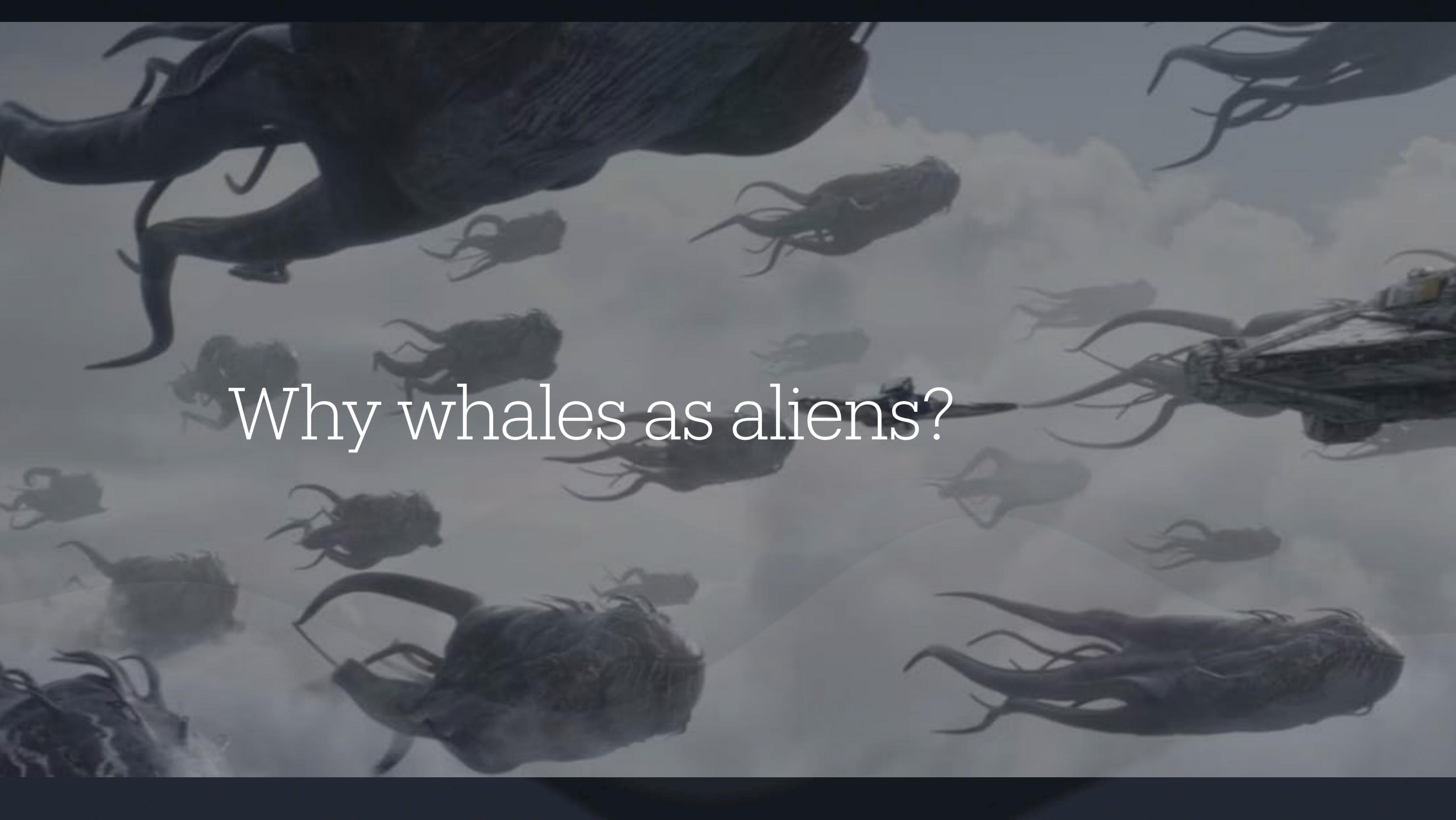


Tracing the Cultural Fabric of Sperm Whale Societies

G. Petri
Turing Institute at Bristol, 5/11/2025

Network Science Institute
at Northeastern University



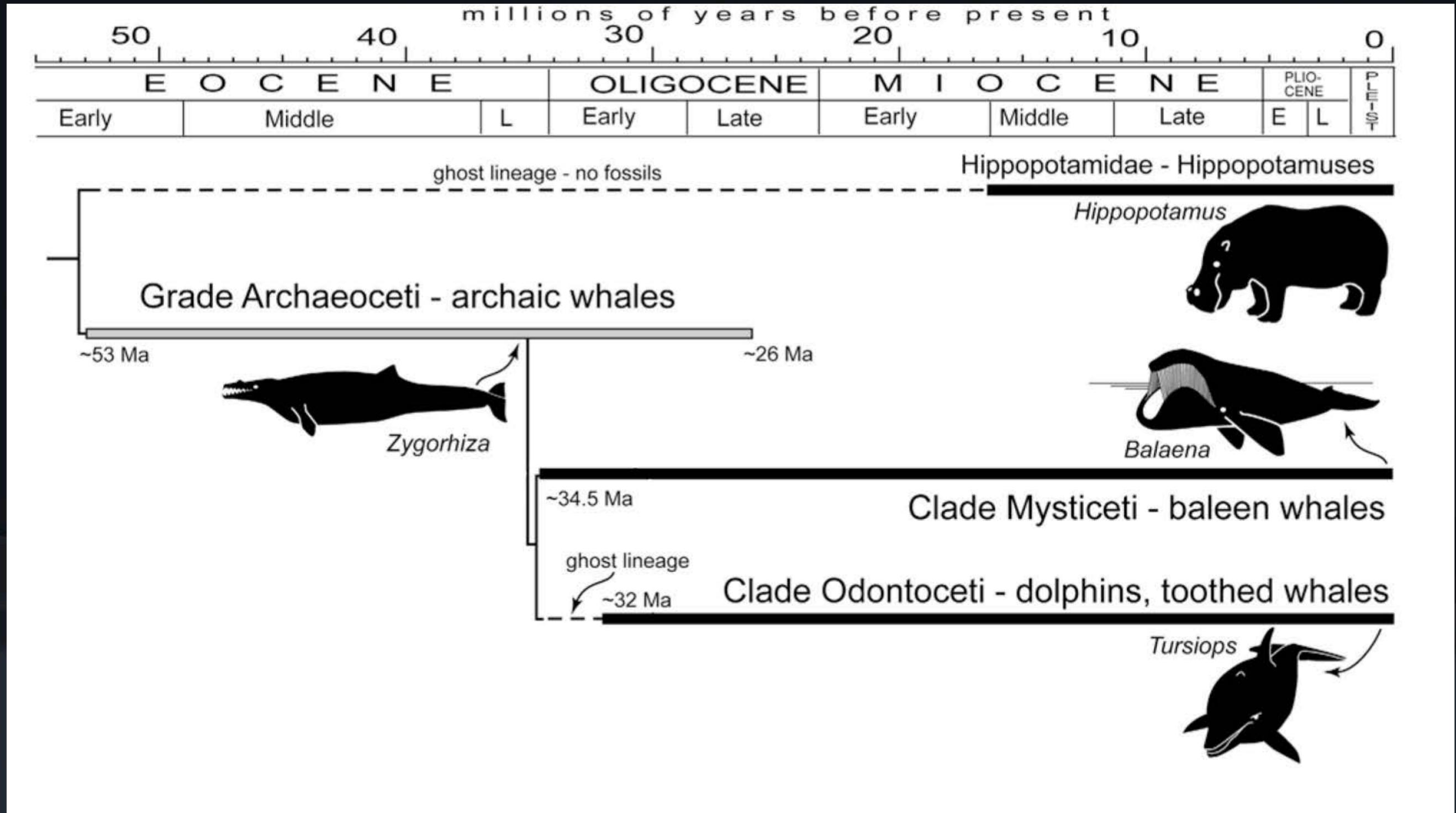
A large group of whales, including several large humpback whales and many smaller baleen whales, are swimming in the ocean. The scene is captured from an underwater perspective, showing the whales' heads and backs as they move through the water. The lighting is somewhat dim, creating a serene and mysterious atmosphere. The text "Why whales as aliens?" is overlaid in the center of the image in a white, serif font.

Why whales as aliens?

A large group of sperm whales swimming in the ocean. The whales are dark in color and have long, pointed heads. They are swimming in various directions, some towards the camera and some away. The water is a light blue-grey color. The text "Why sperm whales?" is overlaid in the center of the image in a white, serif font.

Why sperm whales?

Sperm whales 101

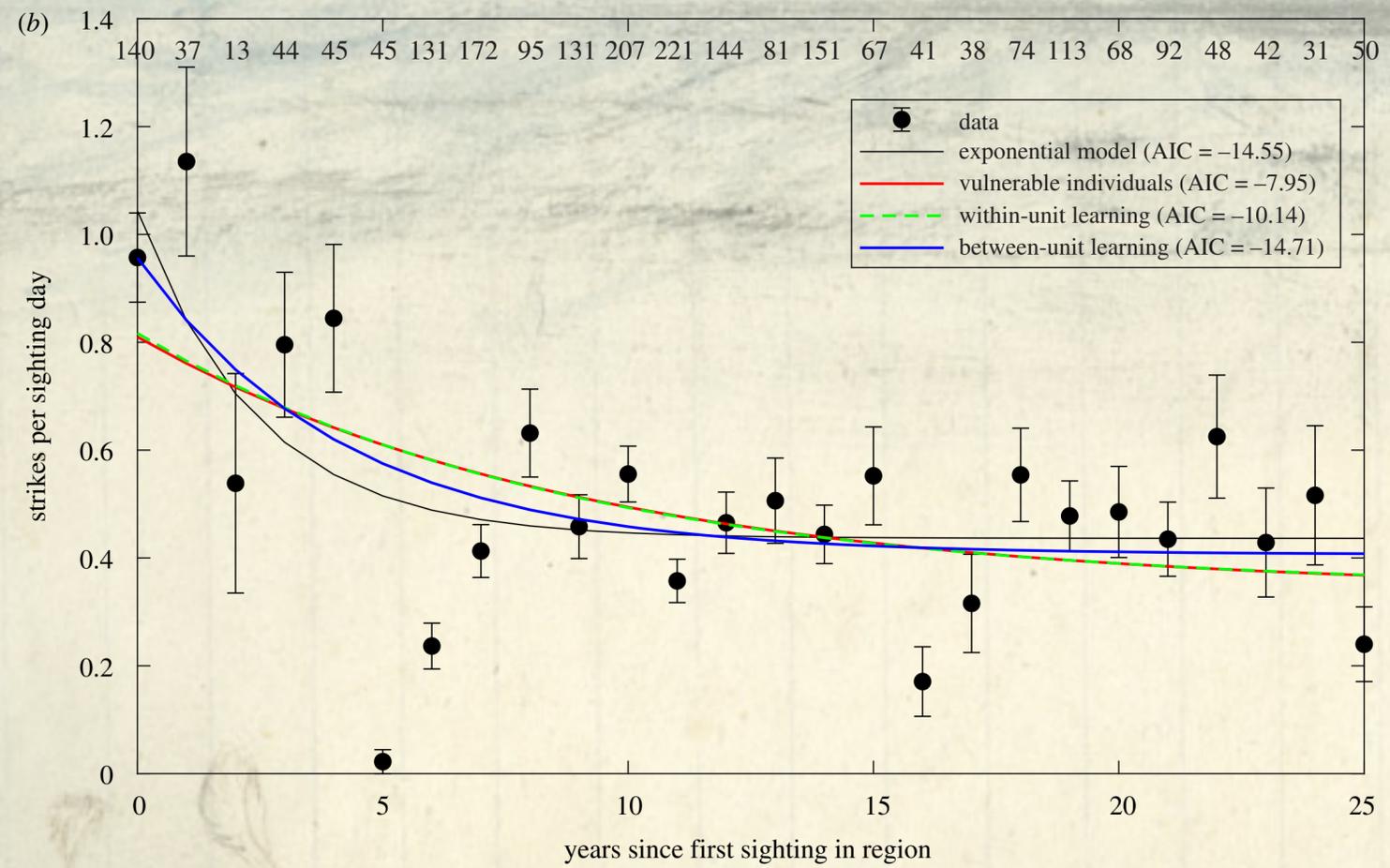


Sperm whales 101

- Largest mammalian brain, complex social societies
 - 300.000 animals right now (~1.1M pre-whaling)



Whitehead, Hal, Tim D. Smith, and Luke Rendell. "Adaptation of sperm whales to open-boat whalers: rapid social learning on a large scale?." *Biology Letters* 17.3 (2021): 20210030.



Whitehead, Hal, Tim D. Smith, and Luke Rendell. "Adaptation of sperm whales to open-boat whalers: rapid social learning on a large scale?." *Biology Letters* 17.3 (2021): 20210030.

Sperm whales 101

- Largest mammalian brain, complex social societies
 - 300.000 animals right now (~1.1M pre-whaling)
- **They live in a different world:**
 - Descend 400-2000m for 30-45min, rest at surface 5-10 minutes

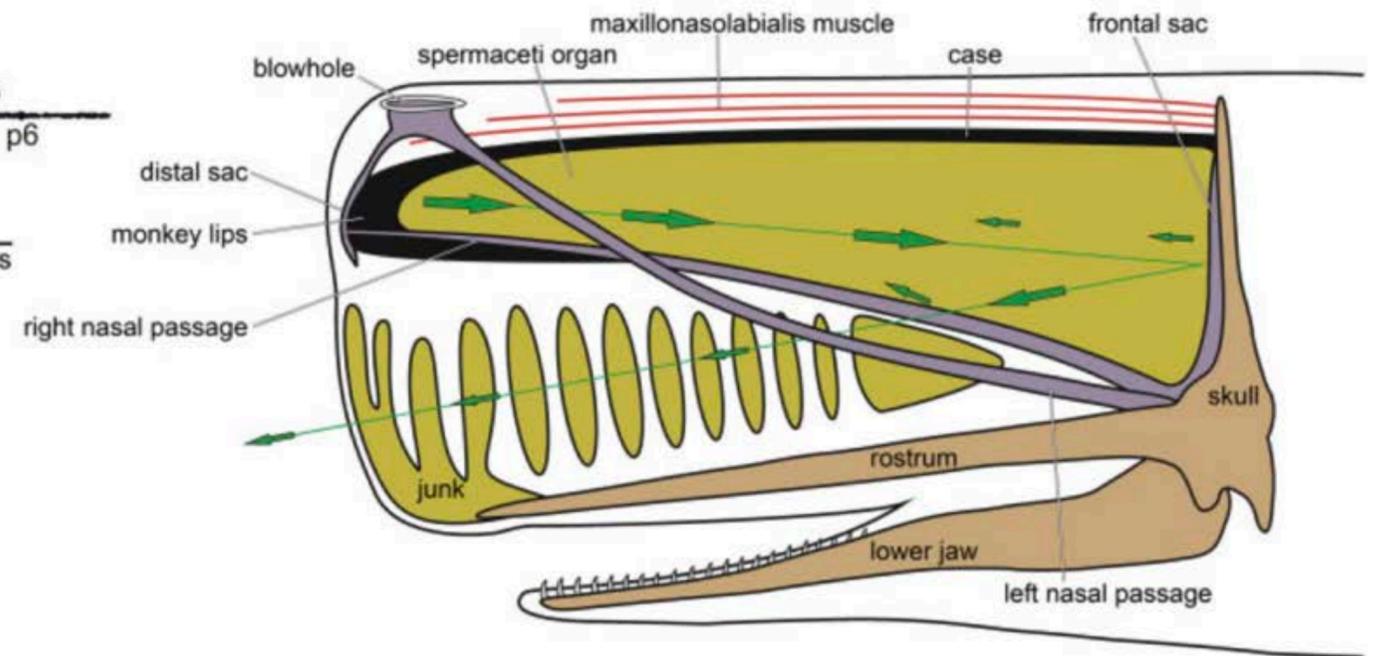
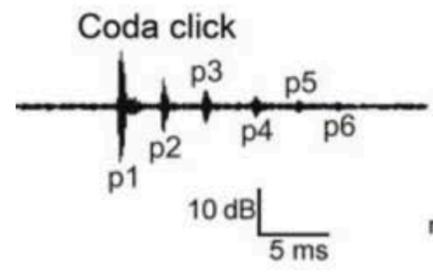
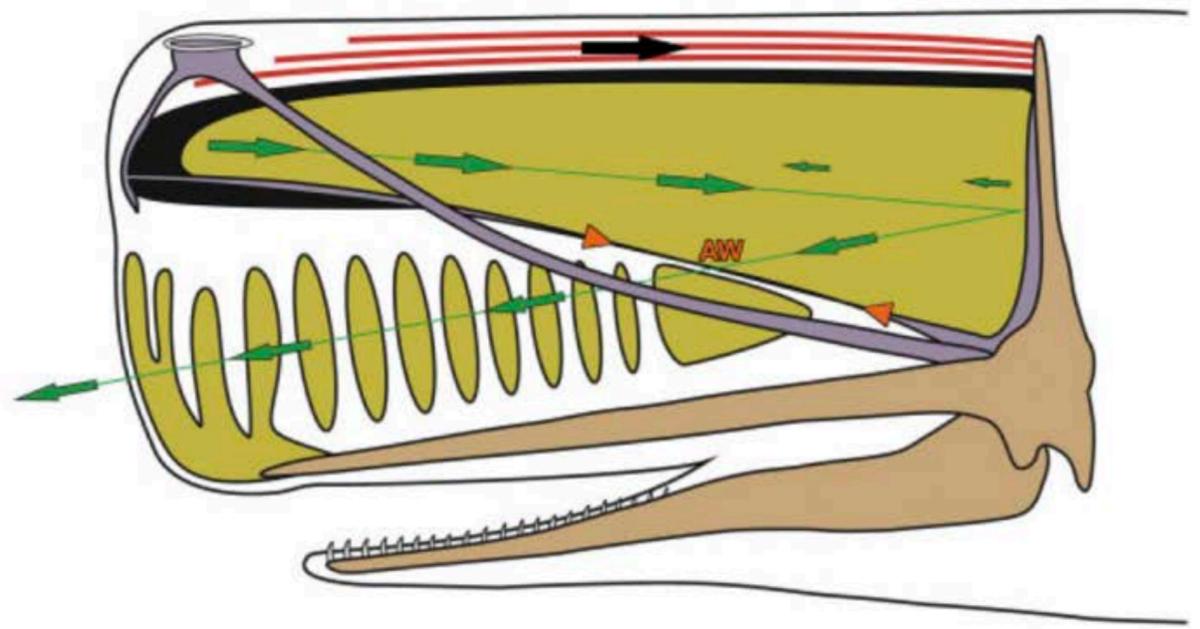
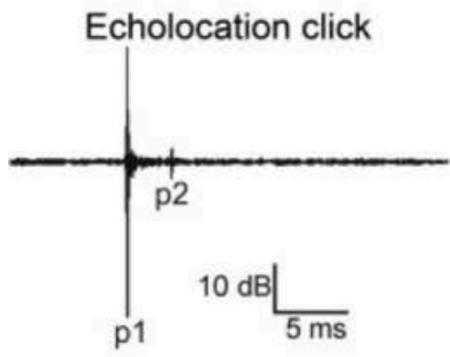


Sperm whales 101

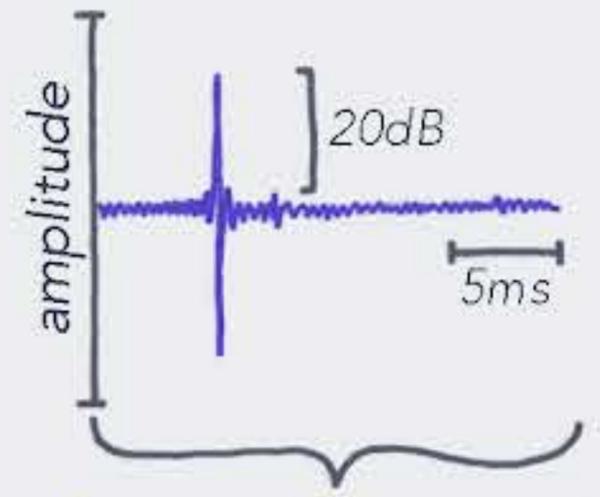
- Largest mammalian brain, complex social societies
 - 300.000 animals right now (~1.1M pre-whaling)
- They live in a different world:
 - Descend 400-2000m for 30-45min, rest at surface 5-10 minutes
- Produce rhythmic social “codas”, patterns of multiple broadband “clicks” for communication



Bent-Horn Model of Sound Production



(B)

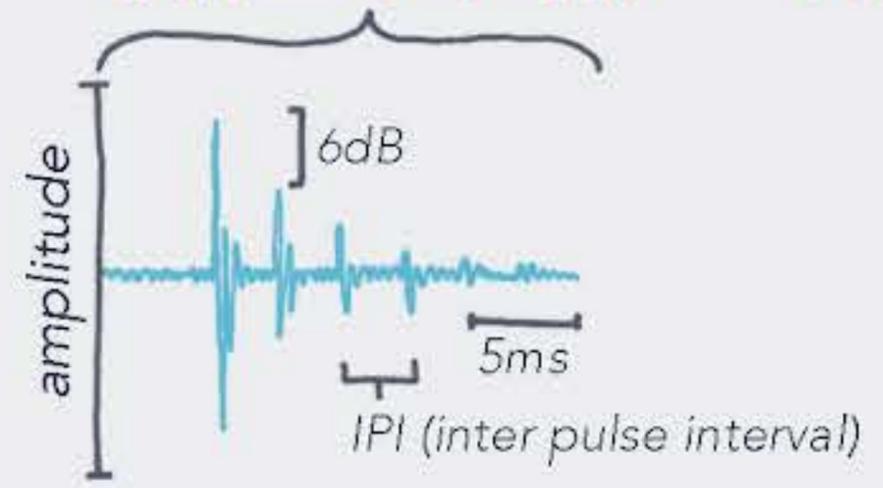


ECHOLOCATION

TIME
(seconds)

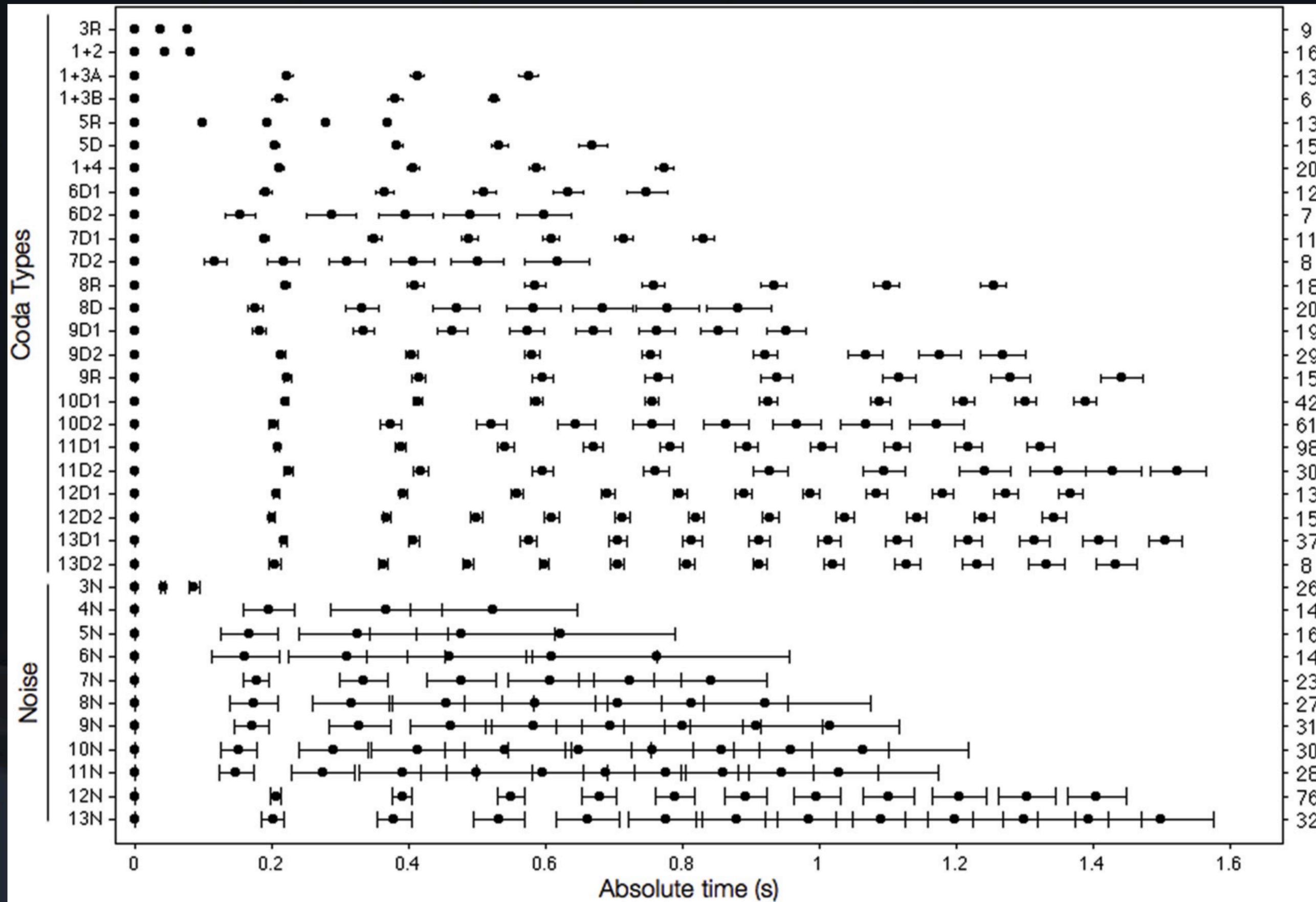
CODA TYPE

CODAS



Coda

ICI
(inter click interval)



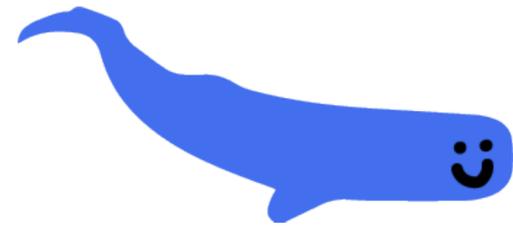


Can we understand them?

1

What CAN we do?
STRUCTURE

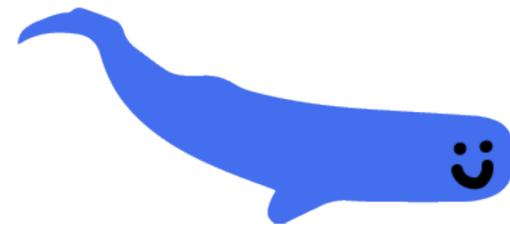
Sperm whales communicate with clicks



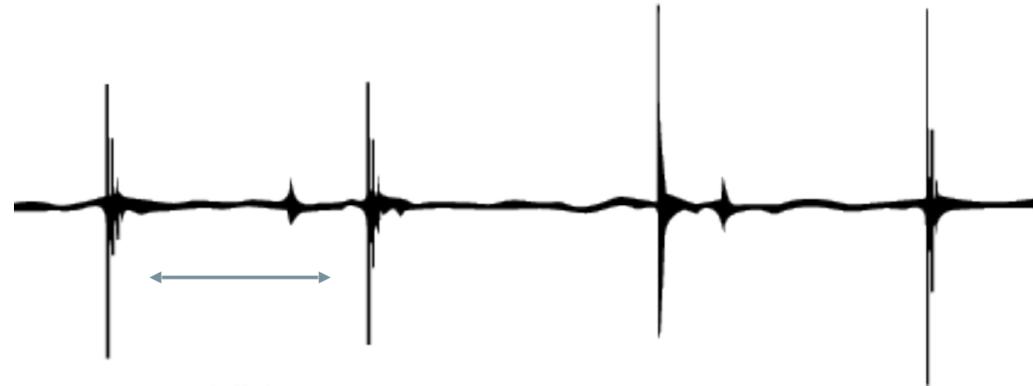
Sperm Whale



Sperm whales communicate with clicks



Sperm Whale



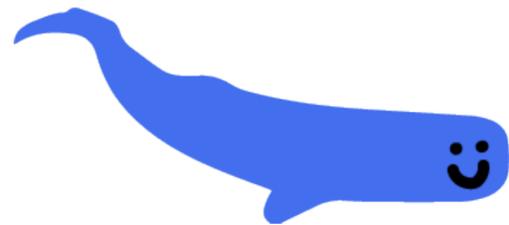
ICI



We consider the sequence of inter-click intervals (ICI)

Clicks form patterns called codas.

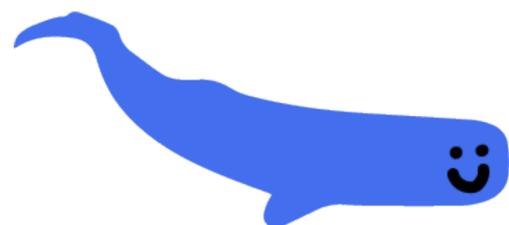
Codas: small clusters of clicks with repeatable patterns.



Sperm Whale



There are different types of codas.

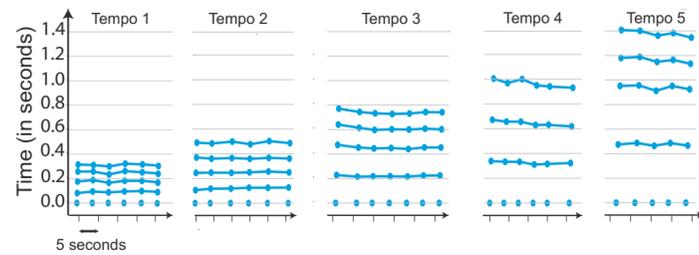


Sperm Whale

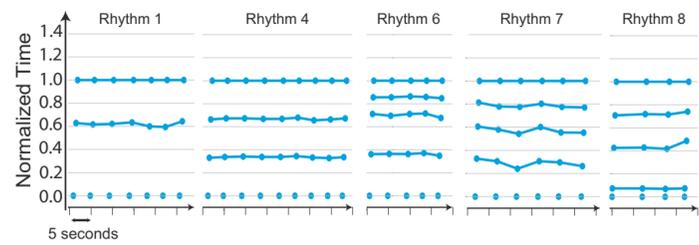


Sperm whale phonetic alphabet

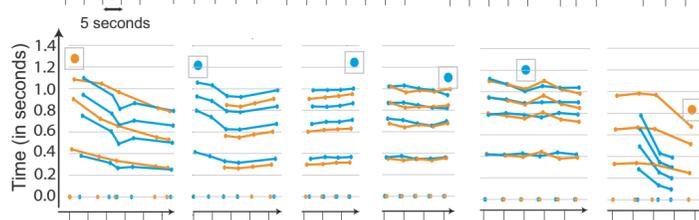
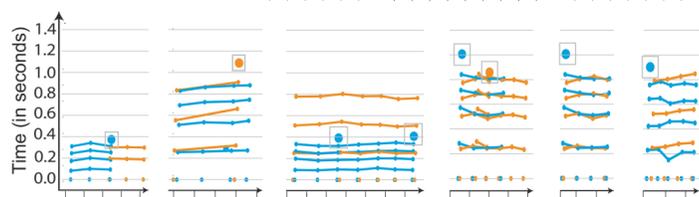
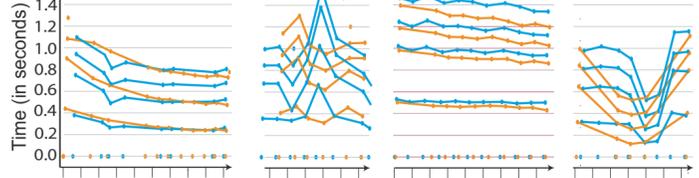
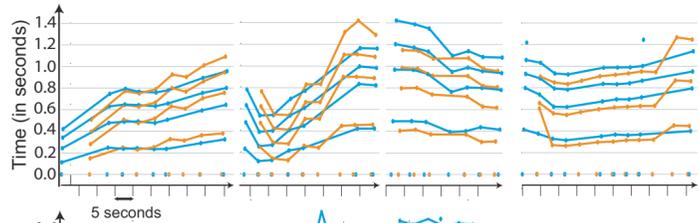
Tempo



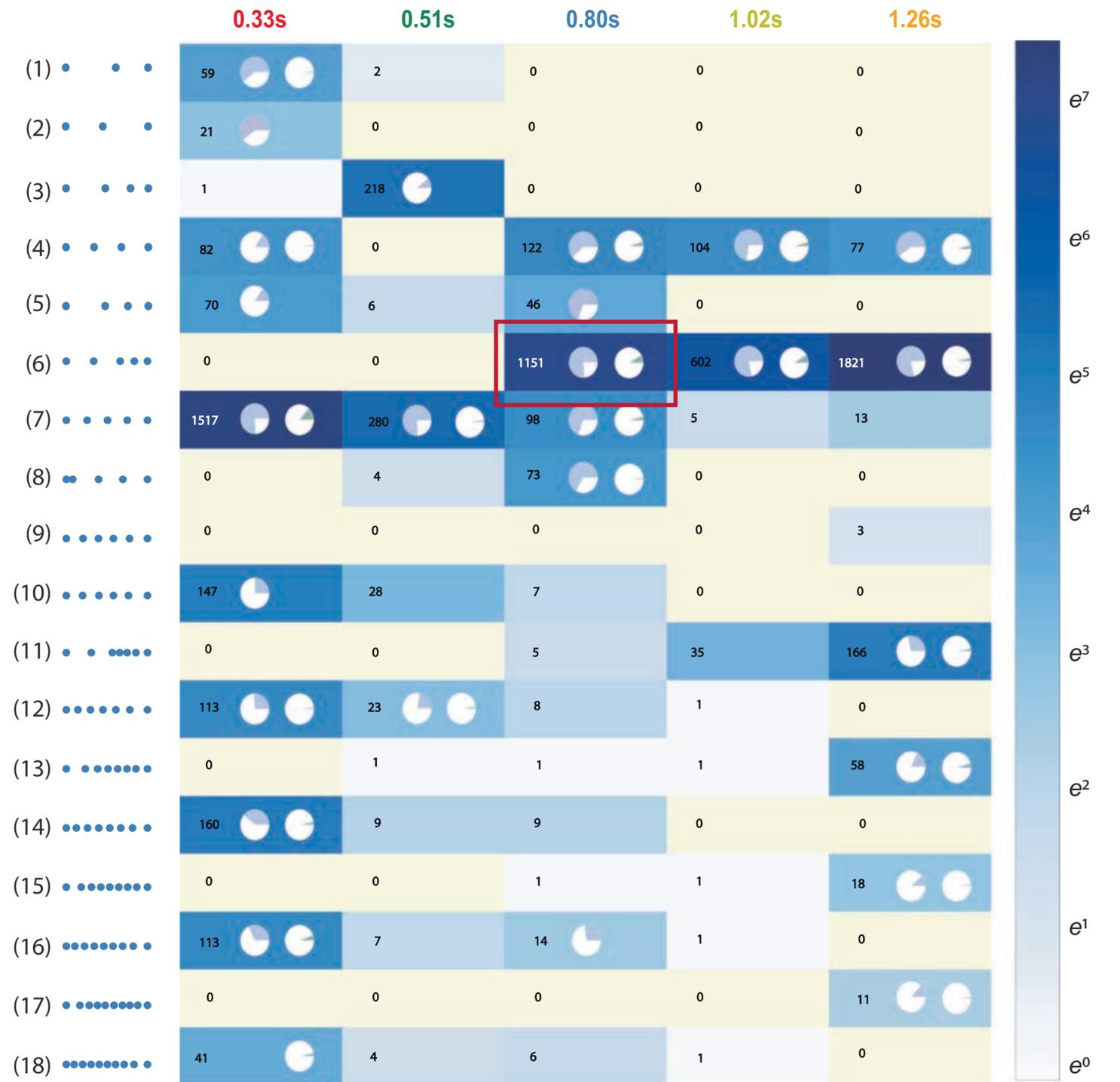
Rhythm



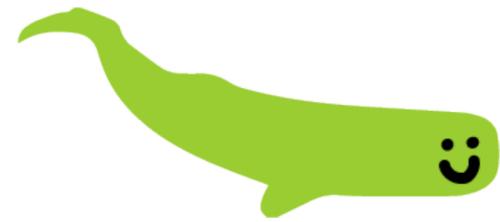
Rubato



Ornamentation



Identity codas are “clan-favourite” coda types.



Clan A



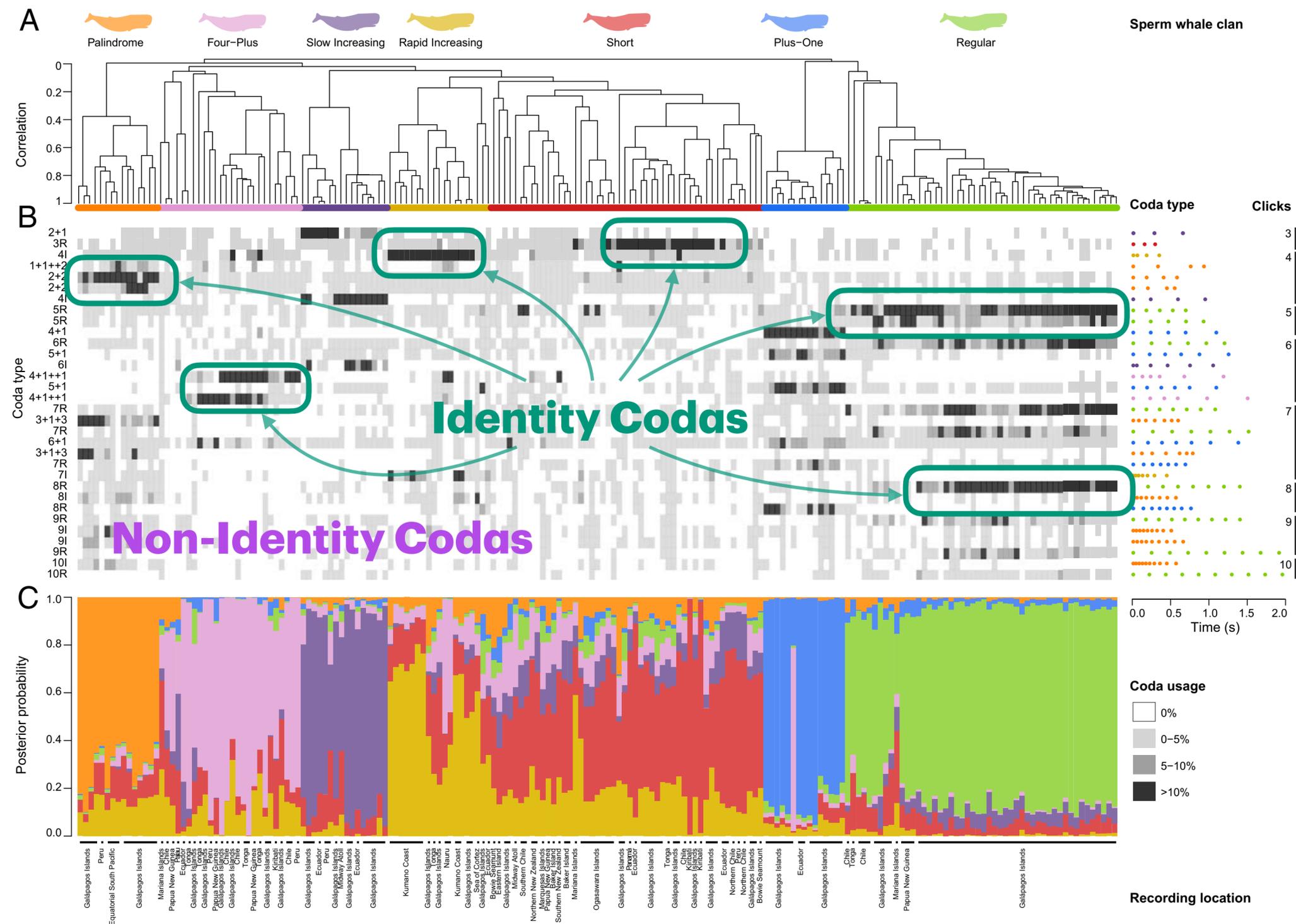
Clan B



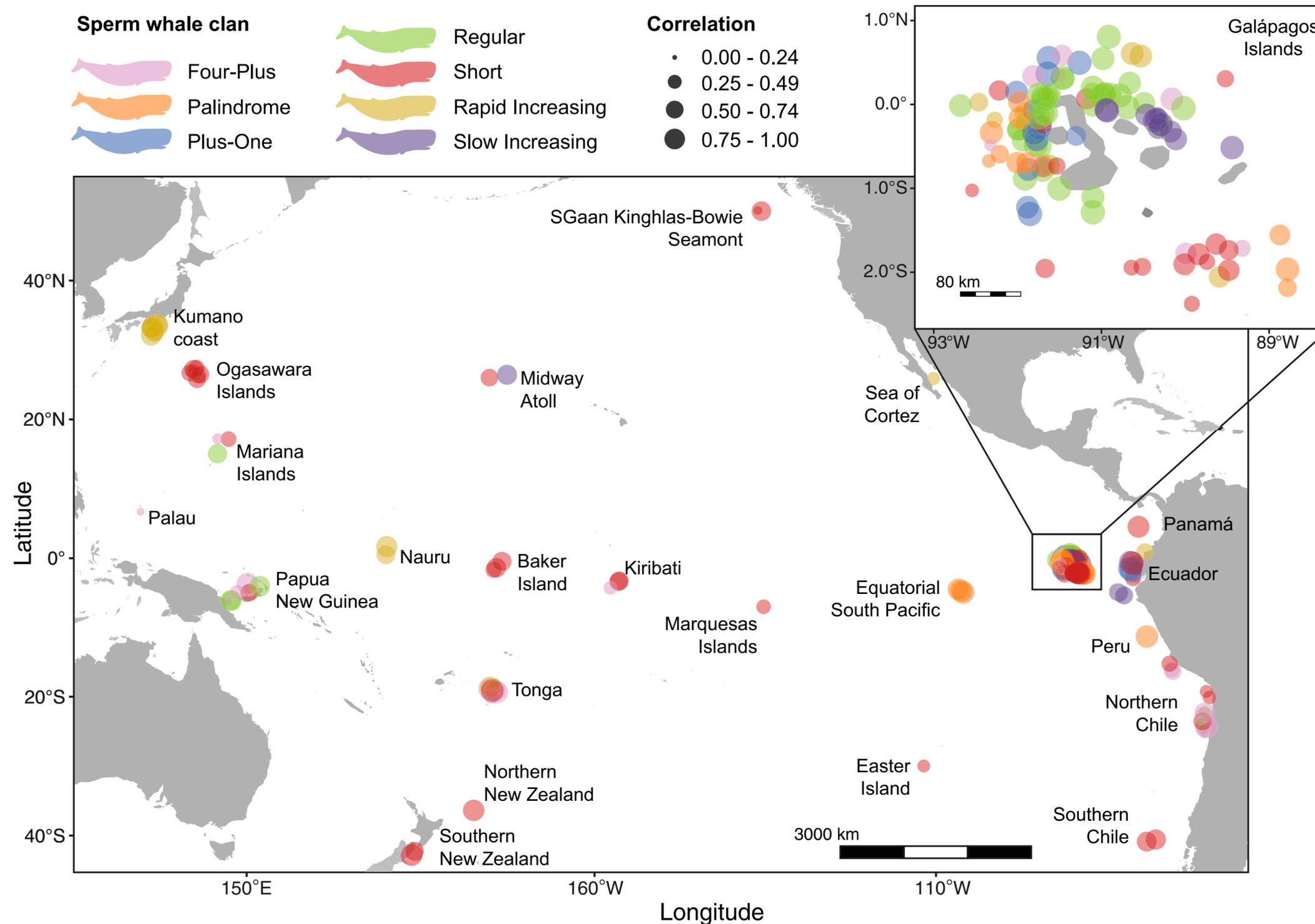
Clan C



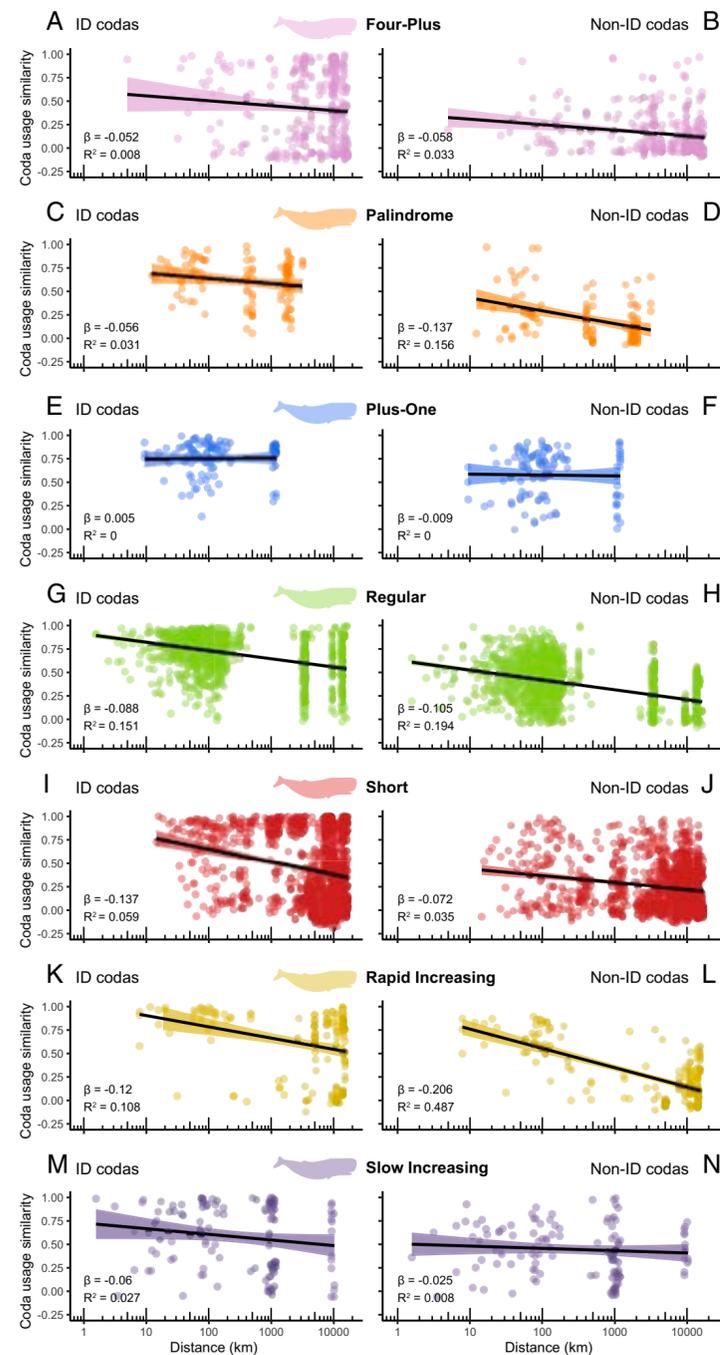
Identity codas as symbolic markers



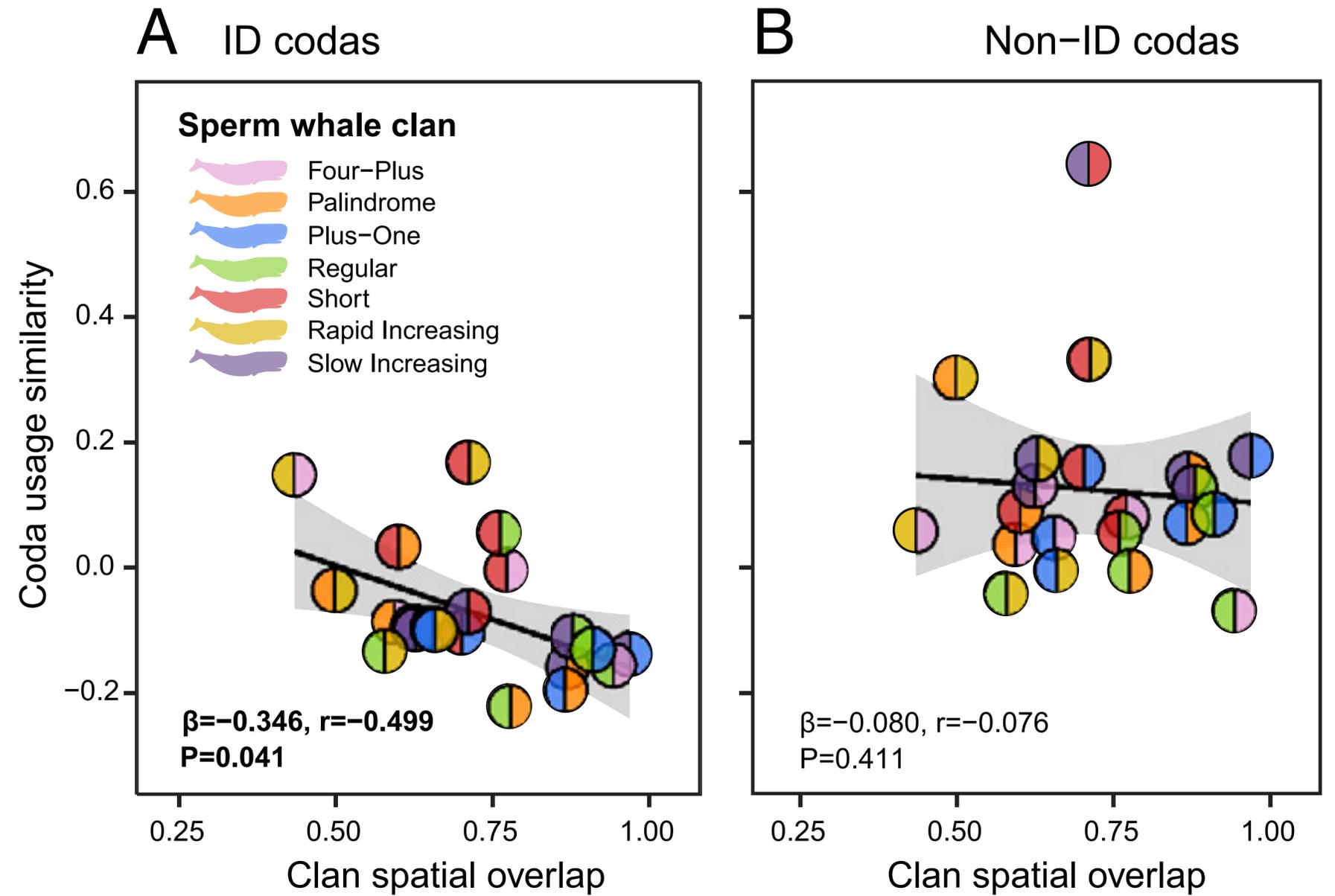
Identity codas as symbolic markers



Identity codas as symbolic markers



Decreasing similarity with distance



Similarity reduces with sympatric overlap

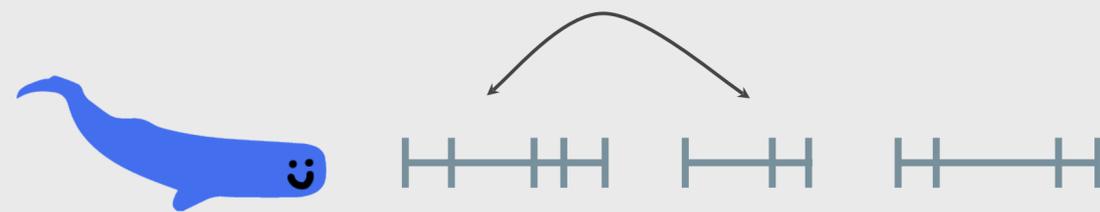
How are
codas put
together?

Previous works

Codas

Vocal repertoire

1. What they say. (vocal repertoire)
2. Cultural markers.
3. ID ~ sympatry.



Hersh, T *et al*, PNAS 2022

Our results

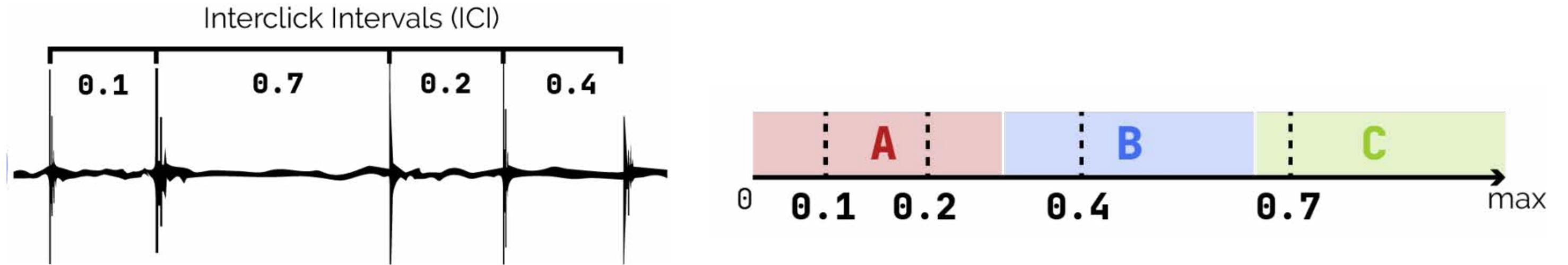
Clicks

Vocal style



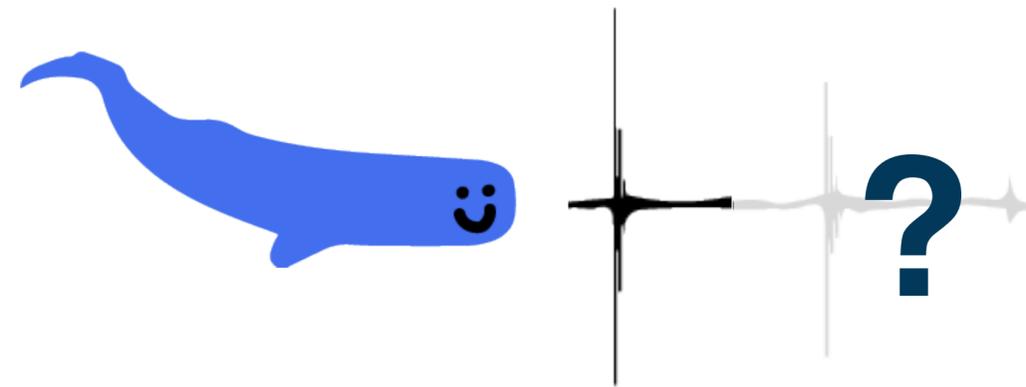
Leitao et al, eLife 2023

Discretization of the continuous ICIs



0.1 • 0.7 • 0.2 • 0.4 **→** **A • C • A • B**

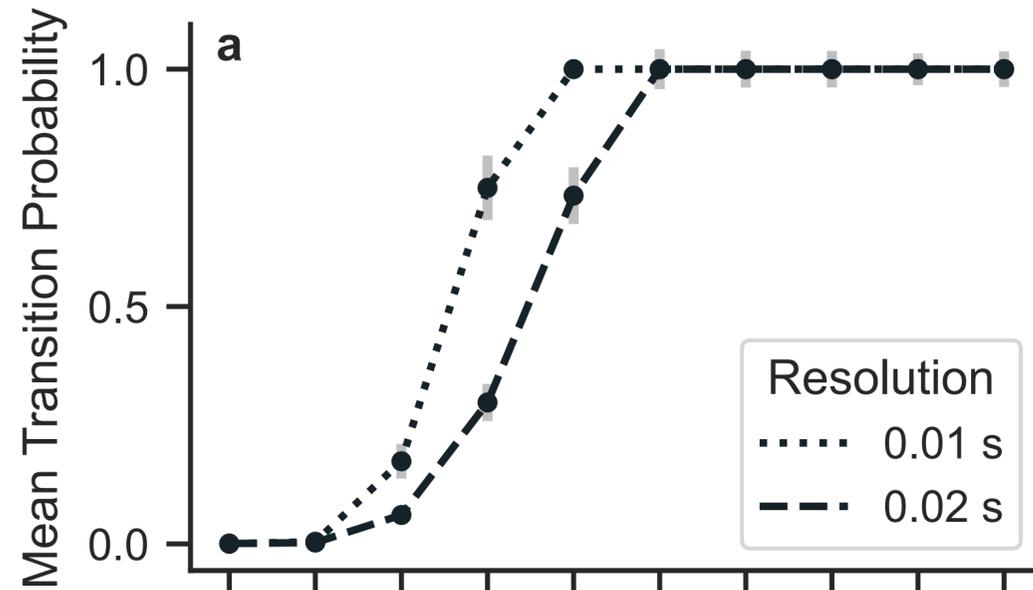
General model for speech comparison



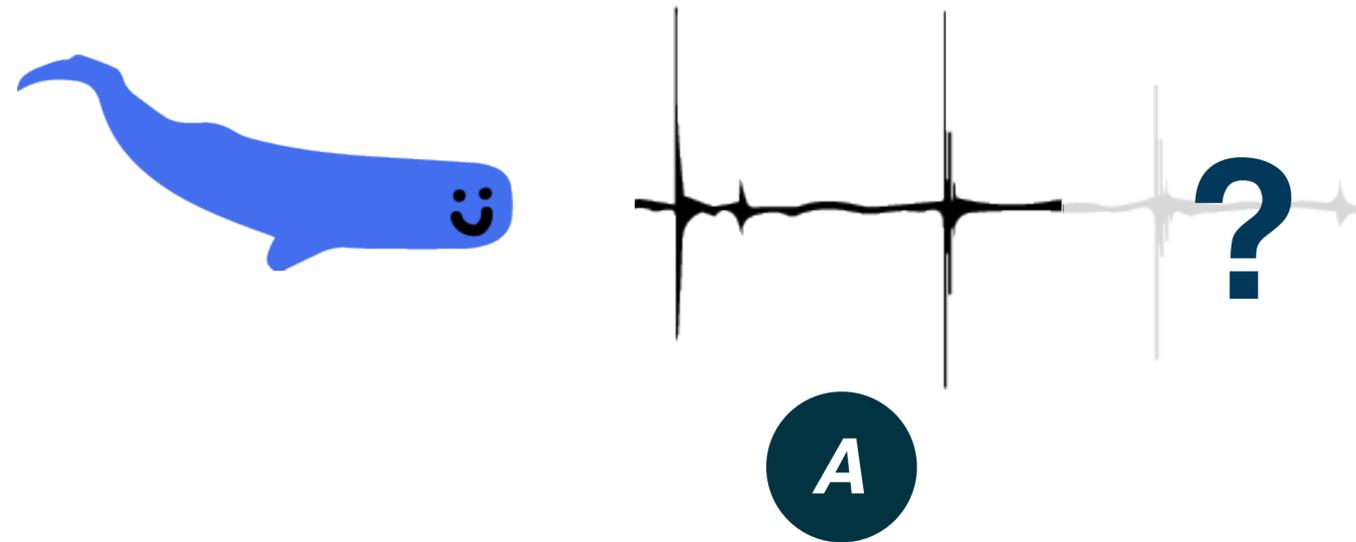
Can we predict the next ICI?

Fixed order Markov chain representation

$$P(X_i|X_0, X_1, \dots, X_{i-1}) = P(X_i|\underbrace{X_{i-h}, \dots, X_{i-1}}_h).$$



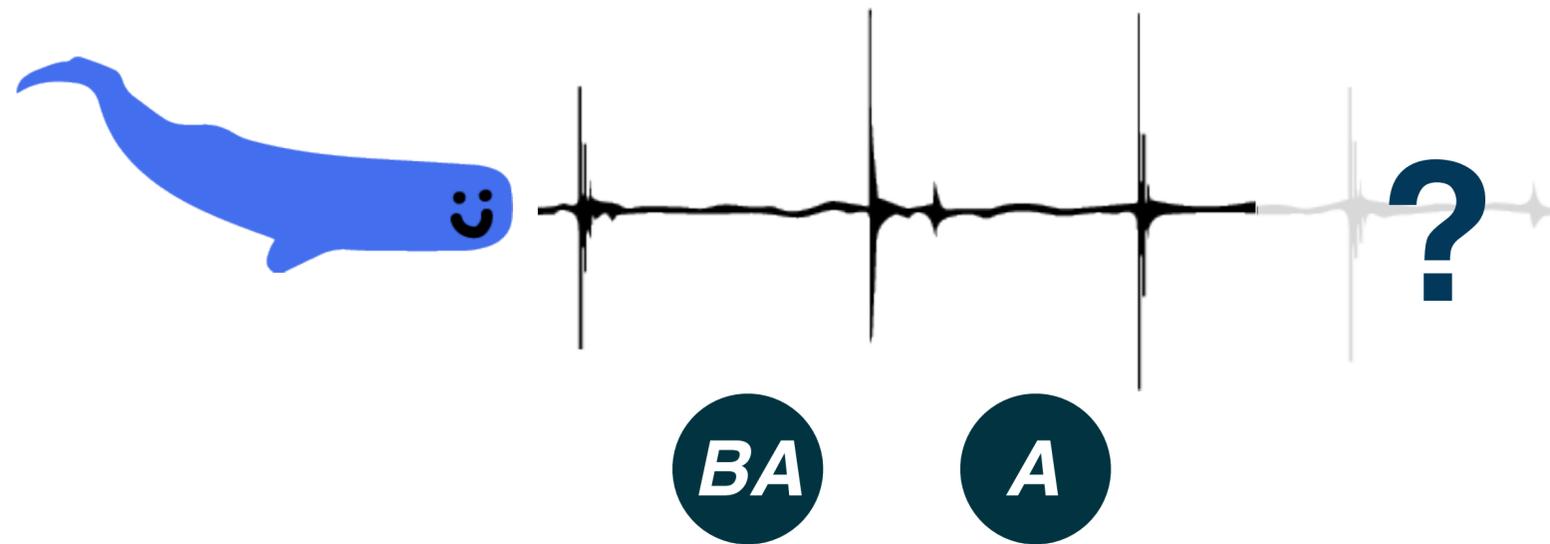
General model for subcode comparison



$$q_A = P(X|A)$$

How does the previous ICI influence the prediction?

General model for subcode comparison



$$D_{KL}(q_{BA} || q_A) > K$$

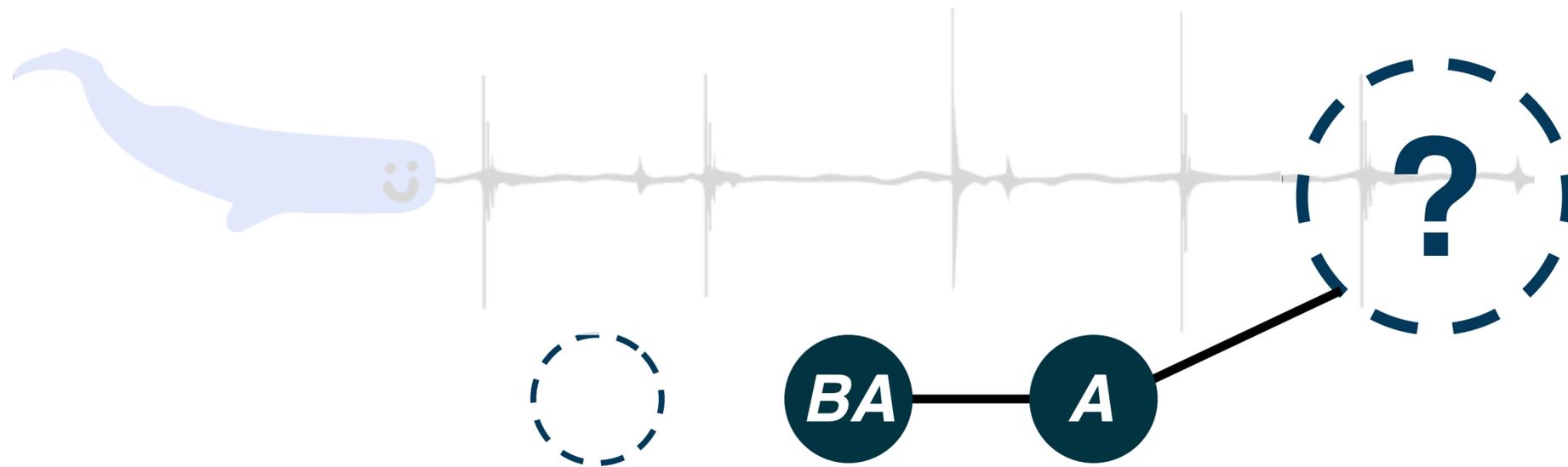
How does the previous ICI influence the prediction?

General model for subcode comparison



We stop increasing memory if the increase does not result in new information.

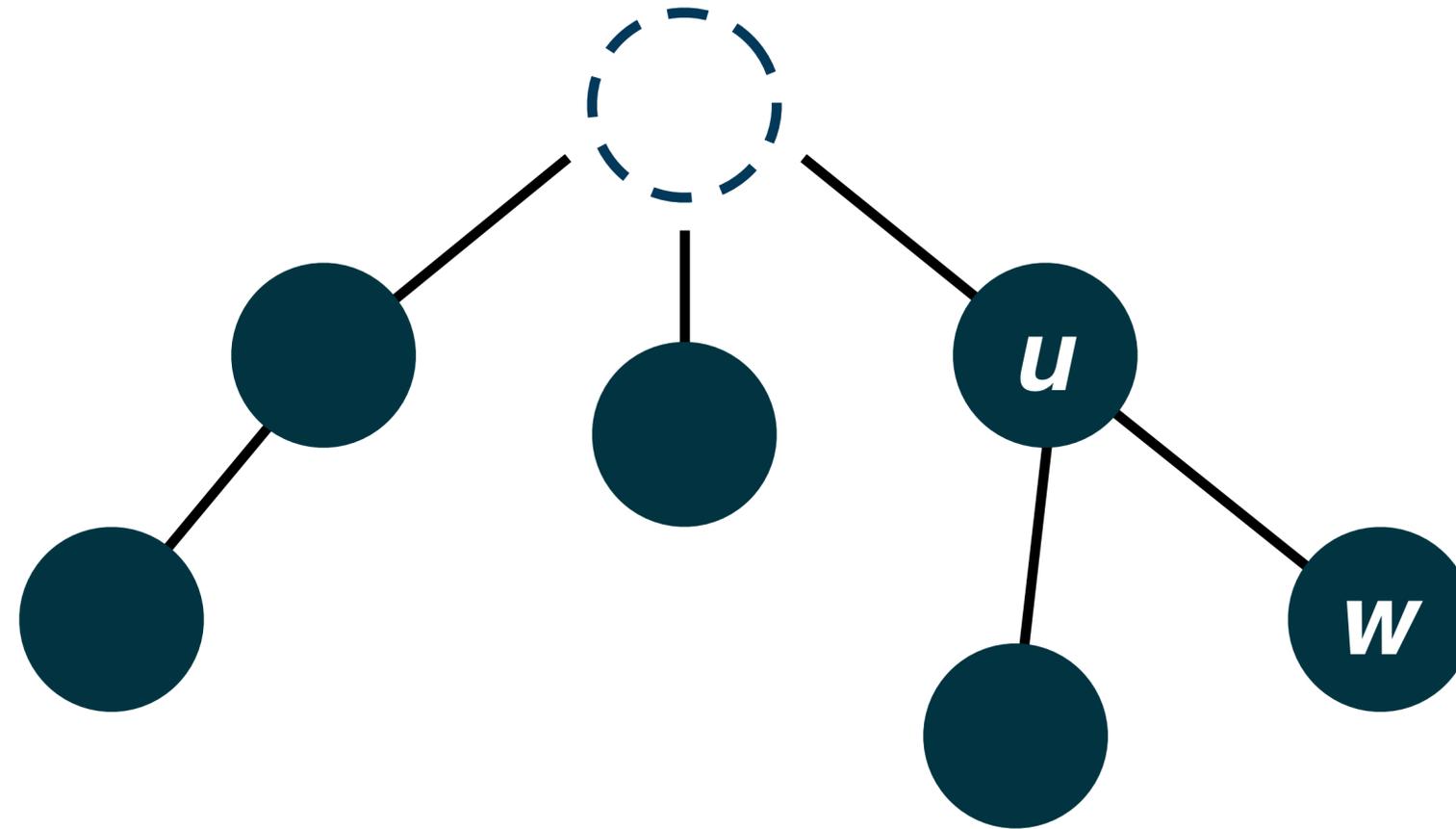
General model for subcode comparison



This process defines a network of unique *contexts*: finite sequences that influence ICI generation.

General model for subcodas comparison

Variable Length Markov Chain approach

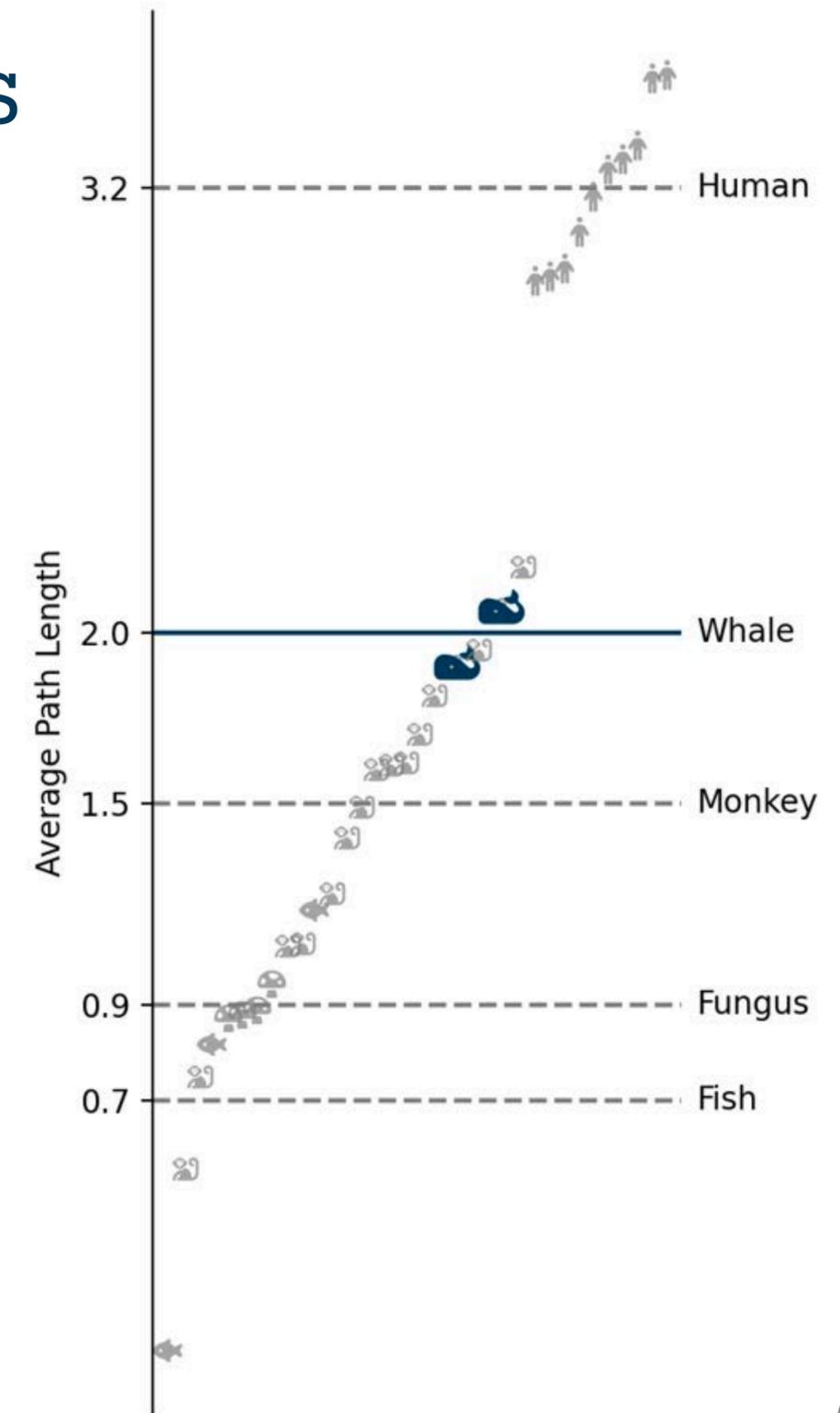
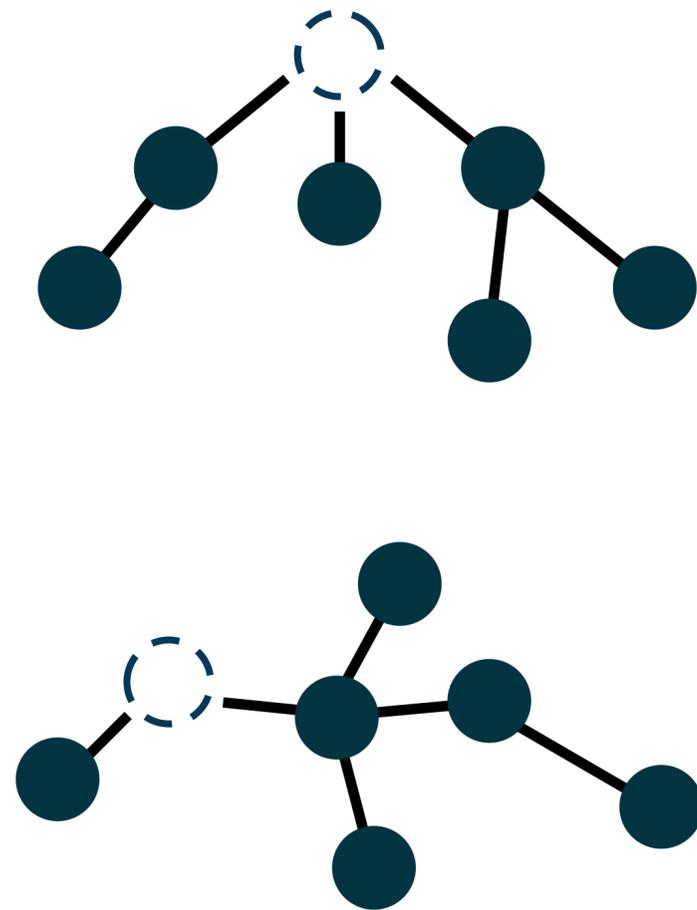


$$q_w = P(X|w)$$

distribution of transition probabilities given context w

VLMC captures speech characteristics

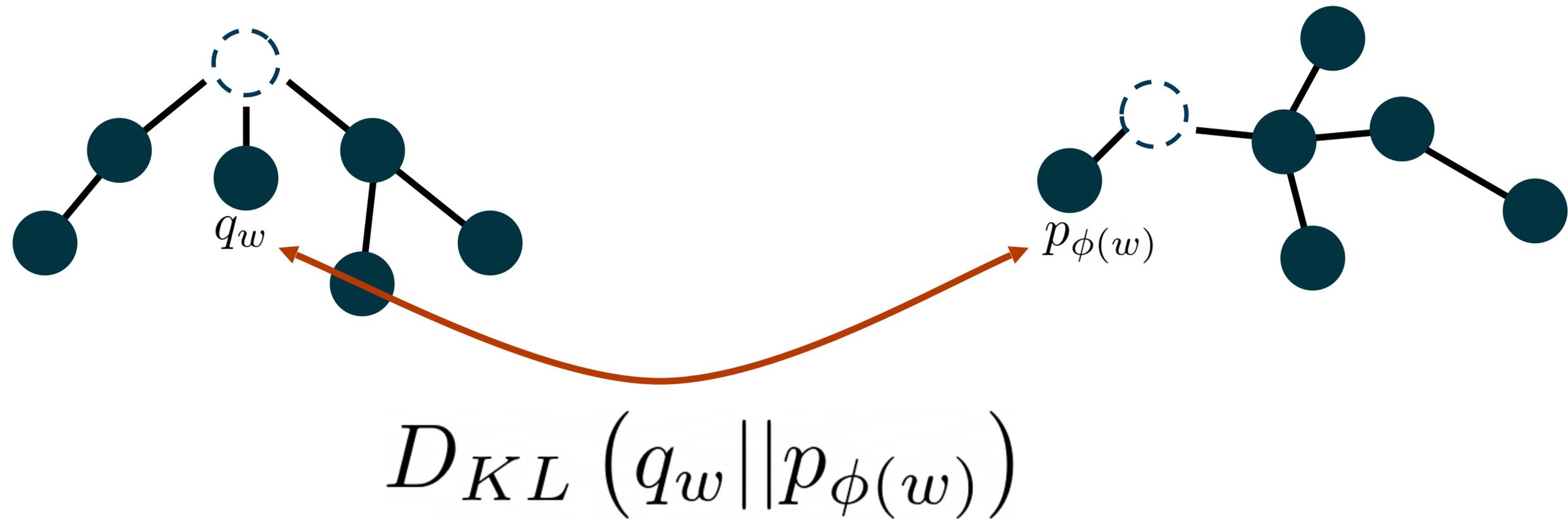
Structural comparison of trees



(work in progress)

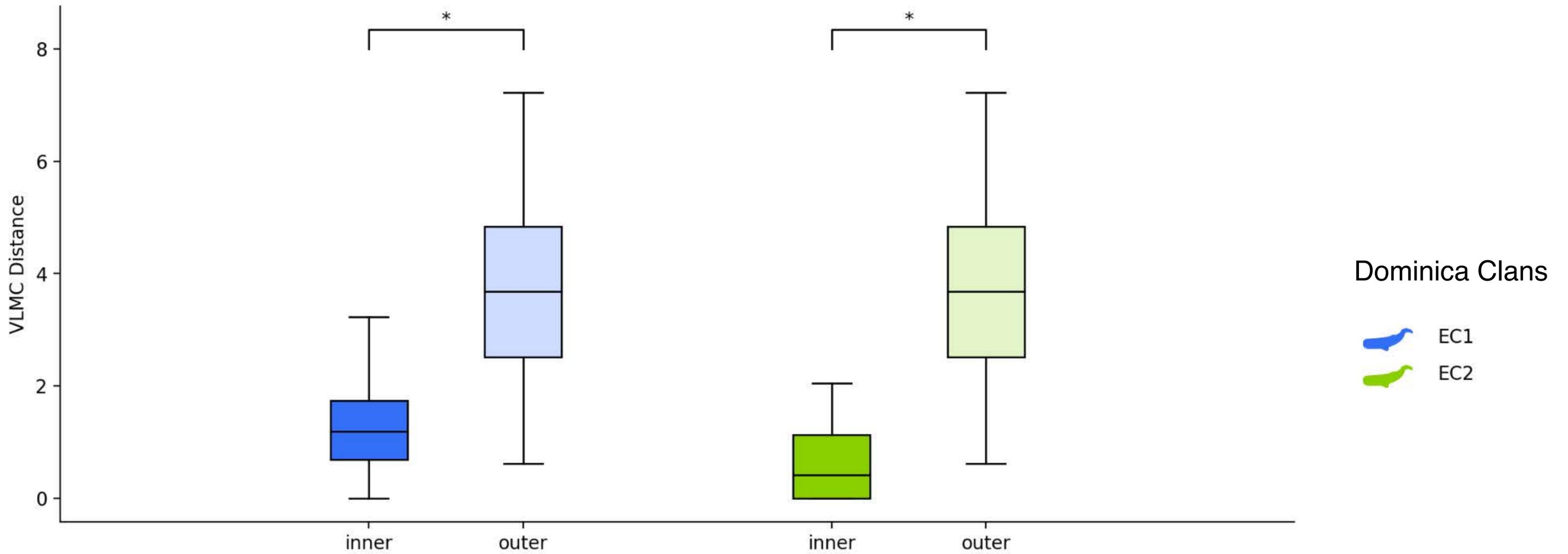
VLMC captures speech characteristics

Quantitative comparison within the same alphabet/species

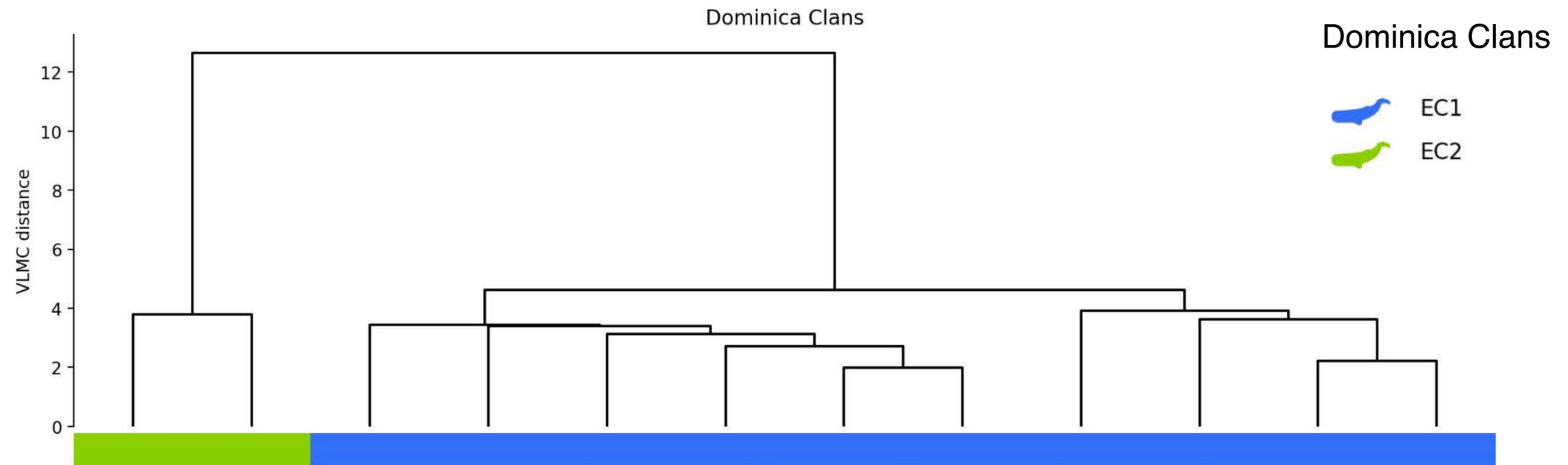


Results

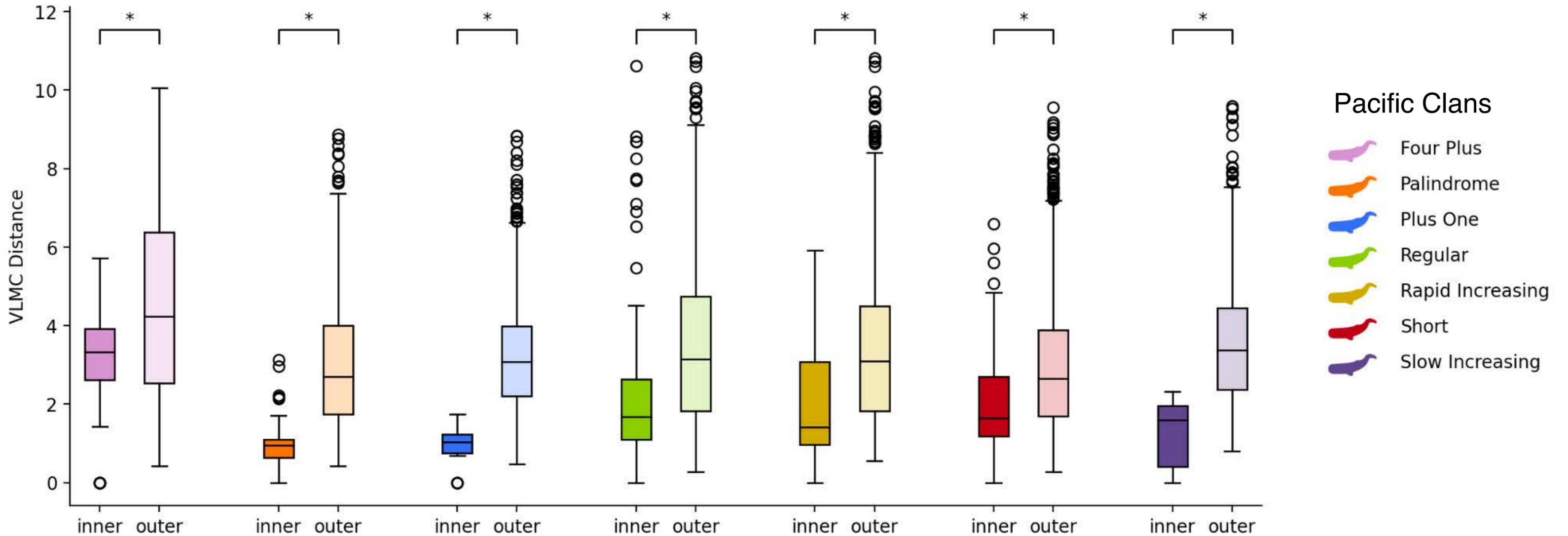
Validation: Vocal clans have distinct vocal styles



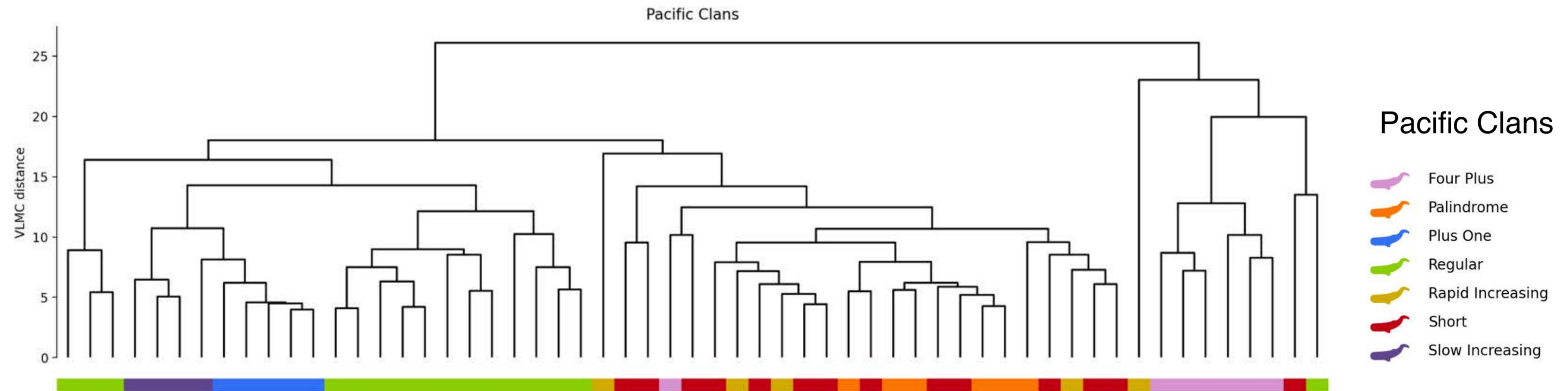
Validation: Vocal style captures social hierarchy



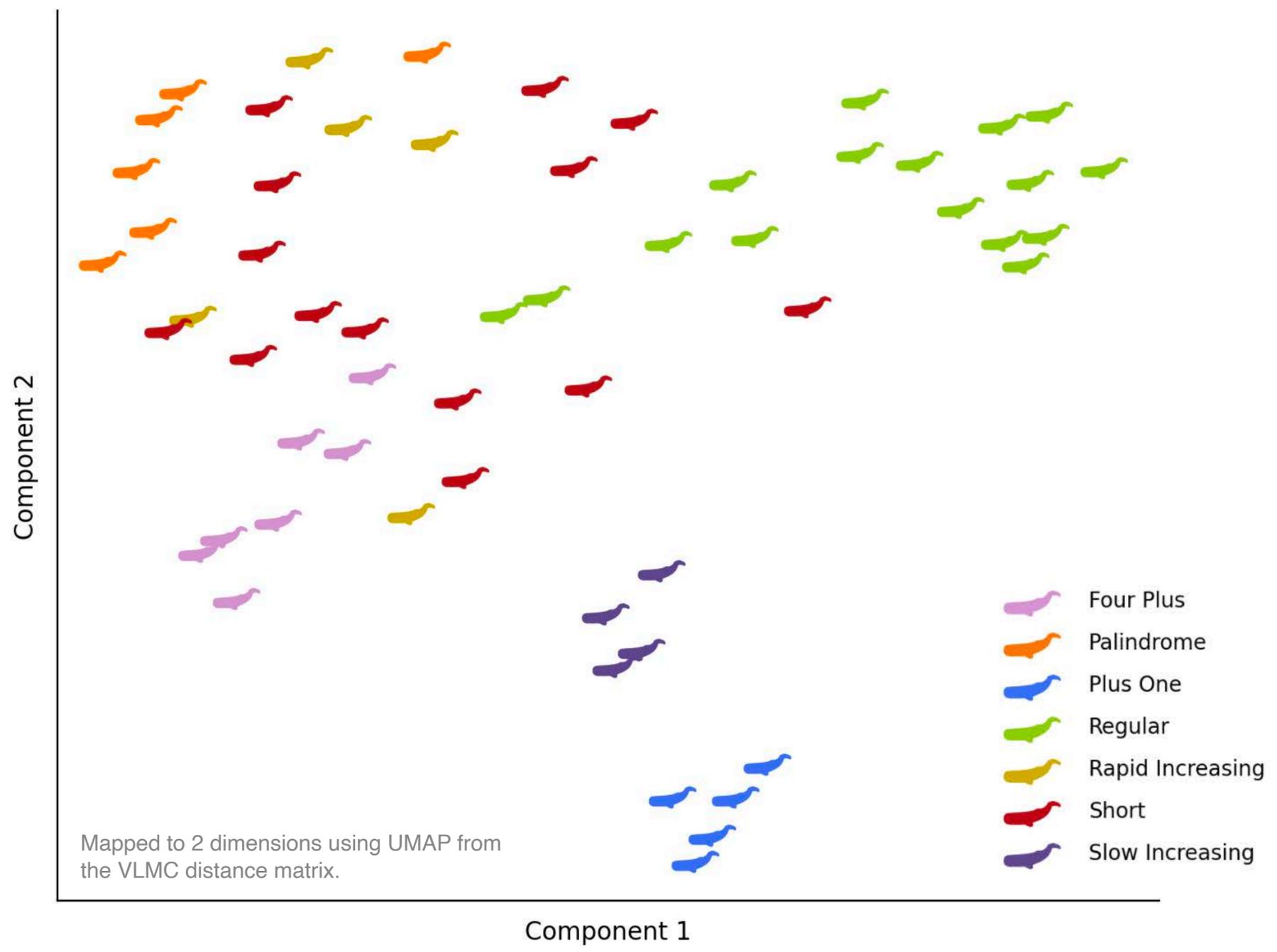
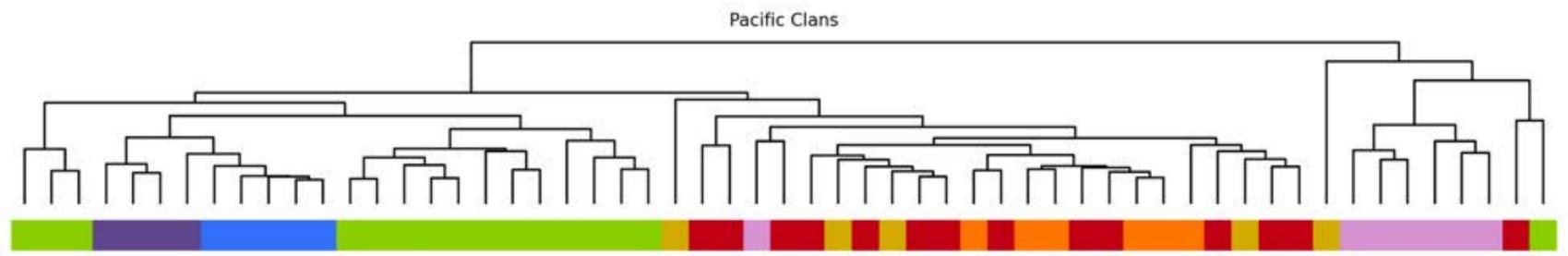
Pacific clans: Vocal clans have distinct vocal styles

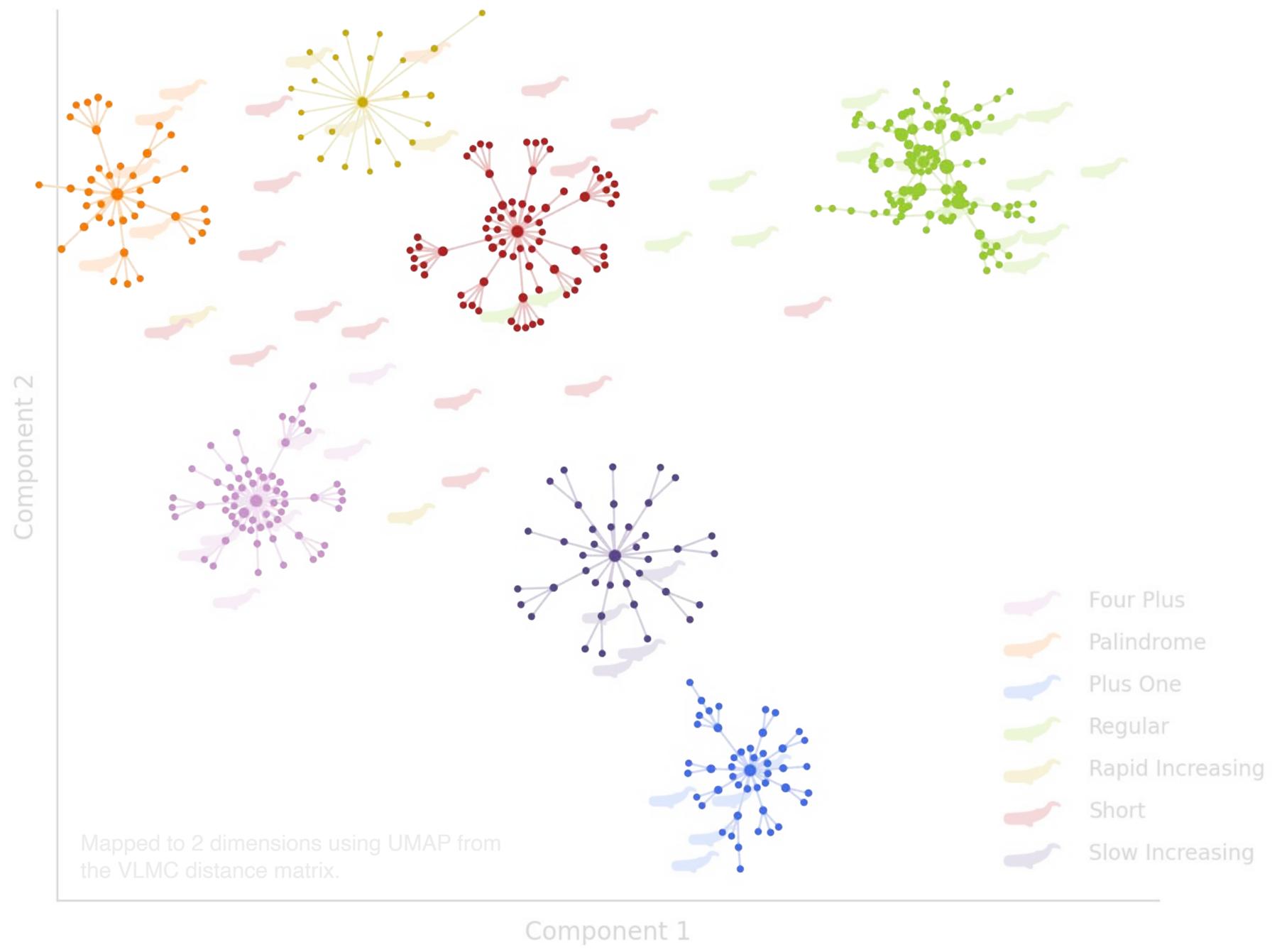
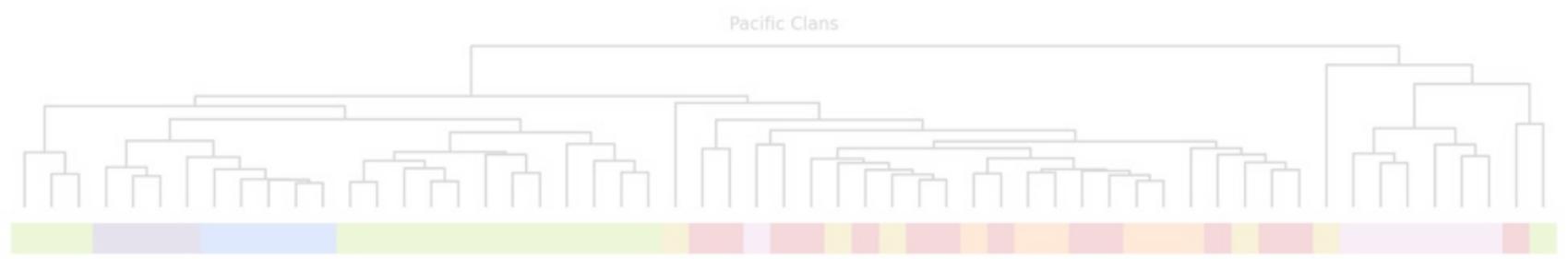


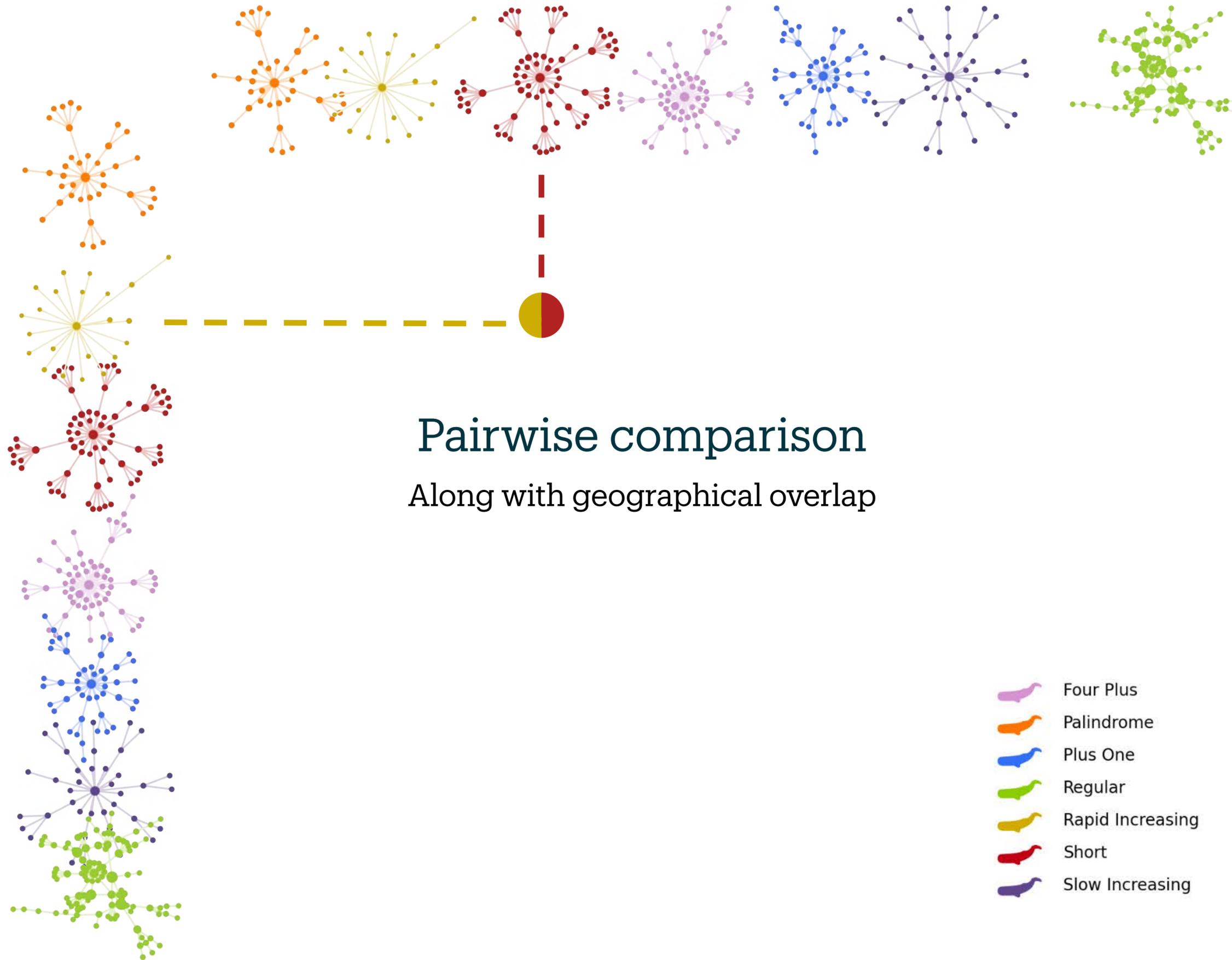
Vocal style captures social hierarchy



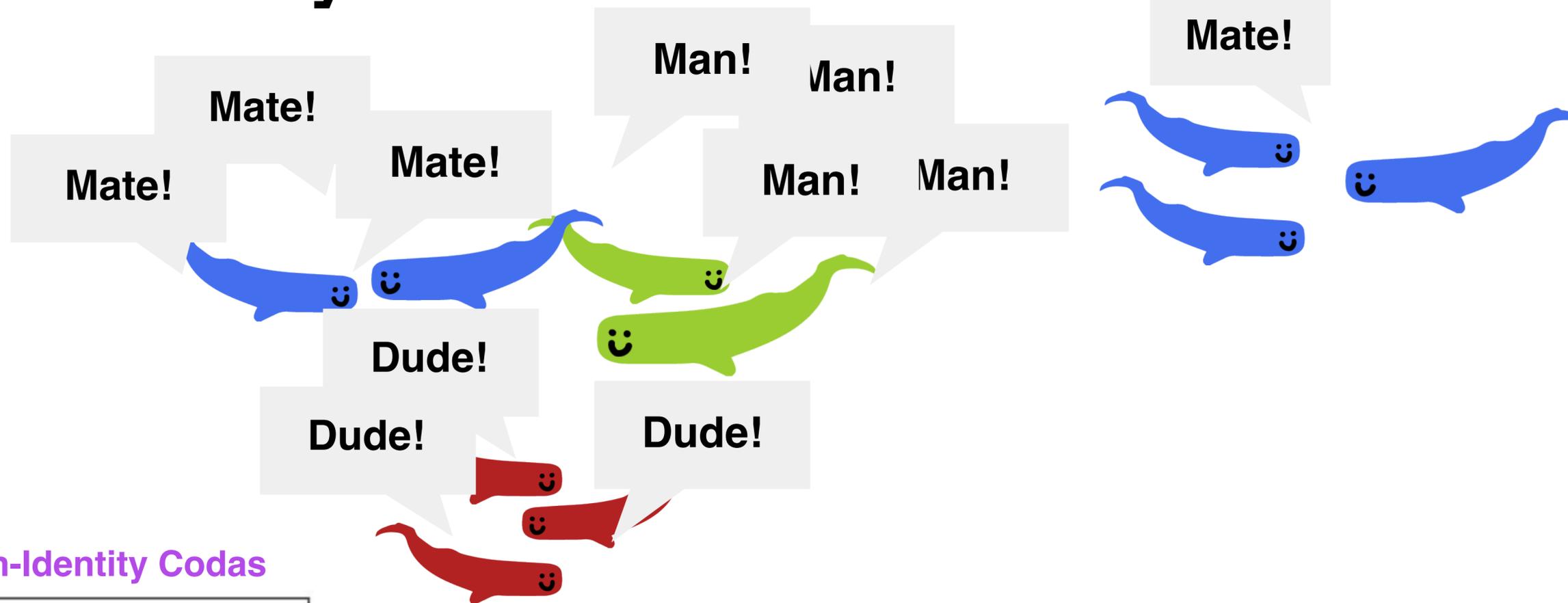
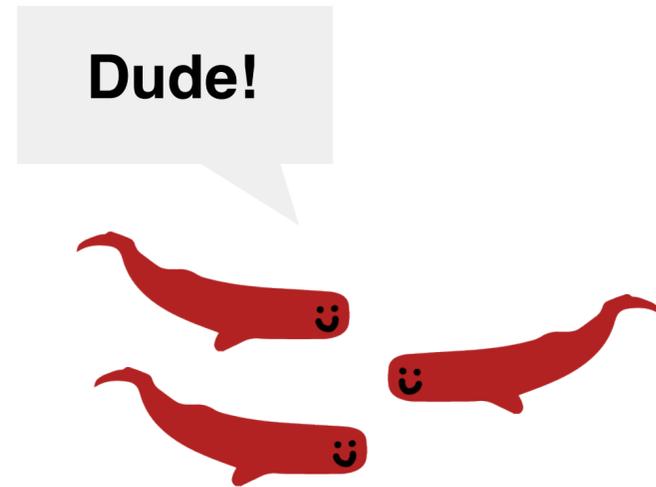
Click generation provides speech classification at a much finer resolution, while coherent with vocal clans.





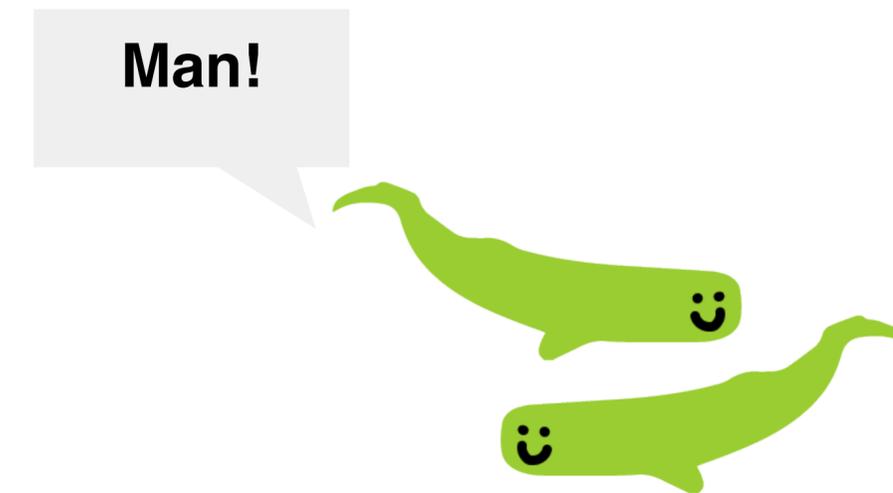
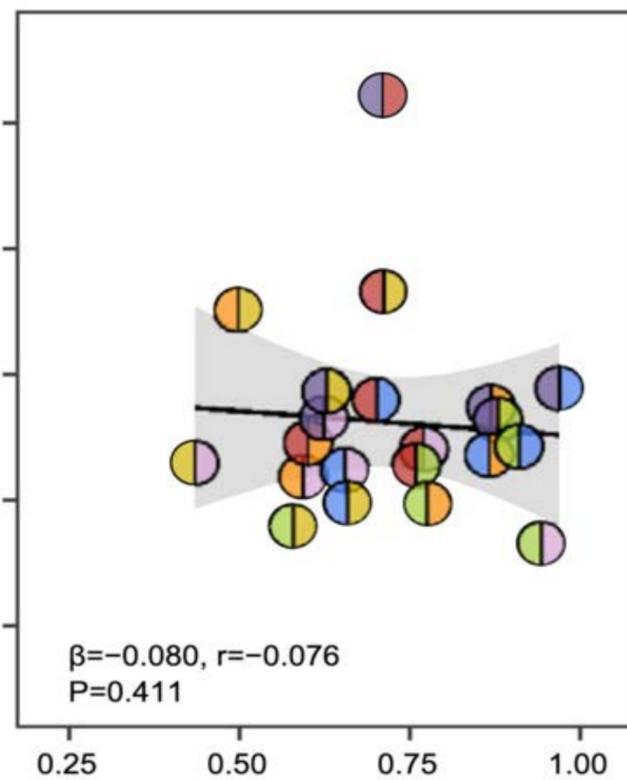
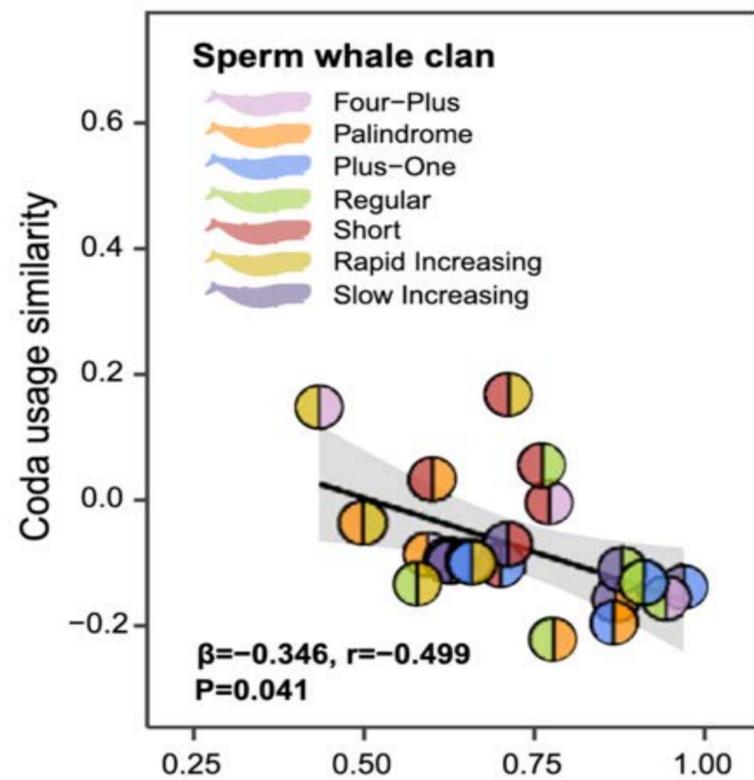


Identity codas as symbolic markers

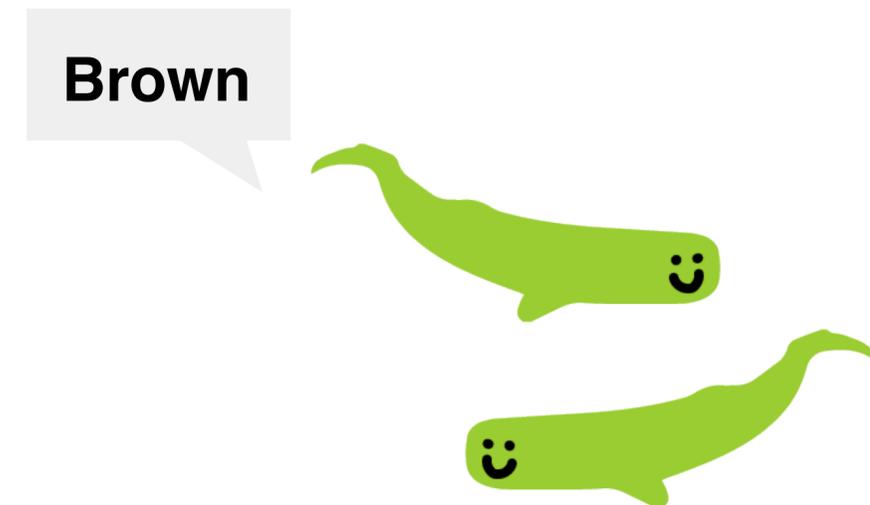
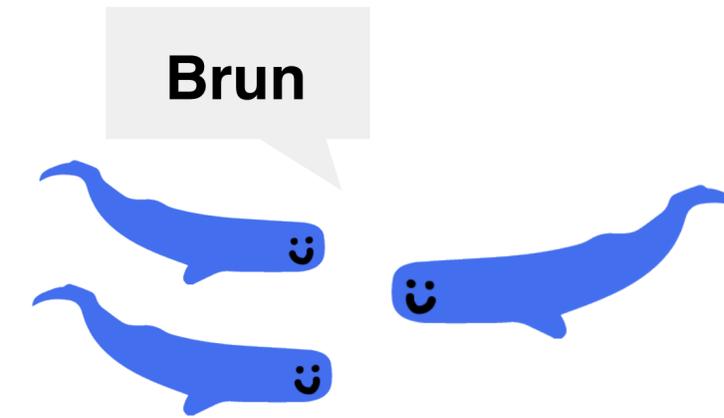
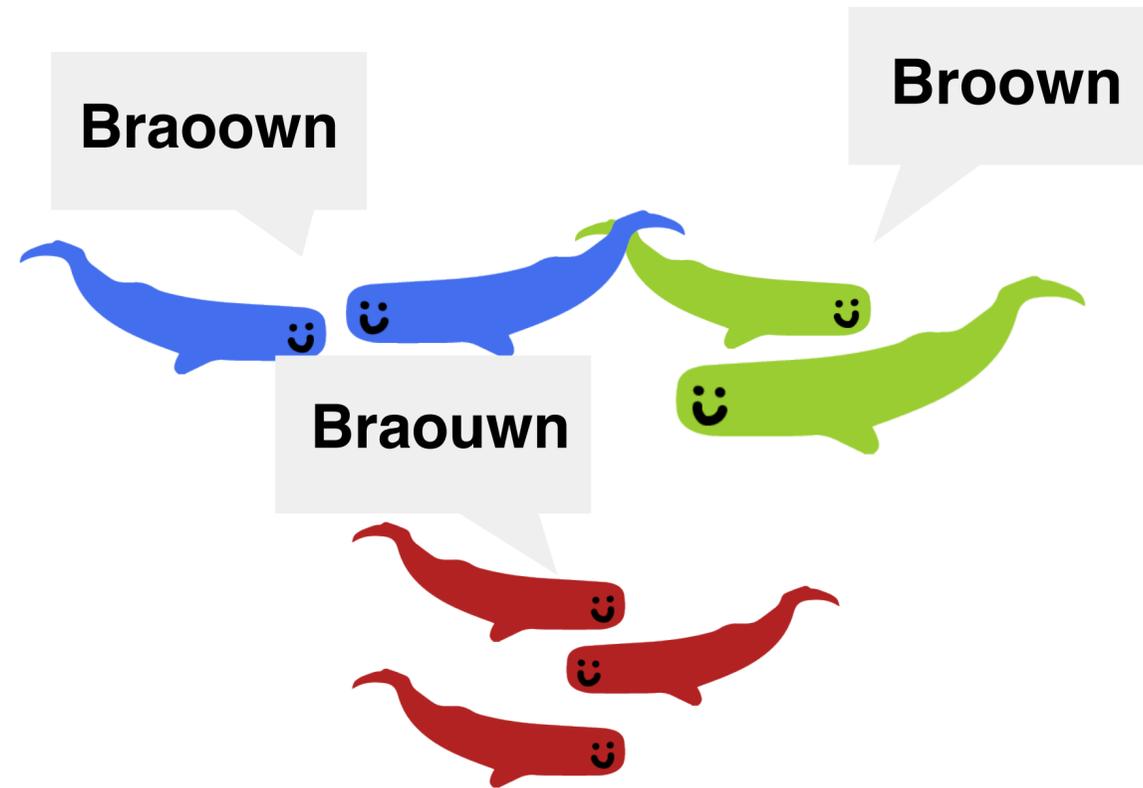
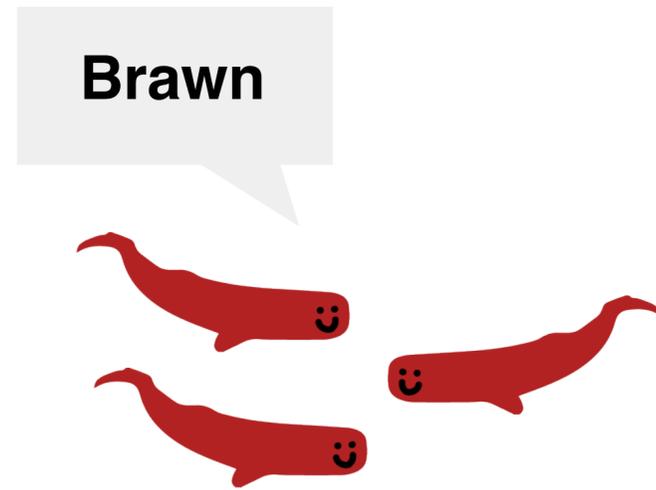


Identity Codas

Non-Identity Codas

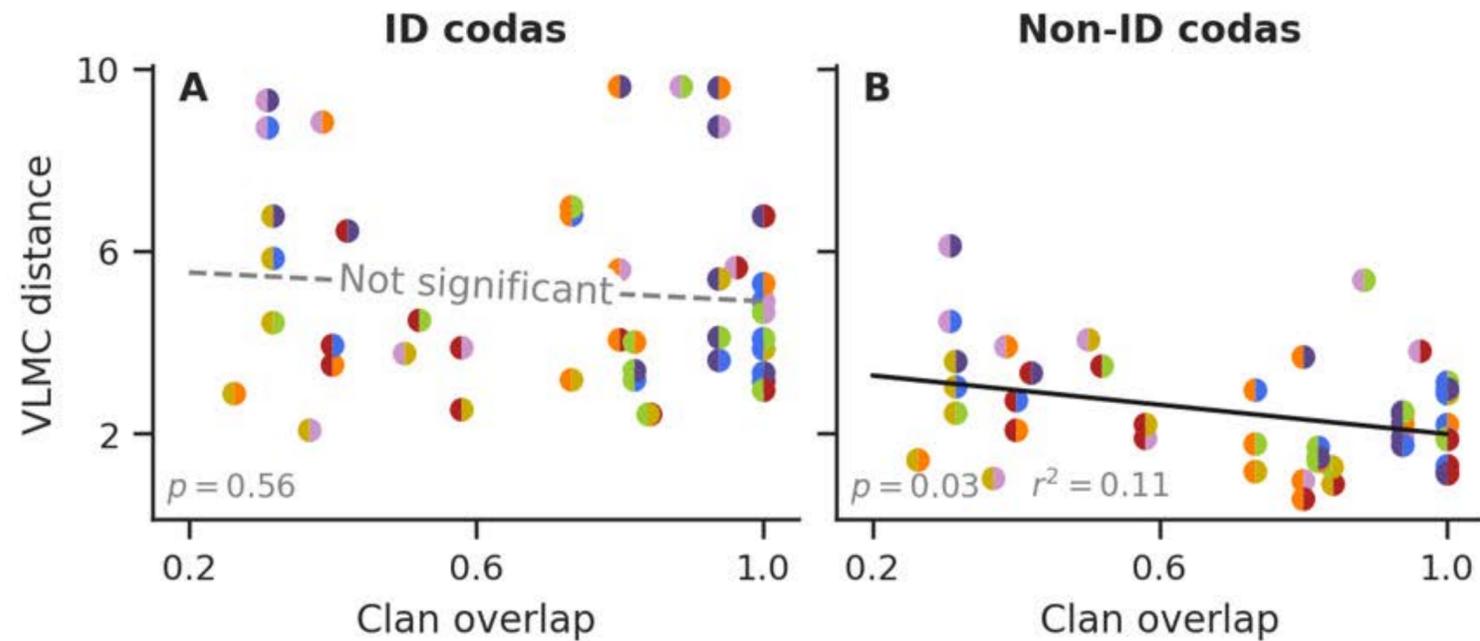


Non-identity codas show social learning



Identity Codas

Non-Identity Codas



Recap

Coda repertoires

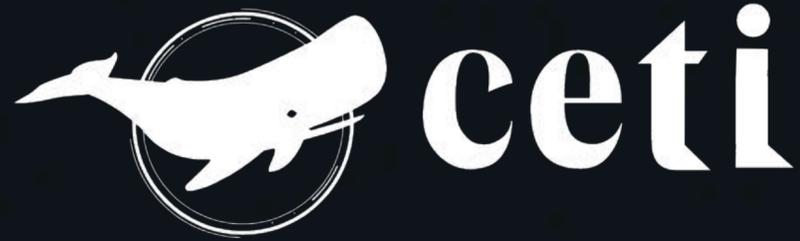
1. What they say. (vocal repertoire)
2. Cultural markers.
3. ID ~ sympatry.

Subcoda structure

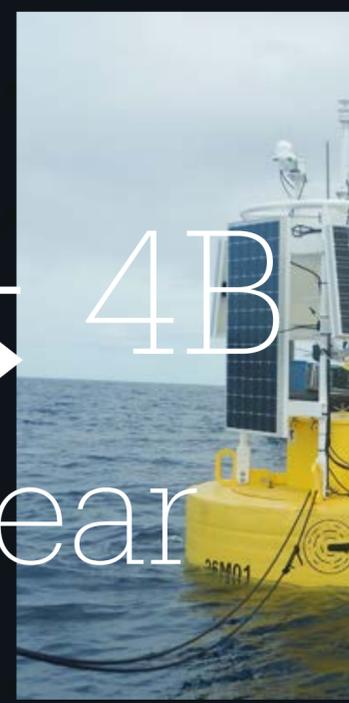
1. How they say it (vocal style)
2. Captures social units.
3. non-ID ~ sympatry
4. Akin to Accents.

Is this **ENOUGH?**

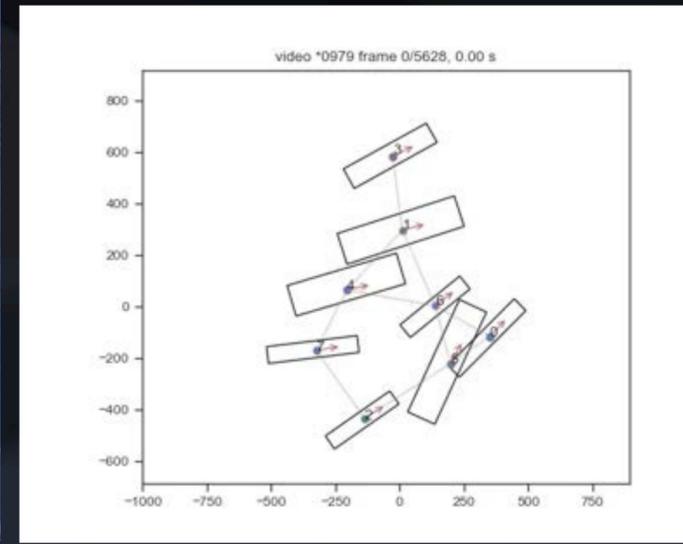
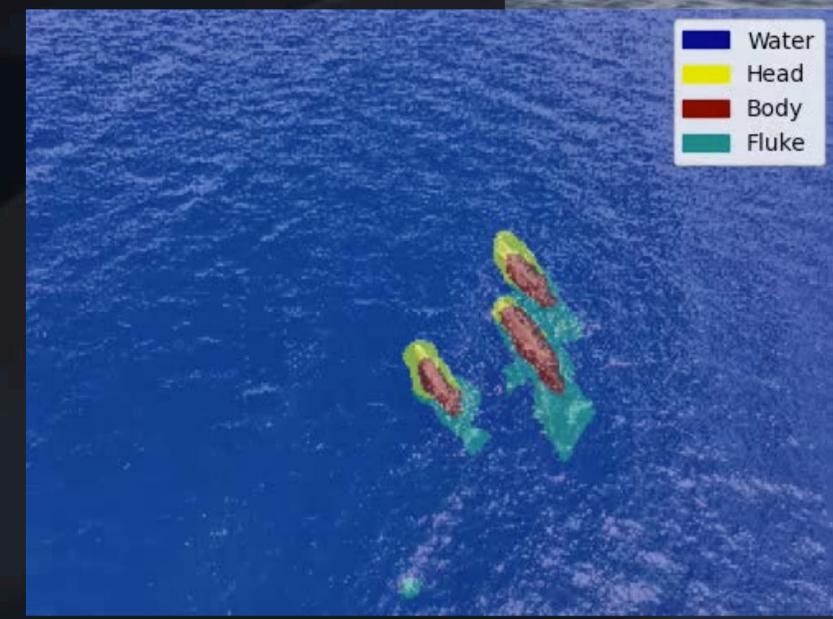
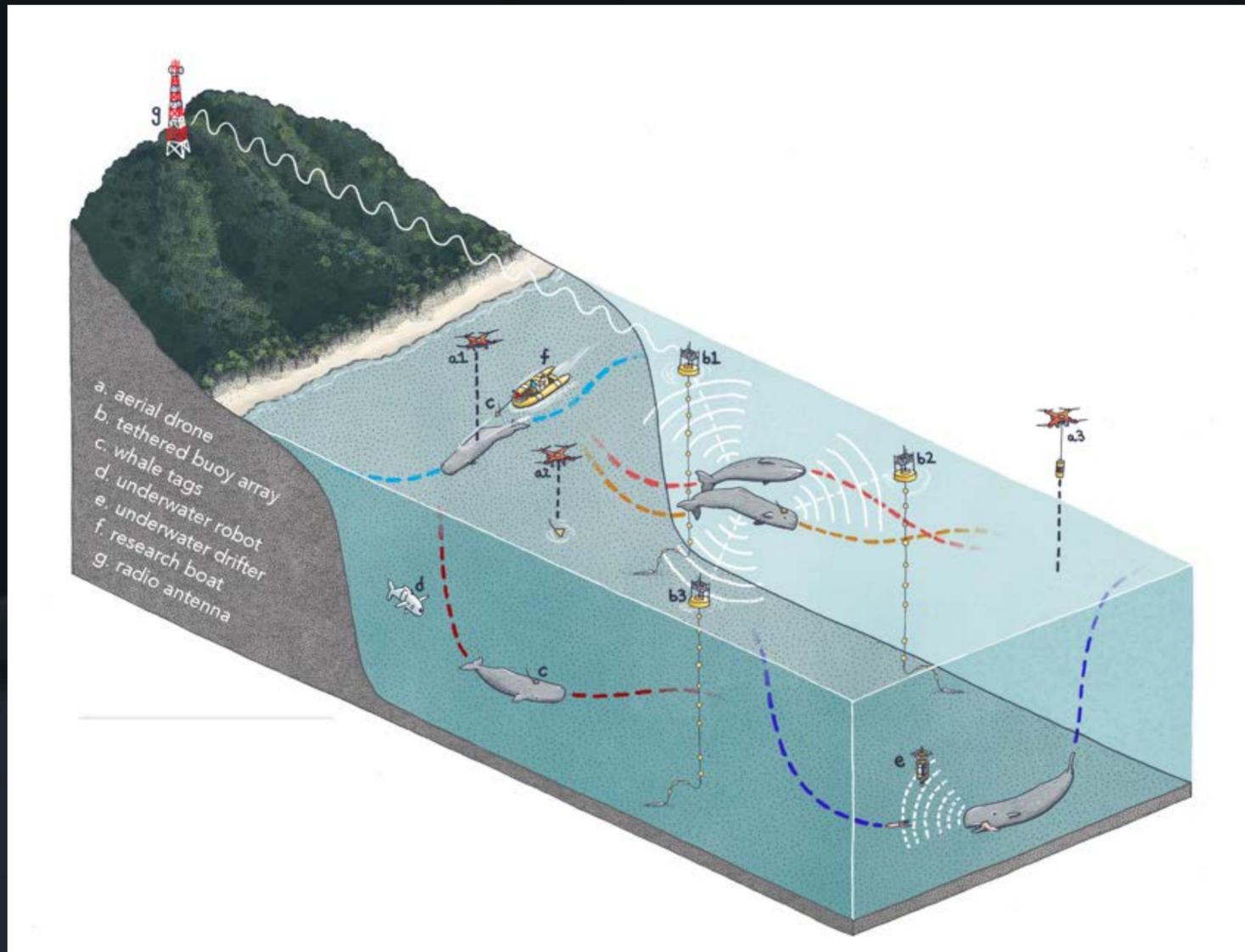
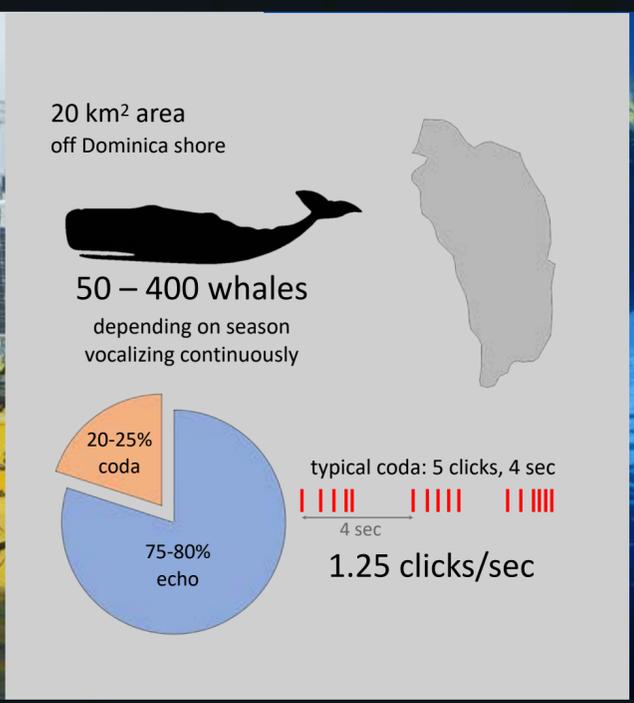
MORE
BEHAVIOUR



Mining context and behaviour



400M → 4B
clicks/year



Why they develop a complex language?



Why they develop a complex language?

JOURNAL ARTICLE

Who Cares? Between-group variation in alloparental caregiving in sperm whales [Get access >](#)

Shane Gero , Dan Engelhaupt , Luke Rendell , Hal Whitehead

Behavioral Ecology, Volume 20, Issue 4, July-August 2009, Pages 838–843,
<https://doi.org/10.1093/beheco/arp068>

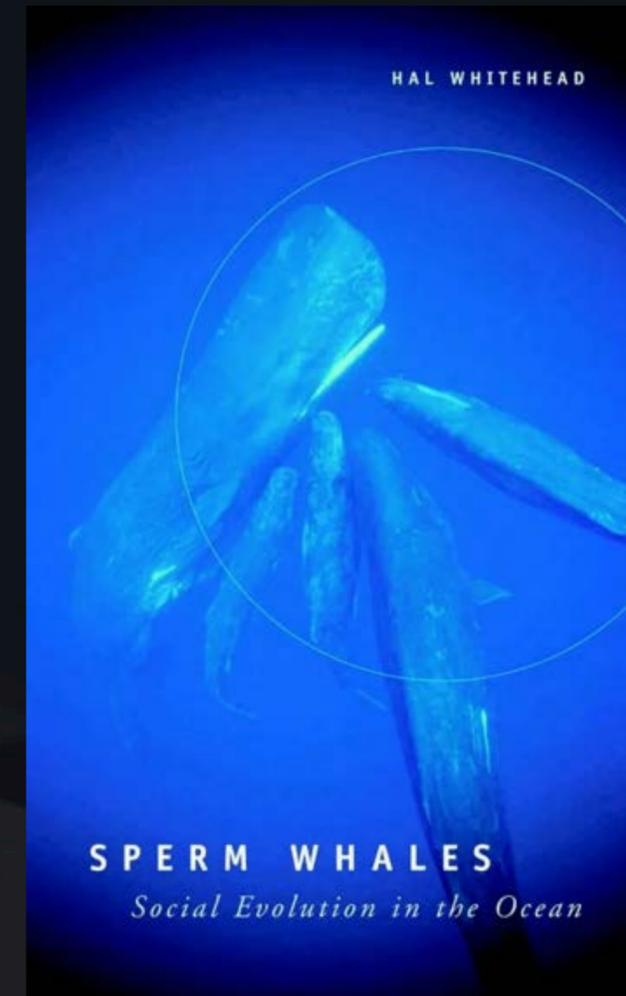
Published: 19 May 2009 [Article history ▾](#)

[Home](#) > [Behavioral Ecology and Sociobiology](#) > Article

Babysitting, dive synchrony, and indications of alloparental care in sperm whales

Published: April 1996

Volume 38, pages 237–244, (1996) [Cite this article](#)



Collective care of calves!
But birth observations are exceedingly rare
4 reported in last 60yr

First recorded birth event

July 8 2023, Dominica



Pre (60-30 min before birth)



During (30-0 min before birth)



Post (0-30 min after birth)



End (170 min after birth)



First recorded birth event

Data collection



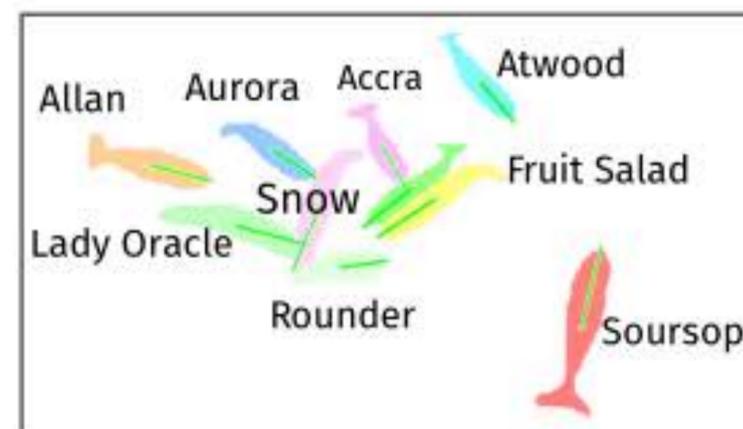
46 minutes of video
spanning 4 hours

Segmentation



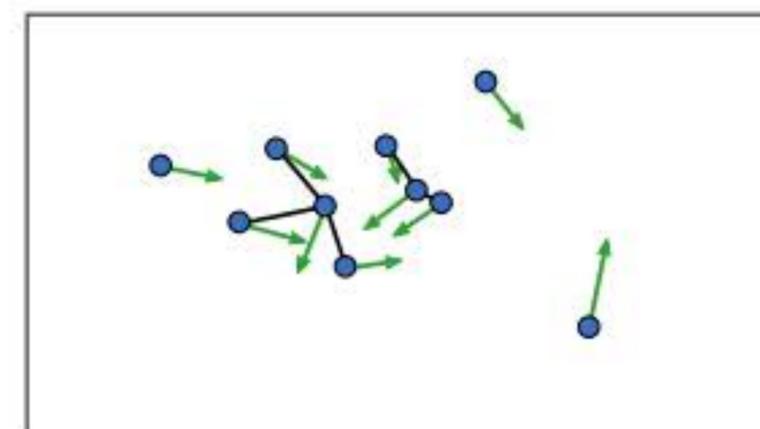
 Track whales
 Detect orientations

Expert annotations



Identify whales
Edit segmentations

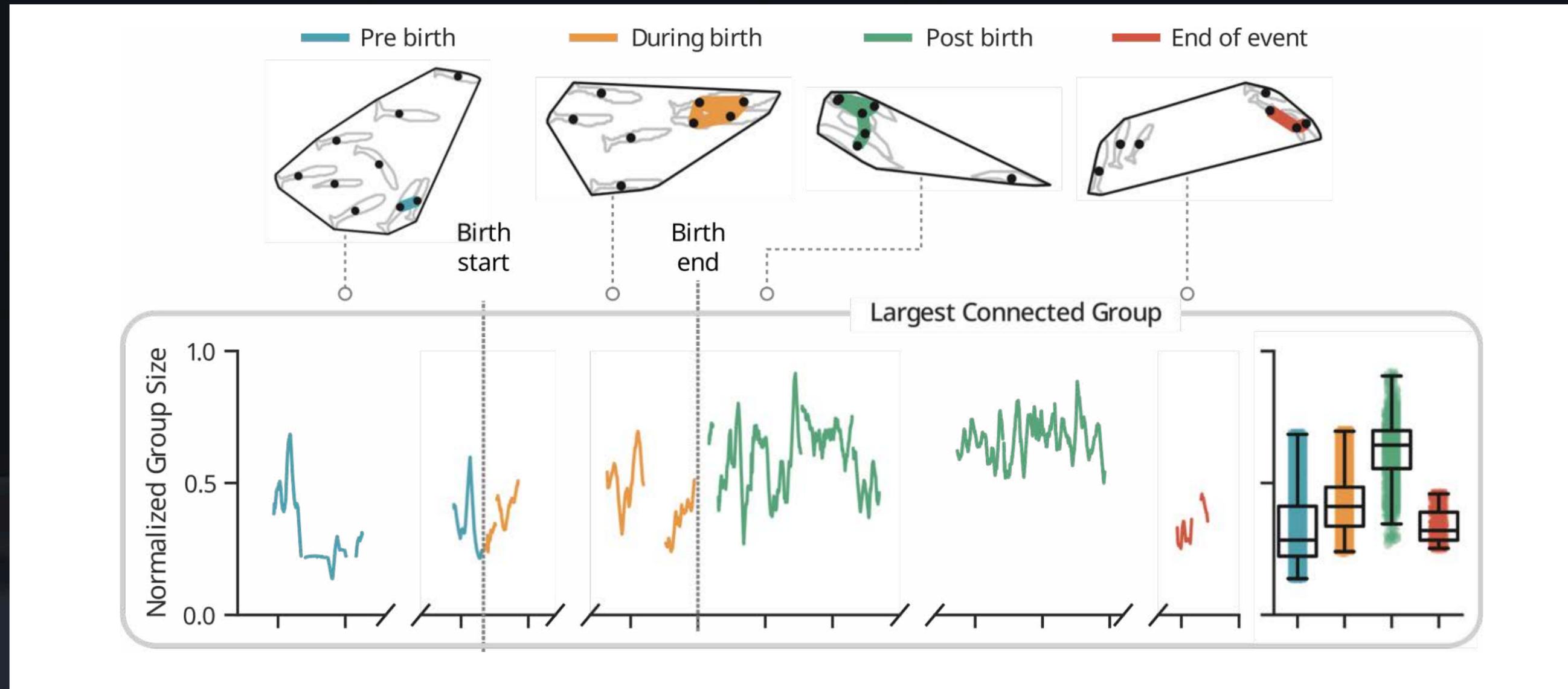
Network analysis



Group dynamics
Individual roles

Network analysis: Macroscale

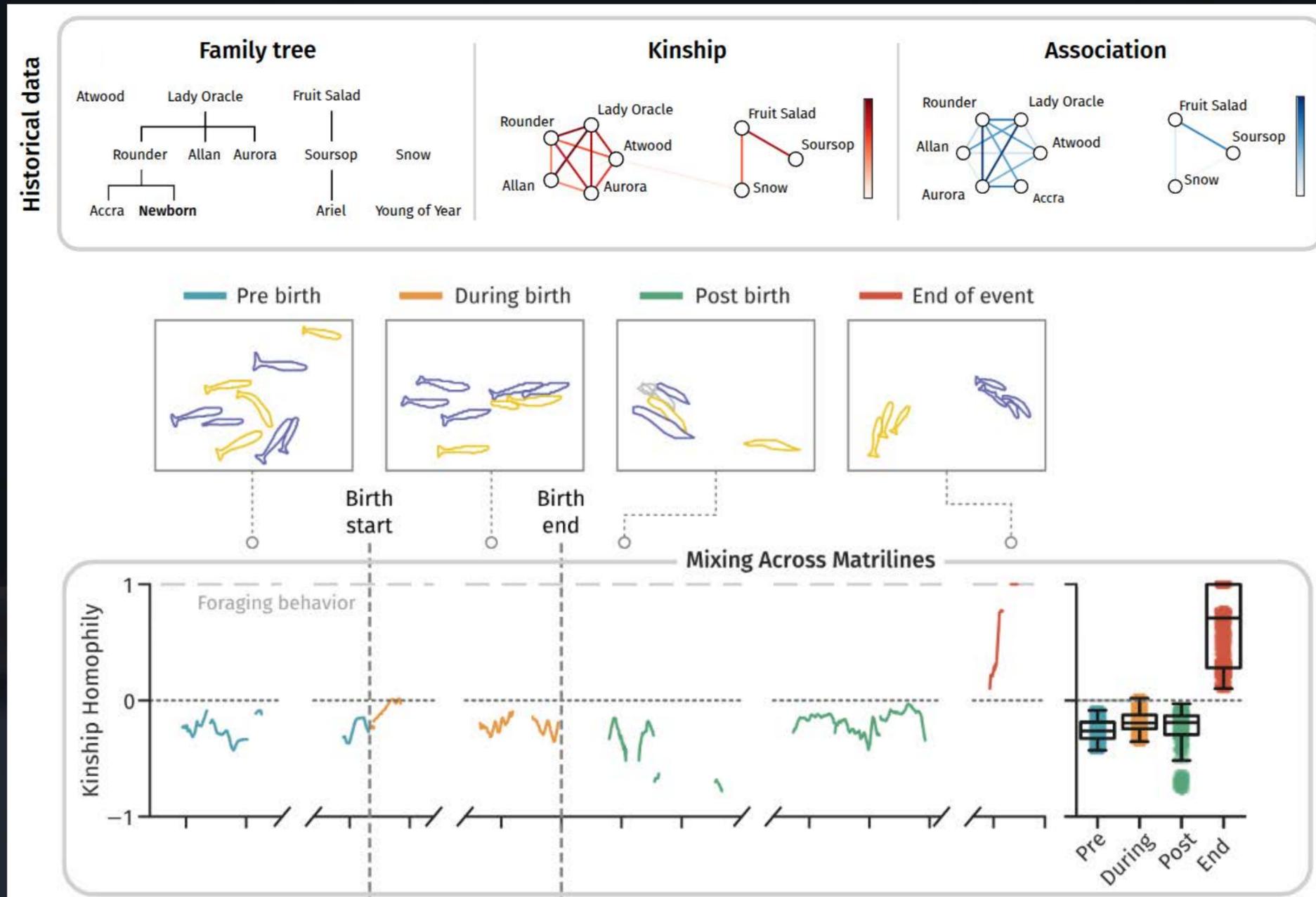
Giant Connected Component



Increases during birth and peaks post birth

Network analysis: Mesoscale

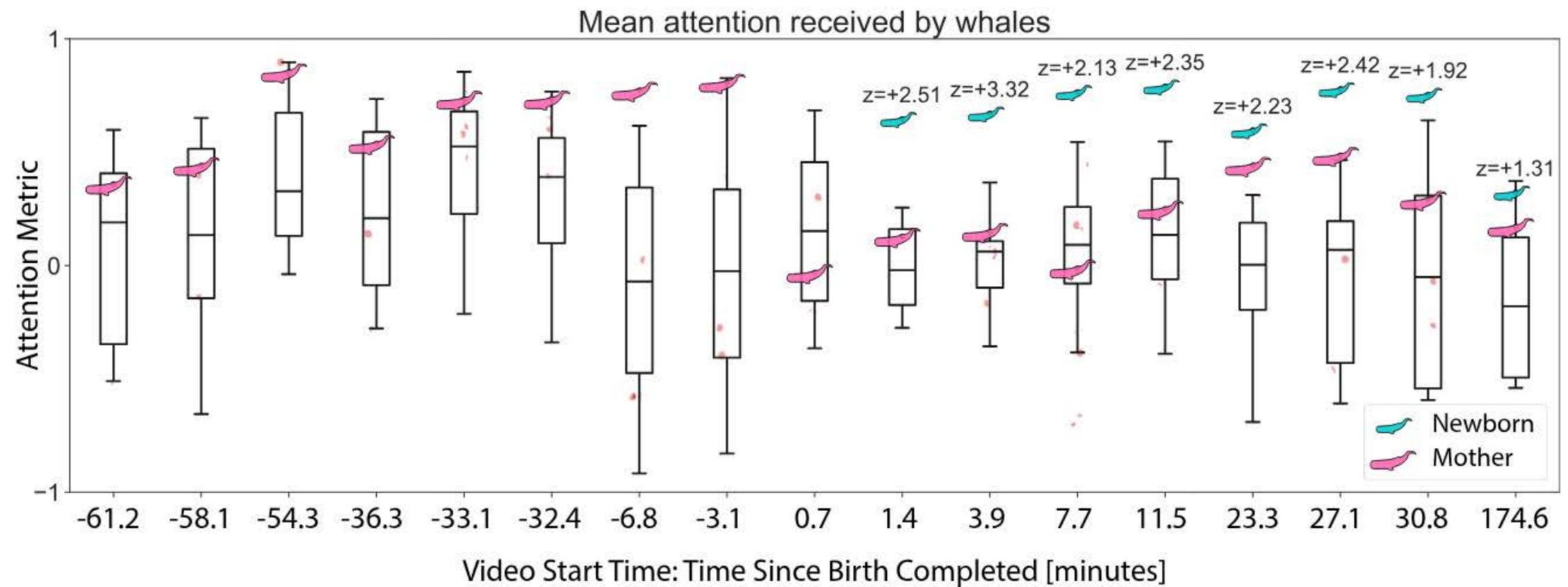
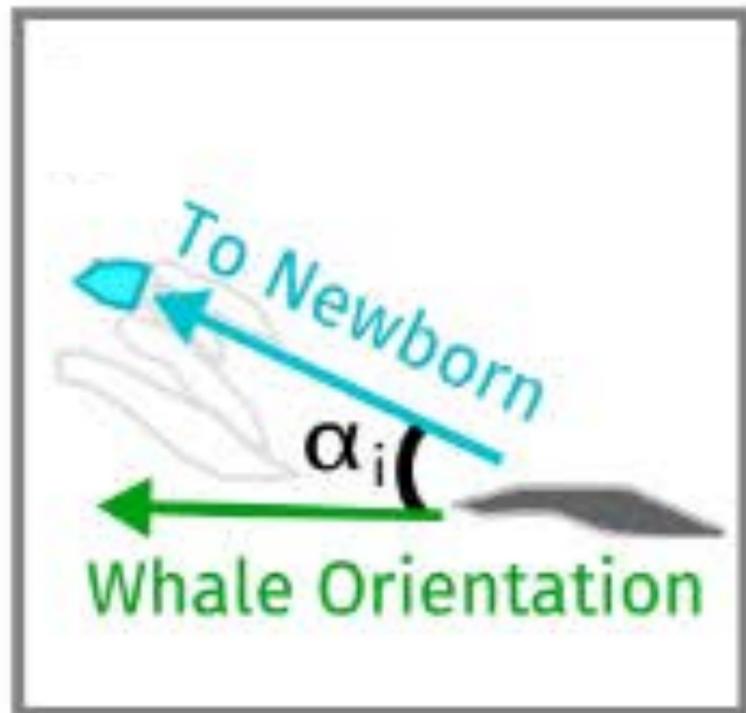
Kin homophily



- During birth: kin mix, homophily ~ 0
- Vast majority of historical data: strictly kin separated, homophily ~ 1

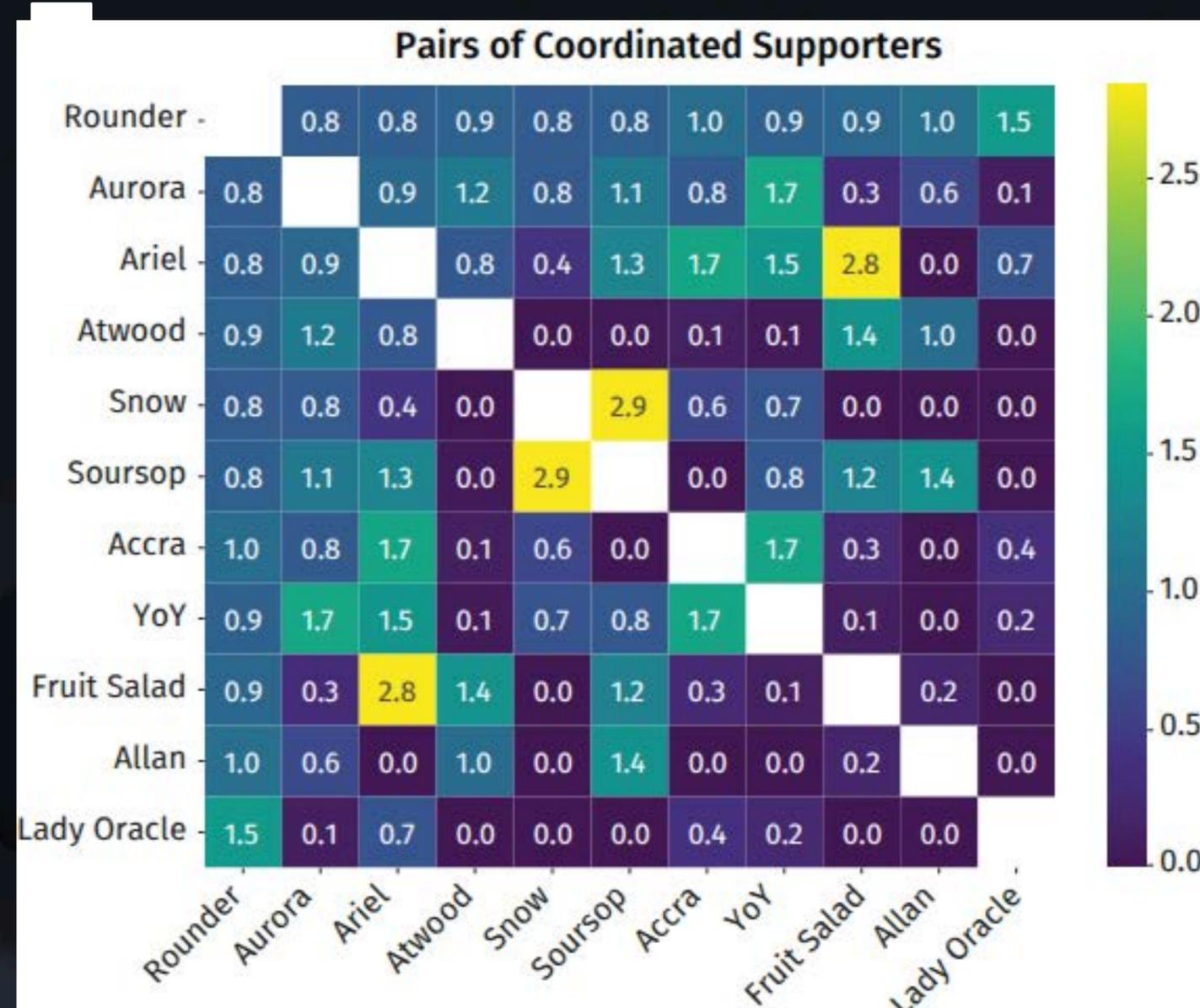
Network analysis: Microscope

Individual level, attention and coordination



Network analysis: Microscope

Individual level, attention and coordination



Outlook

Roger Searle Payne (1935, 2023)

Recap

Coda repertoires

1. What they say. (vocal repertoire)
2. Cultural markers.
3. ID ~ sympatry.

Subcoda structure

1. How they say it (vocal style)
2. Captures social units.
3. non-ID ~ sympatry
4. Akin to Accents.

Development of language

1. First records birth
2. Quantification of group dynamics
3. Evidence of cooperative allocare



Talk to me @lordgrilo Check stuff out @ lordgrilo.github.io



Network Science Institute at Northeastern University

Fifty years ago, people fell in love with the songs of humpback whales, and joined together to ignite a global conservation movement. It's time for us to once again listen to the whales—and, this time, to do it with every bit of empathy and ingenuity we can muster so that we might possibly understand them.

-Dr. Roger Payne, June 5, 2023

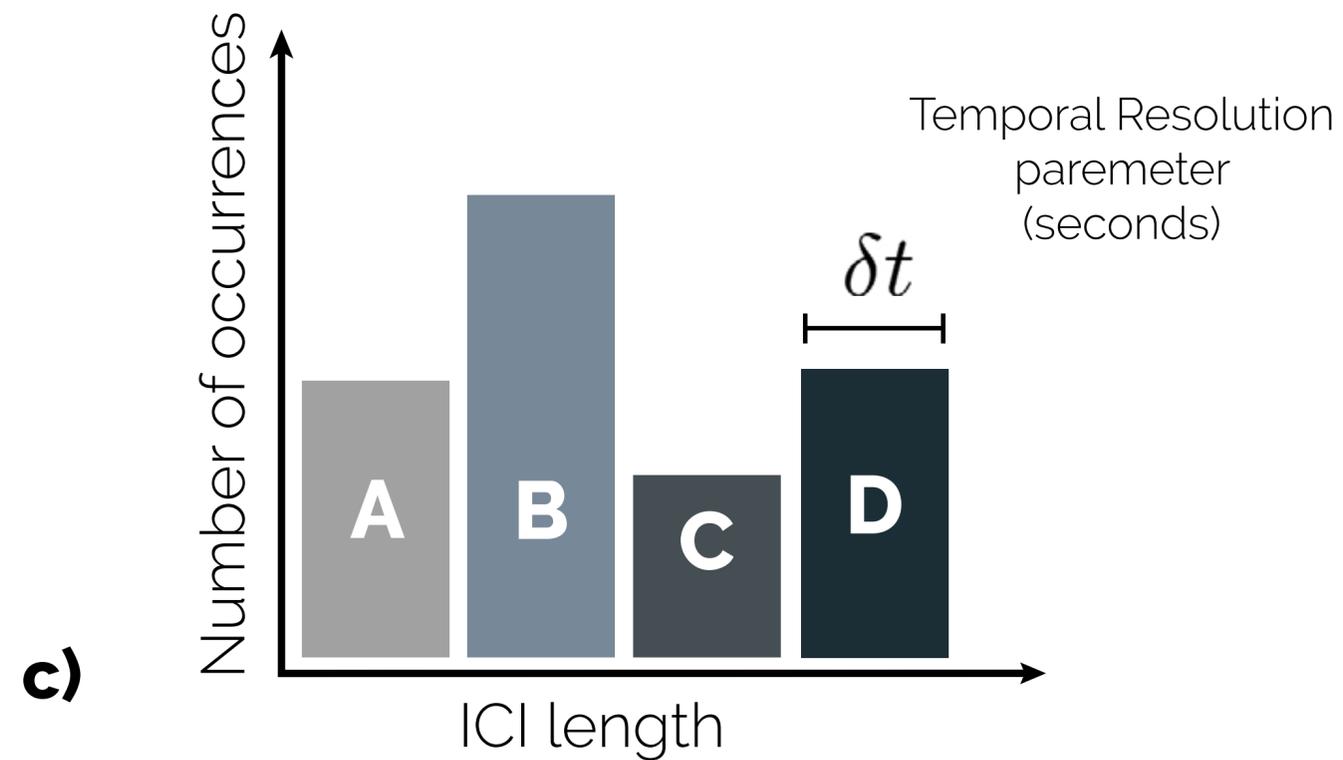
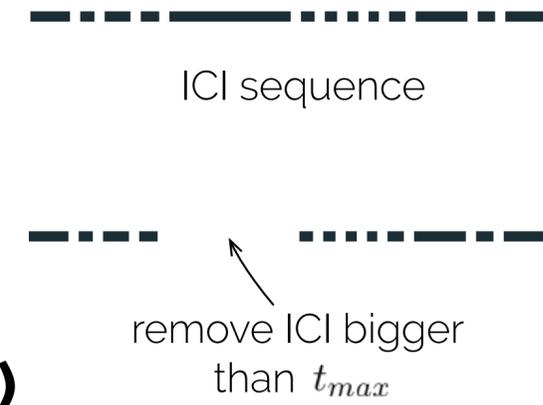
IDEAS • SCIENCE
I Spent My Life Saving the Whales. Now They
Might Save Us

Taylor A. Hersh



Backup

Subcode structure? Symbolic representation

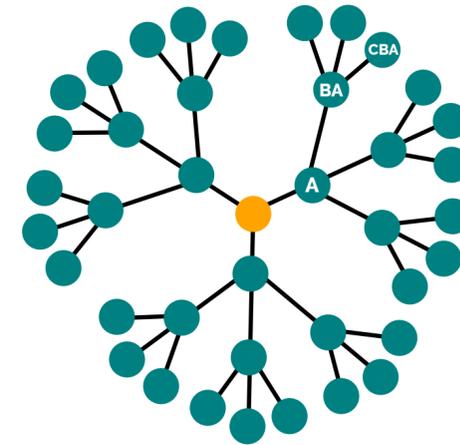


Variable order Markov Chain

$$\mathcal{W} = \bigcup_i^{\infty} \mathcal{X}^i$$

$$q_w(X) = P(X|w)$$

$$q_w(X = x) = P(X = x|w) = \frac{N(wx)}{\sum_{c \in \mathcal{X}} N(wc)}$$

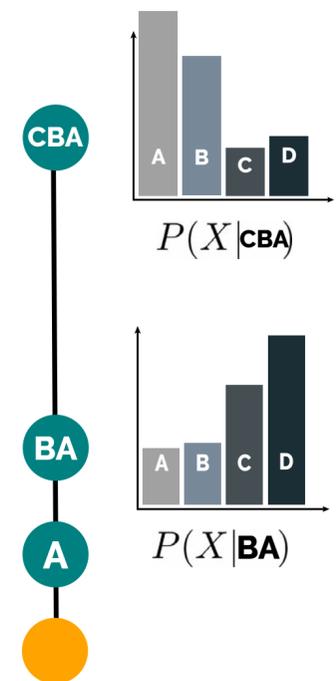


Evaluation of contexts

$$w = \sigma u$$

$$\Delta H_w = N(w) D_{KL}(q_w || q_u)$$

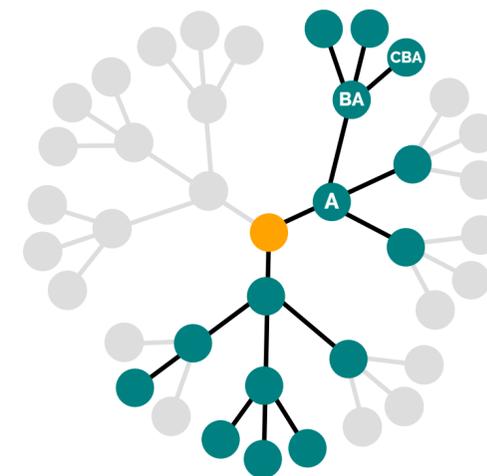
$$= N(w) \sum_{x \in \mathcal{X}} P(x|w) \log \frac{P(x|w)}{P(x|u)}$$



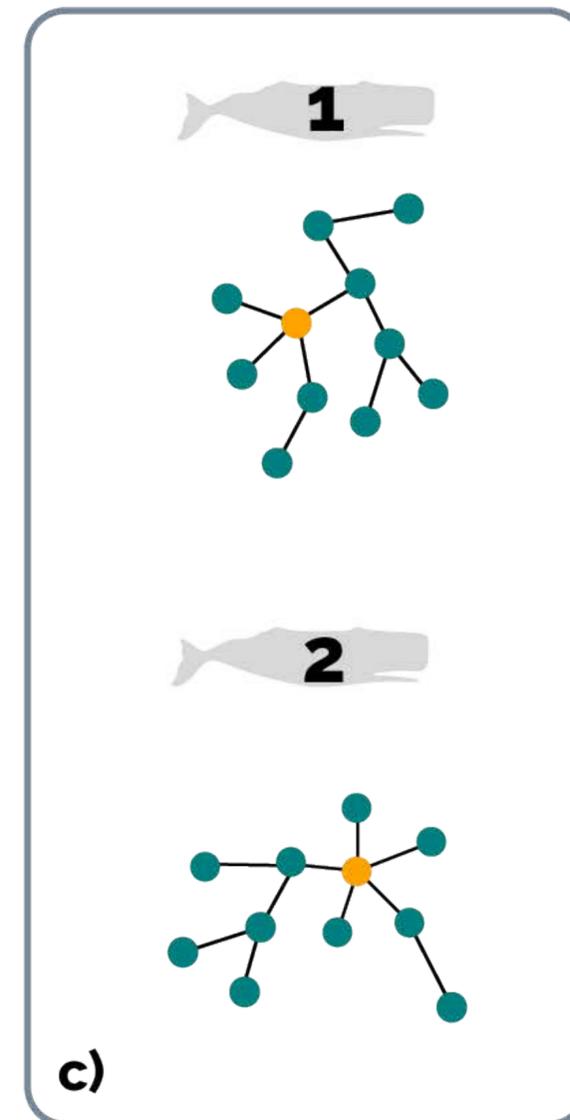
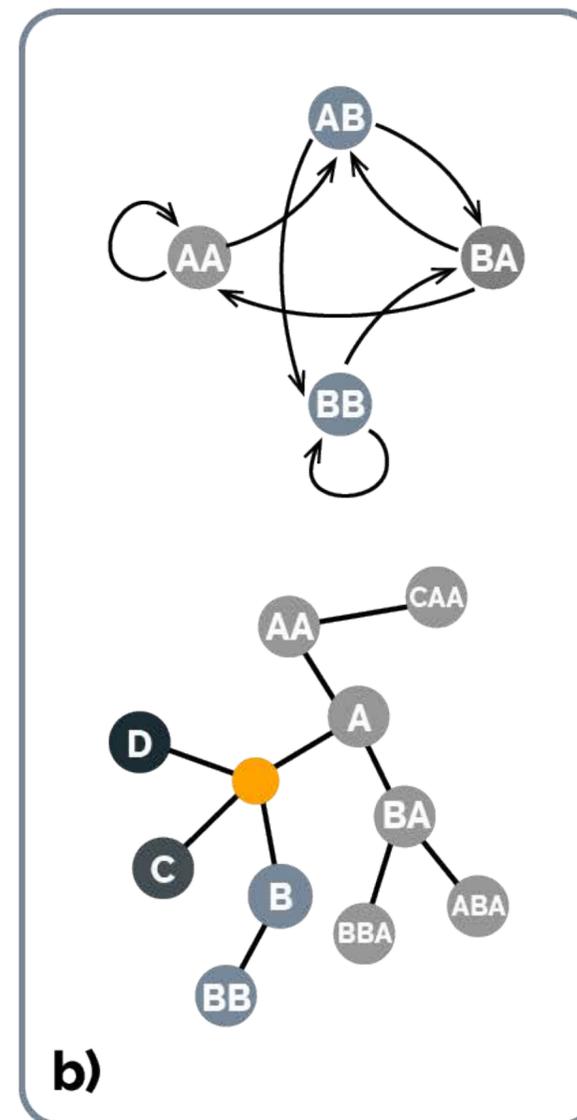
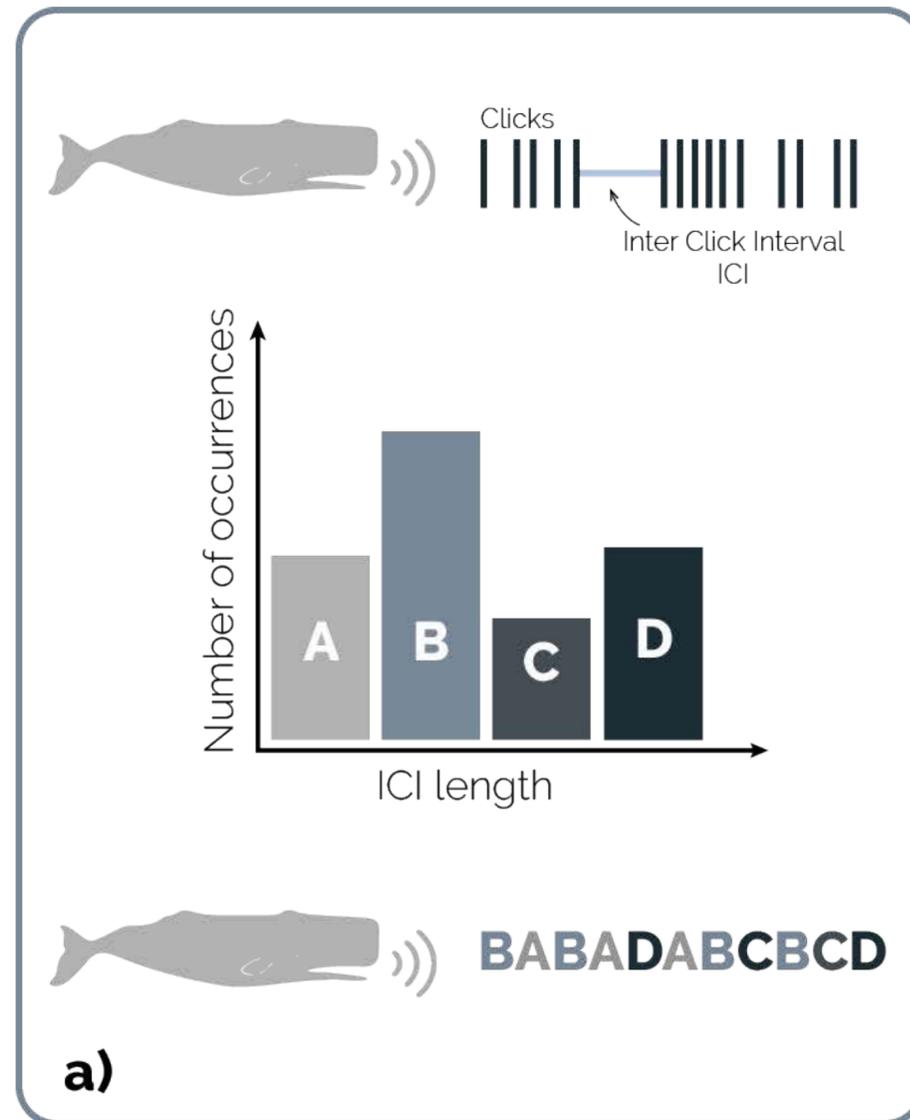
Pruning of states

$$T = \{w \in \mathcal{W}_D | \Delta H_w > K\}$$

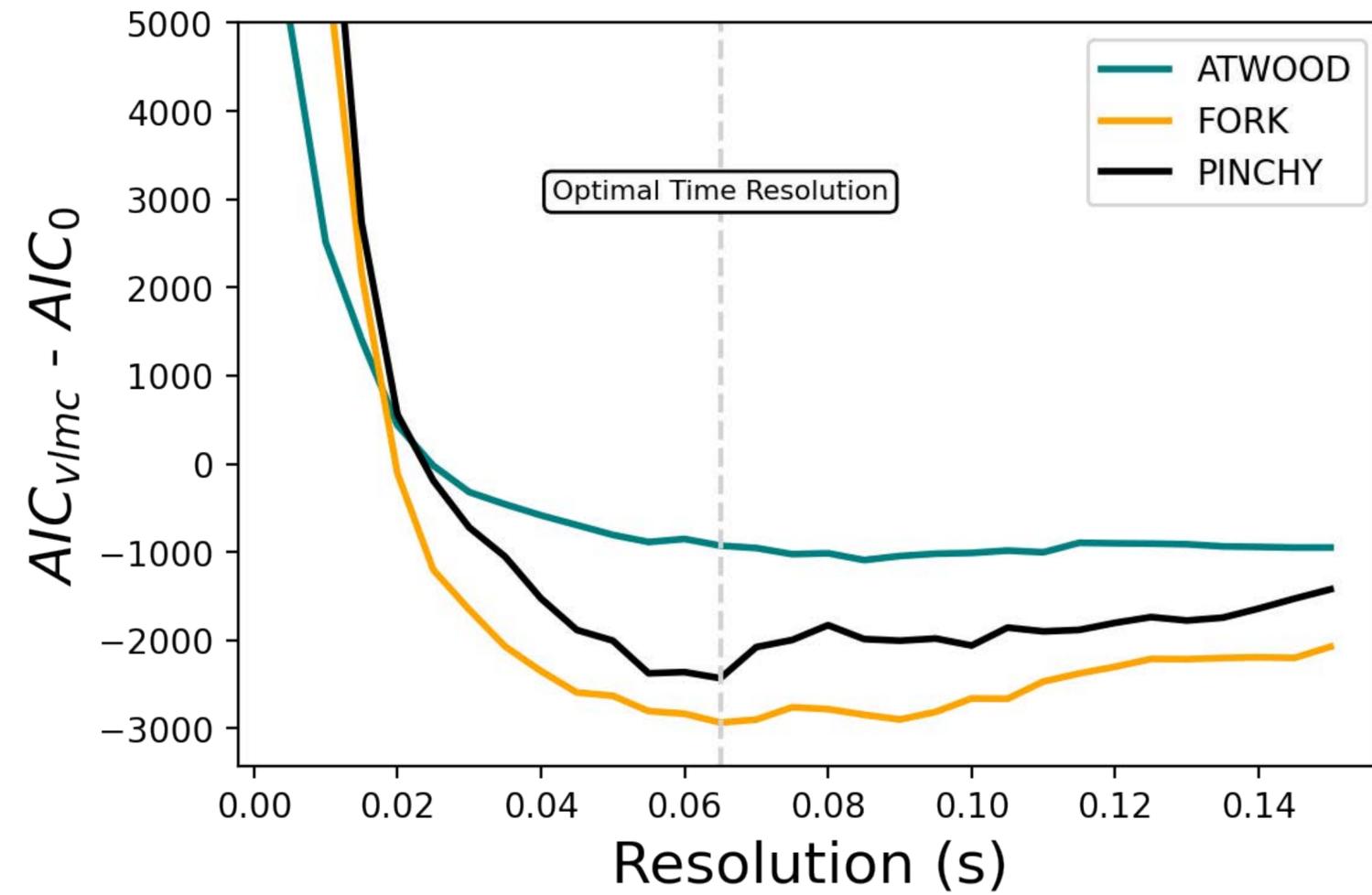
$$\mathcal{L} = \{wx \mid t \in T, x \in \mathcal{X}\}$$



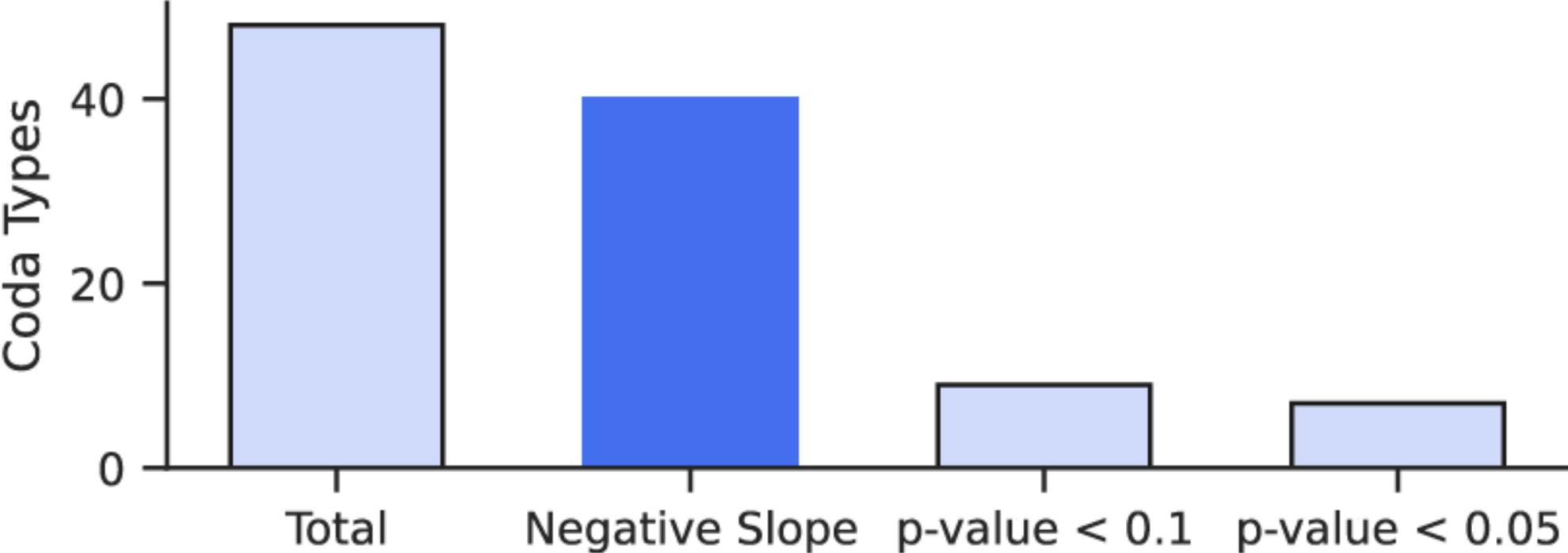
Alphabet Discretization



Coda discretization



Coda Types



Threshold K

