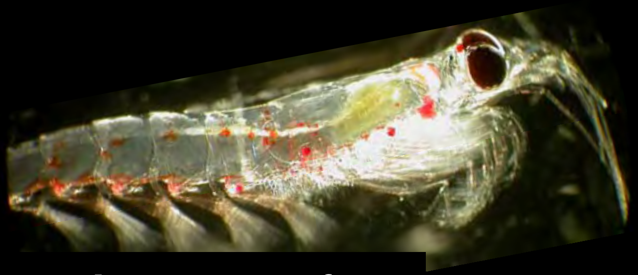
Possible effects of climate variability on the euphausiids *Euphausia pacifica* and *Thysanoessa spinifera* off Newport, OR, USA



Euphausia pacifica

Thysanoessa spinifera

C. Tracy Shaw, Leah R. Feinberg,
Hongsheng Bi, and William T. Peterson

Target Species

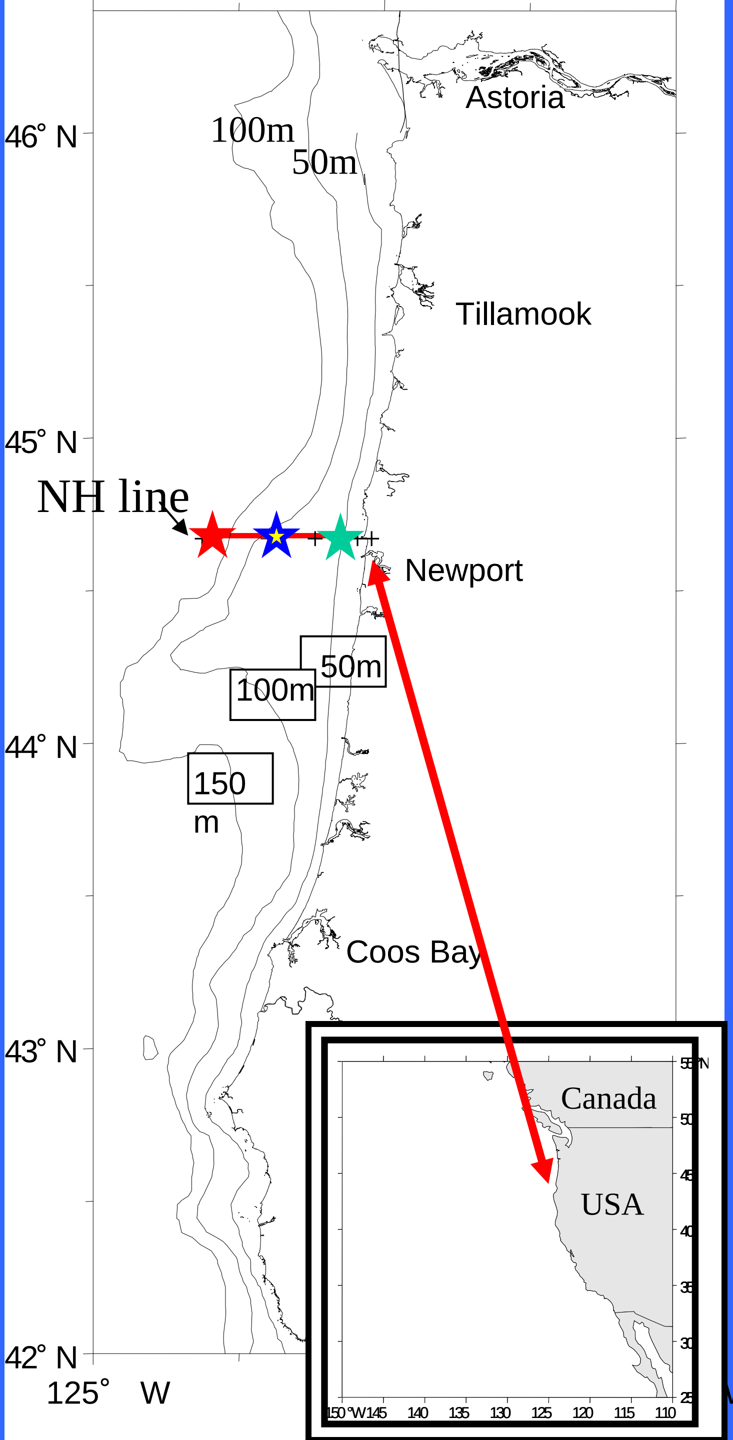
Euphausia pacifica

- 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

Thysanoessa spinifera

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

Time series off Newport, OR (NH line)



- Sampled twice per month for zooplankton by the Peterson lab since 1996
- Sampling for adult euphausiids using night bongo tows starting in 2001
- Environmental conditions
  - warm & cold PDO phases
  - timing of spring and fall transition dates
  - duration of upwelling

Ocean Conditions

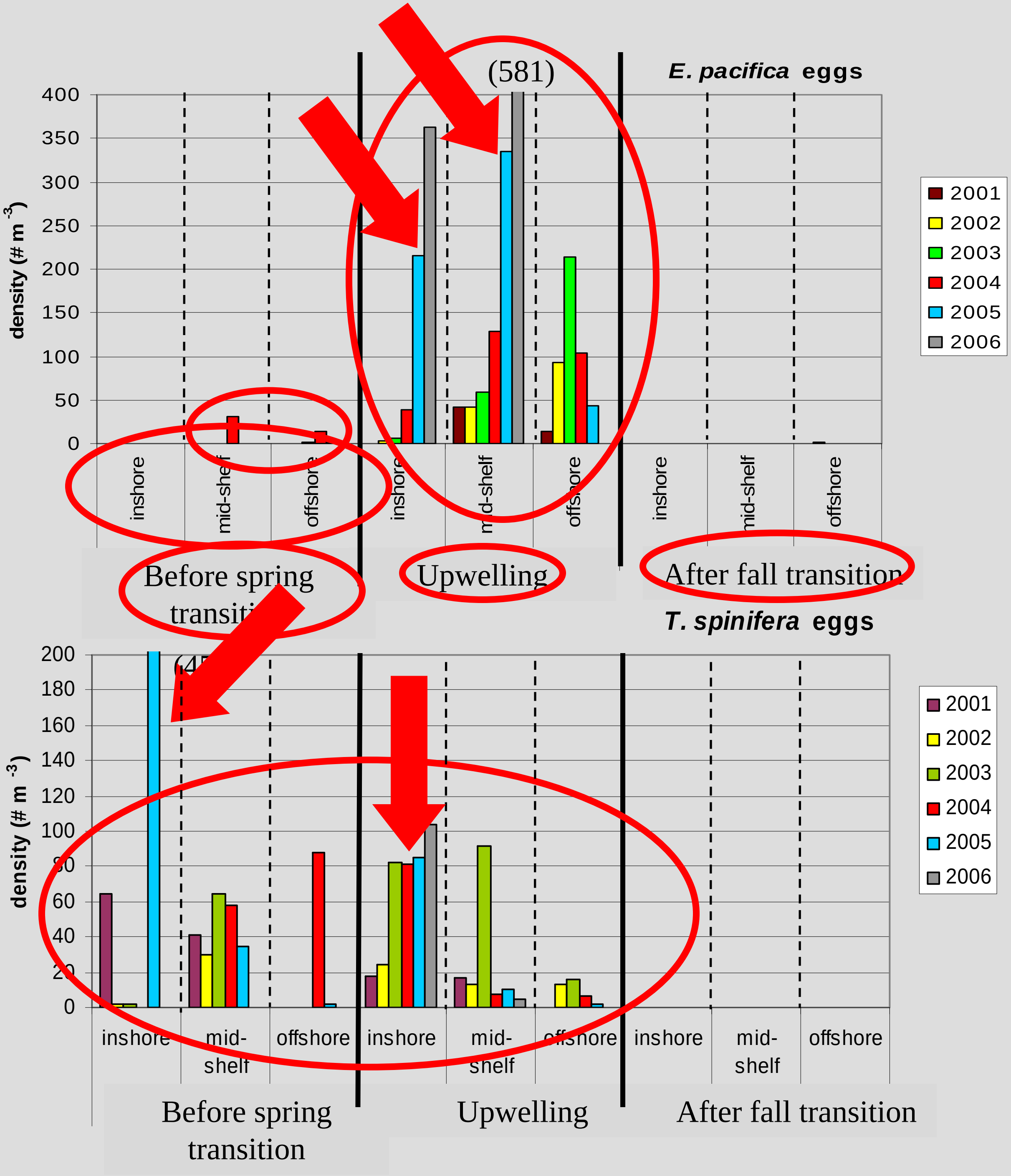
Year	Spring transition (ST)	Fall transition (FT)	Duration of upwelling (mo)	Ocean temp. (PDO phase)
2001	2-Mar	12-Nov	8.5	Cool
2002	21-Mar	6-Nov	7.7	Cool
2003	22-Apr	15-Oct	5.9	Warm
2004	20-Apr	7-Nov	6.7	Warm
2005	25-May	29-Sep	4.2	Warm
2006	22-Apr	31-Oct	6.4	Warm
2007	15-Mar	27-Sep	6.5	Cool
2008	30-Mar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

Cross-shelf distribution

- *E. pacifica* and *T. spinifera*
- Three locations – inshore, midshelf, offshore
- Three seasons – before ST, upwelling, after FT
- 2001-2006
- Life stages
  - Eggs
  - Nauplius
  - Calyptopis
  - Furcilia
  - Juvenile
  - Adult

Eggs

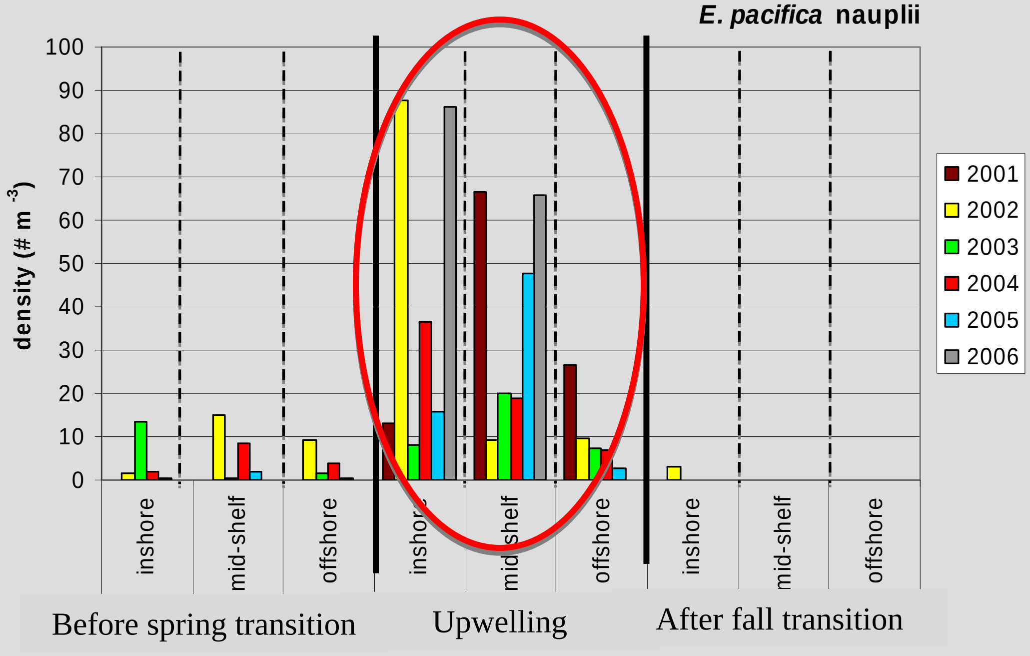
- Ep eggs clearly have a strong association with upwelling
- Ts eggs present at similar densities before and during upwelling
- Ts eggs high inshore during upwelling in warm years
- Ts eggs common prior to ST; Ep eggs present before ST only in 2004
- High Ep reproductive effort in 2005 after late onset of upwelling; high density of Ts eggs before upwelling

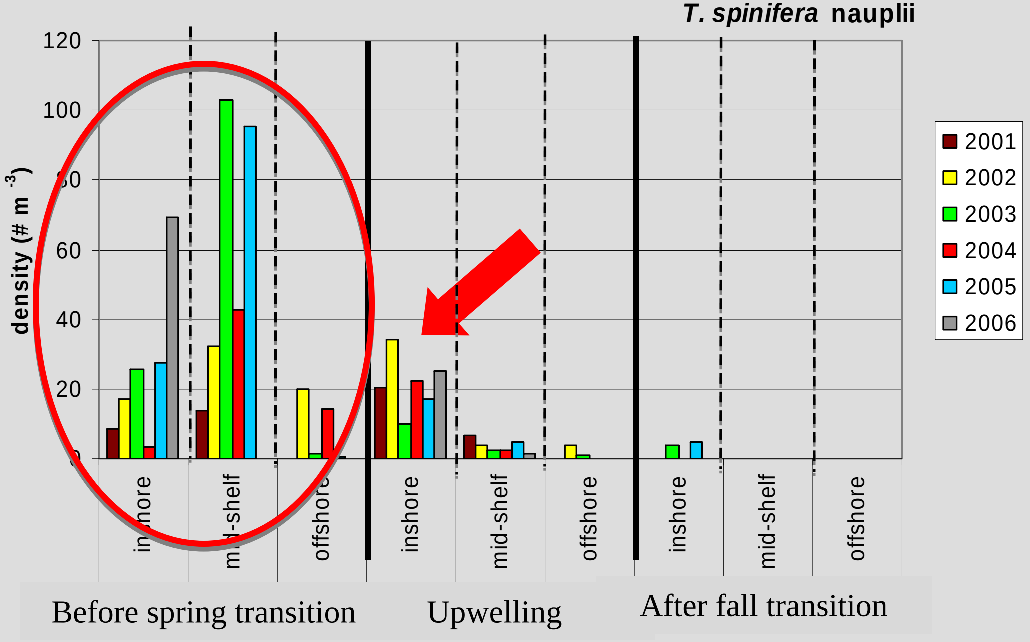


Nauplius

(includes metanauplius)

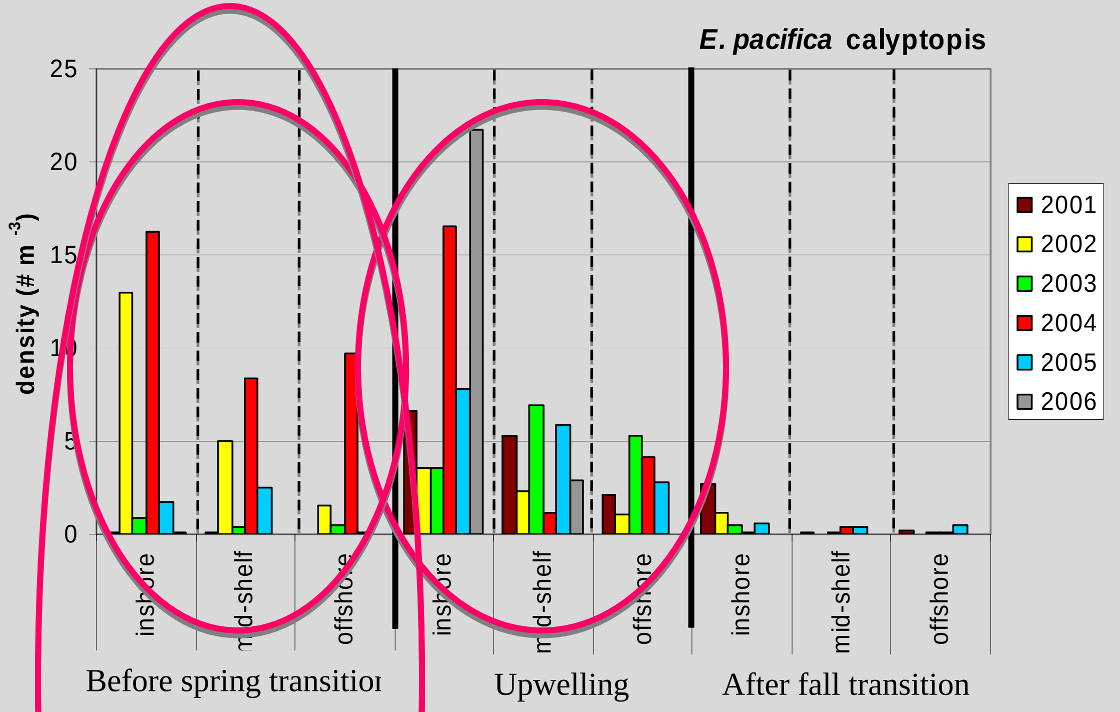
- Patterns similar to eggs since hatching time ~36h: hence Ep nauplii also associated with upwelling
- Ts nauplii highest densities before upwelling season
- Ts present at low densities during upwelling at the inshore station; warm years not consistently higher as with eggs

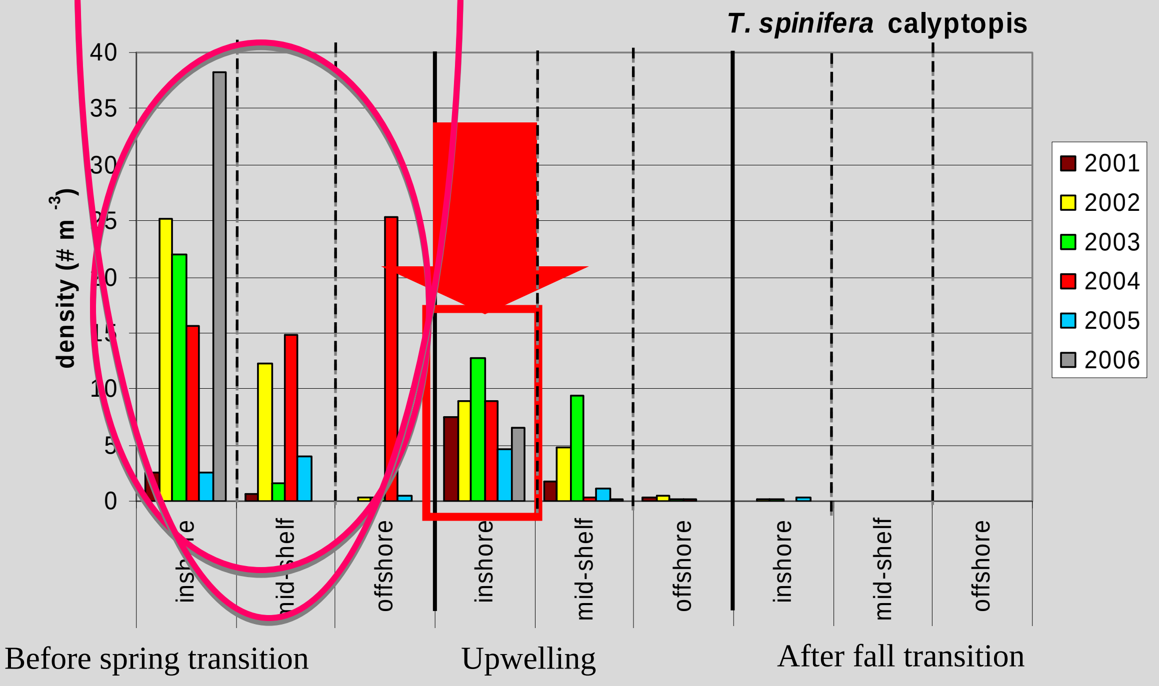




Calyptopis

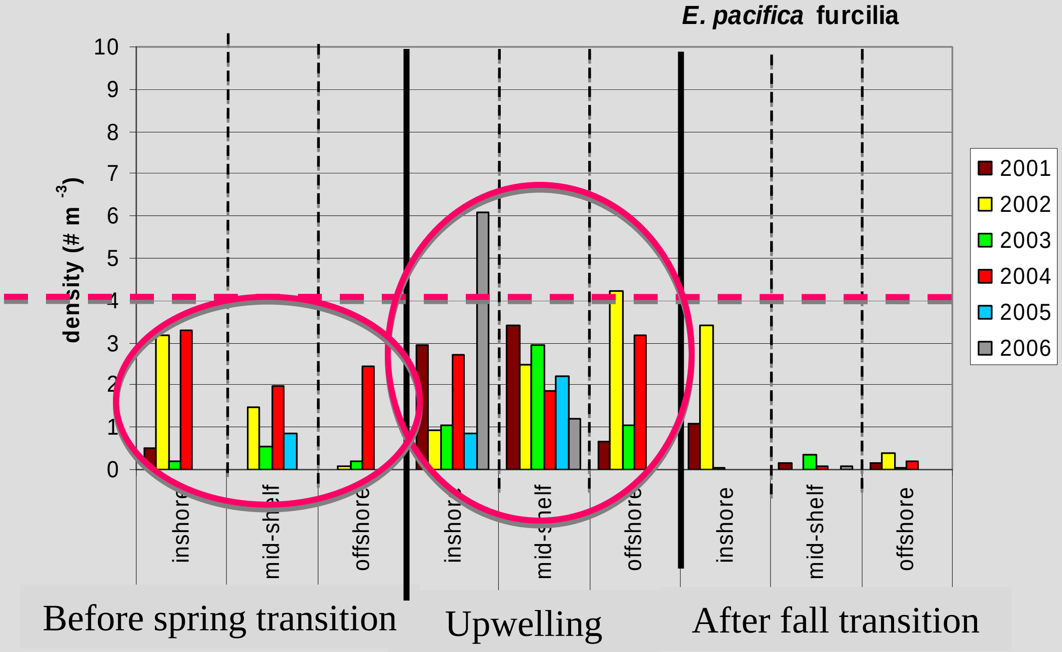
- Ep still strongly associated w/upwelling, but also present prior to spring transition
- Ts values highest before spring transition
- Ts consistently found inshore during upwelling; warmer years not consistently higher
- Ep & Ts at all stations before spring transition in 2004 (red bars)

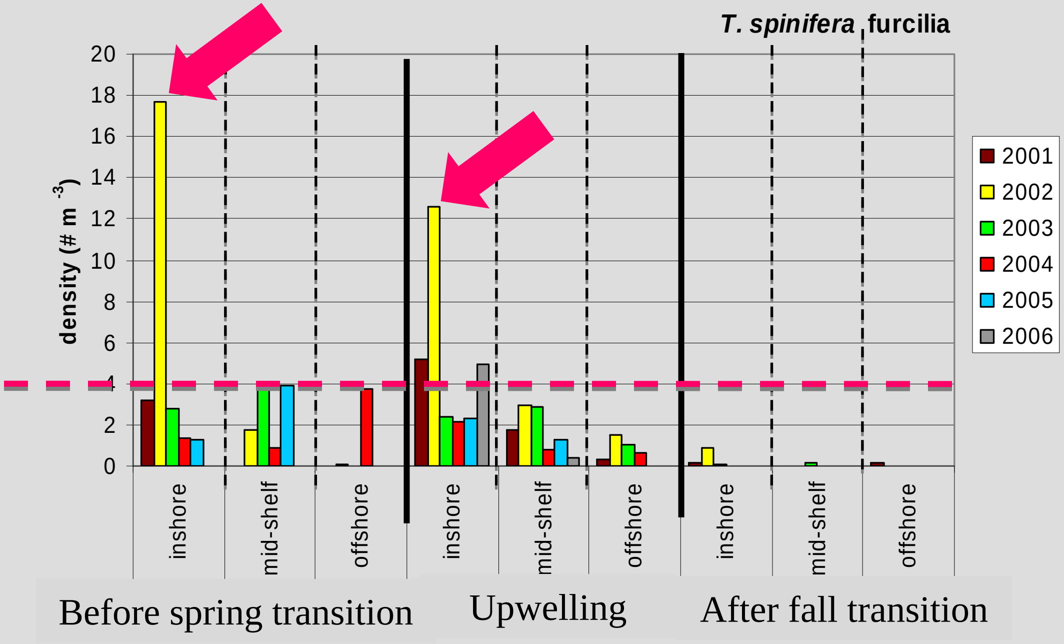




Furcilia

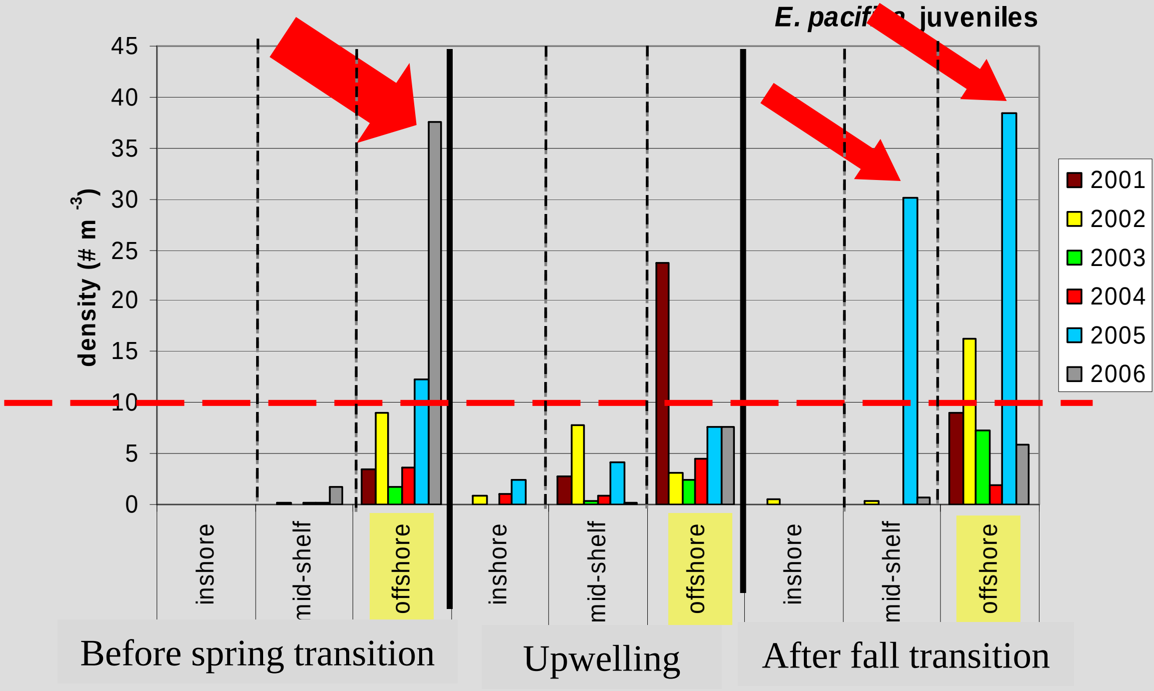
- Densities usually <4 for both species
- In spite of low densities, Ep still associated with upwelling
- Ts densities >4 only in 2002: a cold year with lots of Ts spawning
- Ep & Ts present across the shelf before spring transition in 2004 (red bars)

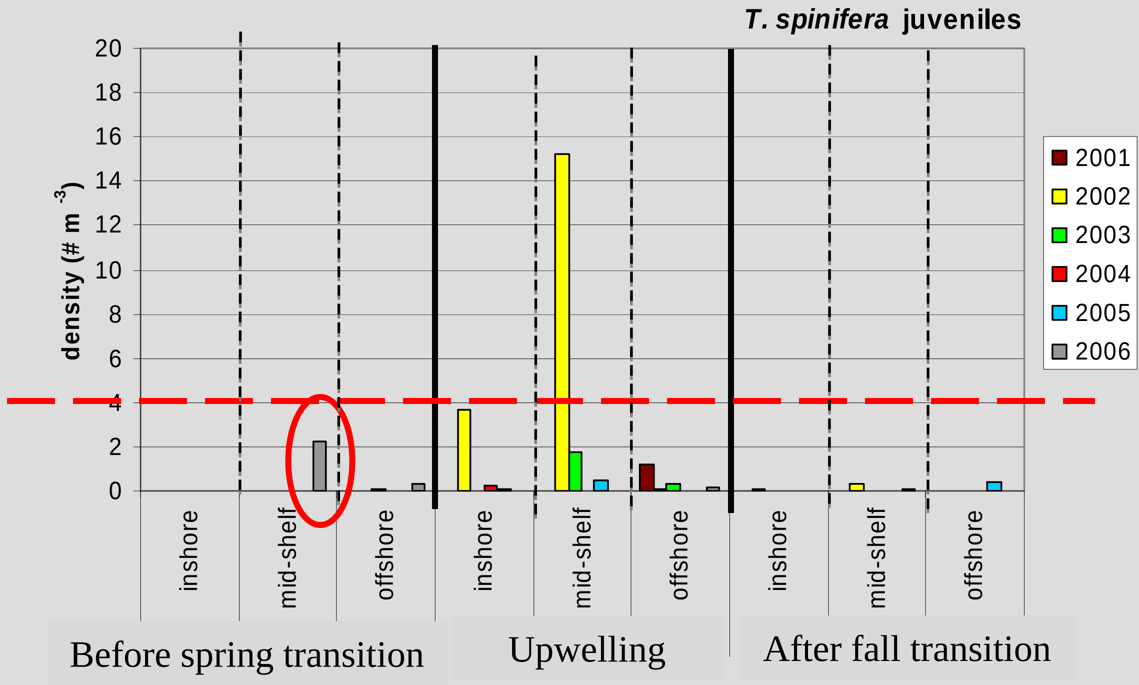




Juvenile

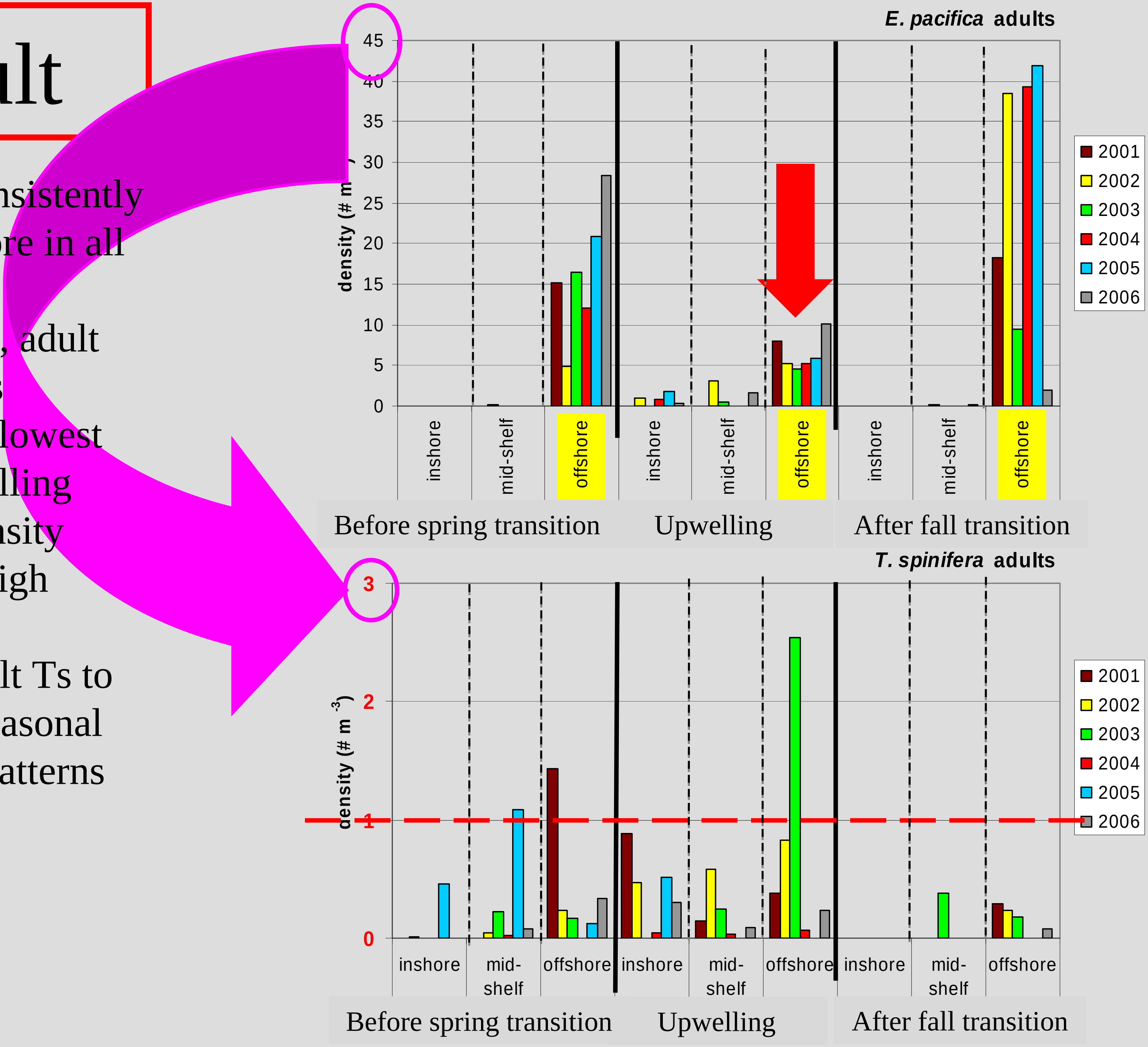
- Ep densities generally <10, often <5
- Ep shifting to offshore
- Lots of Ep juveniles after fall transition in 2005 when spawning effort was delayed by late start to upwelling
- High Ep density before spring transition in 2006 may be these same animals after overwintering
- Juvenile Ts densities generally <4, often <2, high Ts reproductive effort in 2002 led to density ~15
- Ts before ST in 2006 but still a very low density



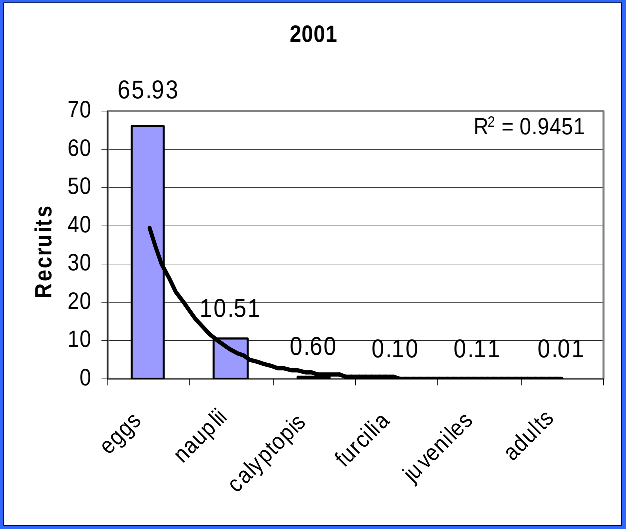


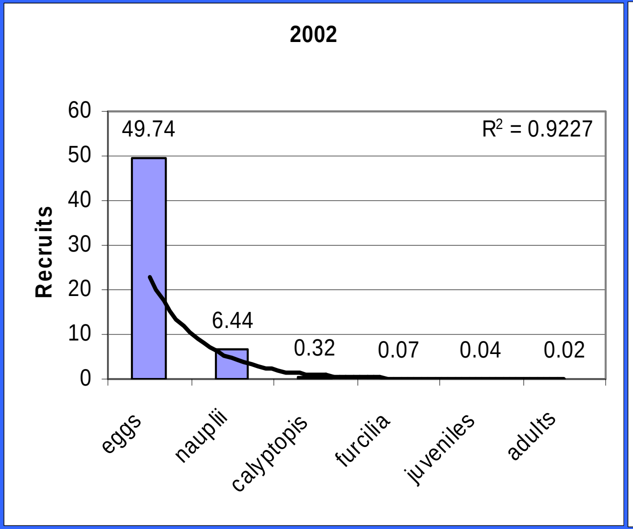
Adult

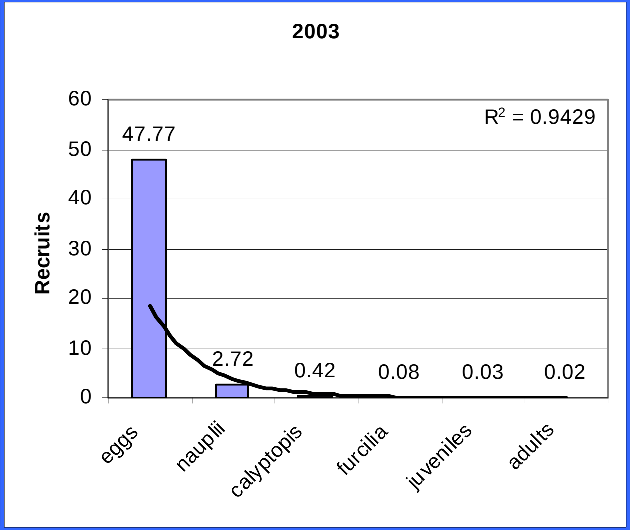
- Adult Ep consistently found offshore in all seasons
- Interestingly, adult Ep density is consistently lowest during upwelling
- Adult Ts density never very high (usually <1)
- Too few adult Ts to determine seasonal abundance patterns

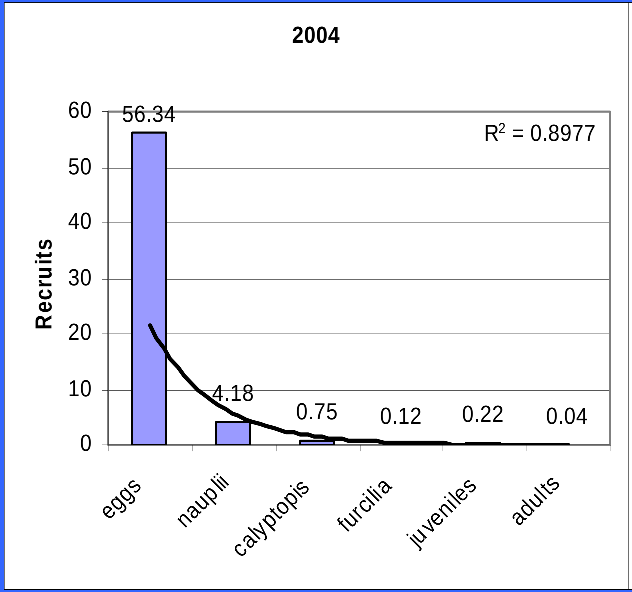


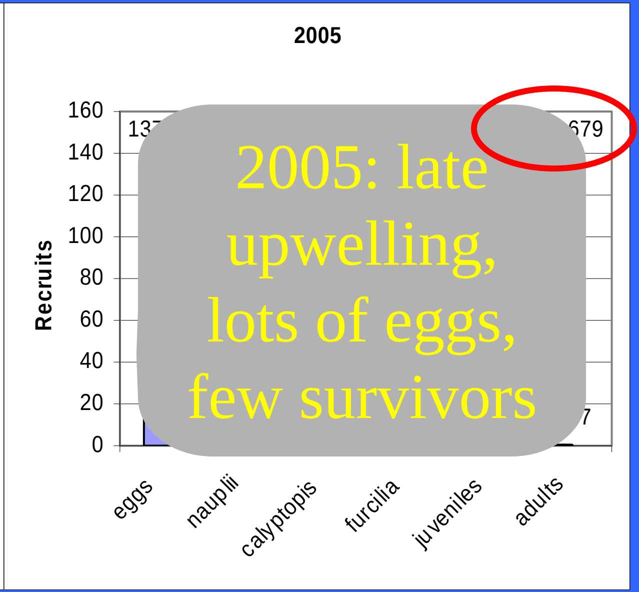
Survivorship Curves





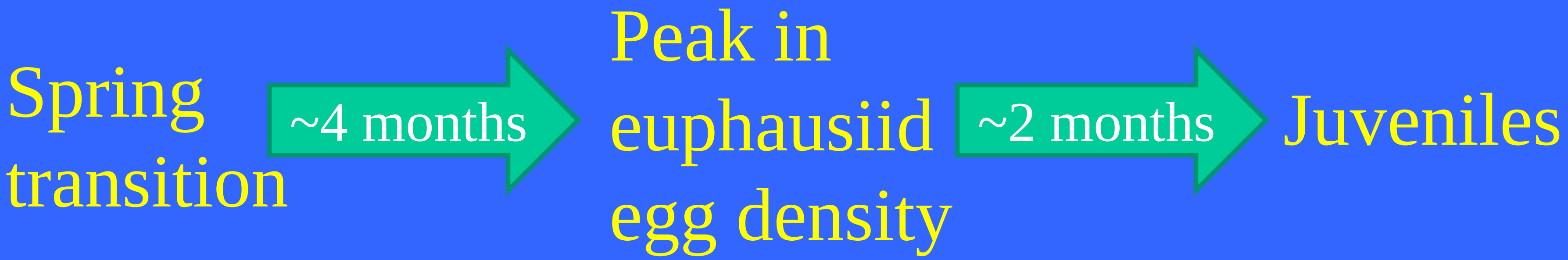






2005: late upwelling, lots of eggs, few survivors

Relationship between *E. pacifica* spawning and timing of spring transition



Spring transition

~4 months

Peak in euphausiid egg density

~2 months

Juveniles

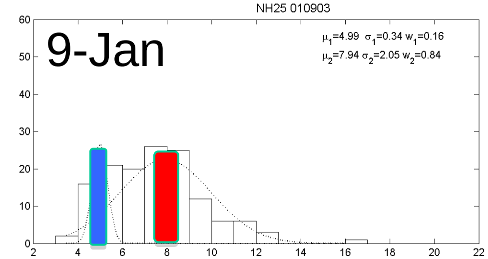
- Consistent pattern for all six years of data regardless of environmental conditions
- *E. pacifica* spawning behavior is highly dependent on upwelling
- Changes in upwelling off the Oregon coast are likely to affect this pattern of euphausiid spawning

E. pacifica cohort analysis

- 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

Cohort caveats

- Cohort analysis assumes resampling of the same population over time
- Patchy distribution of euphausiids may result in disappearance & reappearance of size modes
- Krill grow more slowly at cooler temperatures and can shrink under certain conditions
  - Longer sampling intervals winter plus 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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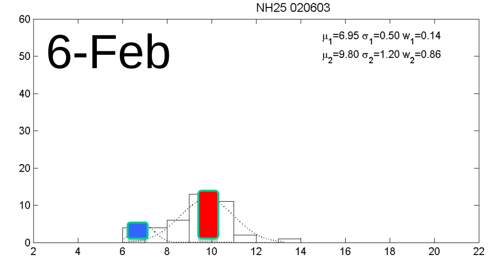
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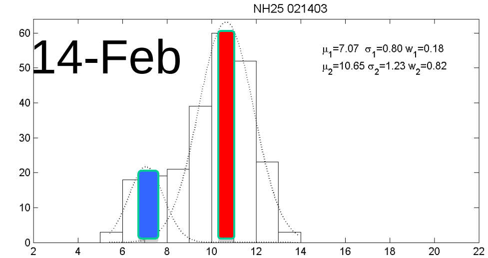
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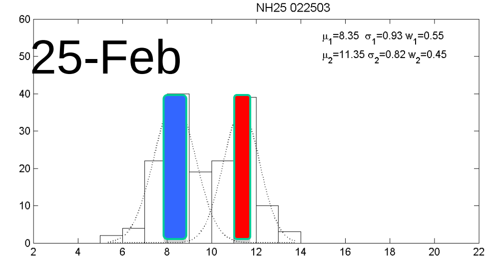
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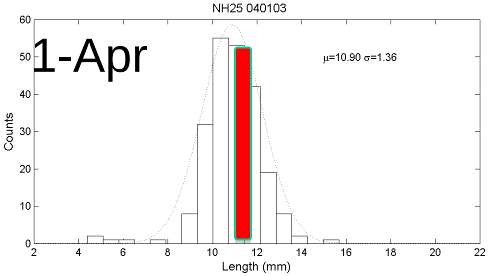
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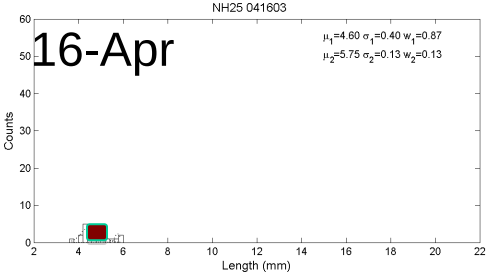
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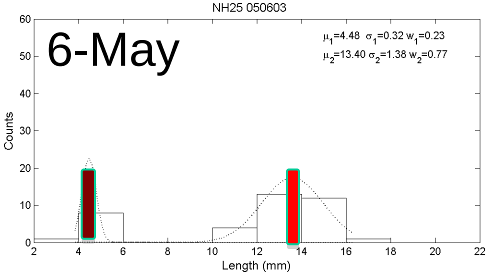
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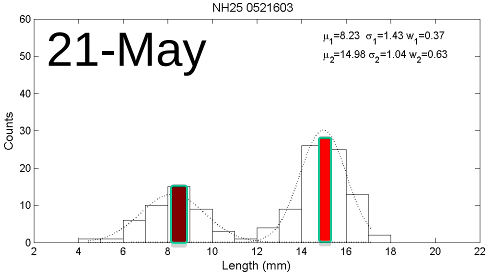
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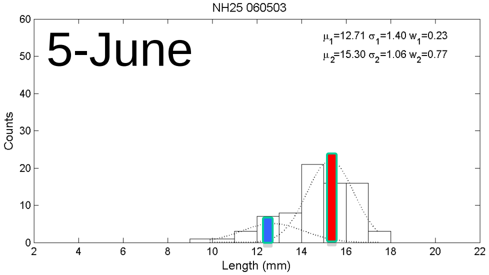
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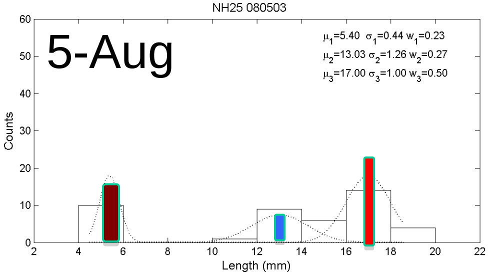
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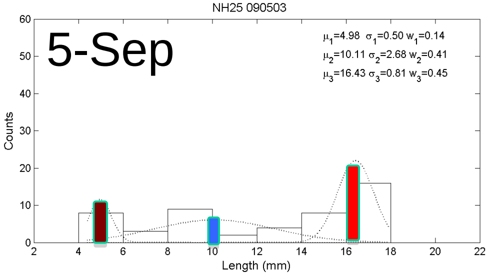
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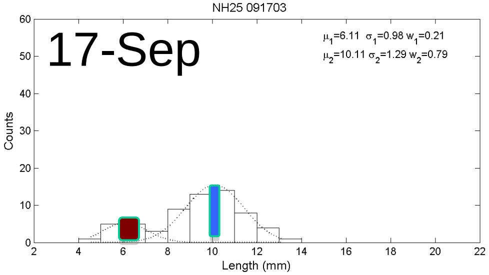
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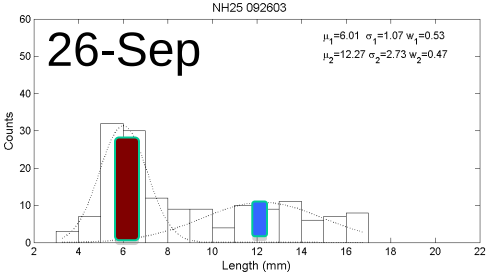
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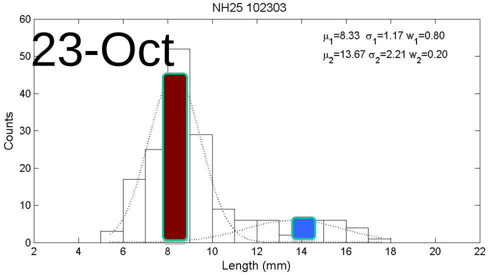
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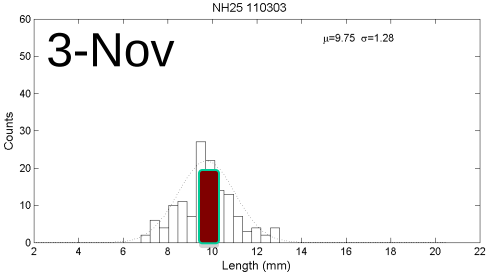
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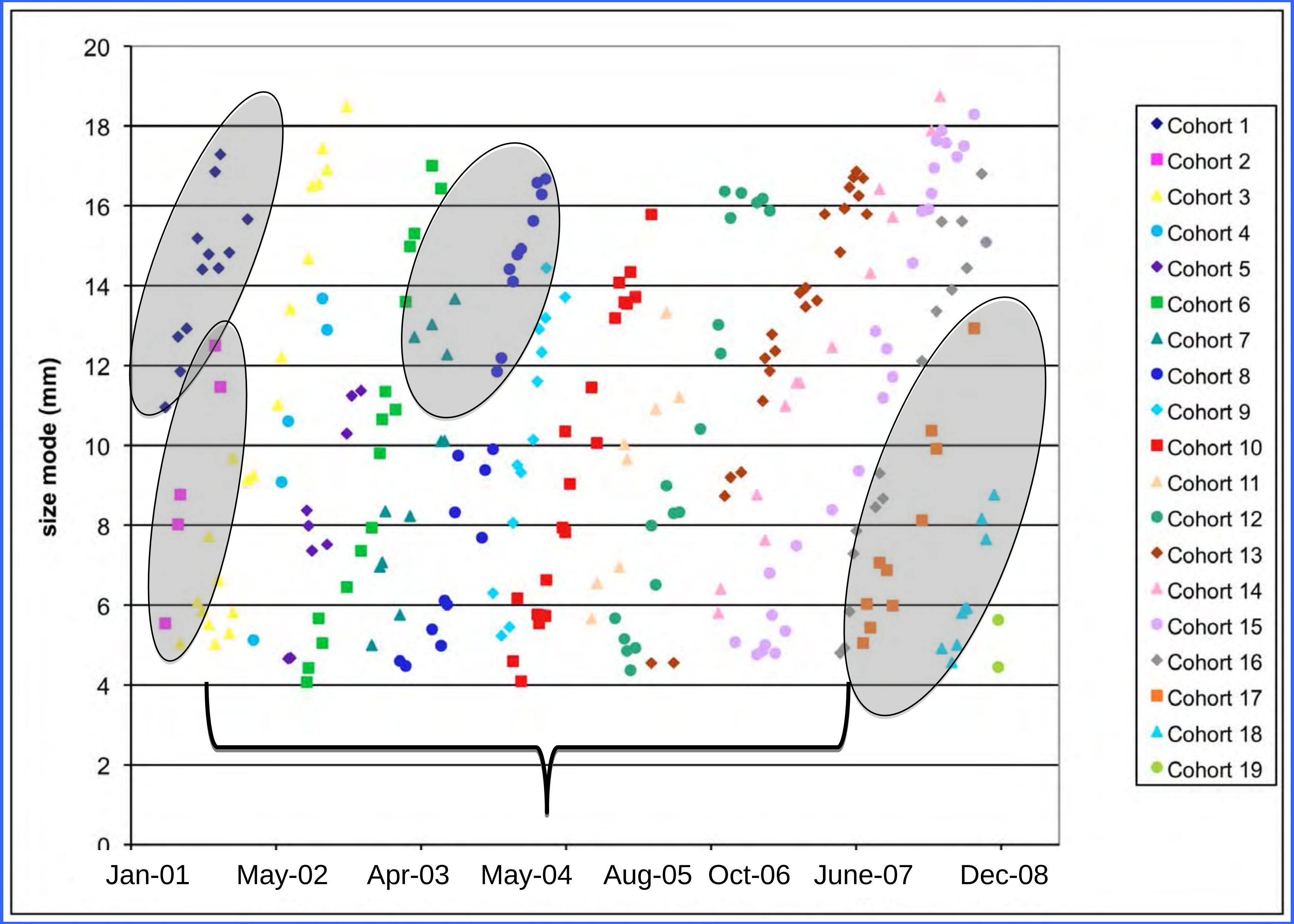
2003

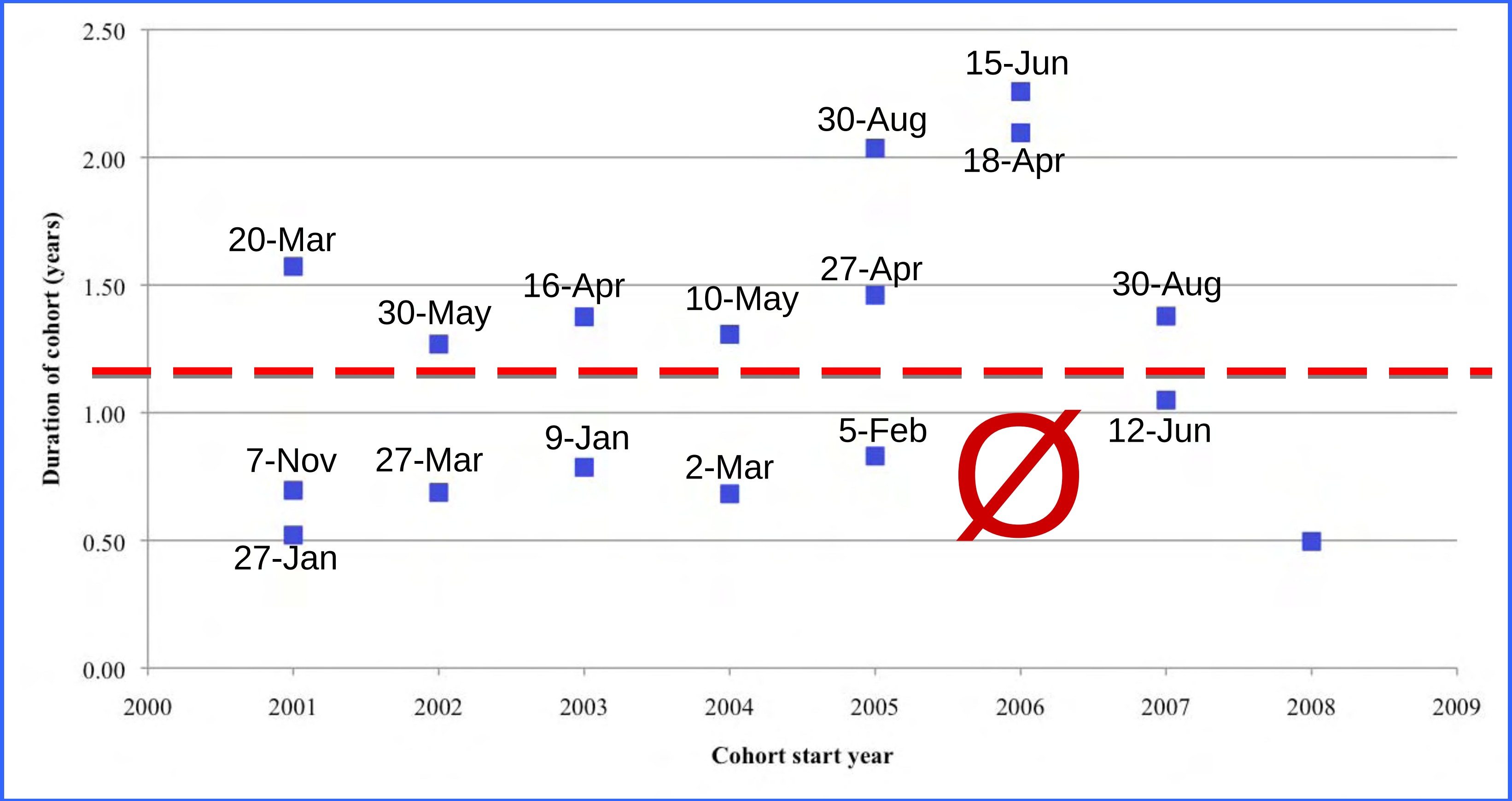
Cohorts 2001-2008



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 <1 yr cohorts (not during upwelling conditions) suggest that these are krill that have overwintered as juveniles or immature adults
- Absence of <1 yr cohort in 2006 is probably due to low survivorship after late 2005 spawning

Things we wish we knew…

- Are there multi-year effects? How might a longer series of warm or cold years affect krill that live for 2+ years?
- What are the preferred prey items for these species? How will climate change affect the availability of preferred prey? How well might krill adapt to a different prey field?
- How quickly can krill adapt to increasing temperatures?
- Mortality rates? How can we tell if the rates change in relation to environmental conditions if we don’t know what they are now?
- A closer look as the conditions prior to the spring transition in 2004 might be informative since all life stages of both species were present at all stations during that time

Summary & Conclusion

- Spring transition
  - – Timing closely tied to *E. pacifica* spawning
  - – *T. spinifera* spawn mainly prior to ST
- Temperature
  - – Not associated with *E. pacifica* distribution
  - – *T. spinifera* distribution strongly dependent on temperature
- Conclusion: effects of climate change will be species-specific for these two species of krill – fun times for modelers ☺

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