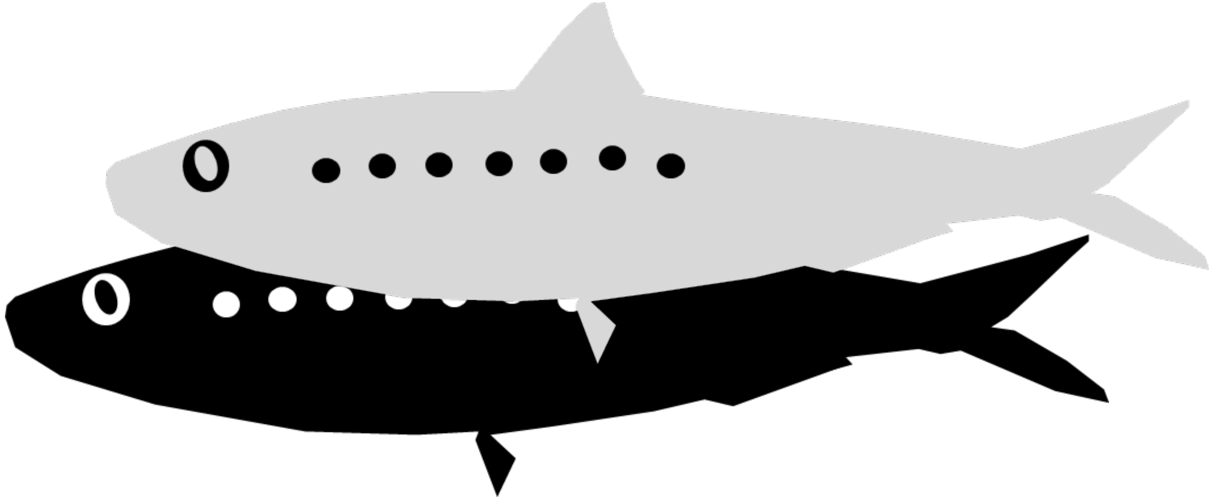
Contrasting life-history responses to climate variability in eastern and western North Pacific sardine populations



Basic ideas of…

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Contrasting life-history responses to climate variability in eastern and western North Pacific sardine populations

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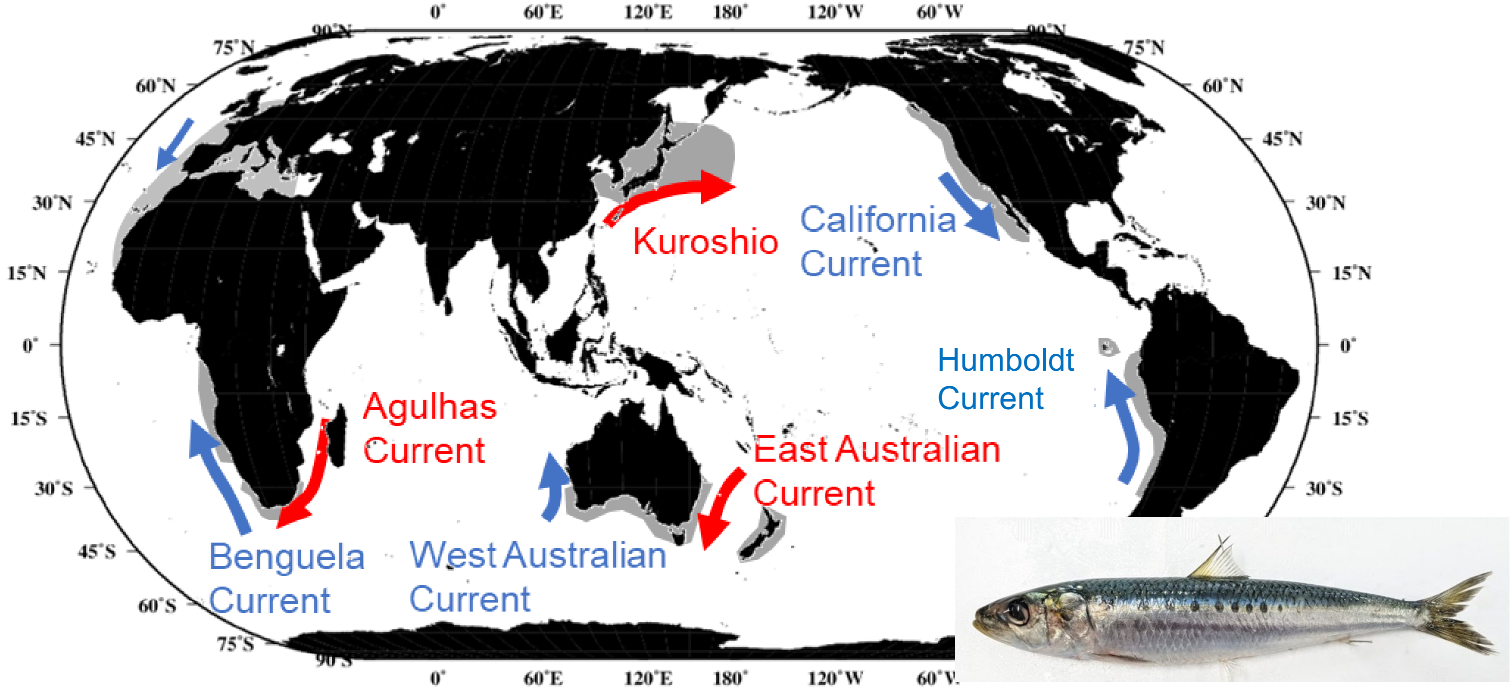
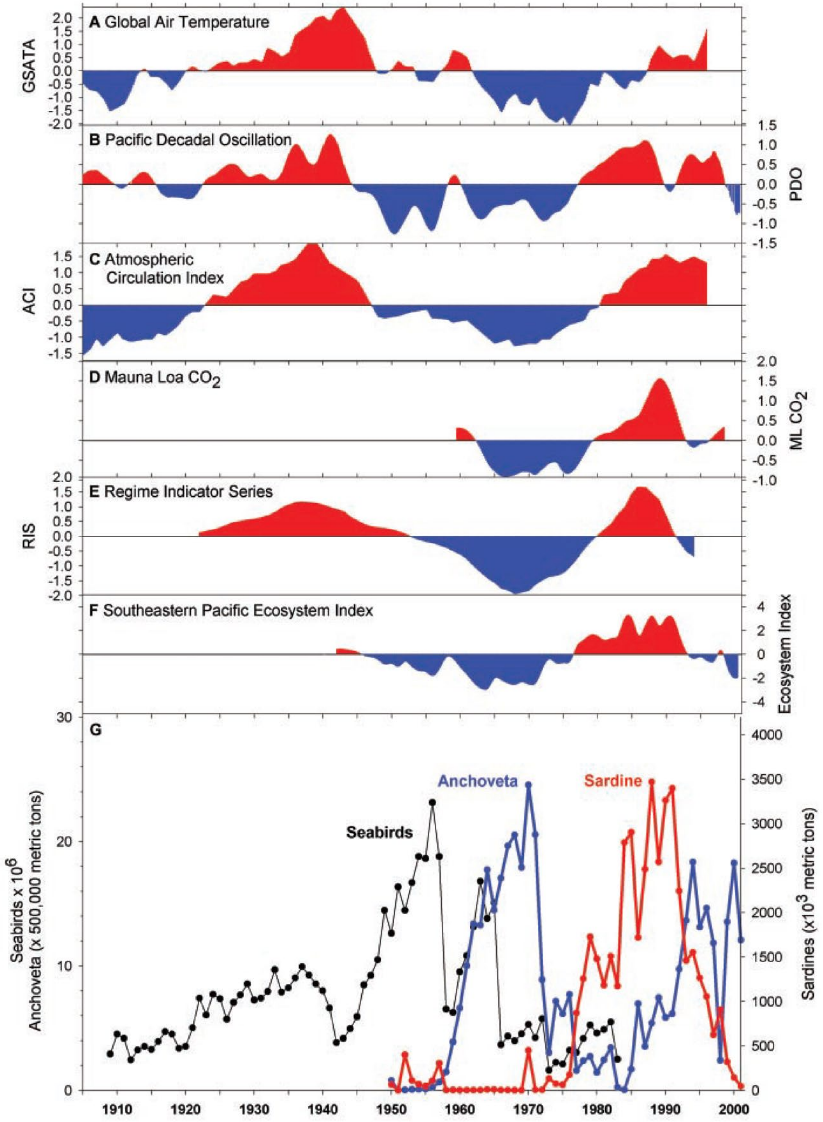
Sardine populations worldwide

Sardinops and *Sardina* distributions





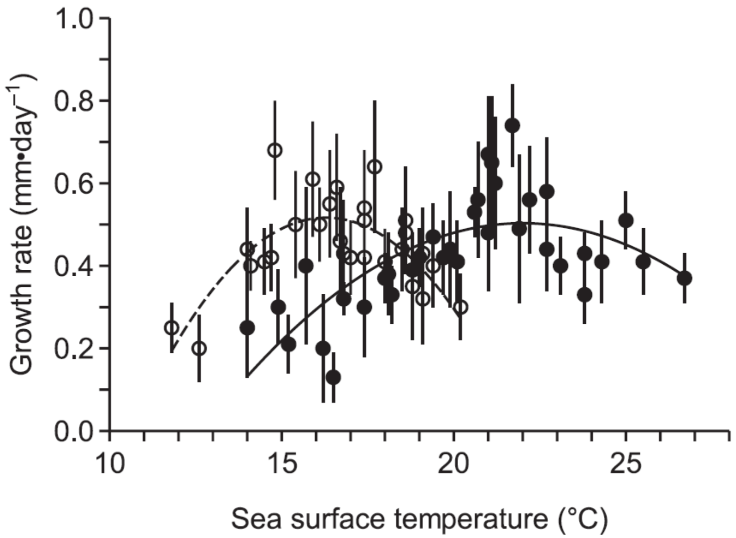
- Are distributed near Western or Eastern boundary currents
- Show intense population fluctuation likely driven by environmental variability… but how?

Chavez et al., 2003

Puzzle: East vs West

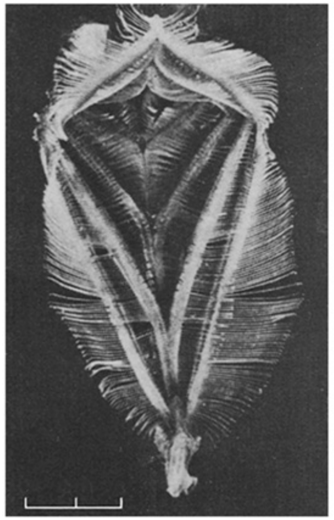
Sardine population tends to increase during...

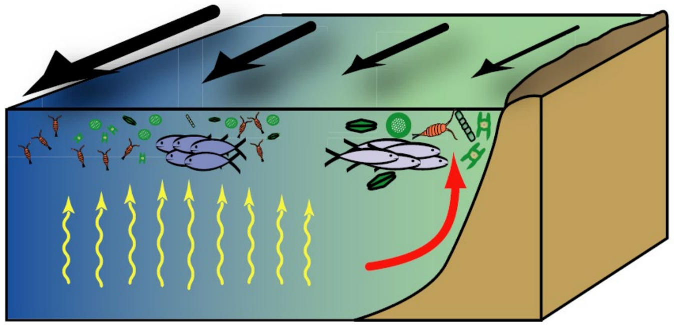
cooler periods
in western North Pacific
(e.g., Yatsu et al., 2005; Nakayama et al., 2018)



Optimal temperature hypothesis (Takasuka et al., 2007)

warmer periods
in eastern North Pacific + other upwelling regions
(e.g., Chavez et al., 2003; Lindegren et al., 2013)





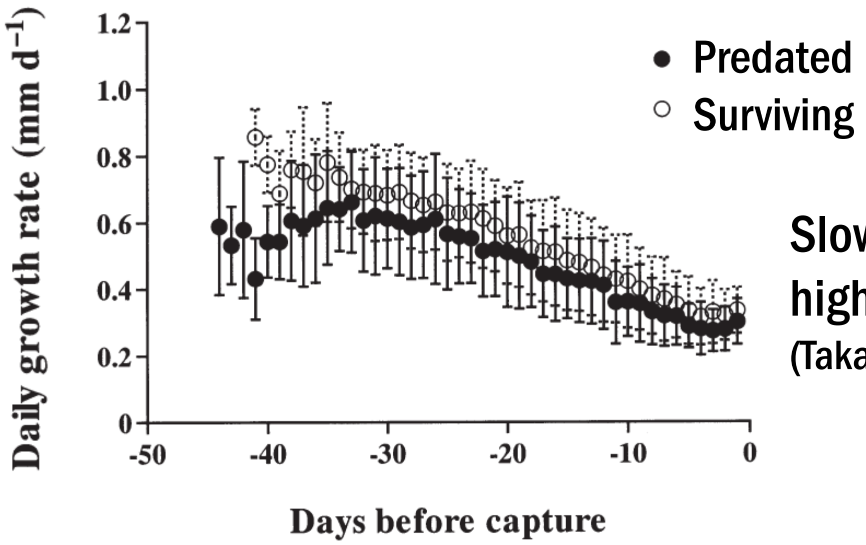
Wind-stress curl upwelling intensity
(Rykaczewski and Checkley 2008)

Trophodynamics hypothesis (van der Lingen et al., 2006)

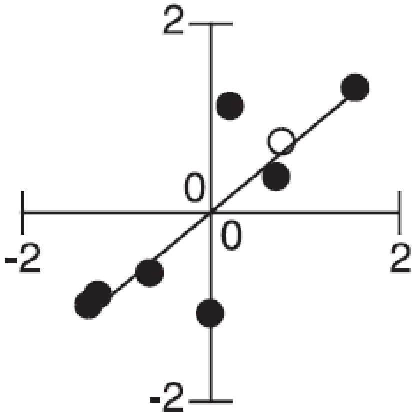
Is it possible to make a theory to explain both comprehensively?
What are the key differences between E and W populations?

Variation of early life growth

Faster growths likely improve survival and recruitment

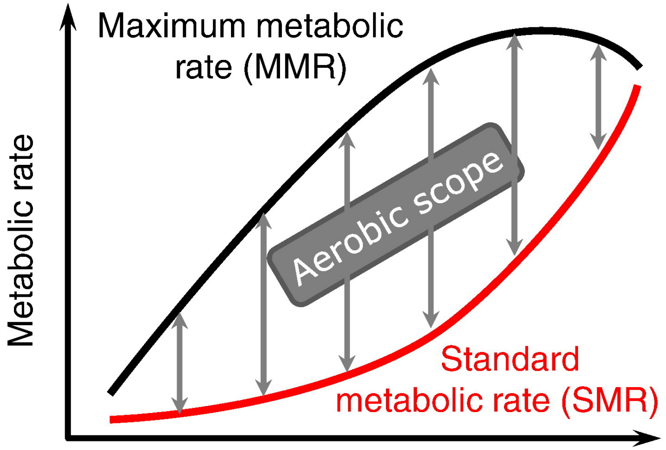


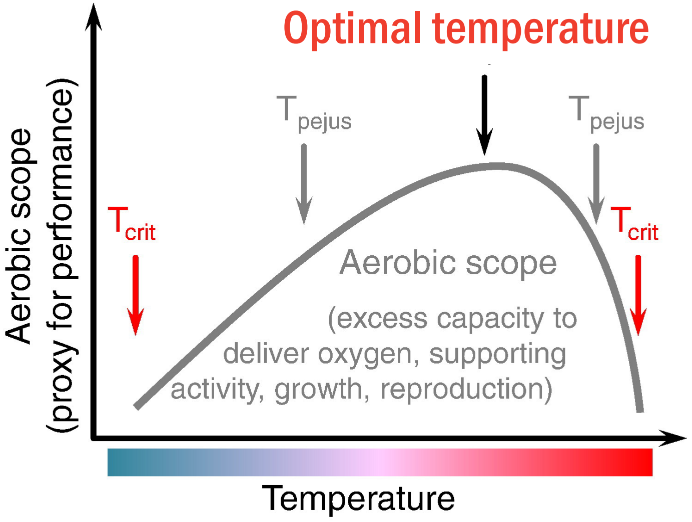
Slower growth to higher mortality
(Takasuka et al., 2003)



Juvenile growth-recruitment for Japanese sardine
(Takahashi et al., 2008; Takasuka et al., 2019)

Temperature can affect growth through prey availability and fish physiology

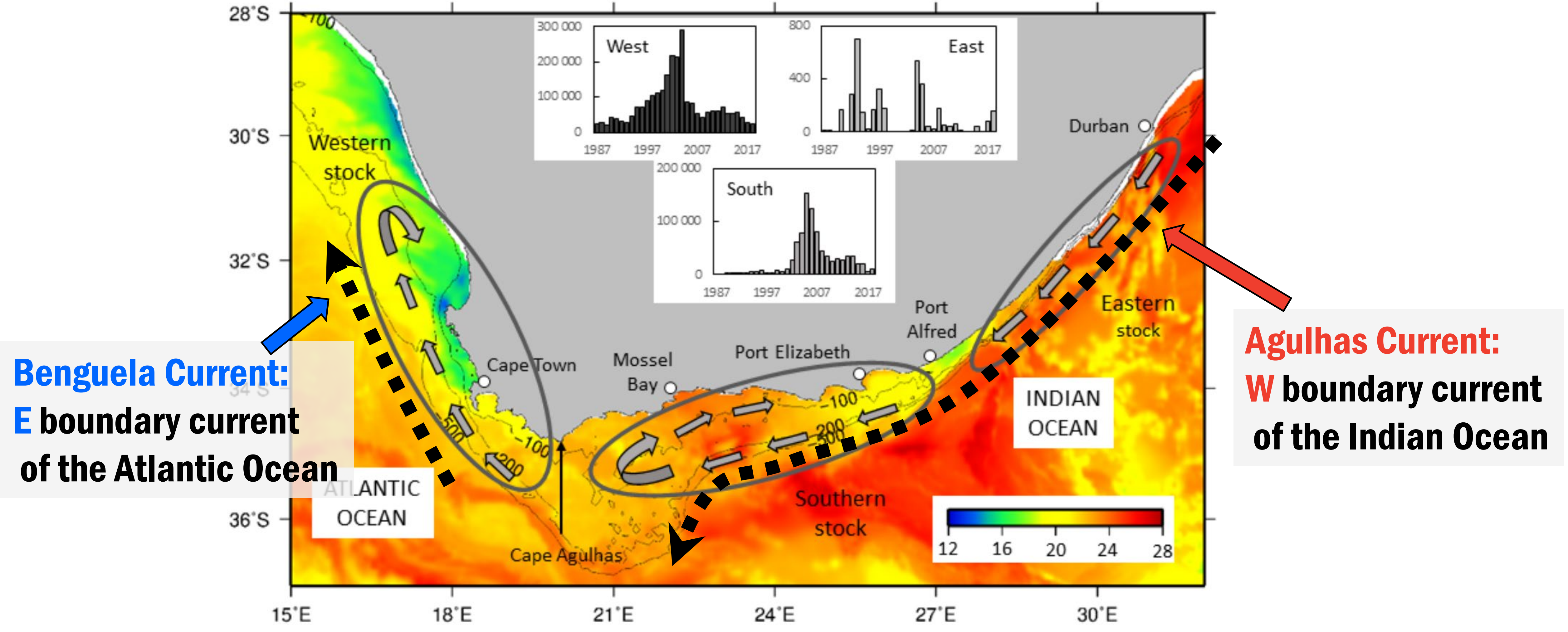




(Verberk et al., 2016)

South Africa: where the east meets the west

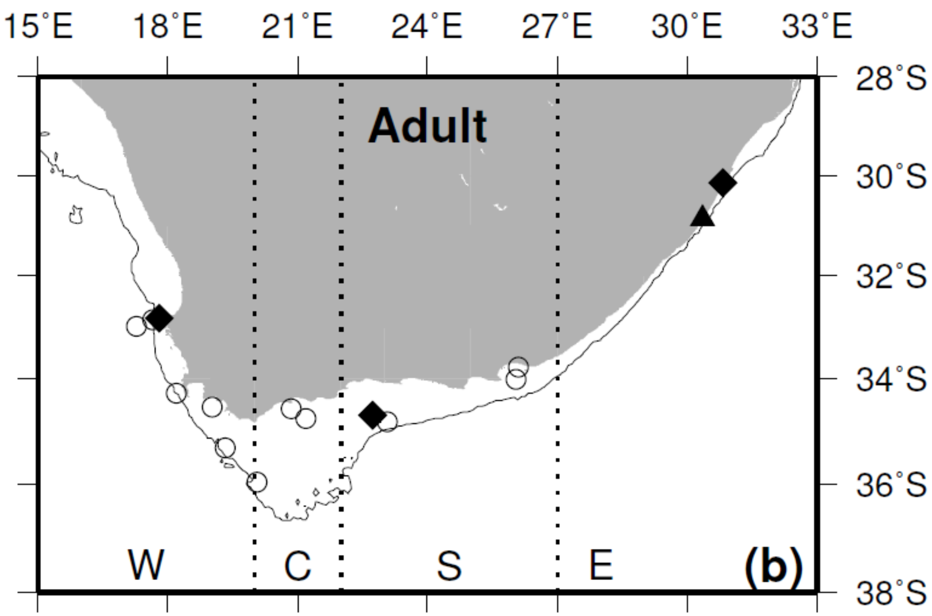
Sakamoto, van der Lingen et al., ICES journal of Marine Science (2020)



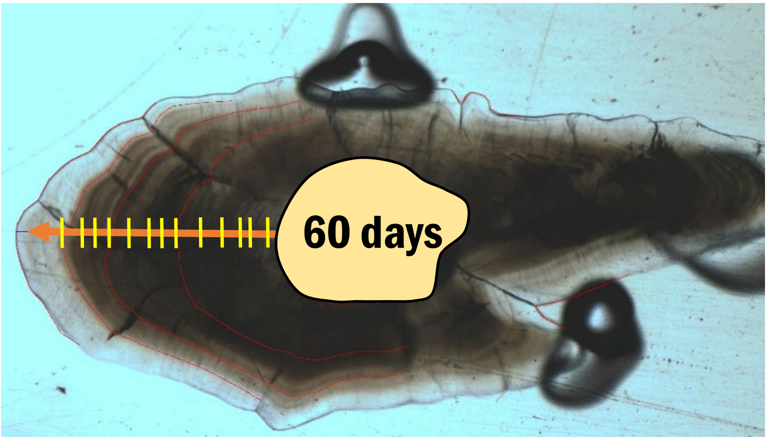
Several subpopulations?

Otolith analyses

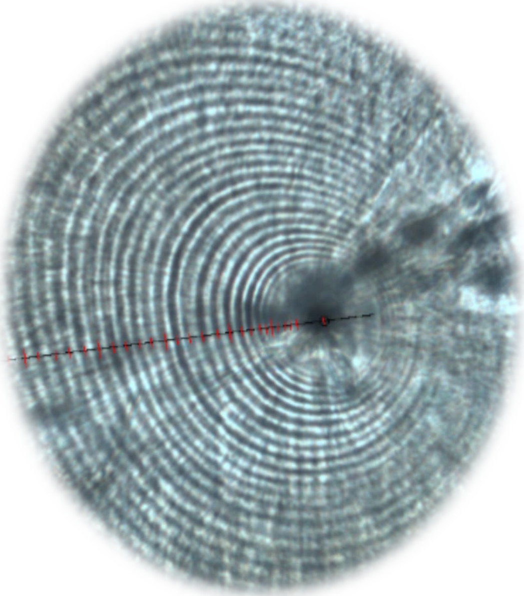
Are nursery environment different by regions?



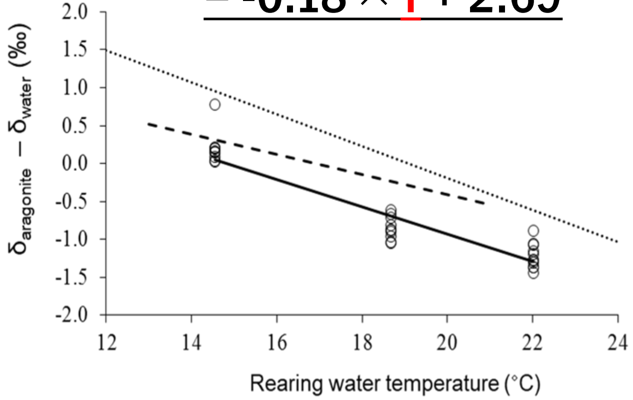
Dr. van der Lingen



367 otoliths from adults and juveniles in 2015-17



Otolith $\delta^{18}O$ - water $\delta^{18}O$ = -0.18 × T + 2.69



(Sakamoto et al., 2017)

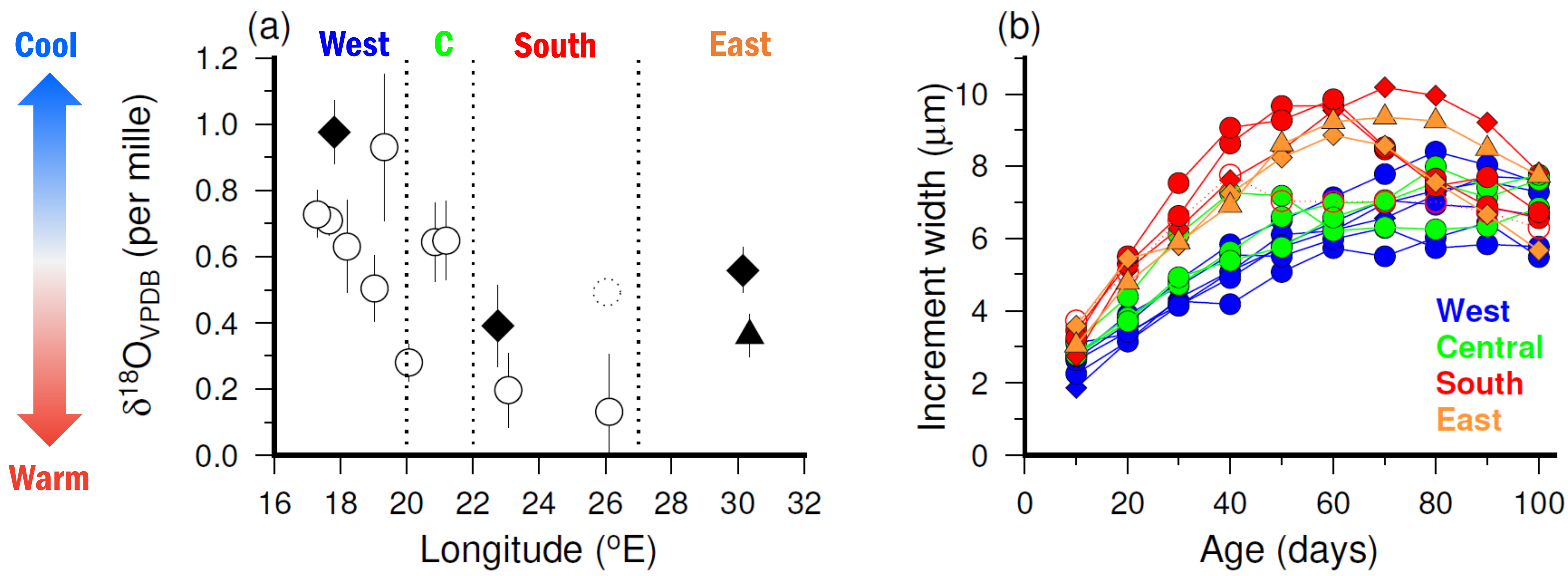
Microstructure analysis

Growth proxy

Oxygen stable isotope ratio ($\delta^{18}O$) analysis (0-60 dph)

Temperature proxy

Different nursery temperature and growth



Nursery temperature (0-60 dph): South (+ East) > West (+ Central)

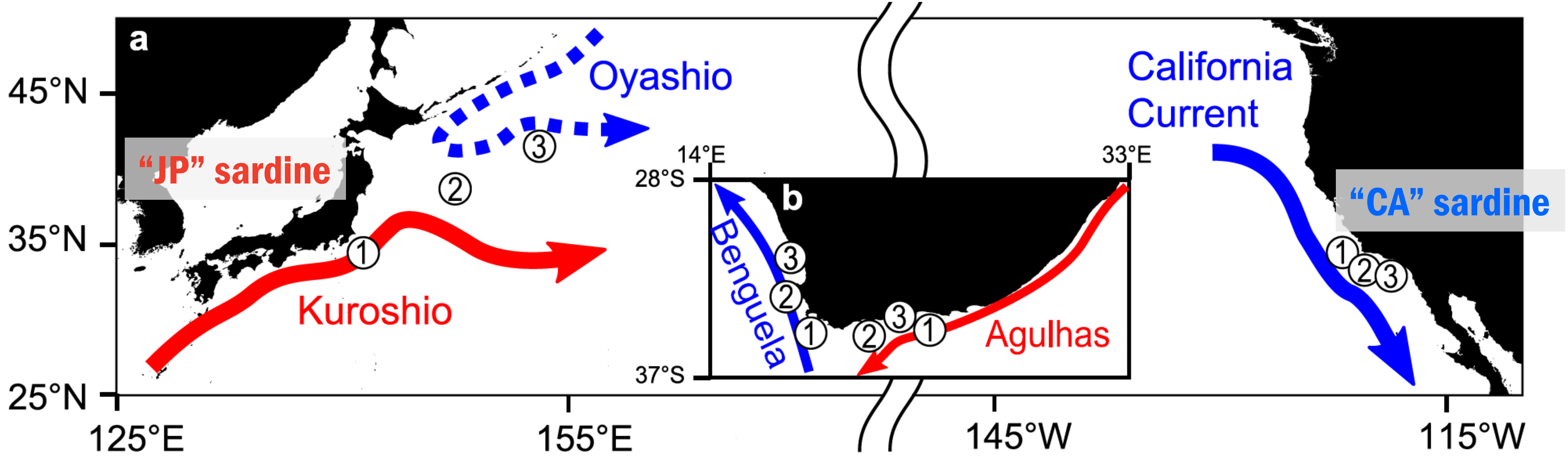
Otolith growth (0-100 dph): South + East > West + Central

Nursery environments may significantly differ between W and E boundary current systems

Sakamoto, van der Lingen et al., ICES journal of Marine Science (2020)

To the North Pacific

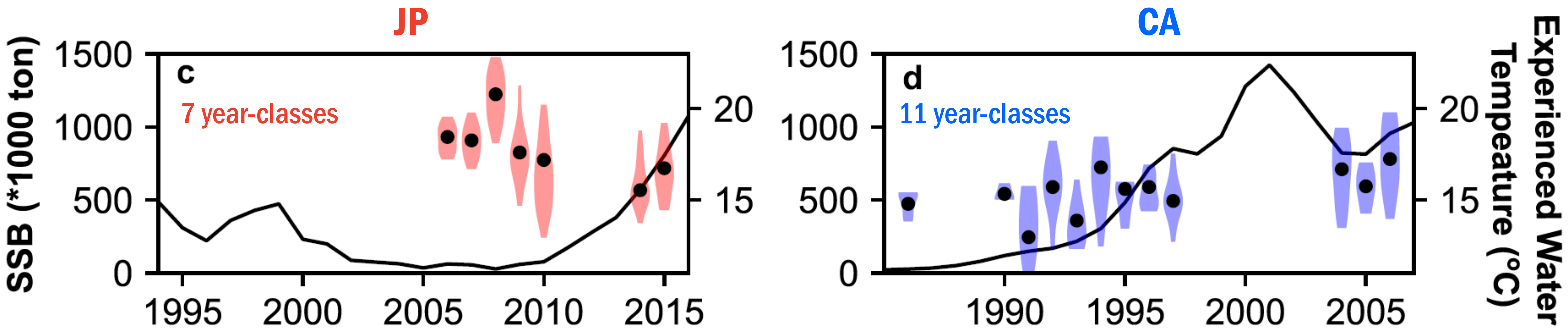
Typical distributions of 1: Larvae (< 35mm SL), 2: Early Juvenile (35-60mm) and 3: Late Juvenile (60-85mm)



- Pacific subpopulation of Japanese sardine: "JP" sardine
- Northern subpopulation of Pacific sardine: "CA" sardine
- Rich literature suggesting opposite responses of population to temperature anomalies (JP ↑ in cooler and CA ↑ in warmer regimes)

How do early life growths respond to temperature variations?

Materials and Methods



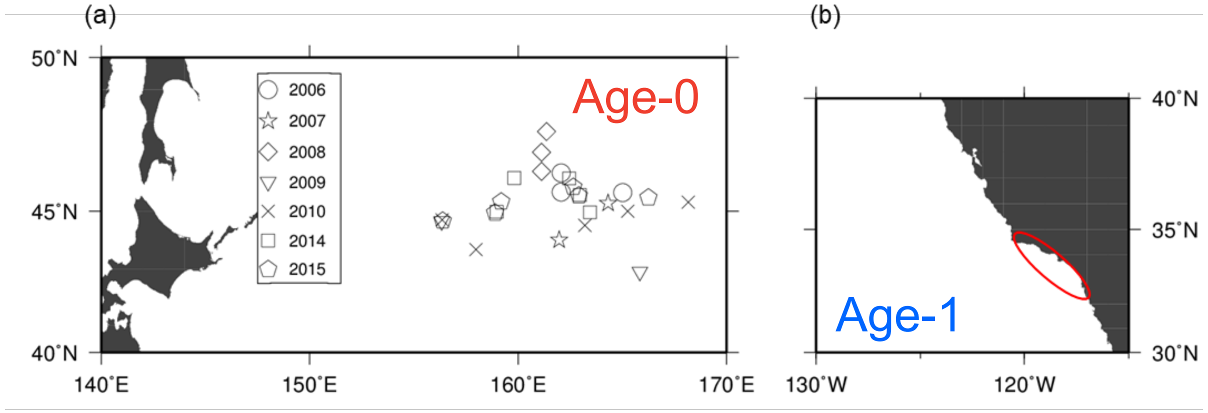
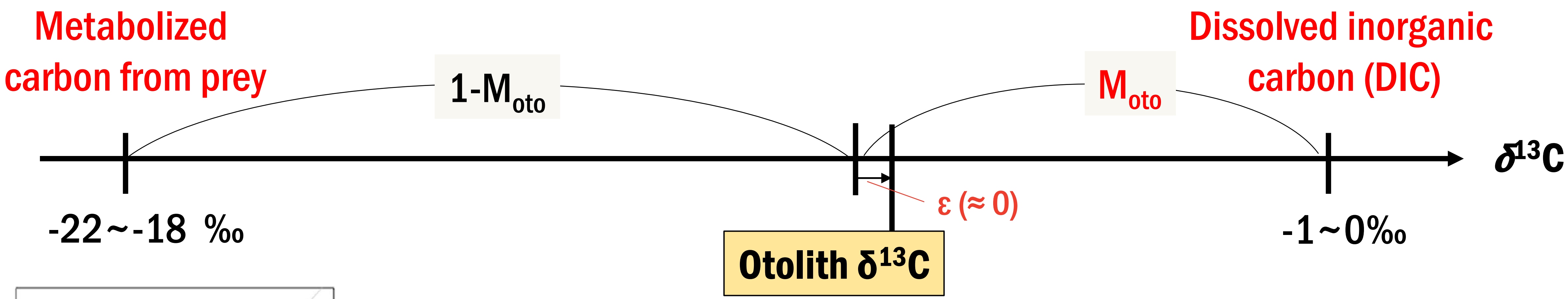


Figure 3. Sampling location for (a) the Japanese sardine and (b) the Californian sardine. The Californian sardine fished in red area was used in this study.

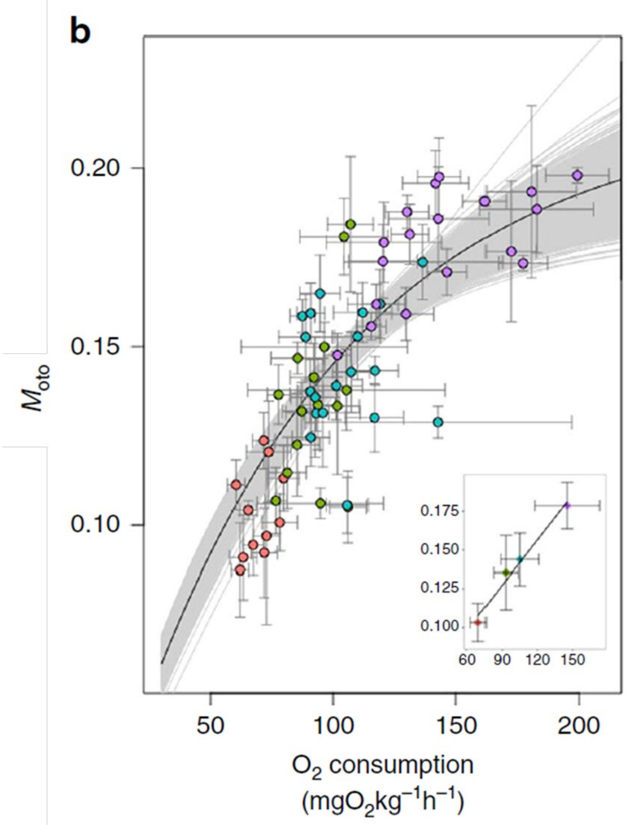
- Otoliths of JP: 156 age-0, CA: 100 age-1 recruits (10～16 cm SL)
- Microstructure (growth)+
  Oxygen (temp.) and carbon stable isotope analysis
  JP: 15-30 days, CA: 30 days resolution
  for 4-5 months from hatch

Otolith carbon isotope ratio: metabolic proxy



M_{oto} = $(\delta^{13}C_{oto} - \delta^{13}C_{DIC}) / (\delta^{13}C_{prey} - \delta^{13}C_{DIC})$ (used literature values)

: proportion of metabolically derived carbon can be used a proxy of field metabolic rate (Chung et al., 2019)



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ARTICLE

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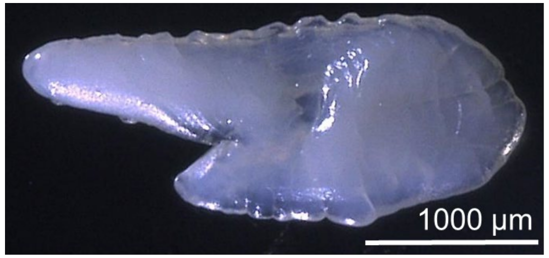
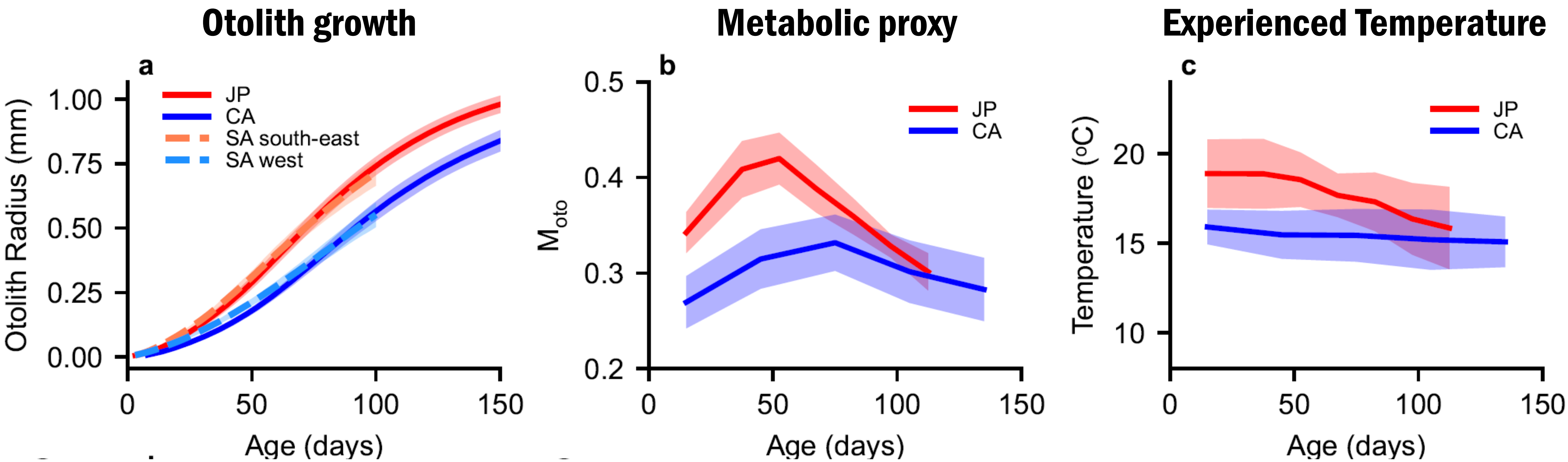
Field metabolic rates of teleost fishes are recorded in otolith carbonate

Ming-Tsung Chung[1], Clive N. Trueman[2], Jane Aanestad Godiksen[3], Mathias Engell Holmstrup[1] & Peter Grønkjær[1]



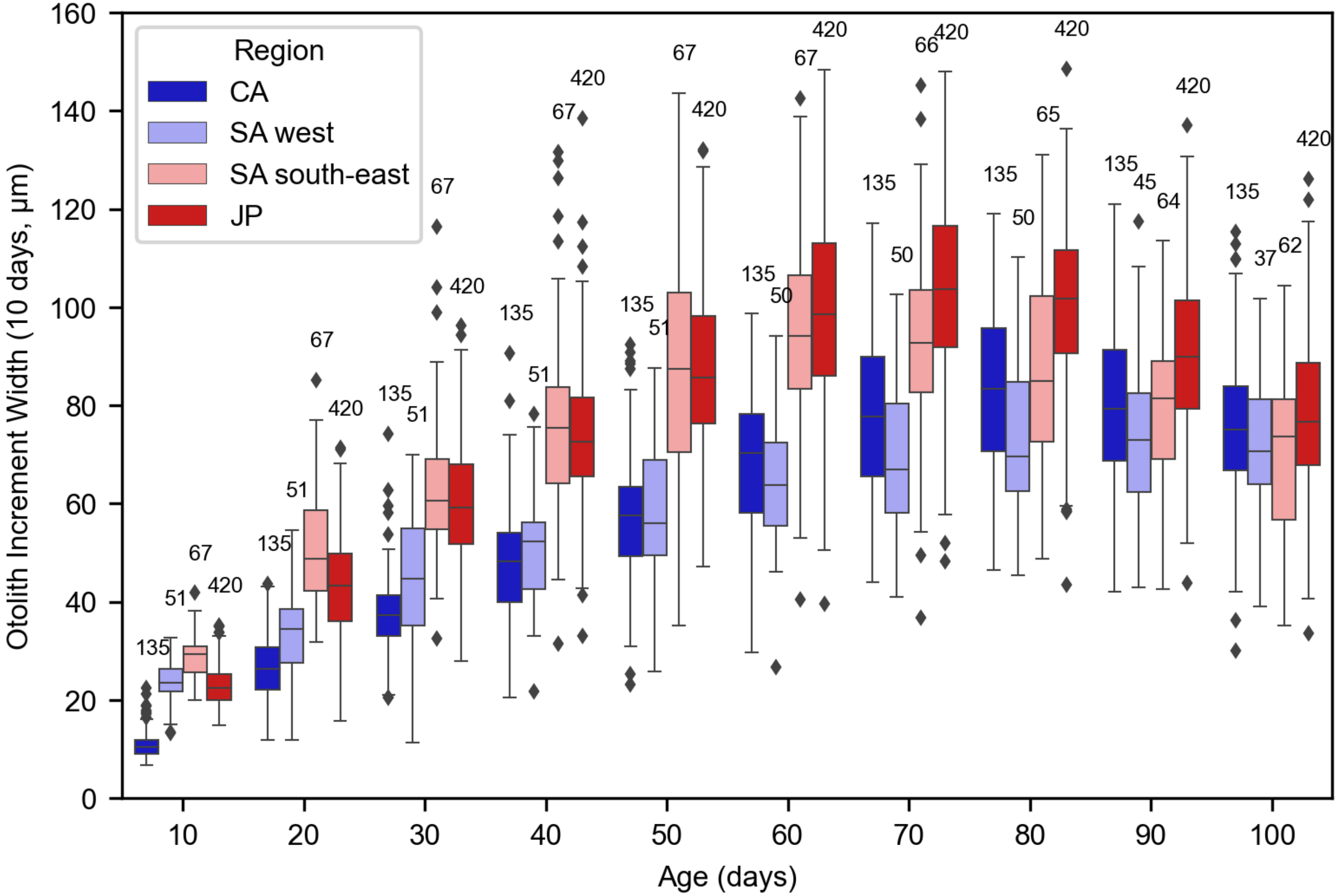
Histories of growth, temperature and metabolic rate can be extracted from a otolith

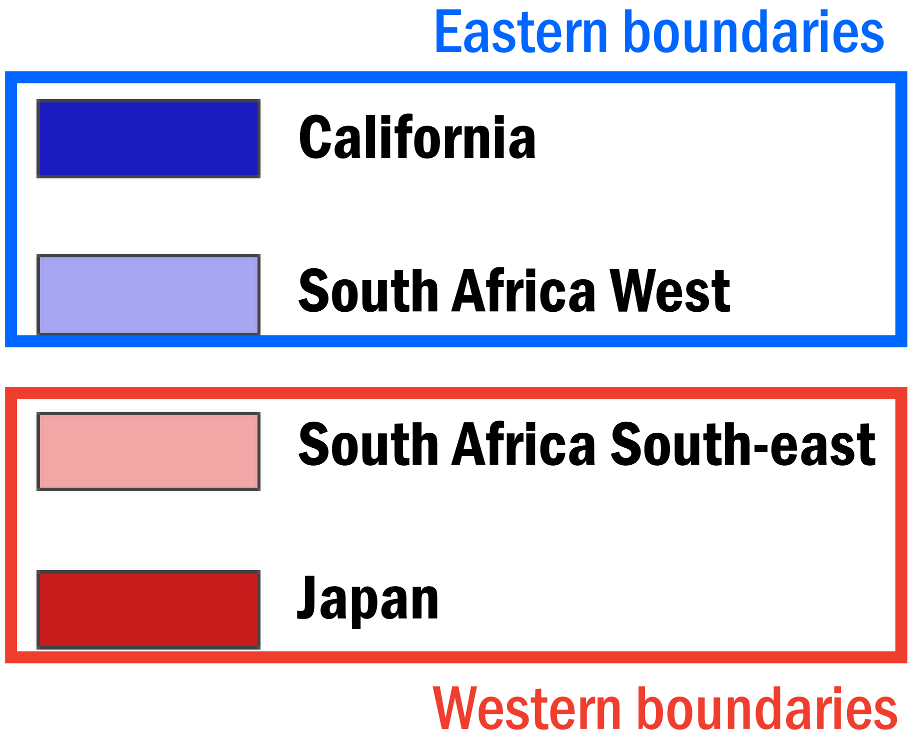
Life history traits



- Early life growth, metabolic rate (M_{oto}) and temperature: JP > CA
- JP mean temperature declining from ~19 to ~16 ^{o}C: northward migration
  CA mean temperature staying around 15-16 ^{o}C: residency around upwelling fronts

Similarity of otolith growth trajectories

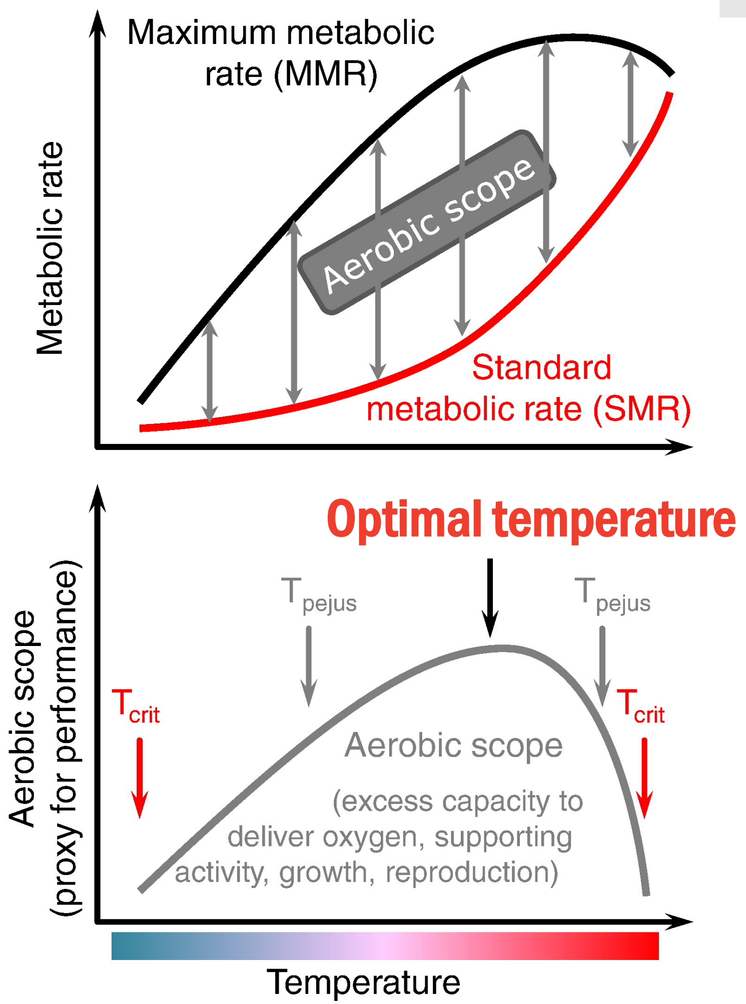




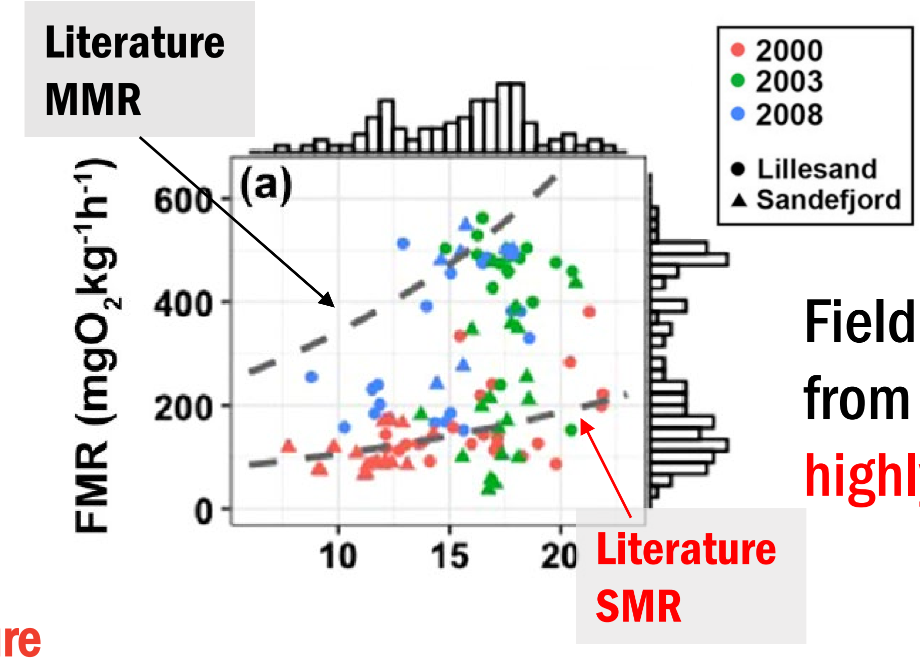
Oceanographic structures strongly affect basic sardine nursery environments and growths

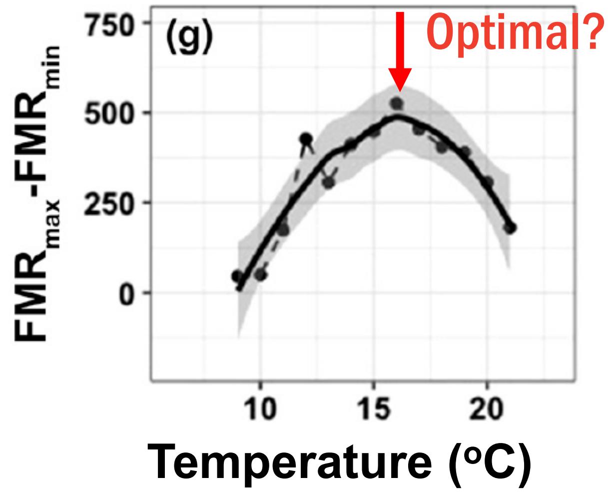
W populations have warmer nursery and higher metabolic and growth rates than E populations

Field metabolic rate and optimal temperature

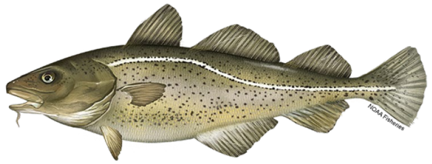


(Verberk et al., 2016)





(Chung et al., 2020)

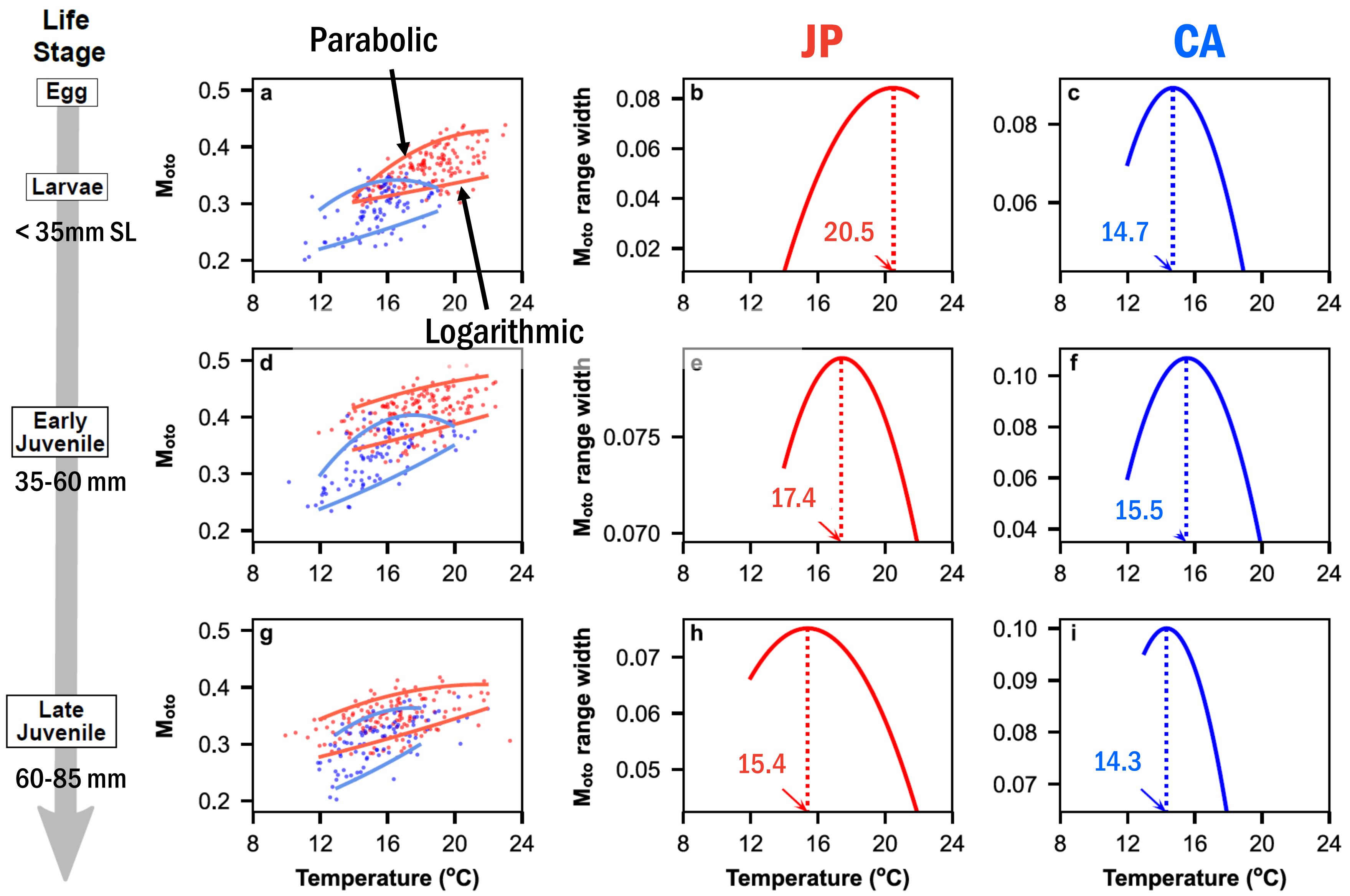


In Norway

Field metabolic rates of cods in Norway from multiple years are **highly variable between MMR and SMR**

The gap between upper and lower limits of field metabolic rates provide an analogue of aerobic scope

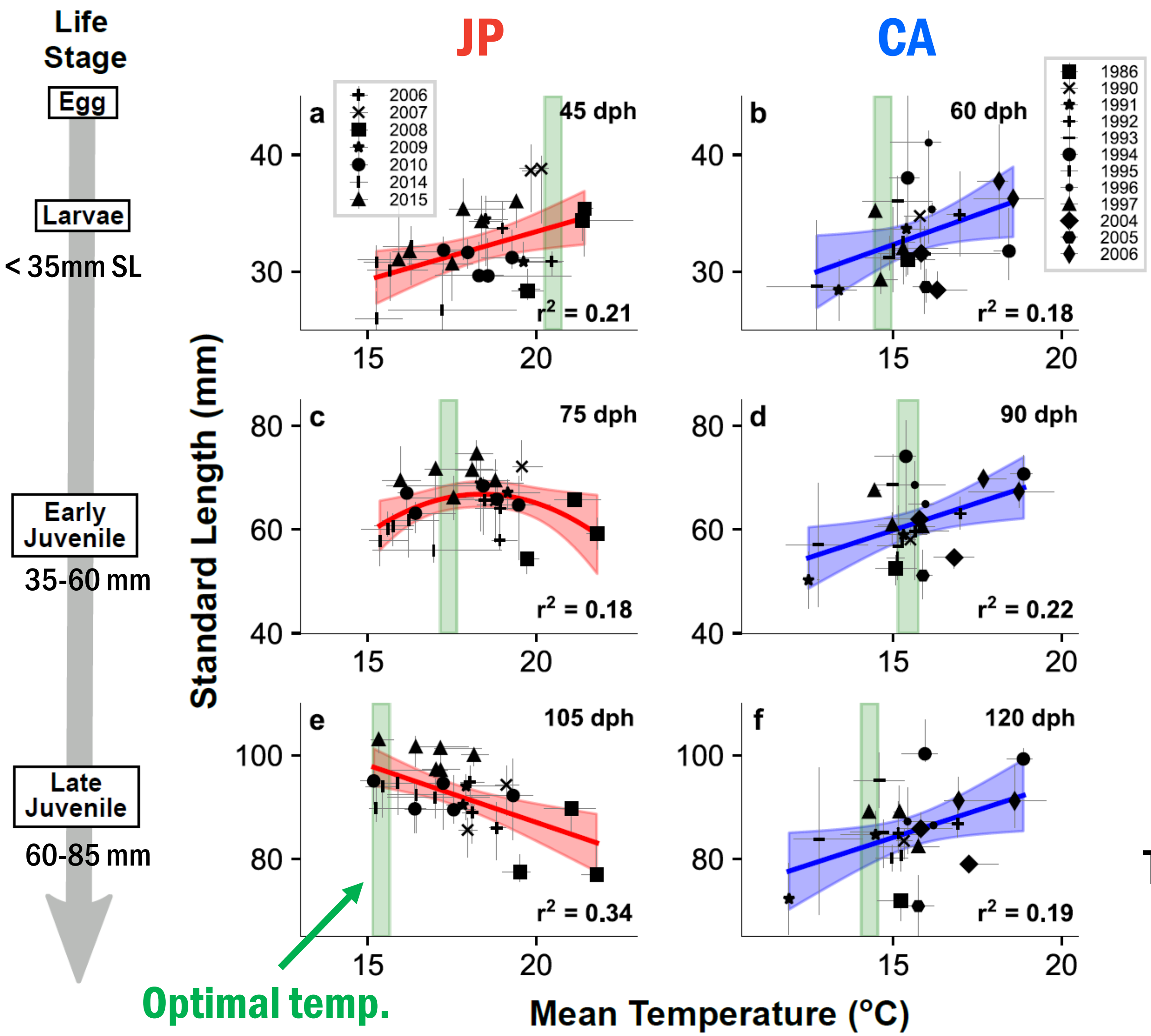
M_{oto} distributions and optimal temperatures



- M_{oto} higher in warmer temp. Lower in CA
- Parabolic fit for 5th percentile Logarithmic fit for 95th percentile to assess the M_{oto} range width
- Optimal temperature (M_{oto} range width maximum) at
  JP: 20.5→17.4→15.4°C
  CA: 14.7→15.5→14.3°C

Different thermal preferences and metabolic responses

Size-temperature relationships



Size at each age and mean temp. until the age

- Larvae: JP positive, CA positive
- Early juvenile: JP dome-shape, CA positive
- Late juvenile: JP negative, CA positive

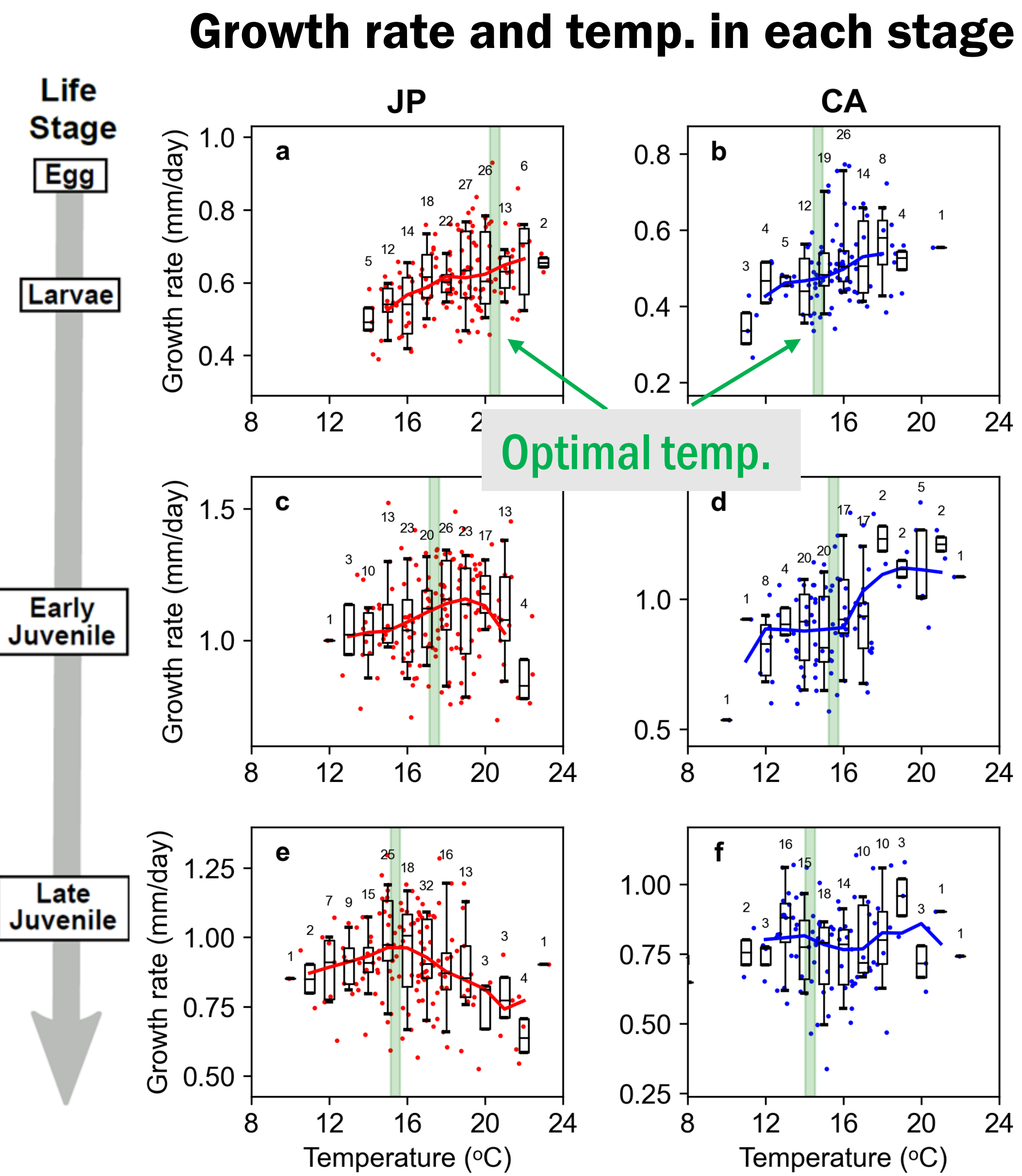
Previous studies suggested…

- larvae abundance did not determine recruitment
- juvenile growth was related to recruitment

(Butler 1987; Watanabe et al,. 1995; Takahashi et al., 2008; Furuichi et al., 2020)

The responses of growth throughout larvae and juvenile may explain the opposite population responses (JP ↑ in cooler and CA ↑ in warmer regimes)

Why opposite?



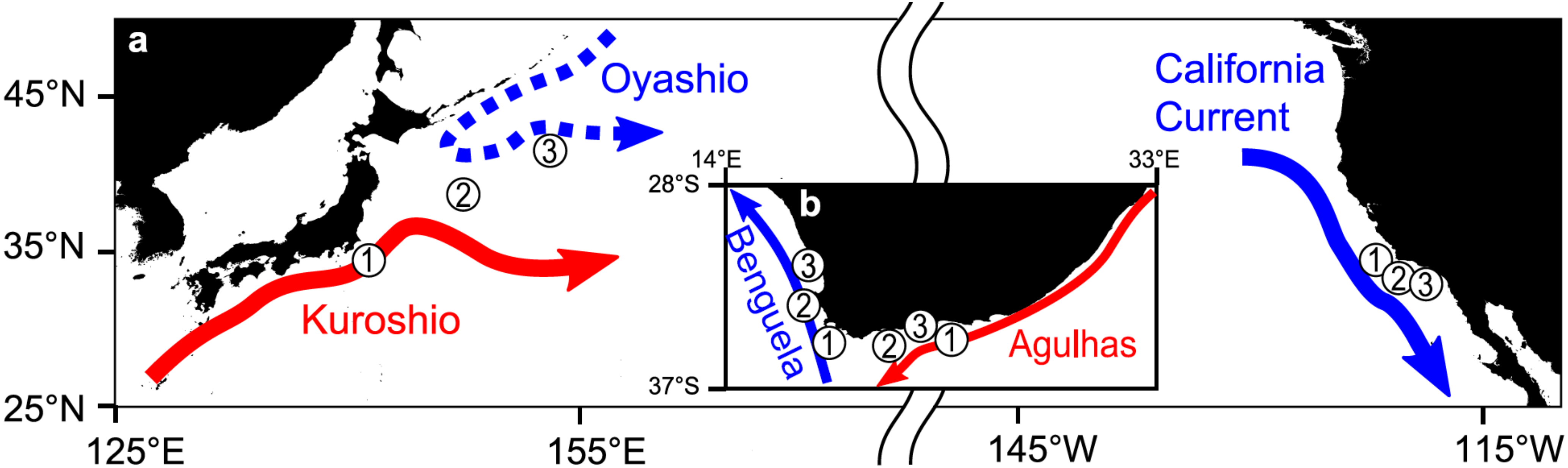
- **JP**: Growth maximized around optimal temperature in each stage
  - ▶ Physiological control under rich energy resources?
- **CA**: Growth maximized in temperatures <u>higher than</u> optimal temperature
  - ▶ Potential ecological disadvantages in cooler waters (e.g., prey size (van der Lingen et al., 2006), low oxygen (Bertrand et al., 2011)?)

▼

Temperature sets the capacity of energy expenditure, actual use may depend on ecological processes

Important is the interaction

Conclusion



In E and W, nursery environment, early life metabolic rate and growth rate are different, and so were the responses the rates to temperature variation, which can explain the population responses

Developing new techniques to divide difficulties into pieces is important to solve fish population puzzles

Acknowledgements

Special thanks:

Noriko Izumoto for contributions to the $\delta^{18}O$ analysis of otolith powders

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