Do South American Sea Lions Eat Farmed Salmon?

![Graph showing the isotopic signatures of natural prey, farm-raised salmonids, and sardines. The natural prey (56%, 49-63%) and farm-raised salmonids (45%, 37-51%) are indicated. Sardines and feral salmon are also shown.](image)

Sepulveda et al. in preparation
Outline

“Mixing Models: Often Used, Rarely Understood”

Linear Mass Balance Mixing Models

Concentration-Dependent Mixing Models

The Assumption of Isotopic Routing

>500 publications have used mixing models in the past 10 years.
Mixing Model Assumptions

(1) You know and have measured all potential sources (diet items).
Ringed Seals (Hudson Bay, Canada)
Missing Prey: Copepods and Amphipods

MUST DEFINE PREY SPACE!
Mixing Model Assumptions

(1) You know and have measured all potential sources.

(2) Trophic discrimination factors are known (and do not vary)
2 Source, 1 Isotope Mass Balance Mixing Model
Trophic Discrimination Factors?

\[
\delta^{13}C_{\text{consumer}} = p_X (\delta^{13}C_X + \Delta^{13}C_X) + p_Y (\delta^{13}C_Y + \Delta^{13}C_Y)
\]
\[1 = p_X + p_Y\]

C\textsubscript{3} Tree (\(\delta^{13}C_X\)) \hspace{2cm} \delta^{13}C_{\text{Consumer}} \hspace{2cm} C\textsubscript{4} Grass (\(\delta^{13}C_Y\))

Trophic Discrimination Factors

\[\Delta^{13}C_{\text{tissue}} = ???\]
Mixing Model Assumptions

(1) You know and have measured all potential sources

(2) Trophic discrimination factors are known (and do not vary)

(3) Equal concentration of elements in dietary sources

OMNIVORES

(4) Equal assimilation of dietary sources
The Omnivore’s Dilemma: Unequal Concentration of Elements in Diet

Berries (carbohydrates)
CARBON

Salmon (protein & lipid)
CARBON & NITROGEN

Grizzly Bear Protein?
(muscle/hair/blood)
Concentration-Dependent Mixing Models


Concentration-Dependent Mixing Model:

\[ \delta^{15}N_{\text{consumer}} = (p_X)('[N_X])(\delta^{15}N_X + \Delta^{15}N_X) + (p_Y)('[N_Y])(\delta^{15}N_Y + \Delta^{15}N_Y) \]

\[ '[N_X] = [N_X] / [N_X] + [N_Y] \]

\[ '[N_Y] = [N_Y] / [N_X] + [N_Y] \]

\[ p_X + p_Y = 1 \]

The model assumes that for each element, the contribution of a food source to a consumer is proportional to the assimilated biomass times the proportional element concentration in that source.
Linear Mixing Model
Brown Bear (Sympatric): 59%S, 31%TP, 10%TM
Black Bear (Sympatric): 12%S, 83%TP, 5%TM
Black Bear (Allopatric): 23%S, 43%TP, 34%TM

Concentration Dependent Model
Brown Bear (Sympatric): 26%S, 48%TP, 26%TM
Black Bear (Sympatric): 0%S, 92%TP, 8%TM
Black Bear (Allopatric): 1%S, 56%TP, 43%TM
Mixing Model Assumptions

(1) You know and have measured all of your sources

(2) Trophic discrimination factors are known (and do not vary)

(3) Equal concentration of elements in dietary sources

(4) Equal assimilation of dietary sources
The Omnivore’s Dilemma: Isotopic Routing

Berries (carbohydrates)

Salmon (protein)

Grizzly Bear Tissues (Protein) (muscle/hair/blood)
Perfect Mixing & Perfect Routing

Berries (carbohydrates)

Salmon (protein & lipid)

Scenario #1: Perfect Mixing

Scenario #2: Perfect Routing

Mixing Models Assume Perfect Mixing

\[ \delta^{13}C_{\text{tissues}} = p\delta^{13}C_{\text{salmon}} + (1-p)\delta^{13}C_{\text{berries}} \]

Sample Preparation Protocols (i.e., lipid-extraction) Assume Perfect Routing of Protein
Why Expect Routing?

Classic (Textbook) Animal Ecophysiology:

Dietary Carbohydrate Lipid Carbon

Dietary Protein Carbon

Energy + Lipid Storage

Tissue Synthesis

Remember, the size of arrows depends on relative intake…
When routing occurs, mixing models overestimate proportion of dietary protein in diet.

The degree of overestimation depends on protein quality.
Nile tilapia fingerlings grown on a synthetic diet

- C$_3$ protein (casein, $\delta^{13}$C = -27‰)
- C$_4$ carbohydrate & lipid ($\delta^{13}$C = -12.5‰)

 Triple Weight to Insure Isotopic Incorporation!

4 Protein Levels (3.75%, 7.5%, 15%, 30%)
5 individual fish per treatment

Kelly and Martinez del Rio 2010
Mixing models overestimate contribution of dietary protein to overall diet by ~10–15%.

Kelly and Martinez del Rio 2010
Take Home Messages

For omnivores, we must pay attention to ROUTING!!!

The problem is likely much more severe in endotherms vs ectotherms.

Systematics will be resolved with amino acid analysis (stay tuned).

Interpretation of data from isotopes relies on knowing which factors control the assimilation, synthesis, and incorporation rates in a tissue.