Development of multispecies models to investigate predator-prey interactions and temperature-mediated predation rates of Pacific cod and other groundfish in the eastern Bering Sea

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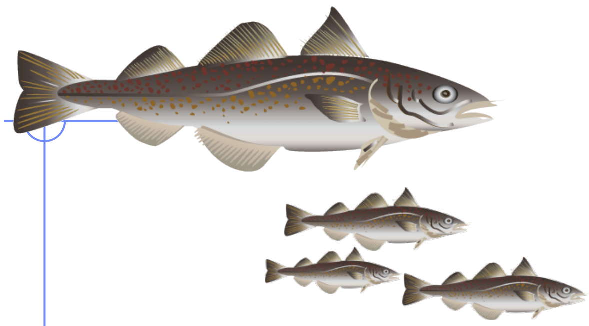
Motivation

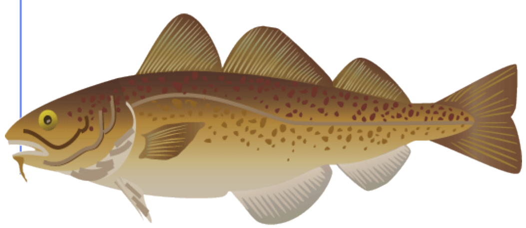
- Groundfish from the eastern Bering Sea (EBS) account for ~40% of all US commercial landings
- EBS groundfish landings are mainly walleye pollock, Pacific cod, and various flatfish species
- Strong and weak year classes of pollock and cod tend to coincide, but flatfish tend to have opposite trends
- Are these patterns due to predator-prey relationships or responses to the environment?
- Can knowledge of the interactions lead to a joint management approach?

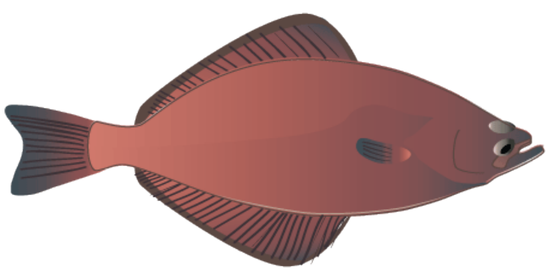
Objectives

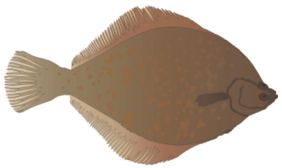
1. Develop multispecies biomass dynamics (MBD) and multispecies delay difference (MDD) models of EBS groundfish species with predatory interactions
2. Project fish biomasses under different management scenarios
3. Investigate the effects of climate on predation and dynamics of the species

Conceptual Model



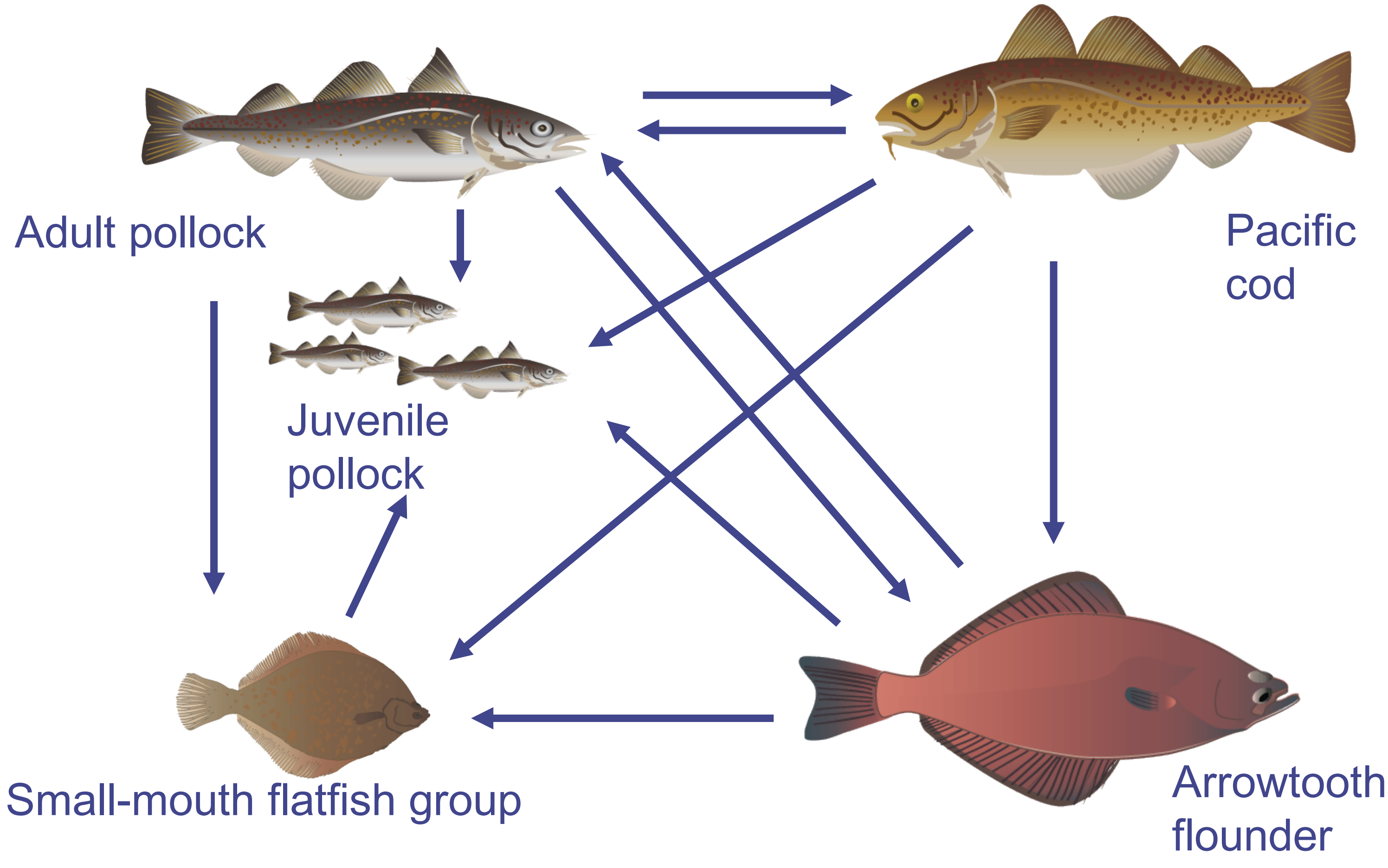




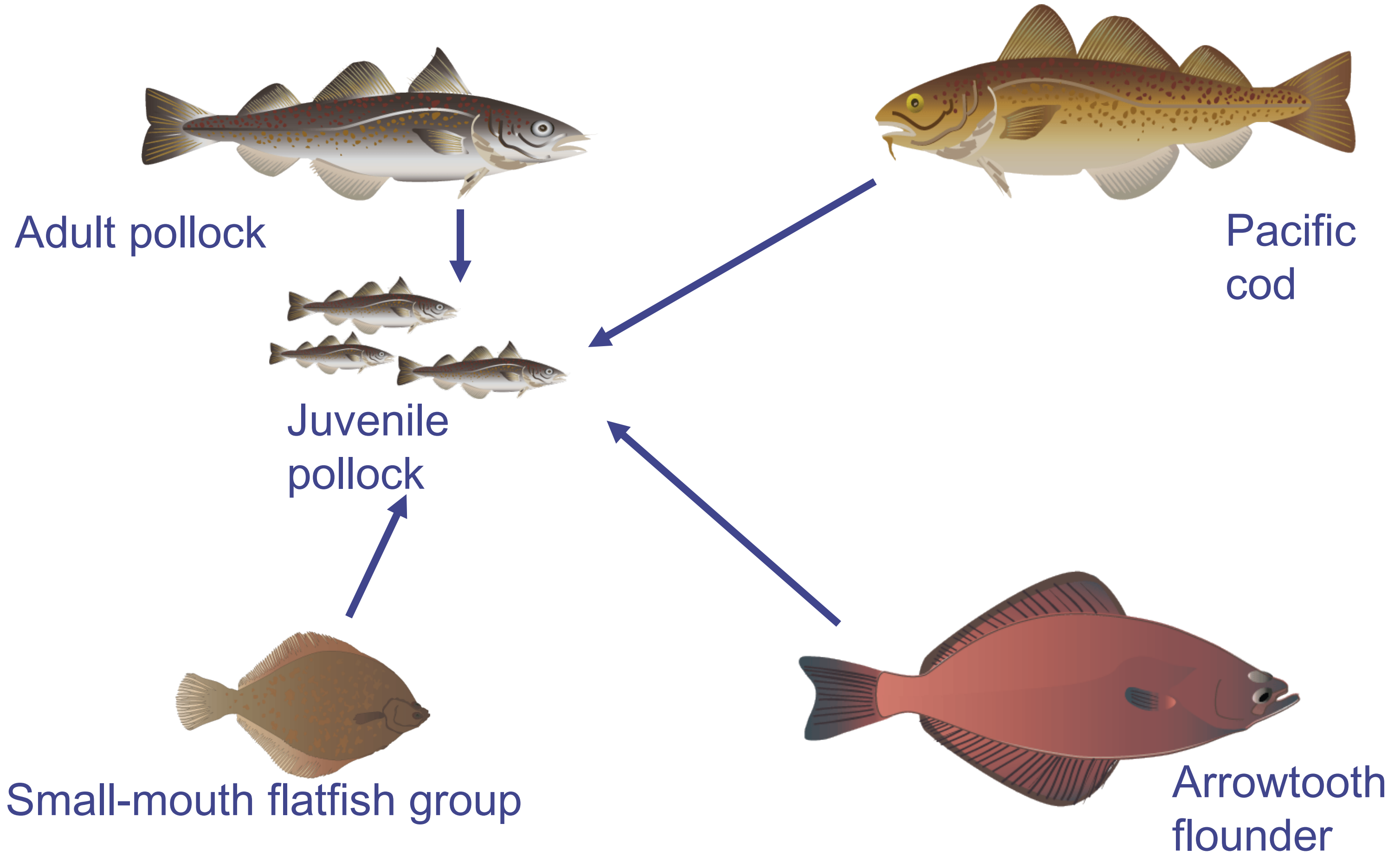


Species	Group
Walleye pollock	Adult pollock (Age 3+)
	Juvenile pollock (Age 0, 1, & 2)
Pacific cod	Pacific cod (Age 1+)
Arrowtooth flounder	Arrowtooth flounder (Age 1+)
Northern rock sole, Alaska plaice Flathead sole, Yellowfin sole	Small-mouth flatfish (Age 1+)

Modeled Trophic Relationships



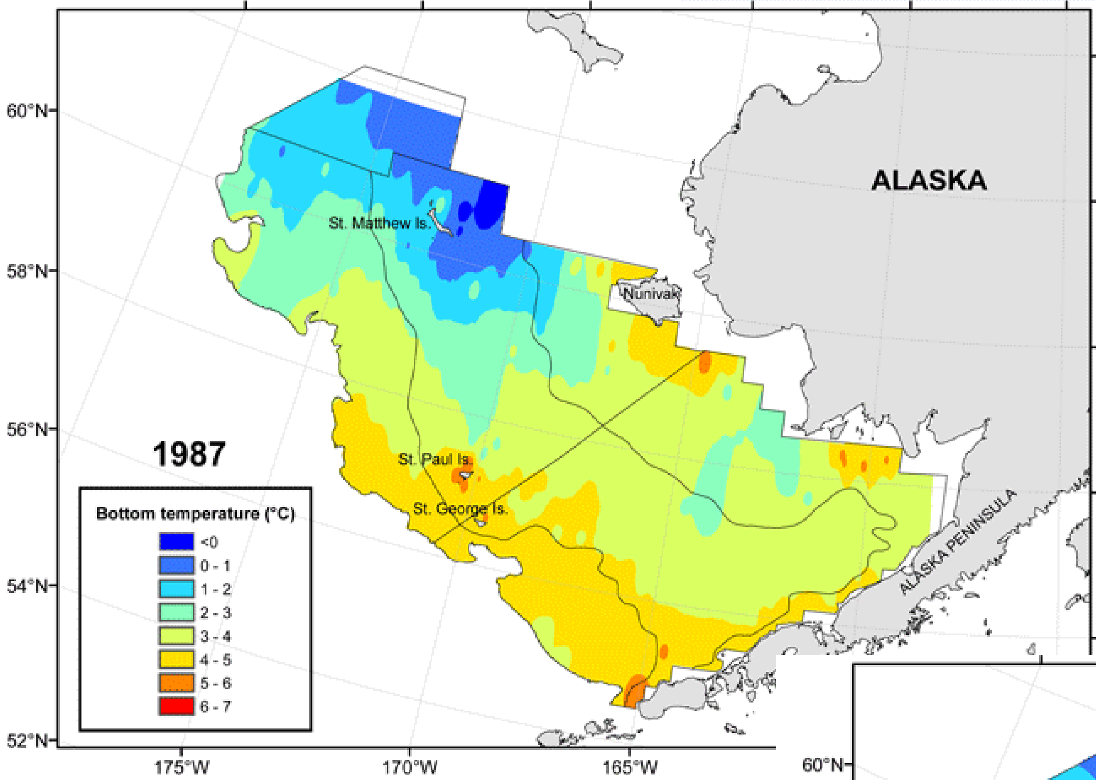
Juvenile Pollock as Prey

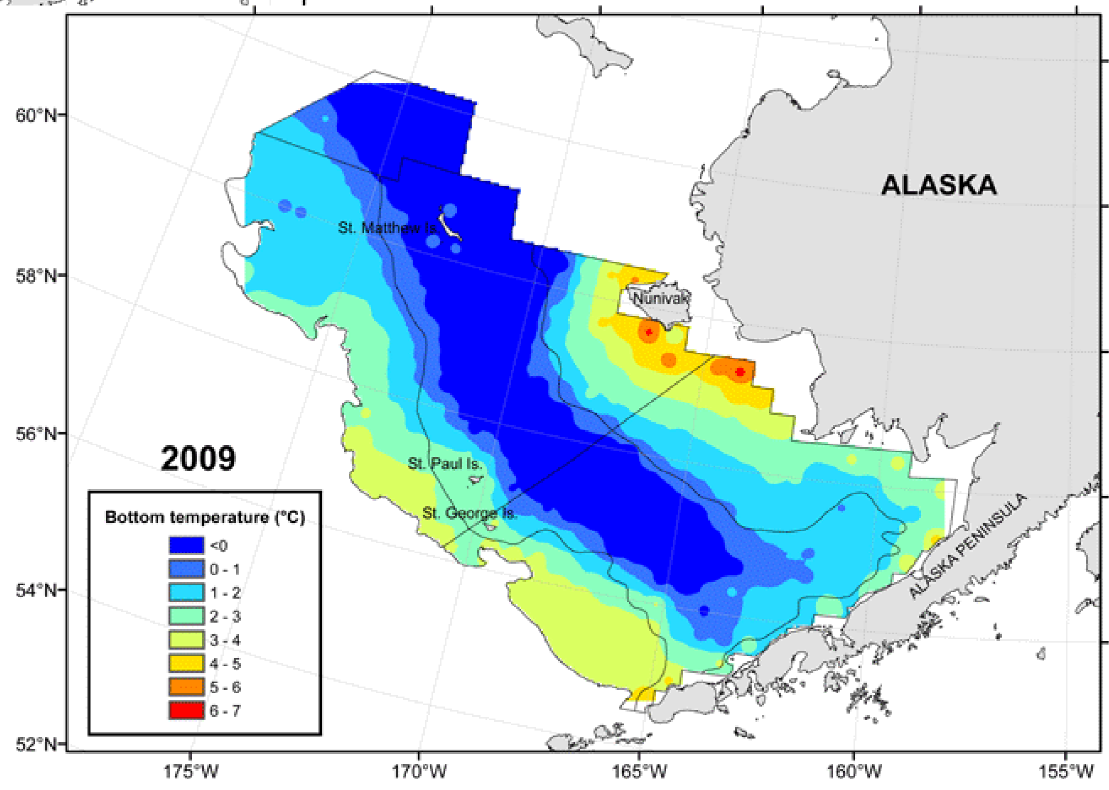


The Cold Pool & Fish Ecology

- Cold pool is a body of very cold water (< 2°C) on the EBS shelf
- Forms in winter when sea ice freezes
- Size of cold pool in summer depends on extent of sea ice the previous winter
- Many subarctic fish avoid cold pool
- Some evidence that age-1 pollock can tolerate colder temperatures than adults

Bottom temperature measured during summer bottom trawl surveys (June – August)

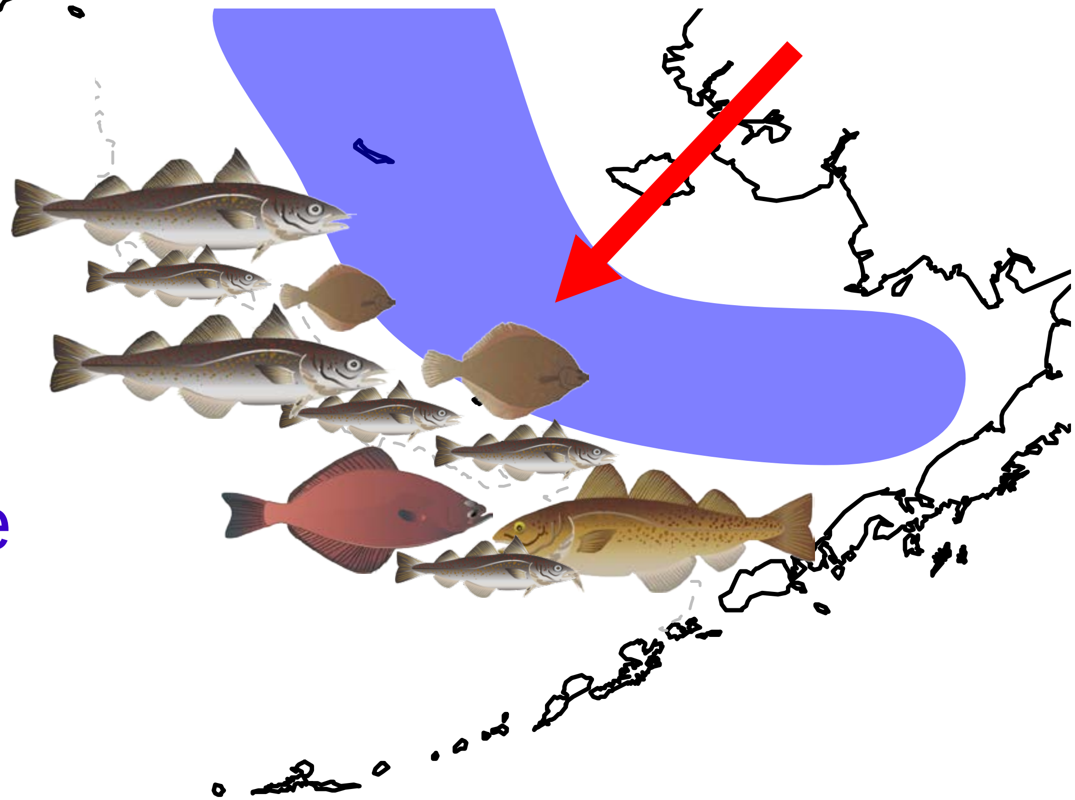




Maps by Bob Lauth, AFSC

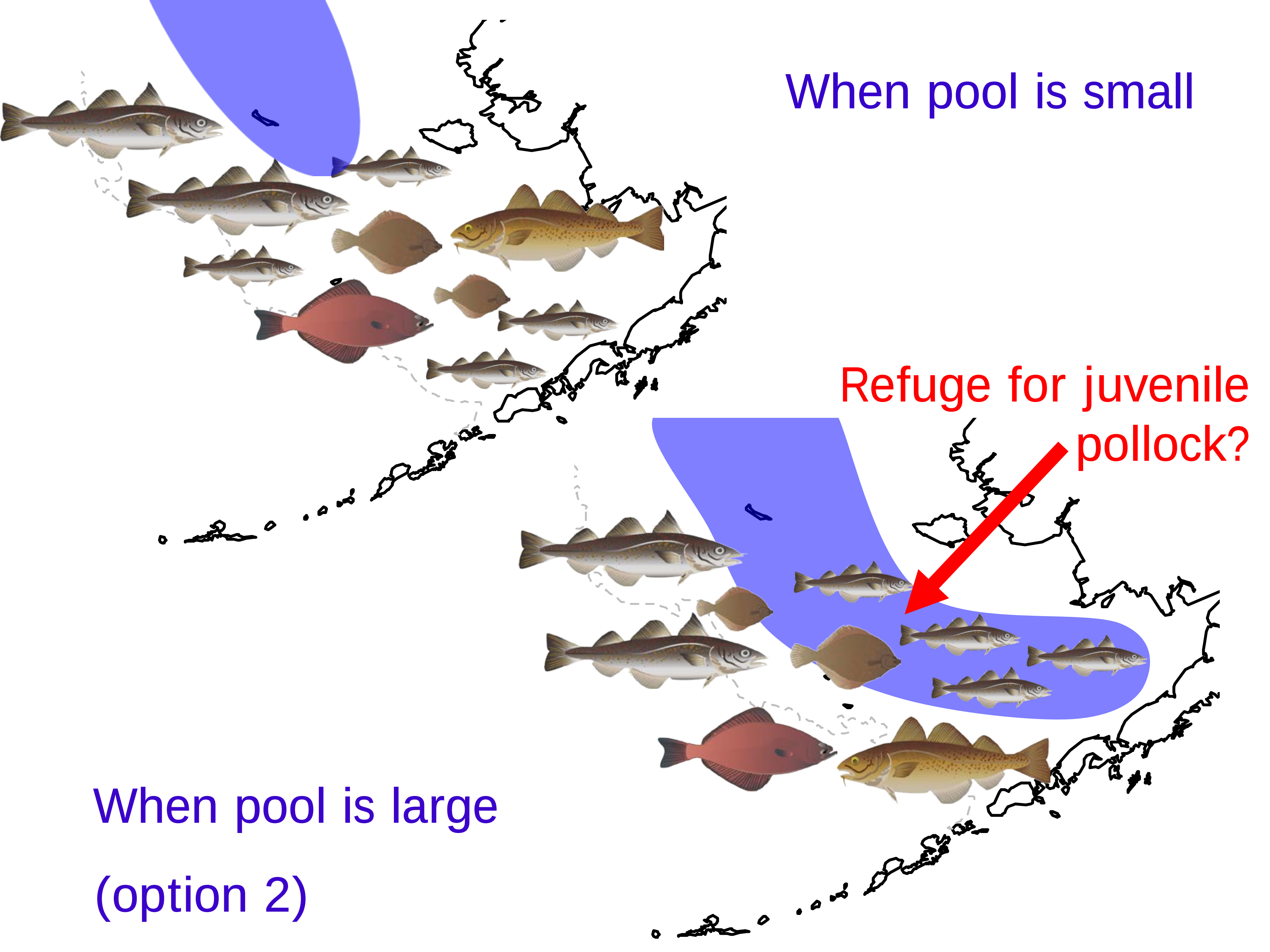
When pool is small

Barrier to all?

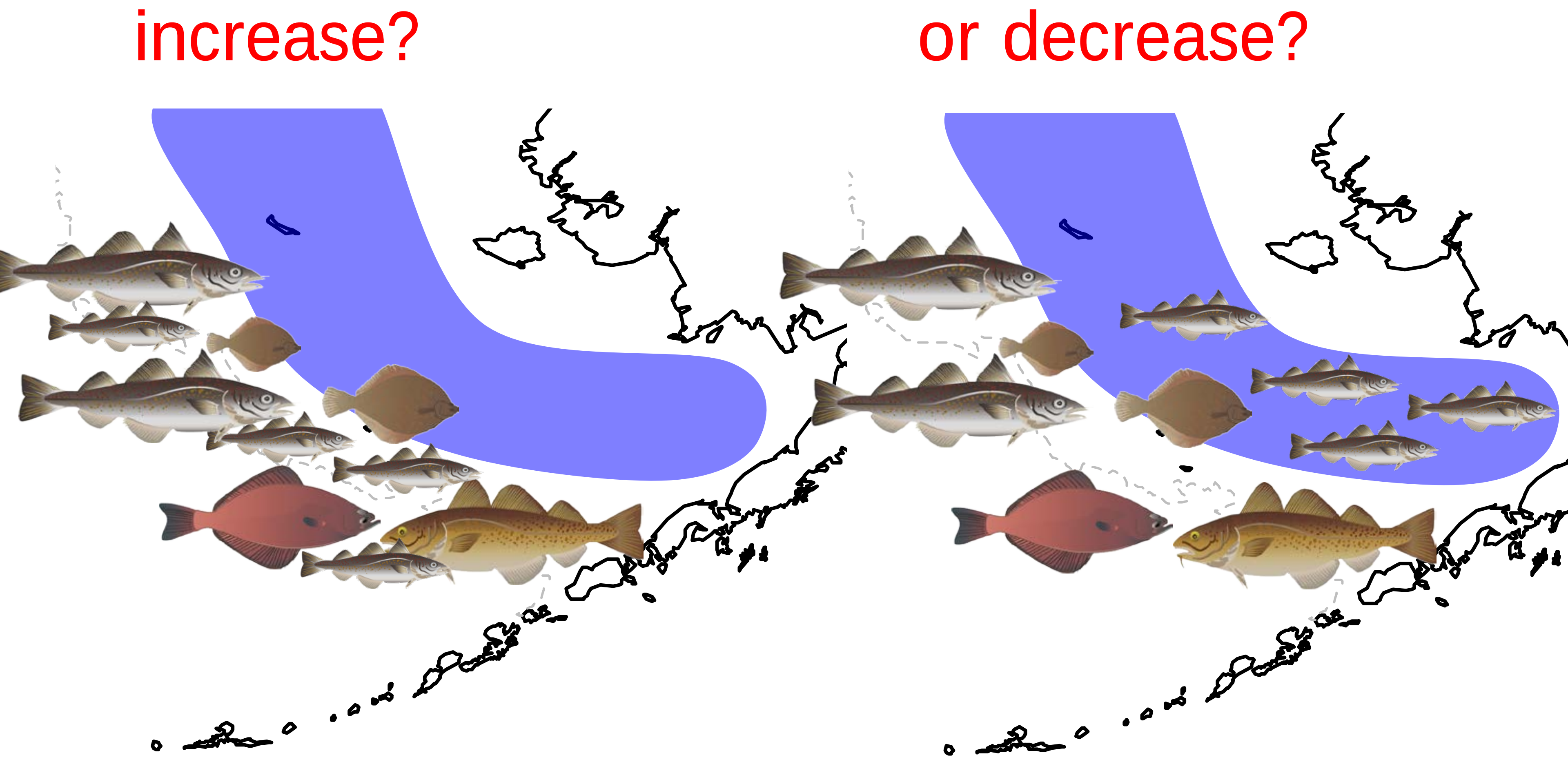


When pool is large

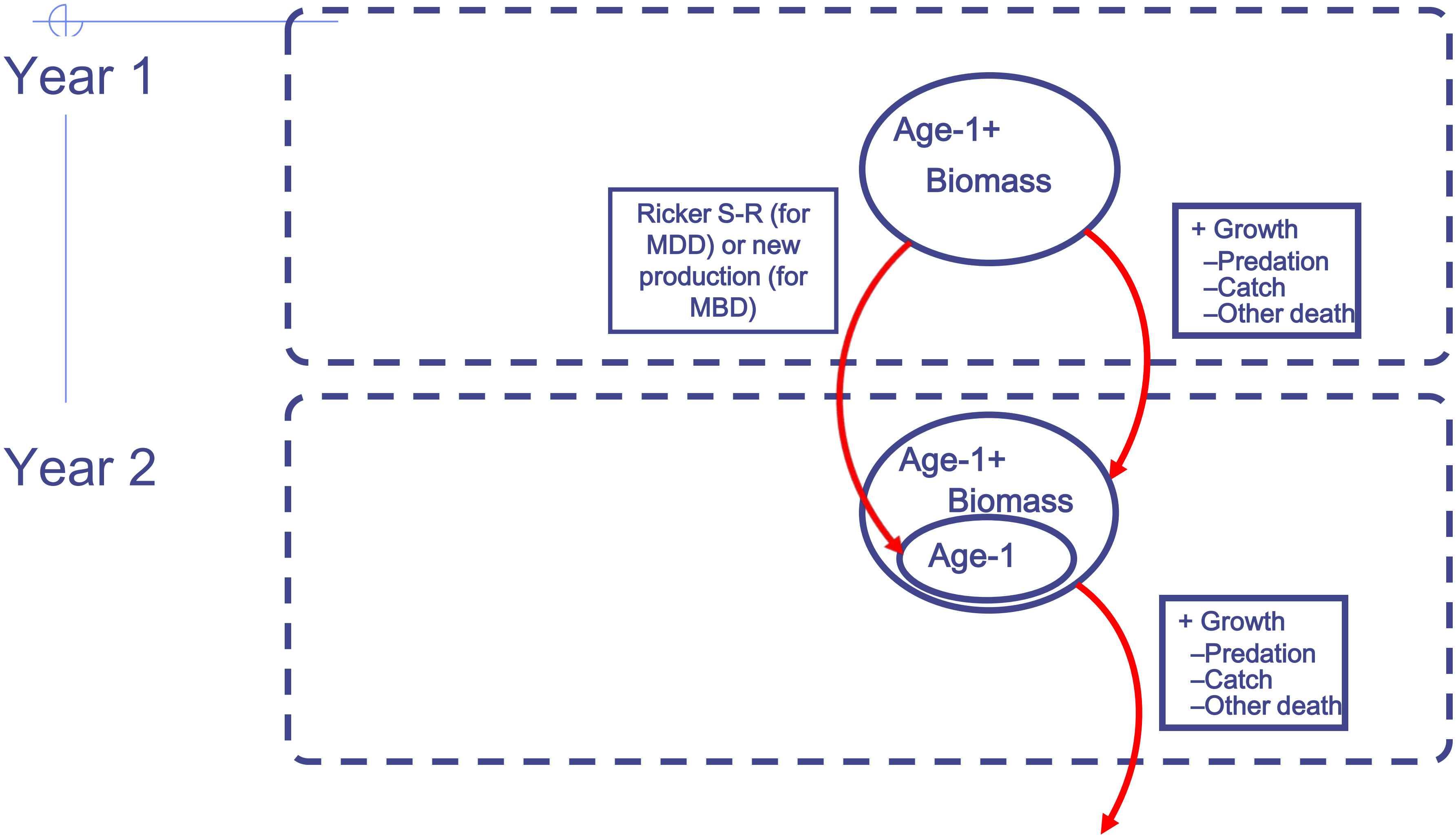
(option 1)

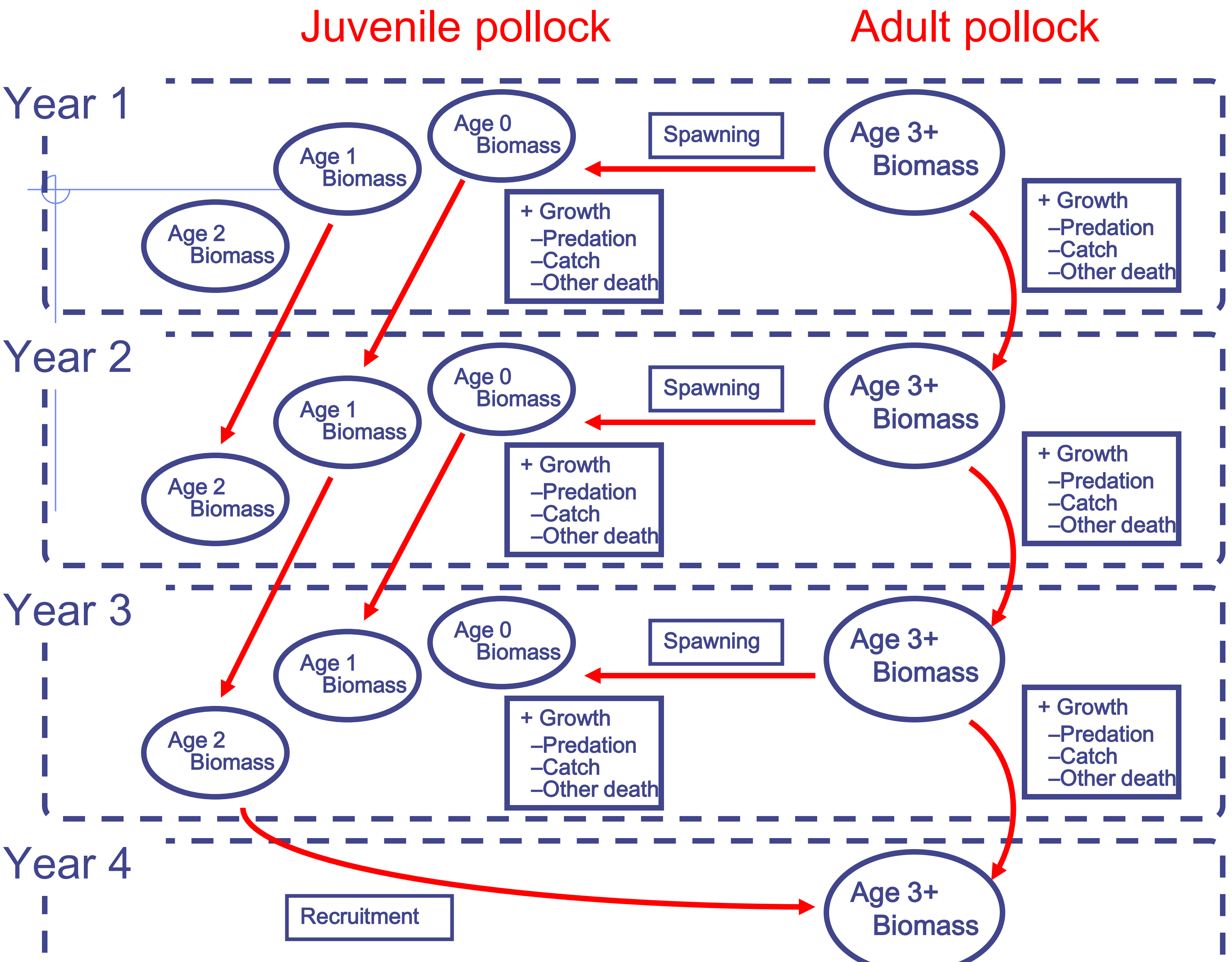

When pool is small
Refuge for juvenile pollock?
When pool is large
(option 2)

With extensive cold pool, does predation



Pacific Cod, Arrowtooth Flounder, and Small-mouth Flatfish Group




Juvenile pollock
Adult pollock
Year 1
Age 1 Biomass
Age 0 Biomass
Spawning
Age 3+ Biomass
Age 2 Biomass
+ Growth –Predation –Catch –Other death
+ Growth –Predation –Catch –Other death
Year 2
Age 0 Biomass
Spawning
Age 3+ Biomass
Age 1 Biomass
Age 2 Biomass
+ Growth –Predation –Catch –Other death
+ Growth –Predation –Catch –Other death
Year 3
Age 0 Biomass
Spawning
Age 3+ Biomass
Age 1 Biomass
Age 2 Biomass
+ Growth –Predation –Catch –Other death
+ Growth –Predation –Catch –Other death
Year 4
Recruitment
Age 3+ Biomass

Modeling of Juvenile Pollock

- Juvenile pollock (ages 0, 1, and 2) were modeled with age structure to account for predation on recruitment at each juvenile stage
- Age-0 pollock modeled to be proportional to adult (age 3+) biomass
- Age-1, age-2, and age-3 pollock biomasses estimated sequentially by accounting for growth, predation, and commercial catch (age-2 and age-3 only)
- Juveniles were modeled identically in MBD and MDD models

Multispecies Biomass Dynamics Model

Basic equation form for species x in year y+1:

$$\hat{B}_{x,y+1} = \hat{B}_{x,y} + r_x \hat{B}_{x,y}\left(1 - \frac{\hat{B}_{x,y}}{k_x}\right) - C_{x,y} - \hat{B}_{pred,x,y},$$

where $\hat{B}_{x,y}$ = biomass estimate of species x in year y,

$C_{x,y}$ = commercial catch in year y,

$\hat{B}_{pred,x,y}$ = estimated predation on species x in year y, and

r_x, k_x = population growth and carrying capacity parameters, respectively, for species x.

Multispecies Biomass Dynamics Model

Equation for pollock also includes a recruitment term:

$$\hat{B}_{p,y+1} = \hat{B}_{p,y} + r_p \hat{B}_{p,y}\left(1 - \frac{\hat{B}_{p,y}}{k_p}\right) - C_{p,y} - \hat{B}_{pred,p,y} + \hat{R}_{p,y+1},$$

where $\hat{R}_{p,y+1}$ = predicted recruitment.

Multispecies Delay Difference Model

Basic equation form for species x in year y+1:

$$\hat{B}_{x,y+1} = (1+\rho_x)s_{x,y}\hat{B}_{x,y} - \rho_x s_{x,y} s_{x,y-1}\hat{B}_{x,y-1} + \hat{R}_{x,y+1},$$

where:

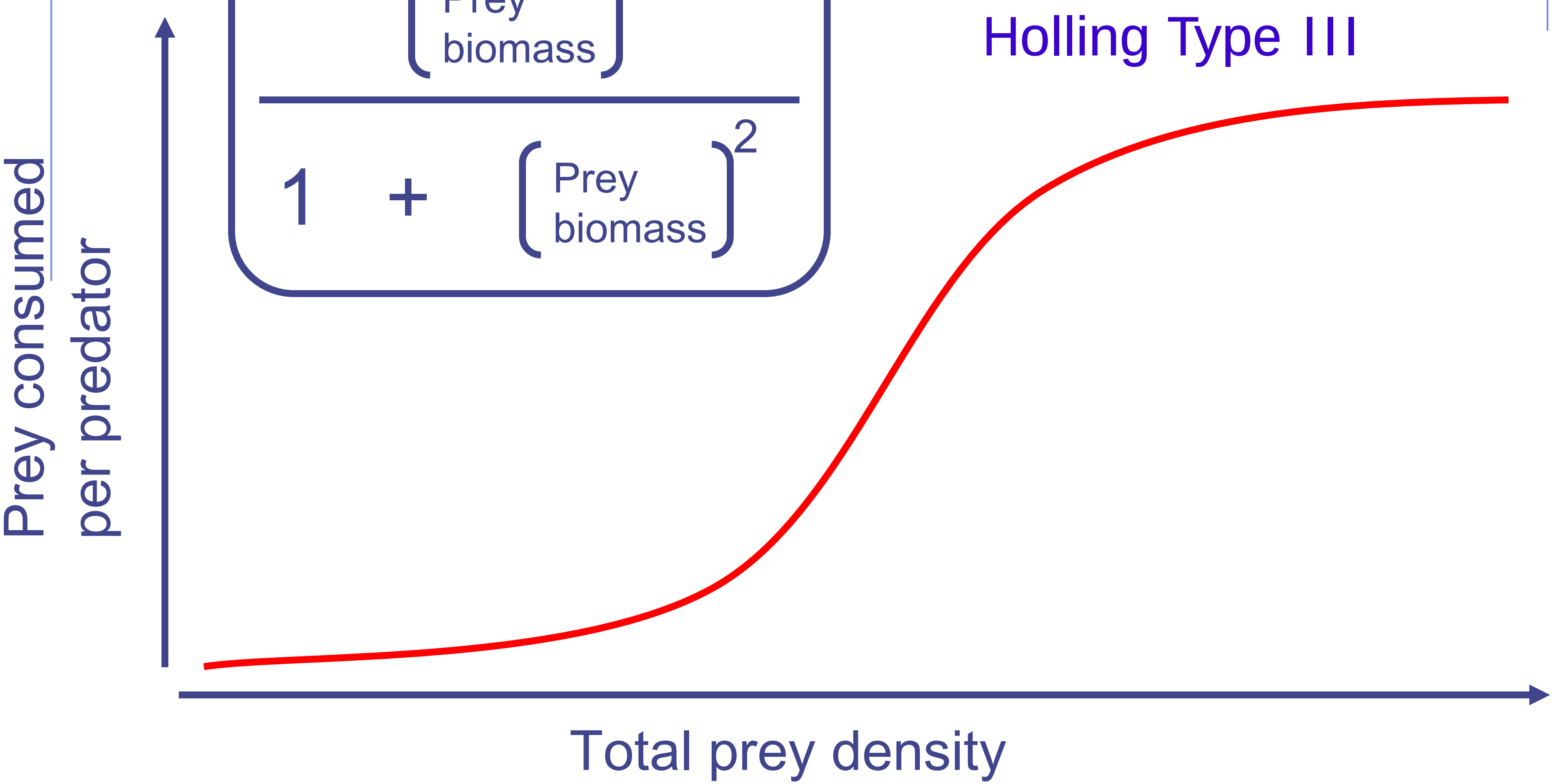
ρ_x = Ford growth parameter for species x,

$s_{x,y}$ = surviving fraction of $\hat{B}_{x,y}$ in the previous year y

Recruitment for all species (except pollock) modeled using a Ricker stock-recruit model.

Predator Functional Response

$$\frac{\left(\text{Prey biomass}\right)^2}{1 + \left(\text{Prey biomass}\right)^2}$$



Model Fitting

Data (NMFS)

- Biomass estimates (adjusted for selectivity)
  - Summer bottom trawl survey
  - Summer mid-water echo-integration trawl (EIT) survey (pollock only)
- Annual catch estimates
- Biomass estimates of prey consumed by predator

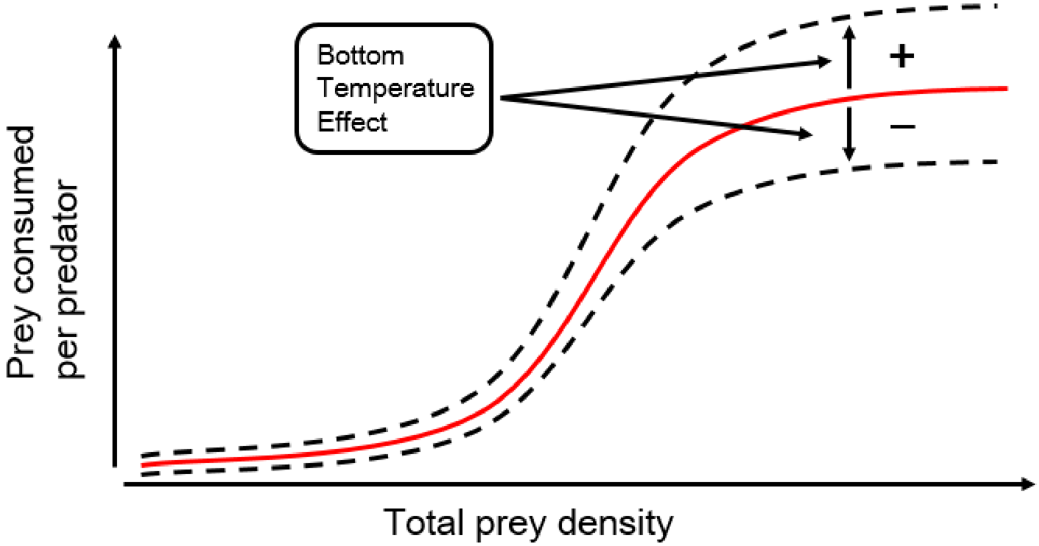
- Models fitted by maximum likelihood
- Precision and bias of model parameters and biological reference points evaluated using Monte Carlo simulations

Effect of Temperature

Temperature effect modeled as:

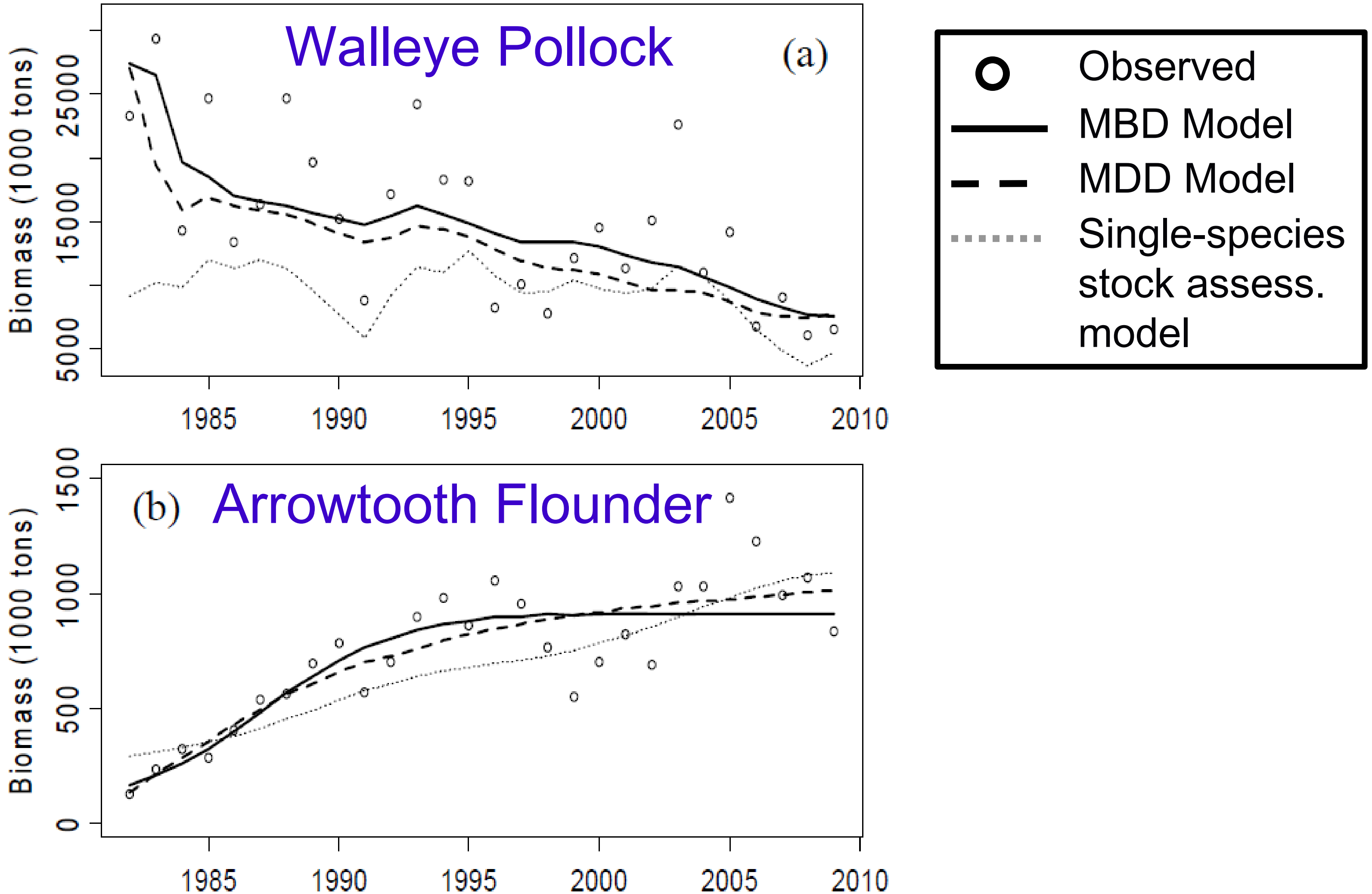
$$d_{za} = \bar{d}_{za} + e_{za} * T_B$$

where d_{za} is predation rate of predator z on juvenile age class a, $\bar{d}_{za}$ is the average predation rate at $T_B = 0$, and e_{za} is the slope.



Evidence for temperature-dependent predation was quantified using AIC_c.

Results: Fits to Biomass



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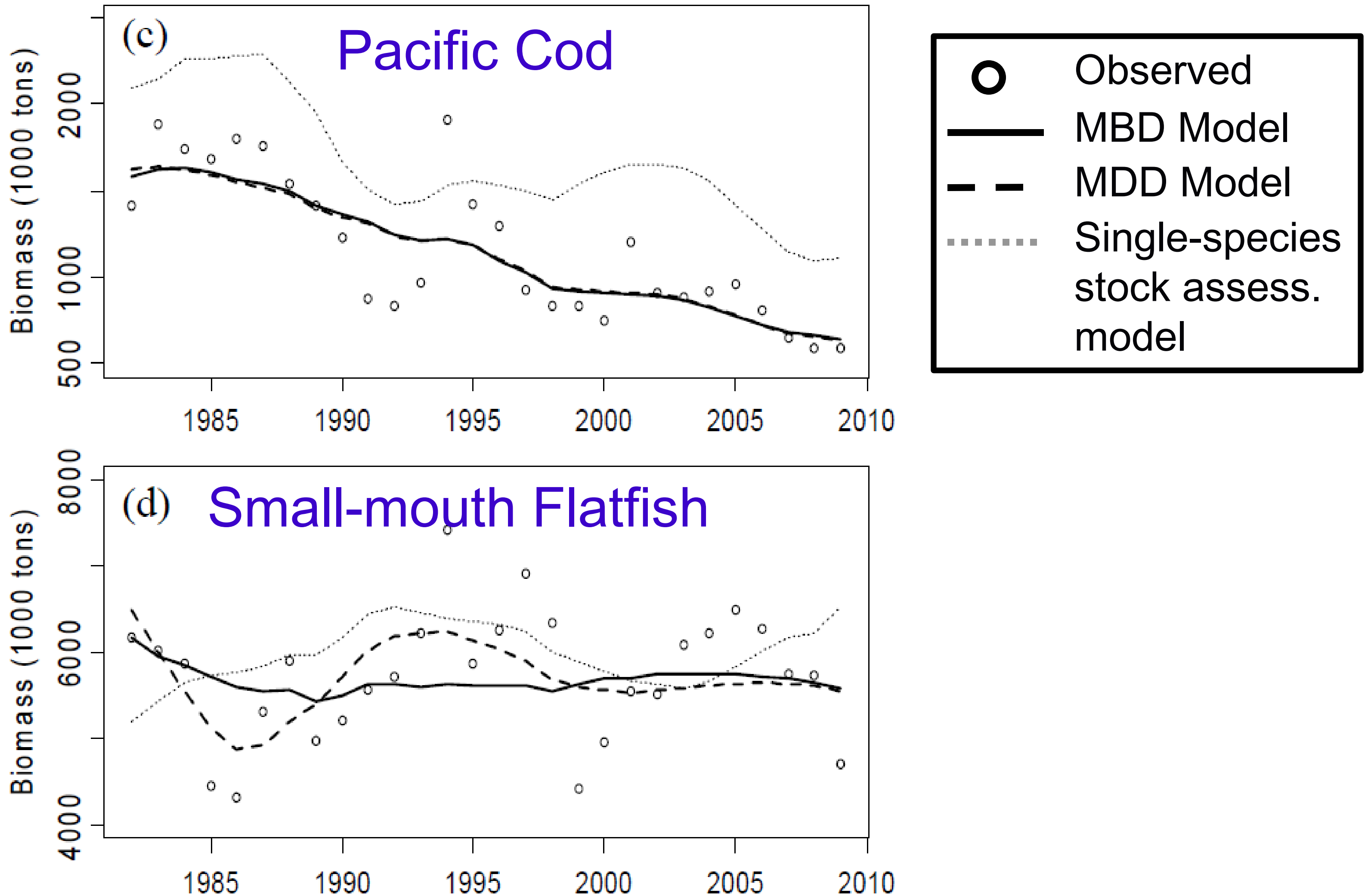


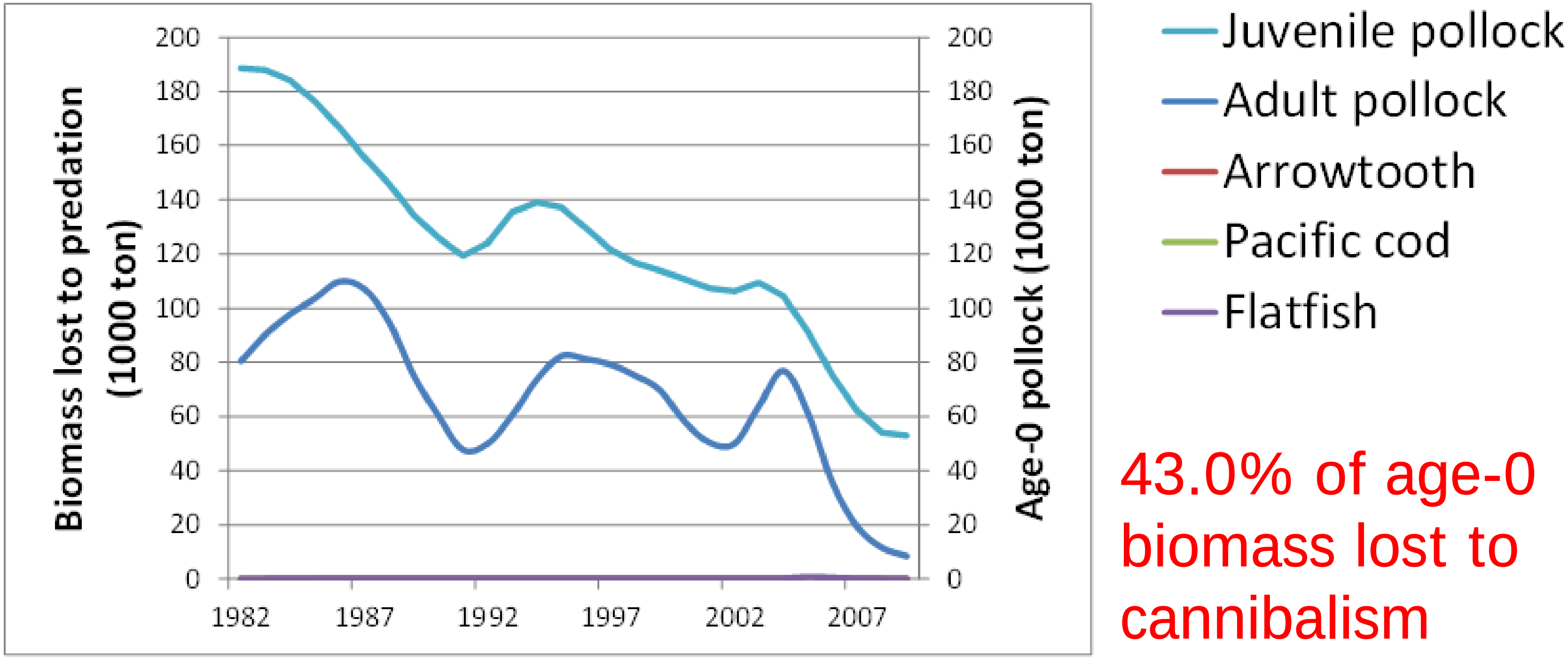
Other General Results

- MBD and MDD models predicted multispecies B_o, MSY, and F_{MSY} to be lower than the sum of estimates from single-species models
- MBD was the preferred model
  - Smaller bias in MSY and B_{MSY}
  - Biomass projections were more precise
  - MDD model produced biologically unrealistic biomass estimates when $F>0.14$

➔ MBD model selected to examine temperature effects

Predation on Age-0 Pollock

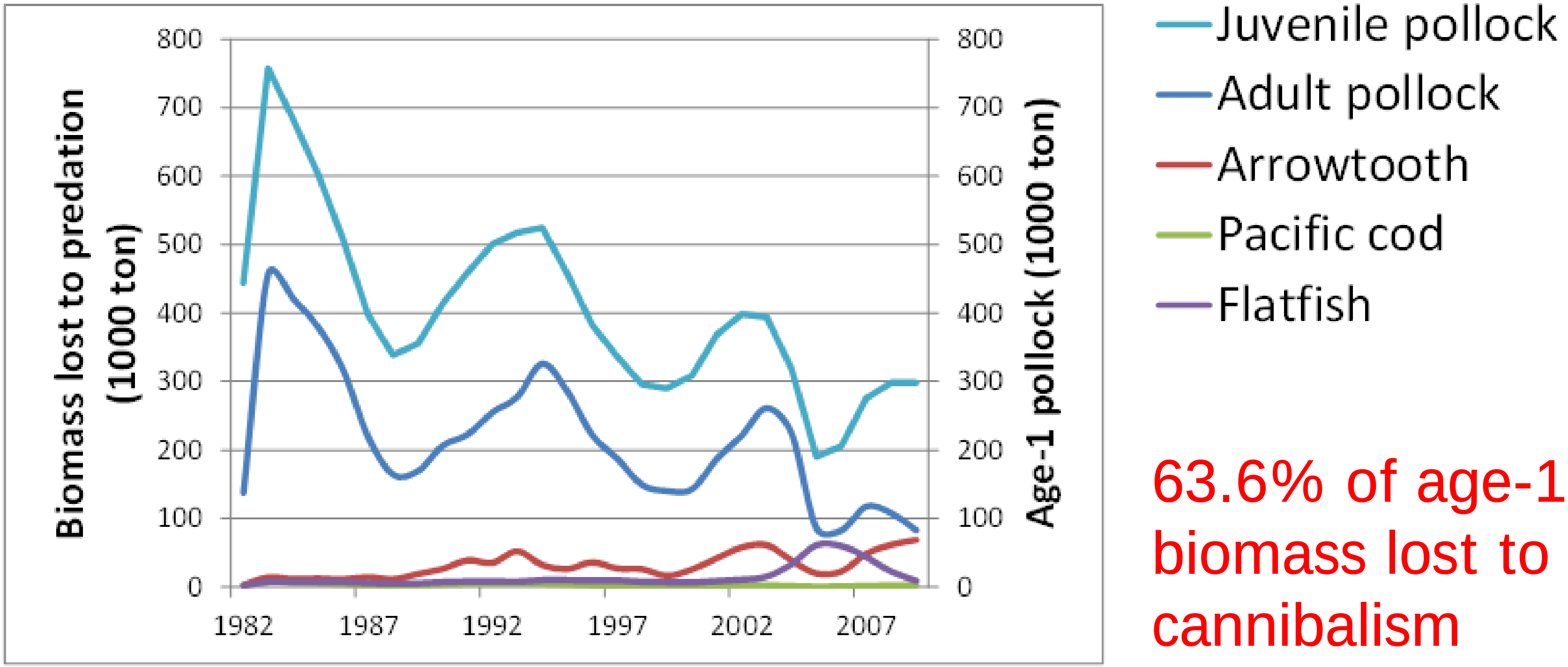
Age-0 pollock biomass and age-0 biomass lost to predation by species



43.0% of age-0 biomass lost to cannibalism

Predation on Age-1 Pollock

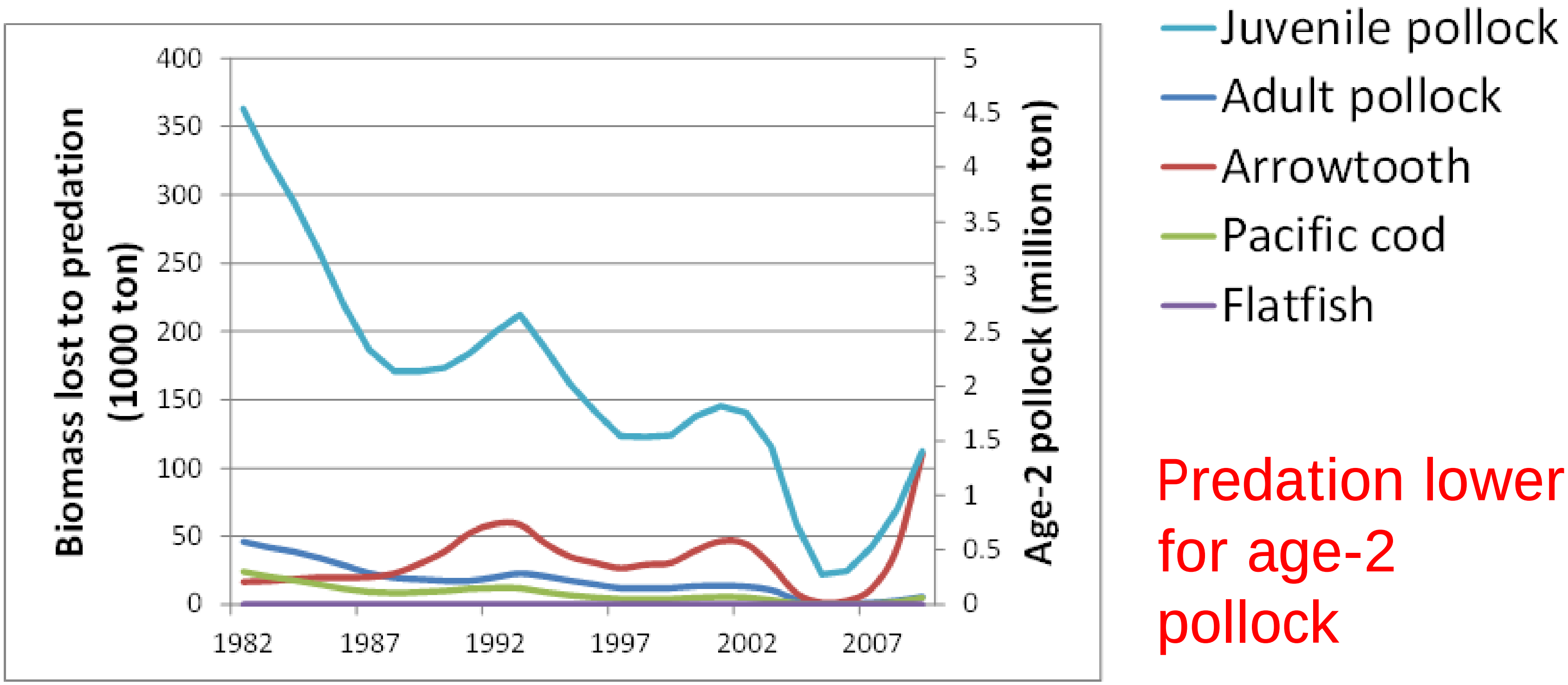
Age-1 pollock biomass and age-1 biomass lost to predation by species



63.6% of age-1 biomass lost to cannibalism

Predation on Age-2 Pollock

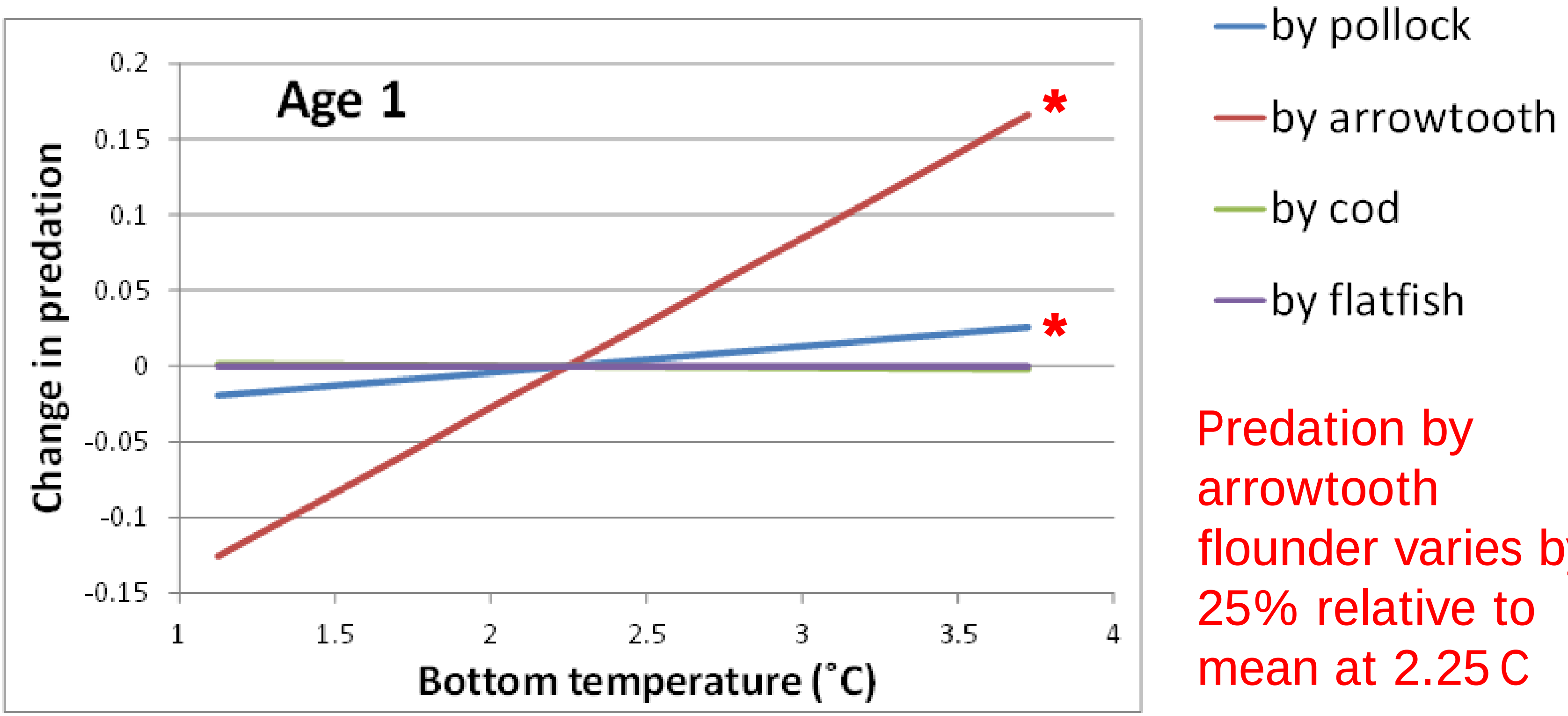
Age-2 pollock biomass and age-2 biomass lost to predation by species



Predation lower for age-2 pollock

Temperature Effects on Predation of Age-1 Pollock

Warmer bottom temperatures increase predation on age-1 pollock by arrowtooth flounder and by adult pollock

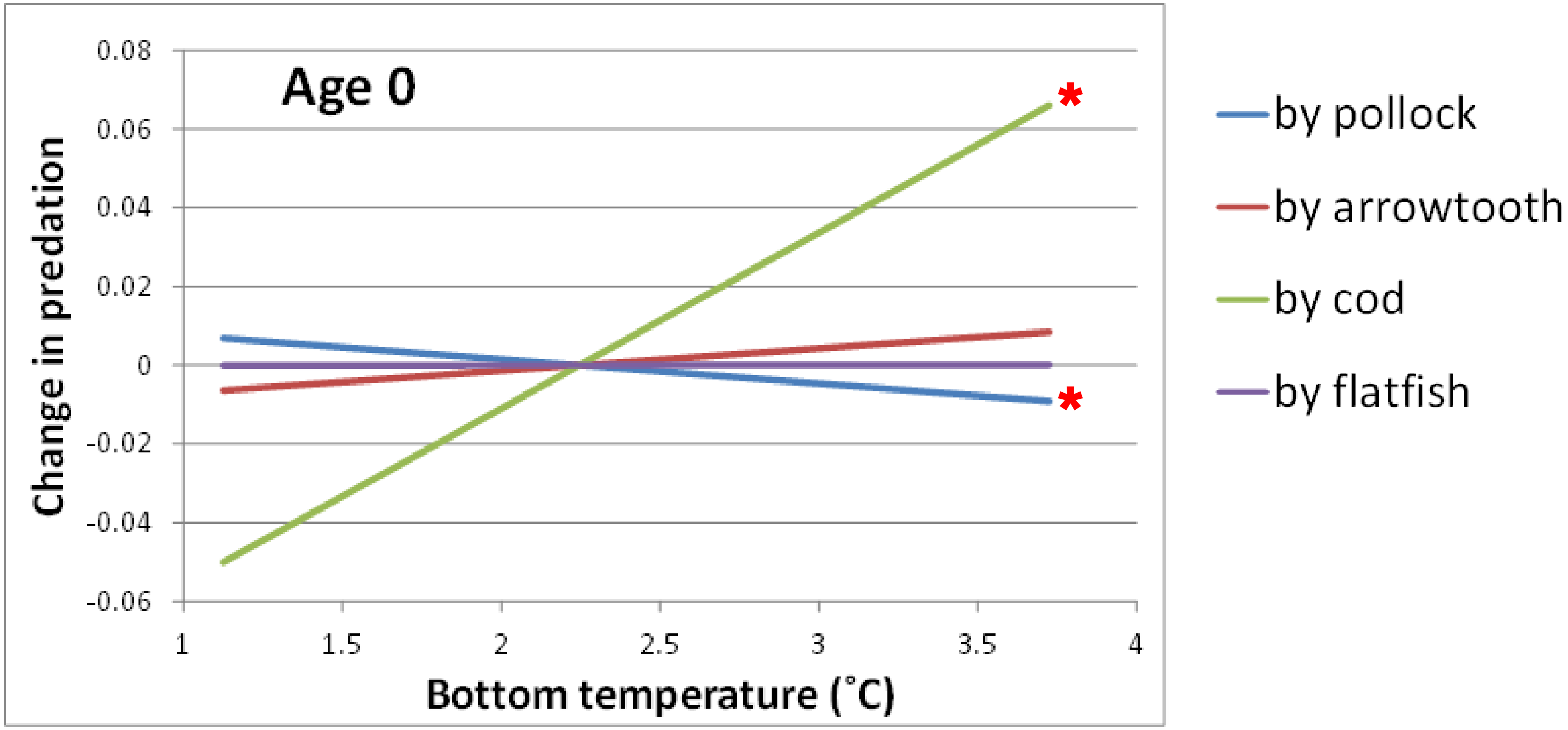


Predation by arrowtooth flounder varies by 25% relative to mean at 2.25 C

* H_o (no effect) rejected using AIC_c

Temperature Effects on Predation of Age-0 Pollock

Warmer bottom temperatures increase predation on age-0 pollock by Pacific cod and decrease predation by adult pollock



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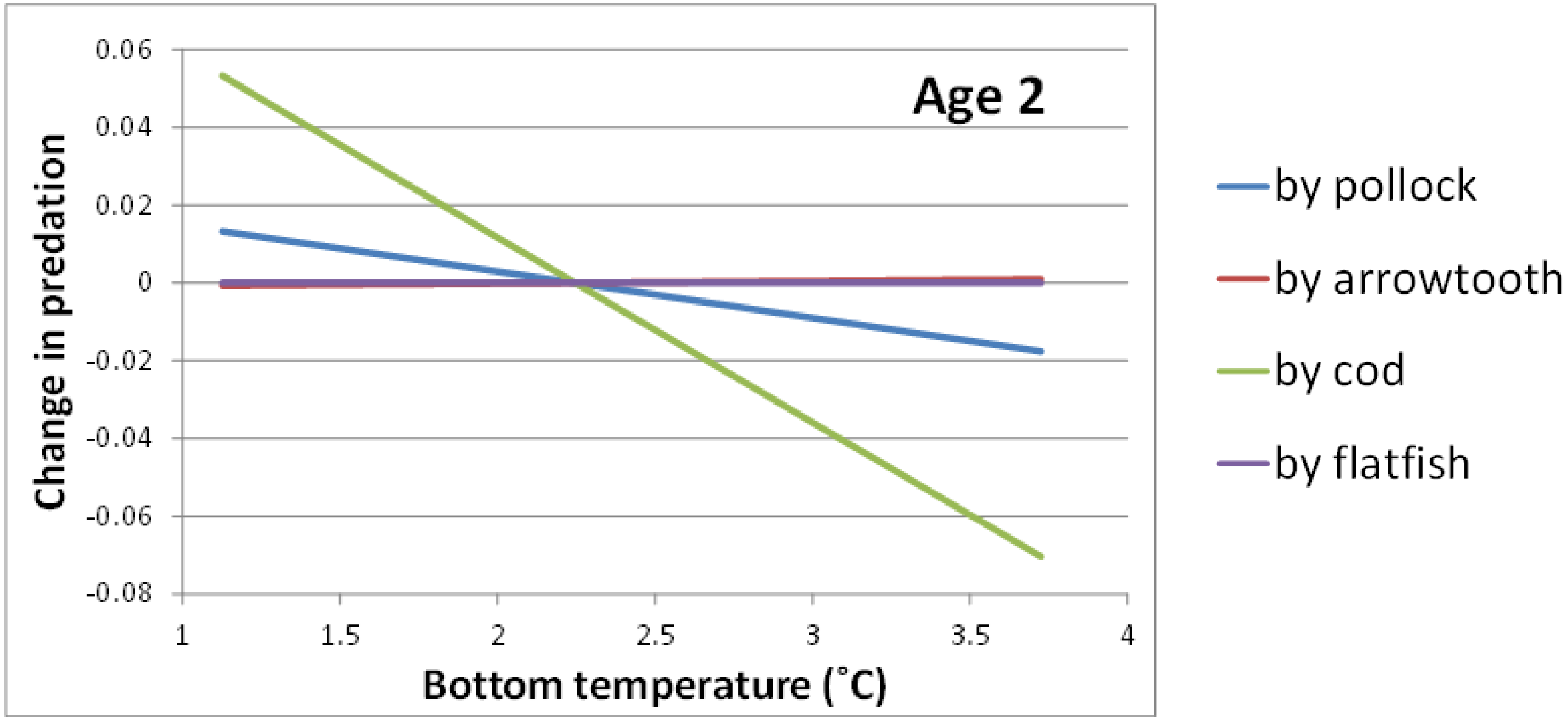
Temperature Effects on Predation of Age-2 Pollock

Non-significant negative effect of bottom temperature on predation of age-2 pollock by cod and adult pollock

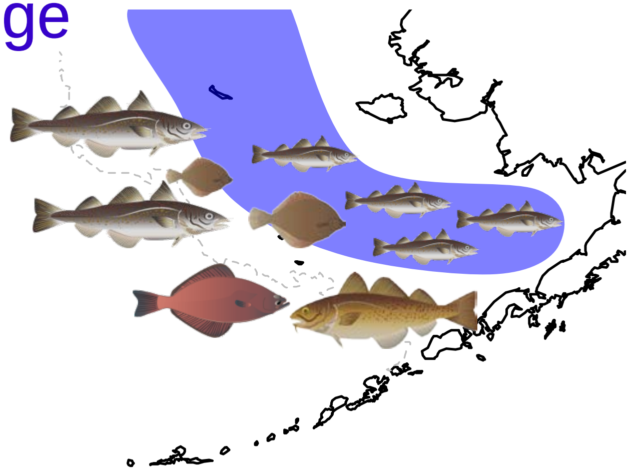


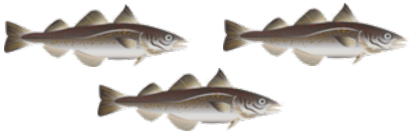
Conclusions

- Both MBD and MDD models using predator-prey interactions successfully captured observed trends in survey biomass over 1982-2009
- Advantages and disadvantages of both approaches, but MBD performs better over all
- As with previous studies, multispecies biological reference points are lower than the sum of estimates from single-species assessments
- Multispecies models are useful to explore long-term effects of harvest strategies for one species on stock dynamics of other groundfish species
- Multispecies models are not yet ready for tactical advice, because many predation parameters are highly uncertain

Conclusions

- Cannibalism by adult pollock is most important form of predation on age-1 and age-0 pollock
- Of the 4 models most strongly supported by the data, the top 3 indicated a positive effect of temperature on predation of juvenile pollock
- Results consistent with cold pool refuge





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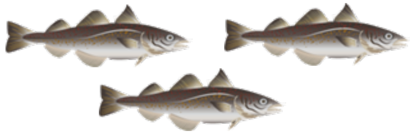
- Mueter et al. (2011) found evidence that warmer temperatures in late summer/autumn are associated with poor feeding conditions of age-0 pollock and reduced recruitment
- Warm temperatures lead to increased predation on age-1 pollock by two major predators



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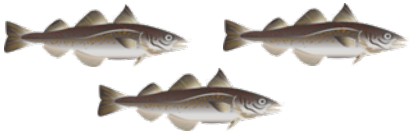
➔ This may lead to a “double whammy” under global warming

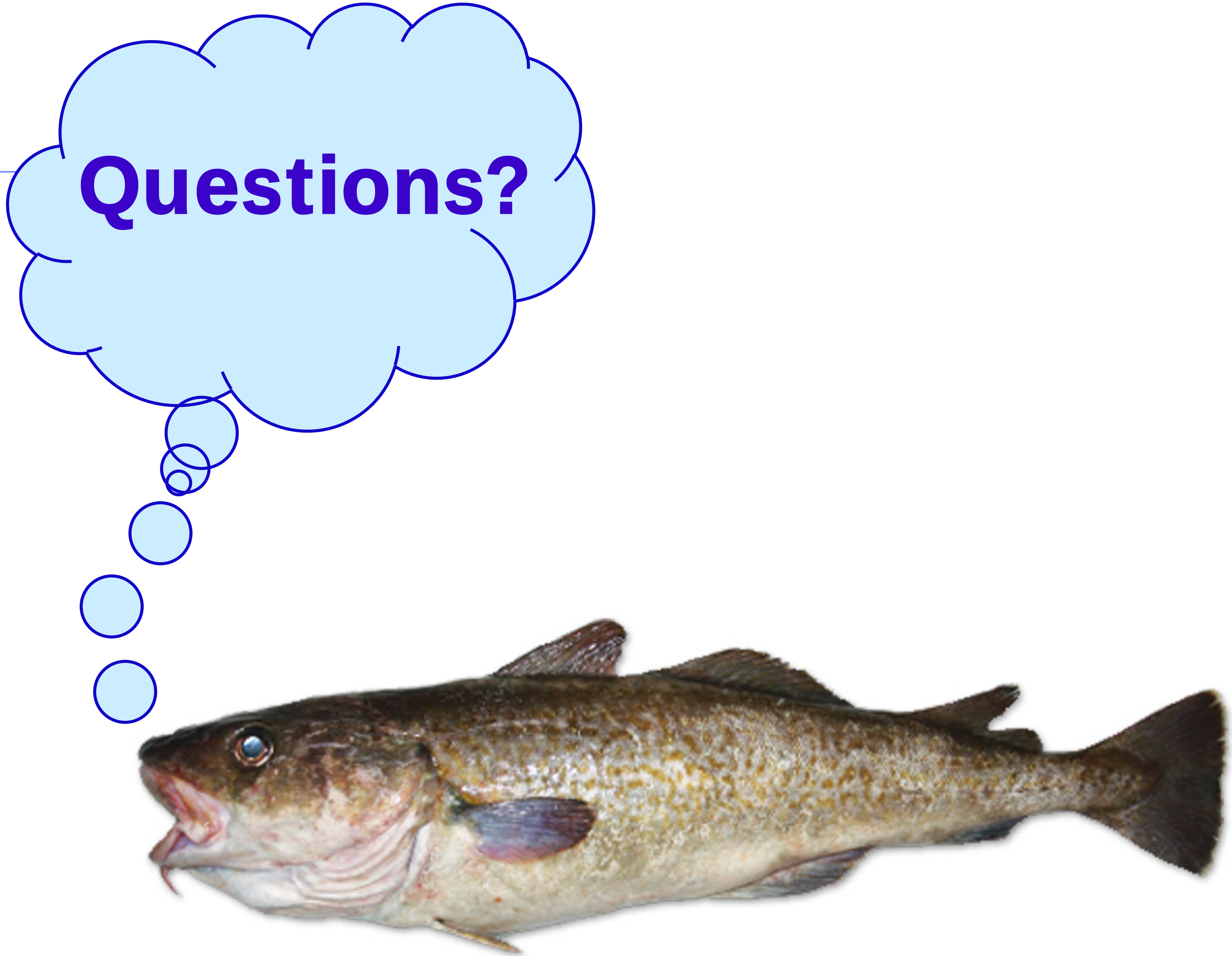


Acknowledgements

Funding provided by:

North Pacific Research Board

Pollock Conservation Cooperative Research Center


Questions?