Interactions between spatial heterogeneity in growth and fishing mortality

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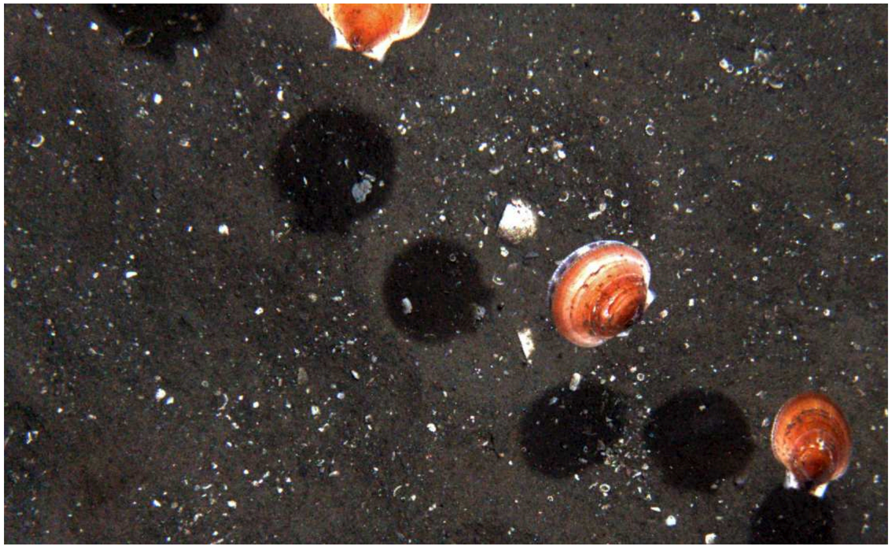
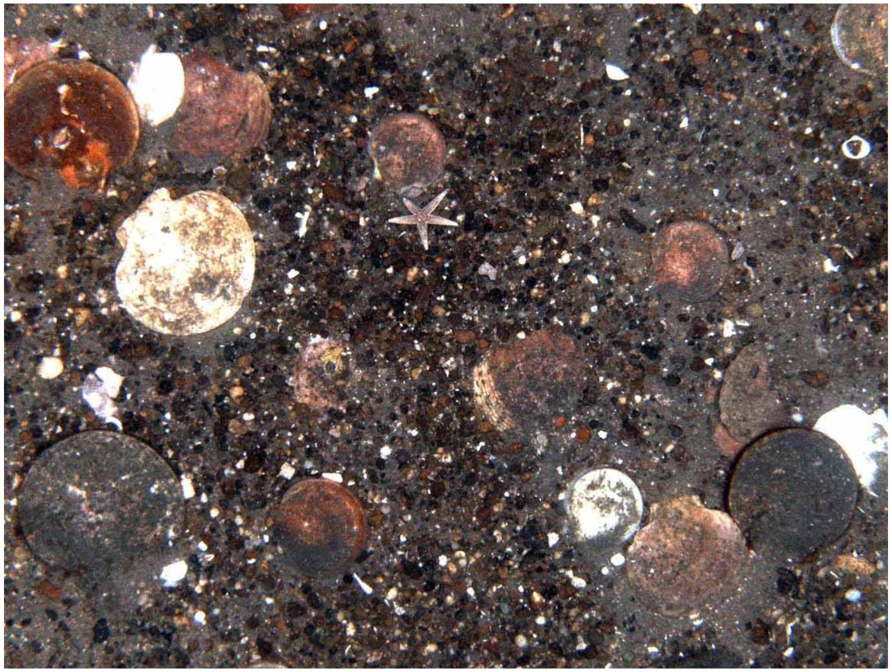
Outline

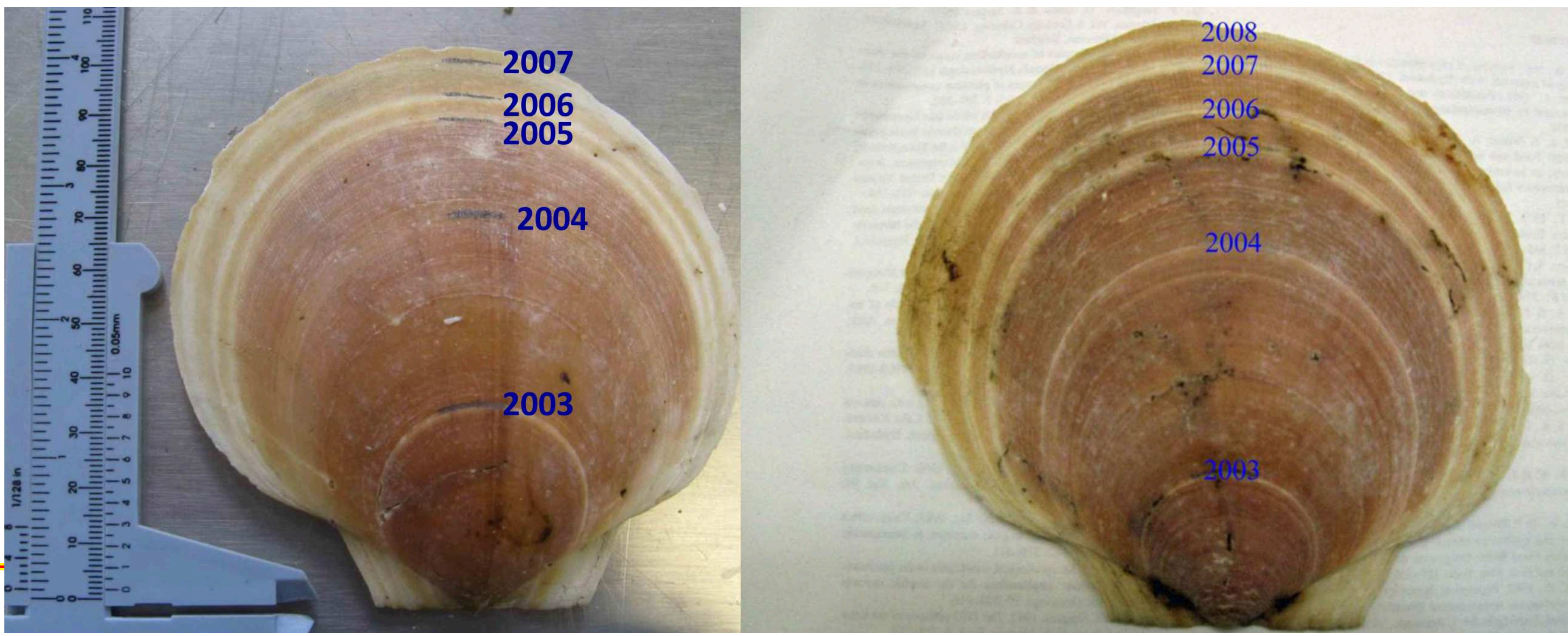
1. Scallop growth rings
2. Growth estimation methodology
3. Spatial growth estimates
4. Interaction between fishing and growth





Scallop growth rings - 1

- Confirmed as being annual marks, starting from first visible ring
- No ring in first year, ring from year 2 and even year 3 sometimes missing or obscure, especially on older shells



Scallop growth rings -2

Ageing is difficult or impossible for some shells, especially larger ones.

We therefore treat the distance between consecutive rings as an annual growth increment, with age unknown.

Estimation methodology - 1

The growth increment form of the Von Bertalanffy equation is (Fabens 1965):

$$
\begin{aligned}
L_{t+1} &= L_t + (L_\infty - L_t)[1 - \exp(-K)] \\
&= \exp(-K)L_t + L_\infty[1 - \exp(-K)]
\end{aligned}
$$

where L_t is the length (or shell height) at time t. Thus, a plot of the L_{t+1} vs. L_t will be a straight line with slope $m = \exp(-K)$ and y-intercept $b = L_\infty(1 - m)$.

Thus, one could estimate K and L_∞ by a linear regression of L_{t+1} vs. L_t, with:

$$K = -\ln m, \text{ and } L_\infty = b/(1 - m)$$

Estimation methodology - 2

Unfortunately, this method is biased when applied to a population where the parameters vary with individual (Sainsbury 1980).

However, we can apply the method on an individual level:

Let K_i and $L_{\infty,i}$ be the growth parameters of the ith individual, and let $m_i = \exp(-K_i)$ and $b_i = L_{\infty,i}(1 - m_i)$ be the corresponding slope and intercept of the L_{t+1} vs L_t plot for that individual.

$$K_i = -\ln(m_i) = -\ln(m + \alpha_i) \simeq -[\ln m + \frac{\alpha_i}{m} - \frac{\alpha_i^2}{2m^2}]$$

where m is the mean slope over the population and α_i is the deviation of the ith individual from that mean.

Estimation methodology - 3

Taking expectations:

$$K = E(K_i) \simeq -\ln m + \frac{\text{Var}(\alpha_i)}{2m^2}$$

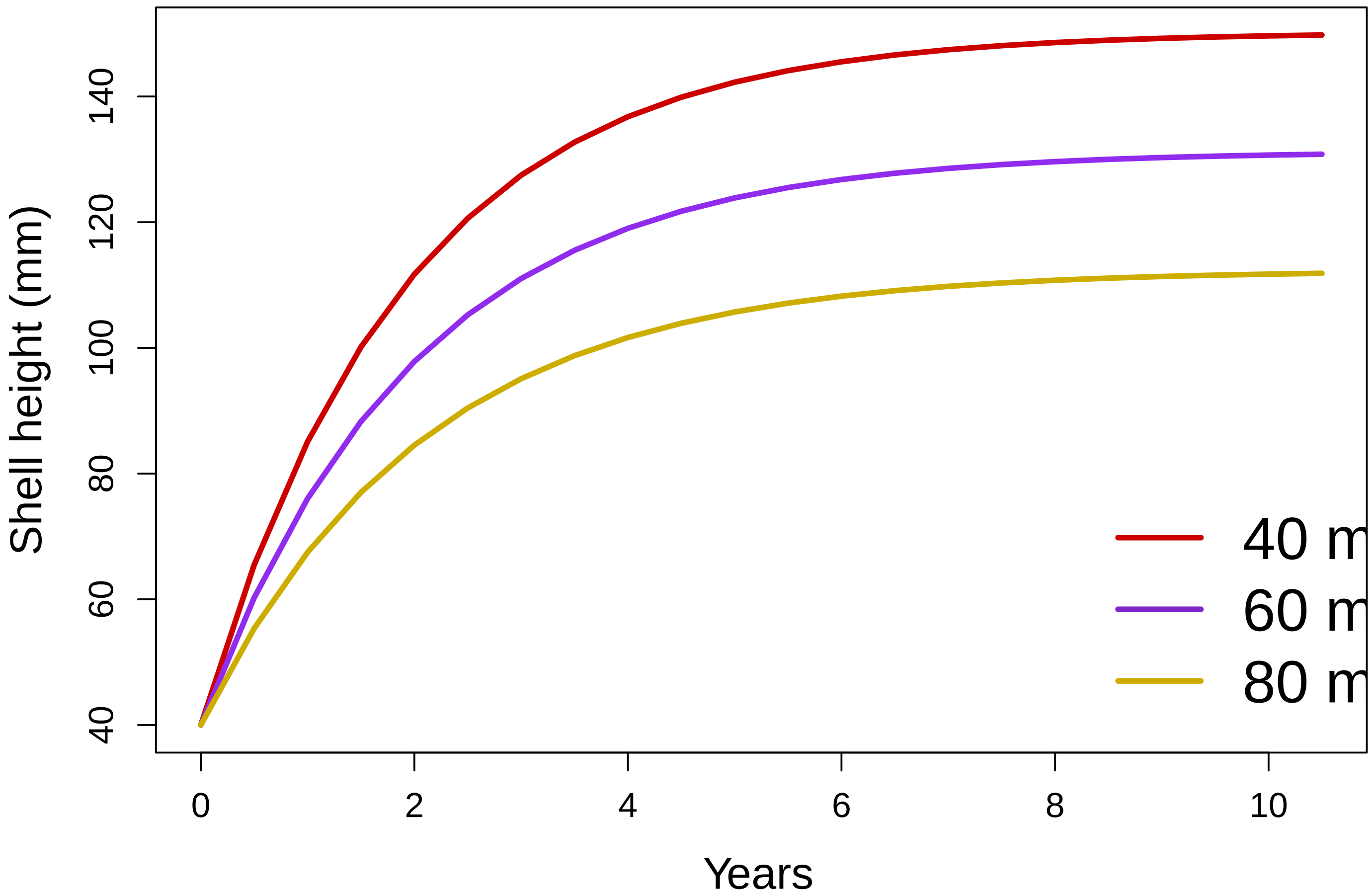
Using similar reasoning,

$$\begin{aligned} L_\infty &= E\left(\frac{b+\beta_i}{1-m-\alpha_i}\right) \\ &\simeq \frac{b}{1-m} + \frac{1}{(1-m)^2}\left[\frac{b\text{Var}(\alpha_i)}{1-m} + \text{Cov}(\alpha_i, \beta_i)\right] \end{aligned}$$

Note that the first term in each case is the original Fabens formula. The second term can thus be viewed as a bias correction

Scallop growth by depth

Growth rates (and meat weight at shell height) in sea scallops decline with depth, mainly affecting L_∞



Sea scallop growth is highly variable depending on depth and other local environmental factors

Big questions

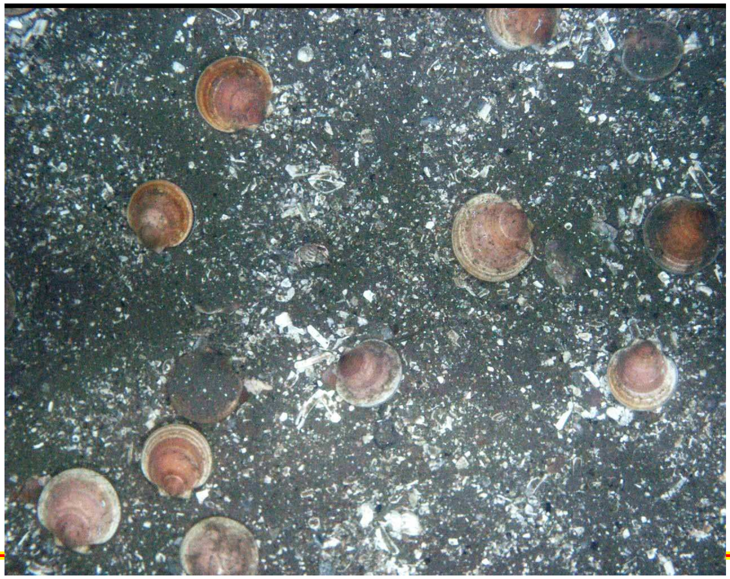
How does this effect fisher behavior?

What are the combined effects of spatial variability of growth and fisher behavior on fishery yield and aggregate population growth rates?

What are the implication for fishery management and assessment?

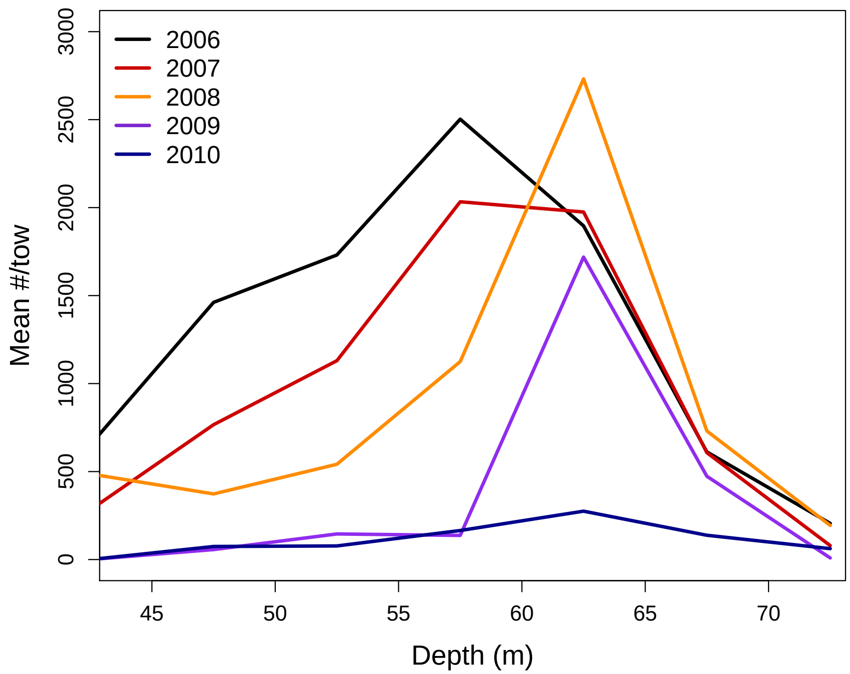
Elephant Trunk Recruitment Event

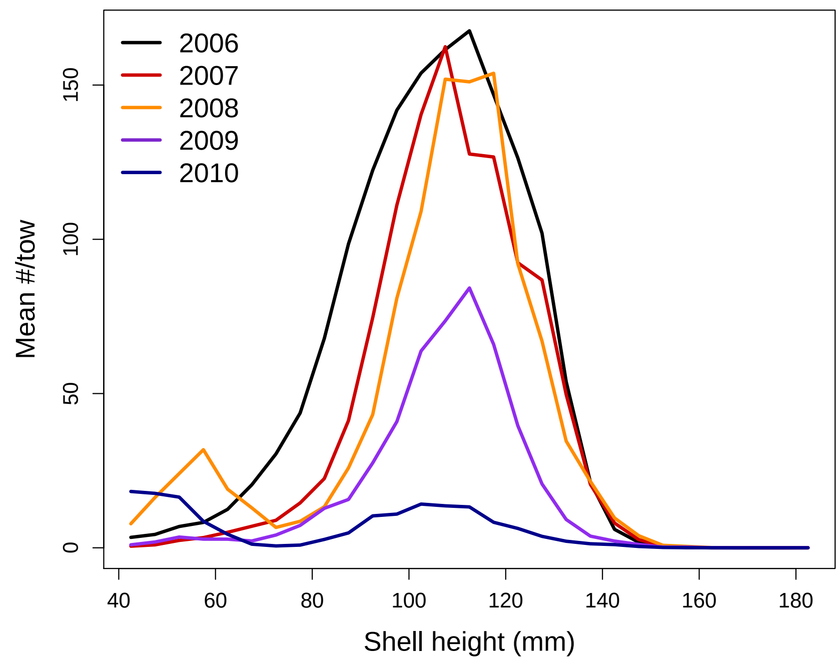
- Very large 2001 year class in the "Elephant Trunk" area offshore of Delaware Bay
- This area was closed in 2004 to protect this year class as part of a rotational management program
- Area reopened in 2007 and fishery continued through 2010. Total landings from this area during 2007-10 worth ~ 500 million

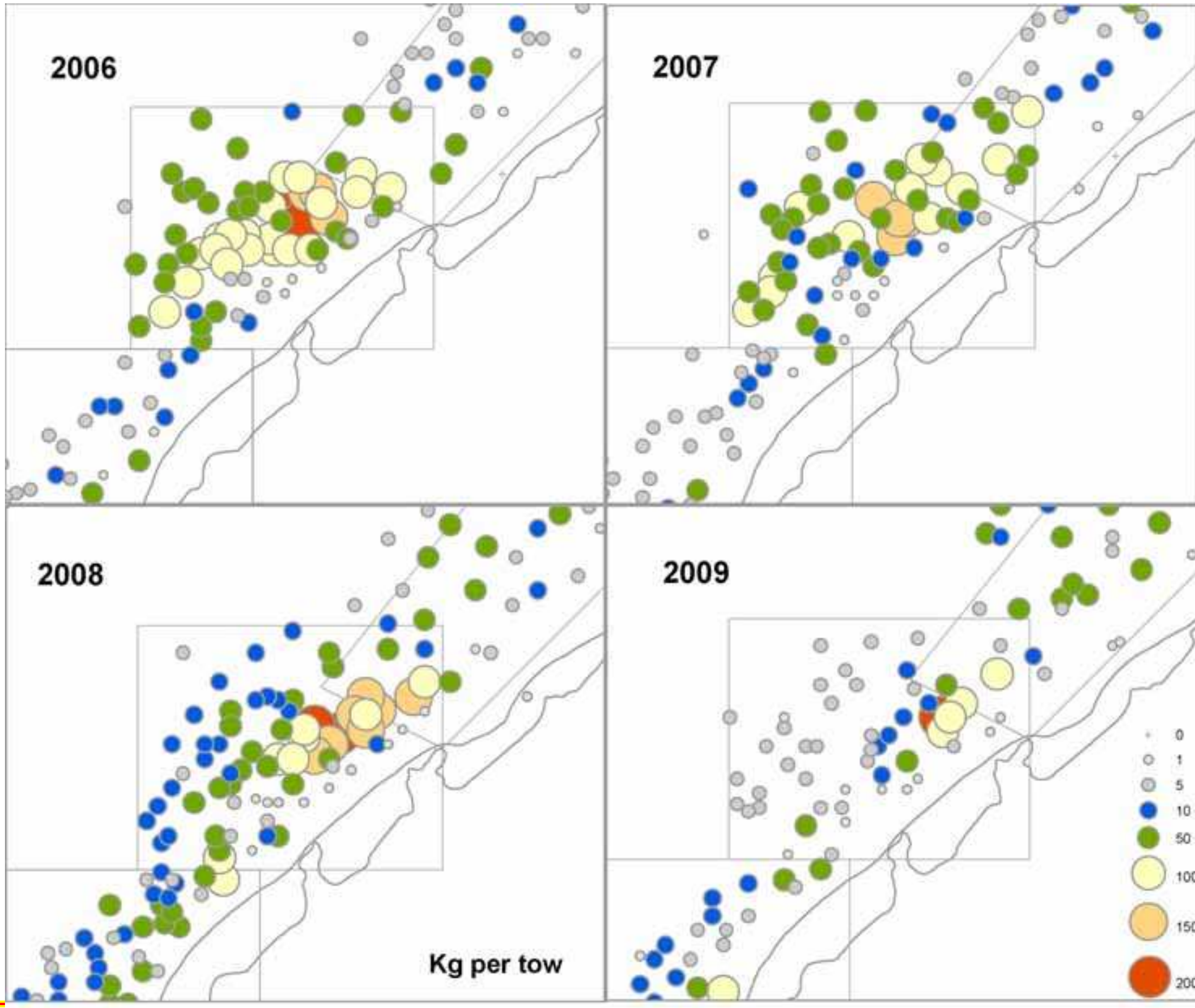
Elephant Trunk Fishery

Fishery began in shallow areas, gradually moving deeper. Deep water scallops only harvested after all other areas depleted

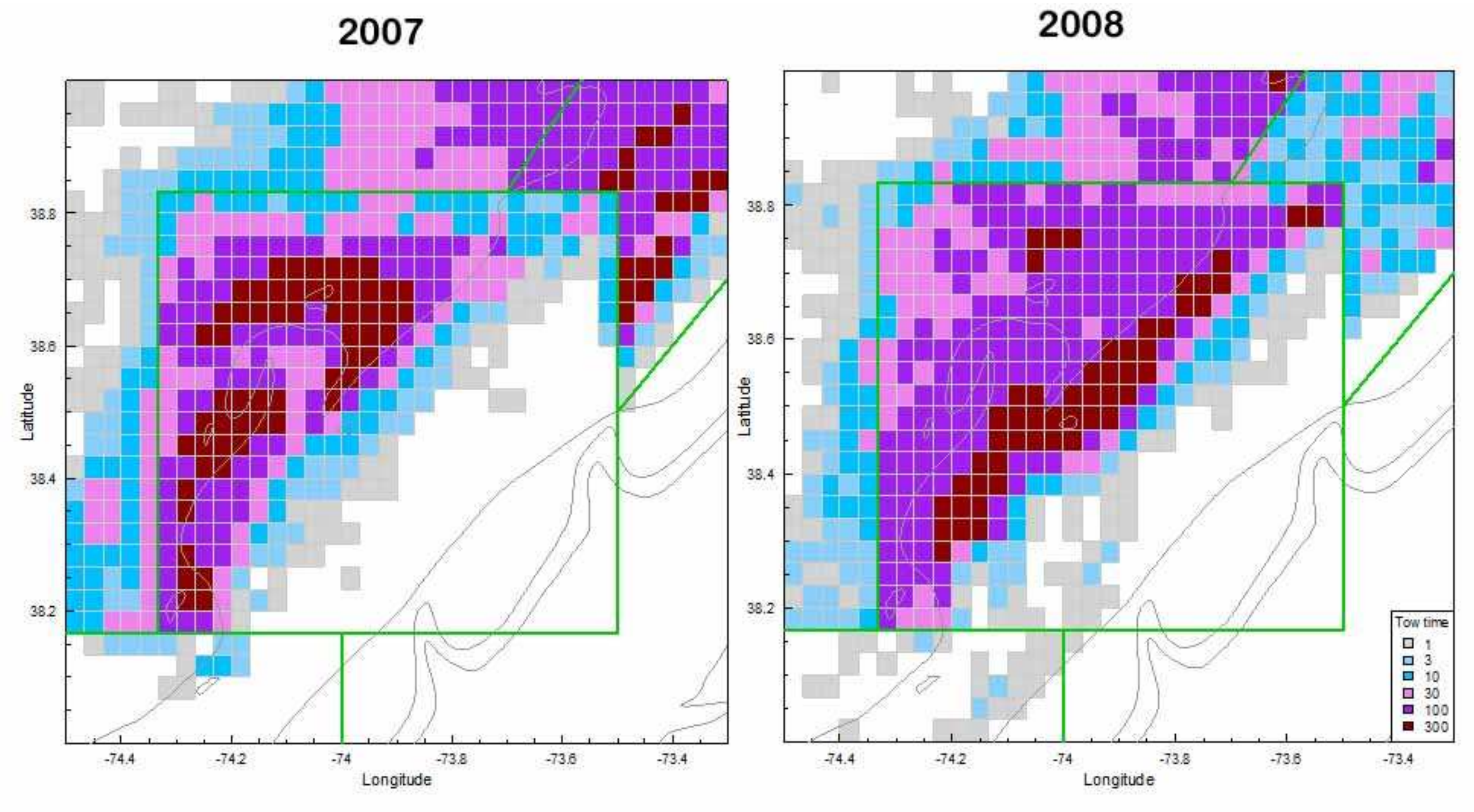




Spatial depletion in Elephant Trunk



Spatial fishing effort in Elephant Trunk from VMS data

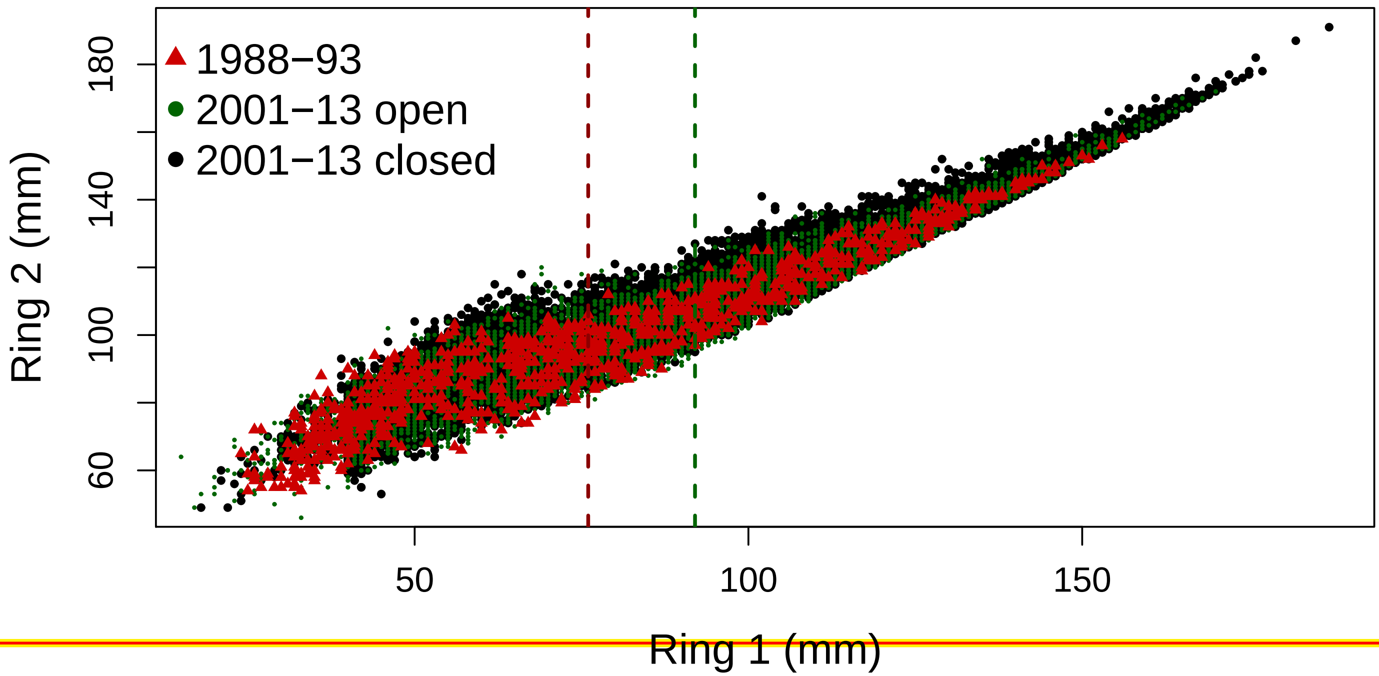


Georges Bank Sea Scallops

Very high fishing mortality during 1988-93

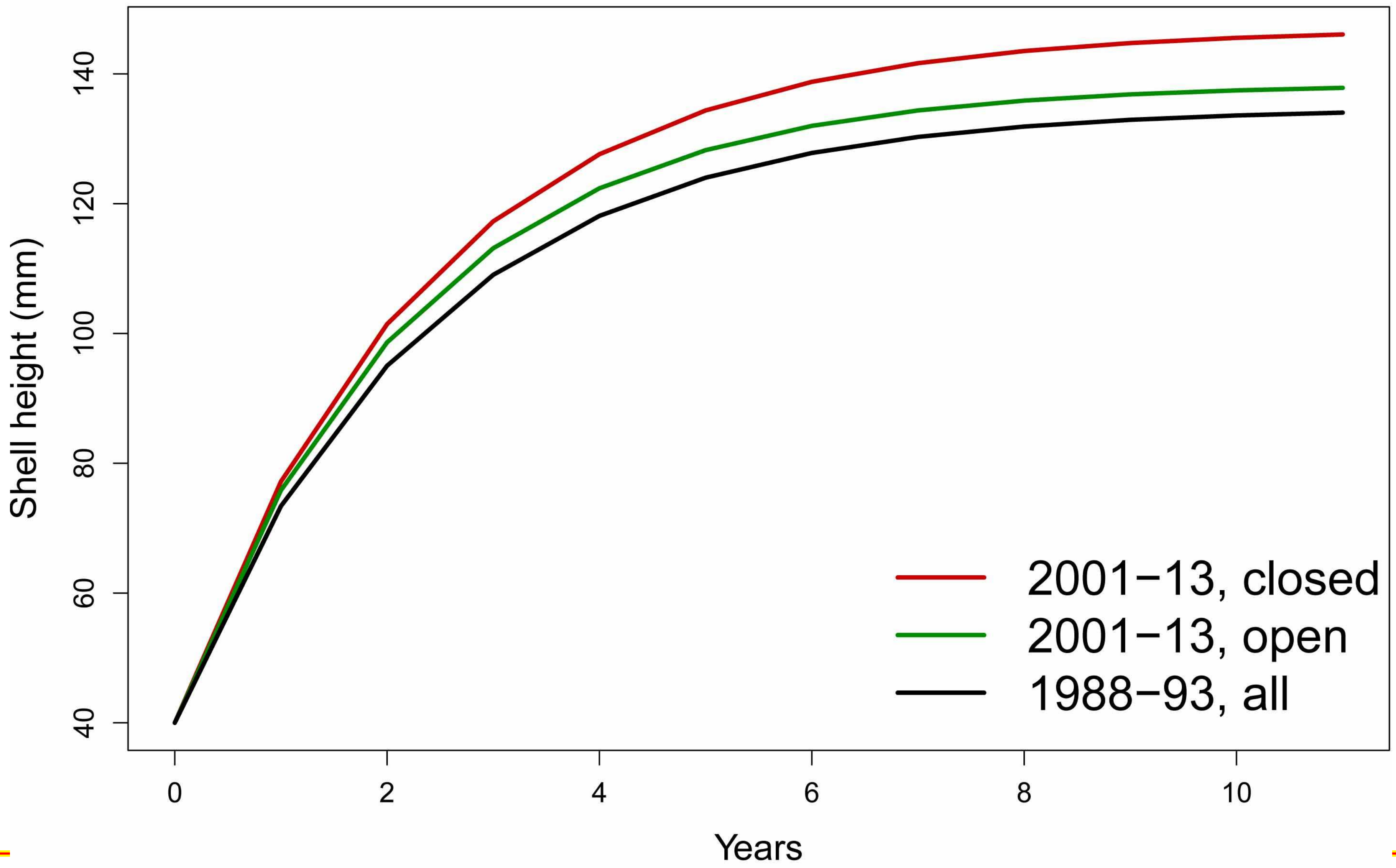
Large areas closed to scalloping in Dec. 1994. Some fishing has been allowed since, but mean F low

Effort reductions in “open” areas after 1994; 2001-13 open area F greater than closed areas but less than in 1988-93



Estimated growth curves for Georges Bank

All curves set @ 70 m depth



Consequencies of growth and fishery variability

- F_{MAX} smallest where L_∞ and F are the largest. Thus, there is a mismatch between the optimal and realized spatial distribution of effort, creating a loss of yield. Note that variability in K does not create this mismatch.
- In the current sea scallop fishery, realized YPR depends more on spatial distribution of F than mean F (Truesdell et al. in. prep.)
- Apparent growth depends on fishing effort
- Models that assume spatially uniform fishing mortality will overestimate yield, creating retrospective patterns