STAC Workshop – 28 March 2017

Blue crab ecology and exploitation in a changing climate.

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Global Warming

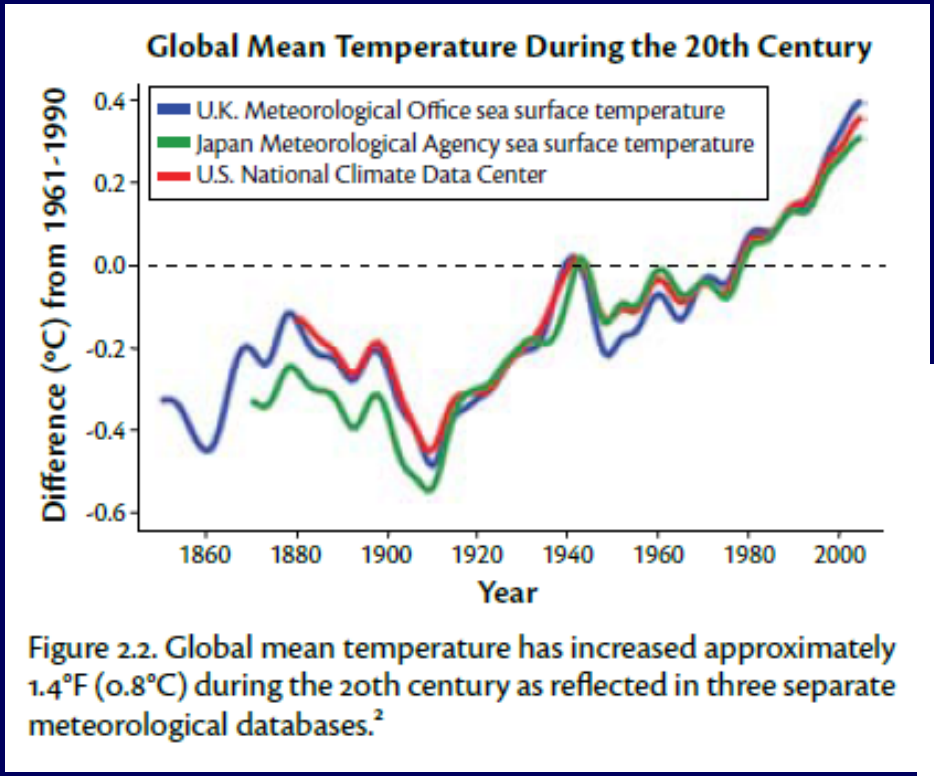
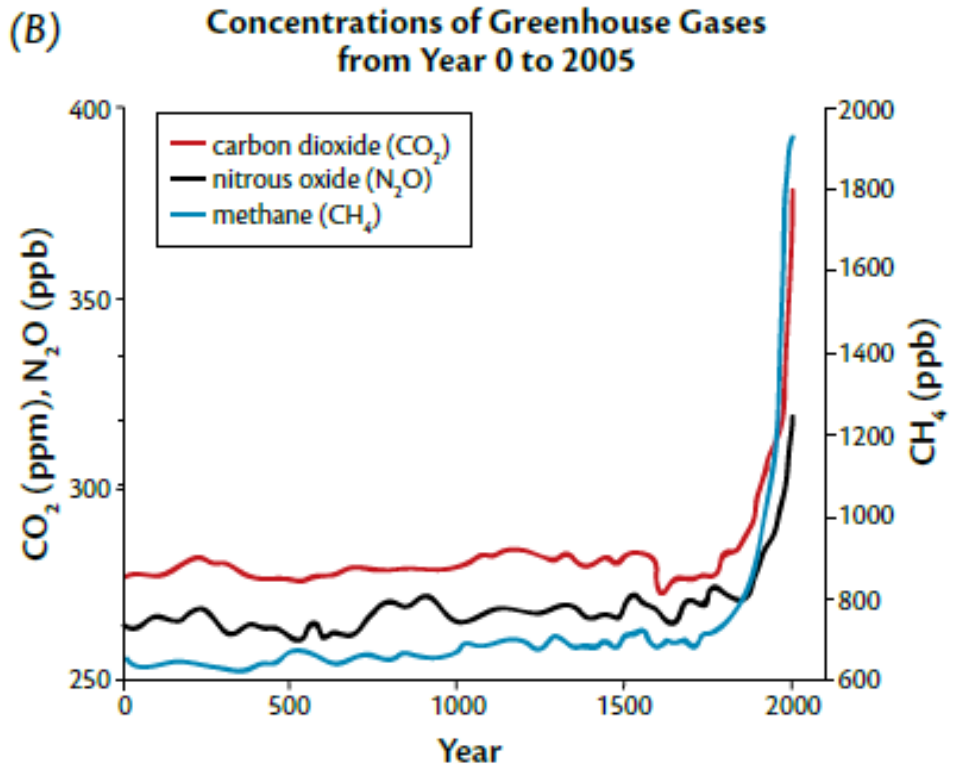
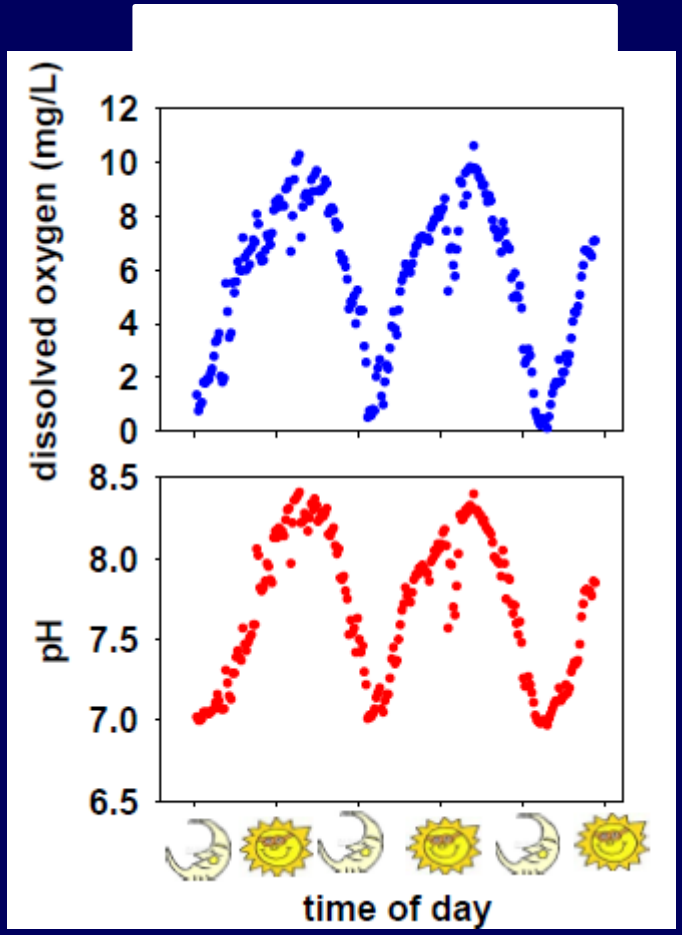


Figure 2.2. Global mean temperature has increased approximately 1.4°F (0.8°C) during the 20th century as reflected in three separate meteorological databases.[2]



Variability in the Chesapeake Bay



Mean pH 1985-2012

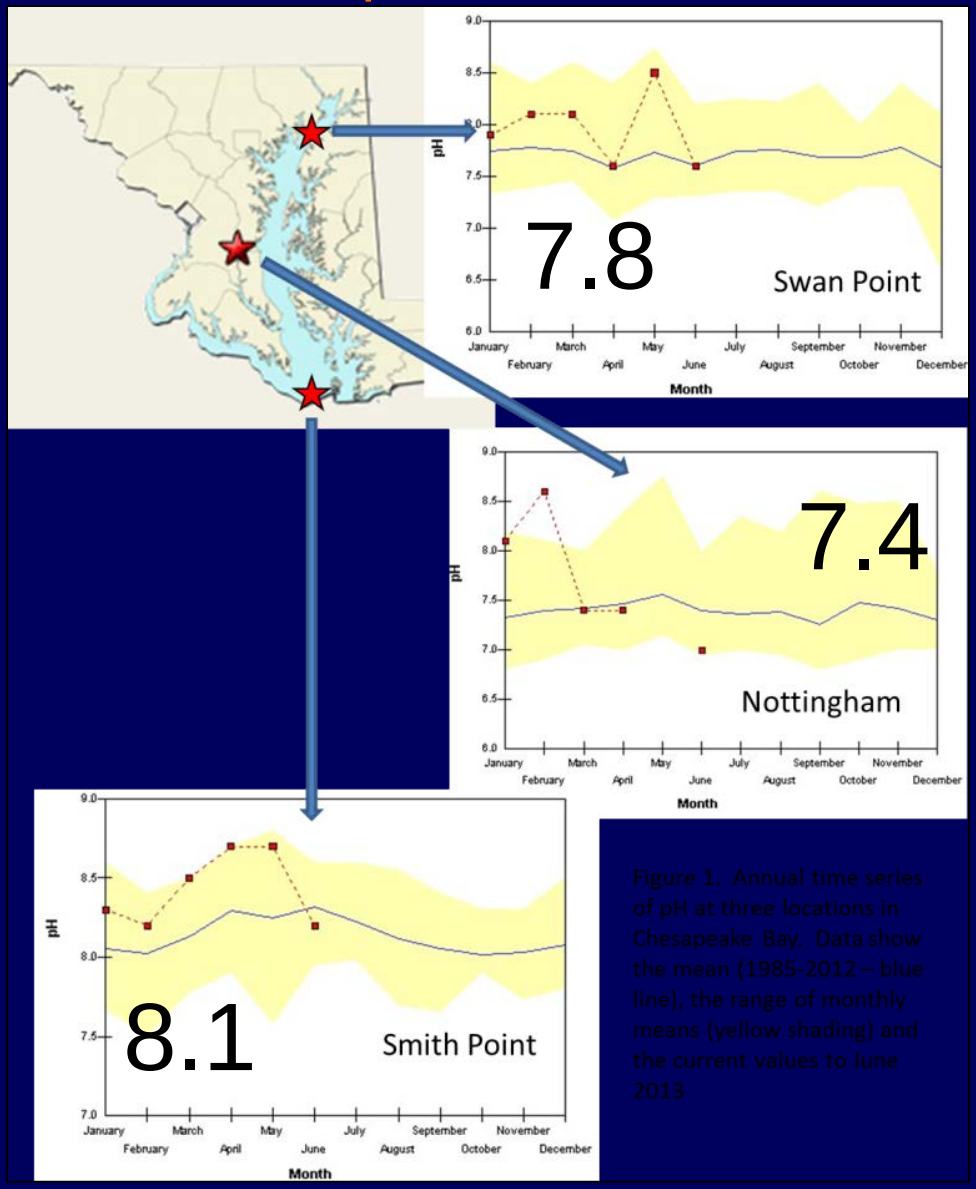
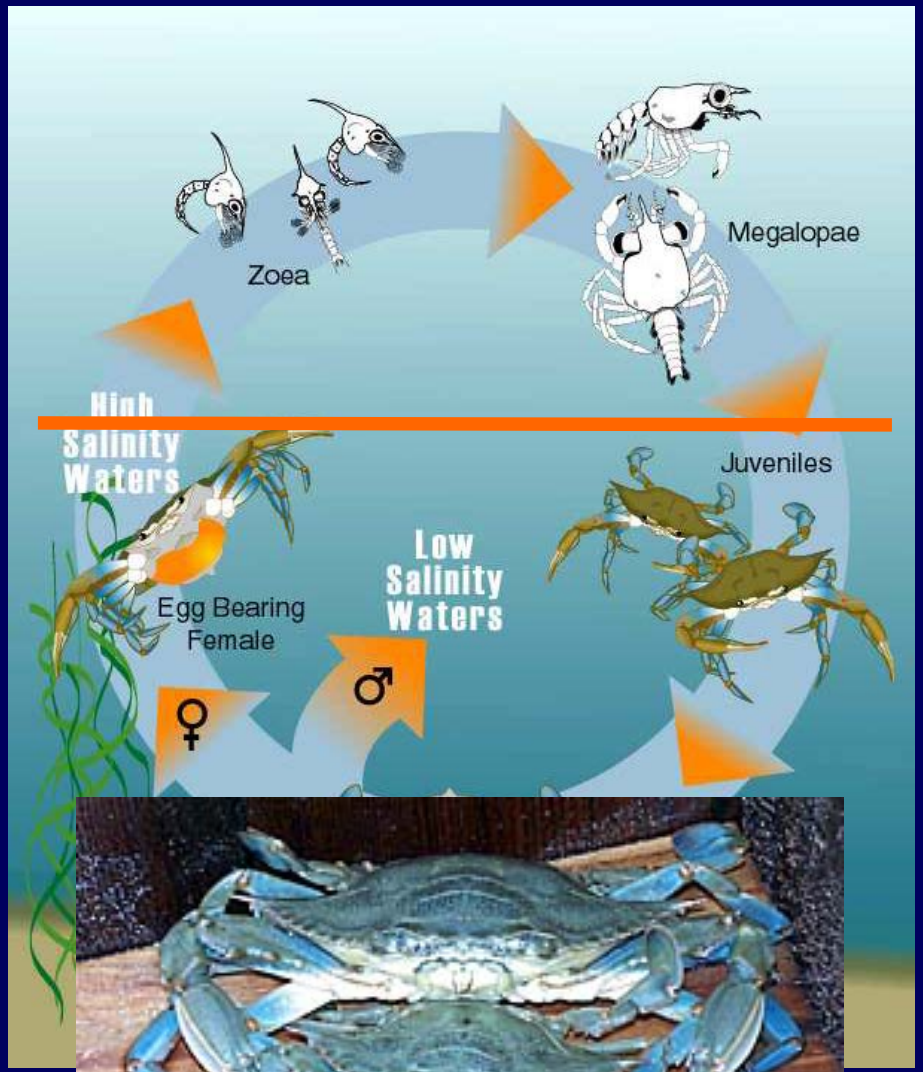


Figure 1. Annual time series of pH at three locations in Chesapeake Bay. Data show the mean (1985-2012 – blue line), the range of monthly means (yellow shading) and the current values to June 2013

http://mddnr.chesapeakebay.net/eyesonthebay/index.cfm

Blue crab life history

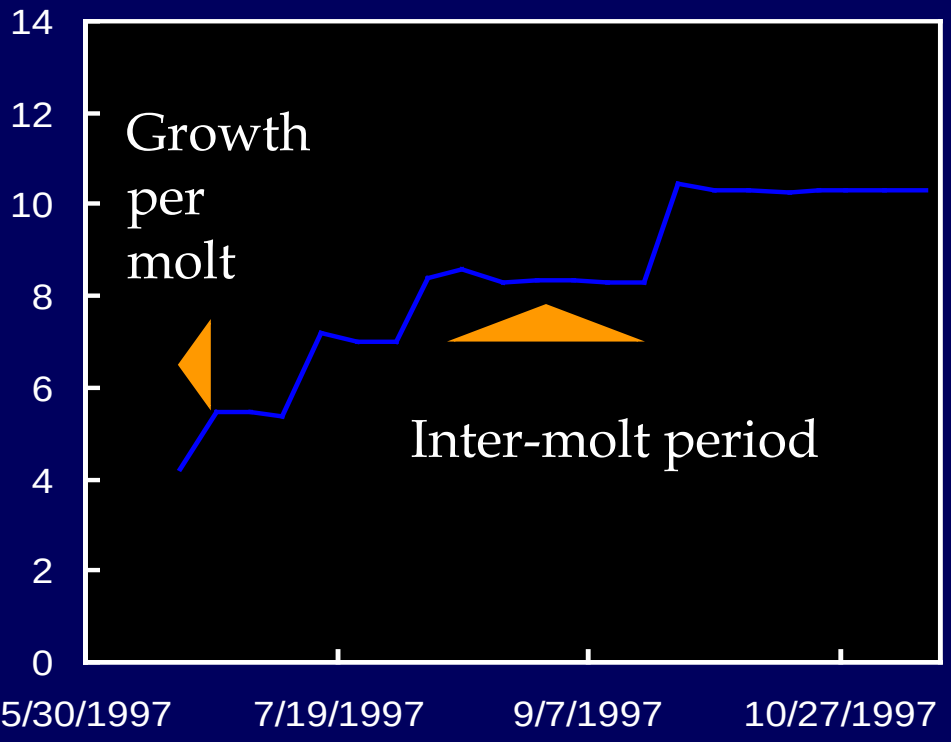


Climate and recruitment

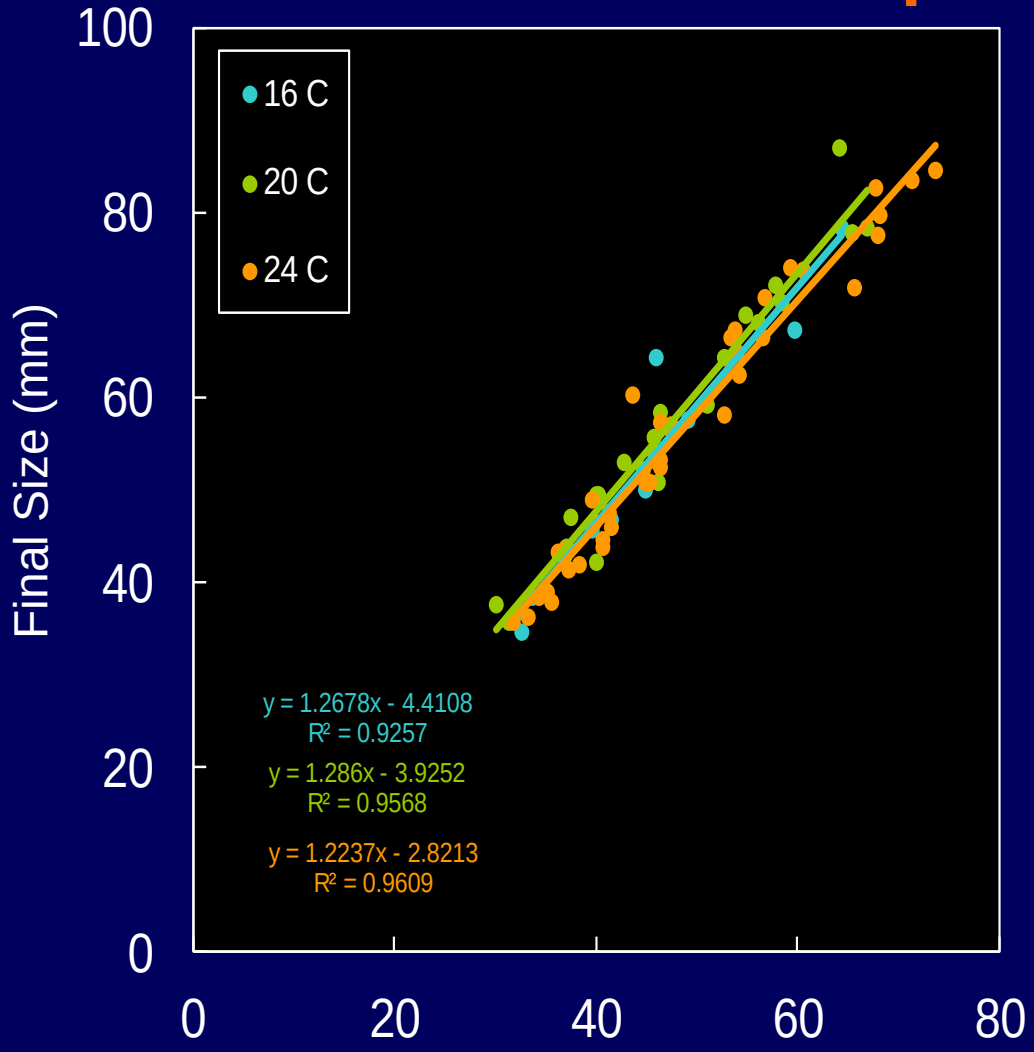
- Recruitment mechanisms poorly understood
  - Recruitment strongly influenced by stock size
  - Role of coastal currents
  - Active behavior
  - Stock –recruit modeling suggests roles for
    - June – Sept wind stress in lower Bay
    - River discharge (other systems)

Growth

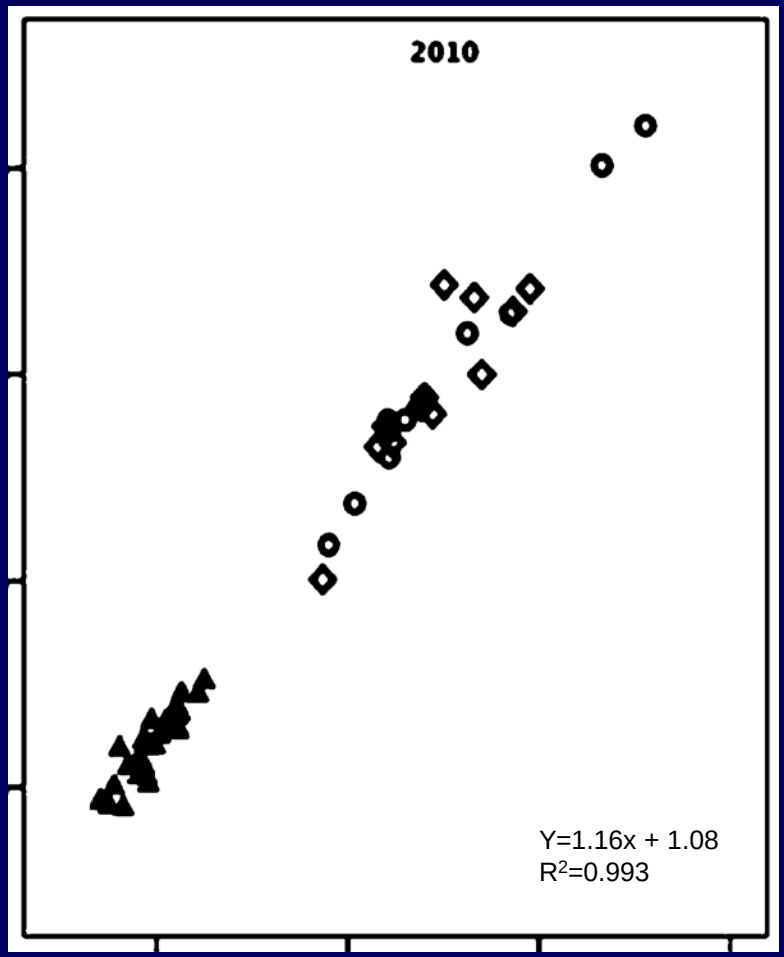
- Growth by molting
- May molt up to 20 times to reach adult size
- Characterized by periods of stasis and rapid increases in size, during which the shell is soft



Growth per molt



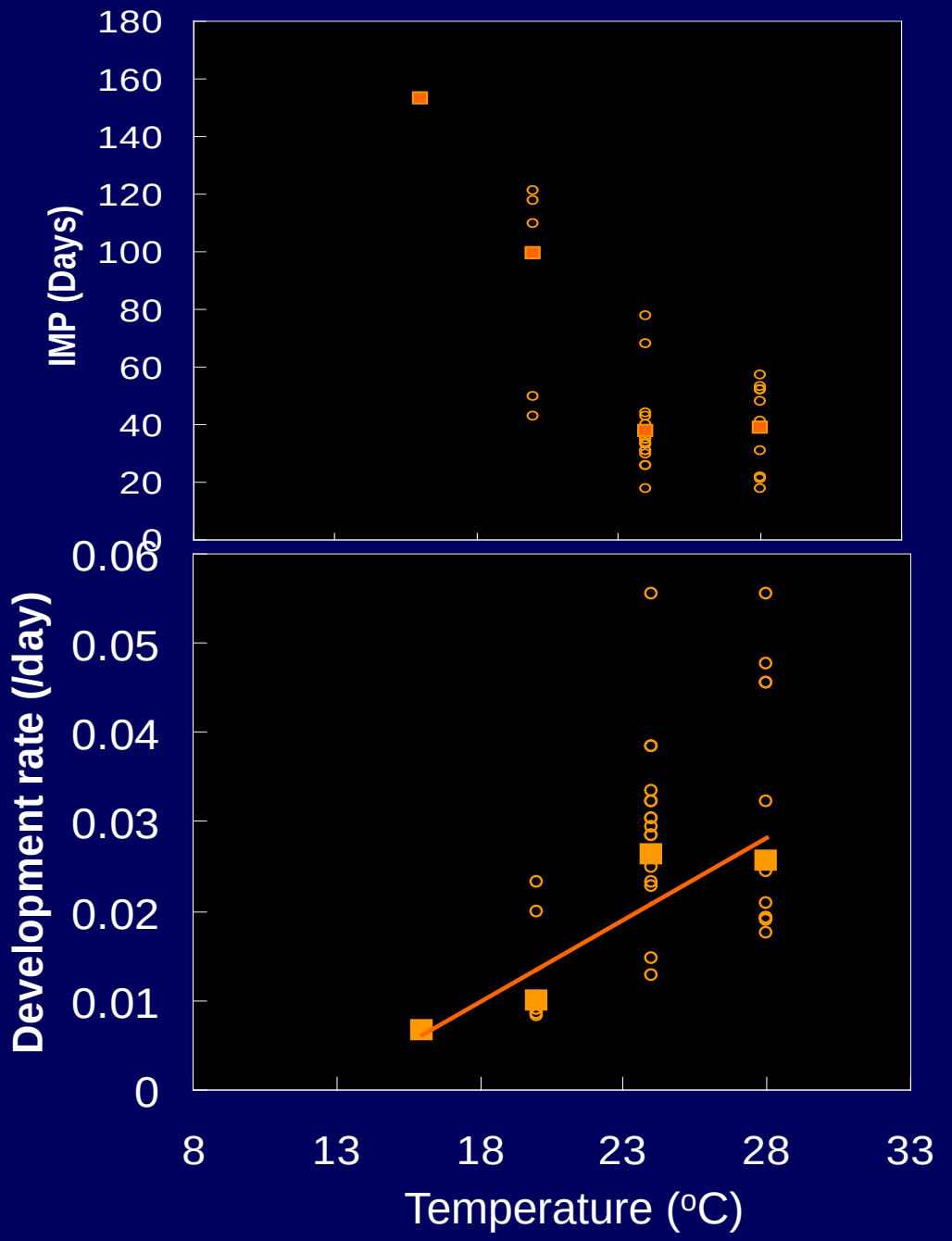
Brylawski et al. 2006



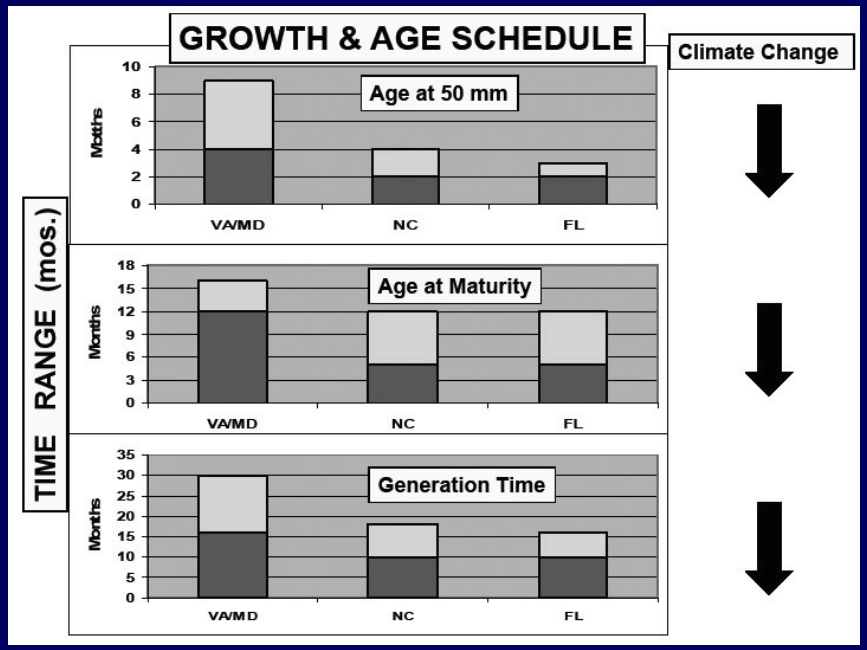
Bilen et al. 2014

Intermolt period

- Intermolt period decreases significantly with temperature
- Development rate increases with temperature and predicts overwintering at ~10-11^{o}C
- IMP increases slightly with size



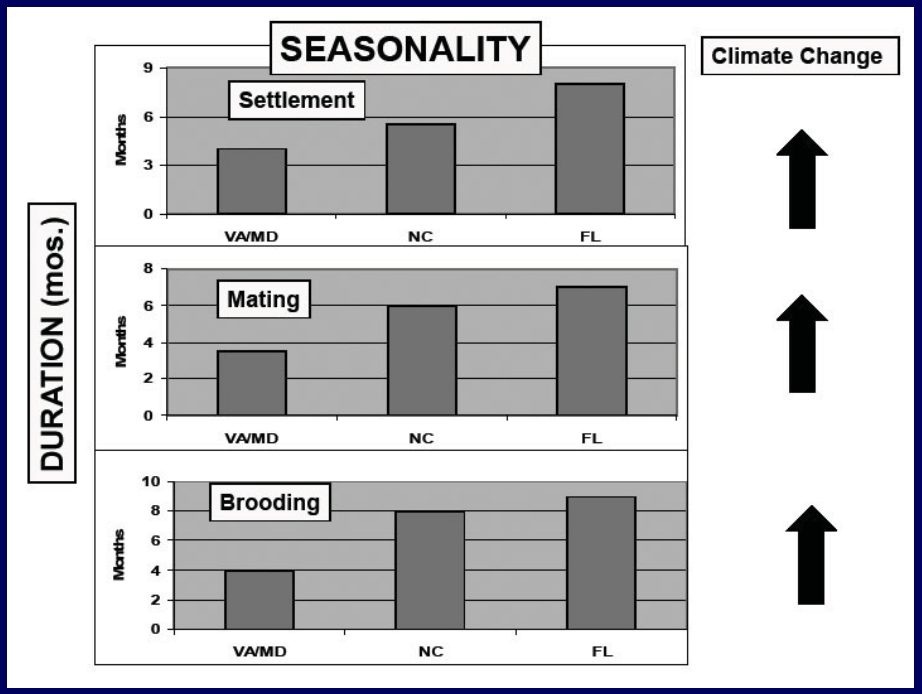
Overall growth



Hines et al. 2010

- Temperature-dependent increases in growth decrease time to specific life history events
- Increases in population productivity expected.

Reproduction



From Hines et al. 2010

- Period suitable for principal reproductive events increases with temperature
- Size at maturity tends to decrease with temperature
- Impacts on fecundity less clear

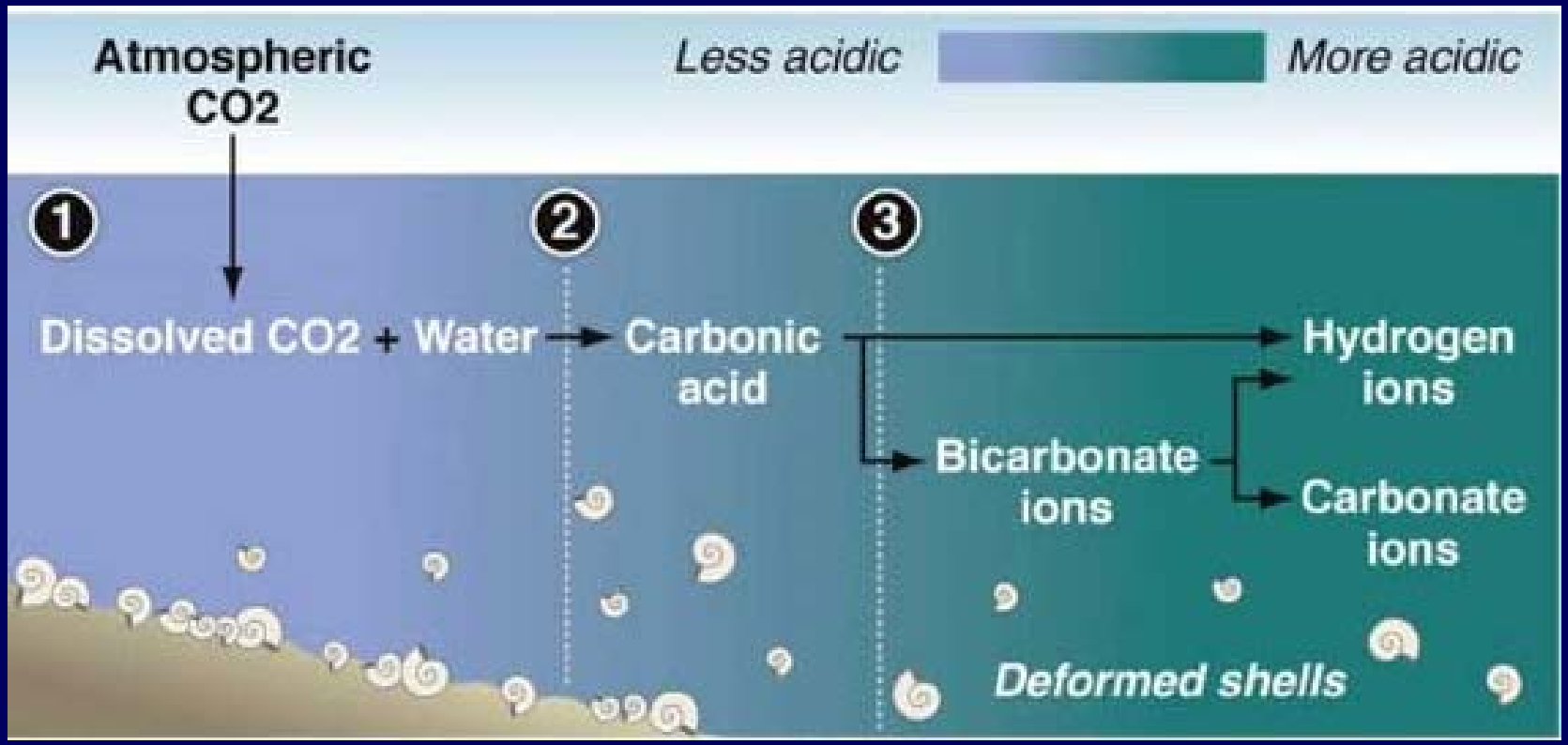
Climate and growth

- Limiting temperature (~9-11 ^{o}C) for growth induces overwinter dormancy.
- Above limiting temperature, growth well described by stochastic degree-day model
- Faster growth reduces time to key life history events
- Data needs: high spatial (<1 km) and temporal (daily) resolution bottom water temperature

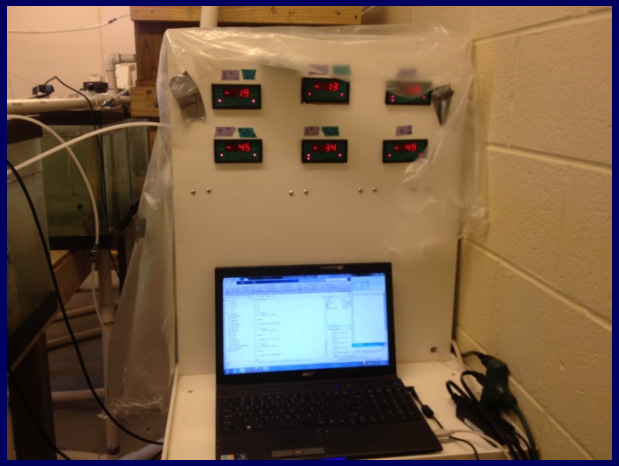
So what in an acidified estuary?

Ocean Acidification

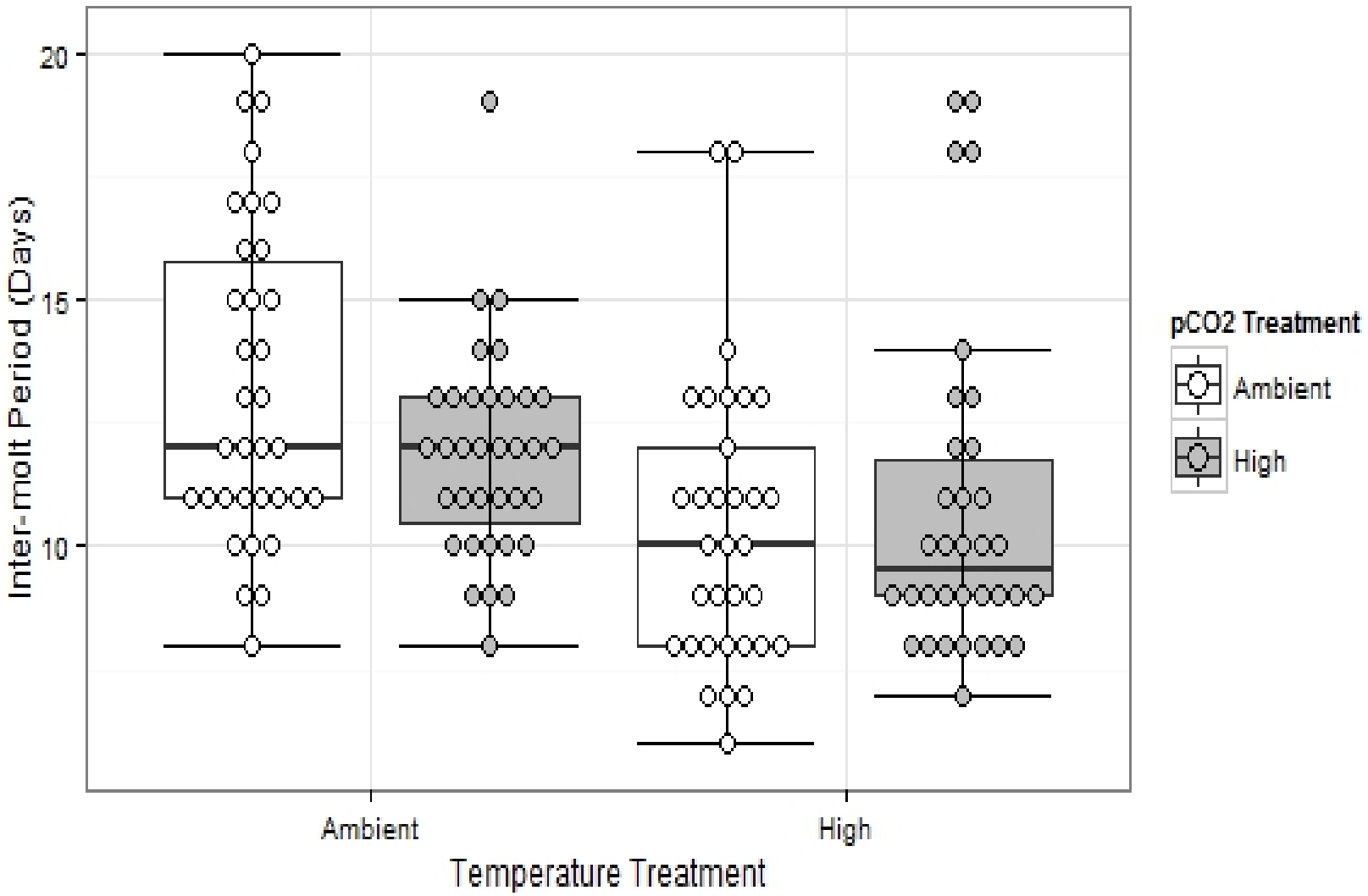
$$CO_{2(aq)} + H_2O_{(l)} \overset{1}{\leftrightarrow} H_2CO_{3(aq)} \overset{2}{\leftrightarrow} H^+_{(aq)} + HCO^-_{3(aq)} \overset{3}{\leftrightarrow} H^+_{(aq)} + CO^{2-}_{3(aq)}$$



Methods: Acidification Growth Experiment



No effect of pH on growth



Conclusions: pCO2 Effects

Response	pCO2
Growth per Molt	No effect
Growth Rate	No effect
Consumption	No effect
Gut Energy Content	Decrease
Muscle Energy Content	Decrease
Carapace Thickness	Decrease*
Carapace [Ca]	Increase*
Carapace % $CaCO_3$	Increase*
Carapace [Mg]#	Increase

Crab growth was not impacted in more acidic water, but energy storage was decreased. These crabs also had thinner shells but with more [Ca], higher %$CaCO_3$, and more [Mg].

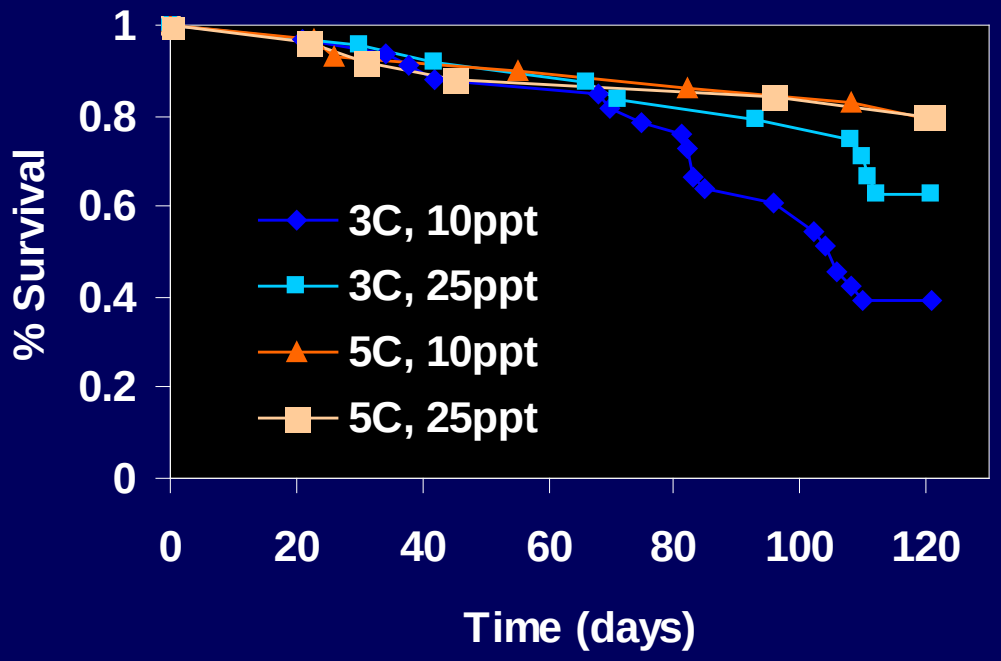
Maintenance of Growth **—** **Less stored energy**
Less protective shell (?)

Climate and acidification

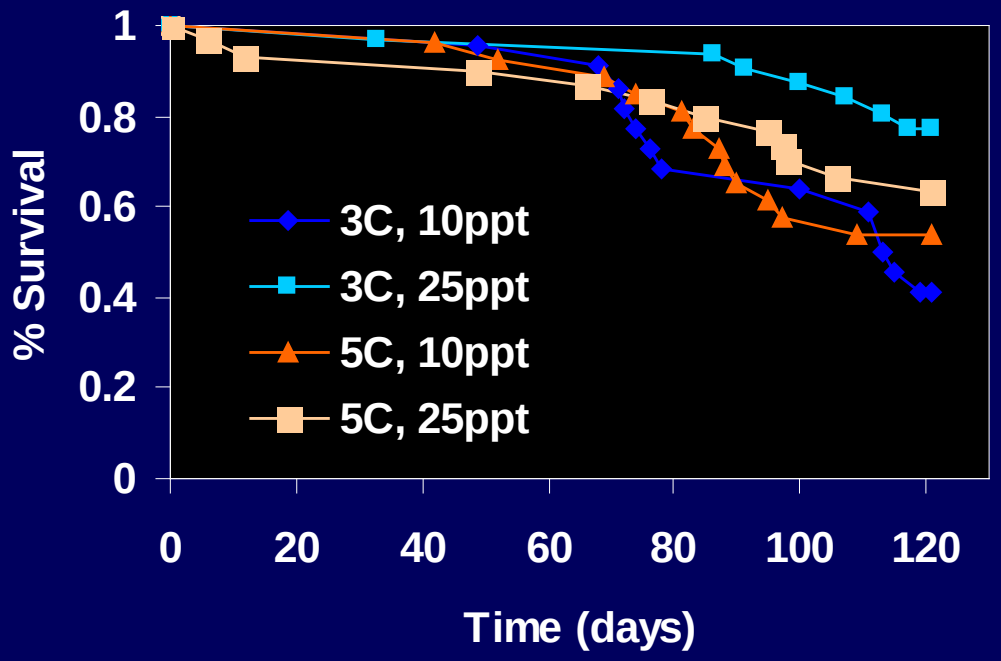
- For juvenile and adult crabs, acidification likely has little effect on growth
- Effects of larval stages unknown
- Potential energetic effect of acidification on ration and on carapace structure, suggesting impacts of acidification on predator-prey interactions.
- Data needs: Uncertain

But what about winter mortality?

Females



Males

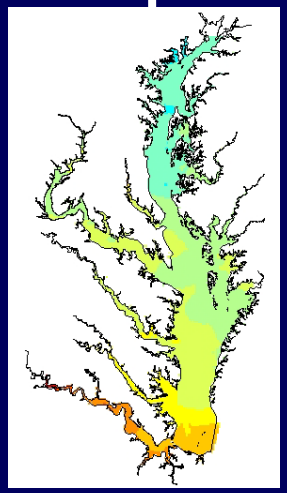


Bauer and Miller 2010

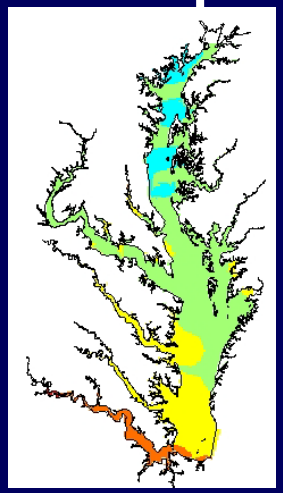
Survival prediction

Survival probability in each cell calculated by inputting the parameter estimates into the survival equation

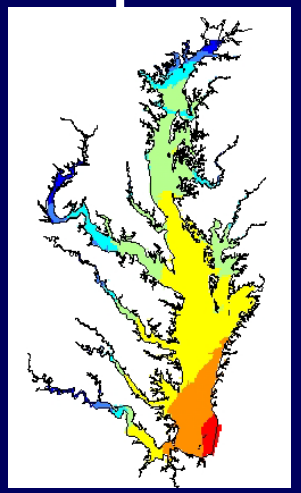
$$S(t) = \exp\left\{-(t)^{\lambda}\exp\left[-\lambda(\beta_0 + \beta_1 \mathrm{Temp} + \beta_2 \mathrm{Sal} + \beta_3 \mathrm{Size})\right]\right\}$$



Winter duration

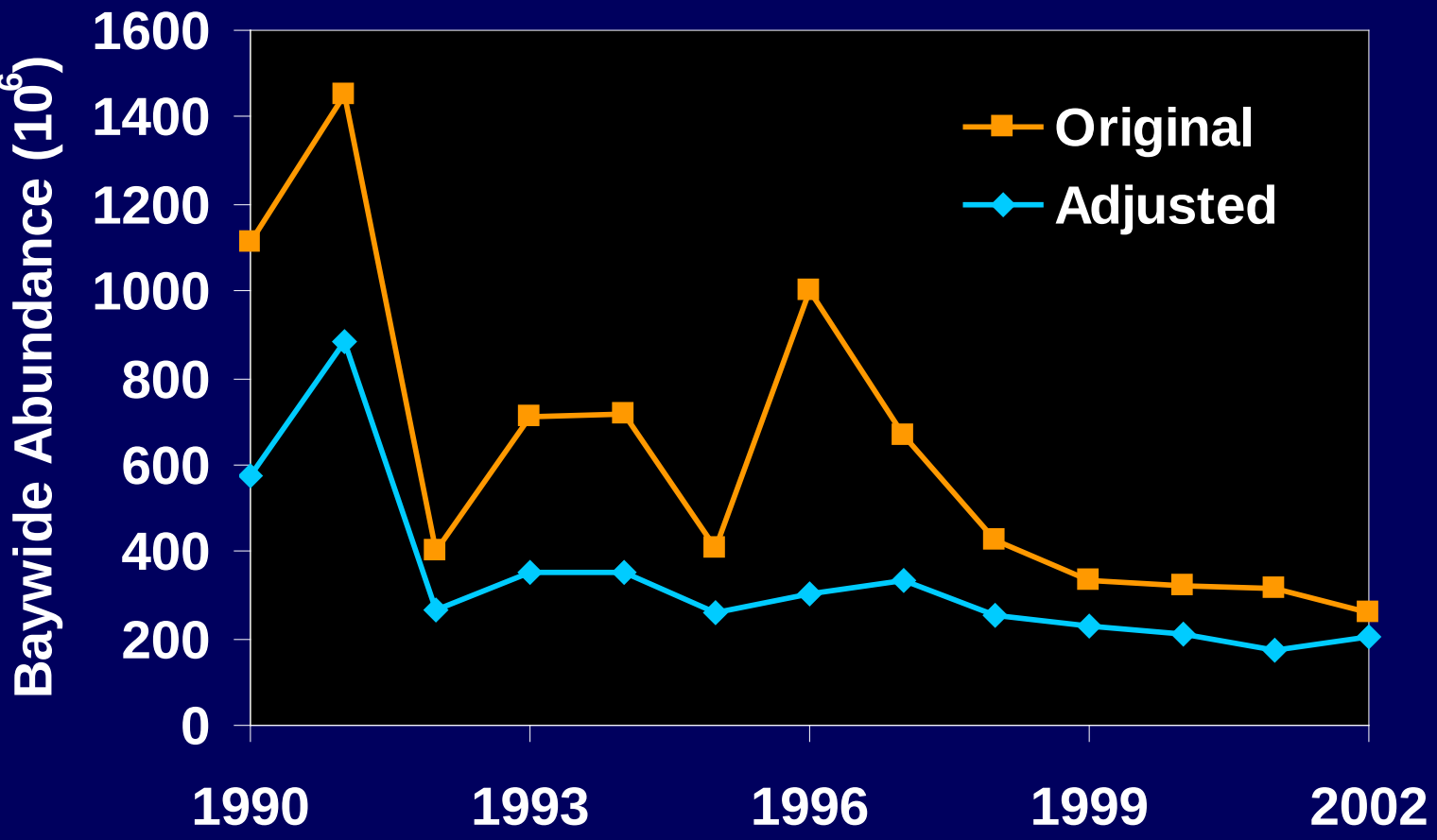


Average Temperature



Average Salinity

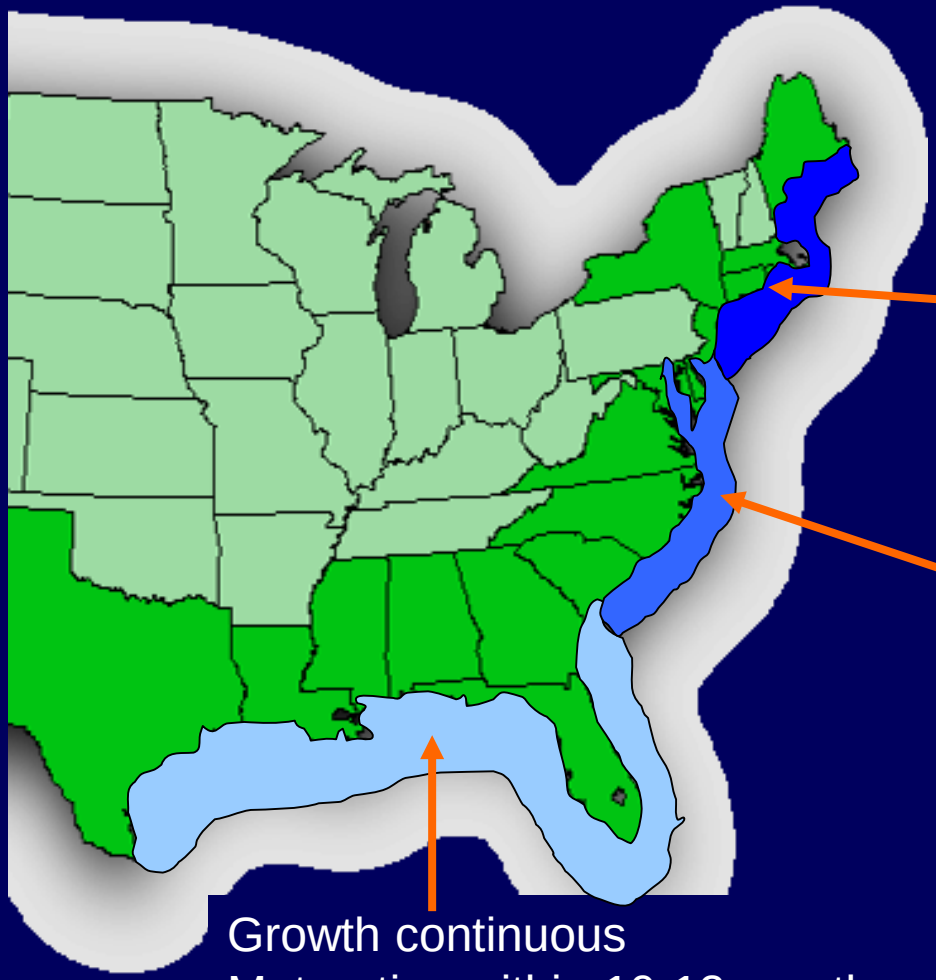
Adjusted abundance



Climate and mortality

- Strong temperature dependency on mortality
  - Decrease in overwinter mortality with increasing winter temperature
  - Assumed increase in mortality during growing season with temperature
- Data needs: (i) high resolution winter temperature maps, (ii) prediction of when overwintering will cease (underway), (iii) high resolution temperature fields during growing season

Life history patterns



Growth seasonal
Maturation within 24 months
Prolonged exposure to size-dependent cannibalism
Temperature-induced winter mortality limitation

Growth seasonal
Maturation within 18-24 months
Moderate exposure to size-dependent cannibalism
Temperature-induced winter mortality regulation in cold years

Growth continuous
Maturation within 10-12 months
Size-dependent cannibalism
No temperature-induced winter mortality

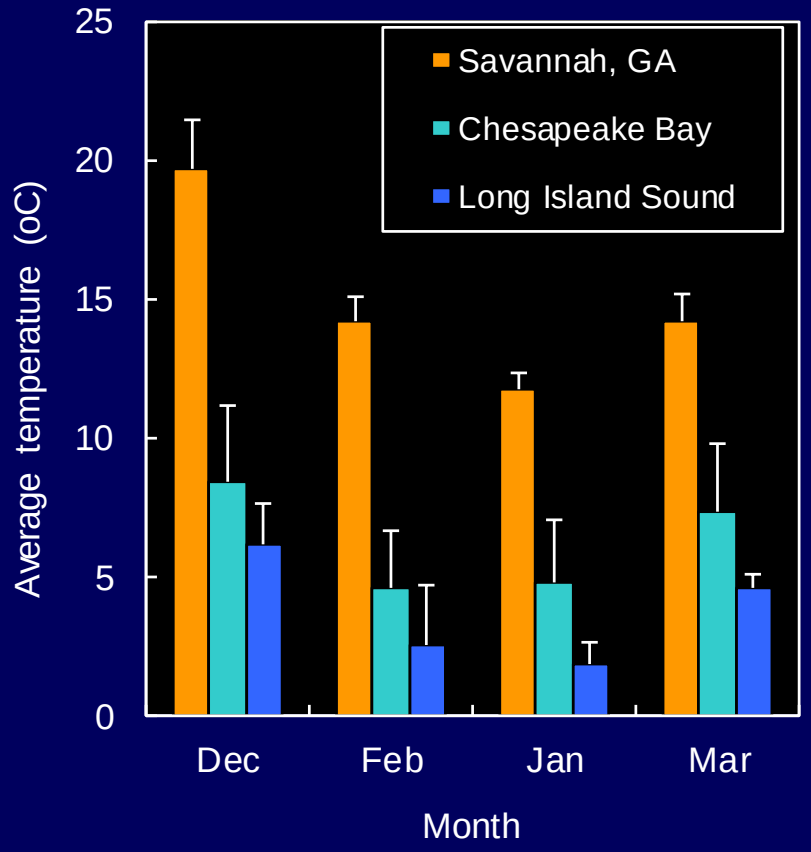
Brylawski and Miller 2006
Bauer and Miller 2010
Hines et al. 2010

So what are the unknown questions

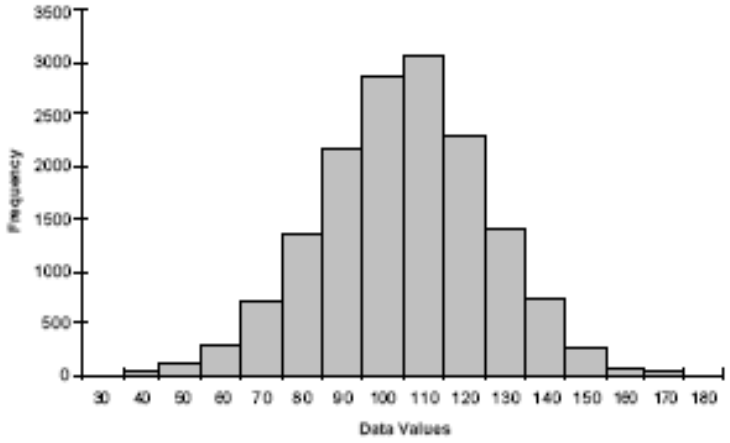
- Impacts of climate change on offshore portion of life-cycle largely unknown
- Impact of climate change on ecosystem components unclear
  - Habitat
  - Predators
- Is the space for time substitution valid for projections

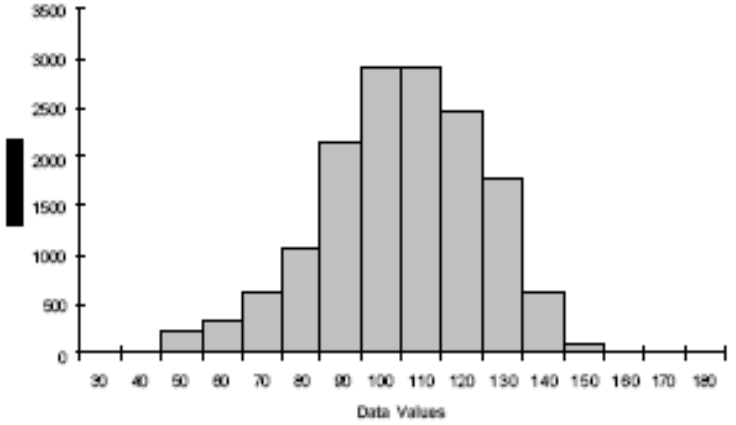
Environmental gradients

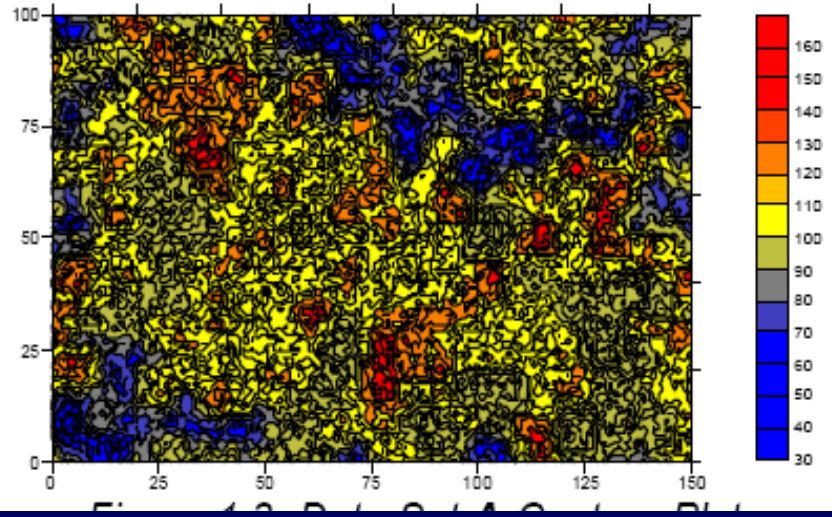
- Average monthly temperature varies considerably over species range
- What is the consequence on growth and survival?

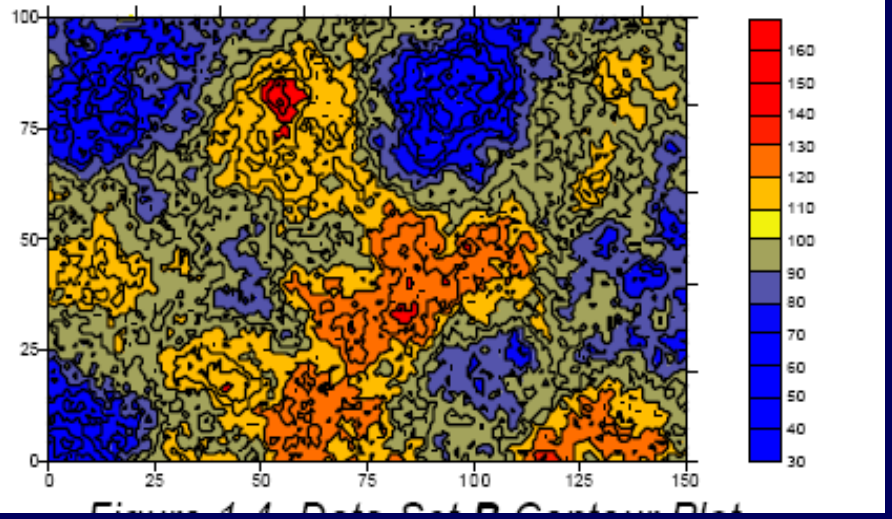


Quantifying spatial pattern



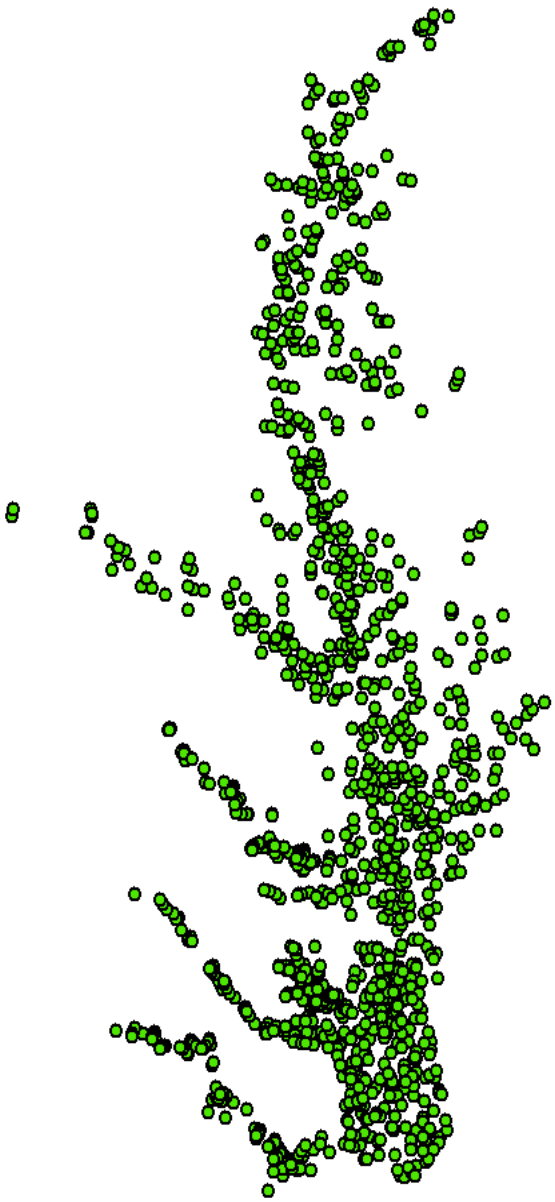






The Winter Dredge Survey (WDS)

- Conducted yearly since 1990
- Winter – crabs are dormant, no movement
- 1 minute tow of a crab dredge
- ~1,500 stations per year



1990-1991

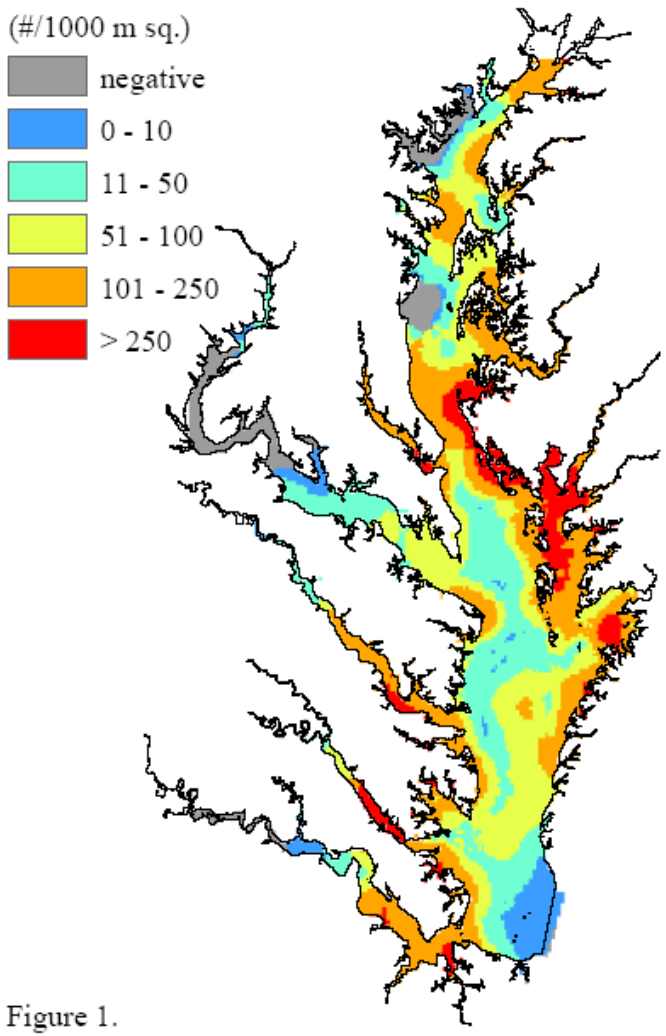
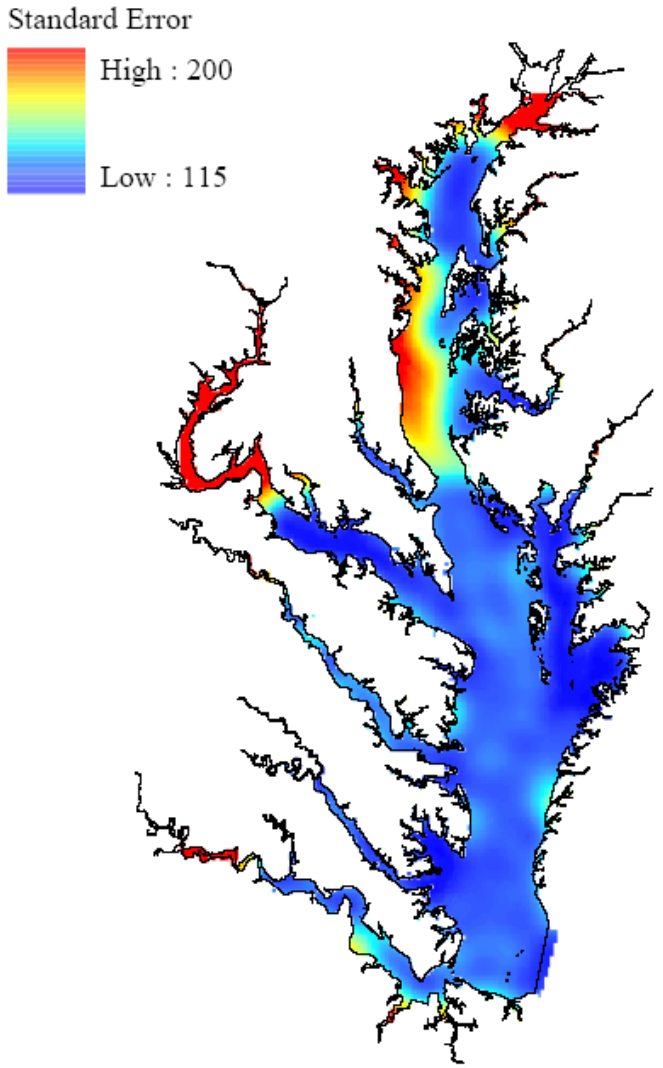


Figure 1.
a. 1990 Blue crab density



b. Standard error of blue crab density

2000-2001

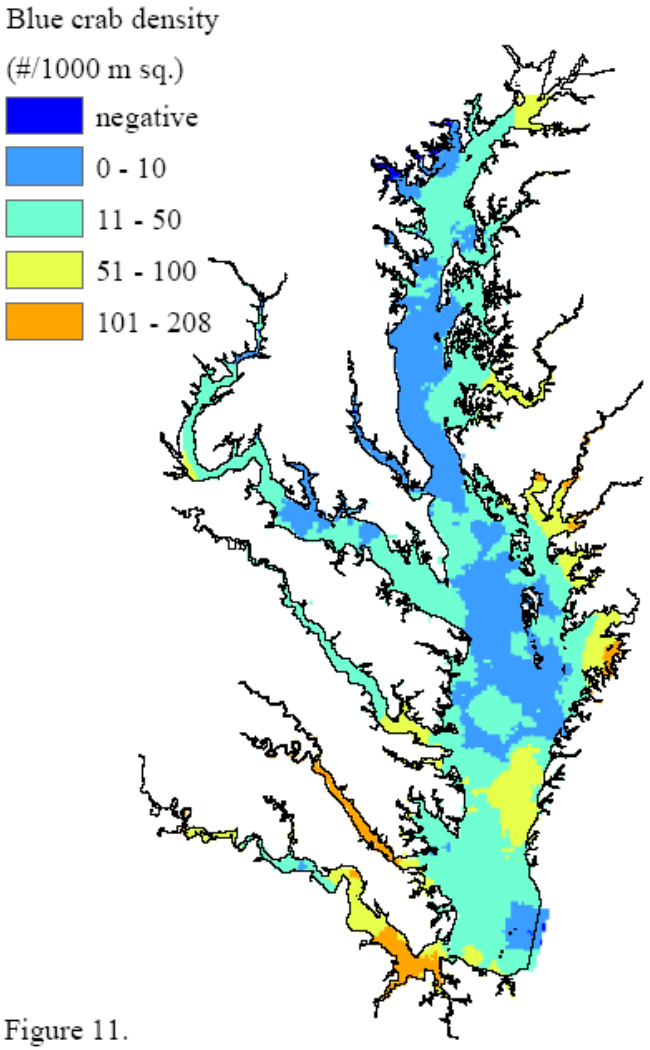
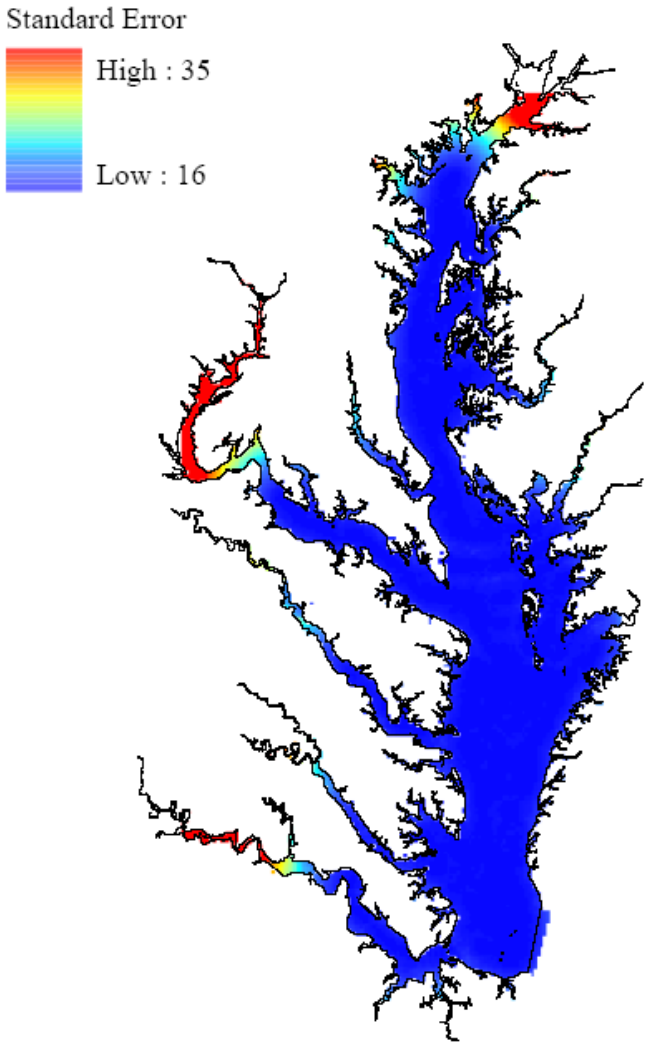
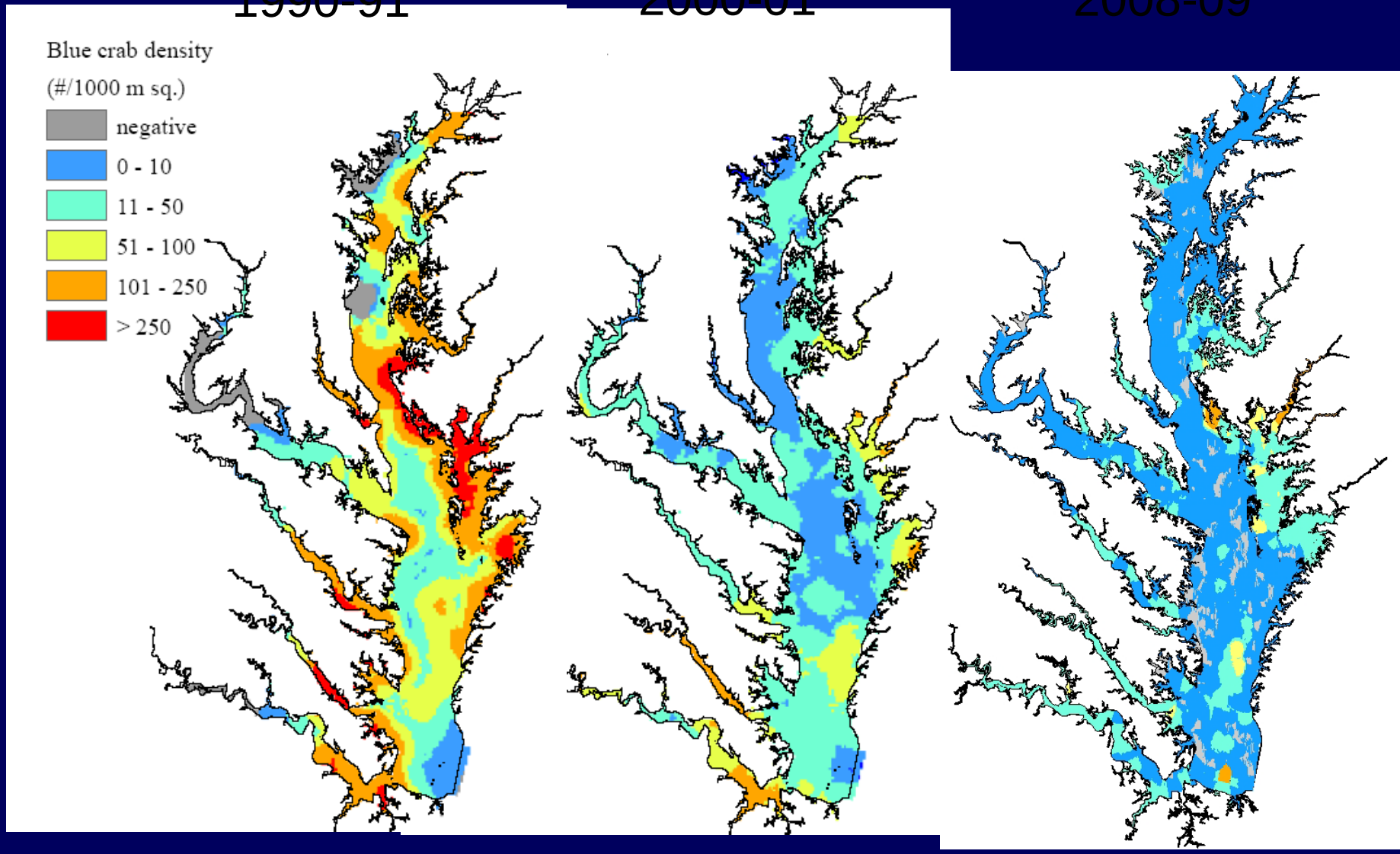


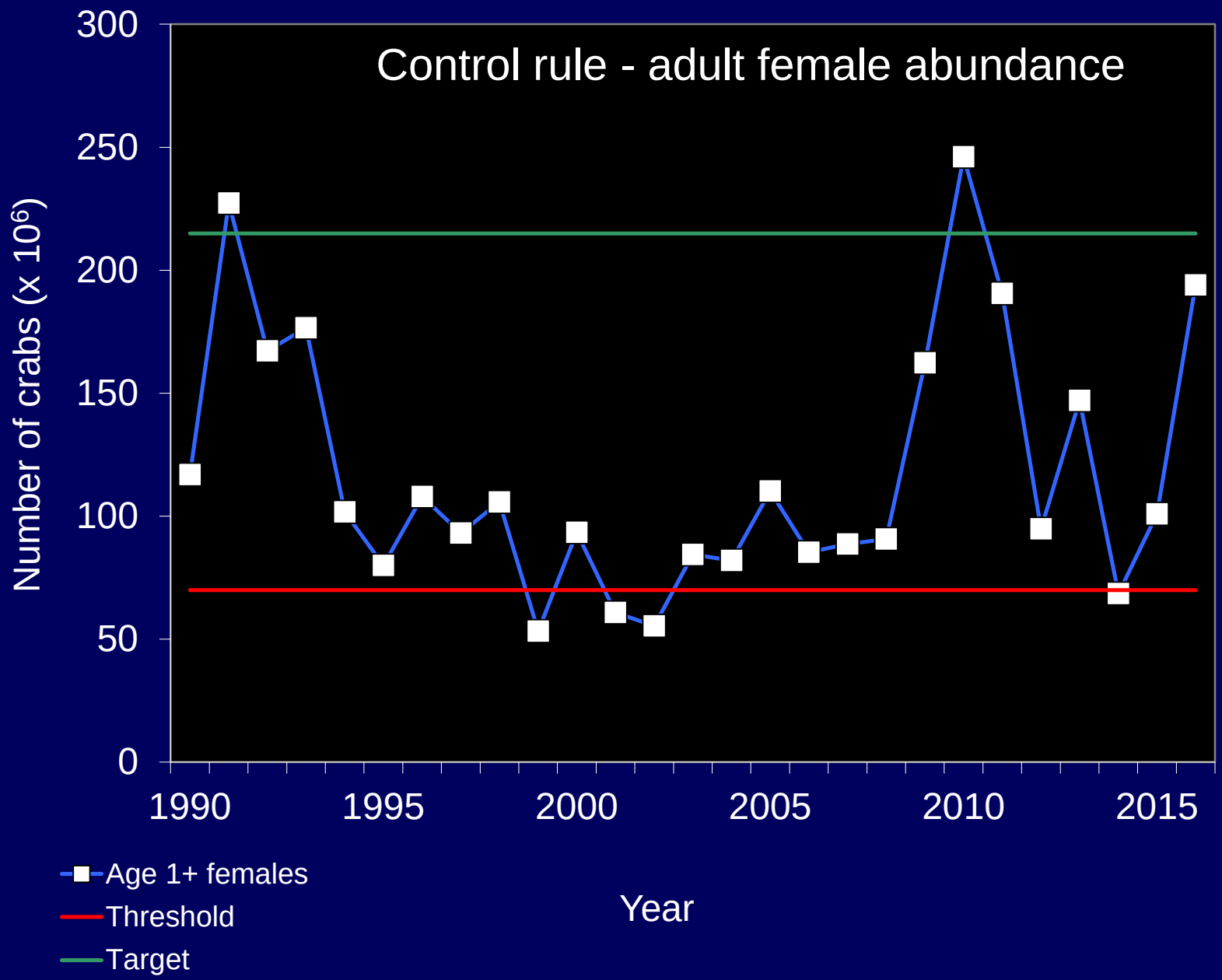
Figure 11.
a. 2000 Blue crab density



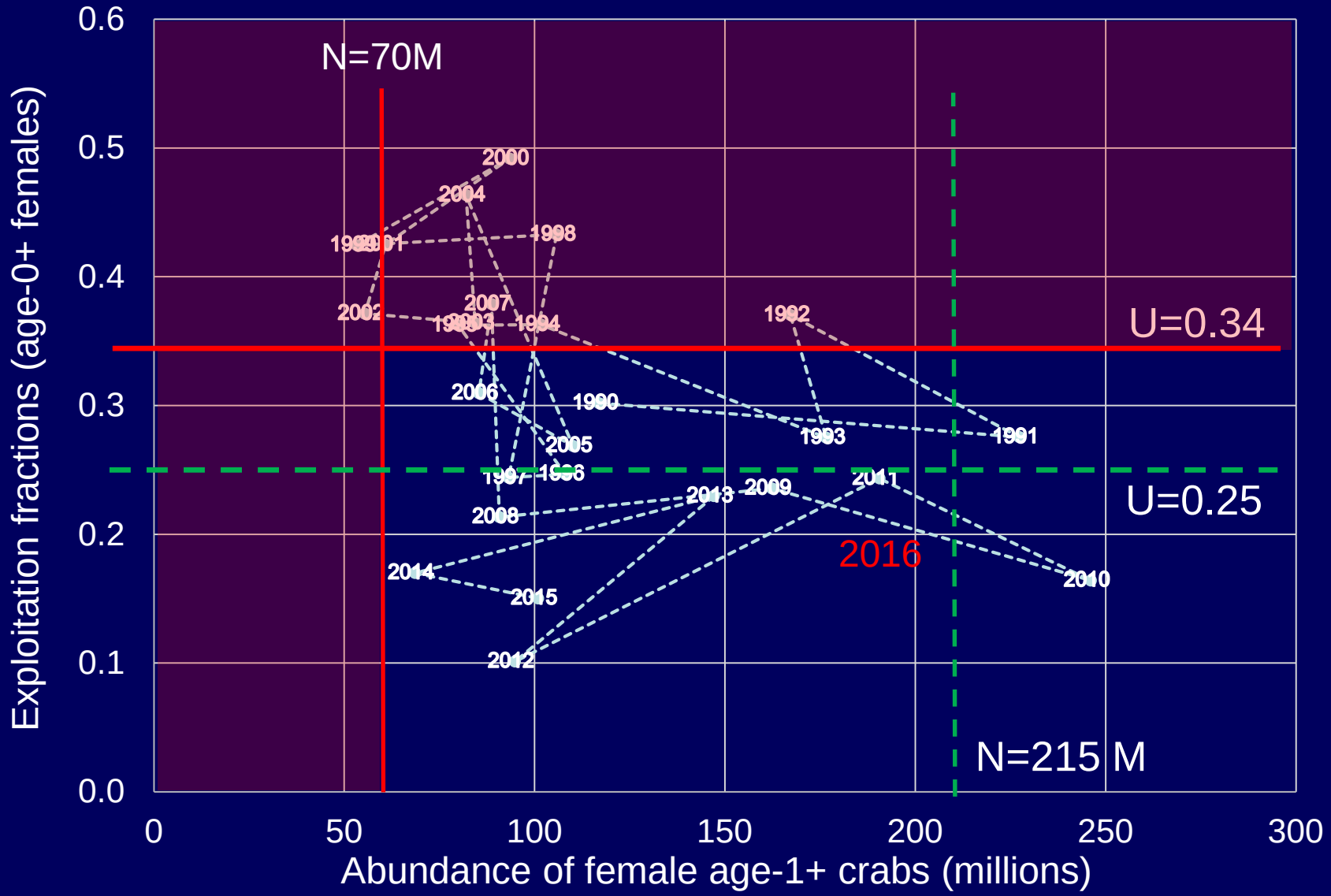
b. Standard error of blue crab density

Crab distribution maps

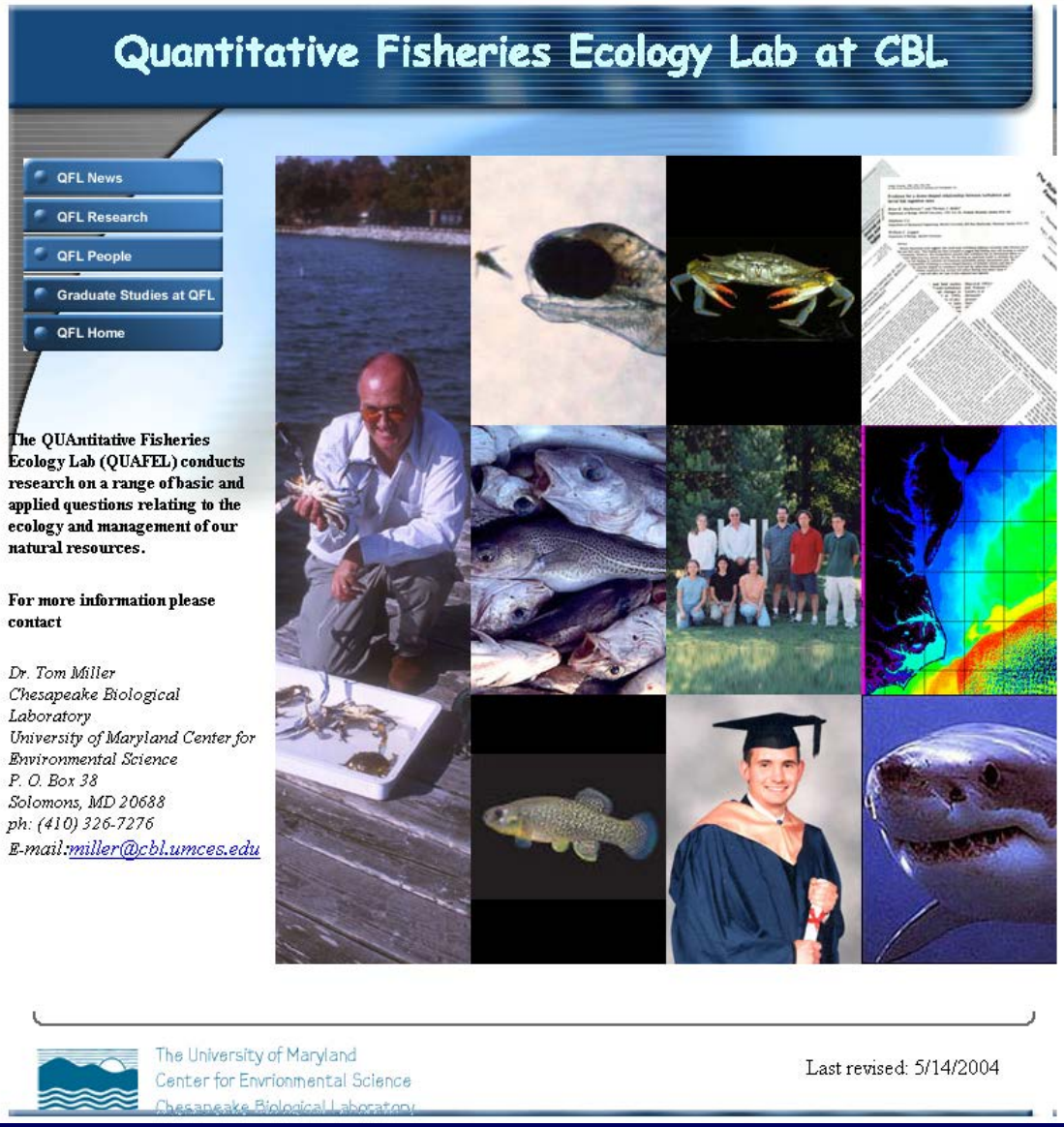


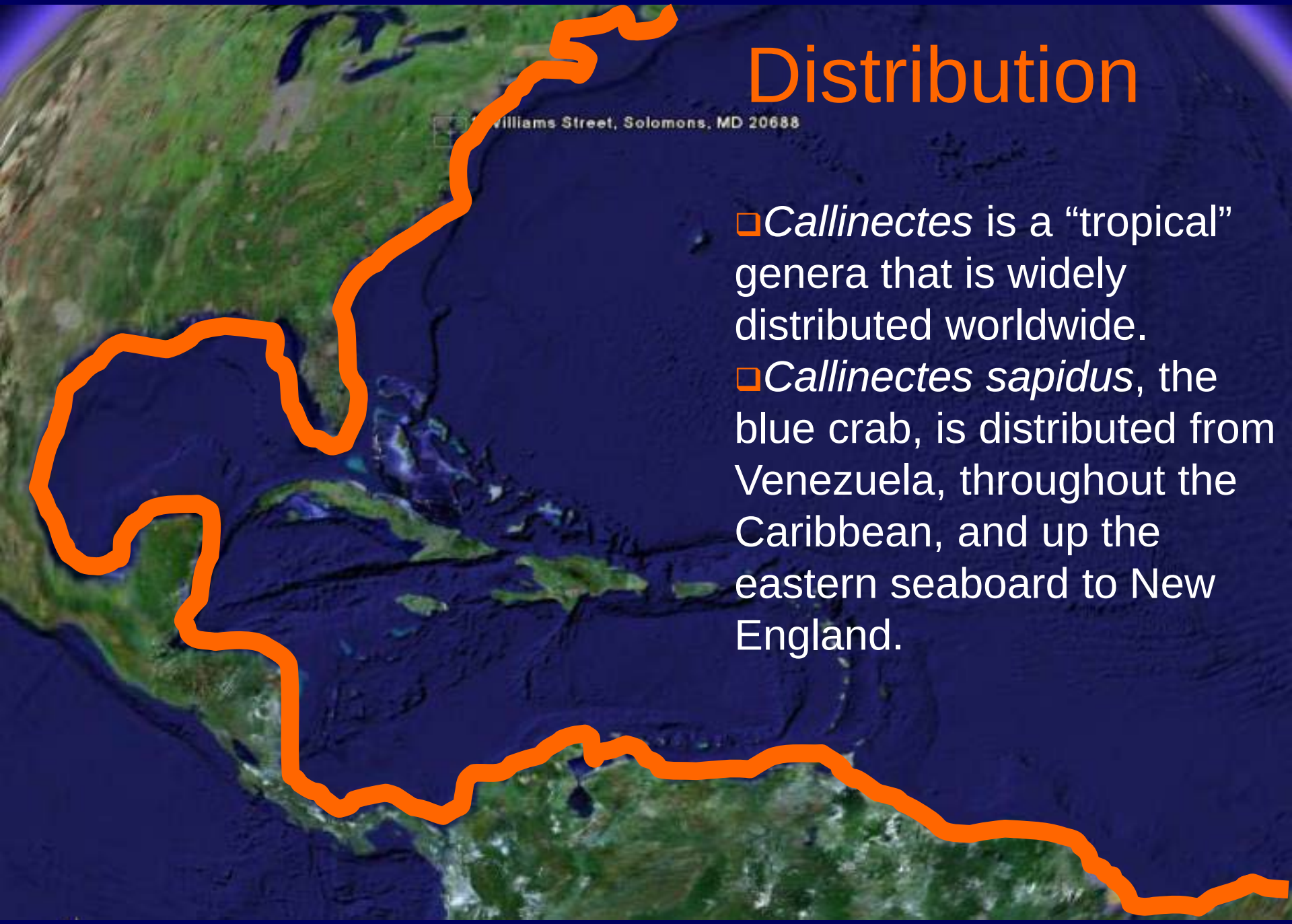

Control rule - adult female abundance
Number of crabs (x 10⁶)
300
250
200
150
100
50
0
1990
1995
2000
2005
2010
2015
Year
Age 1+ females
Threshold
Target

2016 Stock status



http://hjort.cbl.umces.edu



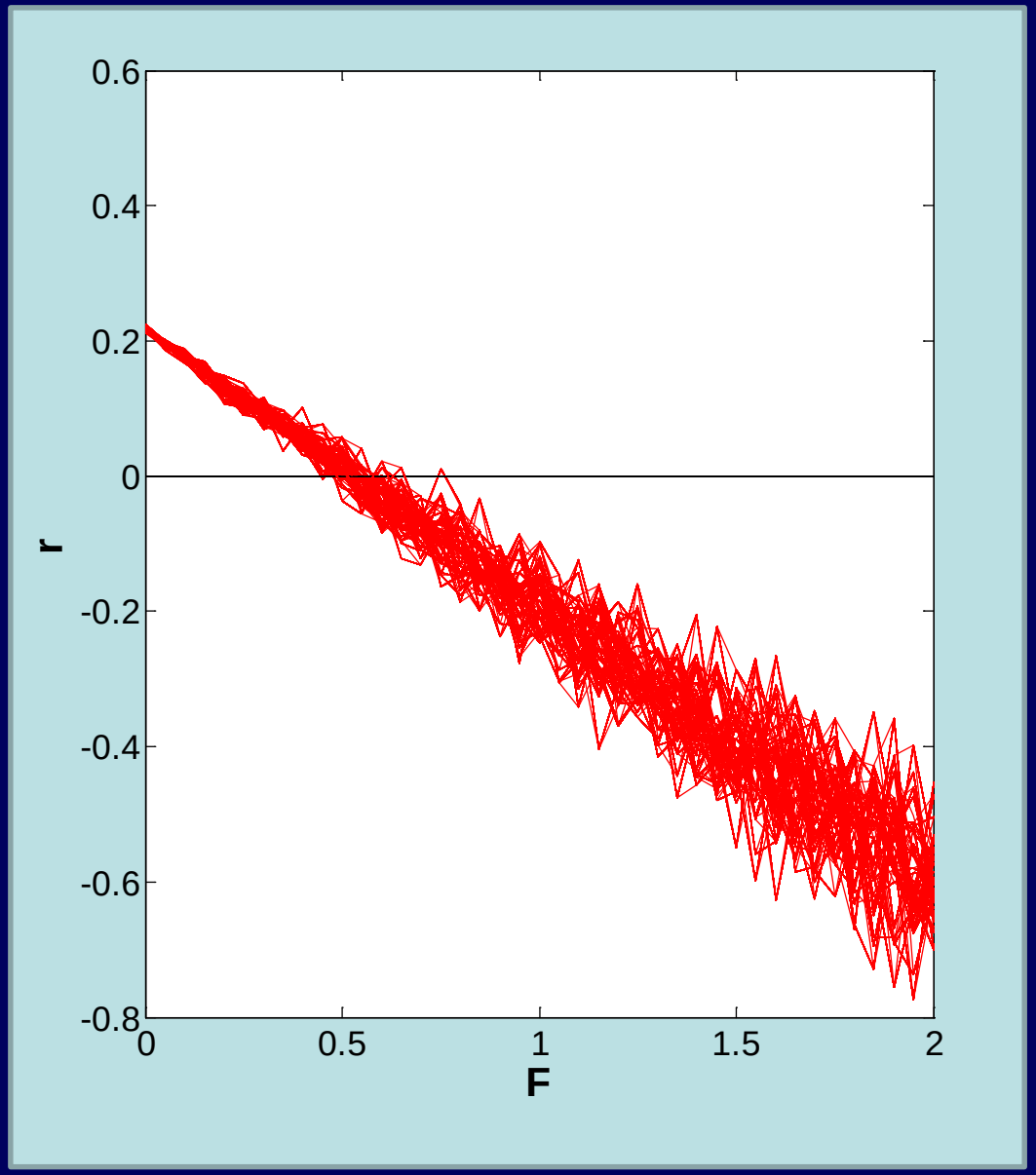


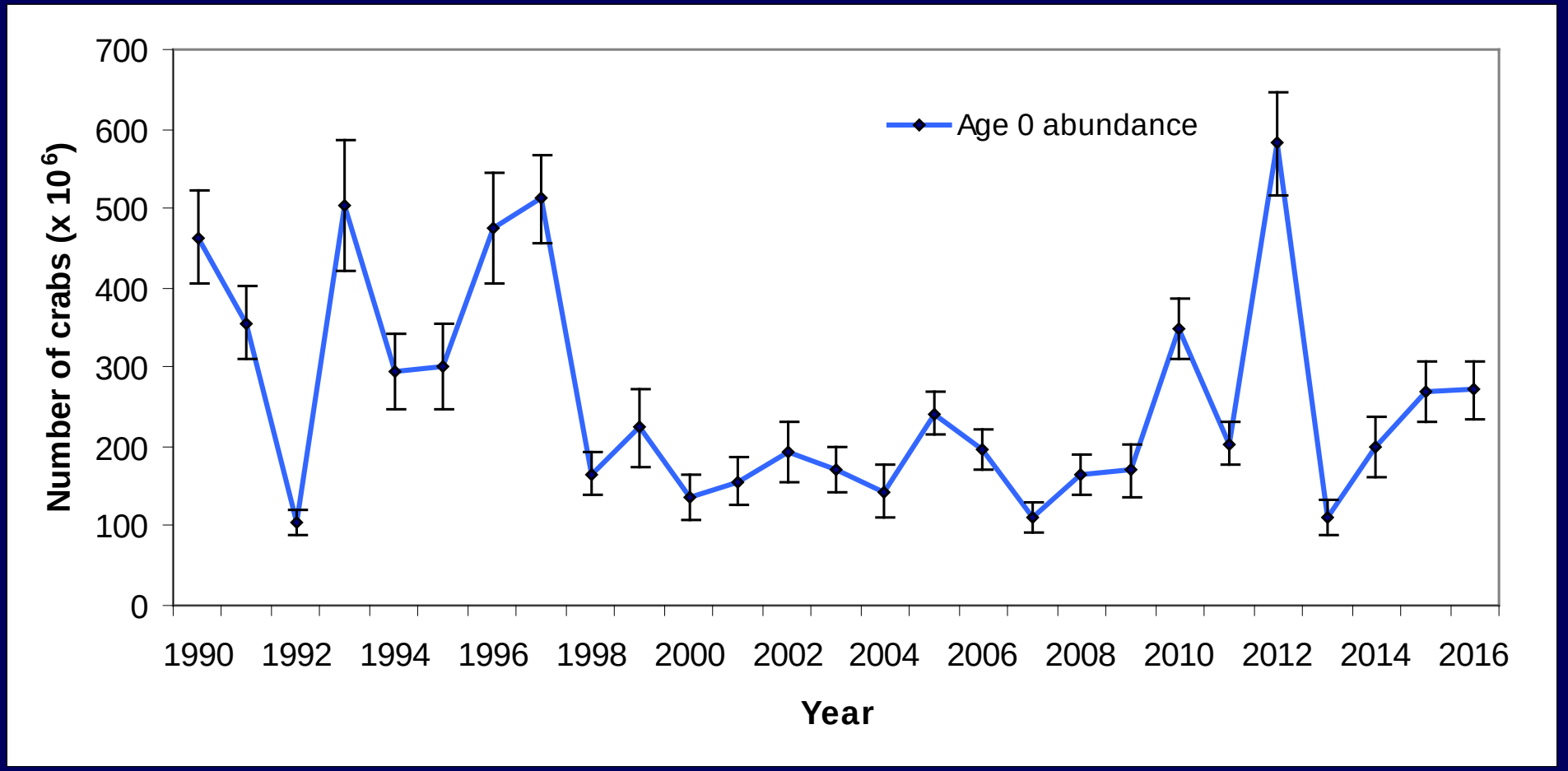
Distribution

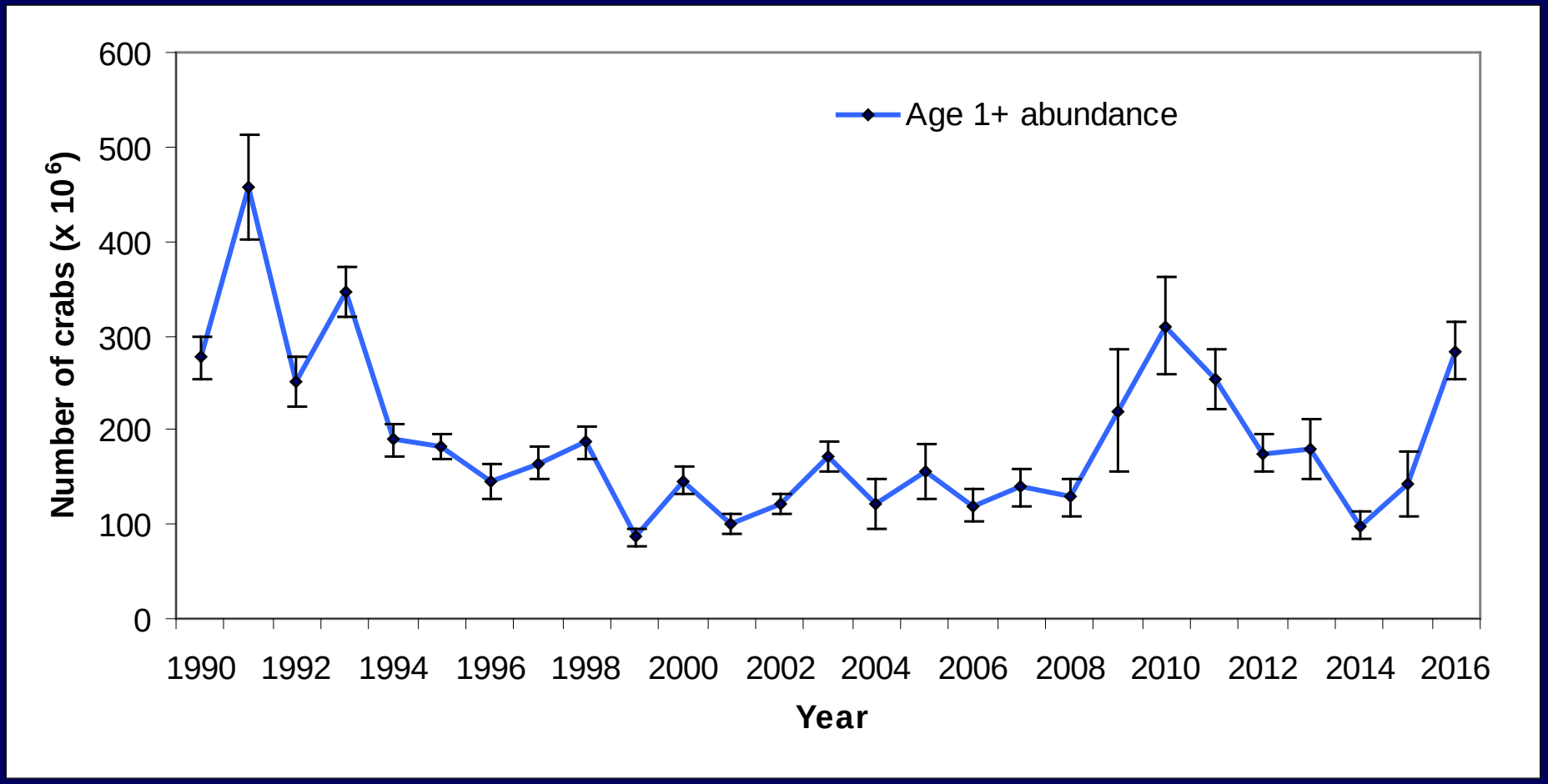
- *Callinectes* is a “tropical” genera that is widely distributed worldwide.
- *Callinectes sapidus*, the blue crab, is distributed from Venezuela, throughout the Caribbean, and up the eastern seaboard to New England.

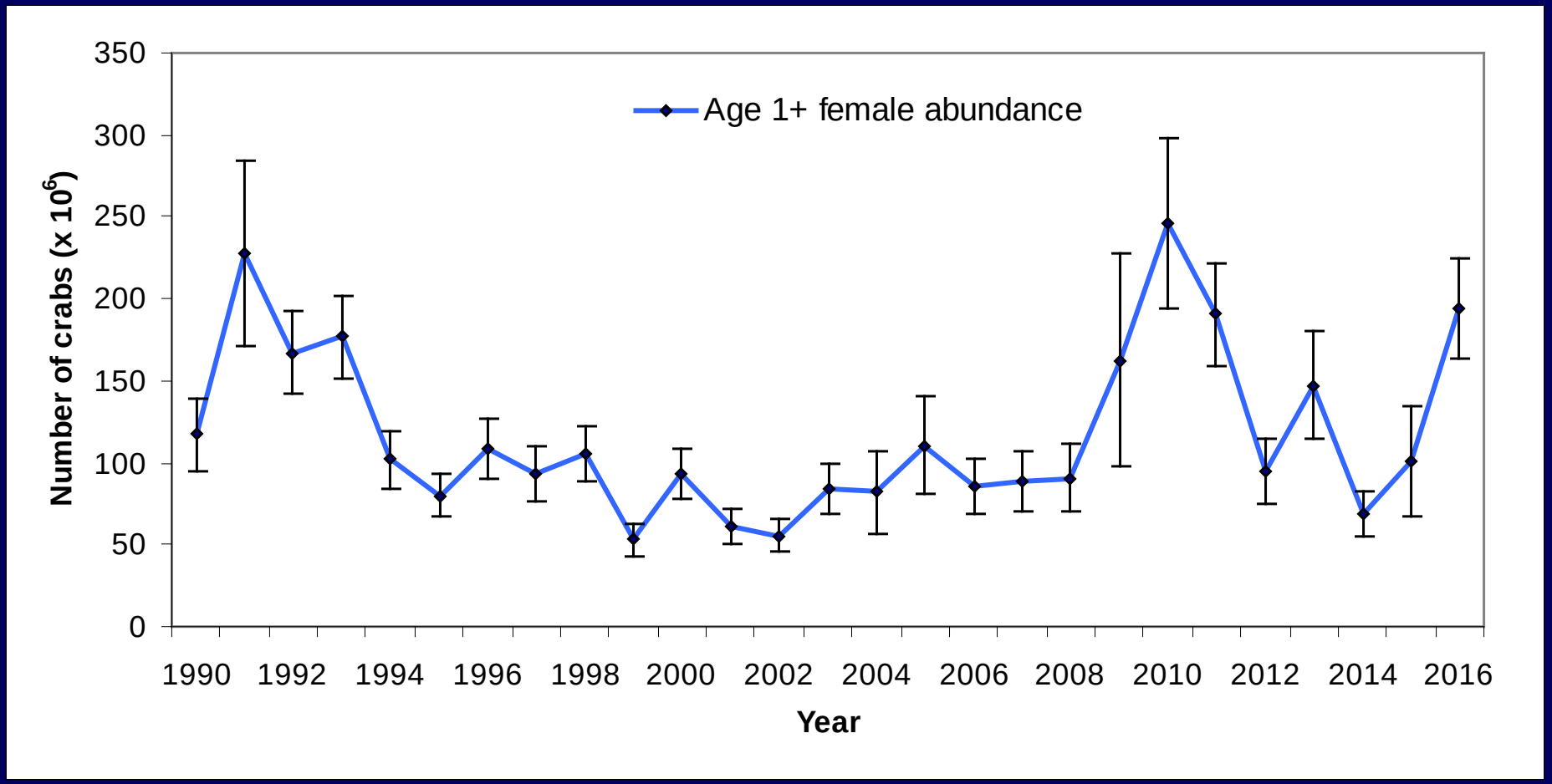
Stochasticity

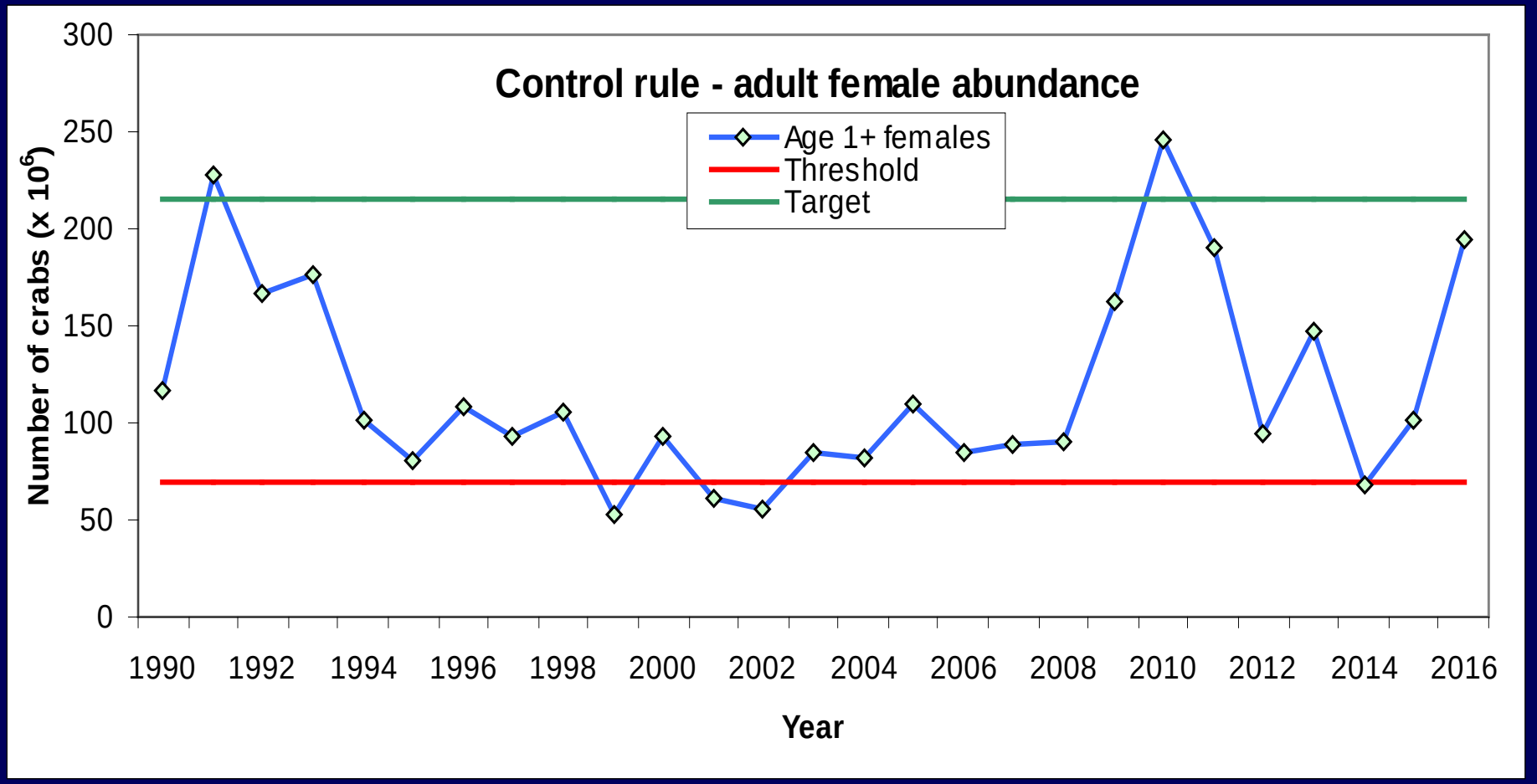
- Detection of patterns revealed in deterministic projections may be masked by stochasticity.

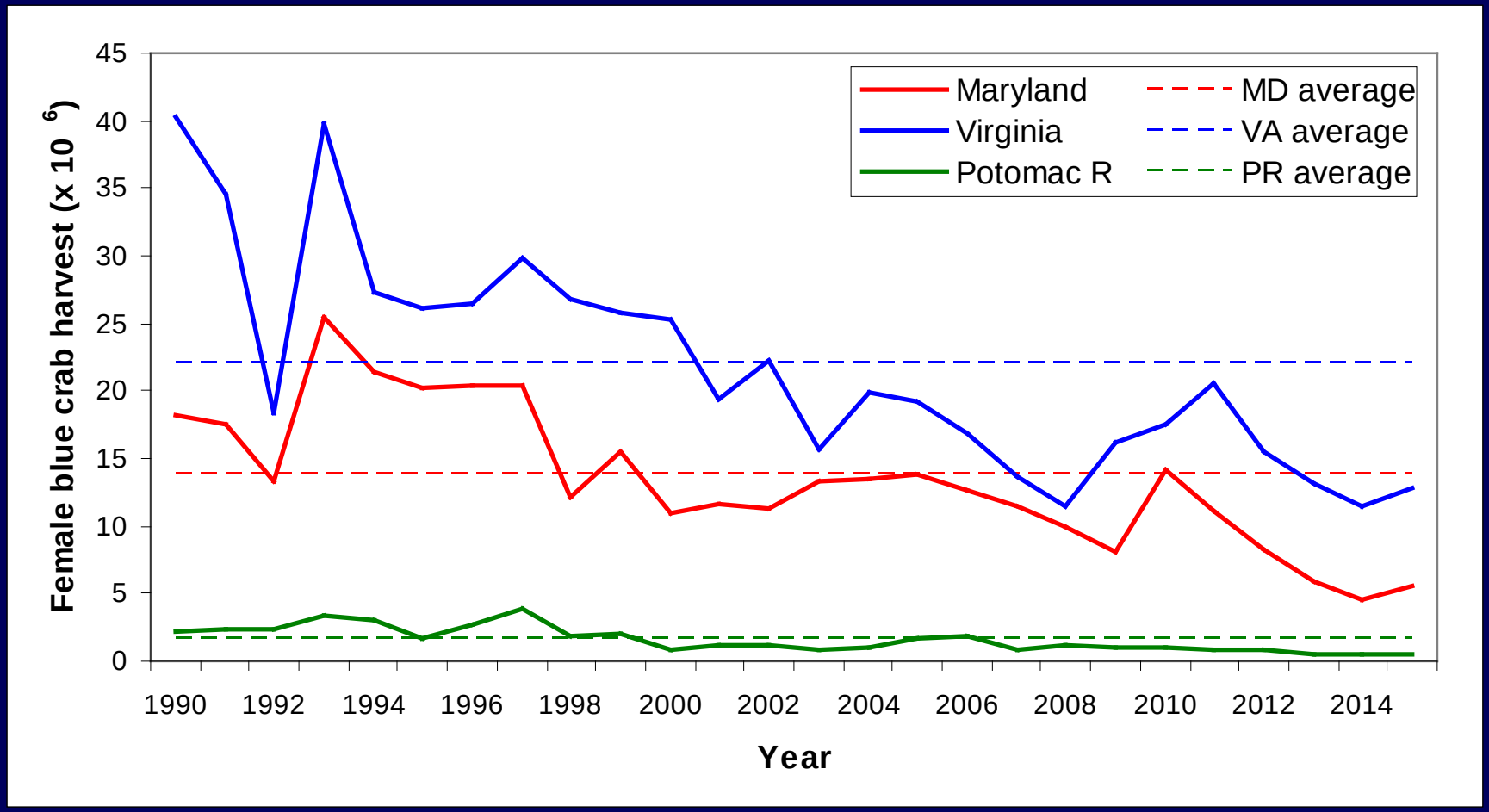


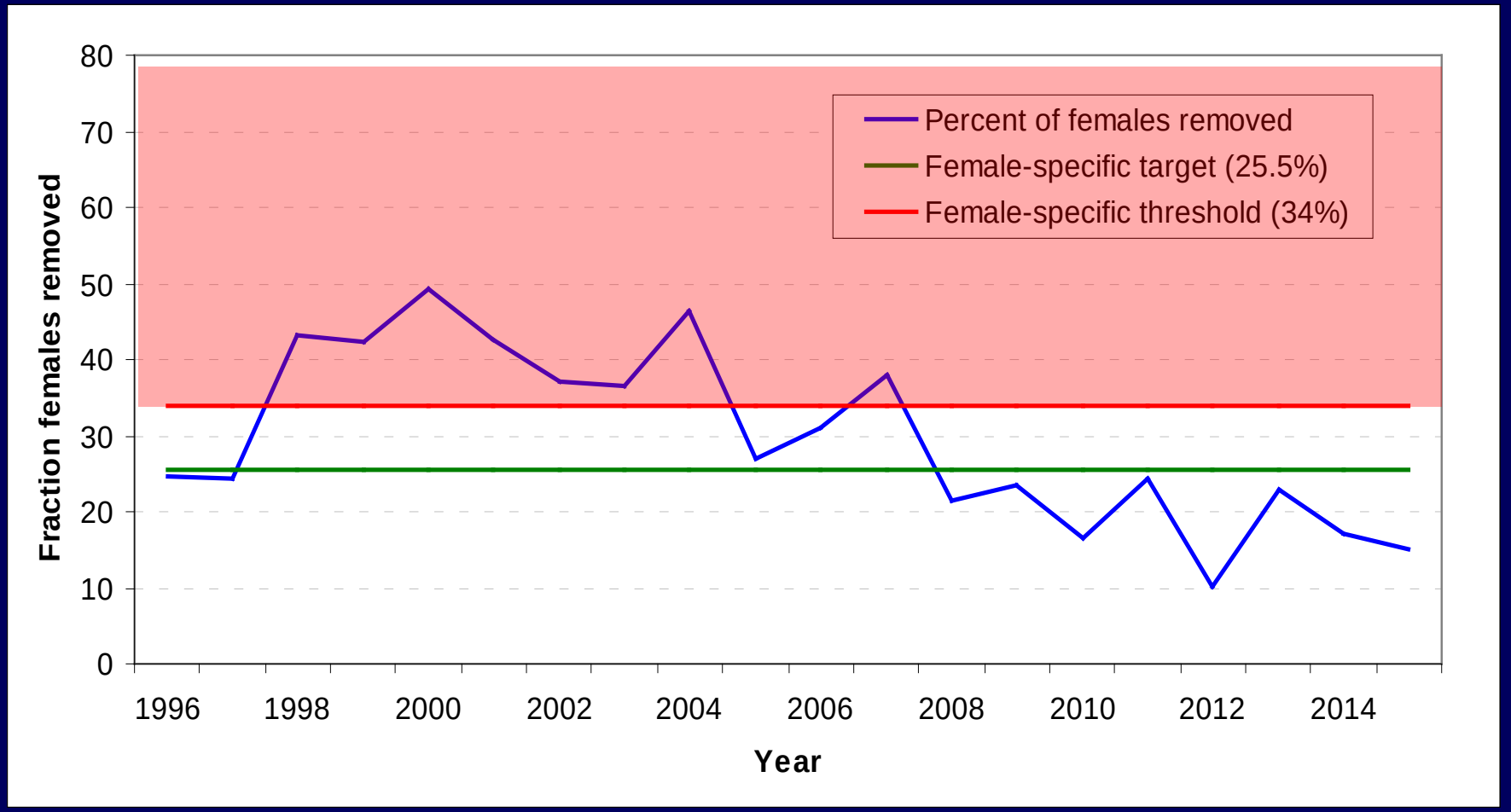

Age 0 abundance
Number of crabs (x 10^6)
Year
0
100
200
300
400
500
600
700
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016


Age 1+ abundance
Number of crabs (x 10^6)
600
500
400
300
200
100
0
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
Year


Age 1+ female abundance
Number of crabs (x 10^6)
350
300
250
200
150
100
50
0
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
Year


Control rule - adult female abundance
Age 1+ females
Threshold
Target
Number of crabs (x 10^6)
300
250
200
150
100
50
0
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
Year


Female blue crab harvest (x 10 6)
45
40
35
30
25
20
15
10
5
0
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
Year
Maryland
Virginia
Potomac R
MD average
VA average
PR average


80
70
60
50
40
30
20
10
0
Fraction females removed
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
Year
Percent of females removed
Female-specific target (25.5%)
Female-specific threshold (34%)

2016 Stock status