Life history of *Euphausia pacifica* in the northern California Current: what can be learned by contrasting field and laboratory studies

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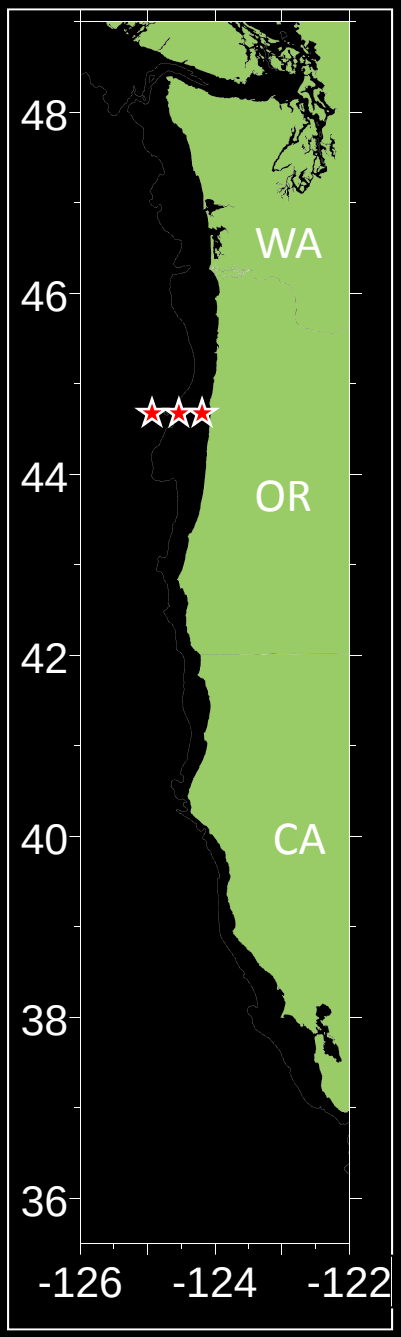
Background

- **Rare opportunity to study euphausiids!**
- 15 years, bi-weekly time-series of zooplankton and hydrographic data off Newport, Oregon, USA
  - Day time vertical nets (200µm)
  - Night time bongo nets (333µm) since 2001
- 11 years of experimental work on euphausiids in the northern California Current
  - Development
  - Growth
  - Reproduction
  - Feeding
- Thanks to GLOBEC NEP, ONR, NASA, NSF, SAIP, NOAA-NWFSC and the persistence of Bill Peterson



Meet *Euphausia pacifica*

Russia

Alaska

Canada

China

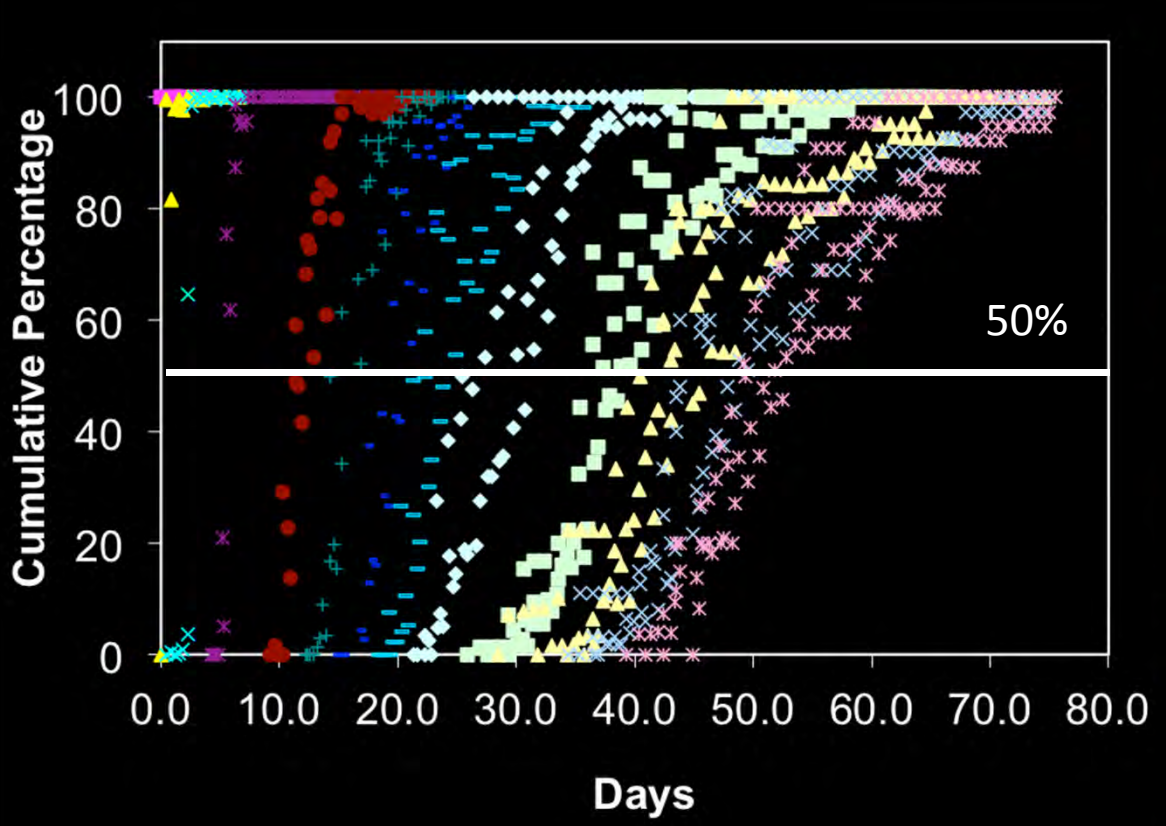
Korea

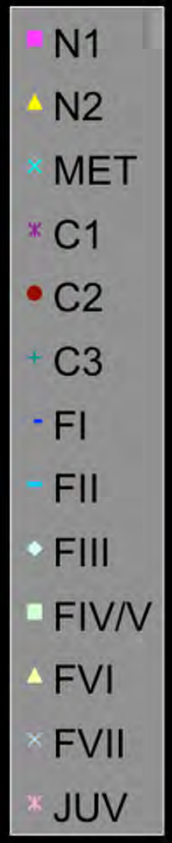
Japan

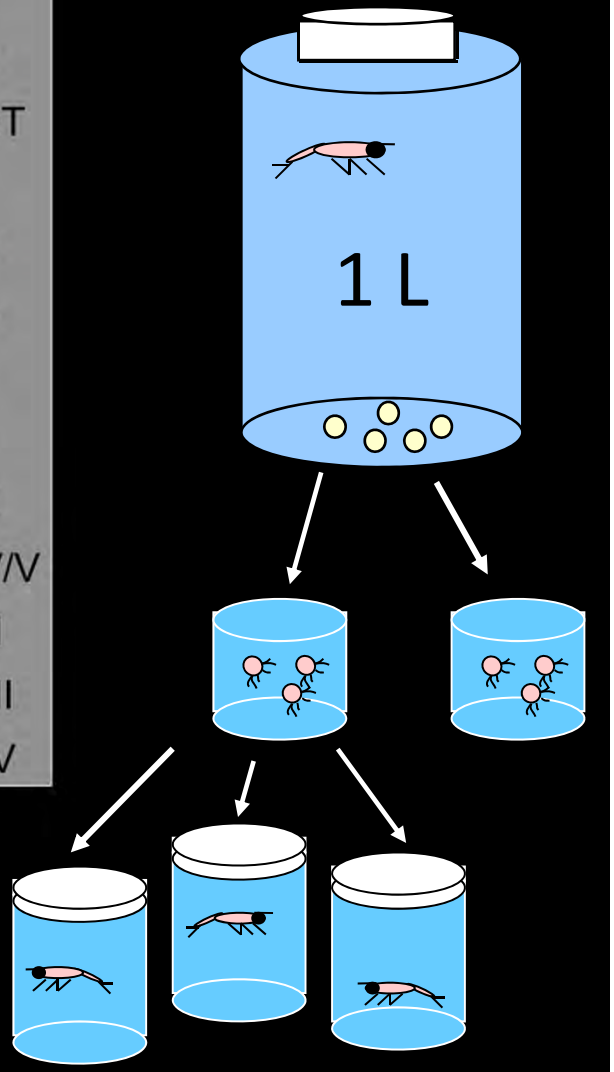
USA

- Broadly distributed across shelf and slope regions of the **North Pacific**
- Dominant euphausiid species from:
  - N. California Current - seasonal upwelling
  - Gulf of Alaska - seasonally stratified
- Important prey for whales, seabirds, and most commercially harvested fish species
- Maximum adult lengths ~25mm
- Omnivores, though they prefer large diatoms when available
- Population dynamics still a relative mystery compared to dominant copepods in the region

Development







- Raised 4 broods of eggs spawned within hours
- Furcilia development monitored in individual jars
- Median time to Juvenile ~2 months at 10.5°C

-Feinberg et al. 2006

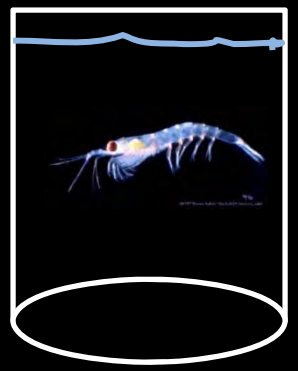
Development Time (days) at 10.5°C

Stage	Median	Range in stage (total days)	
Nauplius 1	0.3	0 - 4.0 (4)	
Nauplius 2	1.1	1.0 - 7.1 (6.1)	~7
Metanauplius	3.0	1.0 - 7.5 (6.5)	
Calyptopis 1	6.4	5.5 - 20.6 (15.1)	
Calyptopis 2	14.1	10.1 - 23.1 (13.1)	~14
Calyptopis 3	17.8	13.5 - 26.1 (12.6)	
Furcilia I	21.3	17.1 – 36.2 (19.1)	~21
Furcilia II	26.7	19.6 – 43.6 (24)	
Furcilia III	32.4	22.5 - 58.2 (35.7)	
Furcilia IV/V	43.4	27.1 - 67.1 (40)	
Furcilia VI	51.0	33.2 – 75.2 (42)	~40
Furcilia VII	55.4	36.7 – 75.0 (38.3)	
Juvenile	58.4	40.6 - 180+	

Feinberg et al. 2006

Growth

- Adult euphausiids continue to molt regularly and can grow, shrink or stay the same size with each molt
  - Size is not a good indicator of age



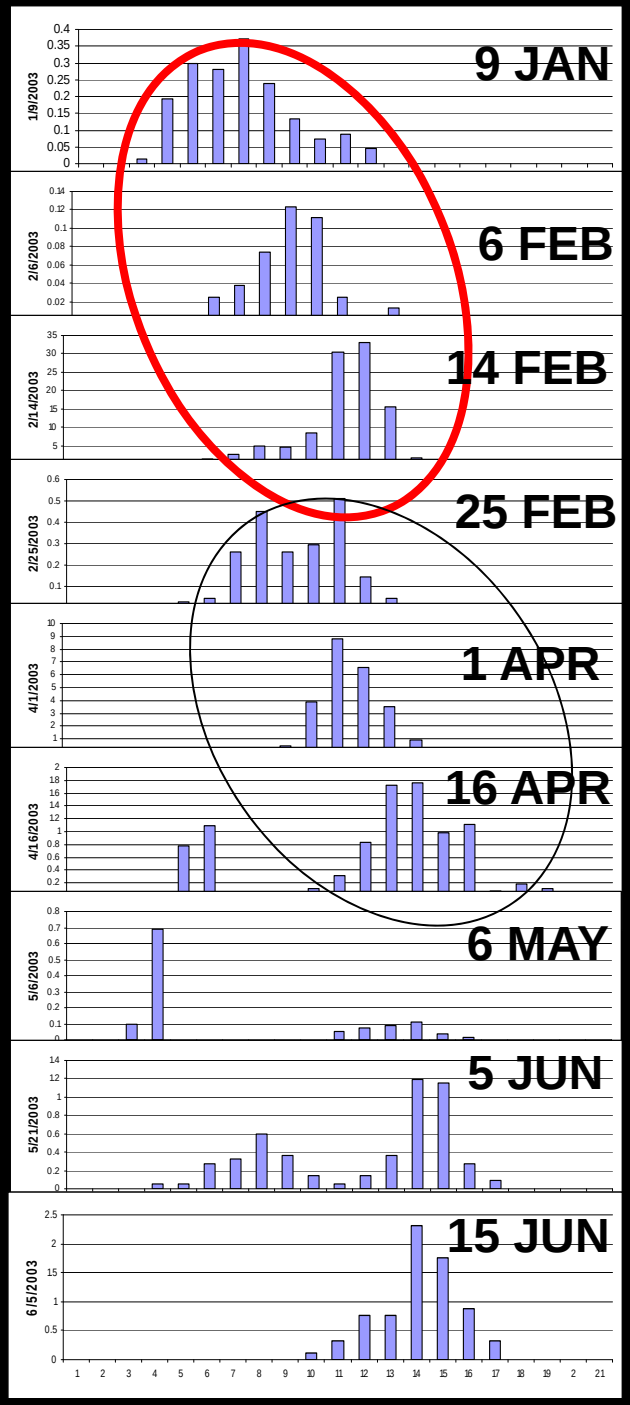
To measure growth:

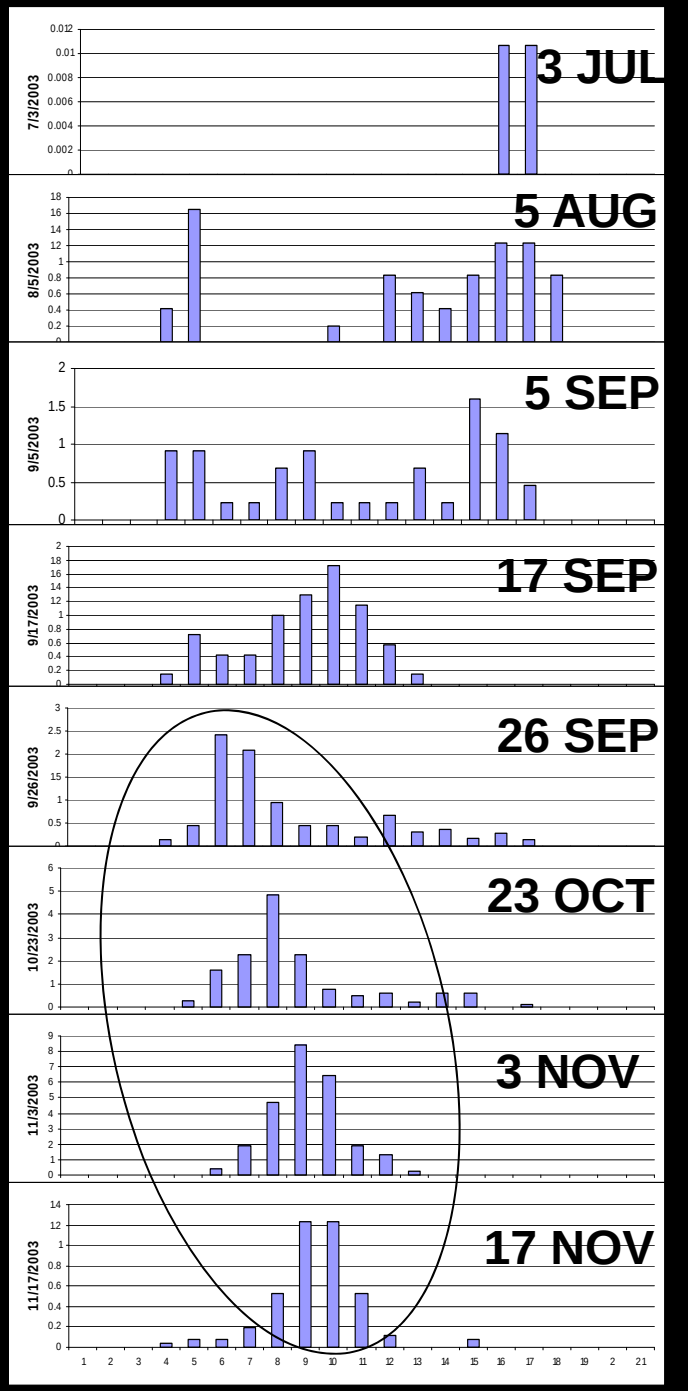
- Cohort Analysis (Modal Progression)
  - Repeated sampling of a field population over regular intervals
  - Night sampling since 2001

- Instantaneous Growth Rate (IGR)
  - Incubations of individual animals to determine inter-molt period and molt increment (mm)
  - 48 hr incubations at 10°C starting in 2000

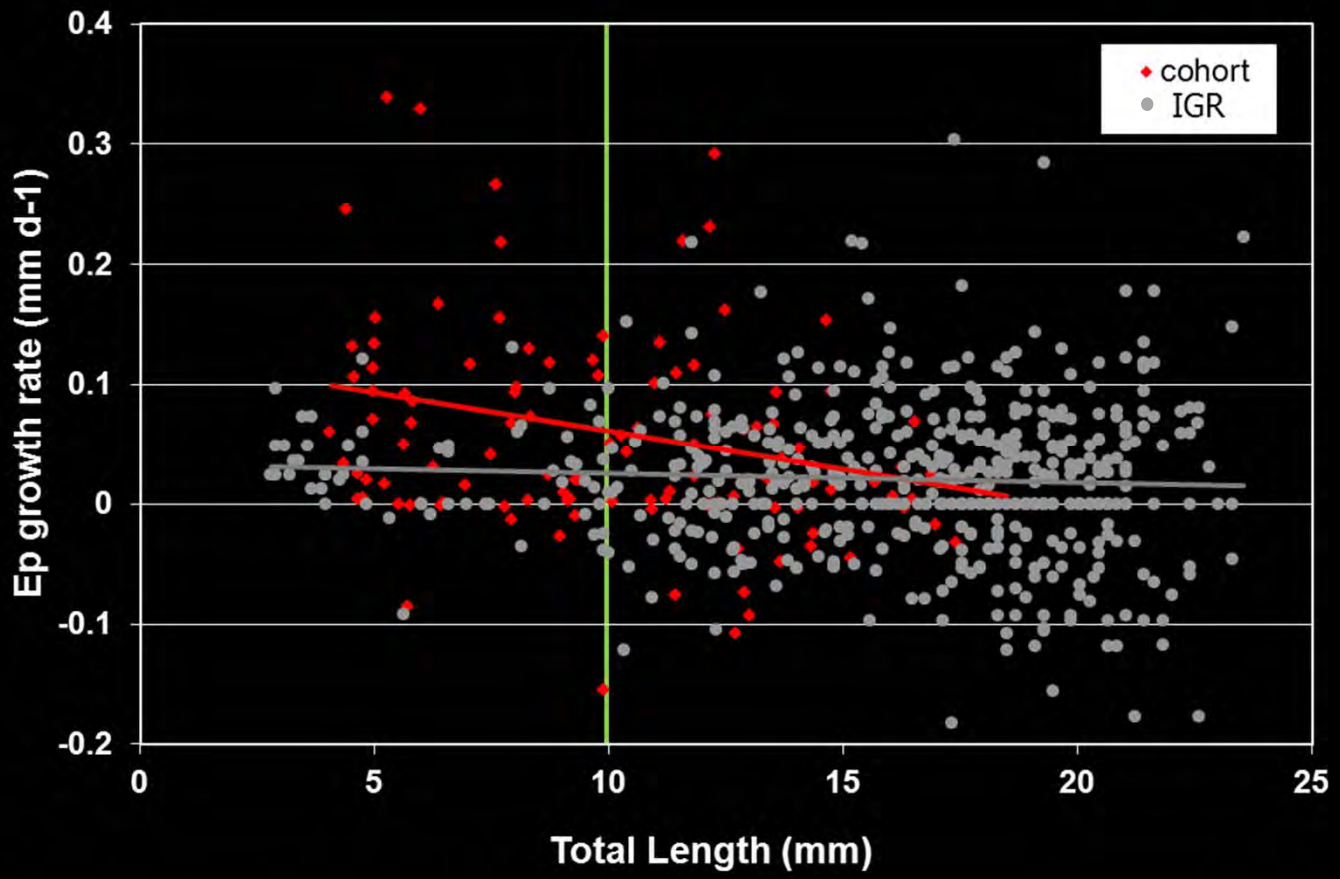
Cohort Data 2003

- Traditional cohort analysis subjective with size modes identified by eye
- Now use maximum likelihood method in MatLab
- Identified at least 17 cohorts from 2001-2008 with long-term growth rates of **0.015-0.034mm d^{-1}**





Cohort and IGR Growth Rates



Mean adult rates:
Cohort = 0.05mm d^{-1}
IGR = 0.02mm d^{-1}

- Both methods show a range in growth rates from ~+0.3 to -0.15mm day^{-1}
- Cohort growth rates (red) show that growth tends to slow as animals reach maturity
- IGR growth rates (gray) show range of individual variability in growth

Growth

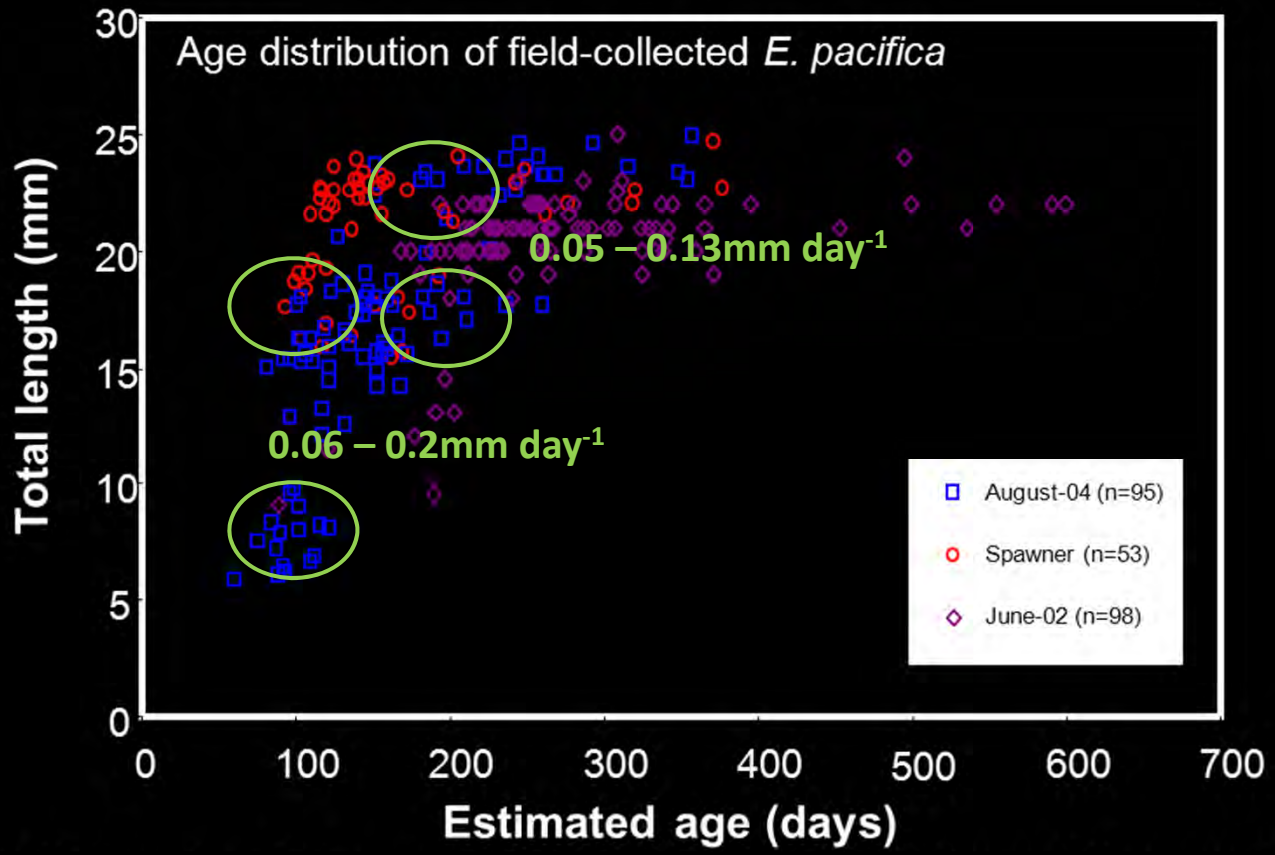
- Cohort analysis allows a view of population level growth
- Cohort weaknesses: influenced by size-specific mortality, cohorts can pile up and get “lost”, assumes that the same population is being sampled repeatedly, underestimates negative growth
- IGR highlights individual variability in growth, and a shorter time-scale
- IGR weaknesses: assumes molting is not synchronous or influenced by incubation, bias towards larger animals
- 2 methods of calculating growth are a good confirmation of each other and they allow us to know when a rate is reasonable

Longevity and Age at Spawning

- Most juveniles and adults were > 100 days but < 1 yr

- *E. pacifica* appears to live no more than two years in the North East Pacific

- Females spawn in multiple age and size classes

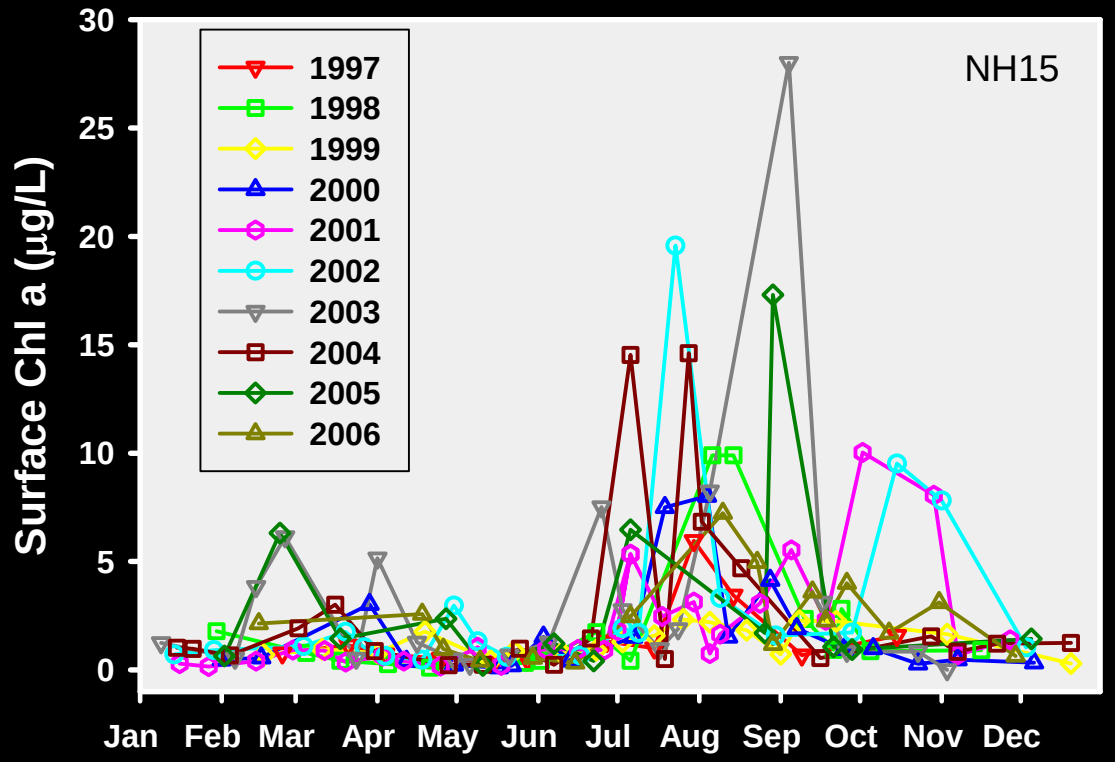


Age estimated using lipofuscin accumulation rate from lab reared animals
Harvey et al. 2010

Reproduction

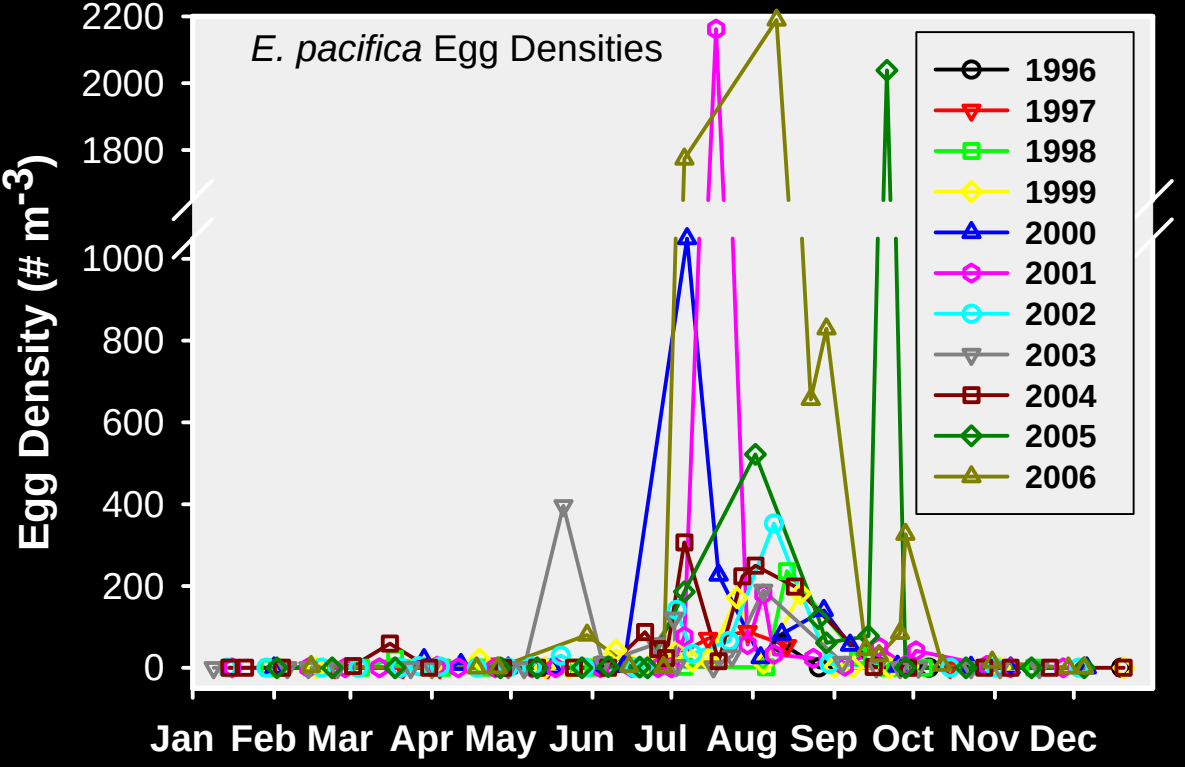
- *E. pacifica* are broadcast spawners, capable of spawning multiple times
- Goal of studying reproduction is to determine fecundity
  - **Brood size**
  - **Inter-brood Period (IBP)**
  - **Duration of the spawning season**
- We can look at these factors from field data, laboratory experiments, and ultimately a combination of the two
- Field: biweekly sampling of eggs, larvae and adults
- Laboratory Experiments: 48h brood size incubations, long-term (3-9 month) fecundity incubations

Chlorophyll *a*



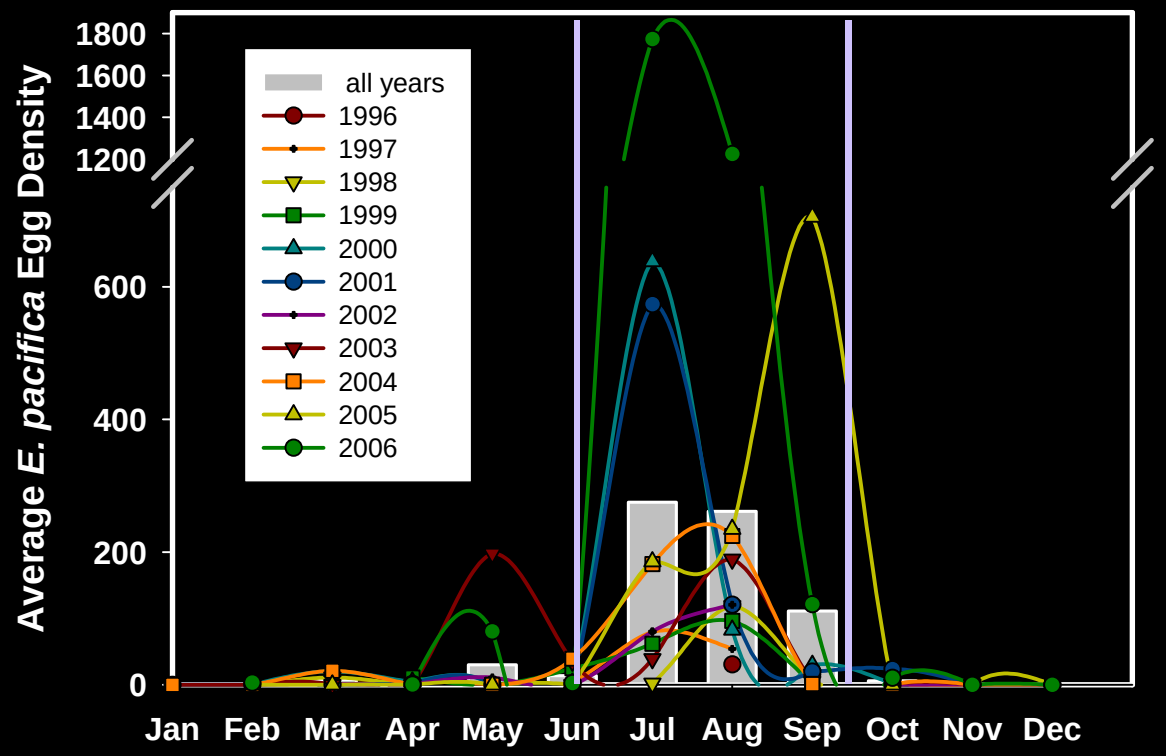
- The northern California Current has strong seasonal (May-Sep) upwelling
- Peaks in surface chlorophyll *a* concentrations on the Oregon shelf are largely associated with upwelling
- Similar pattern in most years, but interannual variability in timing and magnitude of upwelling and phytoplankton blooms

Reproduction (field data)



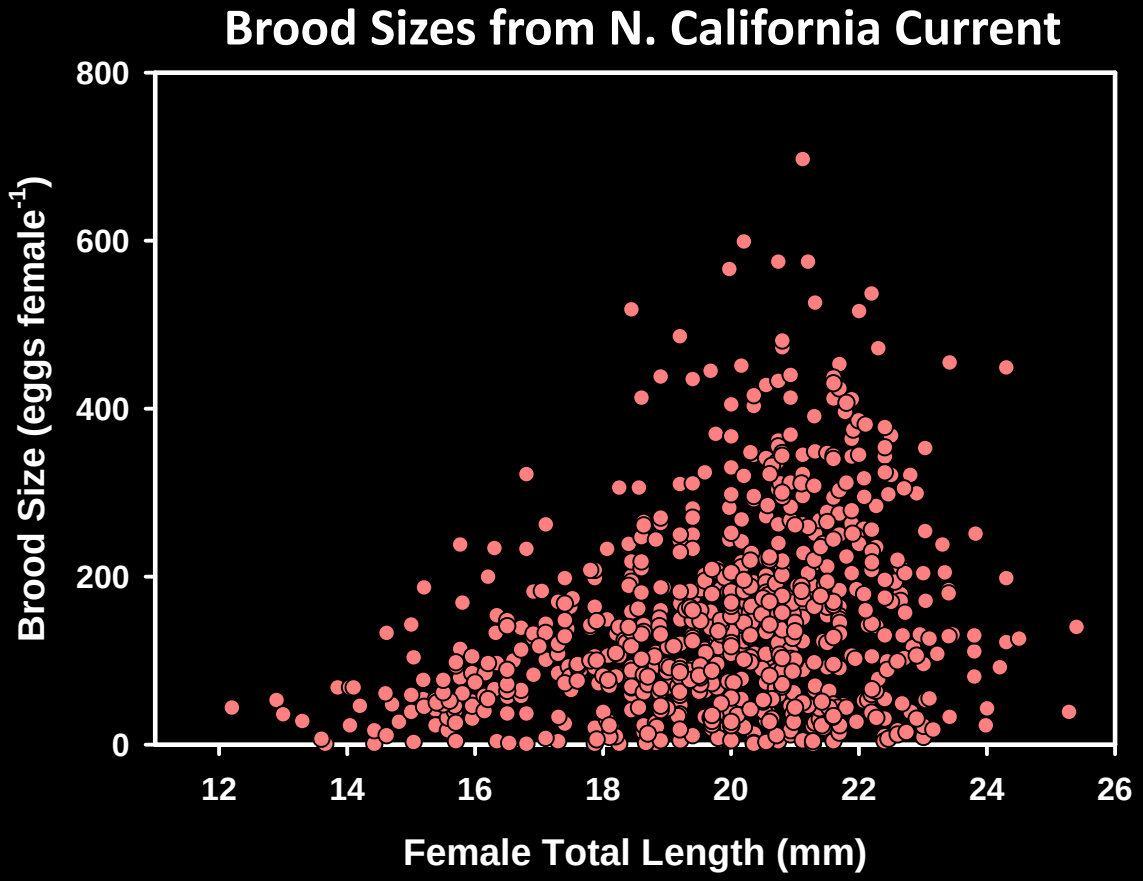
- 11 years of bi-weekly vertical net data from NH15, an outer shelf station where *E. pacifica* larvae are most dense (same station as chl *a* figure)
- Seasonal pattern of egg densities dictated by upwelling and chl *a*
- Helps us to define the spawning season and to investigate the likelihood of continuous vs. intermittent spawning during the season

Reproduction (field data)



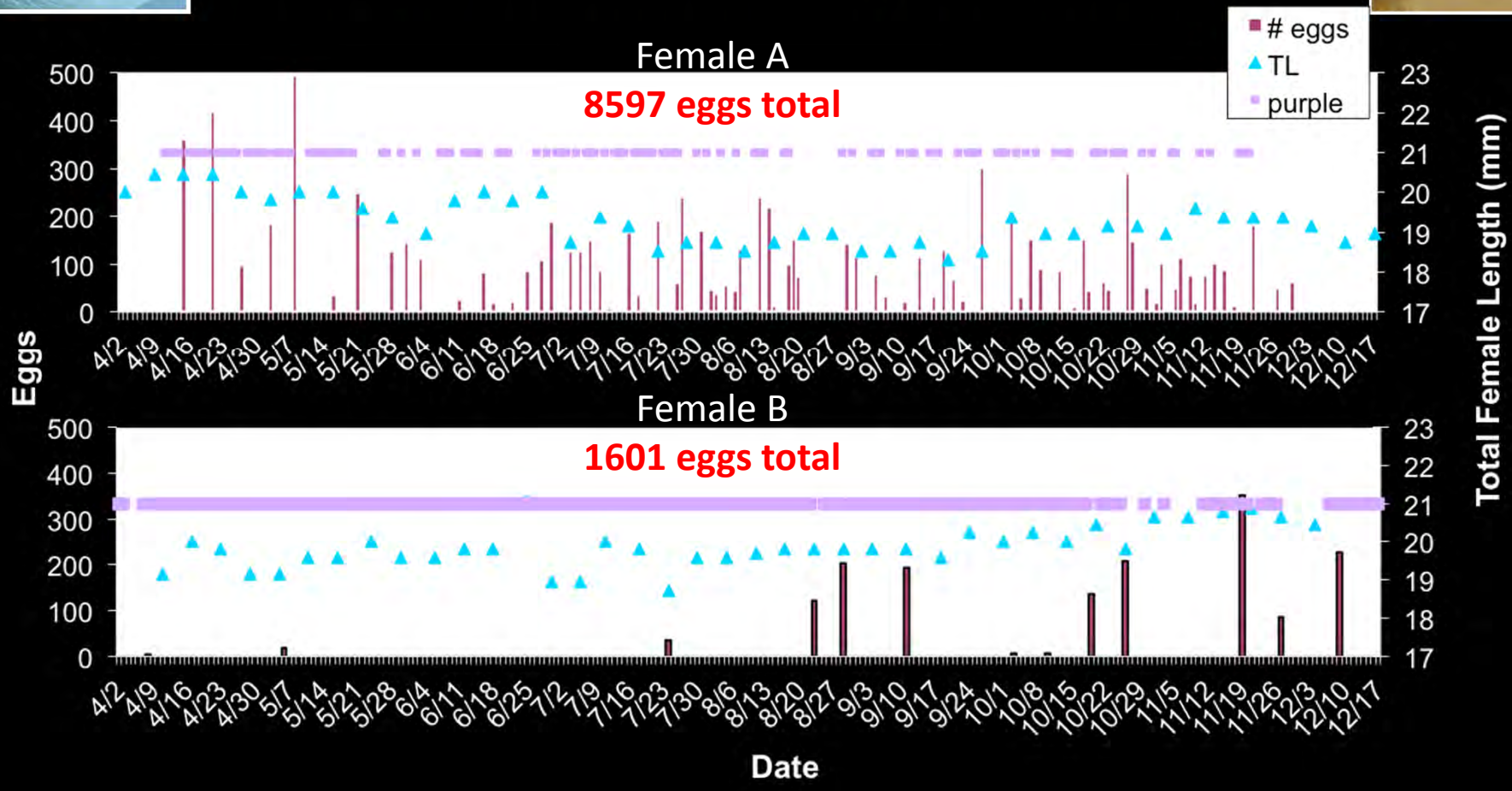
- Large interannual variability in egg densities and timing
- the climatology helps us to see a general spawning season pattern

Reproduction (lab data)



- 48 hour incubations
- ~800 broods
- **Median = 128 eggs, range: 1-697**

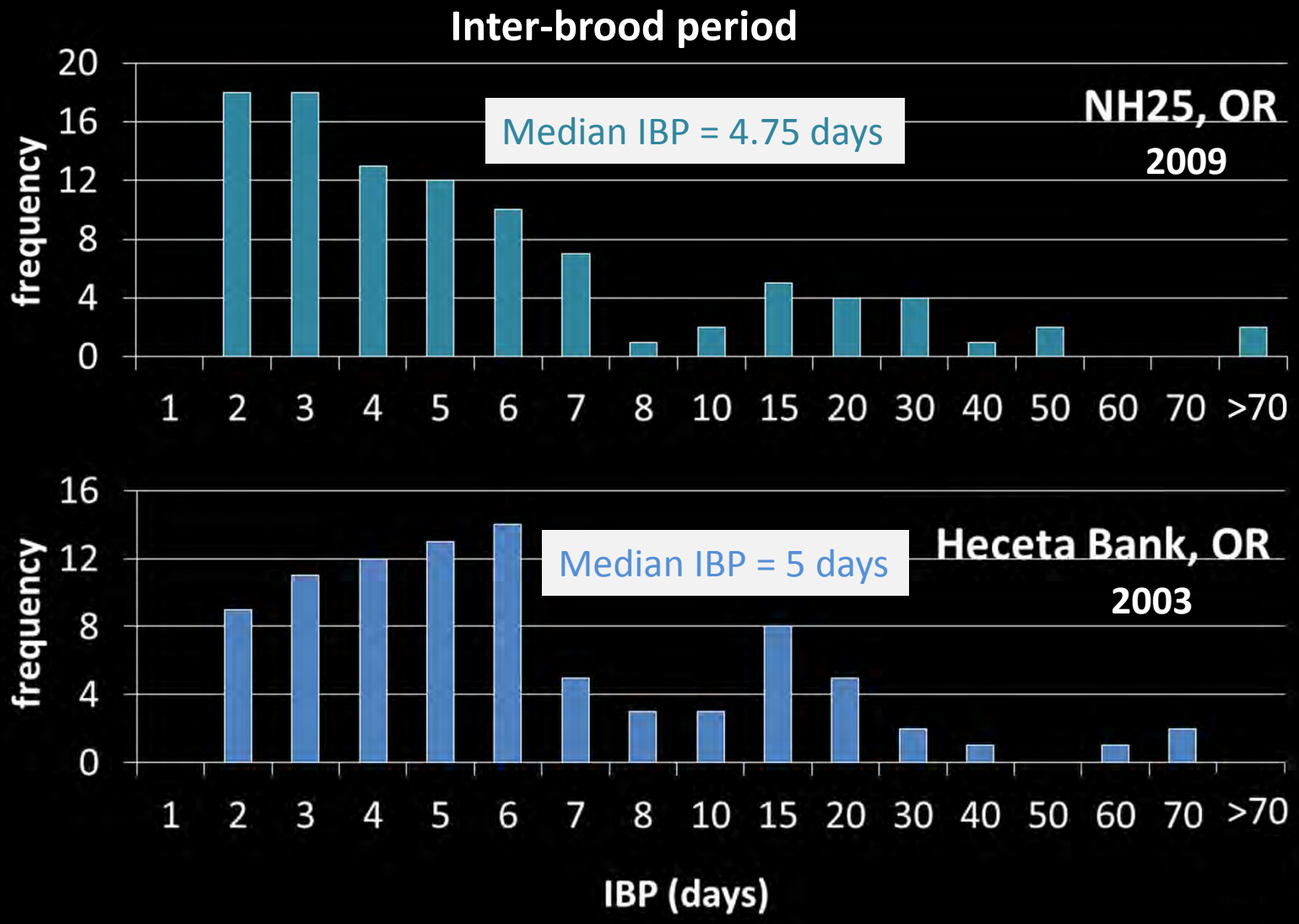
Reproduction (lab data)



- 2 examples from our long-term fecundity experiments
- Females of the same size, from the same location, kept under identical lab conditions
- High variability between females, but also for individual females

Feinberg et al. 2007

Reproduction (lab data)



Reproduction

Summary:

- Duration of spawning season roughly follows upwelling season: ~late June – late September (100 days)
  - but high interannual variability → 46 to 142 days in 1997-2008
- Frequency of spawning (IBP):
  - ~5 days, but ranges from 2-70+
  - Very difficult to estimate from field data
  - Do not estimate using inverse proportion of purple females
- Brood Size: Median = 128, range: 2 – 800 eggs
  - Do not attempt estimates from field densities
- Fecundity: Using median values, 1 female could spawn 128 eggs, 20 times in the summer season to produce a total of **2,560 eggs!**
- Well within the ability of *E. pacifica* as shown by our long-term fecundity experiments

Final Thoughts

- When a study doesn't end how do you know when to stop?
- Seeing is believing…watching a living animal can go a long way in helping you to interpret your data
- Some uses of field data for *E. pacifica* have our blessings:
  - Cohort analysis, determination of the spawning season
- And some do not:
  - Estimations of brood size and frequency
- Knowing the potential rates allows you to be smarter about how far to push the field data
- *E. pacifica v*ariability is high in all ways and may be the key to thriving in a dynamic upwelling region
- For euphausiids, the utility of all rates (no matter how accurate) is still limited by inaccuracies in measurement of biomass
- Thankful to live in a time of plentiful individual based modelers