Cohort data for the euphausiid *Euphausia pacifica* off Newport, OR, USA

Euphausia pacifica

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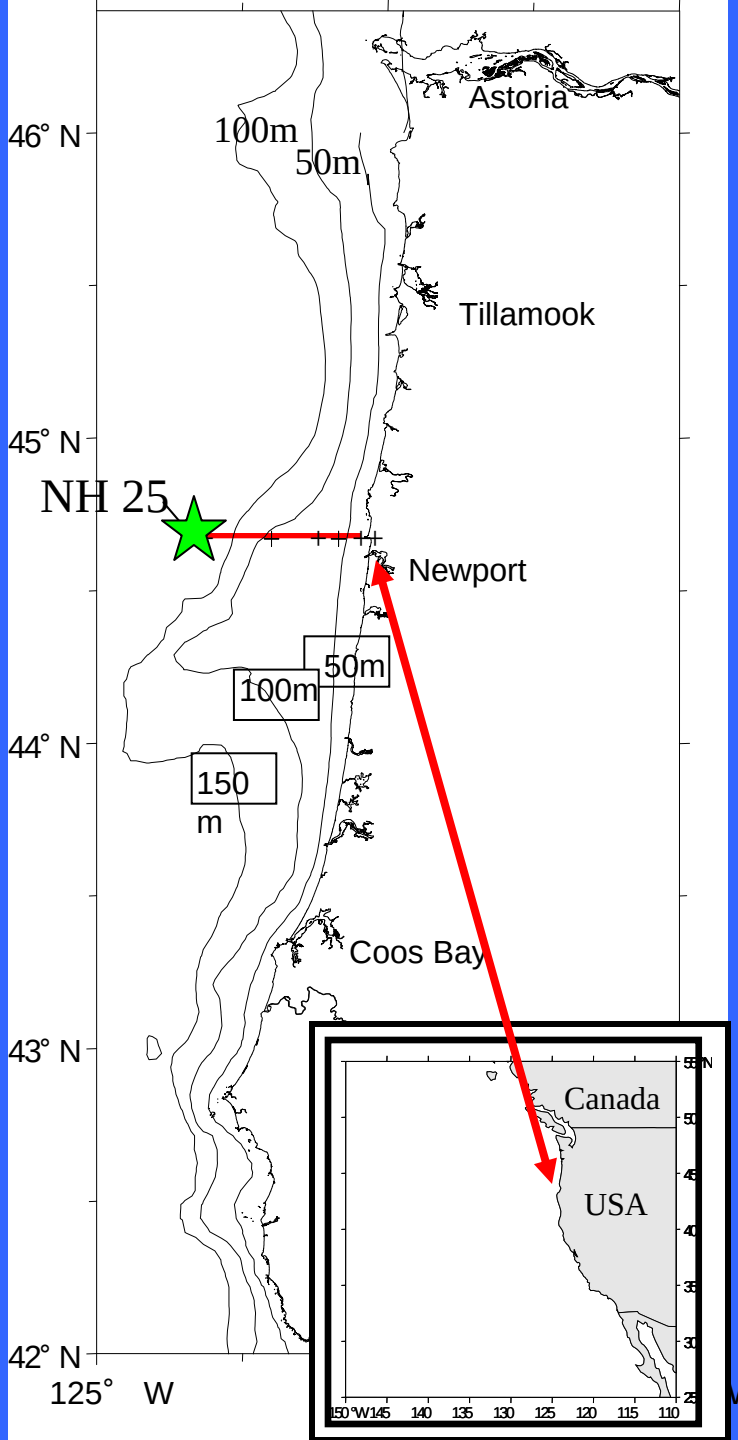
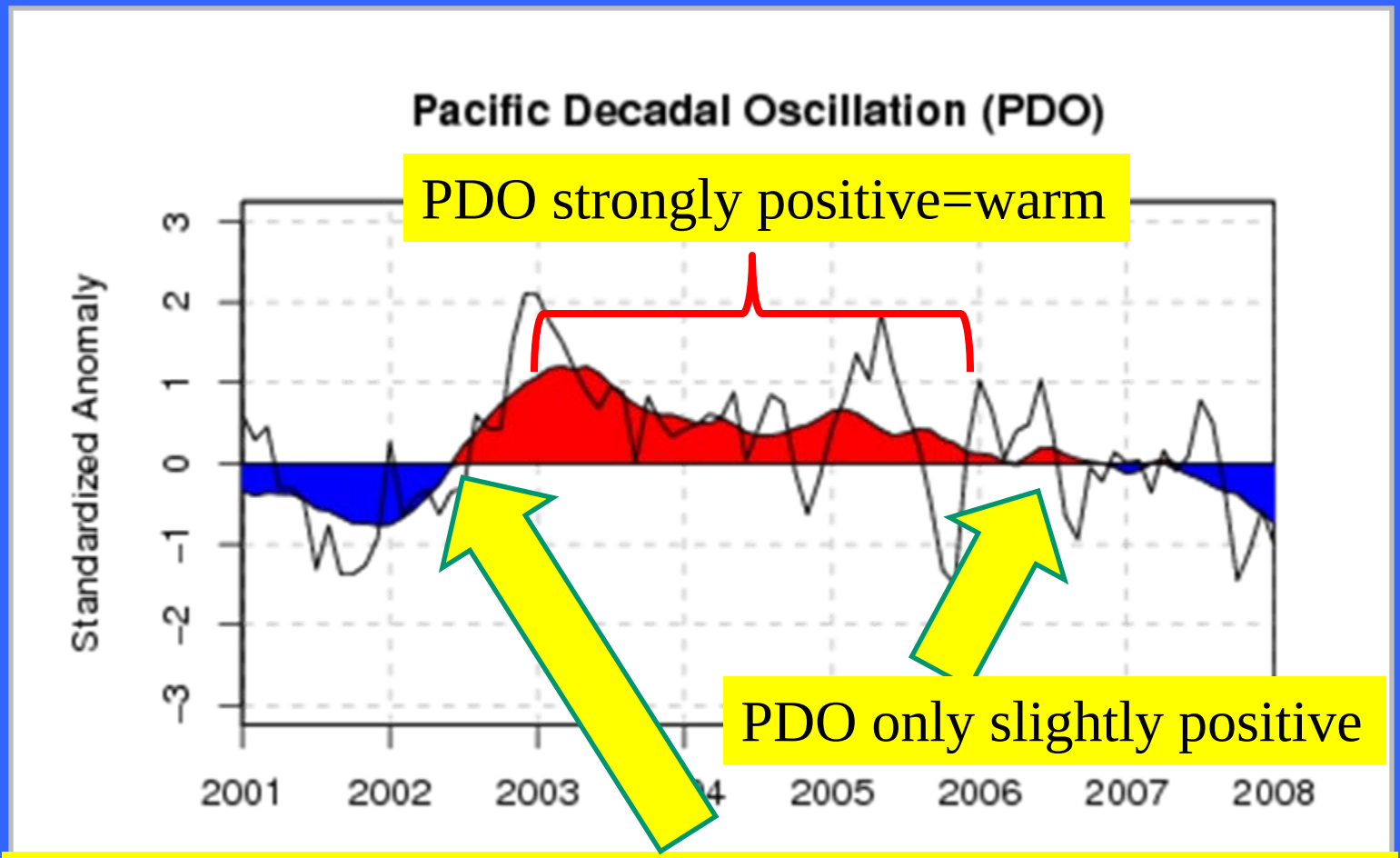


Time series off Newport, OR (NH line)

- 1996 - Start of biweekly sampling by the Peterson lab
  - Chlorophyll-*a* (surface)
  - Euphausiid eggs & larvae
- 2001 – Start of sampling adult euphausiids with nighttime bongo tows
- Instantaneous growth rate (IGR) experiments on live animals since 2001
- Cohort data & IGR expts from station NH25 (★) at the shelf break (40km offshore, ~300m)

Motivation & Objectives

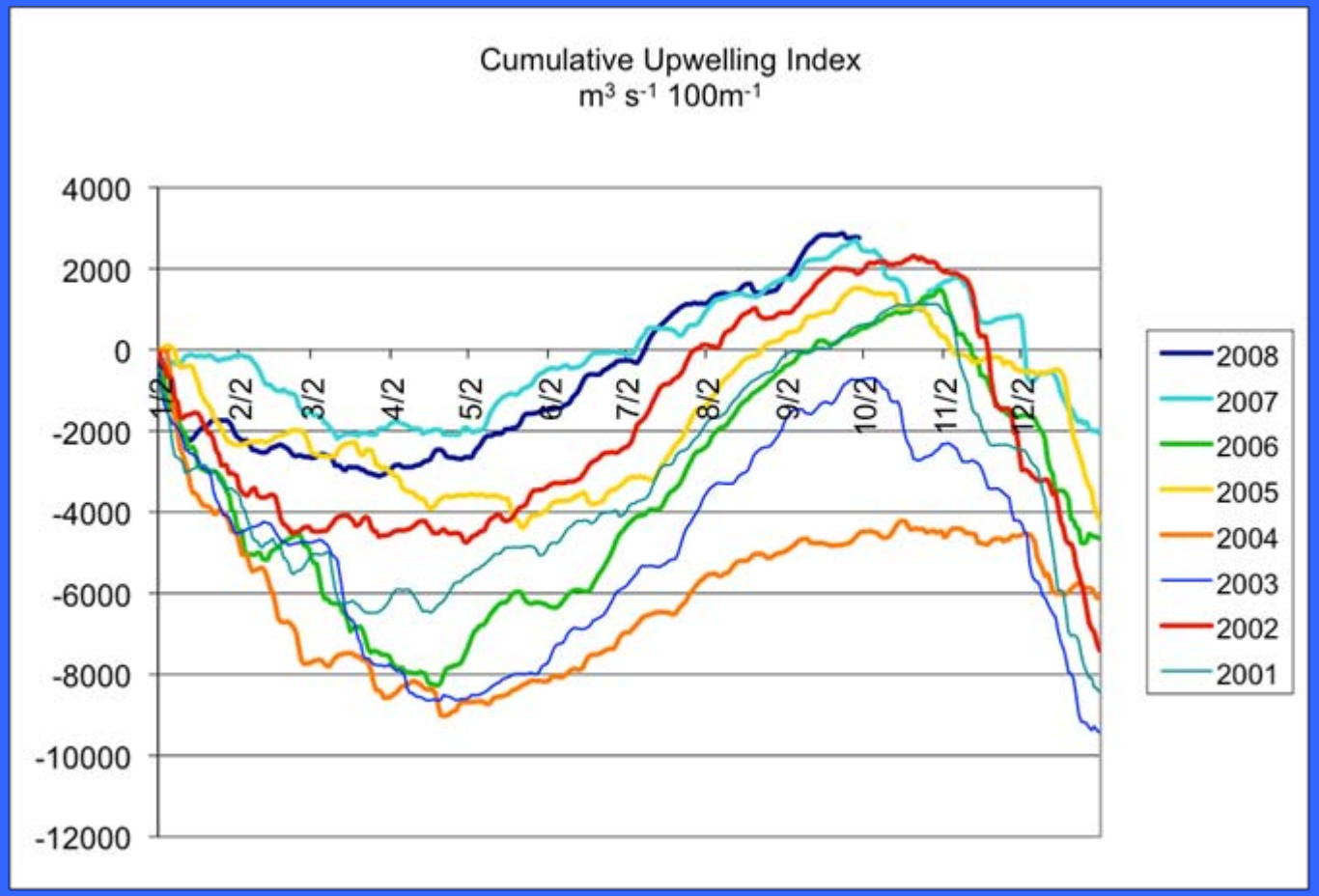
- *Euphausia pacifica* are present in our study area year-round
- We see spawning activity as early as Feb and as late as Oct, in association with phytoplankton blooms
- There is a period of intense spawning activity in July-August which could initiate a cohort that can be followed over time
- *E. pacifica* develop from egg to juvenile in an average of 60 days (Feinberg et al. 2006) - therefore, a cohort that appears about two months after a spawning event could be attributed to those eggs
- Based on biweekly data from 2001-2008:
  - Identify cohorts based on lengths of juveniles and adults
  - Look for interannual variability in cohorts in relation to environmental conditions
  - Compare cohort growth rates to growth rates measured in live animal experiments
  - Create survivorship curves



Note: local SST off Newport, OR lags behind the PDO so while the PDO was warming in 2002 the ocean in our study area was still cold

Graph courtesy of Tom Wainwright, NOAA Fisheries

Cumulative Upwelling Index 2001-2008



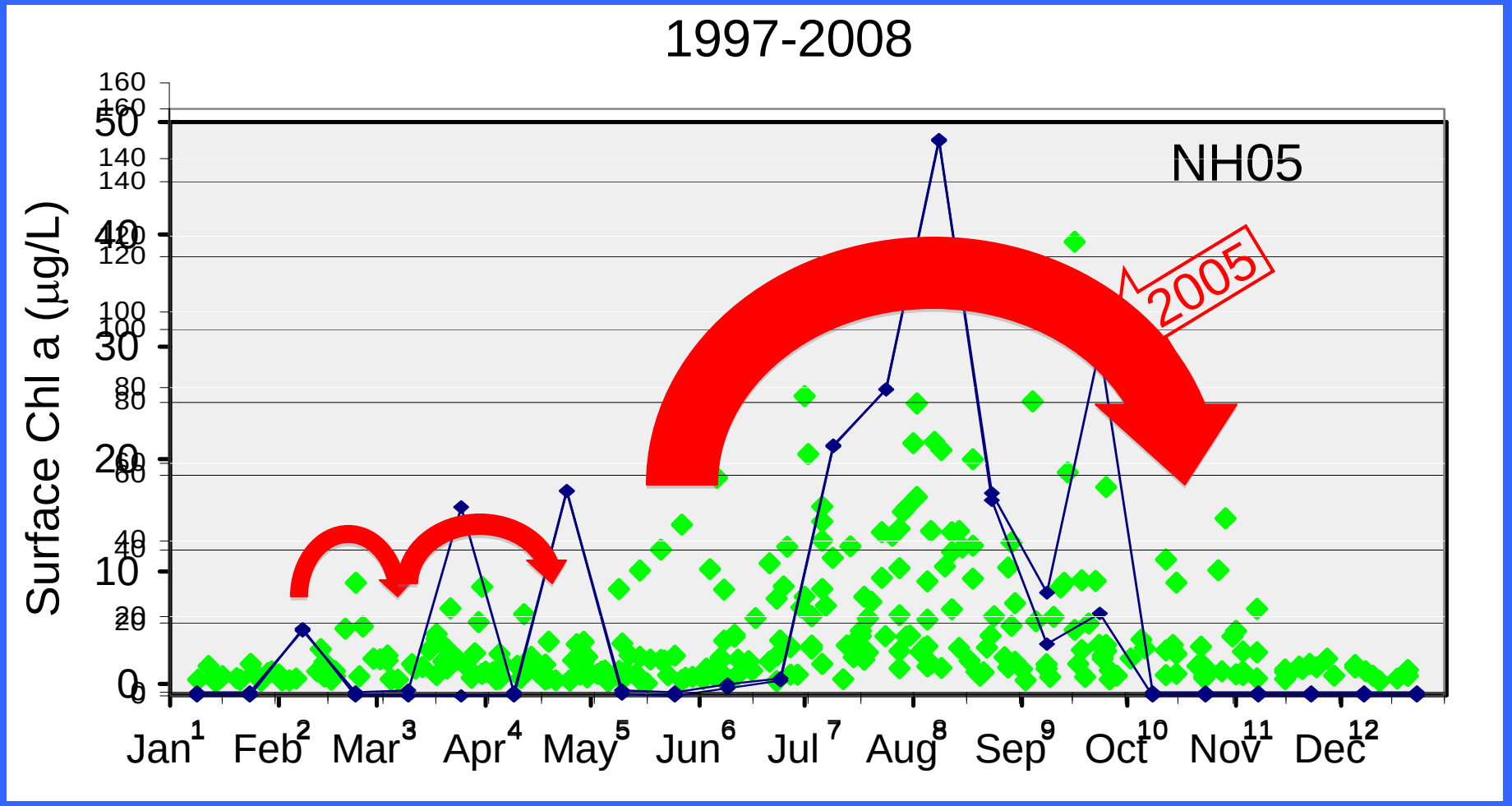
- CUI positive during upwelling season 2001-2002, 2005-2008
- Shortest upwelling seasons:
  - 2003 (5.9 mo.)
  - 2005 (4.2 mo.)
  - Long-term average 6.7 mo.
- 2005 upwelling started ~1 mo. later than average

- http://www.pfel.noaa.gov/products/PFEL/modeled/indices/upwelling/upwelling.html

Methods

- Counted euphausiid eggs from 1/2m vertical net samples to determine timing of high egg density (“egg peak”)
- Counted and measured juvenile and adult *E. pacifica* from nighttime bongo nets
- Identified cohorts using maximum likelihood method in Matlab
- Cohorts based on lengths of juveniles and adults since larval stages were not present in sufficient numbers to identify a size mode

Chlorophyll climatology at Newport



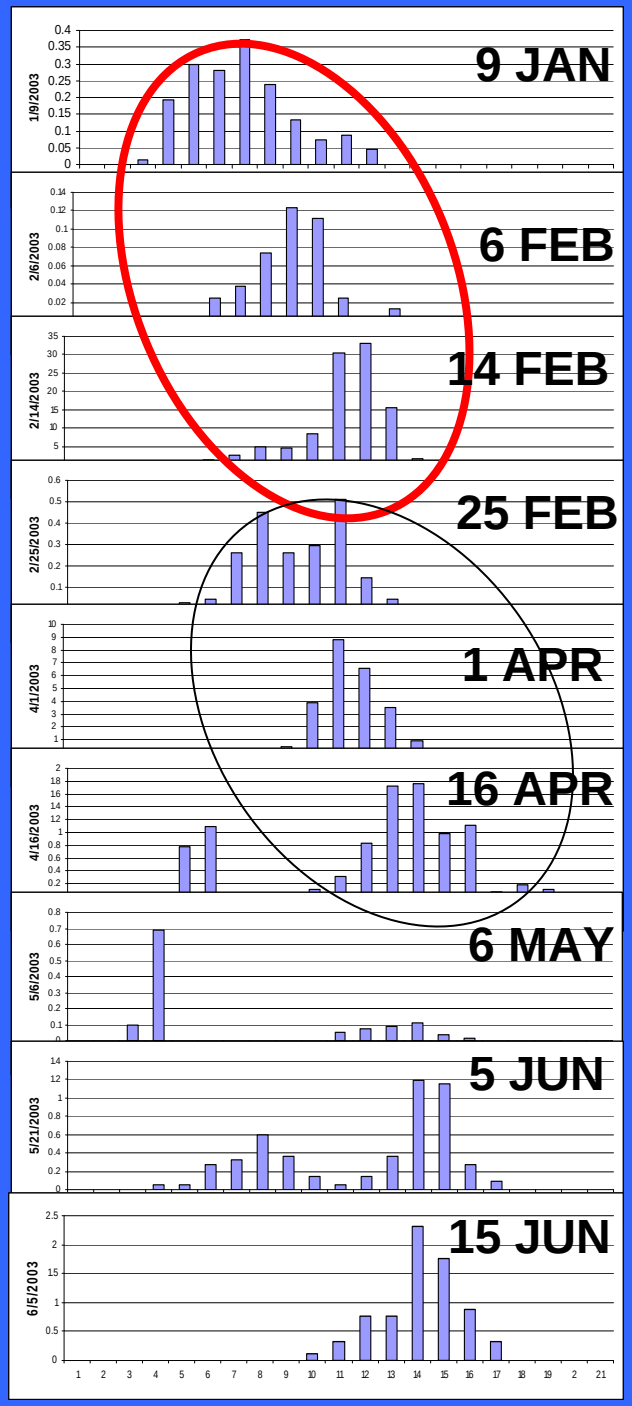
Egg densities associated with chlorophyll blooms

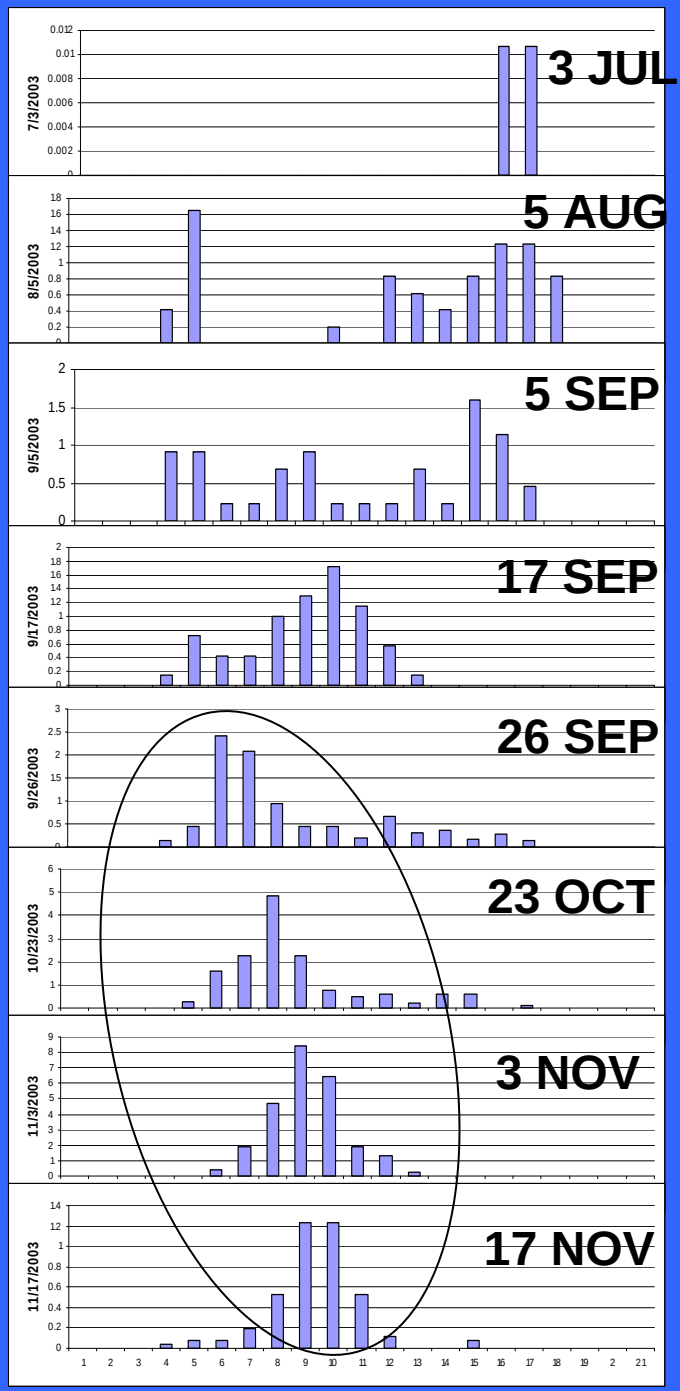
Cohort caveats

- Cohort analysis assumes resampling of the same population over time
- Patchy distribution of euphausiids may explain disappearance & reappearance of size modes
- Krill grow more slowly at cooler temperatures and can shrink under certain conditions
  - Our sampling interval is longer in winter due to weather which, combined with potentially shrinking animals, can make it difficult to follow a cohort
  - Some krill may overwinter as juveniles which can skew the timing between egg peaks & appearance of juveniles
- Cohort size modes may merge as krill grow due to individual variability in development rates

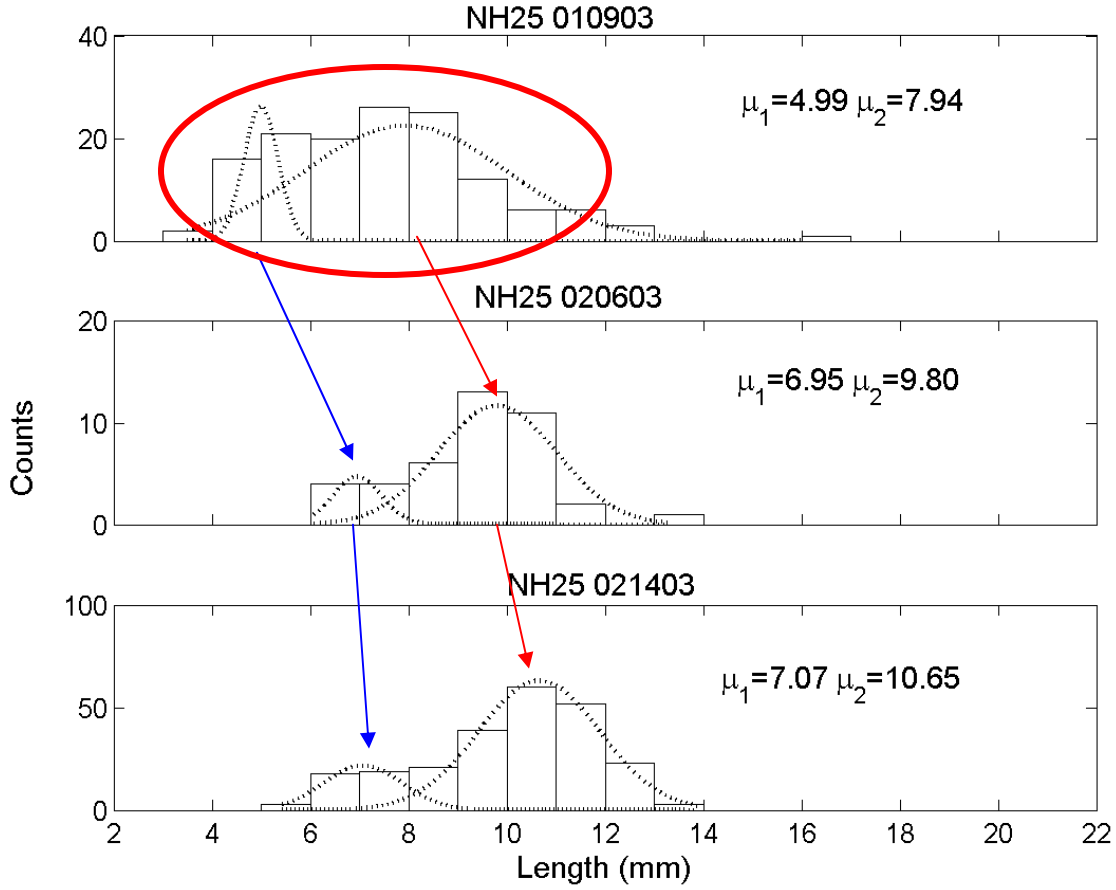
Cohort Data 2003

Traditional cohort analysis subjective with size modes identified by eye.

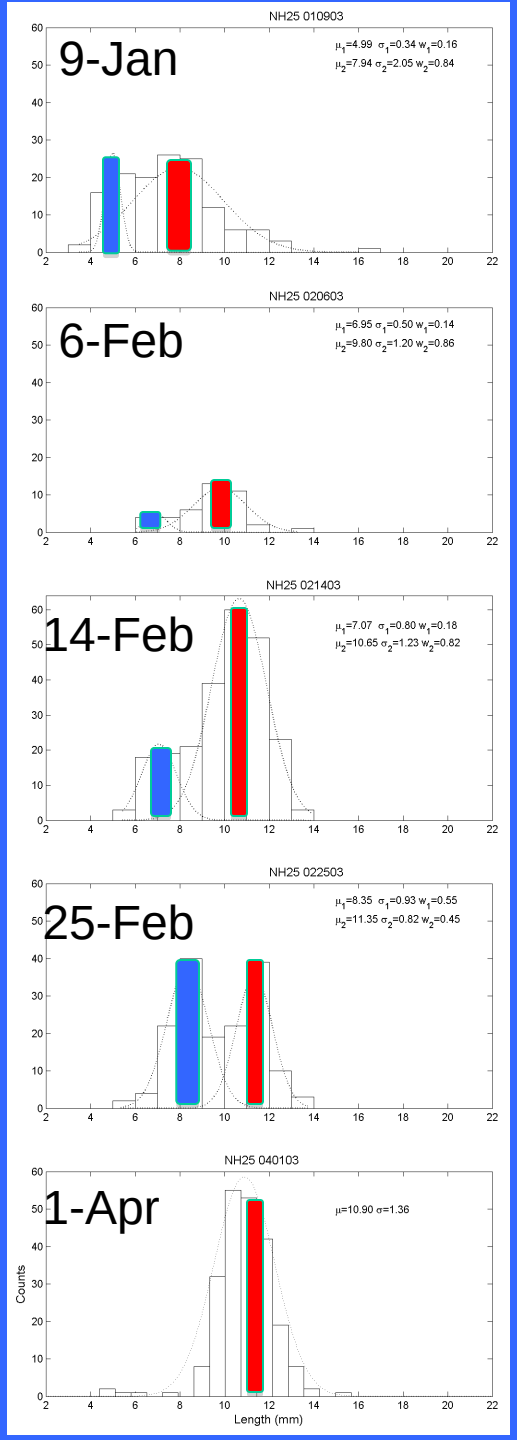


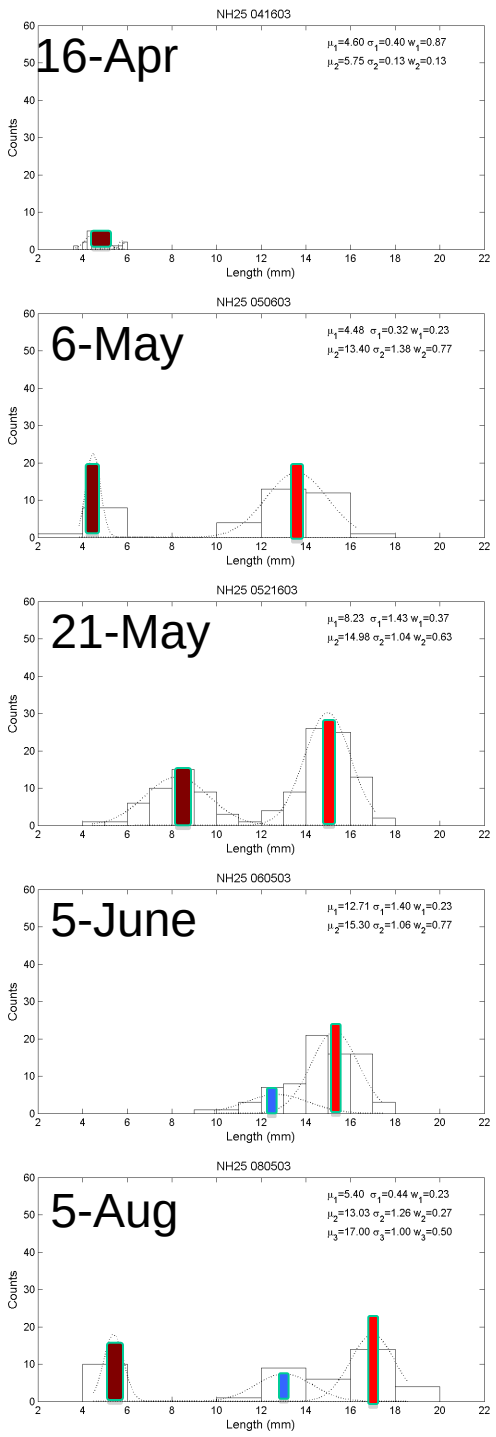


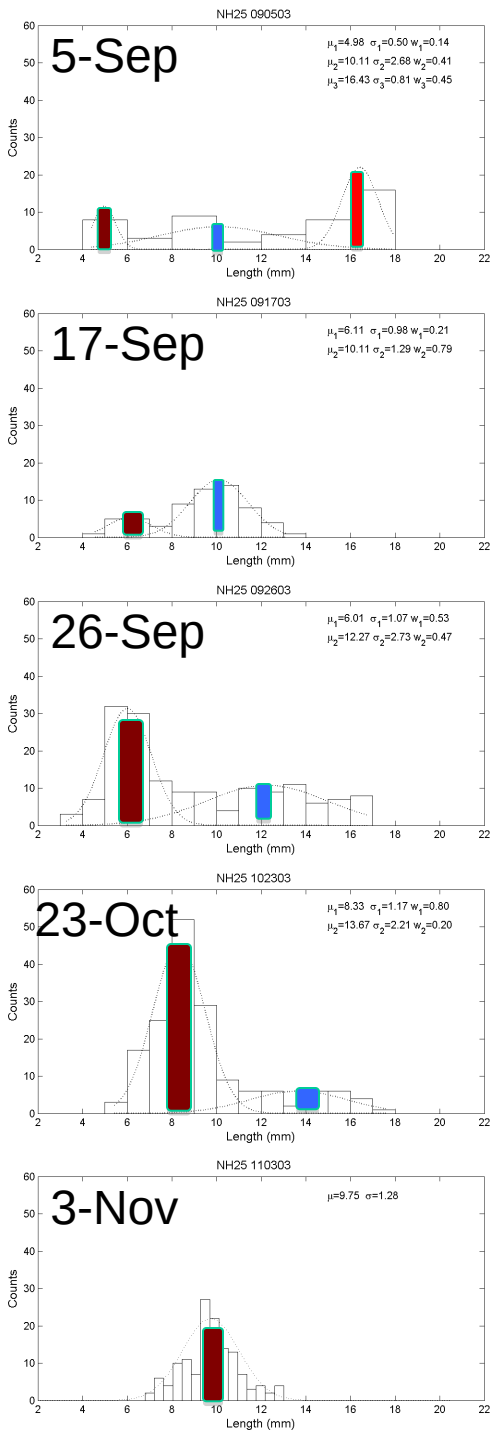
Cohorts from maximum likelihood method



- This technique identifies overlapping distributions
- We calculated growth rates from change in mean length of each size mode from one sampling date to the next

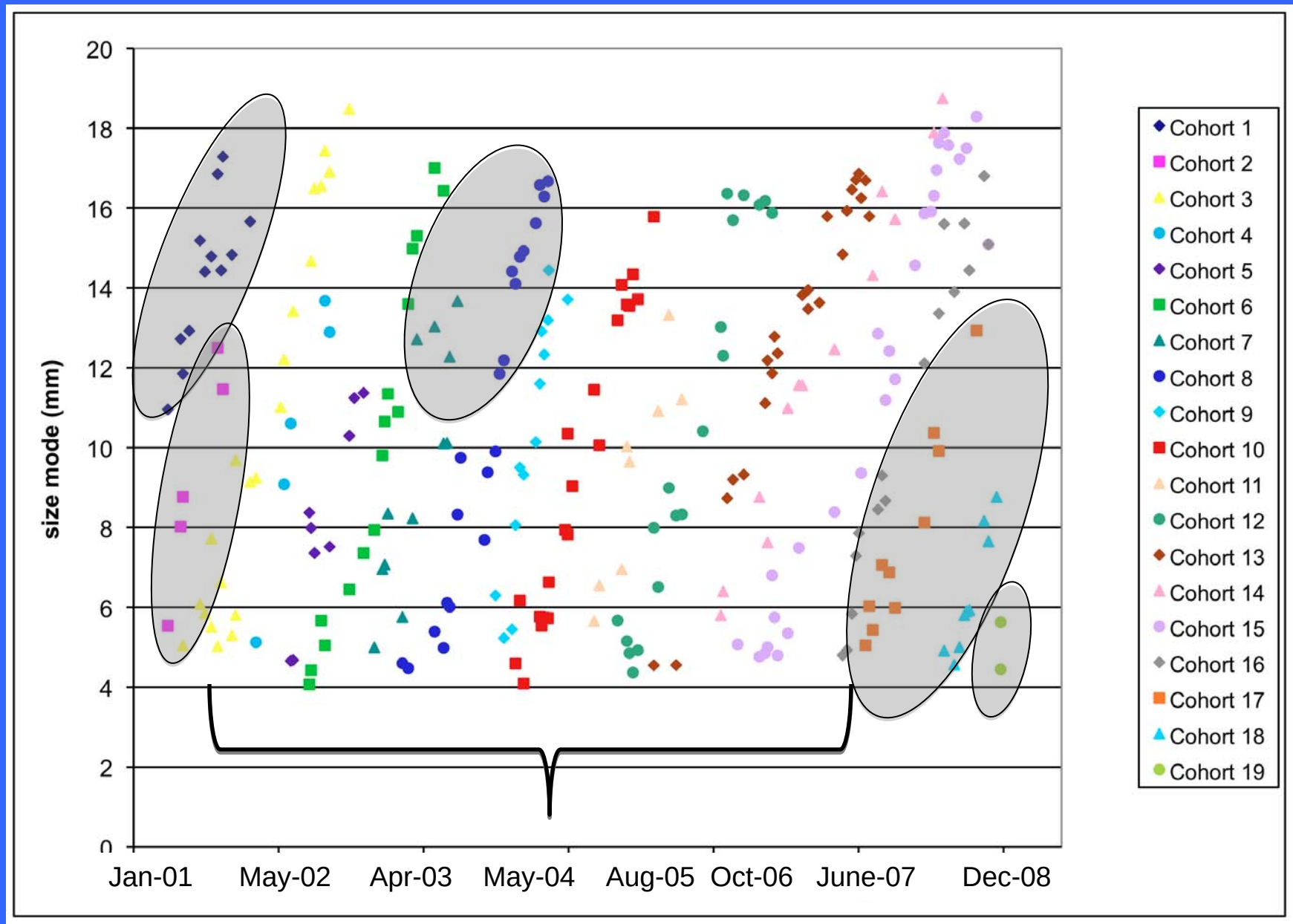

NH25 010903
9-Jan
μ1=4.99 σ1=0.34 w1=0.16
μ2=7.94 σ2=2.05 w2=0.84
NH25 020603
6-Feb
μ1=6.95 σ1=0.50 w1=0.14
μ2=9.80 σ2=1.20 w2=0.86
NH25 021403
14-Feb
μ1=7.07 σ1=0.80 w1=0.18
μ2=10.65 σ2=1.23 w2=0.82
NH25 022503
25-Feb
μ1=8.35 σ1=0.93 w1=0.55
μ2=11.35 σ2=0.82 w2=0.45
NH25 040103
1-Apr
μ=10.90 σ=1.36
Counts
Length (mm)


NH25 041603
16-Apr
μ1=4.60 σ1=0.40 w1=0.87
μ2=5.75 σ2=0.13 w2=0.13
NH25 050603
6-May
μ1=4.48 σ1=0.32 w1=0.23
μ2=13.40 σ2=1.38 w2=0.77
NH25 0521603
21-May
μ1=8.23 σ1=1.43 w1=0.37
μ2=14.98 σ2=1.04 w2=0.63
NH25 060503
5-June
μ1=12.71 σ1=1.40 w1=0.23
μ2=15.30 σ2=1.06 w2=0.77
NH25 080503
5-Aug
μ1=5.40 σ1=0.44 w1=0.23
μ2=13.03 σ2=1.26 w2=0.27
μ3=17.00 σ3=1.00 w3=0.50
Counts
Length (mm)

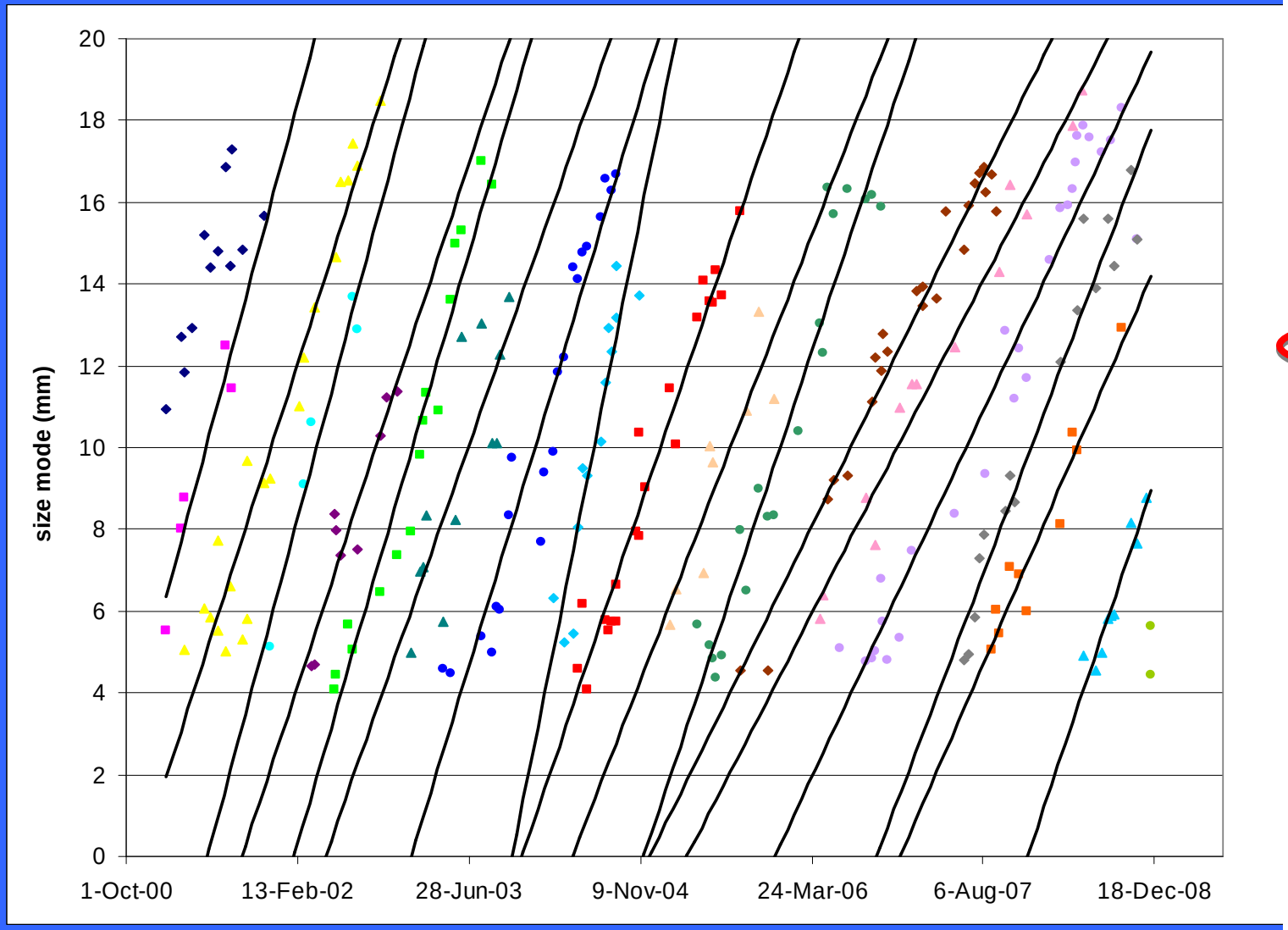

NH25 090503
5-Sep
μ1=4.98 σ1=0.50 w1=0.14
μ2=10.11 σ2=2.68 w2=0.41
μ3=16.43 σ3=0.81 w3=0.45
NH25 091703
17-Sep
μ1=6.11 σ1=0.98 w1=0.21
μ2=10.11 σ2=1.29 w2=0.79
NH25 092603
26-Sep
μ1=6.01 σ1=1.07 w1=0.53
μ2=12.27 σ2=2.73 w2=0.47
NH25 102303
23-Oct
μ1=8.33 σ1=1.17 w1=0.80
μ2=13.67 σ2=2.21 w2=0.20
NH25 110303
3-Nov
μ=9.75 σ=1.28
Counts
Length (mm)

2003

Cohorts 2001-2008



Cohorts 2001-2008



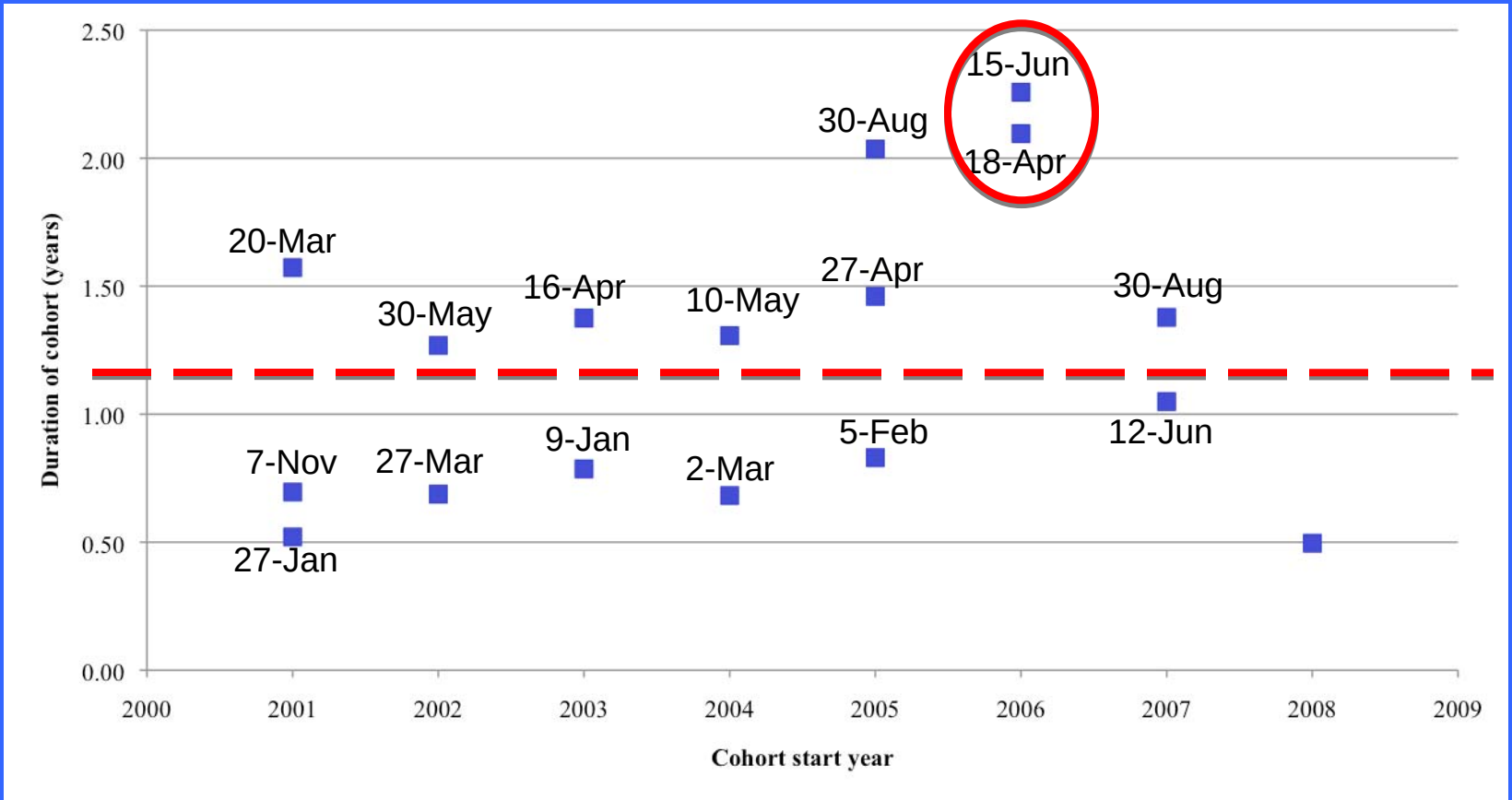
Cohort	R2
Cohort 2	0.9146
Cohort 3	0.9347
Cohort 4	0.9457
Cohort 5	0.8865
Cohort 6	0.9443
Cohort 7	0.591
Cohort 8	0.9308
Cohort 9	0.8699
Cohort 10	0.9519
Cohort 11	0.8113
Cohort 12	0.9317
Cohort 13	0.9662
Cohort 14	0.9734
Cohort 15	0.9404
Cohort 16	0.9492
Cohort 17	0.9333
Cohort 18	0.9131

Similar slopes suggest *E. pacifica* growth rates similar among years of this study.

Cohort Details

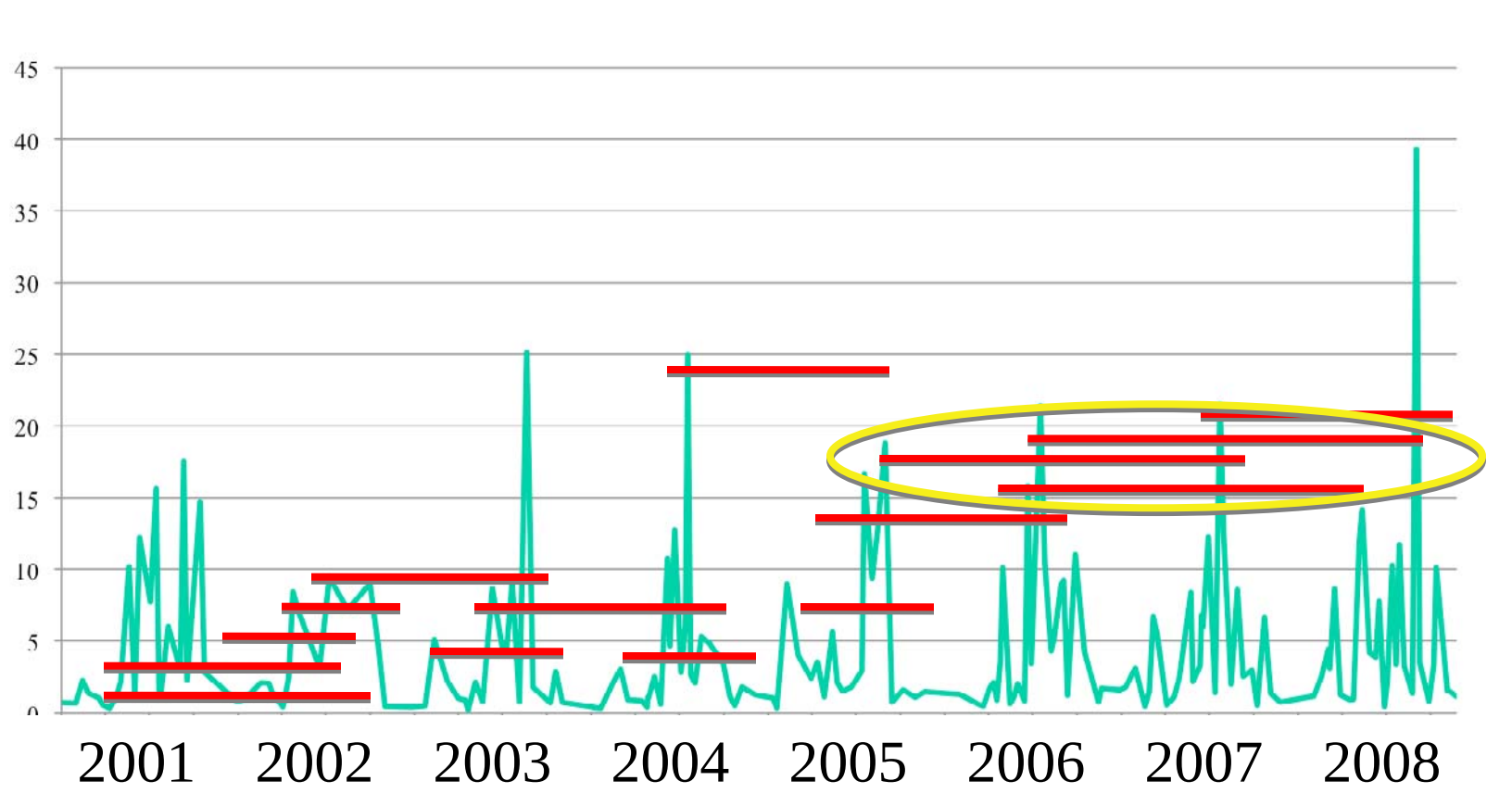
Cohort	Start date	End date	Duration (years)	R^2
Cohort 1	?	7-Nov-01		0.6392
Cohort 2	27-Jan-01	18-Jul-01	*0.47*	0.9146
Cohort 3	20-Mar-01	15-Oct-02	1.57	0.9347
Cohort 4	27-Nov-01	8-Aug-02	0.70	0.9457
Cohort 5	4-Apr-02	3-Dec-02	0.67	0.8865
Cohort 6	30-May-02	5-Sep-03	1.27	0.9443
Cohort 7	9-Jan-03	23-Oct-03	0.79	0.591
Cohort 8	16-Apr-03	30-Aug-04	1.38	0.9308
Cohort 9	2-Mar-04	6-Nov-04	0.68	0.8699
Cohort 10	10-May-04	30-Aug-05	1.31	0.9519
Cohort 11	5-Feb-05	5-Dec-05	0.83	0.8113
Cohort 12	27-Apr-05	12-Oct-06	1.46	0.9317
Cohort 13	30-Aug-05	12-Sep-07	2.04	0.9662
Cohort 14	18-Apr-06	22-May-08	2.10	0.9734
Cohort 15	15-Jun-06	16-Sep-08	2.26	0.9404
Cohort 16	12-Jun-07	27-Oct-08	1.38	0.9492
Cohort 17	30-Aug-07	16-Sep-08	1.05	0.9333
Cohort 18	27-May-08	TBD		
Cohort 19	8-Dec-08	TBD		

Cohort Duration



- Each year except 2006 has a <1yr cohort and a >1yr cohort.
- Start dates of shorter cohorts usually earlier or later in the year (not during upwelling conditions)

Chl-*a* & cohort timing

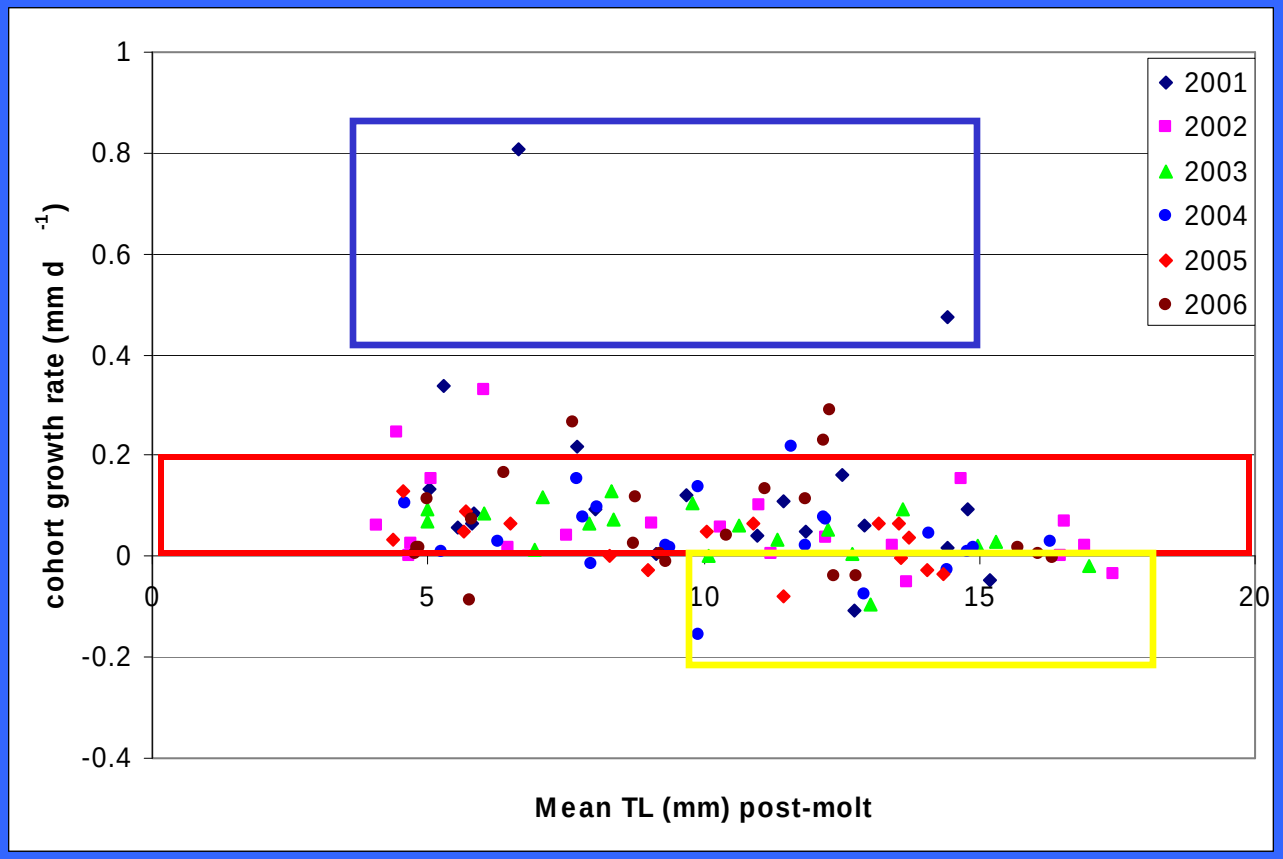


2+ yr cohorts start in association with high chl and experience high chl each summer.

Growth rates: cohorts & experiments

- Cohorts:
  - Growth rate calculated from change in mean length of cohort between sampling dates
- Instantaneous Growth Rate (IGR) experiments:
  - Measures growth of individual krill that molt during a 48h experiment
  - Krill may grow, shrink, or remain the same size
  - Molt approximately every 7 days in our study area
  - Two-week sampling interval probably covers at least two intermolt periods
  - Individual animals could potentially grow and shrink within one sampling interval

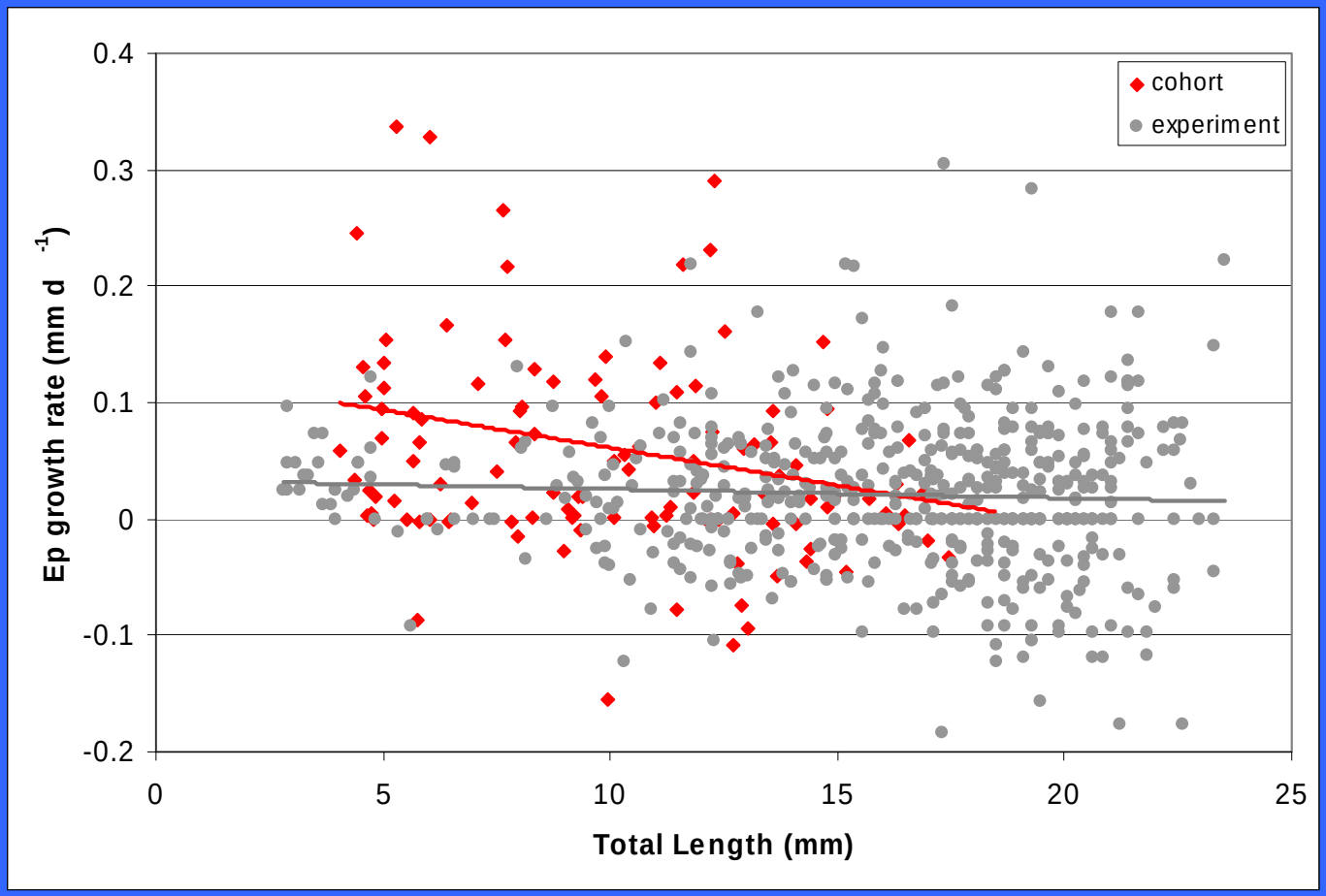
Cohort growth rates



- Growth rates usually 0.01-0.17 mm d^{-1}
- Growth rates above 0.4 mm d^{-1} only in 2001
- Growth rates usually positive, negative growth more common when animals ≥10 mm

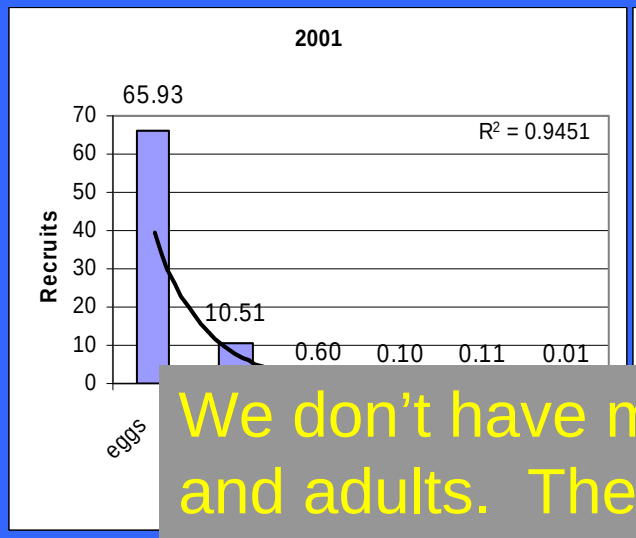
Cohort growth rates consistent among years. Interannual variability minimal if at all.

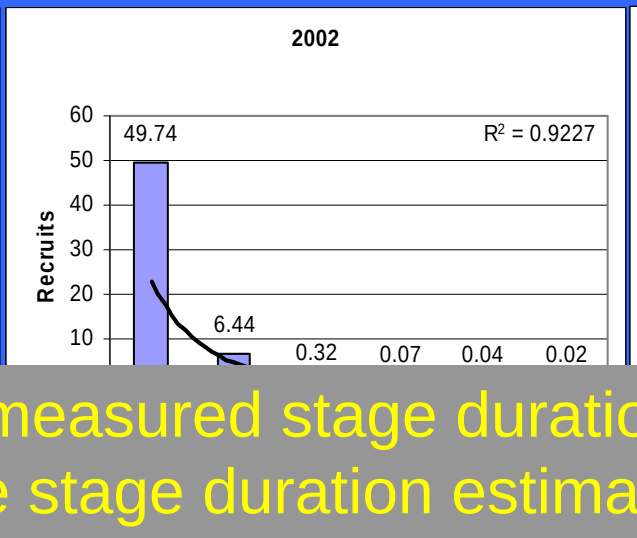
Cohort and IGR (expt) growth rates

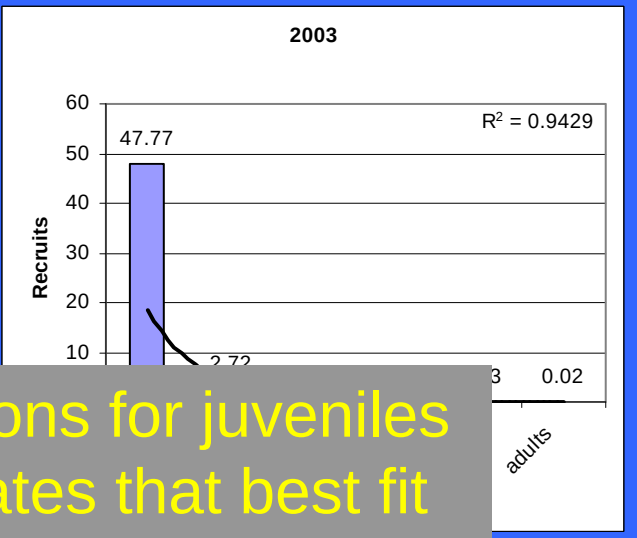


- Cohort growth rates (red) show that growth tends to slow as animals reach maturity
- IGR growth rates (gray) show range of individual variability

Survivorship Curves

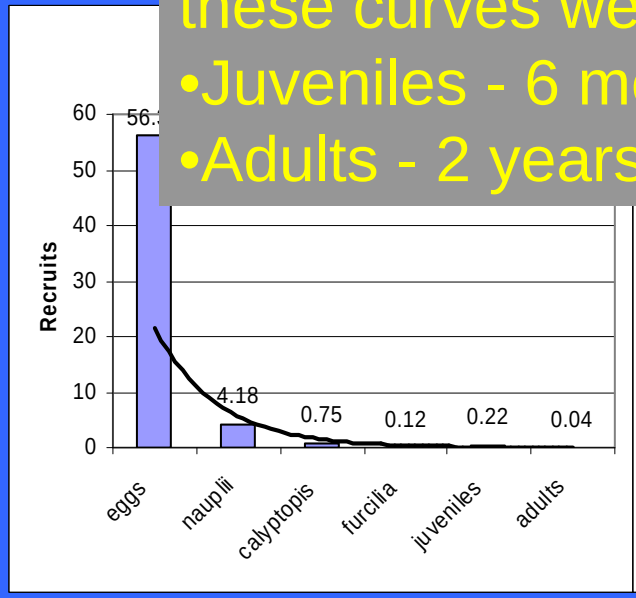


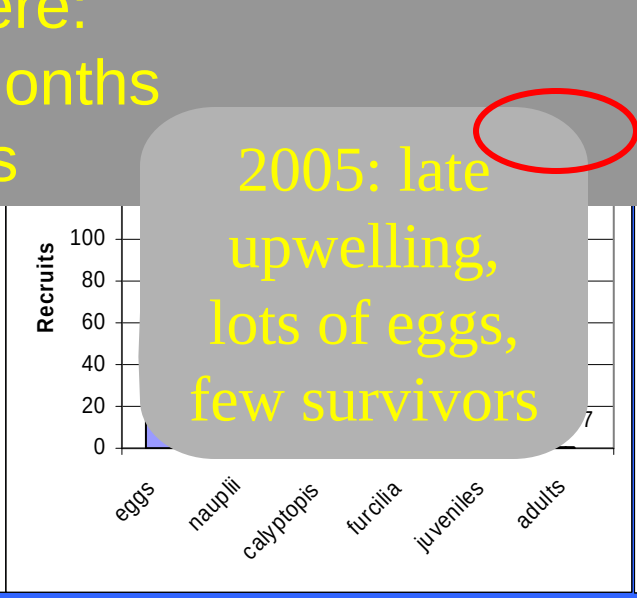




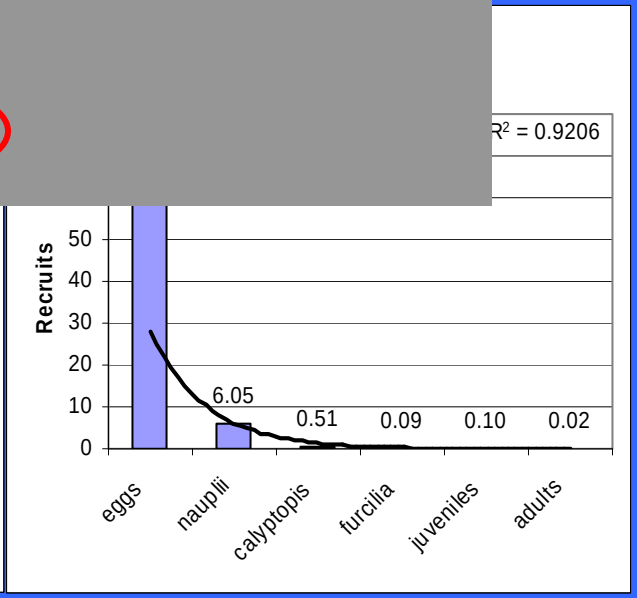
We don't have measured stage durations for juveniles and adults. The stage duration estimates that best fit these curves were:

- Juveniles - 6 months
- Adults - 2 years





2005: late upwelling, lots of eggs, few survivors



Summary & Conclusions

- Cohort analysis using maximum likelihood method and sufficiently short sampling interval can:
  - yield growth rates comparable to IGR experiments
  - identify some incidences of negative growth
- Cohort initiation and growth were similar among years in spite of differences in ocean conditions – variability so far is within tolerance range for *E. pacifica*
- Two or three cohorts initiated per year, often one short duration (<1yr) and one longer (>1.2yr) – implications?
- Survivorship from egg to furcilia was similar among years except in 2005: delayed upwelling → delayed spawning → lower survivorship
- Survivorship curves suggest the juvenile stage lasts about 6 months and that adults live about 2 years

Acknowledgements

- Research vessels: *R/V Sacajawea, R/V Elakha, R/V Wecoma, R/V Atlantis, R/V Frosti, R/V Miller Freeman, R/V McArthur II, R/V New Horizon*

- Funding sources: NOAA/NWFSC, ONR/NOPP, NSF/CoOP/COAST, NOAA-GLOBEC, NSF/CoOP/RISE, NOAA-SAIP

Thanks for help with experiments: Julie Keister, Mitch Vance, Jaime Gómez-Gutiérrez, Rian Hooff, Jesse Lamb, Jennifer Menkel, Jay Peterson.

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