

RANGE-WIDE GRAY WHALE SCIENCE SYMPOSIUM



September 9-10, 2026

Hatfield Marine Science Center

Newport, Oregon

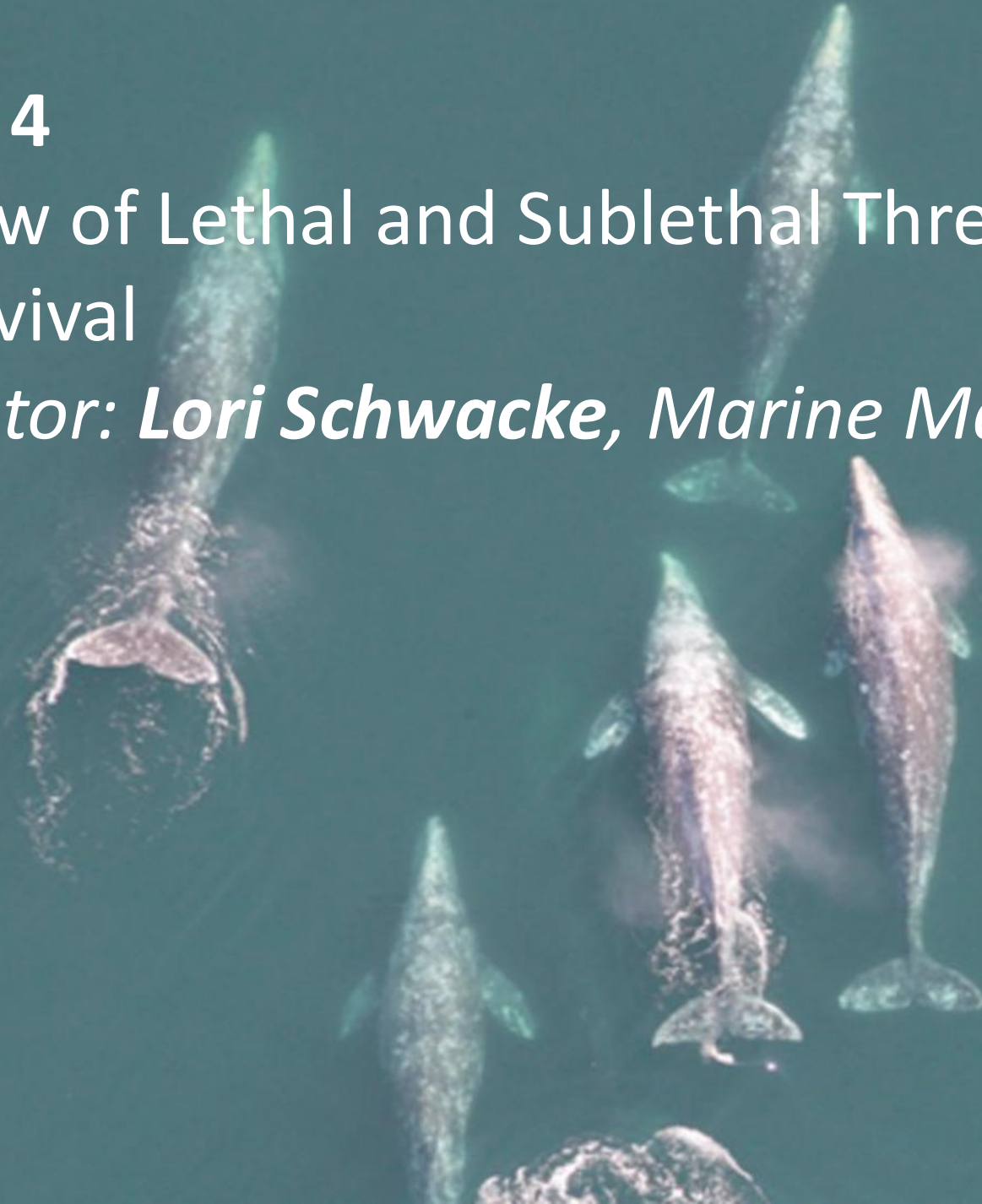


Oregon State University
Marine Mammal
Institute

Session 4

Overview of Lethal and Sublethal Threats to Health and Survival

Moderator: Lori Schwacke, Marine Mammal Commission





**NOAA
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Strandings: Unusual Mortality Event and post-UME update, including Cause of Death Findings



Deborah Fauquier
NOAA Fisheries
September 9, 2026

Gray Whale Stranding Transboundary Team

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Photo: California Academy of Sciences

Unusual Mortality Event Program Background

Congress established the Unusual Mortality Event (UME) Program in 1992 under Title IV of the Marine Mammal Protection Act and defined UMEs as strandings that are:

- **Unexpected**
- **Involve a significant die-off, or new morbidity or mortality pattern of any marine mammal population**
- **Demand an immediate response**
 - *UMEs can be declared based on one or more criteria*
 - *UME declarations trigger federal investigations*
- *UMEs are declared by the trust agency (NOAA Fisheries or USFWS)*

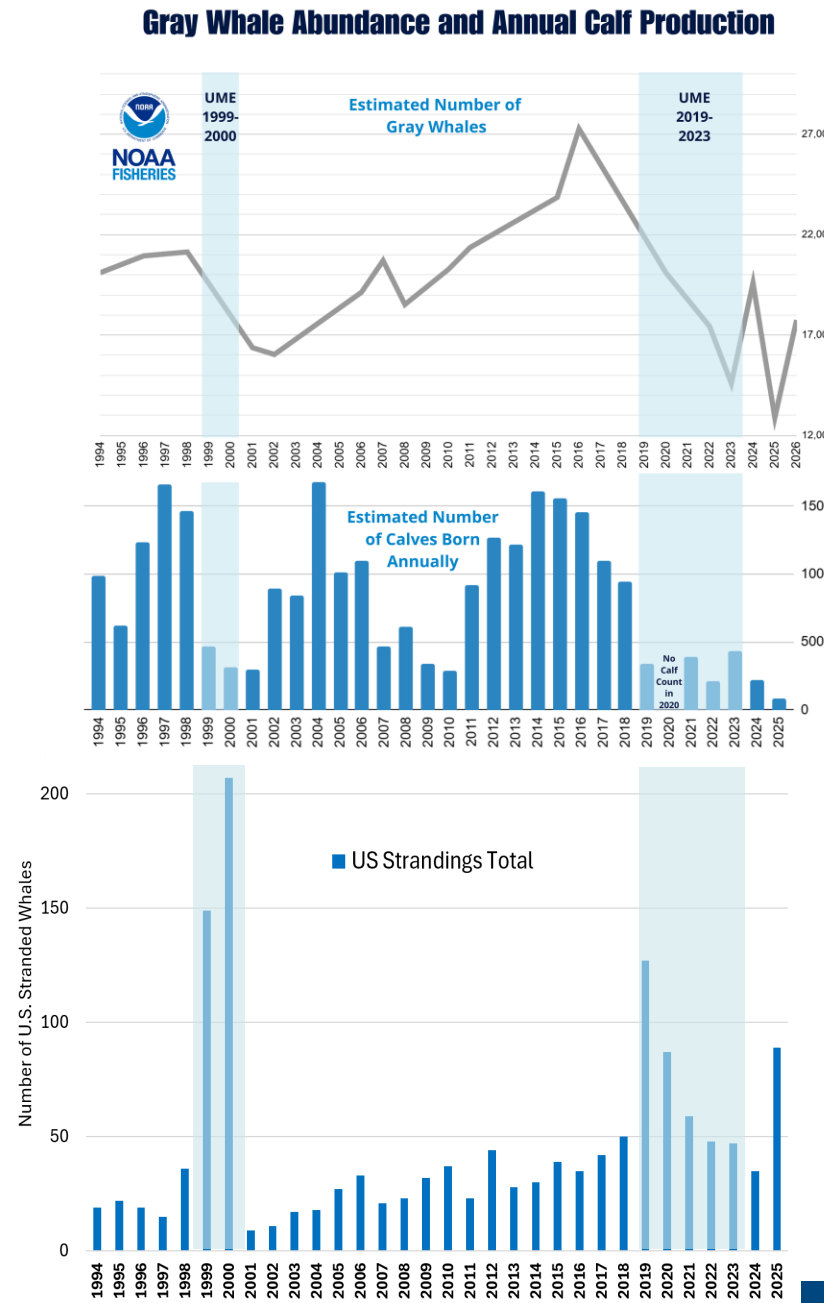
UME Closure -

- UME investigation remains open until the criteria under which the UME was declared have resolved or have become persistent.
- NOAA Fisheries or the USFWS, make the final decision on when to close a UME.

UME Criteria

1. A marked increase in the magnitude or a marked change in the nature of morbidity, mortality or strandings compared with prior records.
2. A temporal change in morbidity, mortality or strandings is occurring.
3. A spatial change in morbidity, mortality or strandings is occurring.
4. The species, age, or sex composition of the affected animals is different than that of animals that are normally affected.
5. Affected animals exhibit similar or unusual pathologic findings, behavior patterns, clinical signs, or general physical condition (e.g., blubber thickness).
6. Potentially significant morbidity, mortality or stranding is observed in species, stocks or populations that are particularly vulnerable (e.g., listed as depleted, threatened or endangered or declining).
7. Morbidity is observed concurrent with or as part of an unexplained continual decline of a marine mammal population, stock, or species.

ENP Gray Whale Abundance, Calf Production & U.S. Strandings



1999-2000 West Coast Gray Whale UME

Location: Mexico to Alaska

Timeframe: 01 January 1999, through 31 December 2000

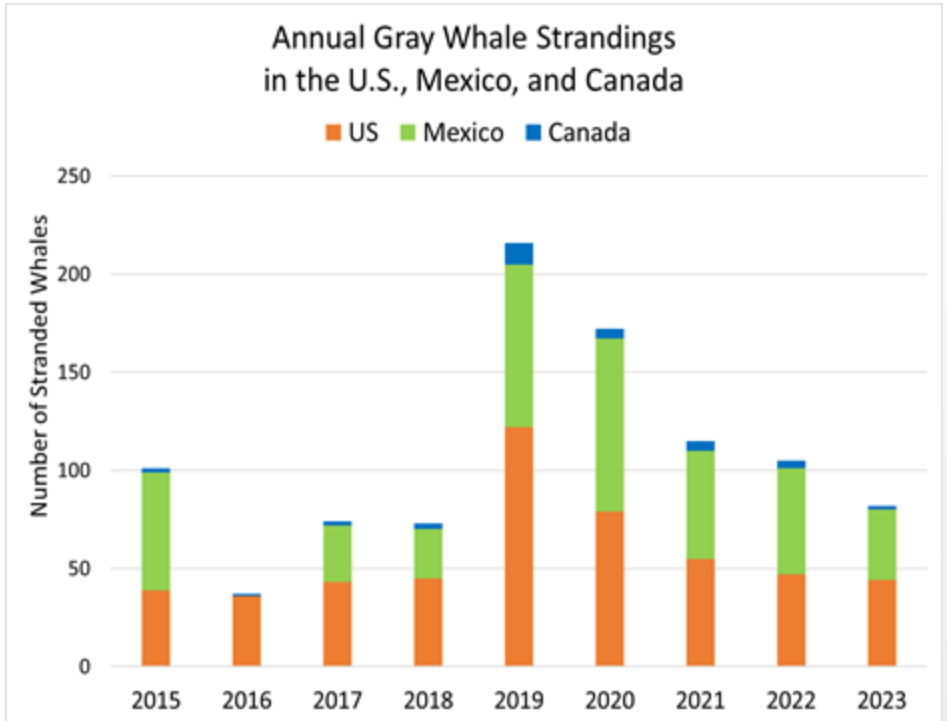
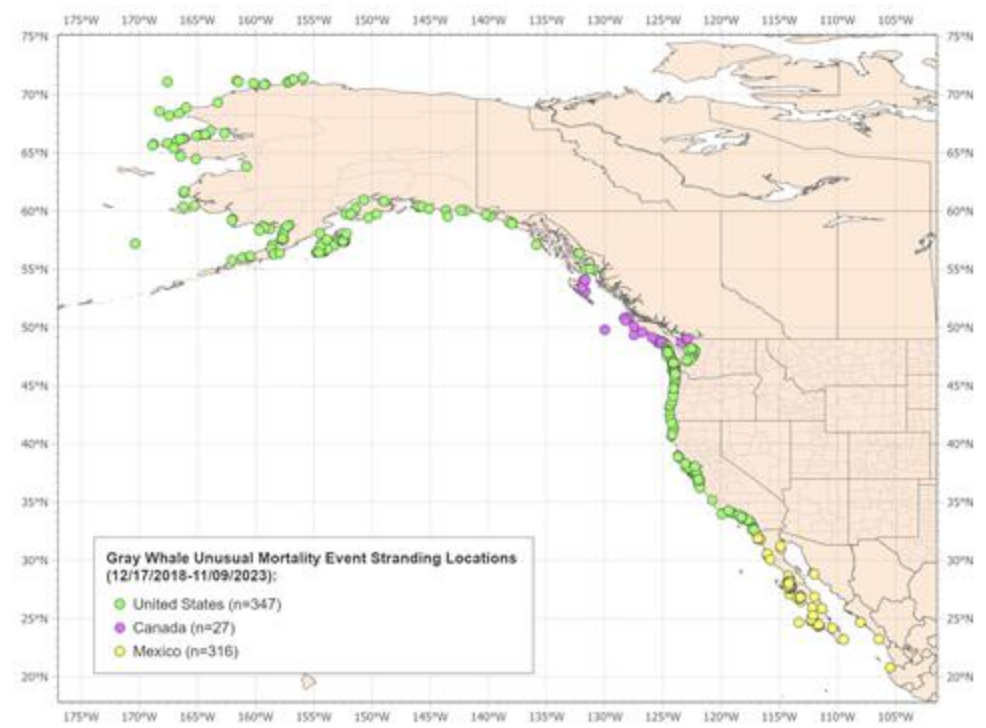
Numbers: 651 whales (288 US; 331 MX; 32 Canada)

Findings: 3 animals with histopathology - brain infection, GI parasites & Domoic acid toxicosis

Preliminary Cause:

- Oceanographic factors that limited food availability for gray whales were identified as likely cause of the UME, with resulting declines in survival rates of adults during this period. ([Gulland et al. 2005](#))
- Some of the stranded whales were emaciated and calf production in 1999 and 2000 was less than one third of that in 1996–98

2019-2023 West Coast Gray Whale UME



Country	2019	2020	2021	2022	2023	Total
Canada	11	5	5	4	2	27
US	122	79	55	47	44	347
Mexico	83*	88	55	54	36	316
Total	216	172	115	105	82	690

Eastern North Pacific gray whale strandings by country from 17 December 2018, through 09 November 2023.
*includes 2 whales that stranded in Mexico in December 2018



2019-2023 West Coast Gray Whale UME

Type of Response for Stranded Gray Whales

Country	Necropsy/Internal Exam	Limited Sampling/Partial Exam	No Response/Photos Only	Unknown	Total
Canada	7	12	7	1	27
U.S.	61	132	149	5	347
Mexico	4	268	44	0	316
Total	72	412	200	6	690



Nutritional Condition of Stranded Gray Whales

Country	Emaciated	Thin	Average/Good	Fat	CBD	Unknown	Total
Canada	1	2	3	0	3	18	27
U.S.	37	51	28	2	219	10	347
Mexico	26	15	21	3	250	1	316
Total	64	68	52	5	472	29	690



2019-2023 West Coast Gray Whale UME

From Raverty et al. 2024 - Cause of death in UME whales from 2019-2021

Examined 12% (61/503) whales with external/internal and/or histopathology data. COD determined in 54% (33/61) of whales.

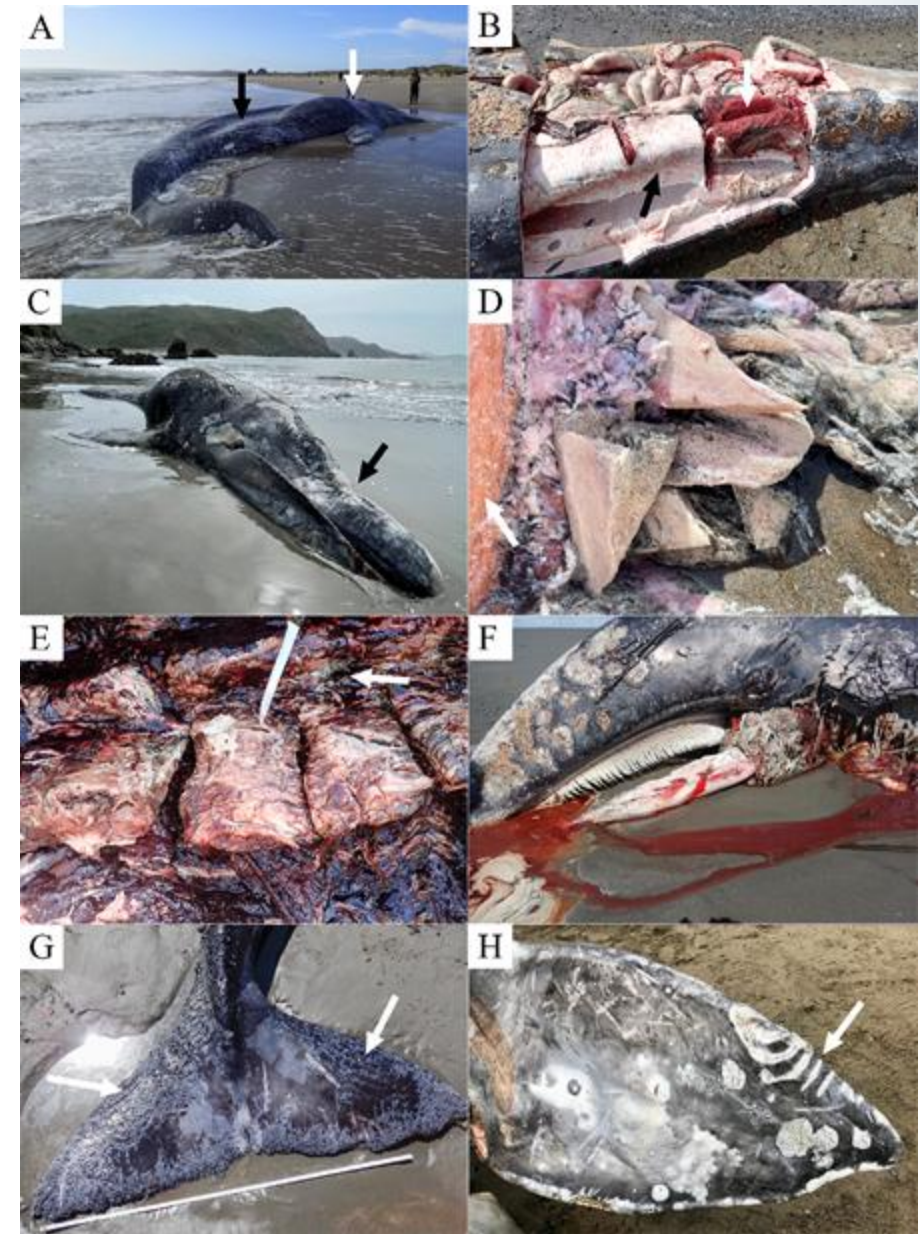
- 26% (16/61) severely emaciated
- 18% (11/61) vessel strike from blunt force trauma
- 5% (3/61) killer whale predation
- 5% (3/61) entanglement/entrapment
- 46% (28/61) no specific cause of death identified

Fig 2. Examples of gross pathology findings.

(A) Adult female gray whale category 1 emaciation showing loss of nuchal adipose tissue (white arrow) and severe epaxial muscle atrophy (black arrow); (B) Sub-adult male gray whale with blubber flensed from the right side to reveal severely atrophied hypaxial muscle (white arrow) and epaxial muscle (black arrow);

(C) Sub-adult female gray whale with concave rostral deformity (arrow) caused by blunt force trauma; (D) Comminuted fracture of the rostral bones of whale C, arrow shows subadjacent hypodermal contusion; (E) Adult male gray whale with exposed thoracic vertebrae showing transverse fractures of the dorsal vertebral processes (indicated by knife point) and muscular hemorrhage (arrow);

(F) Gray whale calf predated by killer whales with loss of the tongue and soft tissue from the mandibles; (G) Flukes from the same calf showing acute epidermal lacerations consistent with killer whale tooth rakes (arrows); (H) Subadult gray whale pectoral flipper showing killer whale tooth rakes on the leading edge (arrow).



2019-2023 West Coast Gray Whale UME

Location: Mexico to Alaska

Timeframe: 17 December 2018, through 09 November 2023.

Numbers: 690 whales (347 US; 316 MX; 27 Canada)

Preliminary Cause:

Ecosystem changes in sub-Arctic and Arctic feeding areas (including both access to and quality of prey) leading to poor nutritional condition, decreased birth rates, and in several whales death due to malnutrition ([Moore et al. 2022](#), [Stewart et al. 2023](#)).

Significant Findings:

- Findings from dead whales supported malnutrition as a common cause of death and did not identify underlying viral infections or biotoxycosis. Additional findings included pre-mortem vessel strikes and killer whale predation ([Raverty et al. 2024](#)).
- The nutritional condition of live gray whales in Mexico was lower than baseline values leading into and overlapping the UME period ([Christiansen et al. 2021](#)).



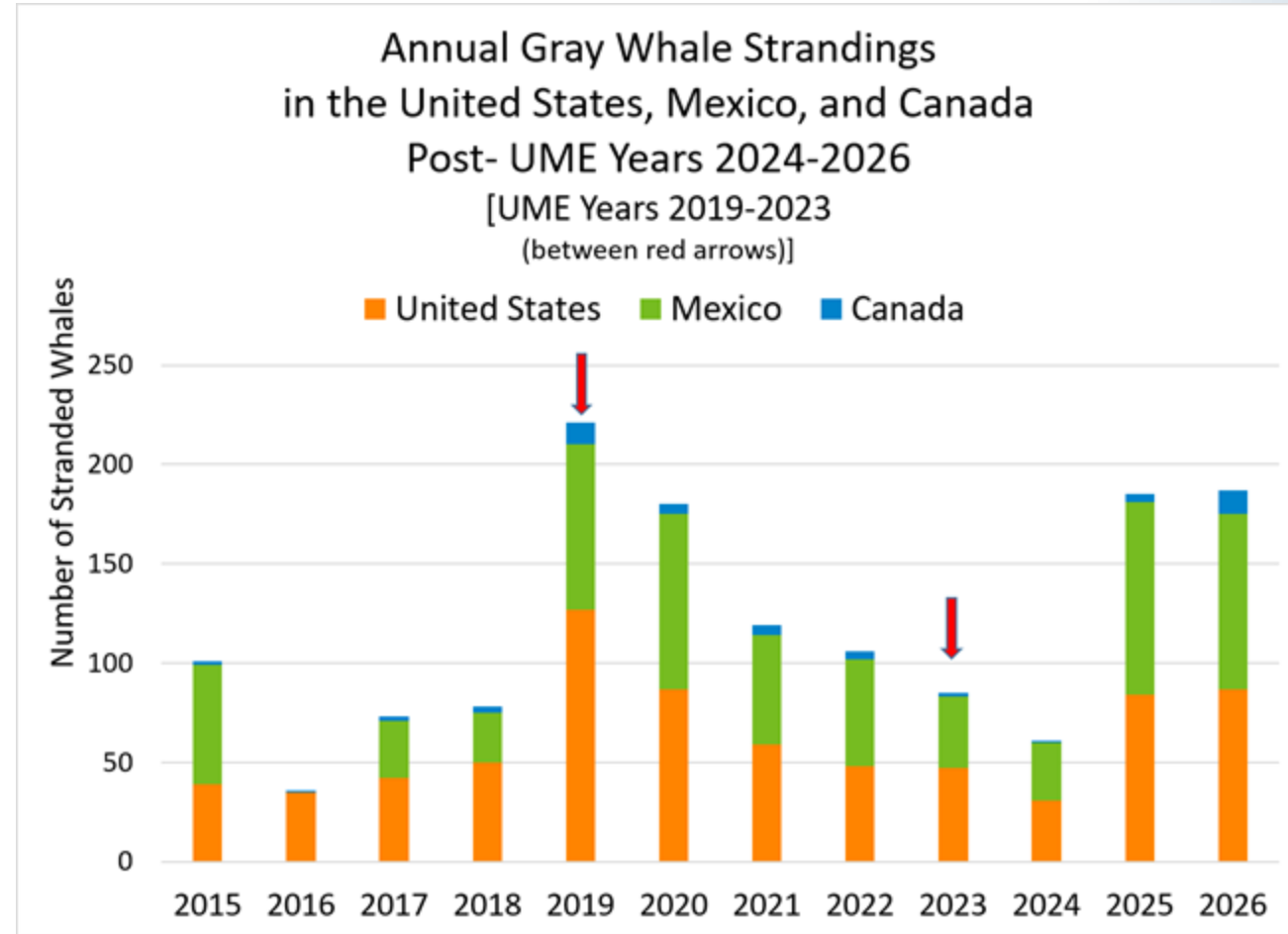
Photo: Fisheries Oceans Canada



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2026 West Coast Gray Whale Post-UME Monitoring

- Continued collaboration between Transboundary Groups for 2024-2026 strandings
- Baseline strandings in 2024, elevated strandings in 2025-2026
- Persistent ecosystem drivers in the sub-arctic and arctic feeding areas
- Consistent cause of death with UME years including malnutrition, and pre-mortem vessel strikes and killer whale predation
- Impacts on Gray Whale population continue with lower abundance and calf production linked to persistent ecosystem changes



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Thank You!

We want to thank the U.S. West Coast, Alaskan, Canadian, and Mexican Marine Mammal Stranding Networks and our state, tribal, local, non-governmental and academic partners for their assistance.



Range-wide assessment of gray whale nutritional state via drone-based photogrammetry

KC Bierlich

Leigh Torres

Marine Mammal Institute,
Oregon State University



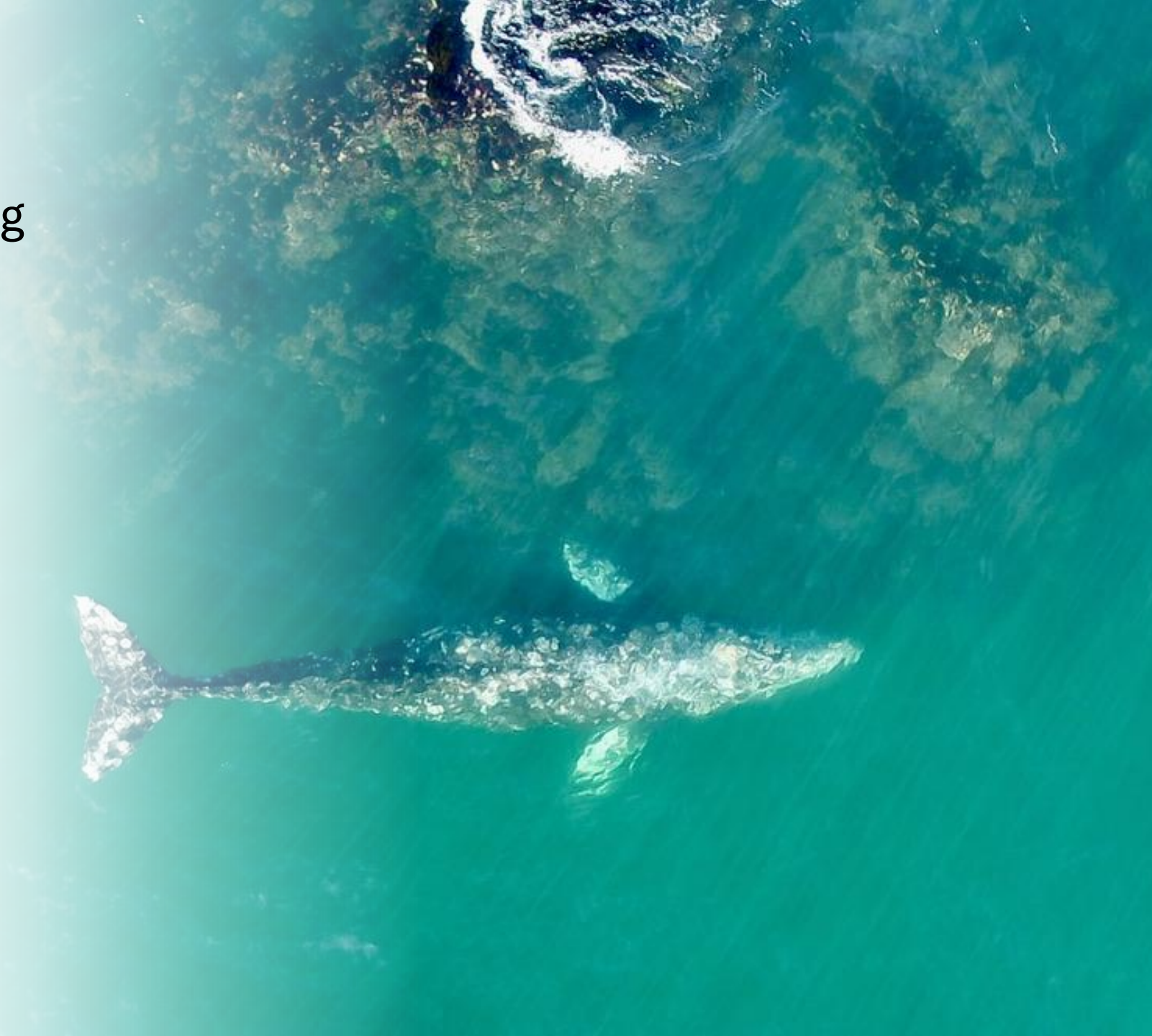
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Range-Wide Gray Whale Science Symposium, Sept. 9-10, 2026

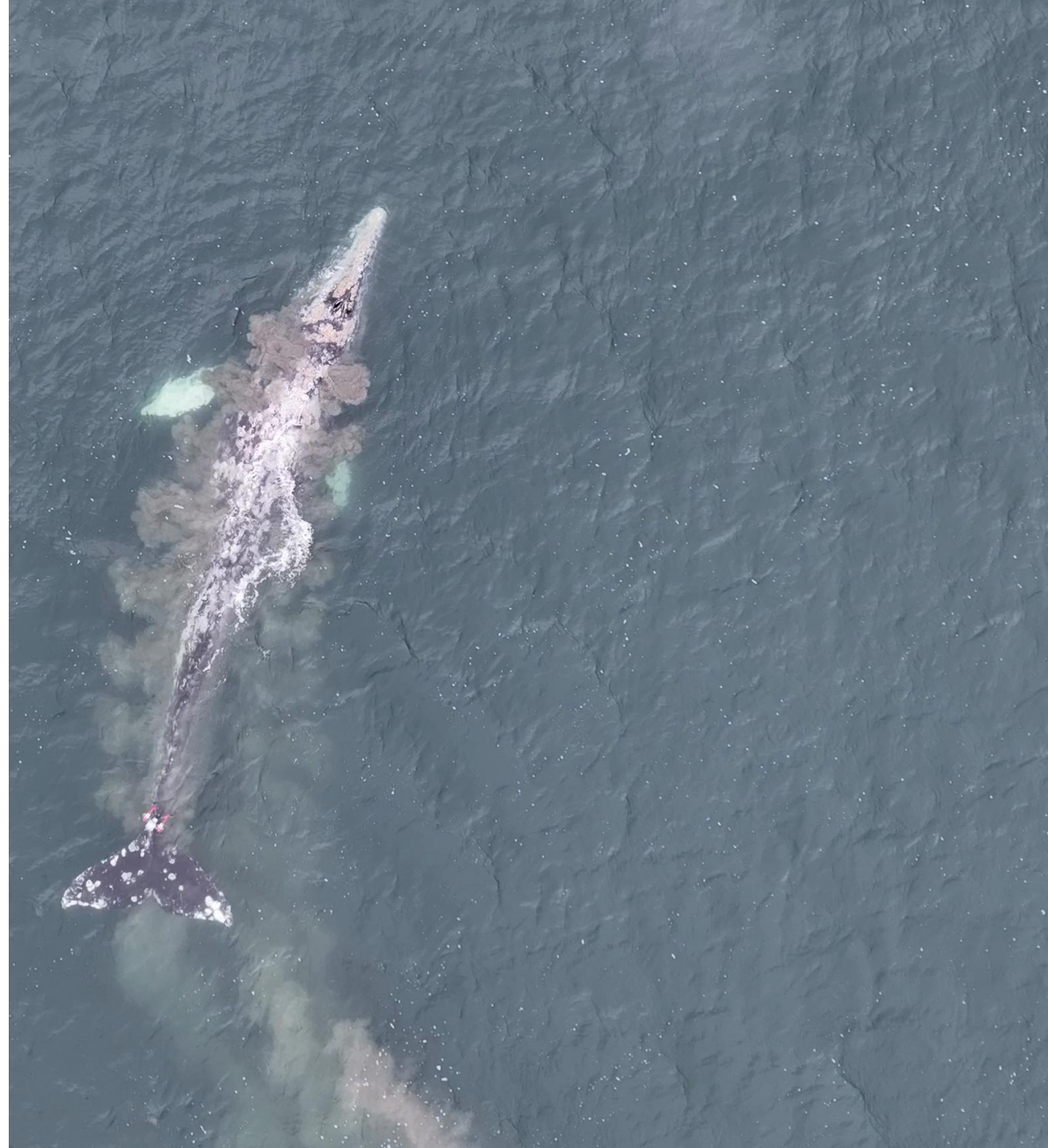
Goal: inspire range-wide collaboration for monitoring gray whale body condition using drones

- Intro to workflow for standardization of measurements from different drones
- Case study: comparison of body condition across range



Body condition from aerial imagery

- External morphology to approximate energy stores
- Represents foraging success & health state





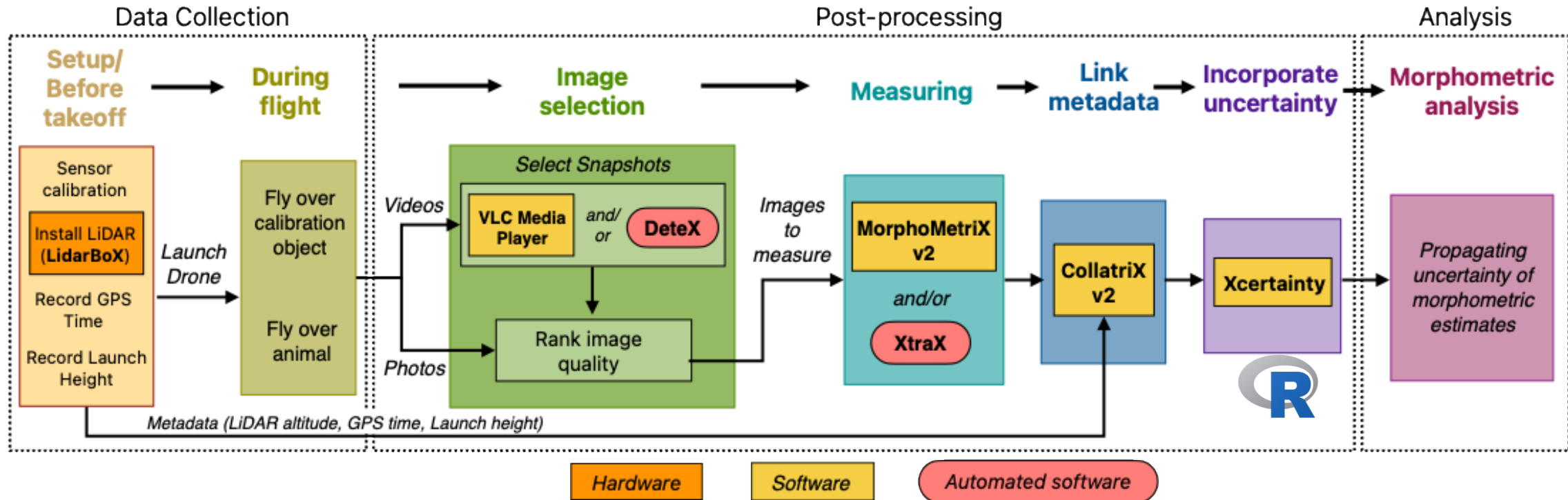
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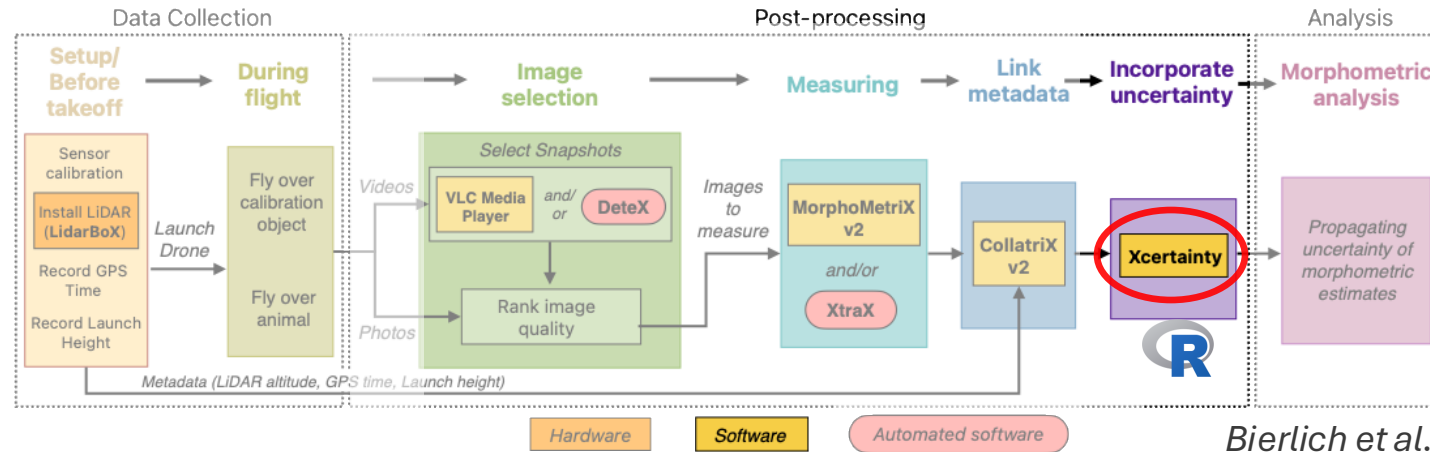


A workflow of open-source tools for drone-based photogrammetry of marine megafauna

PeerJ

Bierlich et al., 2025





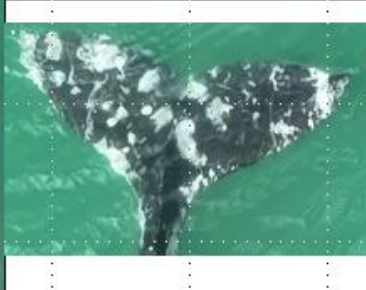
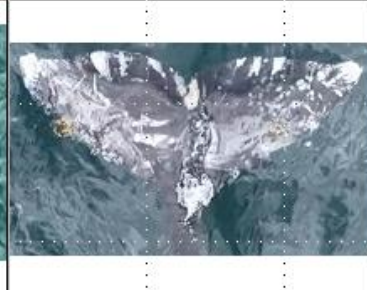
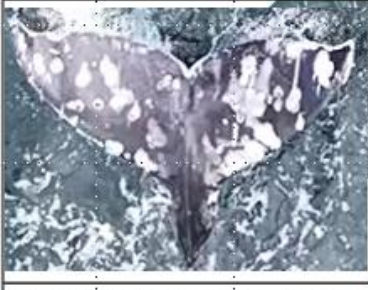
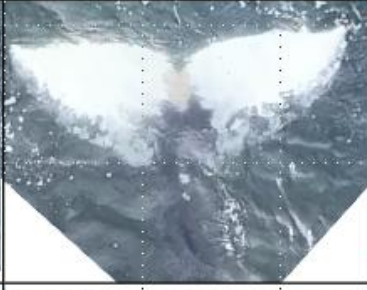
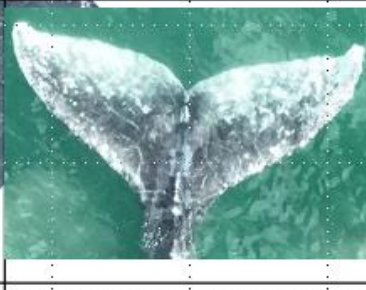
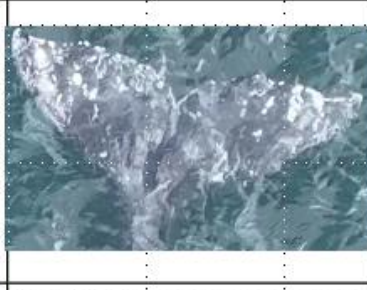
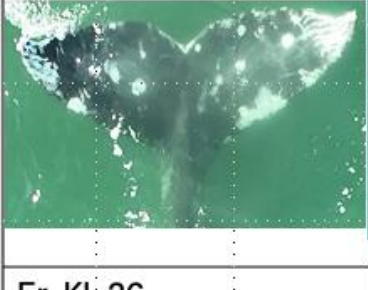
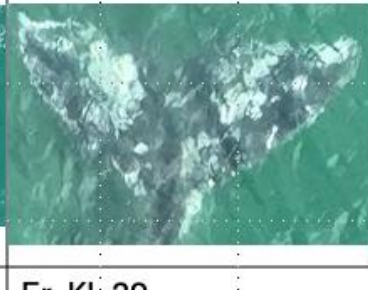
Bierlich et al., 2025

Xcertainty

- R package for quantifying and incorporating photogrammetric uncertainty associated with different drones
- Based on Bayesian statistical model from Bierlich et al. (2021).
- Outputs several body condition metrics with uncertainty
 - *body volume, single widths, BAI*



Aerial ID Catalog

				
Er_KI_16	Er_KI_17	Er_KI_18	Er_KI_19	Er_KI_20
				
Er_KI_21	Er_KI_22	Er_KI_23	Er_KI_24	Er_KI_25
				
Er_KI_26	Er_KI_27 Er_KI_10	Er_KI_28	Er_KI_29	Er_KI_30



Case study: comparing body condition across range

Building Dataset

***n* = 2,211**

Kodiak Island

May 2026 (*n* = 40)
*Sun'aq Tribe, CODEX,
GEMM Lab*

N.E. Chukchi Sea

Jun-Oct. 2016-2019 (*n* = 18)
*Torres et al., 2022, (Amy Willoughby,
NOAA)*

Sitka Sound

April 2026 (*n* = 57)
*Lauren Wild, Jan Straley,
GEMM Lab, CODEX*

West Vancouver Island

March-June 2025-2026 (*n* = 70)
*Mark Sawyer/Ashley Hoyland (WhalesCB) (Permit no.
MML-70) & Cetacean Research Program (DFO)*

San Francisco Bay

Feb – Jun 2026 (*n* = 12)
*Cetacean Conservation Biology Dept.,
The Marine Mammal Center (permit no. 26532)*

Oregon (PCFG)

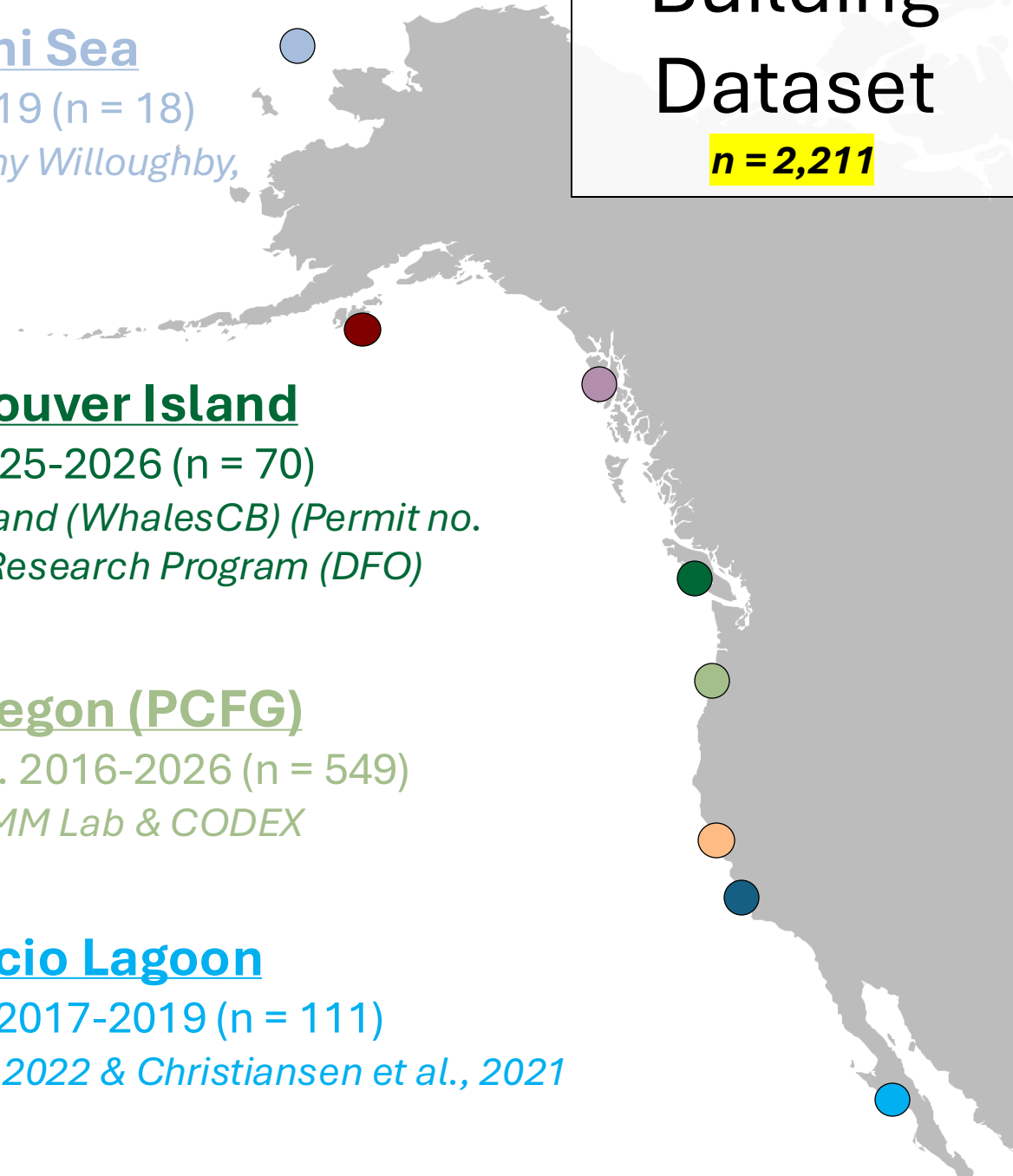
May-Oct. 2016-2026 (*n* = 549)
GEMM Lab & CODEX

Central California

March 1987-2015 (*n* = 1309)
*Stewart et al., 2021, NOAA,
Torres et al (in review)*

San Ignacio Lagoon

Jan-March 2017-2019 (*n* = 111)
Torres et al., 2022 & Christiansen et al., 2021



What is a healthy body condition for gray whales?

- Depends on when in the season, demographic unit, and foraging site

Starting place:

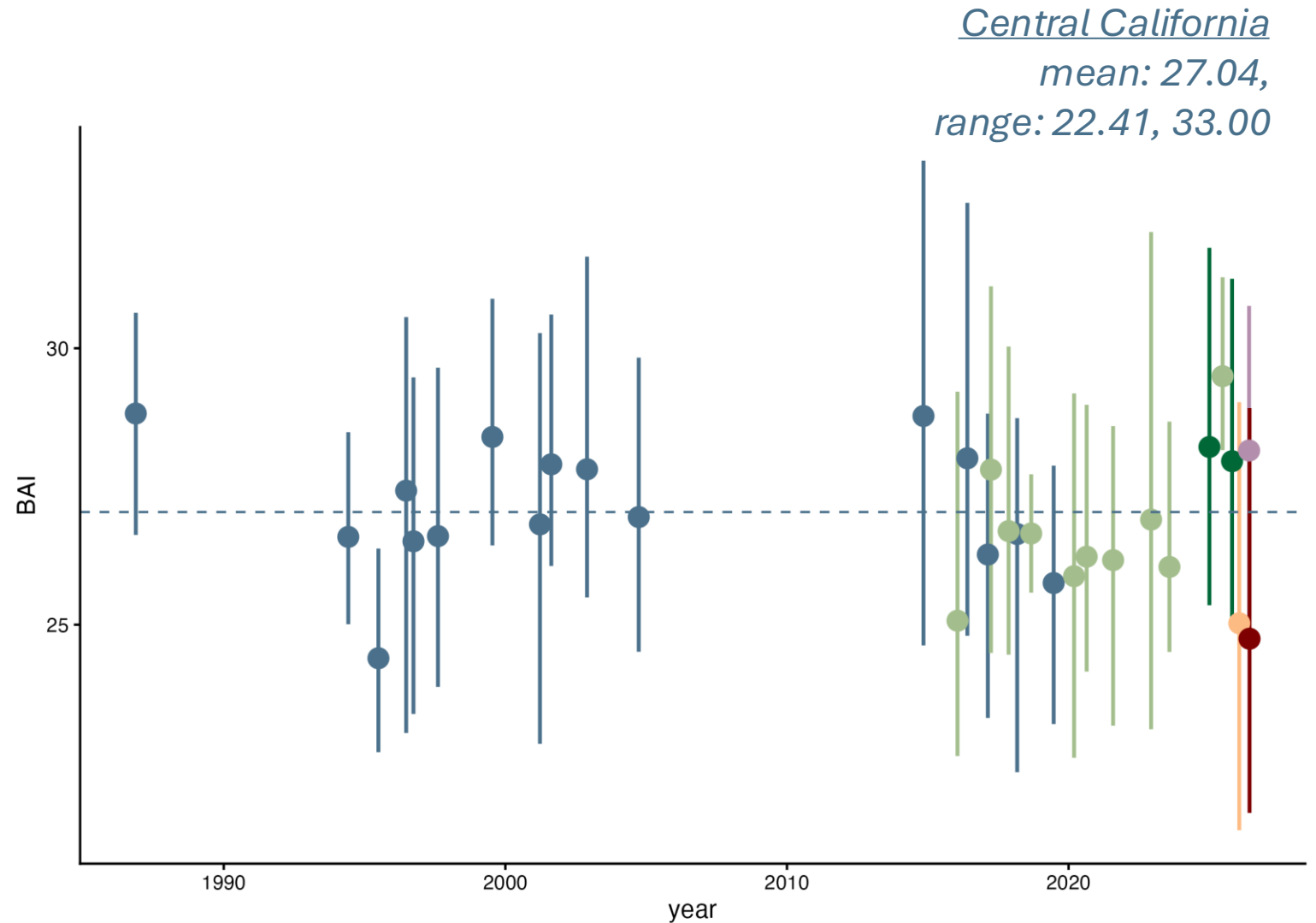
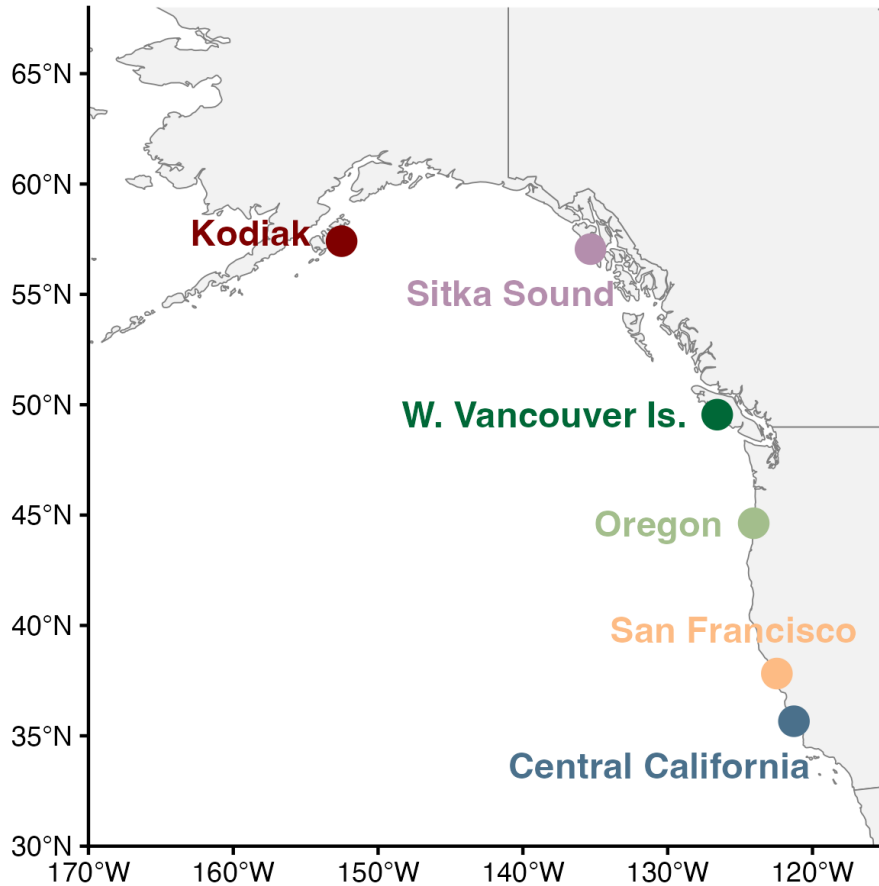
What is “normal” for post-winter fasting, and how do “atypical” feeding sites compare?

➤ BAI during Northbound migration, arrival to feeding sites



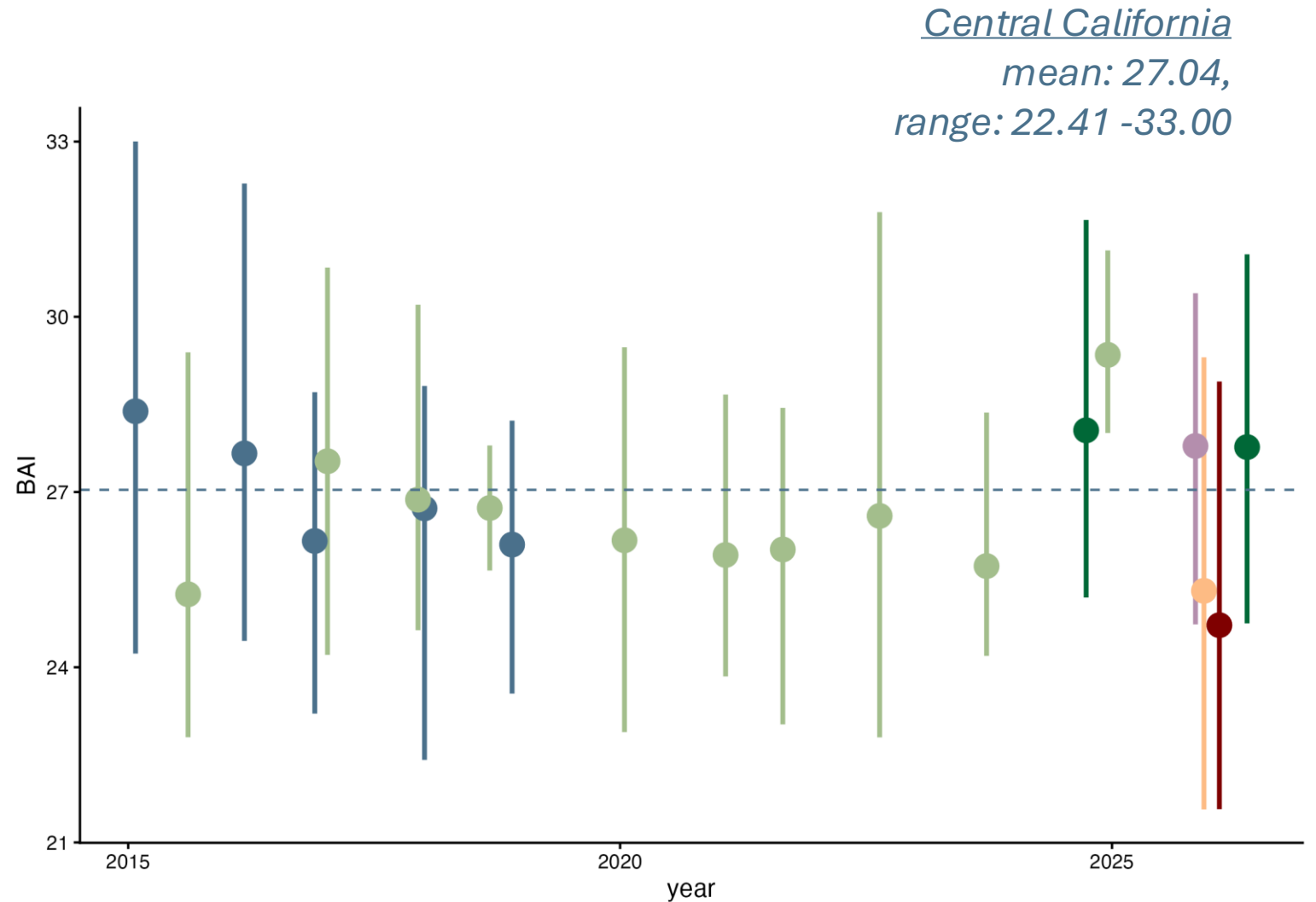
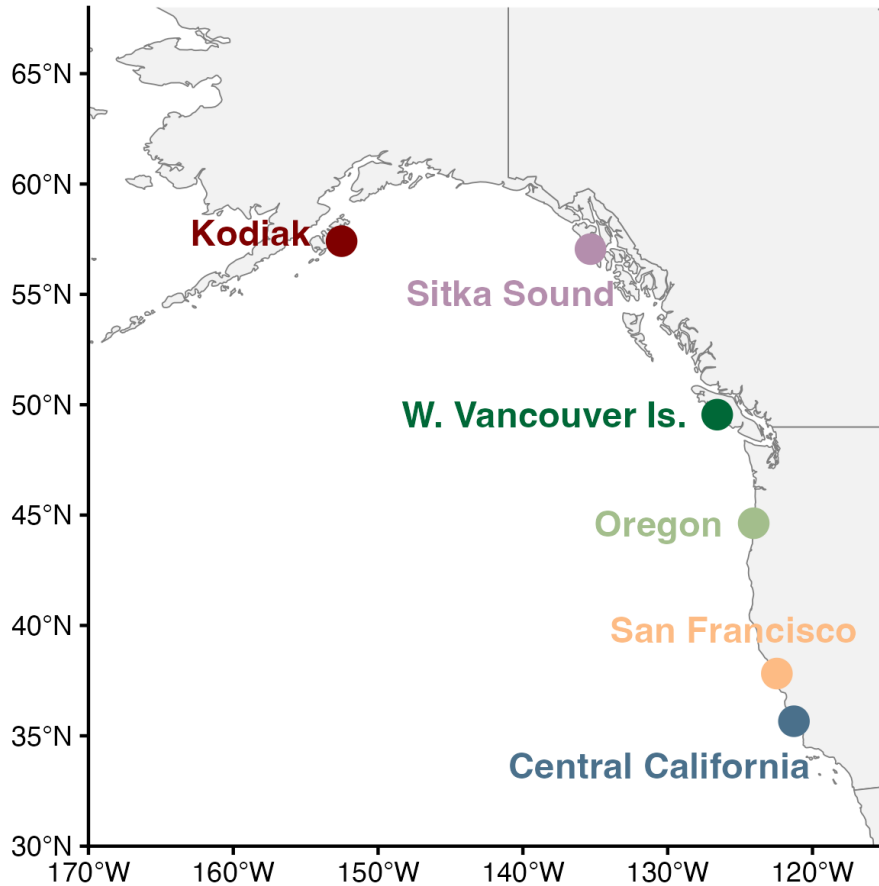
Northbound migration / post-winter

February - June



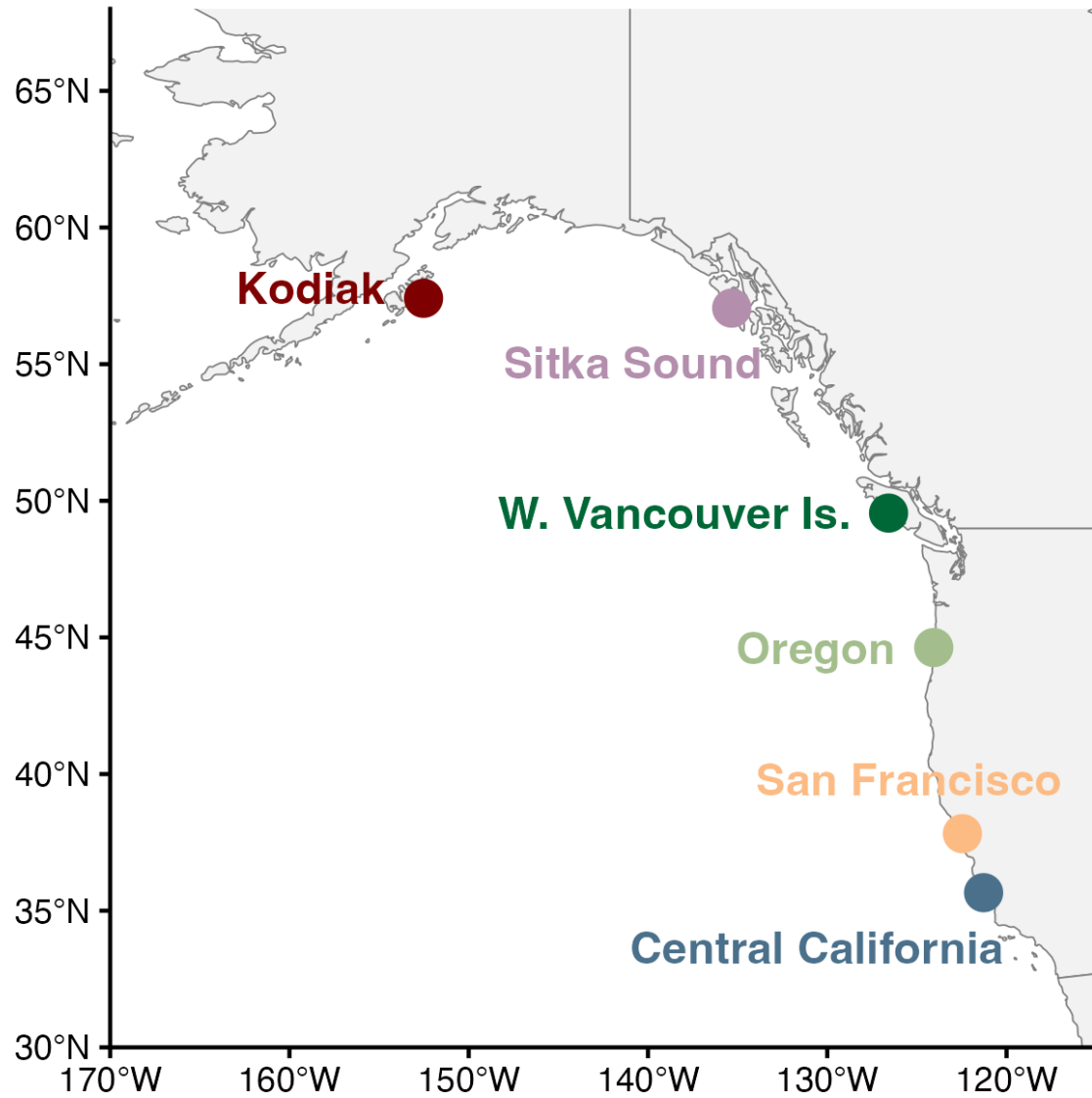
Northbound migration / post-winter

February - June



Northbound migration / post-winter

February - June



What is a healthy body condition for gray whales?

- Depends on when in the season, demographic unit, and foraging site

Starting place:

What is “normal” for post-winter fasting, and how do “atypical” feeding sites compare?

- BAI during Northbound migration, arrival to feeding sites

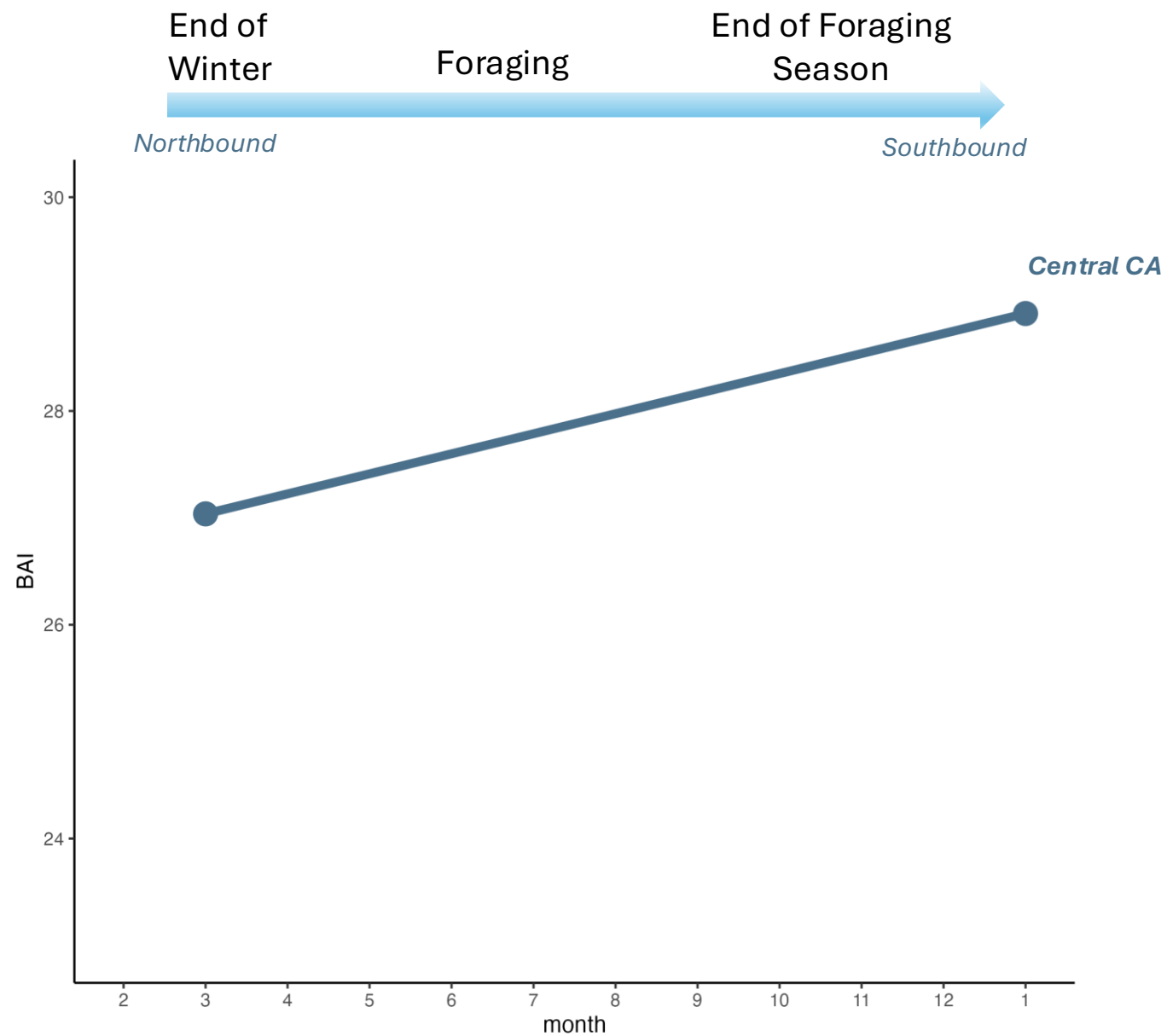
What is a “normal” increase in body condition?

- **Change in BAI throughout year**

Change in BAI across months

Central California (NB -> SB)

- 27.04 → 28.91

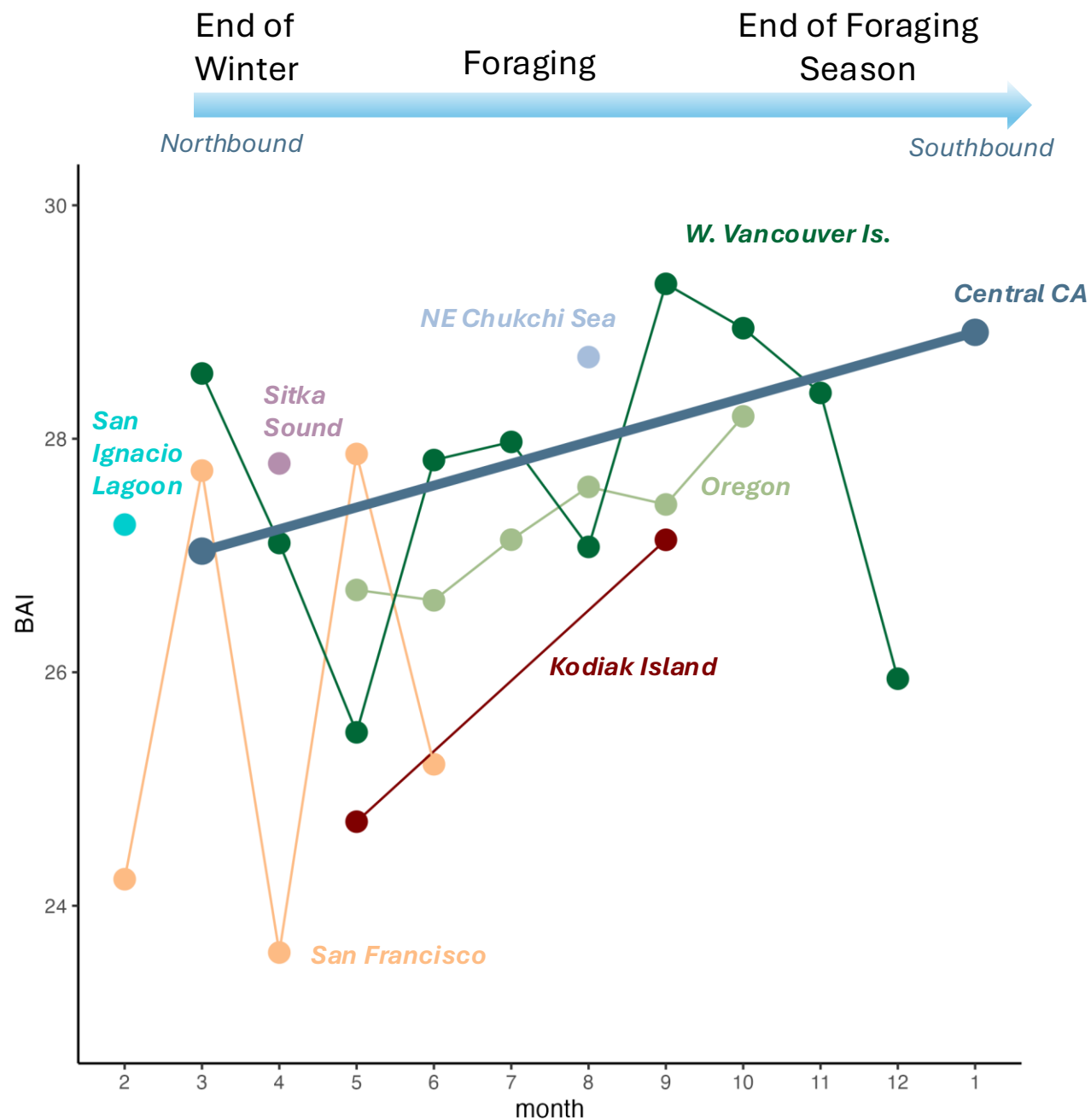


Change in BAI

across months

Central California (NB -> SB)

- $27.04 \rightarrow 28.91$



What is a healthy body condition for gray whales?

- Depends on when in the season, demographic unit, and foraging site

Next Steps:

- Relate body condition to population trends: abundance, calf counts, strandings, etc.
- Individual life history, demographic unit, endocrine state, wounds/scars





Thank you!

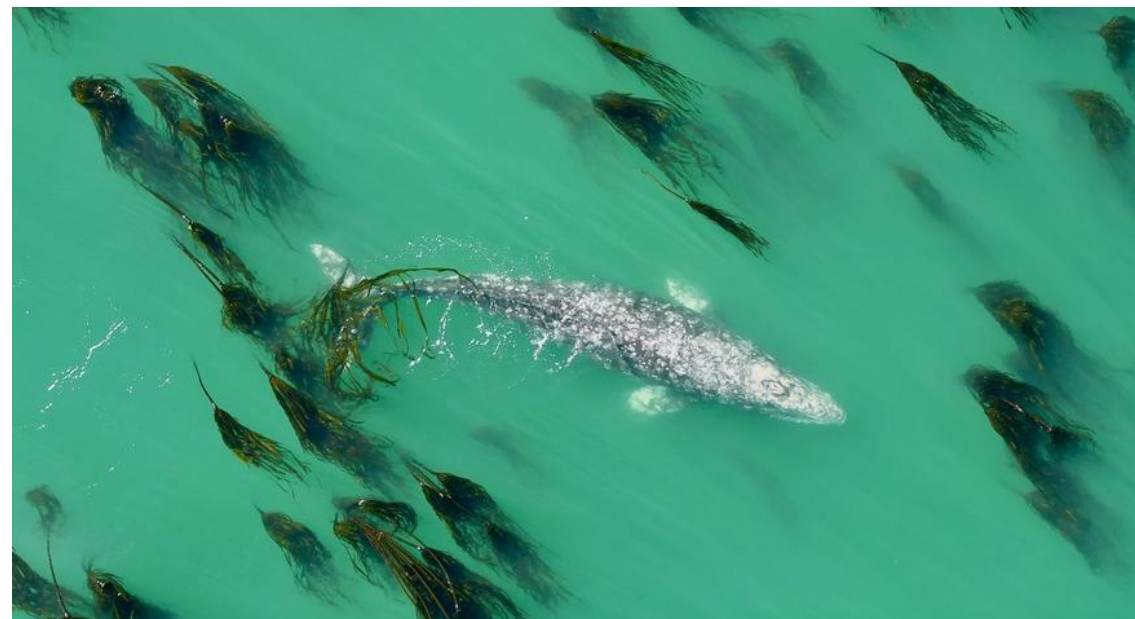
Nat Chazal, Hali Peterson, Sonora Van Diest, Ema Parker, Mella Re, GRANITE Field Team, Ines Hildebrand

Sun'aq Tribe of Kodiak (Matthew Van Daele, Daniel Smith), Andrew Ward, Tyler Randolph, Brian Venua

Whales of Clayoquot & Barkley (Mark Sawyer & Ashley Hoyland)

Cetacean Research Program, DFO (Erin Foster, Kerrith McKay, Thomas Doniol-Valcroze)

Cetacean Conservation Biology Dept., The Marine Mammal Center (Gina Lonati, Norely Faz, Darrin Allen, Marsi Smith, Kierstin Thigpen)



Insights from the Pacific Northwest on alternate feeding areas and nutritional status

John Calambokidis, Jessie Huggins, Hannah Clayton, Amanda Rueda, James Fahlbusch, Kiirsten Flynn, Alex Vanderzee, and Alie Perez, Cascadia Research

John Durban and Holly Fearnbach, SR3

in collaboration with WDFW, Stanford Univ, Orca Network, SeaDoc Society, ORCA Acad, Ocean Alliance, and others

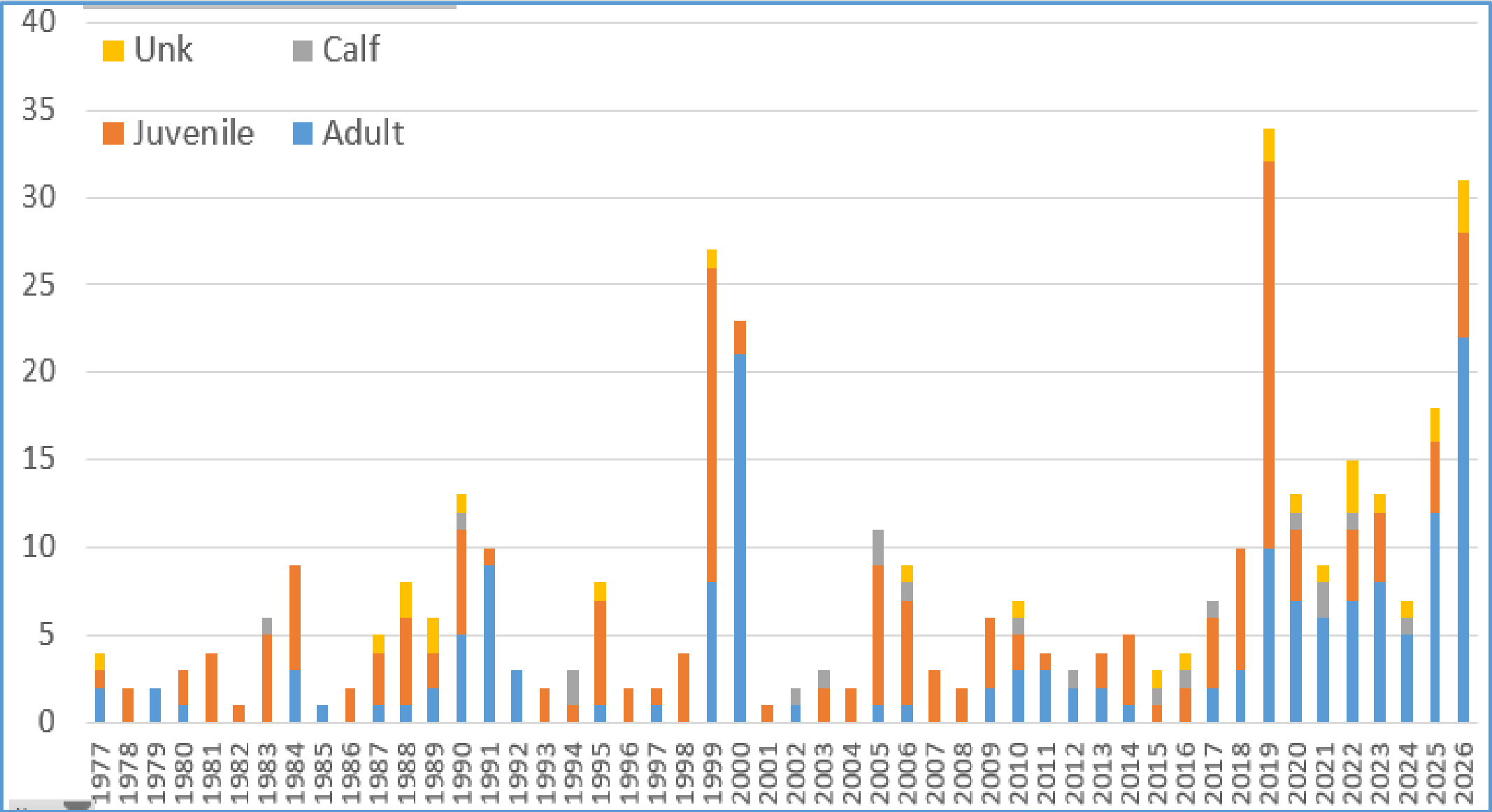


Gray whales in Washington State:

Different groups and different roles

Overall ENP group □ Feed in Arctic waters □ Migrate S in Dec. mostly offshore WA □ Migrates N in March-May	Sounders □ Feed in Spring in N Puget Sound □ Original group from early 1990s □ Now >20 □ Feed mostly on ghost shrimp in intertidal	Pacific Coast Feeding Group □ Feed primarily in the Pac. NW □ 200-250 □ N CA through BC □ Feeding behavior	W Gray whales □ Feed off Sakhalin Is in Russia □ Mostly come to ENP to breed □ Number only a few 100 □ Genetic differences with overall ENP
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Gray Whale Strandings in Washington by Year with Age Classes

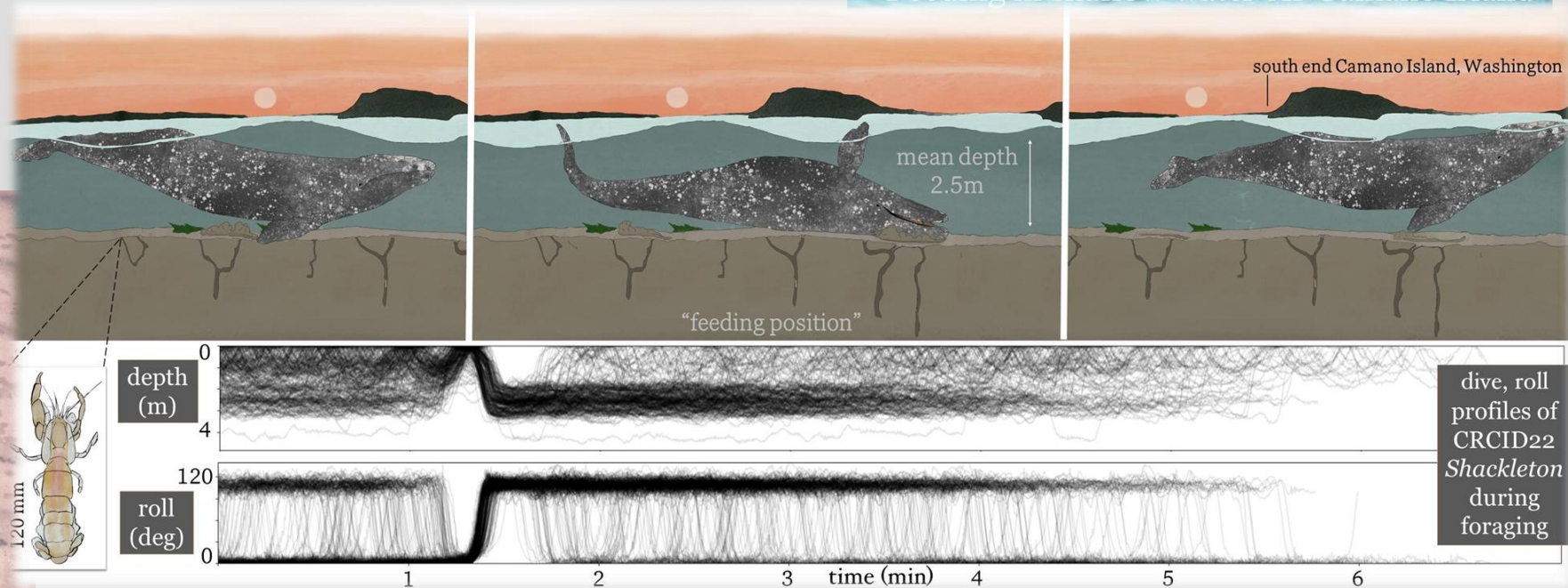
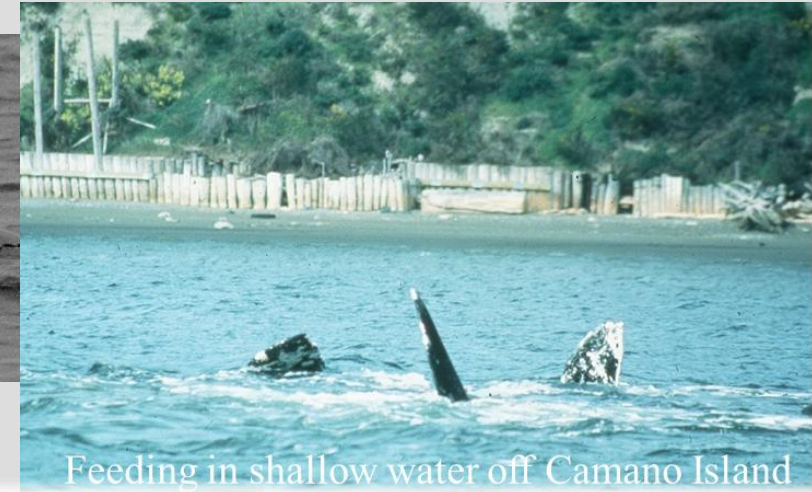
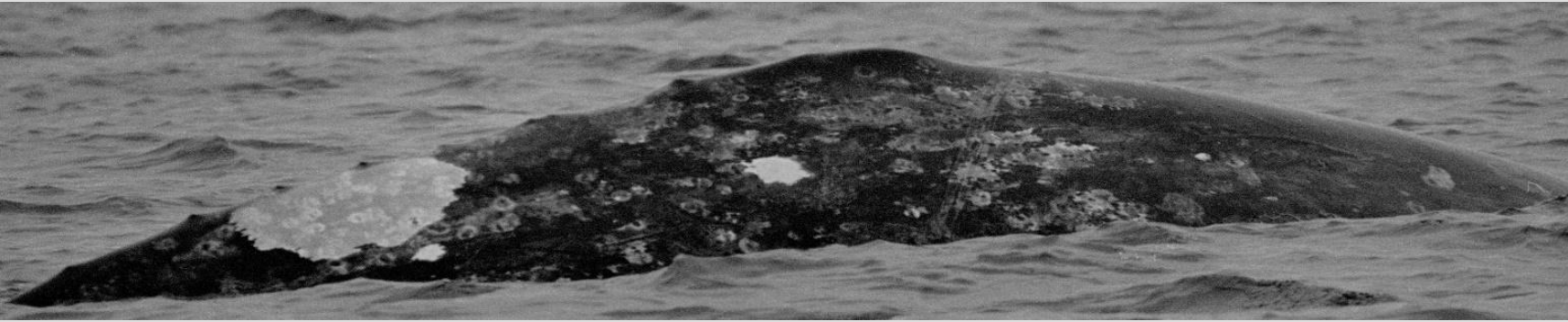


Shift in age classes through mortality events

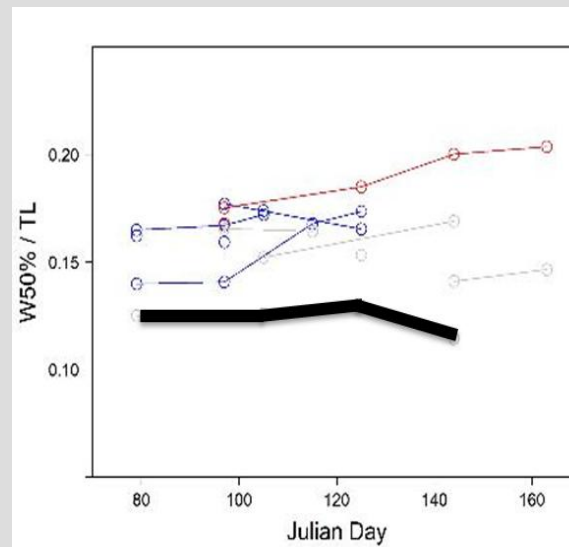
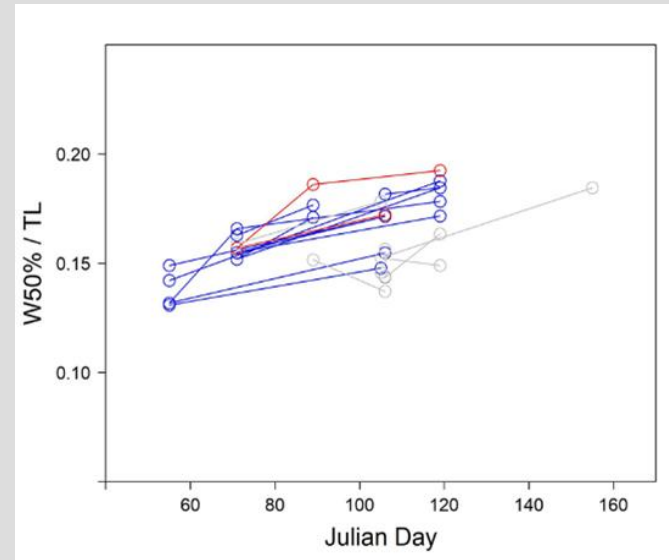
Year	Num.	% Adult	% J uv	Year	Num.	% Adult	% J uv	Year	Num.	% Adult	% J uv
1990	13	38%	46%	1999	27	30%	67%	2019	34	29%	65%
1991	10	90%	10%	2000	23	91%	9%	2020	13	54%	31%
								2021	9	67%	0%
								2022	15	47%	27%
								2023	13	62%	31%
								2024	7	71%	0%
								2025	18	67%	22%
								2026	31	71%	19%

Sounders gray whales

- Primarily seen March through June in N Puget Sound Core group arrived in three waves 1990-91, 1999-2000, & 2019-2022. Cascadia has studied them since 1990

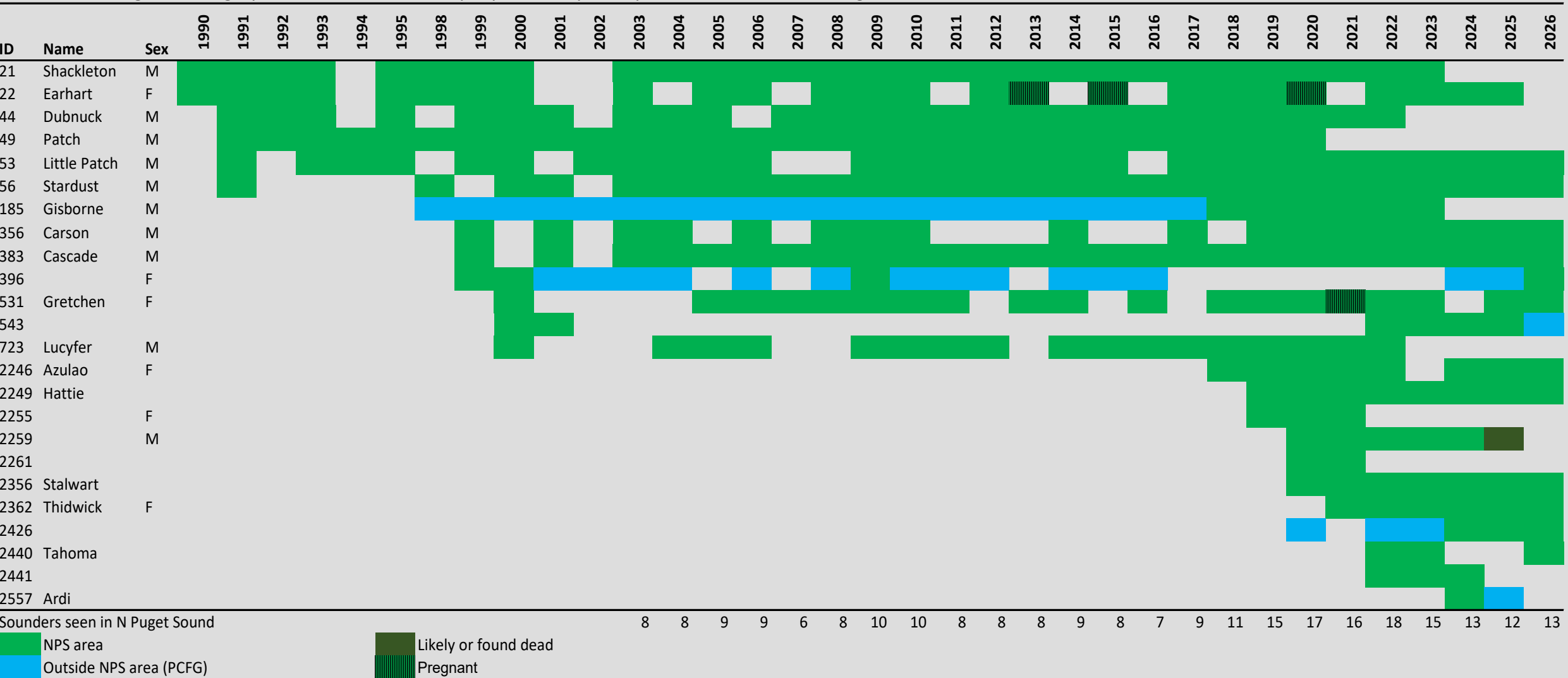


Aerial photogrammetry of gray whales in Northern Puget Sound, 2020-25 by SR3 (Durban and Fearnbach) and Cascadia indicated rapid body growth by most whales but not some newcomers

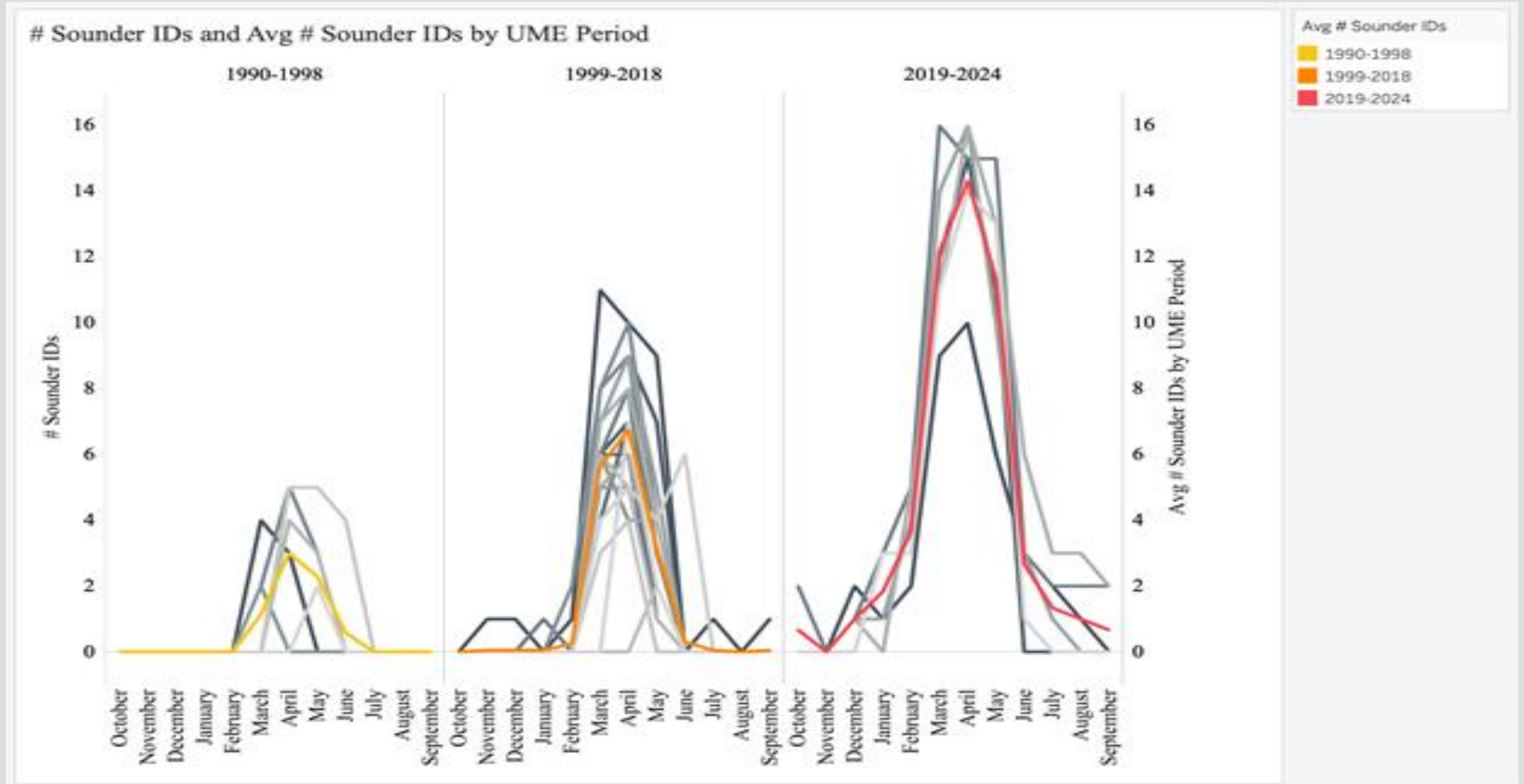


Sounders gray whales feeding in Spring in N Puget Sound showed higher numbers of returning whales in recent years and longer periods of use. Three of the initial six Sounders from 1990-91 have likely died in recent years

Confirmed N Puget Sound gray whale IDs seen in multiple years compiled by Cascadia Research through March 2026



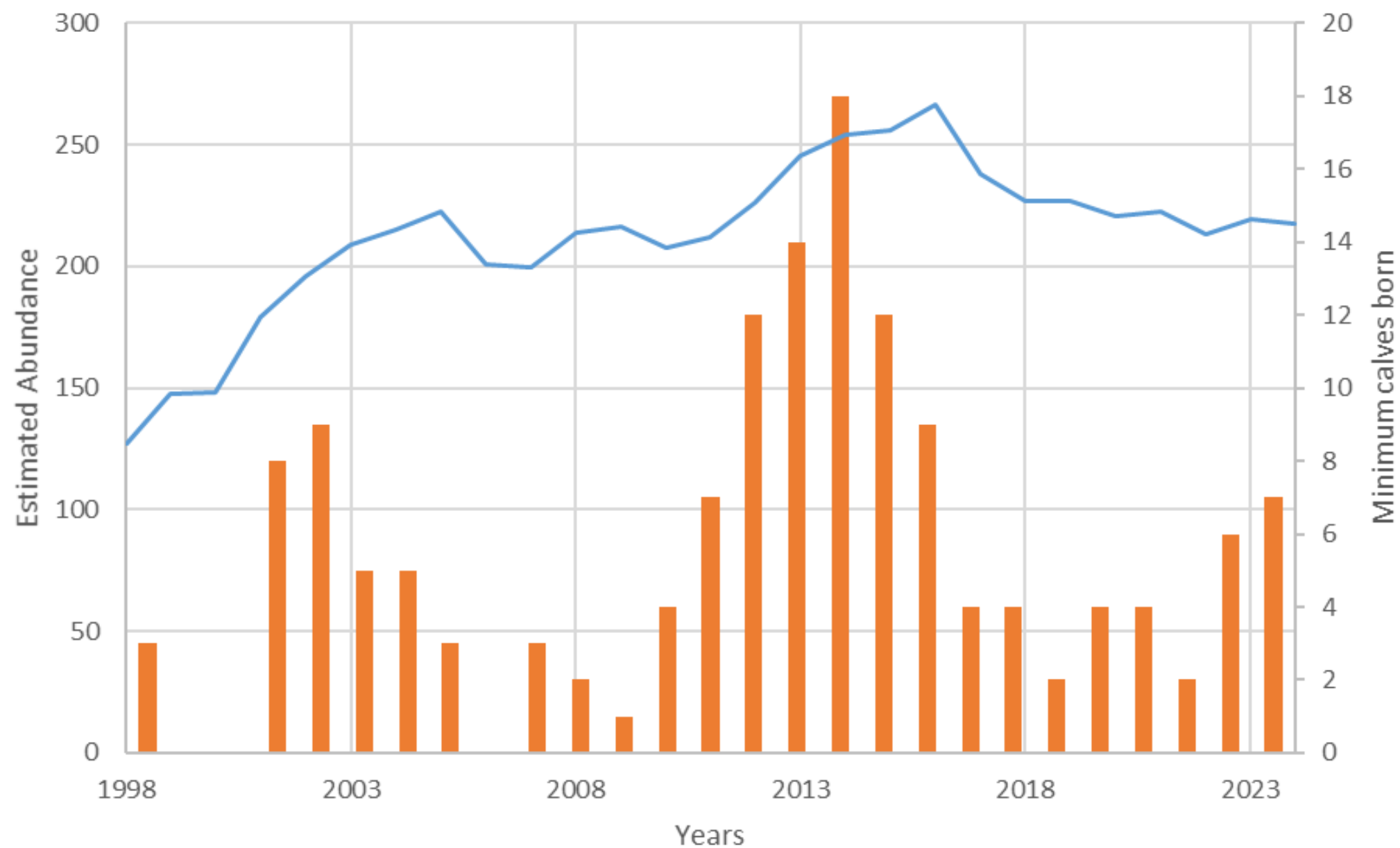
More Sounders staying longer over time



Unusual seasonality of Sounder occurrence in 2020-26

- Early arrivals first seen starting in 2020 with one whale arriving in December.
- Starting in Winter 2021-22, 3-5 long term Sounders have arrived early (Dec or Jan).
- In the most recent season, five whales showed up in late December and early January with 4 of these 5 known females.
- One whale stayed continuously for over a year (January 2022 to May 2023).
- All skipped the migration to Mexico breeding areas to stay and feed.

Estimated PCFG abundance and calves documented



CRC gray whale IDs in 2025

A tale of two areas inside and outside Grays Harbor: So close yet so different

Inside Grays Harbor (left): 15 whales IDed in 2025 of which 60% were known PCFG and 87% had been identified previously mostly inside Grays Harbor, 3 as calves of PCFG whales

Outside Grays Harbor (right): 111 different whales in 2025 from May to October, only 30% known PCFG, 63% never identified previously with no match found. Some of the known PCFG whales were animals seen primarily inside GH but also outside.



Unusual sightings and strandings of gray whales in April-May 2026 in Willapa Bay

Early April 2026, gray whale documenting swimming far up Willapa River before being found dead

May 2026, over a dozen gray whales apparently feeding in n Willapa Bay

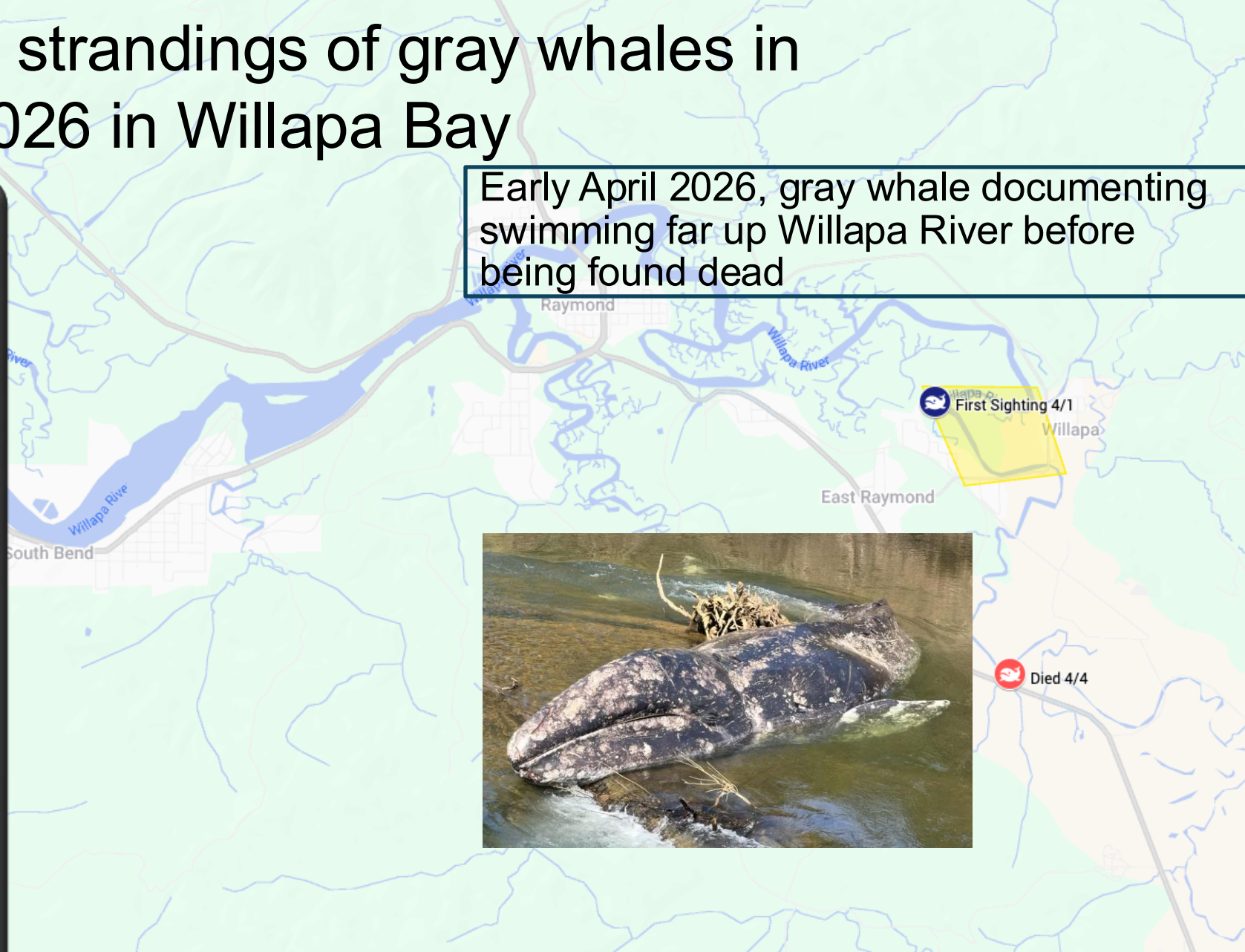


Photo: Hugh Ahnatook

Conclusions

Observations in Washington reveal a number of aspects of the crisis gray whales facing and changes to their feeding including:

- Near record number of strandings in 2026 dominated by adult males
- In 2025 and 2026 gray whales seeking alternate areas to feed sometimes unaware of productive nearby areas especially off Grays Harbor and in Willapa Bay.
- Sounder and PCFG gray whales that predominantly feed outside the Arctic do not show indications of decline and high mortality like the overall ENP population

These findings confirm that the high mortality and decline of the overall ENP population is being driven by a crisis on their primary feeding grounds in the Arctic.

Biomarkers of gray whale physiological status: Assessing stress, reproduction and metabolic state via hormones and novel biomarkers



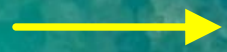
Kathleen Hunt, Ph.D.
MMI Associate Professor



Oregon State University
**Marine Mammal
Institute**

- Why bother with hormones/biomarkers?
- What sample types can we collect?
- Which hormones can we measure?
- What have we learned?
- What next?





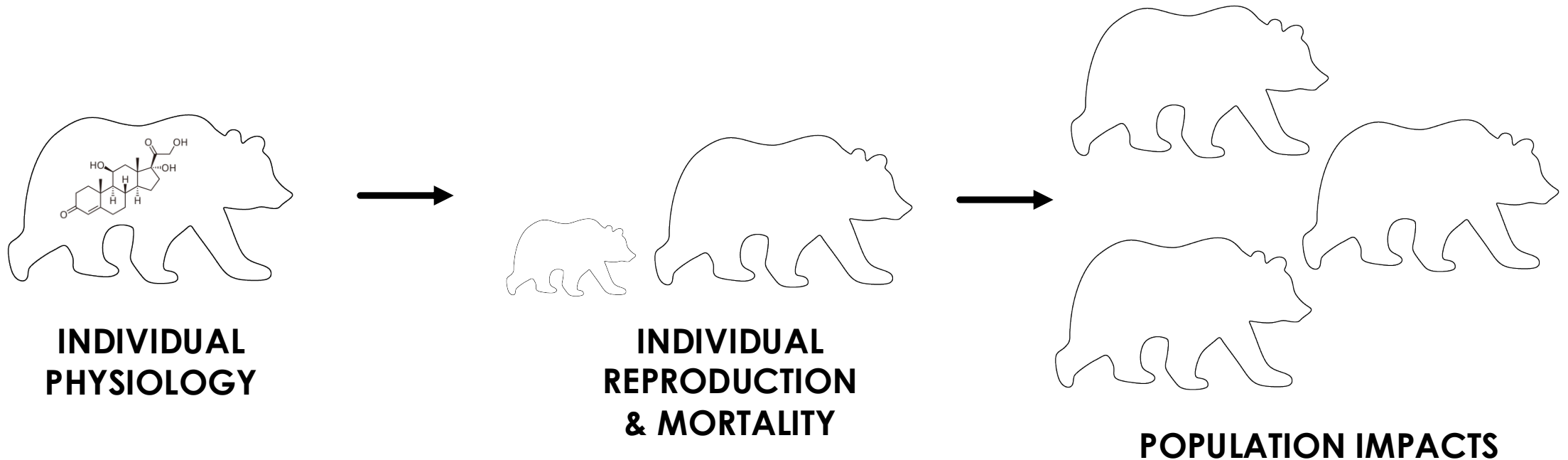
- Why bother with hormones/biomarkers?
- What sample types can we collect?
- Which hormones can we measure?
- What have we learned?
- What next?



Why bother?

Physiology as a **real-time, early-warning indicator**

PHYSIOLOGY = How the body works



**Hormone = a MESSENGER MOLECULE released into the blood;
typically triggers a PHYSIOLOGICAL CHANGE**

Measuring hormones is “eavesdropping on the body’s communication system”

Baleen whales: The most difficult study animals?

The view we want:



The view we get:



No possibility of “clean” blood samples

FORTUNATELY...

There are sample types other than blood

Feces



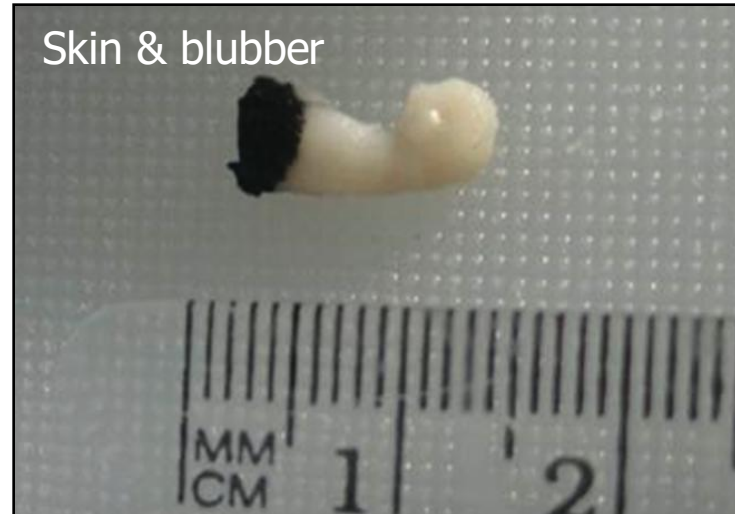
Respiratory vapor ("blow")



Baleen



Skin & blubber

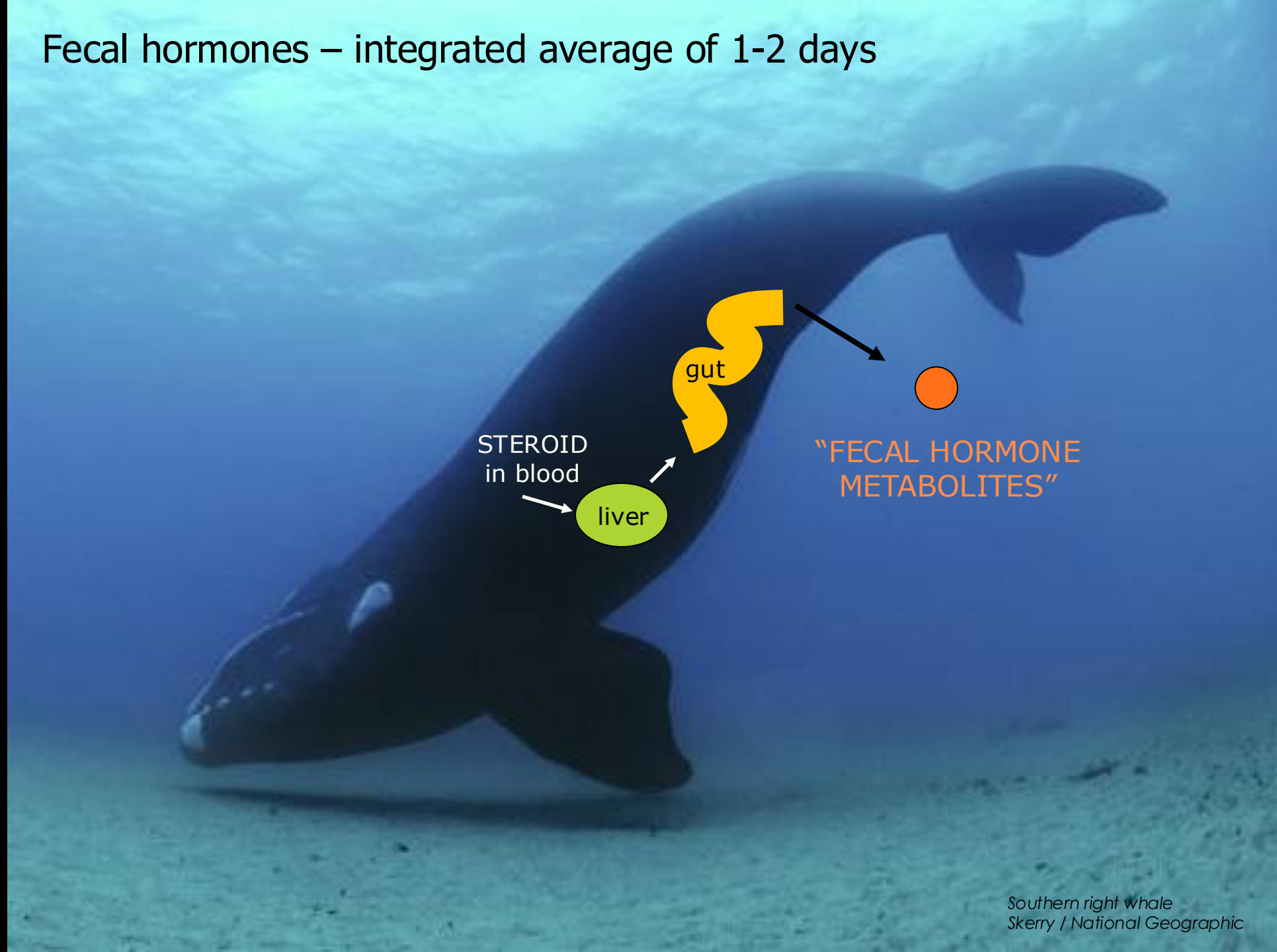


(watch this space)

These all reflect different timeframes
Respiratory vapor – minute of collection (?)



Fecal hormones – integrated average of 1-2 days



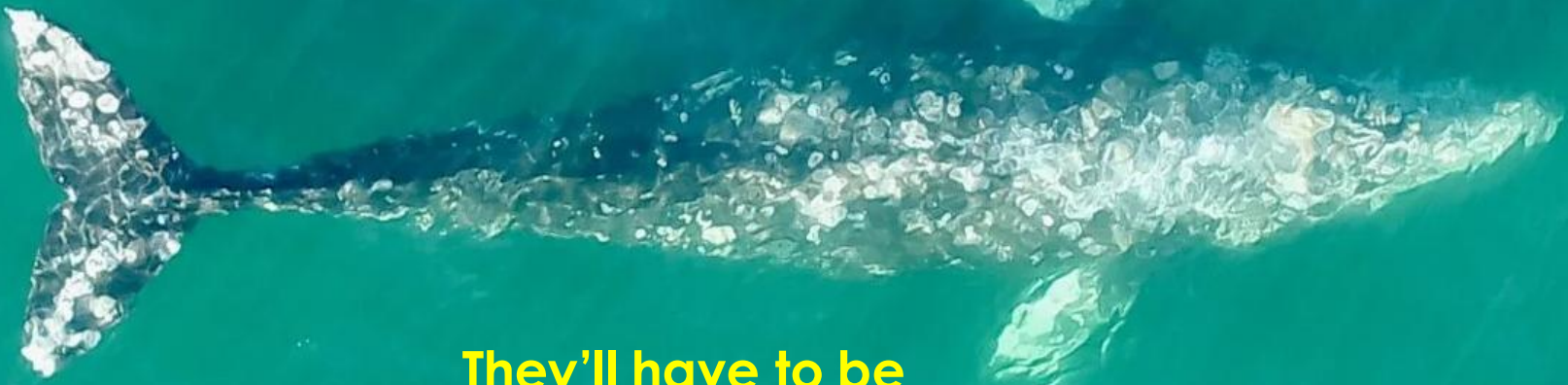
Baleen – records a time series across years

But: Grays are a “short baleen” species

Gray whale calf - Baja



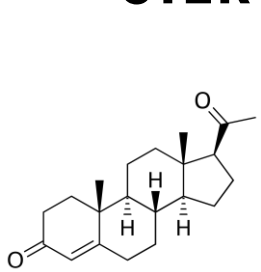
But we still get **~1.5 years of info** – enough to examine “what went wrong”, and WHEN it started going wrong

- 
- Why bother with hormones/biomarkers?
 - What sample types can we collect?
 - • Which hormones/biomarkers can we measure?
 - What have we learned?
 - What next?

They'll have to be
SMALL
and
LIPOPHILIC

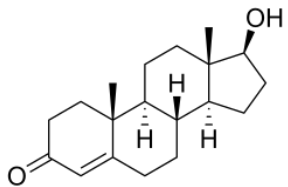
Steroid hormones: a gift from God?

REPRODUCTIVE STEROID HORMONES



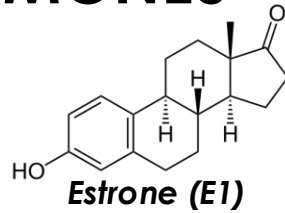
PROGESTERONE

High in pregnancy

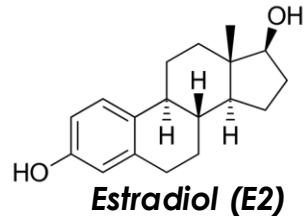


TESTOSTERONE

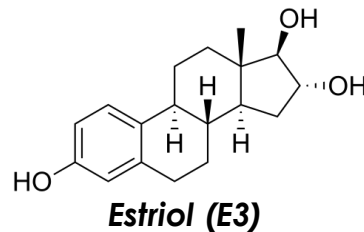
High in breeding males



Estrone (E1)



Estradiol (E2)

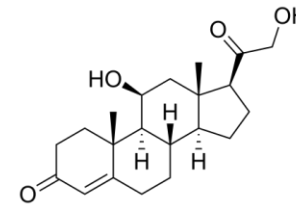


Estriol (E3)

THE ESTROGENS (3)

Ovulation, pregnancy,
lactation

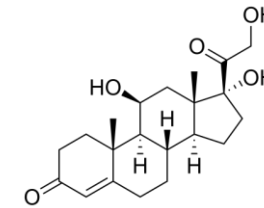
ADRENAL STEROID HORMONES



Corticosterone

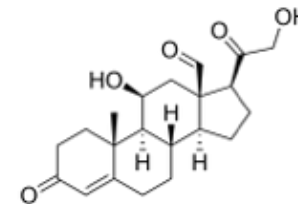
GLUCOCORTICOIDS

Higher during stress



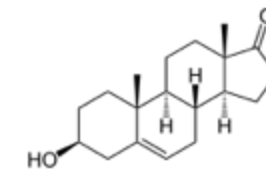
Cortisol

"**Cortisol/DHEA Ratio**" can
elevate
dramatically
during chronic
stress



ALDOSTERONE

Higher during stress
(especially osmotic stress)

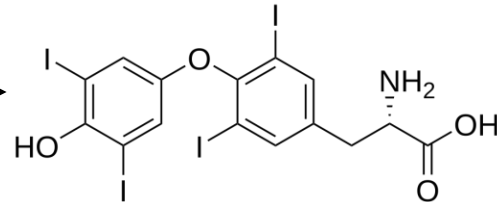
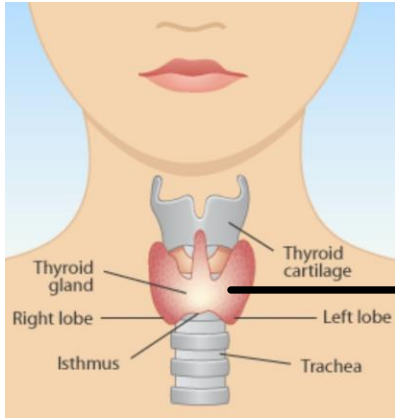


DHEA

Lower in chronic stress

Thyroid hormones

(possibly also a gift from God; jury still out)

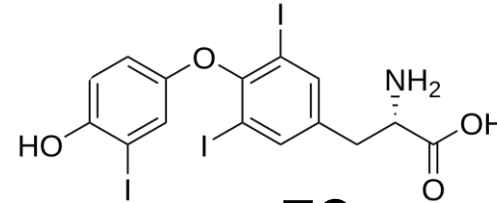


T4

(Thyroxine)

Inactive "pro-hormone"

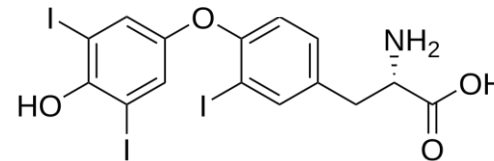
*target tissues
chop off certain
iodines*



T3

(Tri-iodothyronine)

Active hormone!



rT3

(reverse-T3)

*Inactive, AND BLOCKS T3
FROM RECEPTOR*

Concentrations
shift with energetic
& nutritional status
(& activity?
thermoreg needs?)

**Starvation in
mammals:**

**T3 low
and/or
rT3 high;
ratio shifts**

**Thyroid hormones
drive metabolic rate in mammals**

- Why bother with hormones/biomarkers?
- What sample types can we collect?
- Which hormones can we measure?
- • What have we learned?
- What next?



Gray whale hormone data (a sampling)

Fecal hormones:
10 year archive from free-swimming PCFG grays



Torres / GEMM Lab, permit #16111

Assessment of metabolite	Stressed : A simulta condition	Effects of v noise on gra hormones	Assessing concentra anthropog	Assessment of a through drone-ba A Fernandez Ajó, E Pir Royal Society Open Sc	Body size, nutritional probability in a long-	Variation in faecal testosterone levels in male gray whales on a foraging ground relative to maturity and timing
--------------------------	--------------------------------	------------------------------------	-------------------------------	---	---	--

Ten years of fecal glucocorticoid data: (free-swimming PCFGs)

Noise & vessels

One day lag

Higher fecal cort

"Decision to breed"?

Two year lag

Calving probability



Caveats:

- Broad CI's often include 0
- Some effects in only 1 sex

Also important:

Sex, reproductive status, age, day of year, body condition (BAI), other hormones

Pirotta E, Fernandez Ajó A, Bierlich KC, Bird CN, Buck CL, Haver SM, Haxel JH, Hildebrand L, Hunt KE, Lemos LS, New L. Assessing variation in faecal glucocorticoid concentrations in gray whales exposed to anthropogenic stressors. *Conservation Physiology*. 2023;11(1):coad082.

Also (VERY) important:

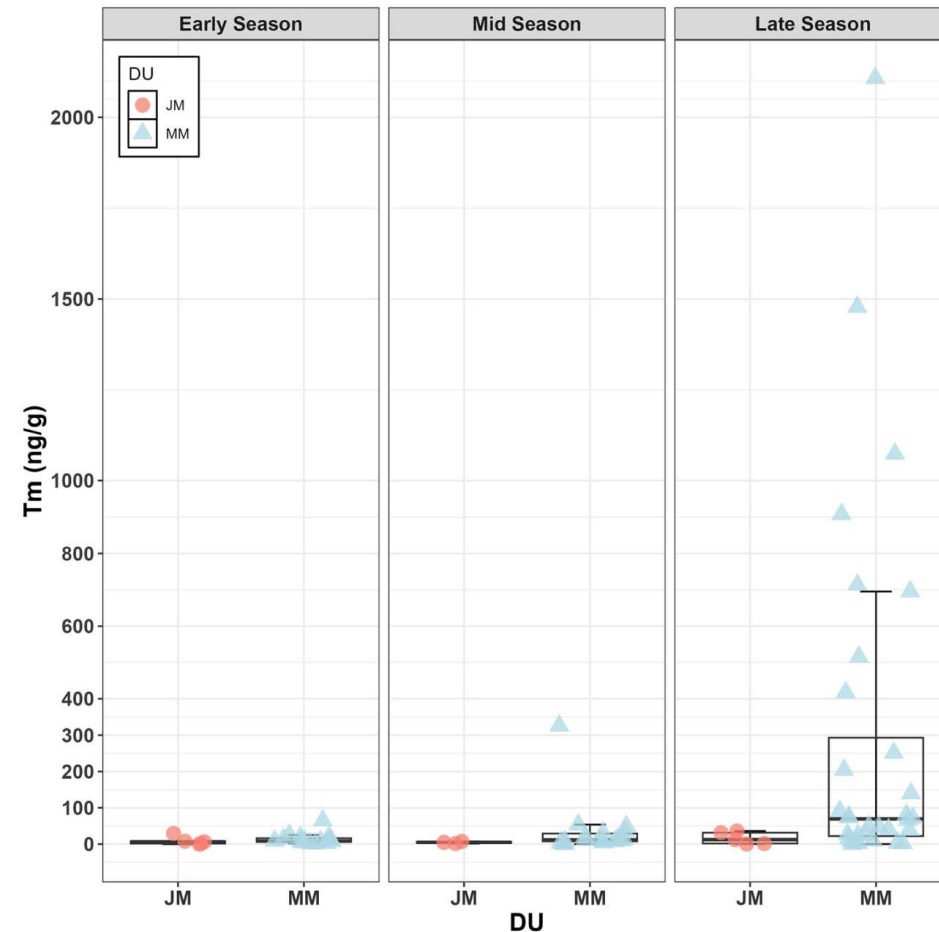
- Female's size
- Female's body condition

Pirotta E, New L, Fernandez Ajó A, Bierlich KC, Bird CN, Buck CL, Hildebrand L, Hunt KE, Calambokidis J, Torres LG. Body size, nutritional state and endocrine state are associated with calving probability in a long-lived marine species. *Journal of Animal Ecology*. 2025 Jul;94(7):1422-34.

A peek at male “decision to breed”: Fecal testosterone in males

Fecal T metabolites increase seasonally – but in **mature** males only, in **late season (fall)** only

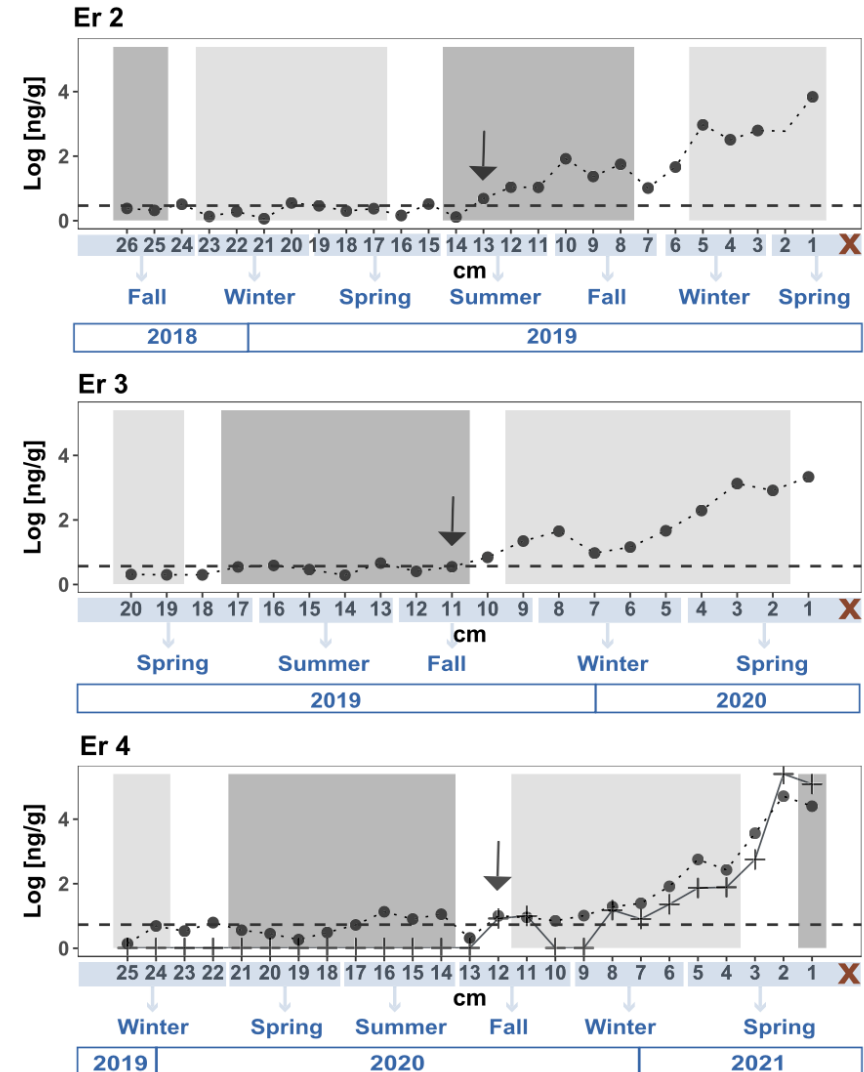
Fernandez Ajó A, Buck CL, Hunt KE, Pirotta E, New L, Dillon D, Bierlich KC, Hildebrand L, Bird CN, Torres LG. Variation in faecal testosterone levels in male gray whales on a foraging ground relative to maturity and timing. Conservation Physiology. 2025;13(1):coae094.



Baleen cort patterns in stranded grays (last ~1.5 years of life)

Cortisol begins
increasing **~9 mos prior**
to death, in late
summer or fall

Ajó AF, Teixeira C, de Mello DM, Dillon D, Rice JM, Buck CL, Hunt KE, Rogers MC, Torres LG. A longitudinal study of endocrinology and foraging ecology of subadult gray whales prior to death based on baleen analysis. General and Comparative Endocrinology. 2024 Jun 1;352:114492.



- Why bother with hormones/biomarkers?
- What sample types can we collect?
- Which hormones can we measure?
- What have we learned?
- • What next?



New sample types?

Feces



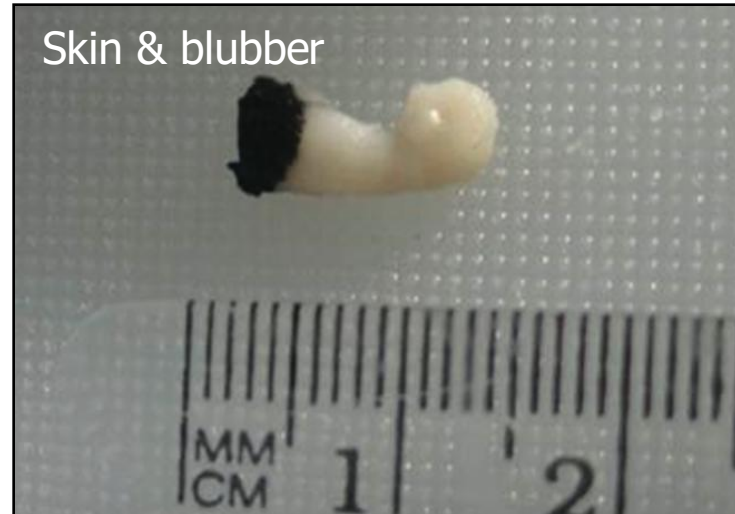
Respiratory vapor ("blow")



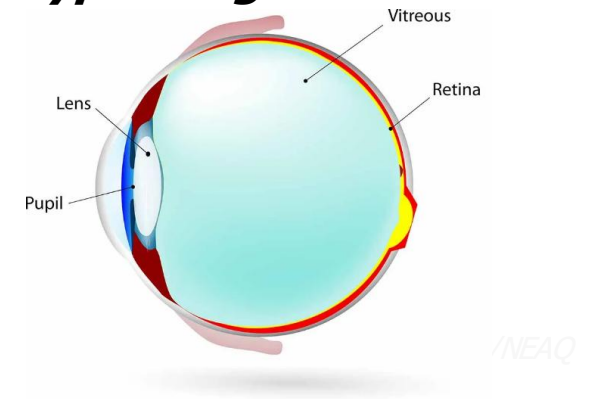
Baleen



Skin & blubber



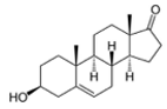
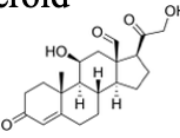
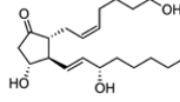
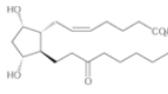
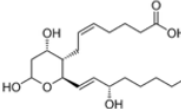
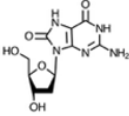
What other sample types might be useful?



New biomarkers?

Many more biomarkers are detectable in gray whale fecal samples:

(Autumn Gray master's thesis – ms in prep)

Abbreviation	Full name	Relevance	Structure	Detectable in gray whale feces?
DHEA	Dehydroepiandrosterone	Declines in chronic stress; cortisol:DHEA ratio rises in chronic stress	Steroid 	YES , good parallelism
ALD	Aldosterone	Elevates in chronic stress and in osmotic stress; marker of general adrenal activity	Steroid 	YES , good parallelism
PGE2	Prostaglandin E2	Marker of inflammation (especially intestinal)	Eicosanoid 	YES , good parallelism
PGFM	Prostaglandin F2α Metabolite	Metabolite of prostaglandin F2α; marker of parturition; declines w stress	Eicosanoid 	YES , good parallelism
TXB2	Thromboxane B2	Metabolite of thromboxane A2; marker of inflammation (esp. cardiovascular)	Eicosanoid 	YES , good parallelism
8-OHdG	Oxidized guanosine	Damaged form of guanine; marker of DNA damage due to oxidative stress; correlates w toxins	Nucleotide 	YES , good parallelism

Thank you!



Oregon State University
Marine Mammal
Institute



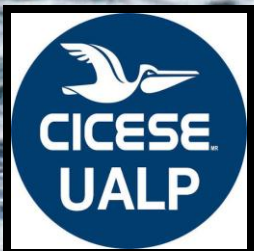
THE EPPLEY FOUNDATION
FOR RESEARCH

Range-Wide Gray Whale Science Symposium



Oregon State University
Marine Mammal
Institute

**Gray whale ecological responses to environmental change during
a prolonged mortality event revealed by baleen stable isotopes:
What can stable isotopes tell us, and what are their limitations?**



Presented by: Dr. Geraldine R. Busquets-Vass

Photo Courtesy of:
GWRP/PRIMMA



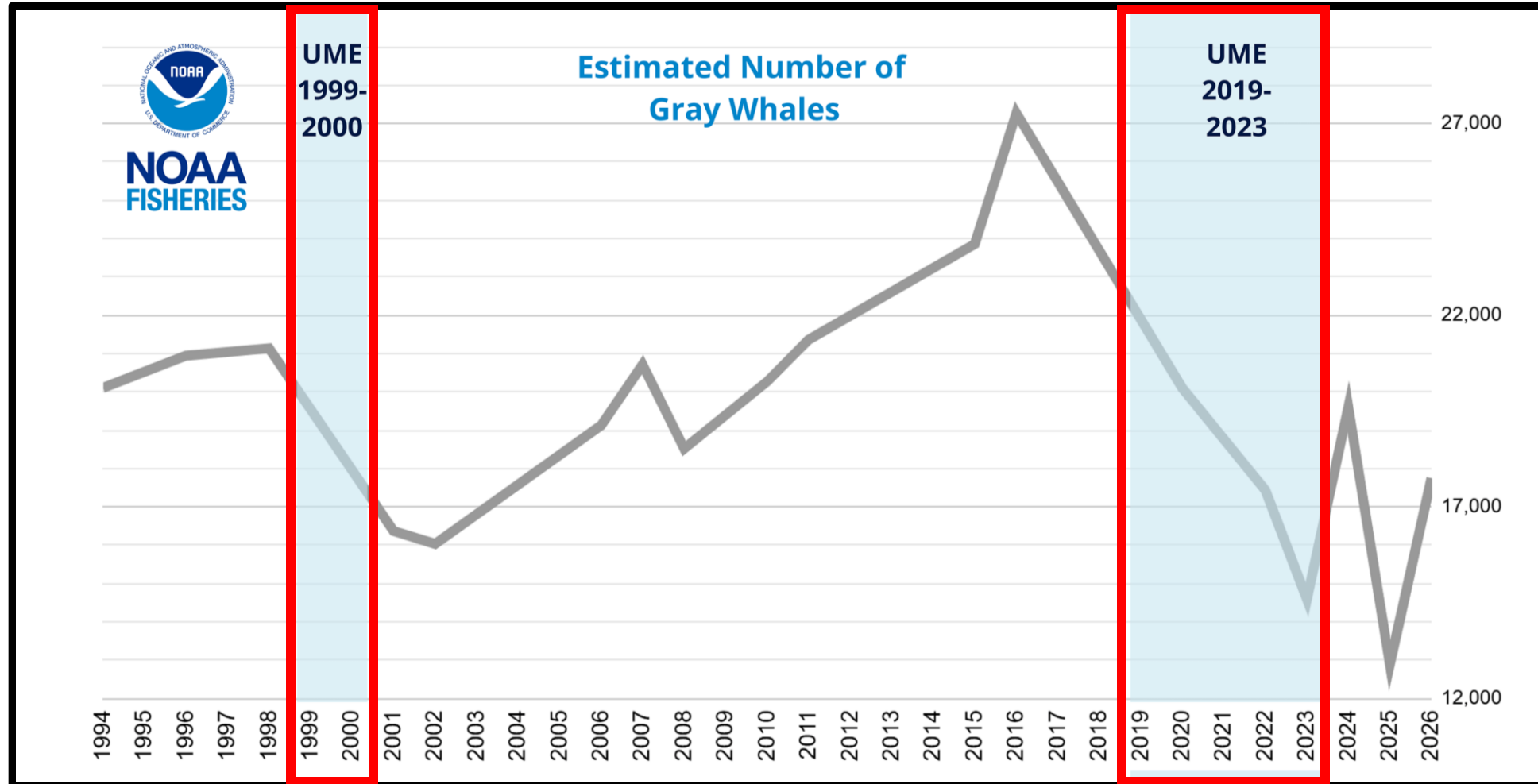
- **Range-Wide Gray Whale Science Symposium**

- **Gray whale Unusual Mortality Event (UME): 2019-2023**
 - **Mortalities continued in 2026**



Photos by: Sergio Martínez-Aguilar

- The species is highly sensitive to changes in resource availability driven by environmental change



Gray whale Unusual Mortality Event (UME)

- We already know that many stranded whales show signs of poor nutritional condition.
- But this raises a more mechanistic question:

What ecological and physiological processes unfold before these animals die?



Stable isotope ratios of nitrogen ($\delta^{15}\text{N}$) and carbon ($\delta^{13}\text{C}$)
in animal tissues can provide insights into
ecological and physiological processes

- Mass spectrometry

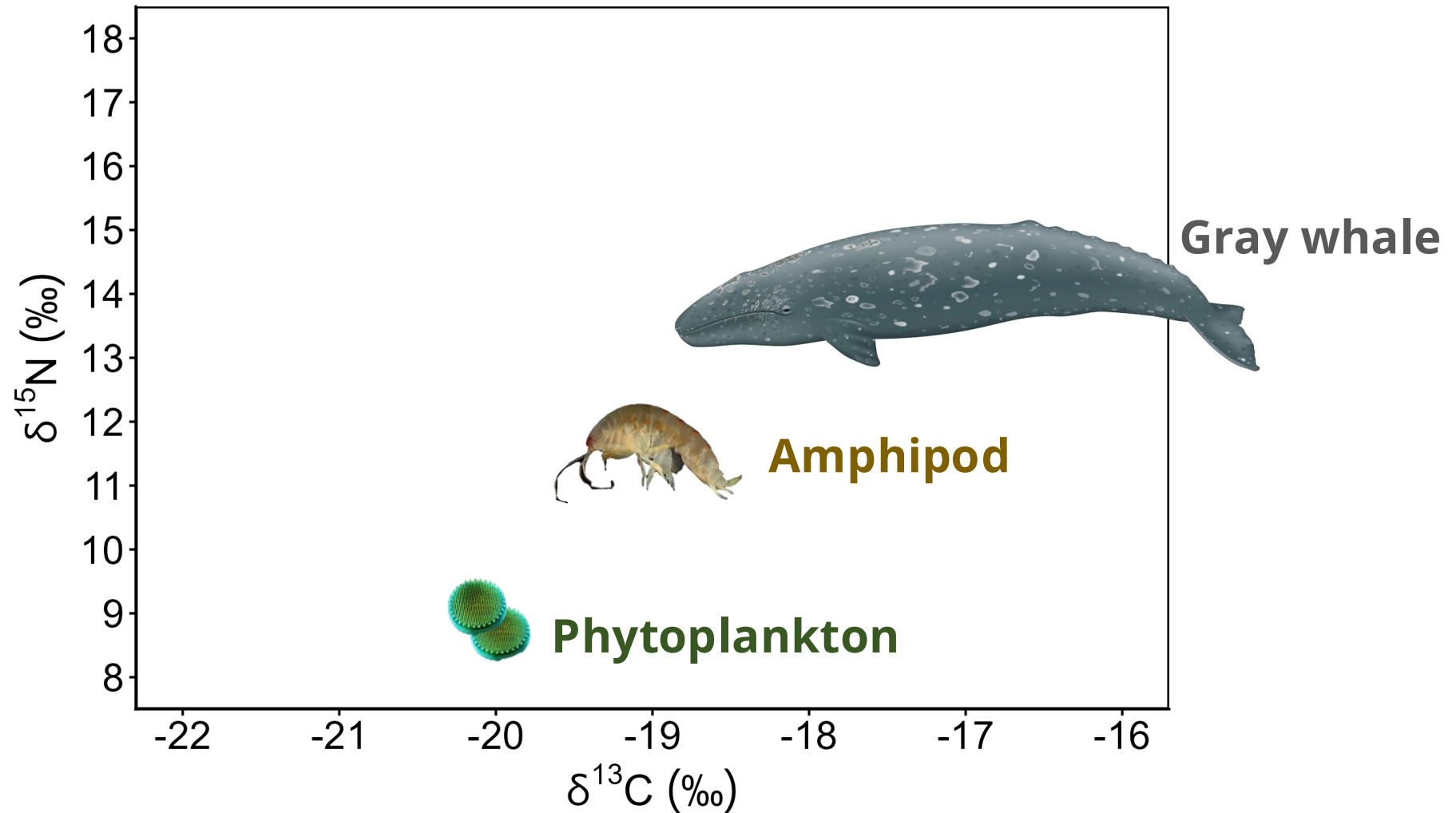
δ (delta): Isotopes ratios (**R**) of the heavy (^{15}N ; ^{13}C) to the light (^{14}N ; ^{12}C) isotopes in any **sample** compared to an internationally accepted **standard**



$$\delta X \left(\text{‰} \right) = \left(\frac{R_{\text{sample}}}{R_{\text{standard}}} - 1 \right) \times 1000$$

per mil

**Stable isotope ratios of nitrogen ($\delta^{15}\text{N}$) and carbon ($\delta^{13}\text{C}$)
in animal tissues can provide insights into
ecological and physiological processes**

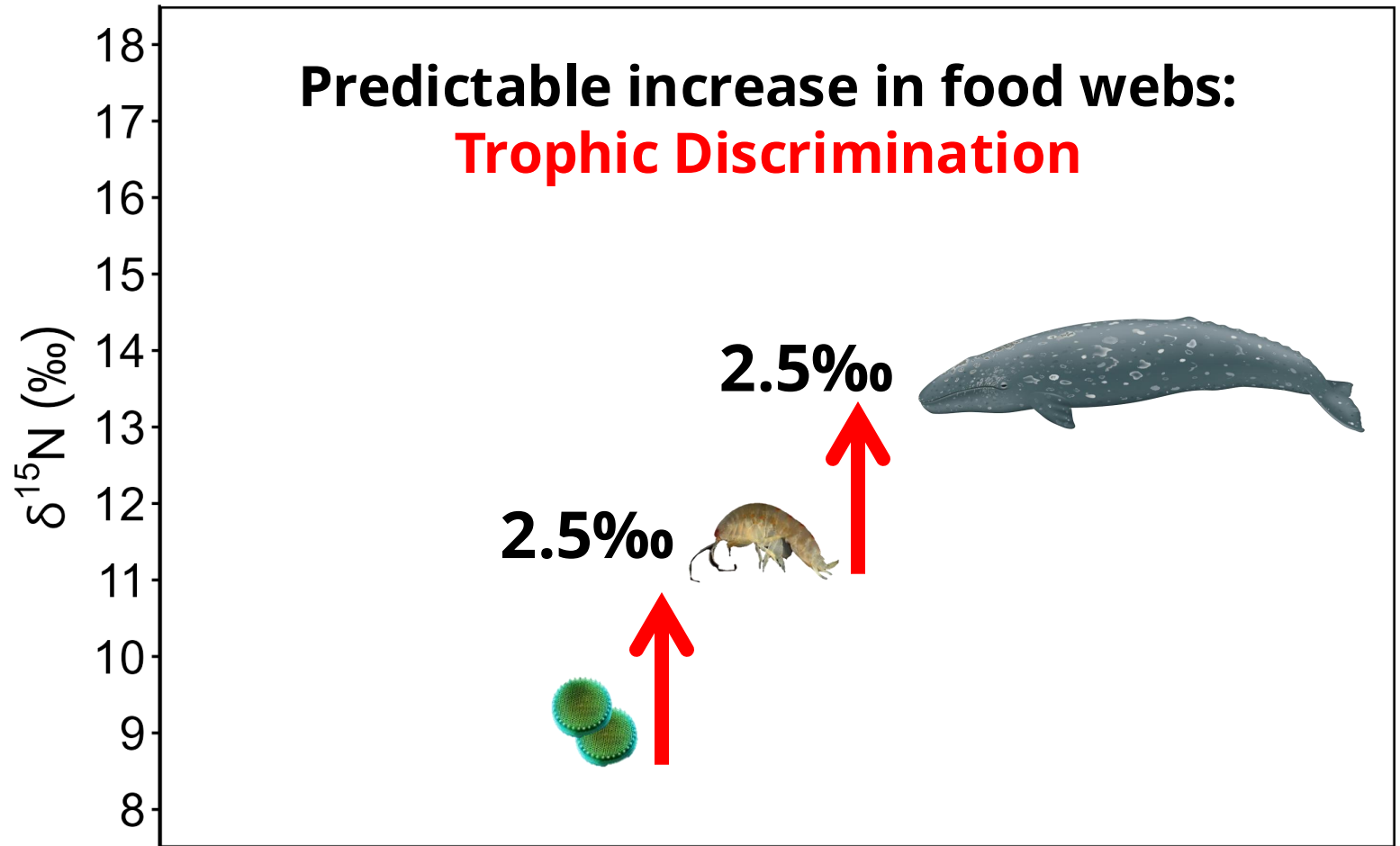


Stable isotope ratios of nitrogen ($\delta^{15}\text{N}$): Trophic level

$\delta^{15}\text{N}$ values:
Provide information on:



Trophic level

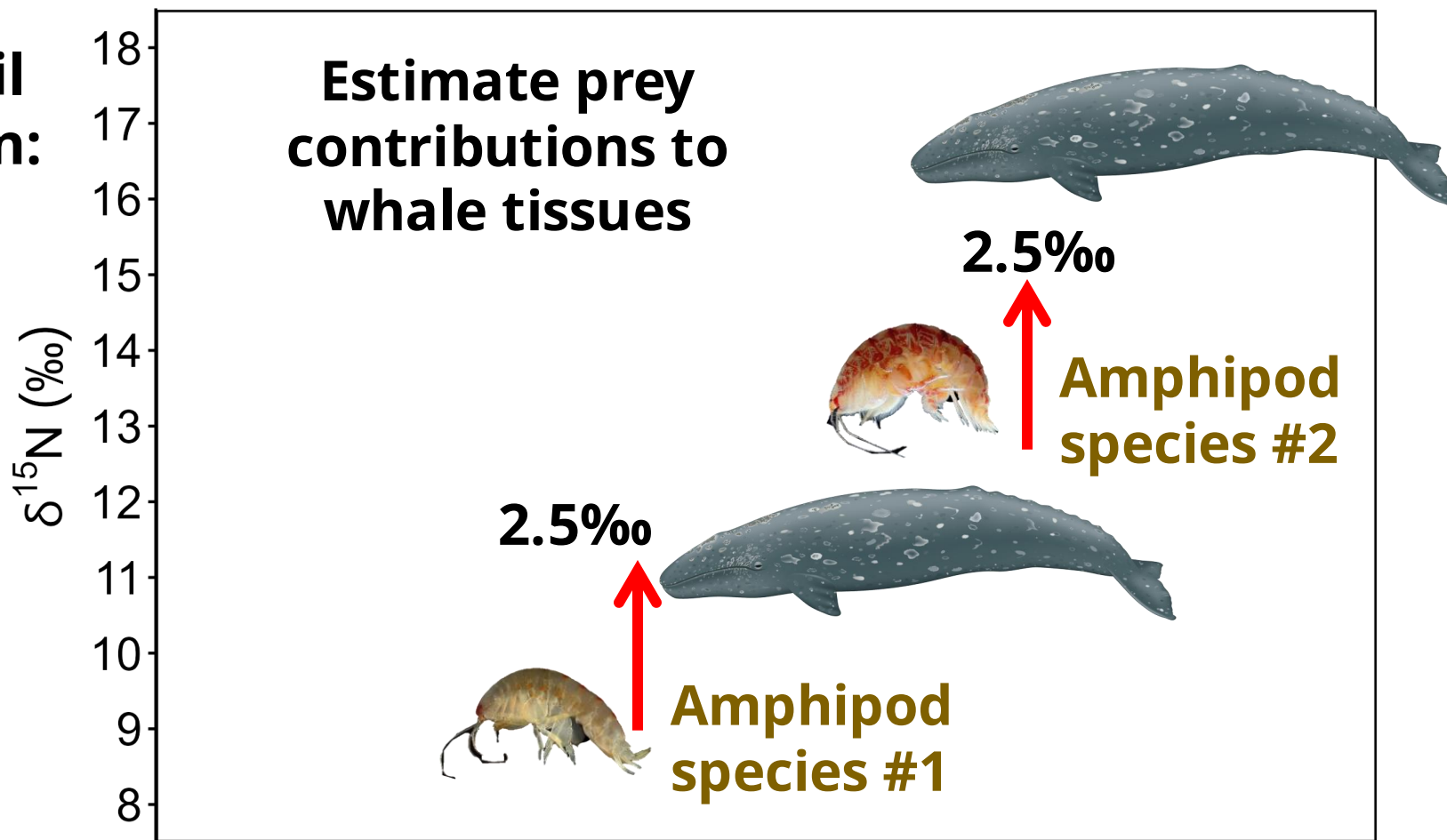


Stable isotope ratios of nitrogen ($\delta^{15}\text{N}$): Diet

$\delta^{15}\text{N}$ values: ‰ per mil
Provide information on:



Trophic level
Diet



Stable isotope ratios of nitrogen ($\delta^{15}\text{N}$): Nutritional stress

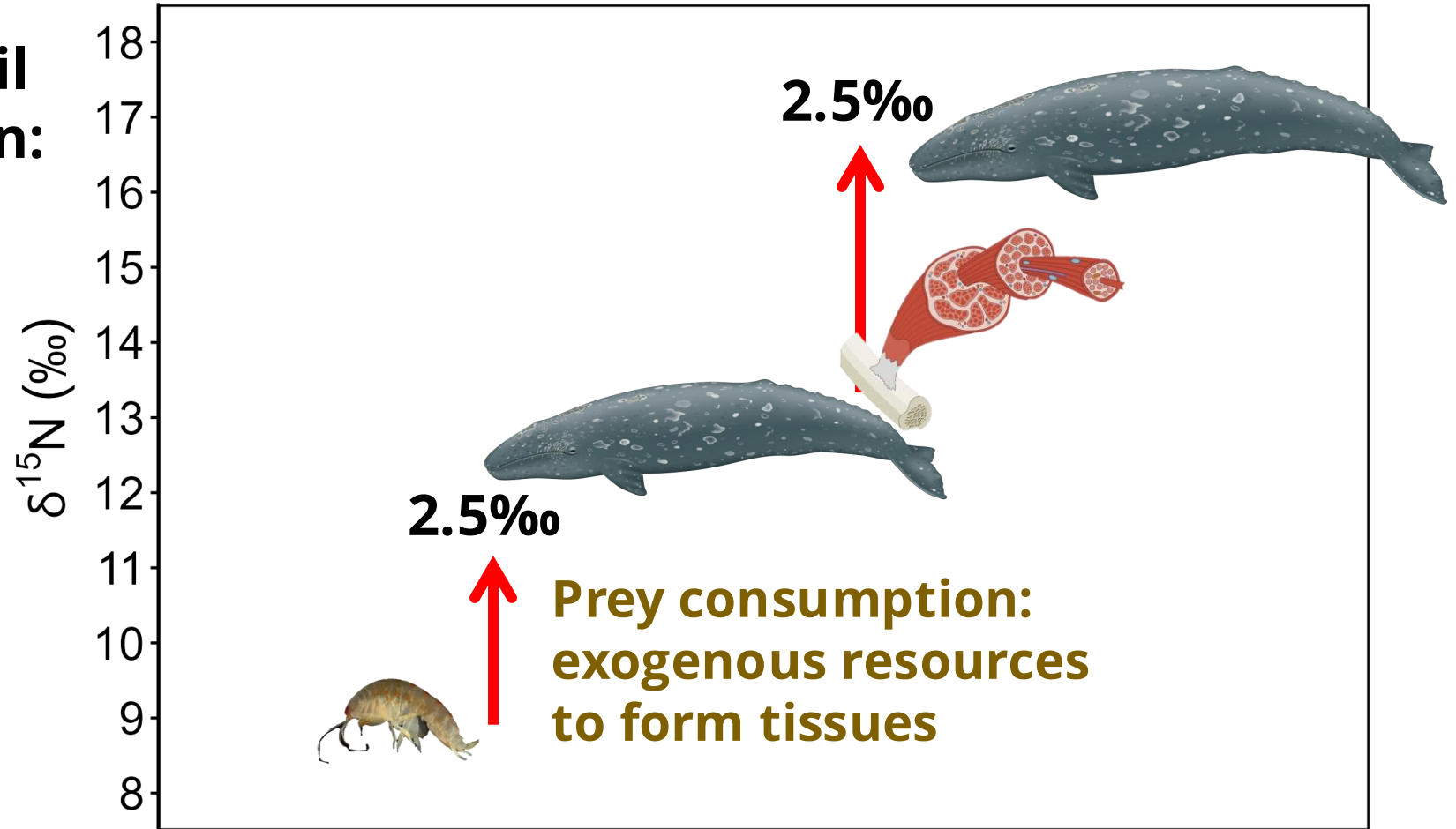
$\delta^{15}\text{N}$ values: ‰ per mil
Provide information on:



Trophic level

Diet

Nutritional stress



Stable isotope ratios of nitrogen ($\delta^{15}\text{N}$): Nutritional stress

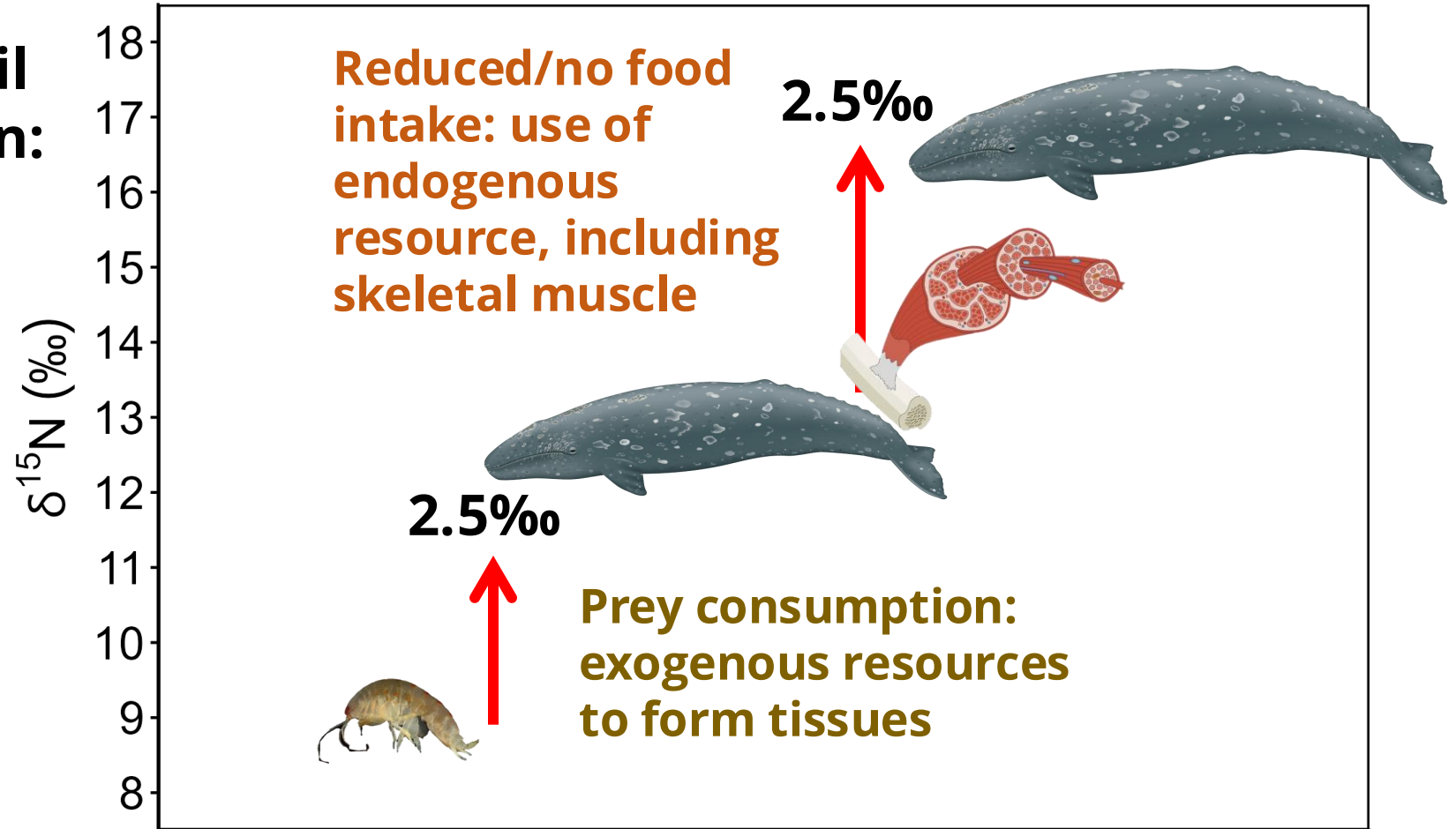
$\delta^{15}\text{N}$ values: ‰ per mil
Provide information on:



Trophic level

Diet

Nutritional stress



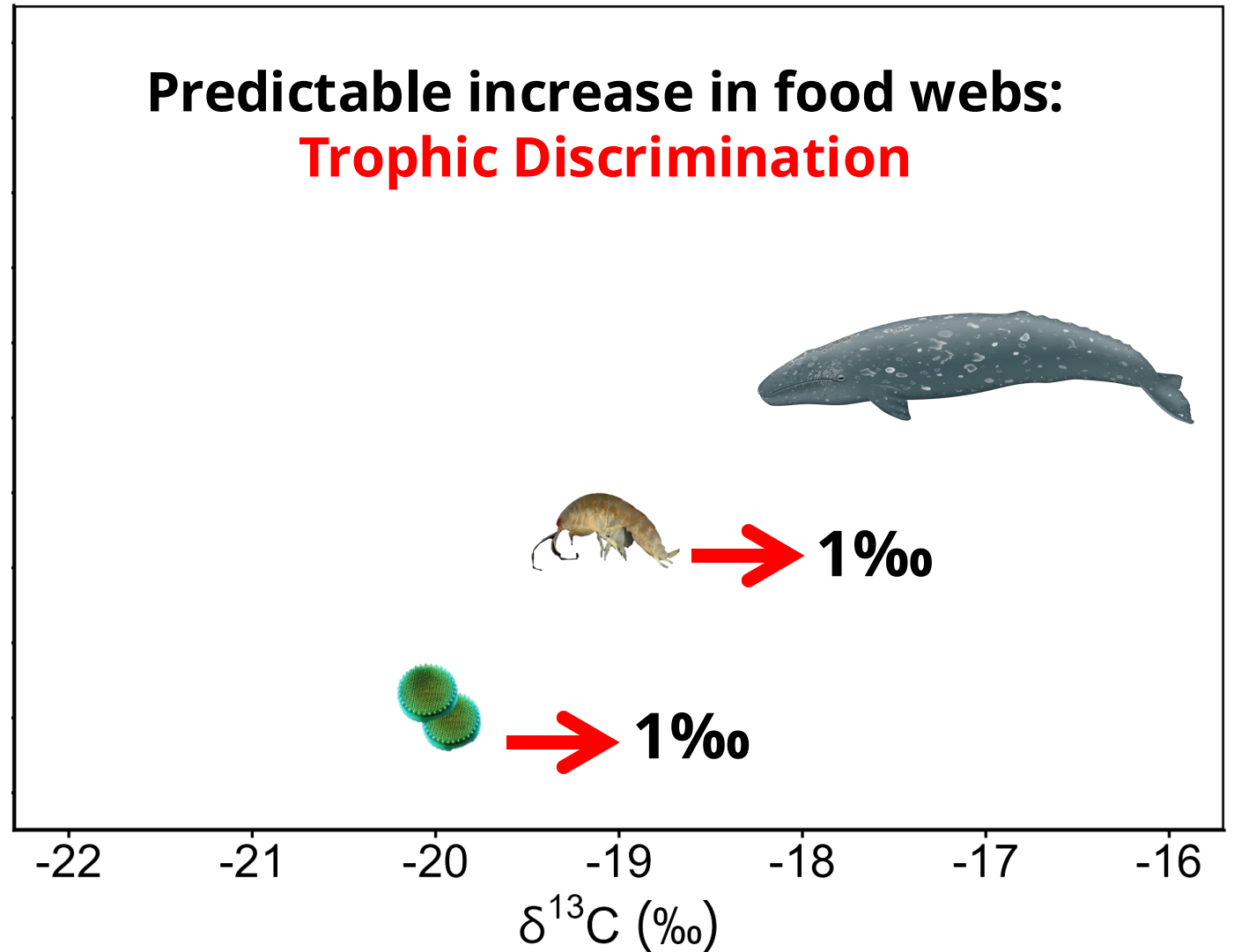
Stable isotope ratios of carbon ($\delta^{13}\text{C}$): Diet

$\delta^{13}\text{C}$ values:
Provide information on:



Diet

Predictable increase in food webs:
Trophic Discrimination



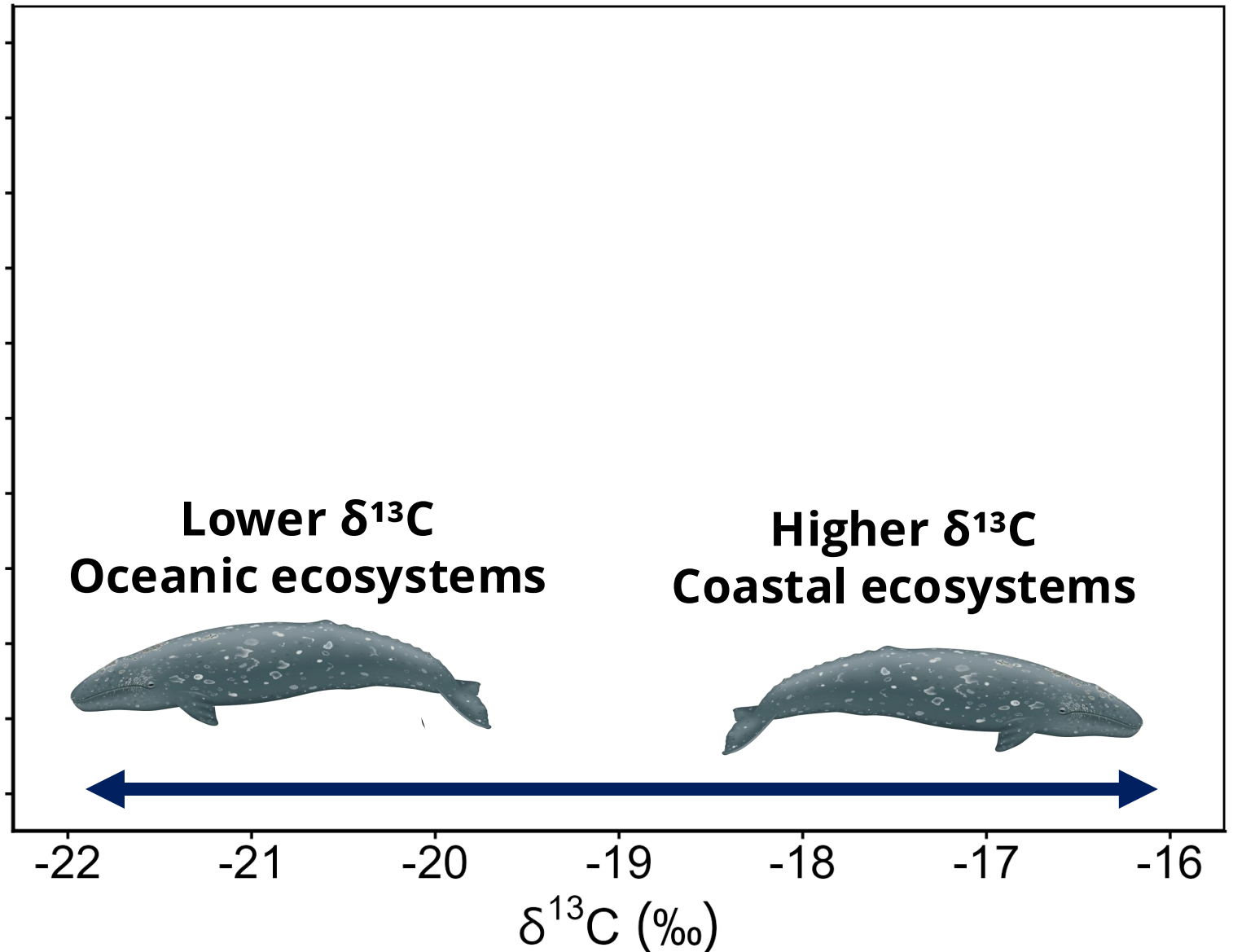
Stable isotope ratios of carbon ($\delta^{13}\text{C}$): Oceanic versus Coastal movement

$\delta^{13}\text{C}$ values:
Provide information on:



Diet

**Oceanic/Coastal
movement**



Stable isotope ratios of nitrogen ($\delta^{15}\text{N}$) and carbon ($\delta^{13}\text{C}$): Migration/Movement

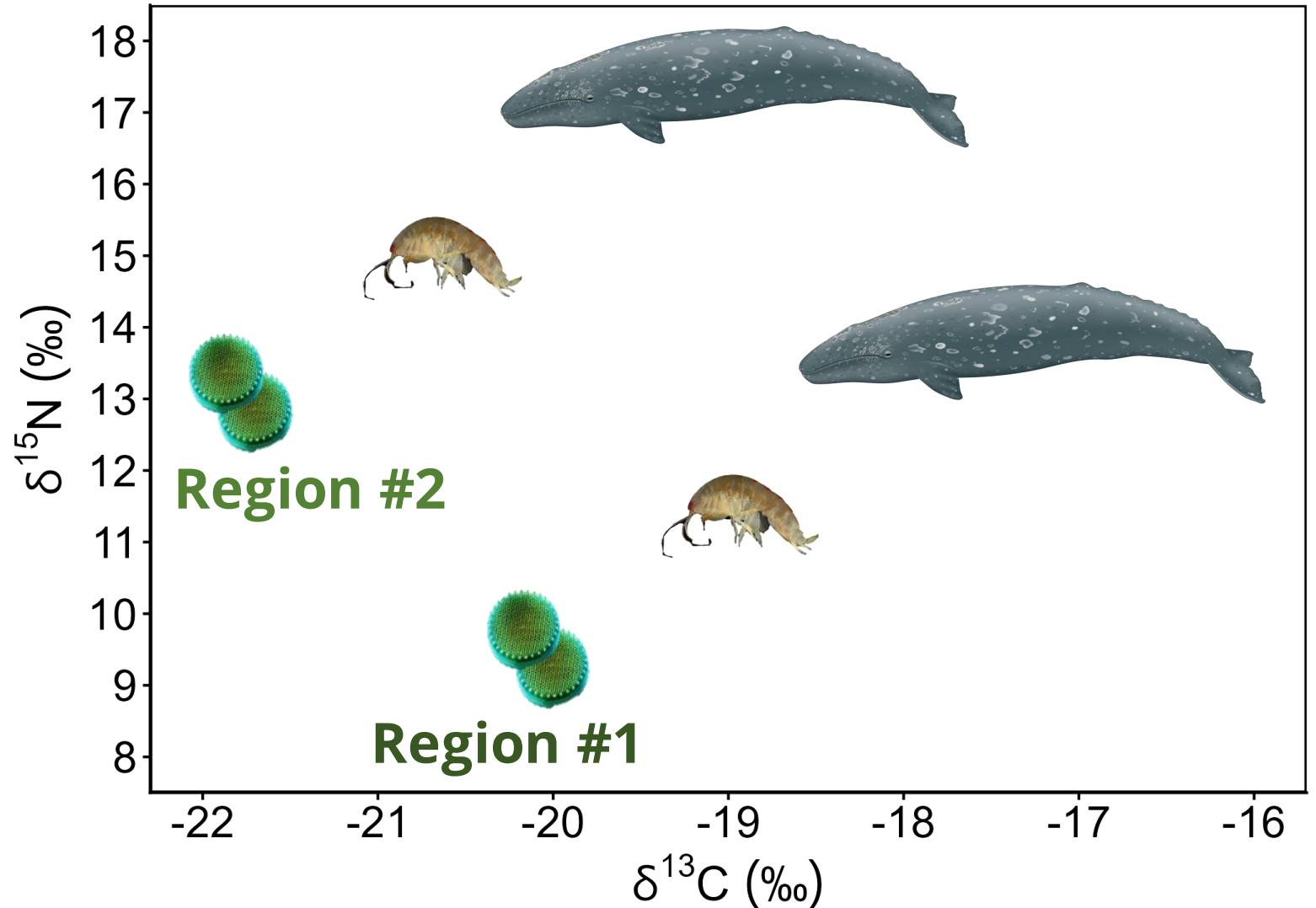
$\delta^{15}\text{N}$ values
 $\delta^{13}\text{C}$ values



Baseline values
propagate in different
regions of the ocean

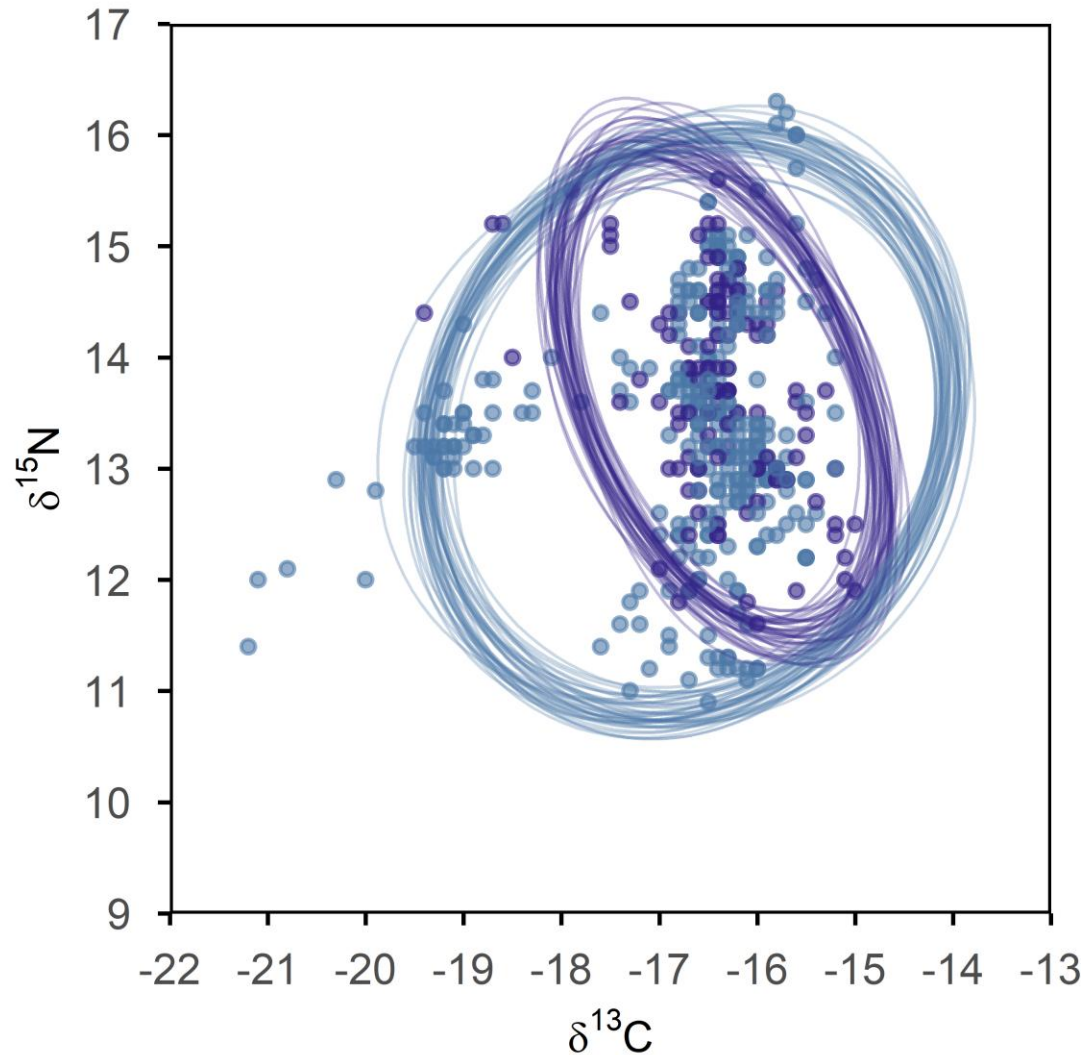


Migration/Movement



Isotopic niche: Estimated from the covariation of stable isotope ratios of nitrogen ($\delta^{15}\text{N}$) and carbon ($\delta^{13}\text{C}$)

Isotopic Niche (‰^2): Represented by ellipses in $\delta^{13}\text{C}$ – $\delta^{15}\text{N}$ space

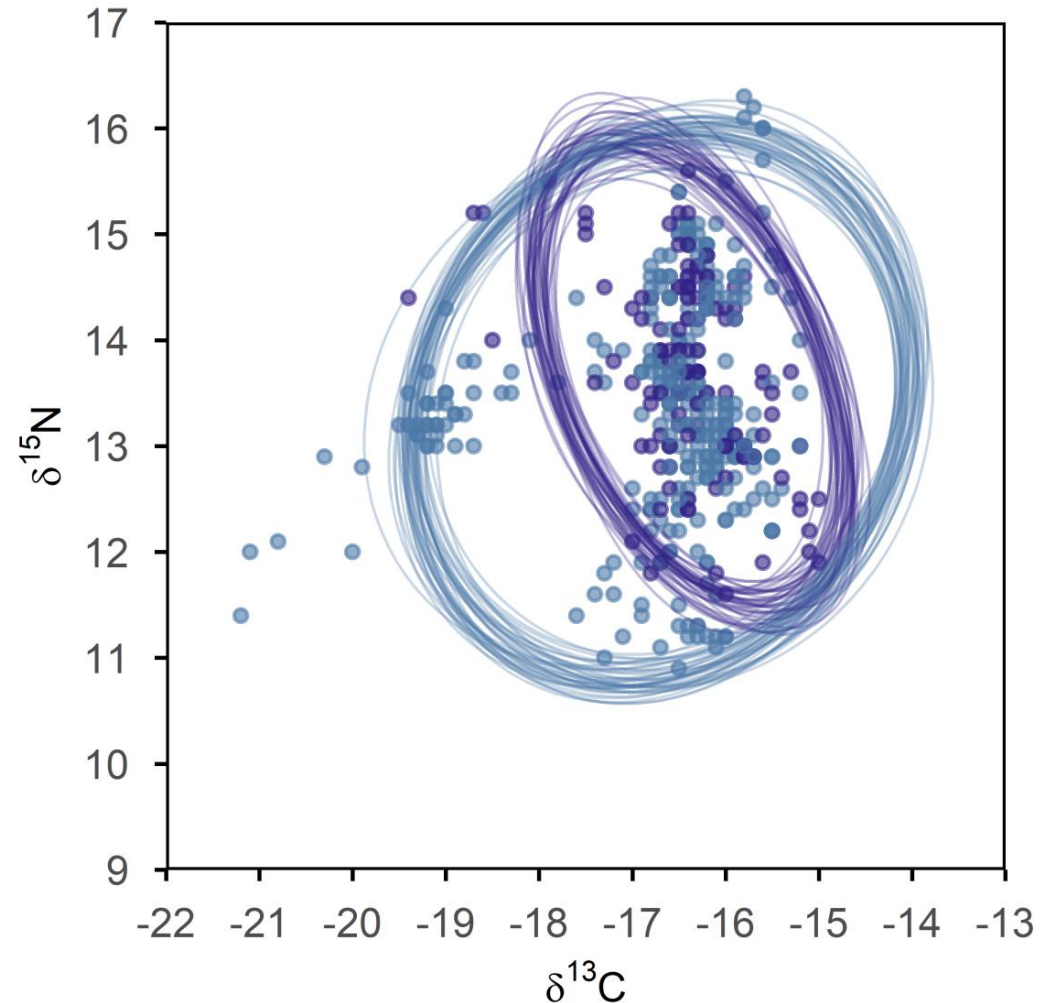


- **Estimated using a Bayesian framework** (e.g., nicheROVER package for R)
- **Ellipses on the figure represent 20 posterior estimations of the isotopic niche of two groups**

Isotopic niche: Estimated from the covariation of stable isotope ratios of nitrogen ($\delta^{15}\text{N}$) and carbon ($\delta^{13}\text{C}$)

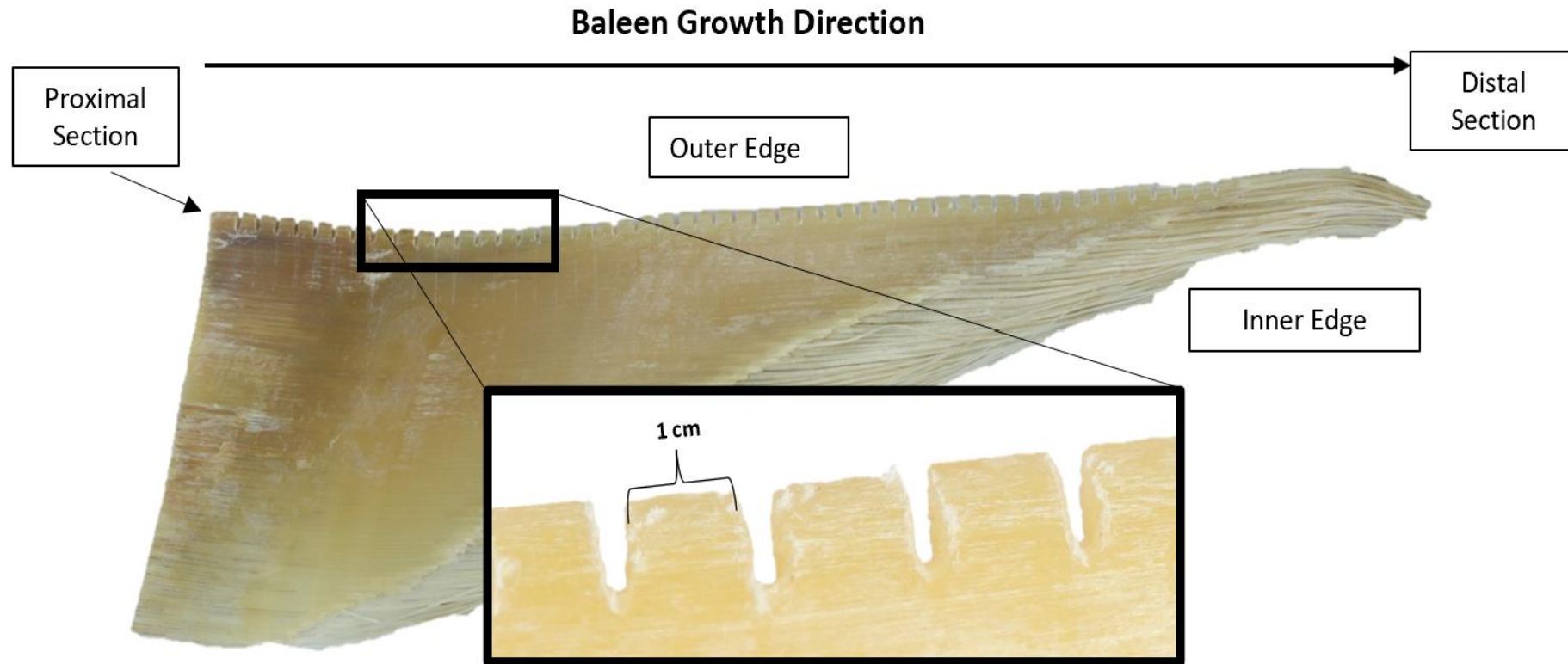
Isotopic Niche (‰^2): Represented by ellipses in $\delta^{13}\text{C}$ – $\delta^{15}\text{N}$ space

- **Niche size/position** → breadth of resource use, and/or foraging habitats
- **Niche overlap** → similarity in resource use
- **Environmental change** → shifts in niche size or position



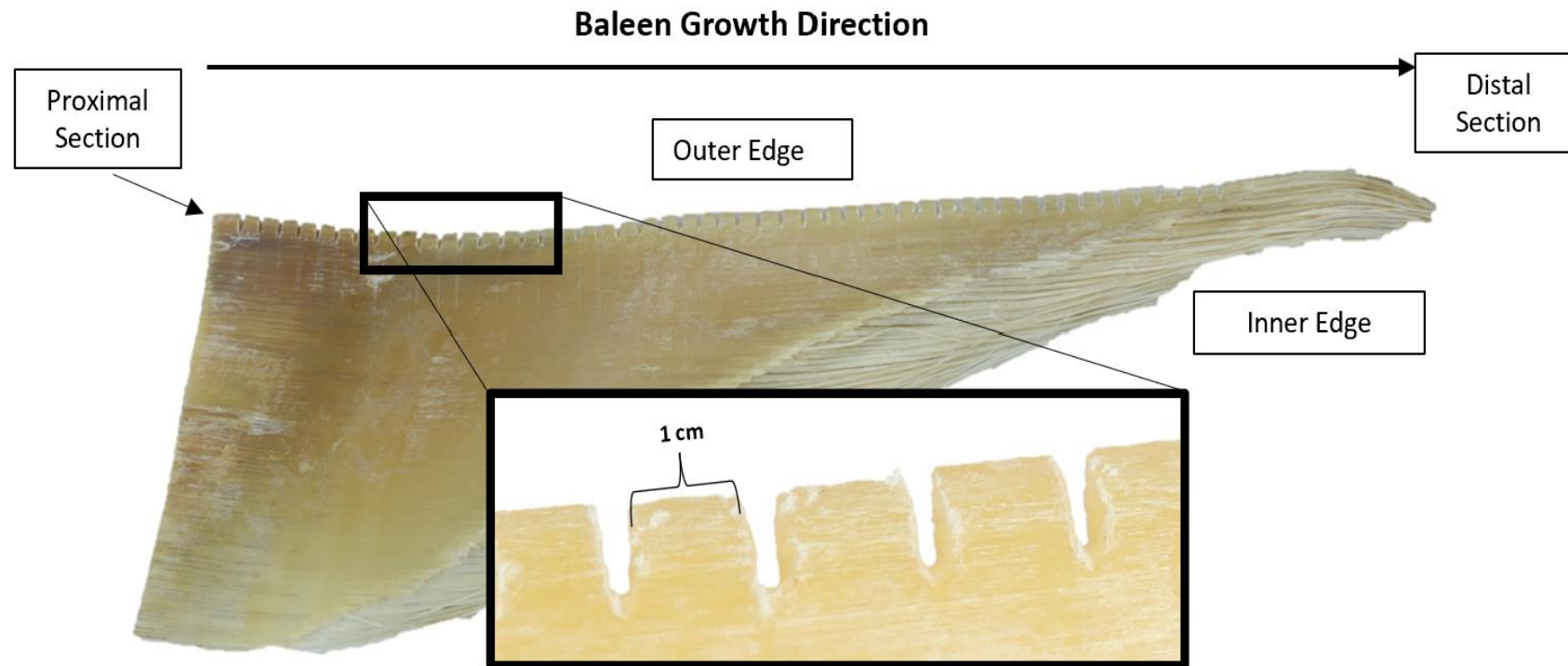
Baleen plates generate a multiyear chronological record of ecological and physiological processes prior to death

Baleen grows sequentially, with new material deposited segment by segment. Once formed, $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values remain stable.

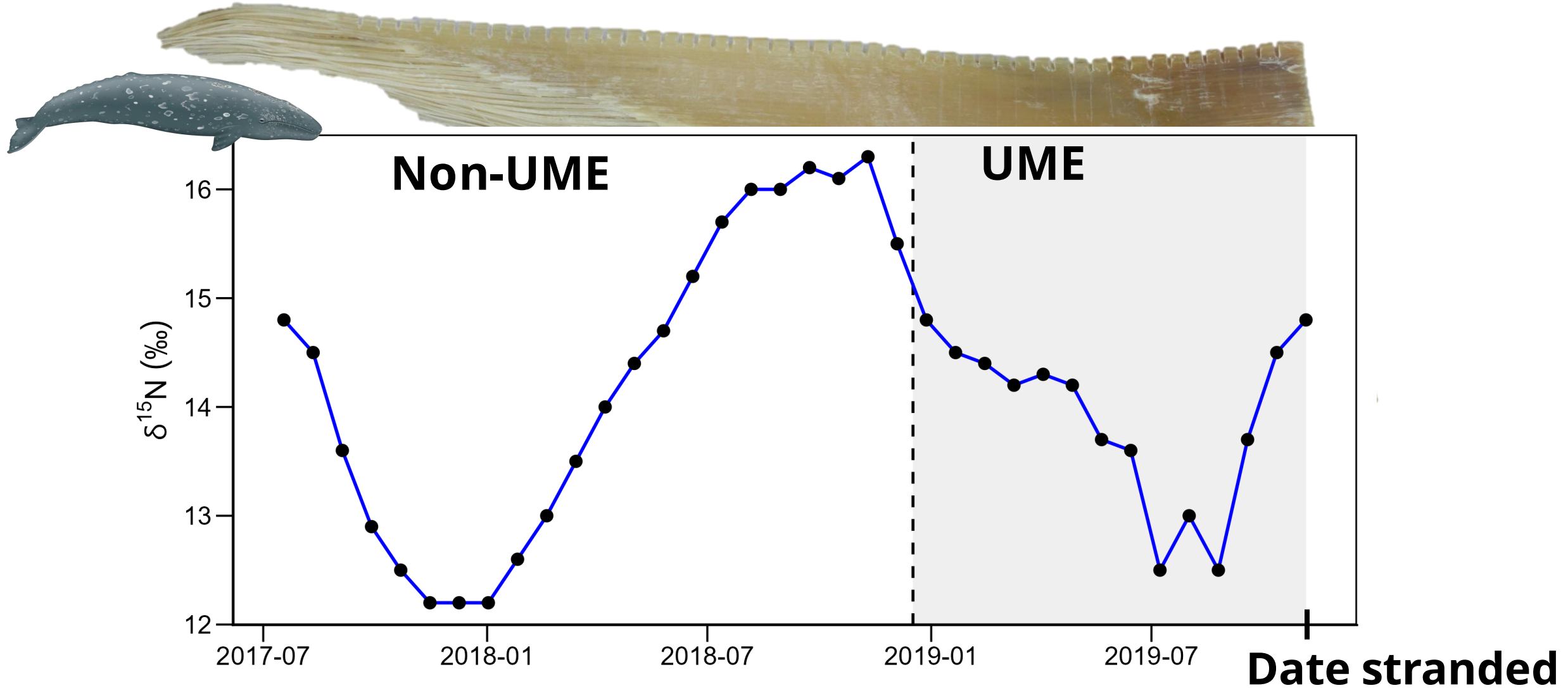


Baleen plates generate a multiyear chronological record of ecological and physiological processes prior to death

- Each centimeter provides ~**15 to 22 days** of information
- Each baleen has **1.5 to 2 years** of information depending on length.



$\delta^{15}\text{N}$ values measured at every centimeter of a gray whale baleen

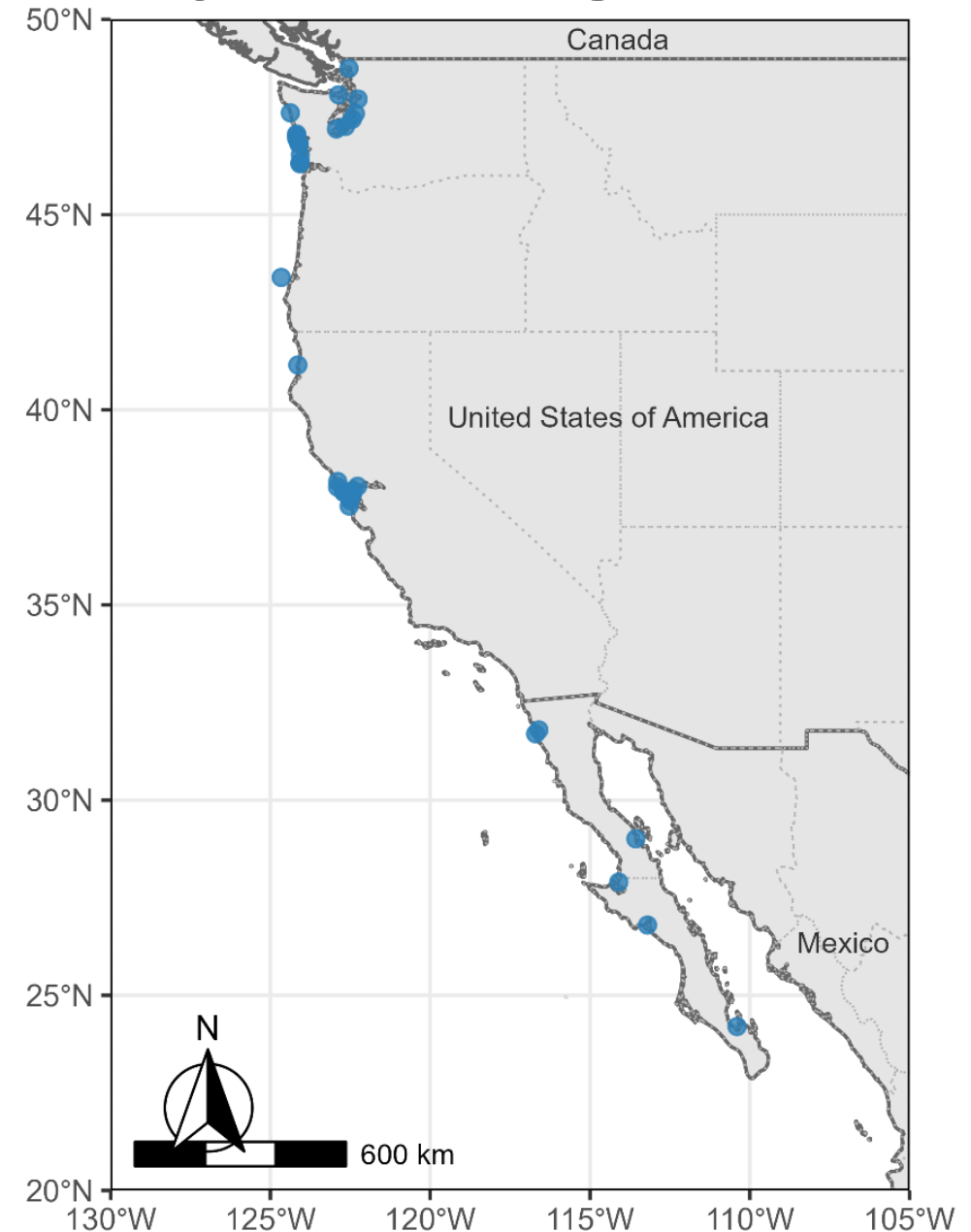


Baleen plates collected during Non-UME and UME periods

N = 51 baleen plates

Period	Count
UME	36
Non-UME	15

Gray Whale Stranding Locations



Baleen plates collected during Non-UME and UME periods

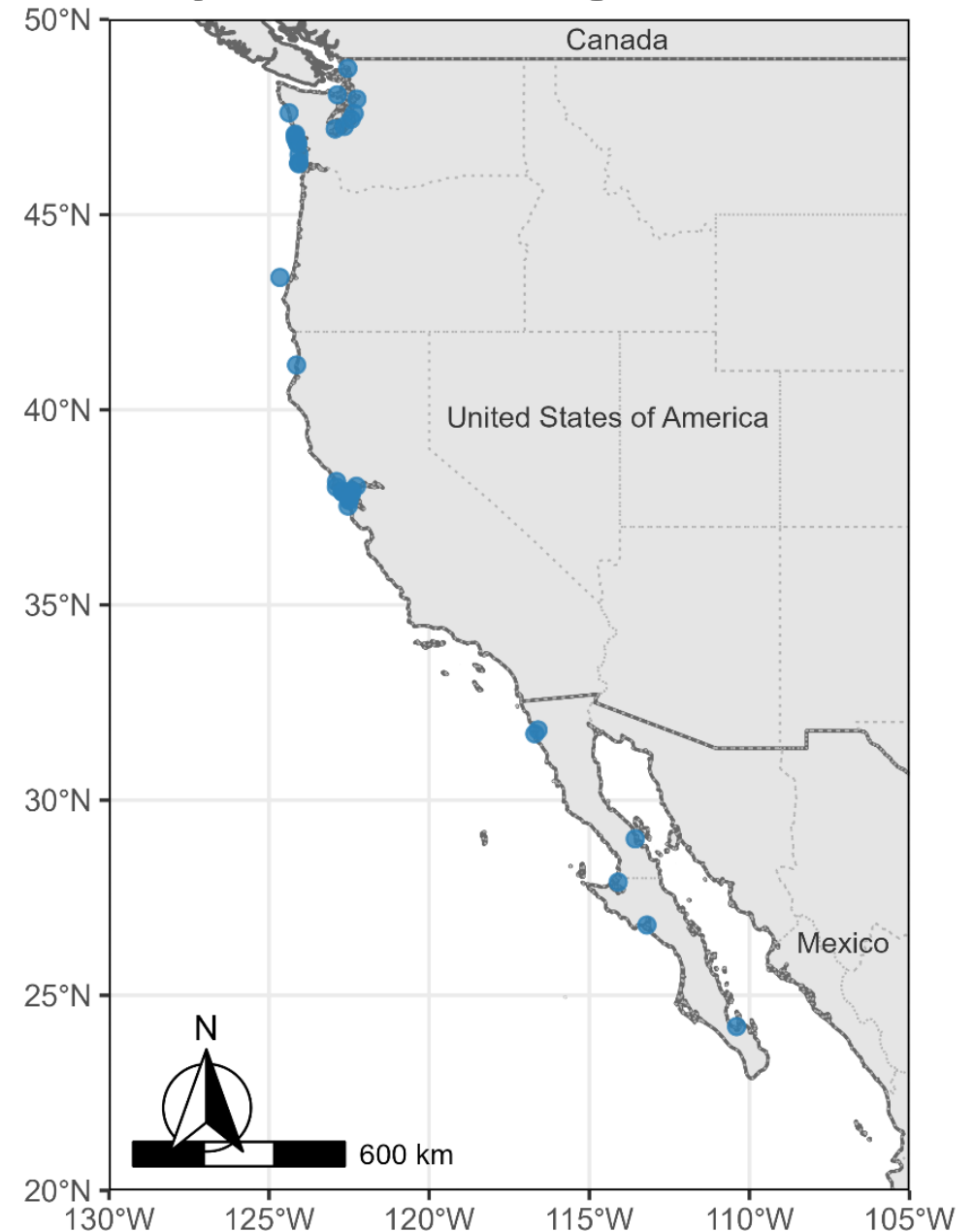
N = 51 baleen plates

Period	Count
UME	36
Non-UME	15

N = 27 baleen plates (*Monumental work!*)
Shout-out to Mikayla Ranspot
and the students who made this possible.

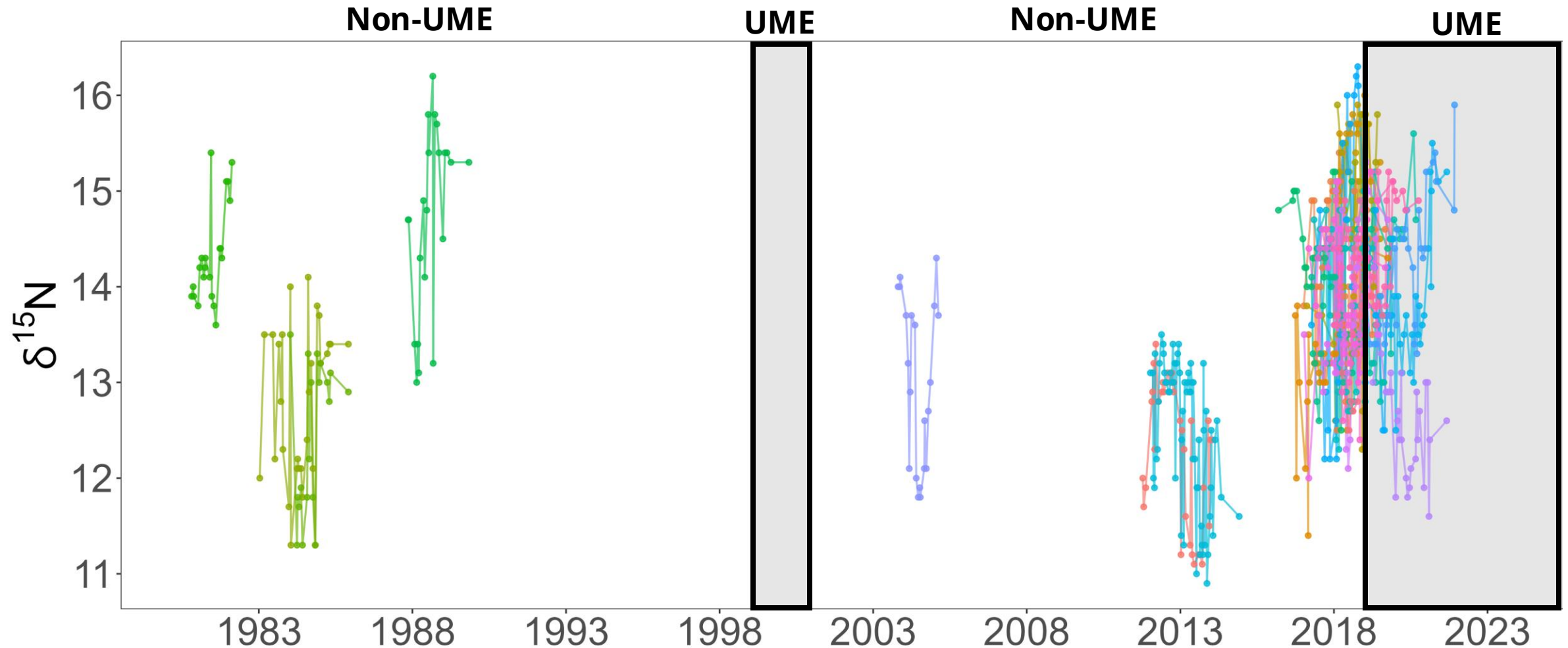
Period	Segments sampled
Non-UME adults	100
Non-UME juveniles	240
UME adults	313
UME juveniles	73

Gray Whale Stranding Locations



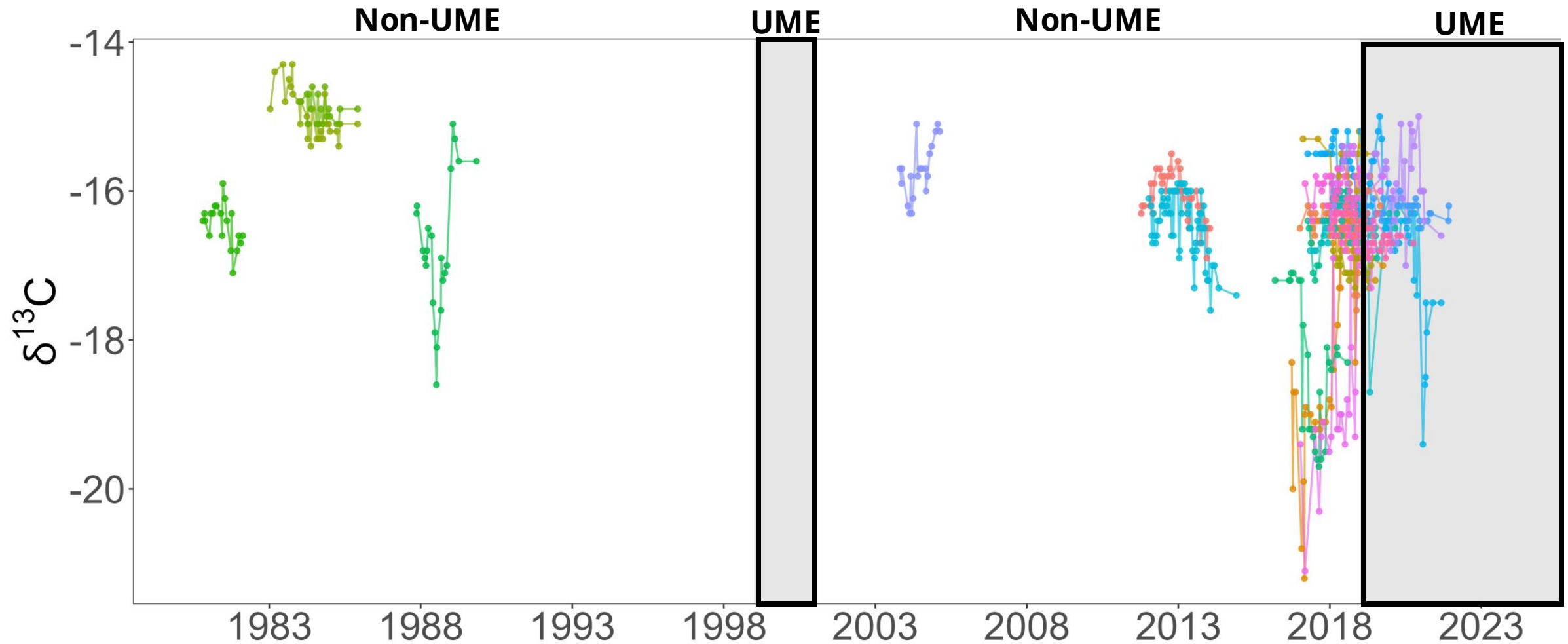
$\delta^{15}\text{N}$ values along the length of 27 baleen plates

- Each color is a different whale: High inter-individual variability



$\delta^{13}\text{C}$ values along the length of 27 baleen plates

- Each color is a different whale: High inter-individual variability



Isotopic niche group estimations for sections of the baleen representing UME and Non-UME in adults and juveniles

Period	Segments sampled
Non-UME adults	100
Non-UME juveniles	240
UME adults	313
UME juveniles	73

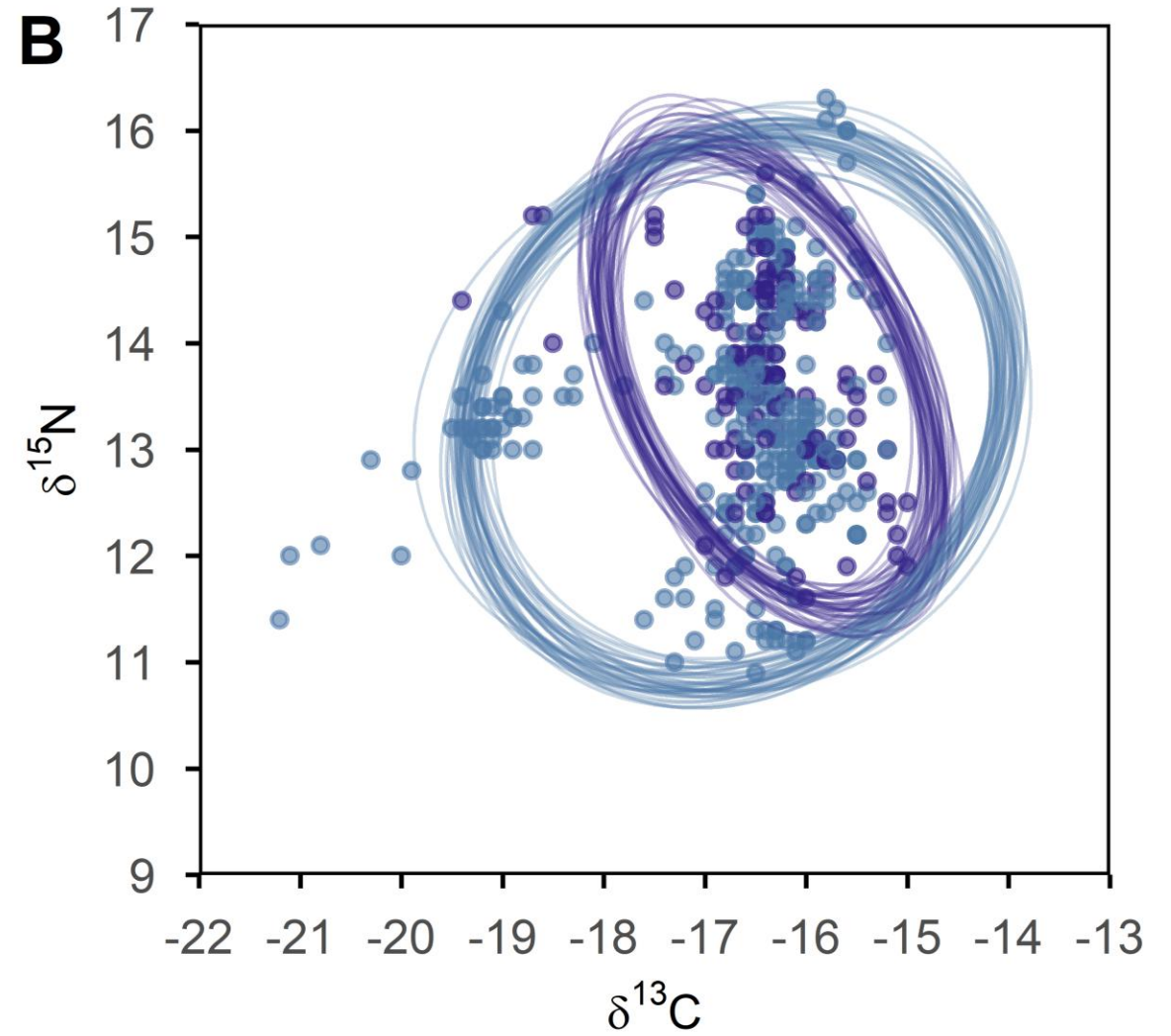
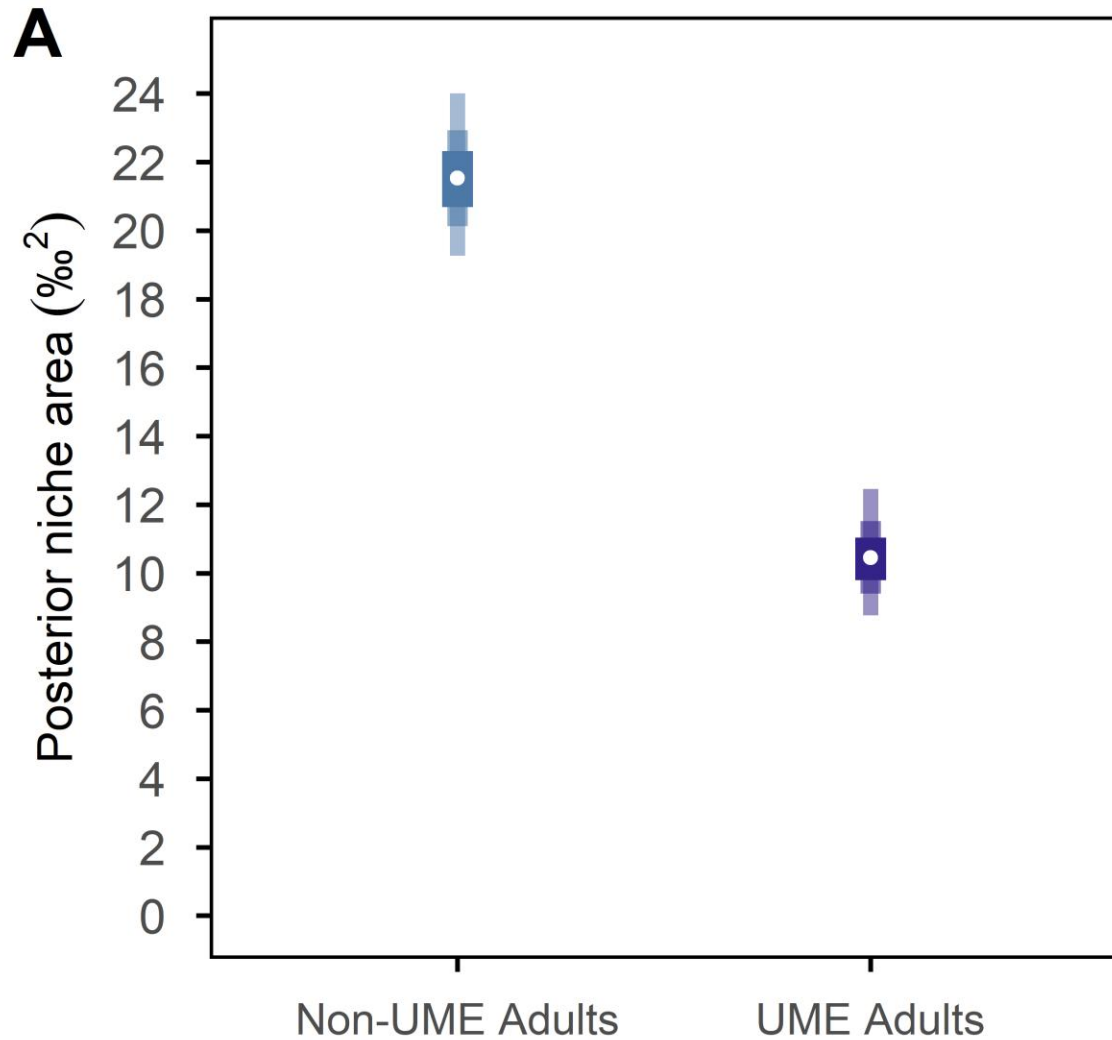
Adults



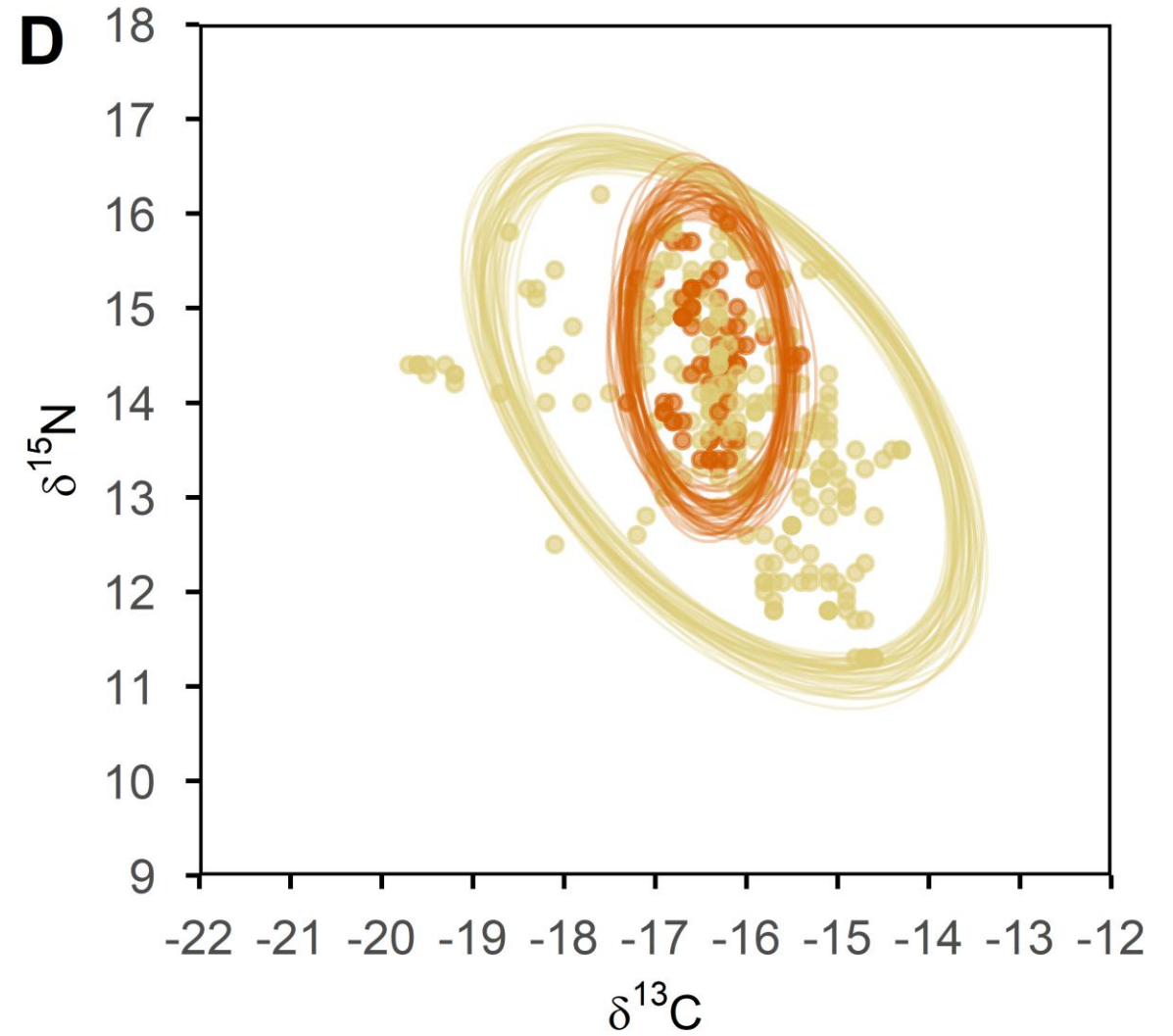
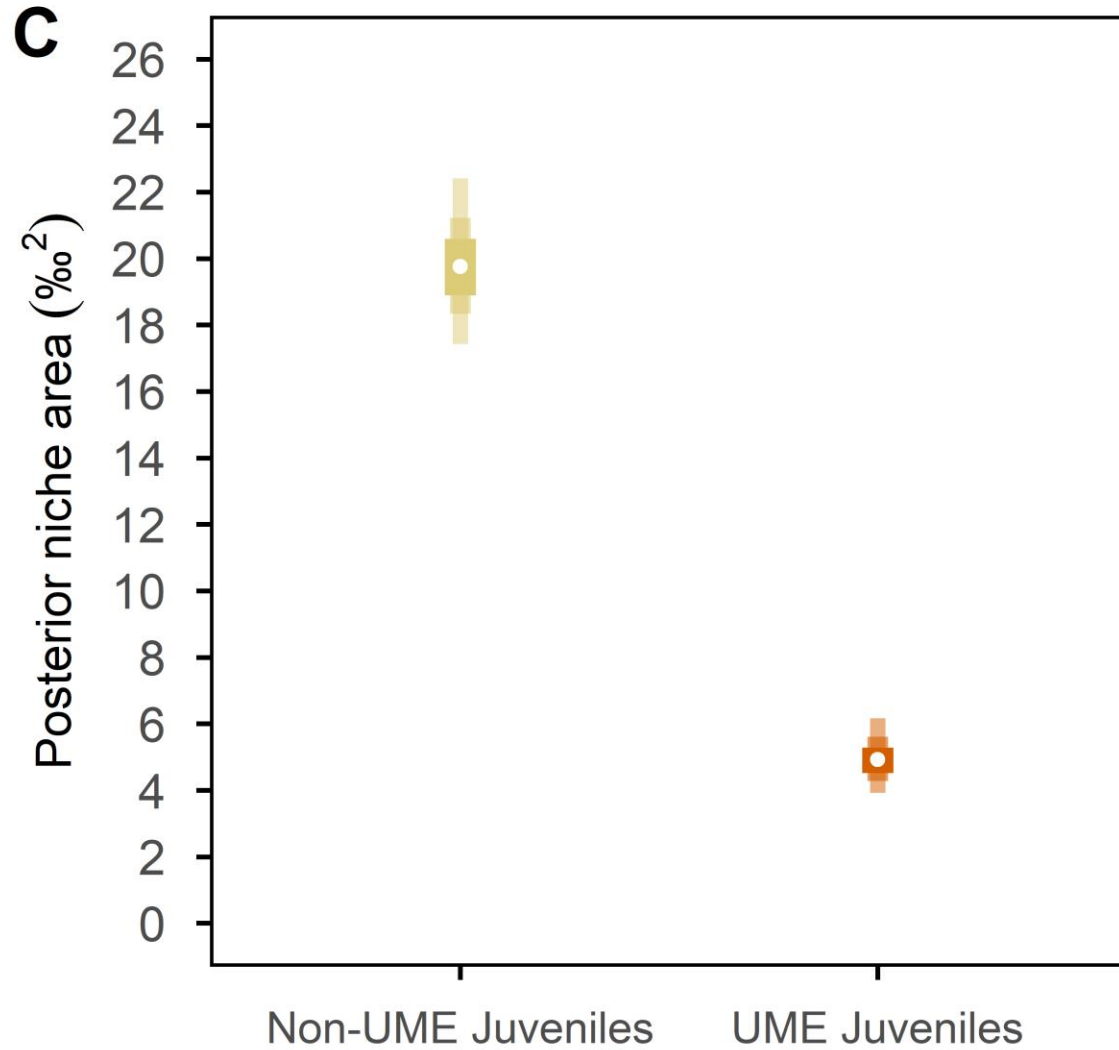
Juveniles



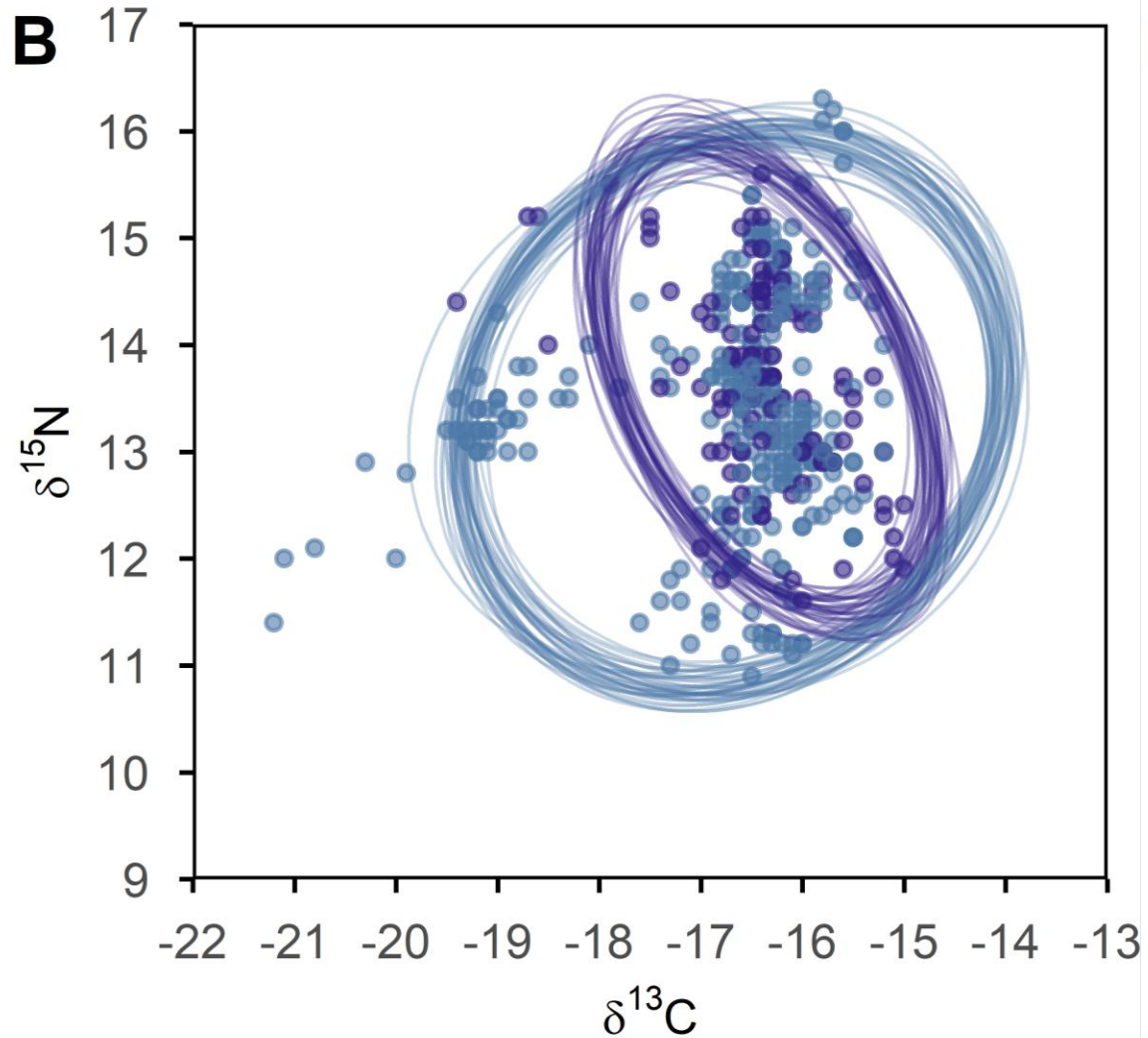
Isotopic niche estimations for sections of the baleen representing UME and Non-UME in adults



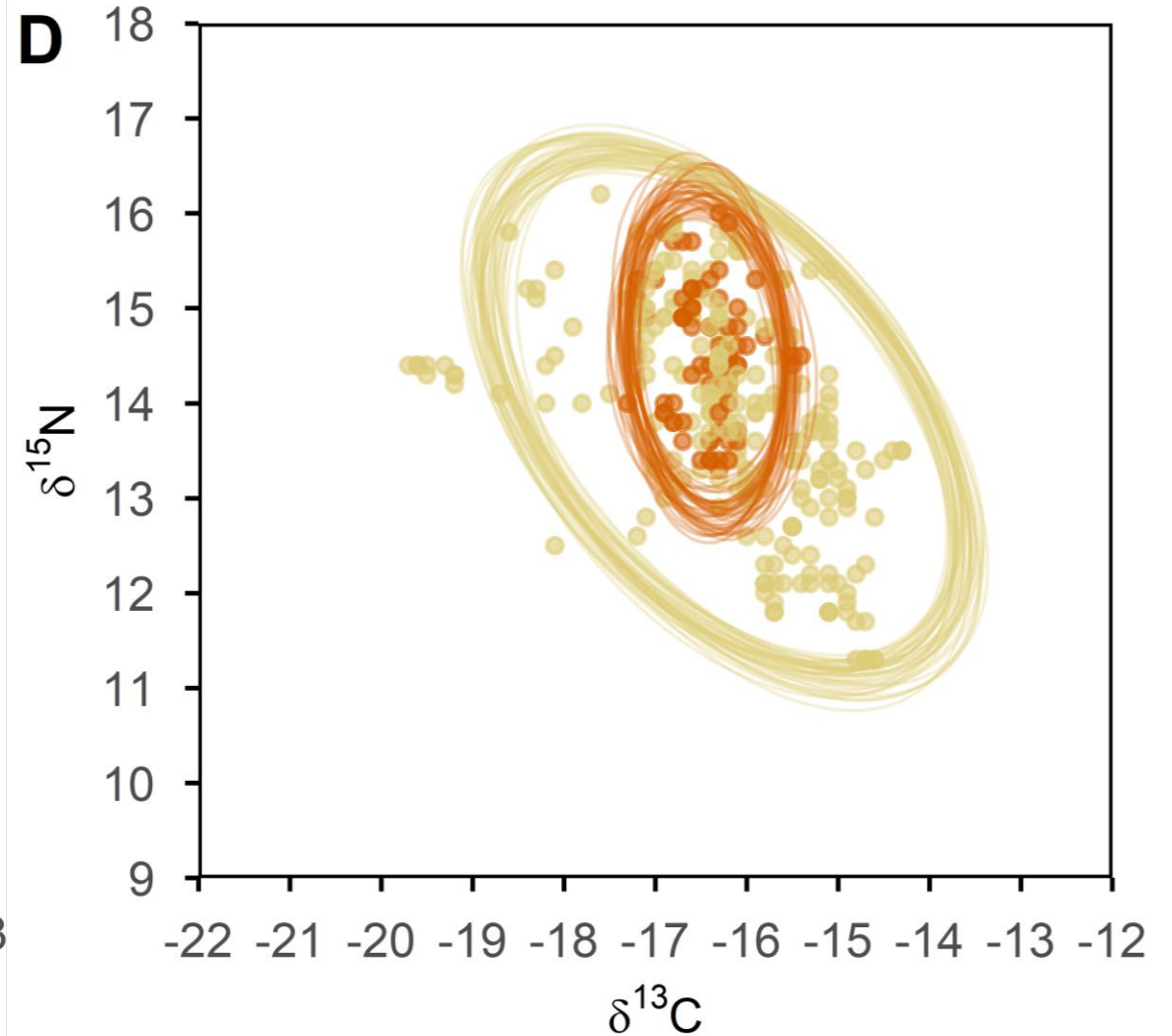
Isotopic niche estimations for sections of the baleen representing UME and Non-UME in juveniles



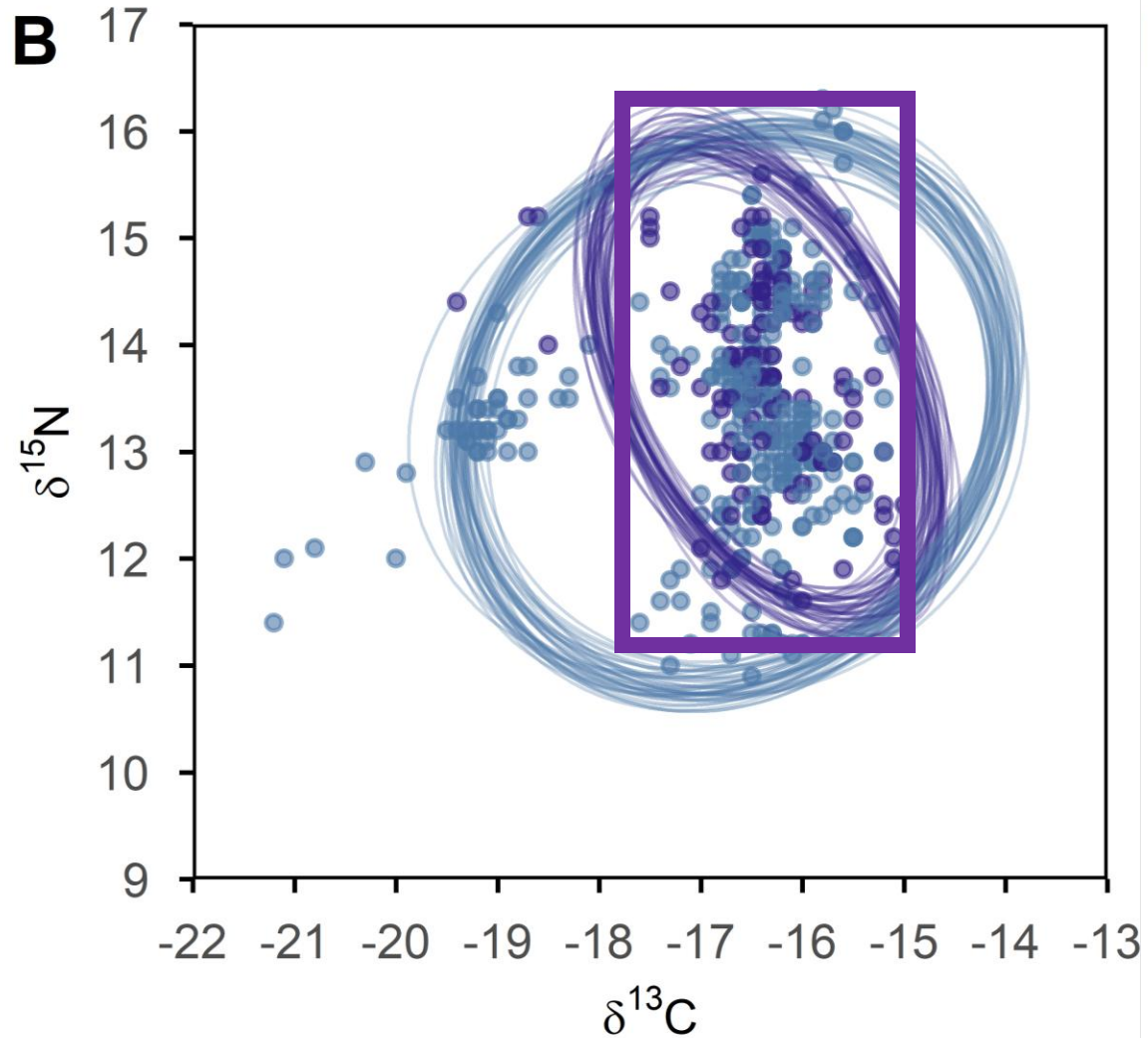
Isotopic niche reduction during UME driven by $\delta^{13}\text{C}$ in adults



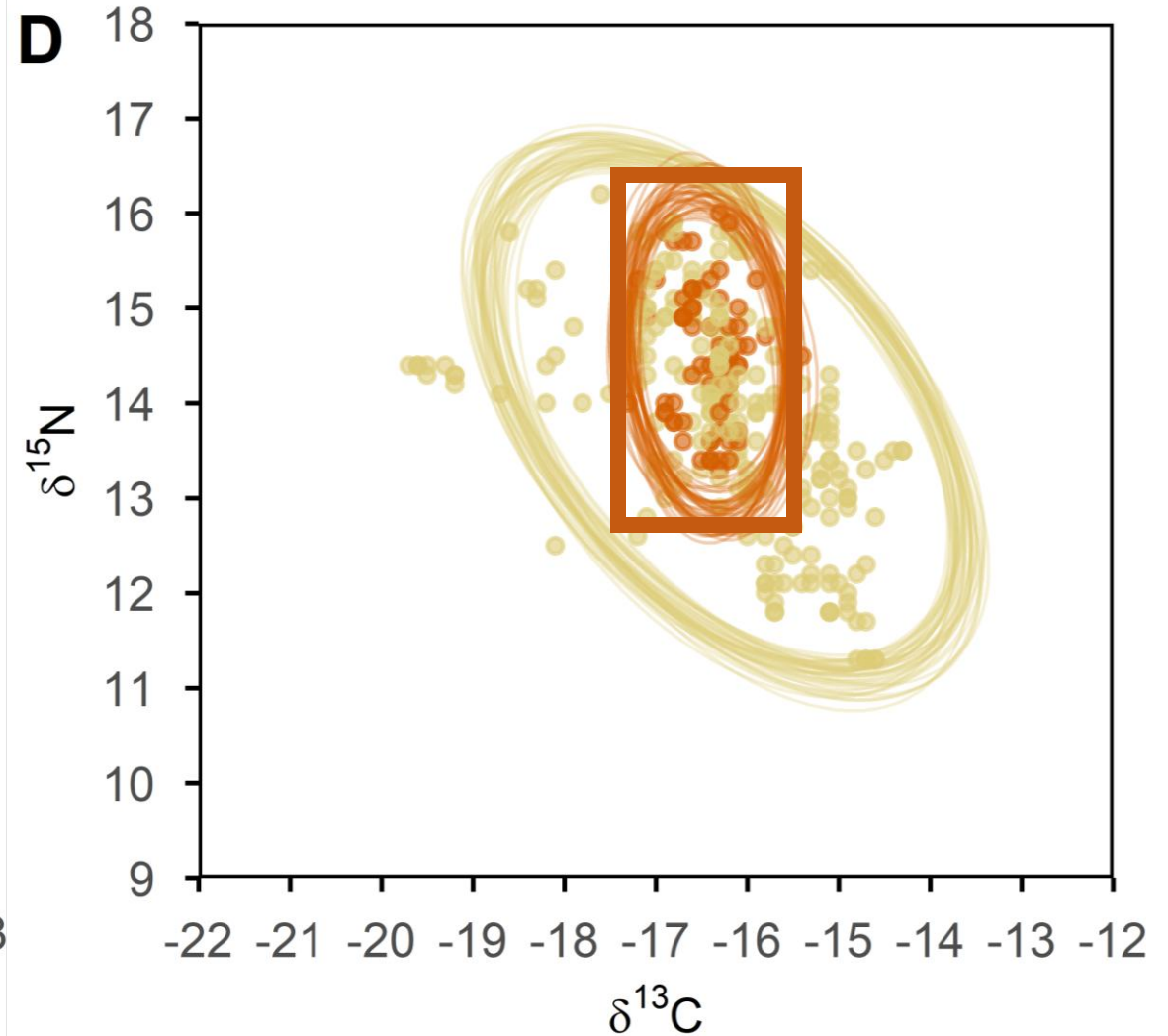
Isotopic niche reduction during UME driven by both in juveniles



Isotopic niche reduction during UME driven by $\delta^{13}\text{C}$ in adults



Isotopic niche reduction during UME driven by both in juveniles

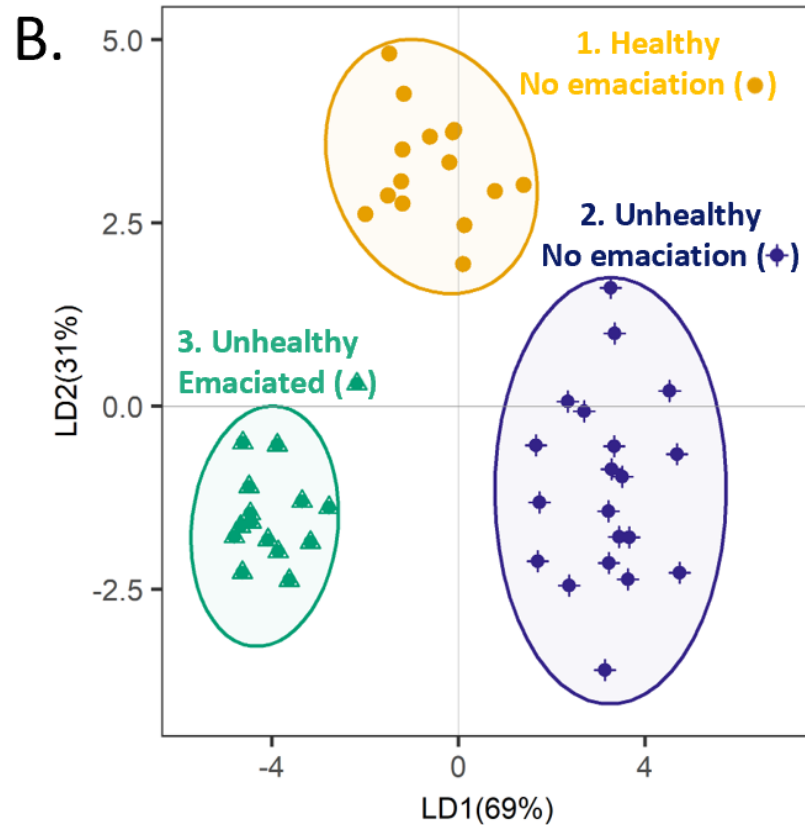


Limitations of using bulk tissue analysis

	LIMITATION
Baseline information	Overlap among foraging habitats and limited information of baseline values
Trophic position	Physiological stress can alter $\delta^{15}\text{N}$, complicating trophic-position estimates
Diet vs. physiology	Difficult to distinguish changes in foraging from physiological responses to fasting and nutritional stress

Amino acid stable isotope analysis can help address some of these limitations

- Identify patterns in nutrient allocation between healthy and nutritionally stressed whales using multivariate analysis of amino-acid values.



Multivariate physiological-state classifications

**PhD. student
Austin Murrell**

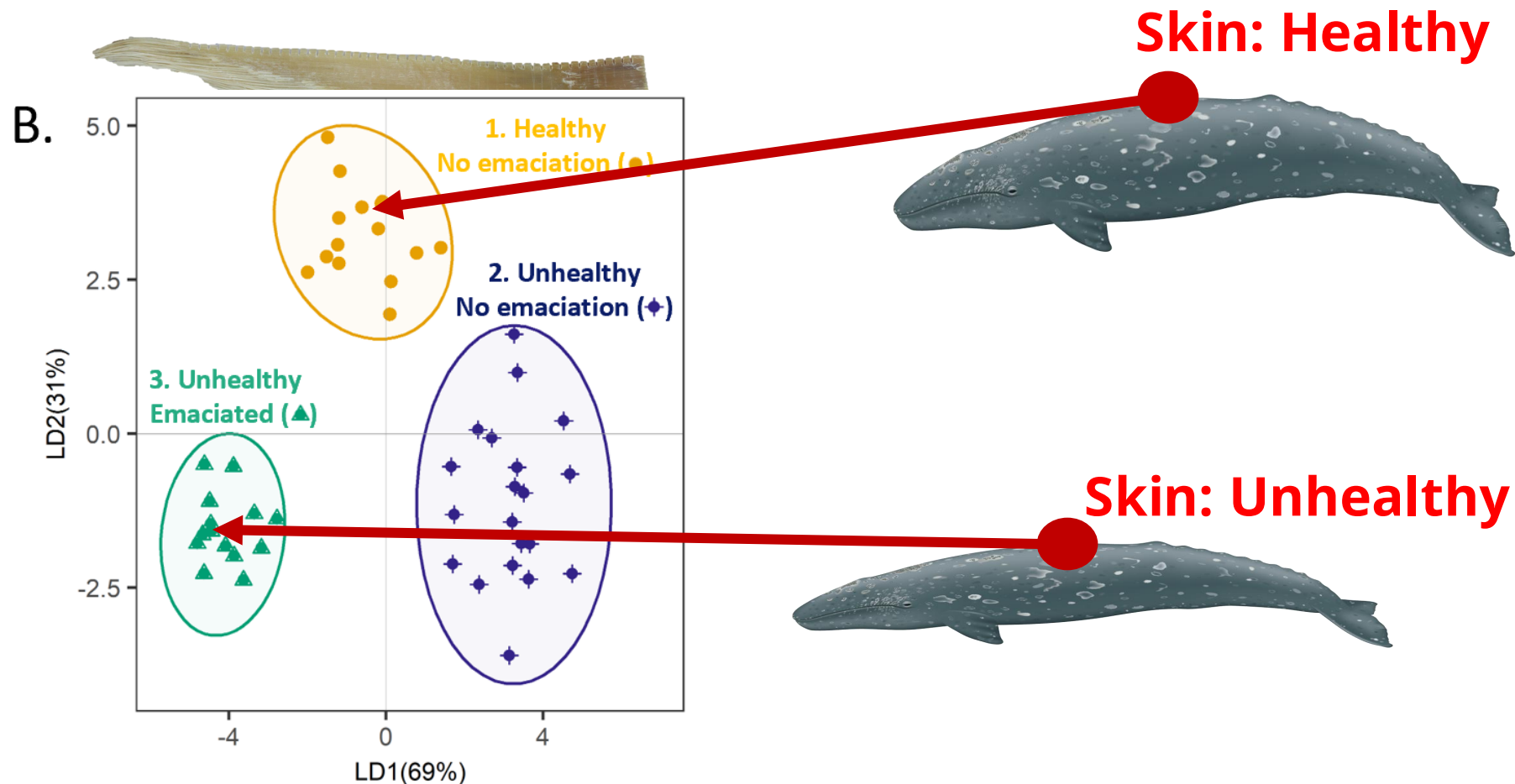


Dr. S. Newsome



Amino acid stable isotope analysis can help address some of these limitations

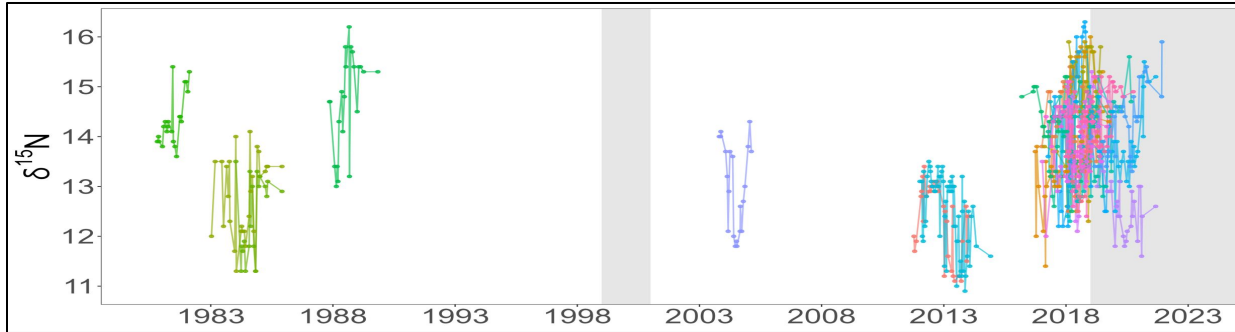
- Compare multivariate physiological-state classifications from baleen with amino-acid patterns from skin biopsies of live whales: **Develop a physiological state assessment tool**



Preliminary findings

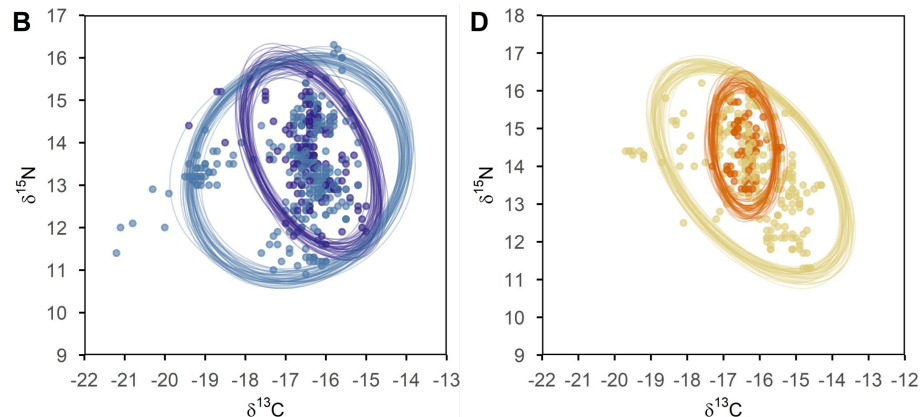
- **High inter-individual variability in baleen $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$** →

Plasticity in foraging strategies and environmental responses



- **Group level Isotopic niche contraction during UME** →

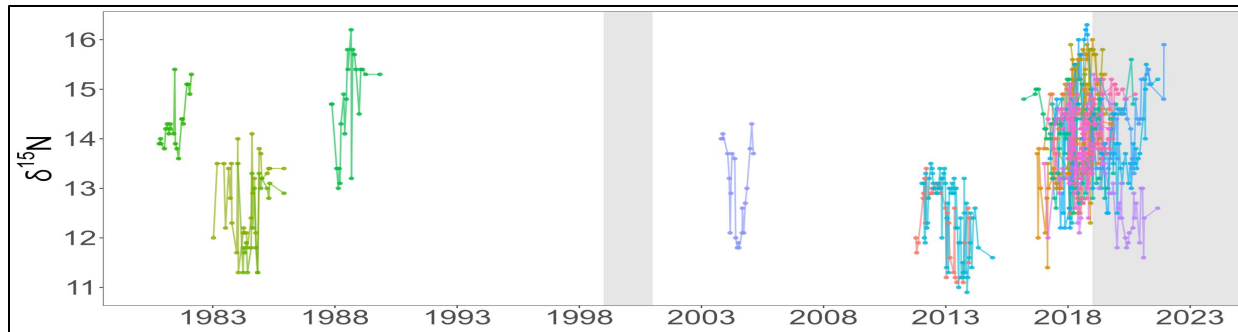
Reduced variability in resource use, foraging habitat, and/or changes in physiological condition



Preliminary findings

- **High inter-individual variability in baleen $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$** →

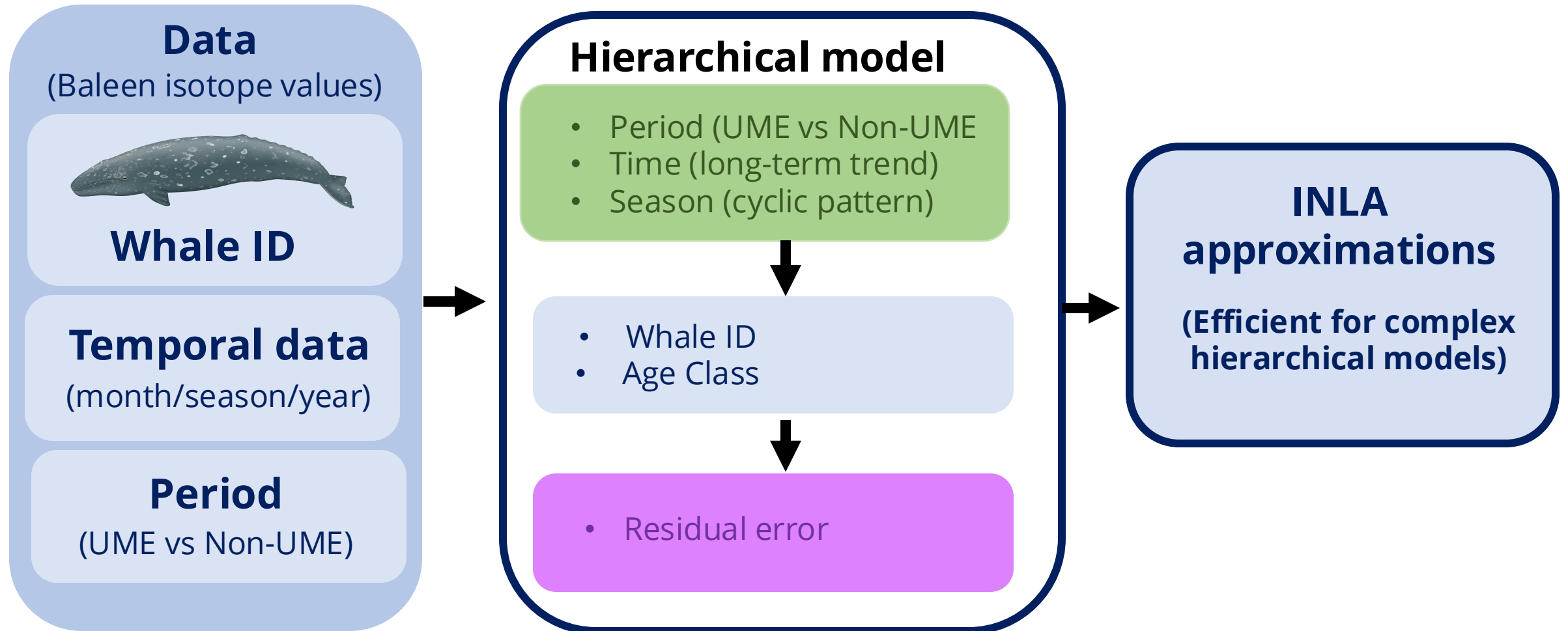
Plasticity in foraging strategies and environmental responses



Next: Identify trends using Bayesian hierarchical models

Temporal variation in $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ along the length of gray whale baleen during Non-UME and UME

- Bayesian hierarchical model using Integrated Nested Laplace Approximation (INLA)



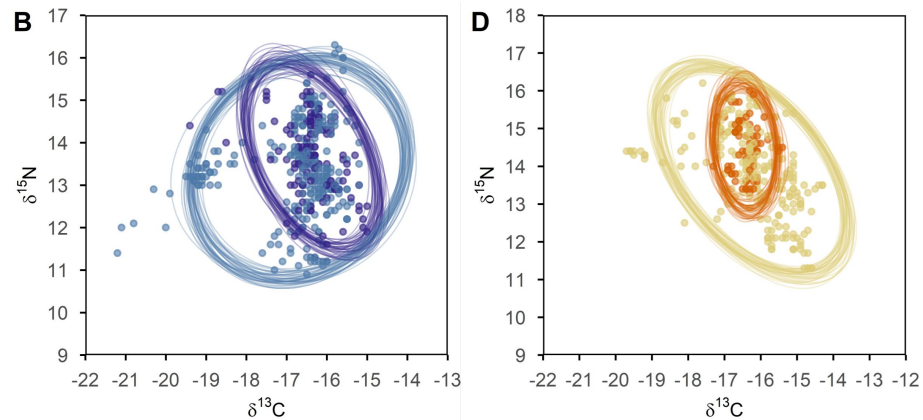
Preliminary findings

- **Group level Isotopic niche contraction during UME**



Reduced variability in resource use, foraging habitat, and/or changes in physiological condition

Next: Amino acid specific stable isotope analysis





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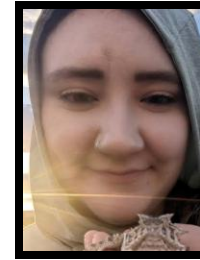
F. Gómez-Díaz



M.Sc. Jacobsen



B.M. A. Murell



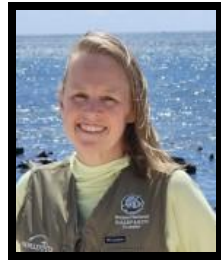
B.M. A. Osborn



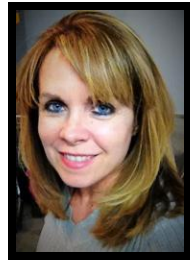
B.S. J. L. Huggins



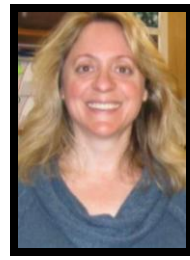
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D'Alessandro



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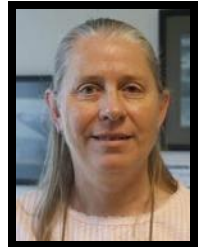
M.B. Denise Greig



B.A. J. Rice



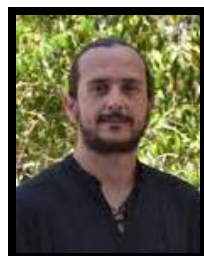
Dr. M.E. Thompson



Dr. G. Heckel



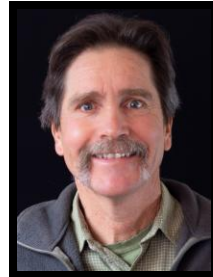
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Oregon State University
Marine Mammal
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Thank you, questions?



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Session 4 Discussion

Overview of Lethal and Sublethal Threats to Health and Survival



KC Bierlich



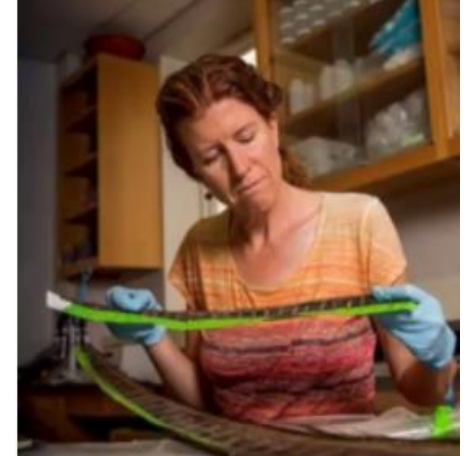
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