Potential effects of climate change on the high seas life history and ecology of steelhead in the North Pacific Ocean

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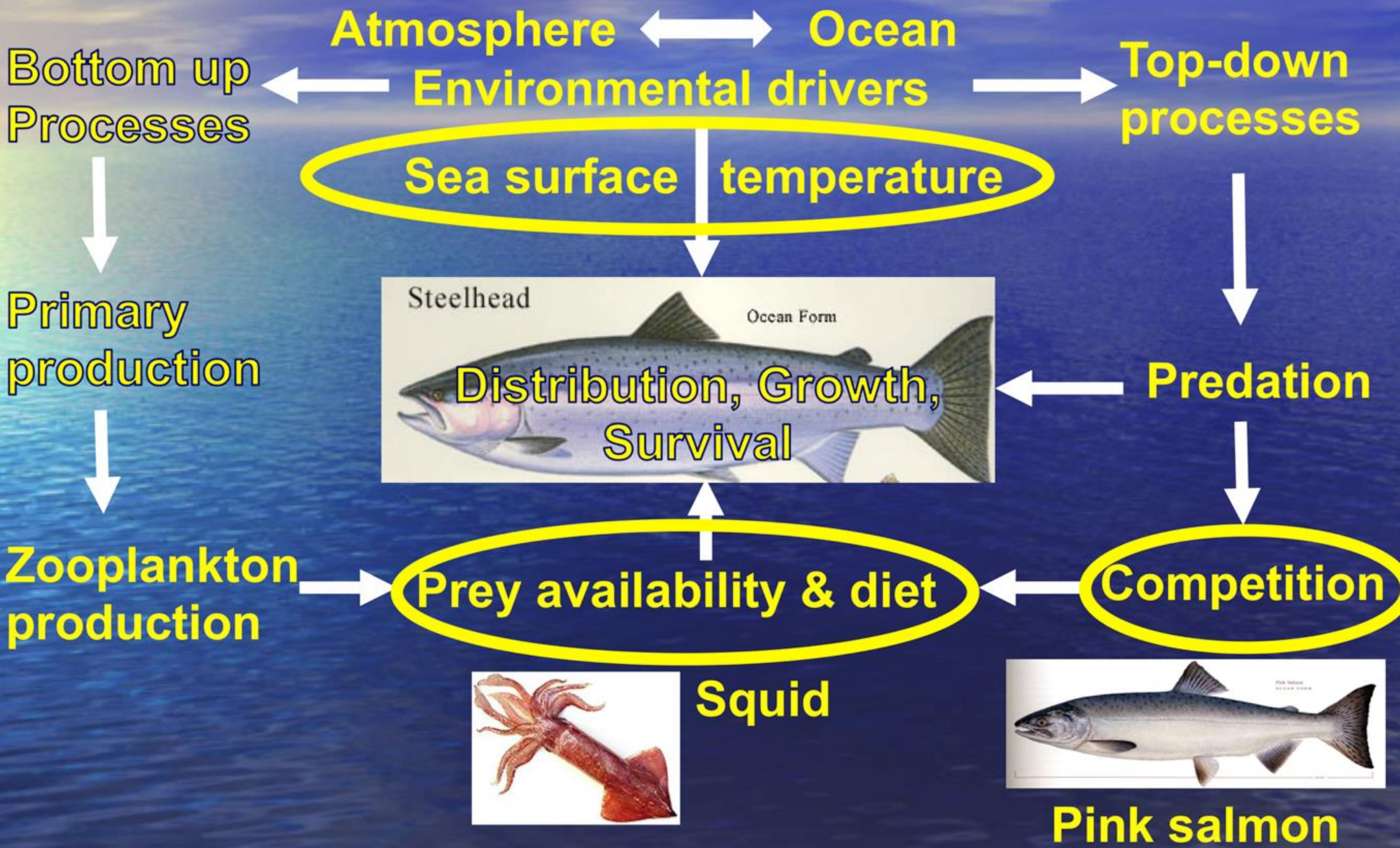
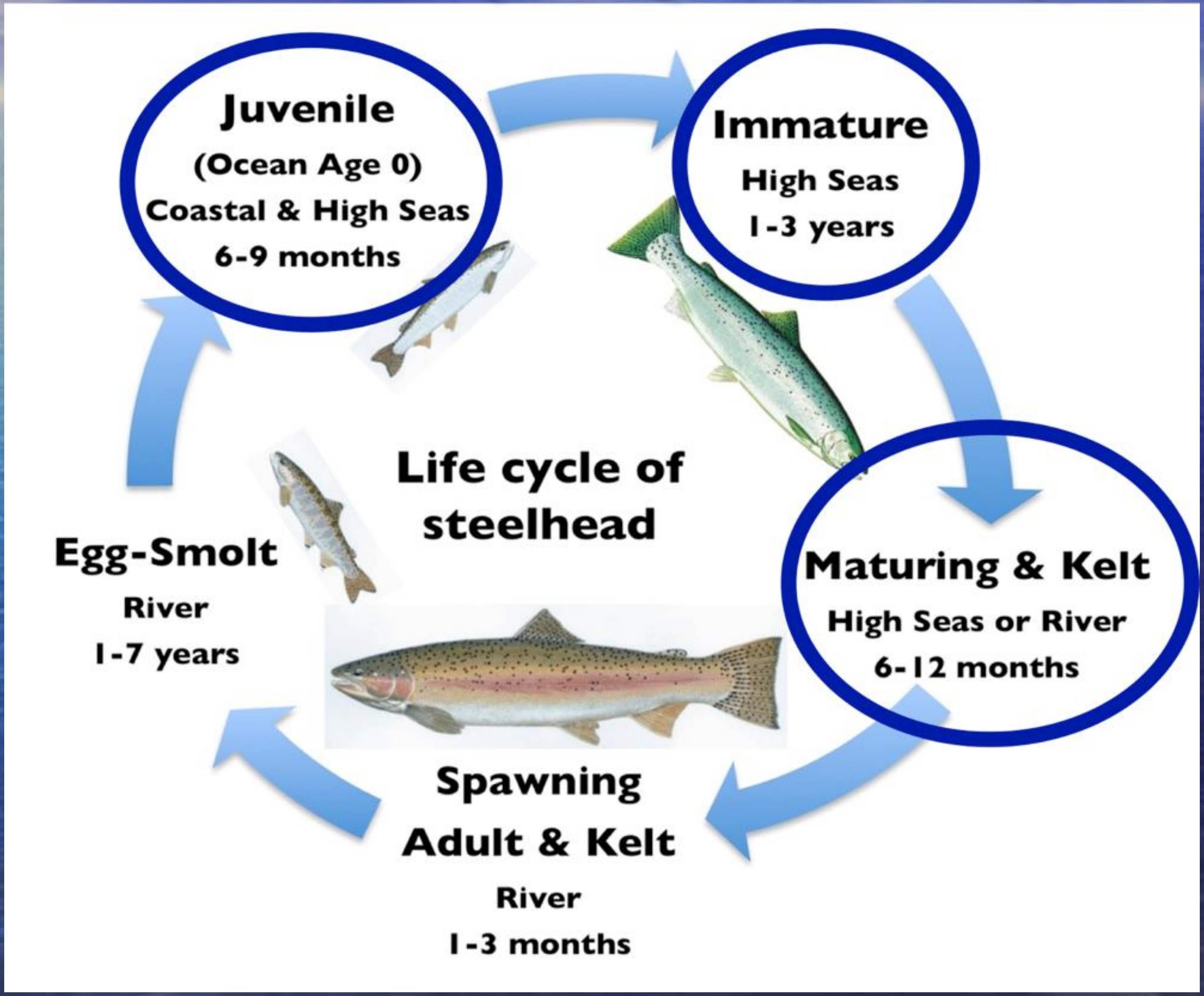
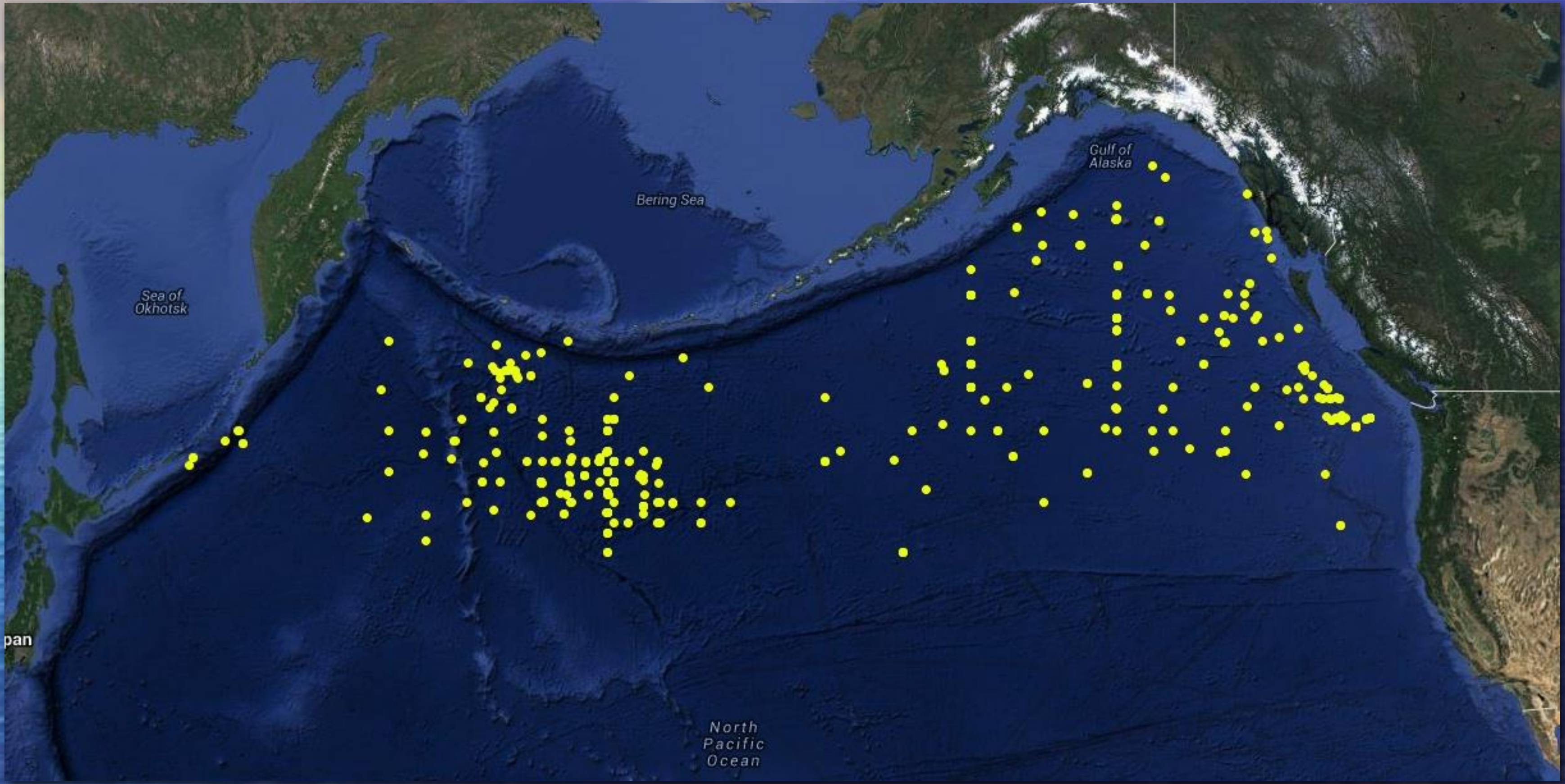
Potential drivers of climate change effects



High seas portion of steelhead life-cycle includes juvenile, immature, maturing, and kelt life-history stages (circled)

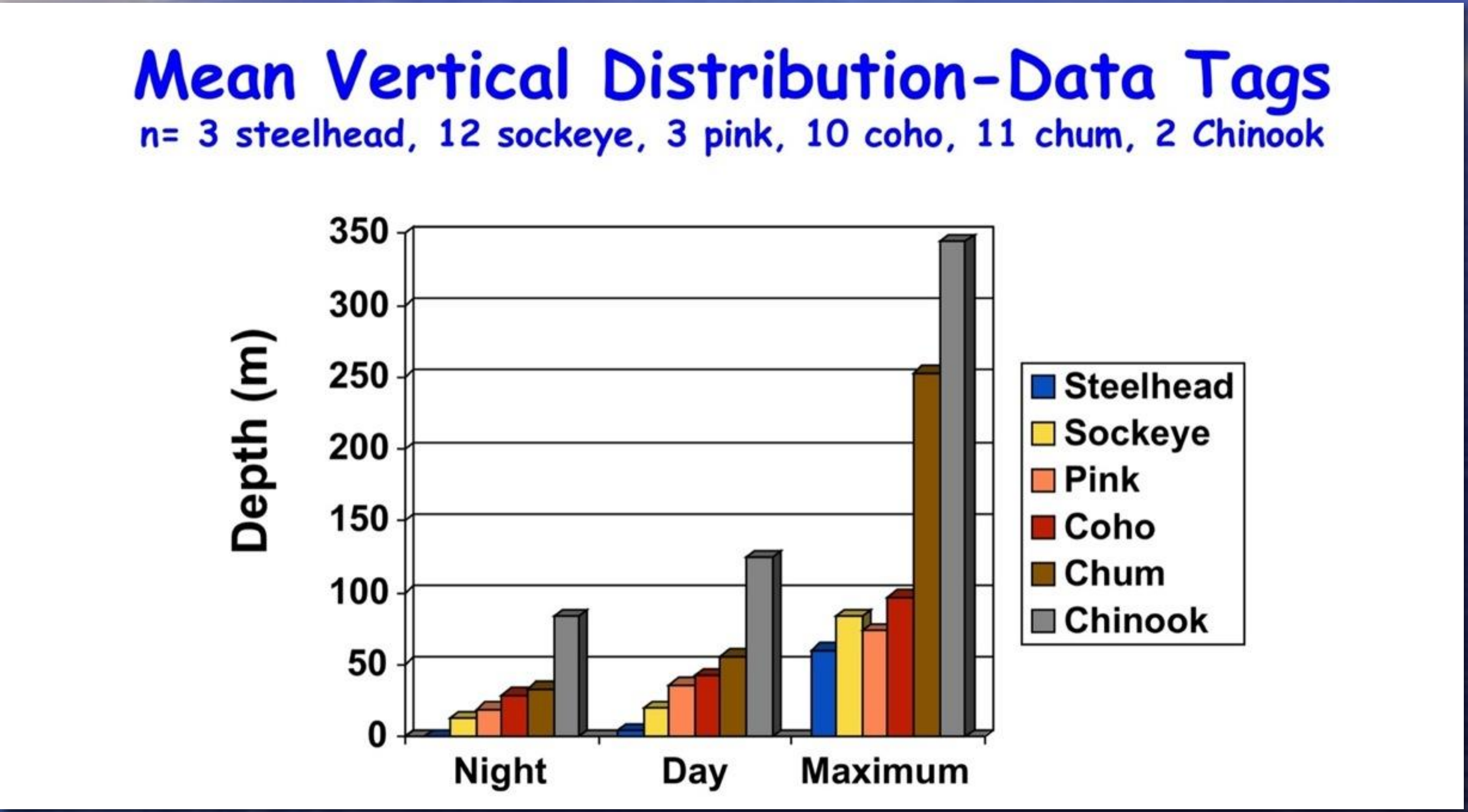


Known distribution of North American steelhead from high seas tag recoveries (yellow dots, n=334, 1954-2013)

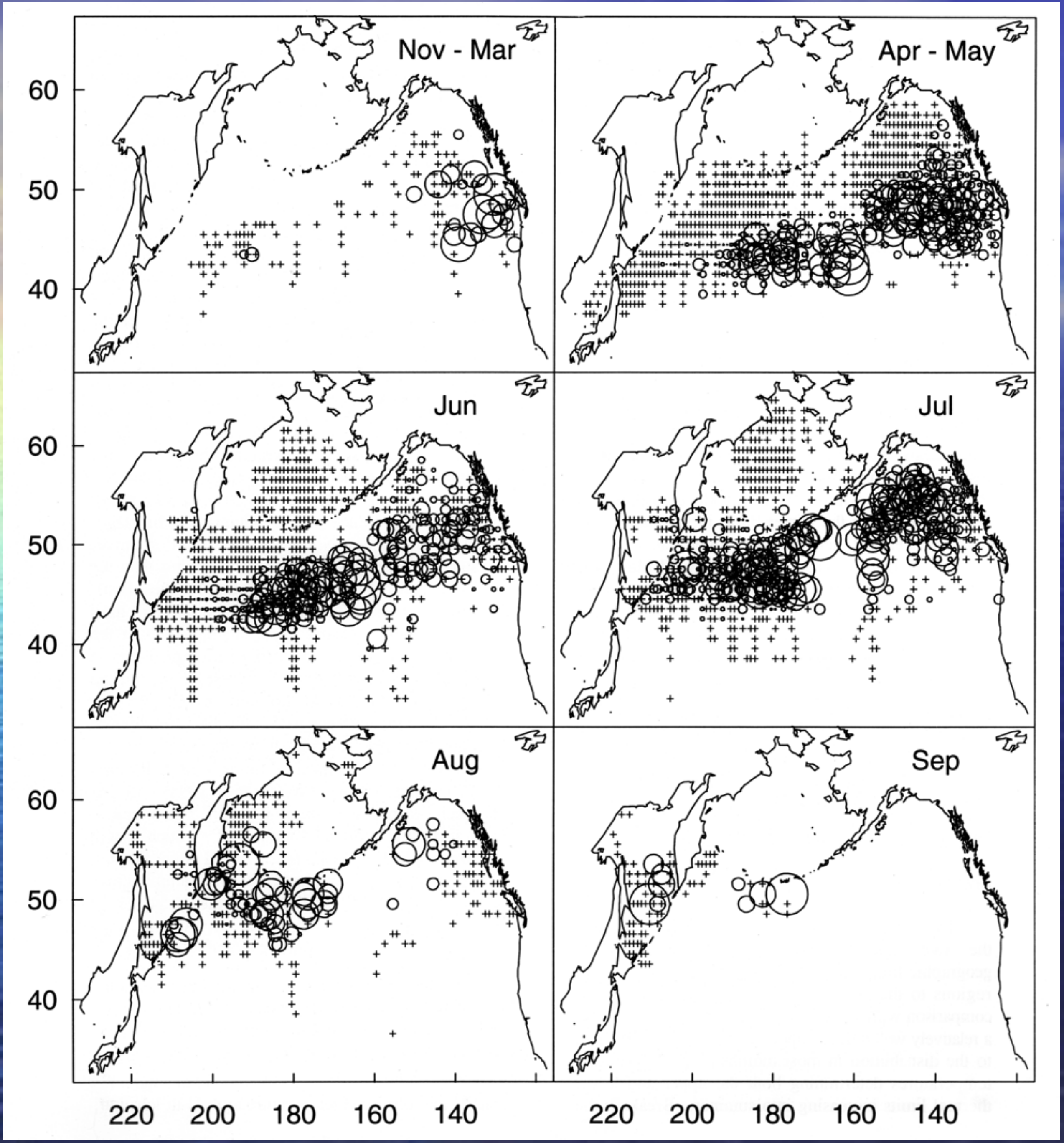


High seas coded-wire tag recovery data available from Pacific States Marine Fisheries Commission, Regional Mark Processing Center; high seas tag recovery data available from North Pacific Anadromous Fish Commission

Sea surface temperature important potential driver of climate change effects because steelhead are distributed at surface



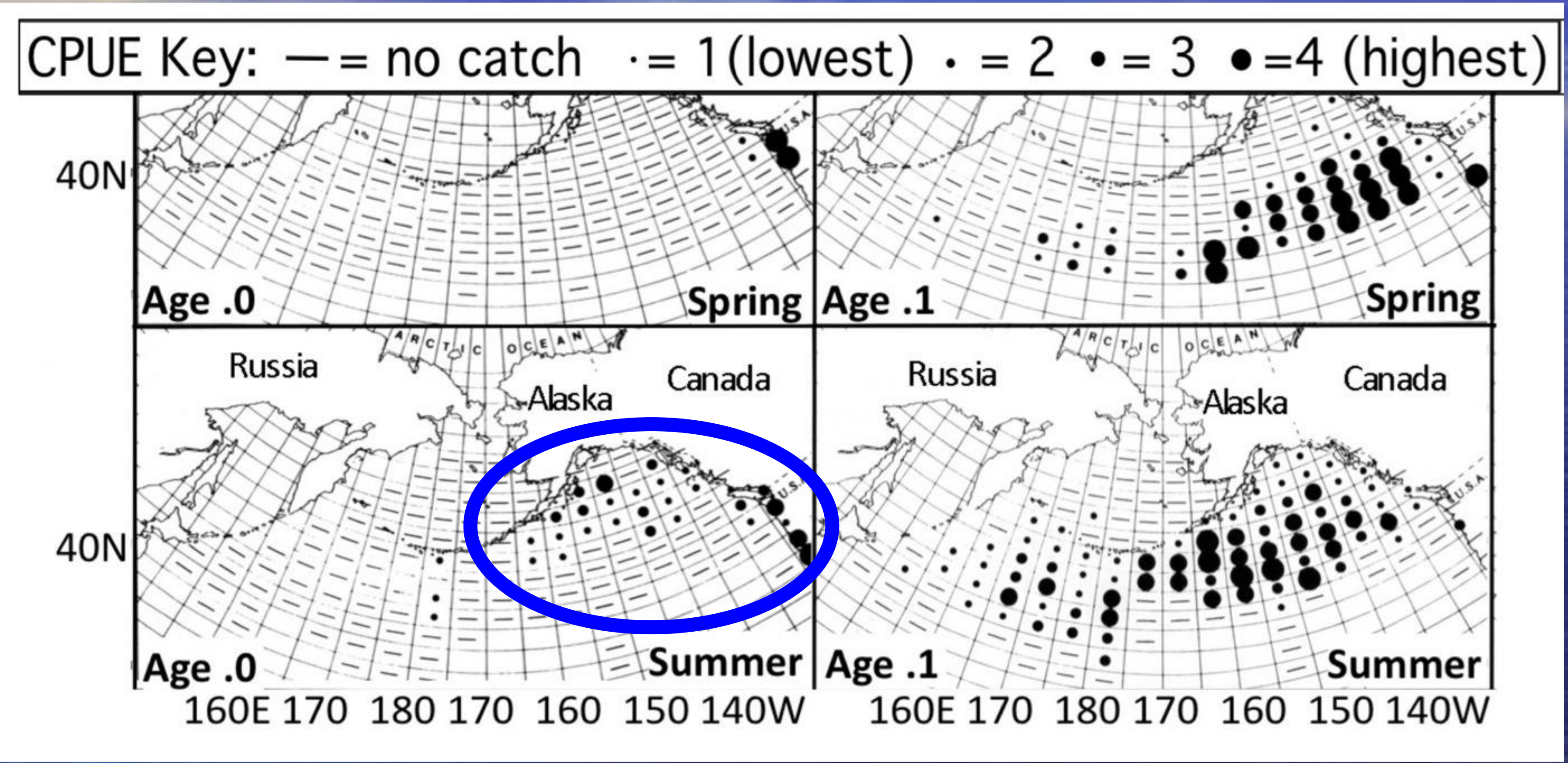
Data from Walker et al. 2000 (Fisheries Oceanography), 2007 (NPAFC Bulletin); Nielson et al. 2011 (CJFAS)



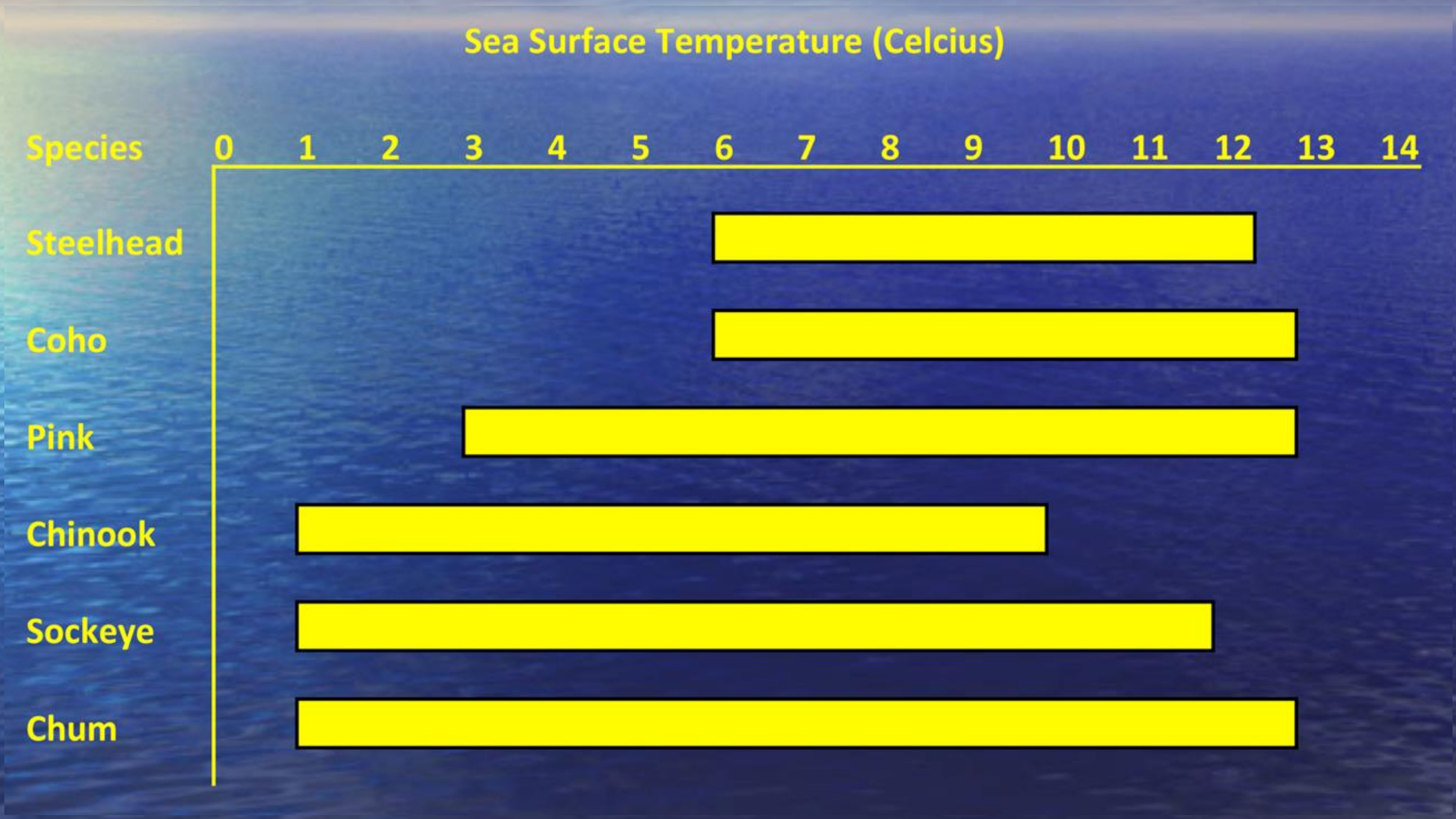
Research vessel survey catch data indicate natural seasonal shifts in horizontal distribution & relative abundance across broad regions in response to temperature

Figure source: Welch et al. 1998

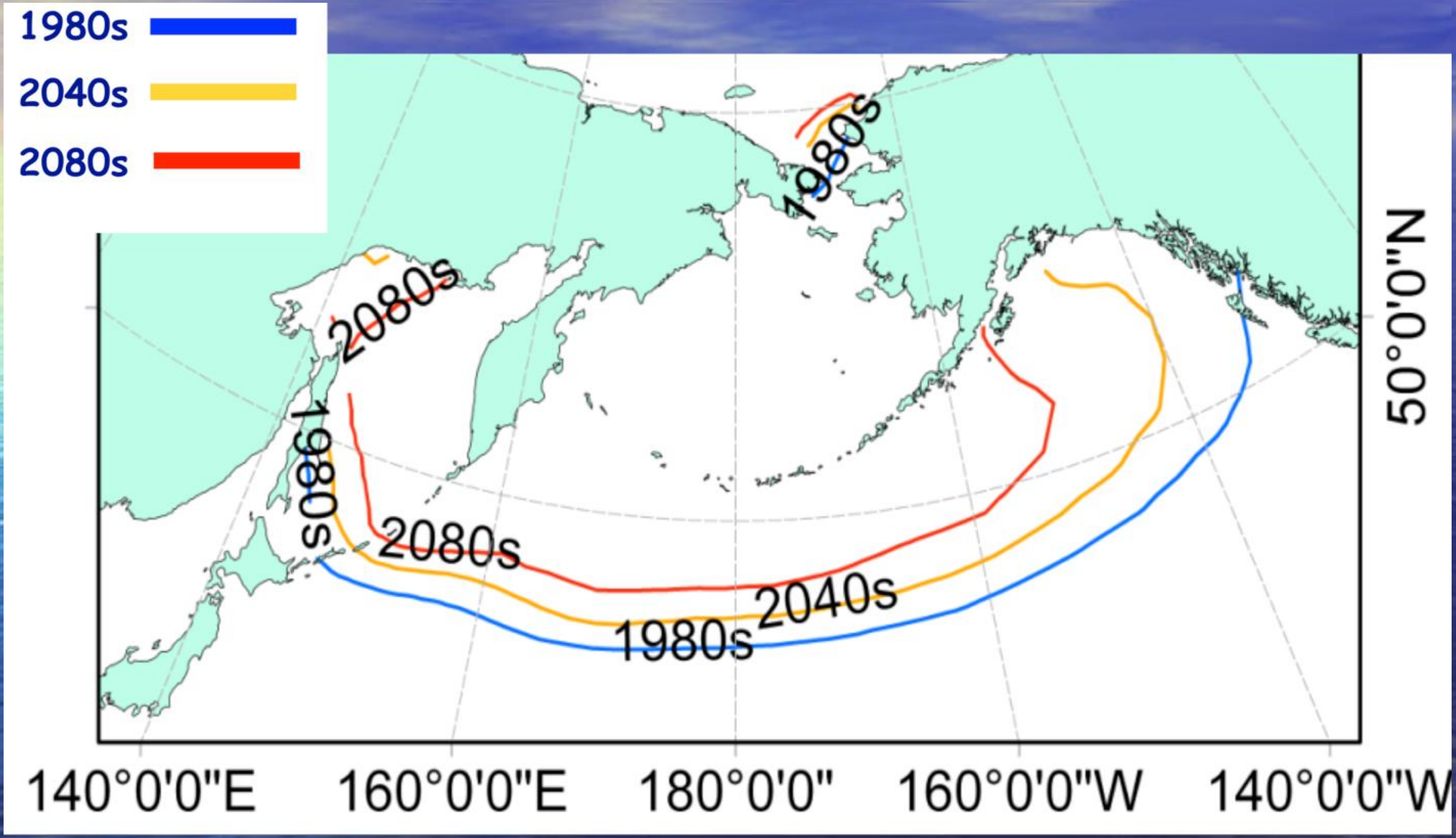
During 1st ocean year N. American juvenile (Age .0) steelhead distributed in Gulf of Alaska (Burgner et al. 1992)



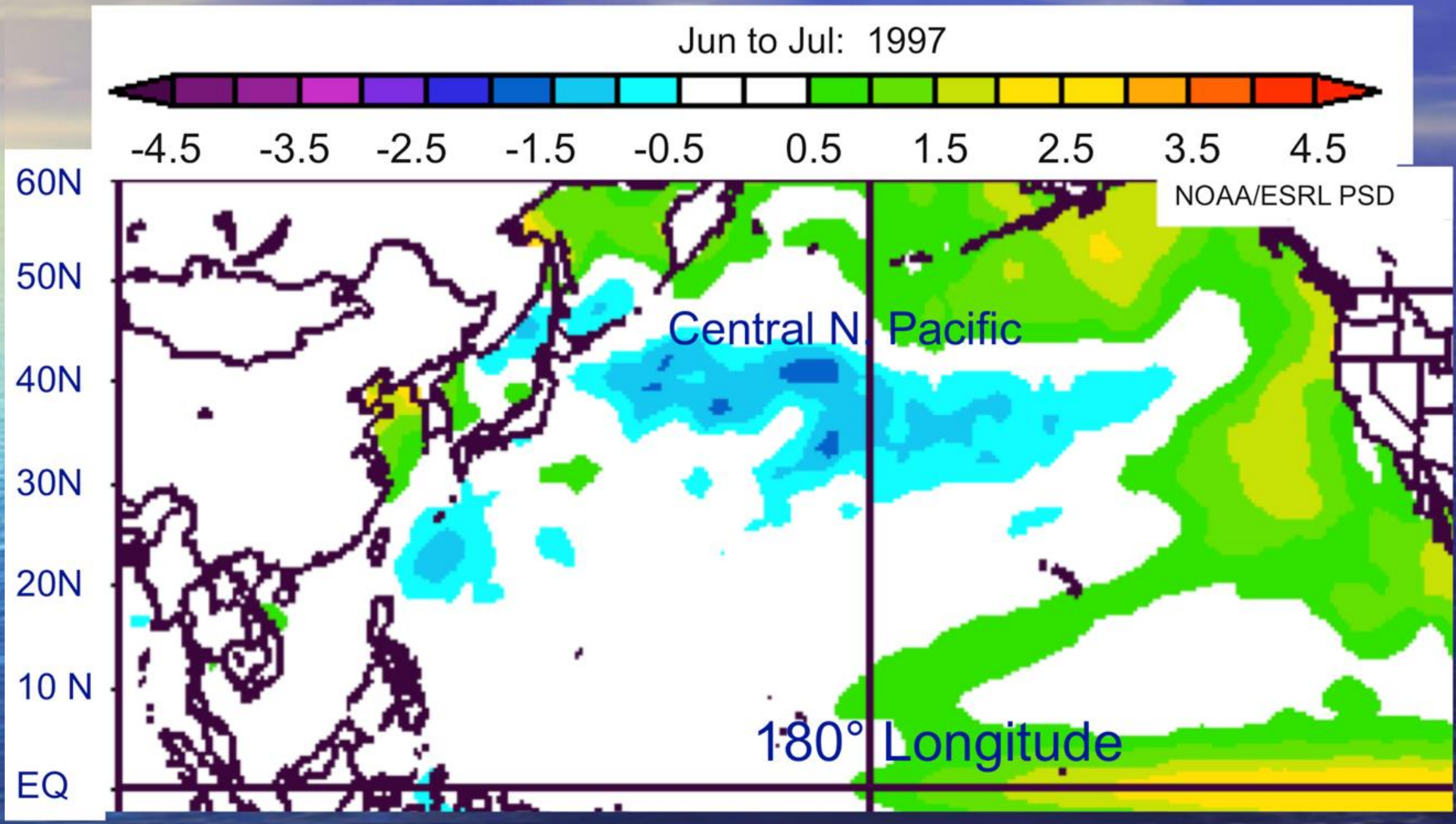
Steelhead most frequently caught at narrow range of spring-fall sea surface temperatures (° C) compared to most other salmon species (Abdul-Aziz et al. 2011)



Summer thermal habitat (6-12.5˚C) shrinks 36% by end of 21st Century (Abdul-Aziz et al. 2011)

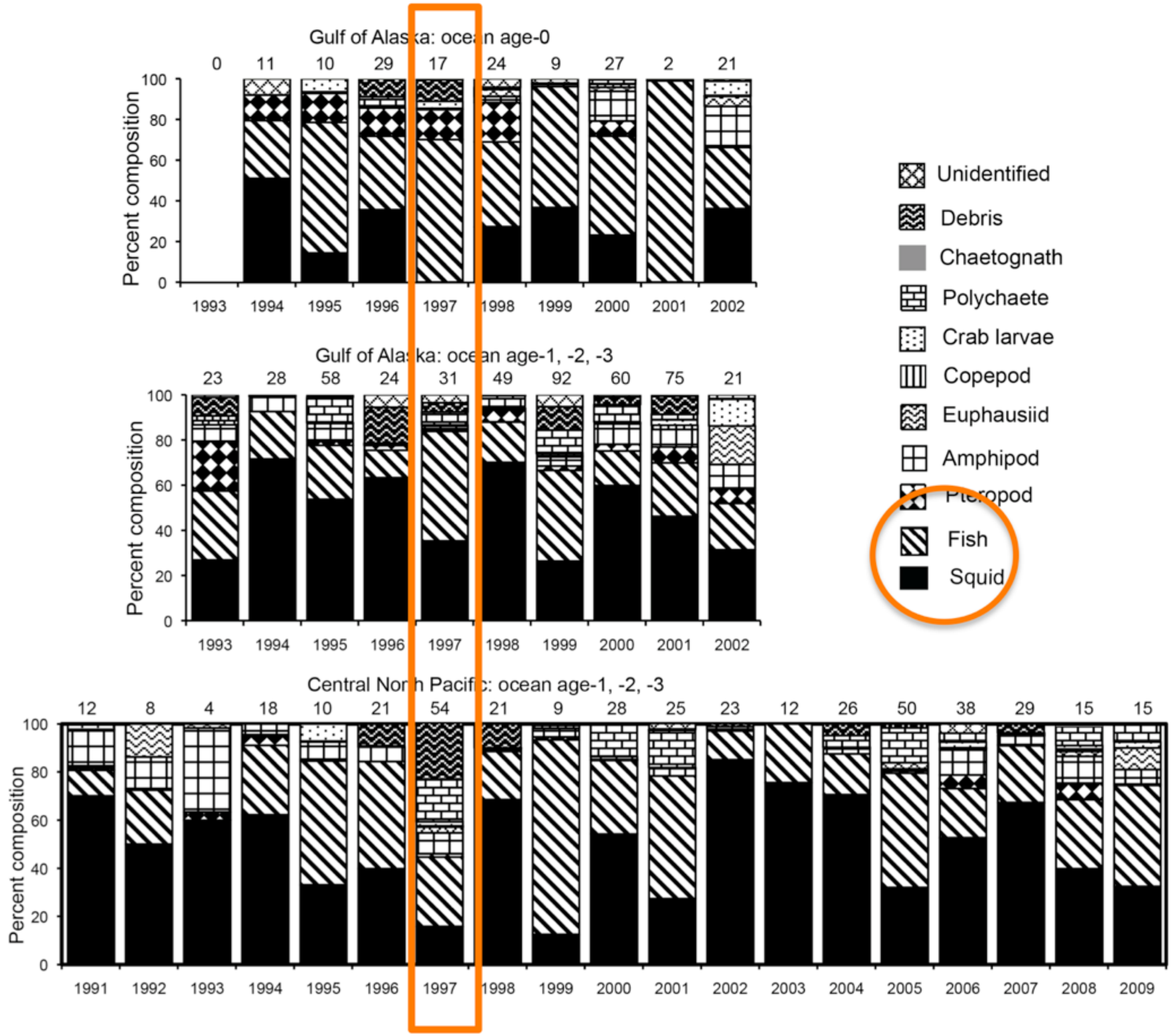


June-July 1997 El Nino SST (˚C) anomaly ~ 2˚ warmer than long-term mean (1981-2010)

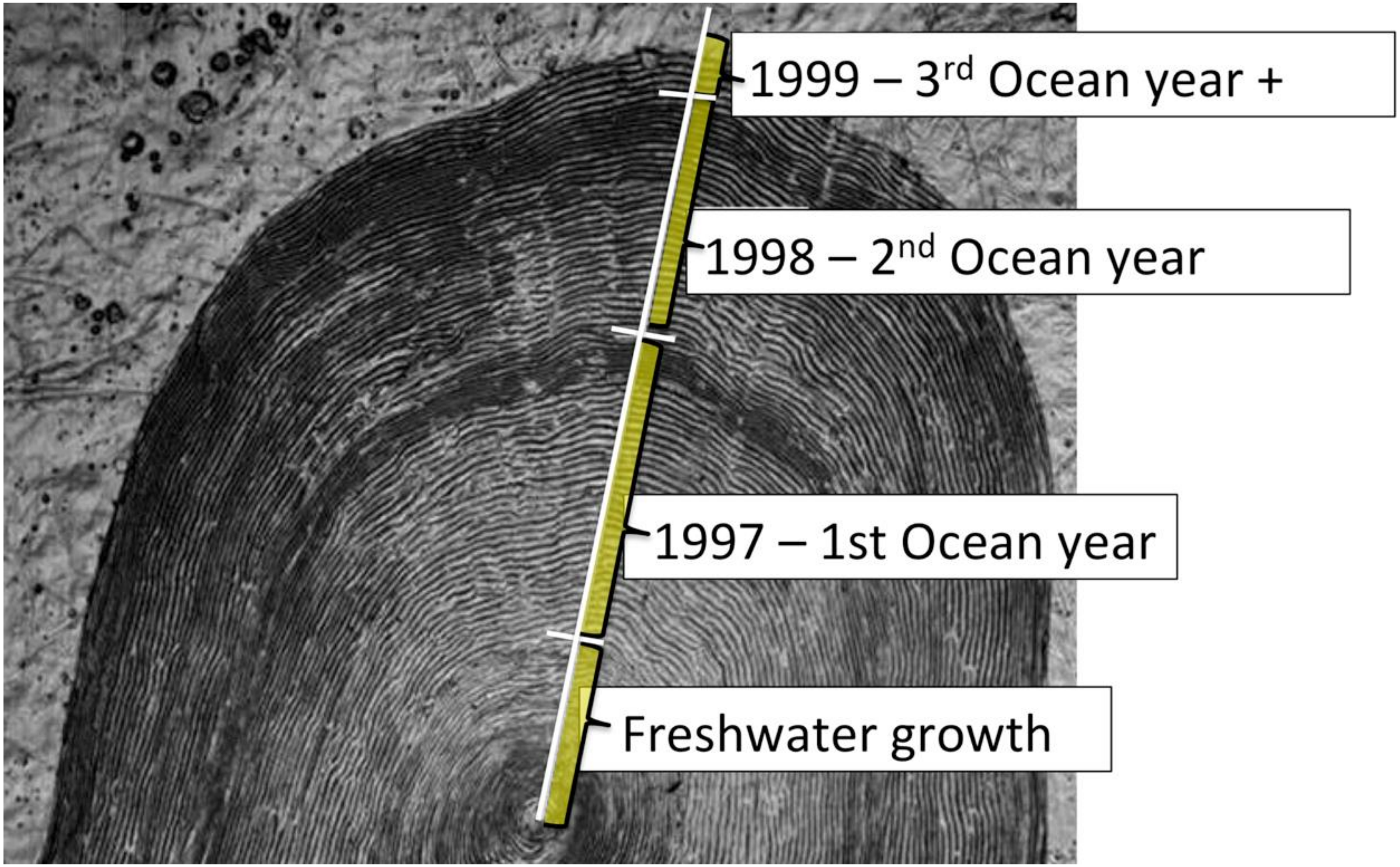


Data source: US Dept. of Commerce, NOAA, Earth System Research Laboratory, Physical Sciences Division, http://www.esrl.noaa.gov/psd/cgi-bin/data/composites/printpage

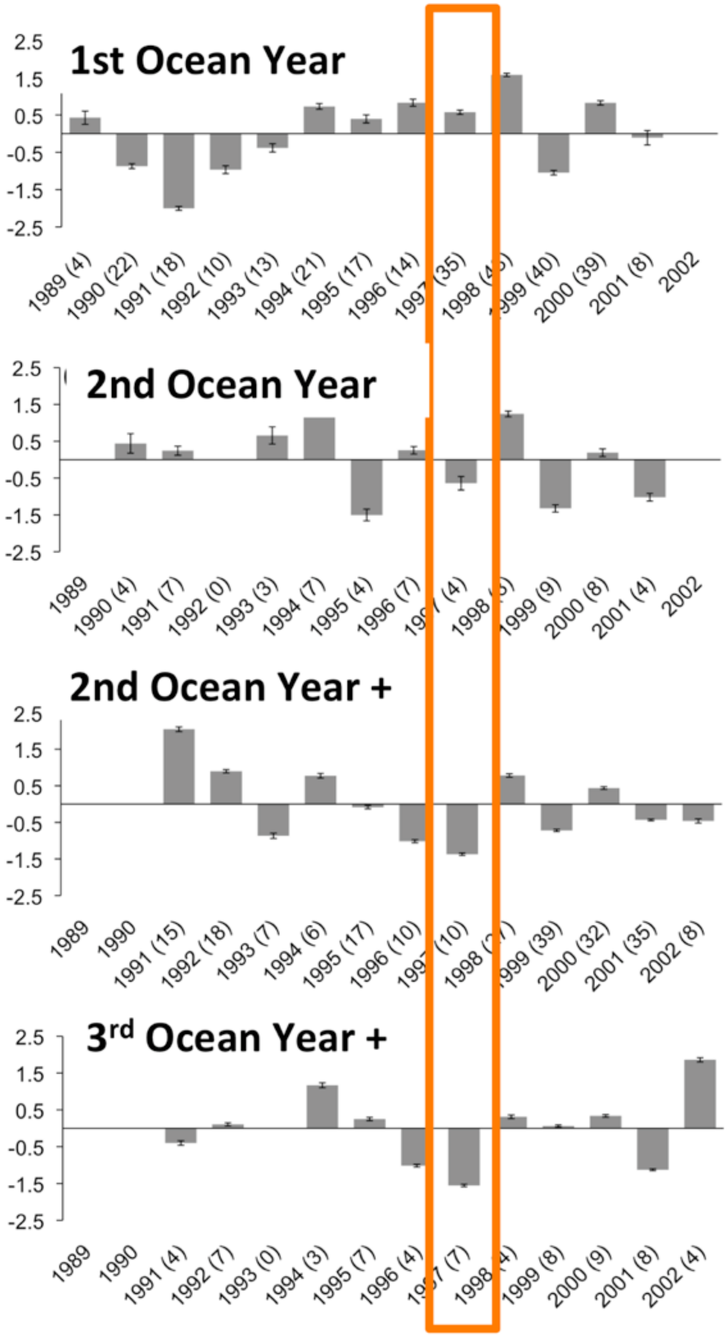
High SSTs (1997 El Niño, orange box) related to decrease in squid in steelhead diets – all age groups and regions (Atcheson et al. 2012a)



Steelhead scales provide a record of ocean growth



Scale of ocean age 2 steelhead caught in Central Subarctic North Pacific Ocean (CNP) in summer 1999 showing measurement axis & annual growth increments

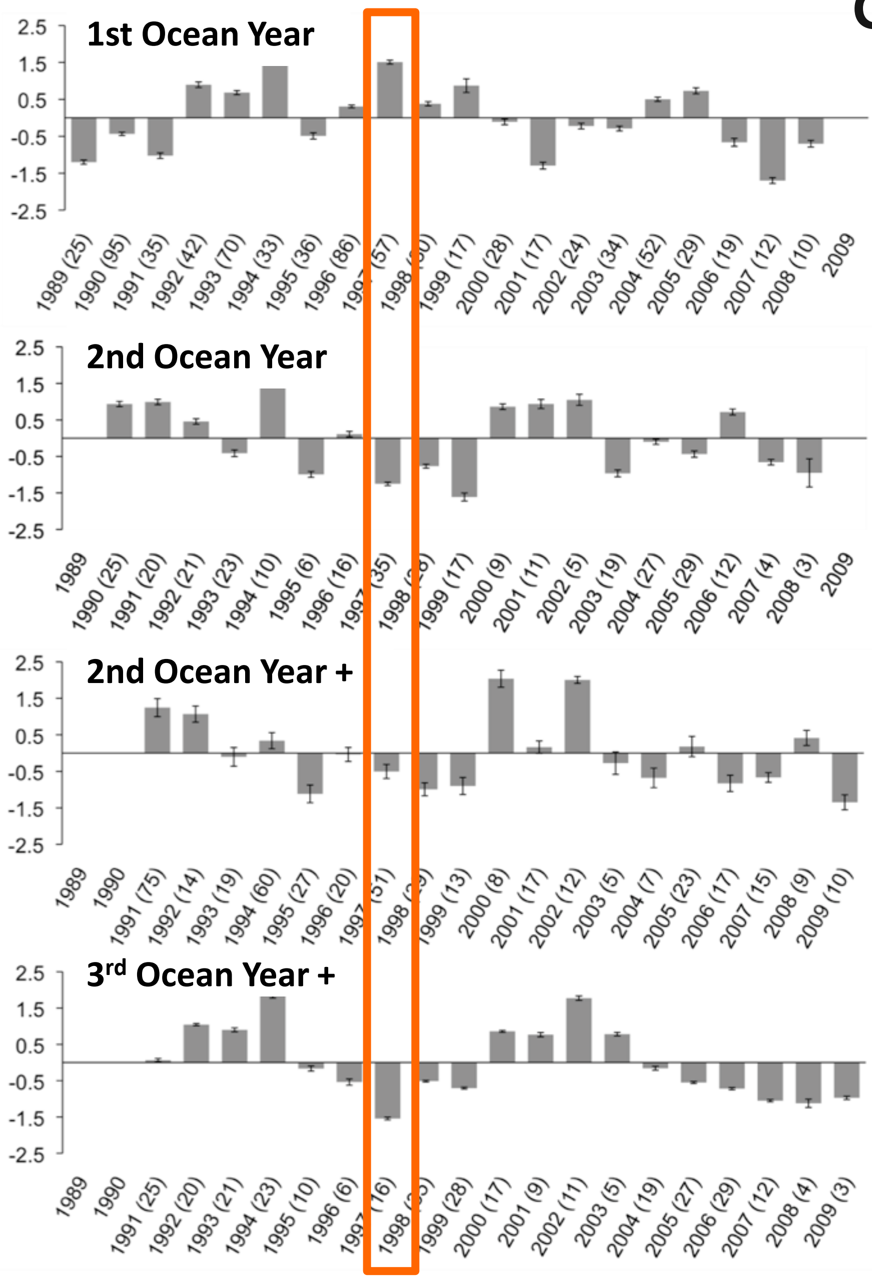


Growth of steelhead caught in Gulf of Alaska

<u>During 1997 El Niño (orange box):</u>

- Above average growth for juveniles (1st ocean year)
- Below average growth for older fish (2nd and 3rd ocean years)

Source: Atcheson et al., unpublished data



Growth of steelhead caught in the Central Subarctic North Pacific

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- Above average growth for juveniles (1st ocean year)
- Below average growth for older fish (2nd and 3rd ocean years)

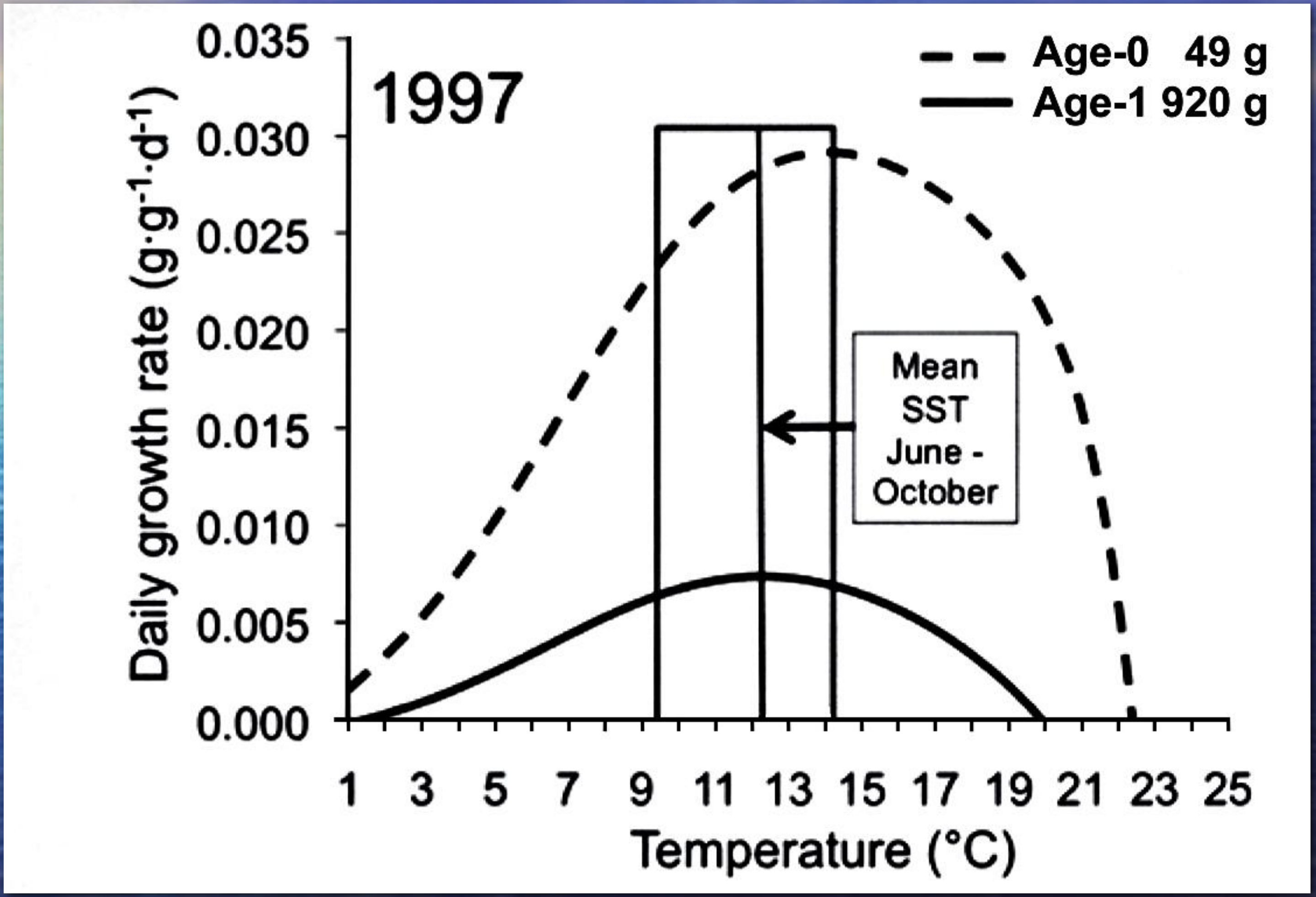
Source: Atcheson et al., unpublished data

Climate and biological (diet & competition) indices correlated with ocean growth of steelhead varied by life history stage & ocean region

Life History Stage	Gulf of Alaska	Central North Pacific
1st ocean year: total annual growth	Diet: + gut fullness + prey quality − prey diversity	Climate: + Winter SST − Summer NOI
2nd ocean year: plus growth	Diet: + prey quality + squid abundance	Diet & Competition: − Empty − EKam pink salmon
2nd ocean year: Plus growth & total annual growth	Climate: + winter SST + summer sea level pressure	Diet & Competition: − Empty − EKam pink salmon
3rd ocean year: plus growth	None	Climate & Diet: − Winter SST + Squid abundance

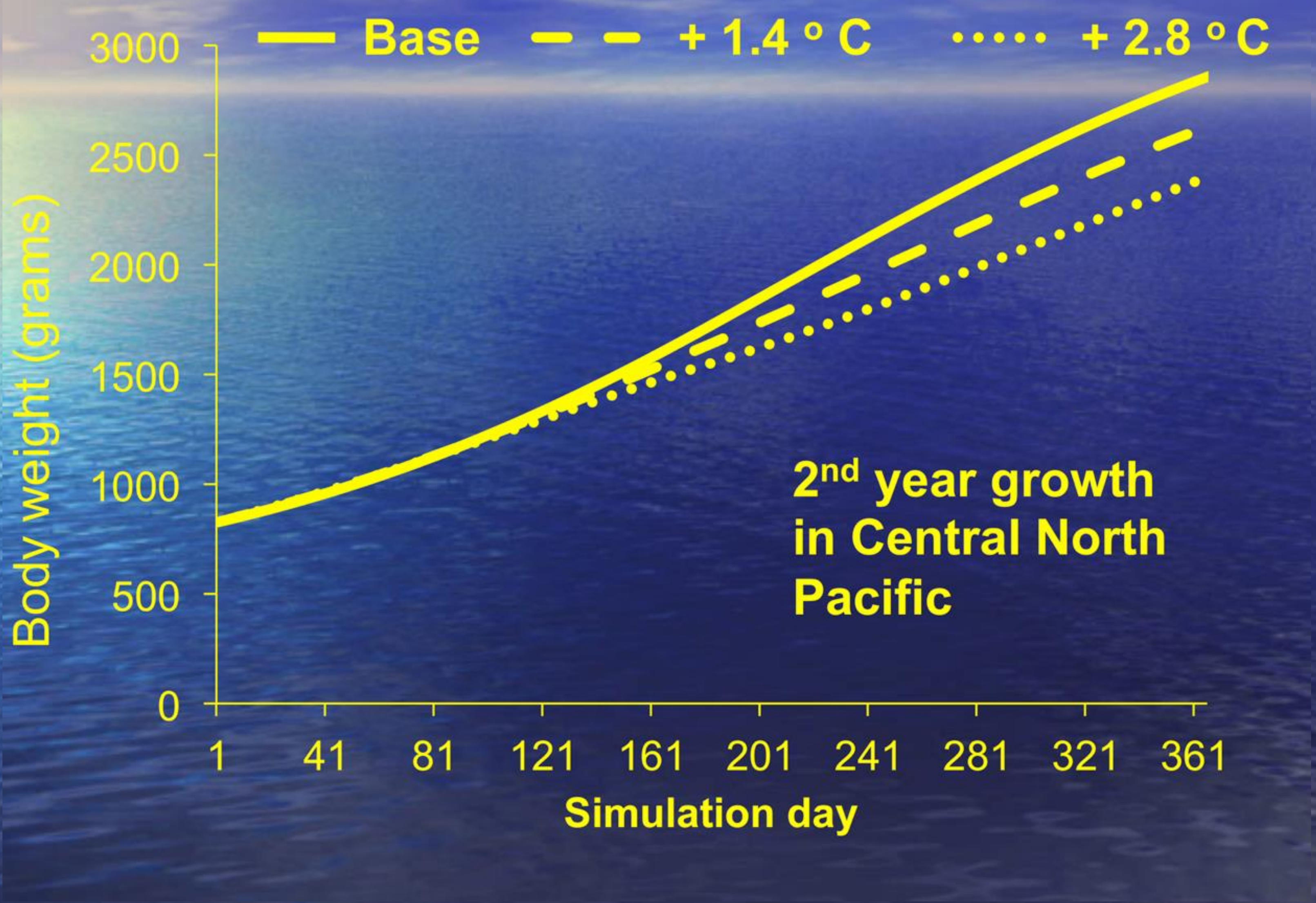
Source: Atcheson et al. unpublished data

Mean SSTs in 1997 were below optimum growth temperature (~14˚ C) for juveniles (Age-0) and optimum (~12˚) for older (Age-1) fish

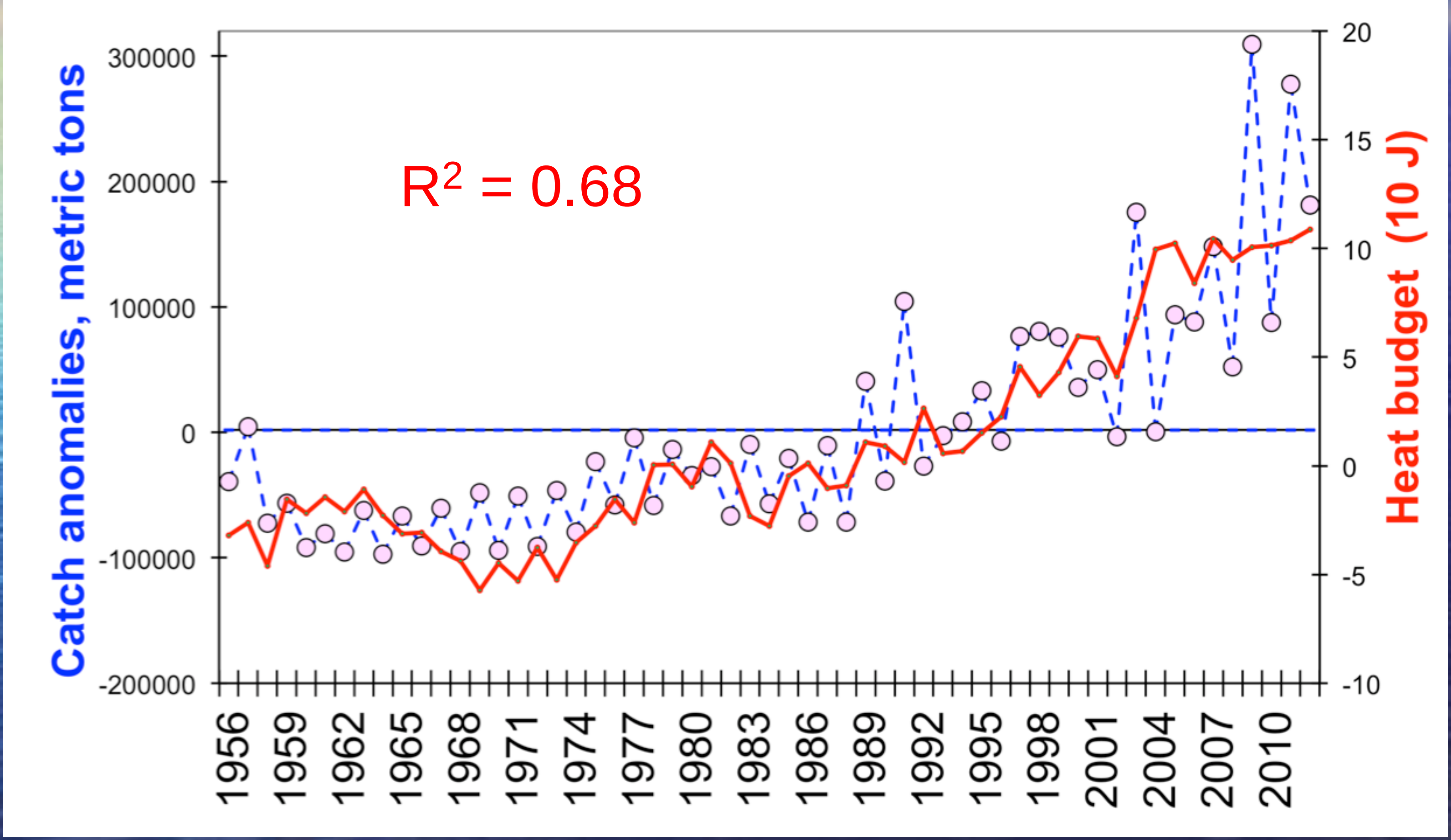


Source: Atcheson et al. 2012b

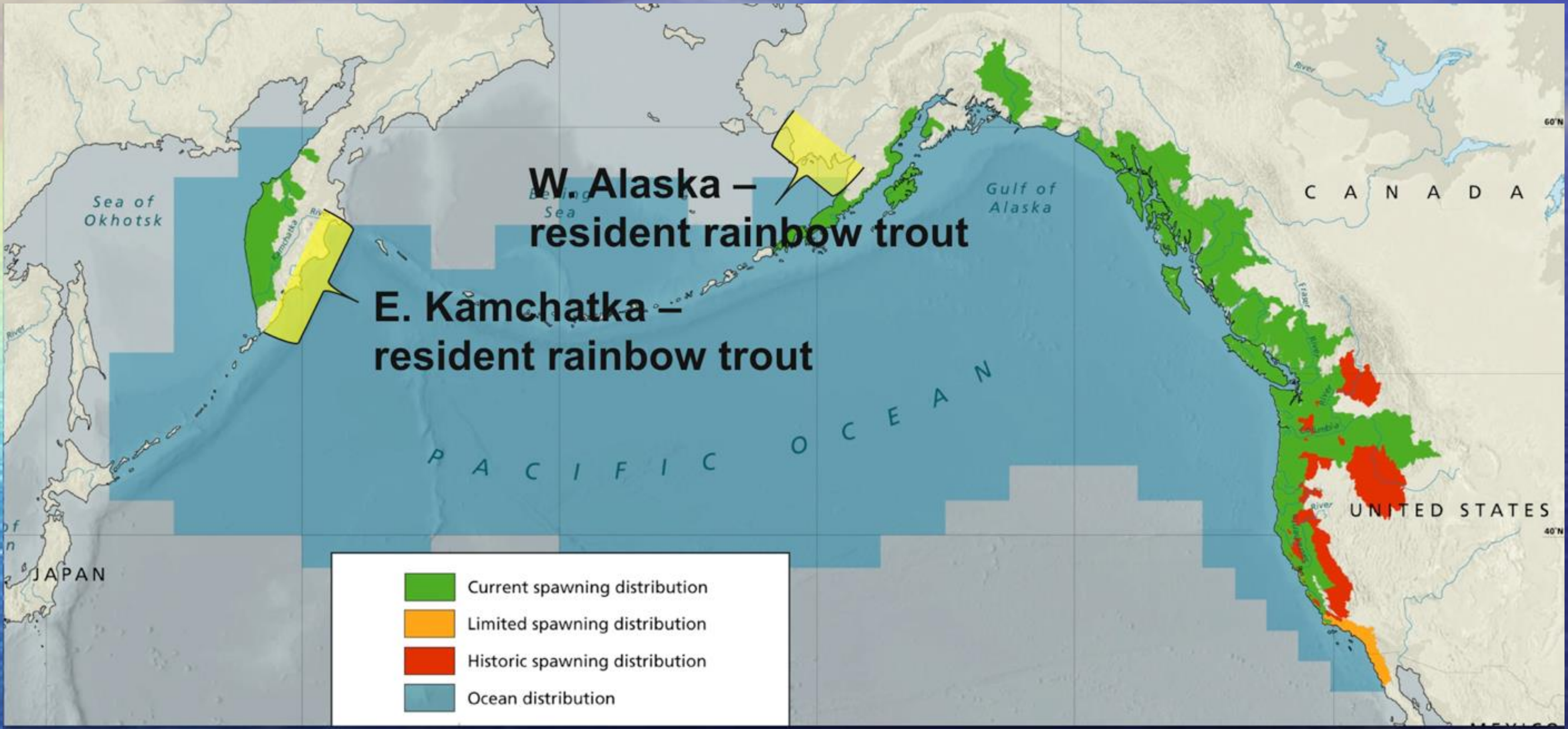
Simulated growth potential under future sea surface temperature scenarios shows reduced steelhead growth as temperatures warm (Atcheson et al. 2012b)



Relationship between world ocean heat content (0-700 m layer, red line, Levitus et al. 2012) and Russian pink salmon catch anomalies (blue dashed line, 1956-2012) Source: V. Radchenko, Pers. Comm.



How will future climate change affect geographic distribution of steelhead in ocean and freshwater?

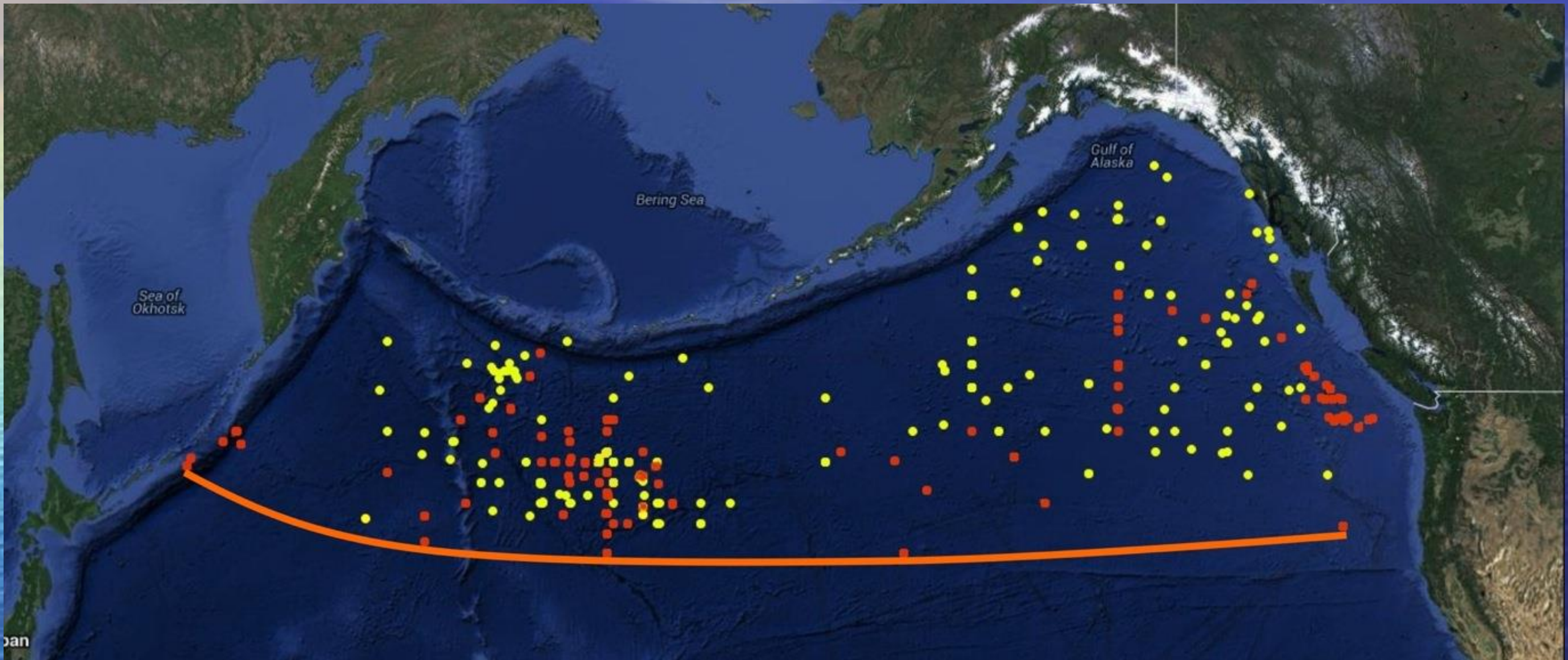


Map Source: Inforain.com/Ecotrust, Map by: Charles Steinback, Andrew Fuller, Created: December 15, 2004. Atlas of Pacific Salmon: The First Map-based Status Assessment of Salmon in the North Pacific.

Summary of potential effects

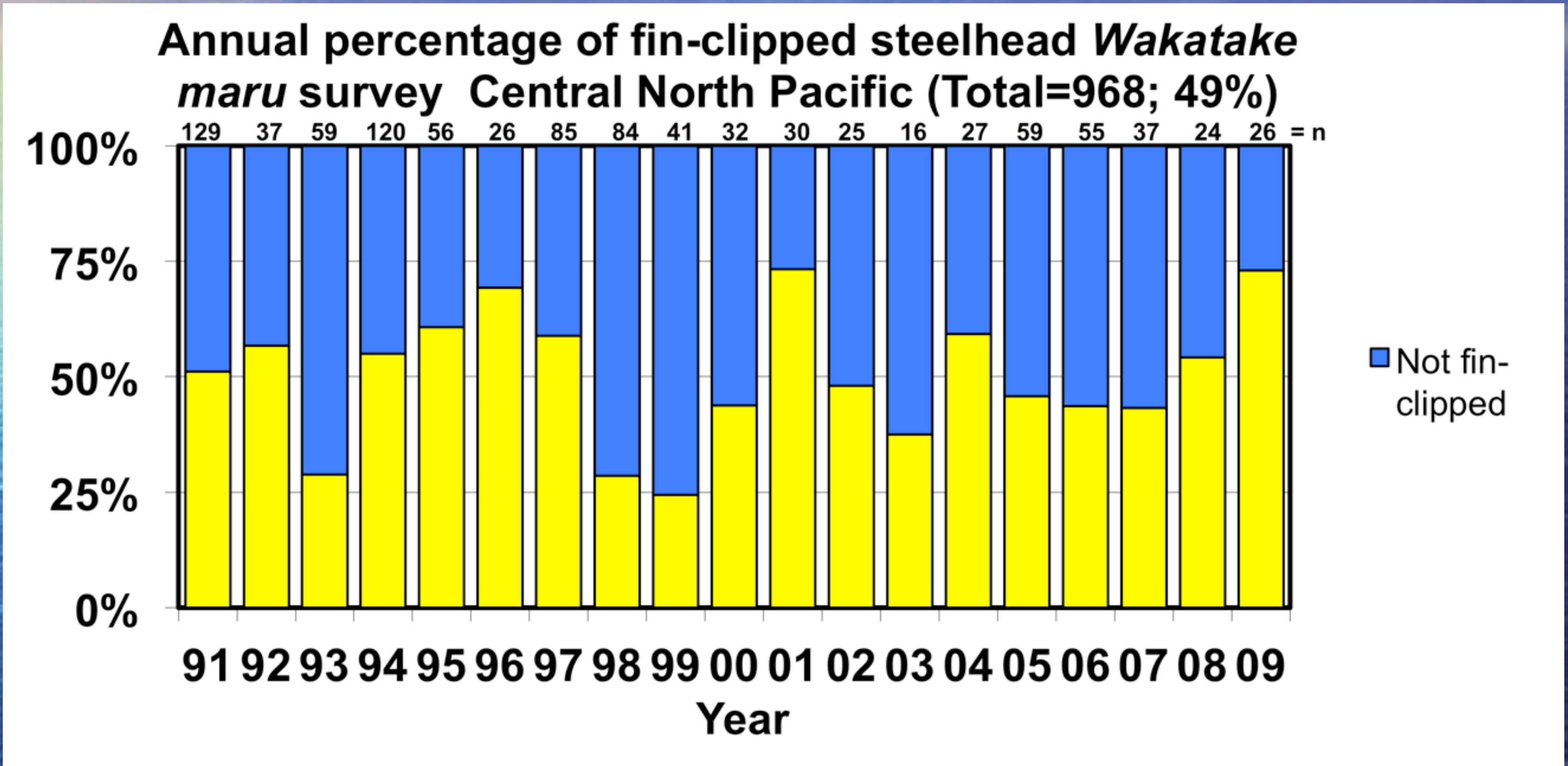
- Decrease in thermal habitat
- Decrease in preferred prey (squid)
- Increase in competition (pink salmon)
- Decrease in growth

Topics for future evaluations of climate change effects: <u>Population-specific responses</u>



Snake River Basin Steelhead (orange dots) are distributed at the southern limit (orange line) of known high seas distribution of North American steelhead

Topics for future evaluations of climate change effects: Hatchery-wild steelhead interactions



Topics for future evaluations of climate change effects: Ocean acidification

Gonatid squid (*Berryteuthis anonychus*) in steelhead stomach (photo by Trey Walker)

Ocean acidifiation may affect the distribution, growth, and abundance of key steelhead prey such as gonatid squid.

Topics for future evaluations of climate change effects : Marine pollution

Plastic marine debris from steelhead stomach (photo by Nancy Davis)

During 1997 El Niño event steelhead ate fewer squid and more marine debris including plastic (Atcheson et al. 2012a)

Potential effects on steelhead, habitat, progeny

- **Mechanical injury, starvation, toxicity**
- **Biomagnification & bioaccumulation of toxic chemicals**
- **Transgenerational epigenetic effects on physiology & behavior**

Acknowledgements for high seas steelhead research

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