Thermal resilience of Delta Smelt: What can we learn from otoliths?

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Introduction

The Sacramento-San Joaquin Bay-Delta forms a vital link in California's water supply and is managed for both human use as well as for several species of threatened and endangered fish, causing significant conflict over limited freshwater resources. The endangered Delta Smelt (*Hypomesus transpacificus*) is at the center of this conflict and its abundance levels are at an all-time low.

Delta Smelt are a small annual fish species exclusive to the Delta. Historically, they were abundant but have experienced a population crash since the 1980s to an all time low abundance during the recent drought (**Fig. 1**).

Regulations were put in place to preserve Delta Smelt via additional fresh water flows, however these regulations are controversial because annual abundance of Delta Smelt is not strongly correlated with freshwater outflow and restrictions on exports have not resulted in the recovery of the species.

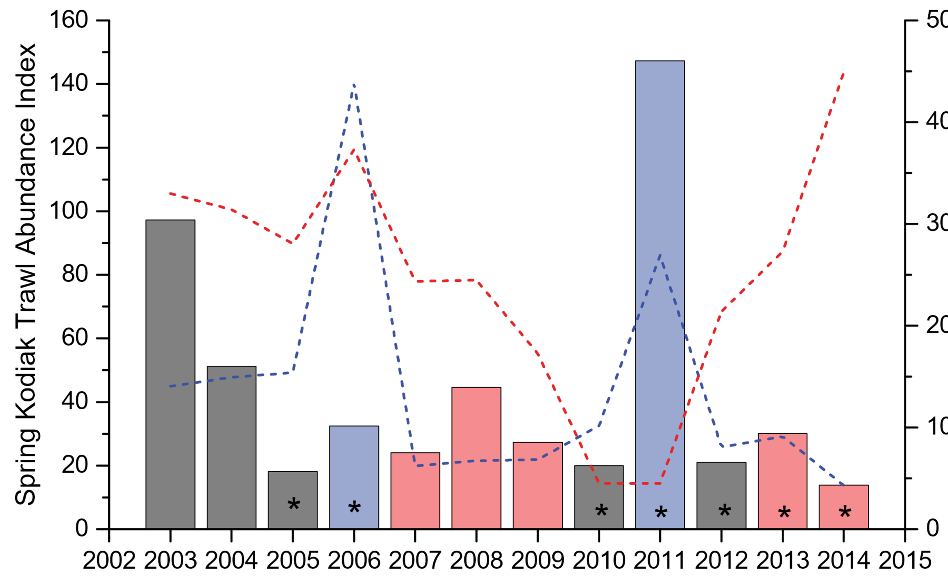

Fig. 1: Abundance of Delta Smelt (from the SKT index), total fresh water outflow in blue (DAYFLOW) and annual mean water temperature (CDEC) in red. Asterisk marks years for which samples are available for oxygen isotope analysis. Drought years are indicated by red color, blue for wet years, and grey for normal.

Delta Smelt Life History

Delta Smelt exhibit a complex life history termed partial migration, where both resident as well as migratory individuals (phenotypes) occur within a genetically homogenous population. The contributions of these phenotypes to the overall population vary between years (**Fig. 2**).

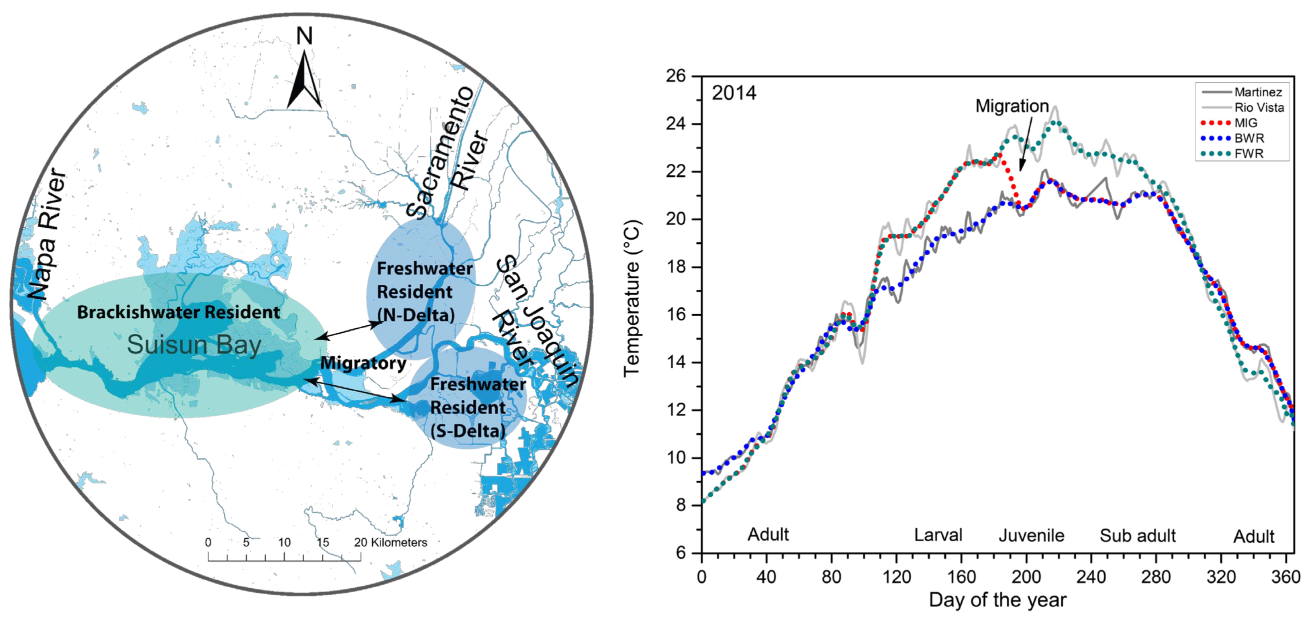

Fig. 2: Geographic location of the different life history phenotypes of Delta Smelt (left) and expected temperature profiles throughout the year (right). Daily average water temperatures from Rio Vista (fresh water) and Martinez (brackish water), in grey.

Having diverse life-history strategies allowed Delta Smelt to persist in the dynamic habitat of the Delta, by spreading the risk of catastrophic mortality between multiple habitats.

- Generally, high freshwater outflow provides benefits for many estuarine species, but for Delta Smelt this relationship is complicated by its diverse life history
- There is a negative relationship between the abundance of Freshwater resident fish and water temperature even in years of high freshwater outflow

Acknowledgements

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Delta Smelt (*Hypomesus transpacificus*)

Aims

Background

We can use otoliths (ear bones) to determine the temperature that a fish has experienced. This can be used to investigate the complex life history of Delta Smelt and understand how their population abundance is affected by freshwater outflow and water temperature.

Methods

Validation study

Experimental design

F1 Delta Smelt kept under controlled laboratory conditions for a year

FCCL (15°C) — T and water change → Putah (20°C) / Putah (16°C) — T and water change → CABA (18°C)

FCCL (15°C)	Putah (20°C) / Putah (16°C)	CABA (18°C)
$\delta^{18}O$ water (VSMOW) -8.25 ‰	$\delta^{18}O$ water (VSMOW) -4.07 ‰ ± 0.26 (n=26)	$\delta^{18}O$ water (VSMOW) -5.28 ‰ ± 0.13 (n=5)
Water collection	Fish and water collection	Fish and water collection

Hatch — Time — Death

140 days — 160 days — 360 days

Results

- Standard materials (NBS19, NBS18) were reproducible during the analytical session and we obtained high accuracy and precision allowing us to resolve changes <1 °C.

Standard	N	$\delta^{18}O$ (‰, VPDB)	2σ	SE
Primary standard: NBS19 [-2.20 ‰ (VPDB)]	26	-2.19	0.24	0.02
Secondary standard: NBS18 [-22.97 ‰ (VPDB)]	20	-23.12	0.74	0.08

- Oxygen isotope profiles from the core of the otolith to the dorsal lobe showed distinct patterns related to changes in the ambient water source and temperature (**Fig. 3**).

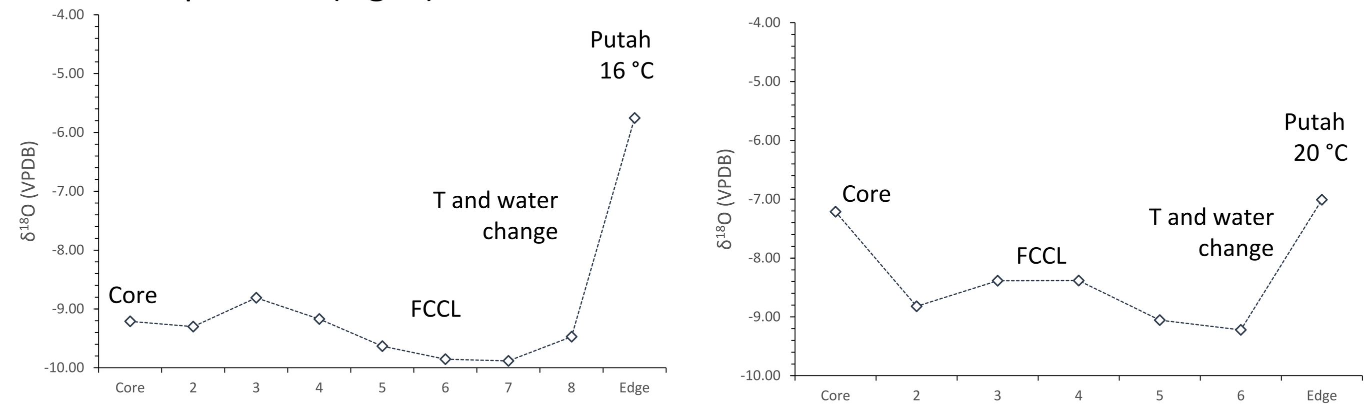
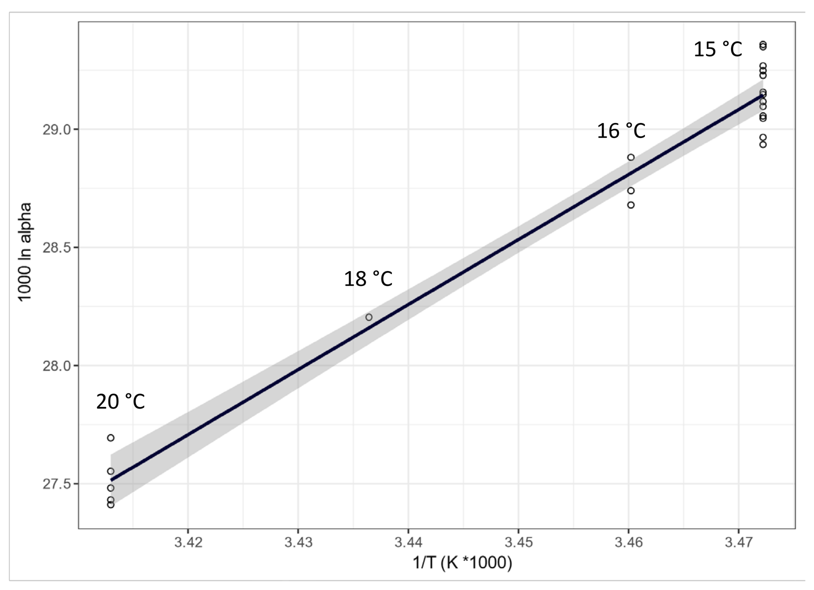


Fig. 3: Example graphs of oxygen isotope profiles across Delta Smelt otoliths. (Left) A fish collected at the Putah Creek facility from 16°C water and (Right) from 20°C water.



- Changes in water source from FCCL to Putah Creek changed $\delta^{18}O$ otolith by ~3 ‰
- A water temperature effect of ~0.3‰ per °C is observed
- Current T estimates are ±1.5°C

Delta Smelt fractionation equation:
$$1000\,ln\,\alpha = 27.52(10^3T\,K^{-1}) - 66.39$$

$$T\,°C = (27.52/(\ln\alpha + 66.39) * 1000) - 273.15$$

Fig. 4: Linear regression model based on 14 Delta Smelt otolith.

- More work is needed to better estimate the Delta Smelt specific fractionation equation to reduce the errors on the temperature estimates.

Conclusions and outlook

Over the next two years we will investigate the temperature dependence of wild Delta Smelt using archived otoliths to improve the abundance to freshwater outflow and temperature relationships. This research can be used by the Interagency Ecological Program (IEP) to understand which habitat conditions Delta Smelt can utilize in different water years, and in turn help us to better manage the limited water resources of California.

Insights from otoliths

Otoliths (fish ear bones) consist of calcium carbonate and form continuous growth increments throughout the life time of a fish (**Fig. 5**). Consequently, they provide us with a powerful archive of age, growth, and water conditions that a fish has experienced. In particular, oxygen isotope ratios ($\delta^{18}O$) measured in otoliths allow for the retrospective determination of water temperature that a fish has experienced.

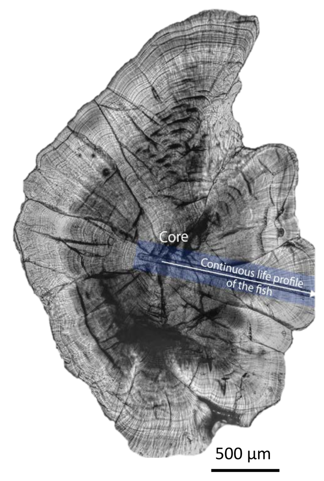


Fig. 5: Delta Smelt otolith cross section showing the aging rings and trajectory used for chemical analysis.

Oxygen isotopes in the environment

$\delta^{18}O$ of water varies in the environment primarily depending on its source and subsequent evaporation and condensation (**Fig. 6**). From the water $\delta^{18}O$ is incorporated into the otolith near equilibrium with the environment, but is subject to a temperature dependent fractionation; the heavier isotope of oxygen (^{18}O) is incorporated into otoliths less than the lighter isotope (^{16}O) with warmer conditions.

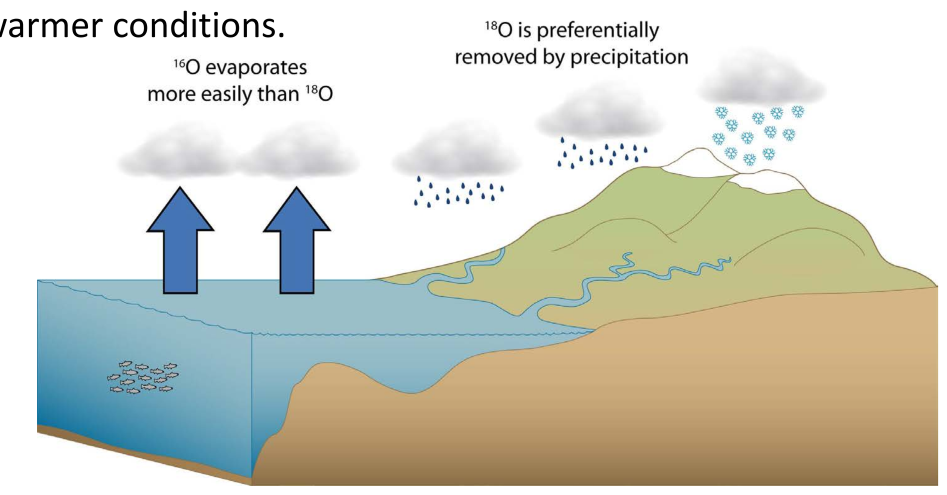
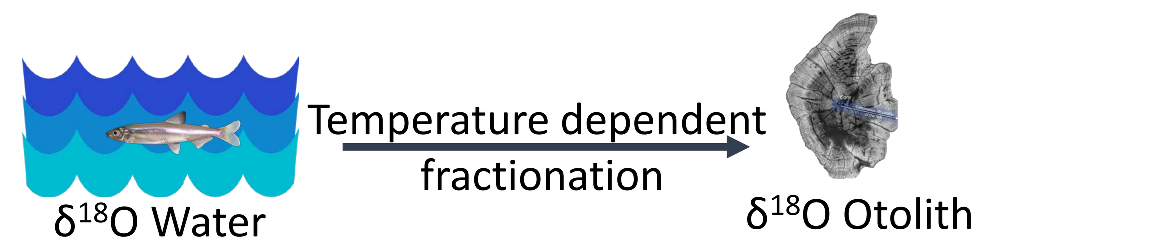


Fig. 6: The oxygen isotope cycle

In order to reconstruct water temperature from $\delta^{18}O$ measurements from the otolith we need to determine the $\delta^{18}O$ value of the water and determine a species specific fractionation equation.



Marine fish	Atlantic croaker $1000\ln\alpha = 18.56(10^3T\,K^{-1}) - 32.54$	(Thorrold et al. 1997)
Fresh water lake fish	Sculpins, dace, minnows, trout, drum $1000\ln\alpha = 18.56(10^3T\,K^{-1}) - 33.49$	(Patterson et al. 1993)
Cold water fish	Arctic char $1000\ln\alpha = 20.43(10^3T\,K^{-1}) - 41.14$	(Godiksen et al. 2012)
Marine fish	Juvenile plaice $1000\ln\alpha = 15.99(10^3T\,K^{-1}) - 24.25$	(Geffen 2012)
Marine fish	Atlantic Cod $1000\ln\alpha = 16.75(10^3T\,K^{-1}) - 27.09$	(Hoie et al. 2004)

TK= temperature in degree Kelvin
fractionation factor $\alpha = (\delta^{18}O_{otolith}+1000)/(\delta^{18}O_{water}+1000)$

Instrumentation

In-situ oxygen isotope ratios were measured at the Research School of Earth Sciences, The Australian National University (ANU), Canberra, Australia using the sensitive high resolution ion micro probe (SHRIMP, **Fig.7**). Analytical profiles started at the core and traverse to the dorsal lobe with a sport size of 40µm and a spacing of 10µm. Profiles were parallel to previously obtained laser scars from $^{87}Sr/^{86}Sr$ analysis and aging lines to maximize life history information (age, growth rate, salinity history and thermal history).

Fig. 7: SHRIMP instrument at the Research School of Earth Sciences, ANU