Possible effects of climate variability on the euphausiids *Euphausia pacifica* and *Thysanoessa spinifera* off Newport, OR, USA

Euphausia pacifica

Thysanoessa spinifera

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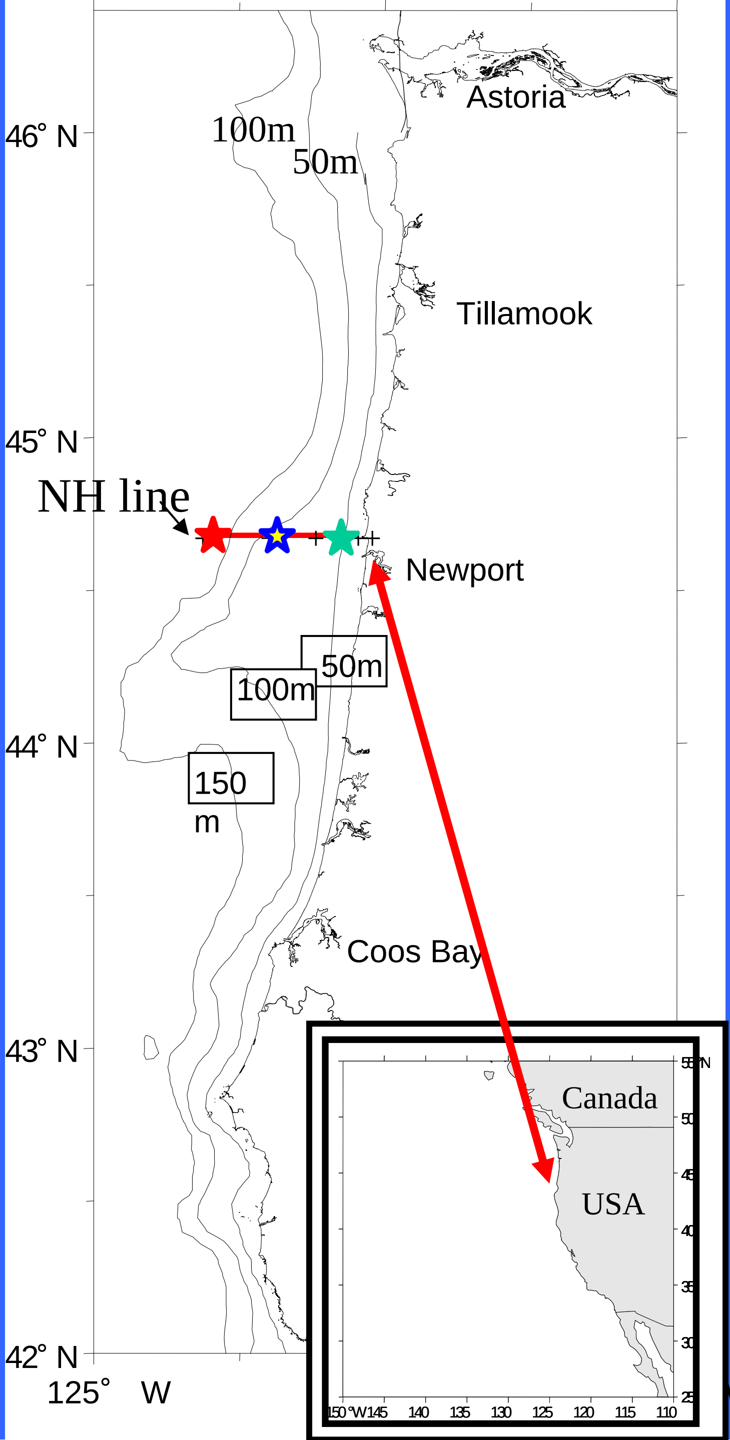


Time series off Newport, OR (NH line)

- Sampled twice per month starting in 1996
- Adult euphausiids sampled with night bongo tows from 2001-present (11 years so far)
- Environmental conditions
  - warm & cold PDO phases
  - timing of spring and fall transition dates
  - duration of upwelling
  - 2002 – anomalously cold due to intrusion of subarctic water

Target Species

Euphausia pacifica

Thysanoessa spinifera

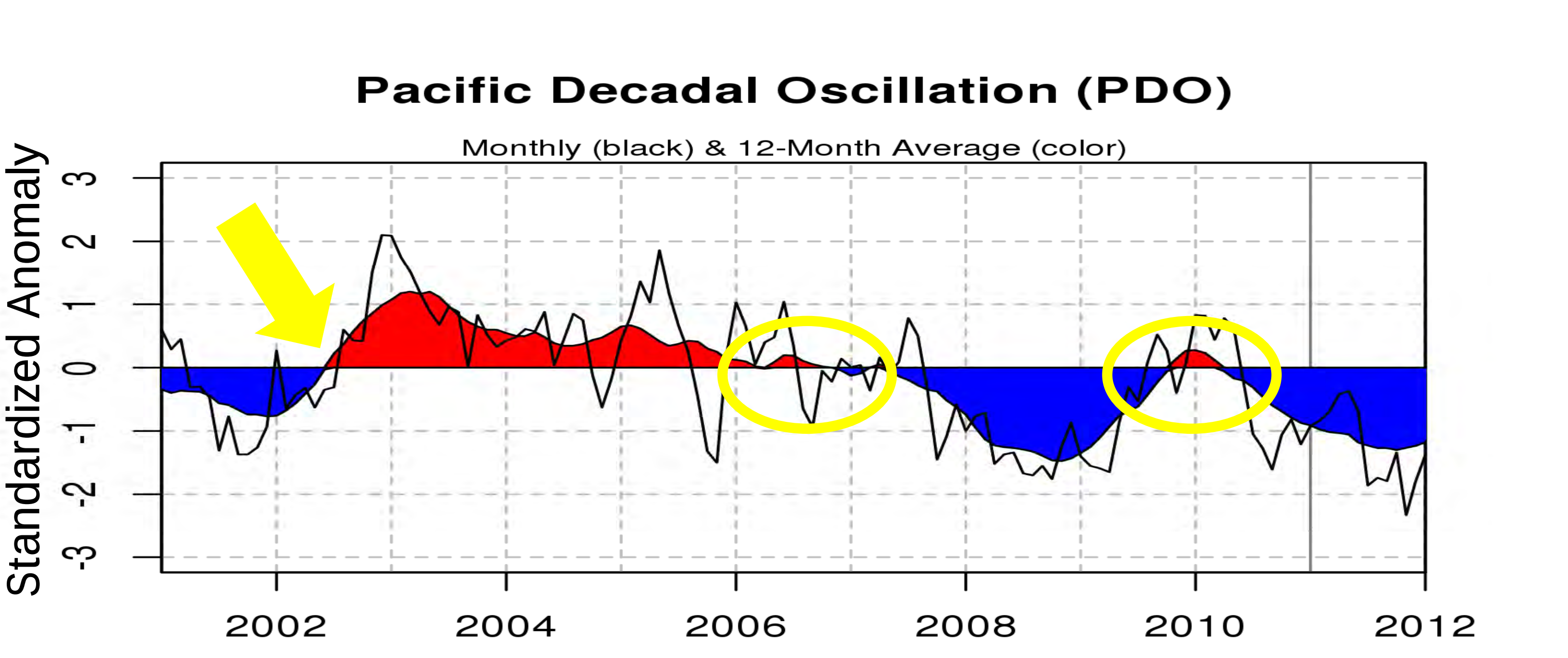
- Generally found at and beyond the shelf break (>200 m depth)
- Intense period of spawning during summer upwelling season
- Present in cool & warm ocean conditions
- Do not store lipids

- Generally found on the shelf (<200 m depth)
- Spawn before & during upwelling, no intense period
- Prefer cooler ocean conditions
- Store lipids

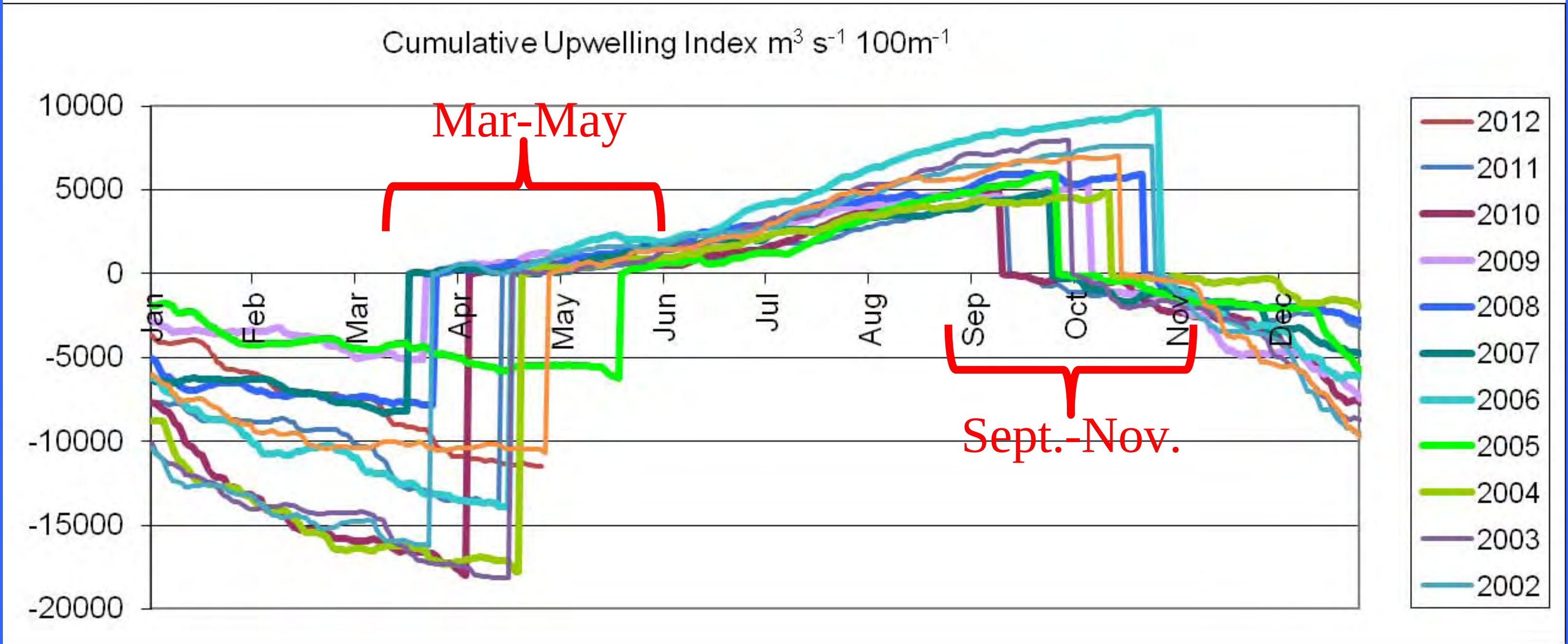
The Question

Based on how krill respond to short-term environmental variability, how might they respond to the effects of climate change?

PDO


Pacific Decadal Oscillation (PDO)
Monthly (black) & 12-Month Average (color)
Standardized Anomaly
3
2
1
0
-1
-2
-3
2002
2004
2006
2008
2010
2012

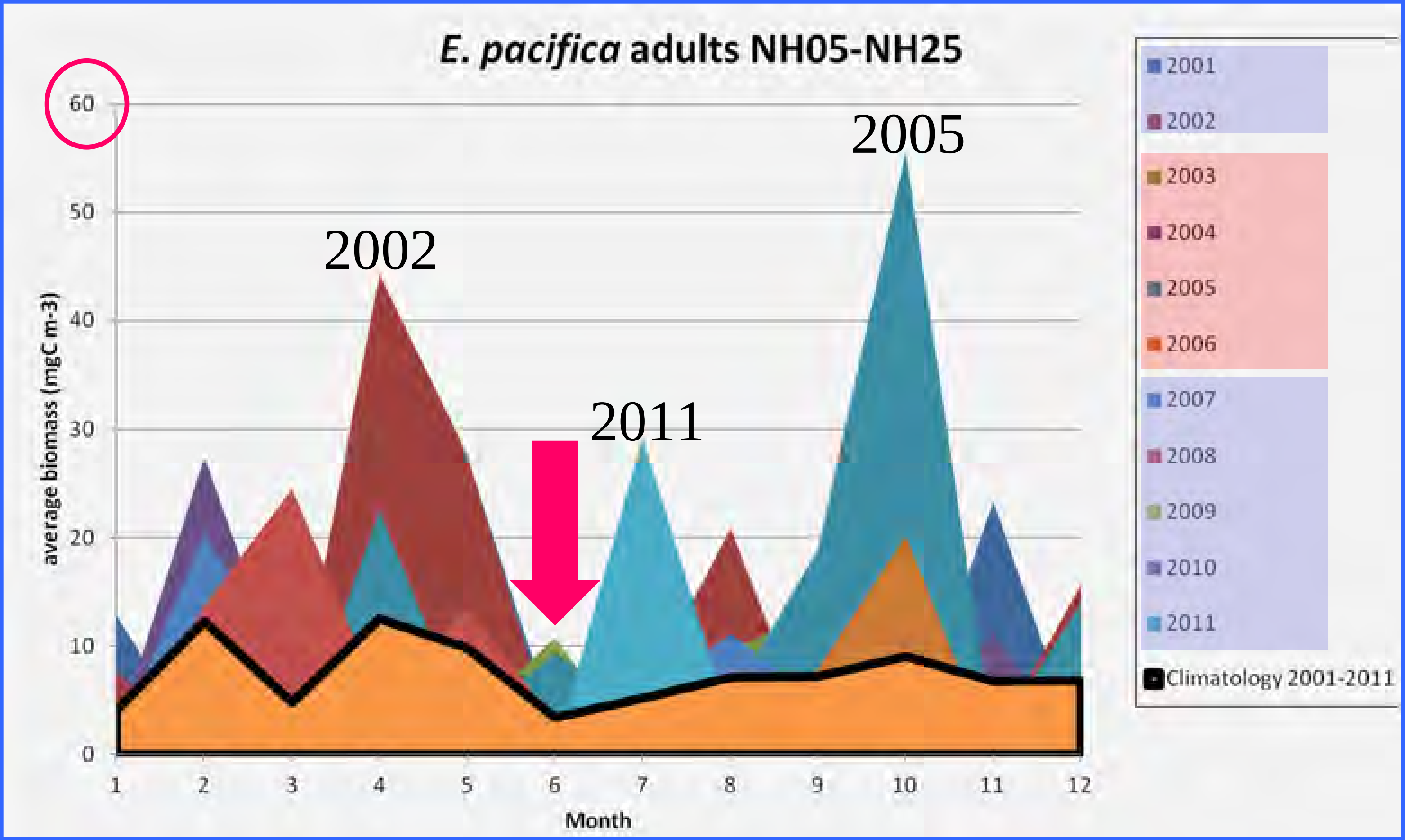
CUI


Cumulative Upwelling Index m3 s-1 100m-1
Mar-May
Sept.-Nov.
10000
5000
0
-5000
-10000
-15000
-20000
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
2012
2011
2010
2009
2008
2007
2006
2005
2004
2003
2002

Ocean Conditions

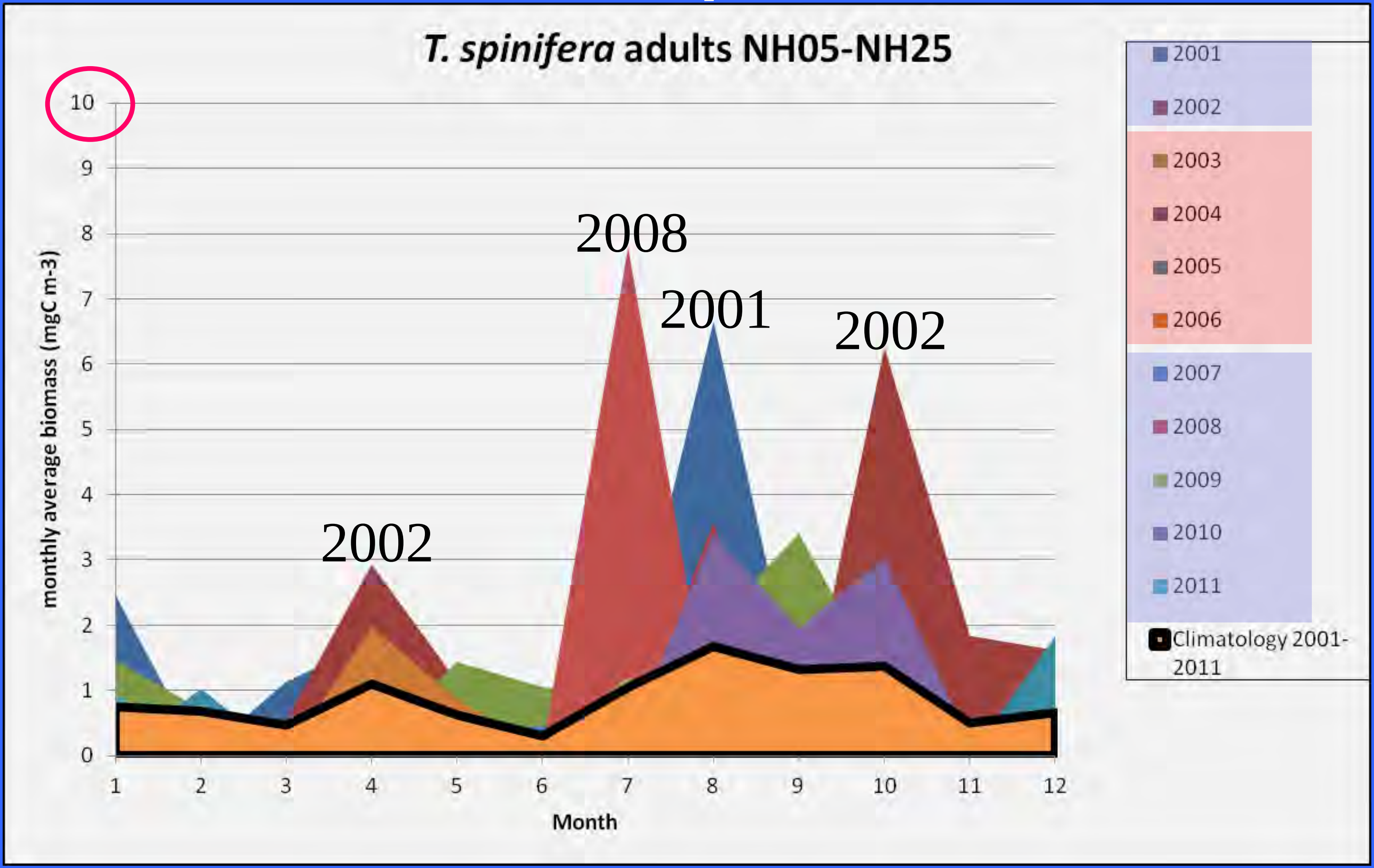
Year	Spring transition (ST)	Fall transition (FT)	Duration of upwelling (mo)	Ocean temp. (PDO phase)
2001	2-Mar	12-Nov	8.5	Cool
2002	21-Mar	6-Nov	7.7	Cool
2003	22-Apr	15-Oct	5.9	Warm
2004	20-Apr	7-Nov	6.7	Warm
2005	25-May	29-Sep	4.2	Warm
2006	22-Apr	31-Oct	6.4	Warm
2007	15-Mar	27-Sep	6.5	Cool
2008	30-Mar	24-Oct	6.9	Cool
2009	8-Mar	6-Oct	7.1	Cool
2010	9-Apr	13-Oct	6.2	Cool
2011	31-Mar	16-Sept	5.6	Cool

Biomass – *E. pacifica* adults



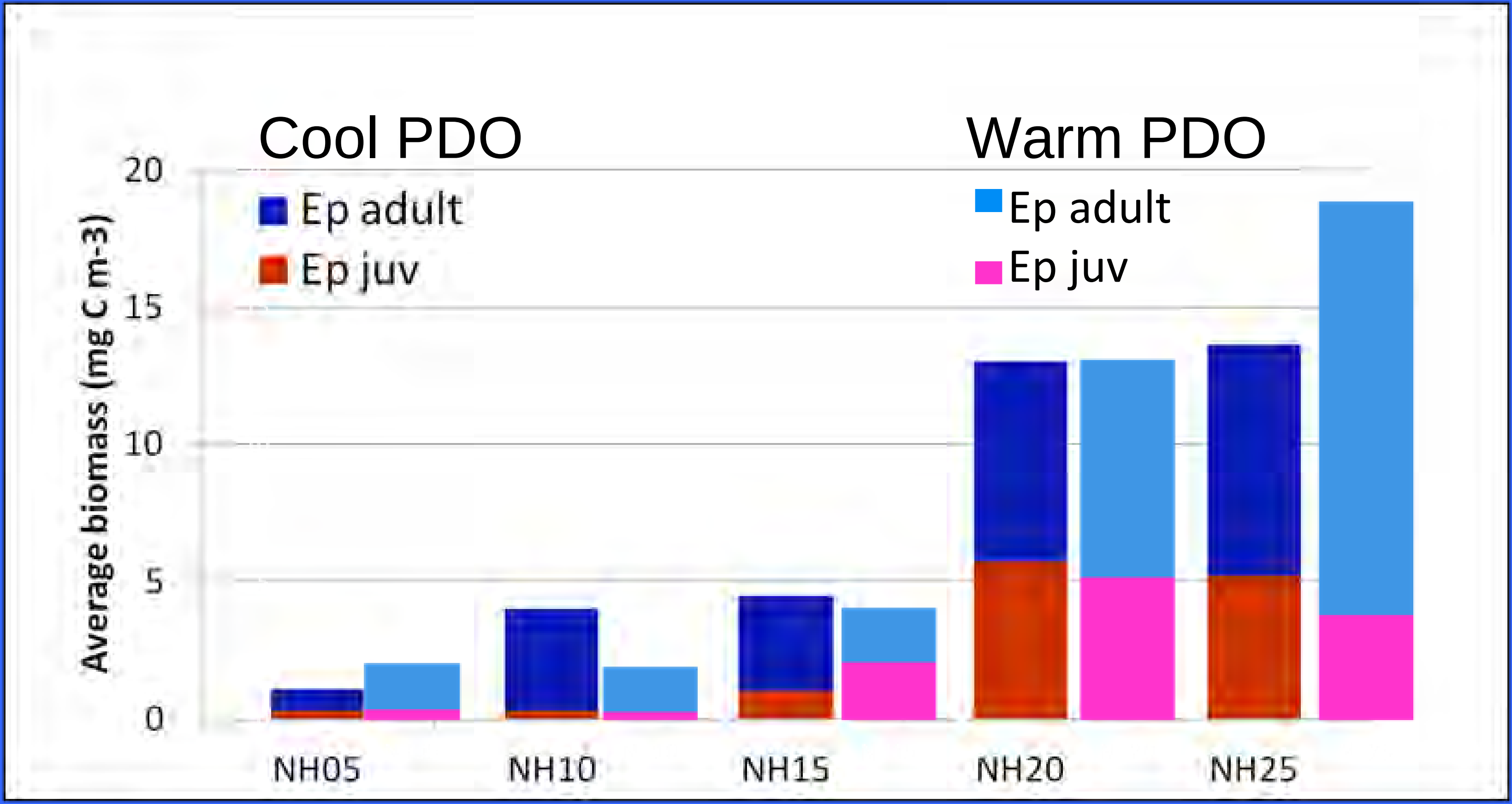
- Climatology ~10 mgC m^{-3} carbon year-round
- High interannual variability
- Lowest biomass consistently in June
- Always present in all years, high biomass can occur in both cool and warm years

Biomass – *T. spinifera* adults



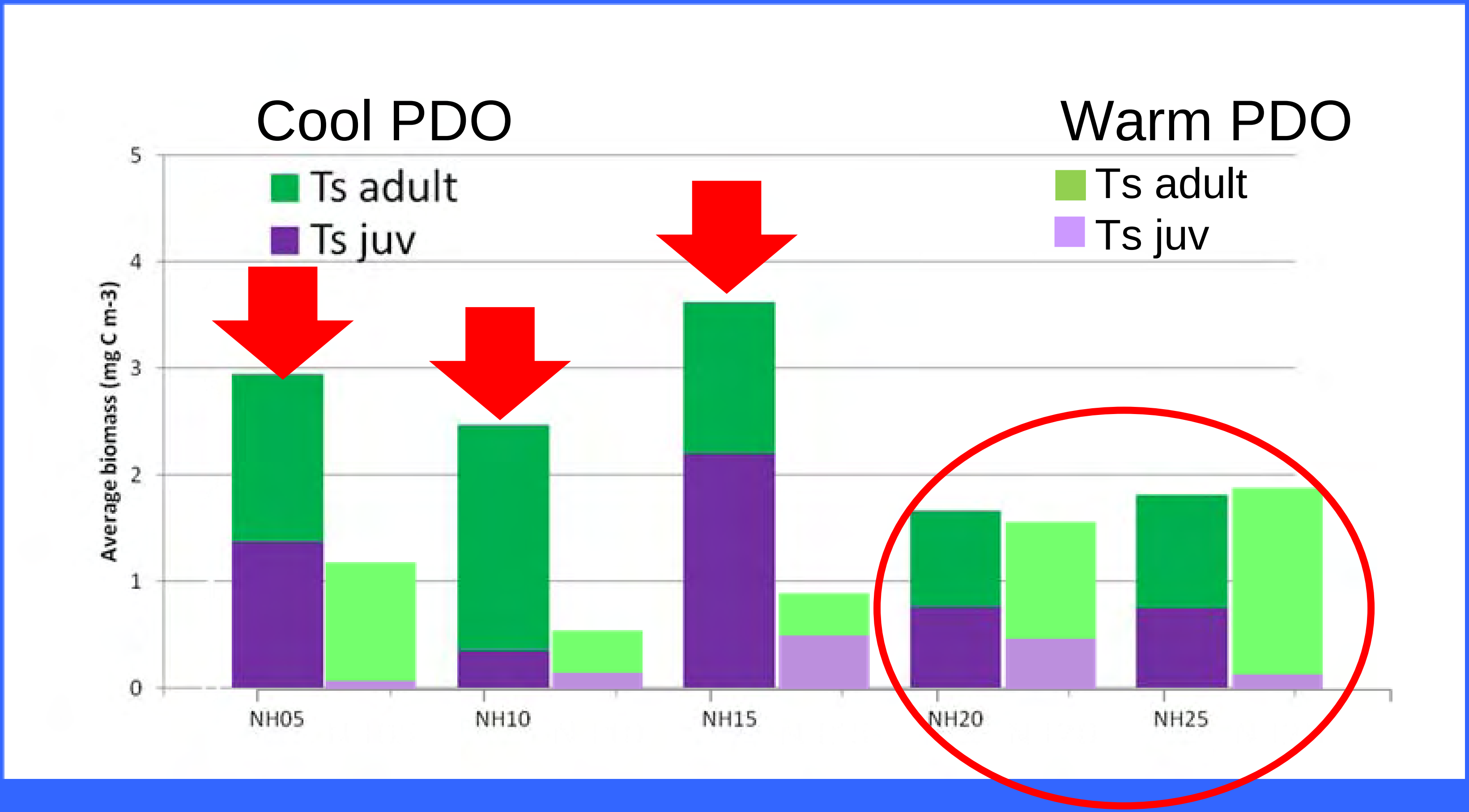
- Climatology ~1 mgC m^{-3} year-round
- High interannual variability
- Higher biomass values occur in cold years
- Rare in warm years

E. pacifica cross-shelf biomass
cool vs. warm PDO



Cross-shelf biomass essentially the same for cool and warm PDO

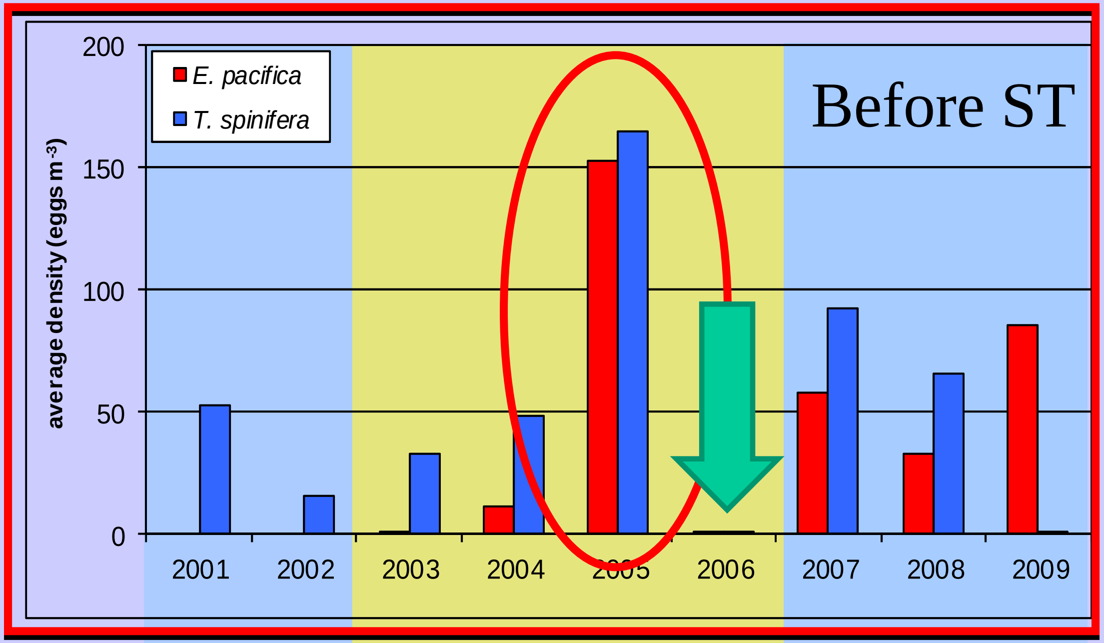
T. spinifera cross-shelf biomass
cool vs. warm PDO

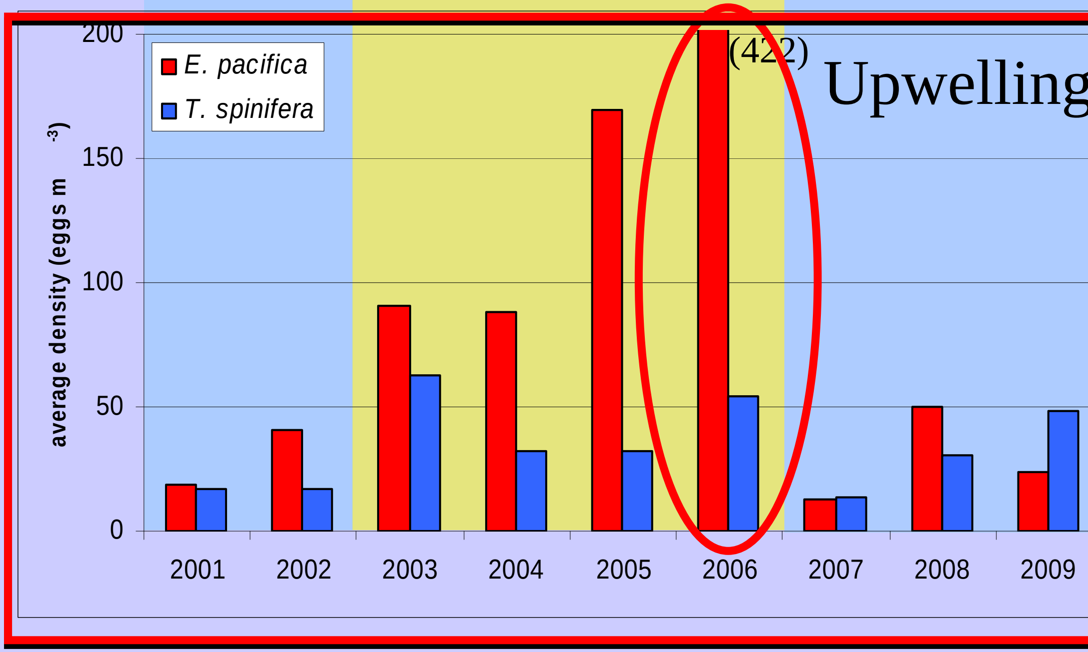


- Biomass offshore essentially the same for cool and warm PDO
- Biomass inshore decidedly higher during cool conditions

Egg Densities

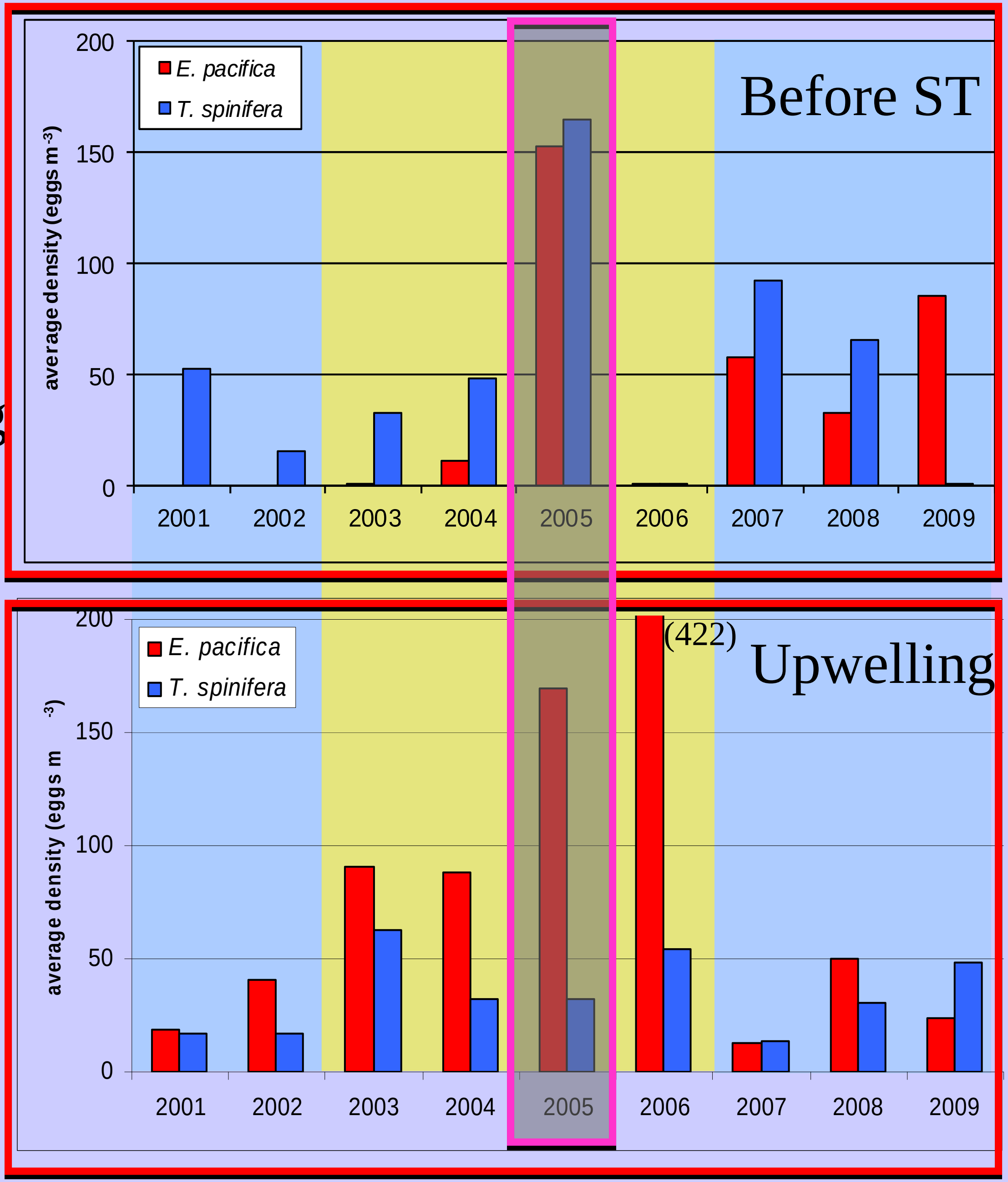
- Before spring transition:
    - Generally more Ts eggs than Ep eggs
    - 2005 high spawning effort by both spp.
    - 2006 no effort at all
- Upwelling:
    - 2006 huge spawning effort by Ep & fairly high for Ts also
    - Ep eggs higher 2003-2006 (warm)
    - Ts eggs always present, generally less abundant than Ep eggs





Egg Densities

- 2005:
  - Upwelling started late and ended early
  - High density of Ep eggs before and during upwelling
  - What was the fate of the resulting larvae?



Juvenile Detection Dates

Year	Early Season	Later Season
2001	27-Jan	20-Mar
2002	27-Mar	30-May
2003	9-Jan	16-Apr
2004	2-Mar	10-May
2005	5-Feb	27-Apr & 30-Aug
2006		16-Apr & 15-June
2007	12-Jun	30-Aug

- Dates when we first see juveniles that we can track as cohorts
- Start dates early season cohorts suggest that these krill have overwintered as juveniles or immature adults
- Absence of early season cohort in 2006 suggests low survivorship after late 2005 spawning; high effort, low return

Relationship between spring transition and *E. pacifica* spawning

Spring transition → ~4 months → Peak in euphausiid egg density → ~2 months → Juveniles

- Consistent pattern regardless of environmental conditions
- *E. pacifica* spawning behavior is highly dependent on upwelling and the associated phytoplankton blooms
- Changes in upwelling off the Oregon coast are likely to affect *E. pacifica* spawning behavior

Summary of Environmental Responses

- *E. pacifica* **Mainly influenced by: upwelling**
  - Biomass similar among cool and warm years
  - Spawning closely tied to timing of spring transition and upwelling
  - Late spring transition + short upwelling season = low overwinter survivorship of juveniles
- *T. spinifera* **Mainly influenced by: PDO**
  - Biomass generally low, higher values only in cool years
  - Spawn before & during upwelling, no peak period
  - 2002: Found far offshore in relation to cold conditions

Species-specific impacts

Euphausia pacifica

Spawn in response to upwelling & subsequent phyto bloom

Delayed upwelling = delayed spawning & possible reduced survivorship & recruitment

Lifespan ~2 years. Two or more years of low recruitment could mean a substantial decline in abundance

Reduced Ep = reduced food supply for some seabirds and commercially important fish

Thysanoessa spinifera

Rare or absent during warmer years

Consistently warmer water = change in distribution, further north or offshore to cooler water

Reduced numbers = fewer krill spawning on shelf and possibility of lower recruitment

Important food source for some nesting seabirds since usually found closer to shore. Longer foraging trips = reduced fledging success.

Bering Sea – sea ice dependent

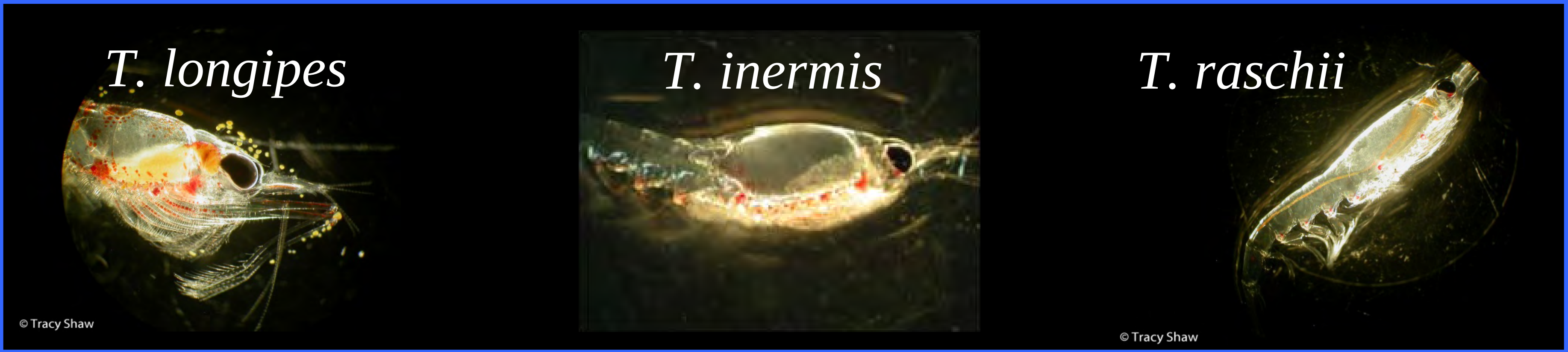
- Oceanic
- Mainly carnivorous
- Spawning – not well known in Bering Sea, April-May in other areas

- Outer shelf & shelf break
- Omnivorous
- Store energy over the winter to fuel reproduction in early spring
- Short spawning season

- Shelf
- Mainly herbivorous
- Spawn later in spring based on ambient food supply
- Prolonged spawning season (depending on available food)

Change their distribution in relation to temperature (Pinchuk & Coyle 2008)

Bering Sea – sea ice dependent



- Based on this information, how would you model "krill" in the Bering Sea?

well known in Bering Sea, April-May in other areas

- Store energy over the winter to fuel reproduction in early spring
- Short spawning season

spring based on ambient food supply

- Prolonged spawning season (depending on available food)

Things we wish we knew...

- How quickly can krill adapt to increasing temperatures?
- Are there multi-year effects? How might a longer series of warm or cold years affect krill that live for 2+ years?
- How will changes in ocean conditions affect availability and abundance of preferred food sources for krill?
  - What are the preferred prey items for these species?
  - How well might krill adapt to a different prey field?
- Mortality rates? How can we tell if the rates change in relation to environmental conditions if we don't know what they are now?
- Will increased numbers of jellyfish eat all the krill eggs?
- Given that different species of krill in the same ecosystem respond differently to changes in the environment, how feasible is it to incorporate species-specific krill responses into models?

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PDO graph courtesy of Tom Wainwright, NOAA
CUI graph courtesy of Jay Peterson, OSU