Pacific salmon and steelhead: life in a changing winter ocean

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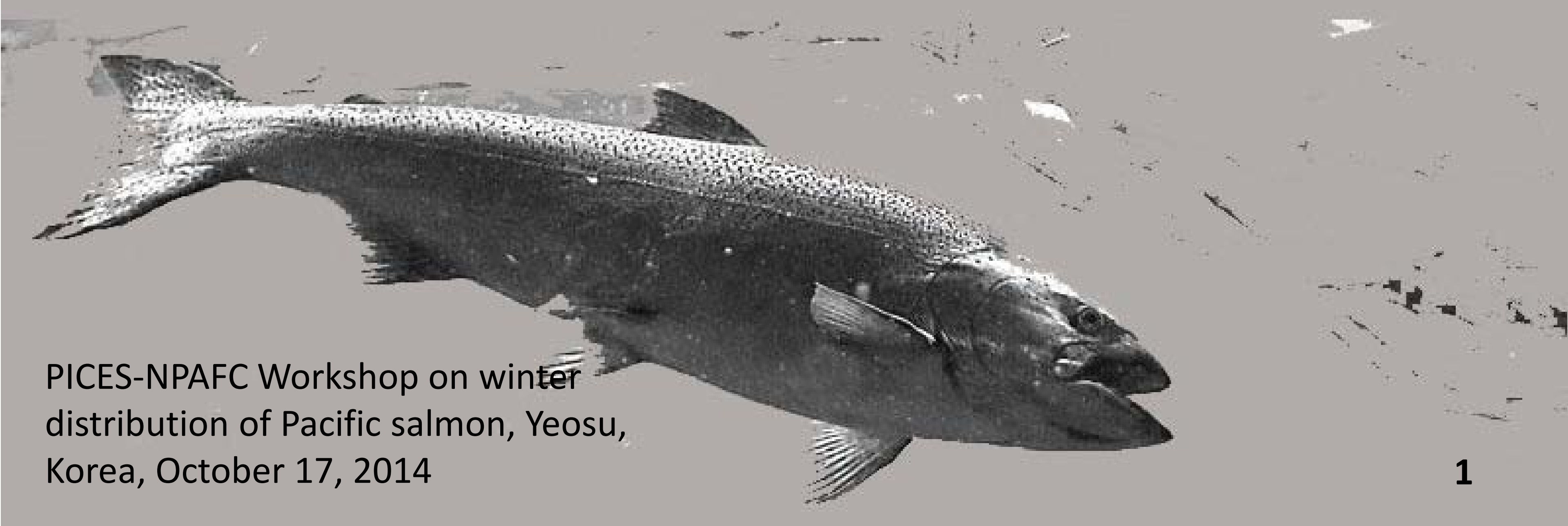


PICES-NPAFC Workshop on winter distribution of Pacific salmon, Yeosu, Korea, October 17, 2014

Where do salmon go in winter? Why? How might this be affected by climate change?

High seas salmon winter research timeline

USA, 1963-1964
Gillnet & Longline

Japan, 1998
trawl

Bering Sea

1950s	1960s	1970s	1980s	1990s	2000s	2010s

North Pacific

Russia (1958/ 1963-65) Gillnet

USA (1962-65/67/69-71) Canada (1963-65), Japan (1967-74) Gillnet & Longline

Russia (1986-92) Trawl

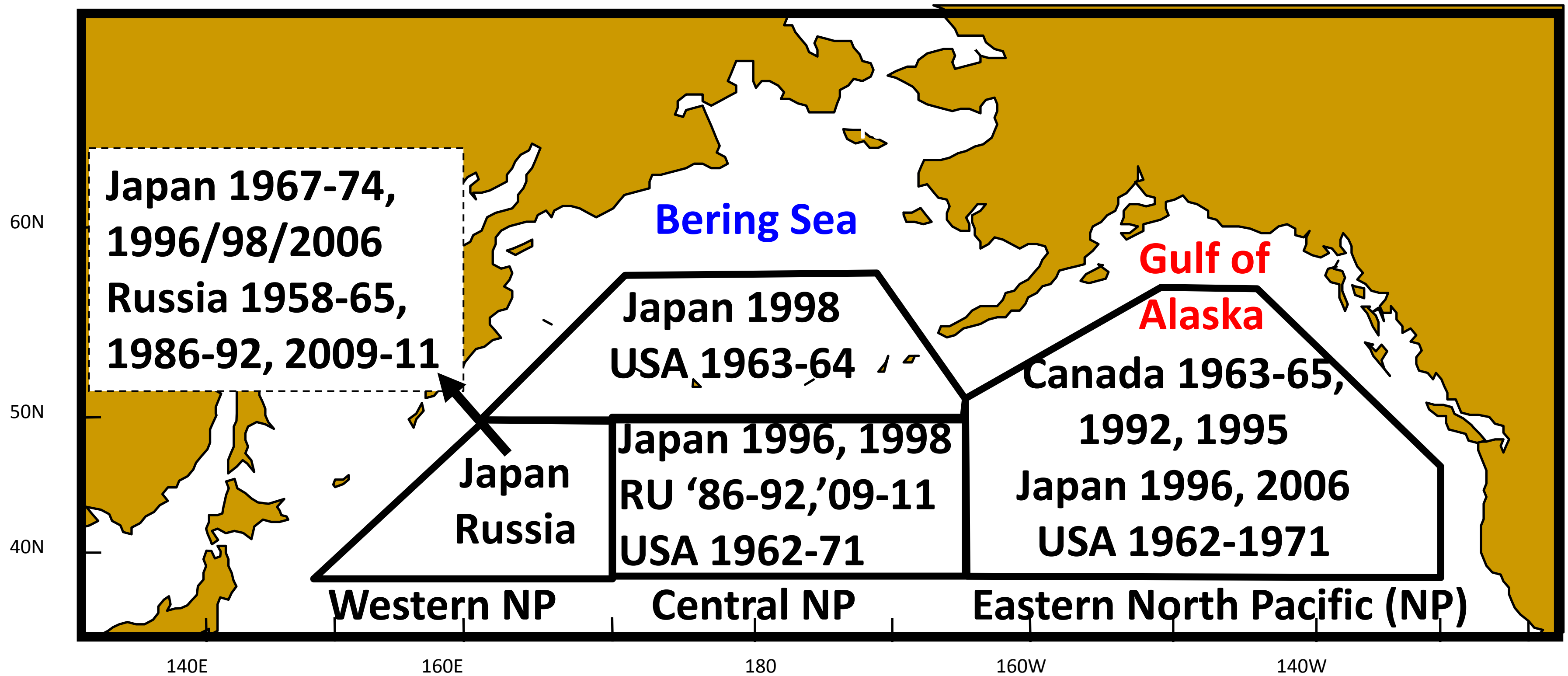
Japan (1992/96/98) Canada (1992/95) Trawl

Japan (2006) Trawl

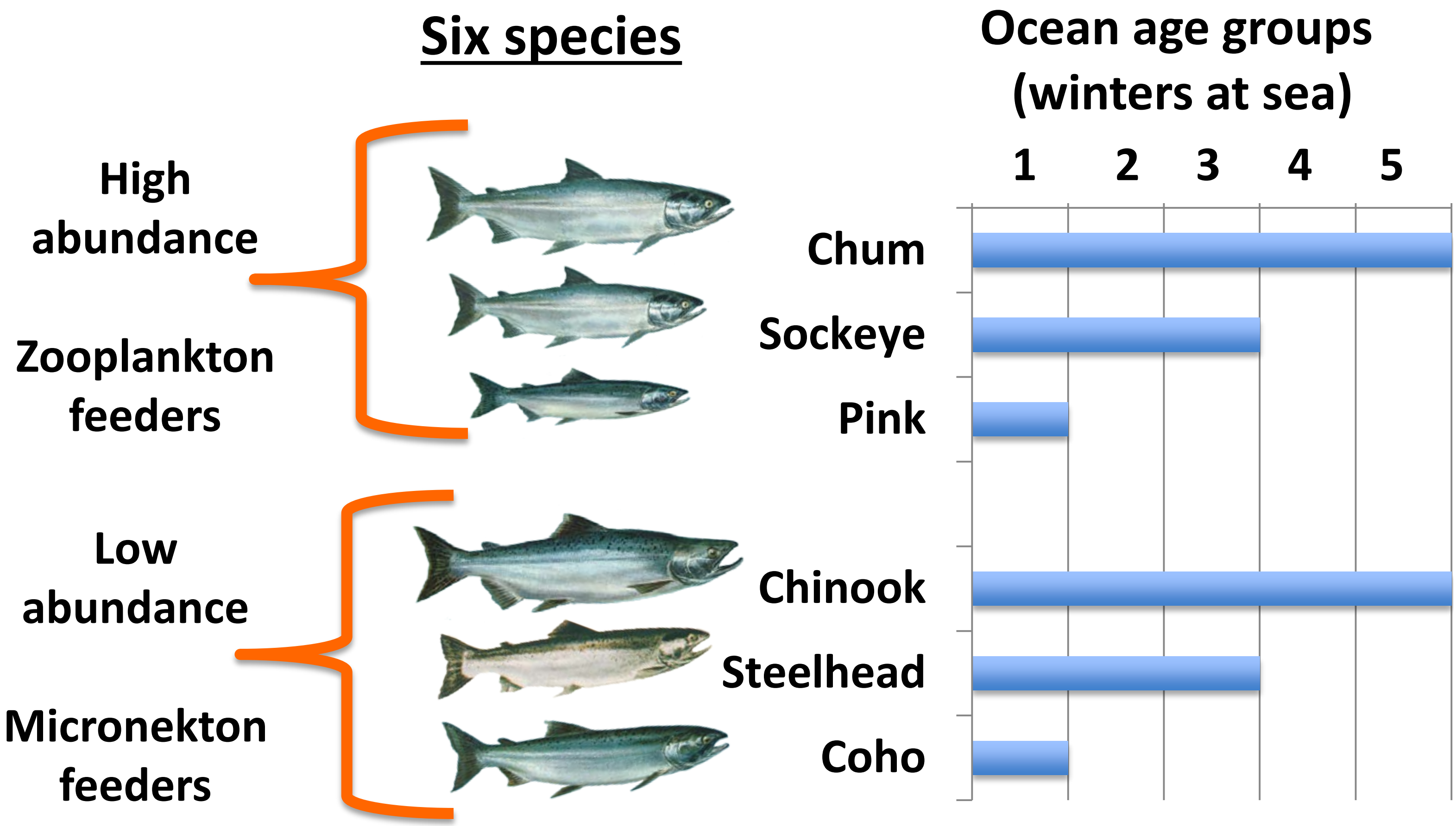
Russia (2009-11) Trawl

Bertha Ann

General Locations of High-Seas Salmon Winter Research



General high-seas salmon winter life history

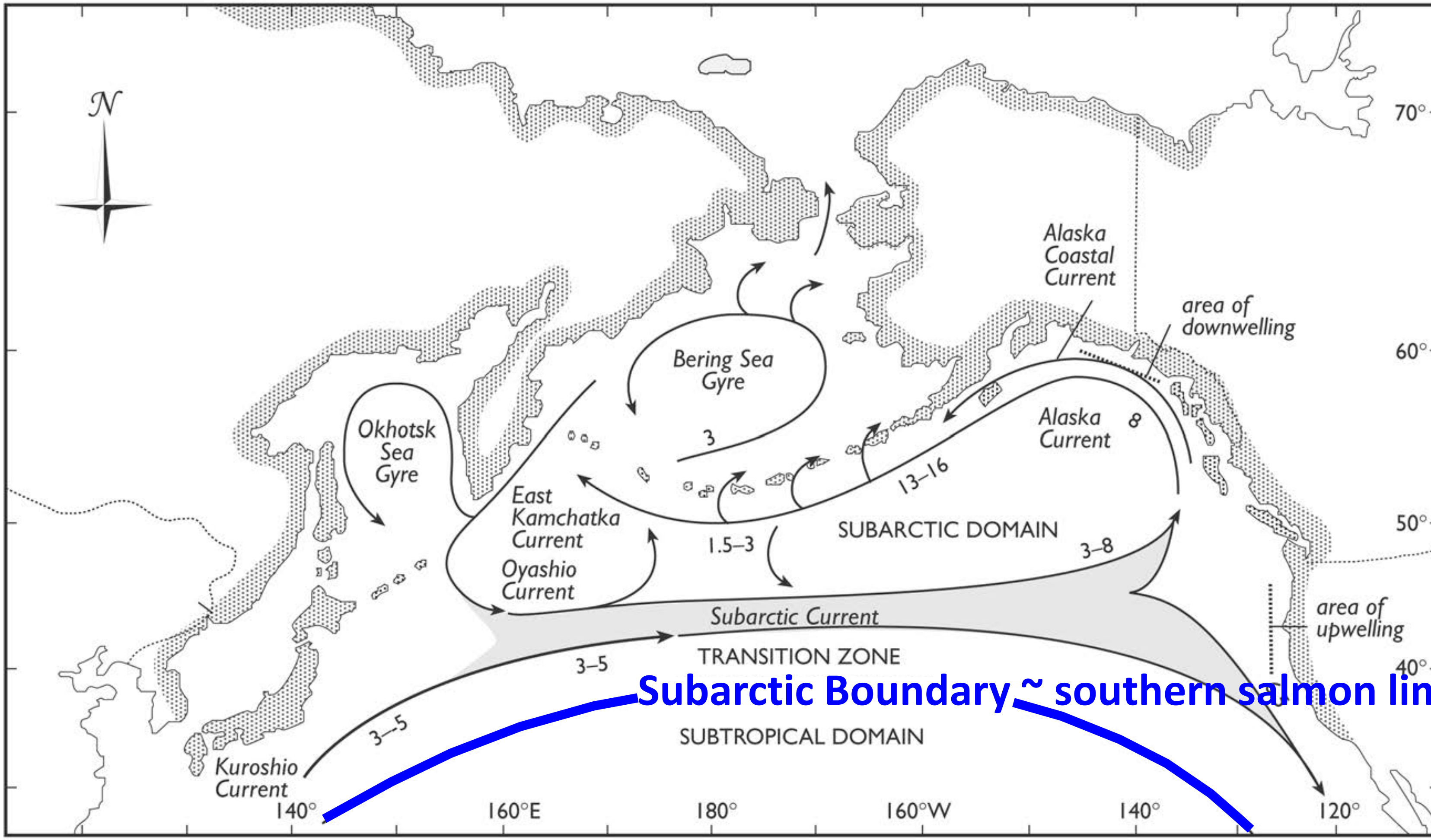


Historical Winter Research-1950s-1970s

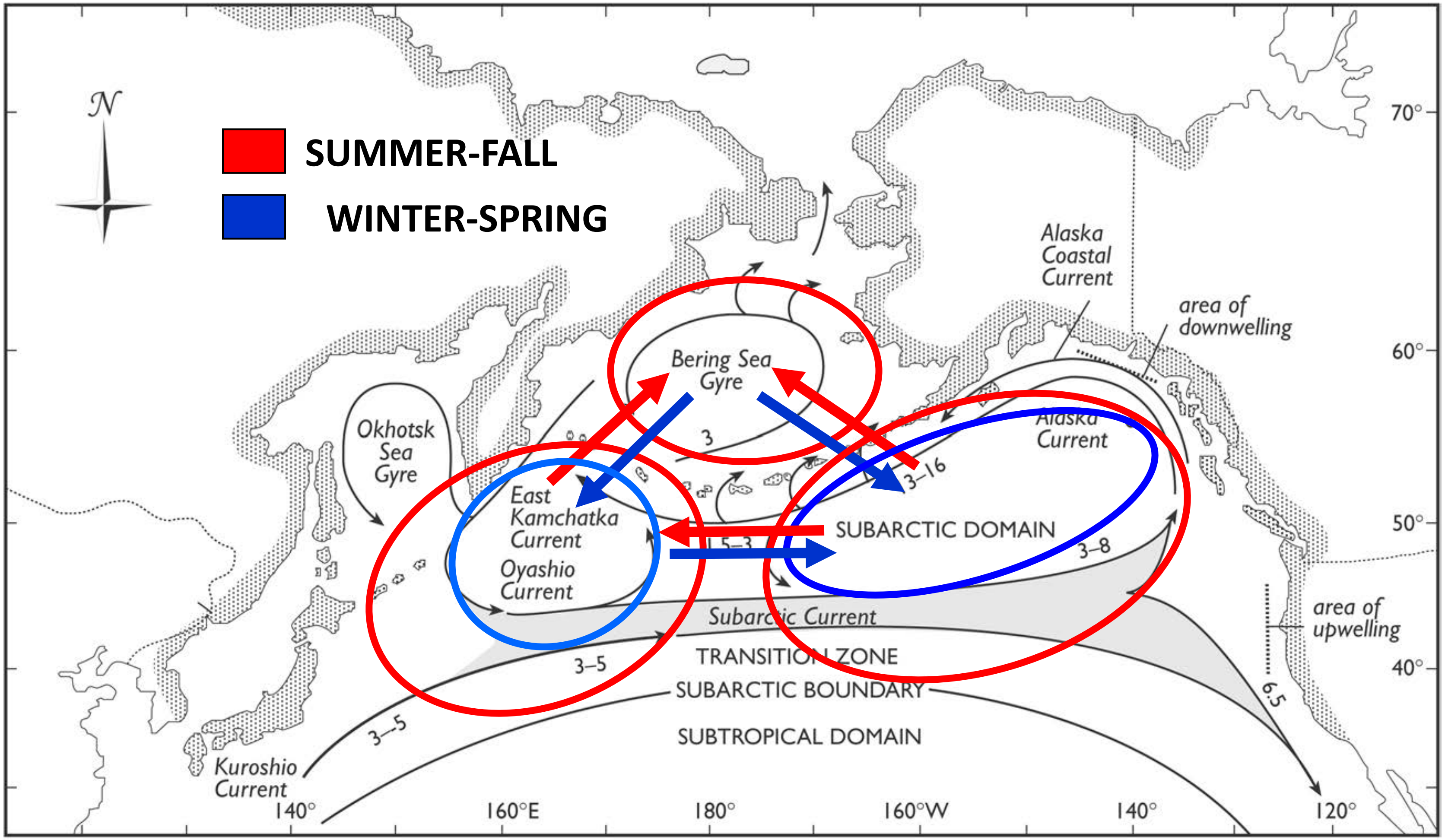
- Determined major oceanographic features
- Discovered seasonal movement patterns
- Established ‘stock concept’ of distribution

Major ocean currents & water masses

Map Source: Quinn (2005) - redrawn from Favorite et al. 1976 and others)

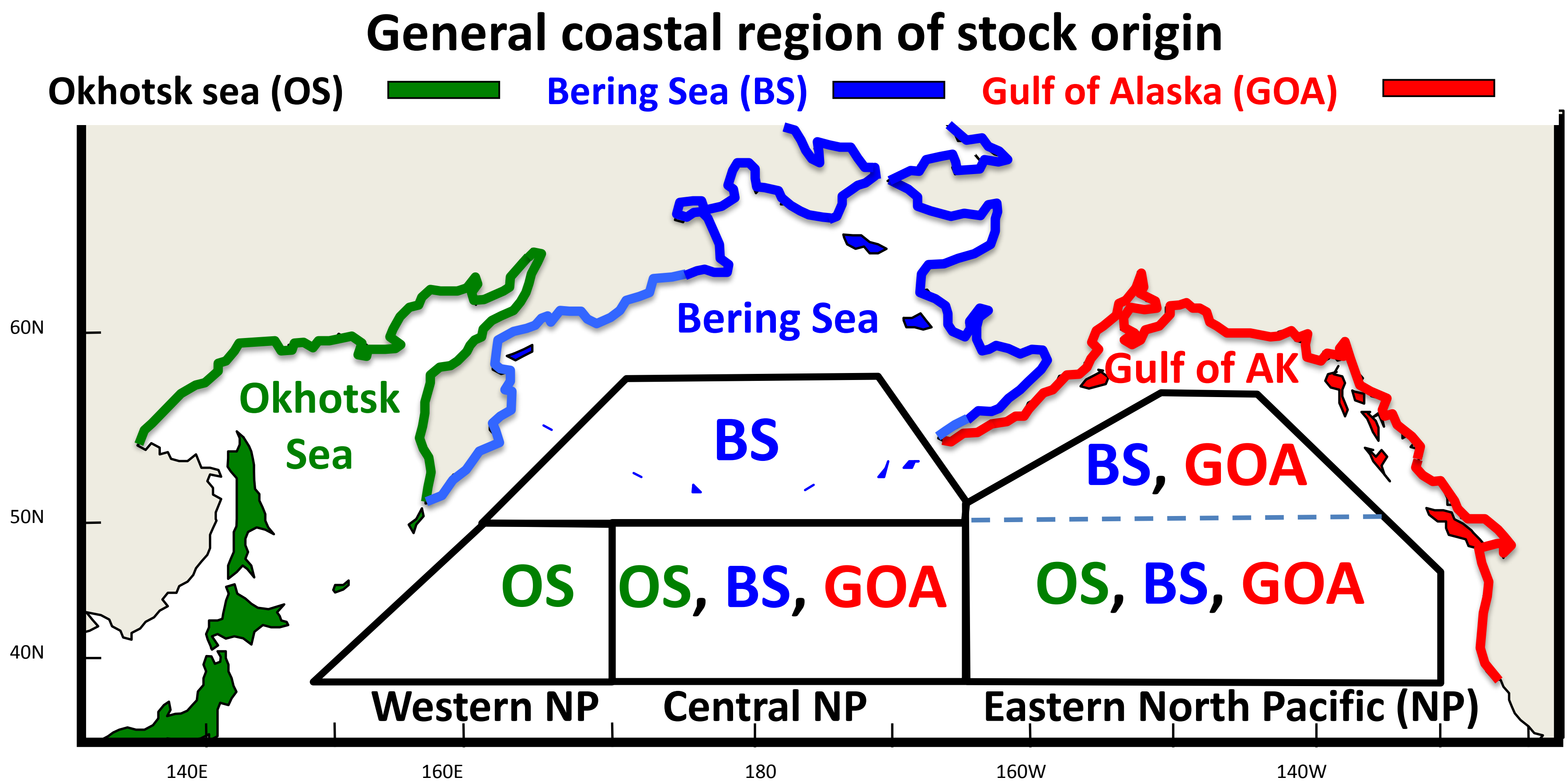


Salmon make seasonal movements across broad fronts
(north & west in summer, south & east in winter)



Source: Myers et al. 2007

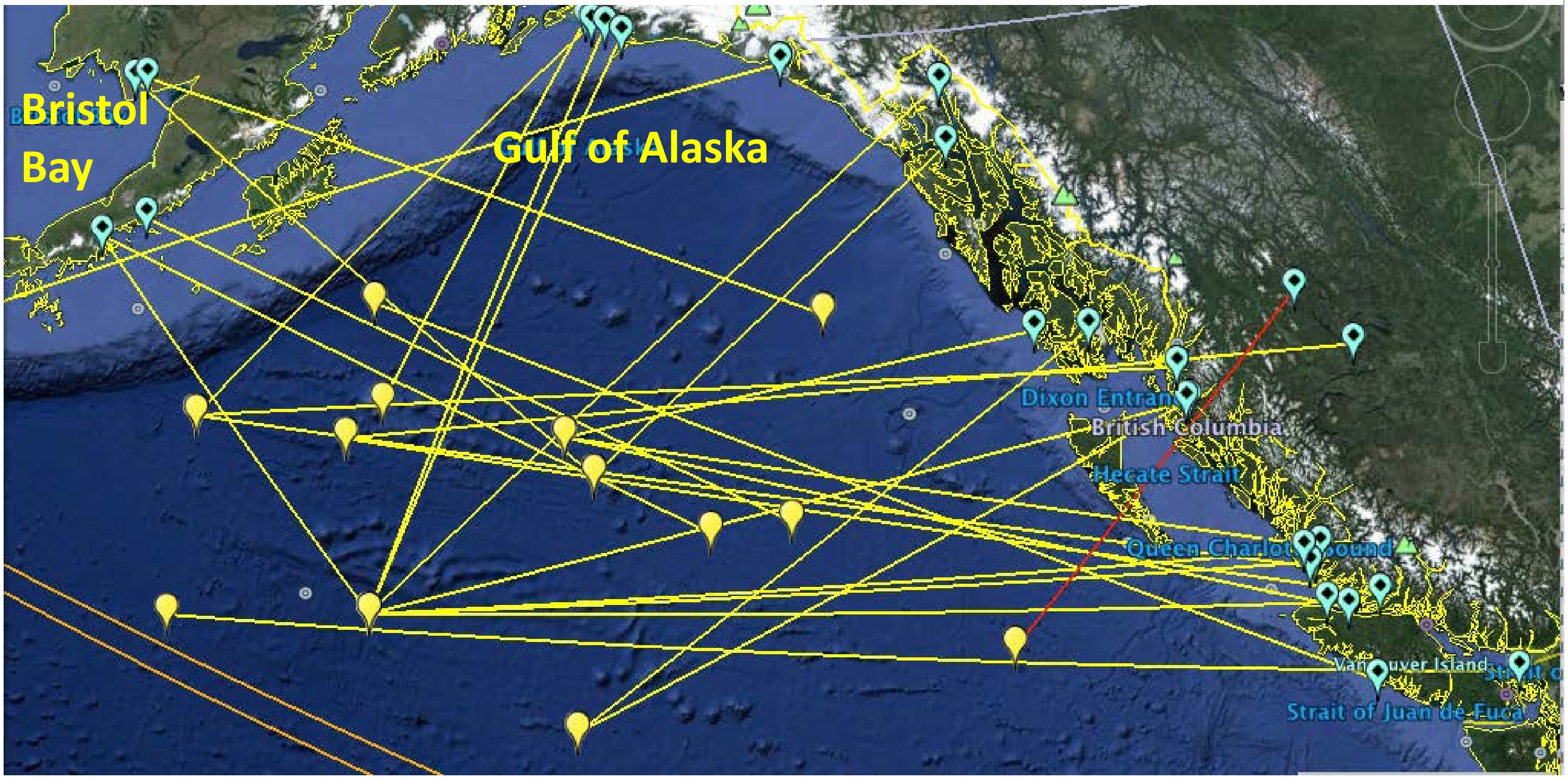
Stock concept: winter distribution differs by stock



Evidence of ecosystem-scale intermixing of sockeye stocks

Historical winter high seas tagging in Gulf of Alaska (GOA)

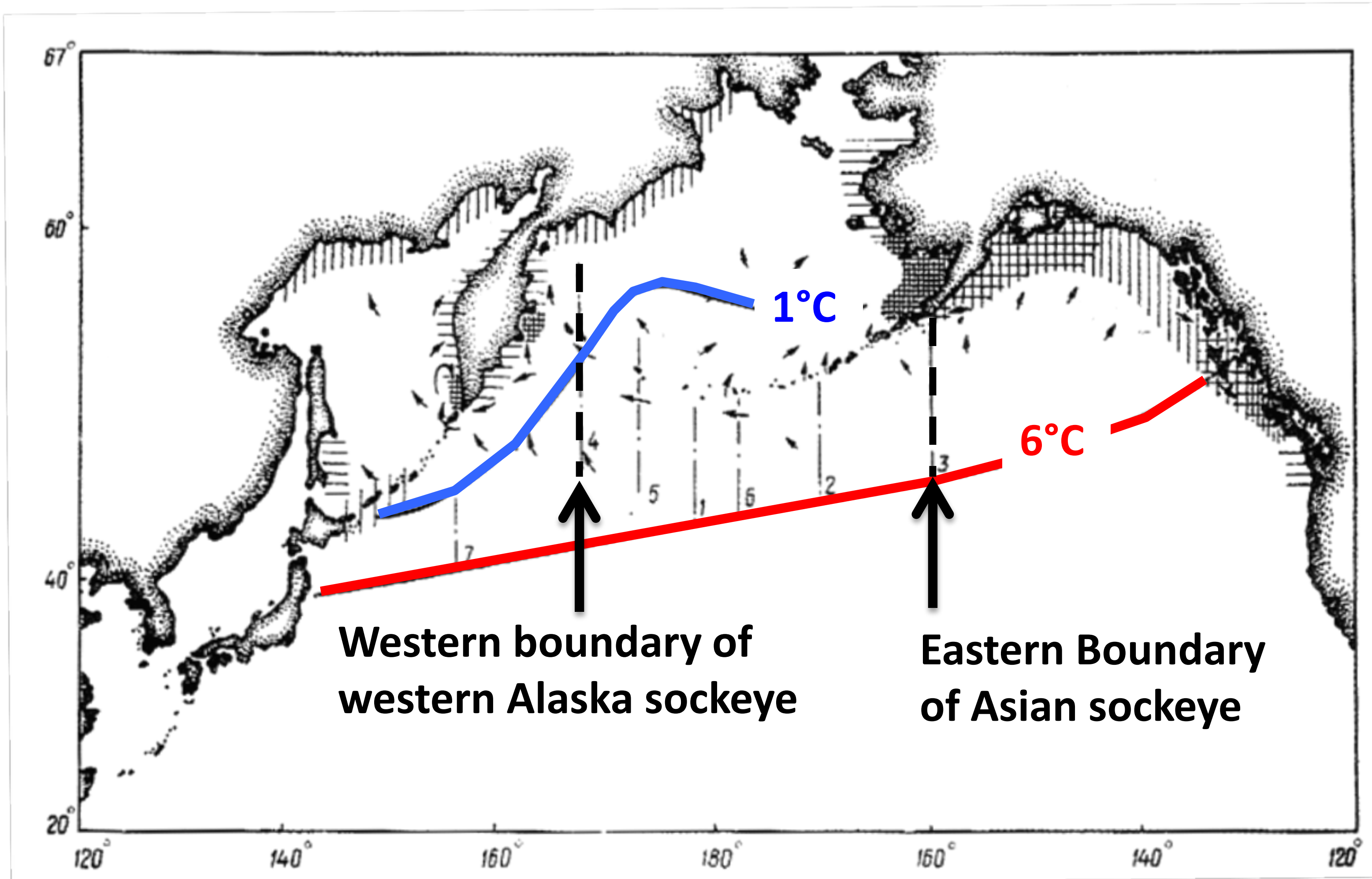
Release location (yellow marker) **Recovery location** (cyan marker) **Maturing sockeye** (yellow line)



Thermal Tolerance Hypothesis: Winter range of salmon is determined by species-specific temperature tolerances

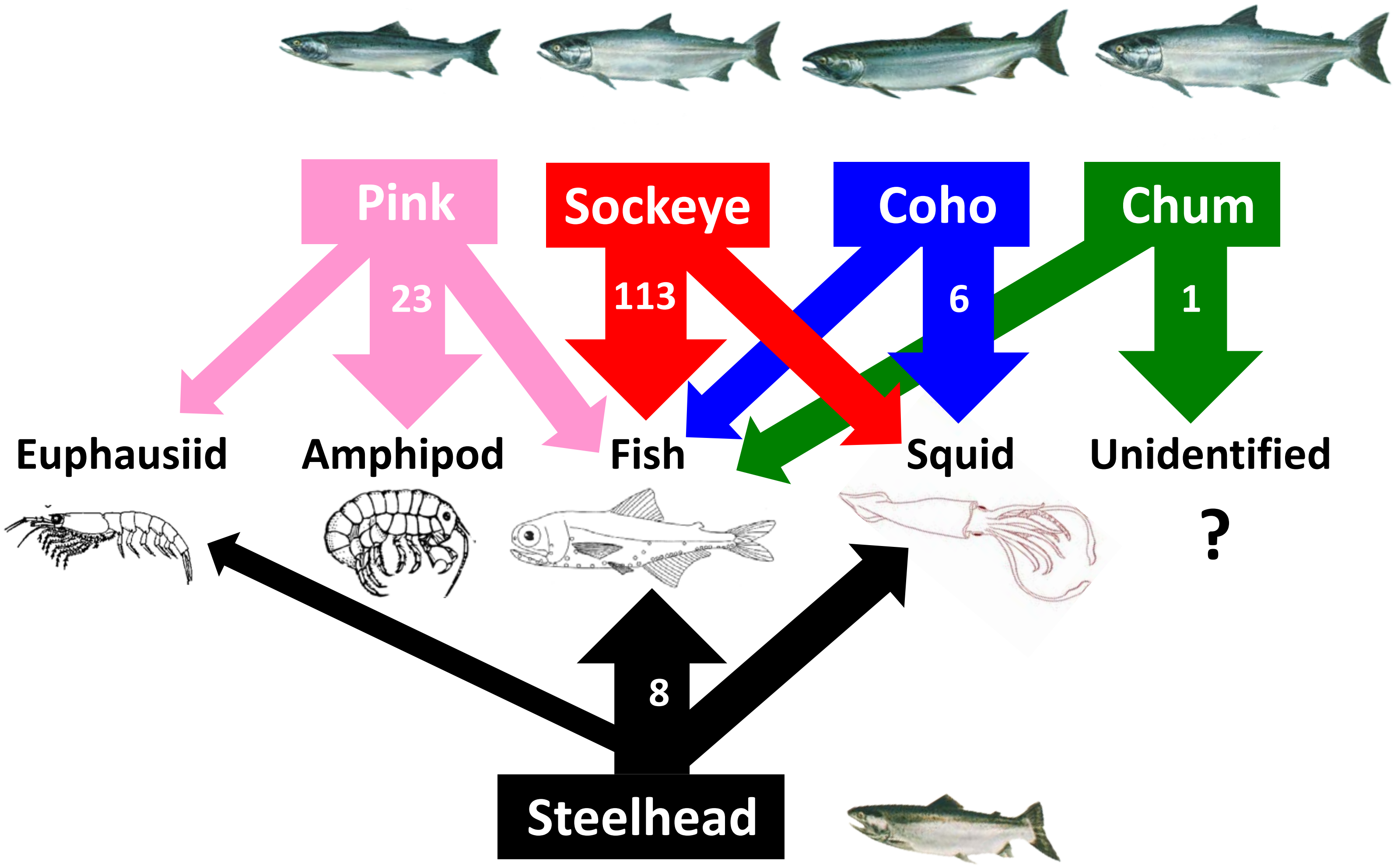
(Manzer et al. 1965, Birman 1985, & others)

Example for sockeye salmon from Birman (1985), based on data from 1960s; thermal boundaries are sea surface temperatures.

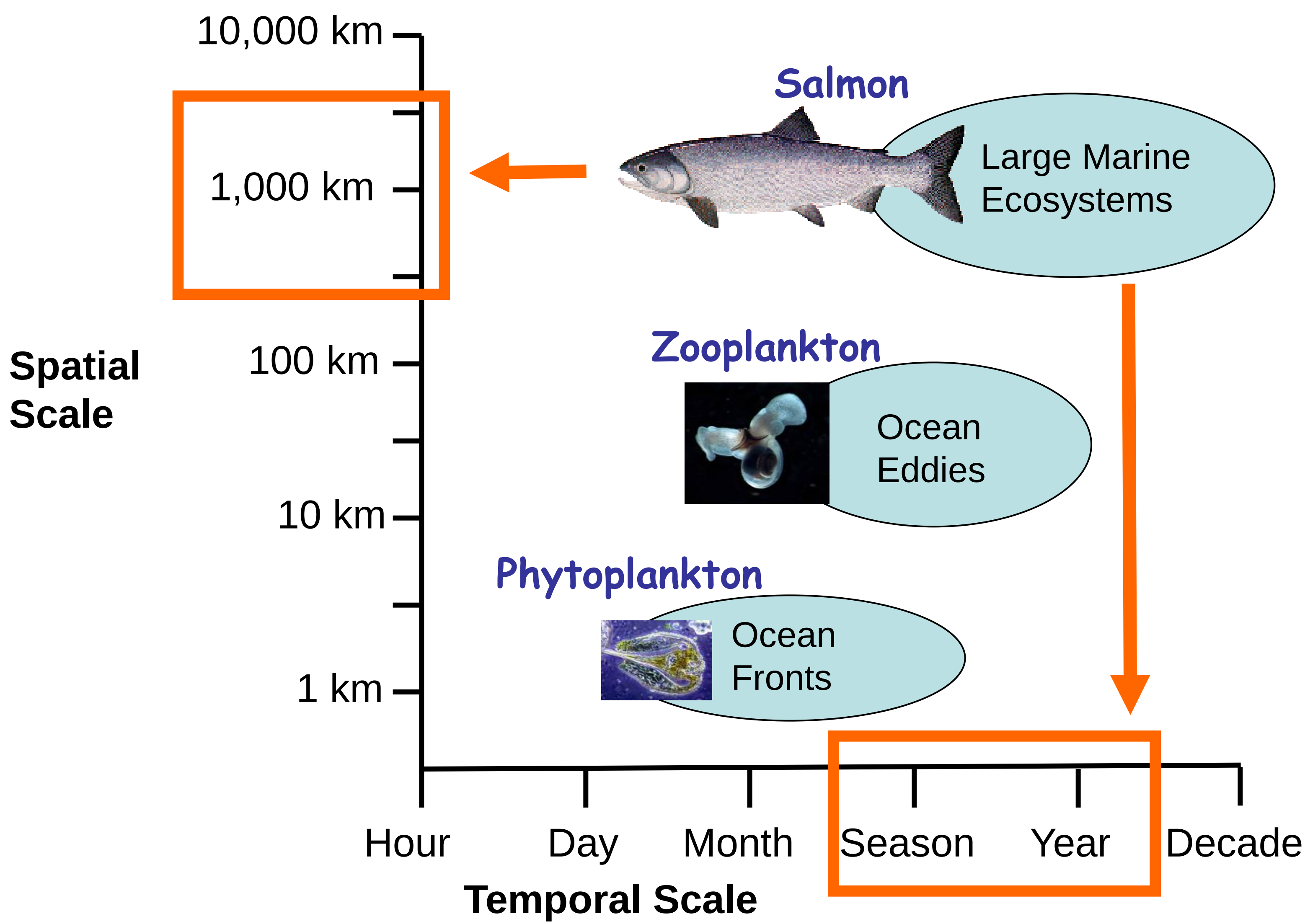


Salmon feed in winter & diets vary by species

Example: major prey of immature and maturing salmon in the Gulf of Alaska
(Source: R.J. LeBrasseur, DFO Canada, unpublished winter 1963-1964 diet data)



Lessons learned: spatial & temporal scales matter



Winter research during 1980s-present

- Development & application of new methods
- Expanded knowledge of winter distribution
- Learned that “why” of distribution is complex

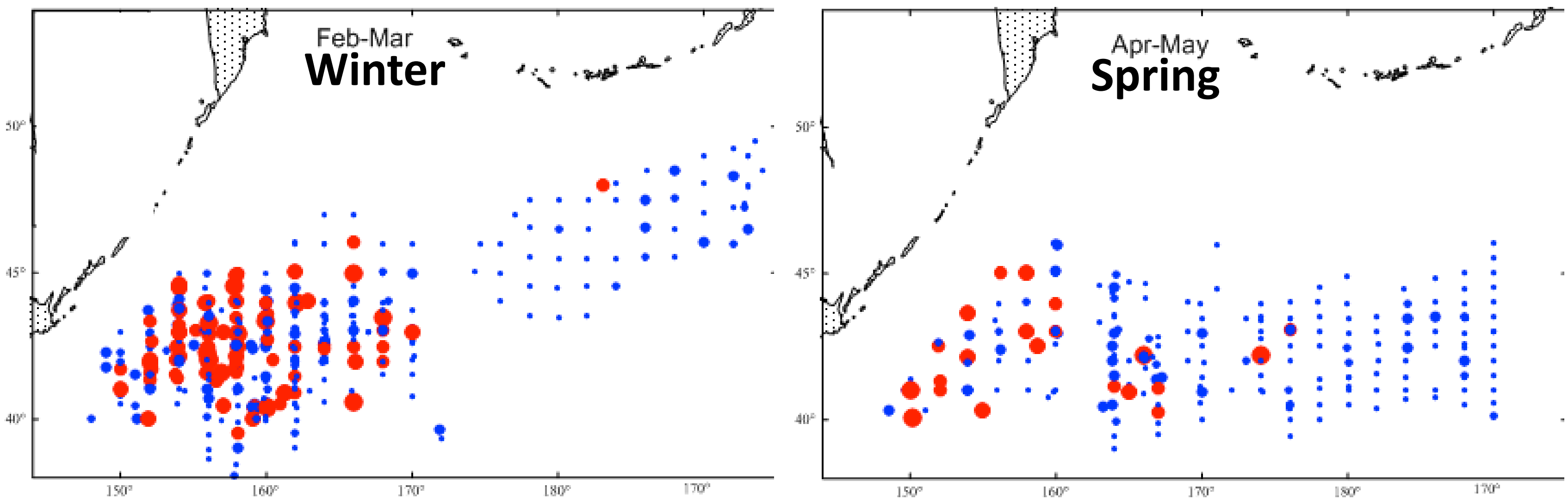
Development & application of new methods

- Fisheries-oceanographic survey methods - Trawls
- Stock-identification techniques - Genetics
- Remote sensing technologies – Data storage tags
- Analytical methods

Trawl surveys provide expanded knowledge of seasonal high seas salmon distribution

Example: Composite catch distribution maps for pink salmon in western & central North Pacific during winter & spring 1986-1992, 2009-2011

Catch %: · 0-0.5 · 0.5-1.0 • 1.0-2.5 • 2.5-5.0 • 5.0-10.0 ● 10.0-50.0

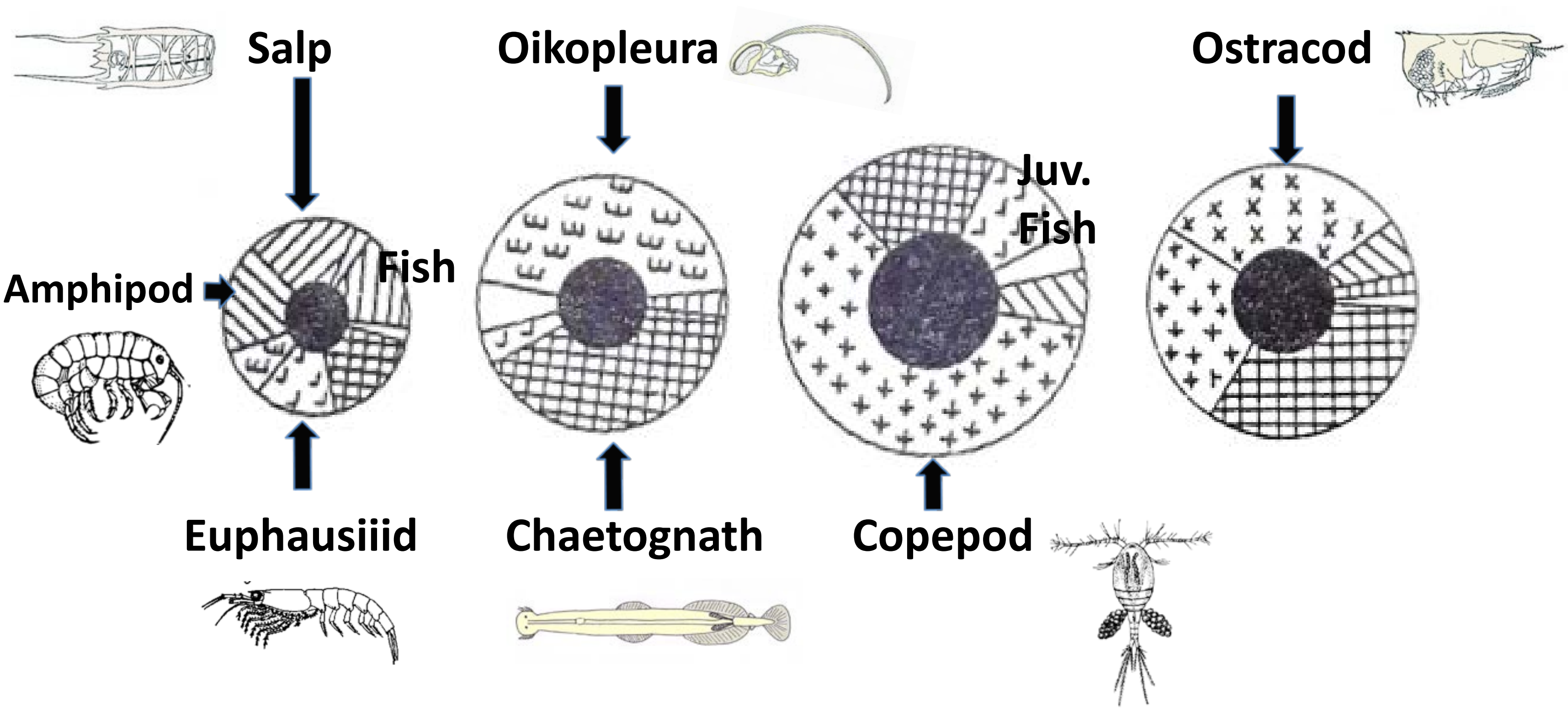


Source: Source: A. Figurkin (Figurkin and Naydenko, 2013; Naydenko and Figurkin, 2014, TINRO Centre Vladivostok)

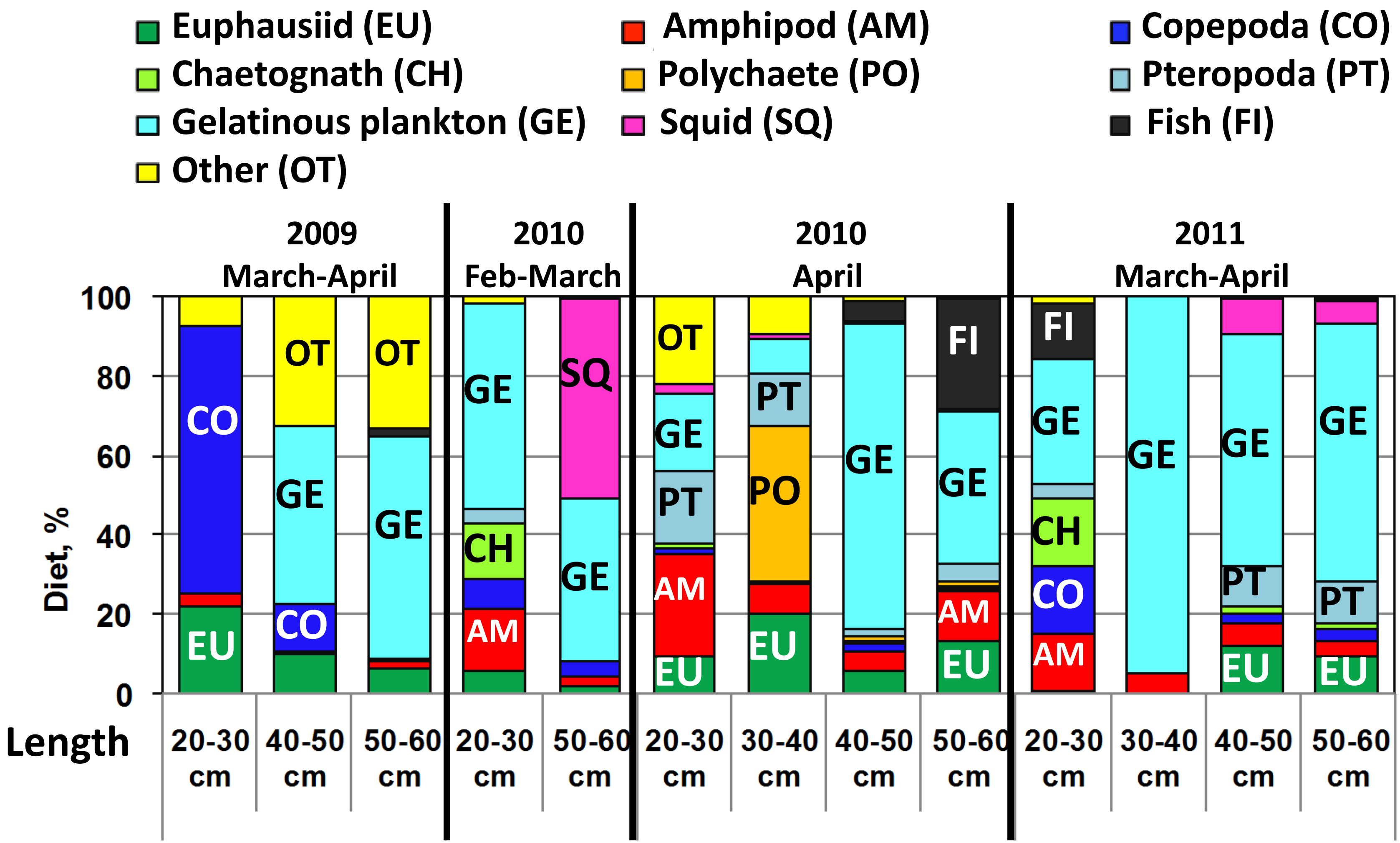
Trawl surveys show salmon feeding varies by region

Example: Pink salmon diet composition and feeding intensity (0/000) during Feb-May 1989 (Tutubalin & Chuchukalo 1992)

Western North Pacific			Central North Pacific
Sub-region AI	Sub- region AII	Sub-region AIII	Region B
L=25-35 cm	L=25-35 cm	L=25-35 cm	L=35-45 cm
n=607	n=278	n=471	n=797
0/000=59.3	0/000=98.7	0/000=149.0	0/000=123.4

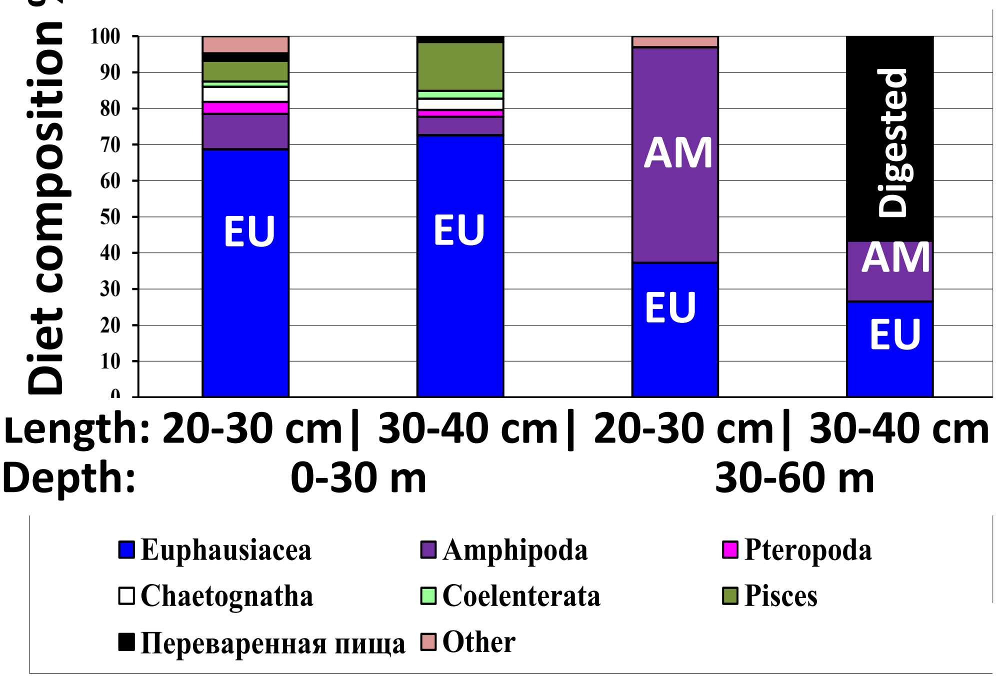


Example: Chum salmon diets vary by year, month, and body size in western Subarctic (Naydenko, et. al. 2010; Kuznetsova 2010; Glebov et al. 2011)

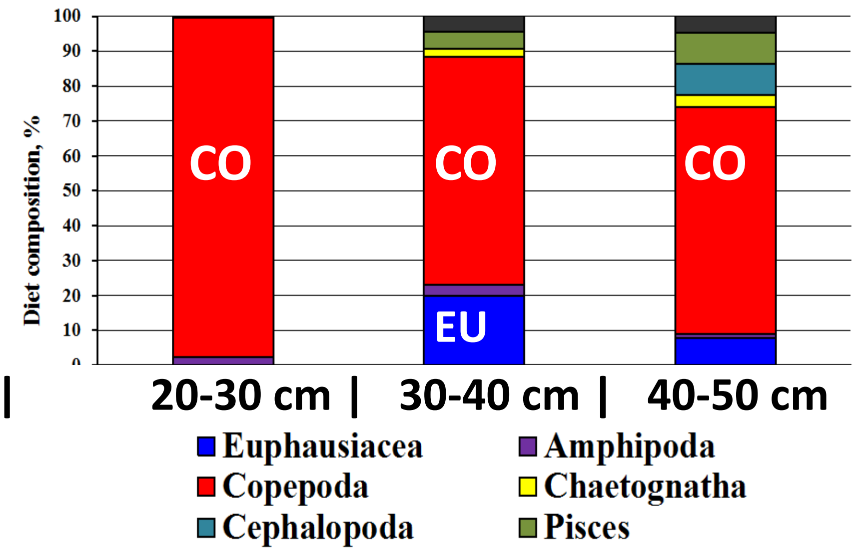


Example: Pink salmon diets in winter-spring 2009-2011 vary by region, body size, and depth
(Naydenko, et. al., 2010; Kuznetsova, 2010; Glebov et al, 2011)

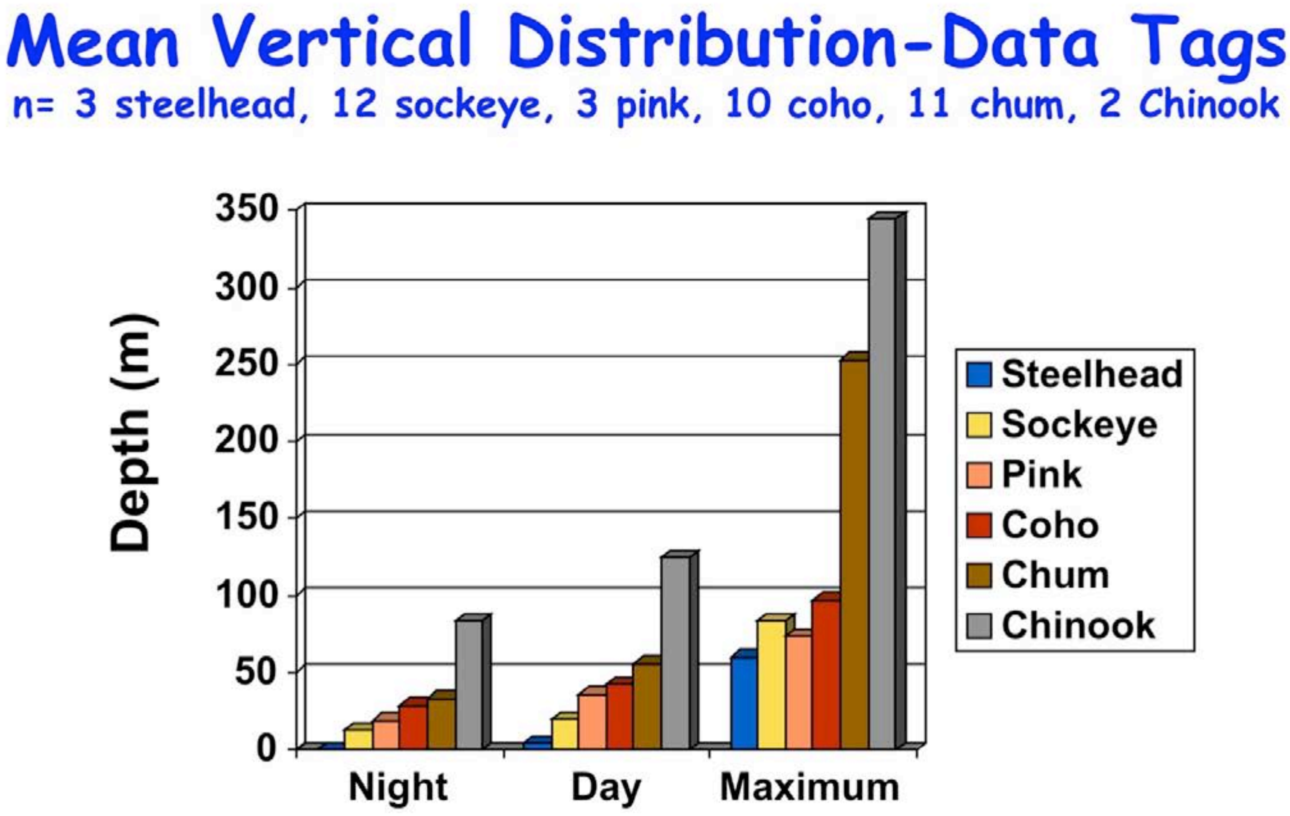
Western Subarctic Zone



Central Subarctic Zone



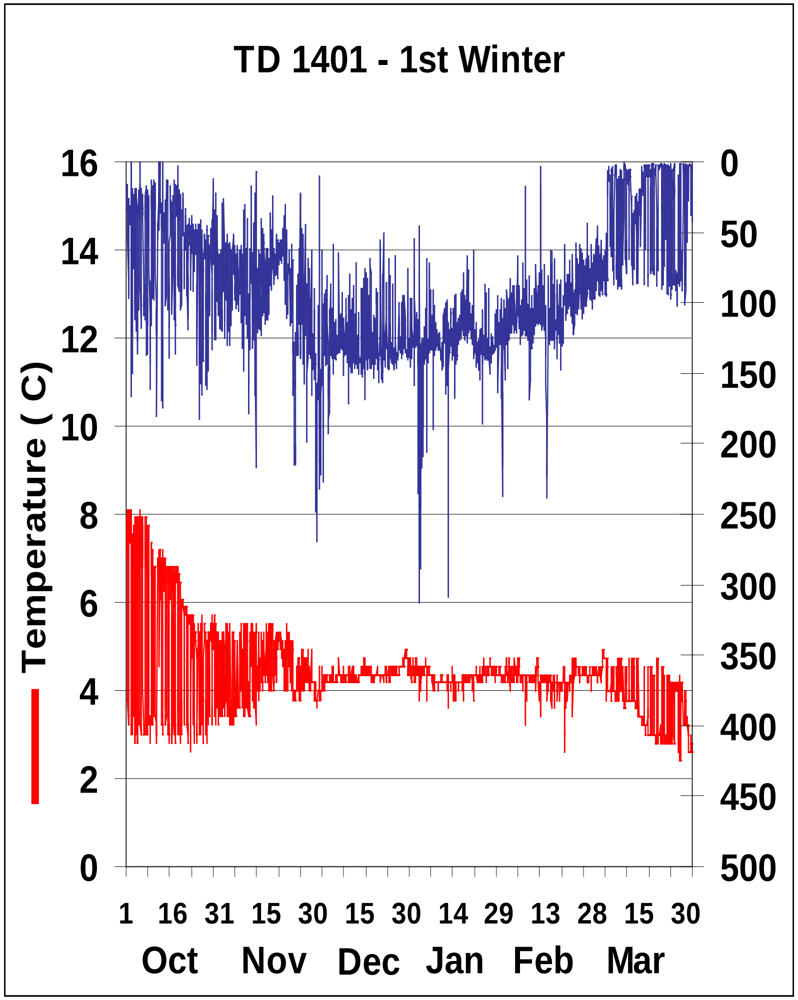
Electronic tags show species-specific differences in high seas vertical distribution

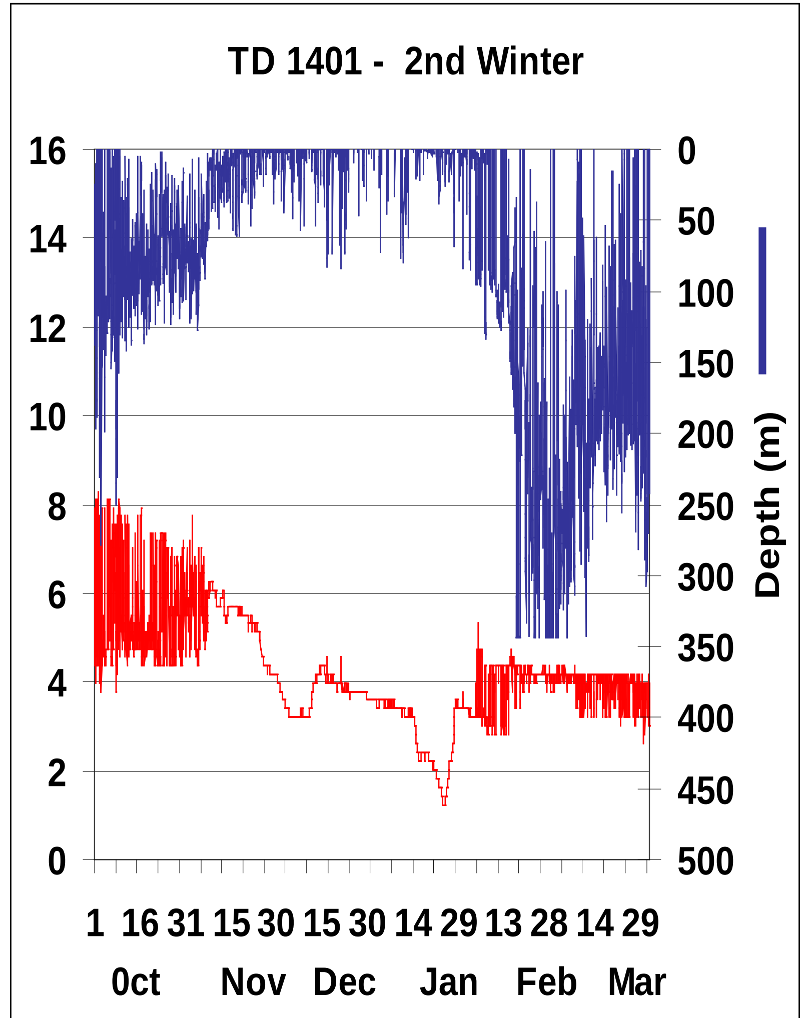


Data from Walker et al. 2000 (Fisheries Oceanography), 2007 (NPAFC Bulletin); Nielson et al. 2011 (CJFAS)

TD tag data show plasticity in winter depth distribution of individual fish

Comparison of Winters – Bering Sea Chinook

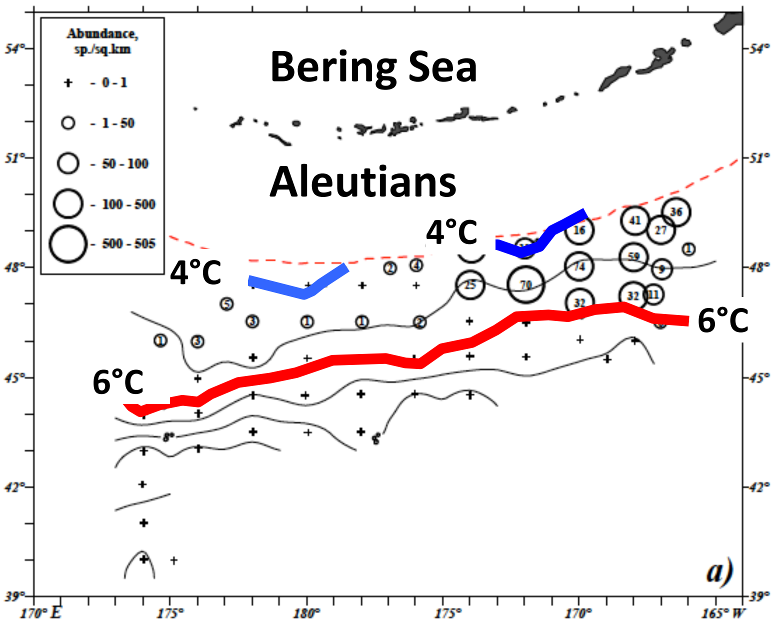




Increased spatial and temporal resolution of species-, age-, & stock-specific distribution with respect to ocean conditions

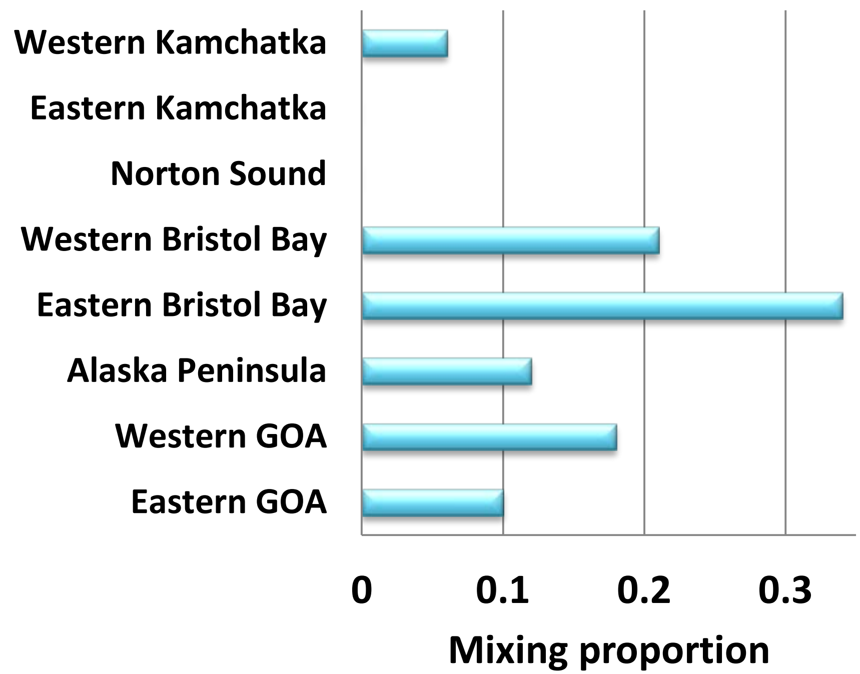
Example: Catch distribution and stock composition of ocean age-1 sockeye salmon caught in central North Pacific in winter 2009

Catch distribution
(Starovoytov et al. 2009 (NPAFC Doc. 1188)



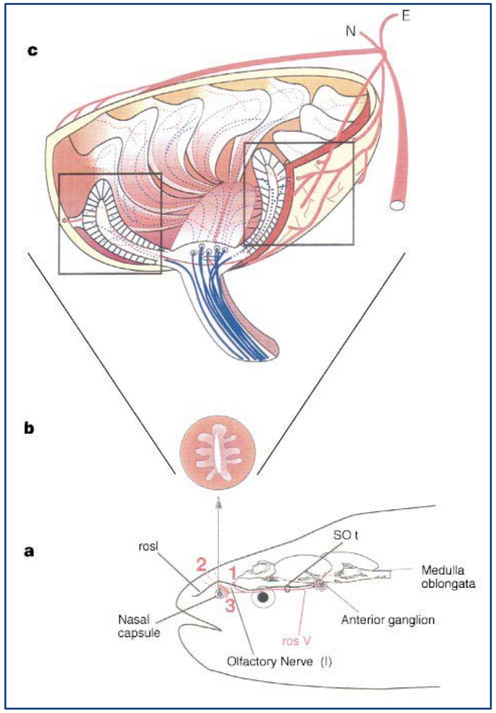
Numbers — catch (inds. per hour of trawling), contour lines indicate SST

Genetic stock composition
(Farley et al. 2011, ICES J Mar Sci 68)



An Inherited Magnetic Map Guides Ocean Navigation in Juvenile Pacific Salmon (Putman et al 2014, Current Biology 24)

- **Experimental demonstration that juvenile salmon respond to magnetic fields by orienting in directions leading toward marine feeding grounds**
- **Salmon use combination of magnetic intensity and inclination angle to assess geographic location**
- **The "magnetic map" of salmon appears to be inherited, as fish had no prior migratory experience**

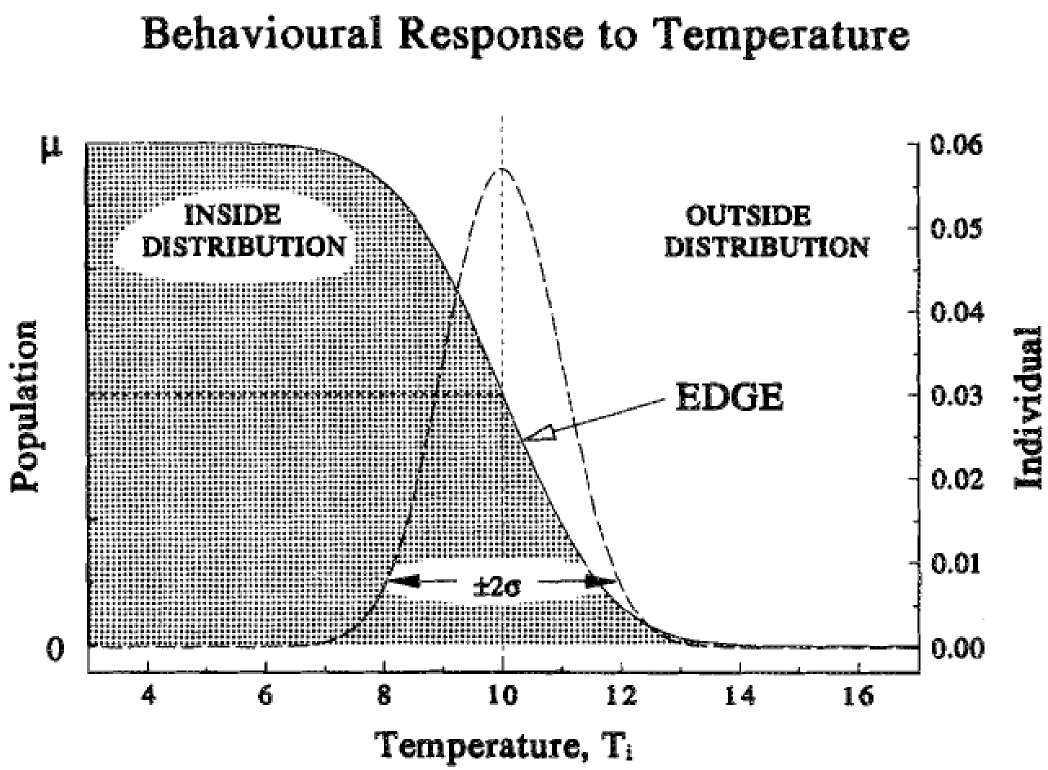


Area in nose of trout where candidate magnetoreceptor cells are located (Walker et al. 1997, Nature 390)

<u>Thermal limits hypothesis</u> (Welch et al. 1994, 1998a, b):

Salmon exhibit species-specific behavioral response to a threshold temperature

Bioenergetic control: Salmon avoid temperatures where basal metabolic rates exceed energy gained from feeding



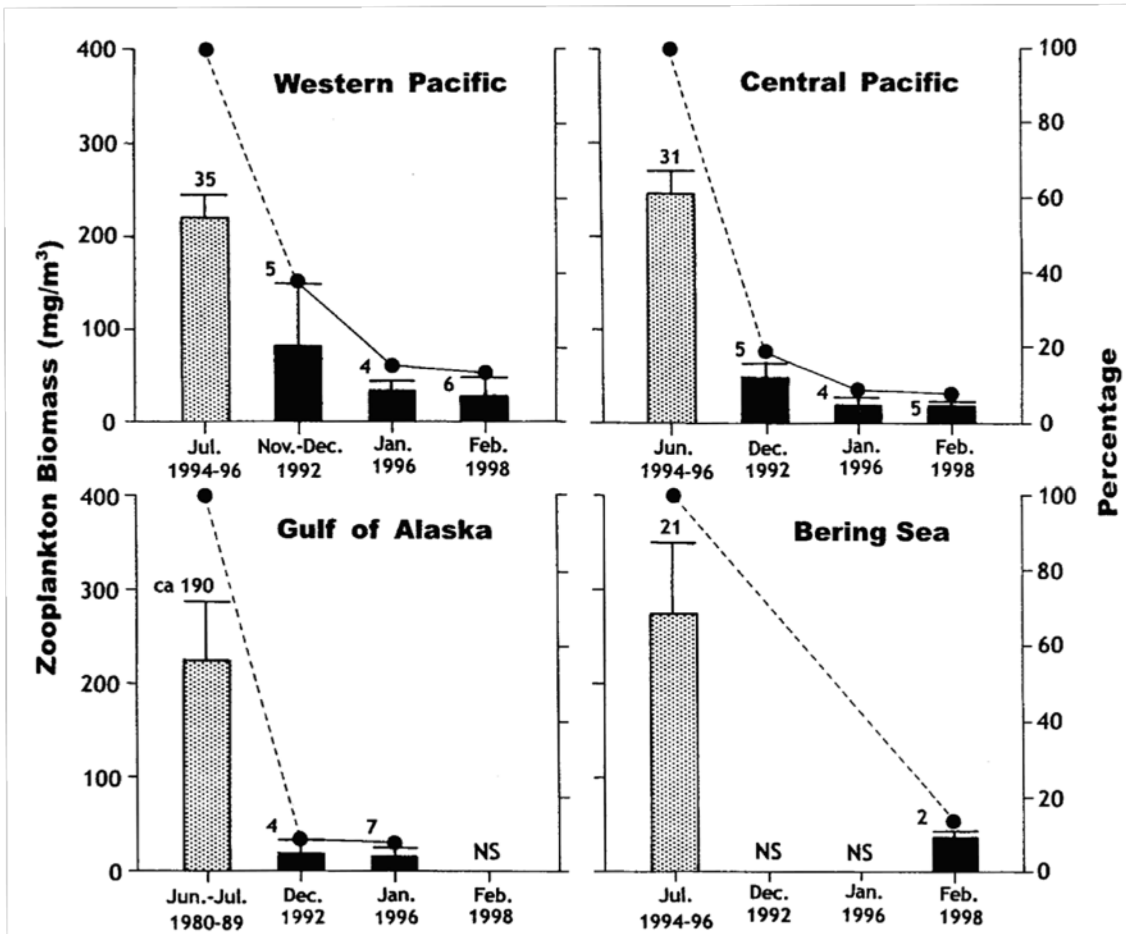
<u>Critical upper limit spring (GOA)</u>

Pink & chum: 10.4°C
Coho: 9.4°C
Sockeye: 8.9°C
Steelhead: ~11°C

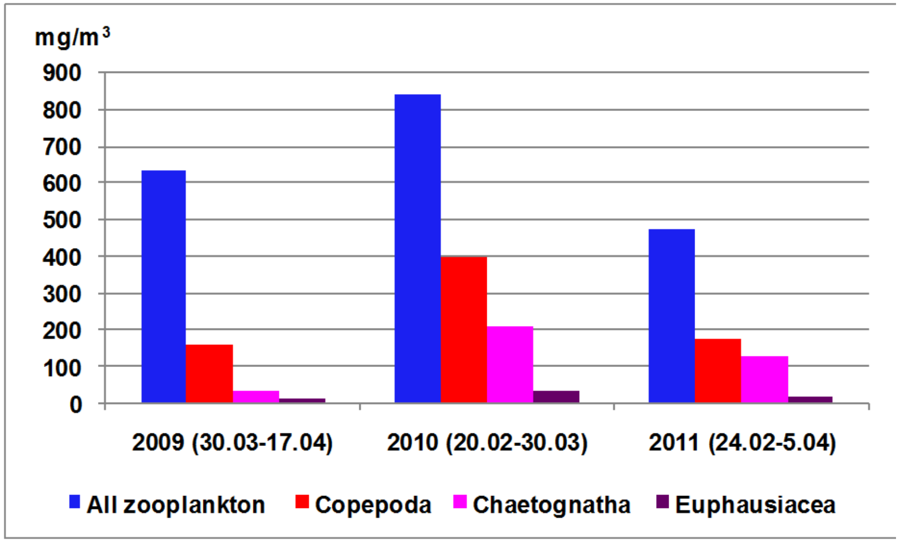
<u>Trans-Pacific winter:</u>

Sockeye: ~7°C

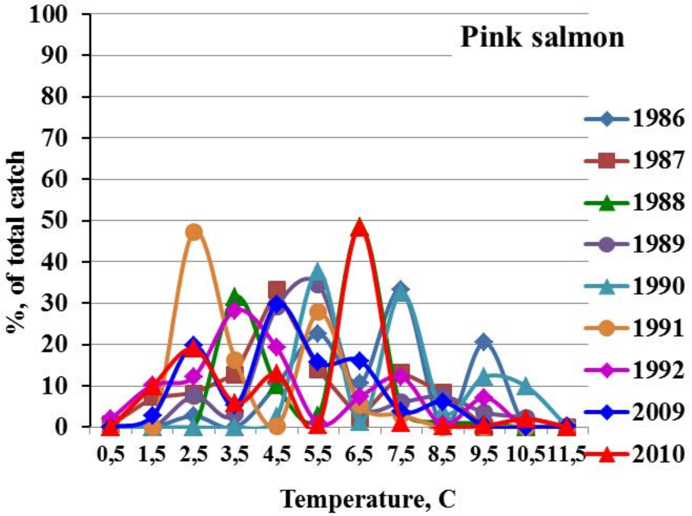
Salmon Overwintering Strategy (SOS) hypothesis (Nagasawa 2000): **Zooplankton biomass is low in winter & salmon are distributed in cold waters (4-8°C) to reduce metabolic rates**



<u>Alternative Overwintering hypothesis (Shuntov and Temnykh, 2008, 2010; Naydenko, 2011; Naydenko and Kuznetsova, 2013)</u>: Zooplankton biomass in winter is not low, and salmon are distributed over a wide range of temperatures (0.5-12.0°C)

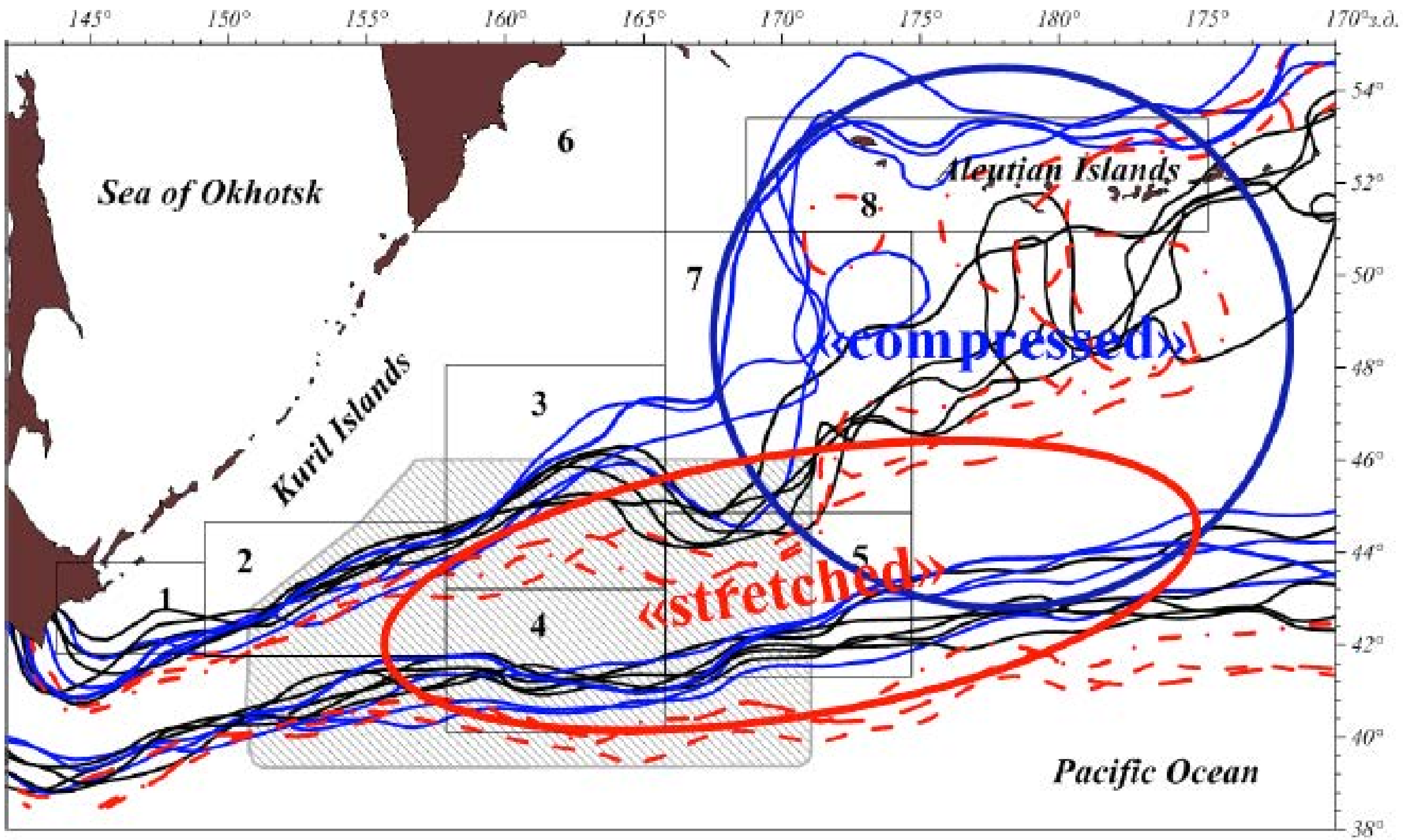


Plankton composition and biomass in the pelagic layer (0-200 m) in the subarctic frontal zone in the North Pacific in February – April 2009-2011 (Naydenko, et. al., 2010; Kuznetsova, 2010)

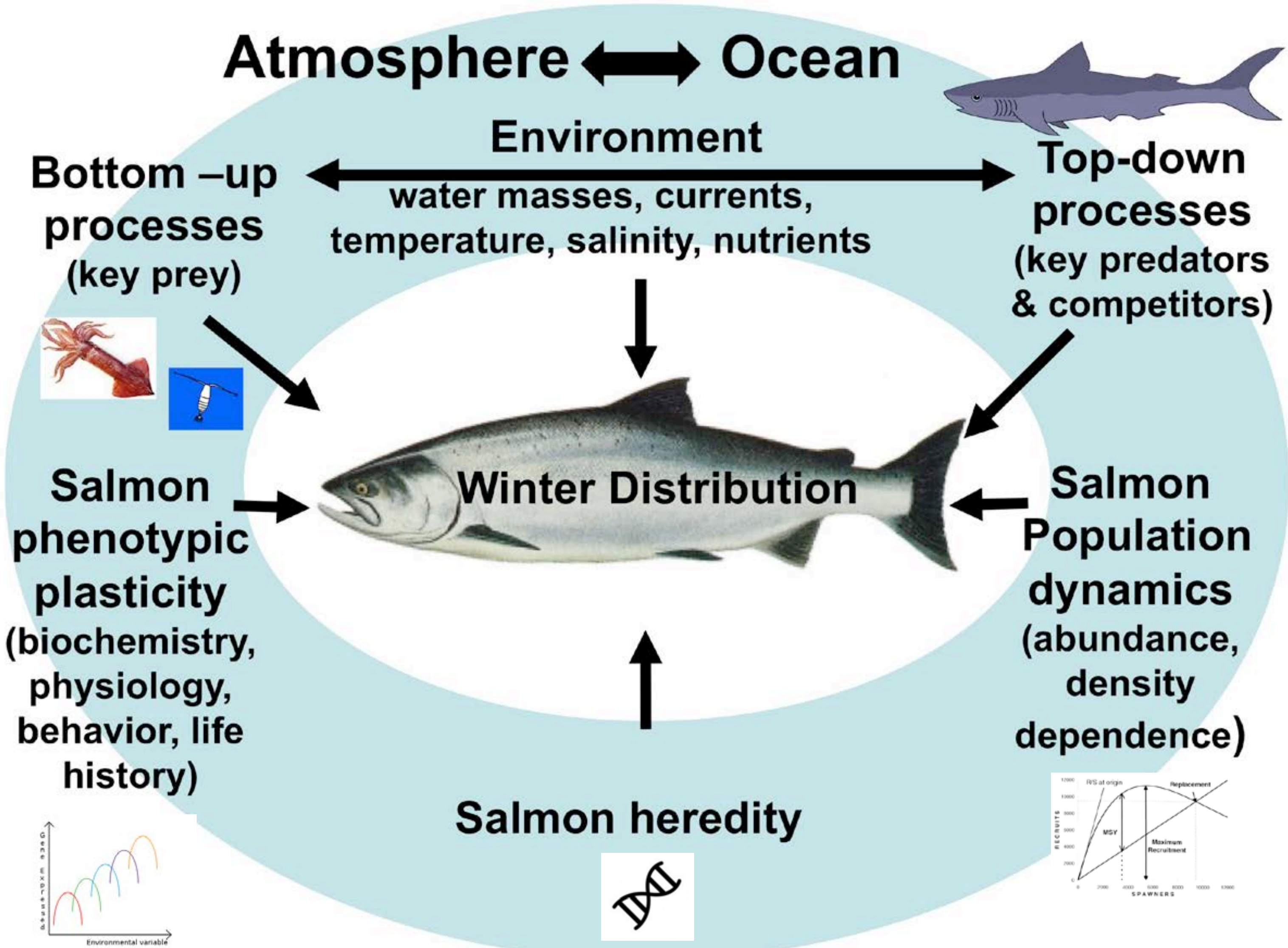


Distribution of pink catches at various values of temperature (t °C) in winter 1986-1992 and 2009-2011 (Figurkin and Naydenko 2013; Naydenko and Figurkin 2014)

<u>Pelagic landscape Zone Hypothesis</u> **(Naydenko and Figurkin 2014): Landscape zone shape determines spatial distribution, & interannual fluctuations in salmon abundance determine quantitative catch distribution**



Lessons learned: “why” of distribution is complex and variable

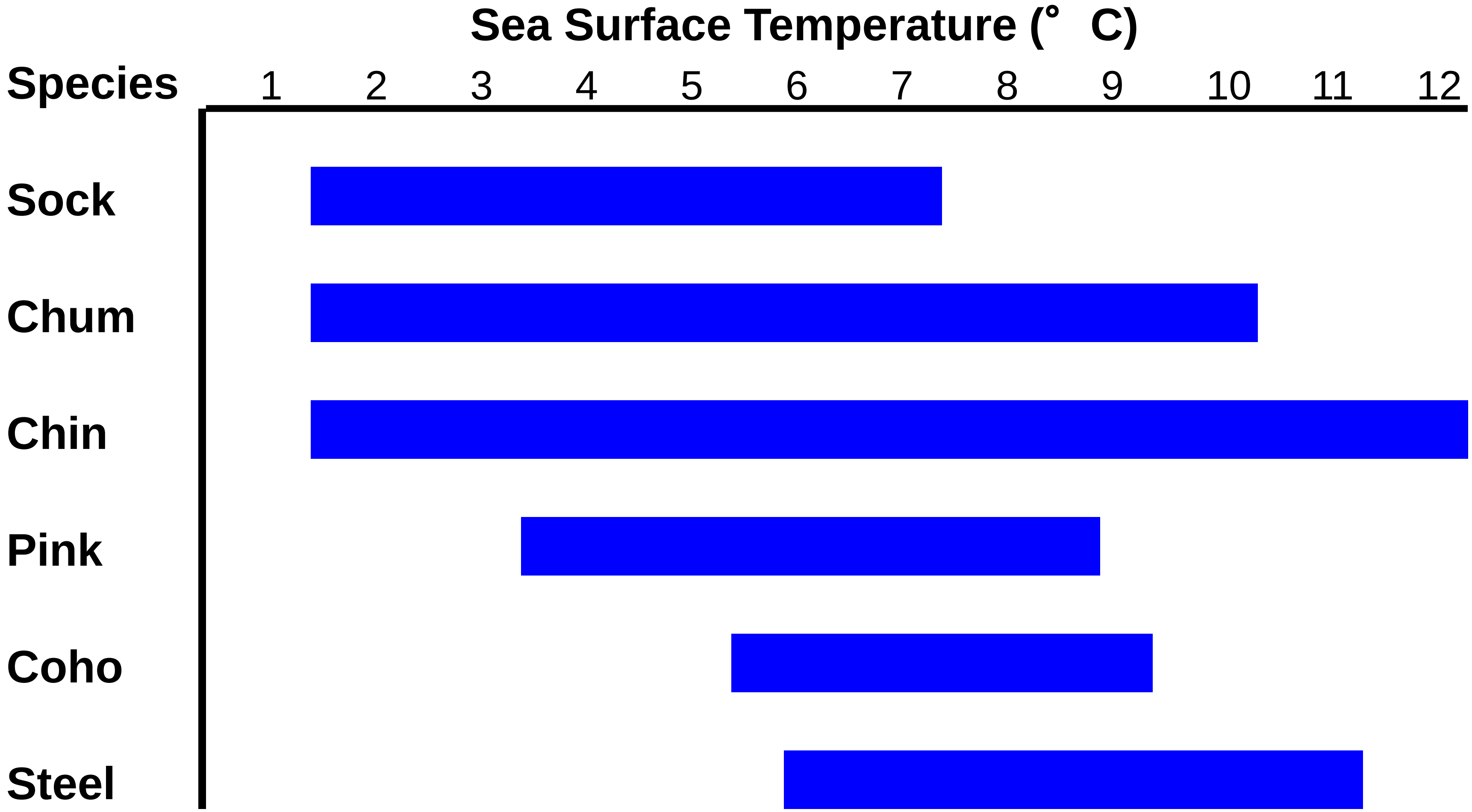


How will climate change affect winter distribution of salmon?

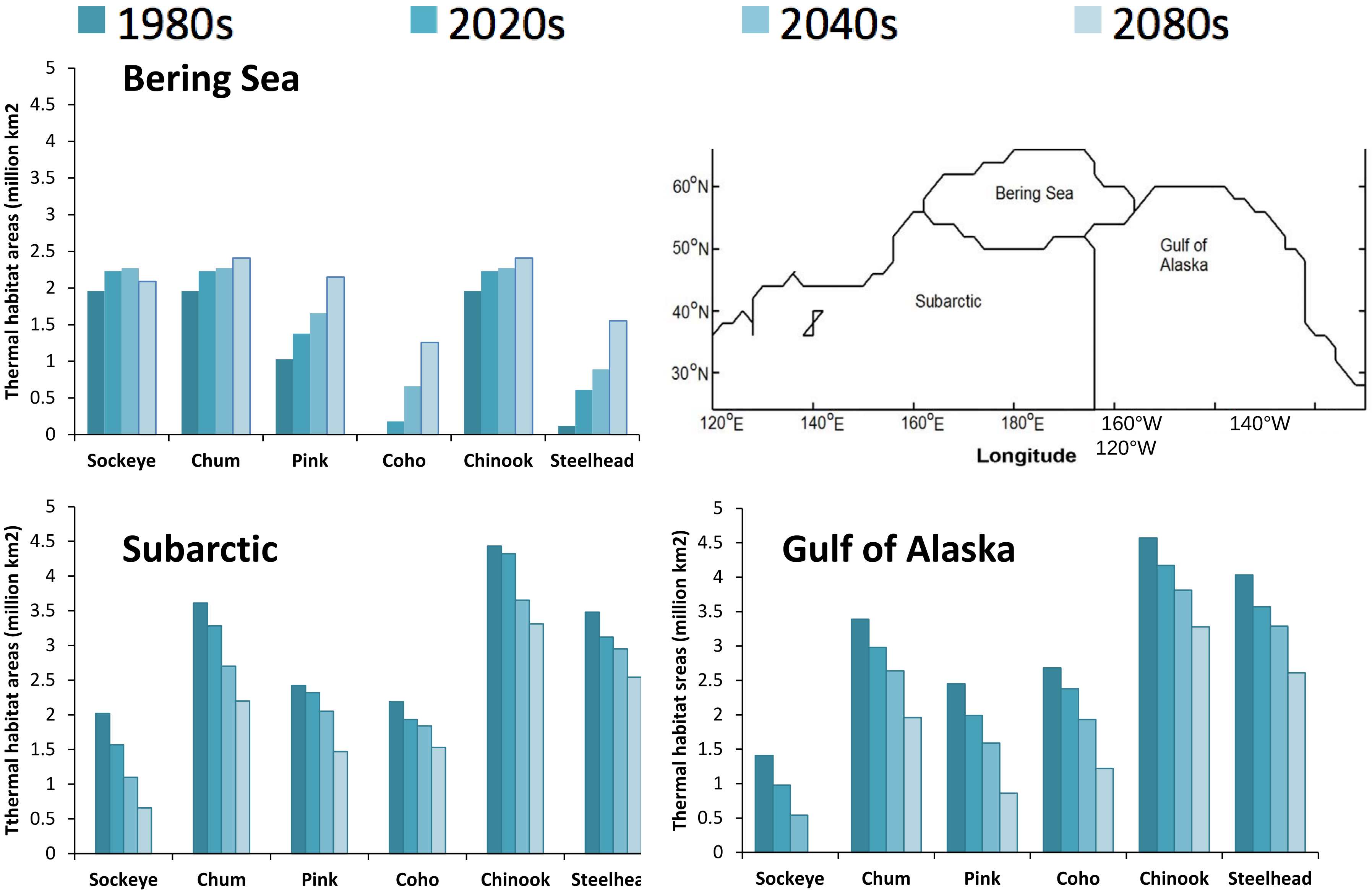
- To date, most studies have focused on projected changes in thermal habitat area (Welch et al. 1998a,b; Azumaya et al. 2007; Kaeriyama 2008; Abdul-Aziz et al. 2011)
- Are there other (non-thermal) habitat characteristics to consider?

Example: Abdul-Aziz et al. (2011) evaluated climate-change effects on species-specific winter thermal habitats

SSTs of "frequent catches" of salmon species



Potential climate change effects on high seas salmon winter thermal habitats in three regions (Abdul-Aziz et al. 2011)



Next steps?

- NPAFC could develop a comprehensive electronic database of high seas salmon winter survey biological and catch data
- PICES could develop an electronic database of relevant ocean conditions
- NPAFC & PICES could collaborate on developing quantitative multispecies, multistage models to help identify key factors influencing winter distribution and to improve understanding of potential future climate change effects
- Determine whether critical periods vary among species and if/when winter is critical?