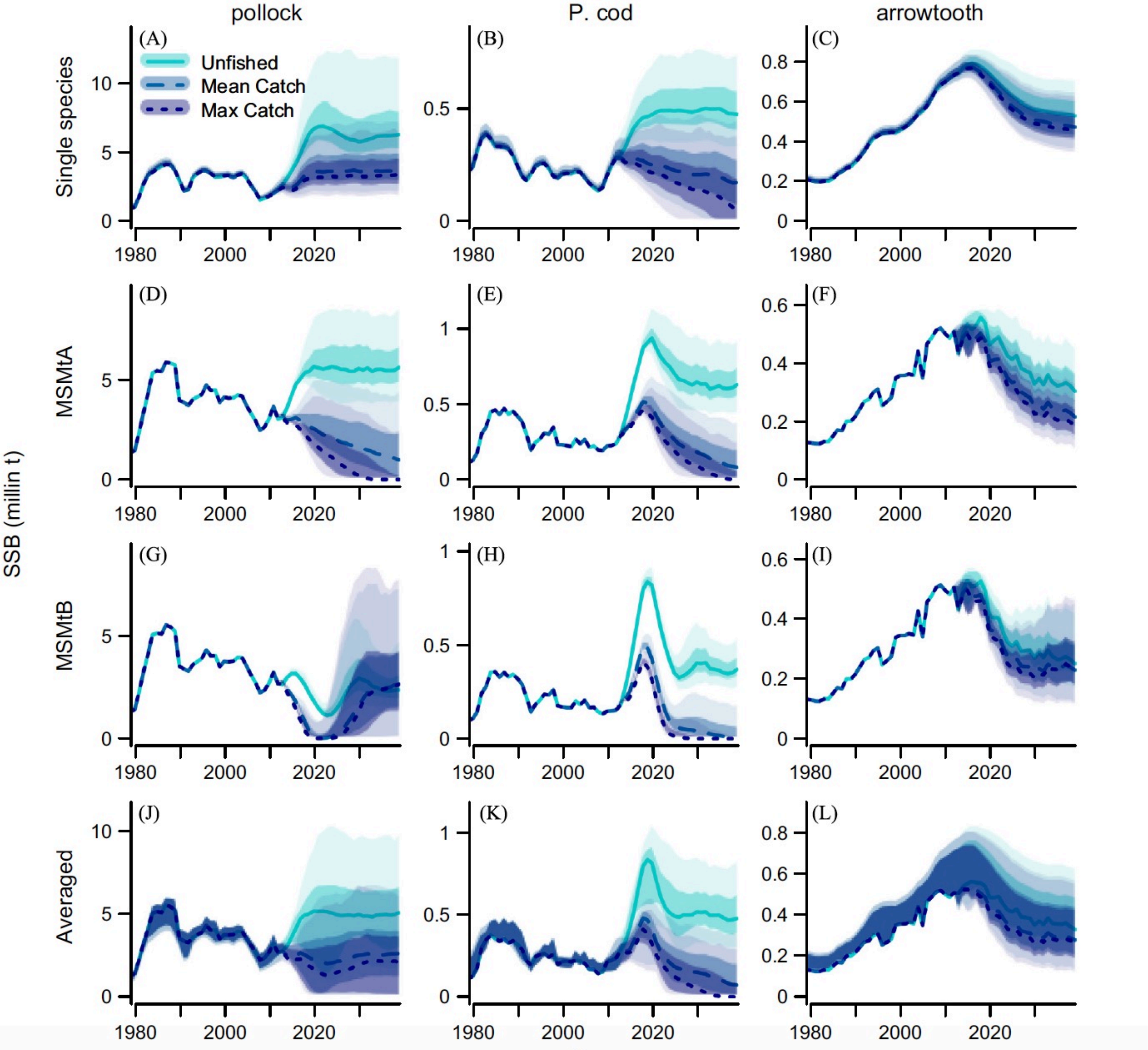


Project with no fishing

Project under mean historical catch

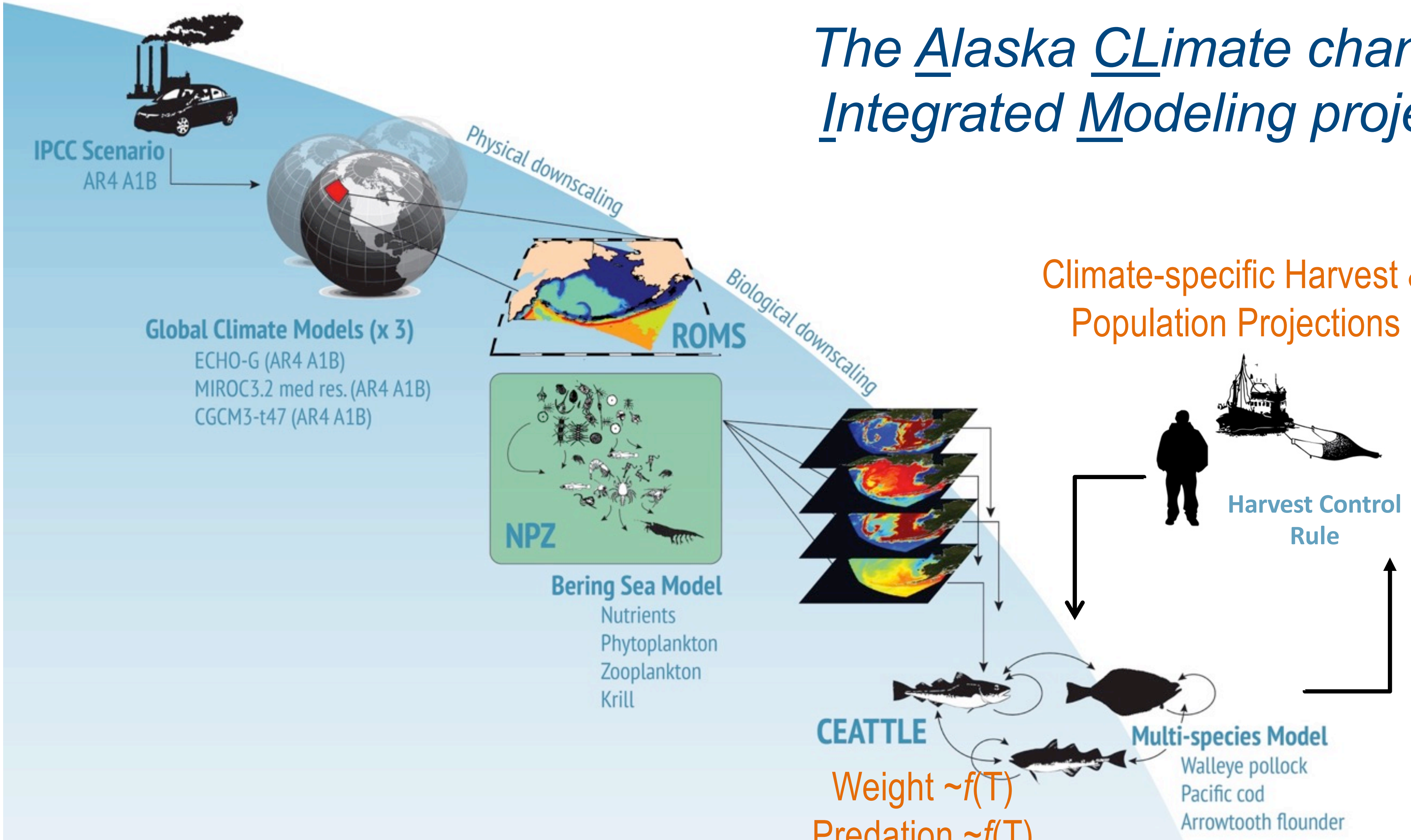
Project under max historical catch

Blended results (all three models)



ACLIM

The Alaska CLimate change Integrated Modeling project

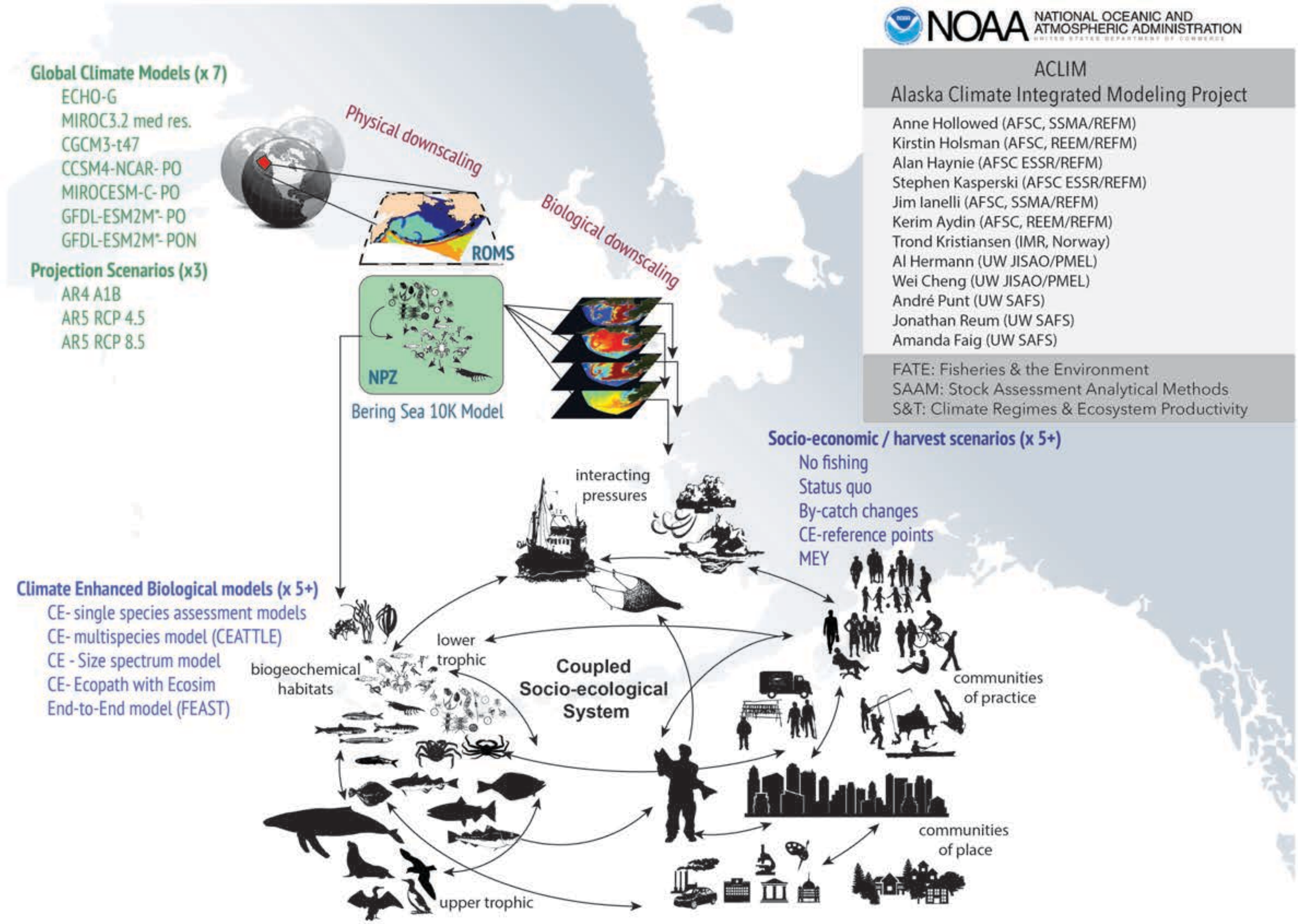


Climate-specific Harvest & Population Projections

Weight ~*f*(T)
Predation ~*f*(T)
Recruitment ~*f*(climate)*

Holsman et al. in prep

ACLIM: Alaska Integrated Modeling Project



NOAA NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
UNITED STATES DEPARTMENT OF COMMERCE

ACLIM
Alaska Climate Integrated Modeling Project

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Jonathan Reum (UW SAFS)
Amanda Faig (UW SAFS)

FATE: Fisheries & the Environment
SAAM: Stock Assessment Analytical Methods
S&T: Climate Regimes & Ecosystem Productivity

Global Climate Models (x 7)
- ECHO-G
- MIROC3.2 med res.
- CGCM3-t47
- CCSM4-NCAR- PO
- MIROCESM-C- PO
- GFDL-ESM2M*- PO
- GFDL-ESM2M*- PON

Projection Scenarios (x3)
- AR4 A1B
- AR5 RCP 4.5
- AR5 RCP 8.5

Socio-economic / harvest scenarios (x 5+)
- No fishing
- Status quo
- By-catch changes
- CE-reference points
- MEY

Climate Enhanced Biological models (x 5+)
- CE- single species assessment models
- CE- multispecies model (CEATTLE)
- CE - Size spectrum model
- CE- Ecopath with Ecosim
- End-to-End model (FEAST)

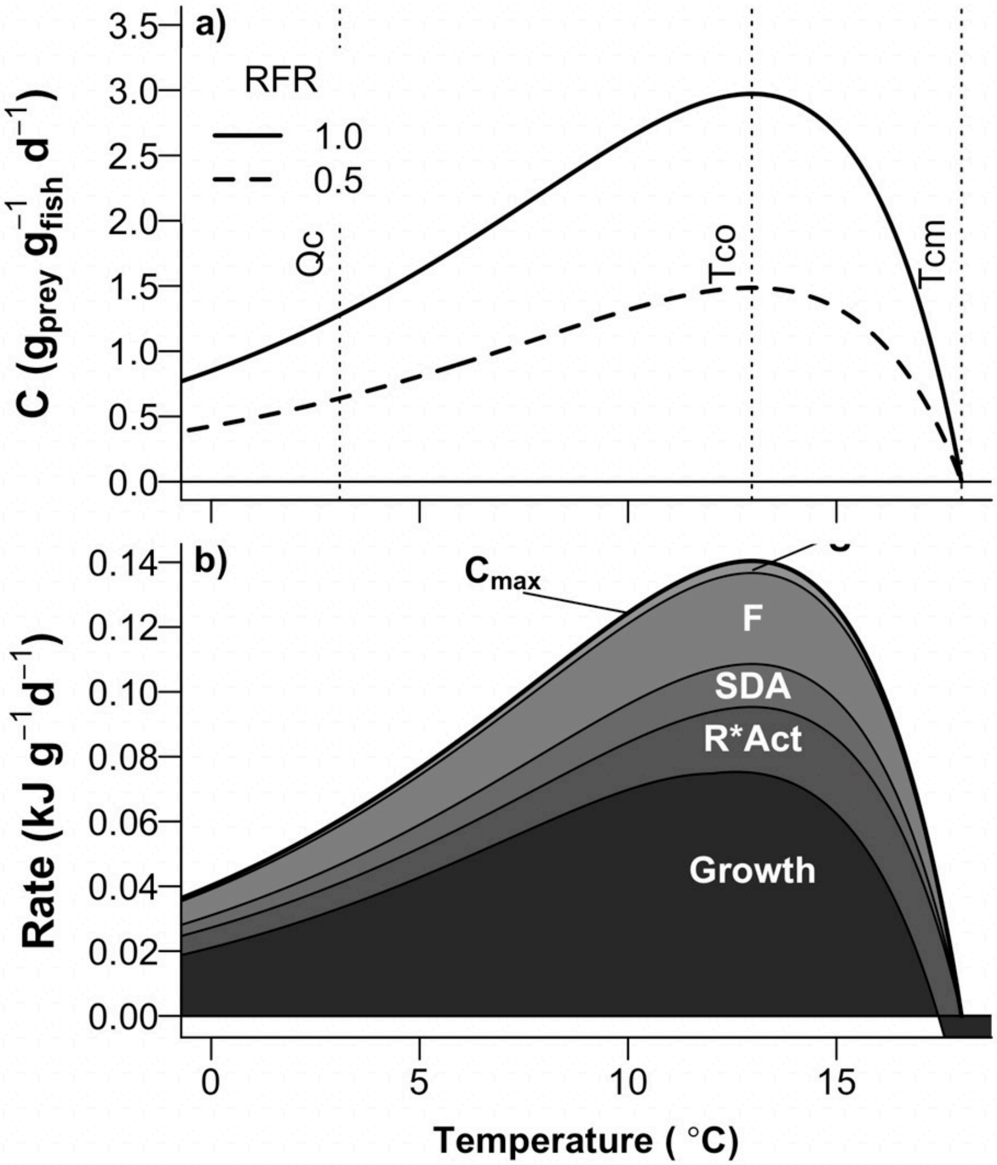
CEATTLE Applications

- Appendix to BSAI pollock assessment
- M2 index for ecosystem status report
- Research:
  - ACLIM – climate MSE
  - Lenfest – NFS
  - Lenfest ocean wealth
  - Overlap- G. Carroll
- FEP: projections under climate change
- Bering Seasons: forecasts under 9mo

Grant Adams – GOA & Rceattle (TMB)

FATE 2016:
Development and application of a climate enhanced multi-species stock assessment model for the Gulf of Alaska to evaluate alternative harvest strategies under climate change.

PIs: Kirstin Holsman*, Martin Dorn, Ingrid Spies, Jim Ianelli, André Punt
Collaborators: Kerim Aydin & Anne Hollowed


a)
RFR
1.0
0.5
Qc
Tco
Tcm
$C\ (g_{prey}\ g_{fish}^{-1}\ d^{-1})$
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
b)
C_{max}
F
SDA
R*Act
Growth
$Rate\ (kJ\ g^{-1}\ d^{-1})$
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
0
5
10
15
Temperature (°C)