Methods to track diadromy

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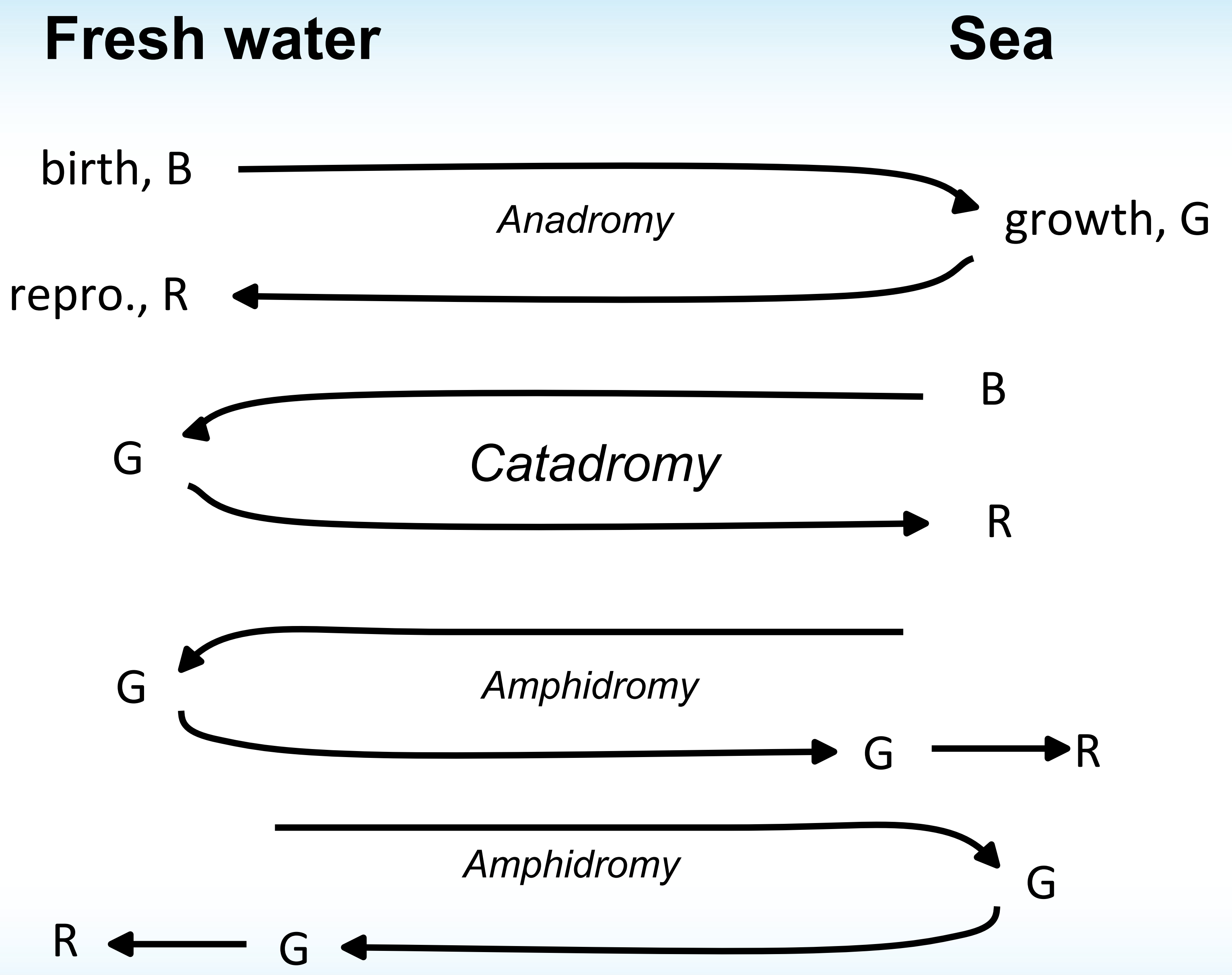
LOCAL AND GLOBAL INITIATIVES:
HOW SCIENCE SUPPORTS MANAGEMENT ACTIONS ON DIADROMOUS FISH

“Textbook Migration”



Fresh water **Sea**

Reality…

Different types of tracking methods

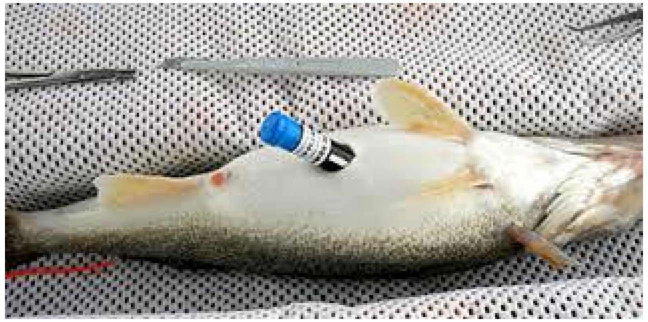
- Artificial tags
- Natural tags
  - Short term
  - Long term (including lifetime)
  - Status (genetic)
  - Presence/absence (eDNA)
- Combined approaches

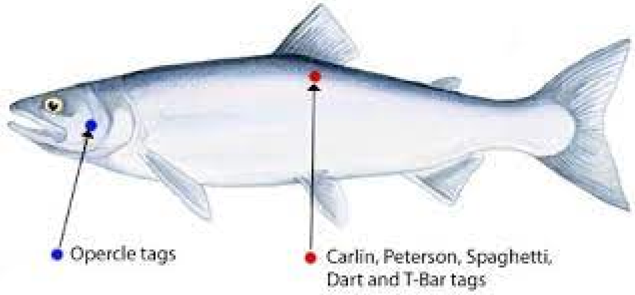
Which method to choose? Depends on your question(s), the study species, life stage, etc.

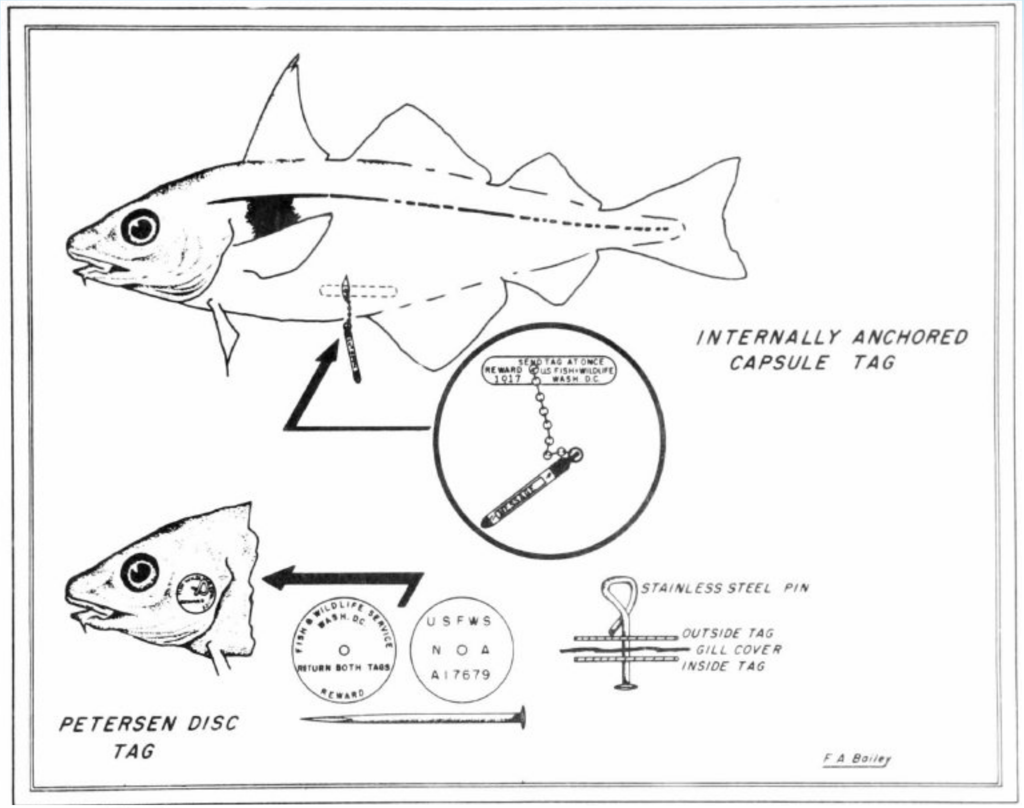
Also, it probably depends on your interests, prior experiences, the papers you read, recommendations, etc.

And your budget…

Artificial tags







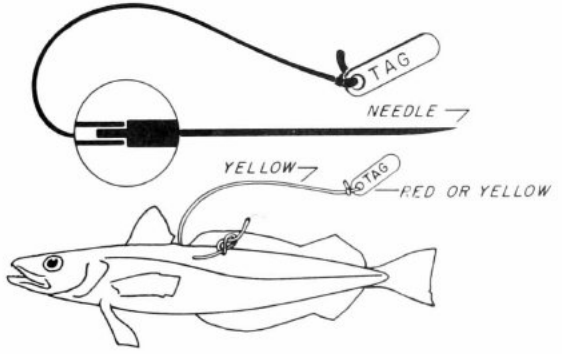


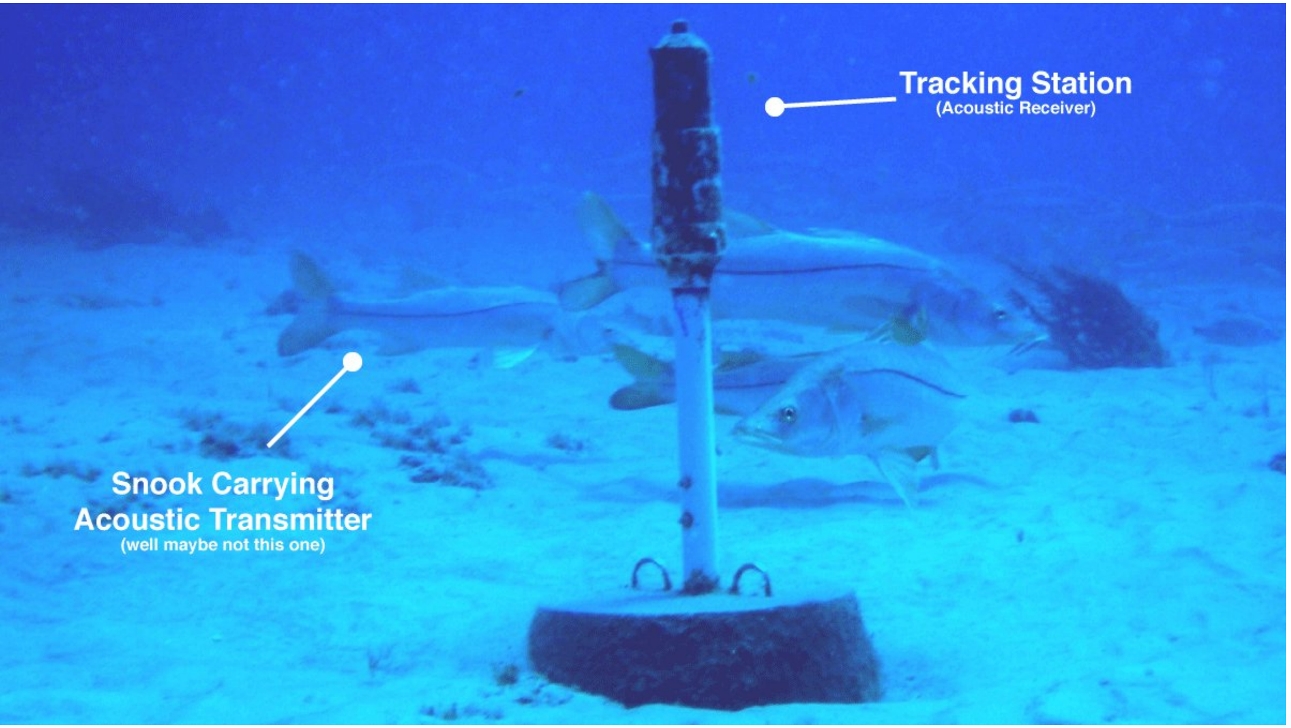
Figure 3.--A vinyl plastic Atkins tag used on silver hake. The needle is used to thread the tubing through the dorsal muscles of the fish.

Jensen, 1962

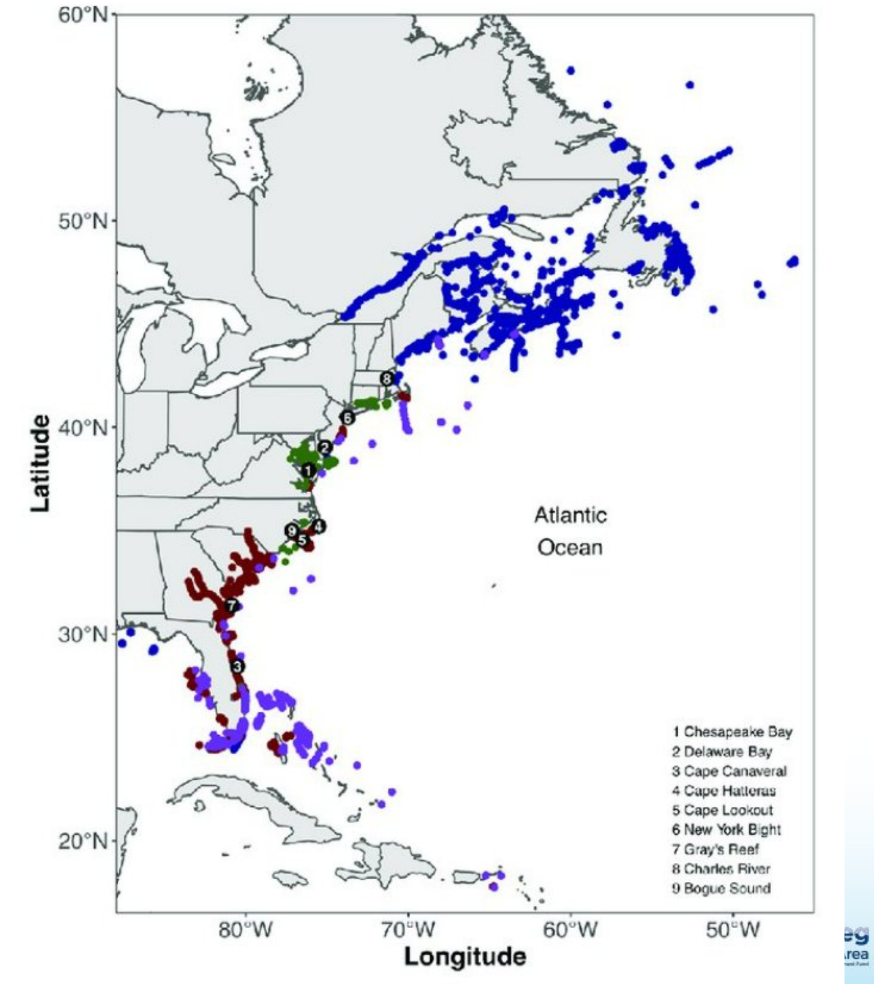
Artificial tags have become quite a large industry! There are many types, for large budgets and small ones.

Electronic tags – riding the techno-development wave

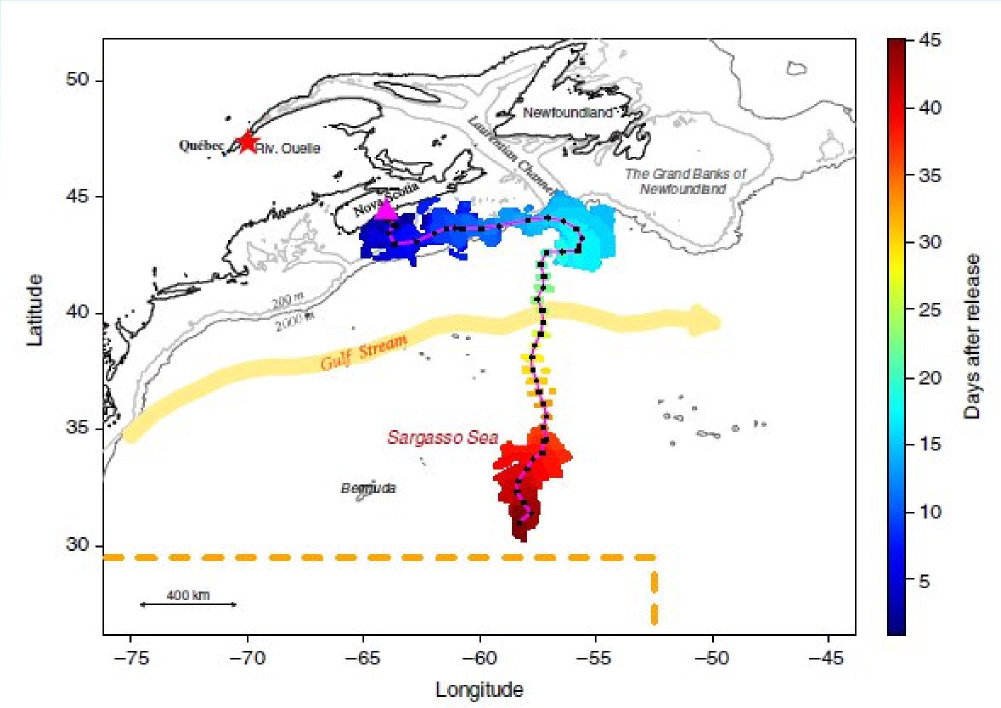
- Active transmitters – e.g., for telemetry; the fish reveal their networks



https://secoora.org/fact/acoustic-telemetry/



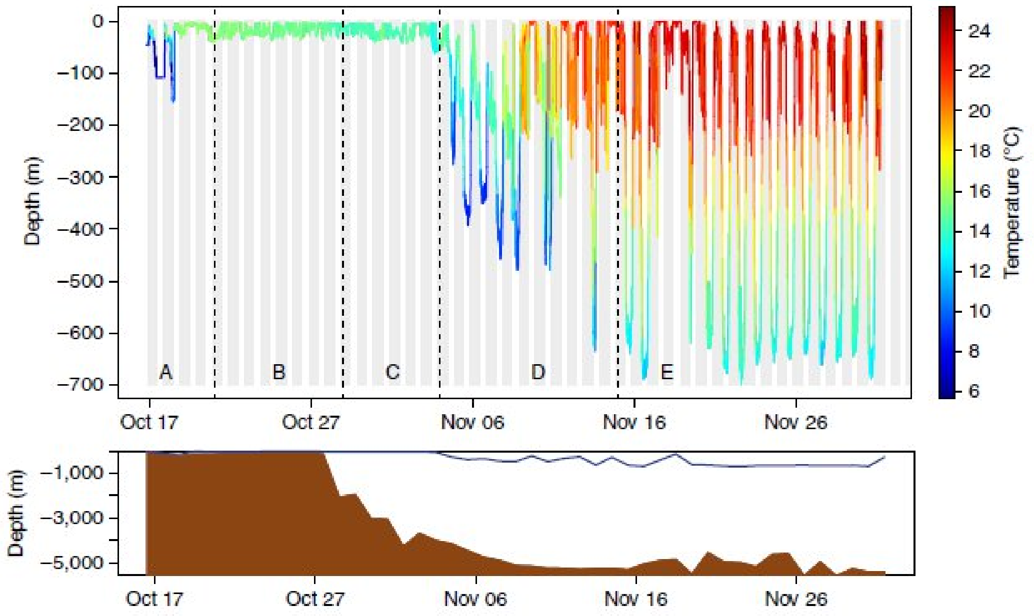
Bangley et al. 2020 *Mar. Coast. Fish.*



Pop-up satellite tags

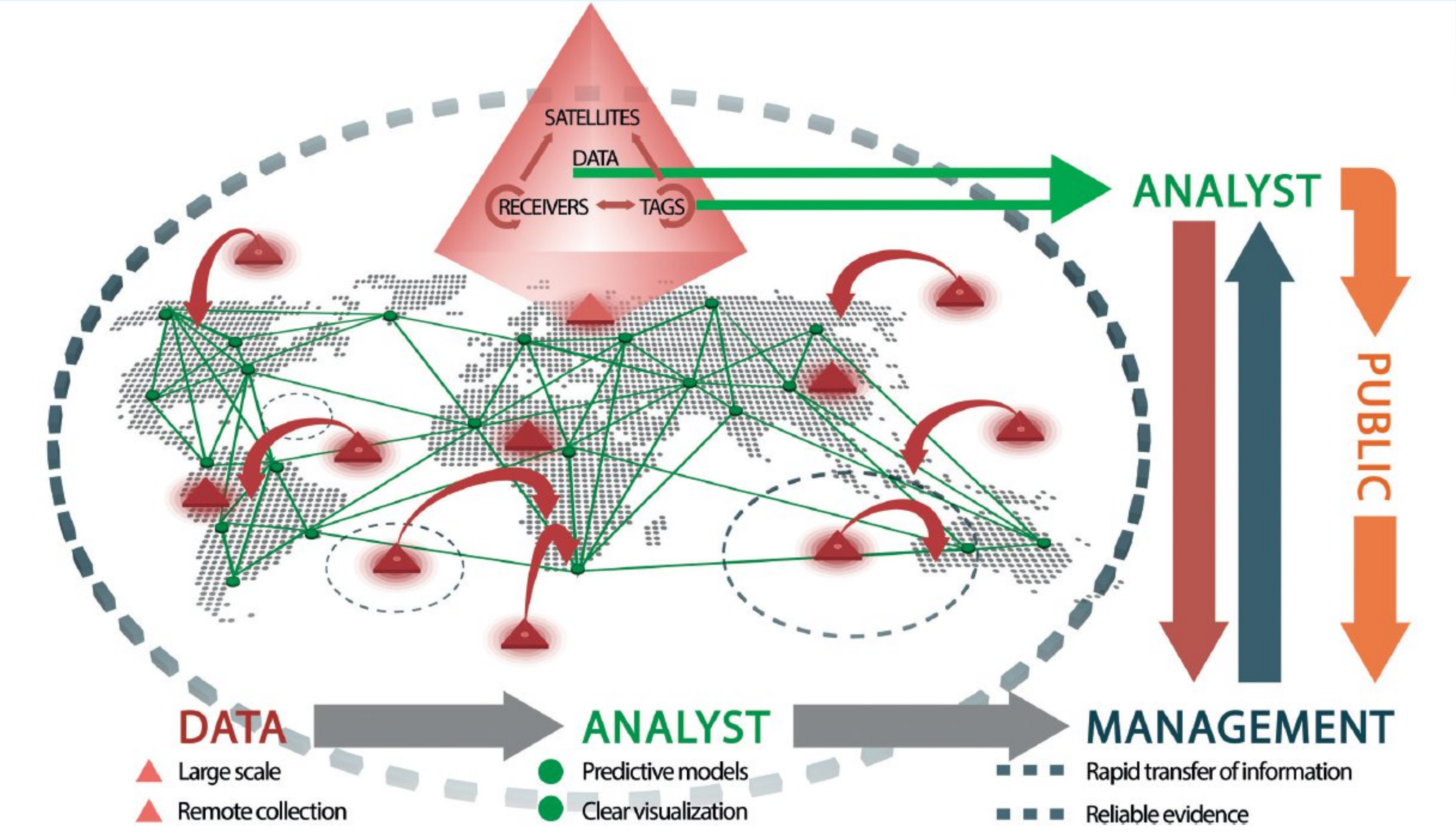
Great for larger animals

Increasing capabilities



| Vertical behaviour of eel #28 equipped with the X-tag #141105 along its journey from the Scotian Shelf to the Sargasso Sea.

Beguér-Pon et al. 2015 *Nature Comm.*



Lennox et al. 2017 *BioScience*

Improvements continue:

- More types of sensors
- Miniaturization
- Longer battery life (or self-powered)
- Tranceivers
- Integration with other data (e.g., ARGOS)

Challenges:

- Tag loss
- Transmitting stops
- Tag stops moving
- Size
- Battery life
- Cost €$$€
- etc

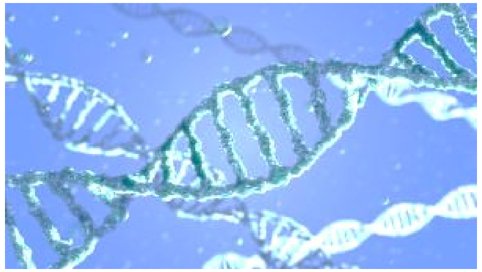
Tags on fish may act as a 'dinner bell' for predators

Wednesday, 19 November 2014

AFP

https://www.abc.net.au/

Natural tags



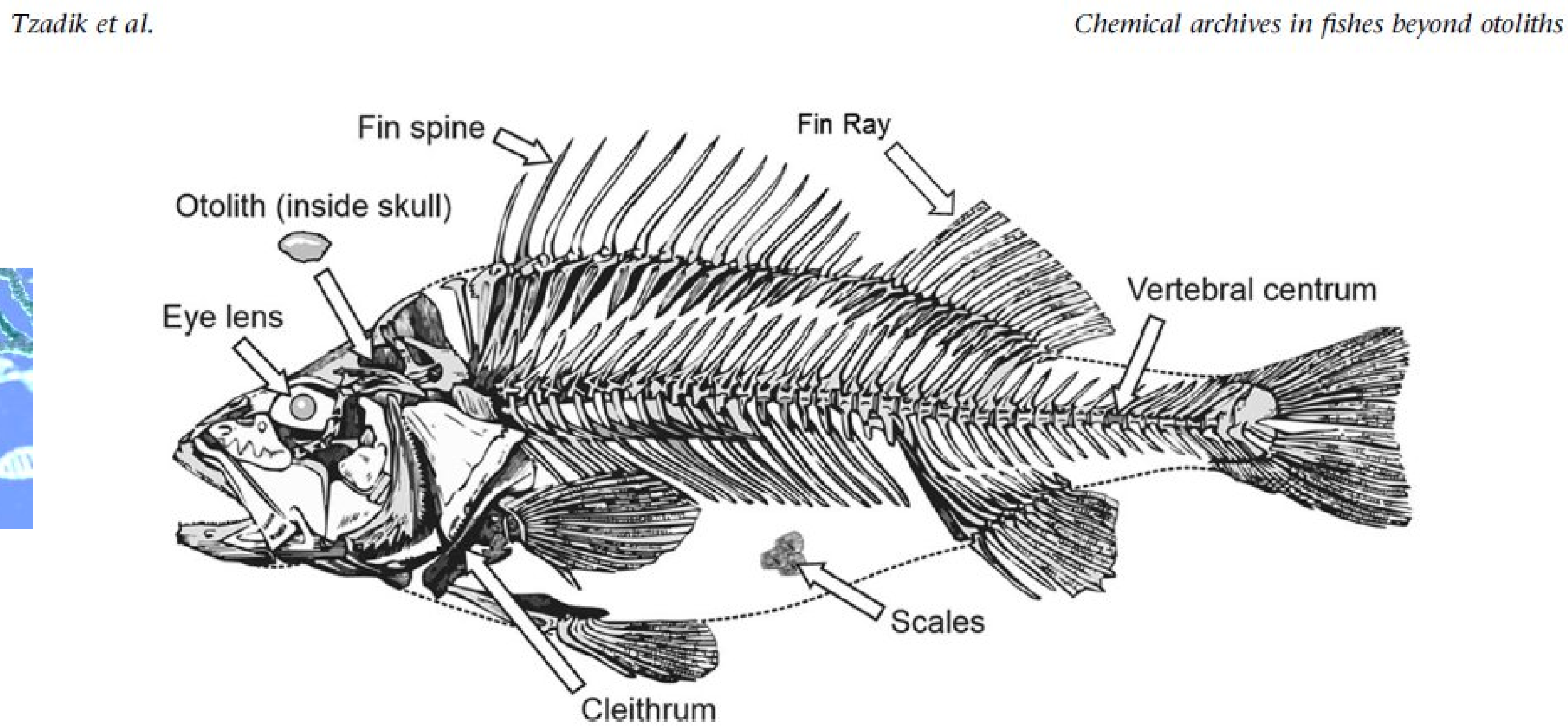
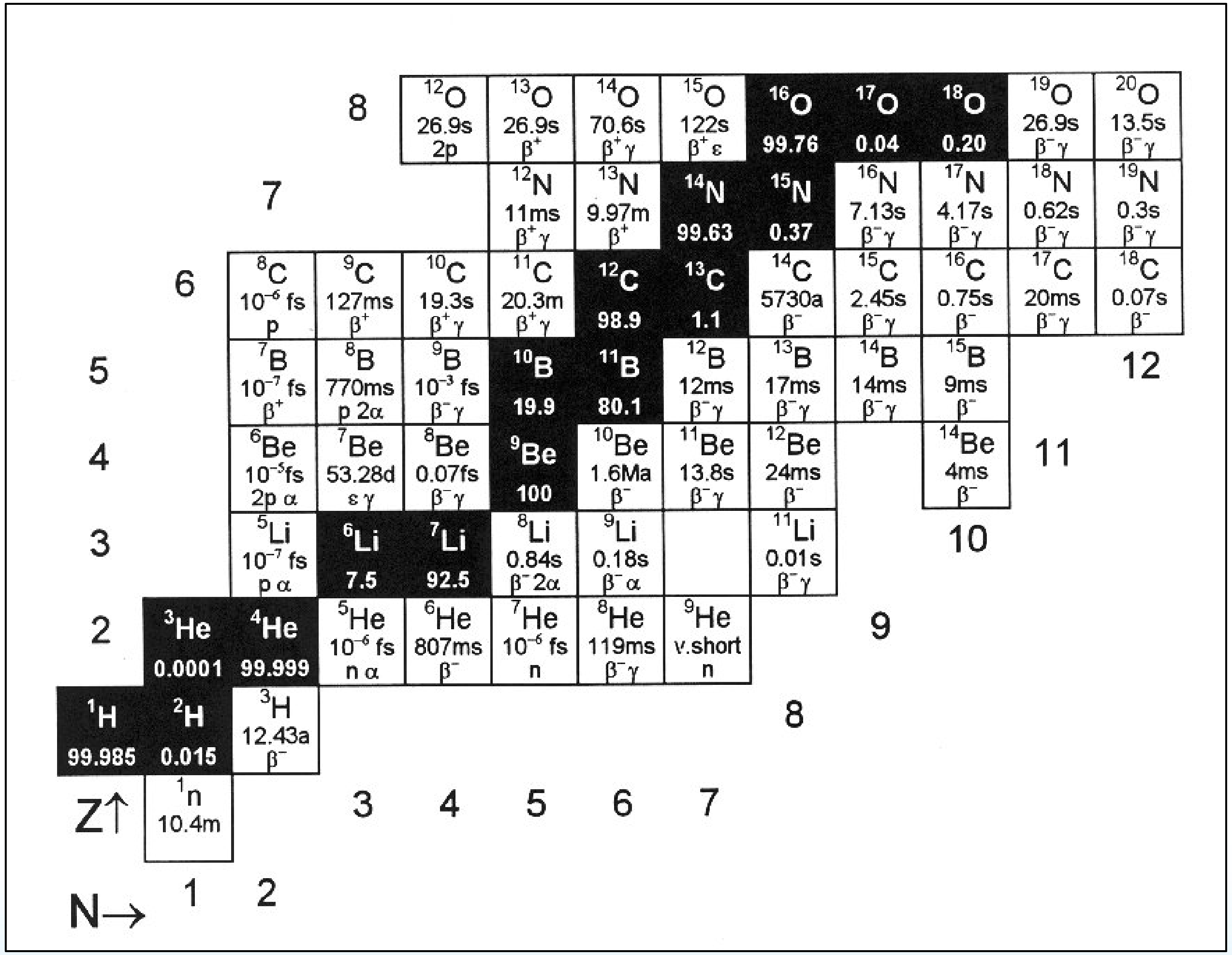


Fig. 1. Basic anatomy of derived fishes. All alternative structures are labeled based on their anatomical locations.

Assumptions for natural tags to work:

- Must have contrasts in the markers (too little contrast → hard to distinguish sites)
- Repeatability (e.g., inter-annual variation)
- Permanency? Understand the “lifetime” of the marker
- Understand (?) what the marker is telling you

Short-term markers: light stable isotopes in fish muscle tissue



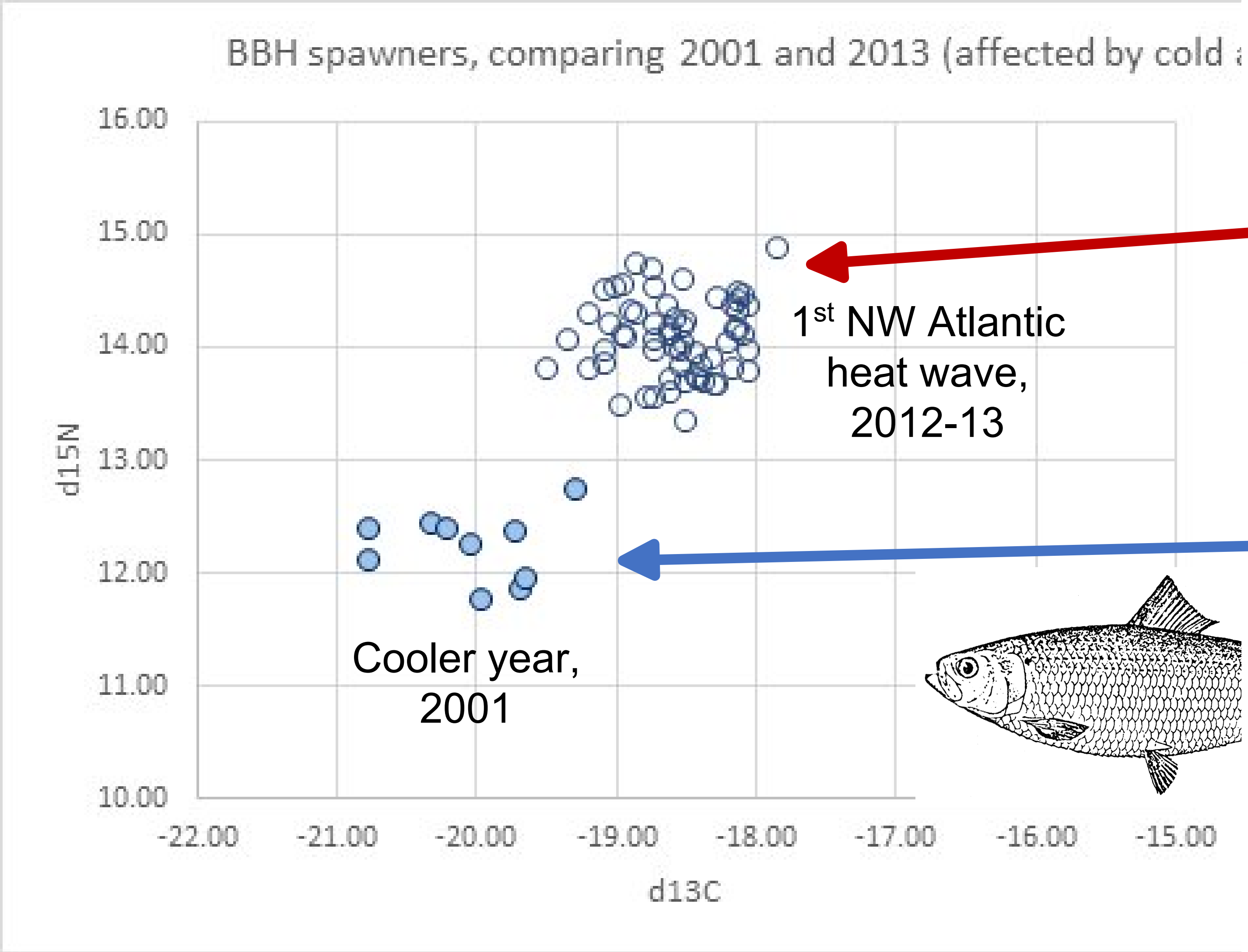
- Light stable isotopes are just that – they are stable
- Tiny differences in relative abundances can provide important ecological information

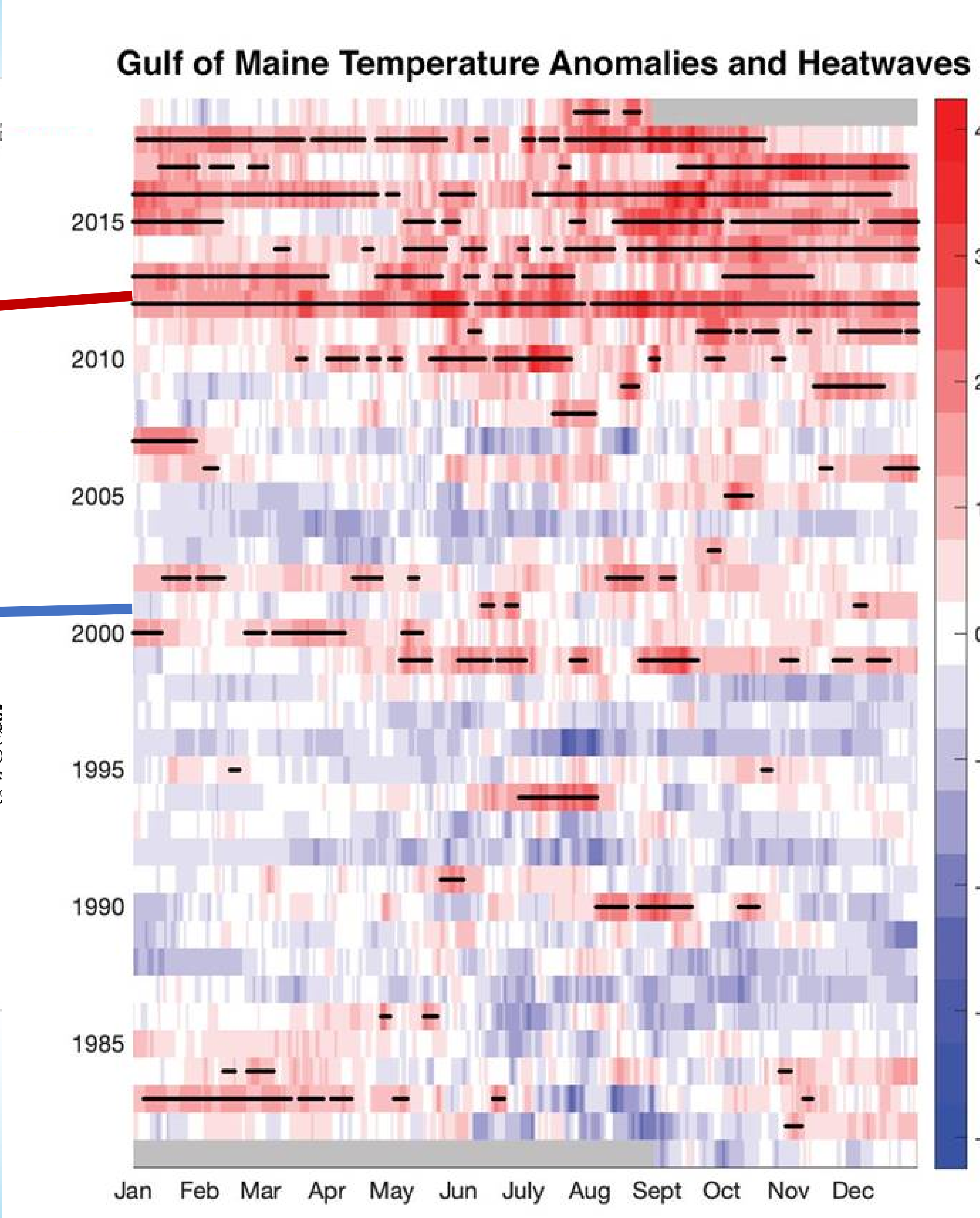
← (stable iso's in black)

Stable isotopes

- Different tissues have different turnover times
  - Muscle tissue ~ 3-4 months: recent info
  - Liver tissue ~ 2 weeks: so, even more recent

- Different stable isotopes provide different info:
  - $\delta^{13}C$, D/H: some info about source
  - $\delta^{15}N$: trophic status
  - $\delta^{34}S$: reducing environments (e.g. hypoxia)
  - $\delta^{18}O$: temperature and/or salinity


BBH spawners, comparing 2001 and 2013 (affected by cold
16.00
15.00
14.00
13.00
12.00
11.00
10.00
d15N
-22.00
-21.00
-20.00
-19.00
-18.00
-17.00
-16.00
-15.00
d13C
1st NW Atlantic heat wave, 2012-13
Cooler year, 2001


Gulf of Maine Temperature Anomalies and Heatwaves
2015
2010
2005
2000
1995
1990
1985
Jan
Feb
Mar
Apr
May
Jun
July
Aug
Sept
Oct
Nov
Dec

More recent developments in Stable Isotope Ecology: use of $\delta^{15}N$ in amino acids ($\delta^{15}N_{aa}$), correcting for phenylalanine trophic increases of $\delta^{15}N$ → $\delta^{15}N_{Base}$

- Reflects the $\delta^{15}N$ of nitrate taken up by 1° producers
- Since nitrate can vary widely, $\delta^{15}N_{Base}$ can be used to track migration
- Can create "$\delta^{15}N_{Base}$ isoscapes" and match up fish markers to geographic locations
- Can also extract material from tissues which grow over time, e.g., bones and eye lenses → lifetime analyses

Isoscape map based on measurements of copepods and estimated $\delta^{15}N$ of phytoplankton

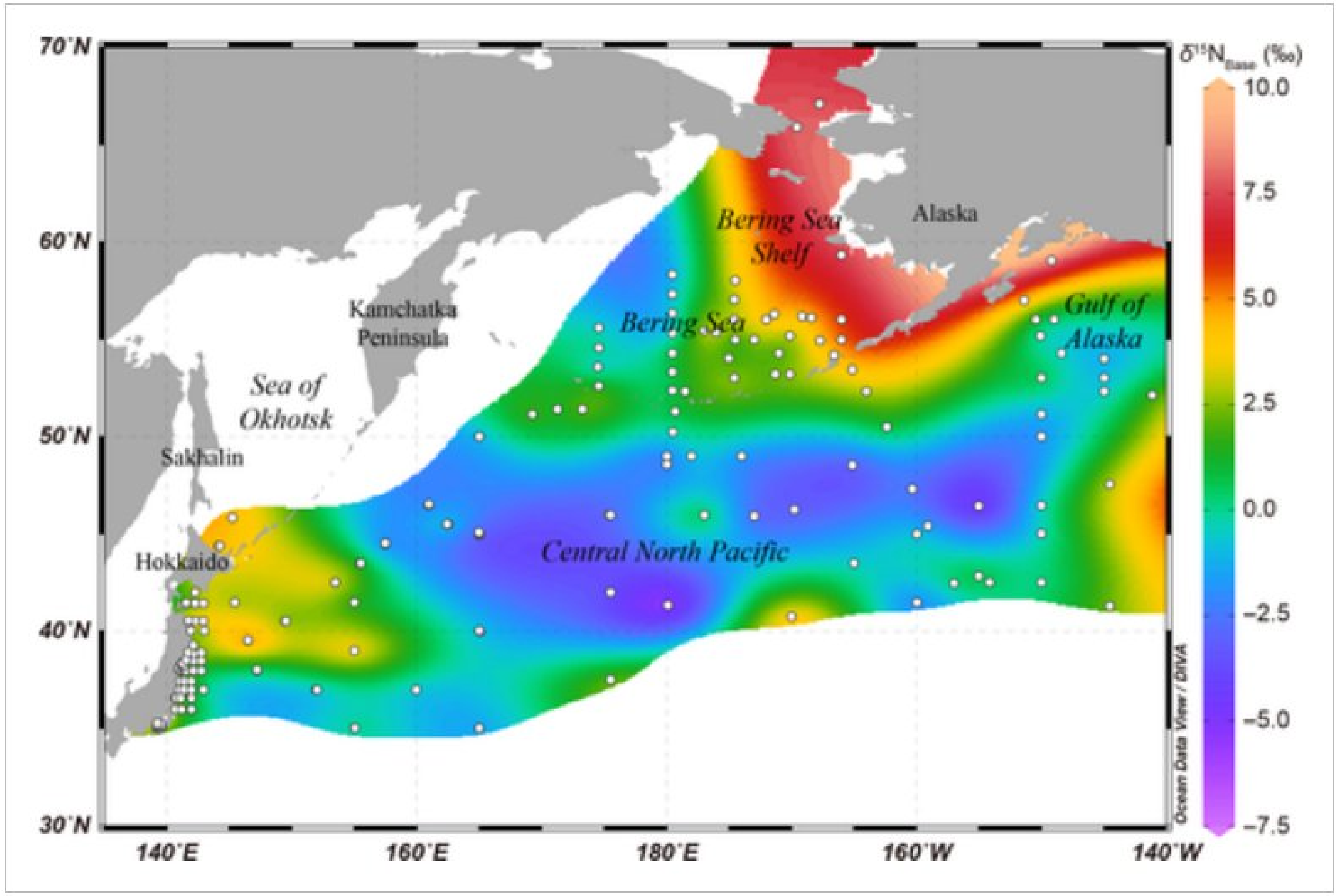


Figure 1

Map of the estimated $\delta^{15}N_{Base}$ isoscape showing the location of zooplankton sampling sites (white circles).

Matsubayashi et al. 2020 Ecology Letters

Predictions of where a chum salmon migrated throughout life, from sections of bone collagen

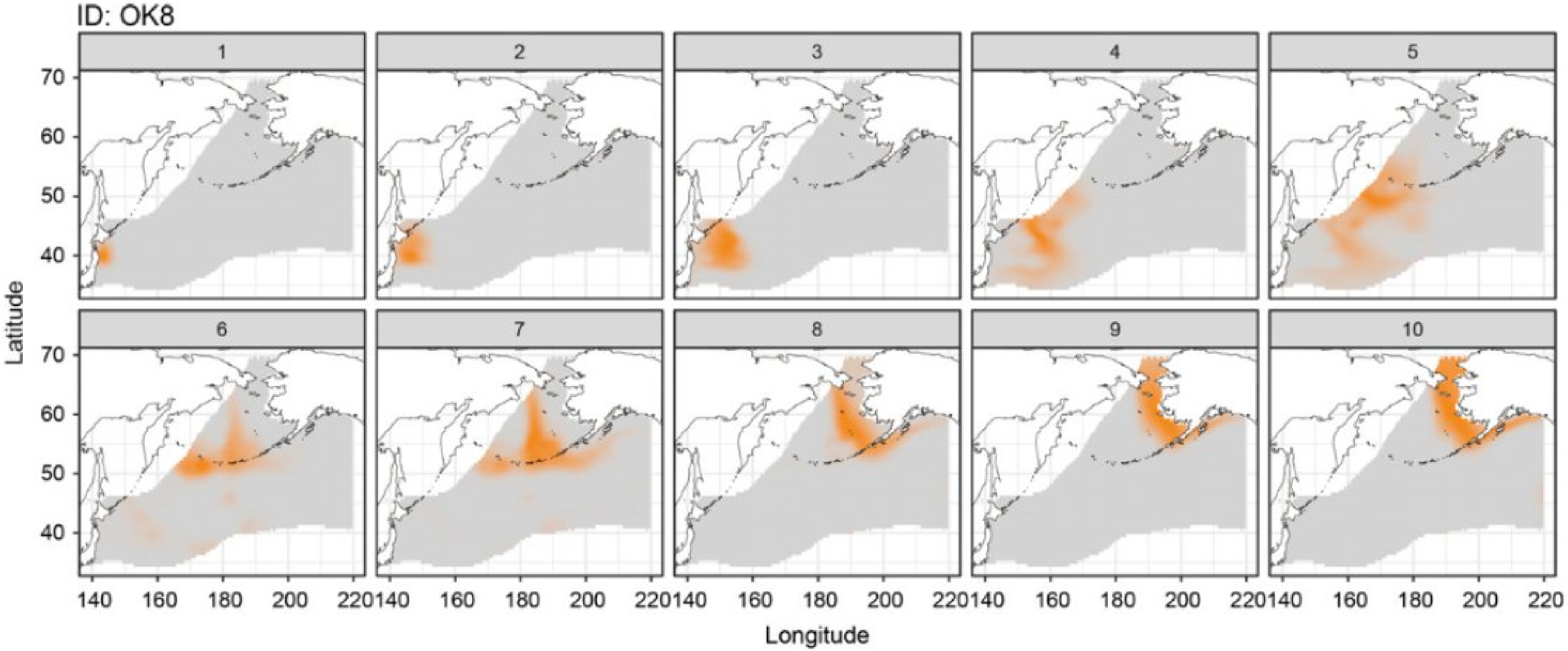
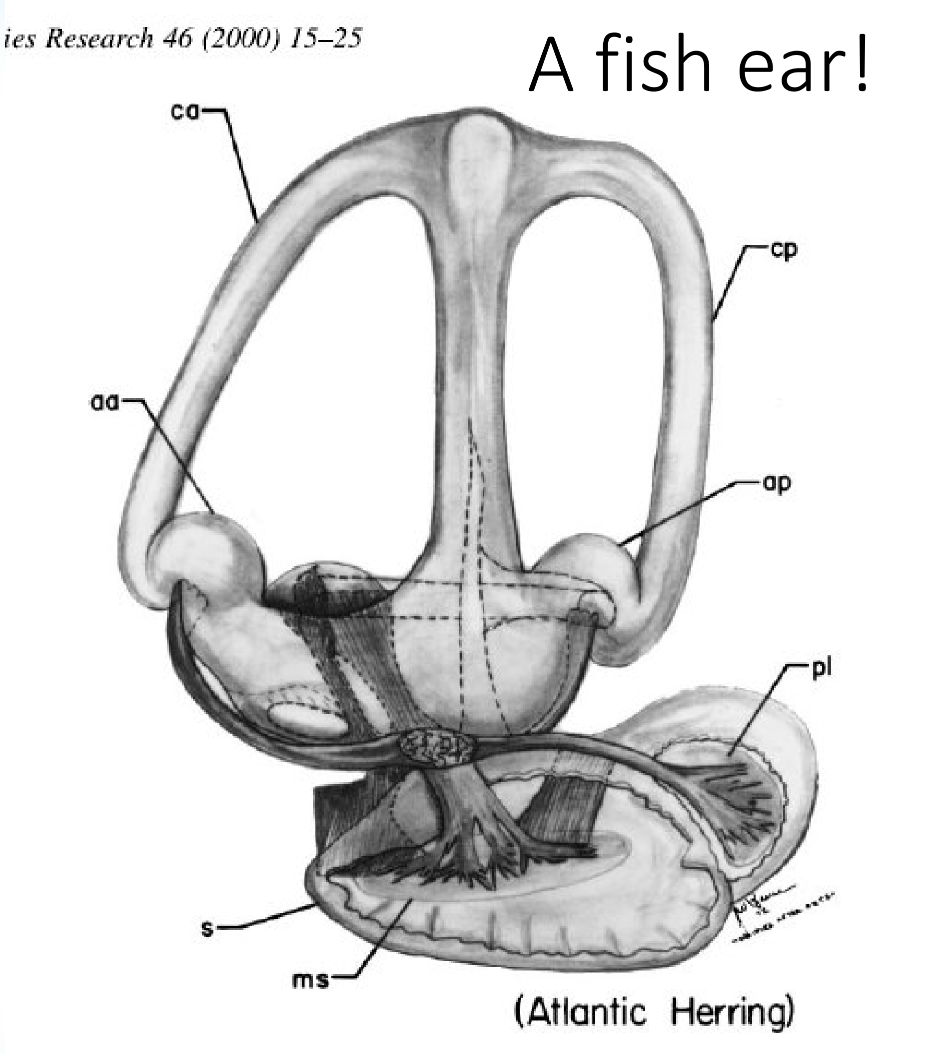
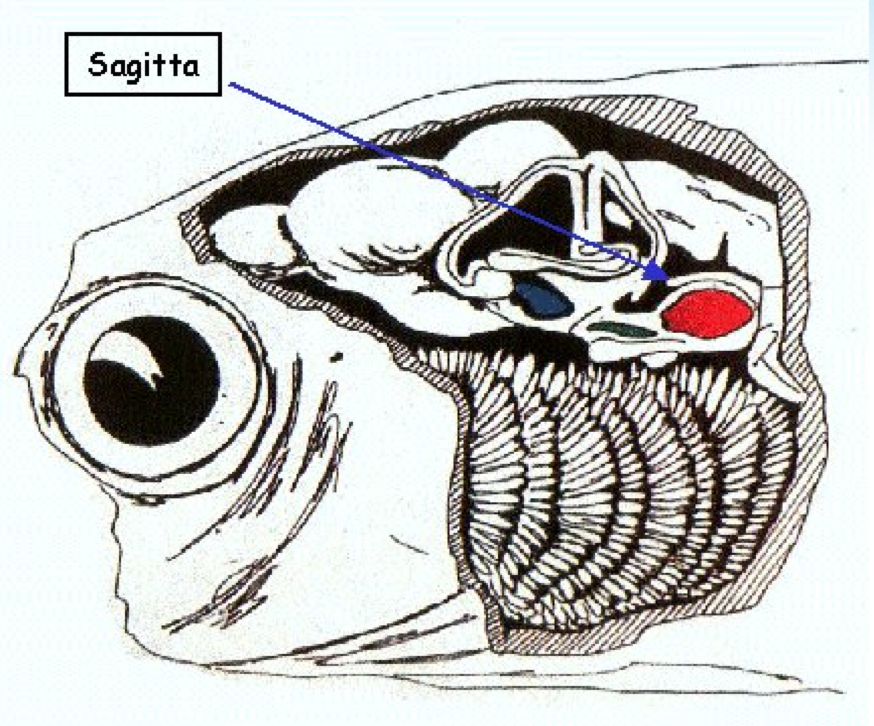


Figure 3 Estimated chum salmon migration areas. Mean presence probabilities for two salmon individuals (IDs: OK2 and OK8) at growth stages 1–10 (panels 1–10, respectively). The colour gradients (tints of orange) indicate presence probability (low to high). The grey area shows the extent of the isoscape.

Matsubayashi et al. 2020 Ecology Letters



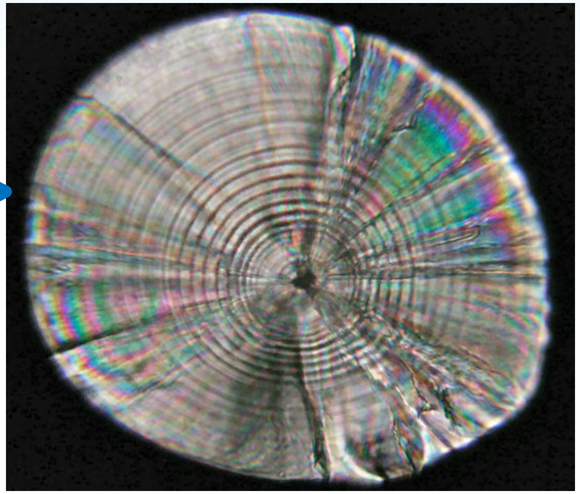
A fish ear!

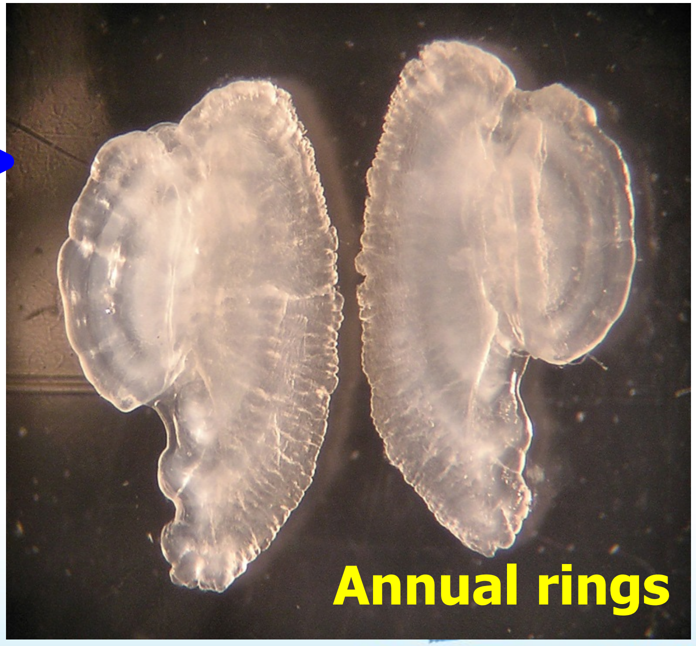


Fish Otoliths

(ear-stones)

Otoliths – built-in chronometers in fish heads…





A c

Chemical information

Photo: NTSB

"childhood"

Ever since the early days of using otolith chemistry, Sr:Ca ratios have been a real “work horse” for tracking diadromy

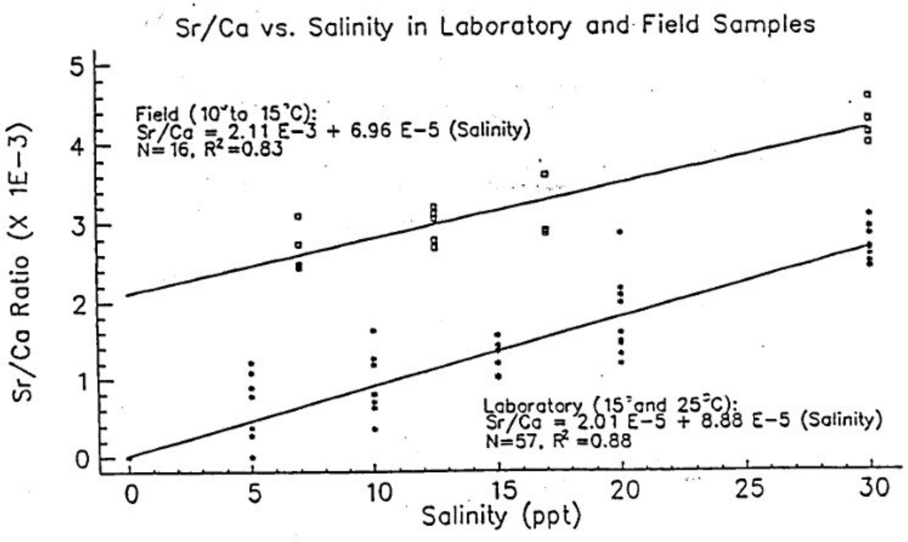


Figure 4. Experiment 1 and Field Verification Samples. Otolith Sr/Ca vs. salinity in laboratory (indicated by asterisks) and field (indicated by open squares) samples.

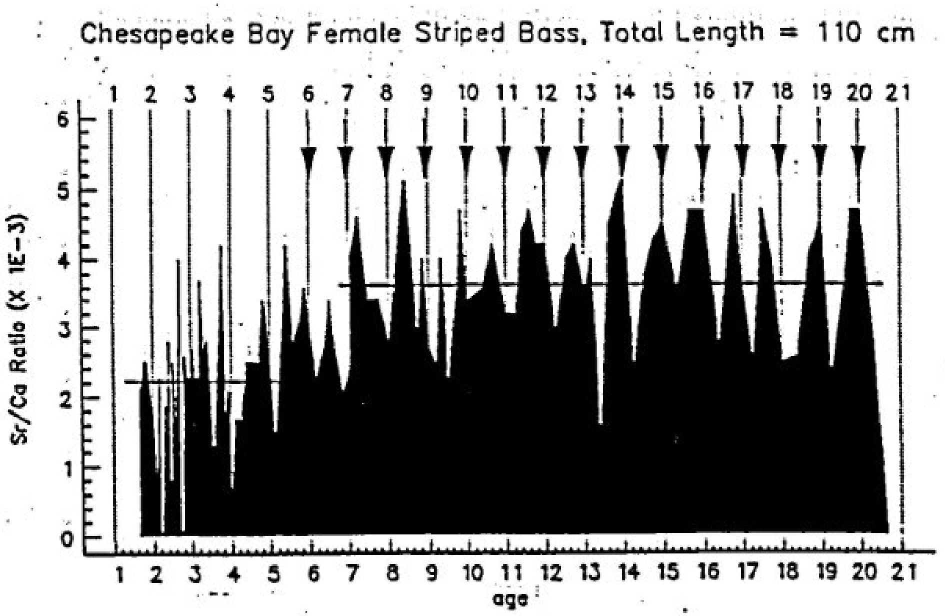


Figure 5. Transect probe of Sr/Ca ratios across annuli for a Chesapeake Bay female striped bass (TL = 110 cm). Peaks and valleys represent coastal and spawning migrations, respectively. Mean Sr/Ca ratios for different portions (ages ≤7 or ages >7) of the transect are shown by horizontal lines. Arrows indicate spawning migrations.

Secor et al. 1993, ICES CM 1993/M:41

Can ask many different types of questions about diadromous fishes with this technique.

Here is an example from my own work, asking:
how common is "non-textbook migration?"

Blueback herring:

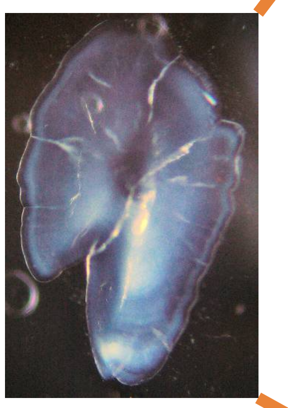
- Anadromous
- Recently found to use many different salinity zones before spawning (poster)

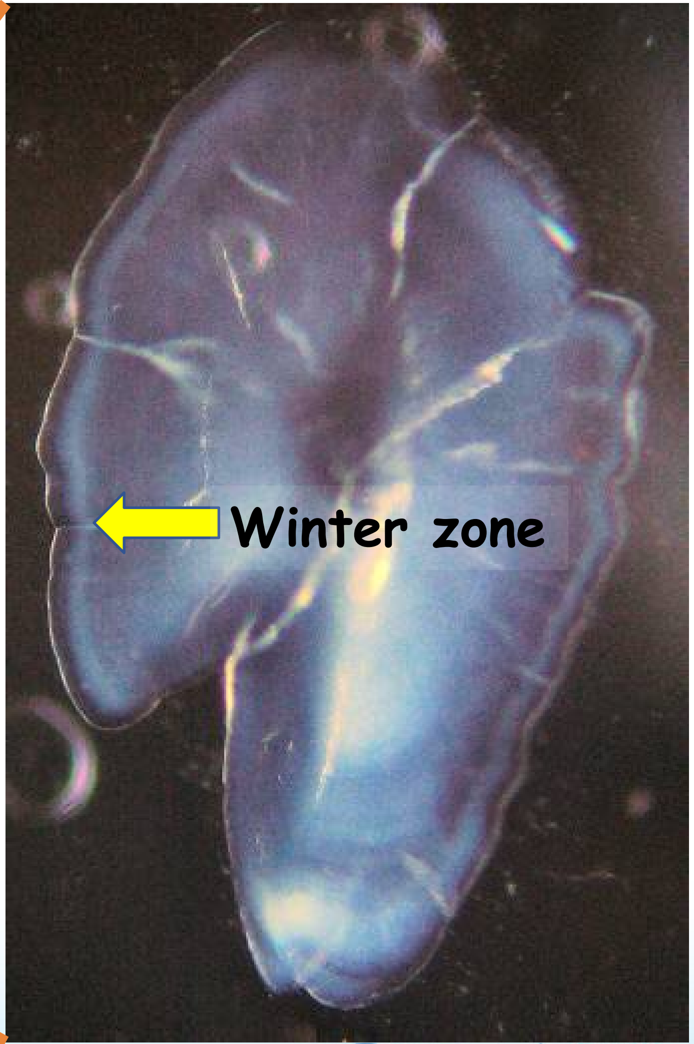
Springtime brings little herring back to the Hudson **in the spawning run**!

What are they doing here??

A pair of adult blueback herring otoliths

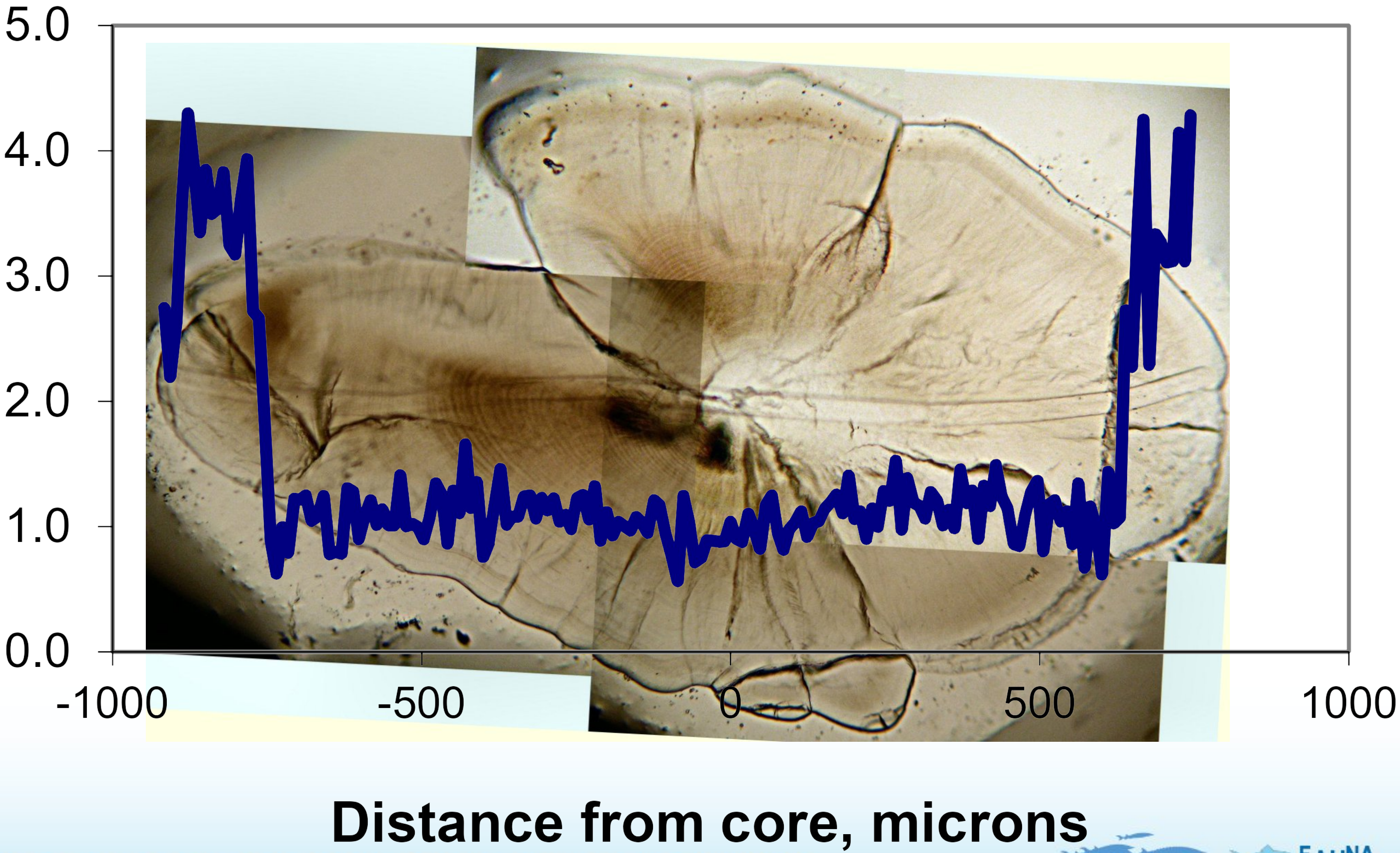
Otolith from a 98-mm yearling caught April 25, 2012 at Troy Dam (entry to Mohawk R.)



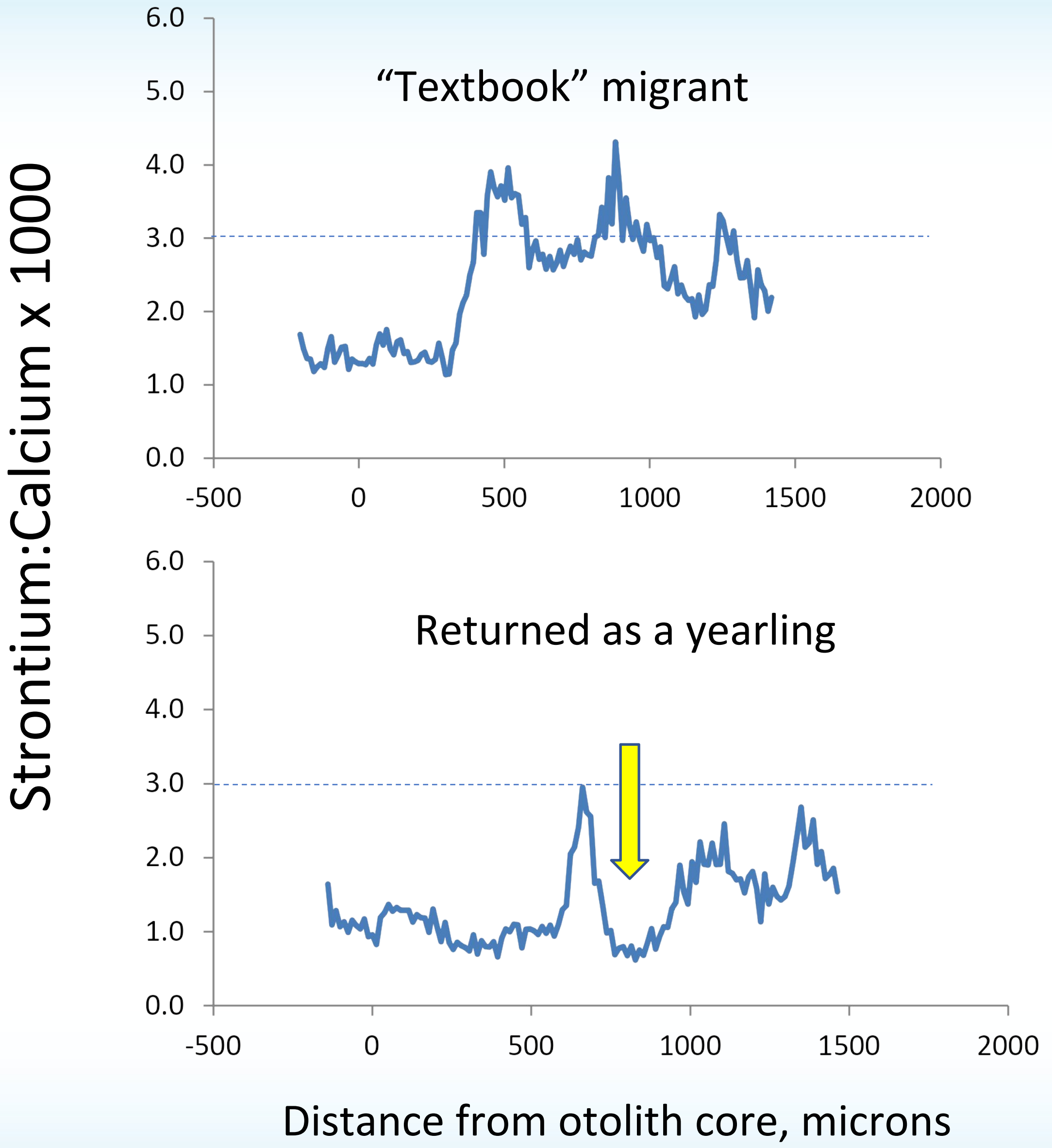


Here is that same "yearling" otolith, ablated with a laser unit to analyze trace elements.

Sr/Ca "jumps" when fish enters seawater



Adult otoliths



It ALSO turns out that we can figure out where in the watershed these fish reared in nurseries, thanks to another biogeochemical tracer…

$^{87/86}Sr$

The ratio of 87 to 86 Sr is related to the age of rocks. Older rocks have higher $^{87/86}Sr$.

And this is taken up nicely in otoliths (just expensive and difficult to analyze)

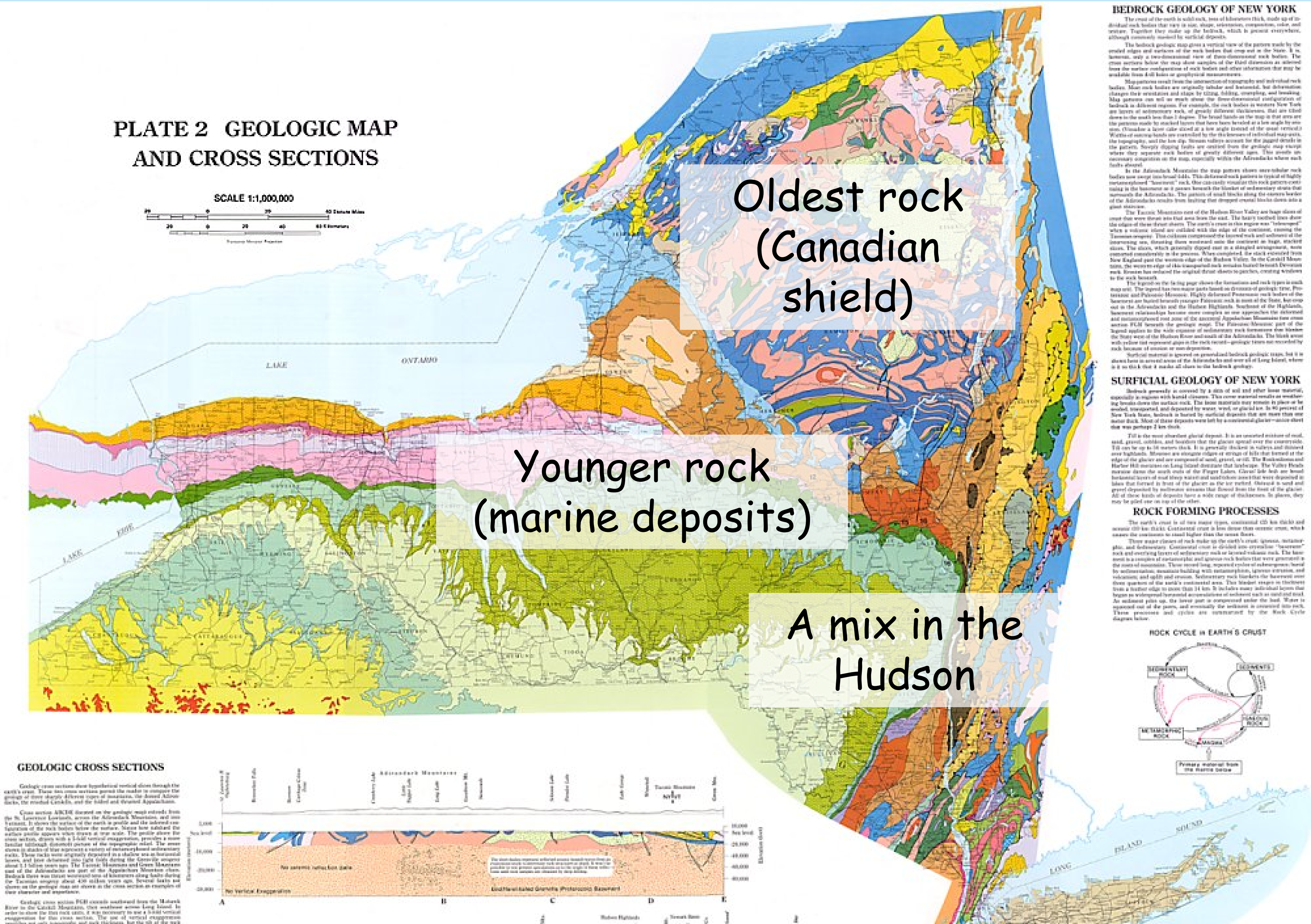
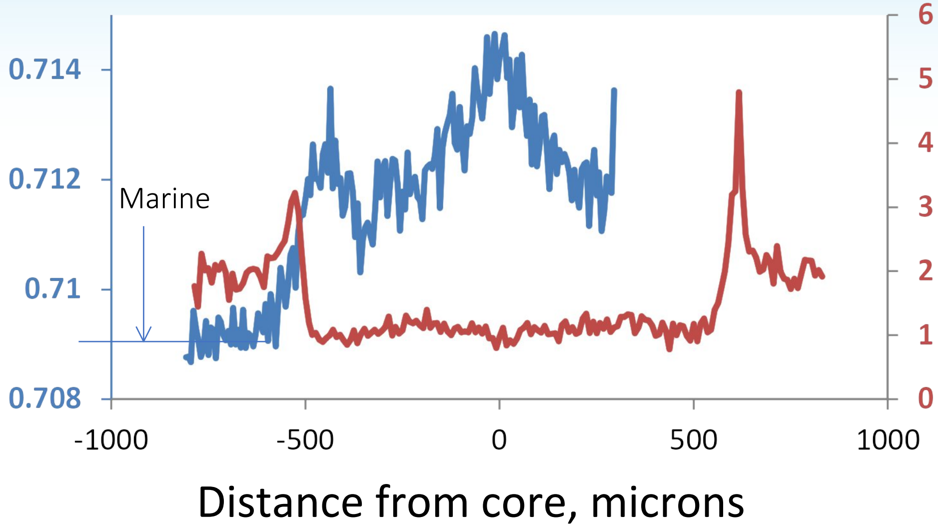


PLATE 2 GEOLOGIC MAP
AND CROSS SECTIONS
SCALE 1:1,000,000
LAKE ONTARIO
LAKE ERIE
BEDROCK GEOLOGY OF NEW YORK
SURFICIAL GEOLOGY OF NEW YORK
ROCK FORMING PROCESSES
GEOLOGIC CROSS SECTIONS
Oldest rock
(Canadian
shield)
Younger rock
(marine deposits)
A mix in the
Hudson

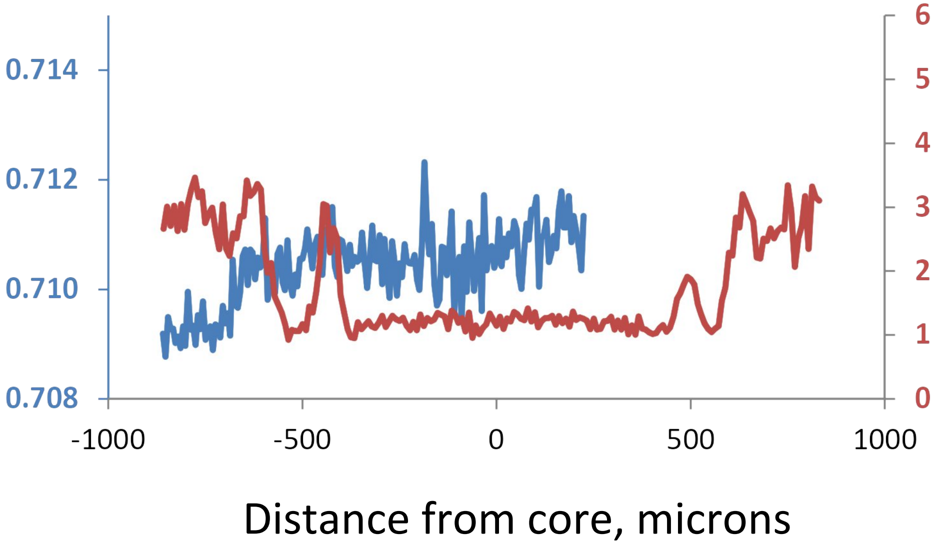
Upper Hudson R. origin



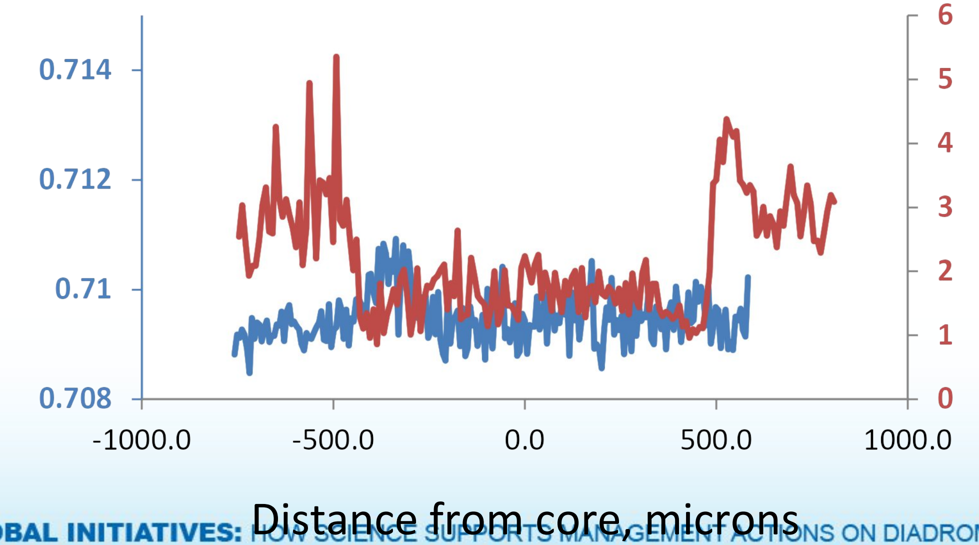
$^{87/86}Sr$

$Sr:Ca \times 10^3$

Hudson R. origin

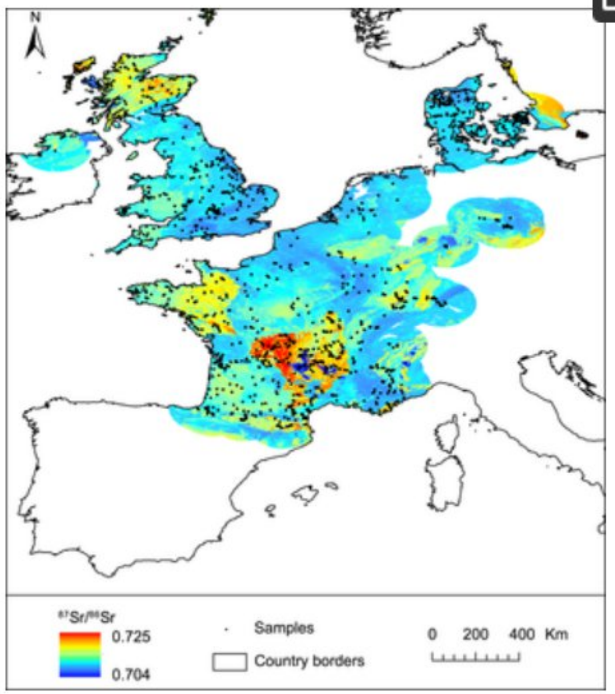


Mohawk R. origin



Isoscapes – modeled spatial predictions of different isotopes of interest – are becoming more powerful

Here is an example of a strontium isoscape generated by random forest regression. And because $^{87/86}$Sr is so popular…



Download:

PPT PowerPoint slide

PNG larger image

TIFF original image

Fig 9. Random forest regression bioavailable ^{87}Sr/^{86}Sr map for Western Europe.
Coastline features are from http://www.naturalearthdata.com/.
https://doi.org/10.1371/journal.pone.0197386.g009

Bataille et al. 2018 PLoS ONE

…the same group generated an isoscape for the globe (!).

Caveat: less certain for large rivers due to the scale at which they integrate Sr.

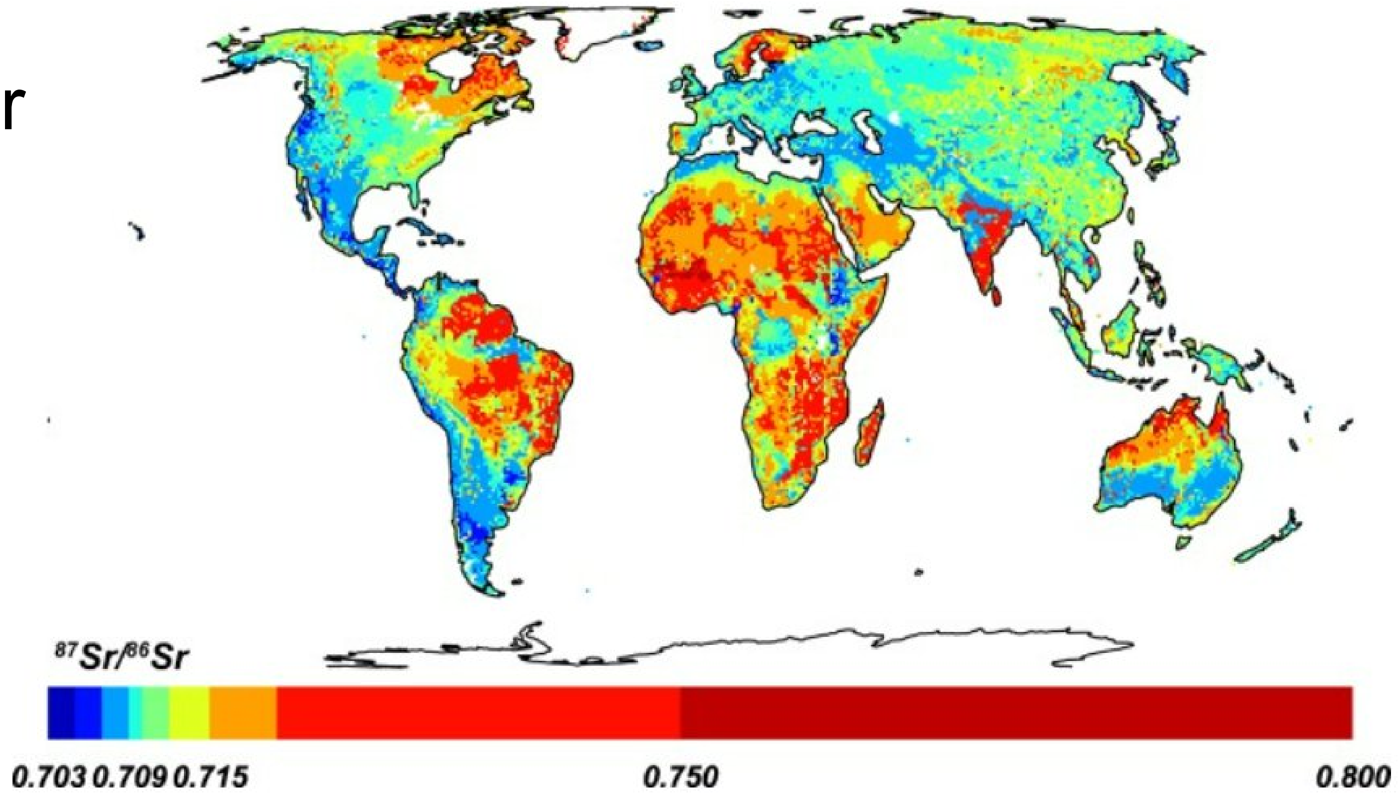


Fig. 9. Global map of predicted bioavailable $^{87}Sr/^{86}Sr$ from random forest regression. This isoscape can be regenerated or updated by including new data using R (See supplementary material, script S1) or directly downloaded at https://drive.google.com/open?id=1g9rCGo3Kd3hz2o5JKkSbgNsGJclvsuQm

Bataille et al. 2020 *Paleogeography, Paleoclimatology, Paleoecology*

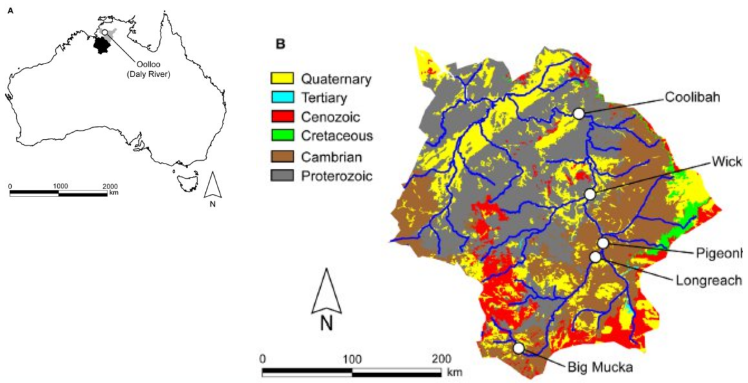
Many examples now of using combined geochemical approaches for diadromous fish otolith chemistry

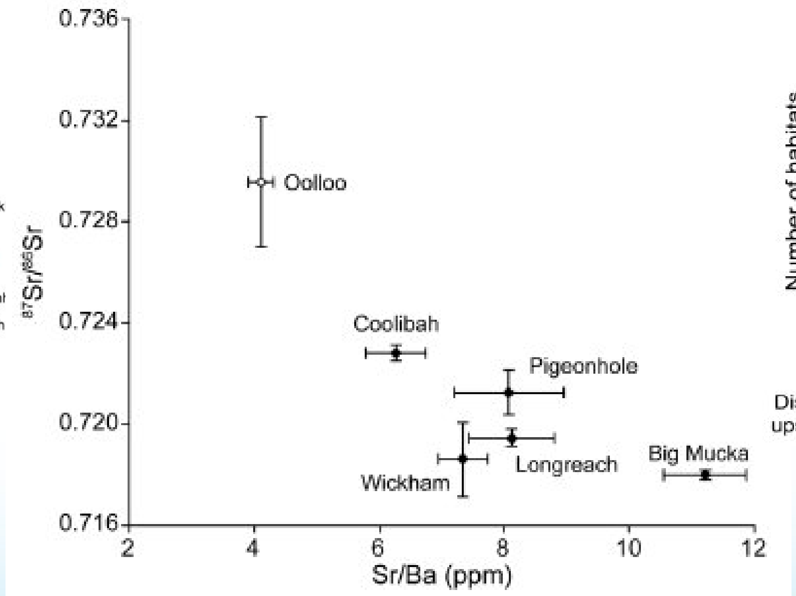
OPEN ACCESS Freely available online PLoS one

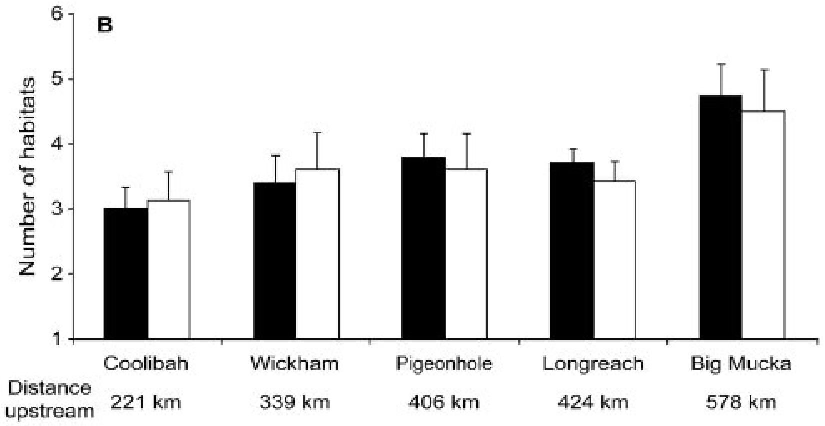
Movements of Diadromous Fish in Large Unregulated Tropical Rivers Inferred from Geochemical Tracers

Benjamin D. Walther[1,2]*, Tim Dempster[3], Mike Letnic[4], Malcolm T. McCulloch[1,5]

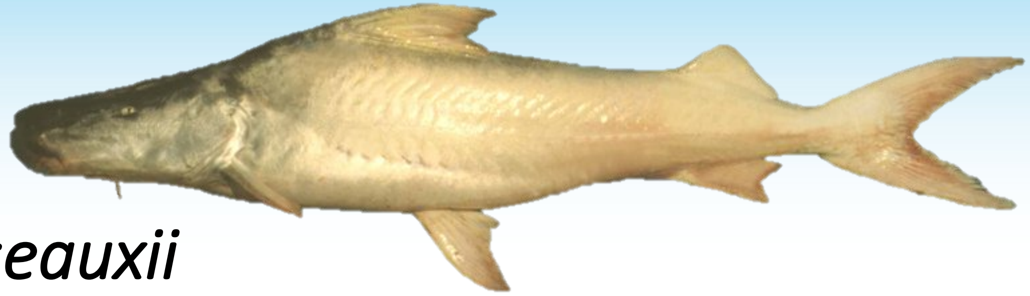
Barramundi, *Lates calcarifer*







AMAZONIA

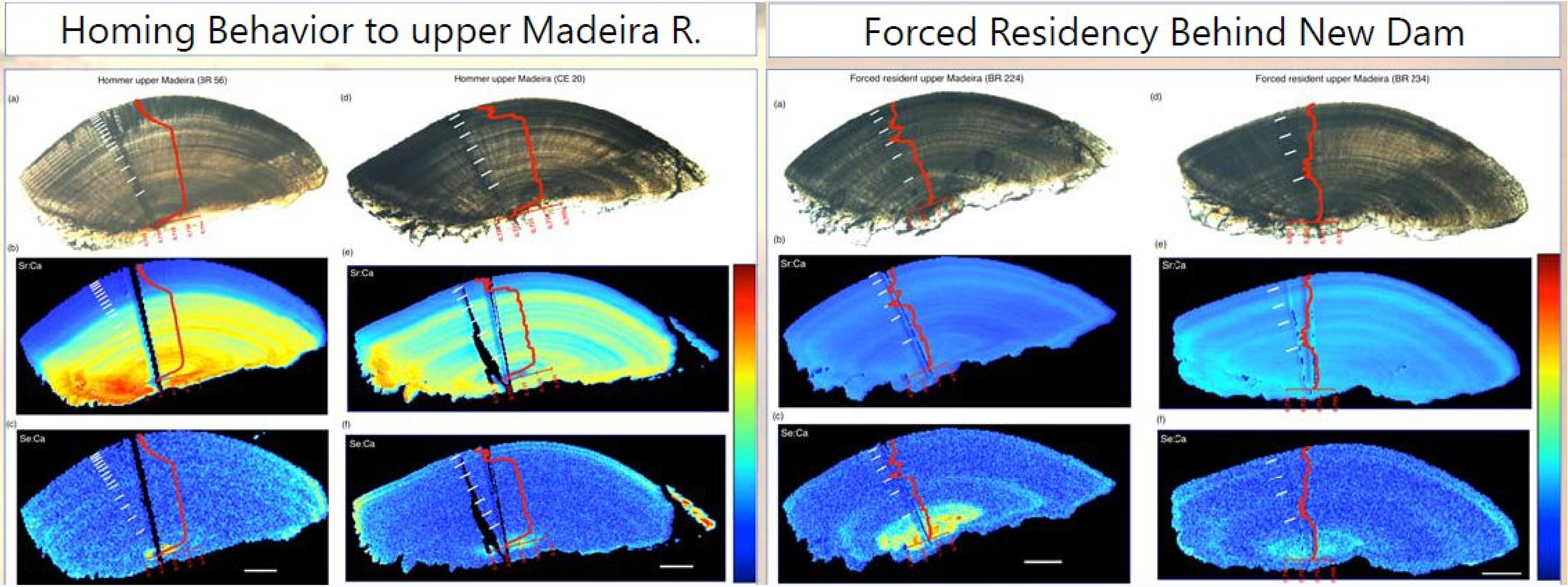


Goliath catfish, *Brachyplatystoma rousseauxii*

$^{87/86}Sr$

Sr/Ca

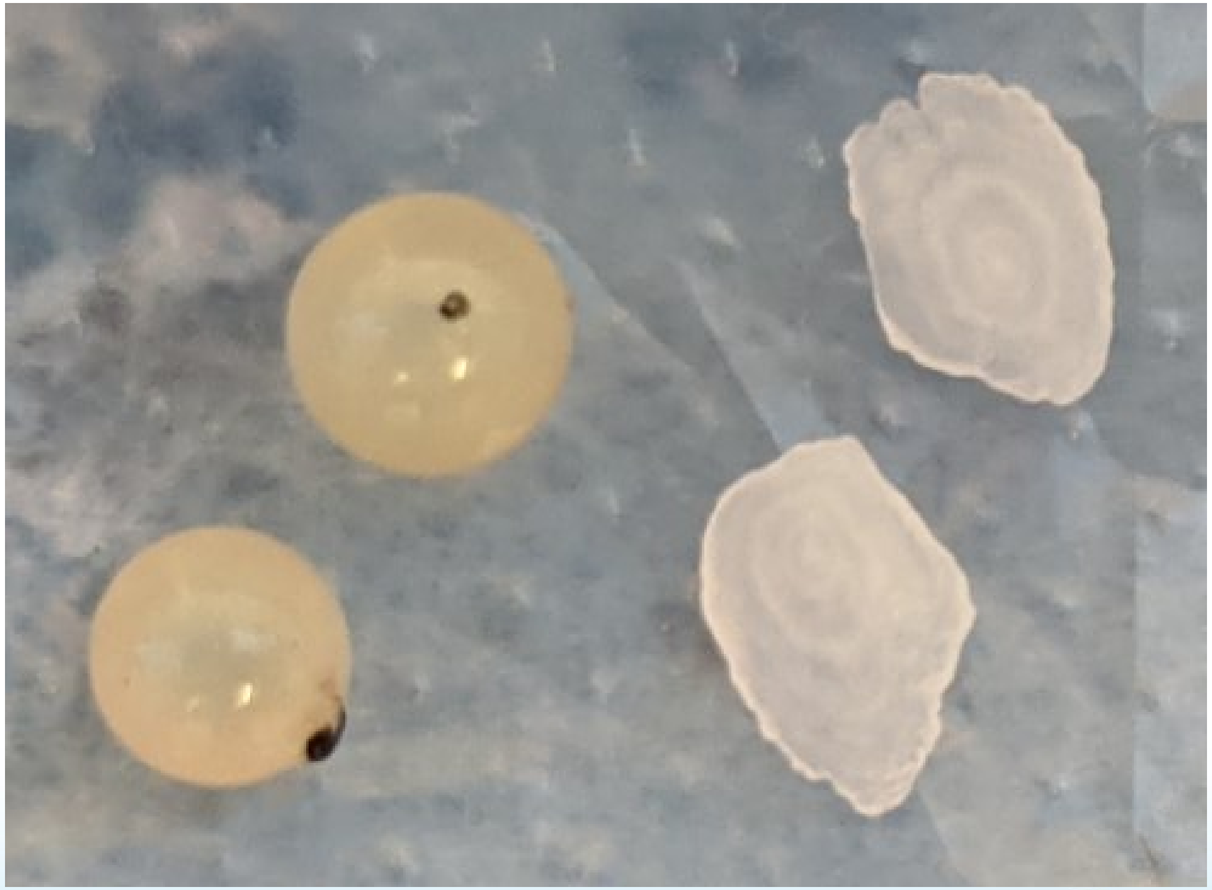
Se/Ca



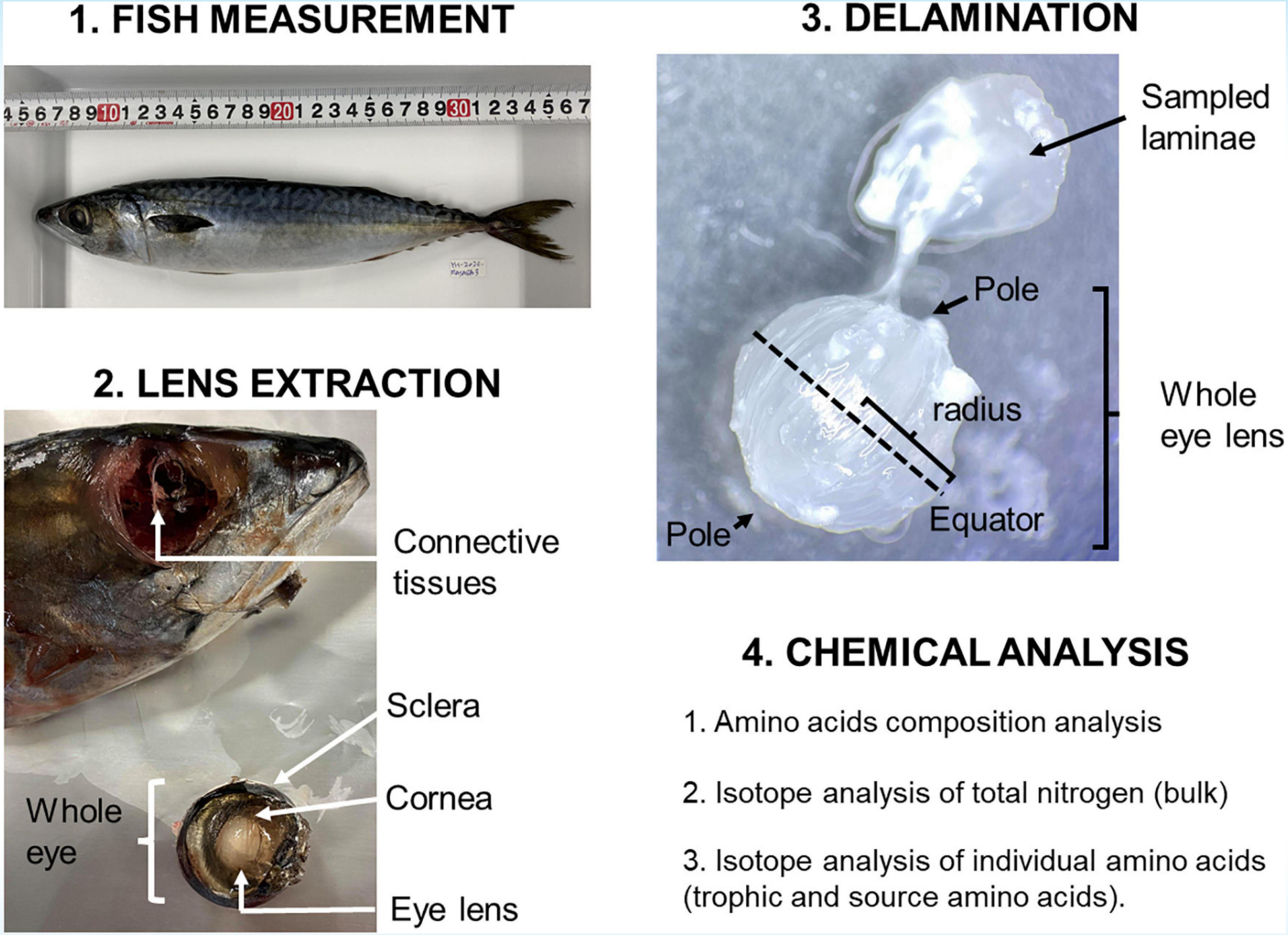
Hauser et al. Freshwater Biology 2020

Fish eye lenses and otoliths – complementary archival structures?

Lenses formed from layers of proteins



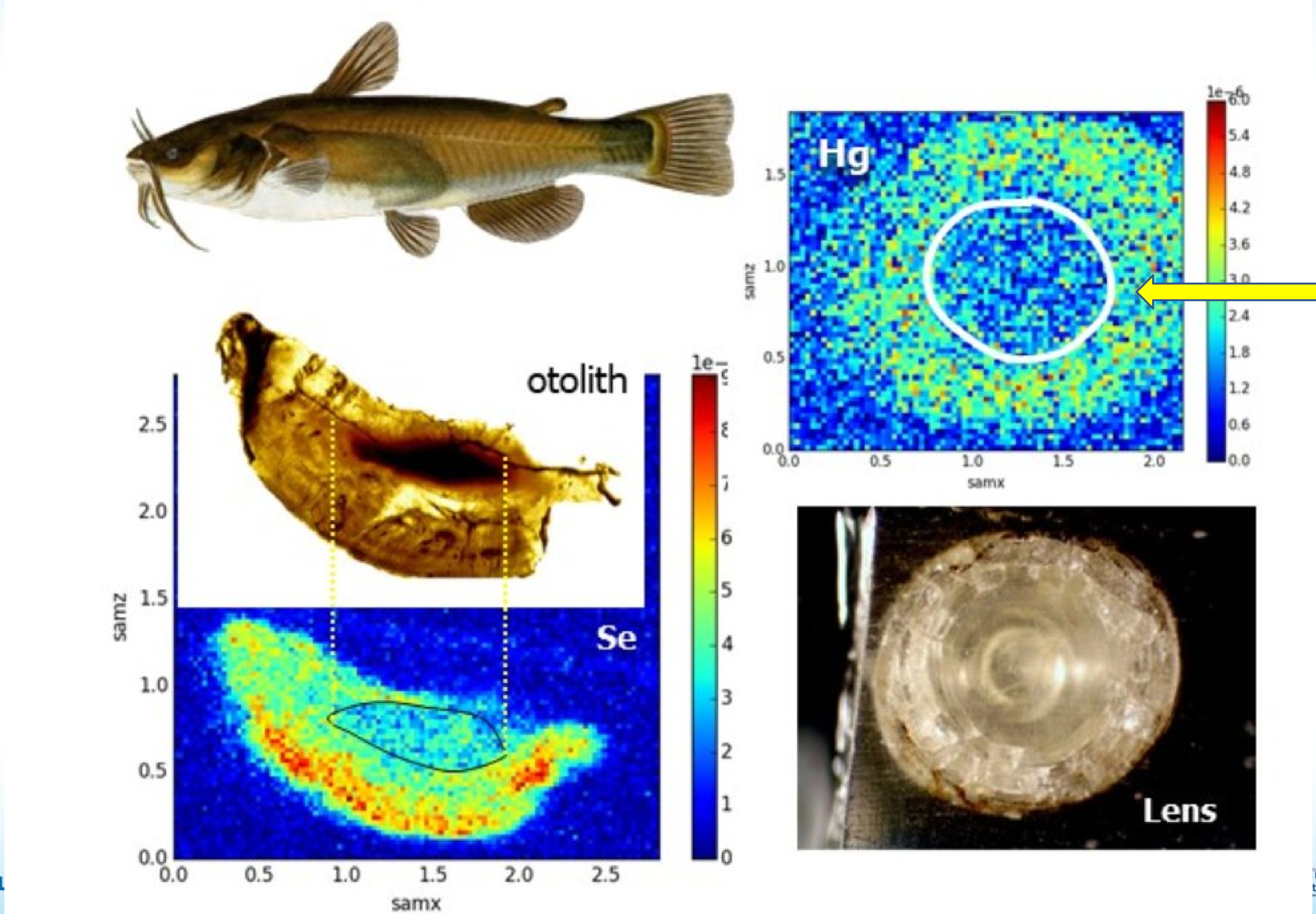
Otoliths are mainly aragonite ($CaCO_3$)



Eye lenses are becoming increasingly popular – amenable both to light stable isotope **and** trace element work

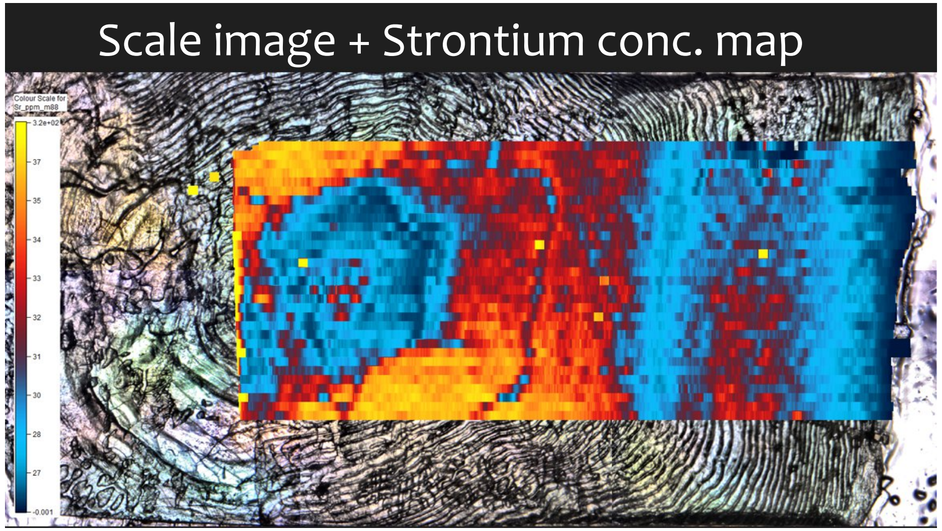
← Harada et al. Front. Mar. Sci., 03 February 2022

A Brown Bullhead catfish in Arbutus Lake: lenses take up Hg!

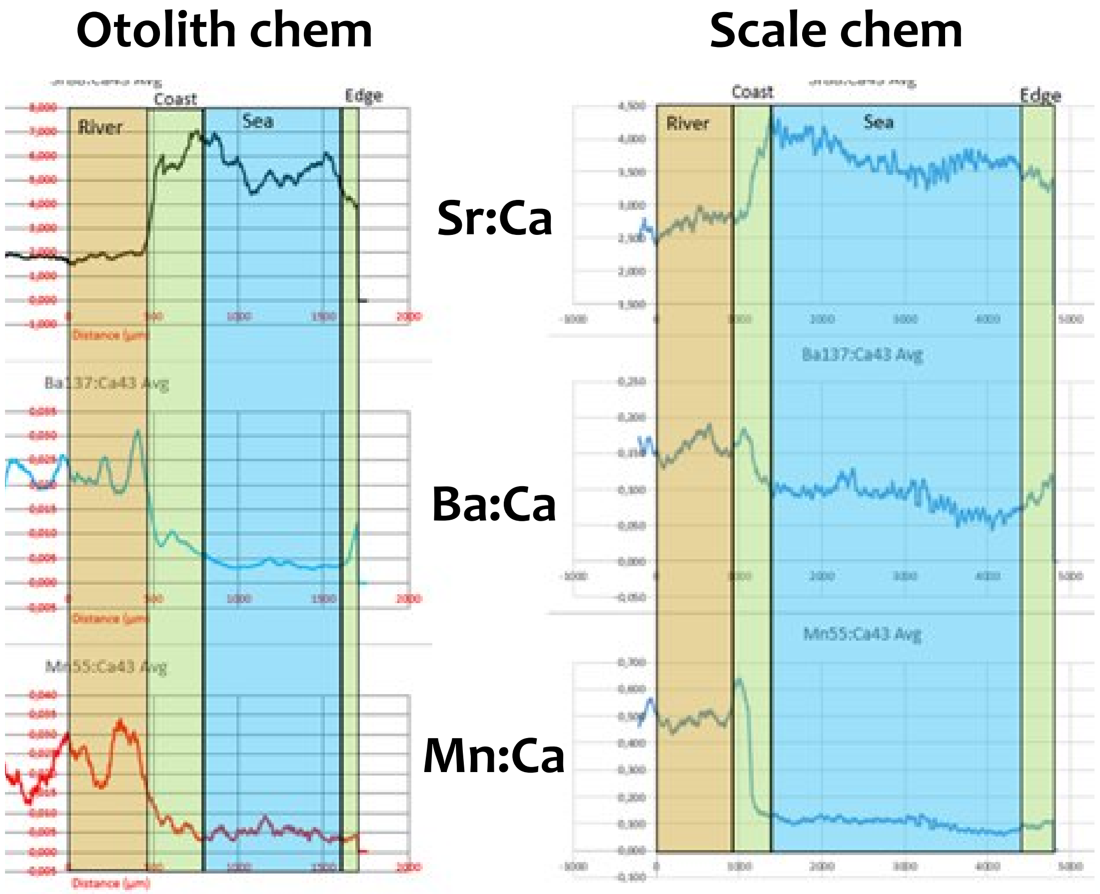


Ontogenetic shift to piscivory

Re-visiting fish scales as chemo-archives



Von Ehr, M. 2022. Novel Scale Chemistry of *Salmo Salar* L. – New Linkage of Otolith and Scale Chemistry to M74 Reproductive Disorder. Master's thesis, SLU



Environmental DNA (eDNA)

DNA released into the environment (skin, blood, gametes, waste, etc.)

⬇

Collection of water or substrate and concentration of genetic material and associated matrix

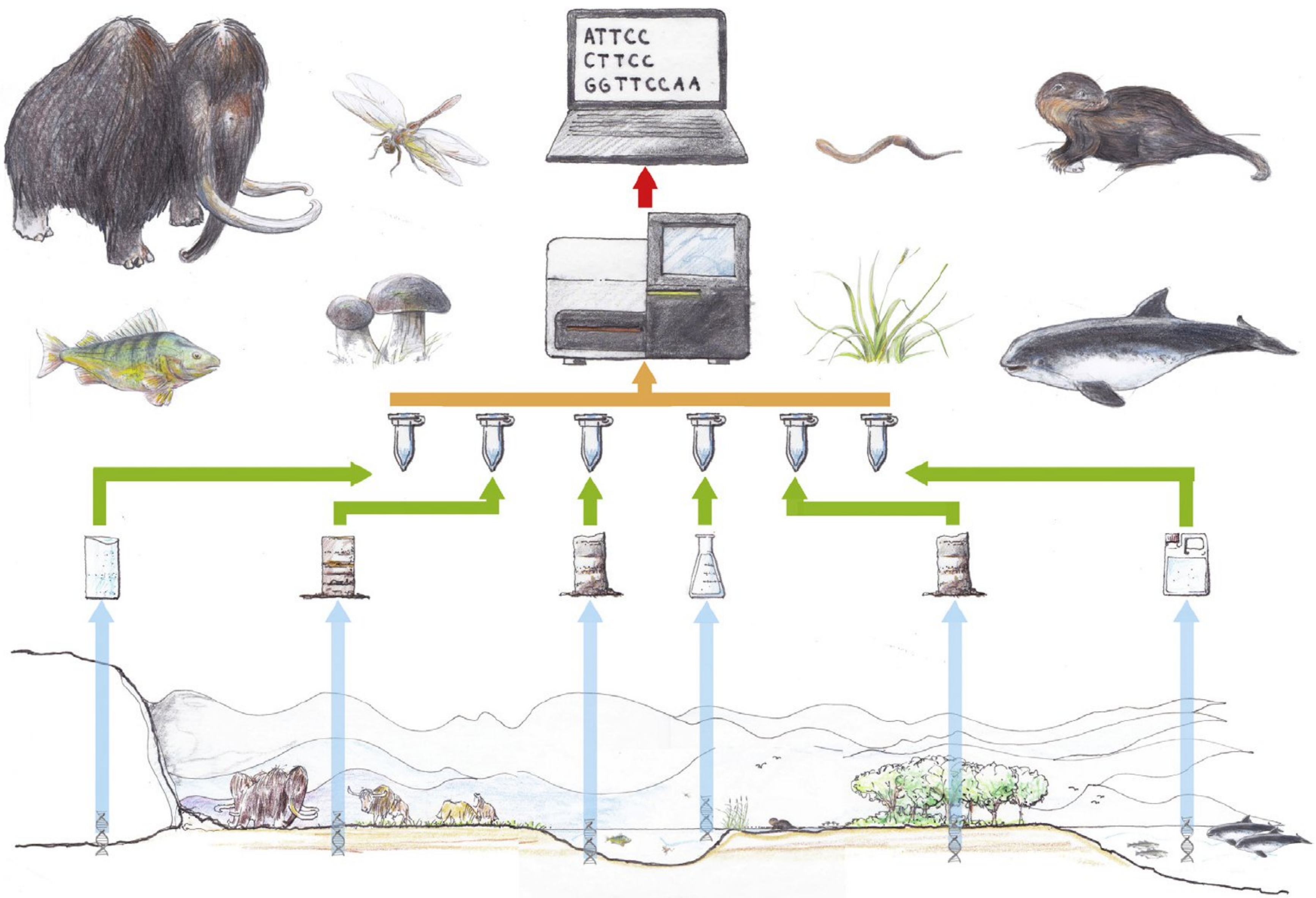
⬇

DNA extraction

⬇

PCR and analysis

P.F. Thomsen, E. Willerslev / Biological Conservation 183 (2015) 4–18



Single-Species Approaches vs. Metabarcoding

Single-species	Genetic target unique to a species of interest	High sensitivity	Rapid, cost-effective data generation	• Invasive species • Rare species • Specific conservation priority
Multi-species Metabarcoding	Broader genetic targets for a community of interest	Lower sensitivity	More involved sample processing and large datasets	• Estimate biodiversity • Assess broad community shifts

eDNA is promising, but mostly not well-resolved yet.
Presence/absence good, quantitative estimates not.

Like other new approaches, needs more work

Summary.

- There now exist quite a number of different approaches to track diadromy
- Some techniques are more mature than others (e.g., parasites, otolith chemistry, DNA)
- Still, new developments are happening in ALL fields
- **Complementarity of approaches** should really strengthen our understanding

Telemetry & other electronic tracking

Geochemical atlases, isoscapes, etc.

“Hard parts” sclero-chronology methods

DNA, eDNA, parasites, and other soft biomarkers

A final thought:

Does anyone want to collaborate on a proposal to use techno-tools to validate chronological biomarkers?

If so, please come talk to me!

Merci pour l'écoute!

Photo via Fish Want Read/VK