Use of egg production of adult female copepods[a] as a measure of secondary production

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[a] Won't be talking about euphausiids at all = just too much information but…..they are very different.

Secondary Production

- Secondary production = the amount of mass produced per unit time.
- Mass can be in terms of weight, carbon, protein or other biochemical measure
- Production by females = eggs by adult females because it assumed that most of their daily "growth" appears as eggs;
- Production by males = sperm, but not measured
- Production by juveniles = molting rate
- Usually done with living animals where a set of individuals are incubated for a set amount of time (24 h)
- Cannot use the "egg-ratio" method due to high mortality of eggs

Egg Production

- Does growth (due to egg production) equal growth of juveniles? *Acartia* vs. *Calanus*
- Is egg production dependent on food? If so, are their functional relationships between “food” and “growth” (as eggs)?
- Can egg production serve as a proxy for secondary production (i.e., is it high in “good years” and low in “bad years”, with “good” and “bad” defined in some reasonable way.
- Show examples of published work as well as recent unpublished studies on *Calanus marshallae* and *Calanus pacificus*

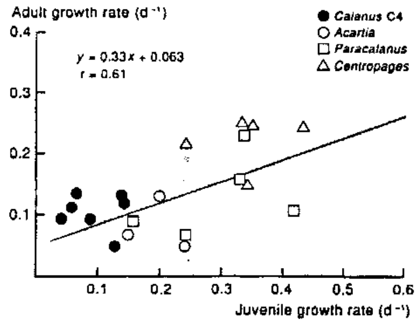


Fig. 9. Relation between adult female growth rates (Y) and juvenile growth rates (X).

W.T.Peterson, P.Tiselius and T.Kiørboe

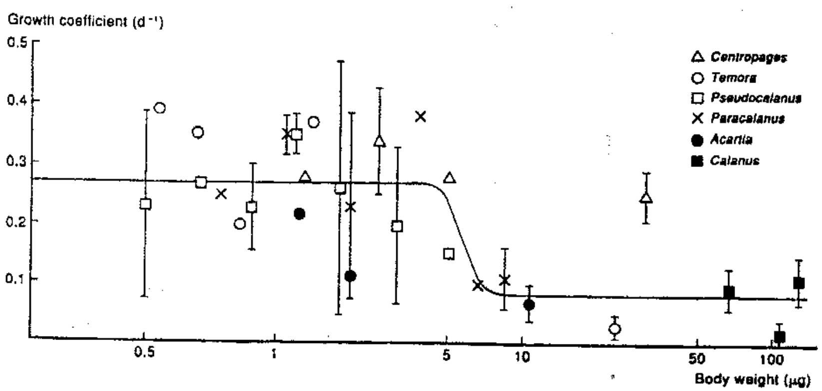


Fig. 10. Relation between growth rate, day^{-1} (Y) and body size, µg dry weight (X). Standard errors are shown where sample sizes were greater than $n = 3$.

Denmark - Skaggerak

- Growth vs body weight
- Adult growth vs juvenile growth

Max growth rate vs. body weight: Agulhas Bank

W.T.Peterson and L.Hutchings

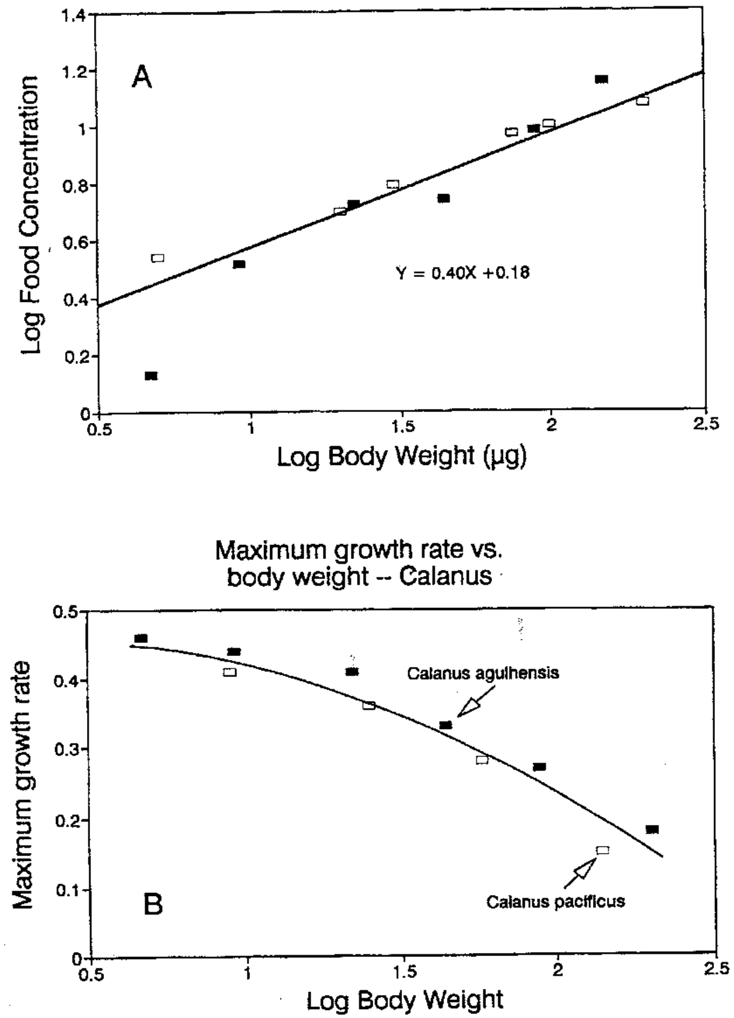


Fig. 8. **(A)** Food concentration at which maximum growth rates were observed as a function of body size, for *C.agulhensis* and *C.pacificus*. One data point was excluded from the regression (0.67, 0.13). **(B)** Relationship between maximum specific growth rate and body weight, showing that smaller (younger) developmental stages of *Calanus* have a higher maximum specific growth rate than larger (older) developmental stages of *Calanus*. The log–linear relationship was log $Y = 2.03 \log X - 0.08$ ($R^2 = 0.93$).

South Africa Upwelling

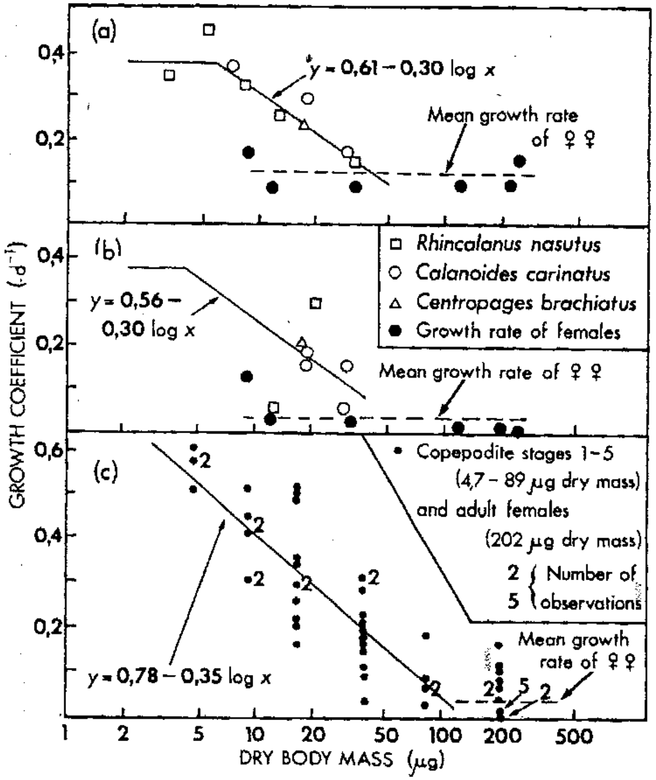


Fig. 10: Relationships between copepod growth rate and body size for copepods from (a) large-cell stations (b) small-cell stations and (c) *Calanus australis* from the Agulhas Bank. The identity of data points for females of each species can be deduced from Tables IV and VI. The regression line in (b) was based on the assumptions that (i) a linear relationship is appropriate, (ii) the line should pass through the mean of the observations ($x = 0{,}16$, $y = 21$) and (iii) the maximum growth rate was 0,37, as measured at the large-cell stations

- Growth vs body weight
- Adult growth vs juvenile growth

Calanus agulhensis on Agulhas Bank

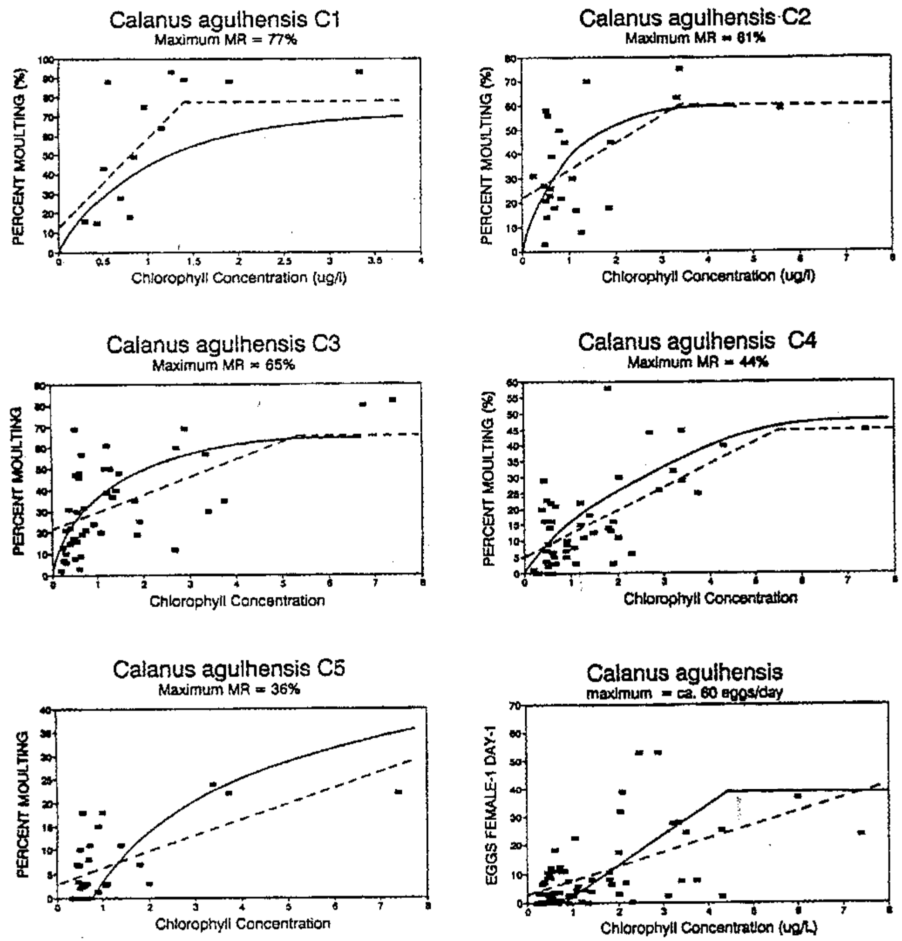


Fig. 7. Scattergrams of moulting rate (MR) versus chlorophyll (CHL) concentration. Maximum moulting rates (and maximum egg production rate) are given in the header of each panel. Curves are Ivlev functions of growth rate versus food concentration from Vidal (1980) for *C.pacificus*. Straight lines are linear regressions of *C.agulhensis* MR on CHL for stages C1–C5 for MR < maximum MR shown for each stage. Horizontal lines are maximum moulting rates, from Peterson and Painting (1991).

South Africa Agulhas Bank *Calanus agulhensis*

- Growth as a function of chlorophyll concentration

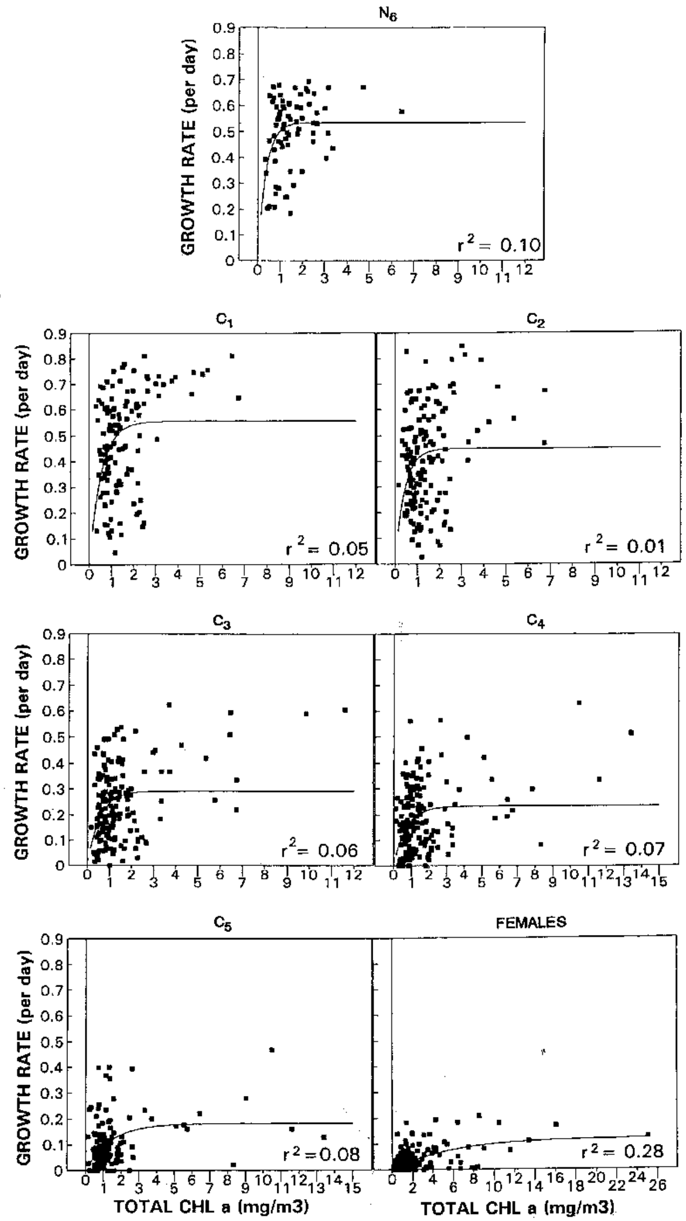


Figure 13. P : B ratios (d^{-1}) vs total Chl *a* (mg m^{-3}) for each stage. Ivlev curves fitted to each series indicate a significant correlation but poor predictability, and maximum rates are underestimated by the regression line.

South Africa
Agulhas Bank
Calanus agulhensis

- Growth as a function of chlorophyll concentration

South Africa Agulhas Bank

Calanus agulhensis

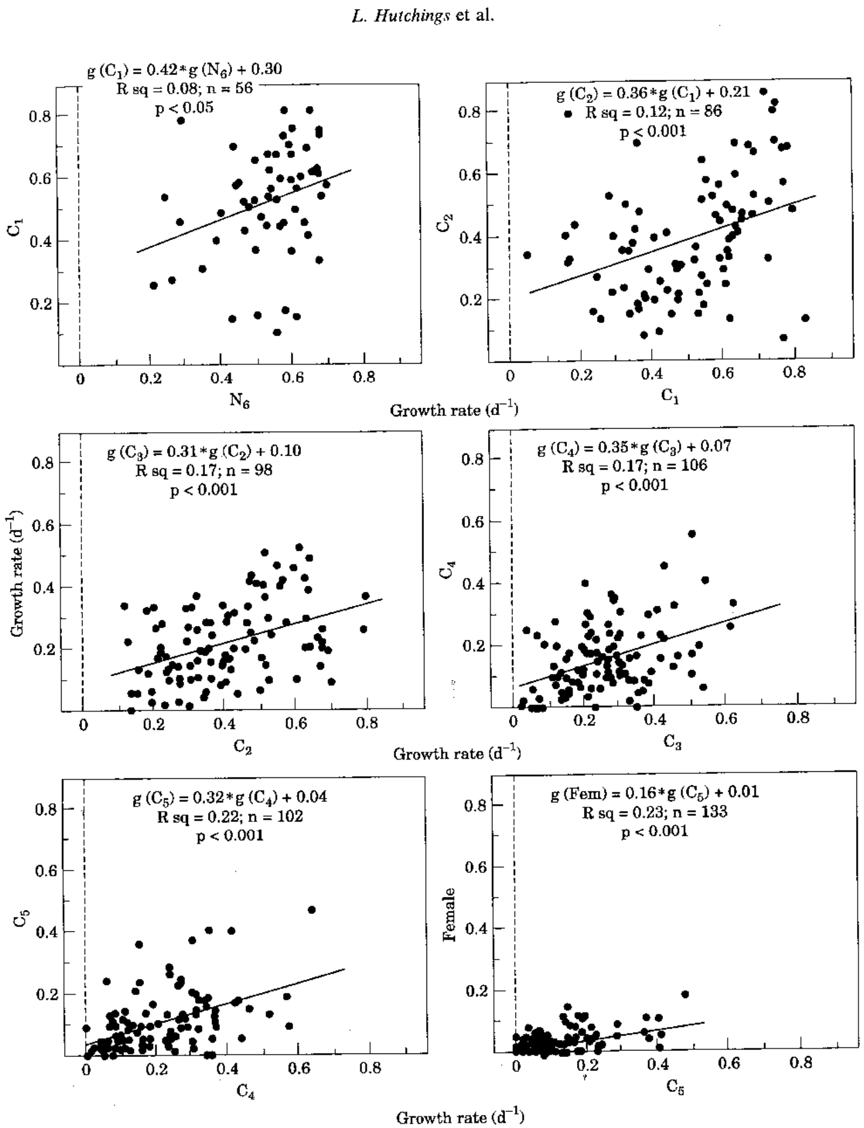
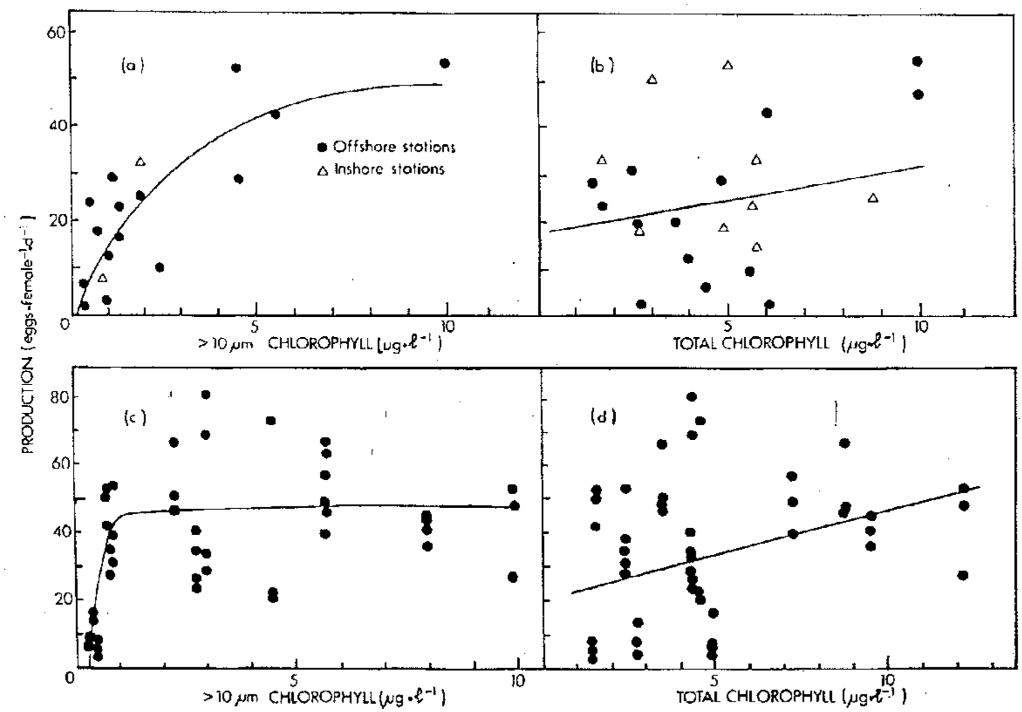


Figure 11. Relationships between growth rates of different stages. r^2 increase with stage, but are generally low.

- Growth between adjacent stages compared

Egg production vs total and size-fractionated chlorophyll: Long Island Sound and Dichato Chile



ig. 7: Scattergrams of egg production against chlorophyll concentration for (a) and (b) *Temora longicornis* and (c) and (d) *Acartia tonsa* in Long Island Sound. For *A. tonsa* the rates are obtained with *in situ* temperatures > 17° C. Data from 30 October and 7 and 20 November shown in Figure 6 are not included because low temperatures rather than food concentration probably limited fecundity on those days

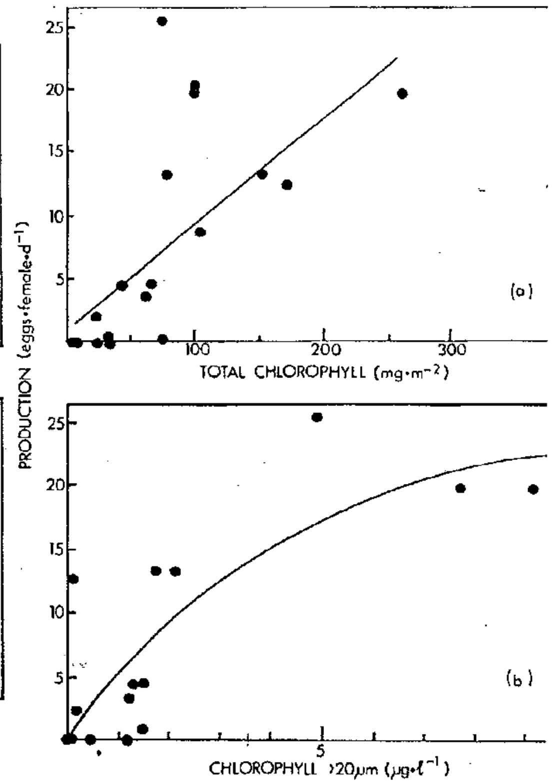
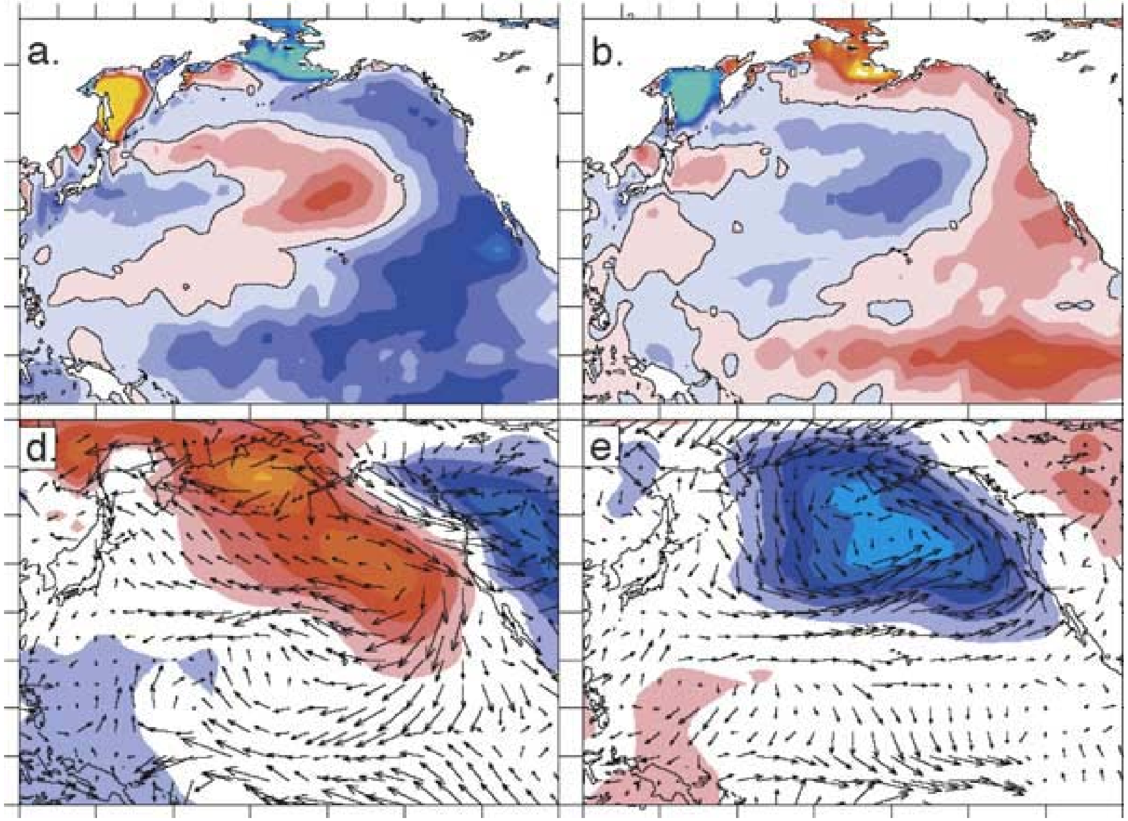


Fig. 11: Scattergrams of fecundity of *Calanus chilen* against chlorophyll concentration for (a) total chlo phyll and (b) the > 20 μm size fraction

Remainder of talk on our work with egg production of female *Calanus marshallae* and *Calanus pacificus* in the upwelling zone off Oregon

Sea Surface Temperature and PDO Pattern

Negative Phase   Positive Phase

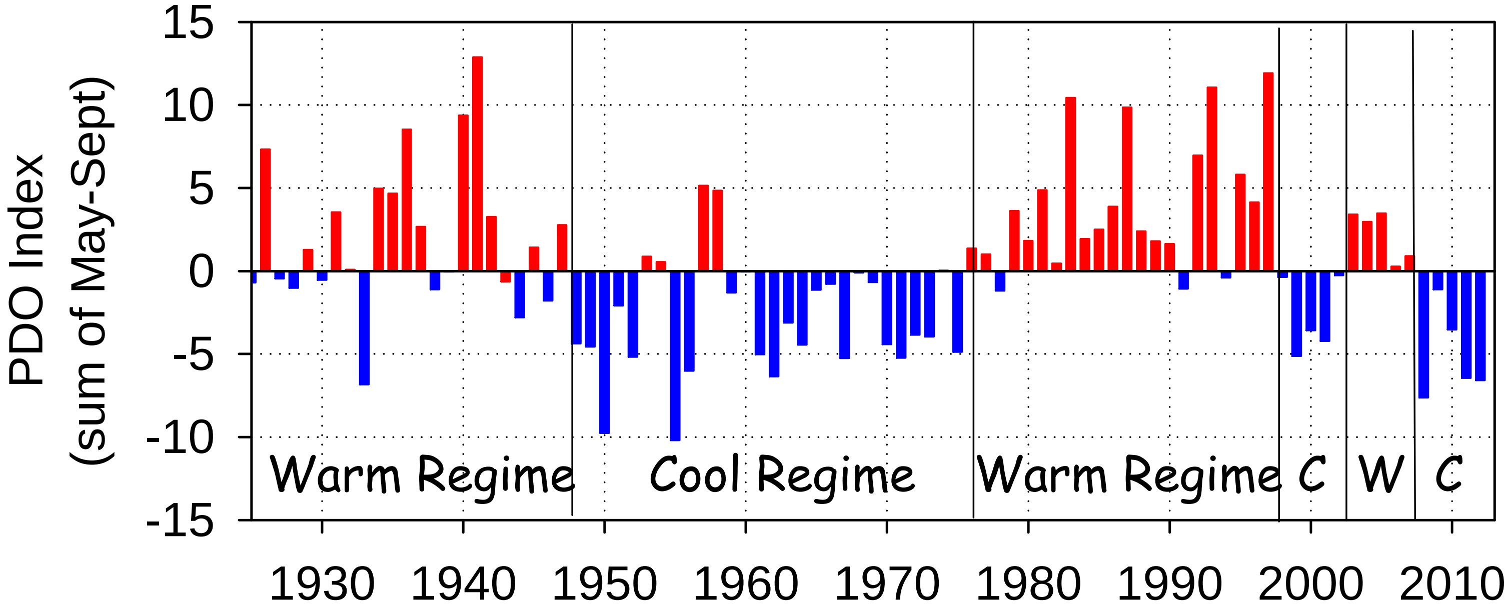


Charts from NOAA/NCEP

Colors (upper) are SST Patterns; colors (lower) are atmospheric pressures; arrows are the winds

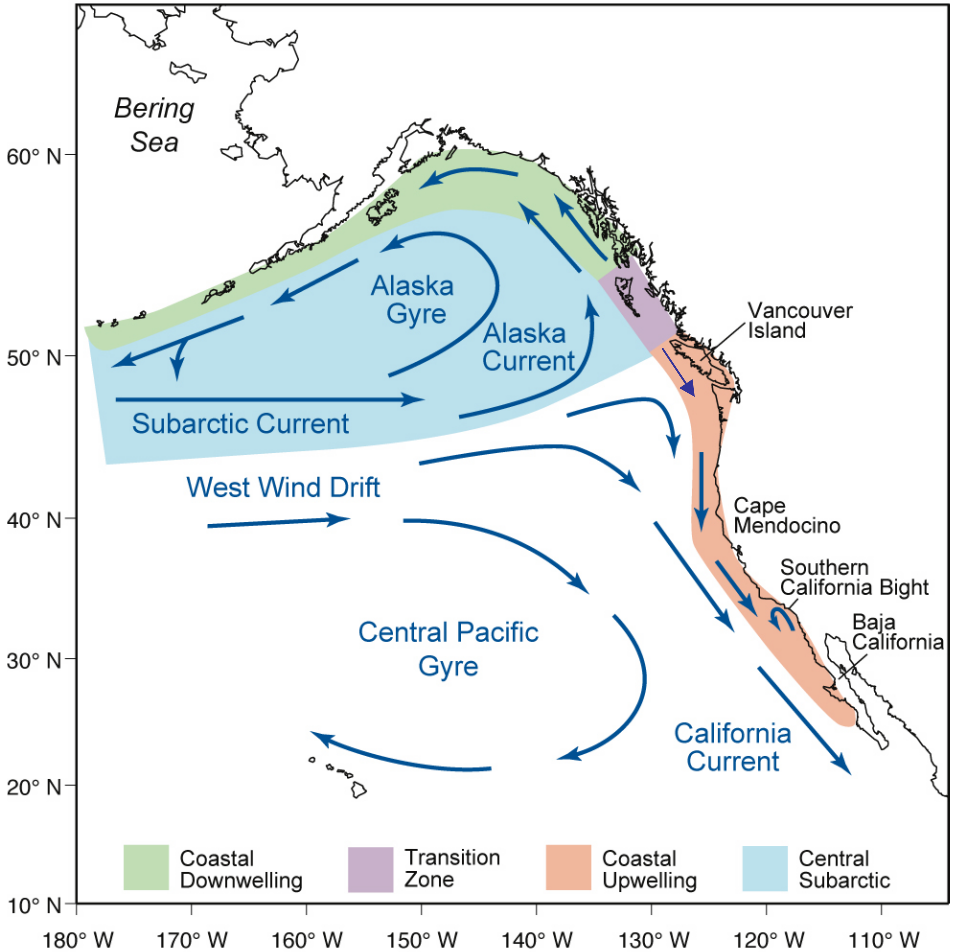
[from Peterson and Schwing 2003 GRL]

PDO: May-Sep Average, 1925-2012



- From 1925-1998, PDO shifted every 20-30 years. Some refer to these as "salmon" regimes (cool) and "sardine" regimes (warm).
- However, we have had two shifts of four years duration recently: 1999-2002 and 2003-2006, and another shift in late 2007, thus we have a natural experiment to test the affects of PDO on marine food chains and salmon populations.
- Note 2008: most negative PDO since 1950, but 2011 and 2012 have also bee quite negative;

Circulation off the Pacific Northwest



Subarctic Current brings cold water and northern species to the N. California Current;

The West Wind Drift brings subtropical water and subtropical species to the N. California Current

Therefore, ecosystem structure is affected by the source waters which feed the California Current.

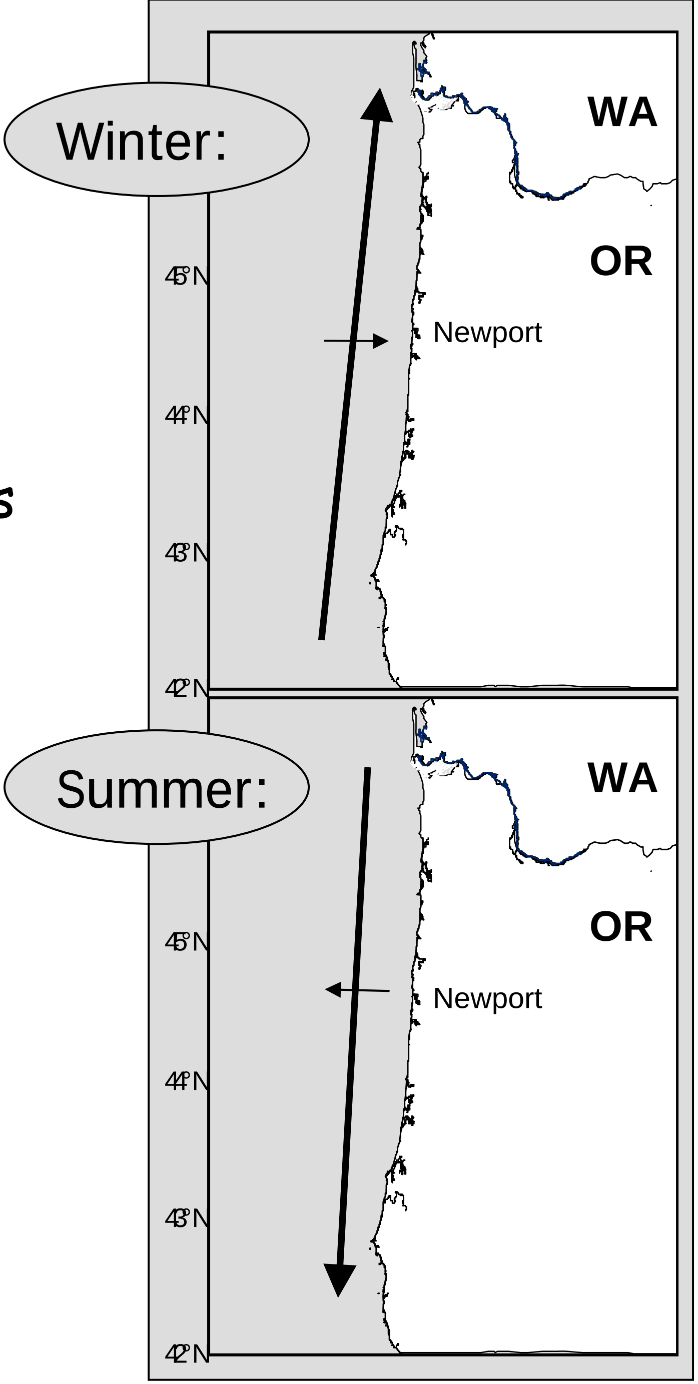
5. Seasonality of winds and current structure off Oregon:

- Winter:
  - Winds from the South
  - Downwelling
  - Poleward-flowing Davidson Current
  - Subtropical and southern plankton species transported northward & onshore
  - Many fish spawn at this time

•Spring Transition in April/May

- Summer:
  - Strong winds from the North
  - Coastal upwelling
  - Equatorward alongshore transport
  - Boreal/northern species transported southward

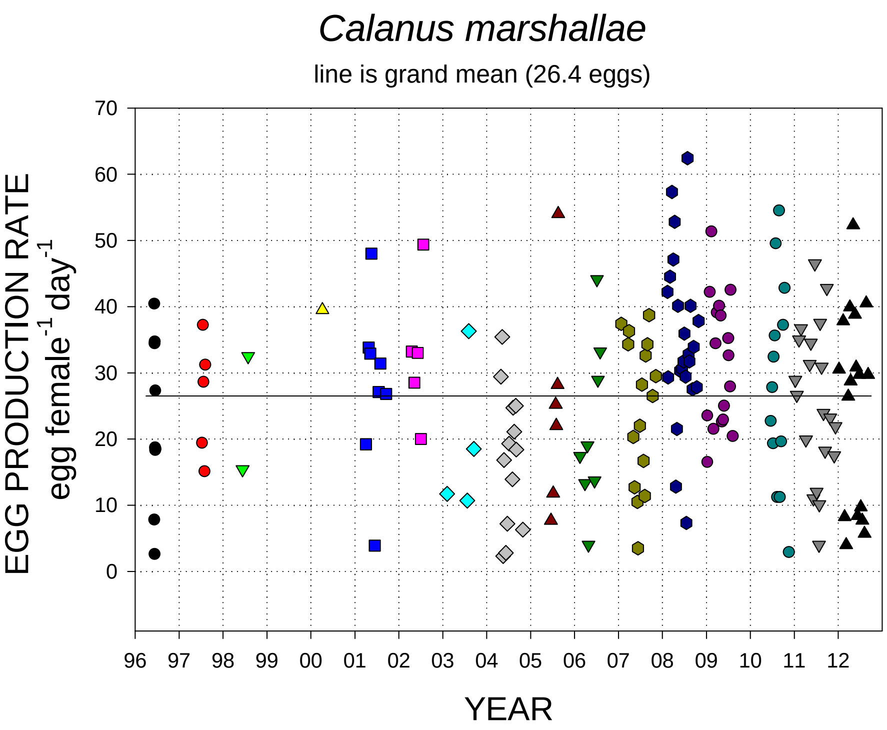
•Fall Transition in September/October

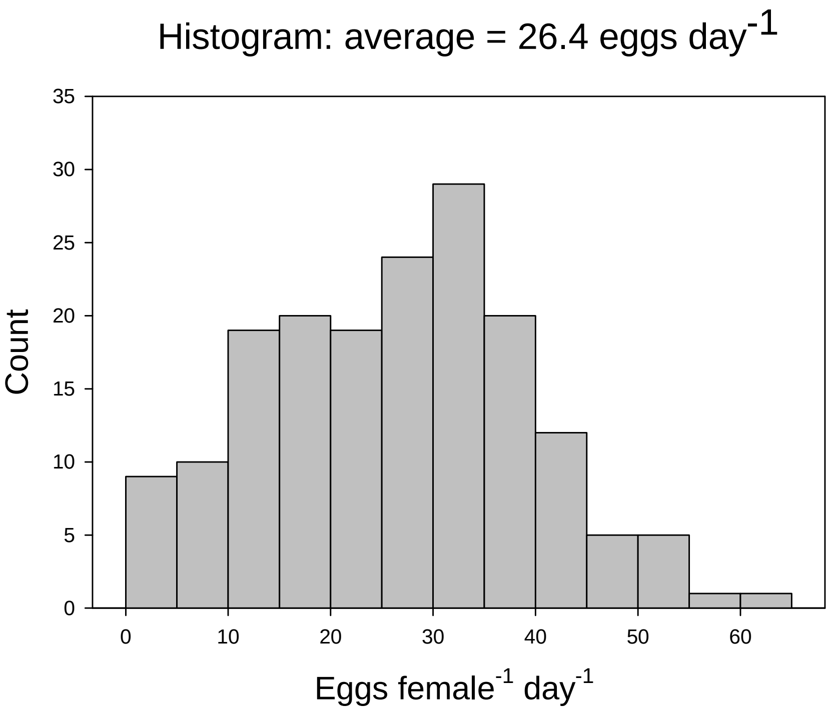


Sampling Program

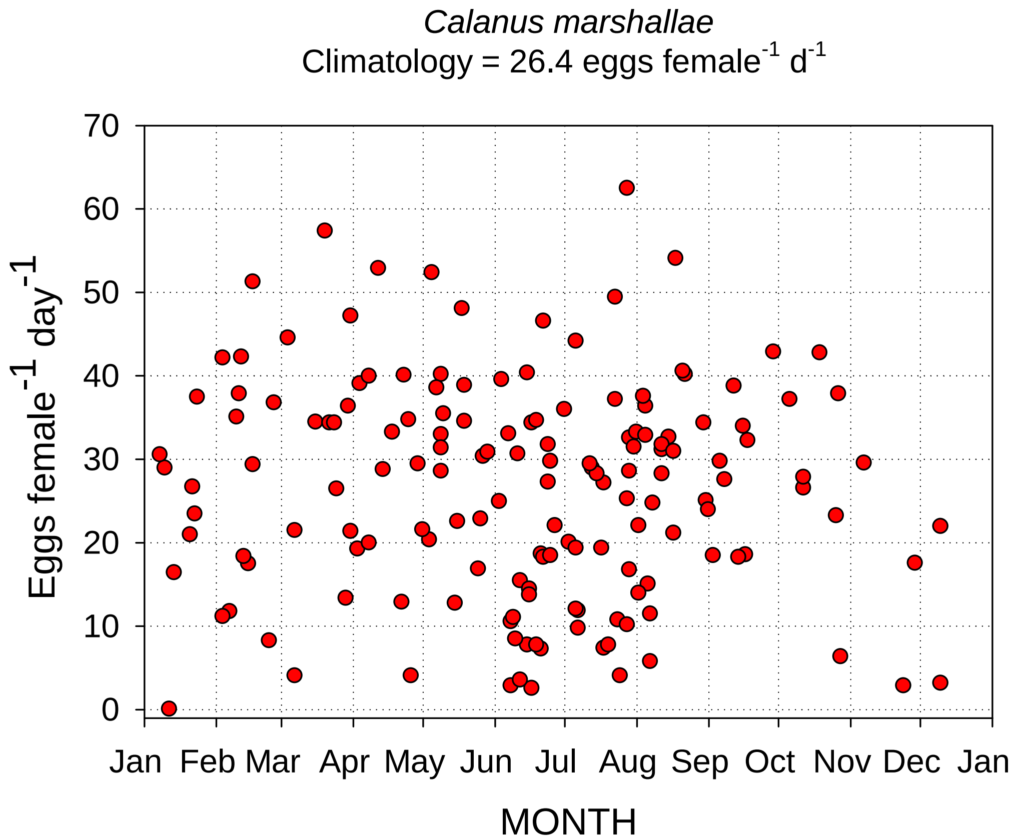
- Go to sea from Newport every two weeks, since 1996.
- Sample copepods with 200 μm mesh ½ m diameter nets towed vertically
- Sample krill at night with 50 cm Bongos with 333 mesh
- Incubate female *Calanus marshallae* and female *Euphausia pacifica*

Egg production by year n = 175 incubations *Calanus marshallae*



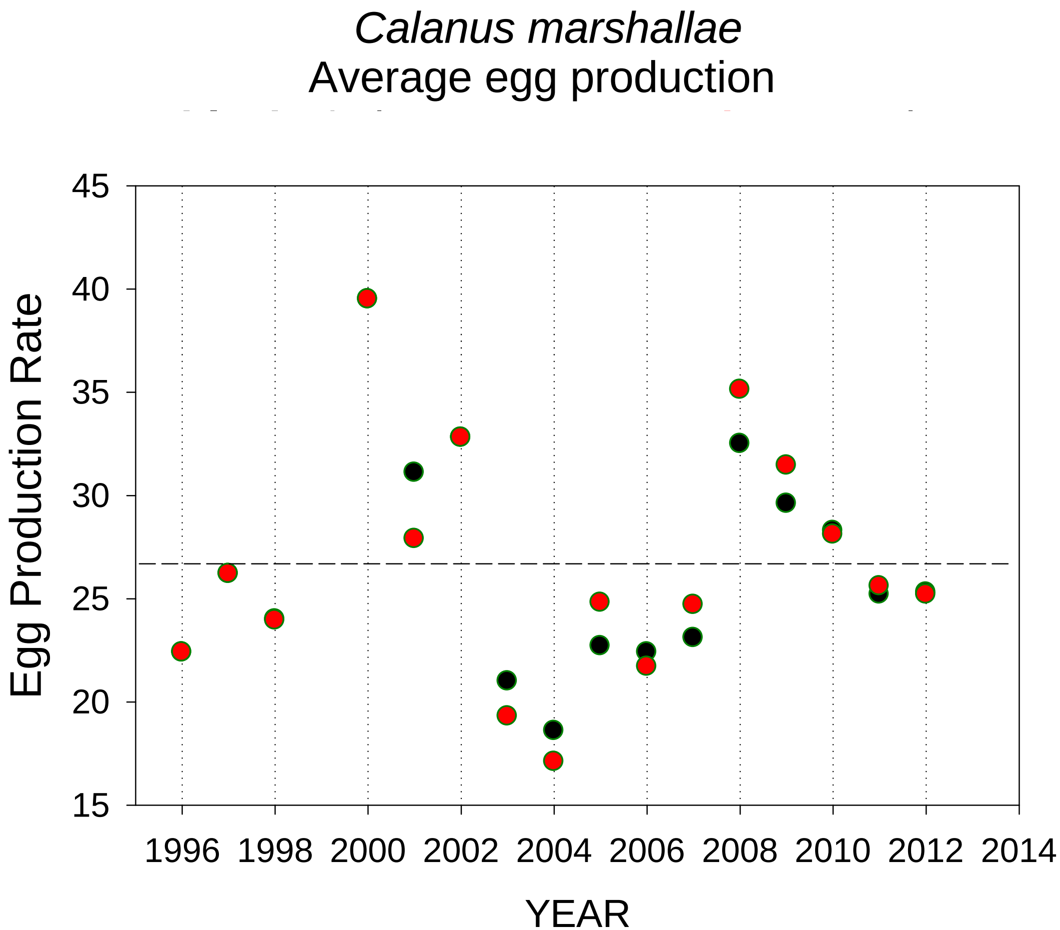


Climatology



- Produce eggs in winter and summer at similar rates
- Jan < 40 eggs female^{-1} d^{-1}
- Feb-Sep 40-60 eggs are common values
- Most females enter diapause in September but in some years, females persist into the winter.
- Produce 4-5 generations per year

Annual & Upwelling Season Average

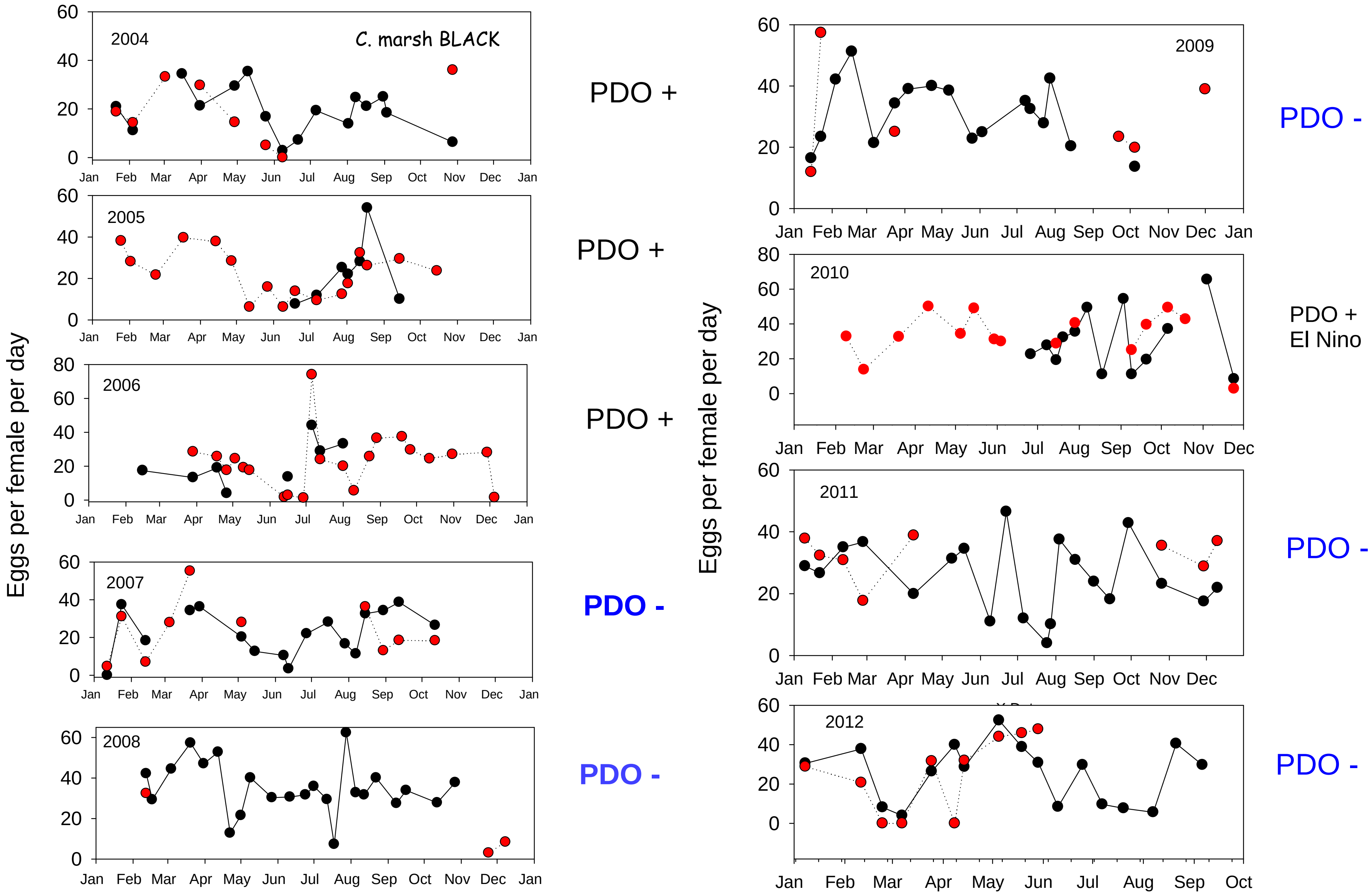


- Black = summer
- Red = annual
- Averages similar among years and among seasons
- Upwelling does not enhance egg production but allows it to happen
- NOTE: Dabob Bay WA: *C. marshallae* enter diapause in May

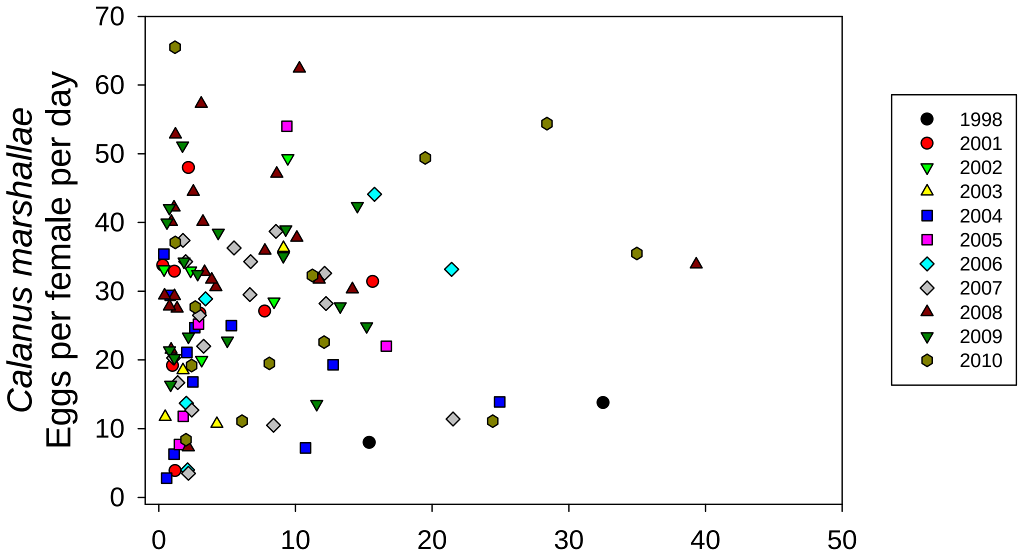
Interested in congeneric *Calanus*

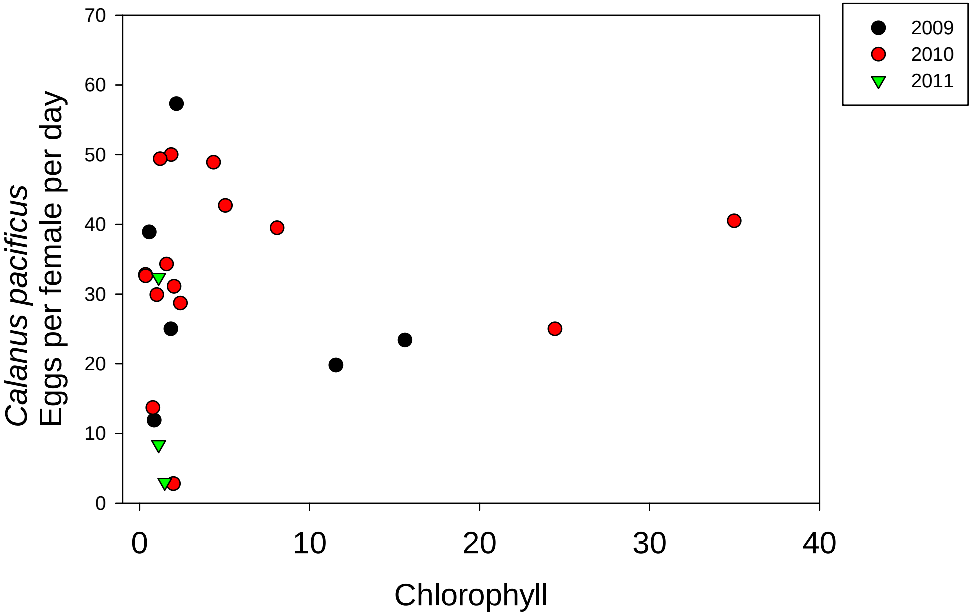
- *Calanus marshallae* and Calanus pacificus co-occur during winter and during greater proportions of the year when the PDO is in positive phase.
- We also incubate female *C. pacificus* when present to compare egg production with *C. marshallae*.
- Why is that?
- What limits the presence of *C. pacificus* in the Oregon upwelling zone to conditions associated with warm phase?
- What aspects of food quality determines egg production rates?

Calanus marshallae and ***C. pacificus***

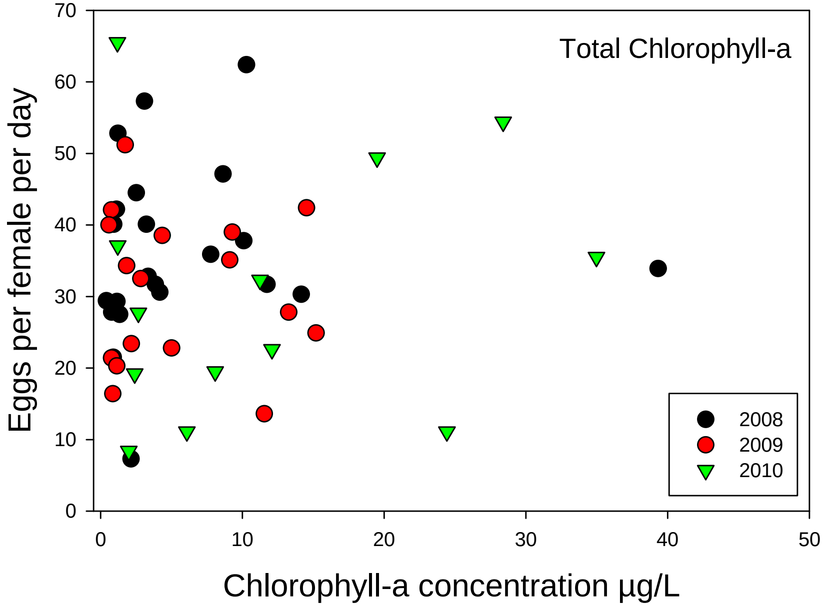


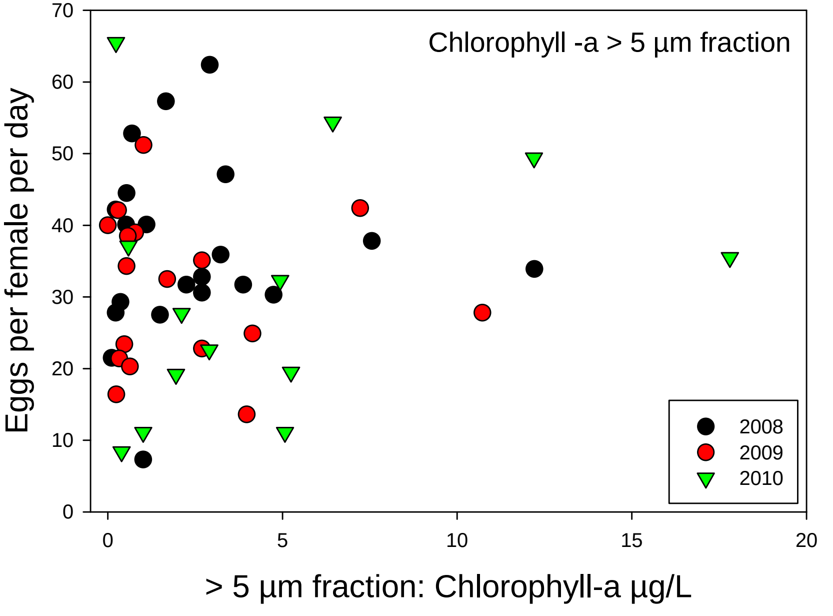
C.marshallae and *C. pacificus*



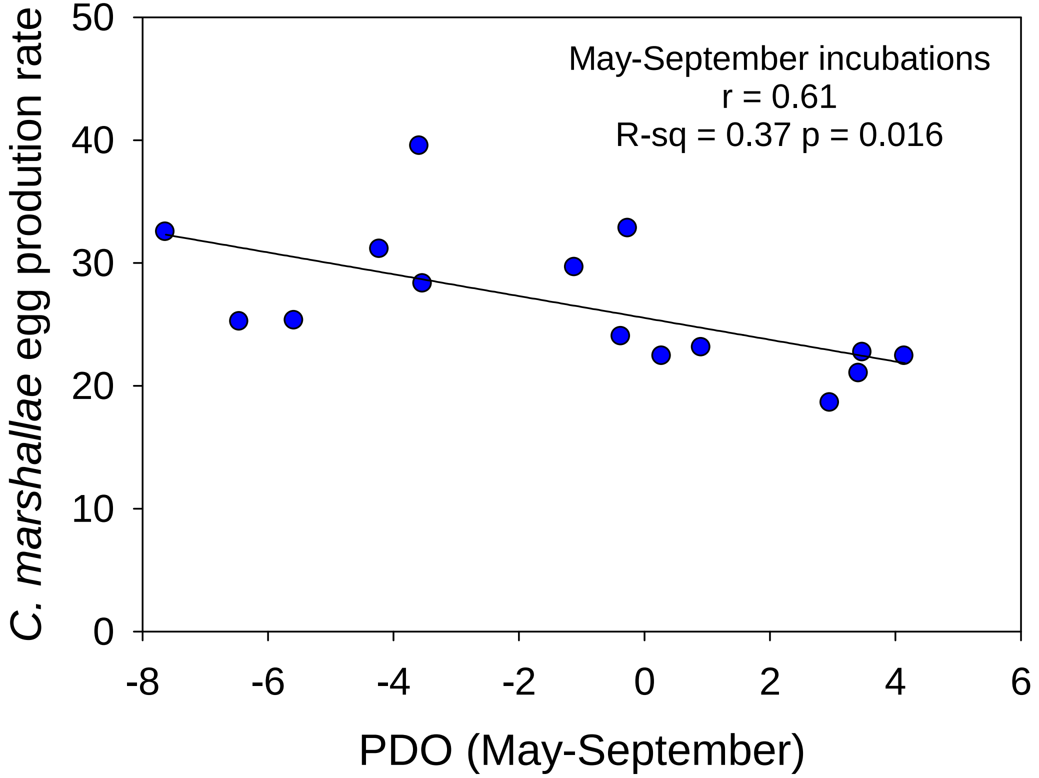


Egg production vs total chlorophyll and the > 5 µm size fraction





PDO seems to explain EPR



Food Quality

- Phytoplankton species (dominance): have counts from 2001-2007 but have not looked at the data yet
- Wonder if phytoplankton carbon is useful?
- Wonder if phytoplankton protein and carbohydrate content is useful?
- Wonder if any of our phytoplankton data are useful because maybe *Calanus* prefer ciliates?

Quote: Larry Hutchings, offered for discussion purposes

Why Bother?

Calanus marshallae: growth in the laboratory

68 Mar. Ecol. Prog. Ser. 29: 61–72, 1986

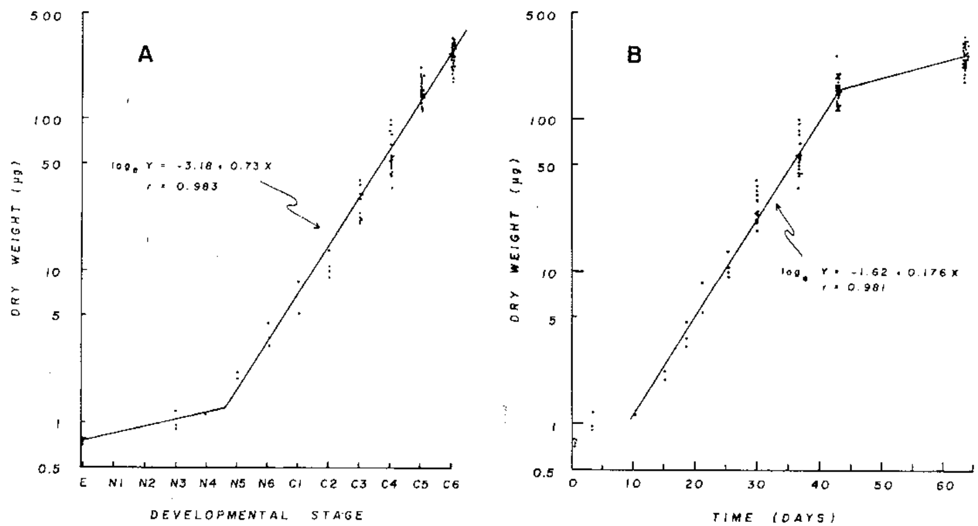


Fig. 7. *Calanus marshallae*. (A) Change in weight with developmental stage. (B) Change in weight with time. Three linear growth phases are seen: (1) from Day 0 to Day 10 (Egg to N4); (2) from Day 10 to Day 43 (N4 to C5); (3) from C5 to female. Specific growth rate from N4 to C5 was 0.176 μg μg^{-1} d^{-1}

- Thalassiosira weisflogii
- Re-do with Rhodomonas?
- Re-do with a mixture of foods