

Methods to track diadromy

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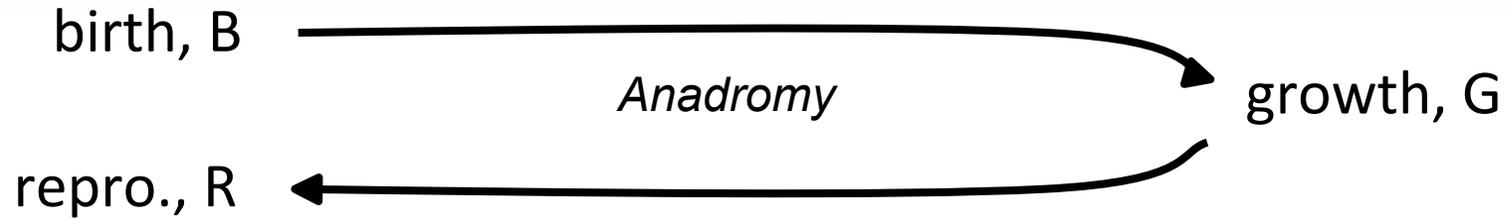


LOCAL AND GLOBAL INITIATIVES:

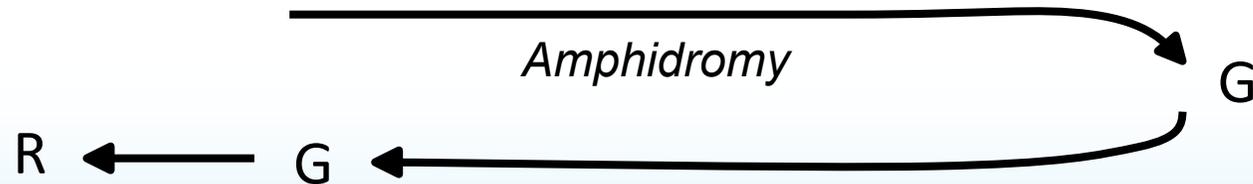
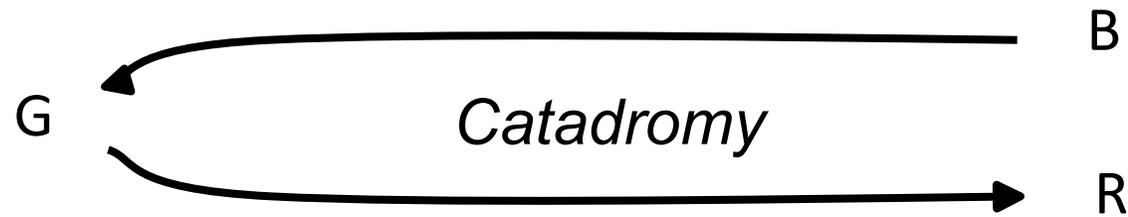
HOW SCIENCE SUPPORTS MANAGEMENT ACTIONS ON DIADROMOUS FISH

Fresh water

Sea



“Textbook Migration”



Fresh water

Sea

Reality...



Different types of tracking methods

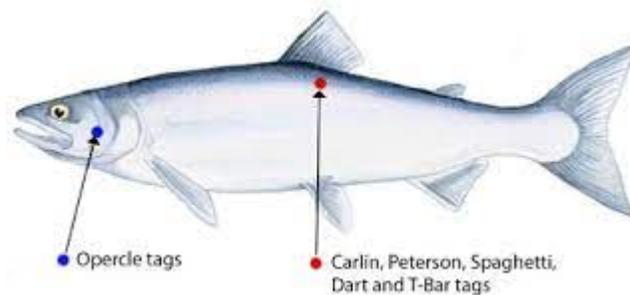
- Artificial tags
- Natural tags
 - Short term
 - Long term (including lifetime)
 - Status (genetic)
 - Presence/absence (eDNA)
- Combined approaches

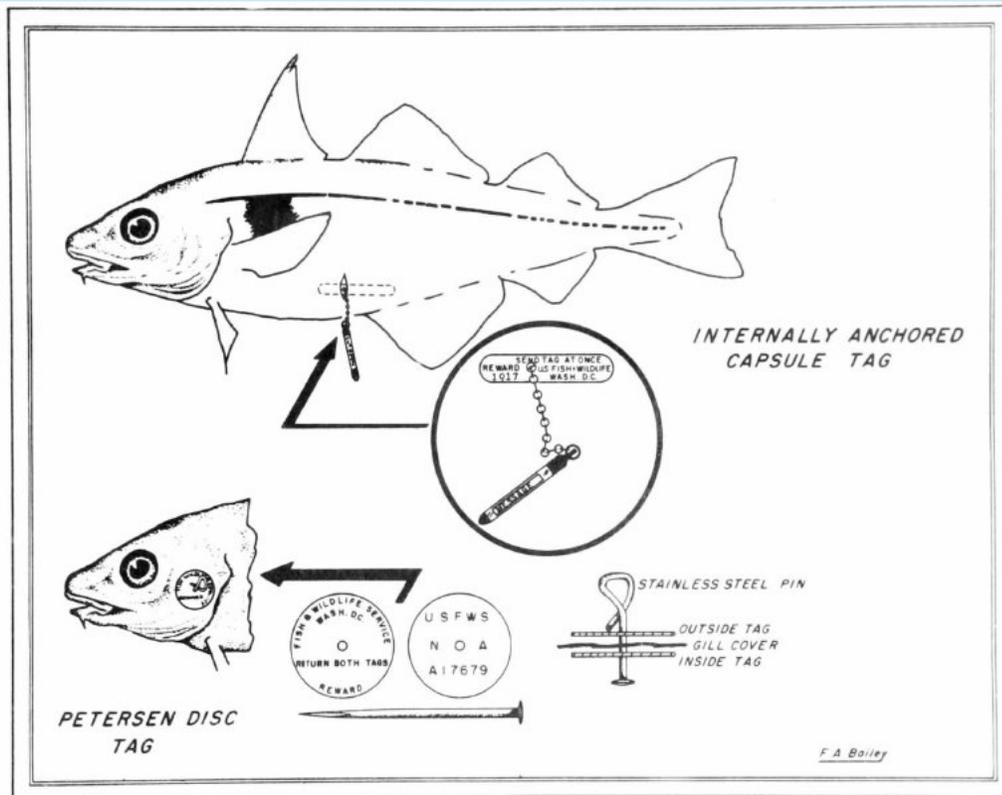
Which method to choose? Depends on your question(s), the study species, life stage, etc.

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

And your budget...

Artificial tags





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

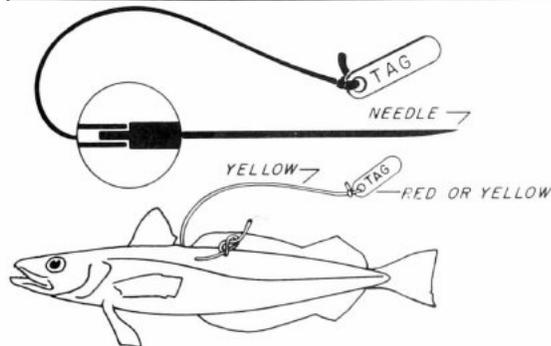
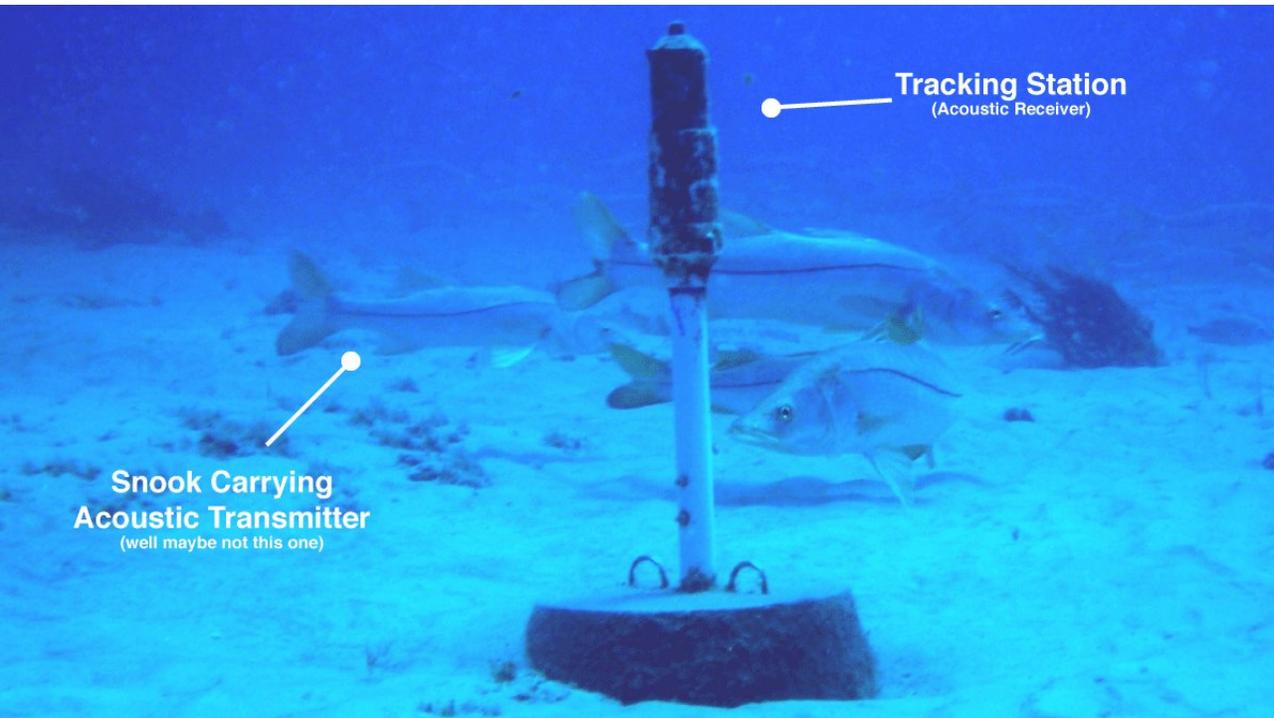


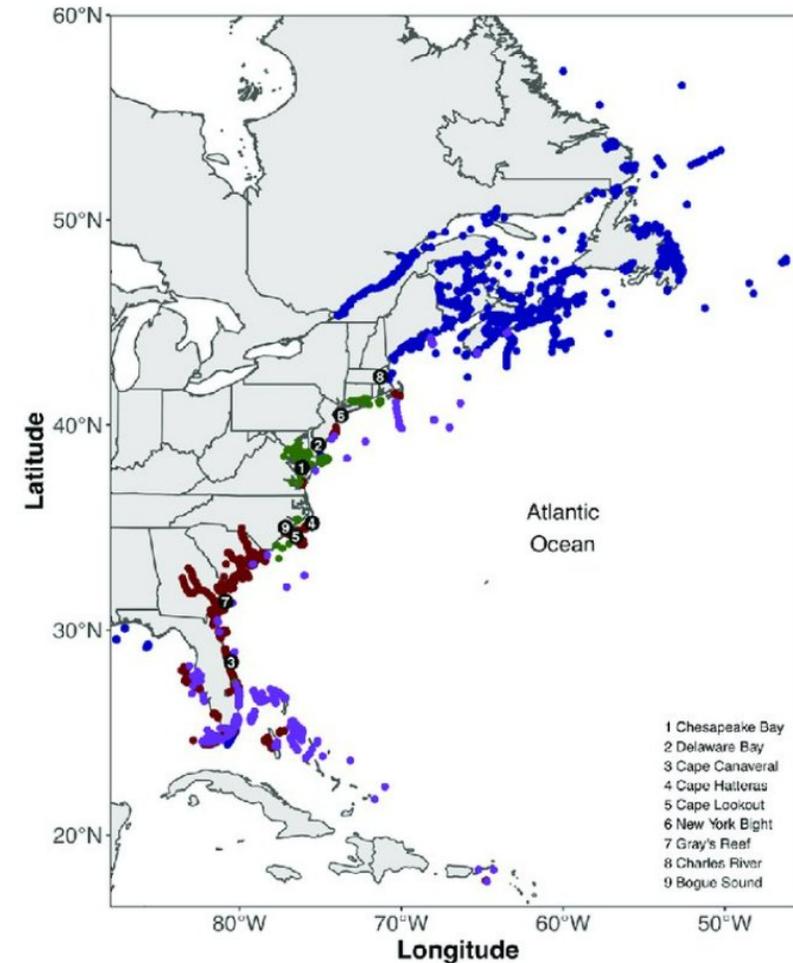
Figure 3.--A vinyl plastic Atkins tag used on silver hake. The needle is used to thread the tubing through the dorsal muscles of the fish.

Electronic tags – riding the techno-development wave

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



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

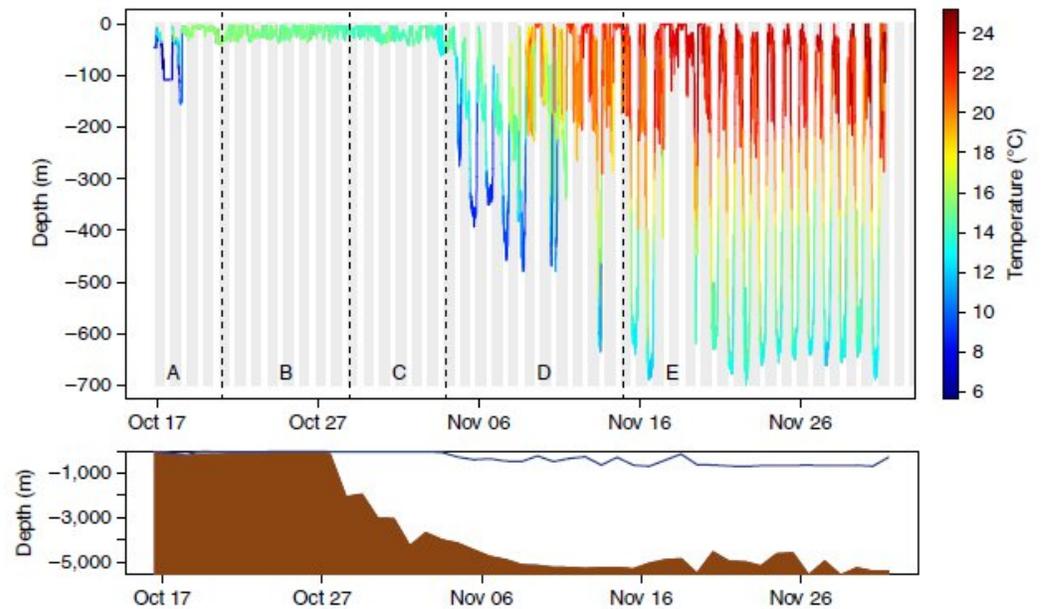
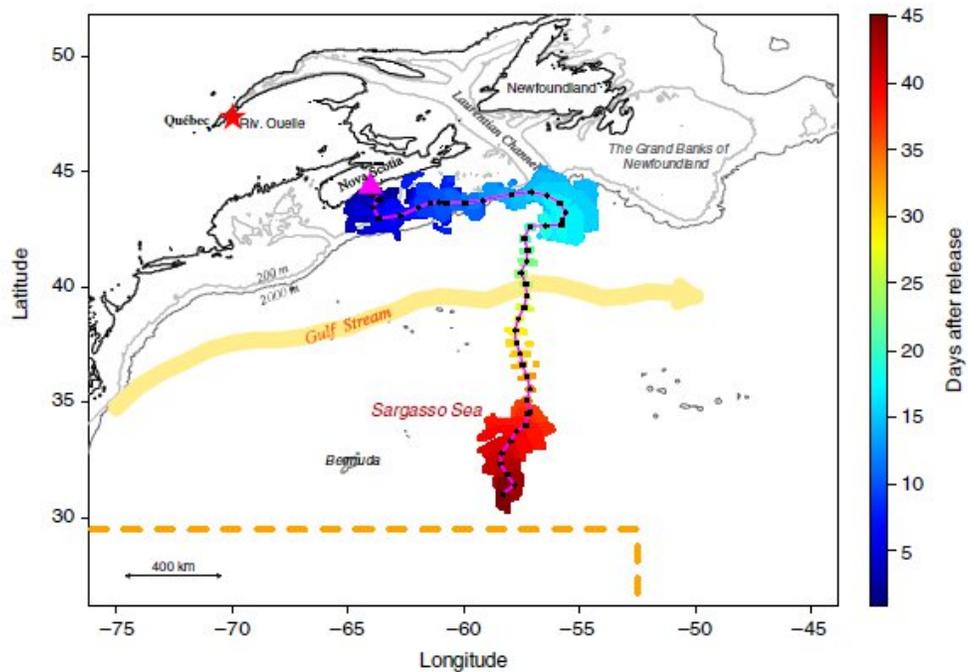


Bangley et al.
2020 Mar.
Coast. Fish.

Pop-up satellite tags

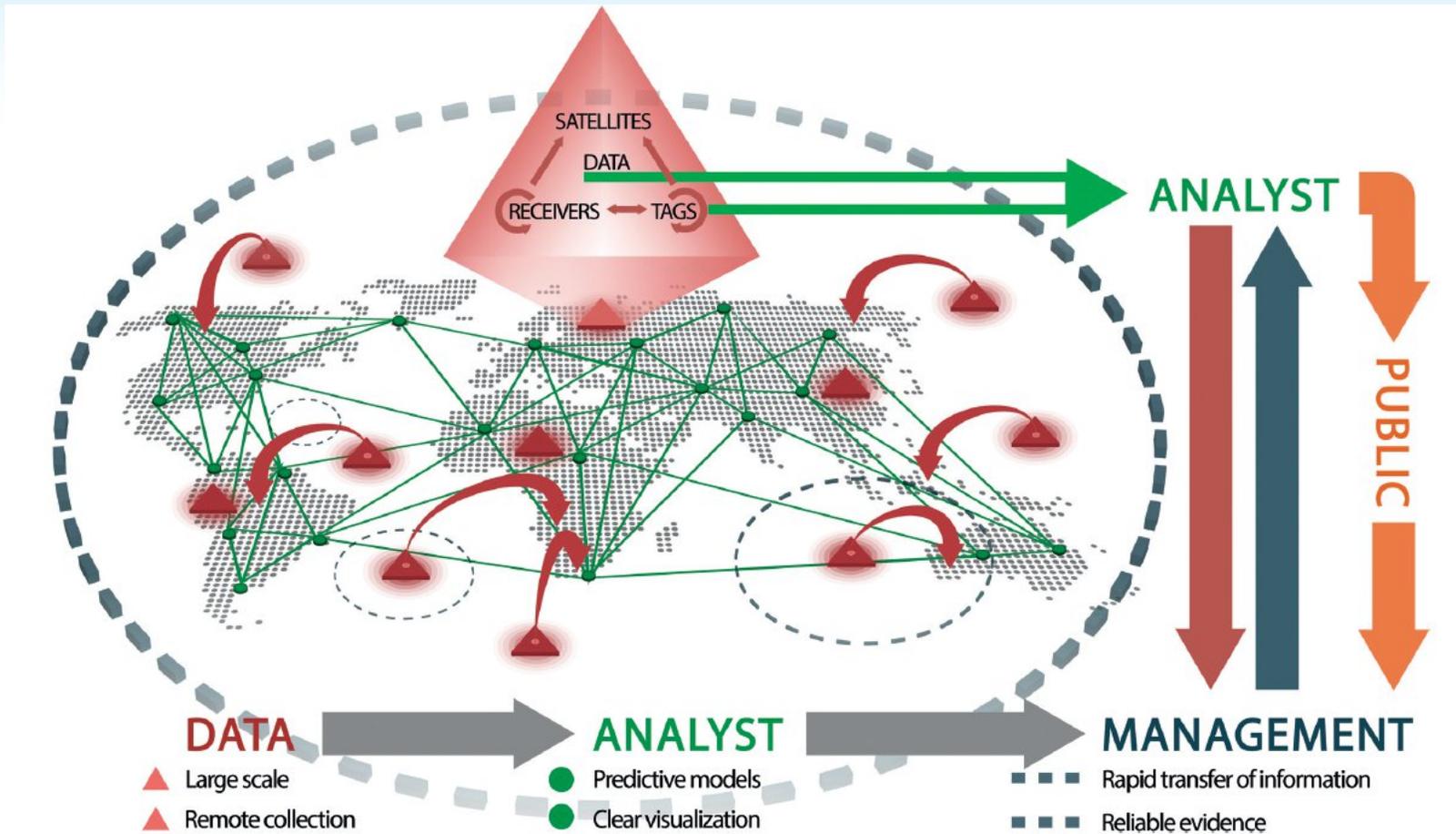
Great for larger animals

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



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

Natural tags

Tzadik et al.

Chemical archives in fishes beyond otoliths

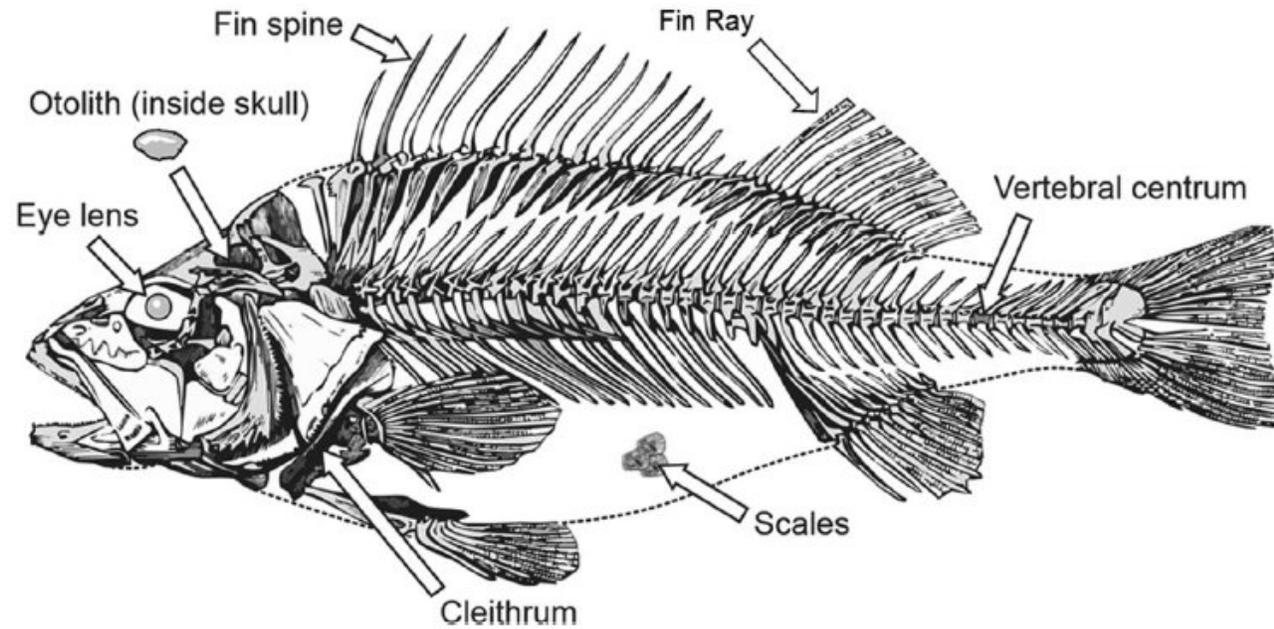


Fig. 1. Basic anatomy of derived fishes. All alternative structures are labeled based on their anatomical locations.

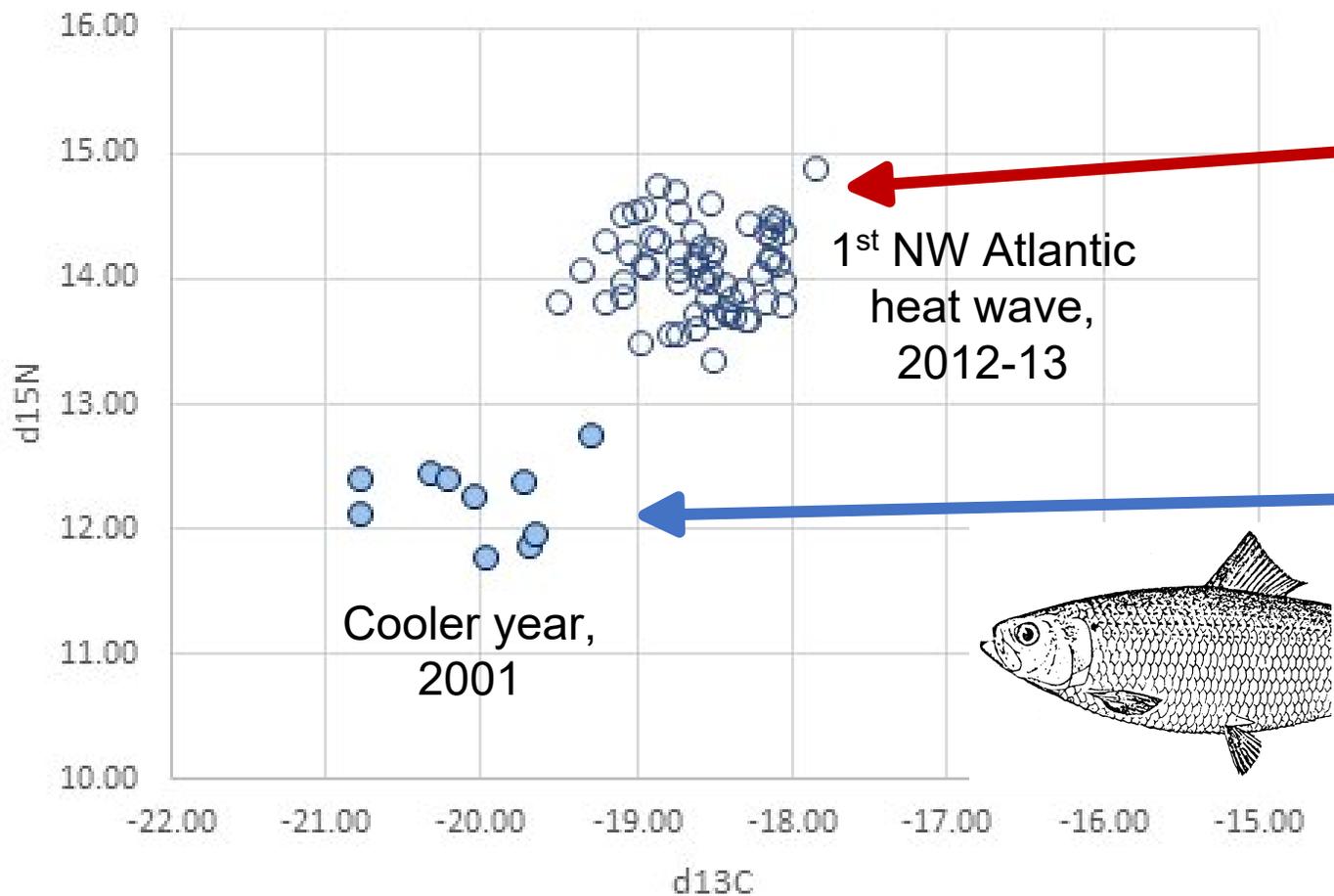
Assumptions for natural tags to work:

- 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

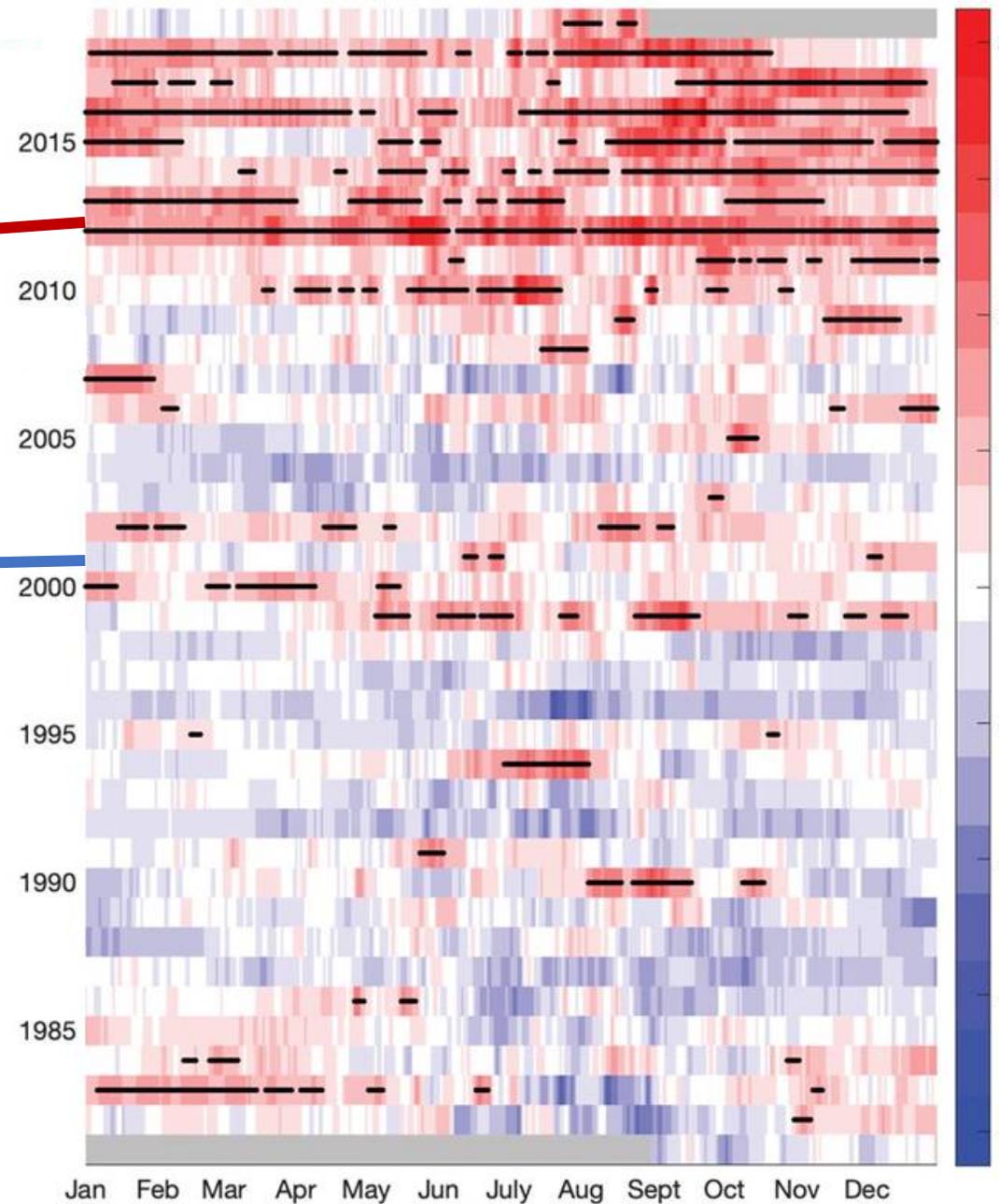
Stable isotopes

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

BBH spawners, comparing 2001 and 2013 (affected by cold)



Gulf of Maine Temperature Anomalies and Heatwaves



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

- Reflects the $\delta^{15}\text{N}$ of nitrate taken up by 1° producers
- Since nitrate can vary widely, $\delta^{15}\text{N}_{\text{Base}}$ can be used to track migration
- Can create “ $\delta^{15}\text{N}_{\text{Base}}$ 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 \rightarrow lifetime analyses

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

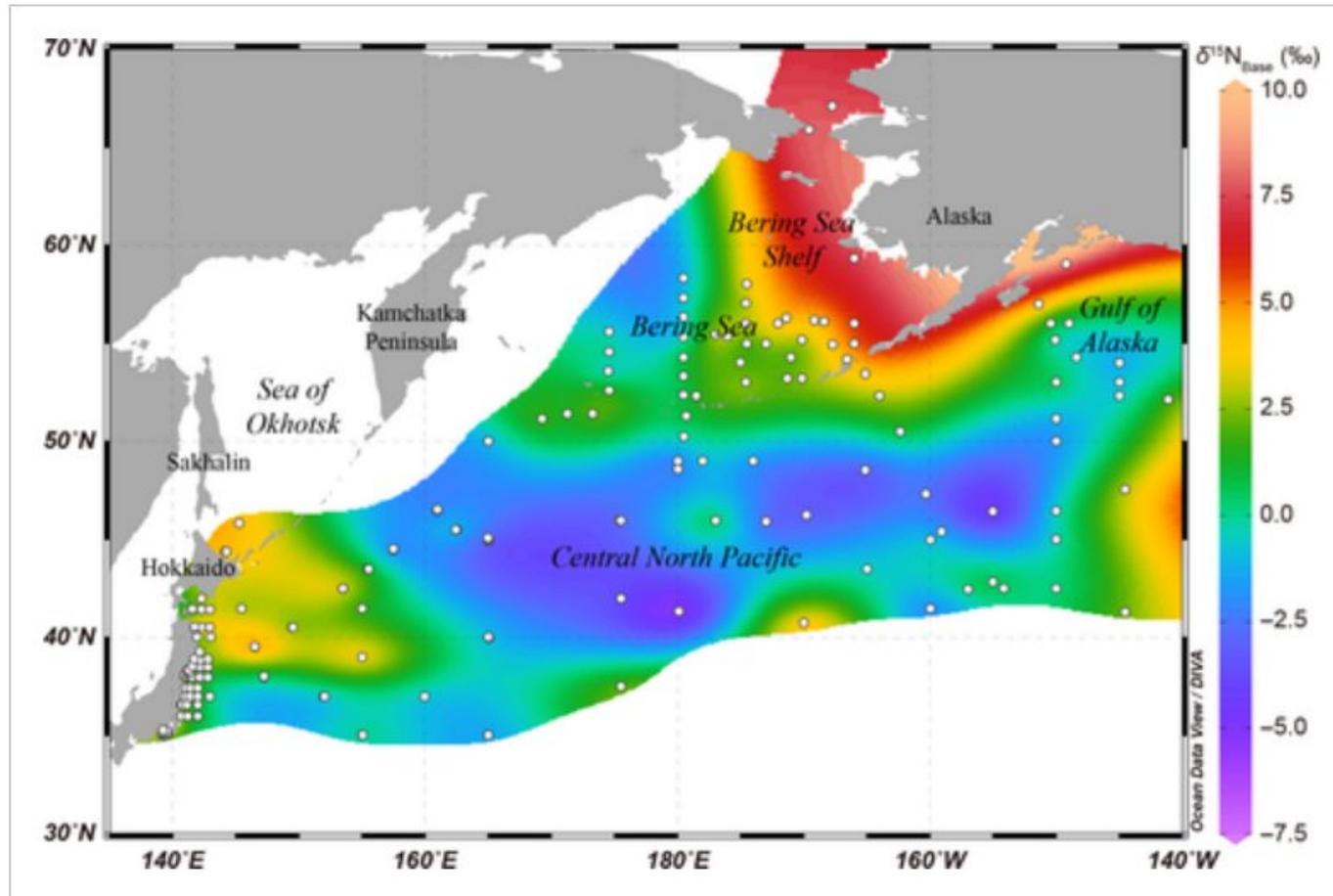


Figure 1

Map of the estimated $\delta^{15}\text{N}_{\text{Base}}$ 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

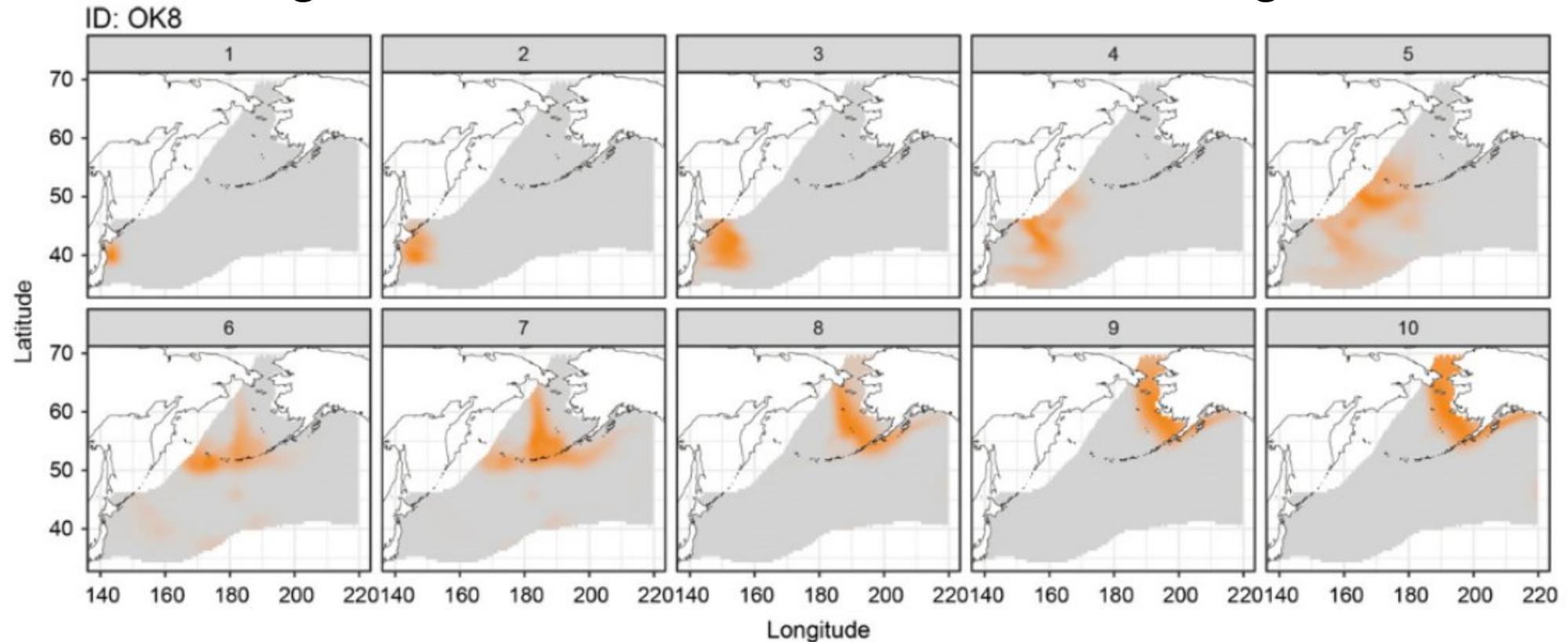
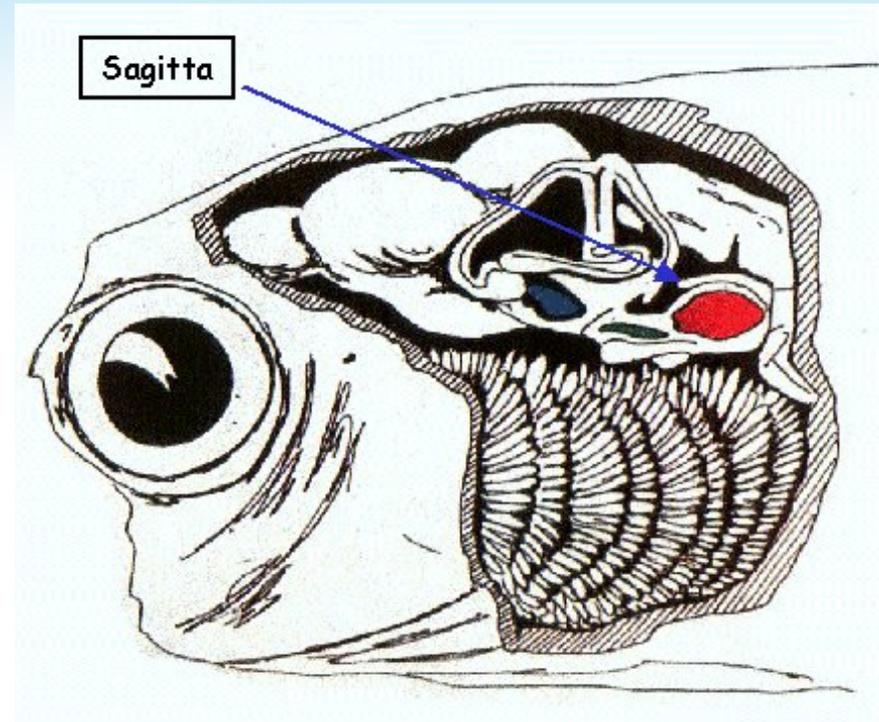
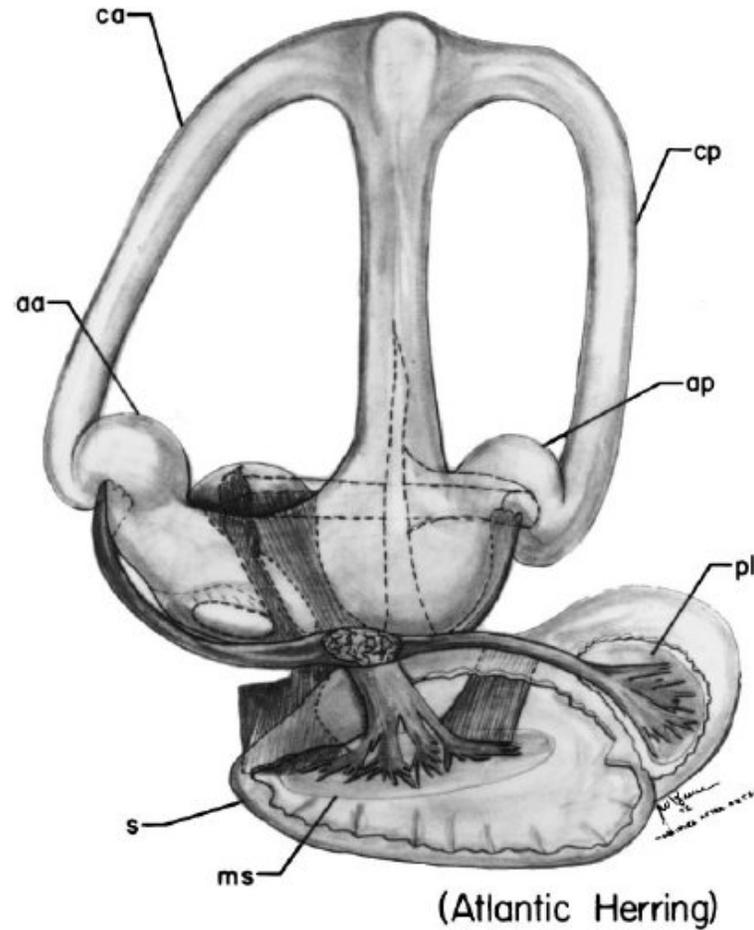


Figure 3 Estimated chum salmon migration areas. Mean presence probabilities for two salmon individuals (IDs: OK2 and OK8) at growth stages 1–10 (panels 1–10, respectively). The colour gradients (tints of orange) indicate presence probability (low to high). The grey area shows the extent of the isoscape.

Matsubayashi et al. 2020 Ecology Letters

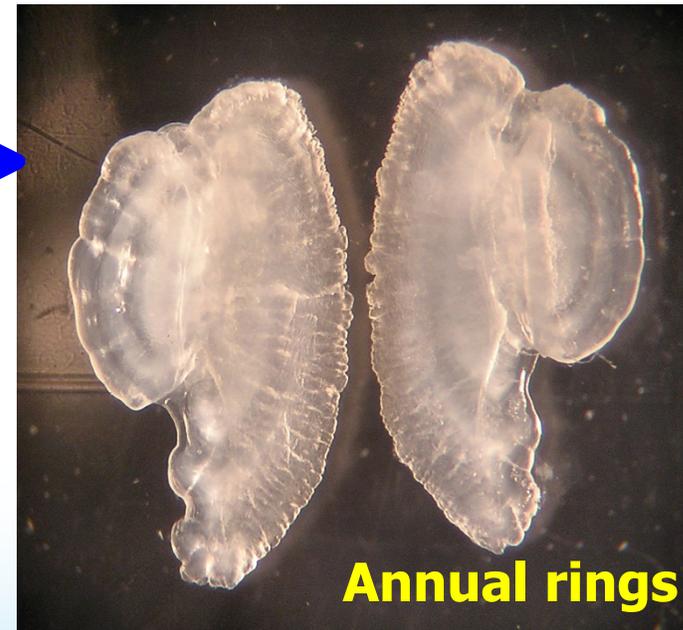
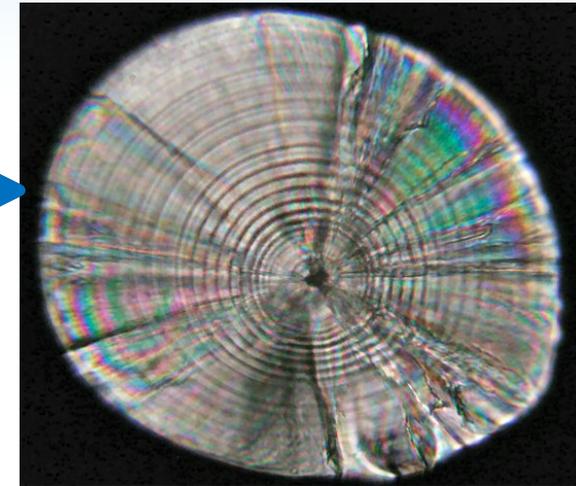
ies Research 46 (2000) 15–25

A fish ear!

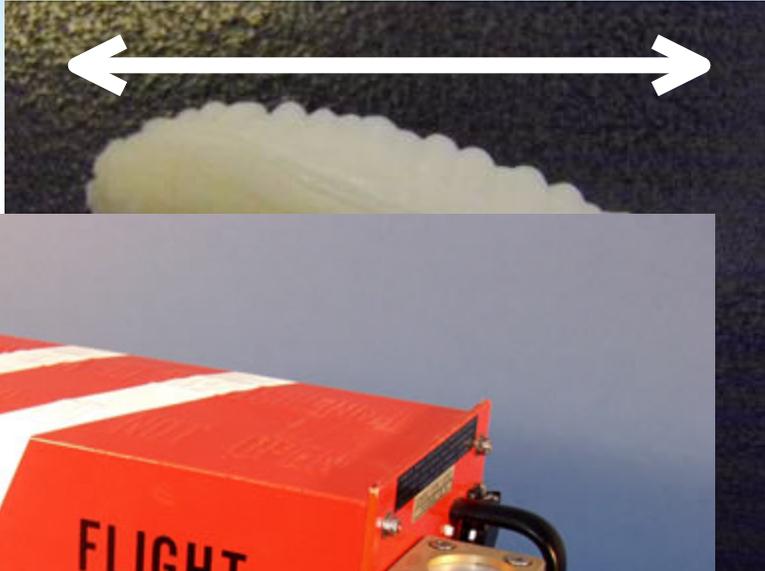


Fish Otoliths (ear-stones)

Otoliths – built-in chronometers in fish heads...



A c

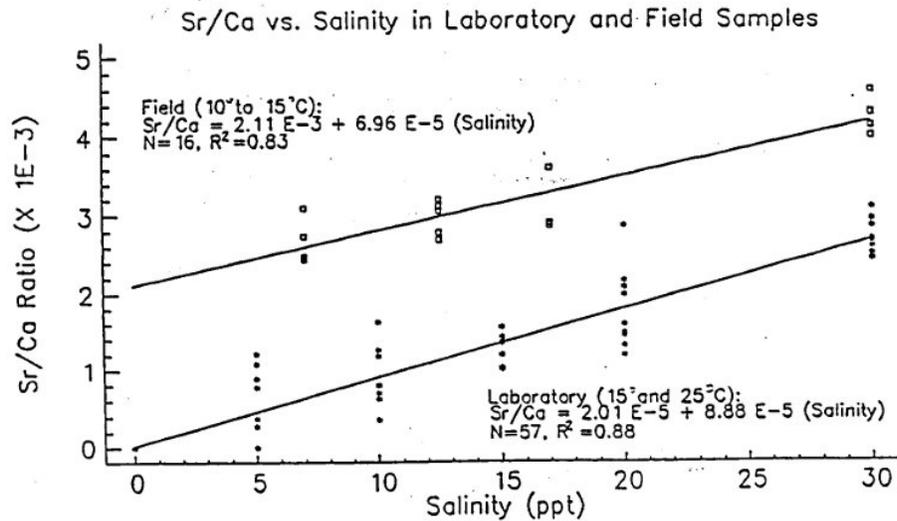


Chemical information

Photo: NTSB

"childhood"

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



Chesapeake Bay Female Striped Bass, Total Length = 110 cm

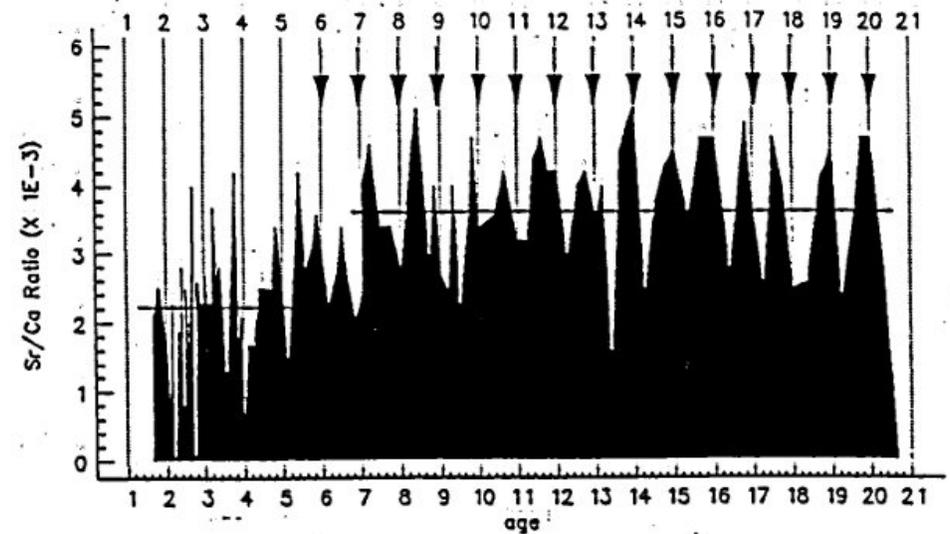


Figure 4. Experiment 1 and Field Verification Samples. Otolith Sr/Ca vs. salinity in laboratory (indicated by asterisks) and field (indicated by open squares) samples.

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?”

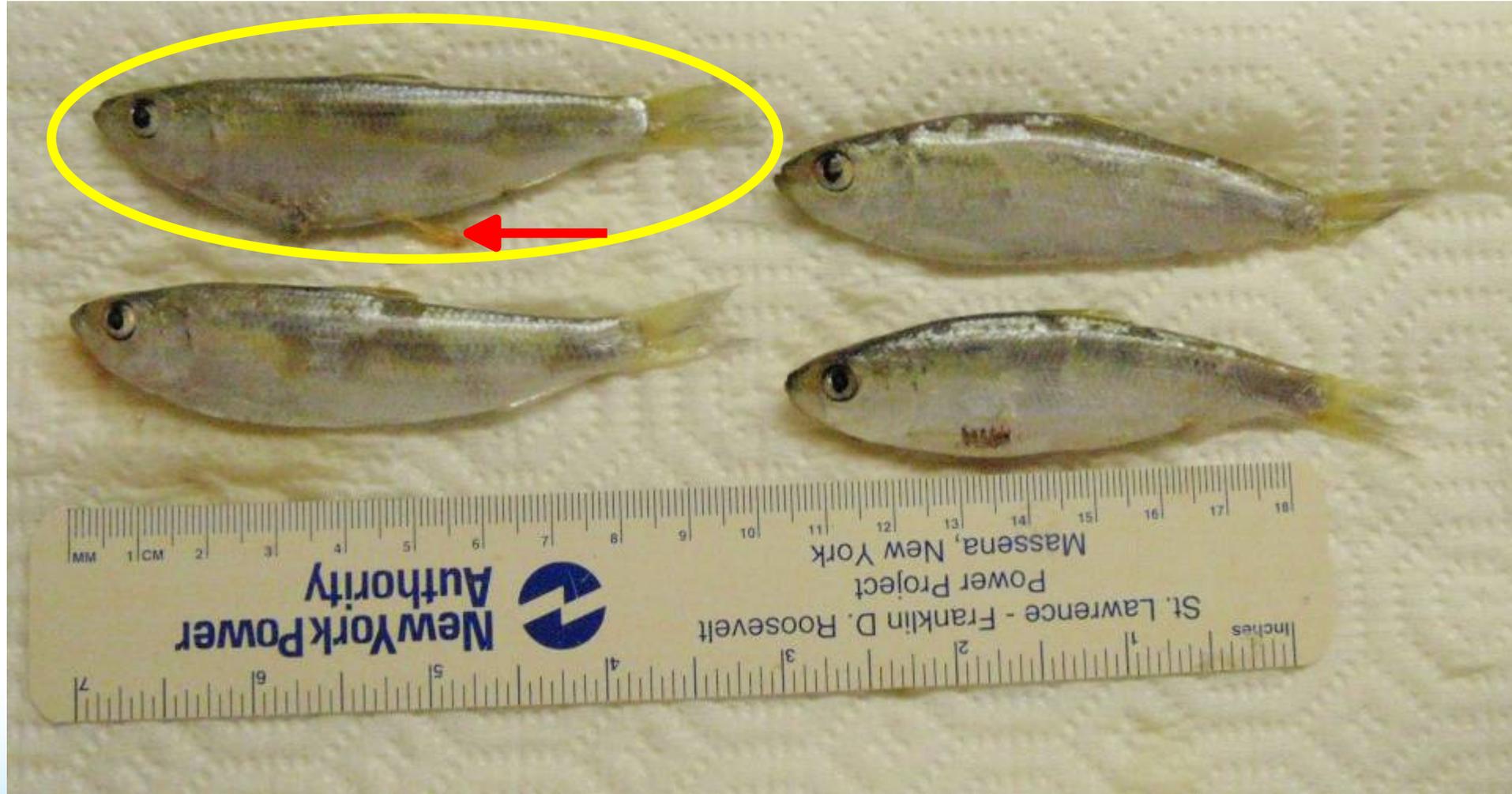
Blueback herring:

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



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

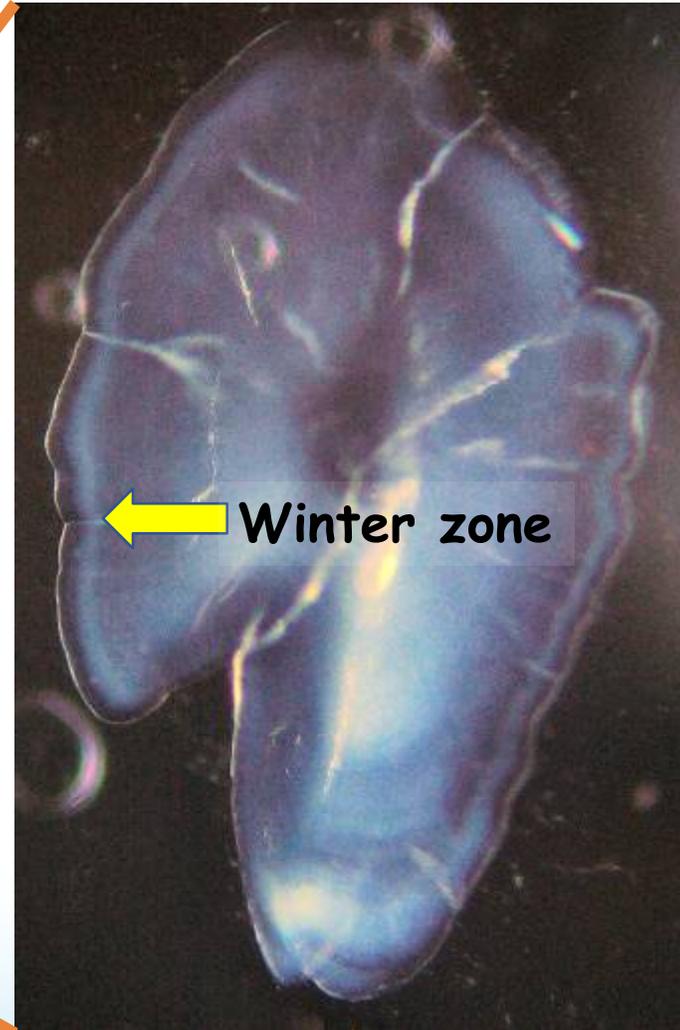
What are they doing here??





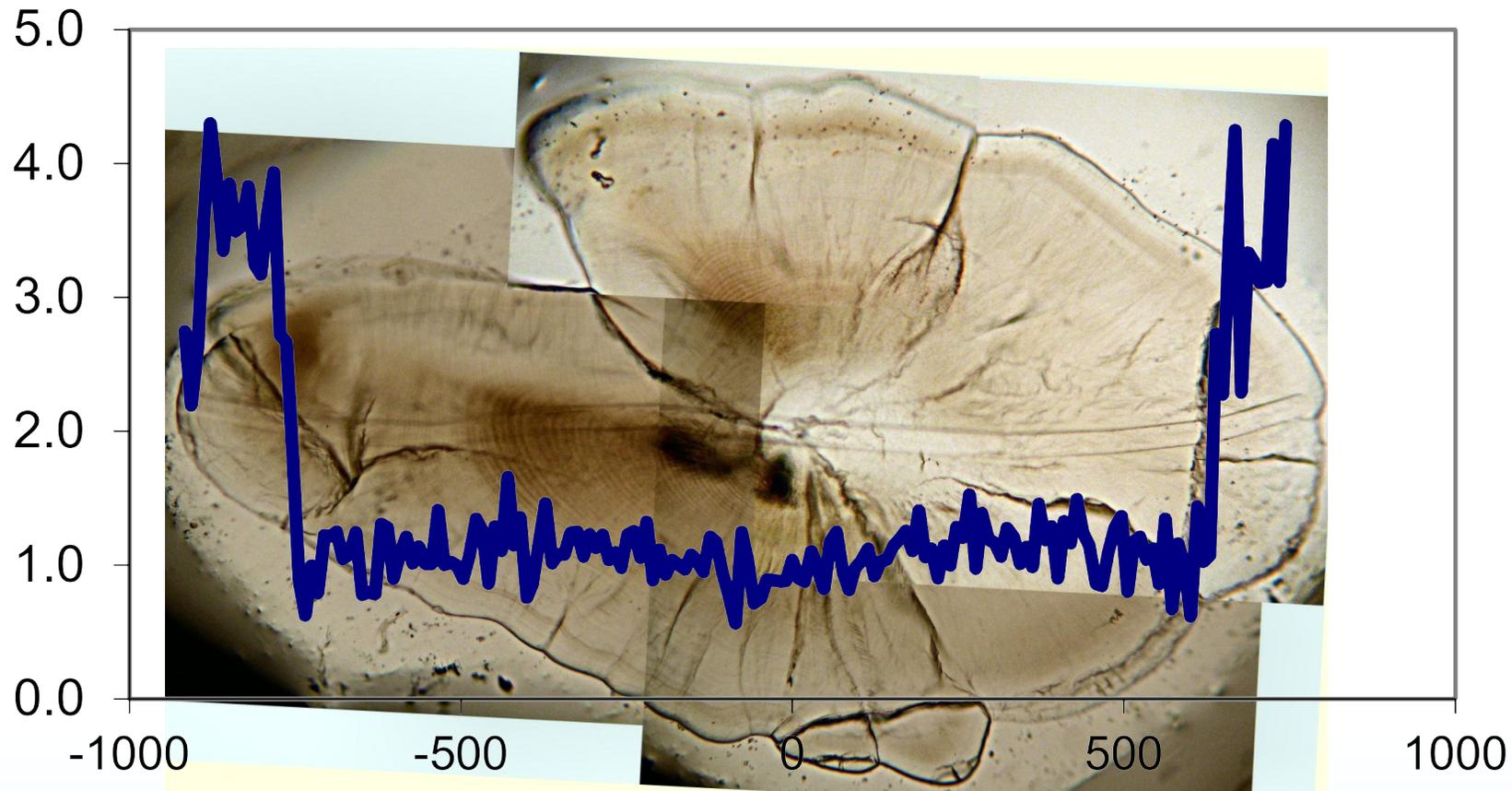
A pair of adult blueback herring otoliths

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



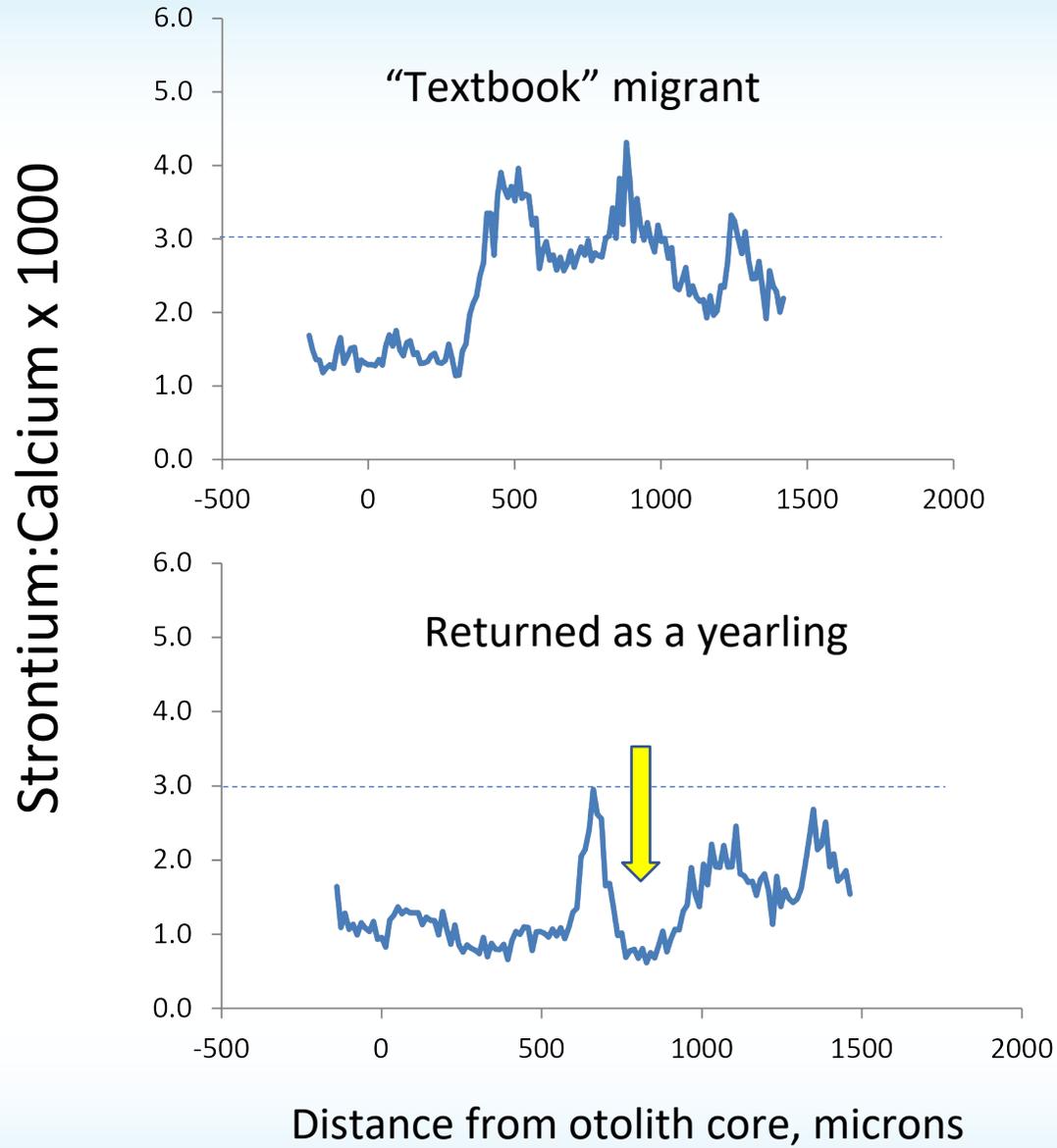
Here is that same "yearling" otolith, ablated with a laser unit to analyze trace elements.

Sr/Ca "jumps" when fish enters seawater



Distance from core, microns

Adult otoliths



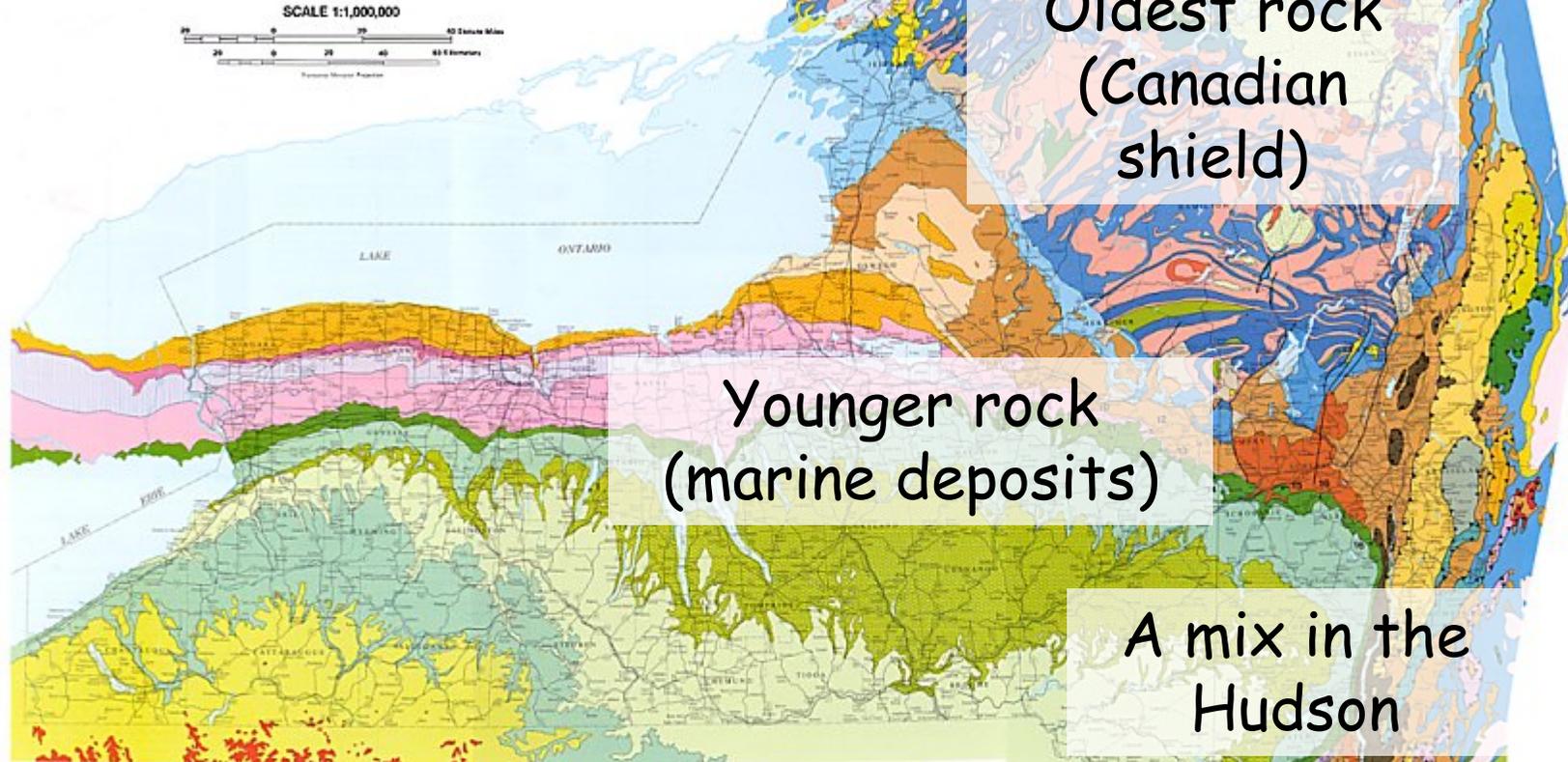
It *ALSO* turns out that we can figure out where in the watershed these fish reared in nurseries, thanks to another biogeochemical tracer...



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

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

PLATE 2 GEOLOGIC MAP AND CROSS SECTIONS



Oldest rock
(Canadian shield)

Younger rock
(marine deposits)

A mix in the Hudson

BEDROCK GEOLOGY OF NEW YORK

The crust of the earth is solid rock, made up of individual rock bodies that vary in size, shape, orientation, composition, color and texture. Together they make up the bedrock, which is generally crystalline, although occasionally marked by earthy deposits.

The bedrock geologic map gives a general view of the patterns made by the varied edges and surfaces of the rock bodies that crop out in the State. It is, however, only a two-dimensional view of three-dimensional rock bodies. The cross sections below the map show examples of the three dimensions as viewed from the surface configurations of rock bodies and their orientation that may be available from field notes or geophysical measurements.

Map patterns reveal some the orientation of topographic and individual rock bodies. Many rock bodies are originally tabular and horizontal, but deformation changes the orientation and shape. In tilting, folding, warping, and fracturing, they patterns can still be made from the three-dimensional configurations of bedrock in different regions. For example, the rock bodies in western New York are layers of sedimentary rock, of greatly different thicknesses, that are tilted down the north less than 1 degree. The local trends on the map in that area are the patterns made by stacked layers that have been leveled at a low angle by erosion. (Imagine a layer cake sliced at a low angle instead of the usual vertical.)

Many of the rock bodies are controlled by the basement or the great thickness of the pattern. Recently dipping beds are controlled from the geologic map except where they separate rock bodies of greatly different ages. This results in secondary patterns on the map, especially within the Adirondack where each body shows.

In the Adirondack Mountains the map pattern shows some tabular rock bodies and some irregular beds. The Adirondack rock patterns in typical of highly metamorphosed "granitic" rock. The irregularity results from the rock pattern existing in the basement as a great thickness of the basement or sedimentary areas that surround the Adirondack. The pattern of small blocks along the eastern border of the Adirondack results from having their original small blocks down into a great distance.

The Taconic Mountains east of the Hudson River Valley are high elevations of crust that were thrust into that area from the east. The high levelled lines show the edges of the great thrust sheets. The north is crust in this region was "submerged" when a volcanic island arc collided with the edge of the continent, creating the Taconic orogeny. This collision compressed the layered rock and sediments of the surrounding sea, forcing them upward onto the continent as high, stacked slices. The slices, which generally dipped east in a shallow arc, were eventually compressed in the process. When completed, the stack extended from New England past the western edge of the Hudson Valley. In the Catskill Mountains, the western edge of the transported rock masses had been thrust downward. However, the original tilted rock bodies were tilted upward, creating a window to the rock beneath.

The legend on the left page shows the formation and rock types in this map area. The legend has two main parts based on geologic time: Precambrian and Phanerozoic. Highly deformed Precambrian rock bodies of the basement are listed beneath various Precambrian rock in most of the State, but are not listed in the Adirondack and the Hudson Highlands. Southward of the Highlands, the basement relationships become more complex as one approaches the deformed and metamorphosed root zone of the ancient Appalachian Mountains two areas across PCB beneath the geologic map. The Precambrian basement part of the legend applies to the wide expanse of sedimentary rock formations from between the three areas of the Hudson River and south of the Adirondack. The thick areas with yellow tint represent areas in the rock record—geologic time not recorded by rock because of erosion or non-deposition.

Horizontal material is shown on general bedrock geologic maps, but it is shown here in several areas of the Adirondack and west of Long Island, where it is so thick that it makes all other bedrock geology.

SURFICIAL GEOLOGY OF NEW YORK

Bedrock geology is covered by a thin of soil and other loose materials, especially in regions with humid climates. The cover material results as weathering levels down the surface rock. The loose materials may remain in place or be washed, transported, and deposited by water, wind, or glacial ice. In the general of New York State, bedrock is buried by surficial deposits that are more than one meter thick. Most of these deposits were left by a continental glacier—masses that was perhaps 2 km thick.

Fill is the most abundant glacial deposit. It is an unsorted mixture of sand, silt, gravel, cobbles, and boulders that the glacier spread over the countryside. Fill can be up to 10 meters thick. It is generally thickest in valleys and thinned over highlands. However, some are single ridges or ridges of hills formed at the edge of the glacier and are composed of sand, gravel, or silt. The Buckhannon and Huron Hill moraines on Long Island illustrate that landscape. The Valley Plains moraine runs the north end of the Finger Lakes. Clastic loess has been deposited between layers of sand dunes and mudstone areas that were deposited in lakes that formed in front of the glacier as the ice melted. Clastic loess is sand and gravel deposited by meltwater streams that flowed from the front of the glacier. All of these kinds of deposits have a wide range of thicknesses. In places, they may be glacial ice on top of the other.

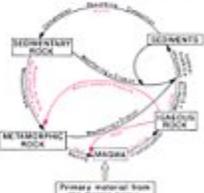
ROCK FORMING PROCESSES

The earth's crust is of two major types, continental (20 km thick) and oceanic (10 km thick). Continental crust is less dense than oceanic crust, which means the continents are raised higher than the ocean floor.

Three major classes of rock make up the earth's crust: igneous, sedimentary, and metamorphic. Continental crust is divided into crystalline "basement" rock and overlying layers of sedimentary rock or layered volcanic rock. The basement is a complex of metamorphic and igneous rock bodies that were generated in the course of mountain building.

Three second long, repeated cycles of submergence, land by sedimentation, mountain building with metamorphism, igneous intrusion, and subsidence, and uplift and erosion. Sedimentary rock bodies the basement over three quarters of the earth's continental area. This kind of stages in thickness into a higher edge to more than 14 km. It takes many individual layers that began as widespread horizontal accumulations of sediment such as sand and silt. An eroding pile up, the lower part in compression under the load. When it compressed out of the gaps, and eventually the sediment, compressed into rock. These processes and cycles are summarized by the Rock Cycle diagram below.

ROCK CYCLE IN EARTH'S CRUST

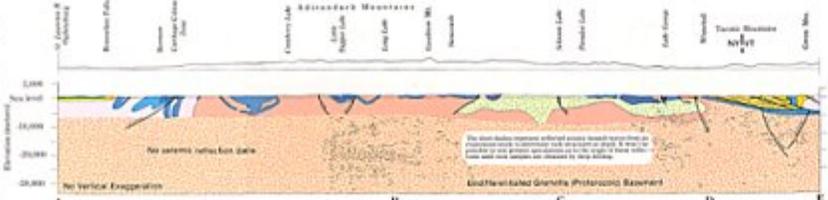


GEOLOGIC CROSS SECTIONS

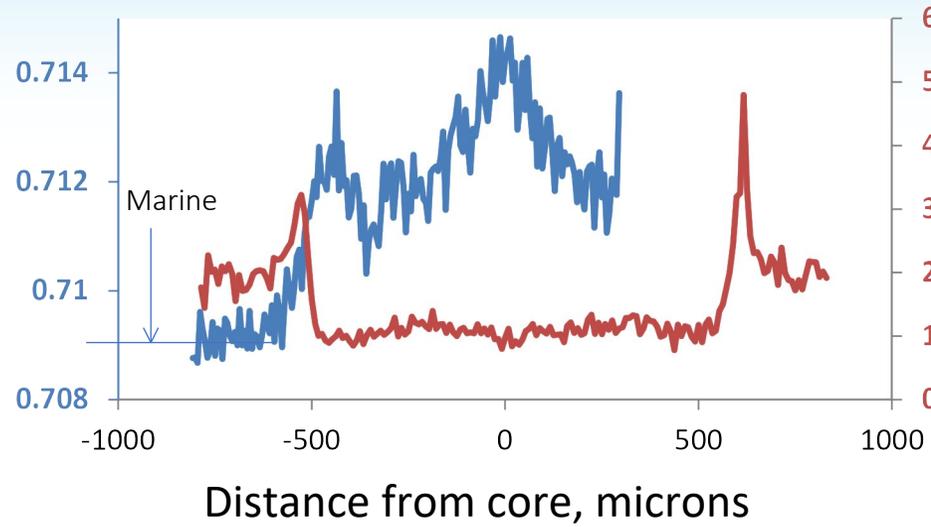
Geologic cross sections show hypothetical vertical slices through the earth's crust. These two cross sections provide the reader to compare the general of more sharply different types of mountains, the Adirondack Mountains, the rounded Catskills, and the folded and thrust Appalachian.

Cross section A-B-C-D-E illustrated on the geologic map extends from the St. Lawrence Lowlands, across the Adirondack Mountains, and into Vermont. It shows the surface of the earth in profile and the subsurface configuration of the rock bodies below the surface. Below the surface the surface profile appears when drawn at true scale. The profile above the cross section, drawn with a 1:400 vertical exaggeration, provides a more detailed (although distorted) picture of the topographic relief. The area shown in brackets of this profile is a section of the Adirondack Mountains. These rocks were originally deposited in a shallow sea as horizontal layers, and later deformed into high folds during the Taconic orogeny about 1.1 billion years ago. The Taconic Mountains and Great Mohawk east of the Adirondack are part of the Appalachian Mountains chain. Bedrock there was thrust westward into of kilometers along faults during the Taconic orogeny about 400 million years ago. Several faults are shown on the geologic map and shown in the cross section as examples of these structures and exposures.

Cross section F-G-H-I-J-K-L-M-N-O-P-Q-R-S-T-U-V-W-X-Y-Z is a section through the Catskill Mountains, that outcrop across Long Island in order to show the thin rock units. It was necessary to use a 1:100 vertical exaggeration for this cross section. The use of vertical exaggeration results in only topographic and rock thickness, but the job of the rock



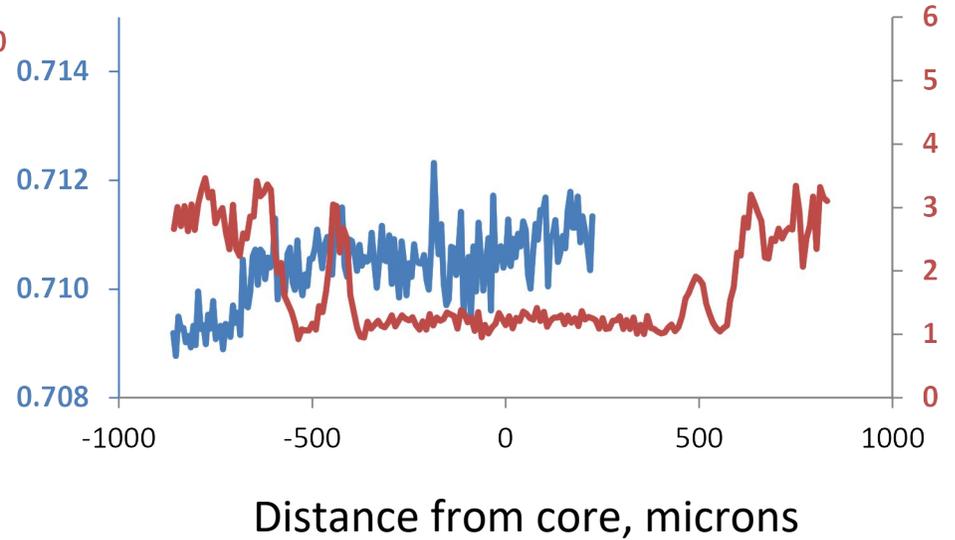
Upper Hudson R. origin



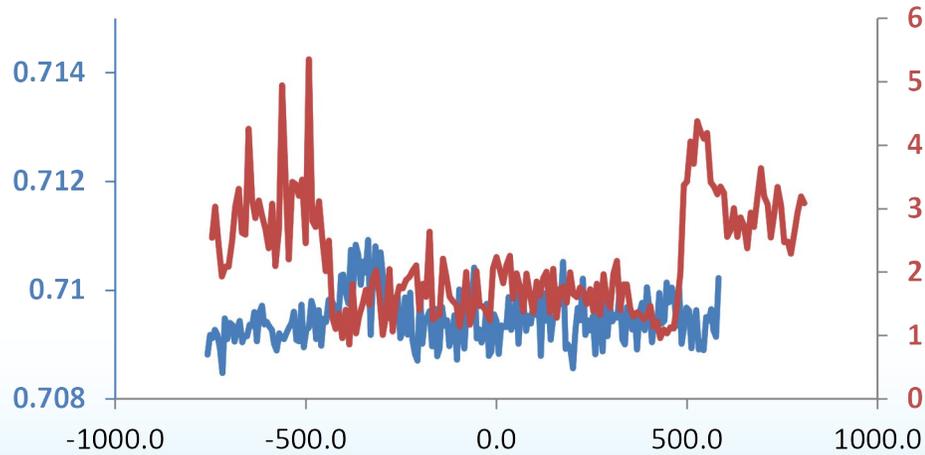
$^{87/86}\text{Sr}$

$\text{Sr:Ca} \times 10^3$

Hudson R. origin



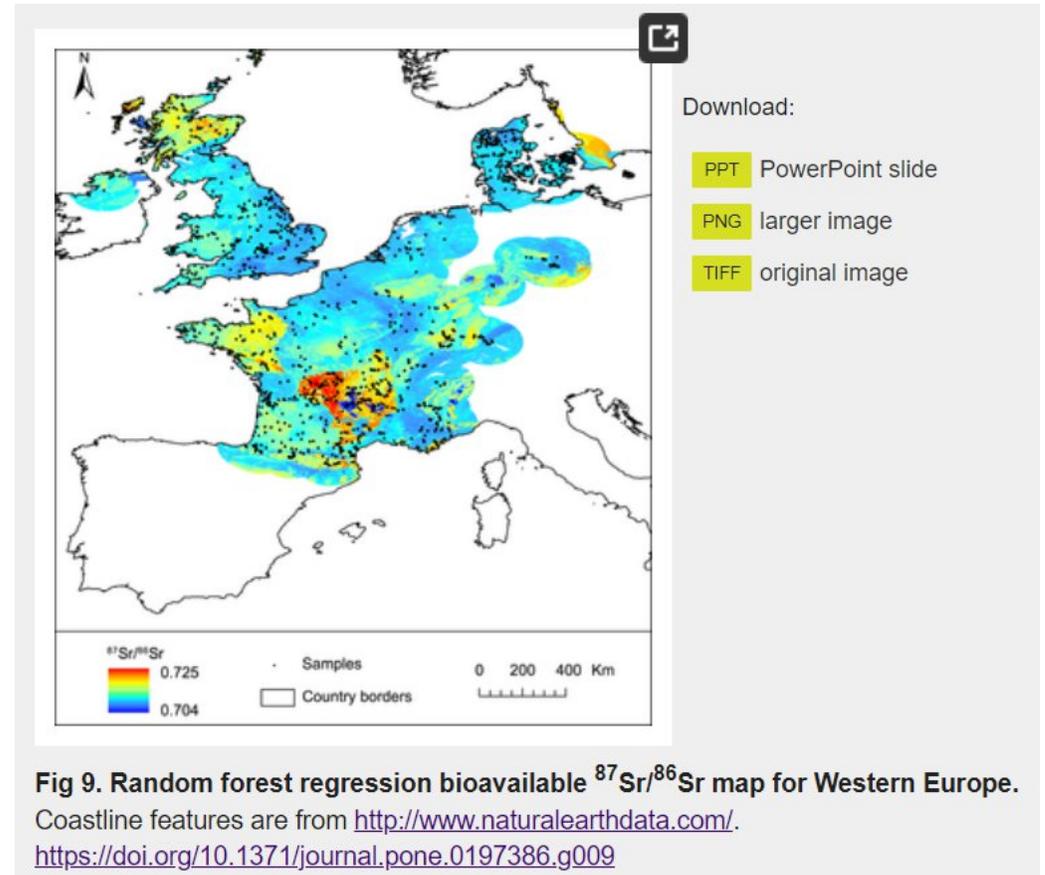
Mohawk R. origin



Distance from core, microns

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 $^{87}/^{86}\text{Sr}$ is so popular...



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.

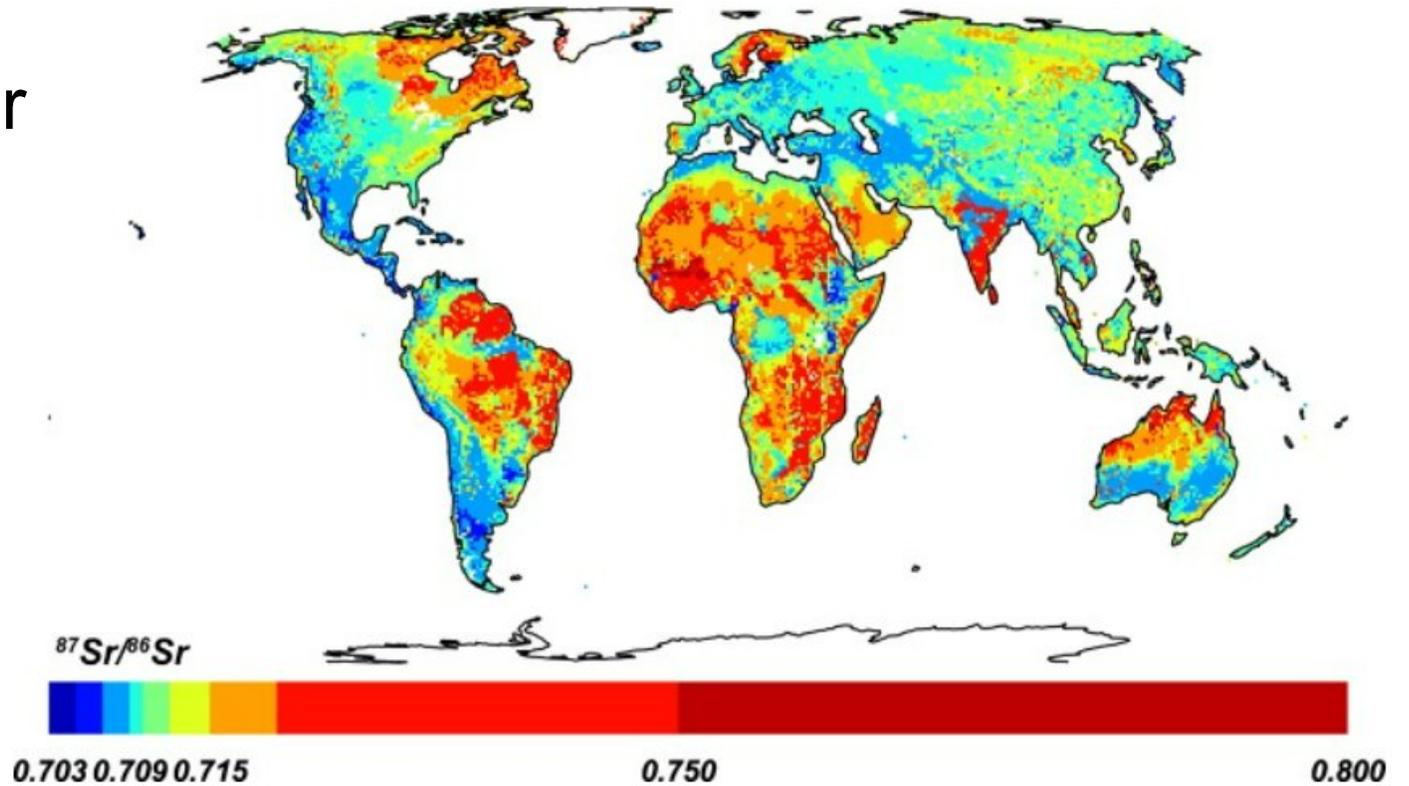


Fig. 9. Global map of predicted bioavailable $^{87}\text{Sr}/^{86}\text{Sr}$ from random forest regression. This isoscape can be regenerated or updated by including new data using R (See supplementary material, script S1) or directly downloaded at <https://drive.google.com/open?id=1g9rCGo3Kd3hz2o5JKkSbgNsGJclvsuQm>

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

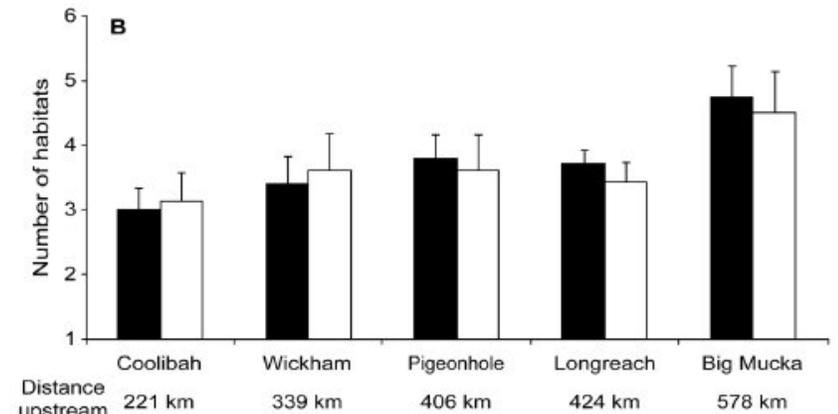
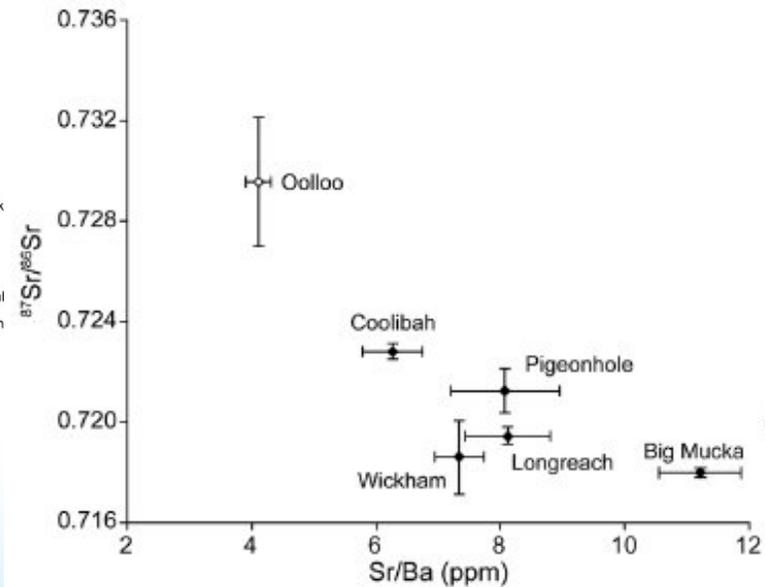
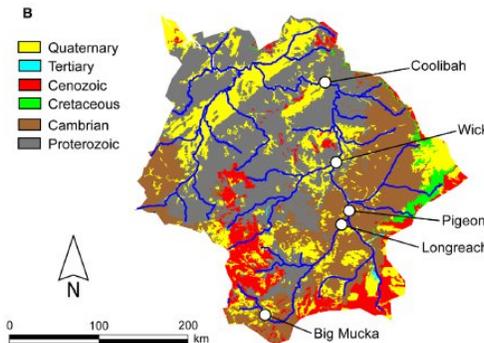
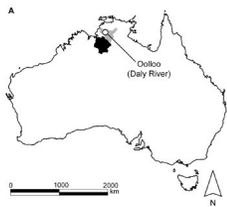
PLoS one

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

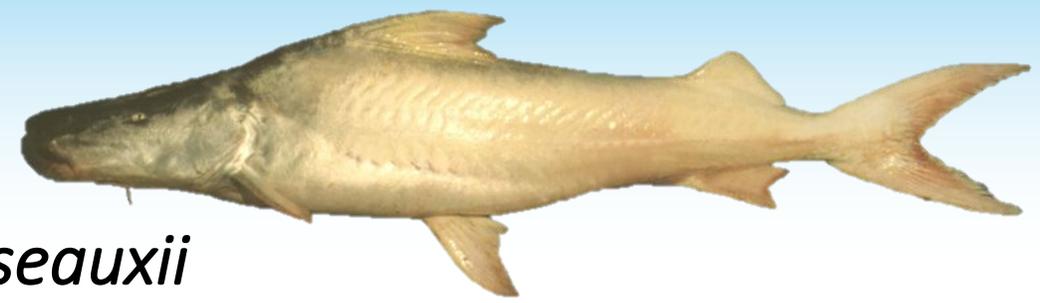
Benjamin D. Walther^{1,2*}, Tim Dempster³, Mike Letnic⁴, Malcolm T. McCulloch^{1,5}



Barramundi, *Lates calcarifer*



AMAZONIA



Goliath catfish, *Brachyplatystoma rousseauxii*

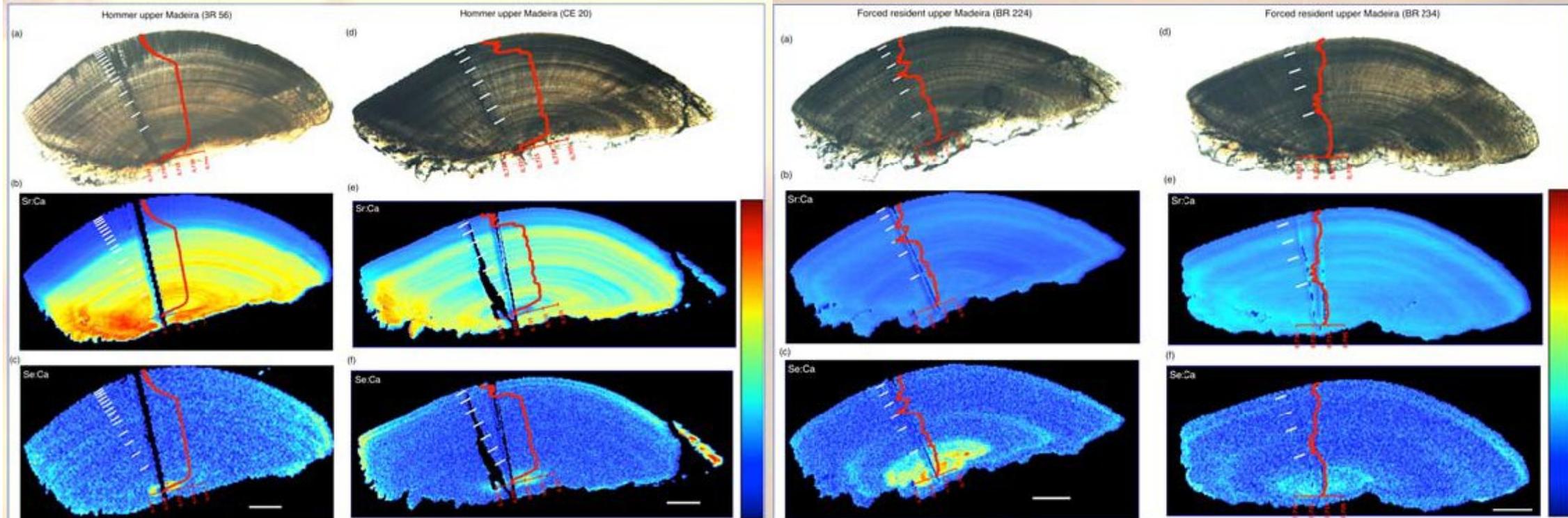
Homing Behavior to upper Madeira R.

Forced Residency Behind New Dam

$^{87}/^{86}\text{Sr}$

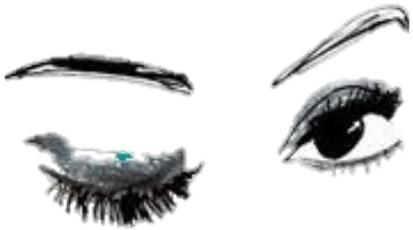
Sr/Ca

Se/Ca

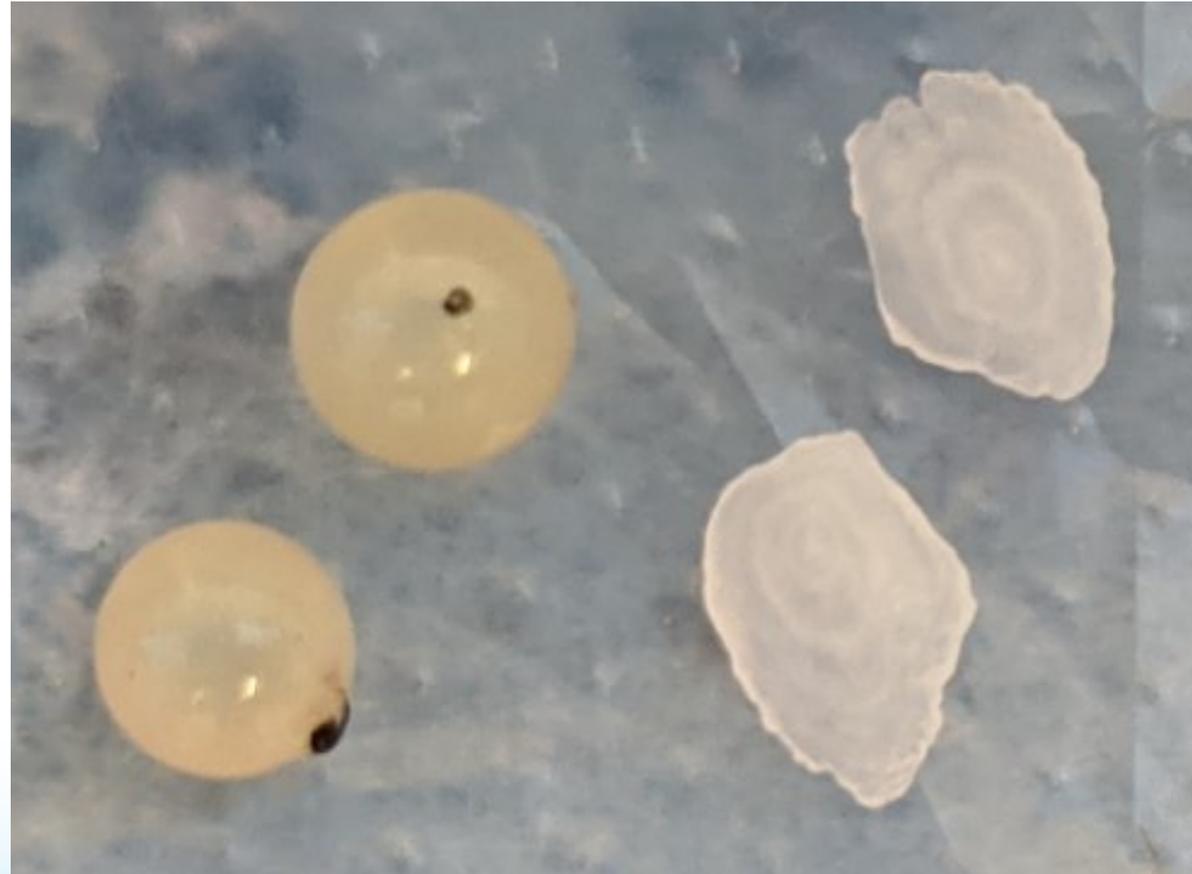


Hauser et al. *Freshwater Biology* 2020

Fish eye lenses and otoliths – complementary archival structures?



Lenses
formed from
layers of
proteins



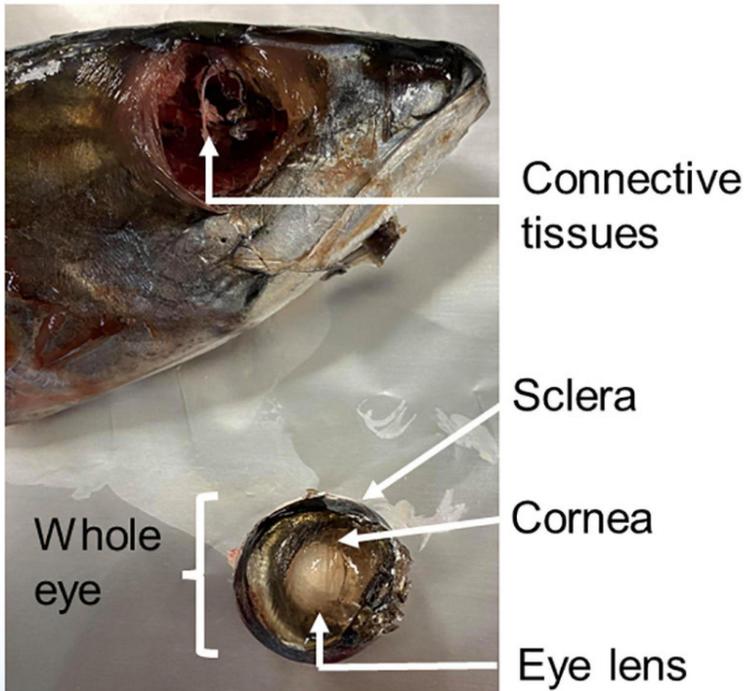
Otoliths are
mainly
aragonite
(CaCO_3)



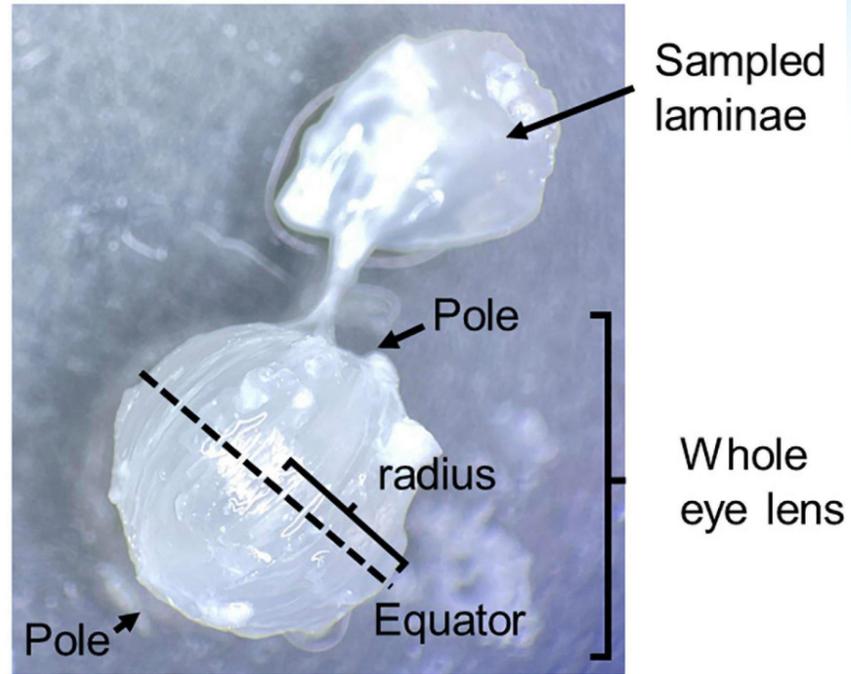
1. FISH MEASUREMENT



2. LENS EXTRACTION



3. DELAMINATION



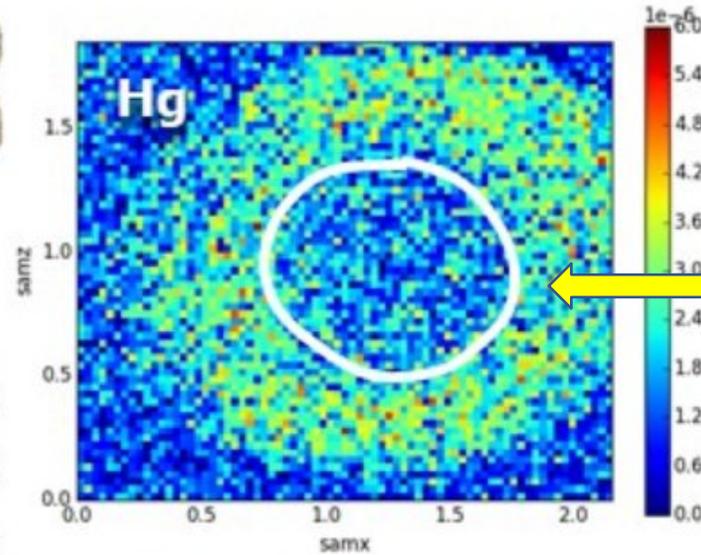
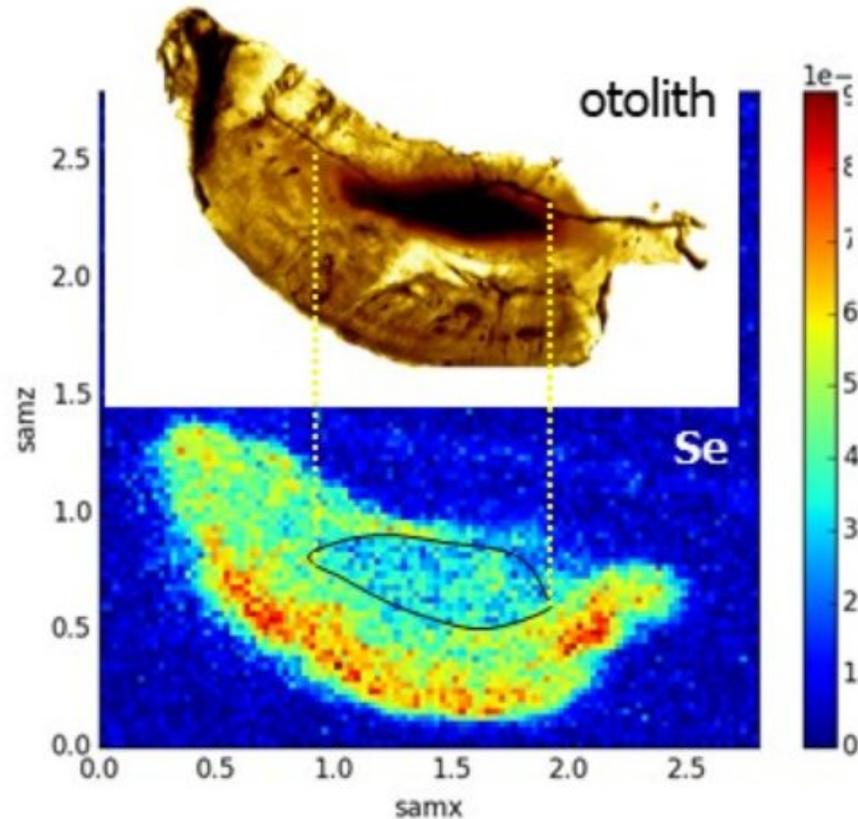
4. CHEMICAL ANALYSIS

1. Amino acids composition analysis
2. Isotope analysis of total nitrogen (bulk)
3. Isotope analysis of individual amino acids (trophic and source amino acids).

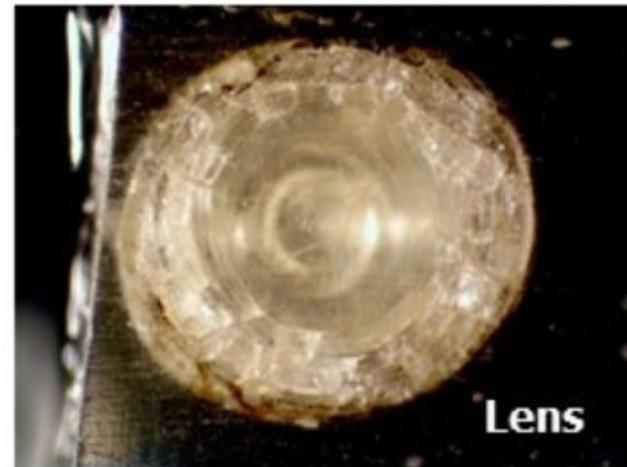
Eye lenses are becoming increasingly popular – amenable both to light stable isotope **and** trace element work

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

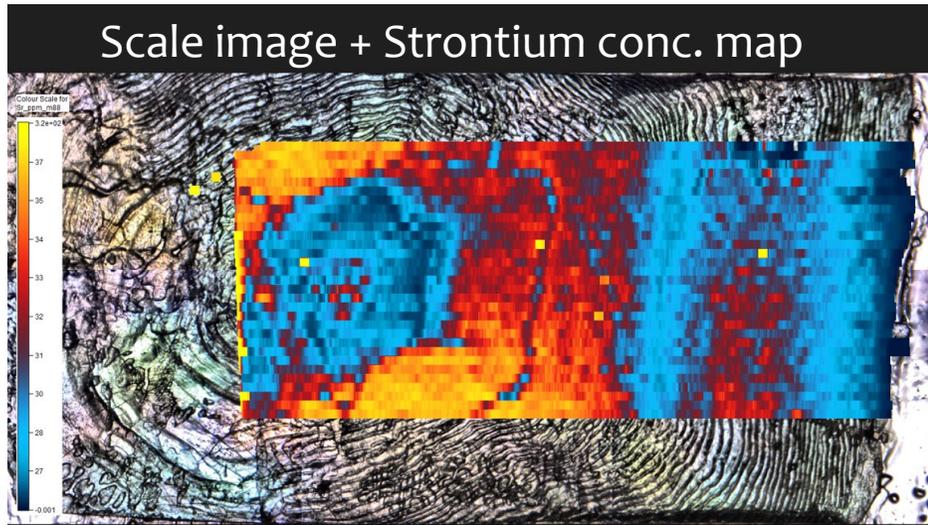
A Brown Bullhead catfish in Arbutus Lake: lenses take up Hg!



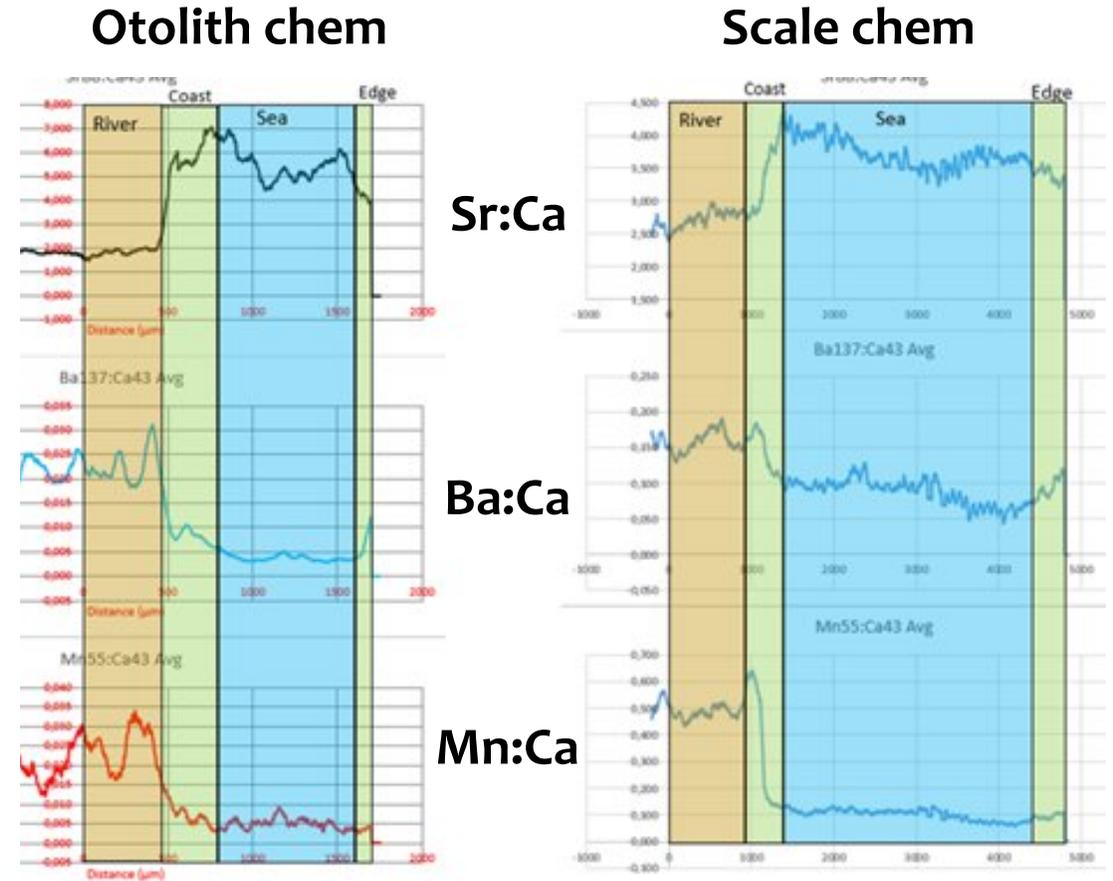
Ontogenetic shift to piscivory



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.)



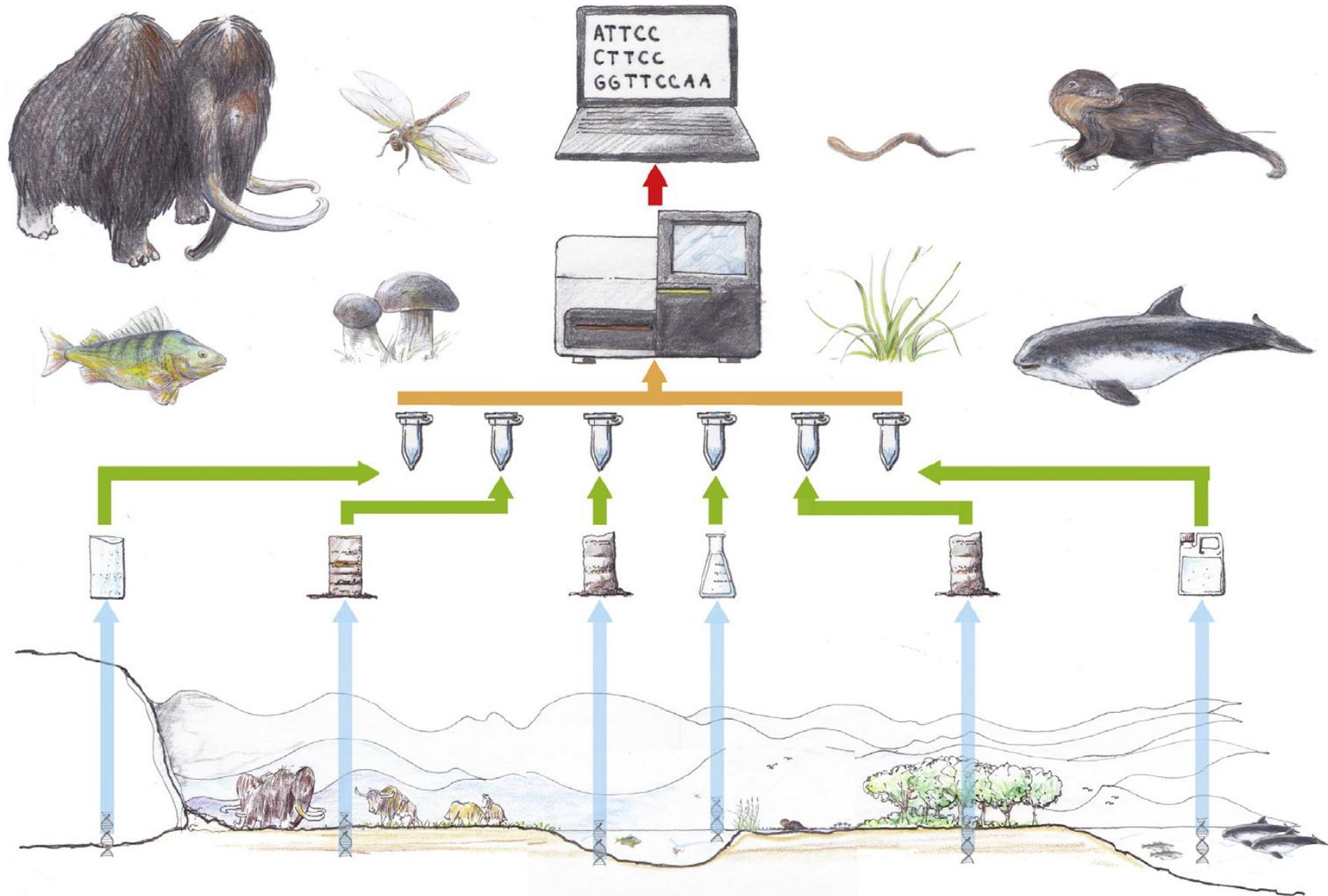
Collection of water or substrate and concentration of genetic material and associated matrix



DNA extraction



PCR and analysis



Single-Species Approaches vs. Metabarcoding

Single-species	Genetic target unique to a species of interest	High sensitivity	Rapid, cost-effective data generation	<ul style="list-style-type: none">• 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	<ul style="list-style-type: none">• 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!

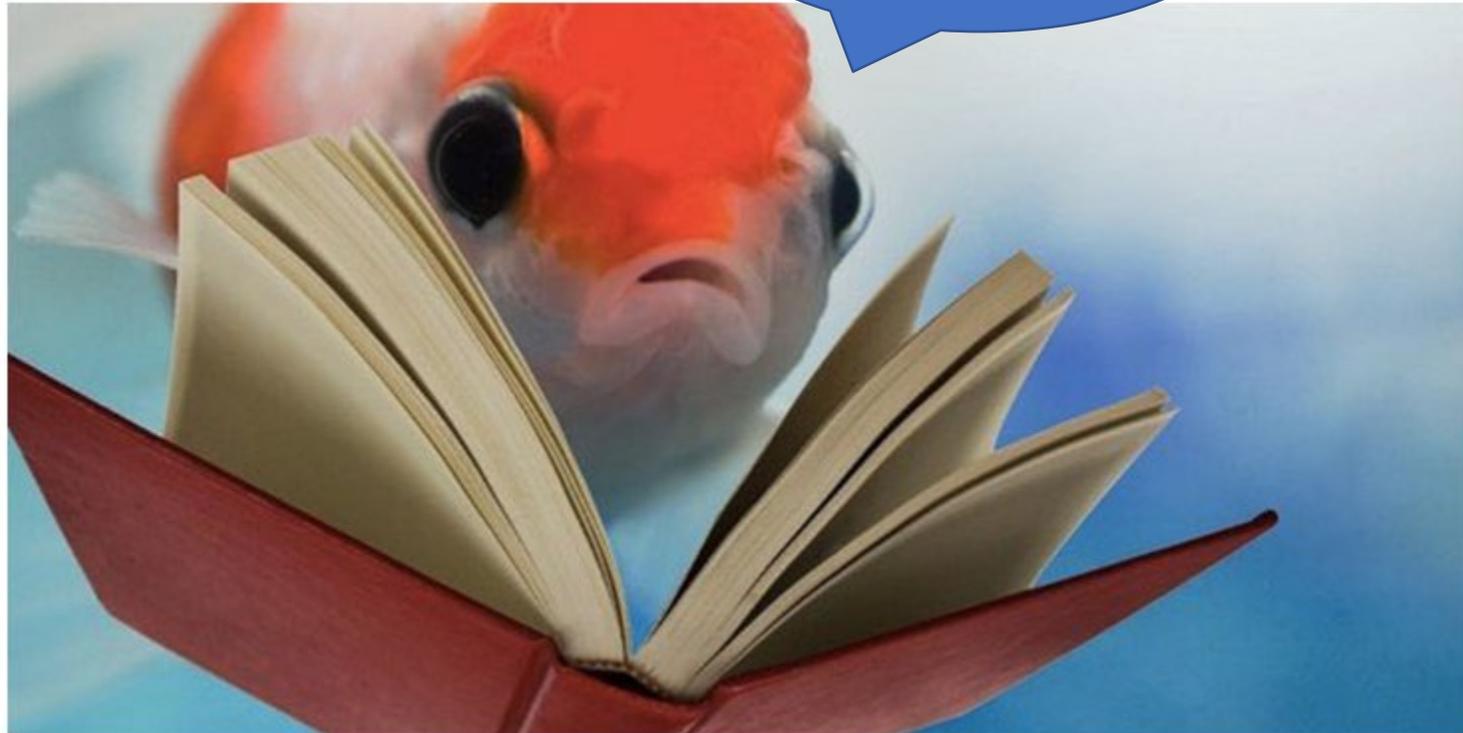


Photo via Fish Want Read/VK











