Tracking the epic journeys of salmon: Advancements in telemetry and microchemistry

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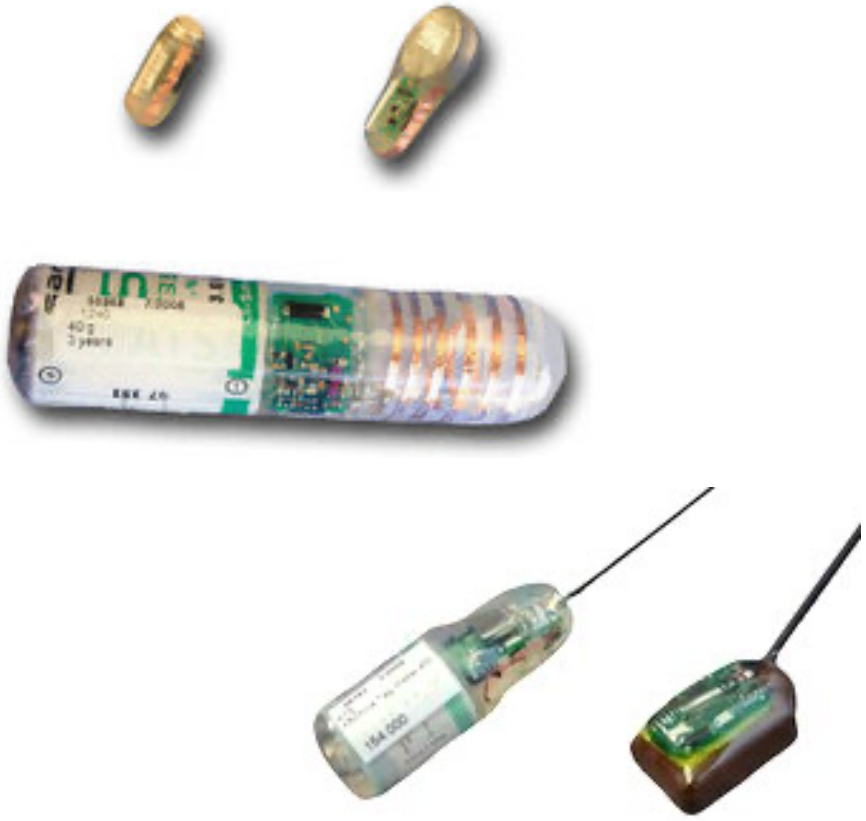
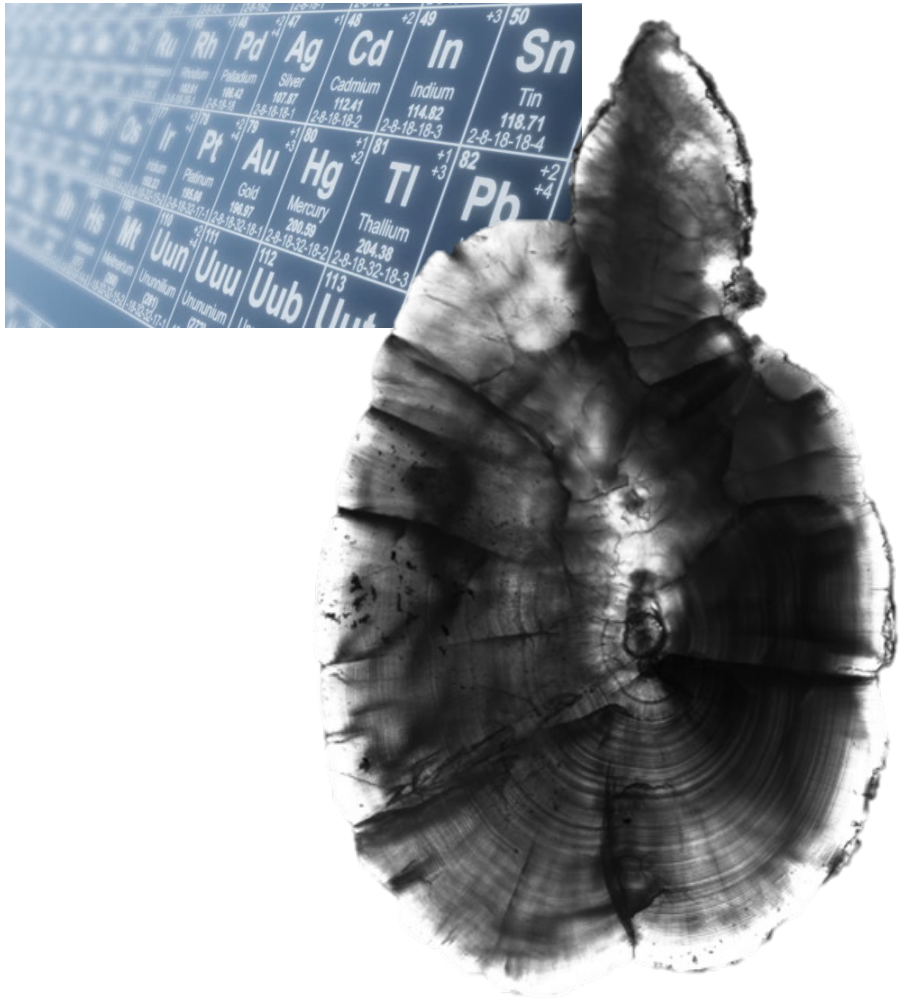
The Questions

- What determines the numbers/rates of returning salmon from the sea?
- Why are so many salmon populations declining (what are the drivers)?

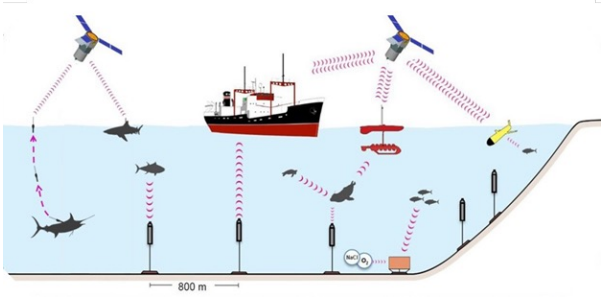
Finding the answer depends on knowing where salmon are, and when, in the sea, their physiological condition before and during marine residence, and the bottlenecks they face.

ELECTRONIC & NATURAL TAGS

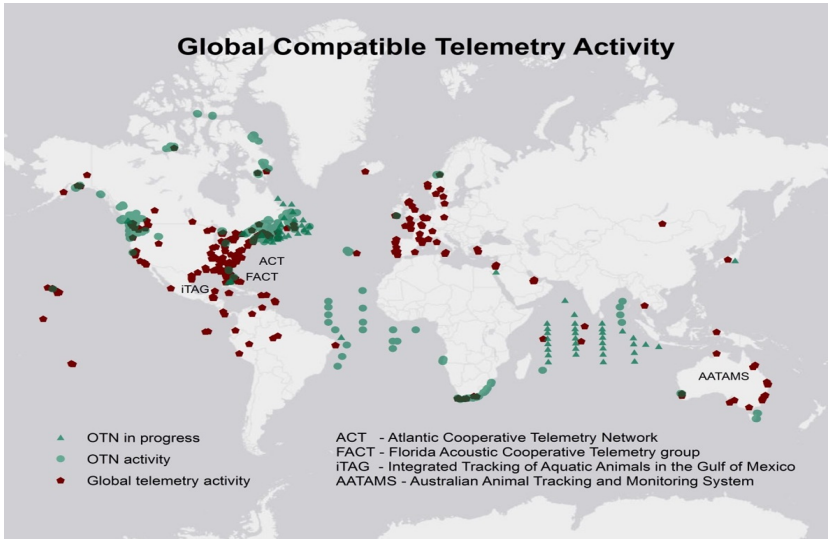


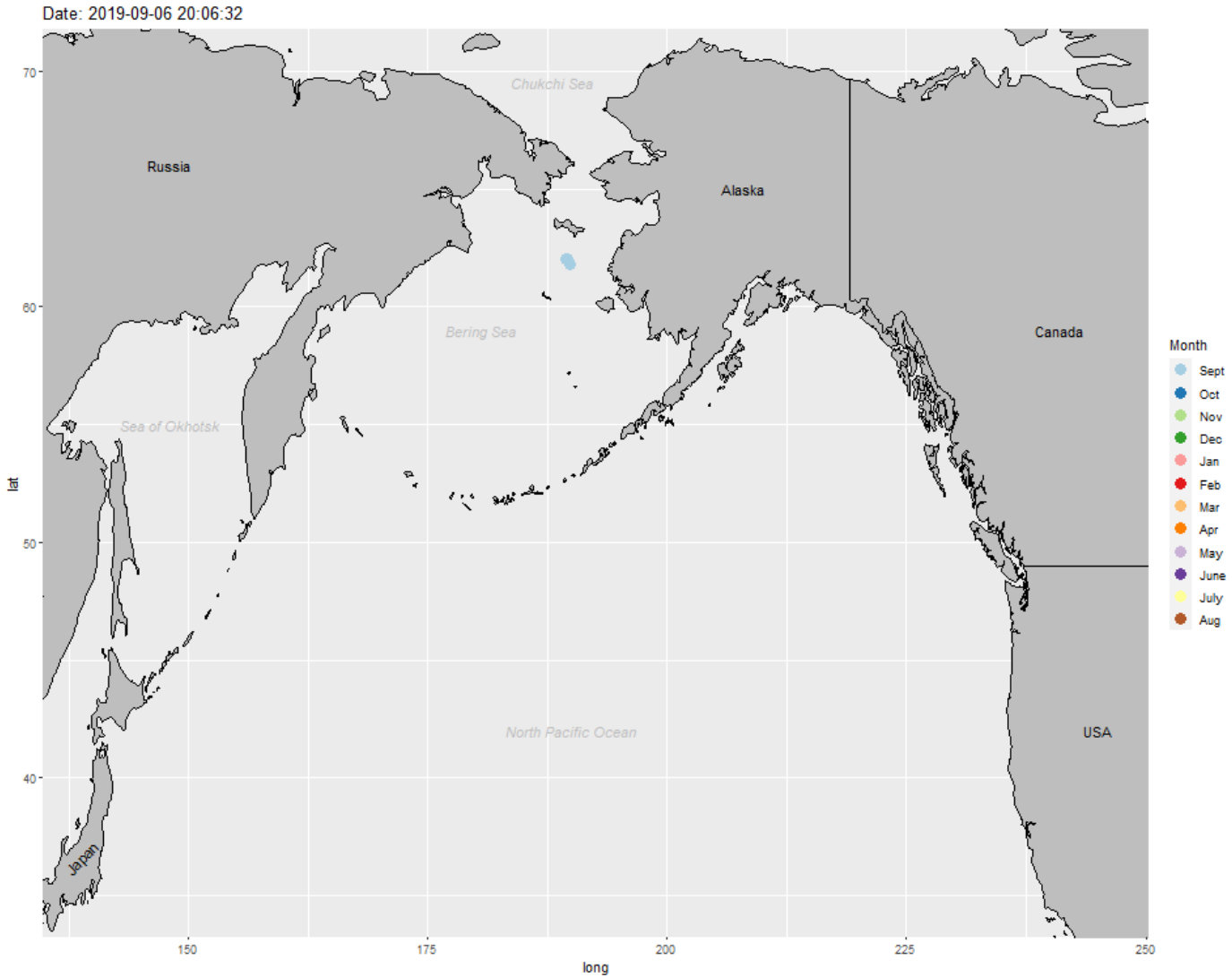


Biotelemetry- electronic tags



- Telemetry- electronic tags in both the Atlantic and the Pacific
- Satellite (> 2 kg fish), DST and and acoustic (> 12 g fish) primary tags
- Give precise (relatively) positioning. Acoustics require receiver networks
- Limited tag lives; can't cover one individual's full life history
- FW to salt water (acoustic)
- Document inter-individual variation
- Allow fishery independent quantitative survival estimates in some cases





Salmon shark map courtesy of S. Garcia, Salmon Ocean Ecology Program, Alaska Department of Fish and Game

Satellite tags and data loggers

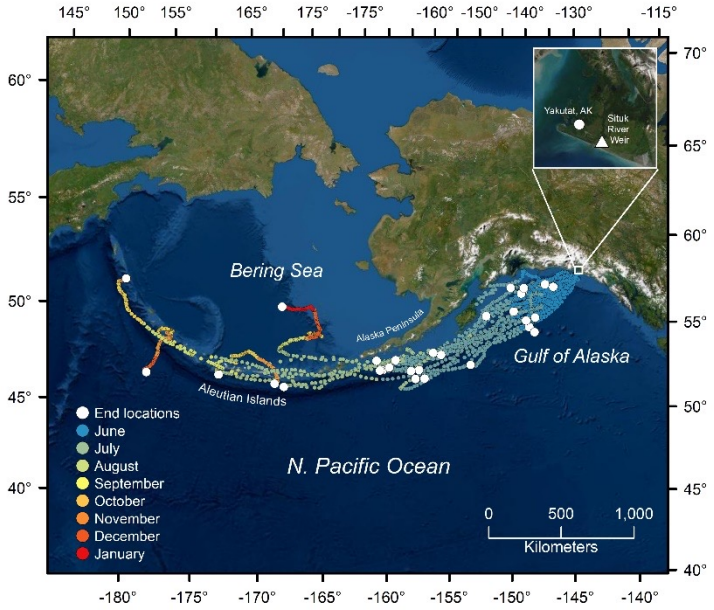
Short-Term, Data-Rich, Hi-Res

- Location and Movements
- Environmental Data
- Limited Biological Data
  - Temperature, salinity, depth sensors
  - Predator/Mortality Tags
  - Accelerometers
- Acoustic tags provide some of this data, but only when in range of a receiver

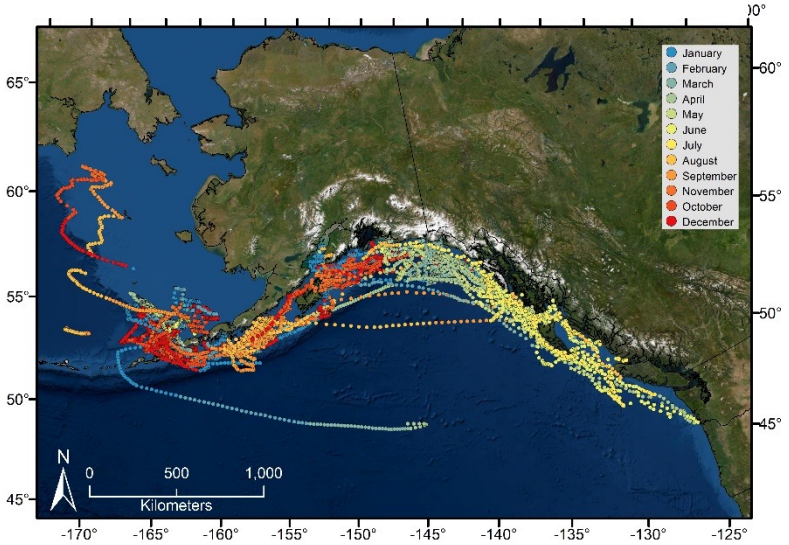
Where and why did they move?

How did movements (e.g., changes in environment) affect survival, growth, health, food habits, reproduction, etc . . .

Pacific salmonid satellite tag tracks



Situk River Steelhead
Courtney et al. 2022

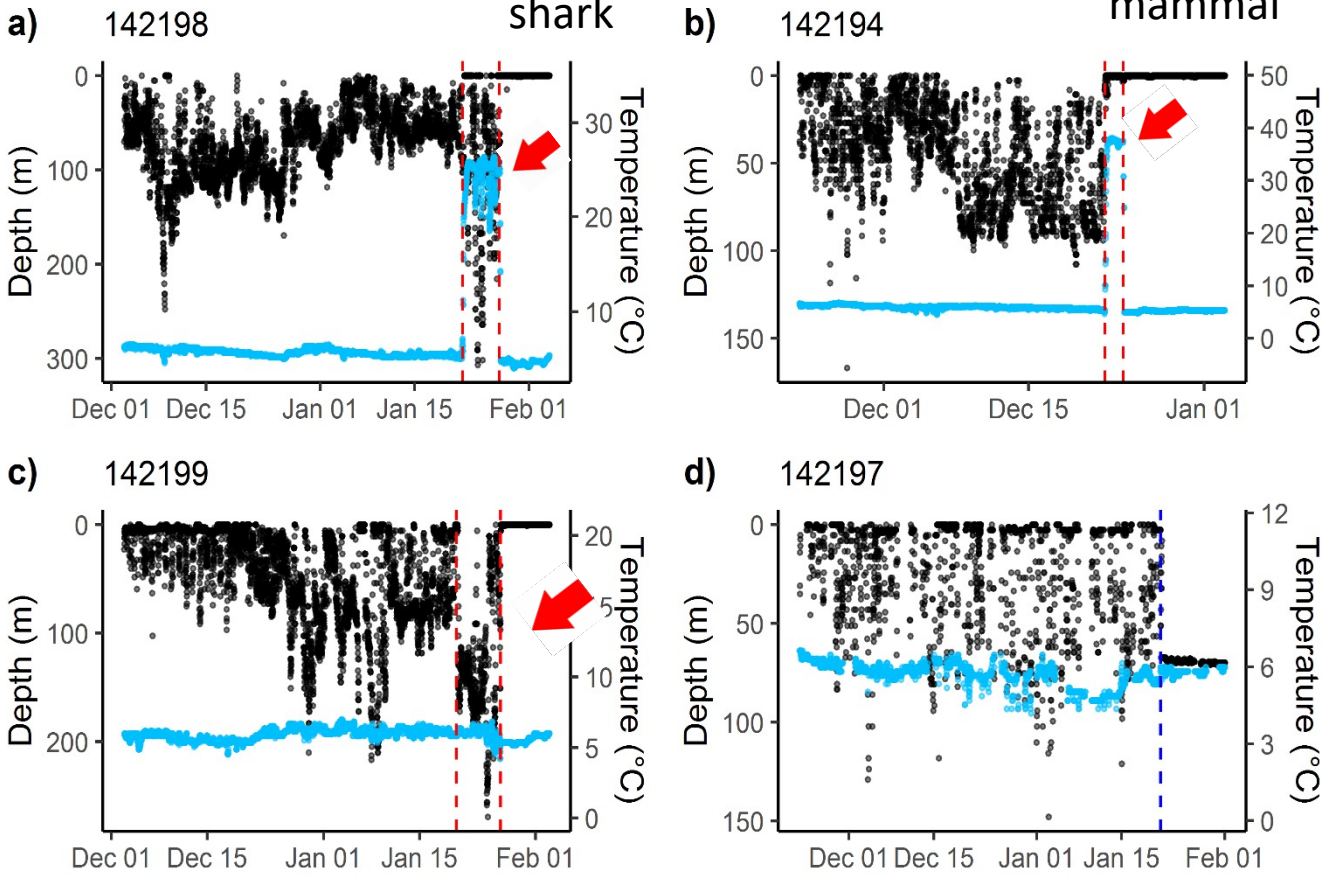


Oct-Dec tagging of Bering Sea Chinook
Courtney et al. 2019,2021

Chinook salmon predation events
Seitz et al. 2019

Salmon shark

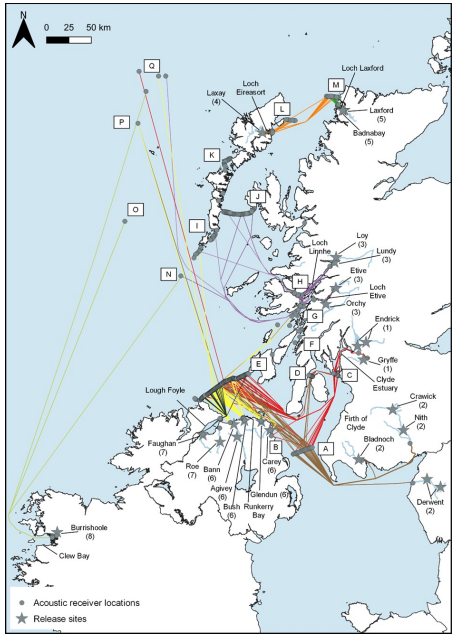
Marine mammal

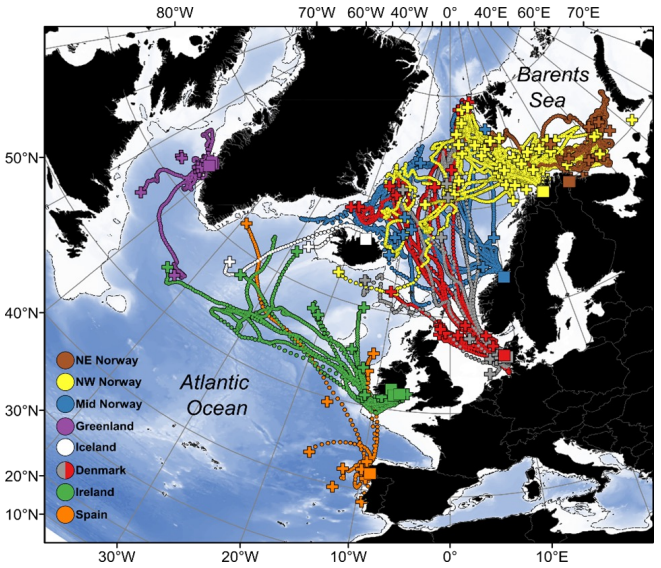


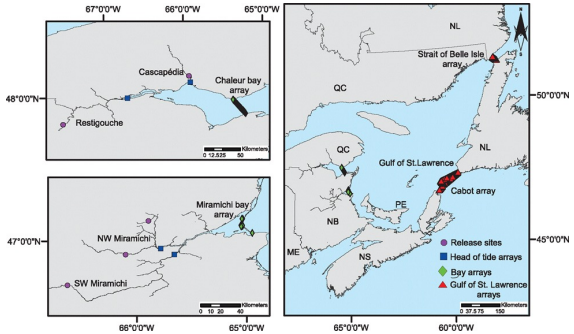
Ectotherm

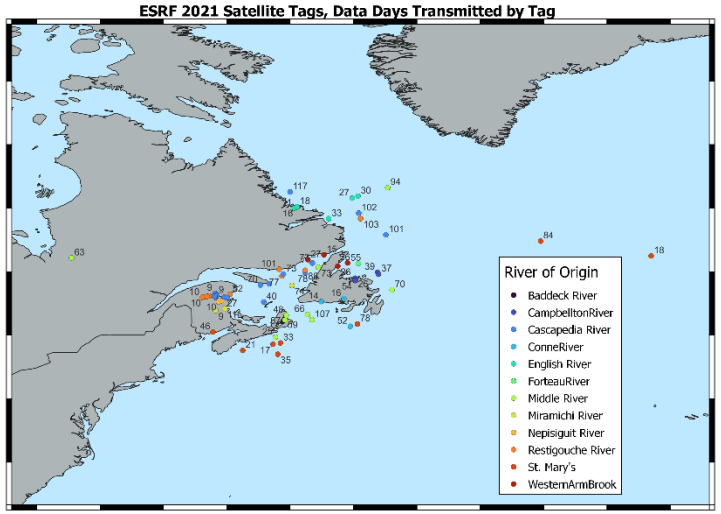
Atlantic salmon - electronic tags

- NE Atlantic:
  - Coastal shelf pathway to the north (e.g., J. Lilly et al. presentation)
  - Likely underestimation of FW mortality (Flavio et al 2020, 2021), affecting modeled ocean survival
  - Repeat spawners tagged with satellite tag show partitioning of the ocean *(Rikardsen et al. 2021 Sci. Rep. 12266)*
- NW Atlantic:
  - Smolt migration along the shelf
  - Synchronous movements of fish from different rivers, but different mortality patterns among populations at different stages (e.g. Chaput et al. 2019 ICES J Mar Sci 76:1107-1121)
  - Major acoustic and satellite tagging of adults underway (ESRF-M. Robertson, DFO PI; ≈ 2000 smolts and kelts tagged to date)
  - Similar habitat partitioning to the NE Atlantic by different populations?

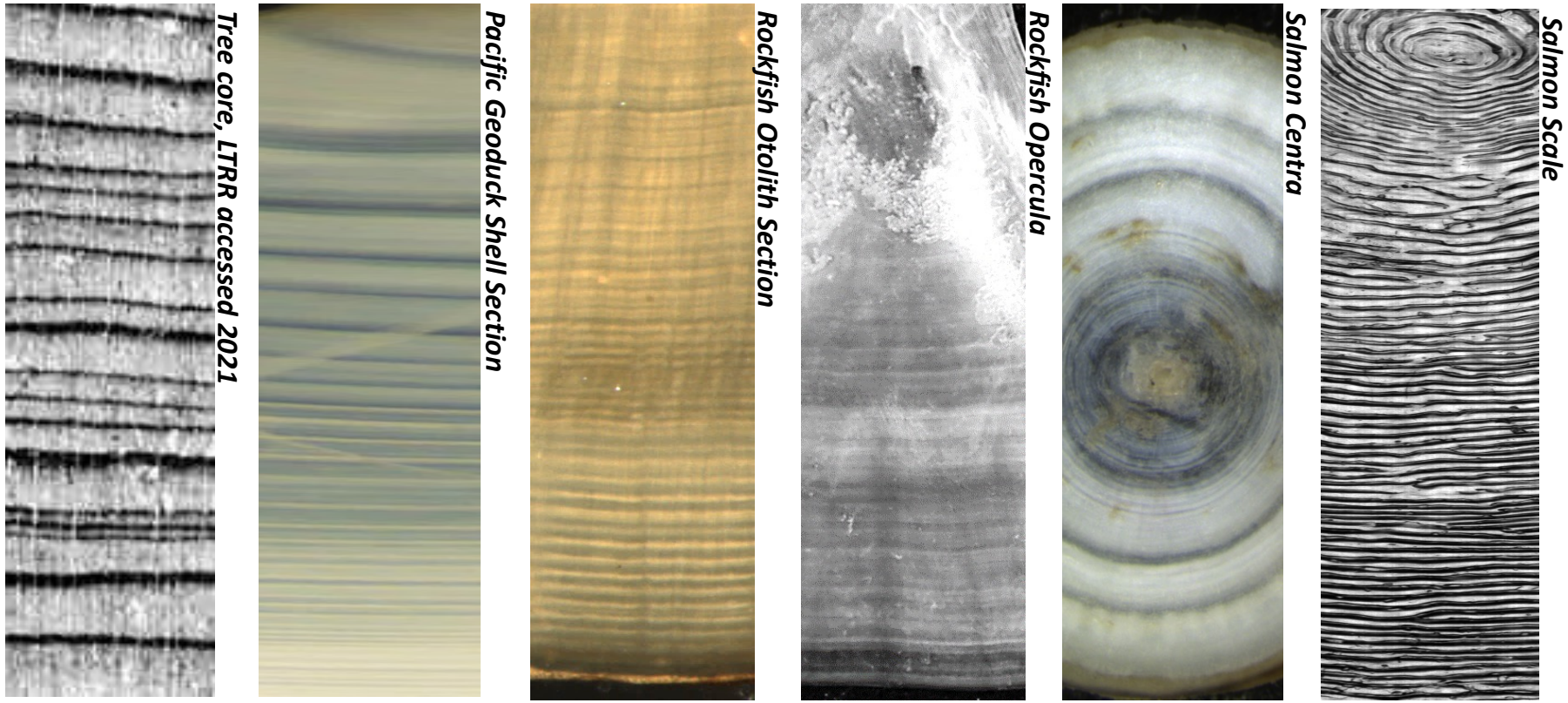




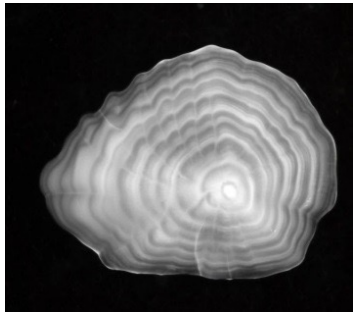


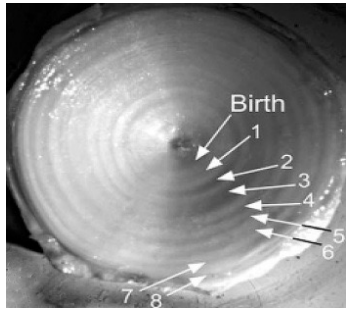


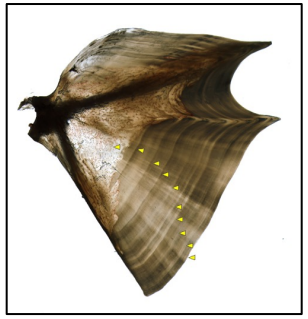
Natural tags

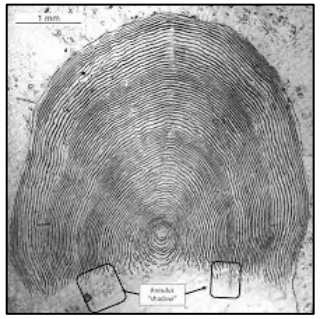


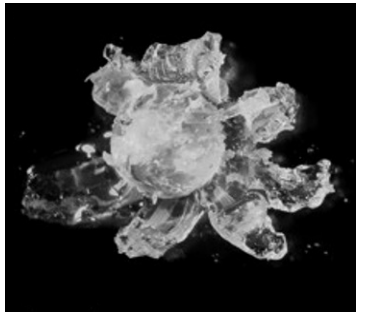
Using temporal changes in chemical composition to reconstruct movements and life histories



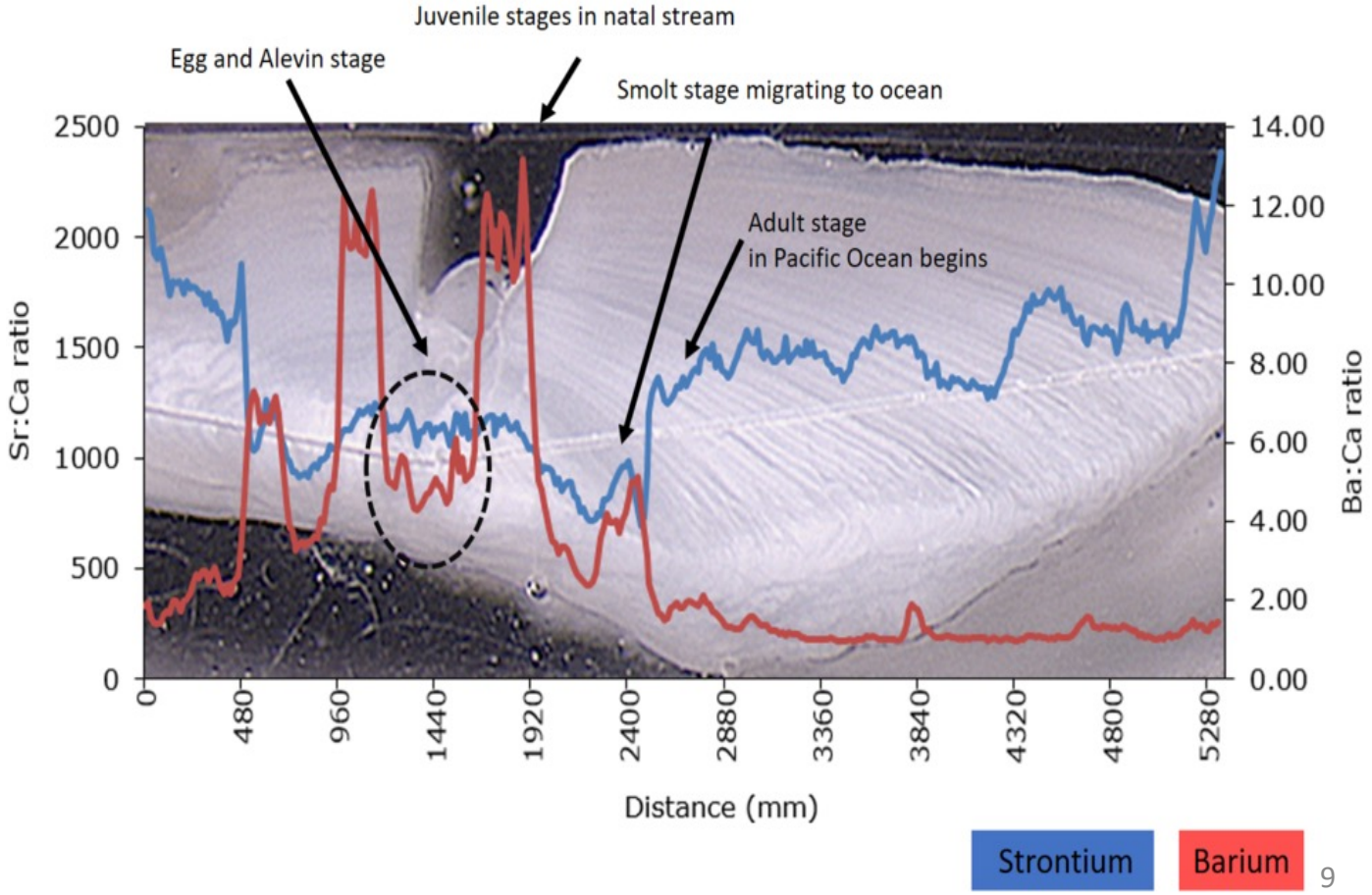








Salmon otolith strontium and barium profiles



Spatial Ecology

$^{87}Sr:^{86}Sr$, Sr:Ca, Ba:Ca, $\delta^{34}S$, trace elements

Trophic Ecology & habitat use

$\delta^{13}C$, $\delta^{15}N$, $\delta^{34}S$ (future CSIA)

Ecophysiology

$\delta^{18}O$, $\delta^{13}C$, increment widths, [Cortisol], [sex hormones]

Stock ID of salmon caught at sea (Pacific salmon – Rachel Johnson UC Davis/NOAA)

Hierarchical approach:

1. Genetic markers

Aggregation --> ID genetic stock

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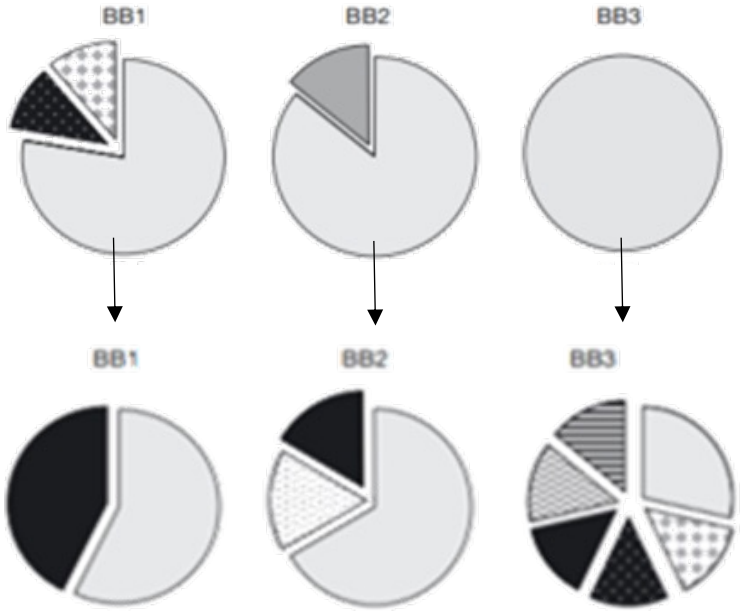
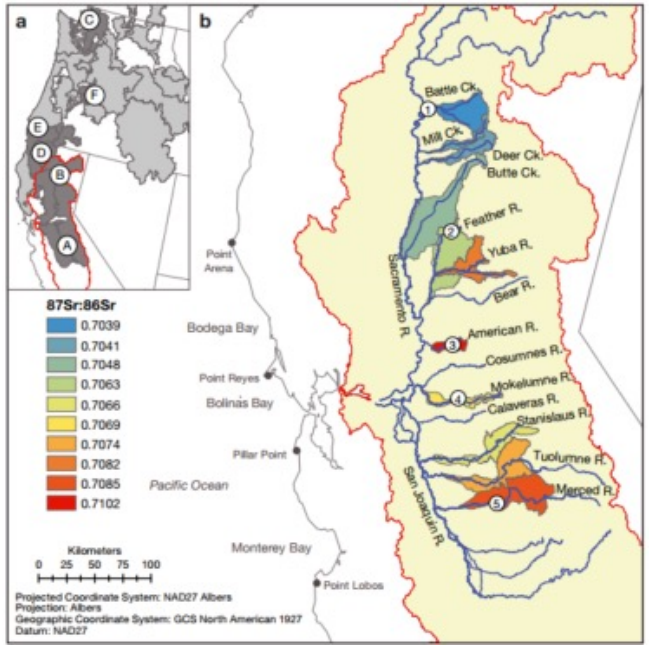
Isotopes and genes reveal freshwater origins of Chinook salmon *Oncorhynchus tshawytscha* aggregations in California's coastal ocean

Rachel C. Johnson[1,2,*], John Carlos Garza[1,3], R. Bruce MacFarlane[1,4], Churchill B. Grimes[1,4], Corey C. Phillis[5,8], Paul L. Koch[6], Peter K. Weber[7], Mark H. Carr[2]

2. Otolith chemistry markers (Sr isotopes)

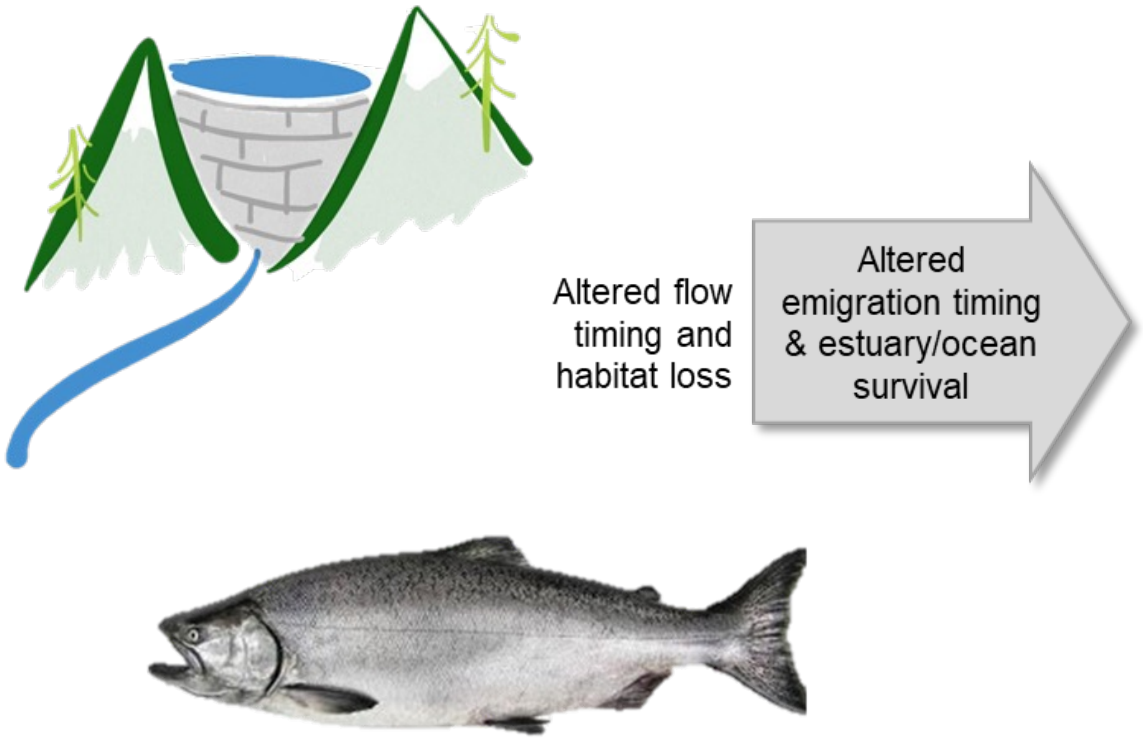
Genetic stock --> ID river of origin

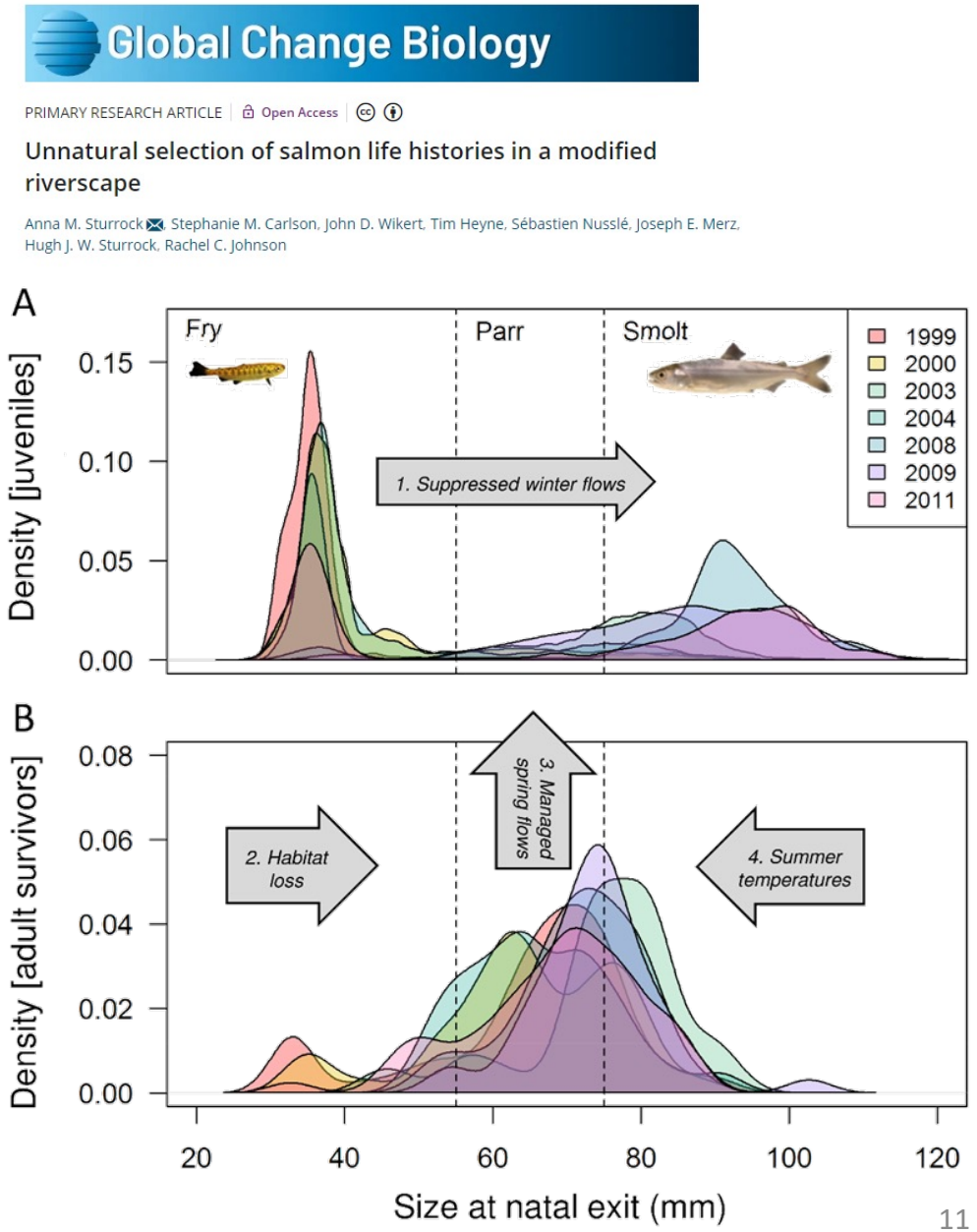




Similar method used in Brennan *et al.* (2019) Science. *Shifting habitat mosaics and fish production across river basins* to highlight important variation in salmon habitat use and productivity across watersheds

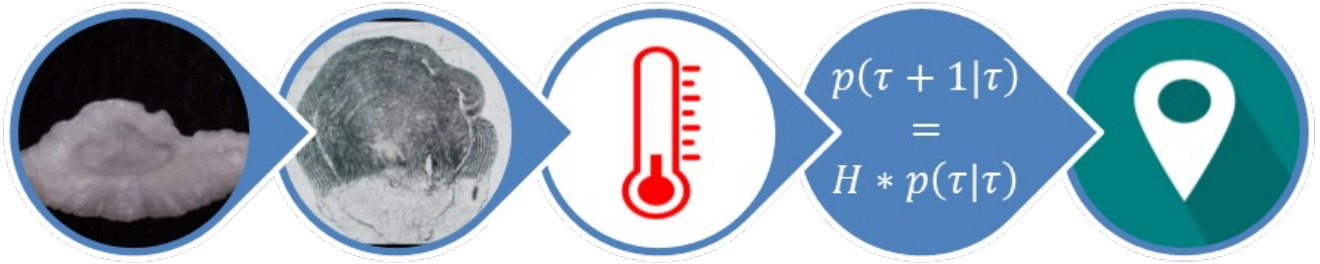
Freshwater carryover effects (Pacific salmon – Anna Sturrock, UC Davis / University of Essex)





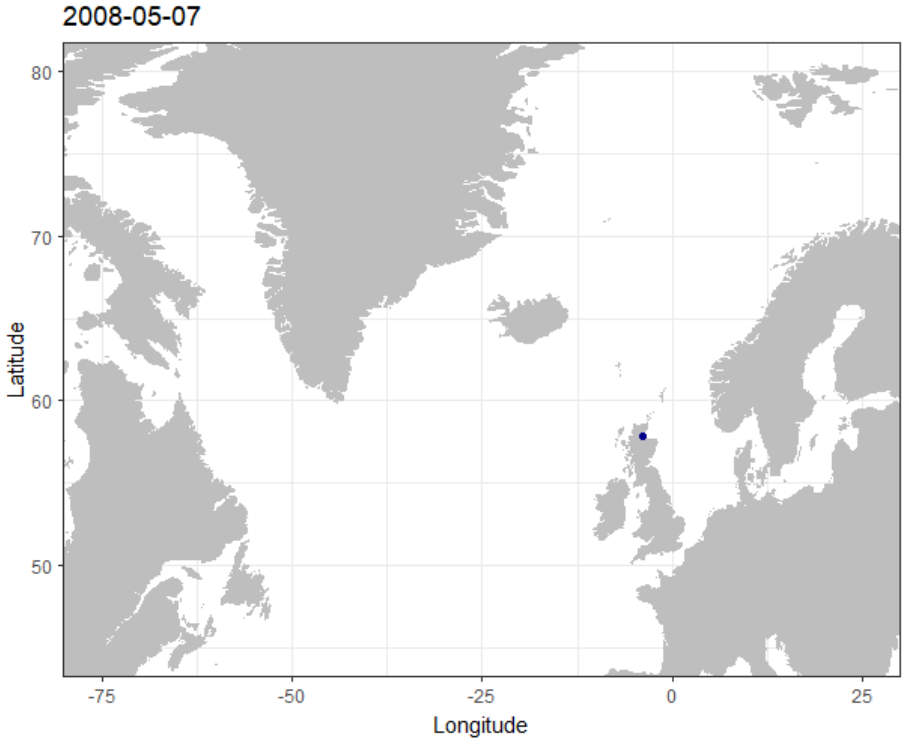
Otolith Sr isotopes highlighted how flow reductions in dammed rivers can drive cohort strength in drought years (Sturrock et al. 2020), but how thermal refugia in undammed rivers can support slow-growing late migrants which enter the ocean during fall and end up being the 'winners' during droughts (Cordoleani et al. 2022)

Otolith isotopes to reconstruct thermal histories and movement at sea (Atlantic salmon – Nora Hanson, Marine Scotland)



Shows potential for tracking movements at sea for smolt to adult life stages

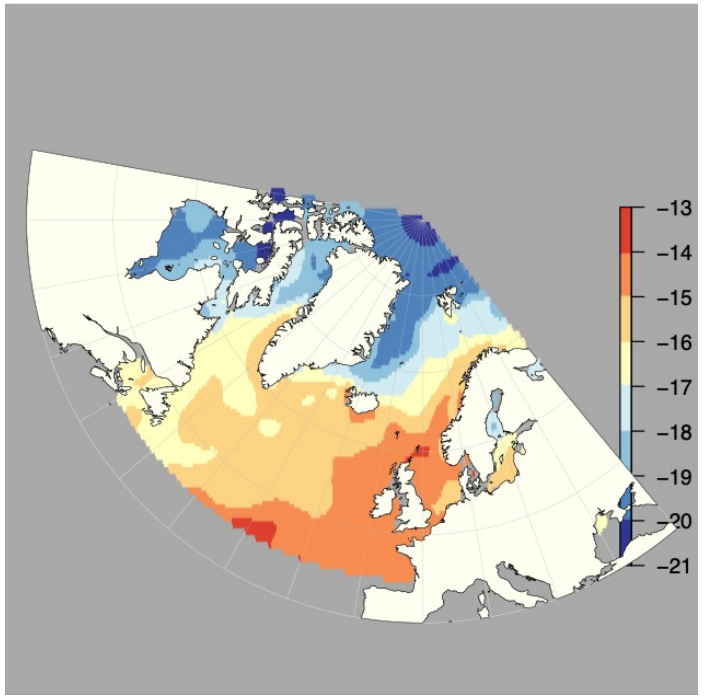
- Model requires assumptions about fish movement, dependent on body length
- Requires refinement using addition data (e.g. via telemetry)
- Potential to be applied retrospectively to any fish caught (not dependent on tag recapture) and for full anadromous stage



Ocean foraging areas of salmon caught in river

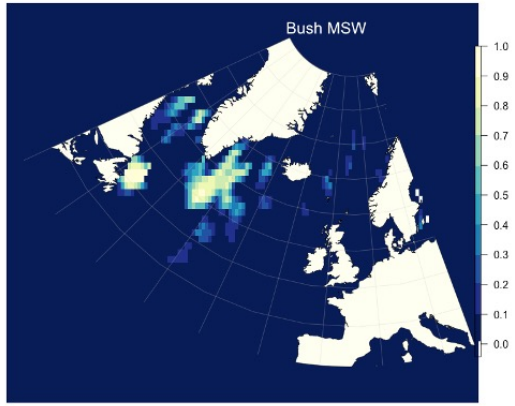
(Clive Trueman, University of Southampton)

Question: are fish returning to geographically close rivers separated during ocean feeding?

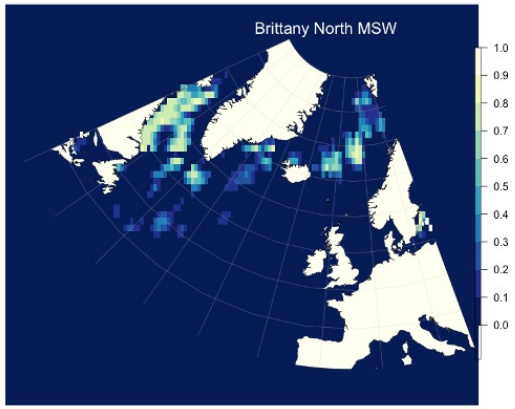


Isoscape for Atlantic scale collagen (i.e. the isotopic composition of scale collagen carbon expected for feeding by area)

Cohort – specific probable feeding areas



Reveals variation in last marine feeding area according to river of origin, sea age and month of return



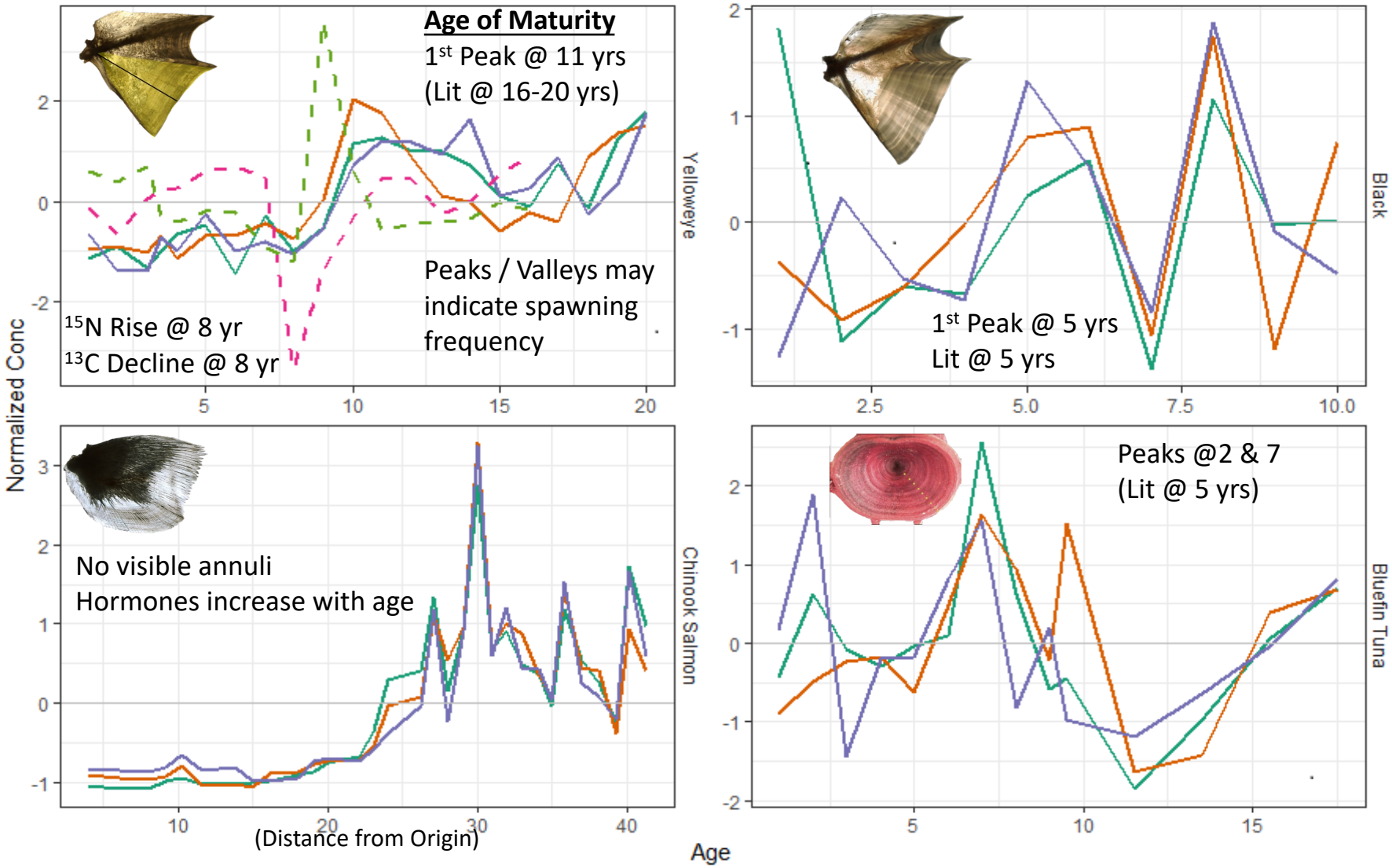
Using biomarkers to reconstruct age at maturity and stress histories

(Dion Oxman, ADF&G)

Progesterone
- Gamete maturation
- Reproductive behavior

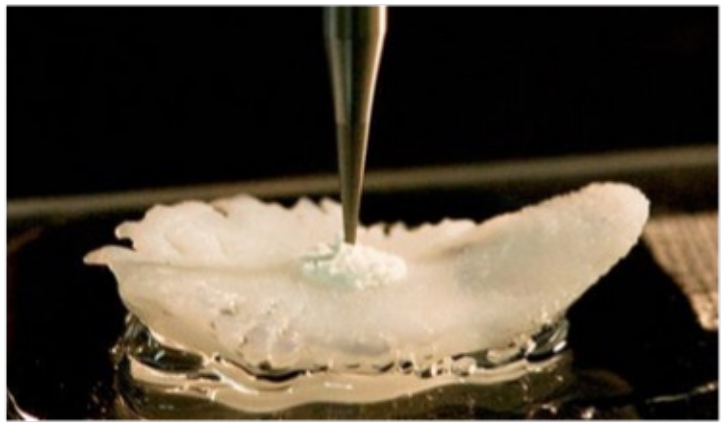
Estradiol
- Ovary Development/Vitellogenesis
- 2nd Sex Characteristics

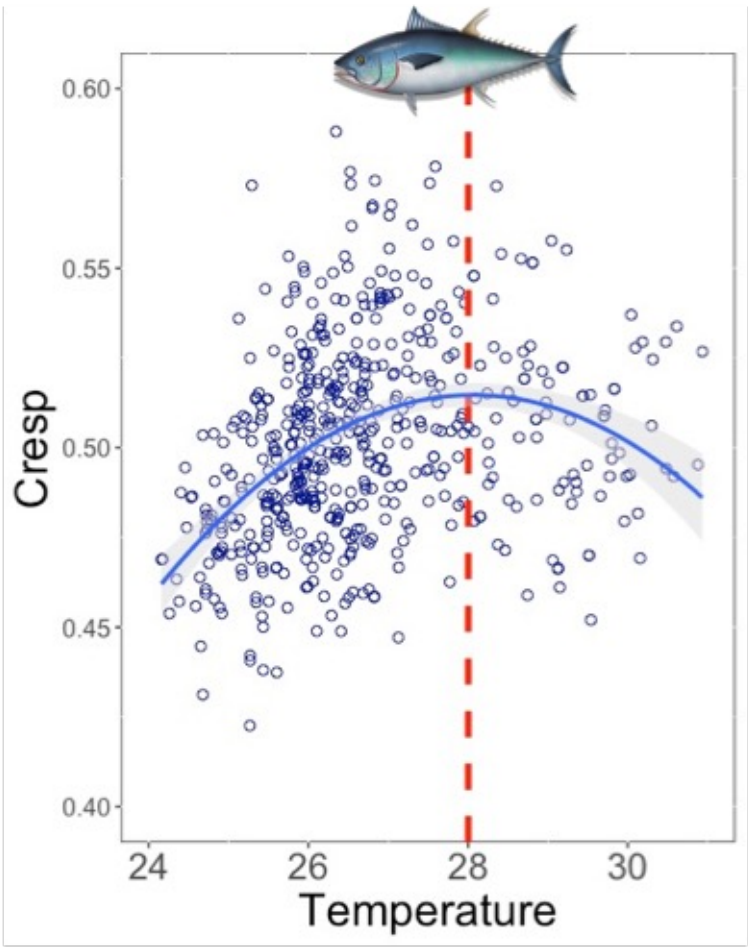
Cortisol
- Stress Response
- Endocrine Function



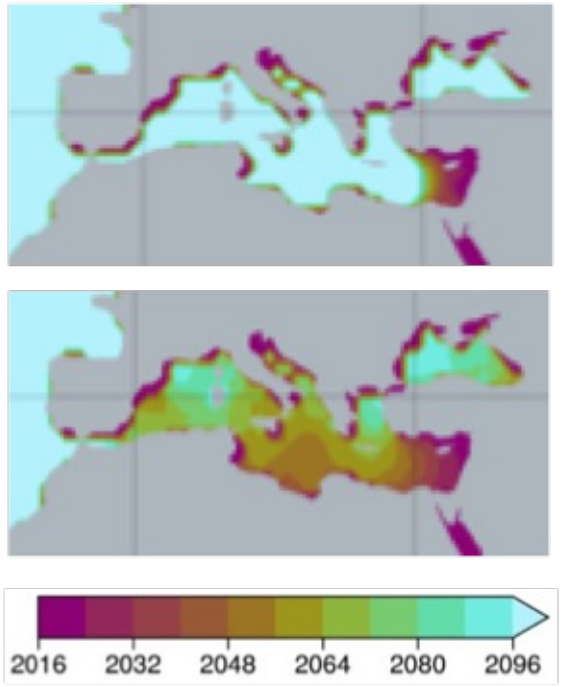
Otolith isotopes to reconstruct thermal and metabolic histories (Clive Trueman, University of Southampton)

Otolith stable isotopes can reveal individual level experienced temperature and field metabolic rate (daily energy expenditure)





Otolith-derived thermal sensitivity of field metabolic rate (juvenile bluefin tuna)
Temperatures above red line limit metabolic performance



Year when sea surface temperatures become limiting for tuna performance under differing climate scenarios

Conclusion

- No single tracking method is answering all our pressing questions
- Use of highly complementary methods is enabling us to piece together more complete histories of salmon migration than ever before
- New methods in development (e.g., ROAM telemetry system)
- A rapidly changing ocean will result in rapidly changing migration and distributions of salmon at sea
  - Coordination of the various research efforts could bring great benefits (e.g., co-collecting and/or archiving complementary samples/information)
  - Enabling such coordination would be a great legacy of the IYS to feed into the United Nations Decade of Ocean Science for Sustainable development?