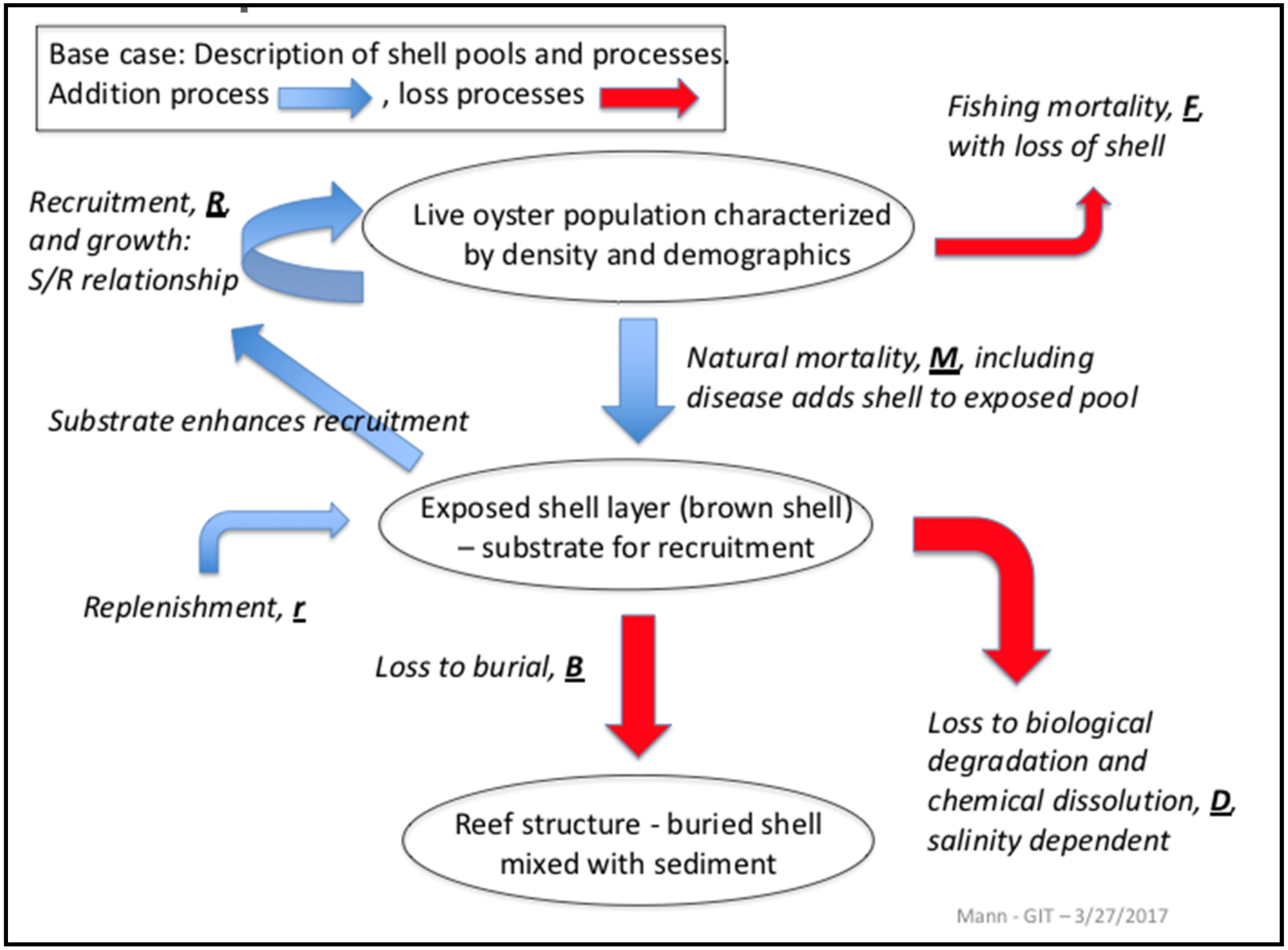
A SHELL BUDGET FOR THE CHESAPEAKE BAY OYSTER RESOURCE: AN UPDATE

The final report for this project was submitted in July 2019 – this is an update on continuing analysis with associated questions…

Roger Mann*, Melissa Southworth, Jim Wesson, Mitch Tarnowski, Mark Homer

*Virginia Institute of Marine Science, Gloucester Point VA 23062.

GIT presentation 2020-01-07

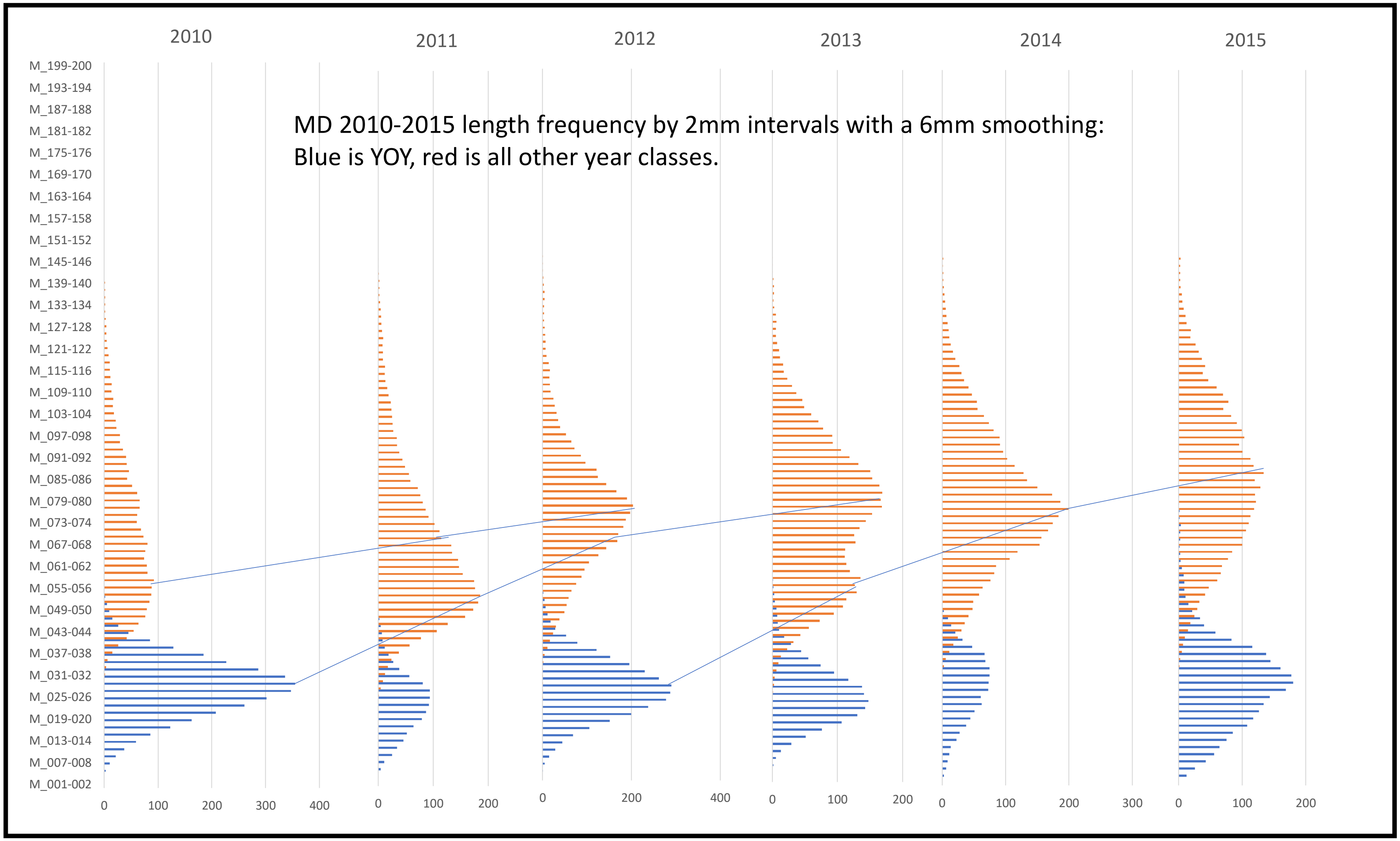


Take home points:

1. To maintain reef integrity shell addition must exceed shell loss.
2. If 1 above cannot be maintained the system will fail – this is non negotiable.
3. Shell addition is through mortality, preferably mortality of big oysters (size and allometry is important).
4. Shell loss is through physical, chemical and biological processes (taphonomy).
5. There are evolutionary yardsticks that apply in this system of reef maintenance.
6. Shell replenishment is not restoration.

Methods

1. Data sets for VA and MD are long term stock assessment: spatial estimates of density of oysters, shell, etc.
2. Convert length demographic to age demographics, and thus generate production and mortality estimates.
3. Estimates as both biomass and shell production/loss.
4. On area bases estimate shell addition to the underlying reef structure from mortality.
5. Estimate taphonomic loss by direct measures of shell density.
6. Calculate shell accretion and turnover rates based on current demographic structure.
7. Accretion compared against sedimentation and sea level rise rates to assess future viability of reef structure.
8. Model oyster mortality based on extant and fossil reefs to estimate reef accretion required to survive recent Holocene sea level rise rates – THIS SETS THE TARGET FOR RESTORATION DEMOGRAPHICS.
9. Consider the role of accreting reefs as alkalinity reservoirs and impact on benthic processes (recruitment, survival, production).



2010
2011
2012
2013
2014
2015
MD 2010-2015 length frequency by 2mm intervals with a 6mm smoothing:
Blue is YOY, red is all other year classes.
M_199-200
M_193-194
M_187-188
M_181-182
M_175-176
M_169-170
M_163-164
M_157-158
M_151-152
M_145-146
M_139-140
M_133-134
M_127-128
M_121-122
M_115-116
M_109-110
M_103-104
M_097-098
M_091-092
M_085-086
M_079-080
M_073-074
M_067-068
M_061-062
M_055-056
M_049-050
M_043-044
M_037-038
M_031-032
M_025-026
M_019-020
M_013-014
M_007-008
M_001-002
0 100 200 300 400
0 100 200
0 200 400
0 100 200
0 100 200 300
0 100 200

Figure 7. Piankatank River oysters, 2006-2016. Age at length, percentage survival (1-mortality), and shell length versus dry meat (SL v DMW) and shell length versus dry shell weights (SL v DSW).

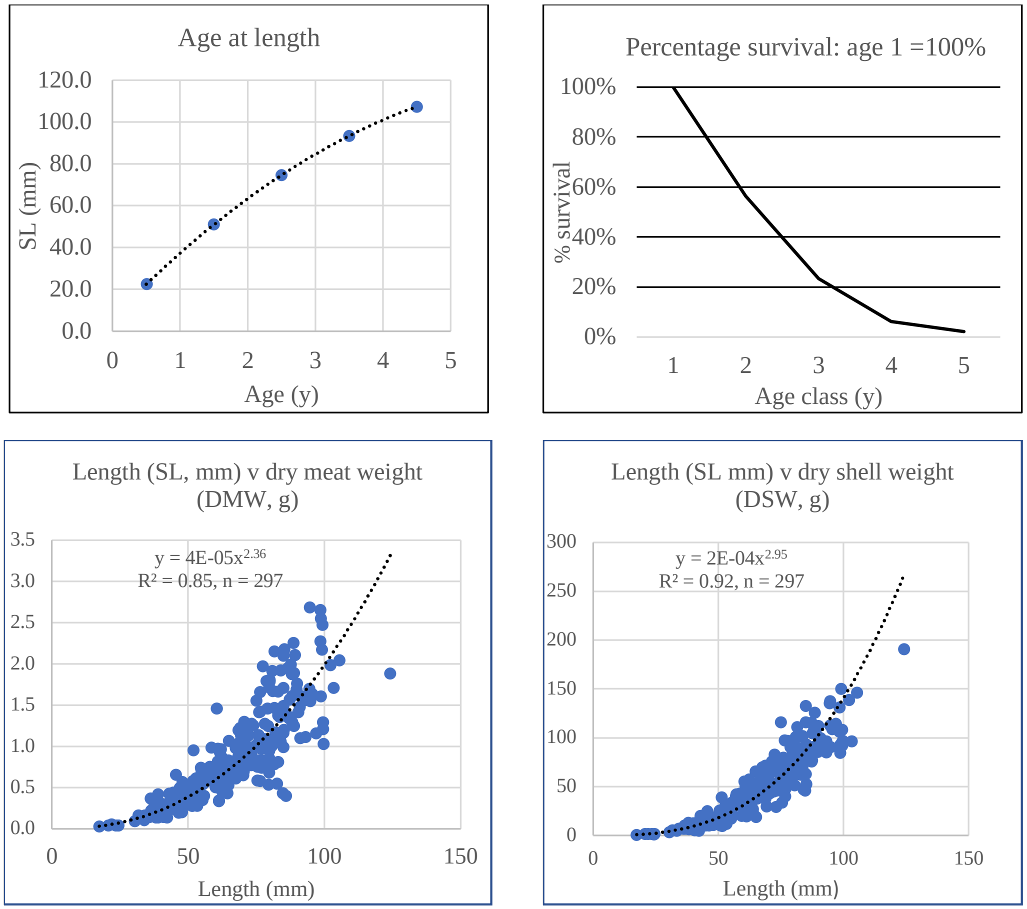


Figure 9A. Piankatank River: partitioning of shell volume (in bushels) 2006-2016 as live shell, brown (oxic) and black (anoxic) shell layers, plus a total value.

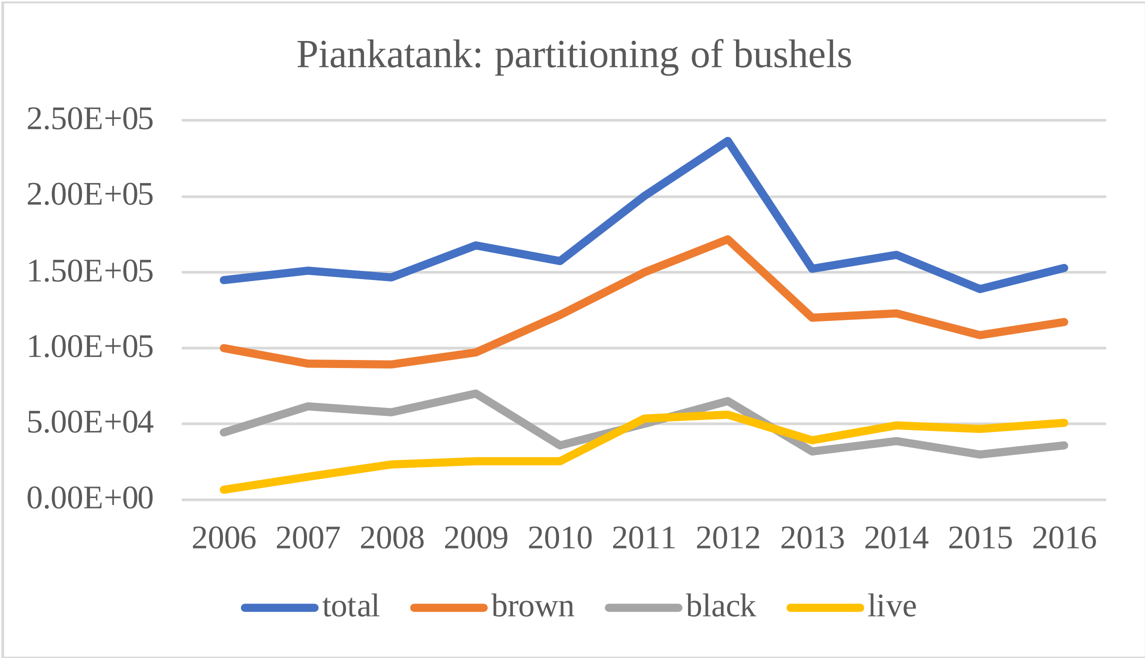
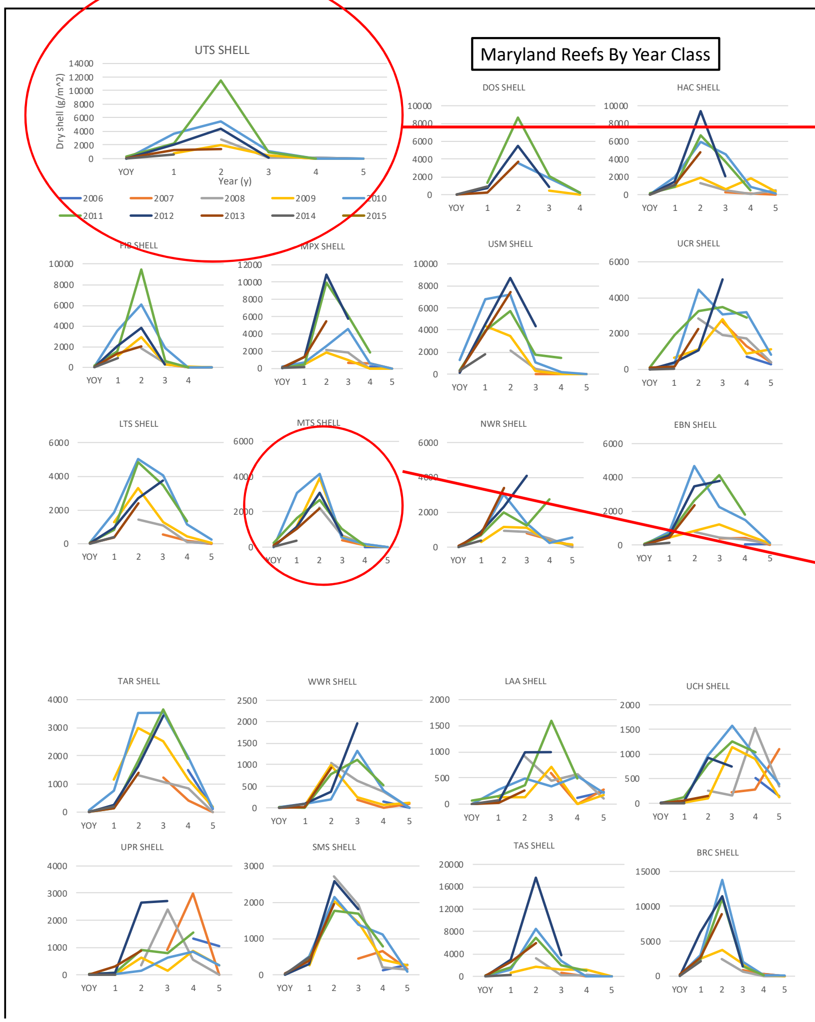
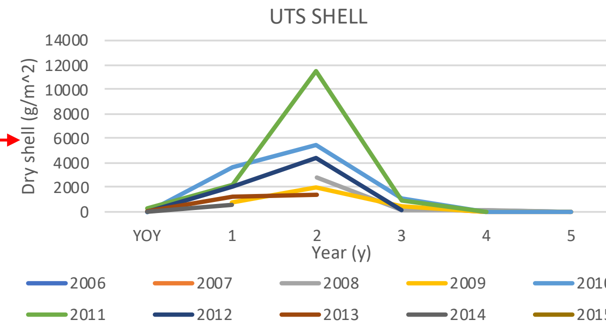


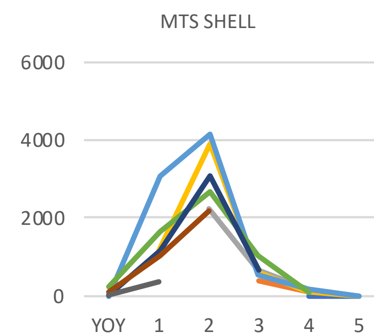
Figure 11. Demographic profile of shell weight per unit area on MD reefs by year class for year classes originating in 2006 through 2015. Note that the plot ordinates have a variety of scales to accommodate spatial differences. The color sequences on the plots are standard across all plots; for example the 2012 year class for MD is mid green for all sites. MD reef labels are given in the accompanying text.



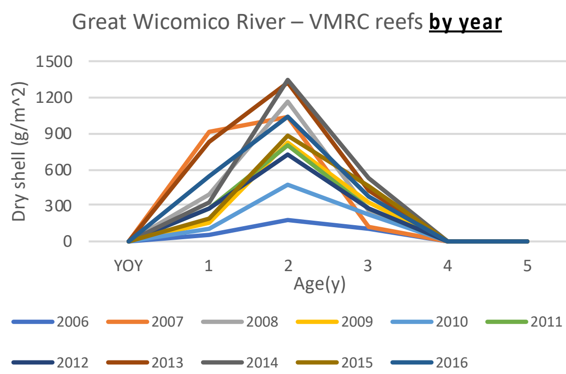
Upper Tangier Sound



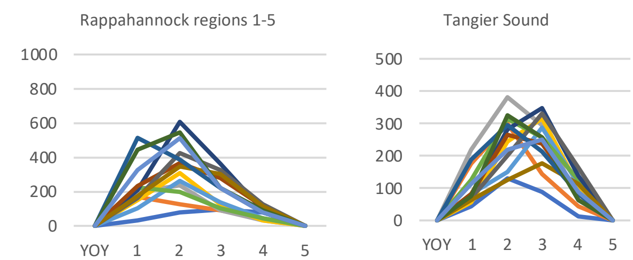
Middle Tangier Sound

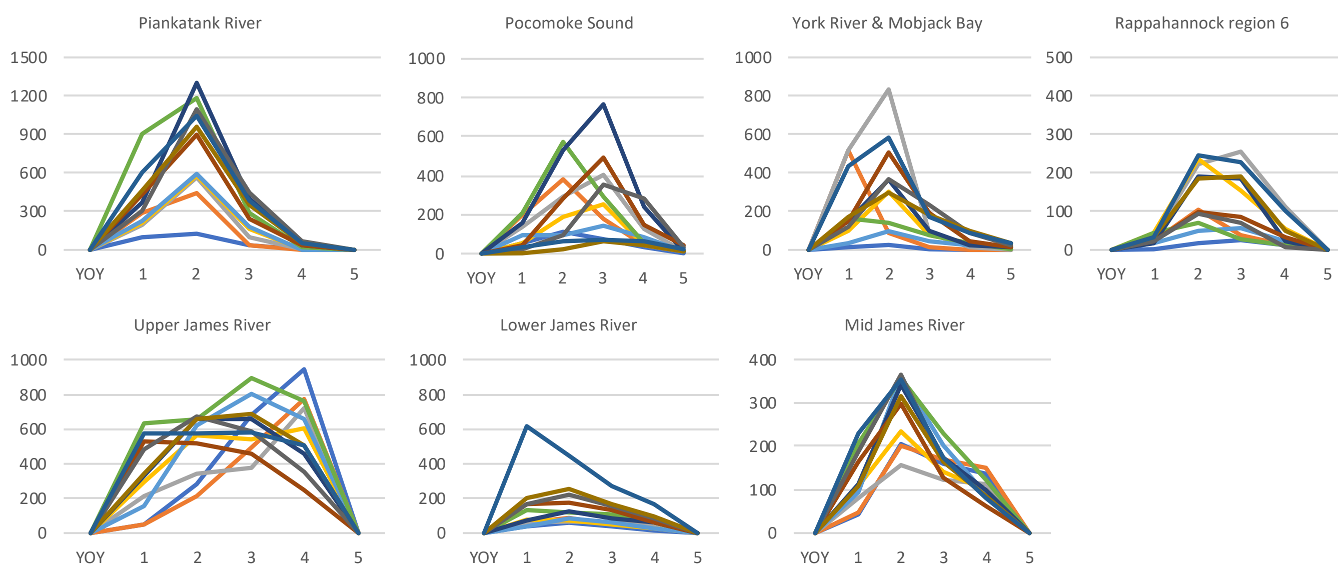


The majority of the shell is in the year 2 year class



Virginia Reefs – By Year





The majority of the shell is in the year 2 and year 3 year classes – the turnover rate of shell in these systems is ~30%/yr

Extant Chesapeake Bay oyster populations have an extreme truncation of demographic structure because of high mortality rates…..

2019 VIMS/VMRC fall survey data

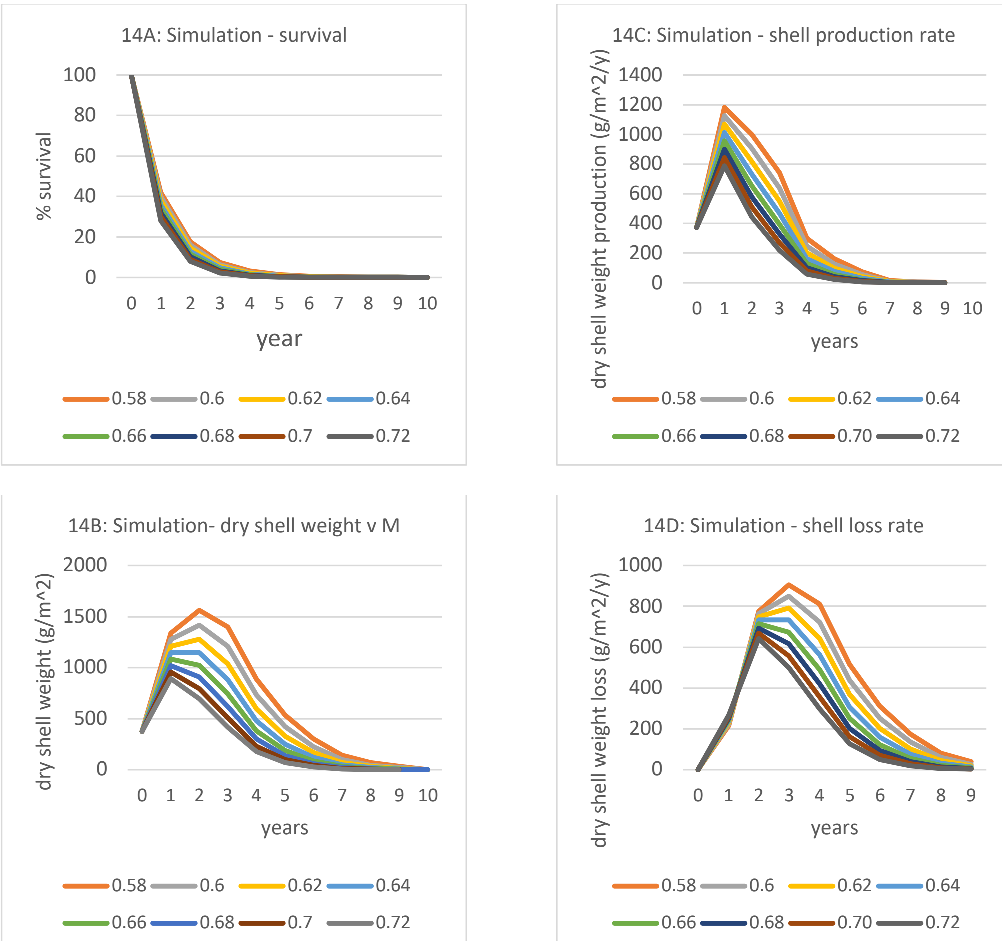
- 1,186 stations
- Total oyster measured. 111,109
- Total YOY. 59,545 (53.6%)
- Total >YOY. 51,564 (46.4%)
- 89.2% are less than 70 mm

- This includes both harvest and non harvest areas

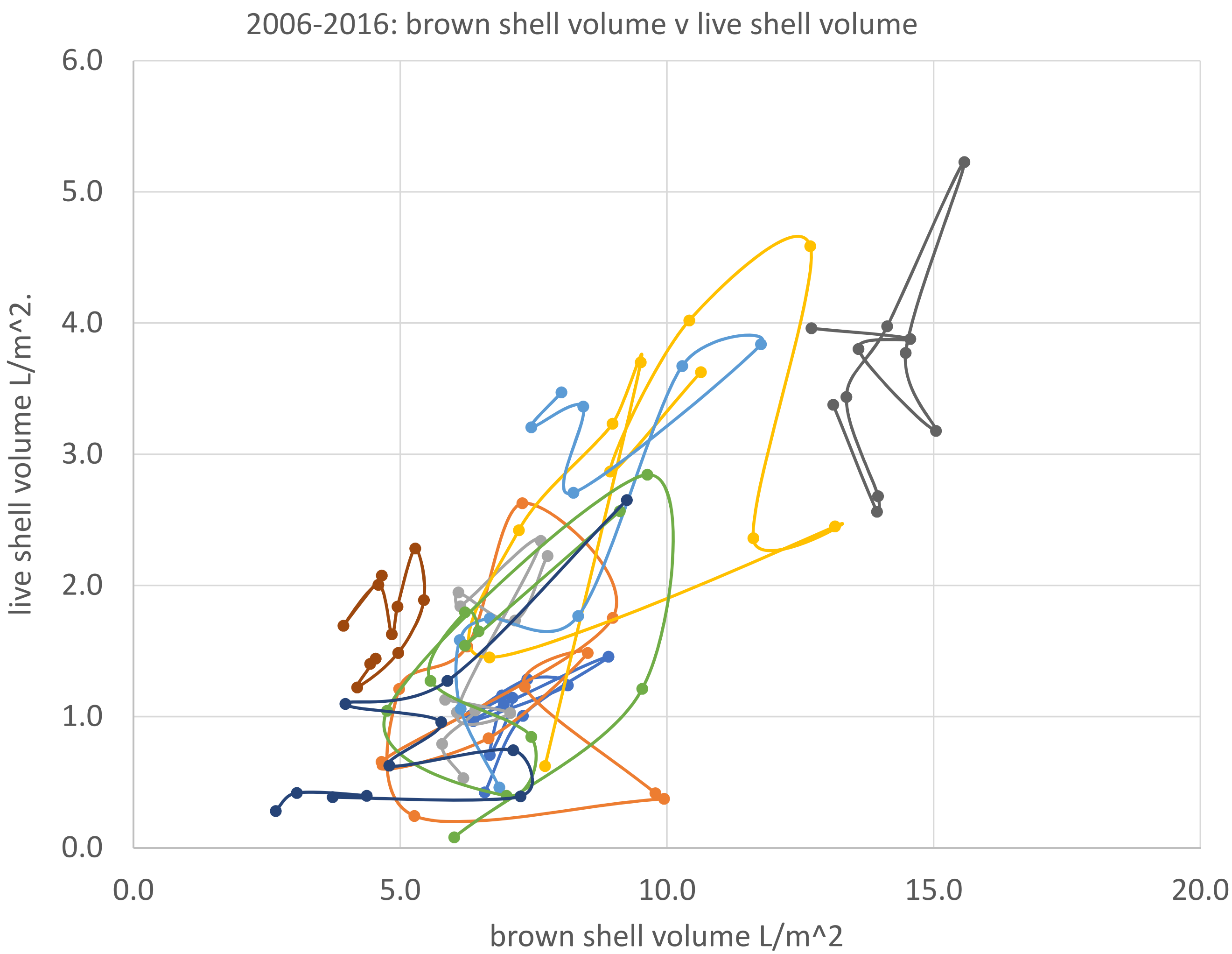
- We have a mortality problem. How does this compare with reef systems in extant pristine or fossil situations?

Size bin (mm)	# Live (non-spat)	% in bin
1-10	30	0.06%
11-20	491	0.95%
21-30	11,121	21.57%
31-40	13,828	26.82%
41-50	9,730	18.87%
51-60	6,392	12.40%
61-70	4,391	8.52%
71-80	2,871	5.57%
81-90	1,584	3.07%
91-100	748	1.45%
101-110	220	0.43%
111-120	103	0.20%
121-130	37	0.07%
131-140	14	0.03%
141-150	2	0.00%
151-160	1	0.00%
161-170	0	0.00%
171-180	1	0.00%
Total oysters	51,564	

Figure 14. Simulations based on Figures 11 and 12. A: survival as a declining function wherein annual mortality, M, is a proportional value between 0.0 (no mortality) and 1.0 (all died). M values are consistent color coded among panels between 0.58 and 0.72. Survival is (1-M). B: standing stock of shell (g m^{-2}). C: annual shell Production (g $m^{-2}y^{-1}$). D: annual shell Loss (g $m^{-2}y^{-1}$). See text for additional details.



This is a simple simulation of current mortality for a single year class. Note the relationship between standing shell, production and loss rates. This does not support accretion. Reefs will decay to baseline level.



Median % of live shell pool transferred annually to brown pool.

Tangier.	**29%**
Pocomoke	**41%**
Rappahannock.	**33%**
Great Wicomico	**32%**
Piankatank	**29%**
York River	**13%**
Lower James.	**21%**
Middle James.	**35%**
Upper James.	37%

Note that the extension does not pass through the origin – this agrees with the suggestion of Powell et al (2012) that reefs have an inherent protective mechanism to limit TAZ volumetric content.

Walles, B., R. Mann, T. Ysebaert, K. Troost, P.M.J. Herman and A. Smaal (2015). Demography of the ecosystem engineer *Crassostrea gigas*, related to vertical reef accretion and reef persistence. Estuarine, Coastal and Shelf Science. 154: 224-233. http://dx.doi.org/1011016/j/eccs.2015.01.006.

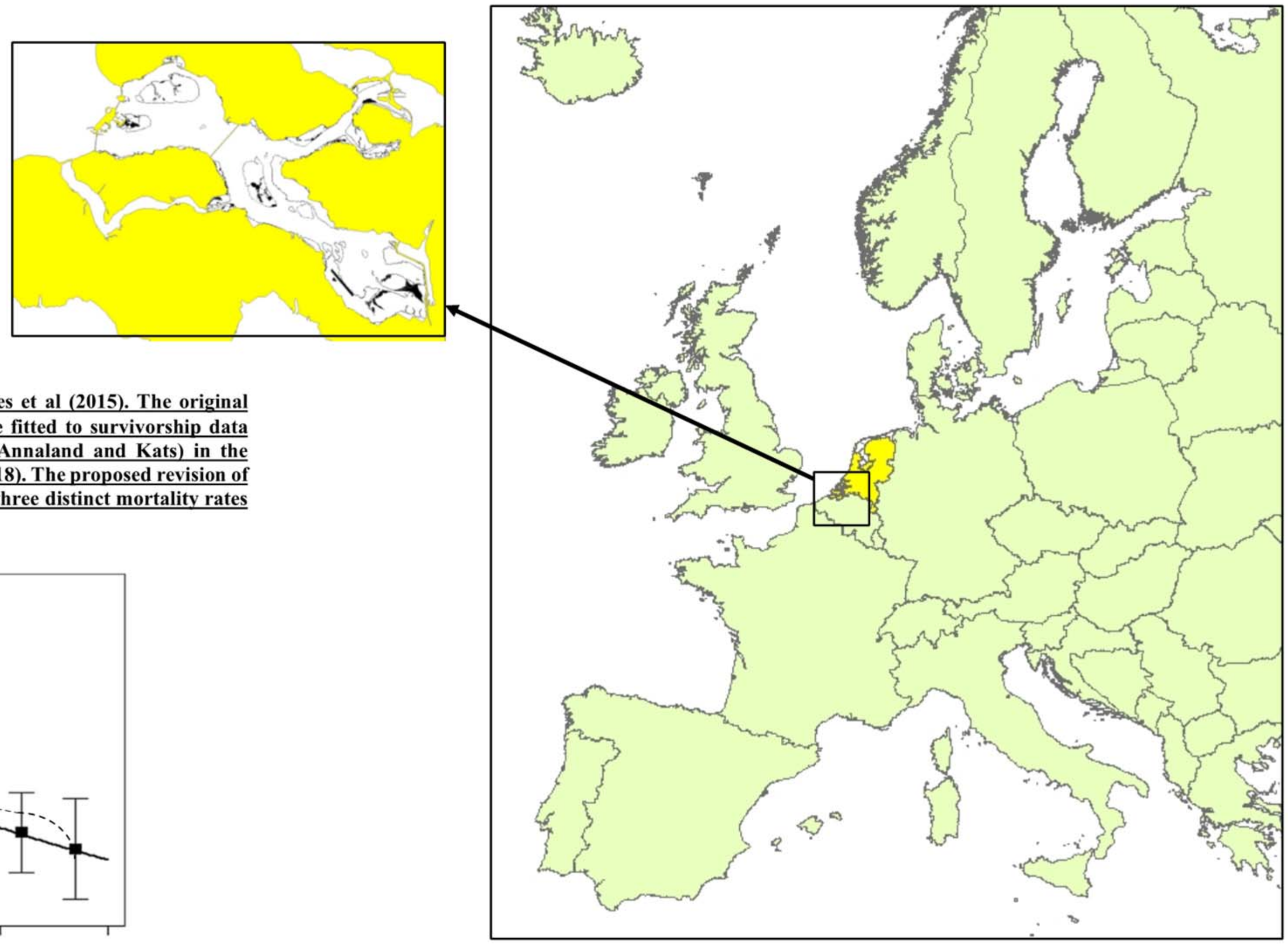


Figure 17. A proposed revision of Figure 5 from Walles et al (2015). The original Weibull distribution fit (λ = 1, κ = 0.6) is the solid line fitted to survivorship data (mean + s.e.) of three oyster populations (Viane, St. Annaland and Kats) in the Oosterschelde estuary, Netherlands (raw data in Figure 18). The proposed revision of the mortality curve is the broken line and incorporates three distinct mortality rates over the life expectancy.

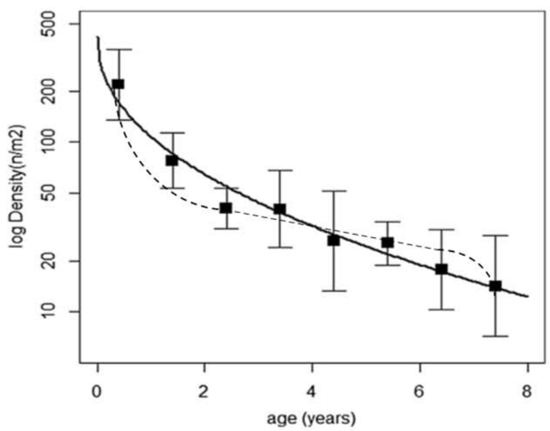
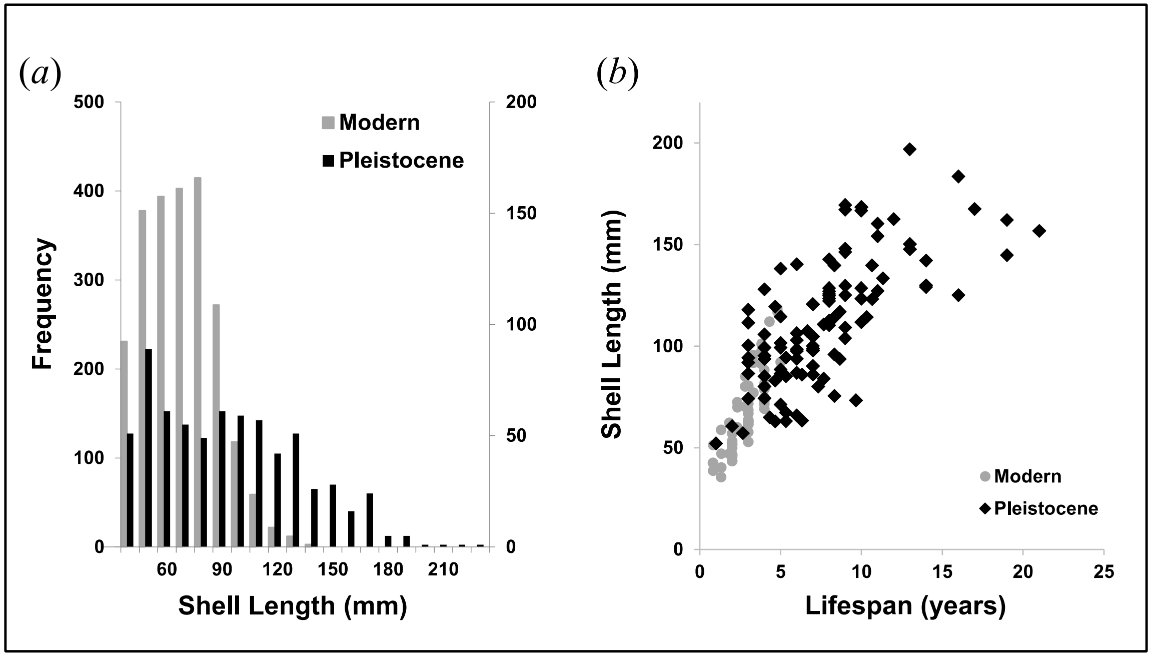
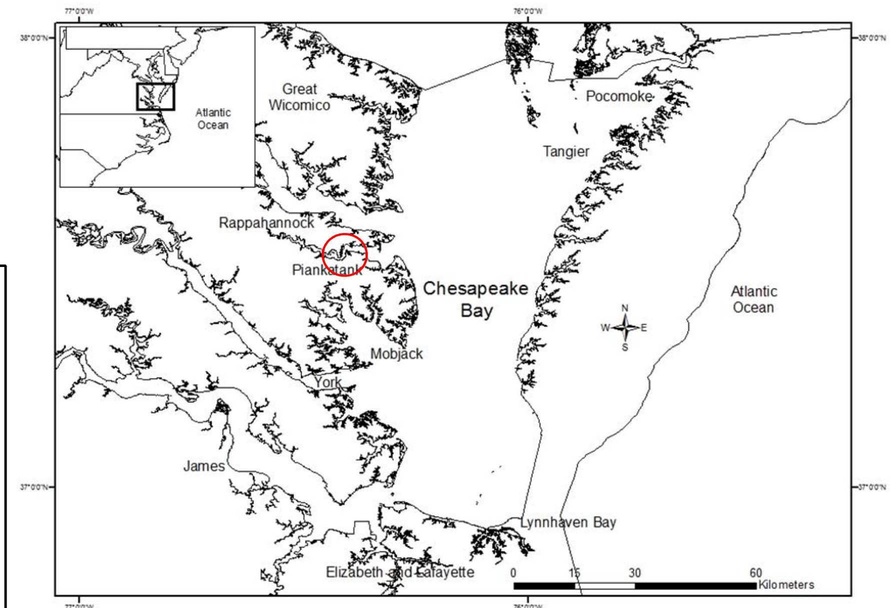
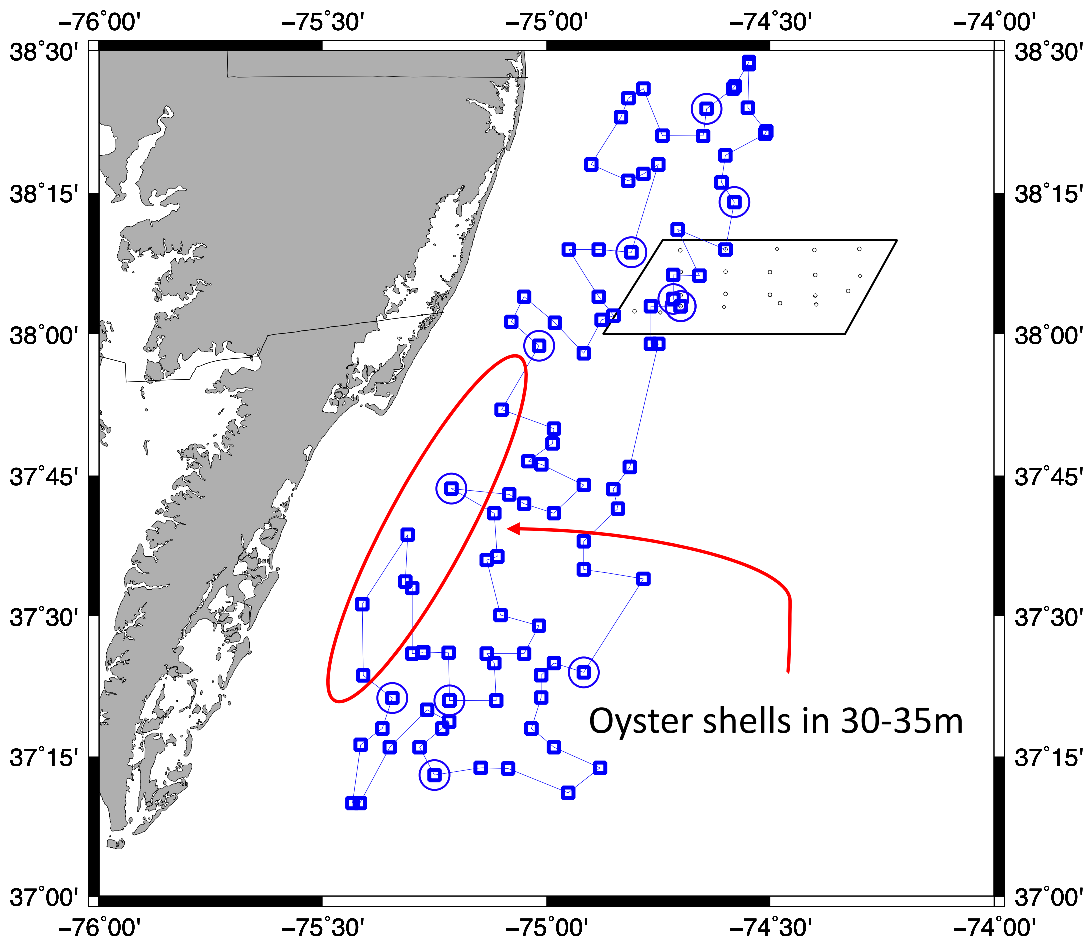


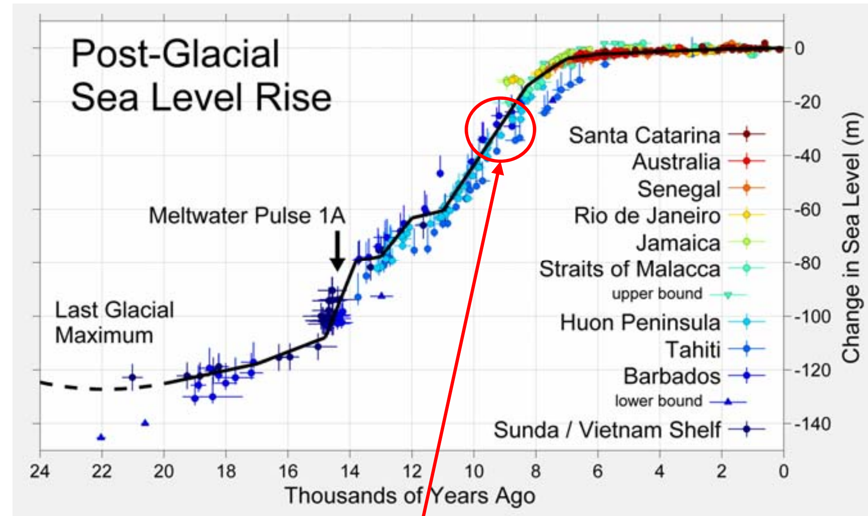
Figure 15. Figure 1 of Lockwood and Mann (2019, in review). Length frequency *(a)* and age at length *(b)* of Pleistocene oyster shells from the Piankatank River VA and modern shells from the James River VA.





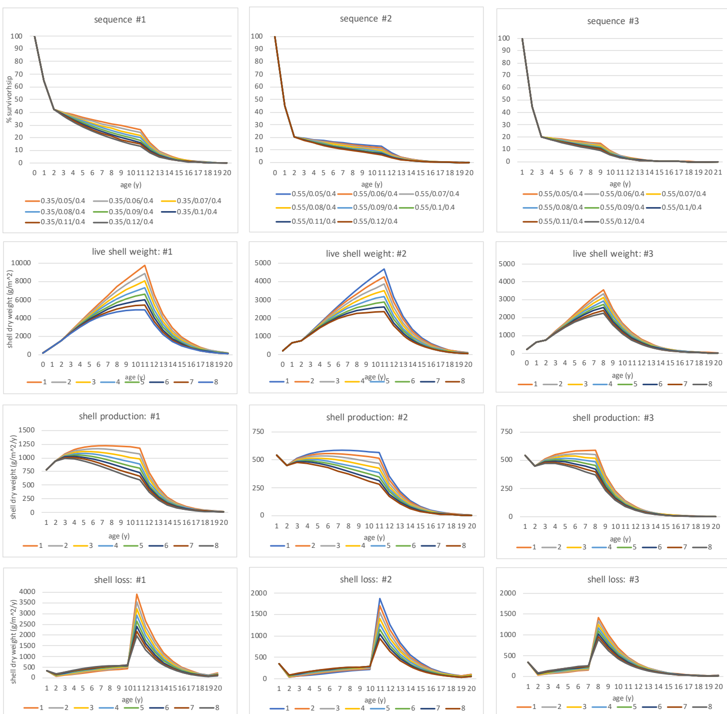
Lockwood R., R. Mann (2019). A conservation paleobiological perspective on Chesapeake Bay oysters. Phil. Transactions of the Royal Society. online at bit.ly/PTB1788

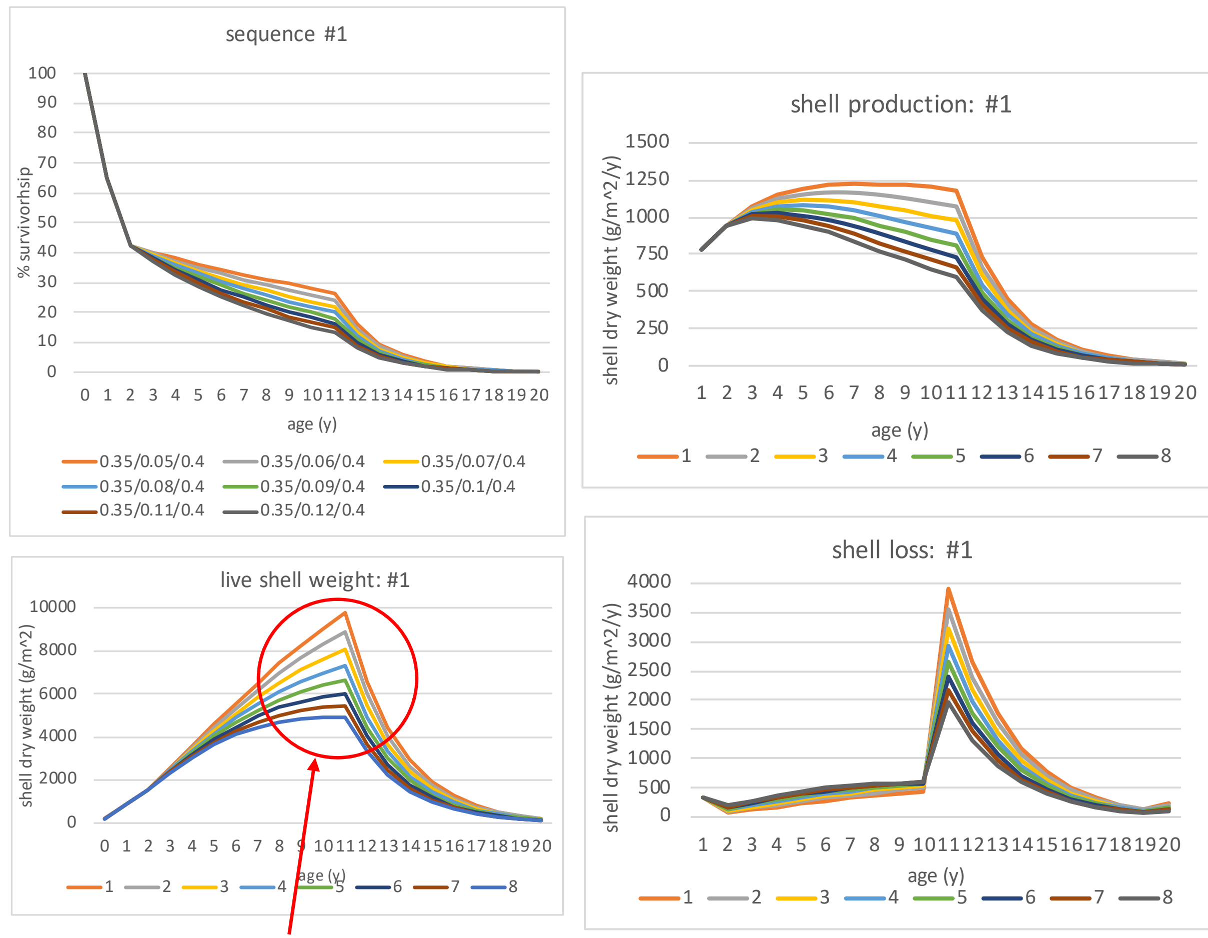




Early Holocene sea level rise ~ 60m in 5000 y, that is 12mm/yr.
This is the baseline accretion rate for oysters to survive. Accounting for taphonomic loss we need a gross accretion rate of ~15mm/yr.
This can only be achieved with a different mortality curve………

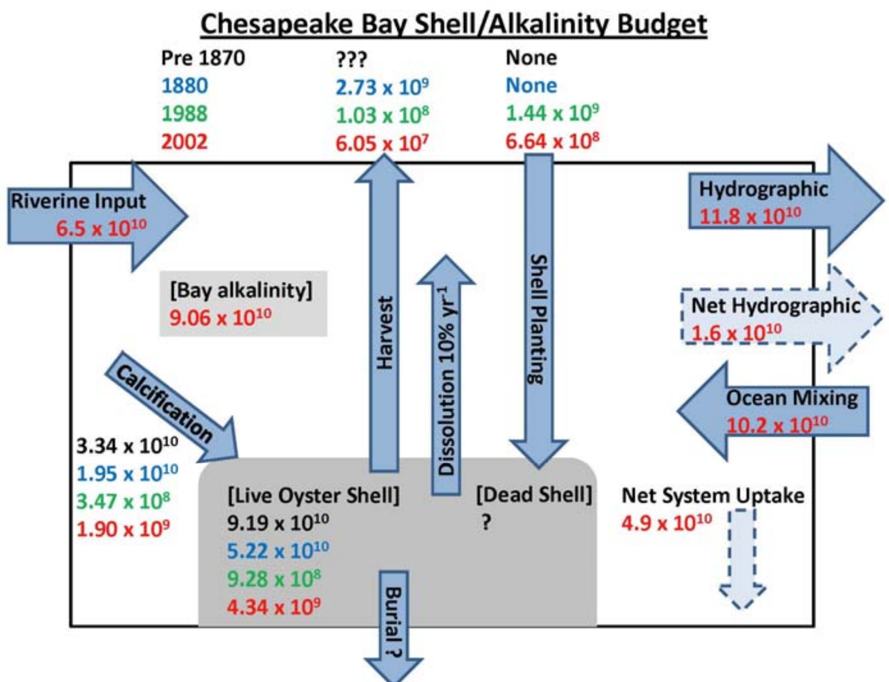
Figure 19. Time series of survival, live shell standing stock (g m^{-2}), shell production and shell loss (g m^{-2} y^{-1}) for an oyster population with an initial density of 100 m^{-2} with varying sequences of mortality over a 20 year period. Sequence #1 is a three part mortality protocol with M1 (0-2y) of 0.35, M2 (3-11 y) increasing from 0.05 to 0.12, and M4 (12-20y) of 0.4. The fossil age at length curve of Figure 1B of Lockwood and Mann (see Figure 15 of this report) is employed. Label 1 through 8 of plots describing live shell weight, shell production and shell loss correspond to mortality rate sequences in the footer of the top panels of each sequence. See Table 9 and text for additional details.





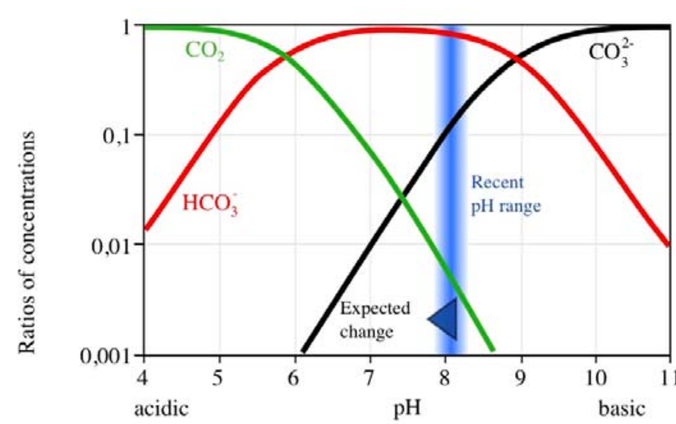
These values are minimally 4-6x higher than extant systems, note this is a single year class

So if we cannot achieve accretion targets then consider using a substrate that does not suffer such rapid taphonomic loss….. This fails to address the fact that **oyster reefs are alkalinity reservoirs** in estuarine and shallow coastal systems , this buffering plays a critical role in carbonate saturation state, which in turn has many biological, especially benthic implications. This is directly analogous to current concerns in coral reefs systems.



All unit in Moles or mole equivalents (Waldbusser, Powell and Mann (2013)
using land-ocean interaction coastal zone (LOICZ) box model of Webb and Smith (1999)

"An explicit focus on pH and organismal acid-base regulation has failed to distinguish the mechanism of failure in highly sensitive bivalve larvae."
"… we show definitively that larval shell development and growth are dependent on seawater saturation state, and not on carbon dioxide partial pressure or pH."
Waldbusser et al 2014: Nature Climate Change



Summary:

1. ***Extant reefs are losing the race with sea level rise and sedimentation; reefs represented in the fossil record had the race in hand. The disparity between the two is stark and unlikely to be reduced given the inability of oysters to survive to older ages in the current Bay ecosystem.***
2. ***There is a fundamental challenge with longevity for Bay oysters and it cannot be blamed entirely on harvest or disease. A broader consideration of the Bay watershed and its input to the Bay should be carefully scrutinized.***
3. ***Truncated population structure reduces input of shell to the underlying reef structure such that the latter is not sustainable without continual shell repletion.***
4. ***Its not just about reef building – its also about creating and maintaining reefs as alkalinity reservoirs that are essential to a wide range of biological process, especially in early life history stages and the benthos.***