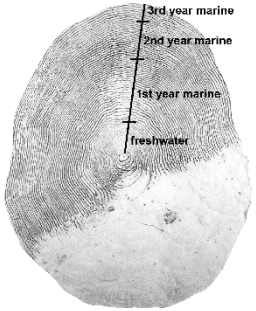
Integrating stable isotope, genetic, and scale sample data to improve estimates of killer whale diets

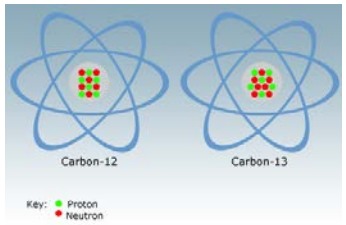
Sandie O'Neill, Dave Herman, Eric Ward, Doug Burrows
Gina Ylitalo

Stable Isotopes: Another tool used to infer the diet of resident killer whales



Scale and tissue fragments from observed feeding events

Genetic analysis of SRKW fecal samples

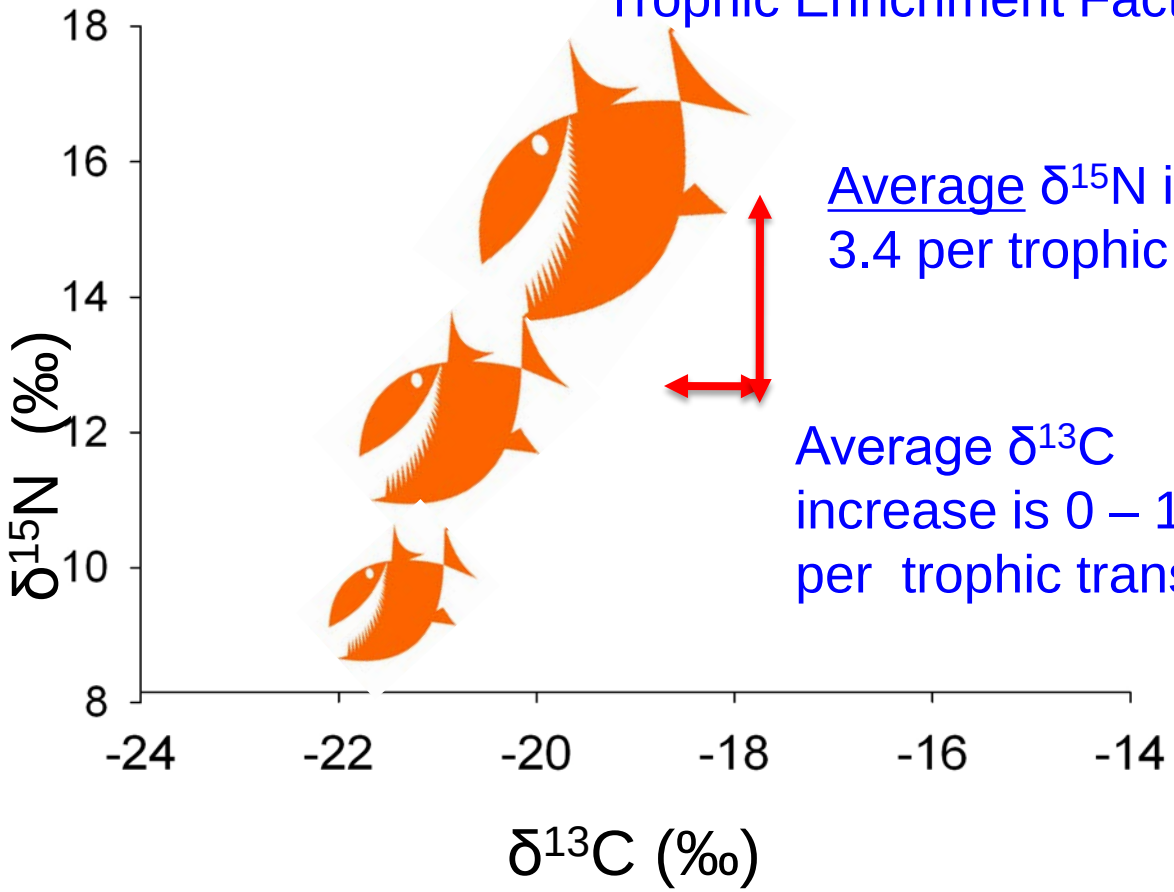


Comparison of stable isotope signatures in whales and the putative prey

Stable Isotope Primer

Trophic Enrichment Factors (TEFs)

Trophic Position



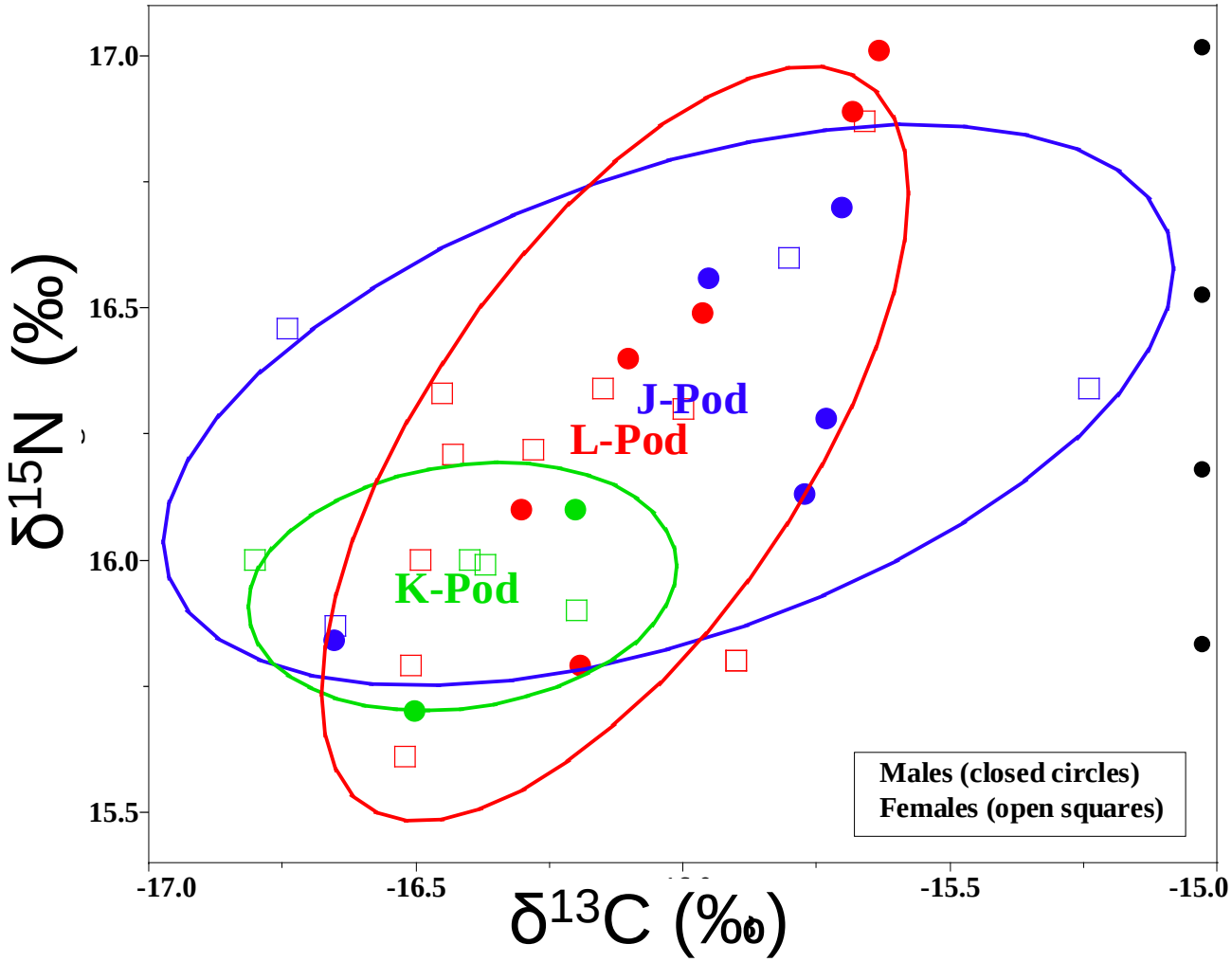
Average $\delta^{15}N$ increase is 3.4 per trophic transfer

Average $\delta^{13}C$ increase is 0 – 1 per trophic transfer

Production Source

offshore ← → coastal

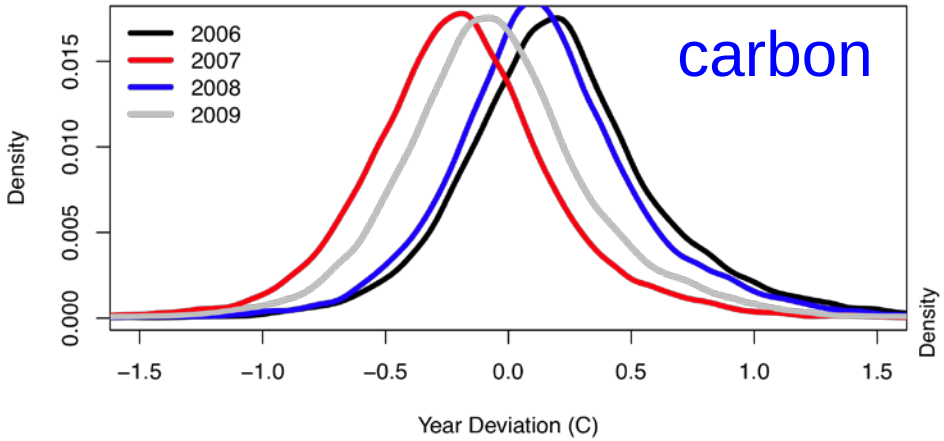
Stable isotope ratios of 3 pods SRKWs

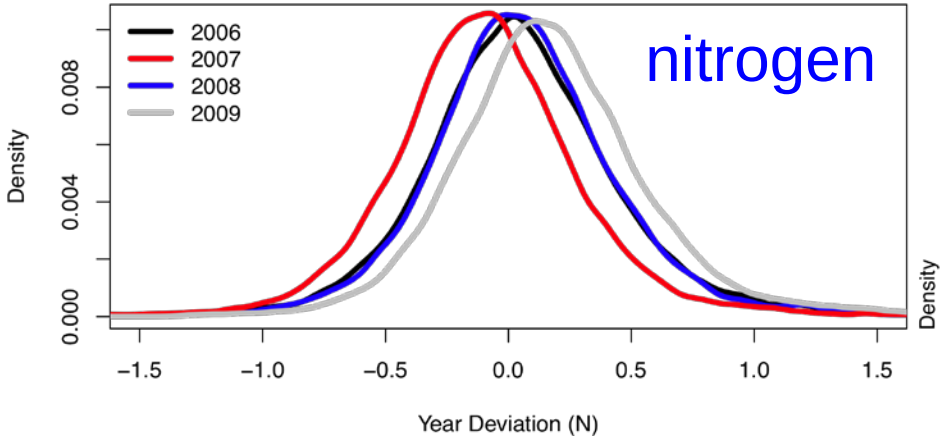


- Skin biopsy samples
- Mostly J & L pods
- 2006 – 2009
- Collected mostly from Apr – Sept but range from Feb – Dec.

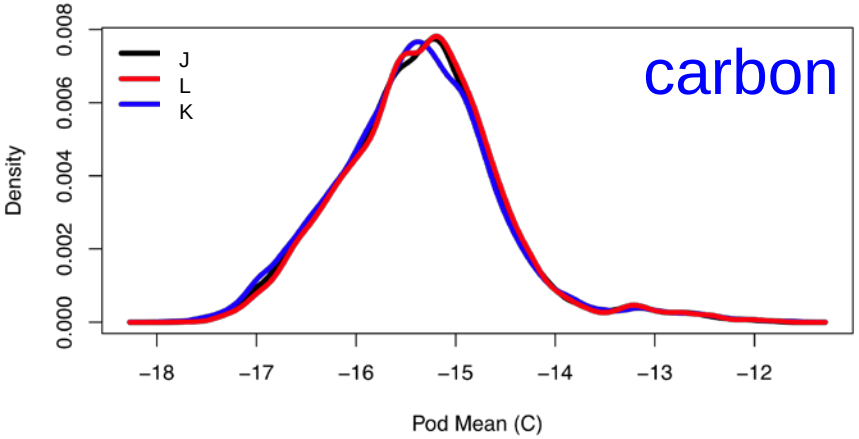
SI variation in SRKW

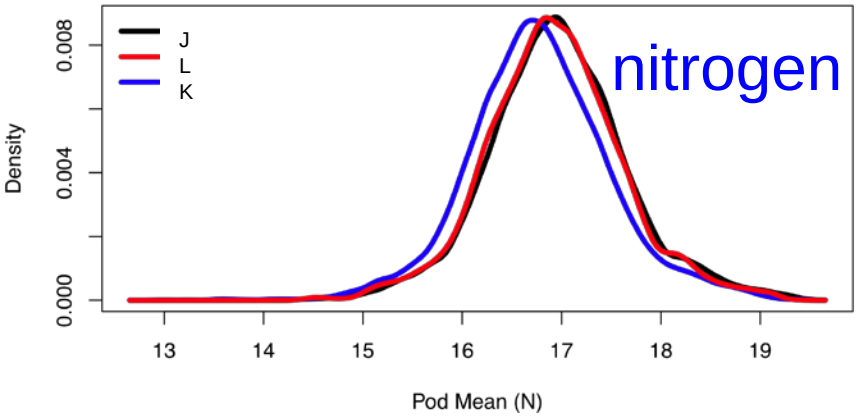
Variability by year



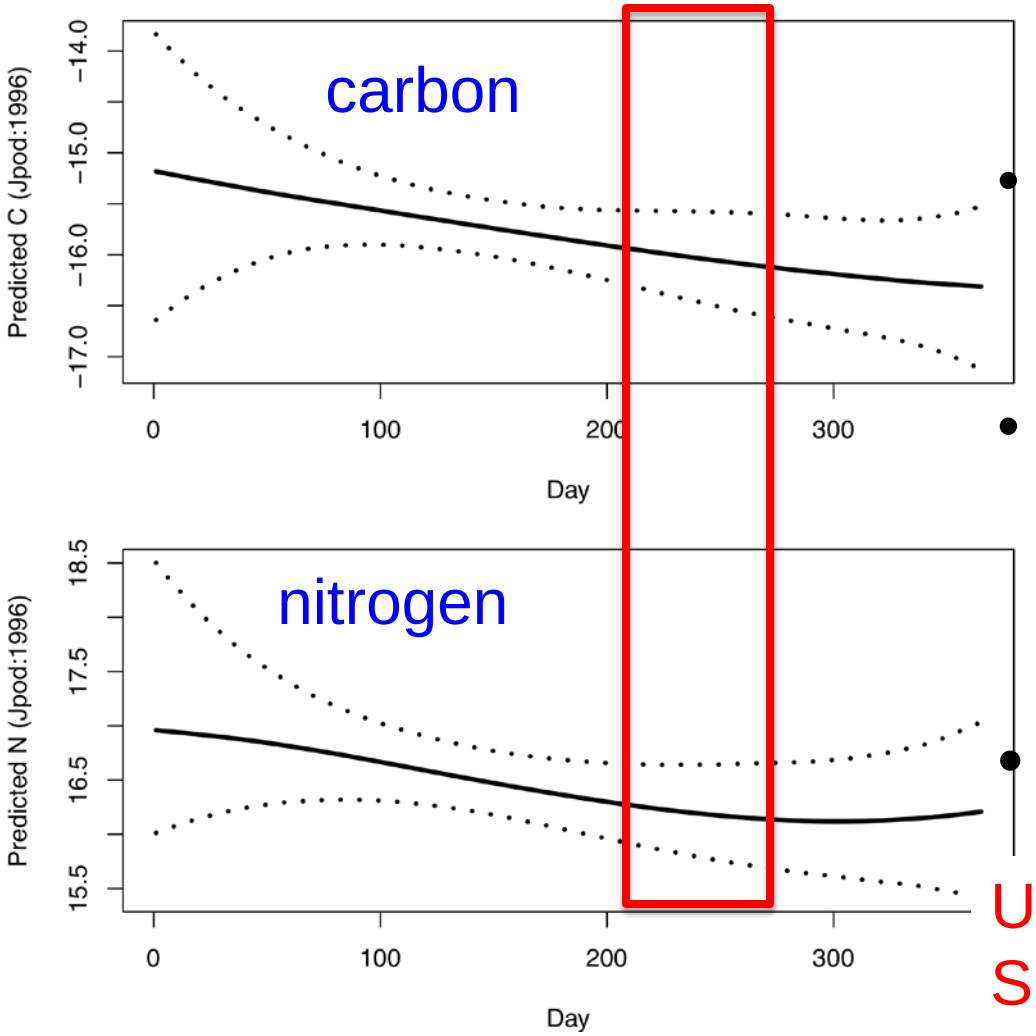


Variability by pod





Seasonal SI variation among SRKW



- Slight declining trend over the year – but uncertainty early/late in the season.
- Change could be due to:
  - shift from Chinook to other species
  - Shift among Chinook stocks?

Use mixing model to look at SI in Aug - September

Two kinds of mixing models were used:

- Classic model using stable isotopes and Trophic Enrichment Factors (TEFs)

- Alternative model that integrates stable isotopes & some diet data (does not use reported TEFs)

Basics of Classic Mixing Models

- IF: you know stable isotopes of consumers

AND

- you know stable isotopes of prey

AND

- you know the species-specific trophic enrichment factors for 15N and 13C

THEN

- You can estimate relative % of diet for each prey item

Stable Isotope Data Used for Mixing Model

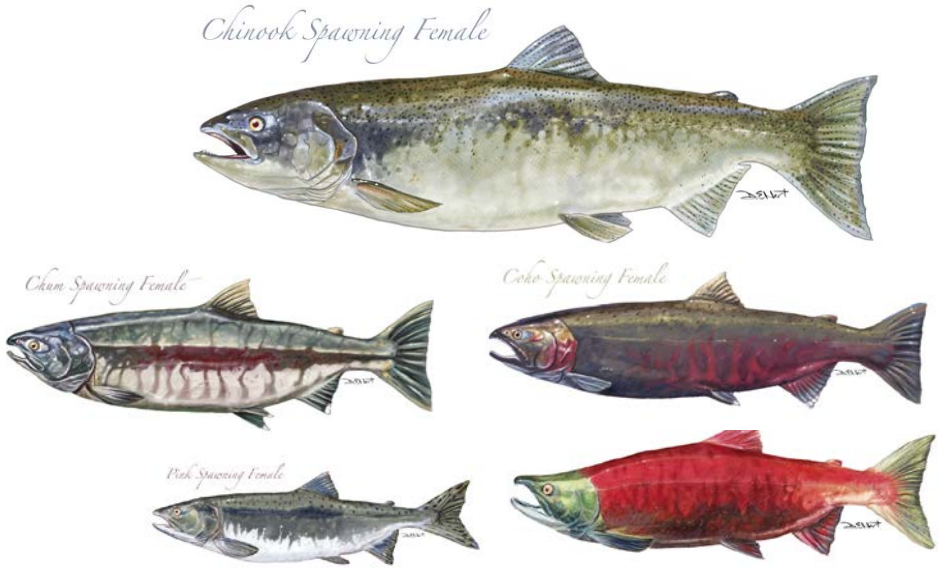
September Samples

- 12 skin biopsy samples
- Years: 2007 – 2009
  - Most (8) are from 2008
- Pod samples
  - 9 Ls, 2 Js, 1 K
- Mostly females
- 9 – 75 years old

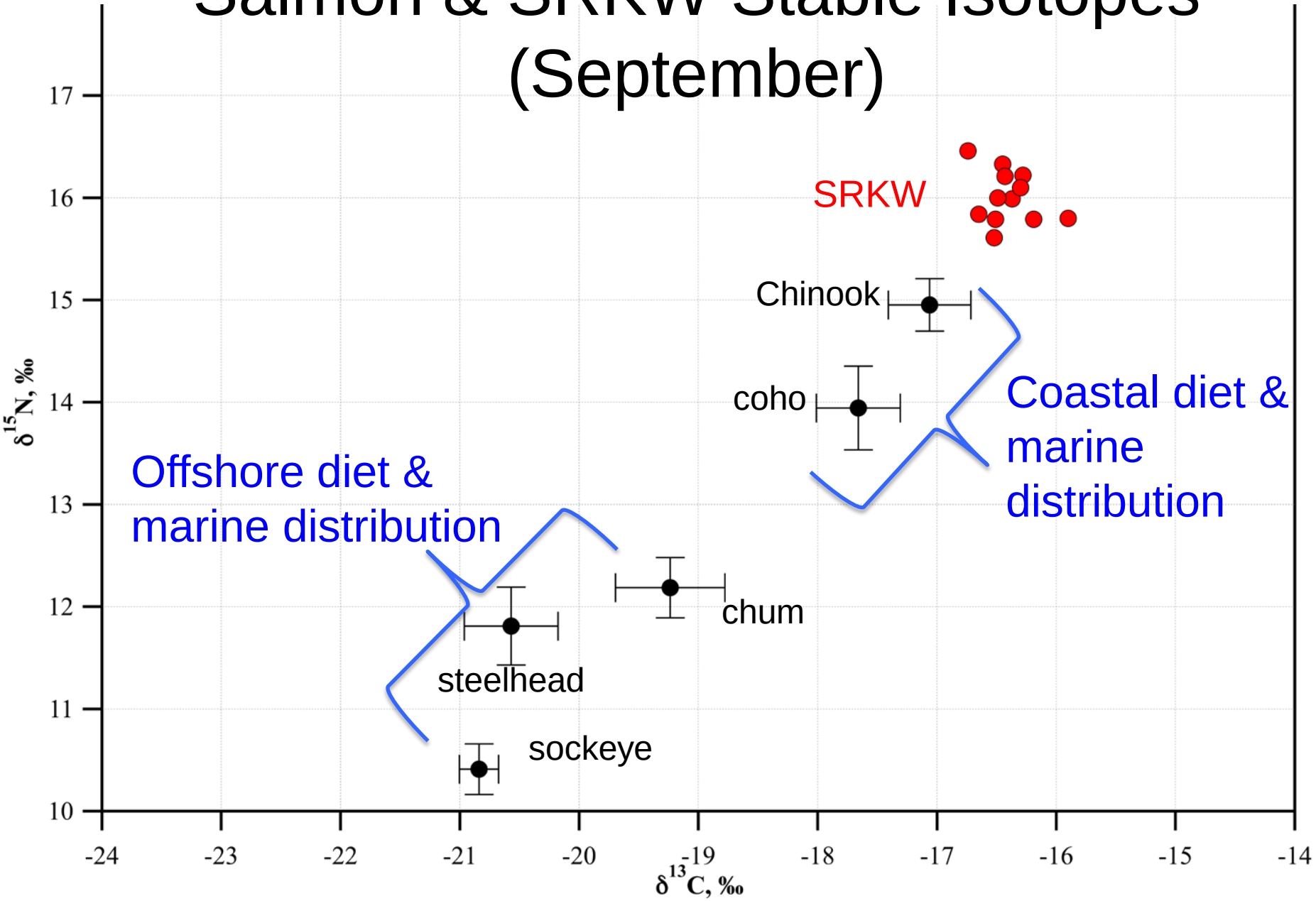
Salmon Isotope Data Used for Mixing Model

Salmon Prey Data

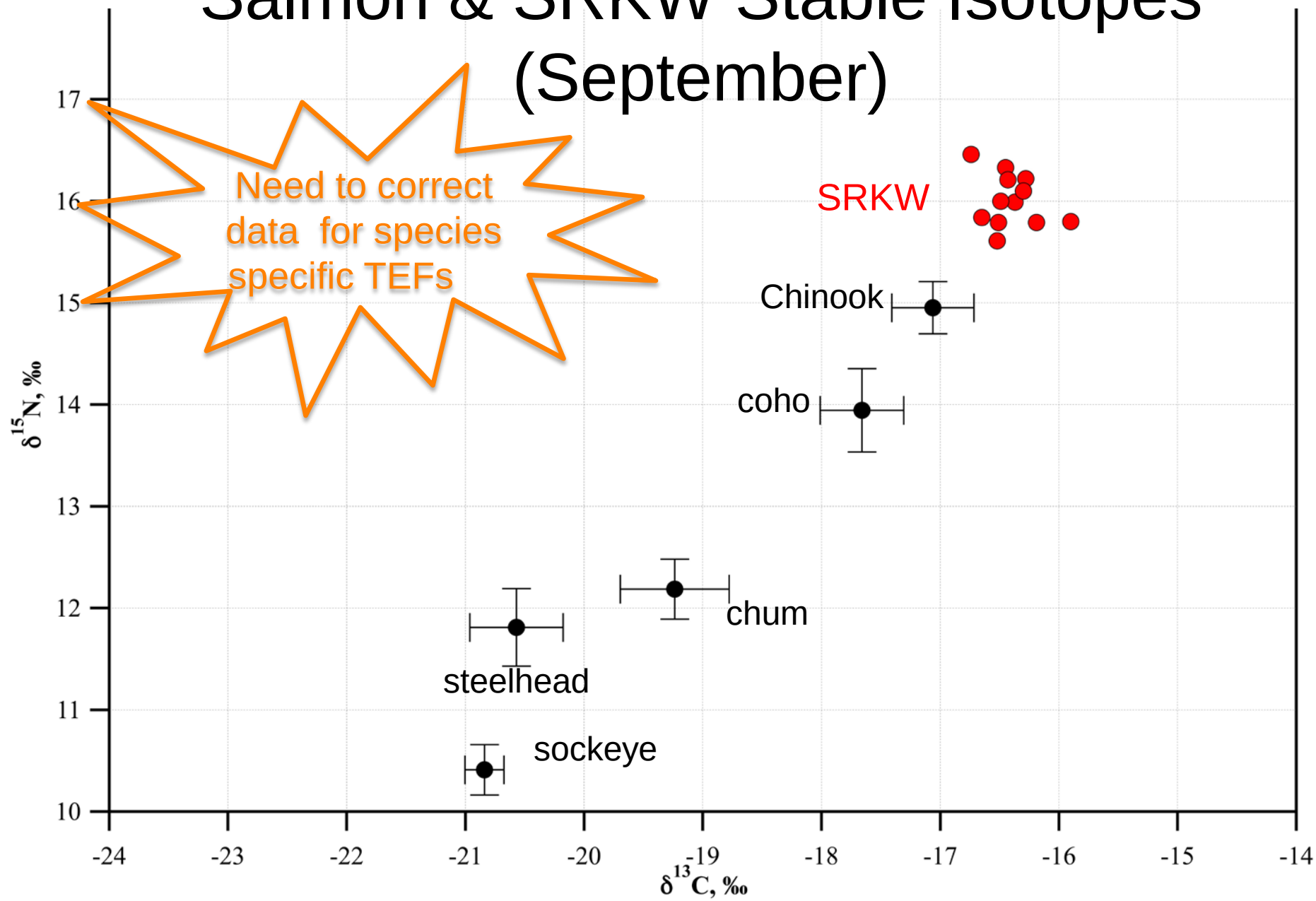
- Whole body samples
  - 115 Chinook (Salish Sea)
  - 35 Coho (Puget Sound)
  - 30 Sockeye (Fraser)
  - 30 Chum (Puget Sound)
- Muscle samples
  - Steelhead (45 WA coast)



Salmon & SRKW Stable Isotopes (September)



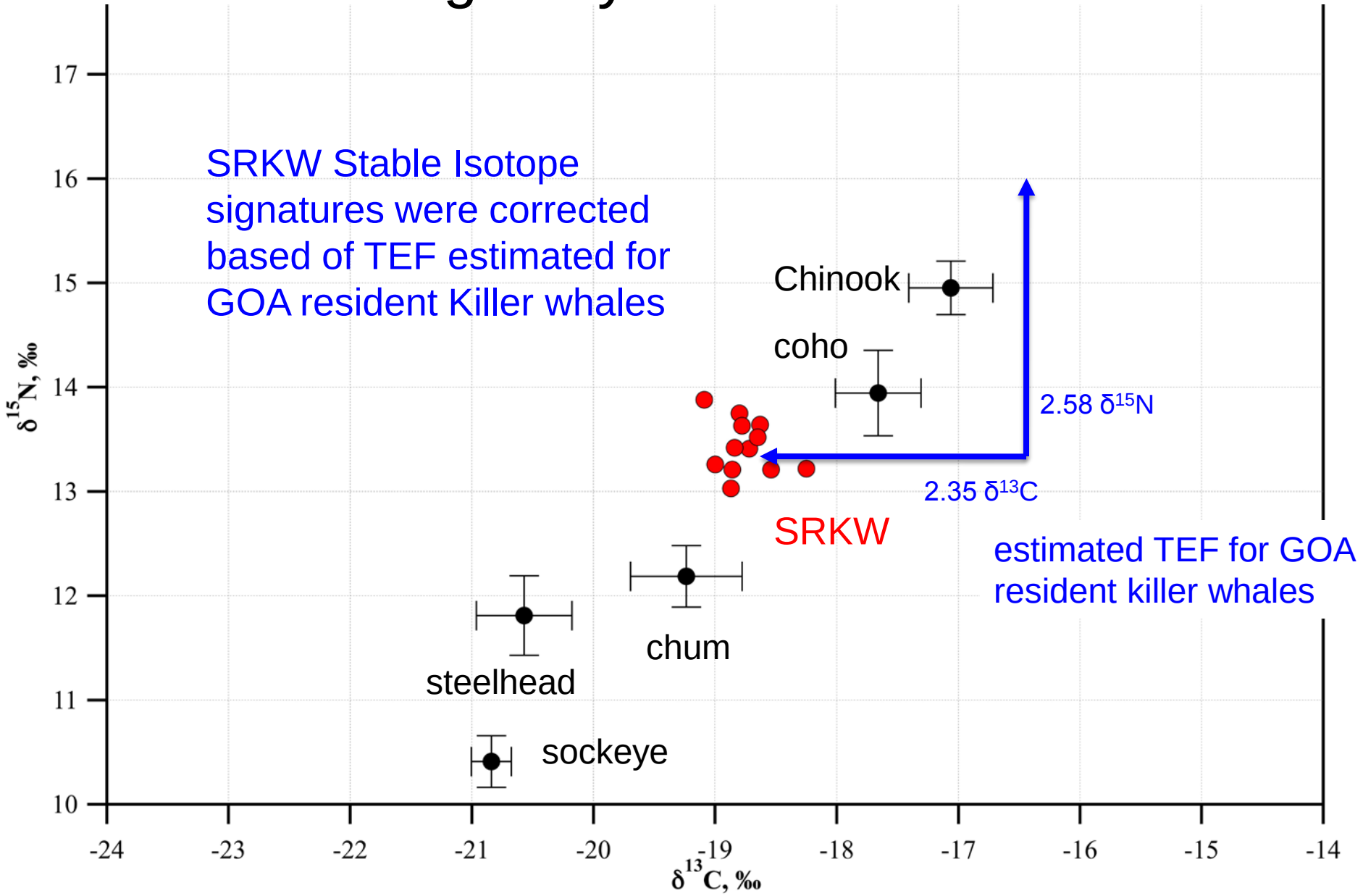
Salmon & SRKW Stable Isotopes (September)



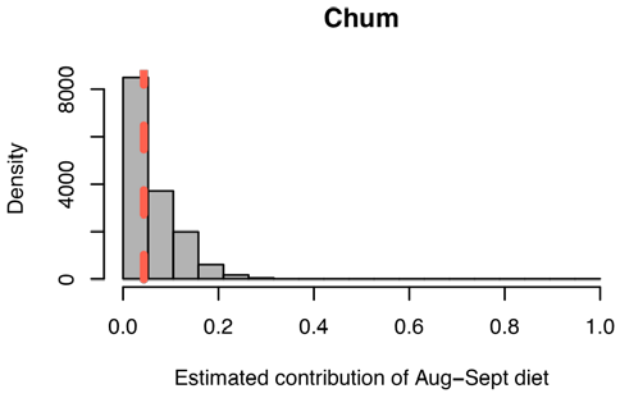
Which TEFs to use for SRKW?

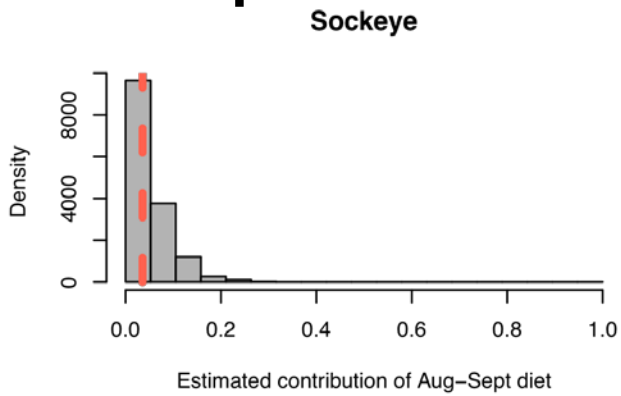
Study Code	Species	d15 N	d13 C	Source
a	Killer whale (wild, GOA)	2.58	2.35	D. Herman, NWFSC
b	Killer whale (captive)	3.18	2.43	Caut et al. 2011
c	Killer whale (captive)	2.83	1.56	Williams et al. 2011 (unpub.Sea World study)
d	Transient KW (wild, Hood Canal)	1.94	2.12	D. Herman, NWFSC

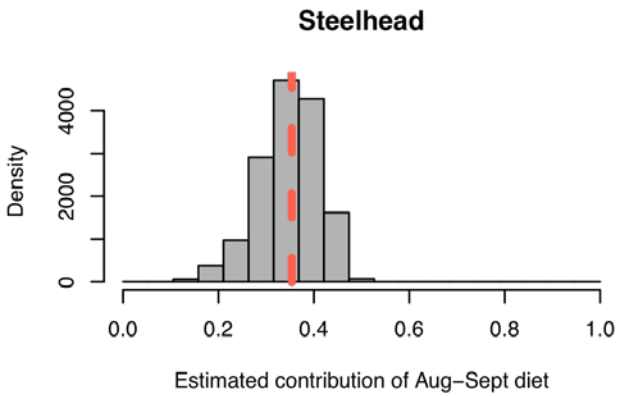
TEFs values greatly influence model outcome

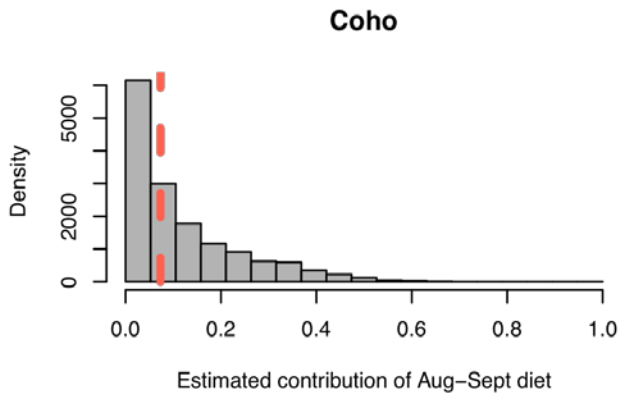


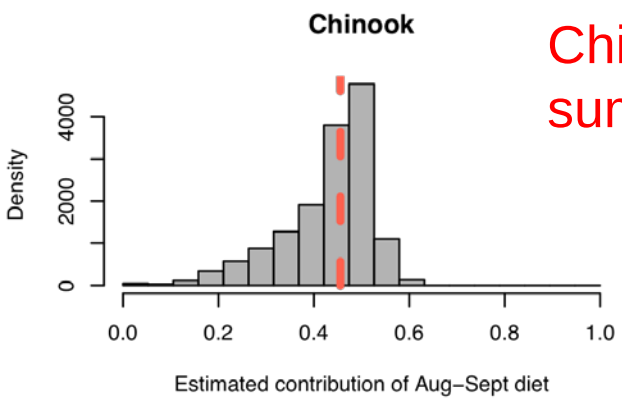
Model results: isotope data only (classic)











MODEL: Median proportion of Chinook salmon in the diet in late summer (Sept) is 43%.

-Scales/Tissue: 70.0%
-Fecal (DNA): 68% – 93%

Alternative model that integrates stable isotopes & some diet data.

- no arbitrary *aprior* section of parameters (i.e.,TEFs)
- use stable isotope data **plus** a subset of diet data (scales) to “inform” diet choice,
- genetic contribution in fecal samples can be used to as a informative prior

Benefits of Alternate Approach

Including isotopes and other data (i.e. scales) in the same model allows us to estimate TEFs from SRKW-prey data

Question -

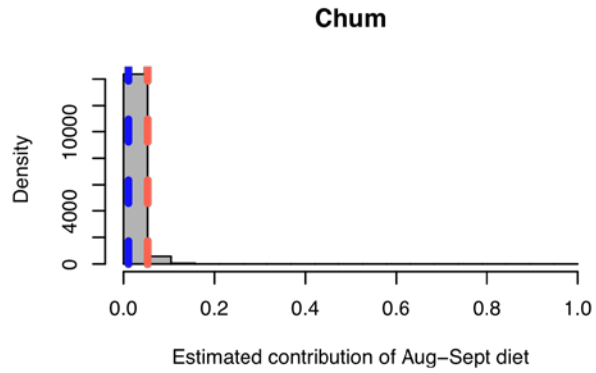
"What would the TEFs need to be for the SI data to be consistent with scale samples and genetic data from fecal samples?"

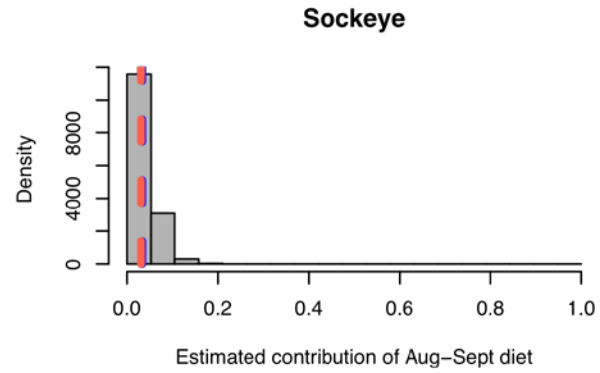
Diet Information Used for Alternate Mixing Model

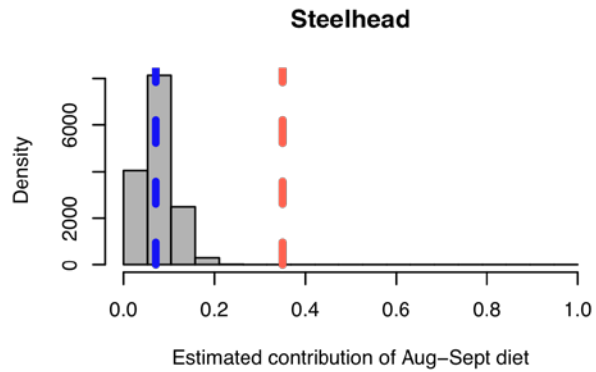
- Scale samples (NWFSC only)
  - Multinomial likelihood, same share diet from Aug-Sept
  - 2004-08: 41 Chinook, 7 coho, 1 sockeye, 3 steelhead

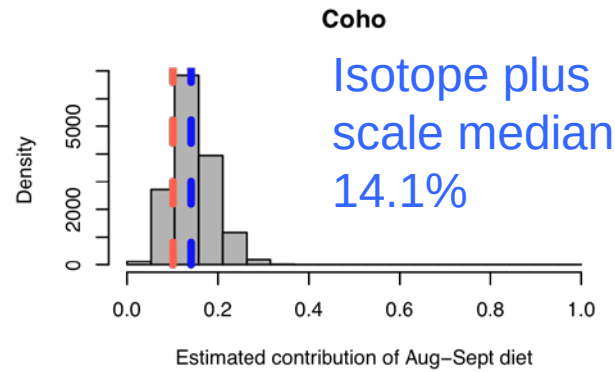
- Fecal samples
  - Genetic (HTS) % prey species in diet
  - Limited measure of uncertainty
  - Used as a prior

Estimated diet (with scales, no genetic prior)



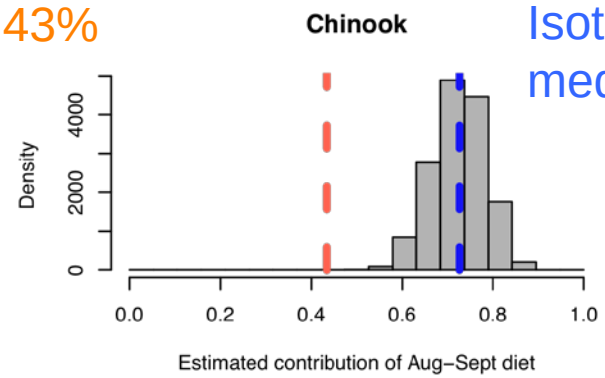






Isotope plus scale median = 14.1%

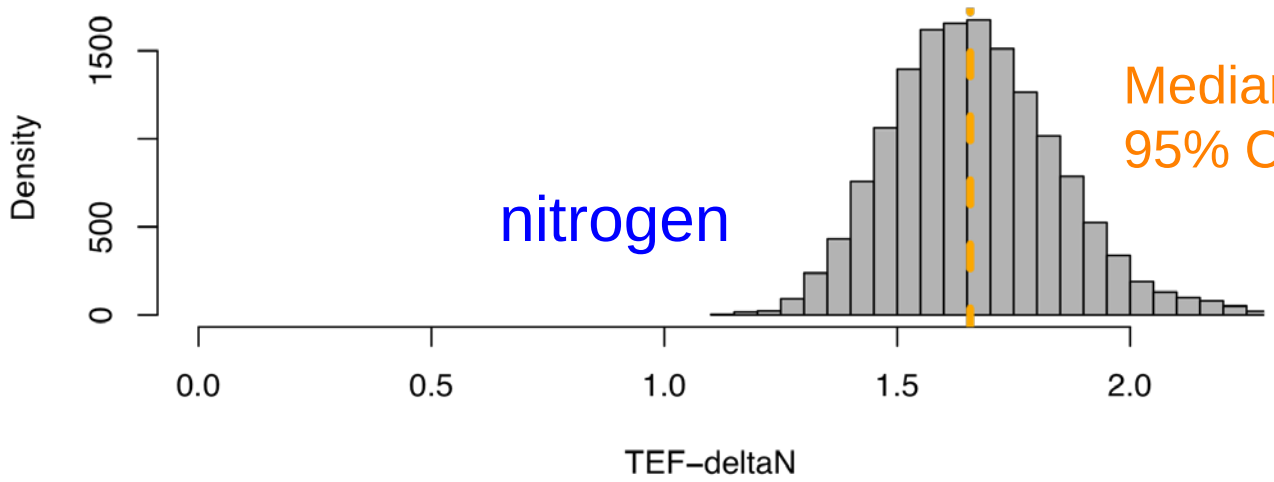
Isotope data median = 43%



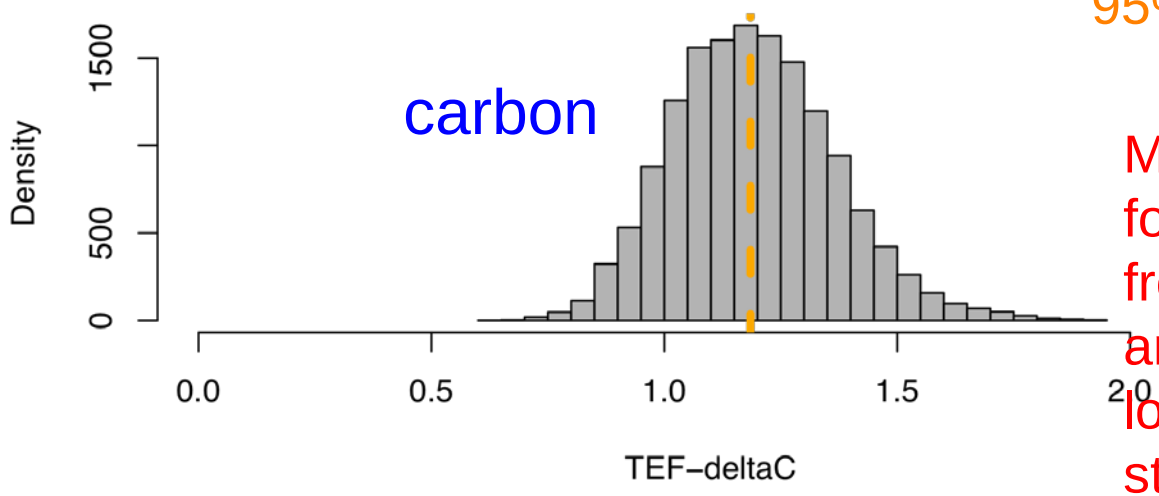
Isotope plus scale median = 72.6%

Probability of Chinook being consumed increases when scale data are included in model

Estimated TEFs (with scales, no genetic prior)



Median TEF = 1.65
95% CI = 1.33 – 2.09



Median TEF = 1.18
95% CI = 0.86 – 1.55

Modeled median TEFs for SRKW estimated from mixing model (this analysis seem are lower than reported studies but may OK

Effect of prior (HTS = genetic info)

- Including prior doesn’t have much effect on TEF estimates
- Very weak influence on diet estimates
- BUT makes both estimates a bit more precise

Stable isotope mixing models, genetic analysis of fecal samples, and scale sample all indicate that Chinook are the dominant prey in September, followed by coho, but the estimates varied….

Summary of % Chinook in Aug-Sept Diet

Technique	Details	Year Whales Sampled	Est. % Chinook in Diet
Isotope Models	isotopes only (reported TEF)	2008	43.3
	(modeled TEF)	2008	72.6
Fecals (Genetics -HTS)	-	2005 - 2008	68.6 – 88.2
	-	2008- 2009, 2011	93.2
Scales/Tissues	-	2004- 2009, 2011	82.5

Summary of TEFs

Species	d15 N	d13 C	Source
Killer whale (wild, GOA)	2.58	2.35	D. Herman, NWFSC
Killer whale (captive)	3.18	2.43	Caut et al. 2011
Killer whale (captive)	2.83	1.56	Williams et al. 2011 (unpub.Sea World study)
Transient KW (wild, Hood Canal)	1.94	2.12	D. Herman, NWFSC
SRKW (modeled)	1.65 (1.34 – 2.09)	1.18 (0.86 – 1.55)	This analysis

Modeled median TEFs for SRKW estimated from mixing model (this analysis) are lower than other studies, BUT 95% CI encompasses values from transient KWs

Why might model estimated TEFs be low?

Technical Difficulties….

- TEF values used for “classic” stable isotope mixing model were too high?
- Data sources represent different time scales
  - SI data (weeks to months) > Genetic data from fecals (days) > Scale samples (1 feeding event)
- Techniques applied to samples from different years
- Time frame represented by whale biopsy samples may not equal Aug – Sept

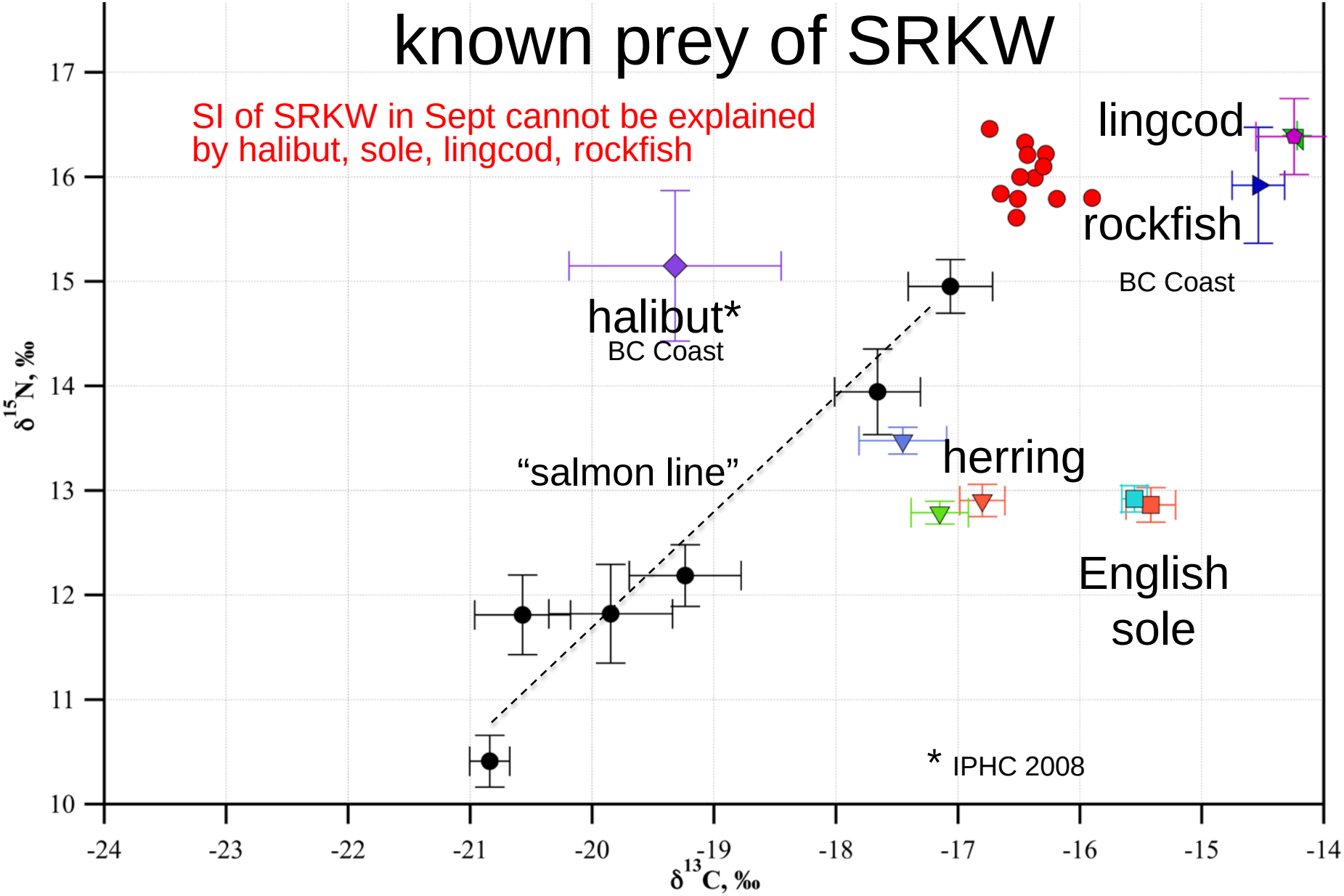
Why might modeled TEFs be low?

Biological Hypotheses:

- SRKW eat more juvenile Chinook than we think
  - Some evidence of a decline in trophic level (i.e., delta N) for smaller fish.
  - This difference alone IS NOT enough to account for the difference in TEFs

- SRKW eat lower trophic species not detected in scale samples, and difficult to detect with genetic

Stable isotopes of salmon vs. other known prey of SRKW



Why might modeled TEFs be low?

Biological Hypotheses:

- SRKW eat more juvenile Chinook than we think
  - Some evidence of a decline in trophic level (i.e., delta N) for smaller fish.
  - This difference alone IS NOT enough to account for the difference in TEFs

- SRKW eat lower trophic species not detected in scale samples, and difficult to detect with genetic
  - not evident

- SRKW eating more eating more chum, sockeye or steelhead apparent in the scale samples

Conclusions

?

Slides for

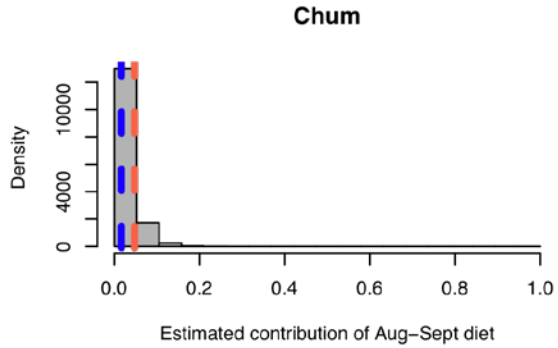
- Alternate Model
- September scales

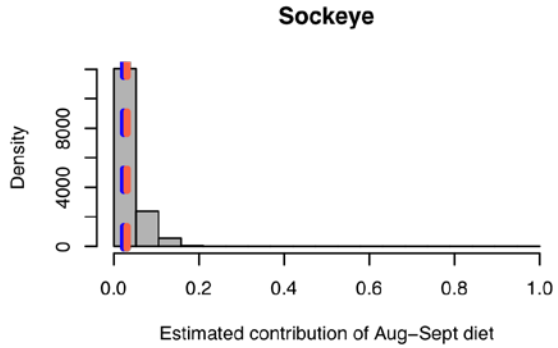
Other Diet Information Available

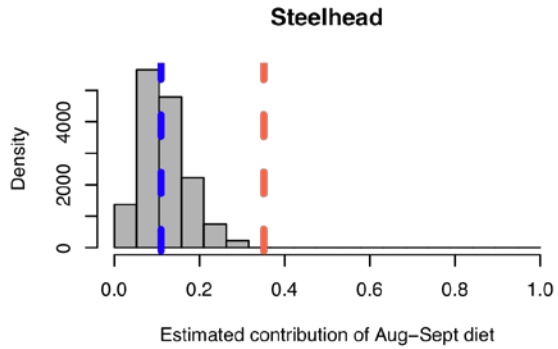
- Scale samples
  - Multinomial likelihood, same share diet from Sept
  - 28 scales
  - XX Chinook, X, coho, X chum, etc.
  - 2004, 2006, 2007, 2008, 2009

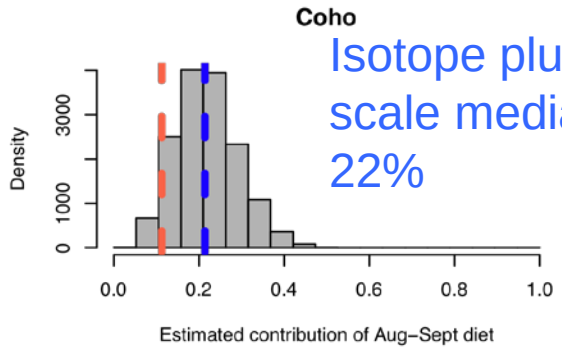
- Fecal samples
  - HTS genetic %
  - But no measure of uncertainty
  - used as an uninformative prior

Estimated diet (with scales, no fecal prior)



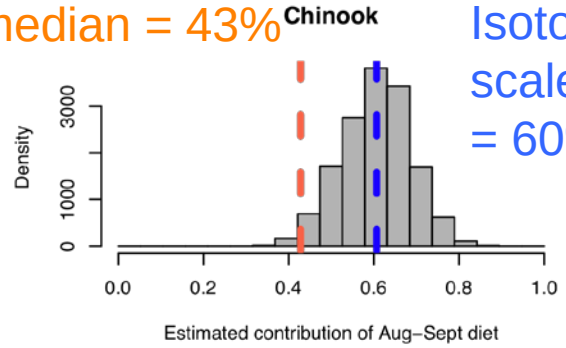






Isotope plus scale median = 22%

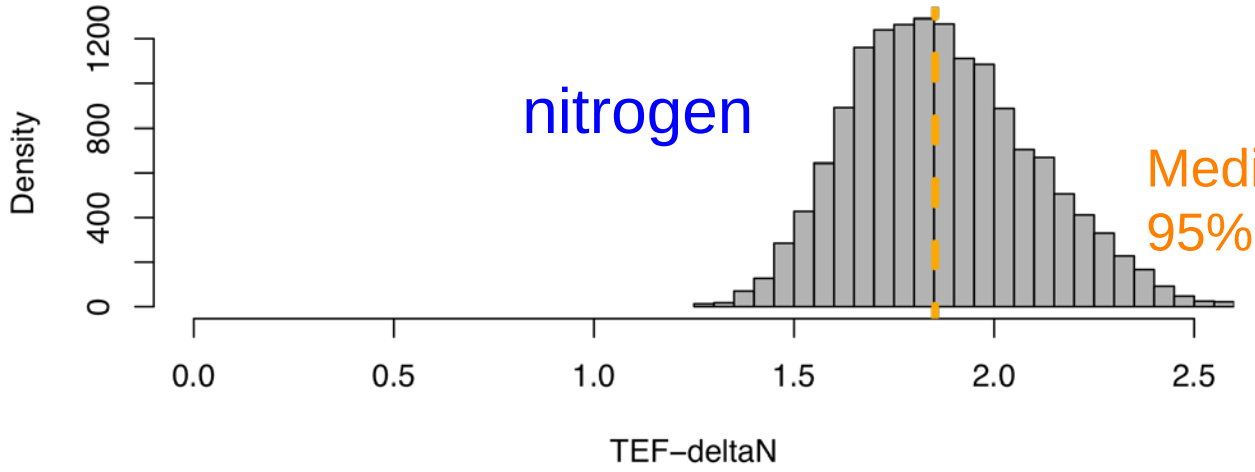
Isotope data median = 43%



Isotope plus scale median = 60%

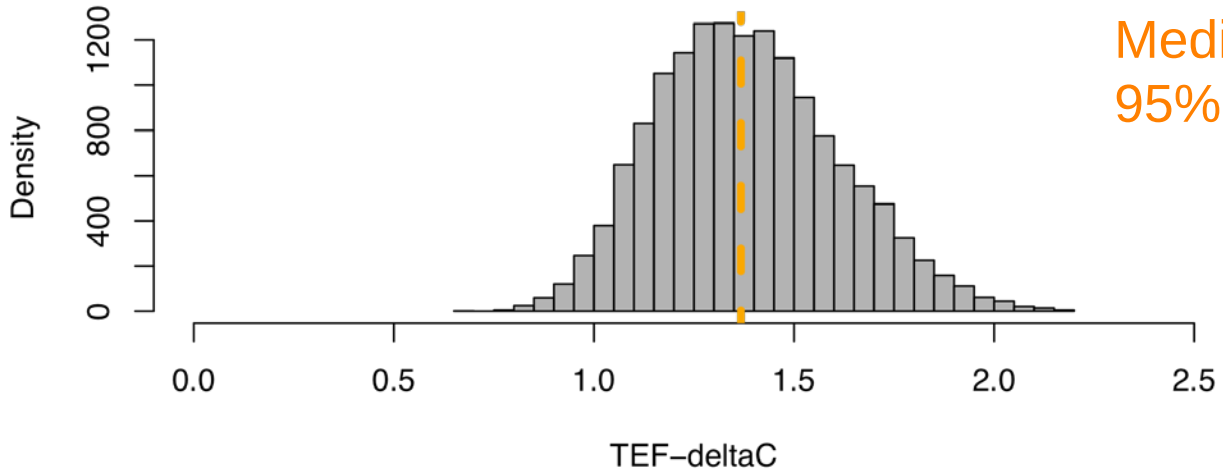
Probability of Chinook and coho consumed increases when scale data are included in the model – BUT scale & SRKW isotope data are from different years.

Estimated TEFs (with scales, no NGS prior)



Median TEF = 1.89
95% CI = 1.48 - 2.37

carbon



Median TEF = 1.40
95% CI = 0.99 – 1.90

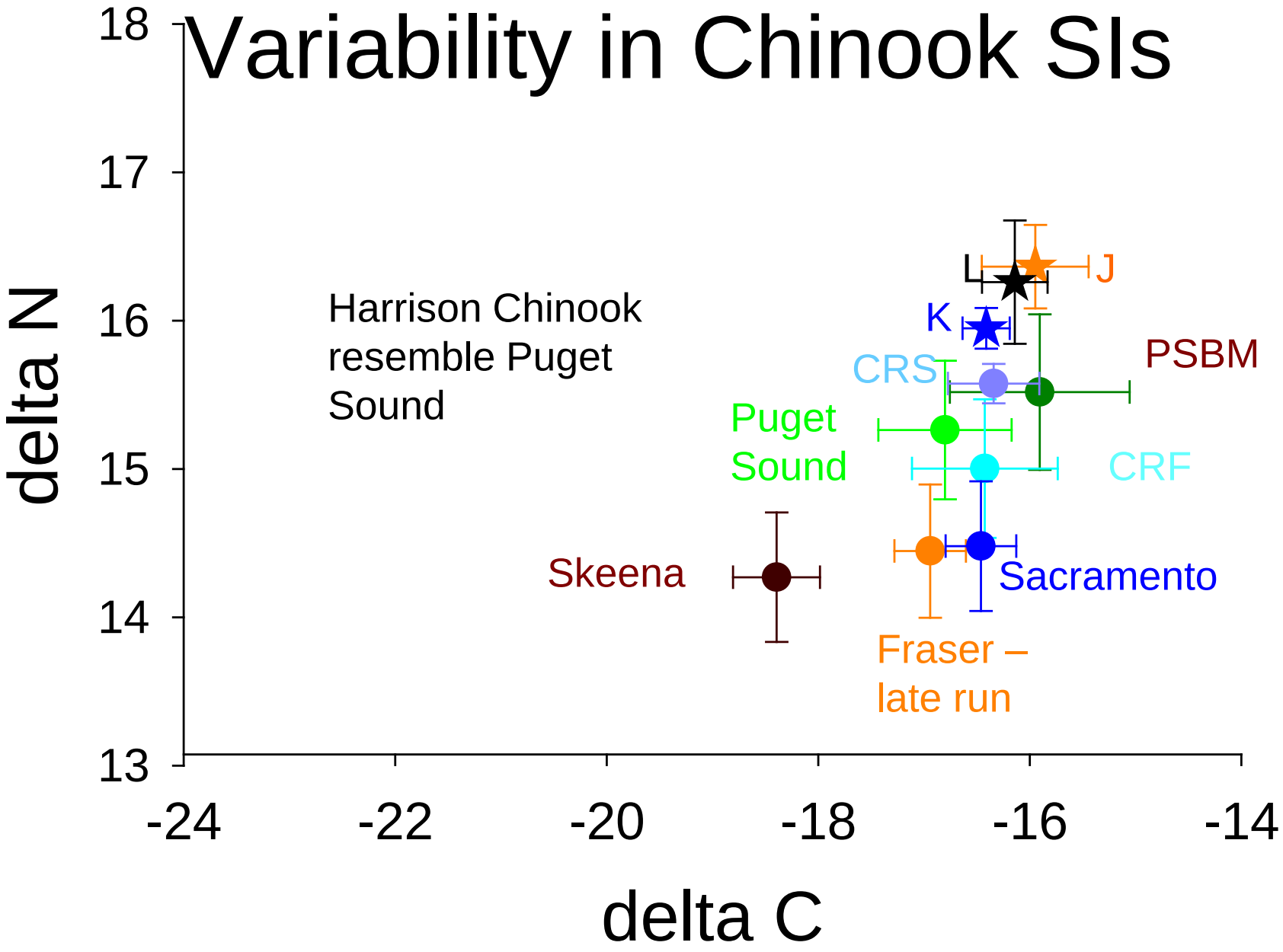
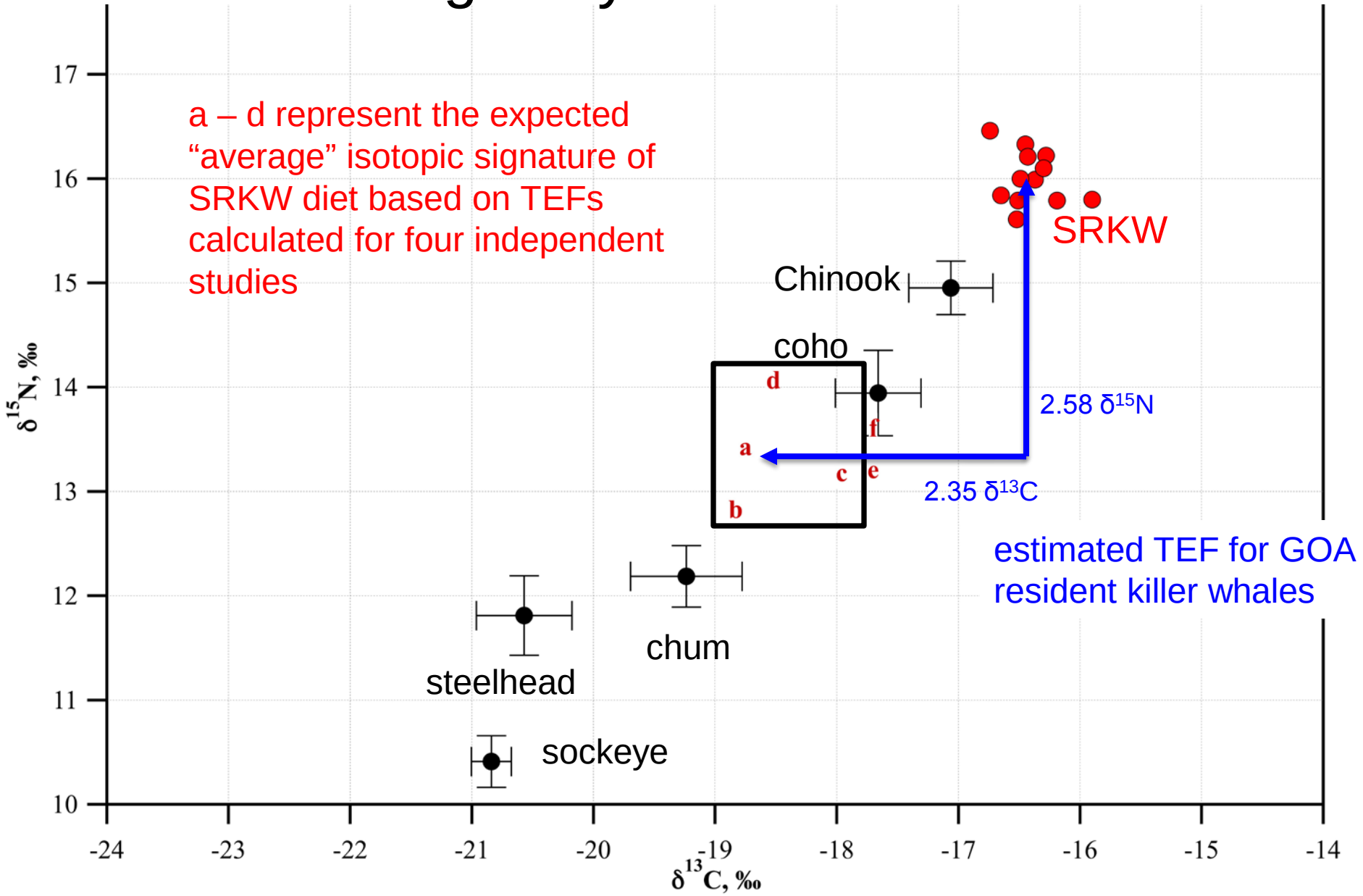
Summary of TEFs

Species	d15 N	d13 C	Source
Killer whale (wild, GOA)	2.58	2.35	D. Herman, NWFSC
Killer whale (captive)	3.18	2.43	Caut et al. 2011
Killer whale (captive)	2.83	1.56	Williams et al. 2011 (unpub.Sea World study)
Transient KW (wild, Hood Canal)	1.94	2.12	D. Herman, NWFSC
SRKW (modeled)	1.89 (1.48 – 2.37)	1.40 (0.99 – 1.90)	This analysis

Median TEFs for SRKW estimated from mixing model (this analysis) are slightly lower than other studies (especially d15N), BUT 95% CI encompasses values from other studies.

Summary of % Chinook in Sept Diet

Technique	Details	Year Whales Sampled	Est. % Chinook in Diet
Isotope Models	isotopes only (fixed TEF)	2008	43.3
	isotope & scales	2008	60.2
Fecals (Genetics -HTS)	-	2005 - 2008	68.6
	-	2009 - 2011	93.0
Scales/Tissues	-	2004- 2009, 2011	70.0


Variability in Chinook SIs
Harrison Chinook resemble Puget Sound
L
J
K
PSBM
CRS
Puget Sound
CRF
Skeena
Sacramento
Fraser – late run
delta N
delta C
18
17
16
15
14
13
-24
-22
-20
-18
-16
-14

TEFs values greatly influence model outcome