Ecosystem chemistry:
Reconstructing a century of pinniped trophic position and biogeochemical indices in the northeast Pacific using archival museum specimens

Megan L. Feddern

Quantitative Seminar, Winter 2021

Gordon Holtgrieve, Eric Ward

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Overview

1. Ecological Applications of Stable Isotopes (nitrogen and carbon)

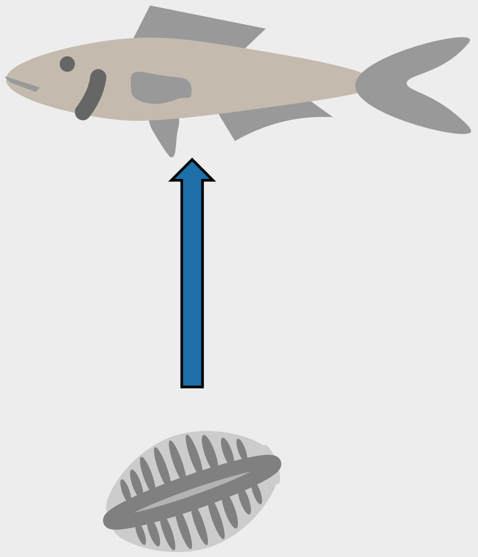
2. Challenges in Ecological Stable Isotope Applications
    - Biogeochemistry
    - Physiology

3. Case Study: Harbor Seal trophic position in WA
    1. Parameterizing harbor seal trophic position equations
    2. How does harbor seal trophic ecology respond to environmental change and prey availability?

$\delta^{15}N$ to calculate consumer trophic position

$$\delta^{15}N\ (‰\ \text{vs. air}) = \left(\frac{(^{15}N/^{14}N)_{Sample}}{(^{15}N/^{14}N)_{Air}} - 1 \right) * 1000$$

Standard



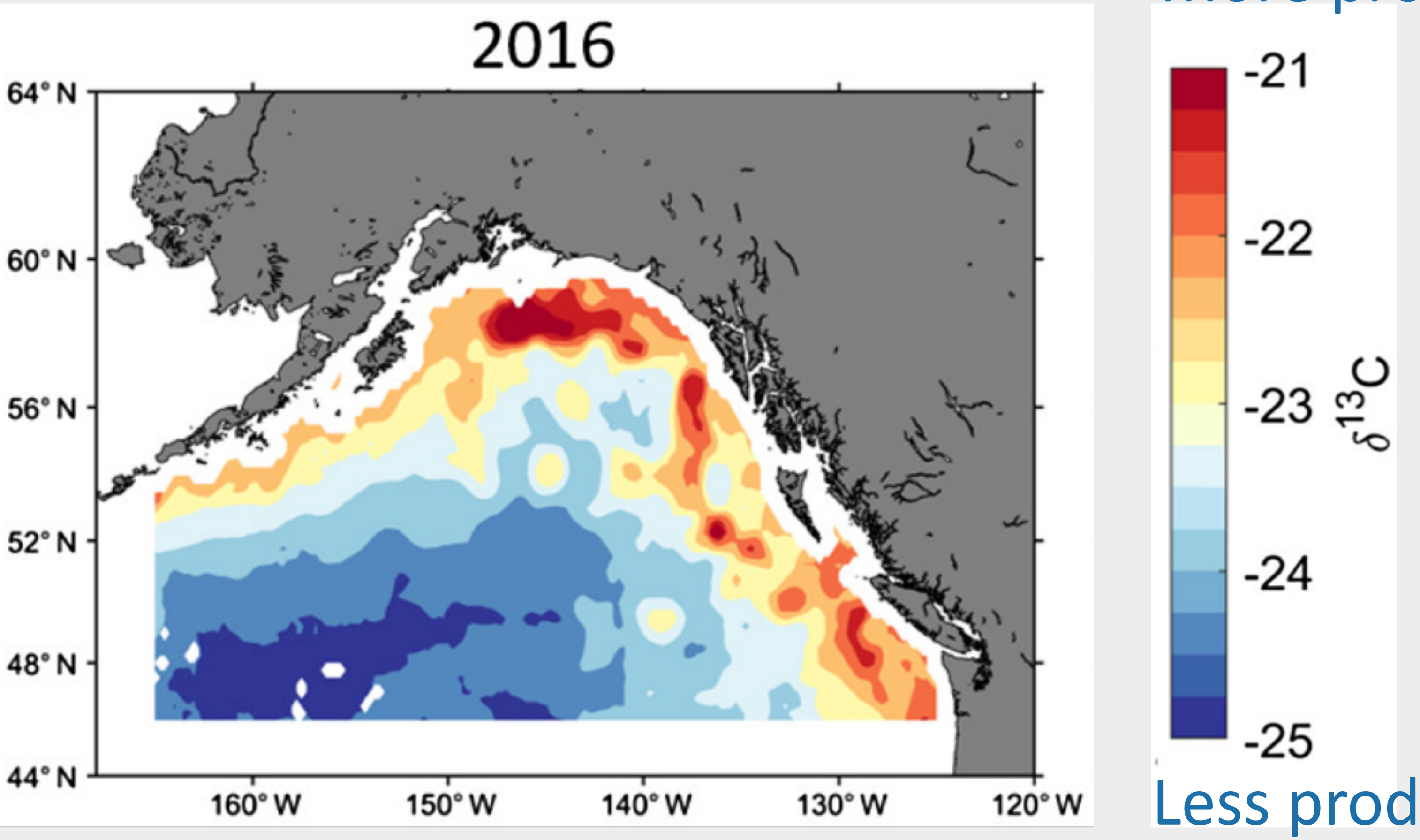
$\delta^{15}N_{Consumer}$

Trophic Enrichment:
Preferential assimilation of 15N

$\delta^{15}N_{Primary\ Producer}$

$\delta^{13}C$ to calculate movement/foraging location and carbon sources

More productive



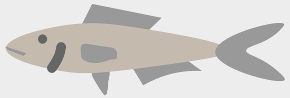
Less productive

Sources
- Terrestrial
- Marine derived
- C3 plants
- C4 plants

Espinasse et al. 2019. Global Ecology and Biogeography, Volume: 29, Issue: 2, Pages: 246-261, First published: 12 November 2019, DOI: (10.1111/geb.13022)

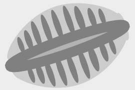
2. Challenges in Ecological Stable Isotope Applications

Variations in biogeochemistry: nitrogen resources



$\delta^{15}N_{Consumer}$

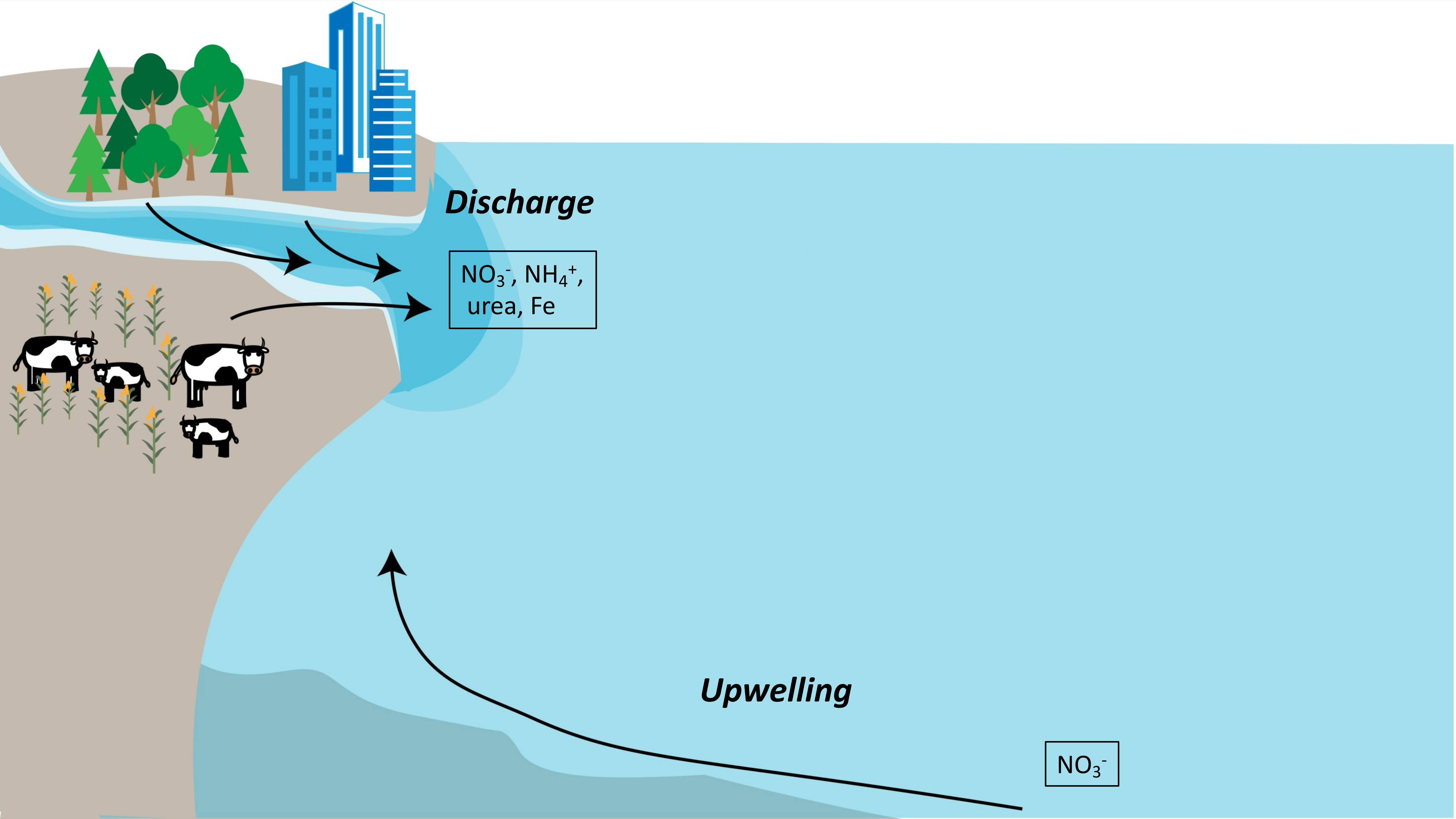
Trophic Enrichment:
Preferential assimilation of 15N

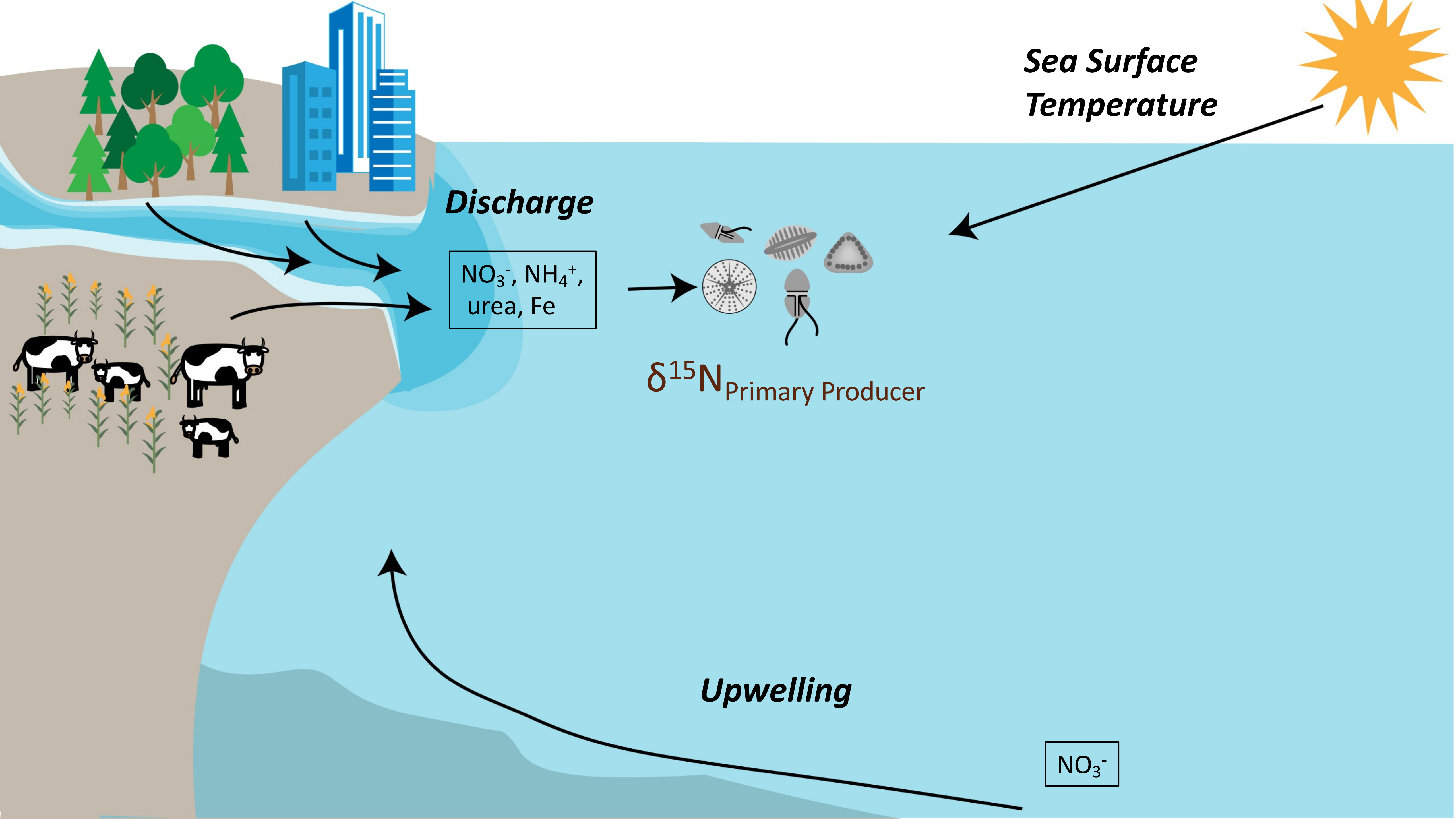


$\delta^{15}N_{Primary\ Producer}$

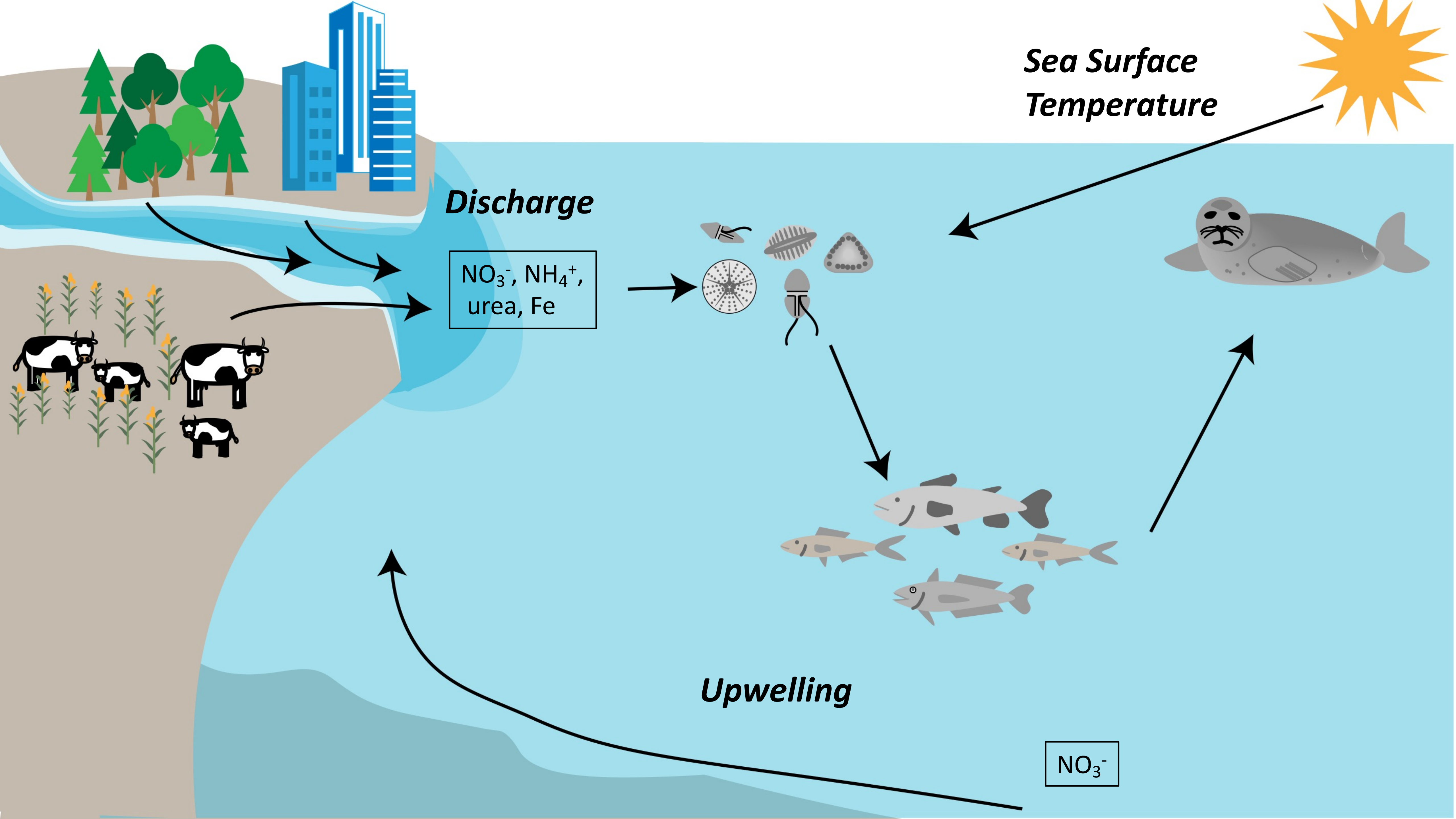
- **Nitrogen Sources (NO_3^-, NH_4^+, urea)**
- **Isotope composition of N**
- Light availability, taxa

$$\text{Trophic Position} = \frac{\delta^{15}N_{Consumer} - \delta^{15}N_{\text{[redacted]}\,Producer}}{\text{Trophic Enrichment Factor}}$$

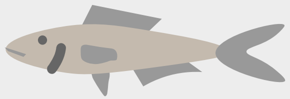

Discharge
NO_3^-, NH_4^+, urea, Fe
Upwelling
NO_3^-



Sea Surface Temperature
Discharge
NO_3^-, NH_4^+, urea, Fe
$\delta^{15}N_{Primary\ Producer}$
Upwelling
NO_3^-


Sea Surface Temperature
Discharge
NO_3^-, NH_4^+, urea, Fe
Upwelling
NO_3^-

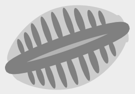
Variations in physiology: trophic enrichment



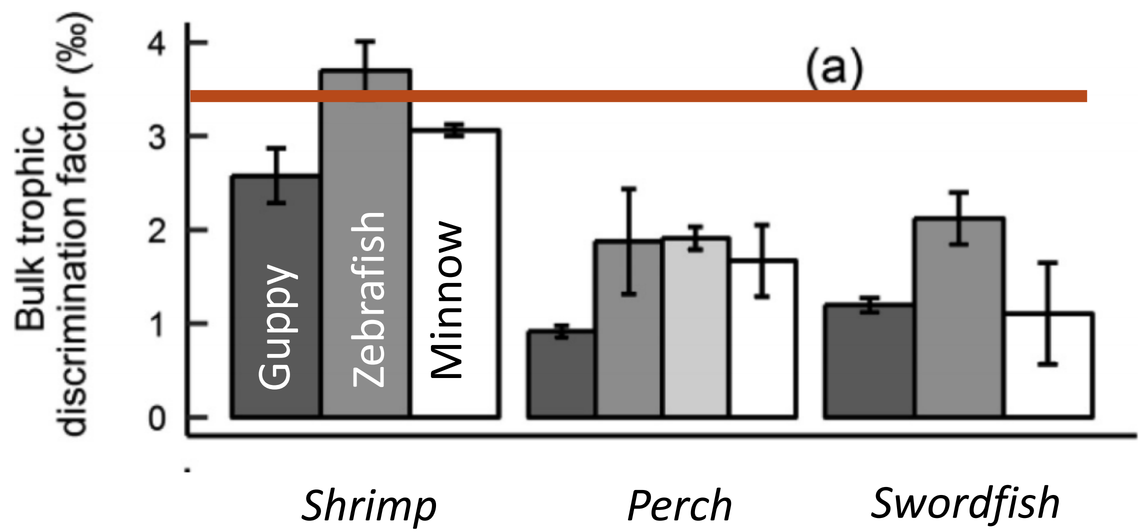
$\delta^{15}N_{Consumer}$

Trophic Enrichment:
Preferential assimilation of 15N

- **Diet Quality**
- **Growth**
- **Disease**
- **Tissue you sample**



$\delta^{15}N_{Primary\ Producer}$

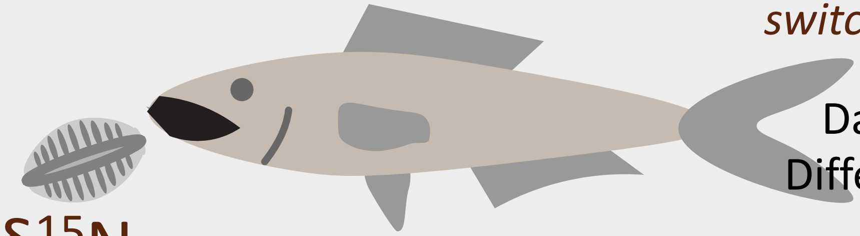


Blanke et al. 2017

$$\text{Trophic Position} = \frac{\delta^{15}N_{Consumer} - \delta^{15}N_{Primary\ Producer}}{\text{Trophic Enrichment Factor}}$$

3.4‰

Variations in physiology: tissue turnover



$\delta^{15}N_{\text{Primary Producer}}$

What about prey switching???

Day 10: Eat Different Food

What about movement???

Day 45: Migrates

Day 0: Eat Food

Day 5: Blood

Day 20: Liver

Day 80: Muscle

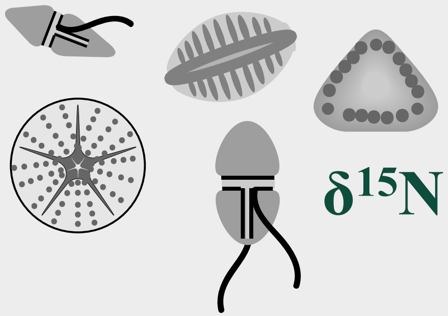
In Summary

1. $\delta^{15}N_{Primary\ Producer}$ needs to be measured in dynamic systems
2. Applying a single trophic enrichment may introduced error into trophic position calculations
3. Coupling $\delta^{15}N_{Primary\ Producer}$ and $\delta^{15}N_{Consumer}$ is important

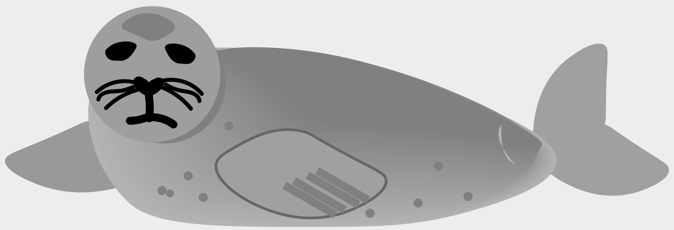
- Measuring $\delta^{15}N$ in individual compounds (amino acids) can be more informative
- Careful parameterization of the trophic position equation is beneficial

3. Parameterizing harbor seal trophic position equations

Scaling to Food Webs: Source Amino Acids

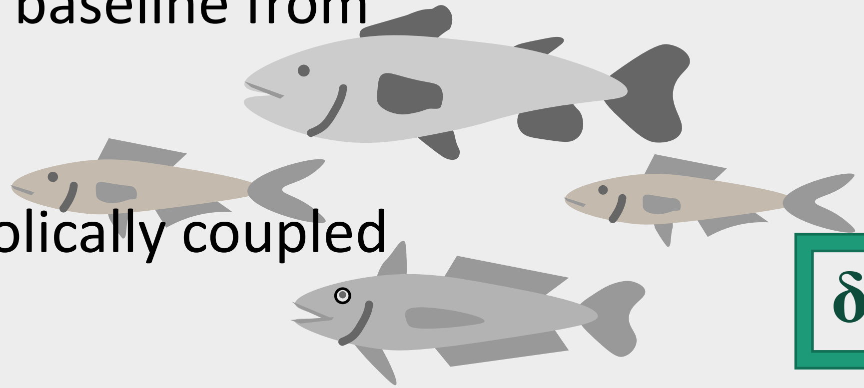


$\delta^{15}N$ of phenylalanine =



Conserved

- Eliminates trophic enrichment
- Directly measures baseline from consumer tissue
- Baseline is metabolically coupled with consumer

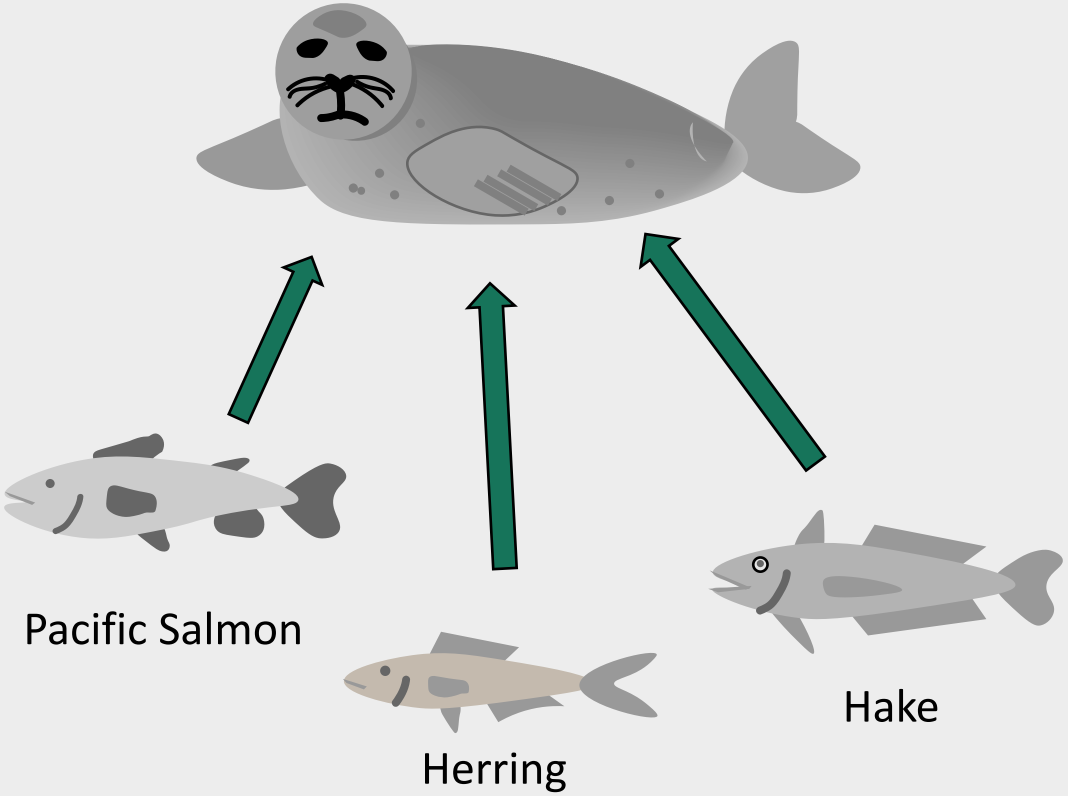


Conserved

Source Amino Acids

$\delta^{15}N$ of phenylalanine

Generalists integrate over multiple resource pathways



Limited migration, high site fidelity

Are not utilizing resources in different locations

5 - 10 km from haul out sites and at depths < 200 m

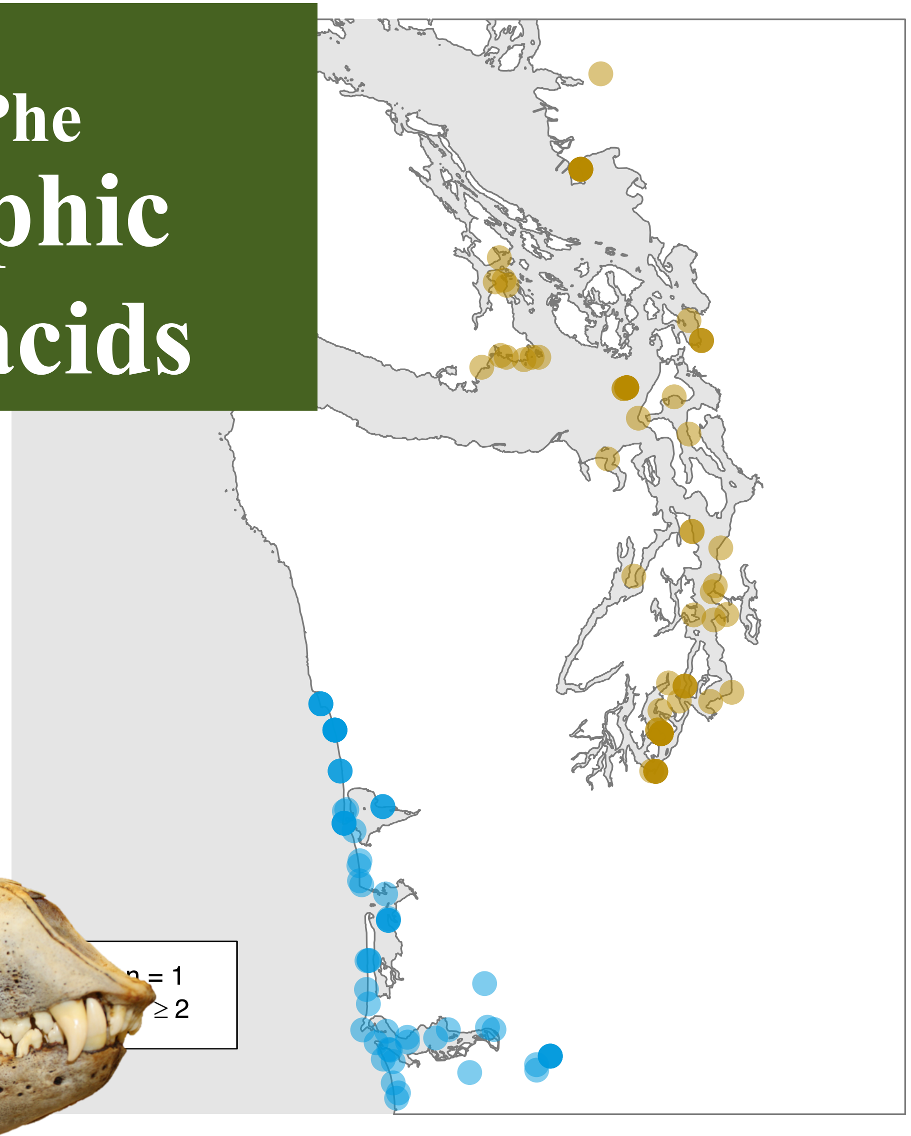
Are not susceptible to integrating nearshore vs. offshore $\delta^{13}C$ gradients

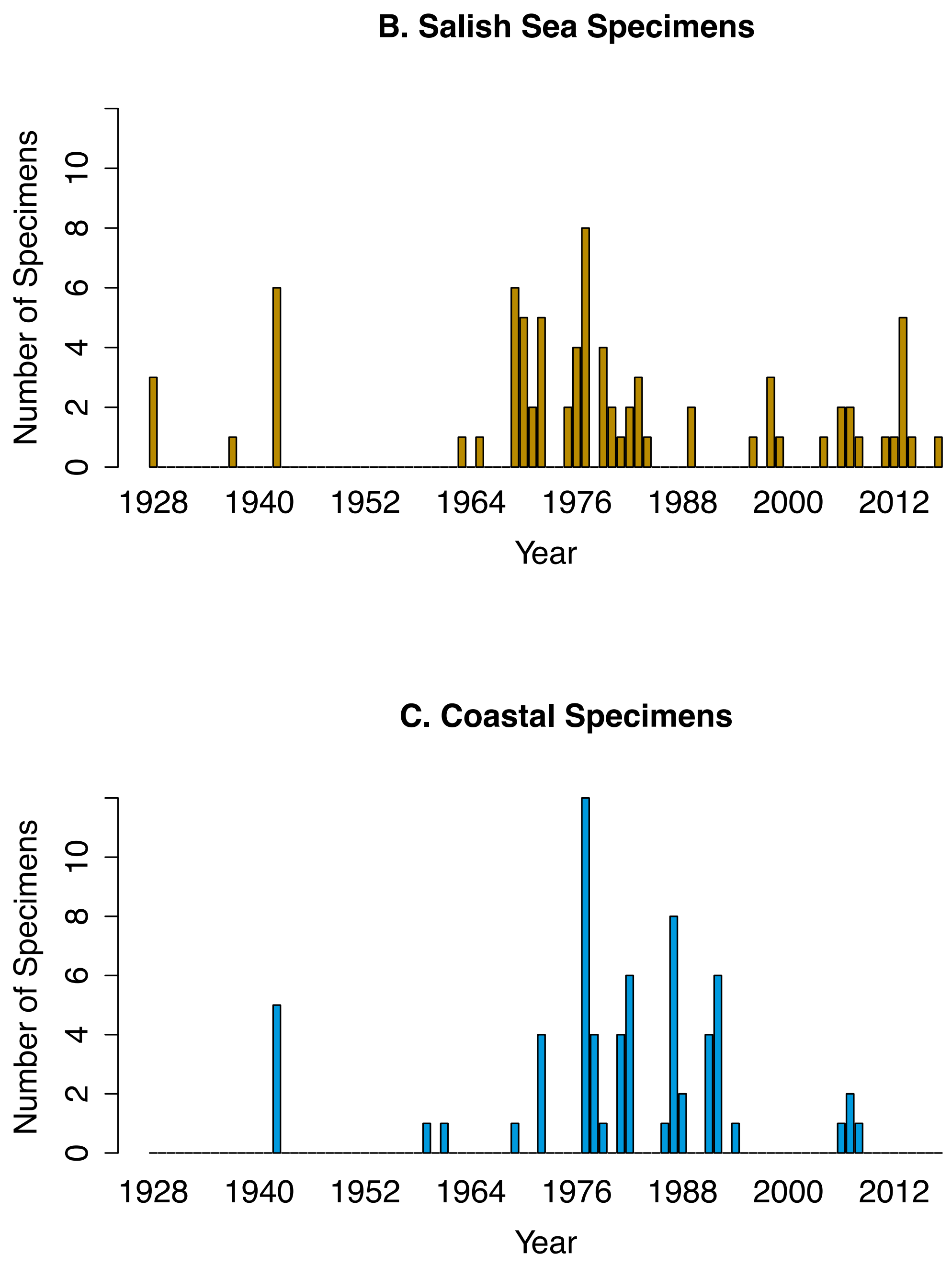
Controlled feeding studies

Minimal trophic enrichment

Optimal consumer for stable isotope interpretation

$\delta^{15}N_{Phe}$ + 9 trophic amino acids





Parameterizing the trophic position equation: Amino Acids

$$\text{Trophic Position} = \frac{\delta^{15}N_{Consumer} - \delta^{15}N_{Primary\ Producer}}{\text{Trophic Enrichment Factor}}$$

Glutamic Acid

Phenyalanine

$$\text{Trophic Position} = \frac{\delta^{15}N_{Trophic,\ Amino\ Acid} - \delta^{15}N_{Source,\ Amino\ Acid} - \beta}{\text{Trophic Enrichment Factor}} + 1$$

Fractionation of primary production

Amino acids
Trophic amino acids
Alanine
Aspartic acid
Glutamic acid
Leucine
Proline
Valine
Source amino acids
Glycine
Lysine
Methionine
Phenylalanine
Serine

Addressing Trophic Enrichment Factor Variability: Primary Production

$$\text{Trophic Position} = \frac{\delta^{15}N_{Consumer} - \delta^{15}N_{Primary\ Producer}}{\text{Trophic Enrichment Factor}}$$

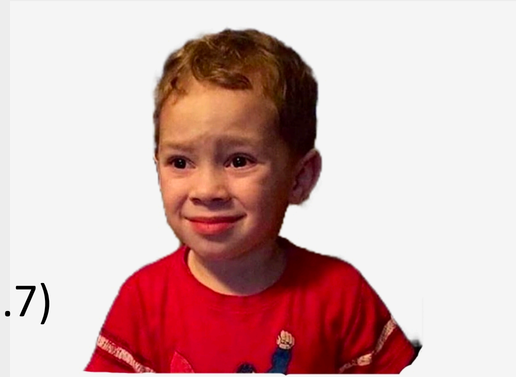
β of marine diatoms (C3) is 2.9

$$\text{Trophic Position} = \frac{\delta^{15}N_{Trophic,\ Amino\ Acid} - \delta^{15}N_{Source,\ Amino\ Acid} - \beta}{\text{Trophic Enrichment Factor}} + 1$$

7.6
"classic"

BUT...Germain et al. 2013 found harbor seal trophic enrichment factor is 4.3???

AND...Feddern et al. 2021 found C4 (seagrasses) plants contribute to WA food webs (β = -8.7)



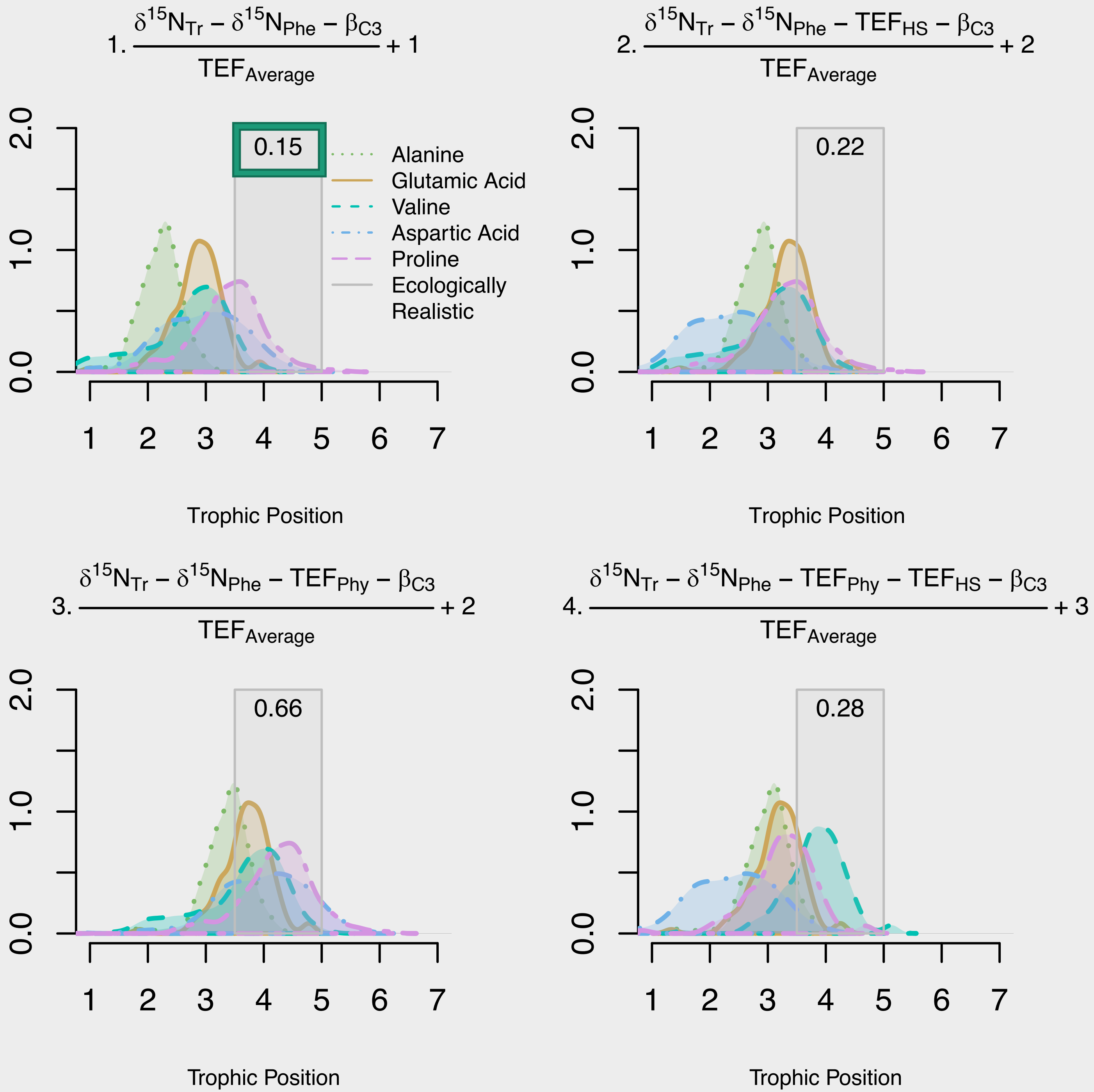
How should we parameterize trophic position?

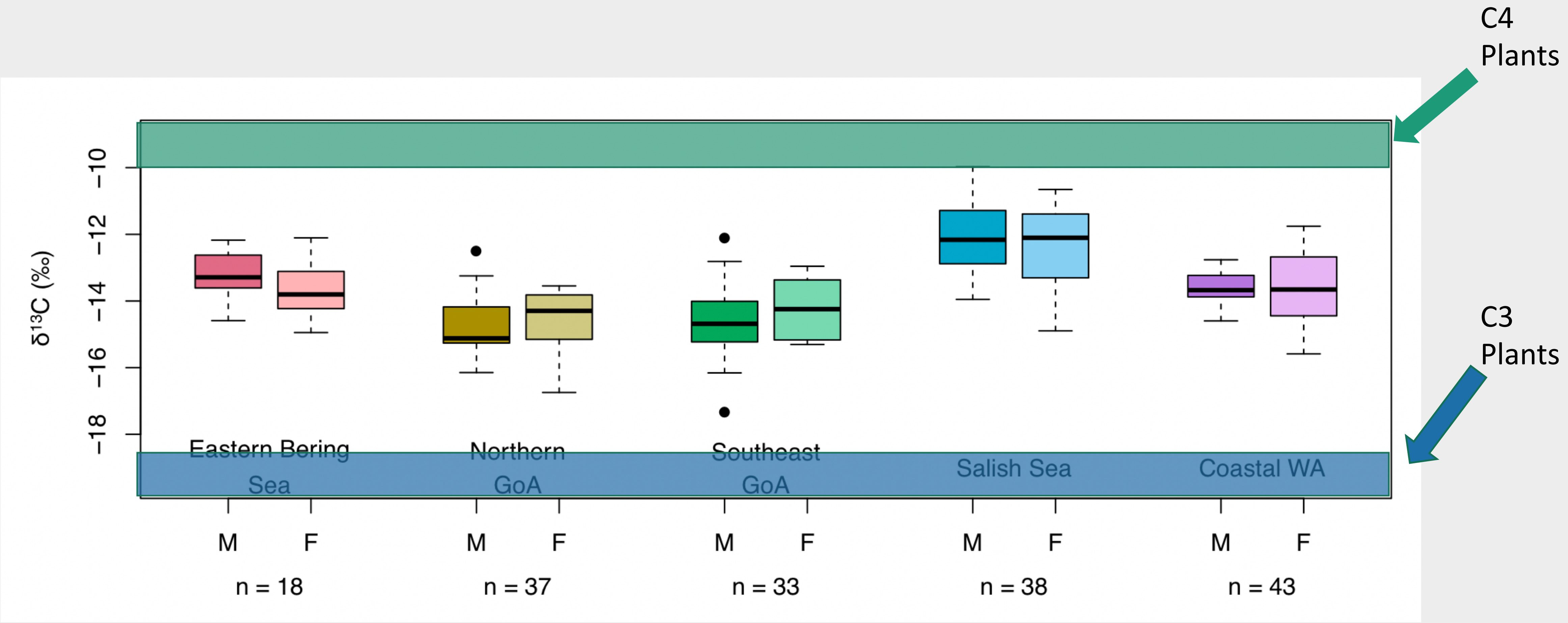
Diatoms (C3) | Seagrasses (C4) | Weighted C3 + C4 | Harbor Seal TEF | "Classic" TEF | Average across multiple taxa

Trophic Amino Acid	$\beta_{Diatoms}$ Nielsen et al. 2015	$\beta_{Seagrass}$ Vander Zanden et al. 2013	$\beta_{Weighted}$ This study	$TEF_{Harbor\ Seal}$ Germain et al. 2013	$TEF_{Plankton}$ Chikaraishi et al. 2009	$TEF_{Average}$ Nielsen et al. 2015
Glutamic acid (Glu)	2.9	[illegible]	[illegible]	3.4	7.6	6.6
Alanine (Ala)	2.8	-8.0	-3.6	2.5	5.6	6.8
Aspartic Acid (Asp)	1.8	-7.3	-4.2	3.5	5.4* Nielsen et al. 2015	5.4*
Valine (Val)	3.4	-6.8	-2.6	7.5	4.2	4.6
Proline (Pro)	2.7	-7.7* Not reported used average of other AAs		5.5	5.0	5.0

- Which beta should we use?
- How should we incorporate different trophic enrichment factors?
- Which amino acids should we use?

Effect of different Trophic Enrichment Factors of Trophic Position



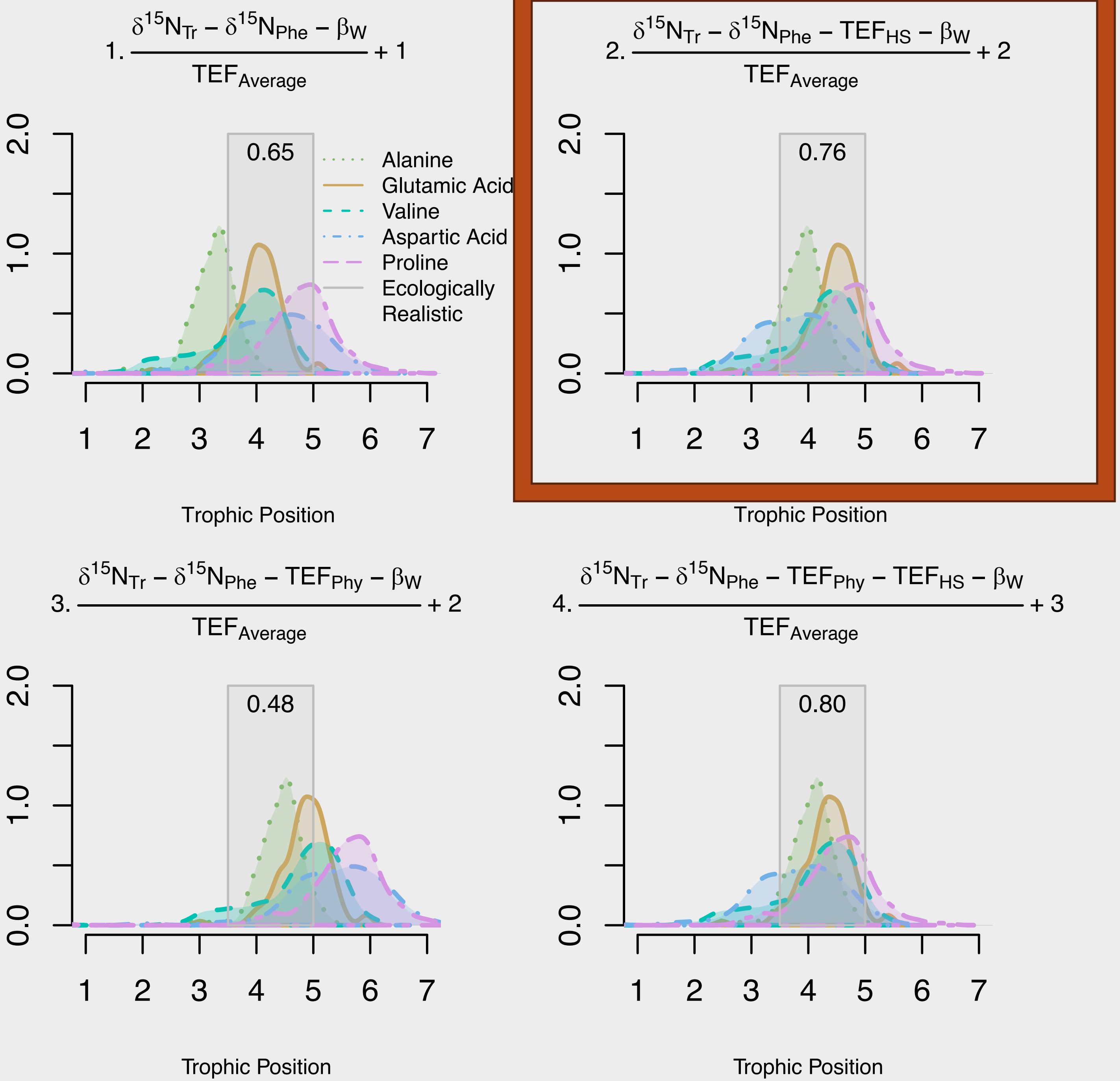


$$\%C4 = \frac{\delta^{13}C_{\text{Harbor Seal}} - \delta^{13}C_{C4}}{\delta^{13}C_{C4} - \delta^{13}C_{C3}} / \ 100$$

$$\beta_w = (\beta_{C4,Tr} * \%C4) + (\beta_{C3,Tr} * (1 - \%C4))$$

Feddern et al. 2021

Consideration for a weighted Beta



- Which beta should we use?
- How should we incorporate different trophic enrichment factors?
- Which amino acids should we use?
- What about tissue turnover?

Trophic Amino Acid	$\beta_{Diatoms}$ Nielsen et al. 2015	$\beta_{Seagrass}$ Vander Zanden et al. 2013	$\beta_{Weighted}$ This study	$TEF_{Harbor\ Seal}$ Germain et al. 2013	$TEF_{Plankton}$ Chikaraishi et al. 2009	$TEF_{Average}$ Nielsen et al. 2015
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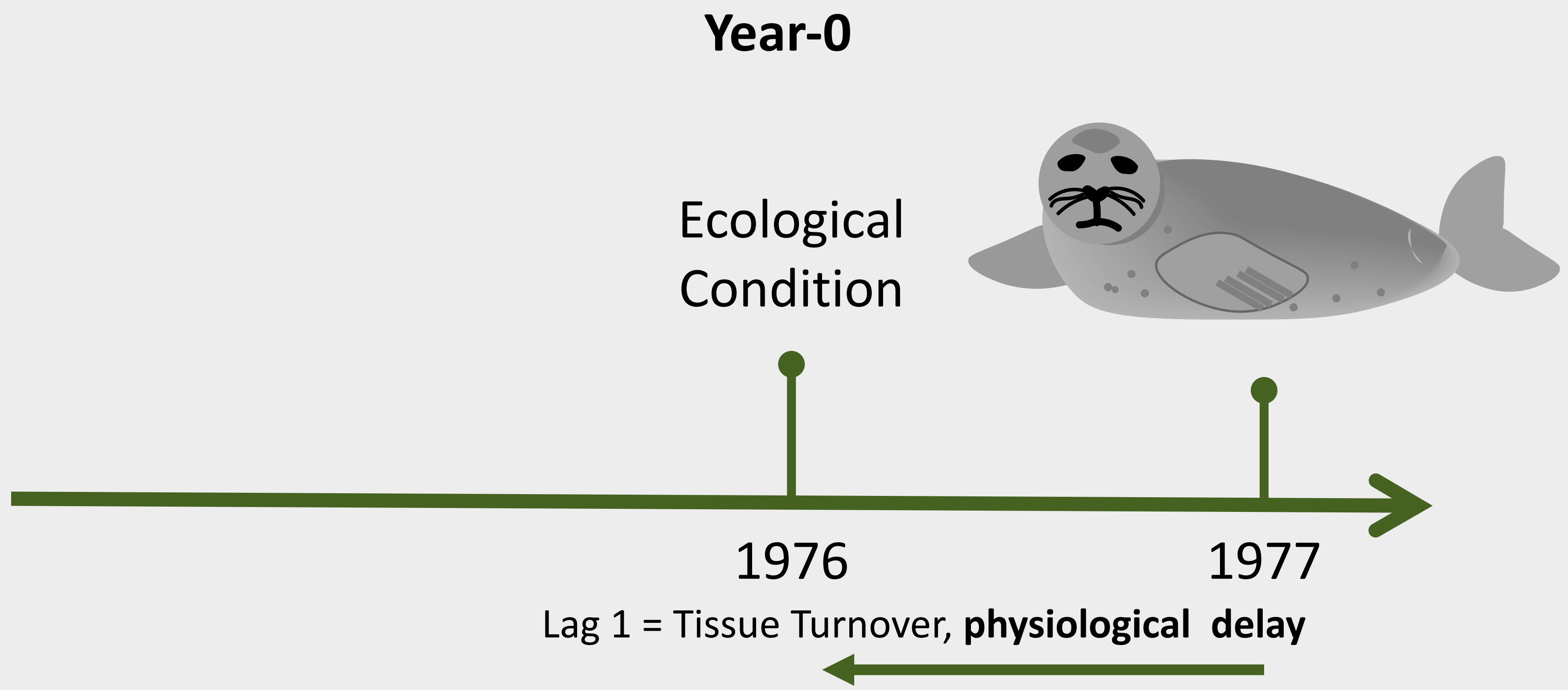
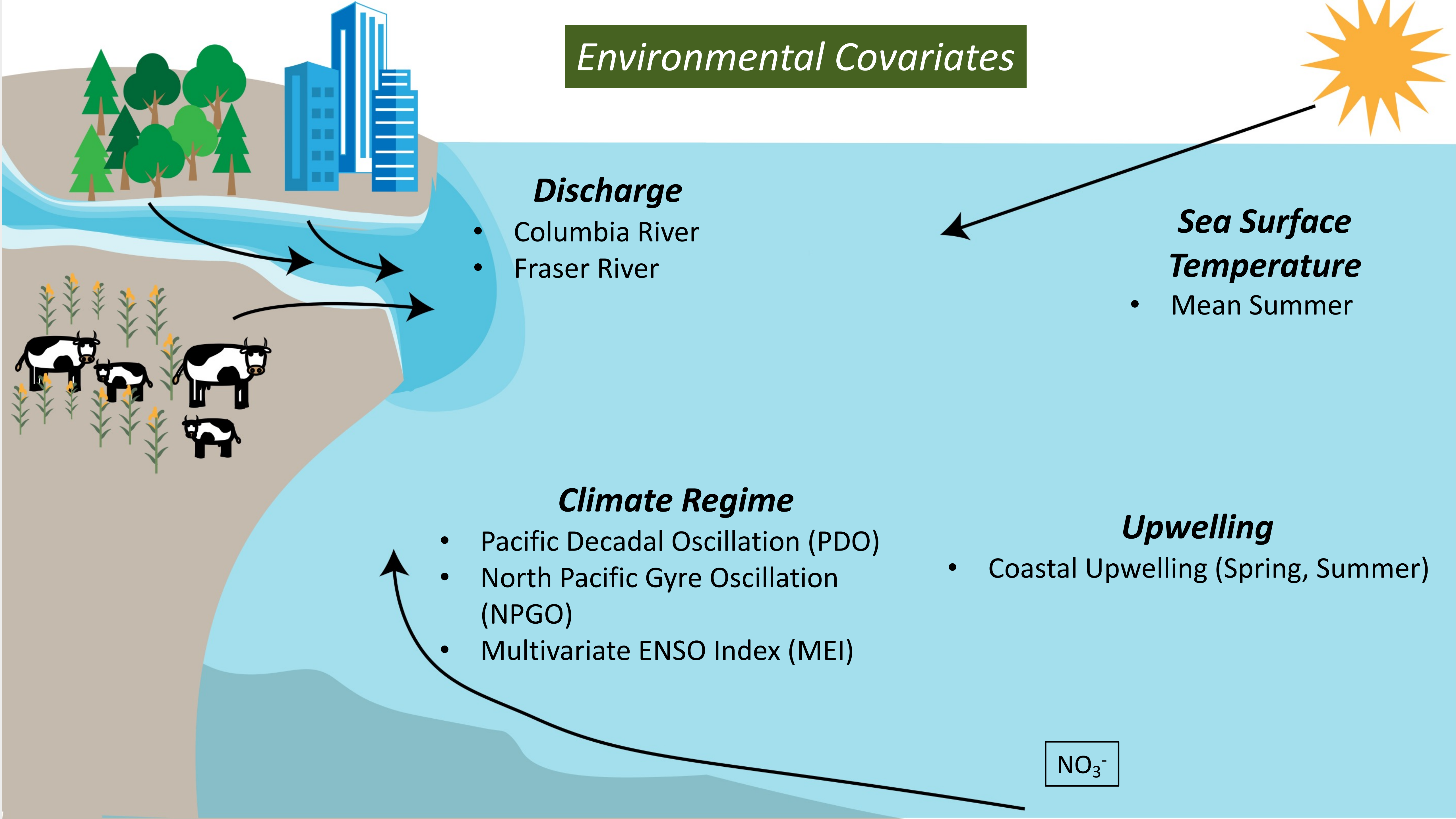
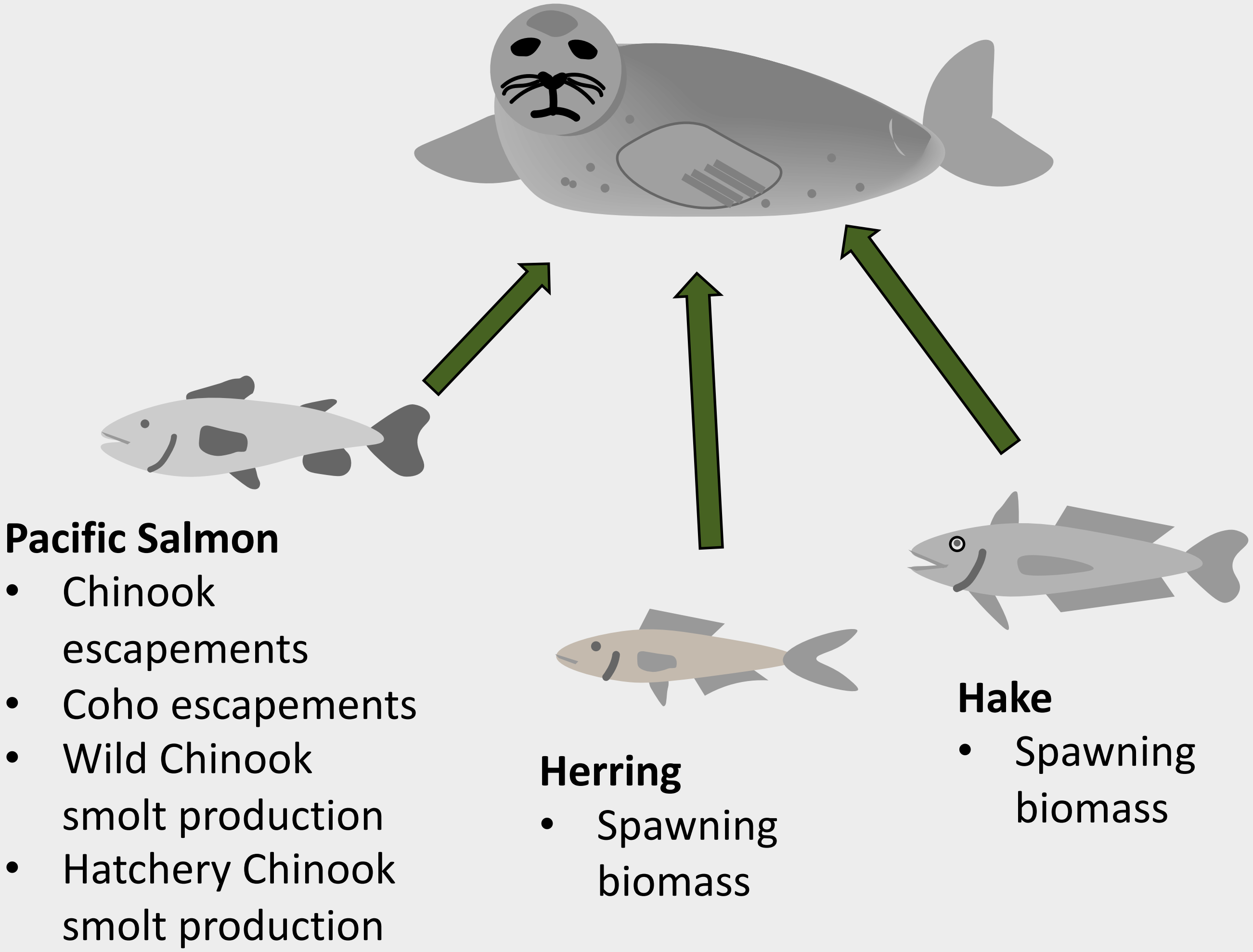
Applying temporal lag: tissue turnover



4. How does harbor seal trophic ecology respond to environmental change and prey availability?


Environmental Covariates
Discharge
• Columbia River
• Fraser River
Sea Surface Temperature
• Mean Summer
Climate Regime
• Pacific Decadal Oscillation (PDO)
• North Pacific Gyre Oscillation (NPGO)
• Multivariate ENSO Index (MEI)
Upwelling
• Coastal Upwelling (Spring, Summer)
NO_3^-

Prey Covariates



Modelling food web assimilated resources through time, with the environment

TIME LAGS ASSOCIATED WITH EFFECTS OF OCEANIC CONDITIONS ON SEABIRD BREEDING IN THE SALISH SEA REGION OF THE NORTHERN CALIFORNIA CURRENT SYSTEM

RASHIDA S. SMITH[1], LYNELLE M. WELDON[2], JAMES L. HAYWARD[1] & SHANDELLE M. HENSON[1,2]

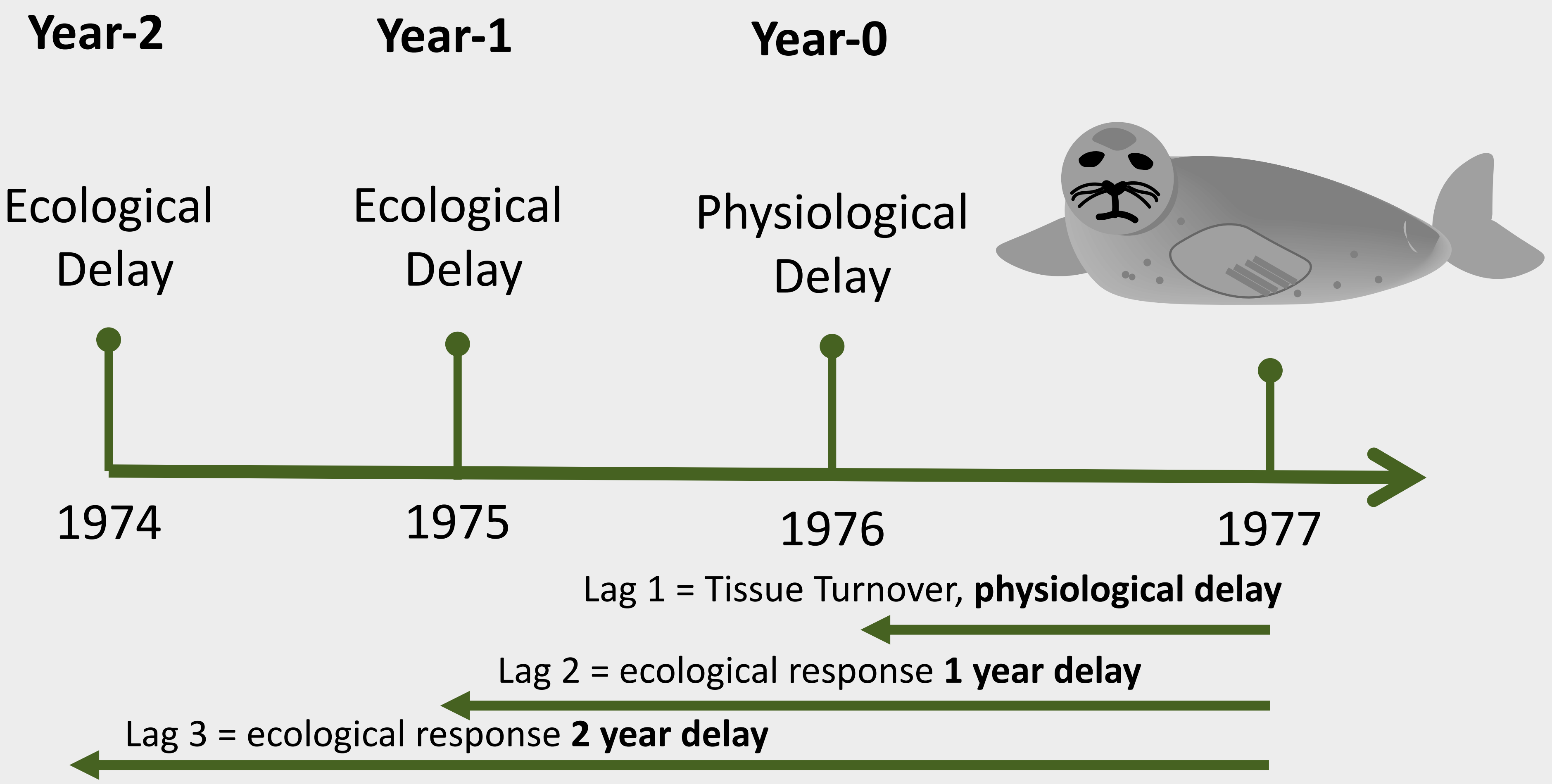
Historical fluctuations and recent observations of Northern Anchovy *Engraulis mordax* in the Salish Sea

Check for updates

William D.P. Duguid[a,*], Jennifer L. Boldt[b], Lia Chalifour[a], Correigh M. Greene[c], Moira Galbraith[d], Doug Hay[e], Dayv Lowry[f], Skip McKinnell[g], Chrys M. Neville[b], Jessica Qualley[a], Todd Sandell[h], Matthew Thompson[b], Marc Trudel[a,i], Kelly Young[d], Francis Juanes[a]

ment of Northern Anchovy occurs within the Salish Sea. Most periods of elevated Northern Anchovy abundance in the last century have corresponded to, or lagged periods of elevated ocean temperatures. While a 2005 peak

Applying temporal lags: delay in ecological response



Modelling food web assimilated resources through time, with the environment

- Data challenges: large temporal gaps, more than one observation at one time

1. Environmental Model
   - $y_{t-lag} = \alpha_{j[t]} + \beta x_t + \epsilon$

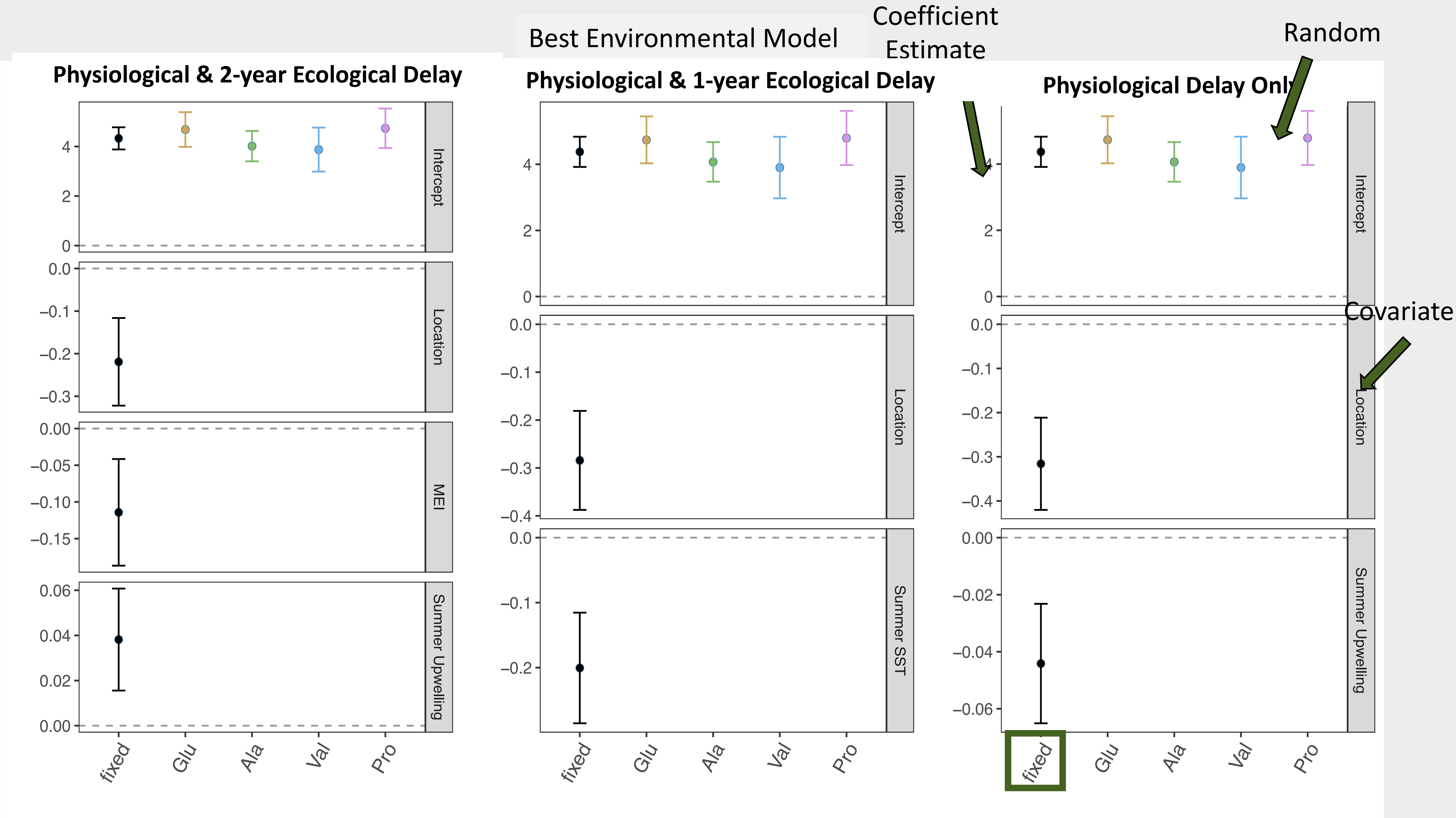
   Environmental Covariates

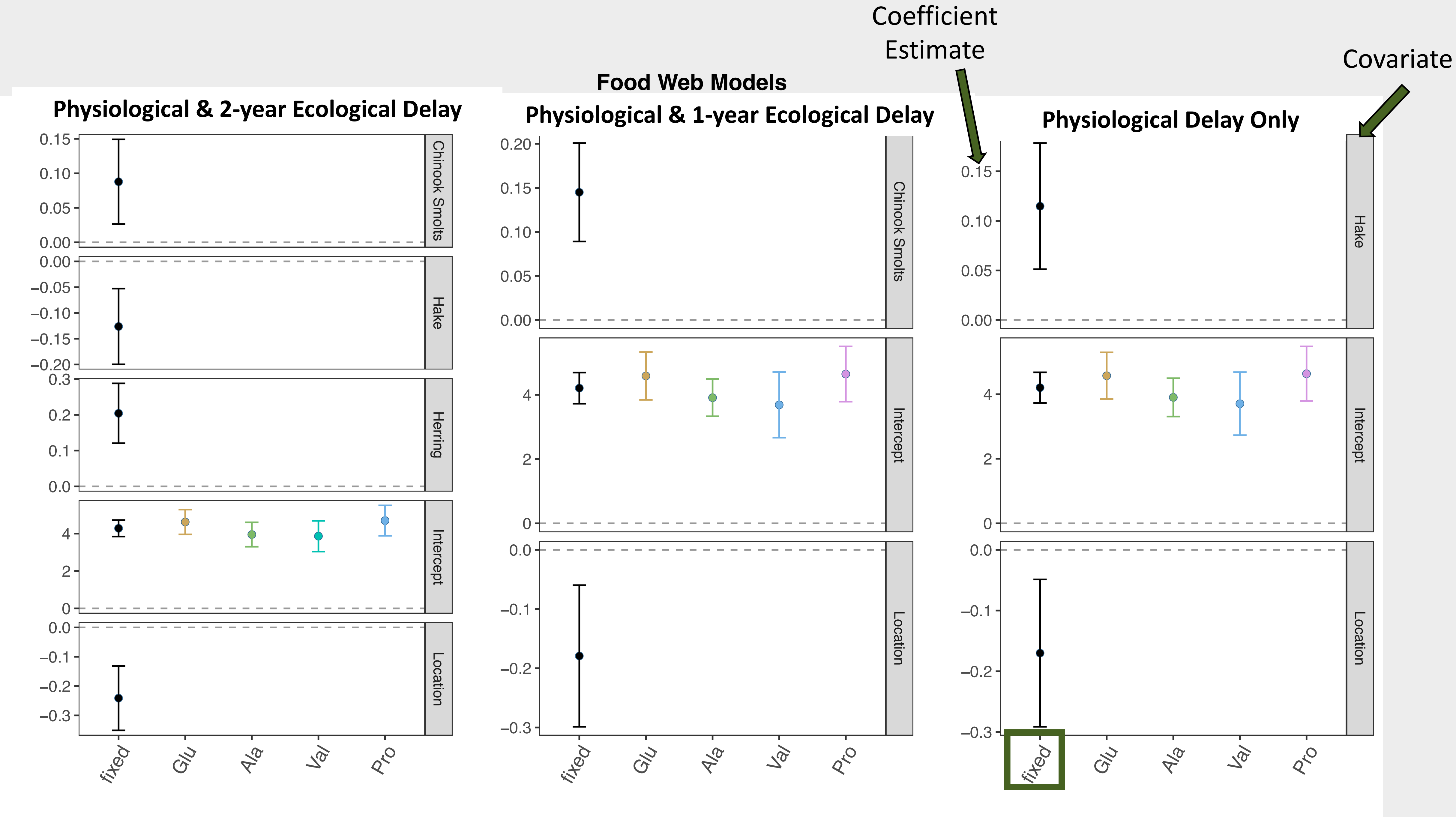
2. Food Web Model
   - $y_{t-lag} = \alpha_{j[t]} + \beta x_t + \epsilon$

   Amino Acid

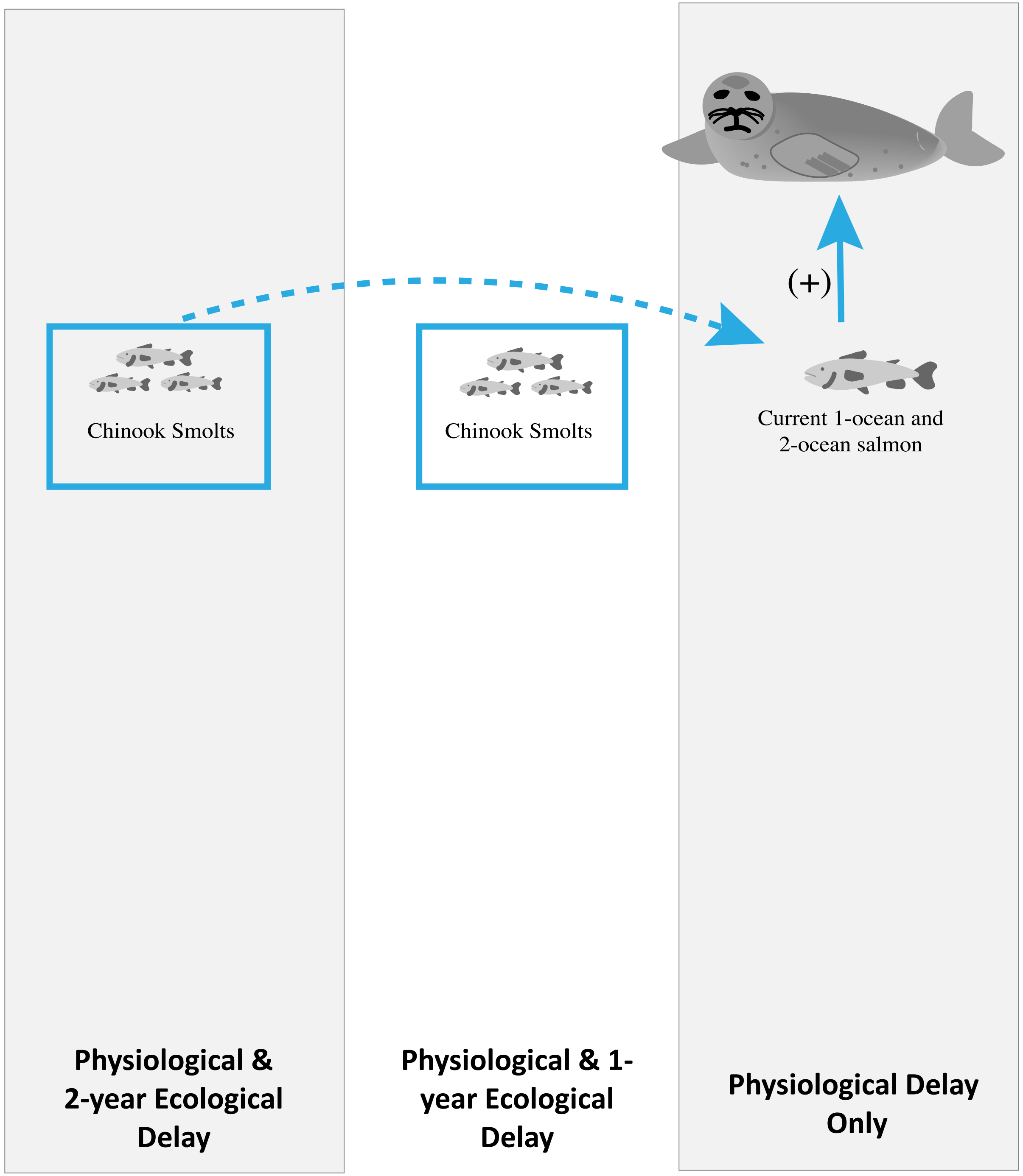
   Prey Availability Covariates

- Lag: 1, 2, 3 year lag
- Random effect *j* is amino acid (glutamic acid, alanine, proline, valine)


Best Environmental Model
Coefficient Estimate
Random
Covariate
Physiological & 2-year Ecological Delay
Physiological & 1-year Ecological Delay
Physiological Delay Only
Intercept
Location
MEI
Summer Upwelling
Summer SST
fixed
Glu
Ala
Val
Pro

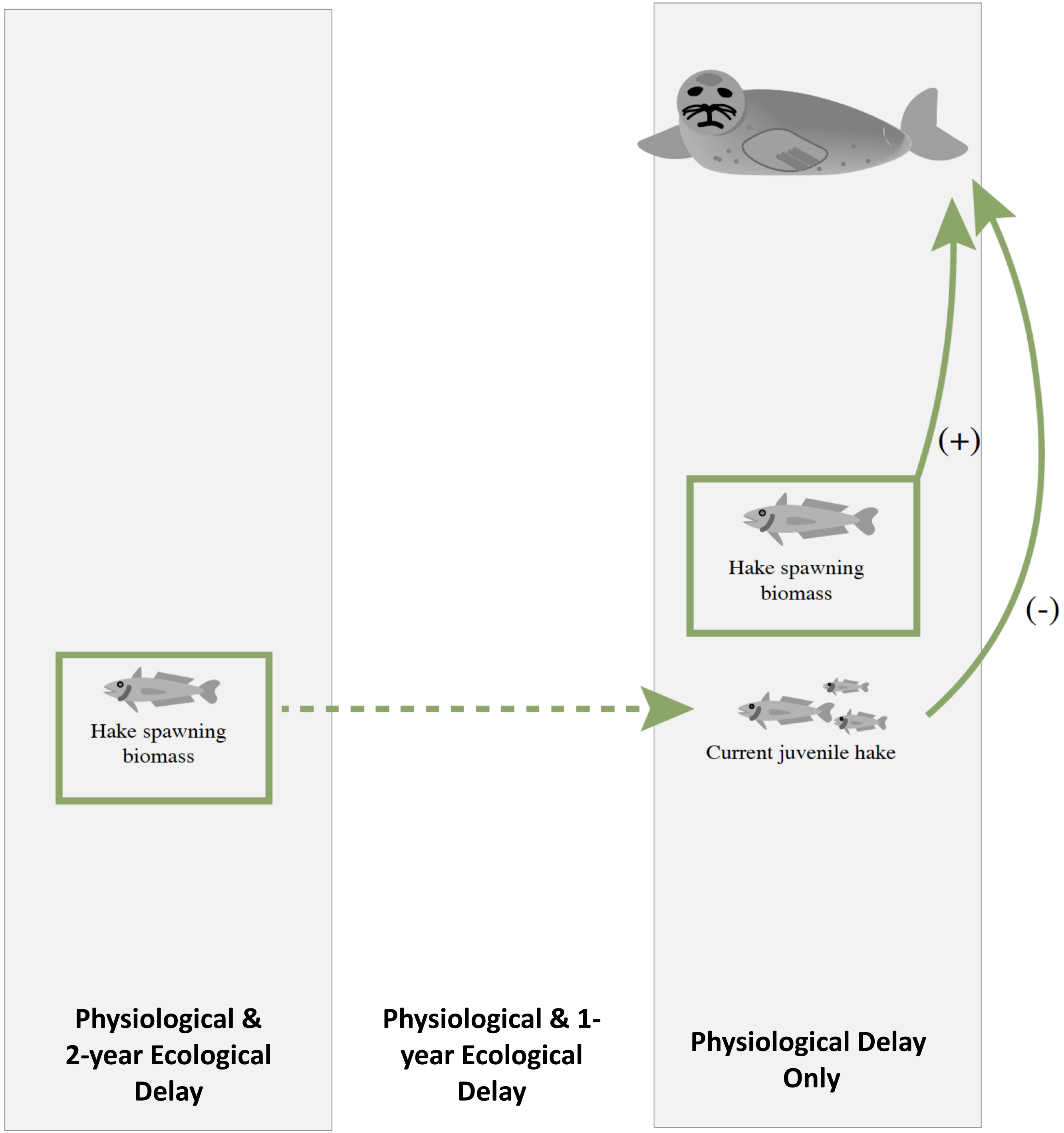


Coefficient Estimate
Covariate
Food Web Models
Physiological & 2-year Ecological Delay
Physiological & 1-year Ecological Delay
Physiological Delay Only
Chinook Smolts
Hake
Herring
Intercept
Location
fixed
Glu
Ala
Val
Pro

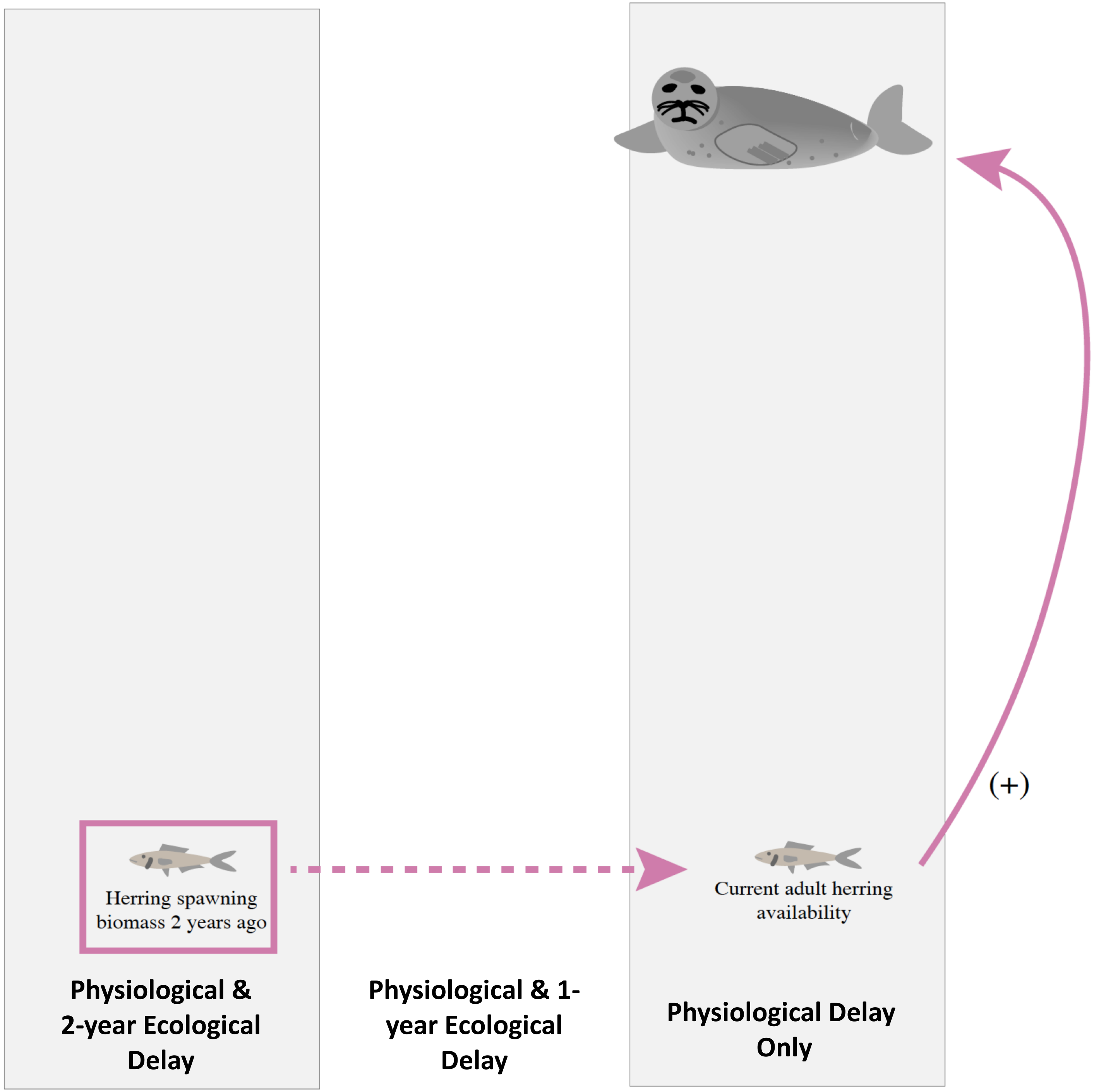


Chinook smolts in the previous 2 years appear to be better predictors of what is available to predators than current escapements

Both juvenile and adult hake influence harbor seal trophic ecology



Herring spawning biomass in previous years has a bigger effect on current harbor seal trophic ecology than current spawning biomass



Summary

- Careful decision of parameterization can lead to more informative analyses
- Including lags for delayed ecological responses and tissue turnover is important
- Prey covariates that don’t represent availability to predators may miss important relationships

Collaborators and Acknowledgements

UNIVERSITY OF ALASKA
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MUSEUM

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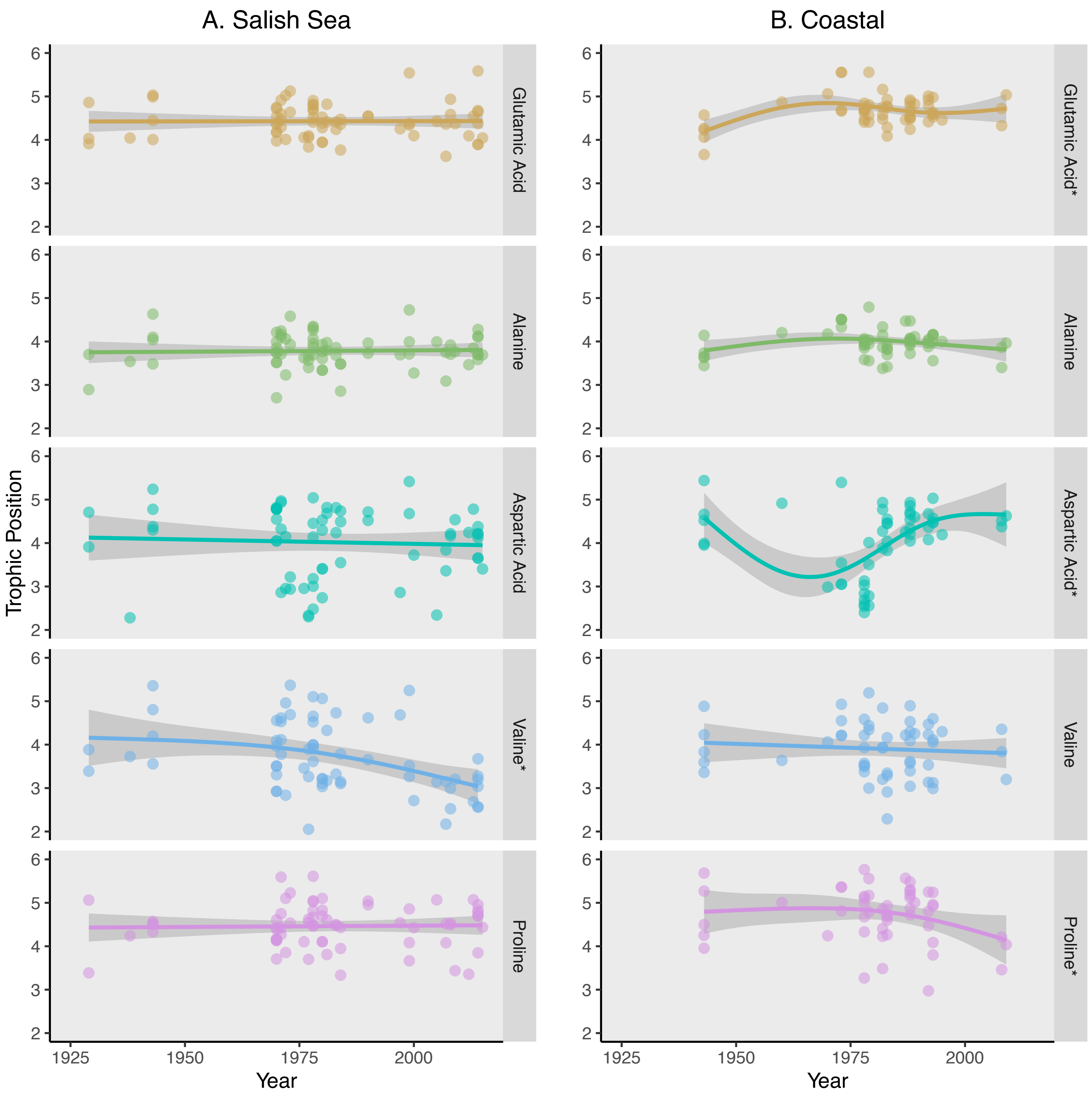
NOAA
U.S. DEPARTMENT OF COMMERCE

Sea Grant
Washington

Smithsonian
Institution

ROYAL BC
MUSEUM



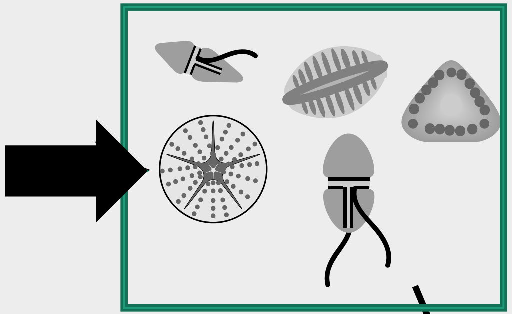
A. Salish Sea
B. Coastal
Trophic Position
Glutamic Acid
Glutamic Acid*
Alanine
Alanine
Aspartic Acid
Aspartic Acid*
Valine*
Valine
Proline
Proline*
6
5
4
3
2
1925
1950
1975
2000
Year
Year

How does the environment impact ***resource utilization*** by coastal marine food webs?

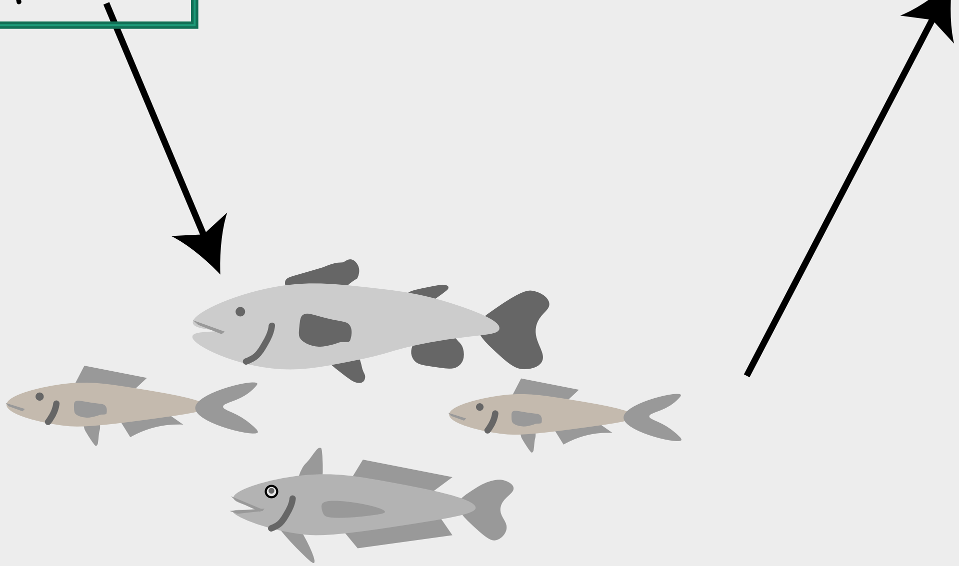
Challenges of Scale

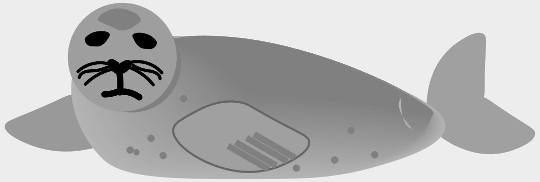
NO_3^-, NH_4^+, urea

1. We can measure resources directly



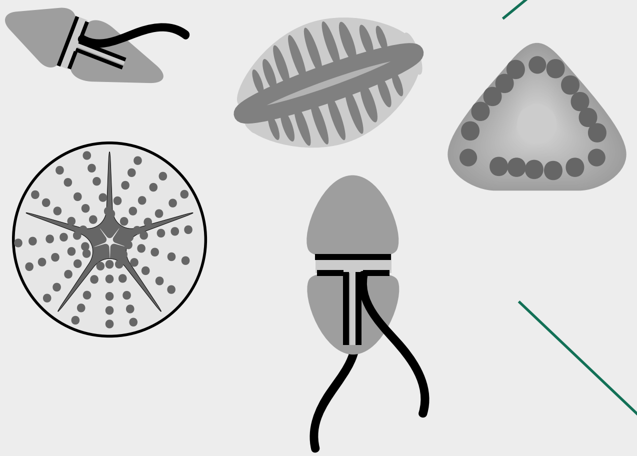
2. We can measure primary producers directly





Availability ≠ Utilization

Utilizing Chemical Tracers



$\delta^{13}C$

- Community Composition
- Cellular Growth
- $[CO_2]$

Additive & Subtractive

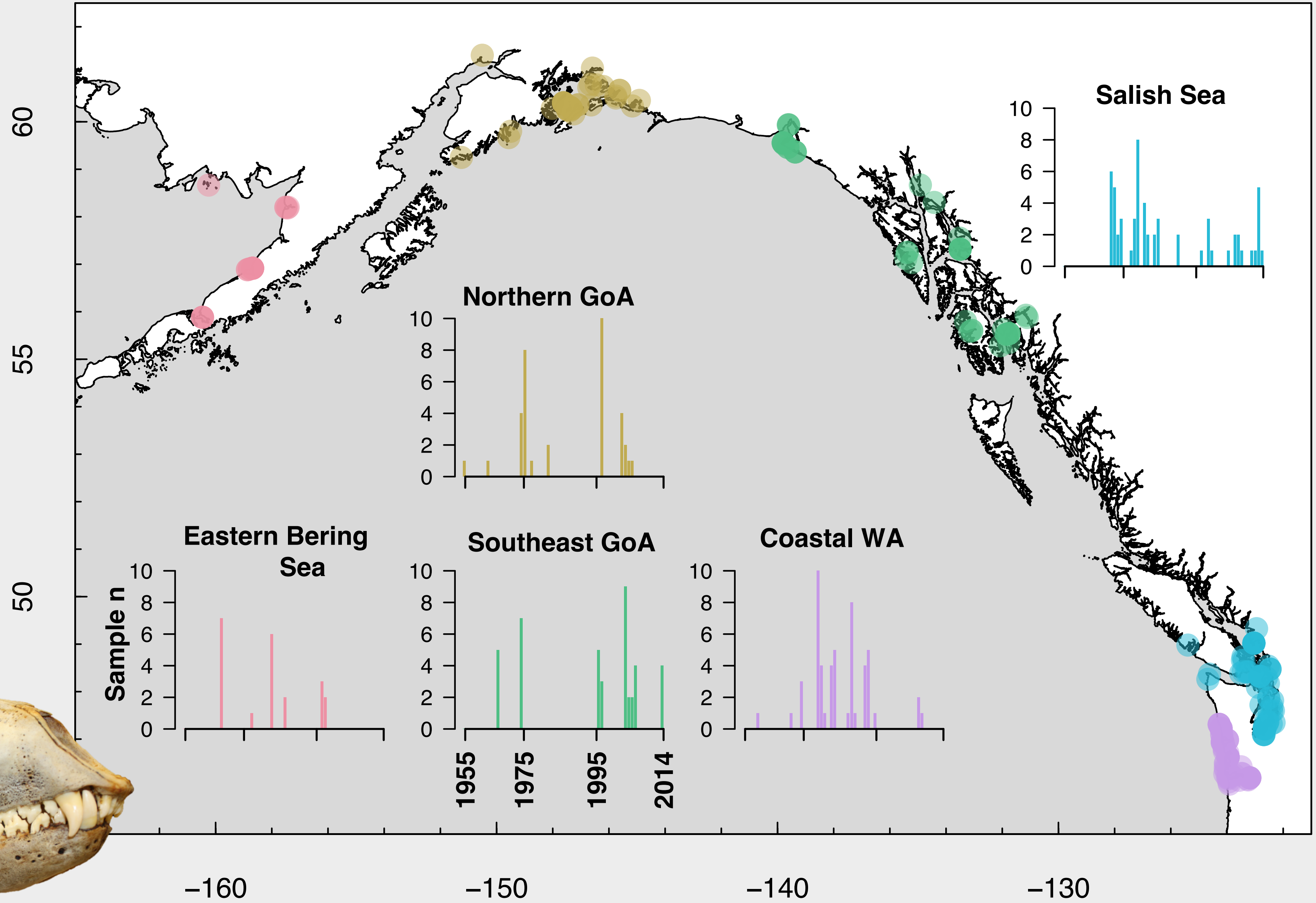
$\delta^{15}N$

- Nitrogen Sources
- Isotope composition of N

Large scale indicators

$\delta^{15}N_{Phe}$

$\delta^{13}C$



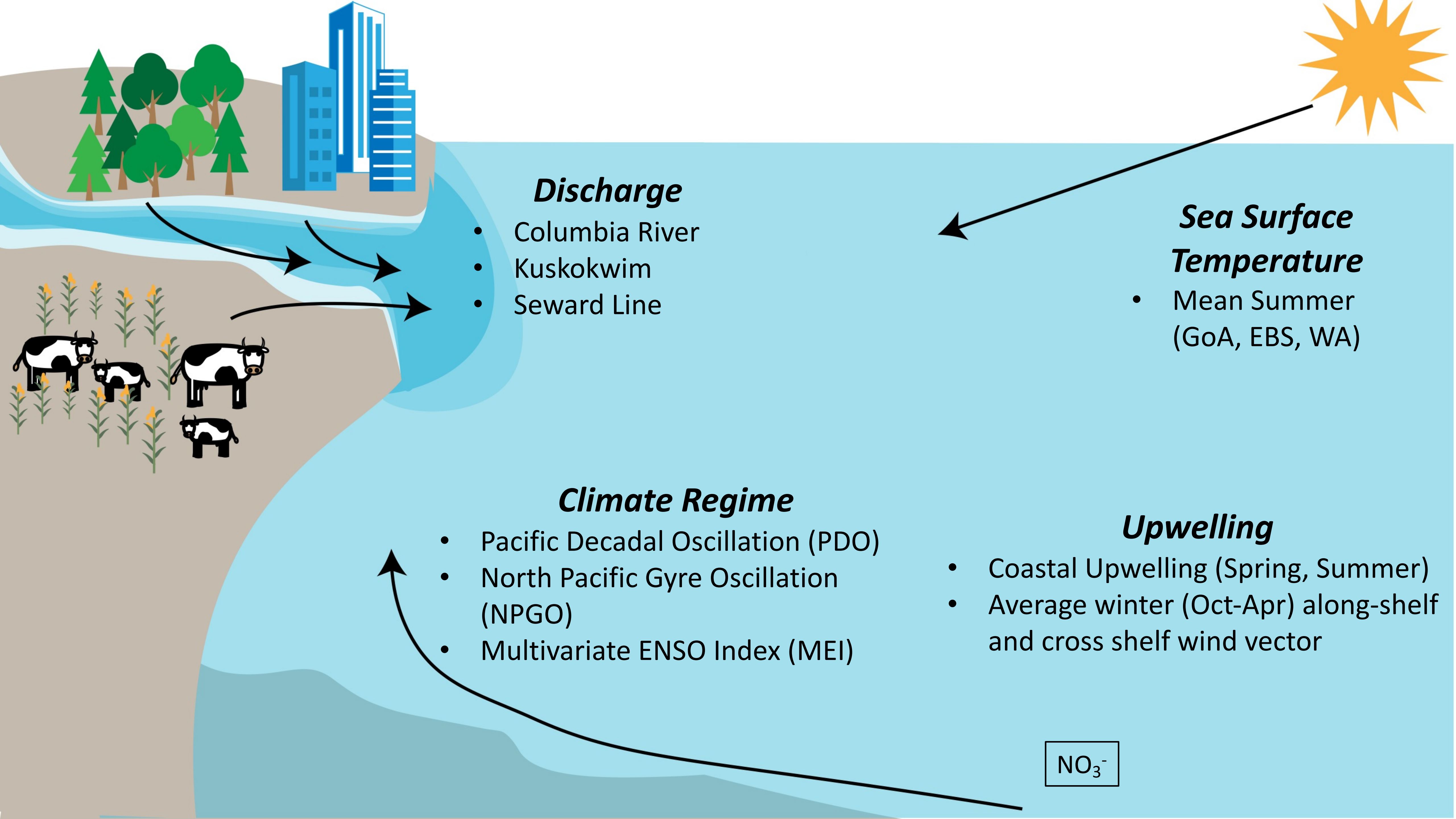
Modelling food web assimilated resources through time, with the environment

- Data challenges: large temporal gaps, more than one observation at one time

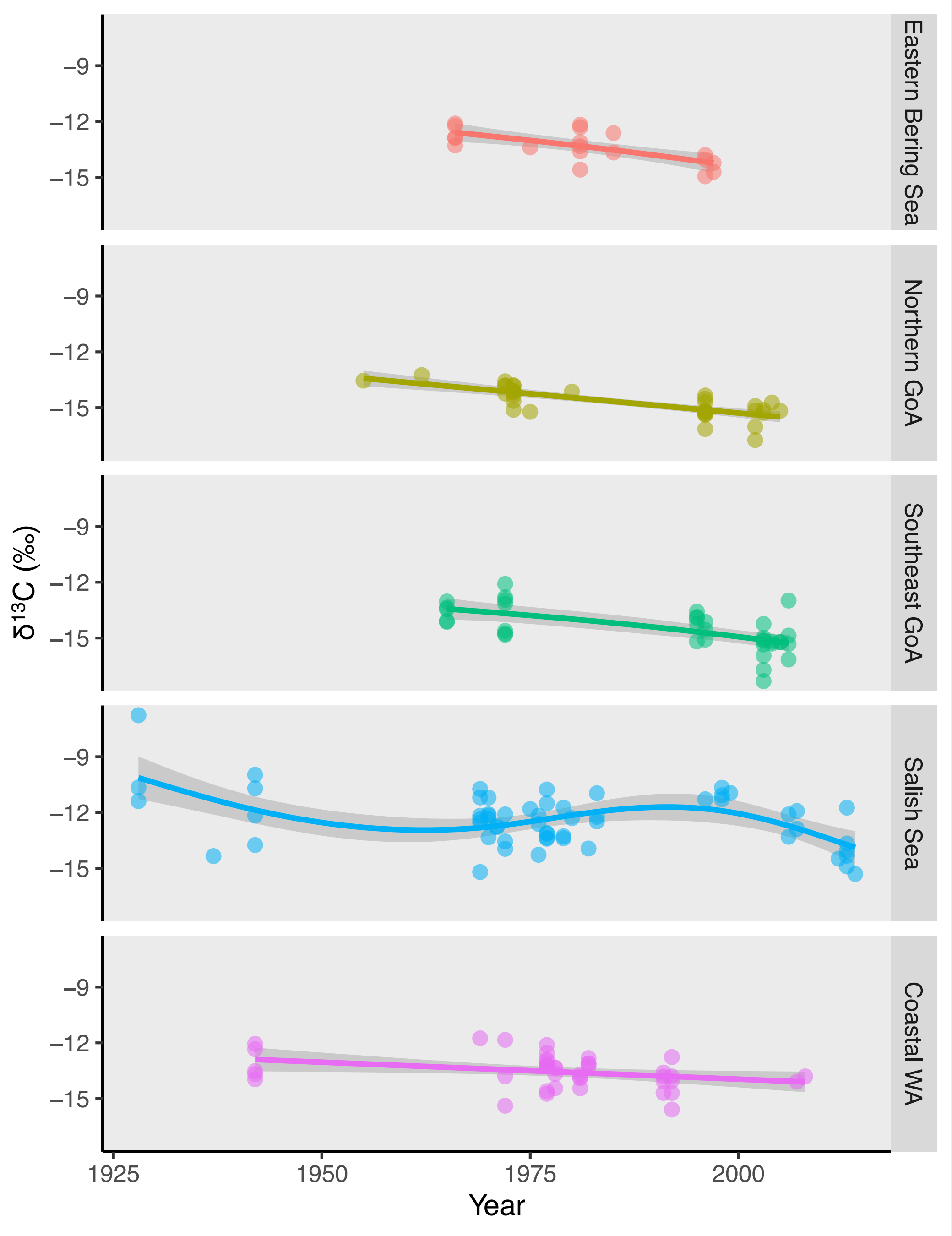
1. Changes through time: generalized additive model
   - Gaussian($E(y_i) = \alpha + \beta_1 + f_1(x_{1i})$, k = 6

2. Correlation with environmental covariates
   - $y_{t-1} = \alpha + \boldsymbol{\beta} x_t$

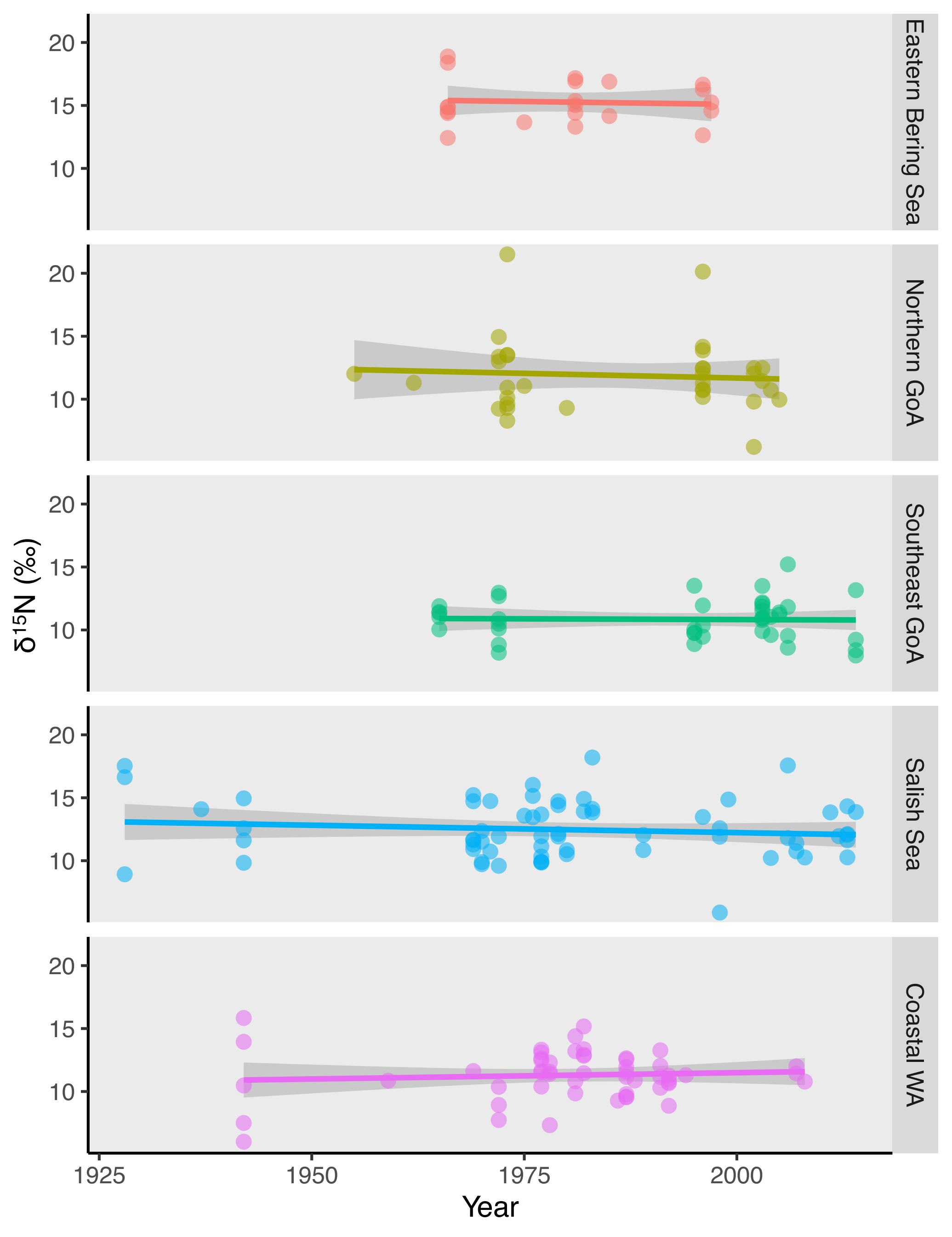
Amino acids	$t_{0.5}$ (95% CI)
Trophic amino acids	
Alanine	642 (411, 1467)
Aspartic acid	1530 (908, 4881)
Glutamic acid	940 (694, 1453)
Leucine	905 (572, 2163)
Proline	369 (196, 3151)
Valine	942 (619, 1962)
Source amino acids	
Glycine	163 (89, 1004)
Lysine	706 (360, 18098)
Methionine	2168 (1223, 9562)
Phenylalanine	780 (459, 2576)
Serine	2280 (1714, 3404)

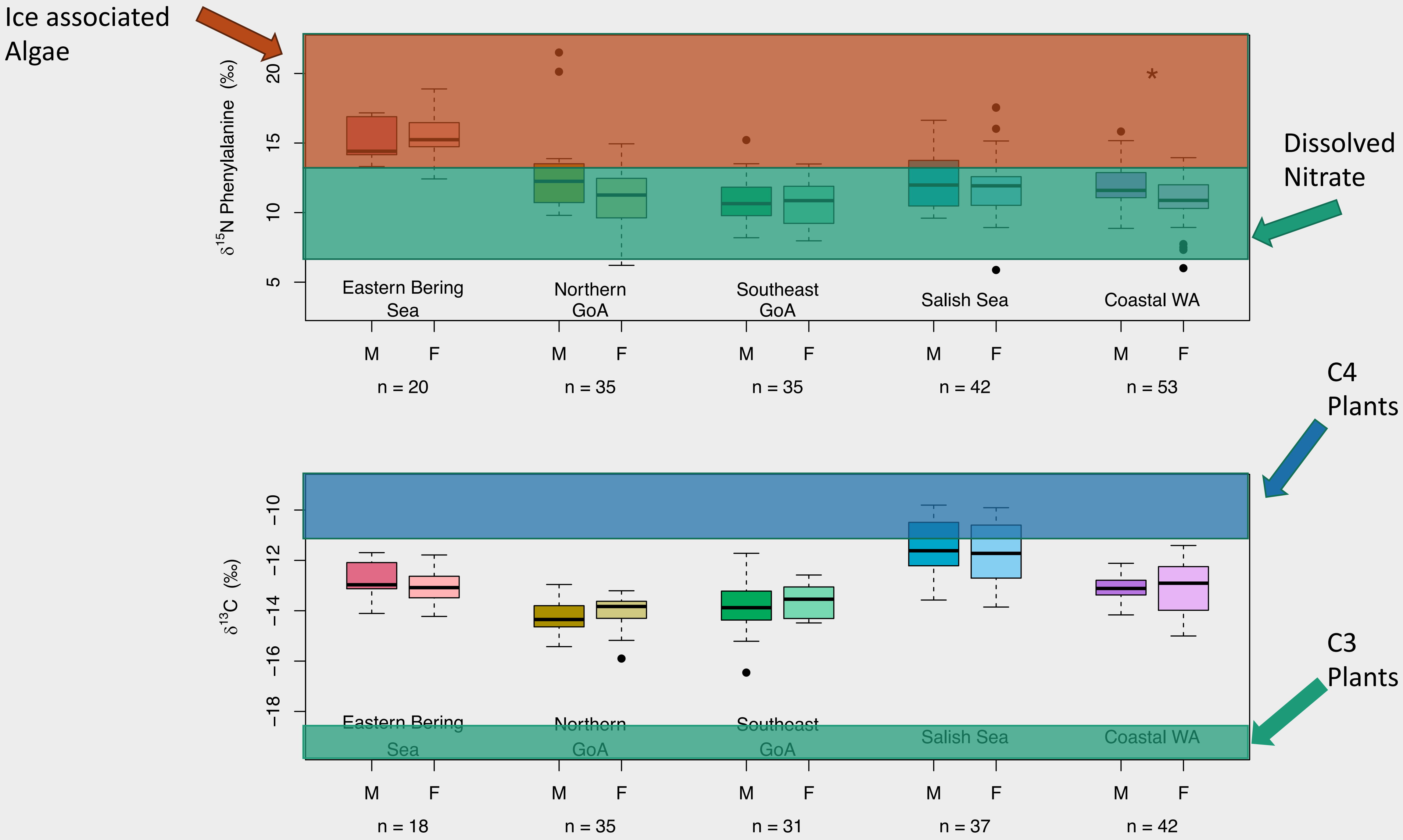

Discharge
• Columbia River
• Kuskokwim
• Seward Line
Sea Surface Temperature
• Mean Summer (GoA, EBS, WA)
Climate Regime
• Pacific Decadal Oscillation (PDO)
• North Pacific Gyre Oscillation (NPGO)
• Multivariate ENSO Index (MEI)
Upwelling
• Coastal Upwelling (Spring, Summer)
• Average winter (Oct-Apr) along-shelf and cross shelf wind vector
NO_3^-

1. $\delta^{13}C$ decreases during recent decades in most regions



1. $\delta^{15}N_{Phe}$ is variable but relatively stable through time across regions

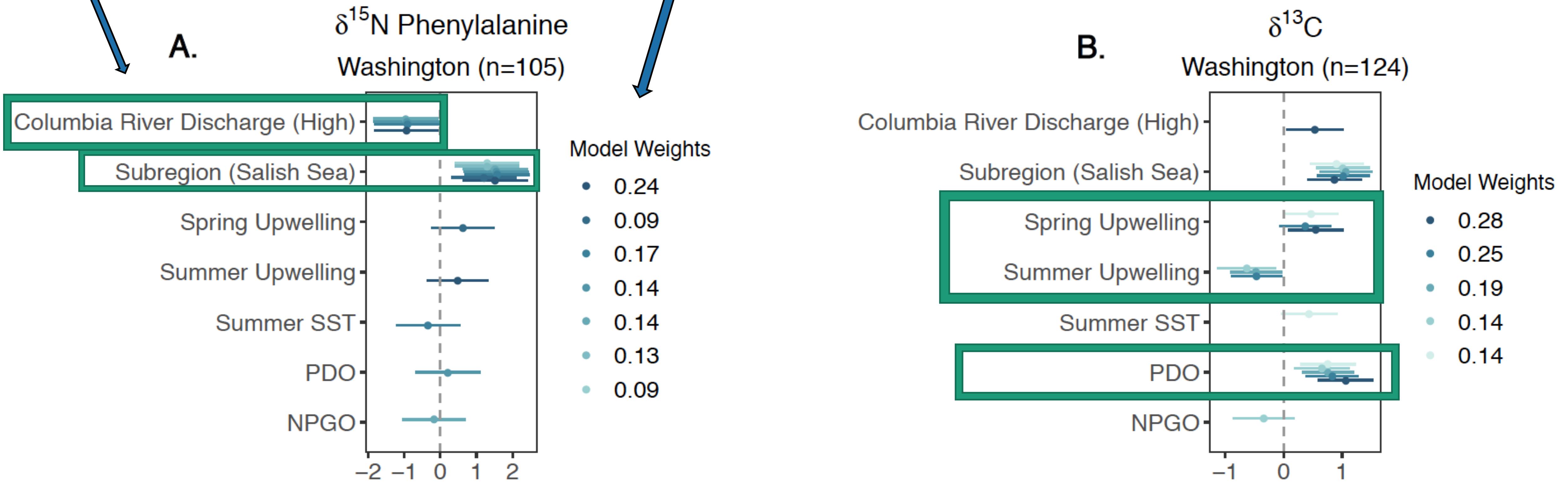




Ice associated
Algae
Dissolved
Nitrate
C4
Plants
C3
Plants
δ15N Phenylalanine (‰)
20
15
10
5
Eastern Bering
Sea
Northern
GoA
Southeast
GoA
Salish Sea
Coastal WA
M
F
n = 20
n = 35
n = 35
n = 42
n = 53
δ13C (‰)
−10
−12
−14
−16
−18
n = 18
n = 35
n = 31
n = 37
n = 42

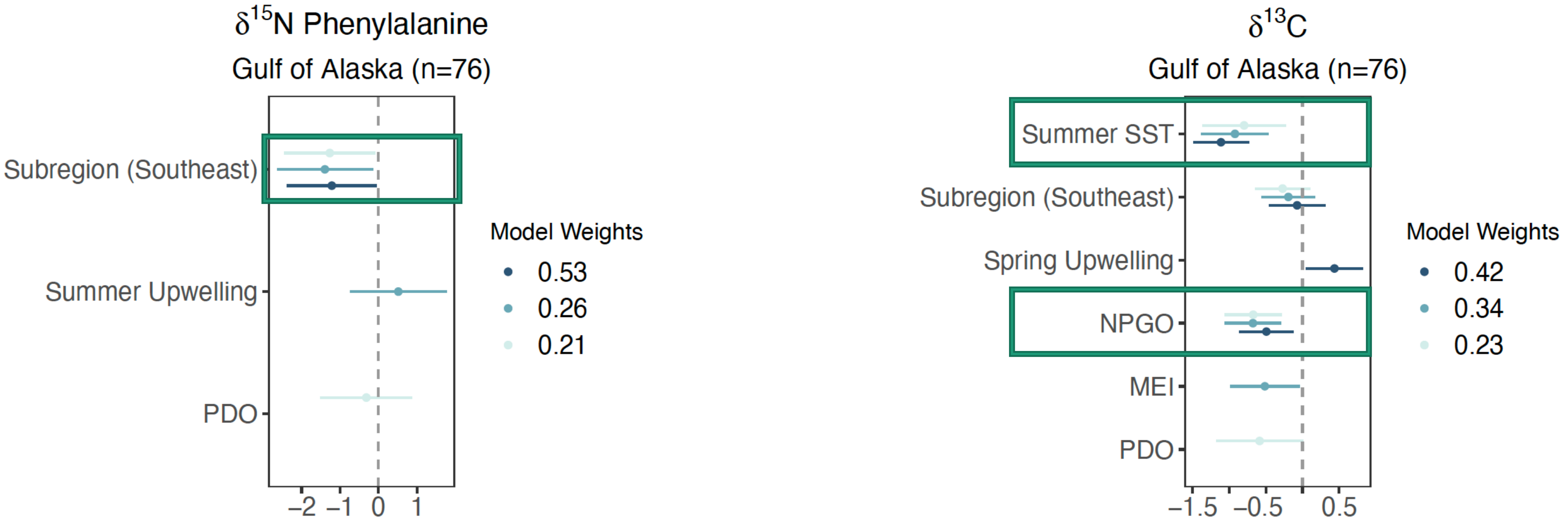
Time series covariates

delAIC < 2

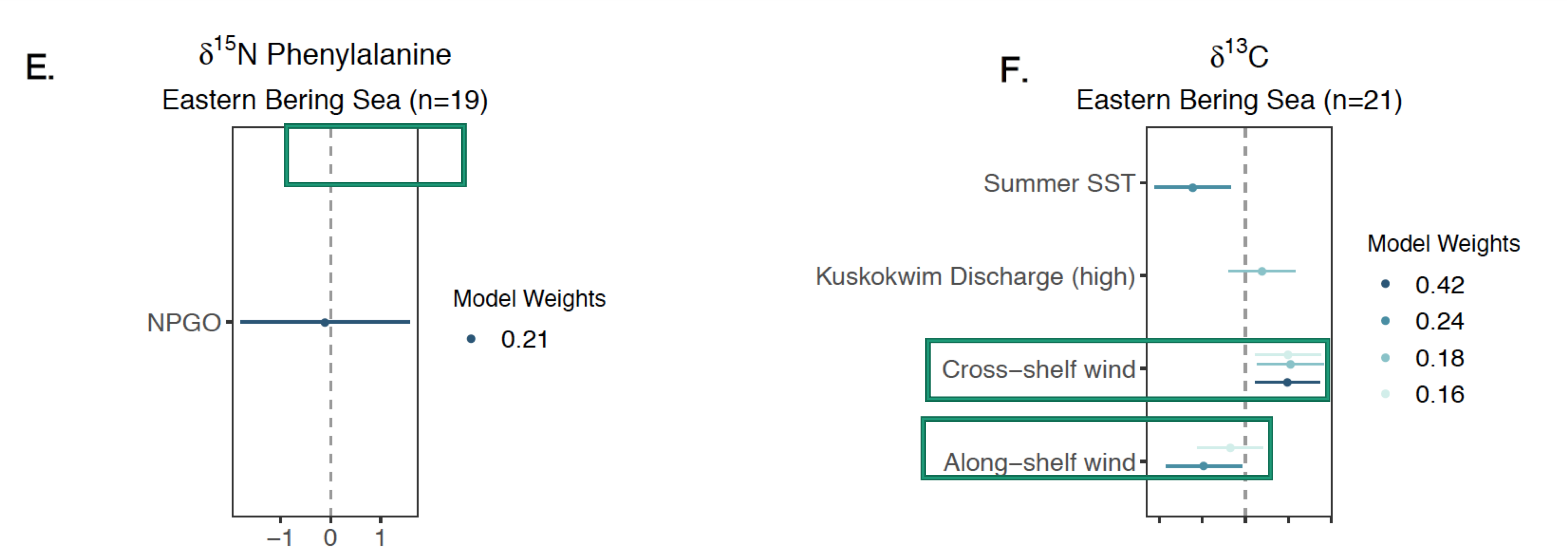


Covariate Values

GULF OF ALASKA



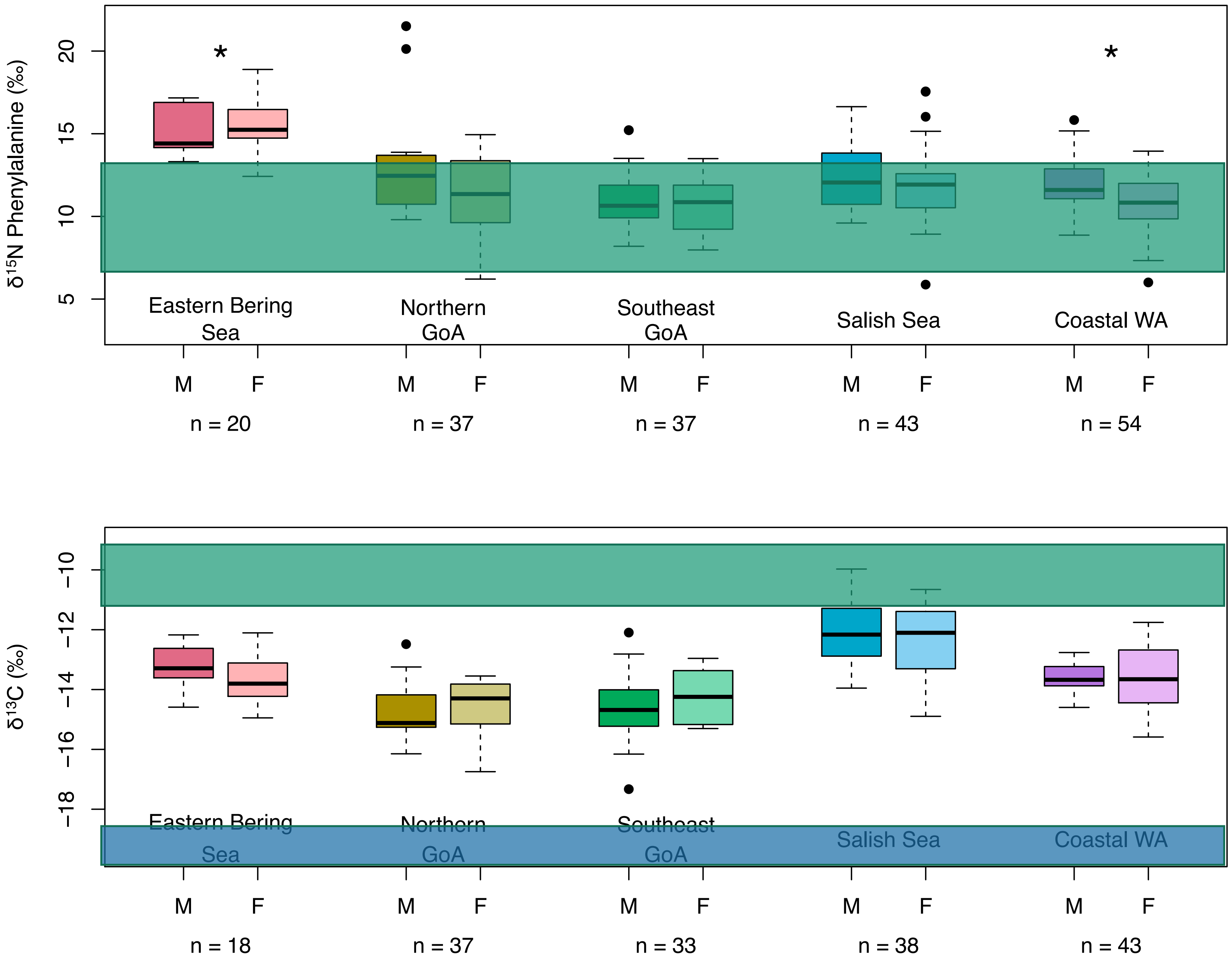
EASTERN BERING SEA



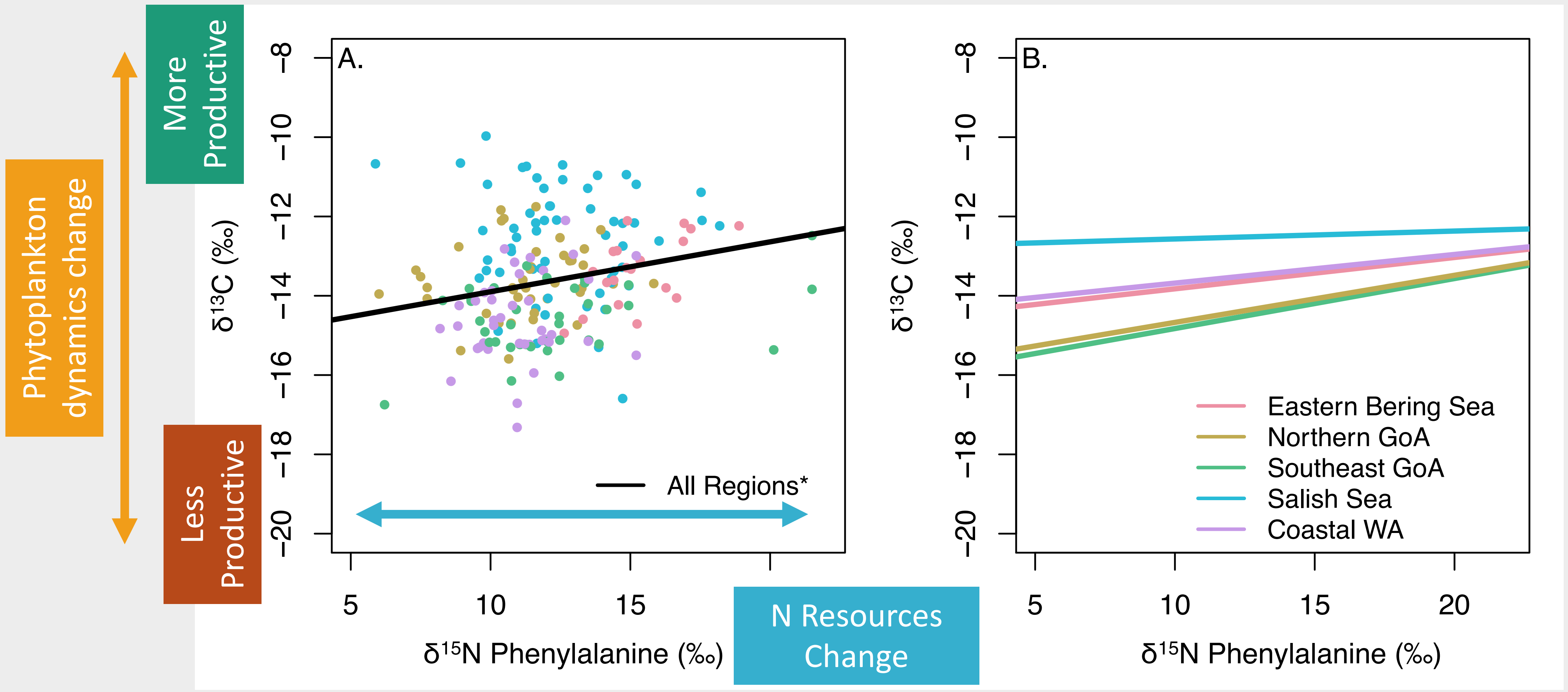
In Summary

- Measuring $\delta^{15}N$ of individual provides an internal proxy of $\delta^{15}N_{Primary\ Producer}$
- Measuring $\delta^{15}N$ of individual compounds eliminates the issues of $\delta^{15}N_{Primary\ Producer}$ and $\delta^{15}N_{Consumer}$ coupling
- Measuring $\delta^{15}N$ in individual compounds (amino acids) gives us distinct ecological information

Sex specific foraging patterns are not a long-term phenomenon

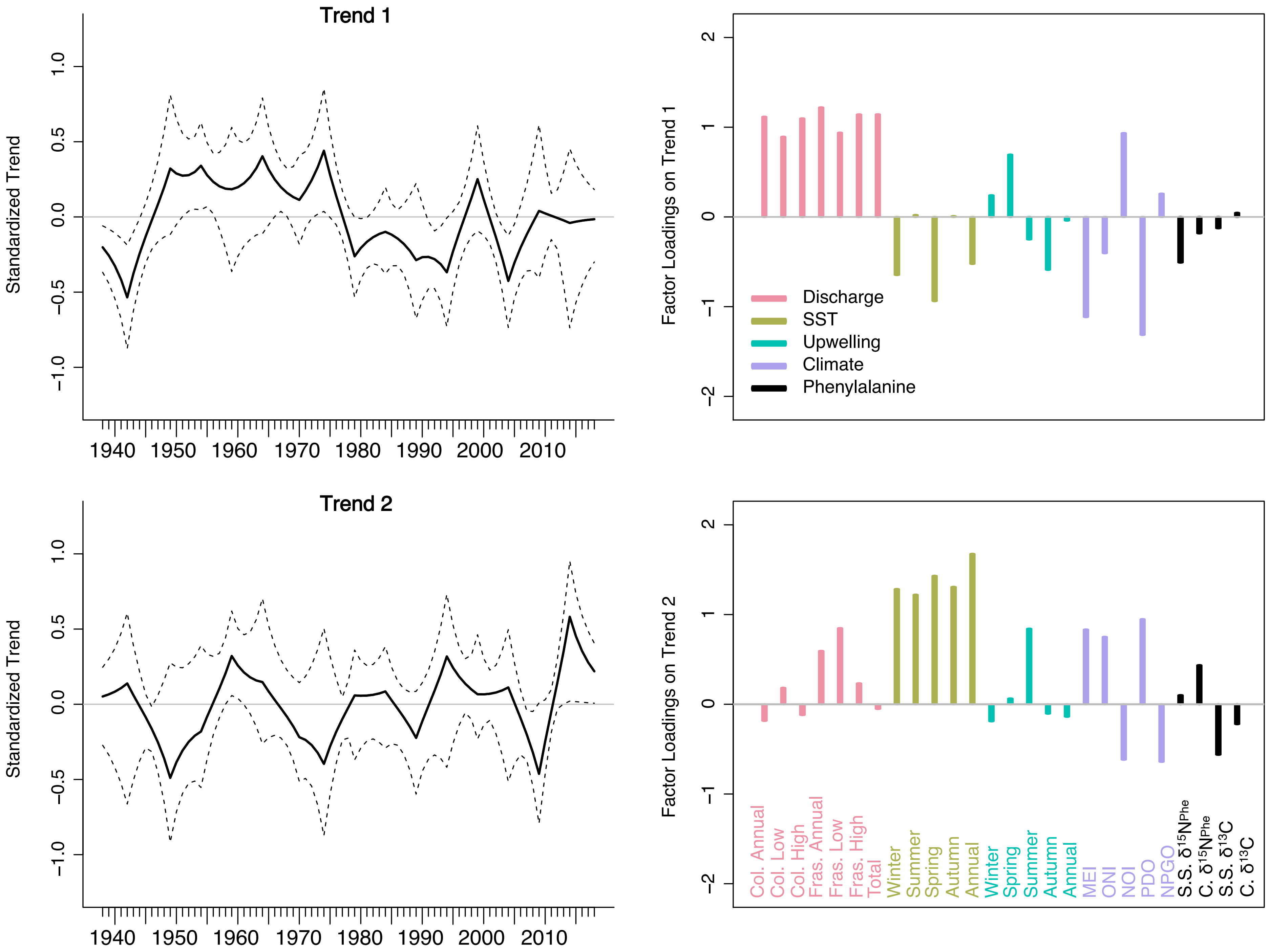


Variation in bottom up control of food web assimilated productivity by nitrogen resources

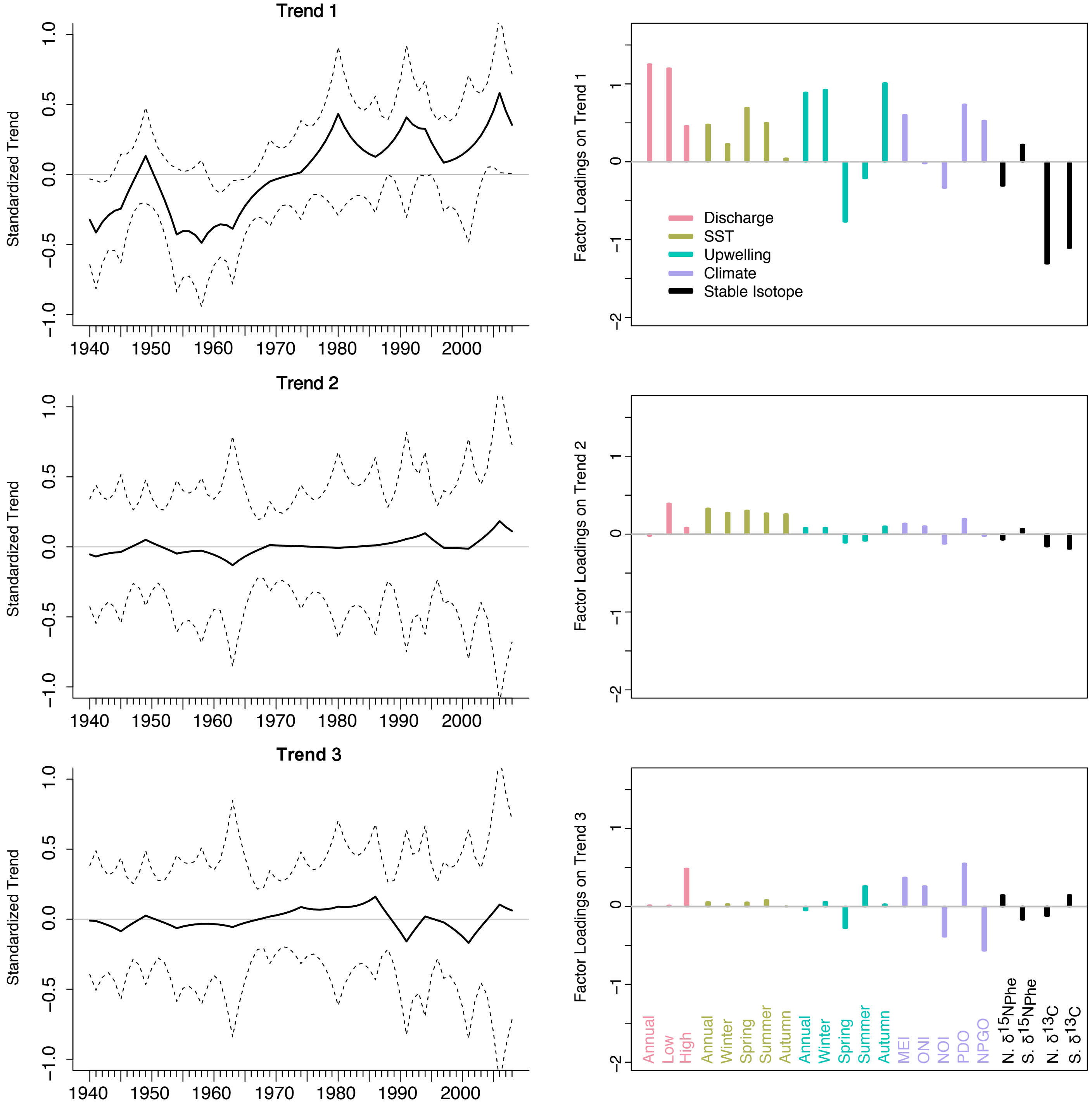


How does the environment impact ***resource utilization by coastal marine food webs?***

How does the environment impact resource utilization by coastal marine food webs?



Trend 1
Trend 2
Standardized Trend
Factor Loadings on Trend 1
Factor Loadings on Trend 2
Discharge
SST
Upwelling
Climate
Phenylalanine
Col. Annual
Col. Low
Col. High
Fras. Annual
Fras. Low
Fras. High
Total
Winter
Summer
Spring
Autumn
Annual
Winter
Spring
Summer
Autumn
Annual
MEI
ONI
NOI
PDO
NPGO
S.S. δ15NPhe
C. δ15NPhe
S.S. δ13C
C. δ13C



Trend 1
Trend 2
Trend 3
Standardized Trend
1940
1950
1960
1970
1980
1990
2000
Factor Loadings on Trend 1
Factor Loadings on Trend 2
Factor Loadings on Trend 3
Discharge
SST
Upwelling
Climate
Stable Isotope
Annual
Low
High
Annual
Winter
Spring
Summer
Autumn
Annual
Winter
Spring
Summer
Autumn
MEI
ONI
NOI
PDO
NPGO
N. δ15NPhe
S. δ15NPhe
N. δ13C
S. δ13C