Climate Change and Oysters in the Chesapeake Bay

Roger Mann and Ryan Carnegie
Virginia Institute of Marine Science
Gloucester Point, VA 23062

presentation to

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rmann@vims.edu, carnegie@vims.edu

Questions and answers in the context of Chesapeake Bay climate change.

- Why bother with oysters anyway?
- What is the impact of climate driven changes in temperature and/or salinity in isolation on oysters?
- What is the impact of changing water chemistry on oysters?
- What is the impact of diseases on the resident oyster population?
- Can we proactively manage any of it?

Why bother? Part 1: Oysters are central to the food web. (Ulanowicz and Tuttle 1992).

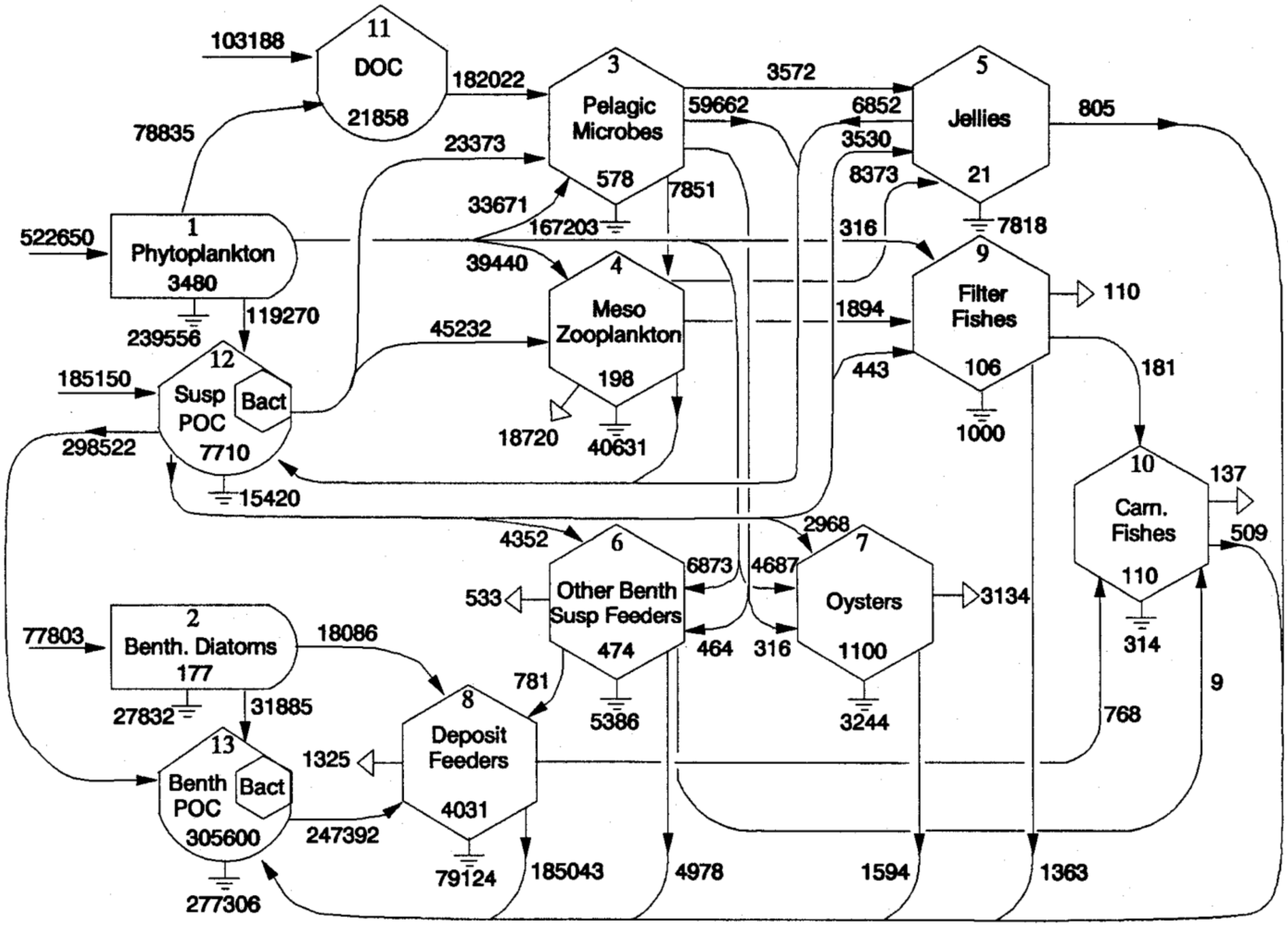
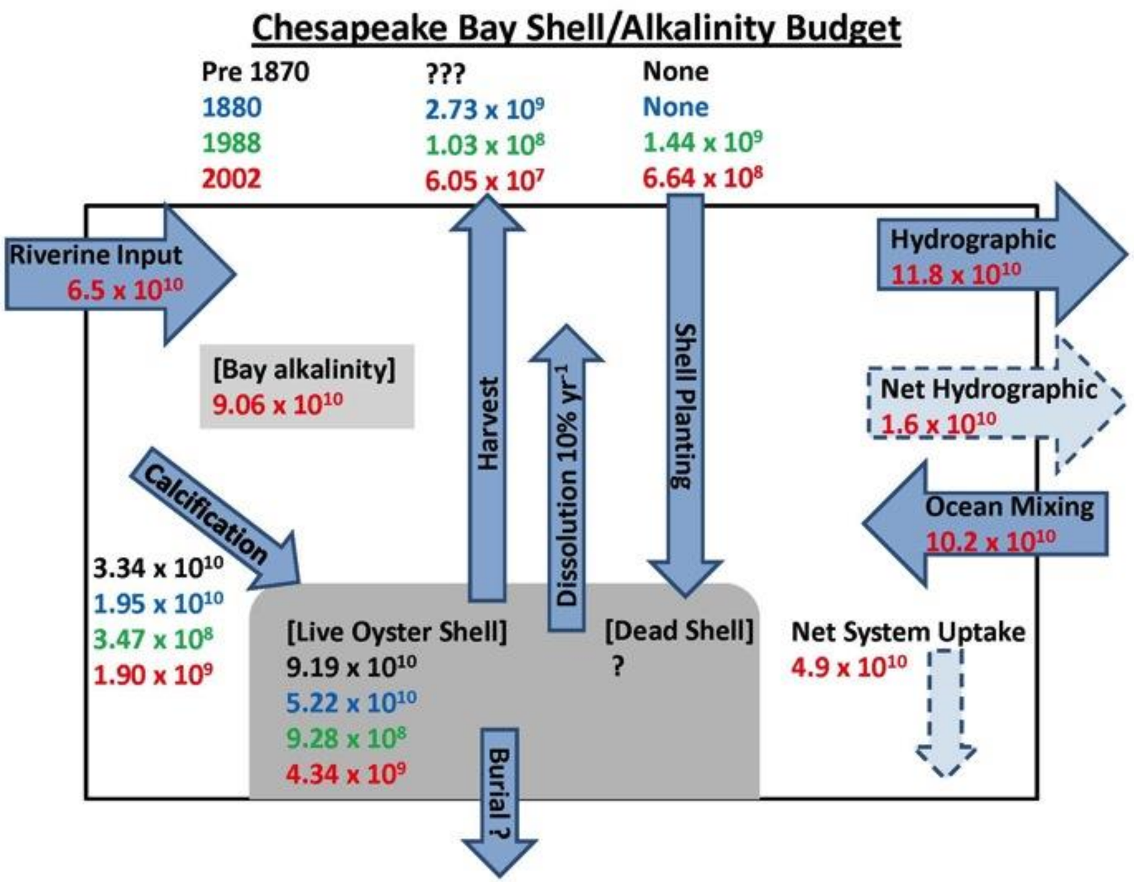


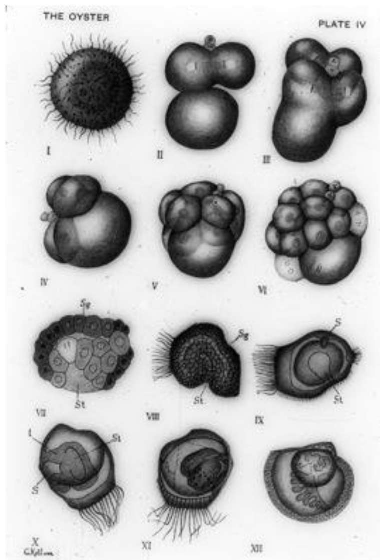
Fig. 1. Carbon flows (mg m⁻²yr⁻¹) and stocks (mg m⁻²) for 13 components of the mesohaline Chesapeake Bay ecosystem. Ground symbols represent respirations; open arrows, exports. This network is an aggregated version of the annual budget appearing in Fig. 7 of Baird and Ulanowicz (1989).

Why bother? Part 2: They create their own habitat (very unusual among bivalves), habitat for many other species, and in doing so are central to the Bay Alkalinity Budget.

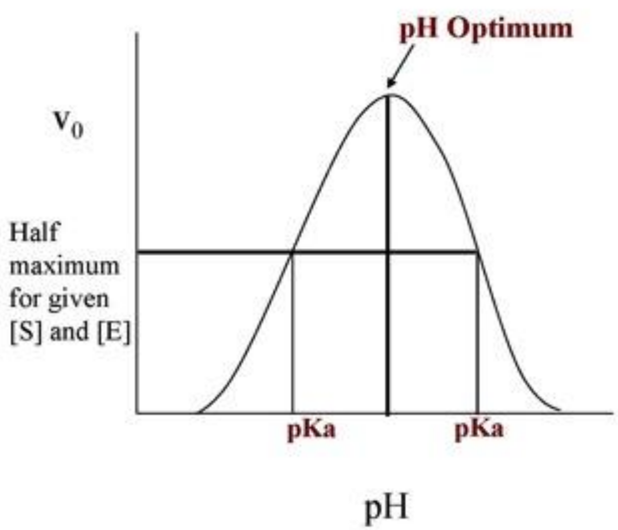


All unit in Moles or mole equivalents (Waldbusser, Powell and Mann (2013) Ecology).
We use land-ocean interaction coastal zone (LOICZ) box model of Webb and Smith (1999).
Note the reduction in alkalinity "reserve" in 140 years.

How does shell moderate conditions at the sediment water interface?

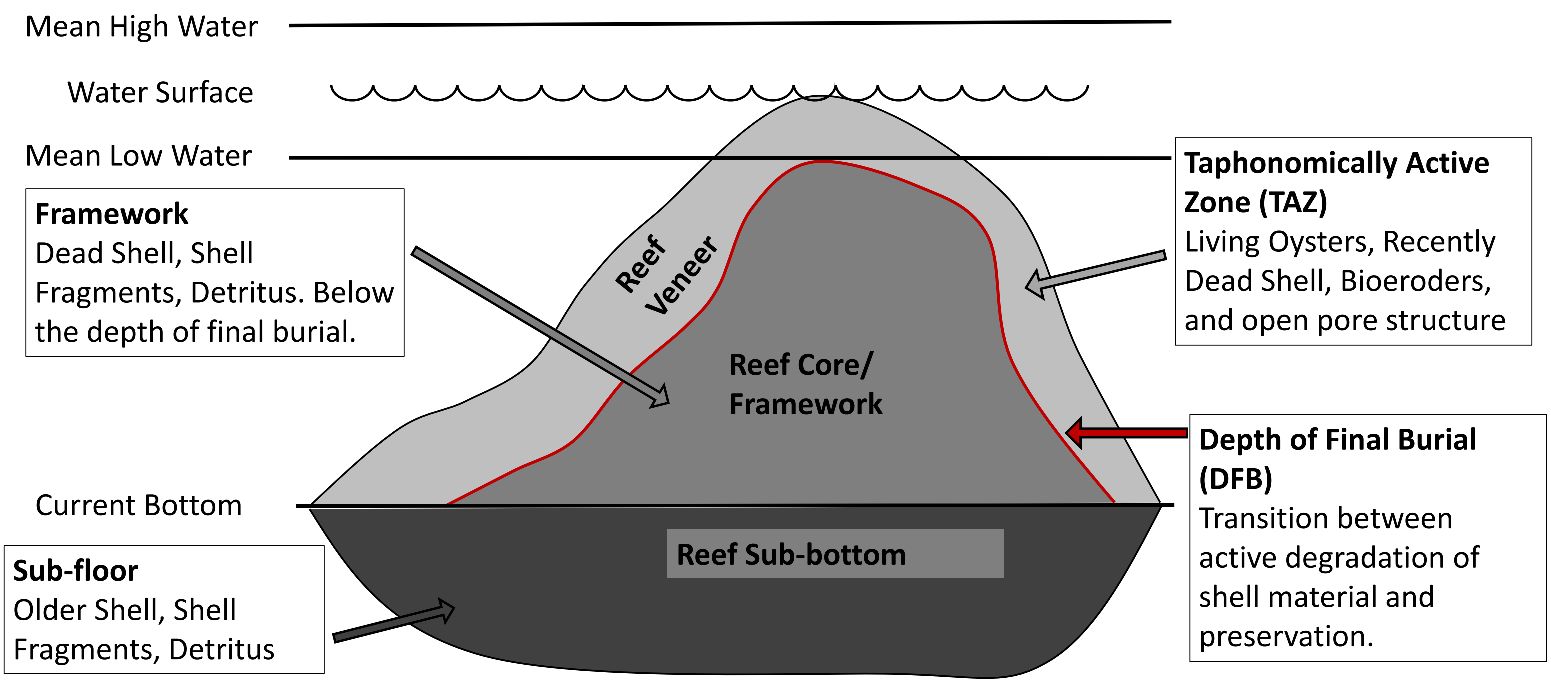


Graphic: W.K. Brooks (1905) The Oyster

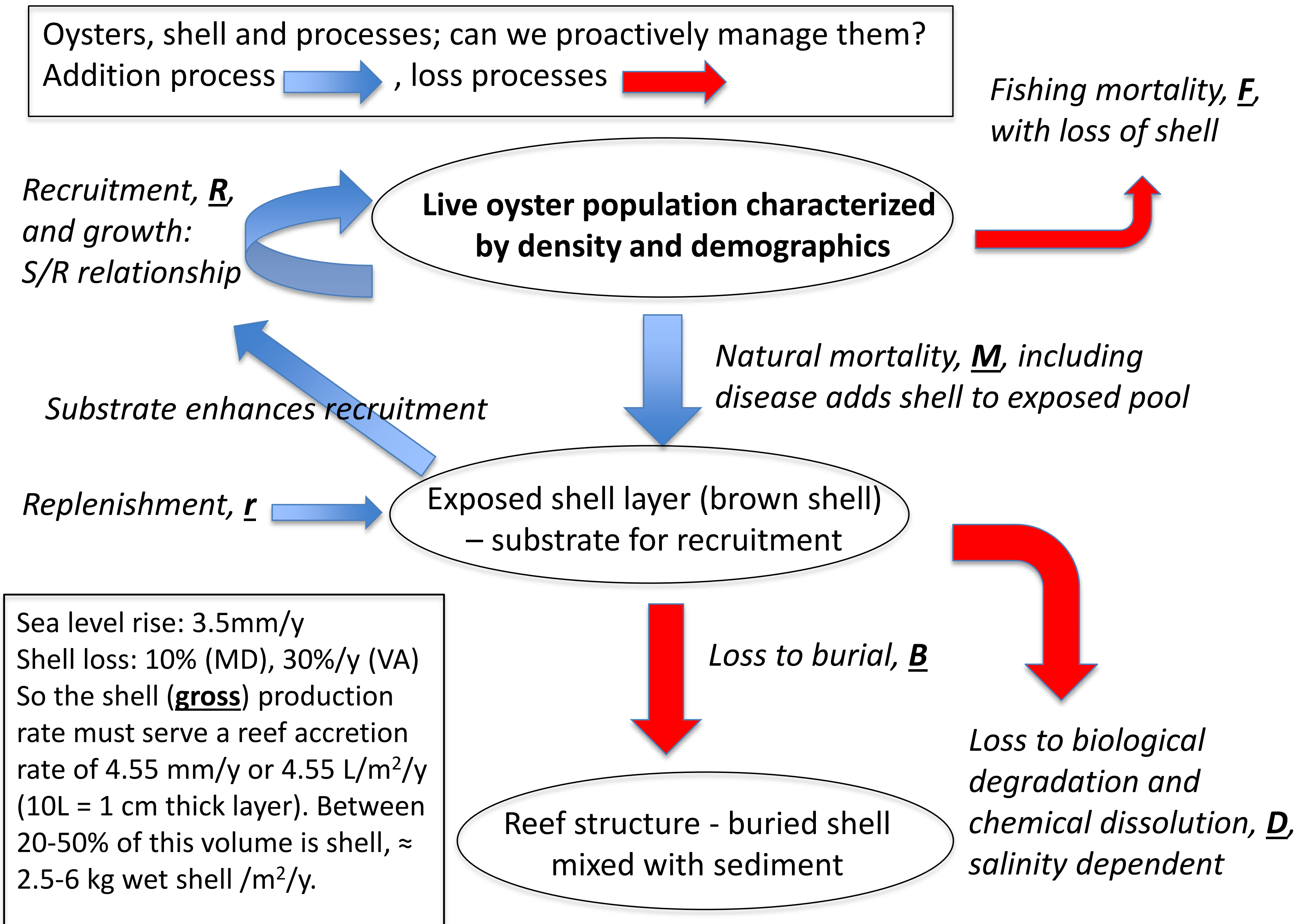


- Water column organics fall to the interface where they produce acid that is neutralized by carbonate.
- The literature portrayal: below the interface as a region of carbonate dissolution “attacking” shells of metamorphosed molluscs… but it is much more.
- The typical invertebrate larval egg is between 75 and 300 microns diameter.
- The swimming ciliated form approximates 300-1000 microns at metamorphosis: max size is all about Reynolds numbers and viscosity.
- Its all about surface exchange properties, and enzyme pH optima.
- This implicates all ciliated invertebrate larvae, and thus all estuarine food chains.

Oyster reefs are complex biological, physical and geochemical structures: biogenic carbonate is added through growth, then transferred to the shell pool through mortality, recycled back to the water column through taphonomy, lost to burial, but also exhumed through feedback loops – but this is *all driven by oyster population dynamics*.



graphic from Waldbusser, Powell and Mann. (2013) Ecology 94(4): 895-903



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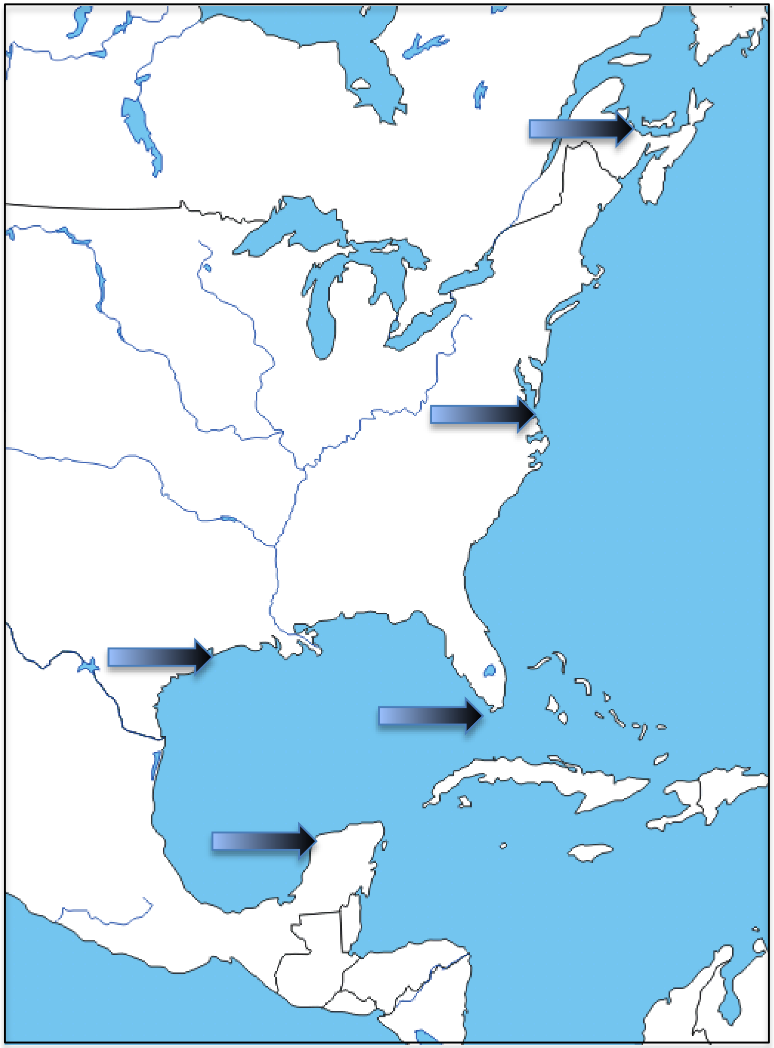
Impact of climate driven changes in temperature and/or salinity on oysters?



Annual temperature ranges:

PEI (Charlottetown) NS: -1.1 – 18.3^{o}C

Chesapeake Bay: 4 - 30^{o}C

Key West FL: 21.5 – 31.5^{o}C

Galveston TX: 12.5 – 31.0^{o}C

Yucatan peninsula: 23.4 – 29.3^{o}C

Temperature projections alone do not represent a threat to the survival of oysters in the Chesapeake Bay. Salinity projections may modify upriver-downriver distributions, but only marginally.

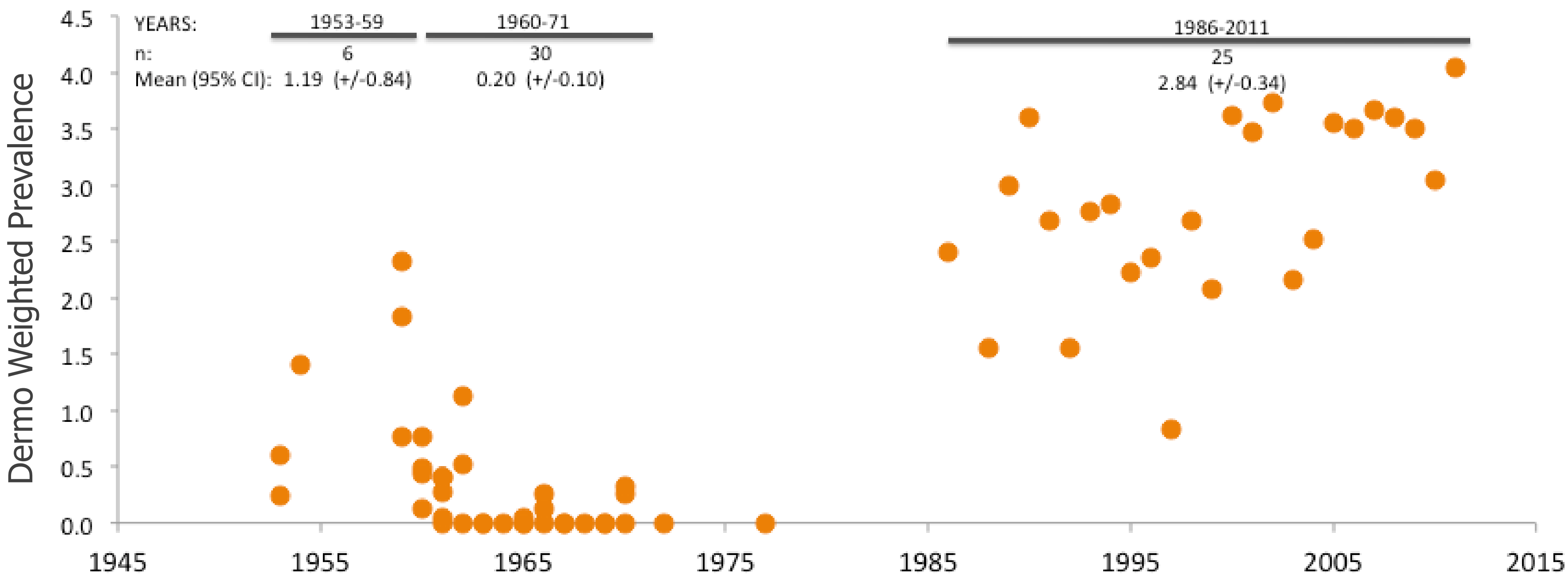
Impact of changing water chemistry on oysters?

- This is not about atmospheric CO_2 driven changes in pH, its about watershed inputs (pollutants, anthropogenic toxins), eutrophication driven changes in pH (and HAB's?) and, probably more so, carbonate saturation state.
- "Ocean acidification results in co-varying inorganic carbon system variables. Of these, ***an explicit focus on pH and organismal acid-base regulation in has failed to distinguish the mechanism of failure in highly sensitive bivalve larvae***. …..we show definitively that larval bivalve shell development and ***growth are dependent on seawater saturation state***, and not on carbon dioxide partial pressure or pH. Although other physiological processes are affected by pH, mineral saturation state thresholds will be crossed decades to centuries ahead of pH thresholds due to the non-linear changes in the carbonate system variables as carbon dioxide is added. Our findings ….are consistent with a previous model of ocean acidification ***impacts due to rapid calcification in bivalve larvae, and suggest a fundamental ocean acidification bottleneck at early life-history for some marine keystone species***." (Waldbusser et al, Nature Climate Change, 2014)
- We remain poorly informed in the context of the Chesapeake Bay, especially so with respect to oyster larvae…….

Impact of diseases on oysters?

- This is in two parts: climate on diseases and the disease-oyster interaction.
- Diseases are moderated by temperature and salinity. This is a fluid situation as the native Dermo (*Perkinsus marinus*) evolves in response to competition with the introduced MSX (*Haplosporidium nelsoni*), and the oyster responds to both these changing disease challenges.
- Summary of recent changes in disease.
- Summary of “immediate” impact on oysters.
- Long term predictions for impact on population dynamics of oysters… *preserving ecological and economic services are all about population dynamics and demographics.*
- What do we need to know – new research questions.

Increasing Dermo Disease



Dermo disease at historically high levels in recent years:
Emergence of a hypervirulent parasite phenotype
Environment increasingly favorable for disease (warm and salty)

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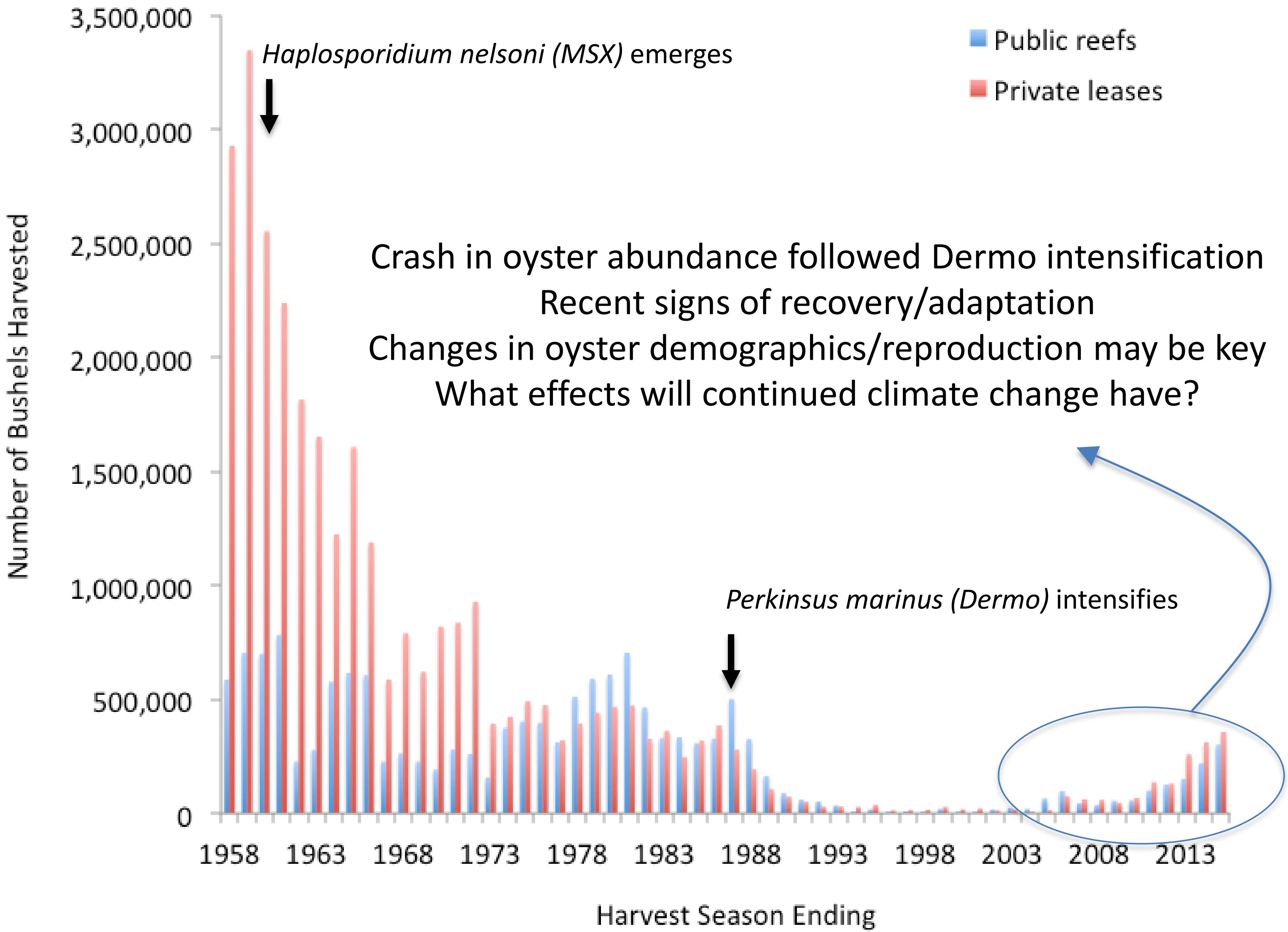

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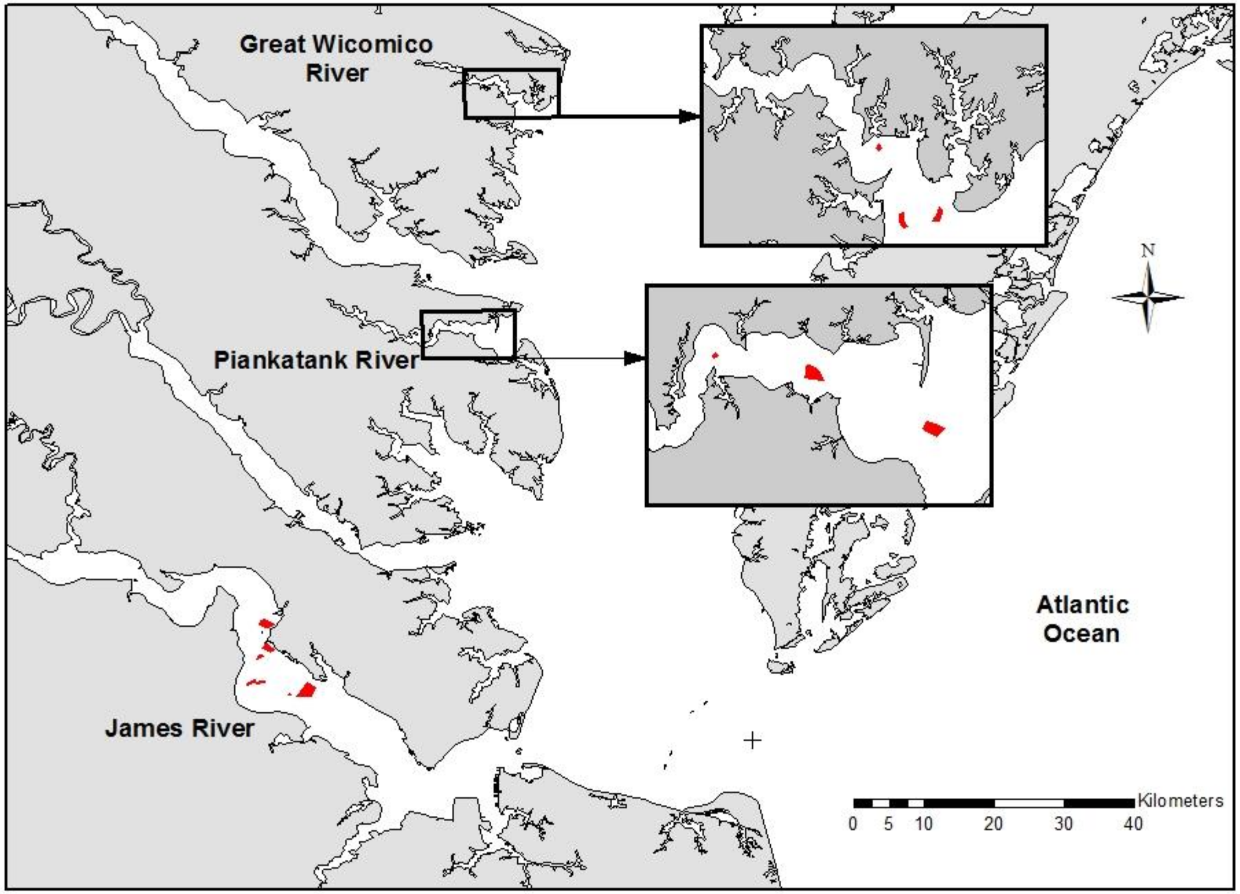
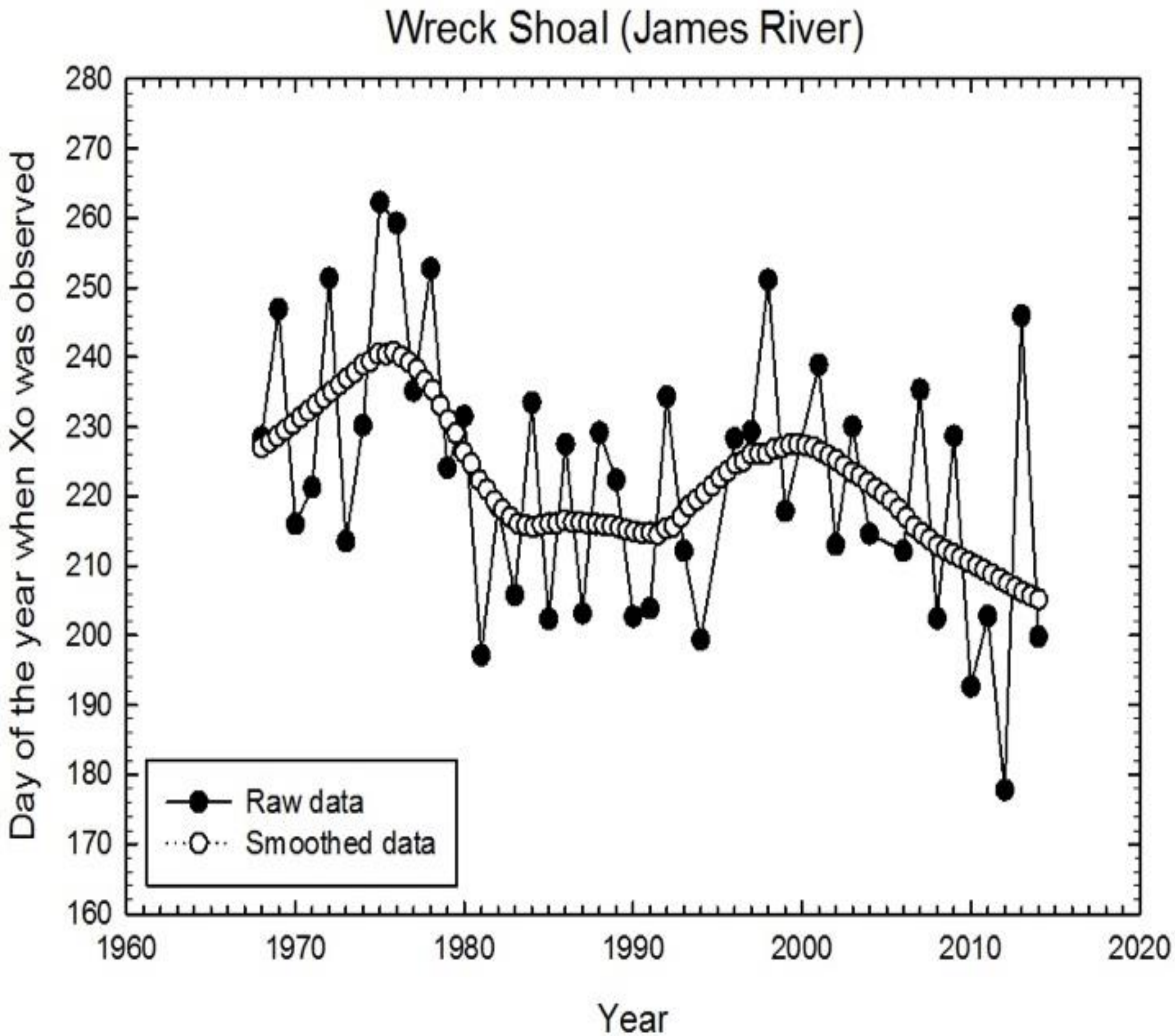
Are we observing changes in oyster reproduction and demographics?



- The recent period of oyster expansion is coincident with a progression to earlier recruitment: Xo is the day of 50th percentile recruitment.
- Over that same period the the median length of the YOY has increased.
- Both are arguably related to progressive climate change impacts.



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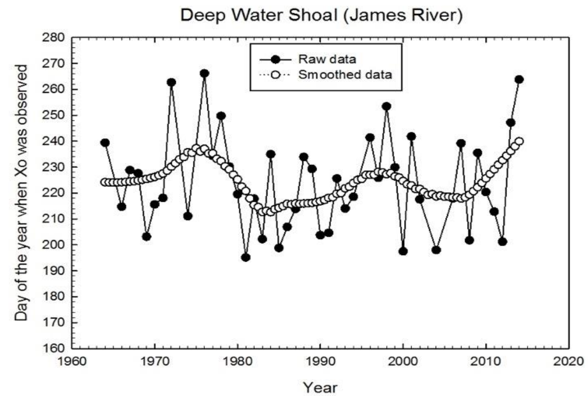
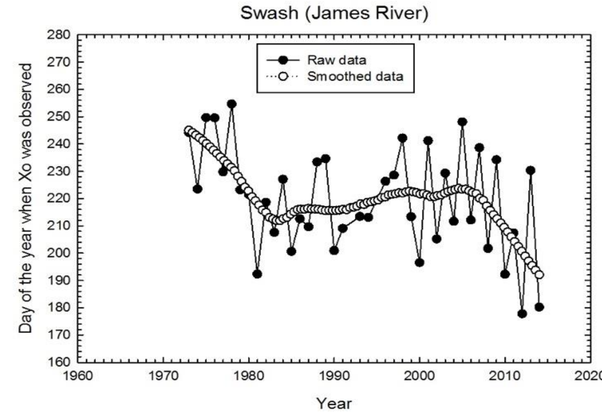
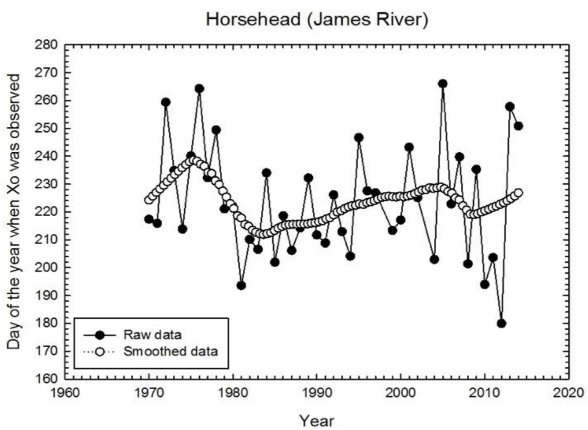
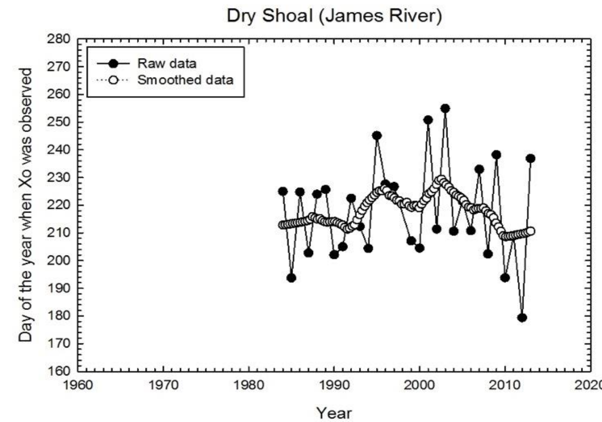
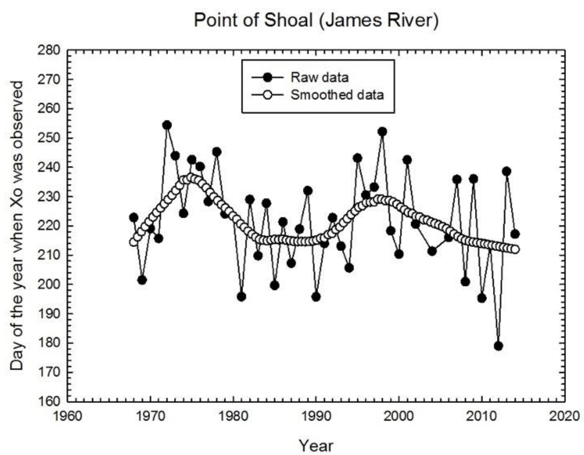
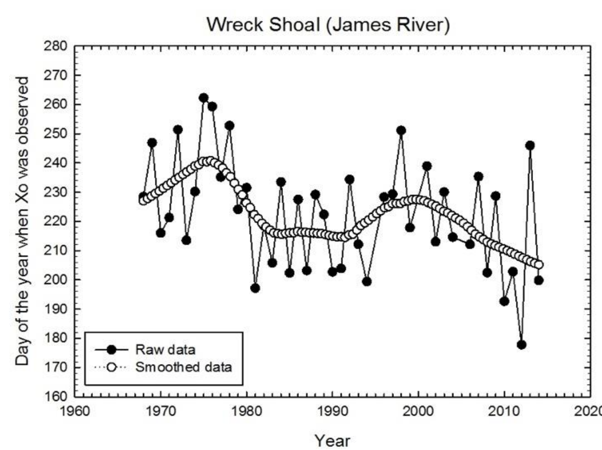

Deep Water Shoal (James River)
Raw data
Smoothed data
Day of the year when Xo was observed
Year

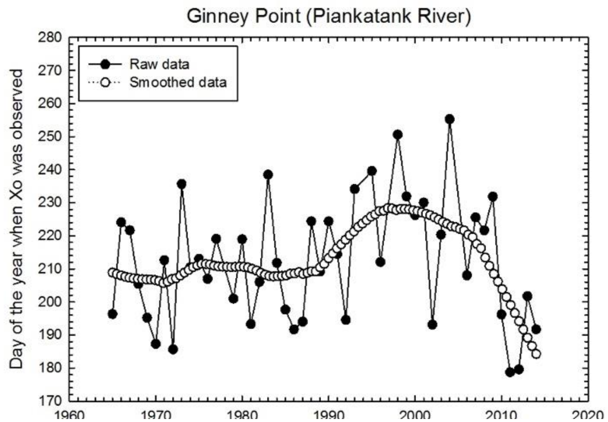

Swash (James River)
Raw data
Smoothed data
Day of the year when Xo was observed
Year

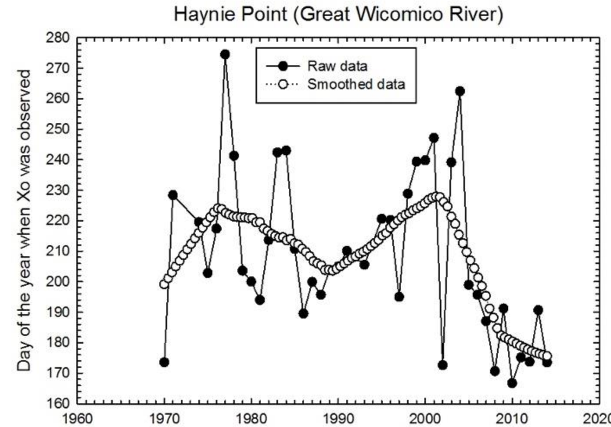

Horsehead (James River)
Raw data
Smoothed data
Day of the year when Xo was observed
Year

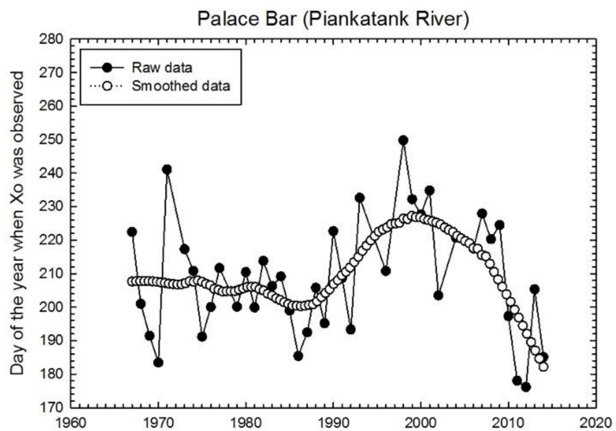

Dry Shoal (James River)
Raw data
Smoothed data
Day of the year when Xo was observed
Year

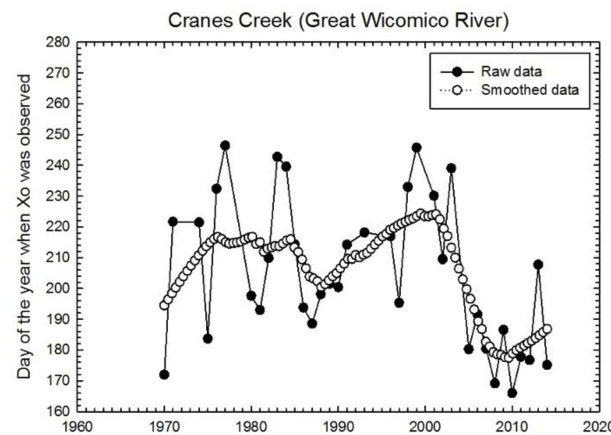

Point of Shoal (James River)
Raw data
Smoothed data
Day of the year when Xo was observed
Year

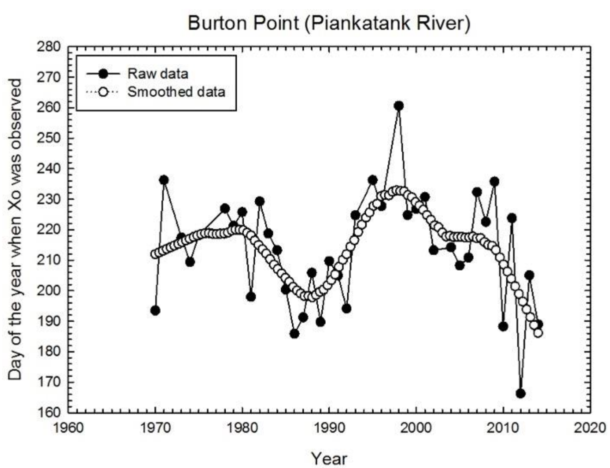

Wreck Shoal (James River)
Raw data
Smoothed data
Day of the year when Xo was observed
Year

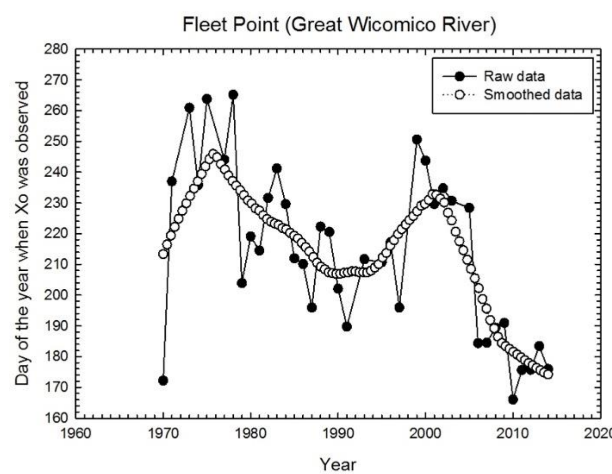

Ginney Point (Piankatank River)
Raw data
Smoothed data
Day of the year when Xo was observed

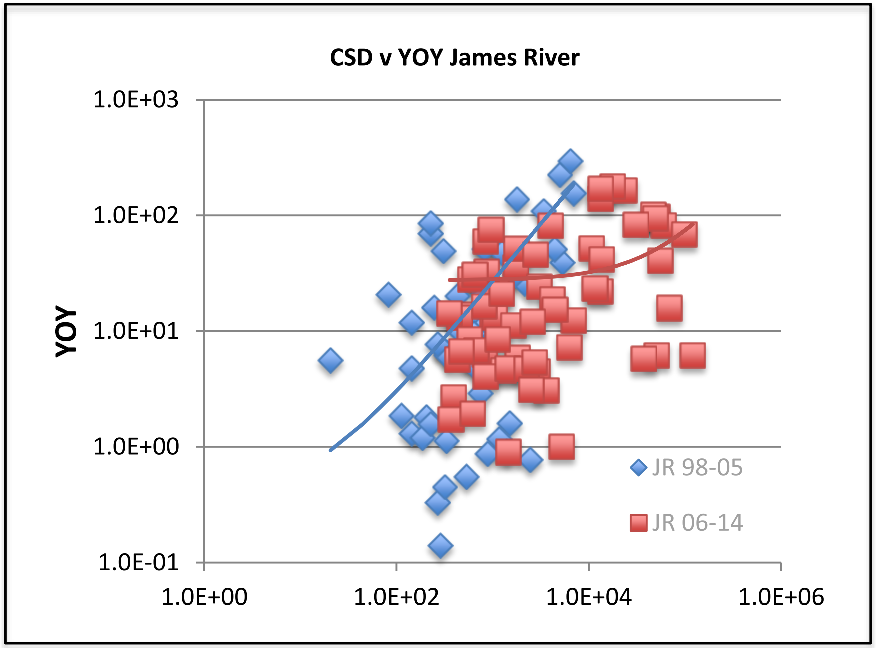

Haynie Point (Great Wicomico River)
Raw data
Smoothed data
Day of the year when Xo was observed

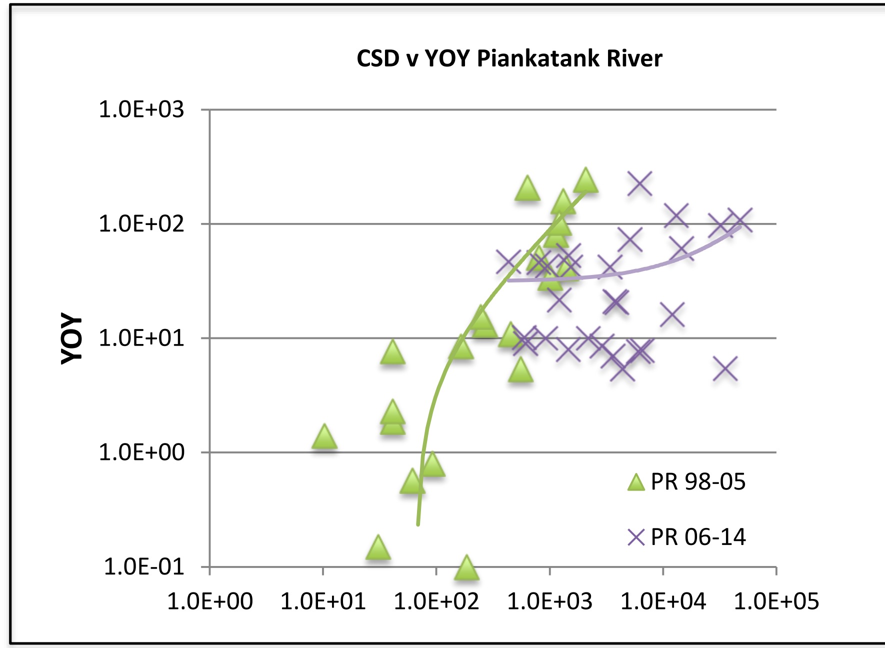

Palace Bar (Piankatank River)
Raw data
Smoothed data
Day of the year when Xo was observed

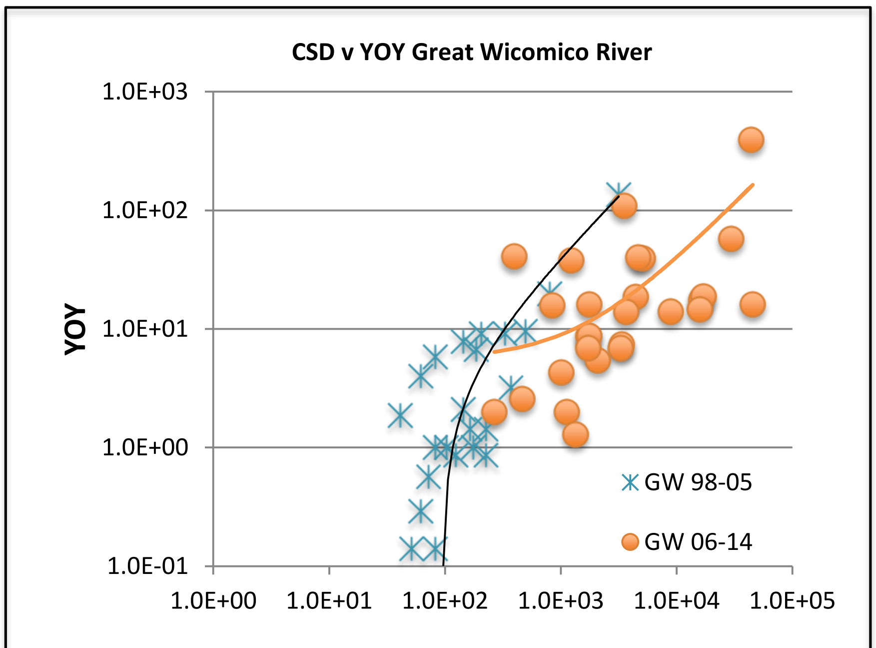

Cranes Creek (Great Wicomico River)
Raw data
Smoothed data
Day of the year when Xo was observed


Burton Point (Piankatank River)
Raw data
Smoothed data
Day of the year when Xo was observed
Year

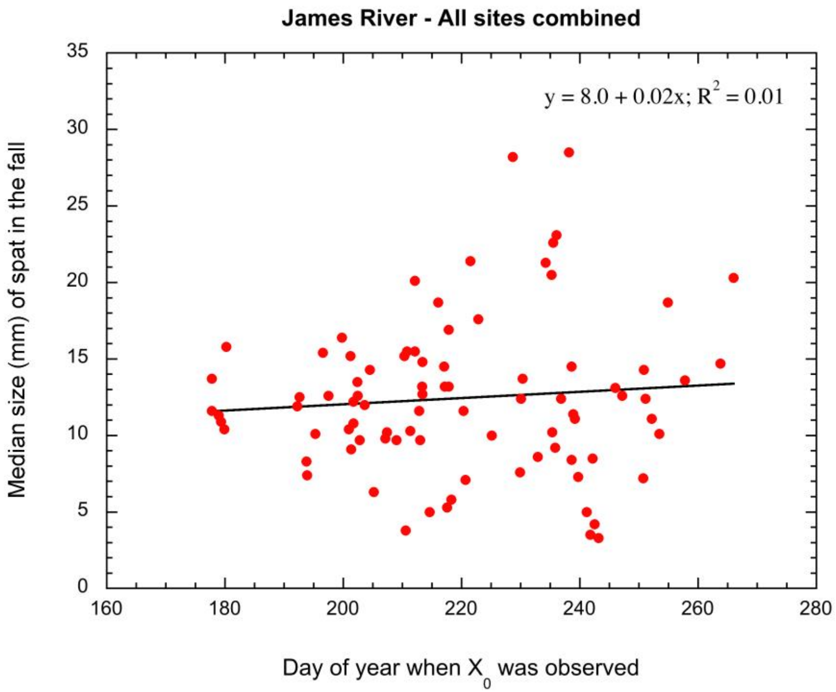

Fleet Point (Great Wicomico River)
Raw data
Smoothed data
Day of the year when Xo was observed
Year

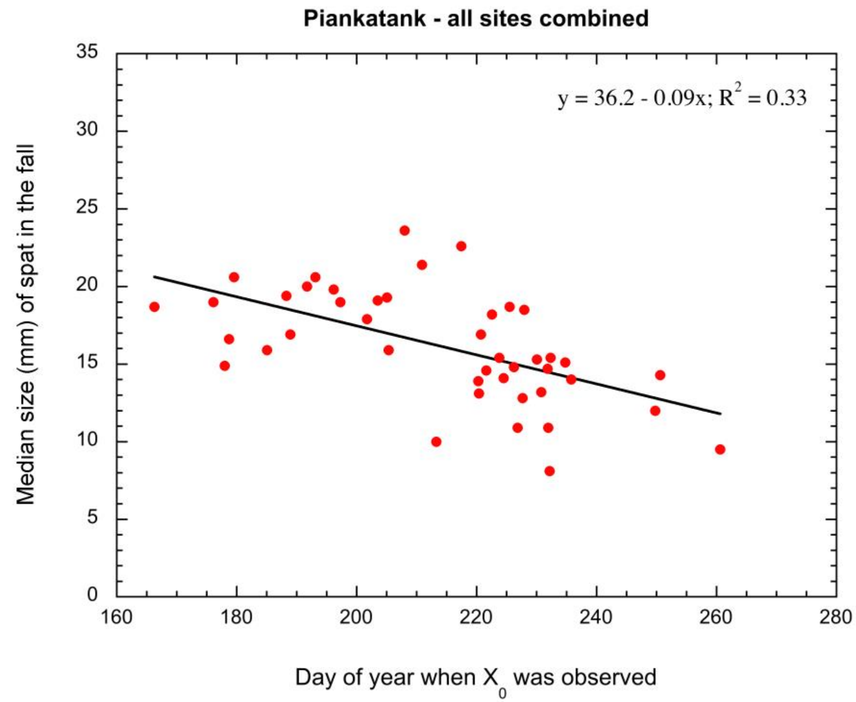


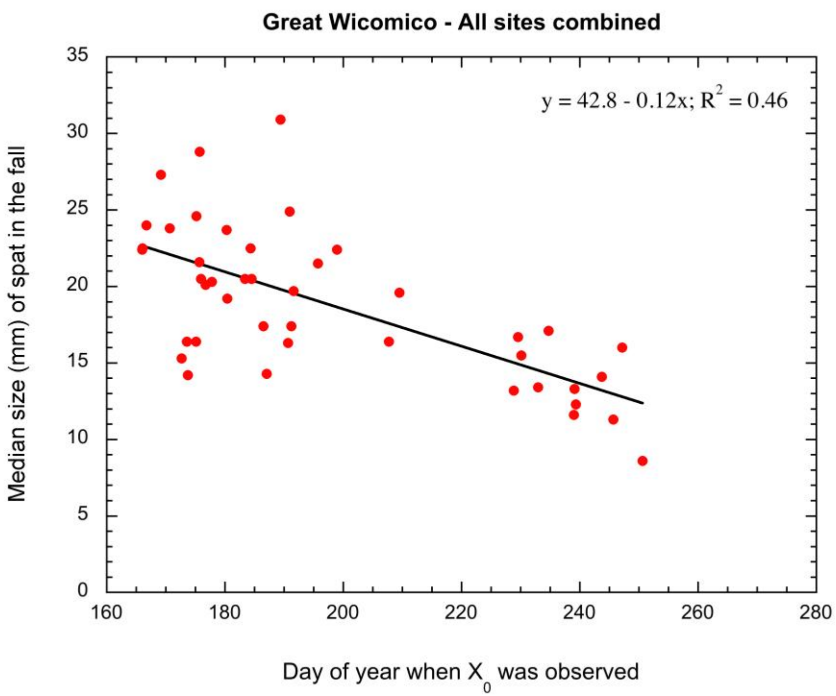




Plots of Cumulative Spat Density (recruitment as portrayed in prior graphic) versus YOY, by river, illustrate an order of magnitude increase in early post recruit mortality in 2004-2005 – in three independent systems! This is environmentally coordinated …. A climate driven signal?



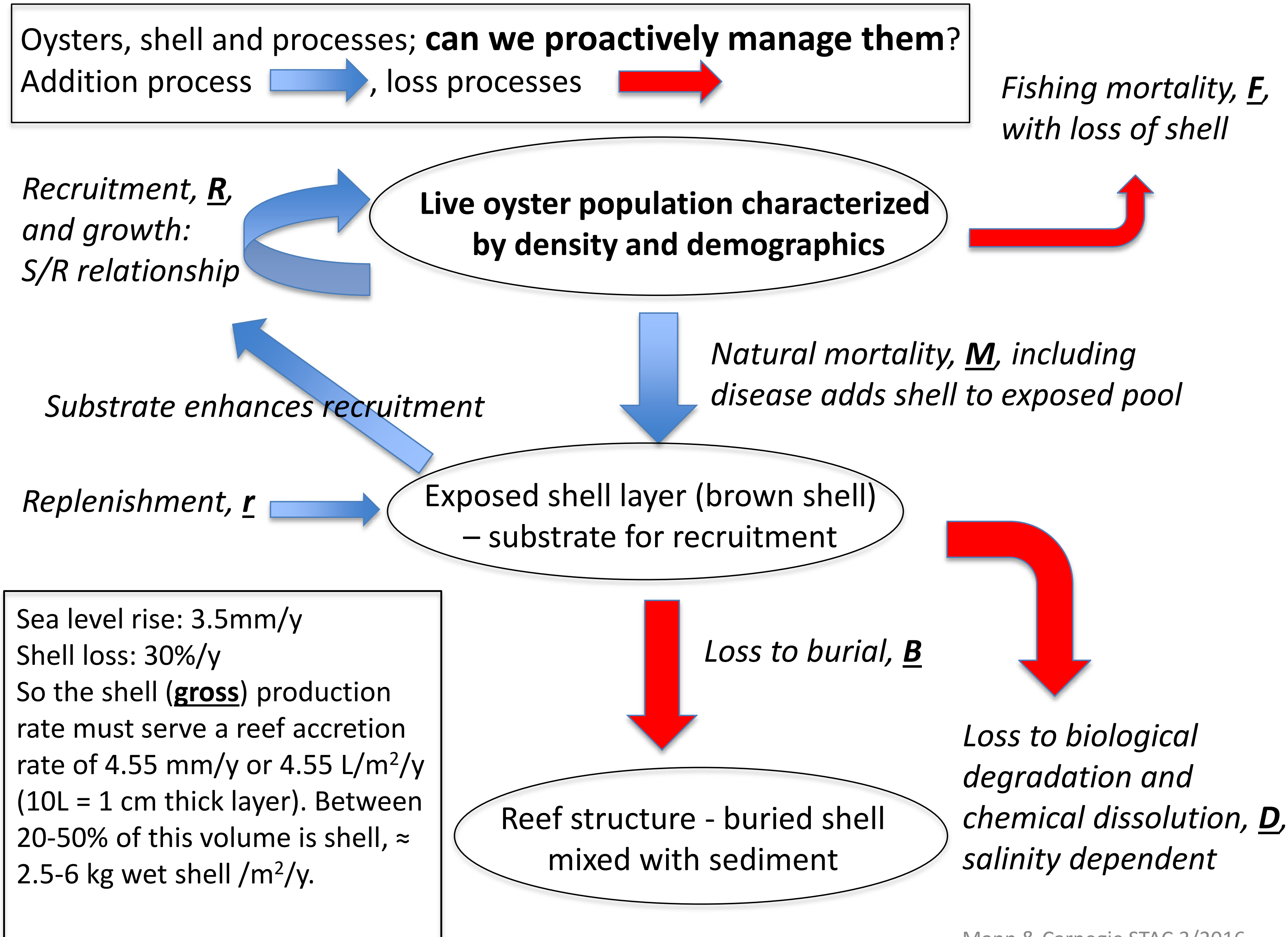




1998-2015 data: in the James River there is no relationship between Xo and the median length of YOY in the fall – the system is moderated by size and watershed influences…. By contrast there is a stronger trend in the small watershed systems of the Great Wicomico and the Piankatank Rivers.

New Questions On Disease, Reproduction and Demographics

- Will continued Dermo intensification outpace oysters' ability to adapt/respond?
- Or will increased disease equate to increased pressure to evolve genuine disease resistance (rather than tolerance)?
- And what about MSX: increasingly warm and eutrophic Chesapeake Bay is increasingly favorable for MSX?
- Will the recent trend toward disease resistance continue, or will MSX reemerge as a major threat?
- Will the truncation/retraction of the formerly extended recruitment period continue?
- What are the implications of increased post recruit mortality?
- What are the implications of increasing YOY median size?
- What drives these trends in terms of environmental and biological interactions and what are the end points?
- What are the implications of all of the above on adult growth, longevity and eventual contribution to the underlying shell pool?
- Can we proactively manage it (even in part)?



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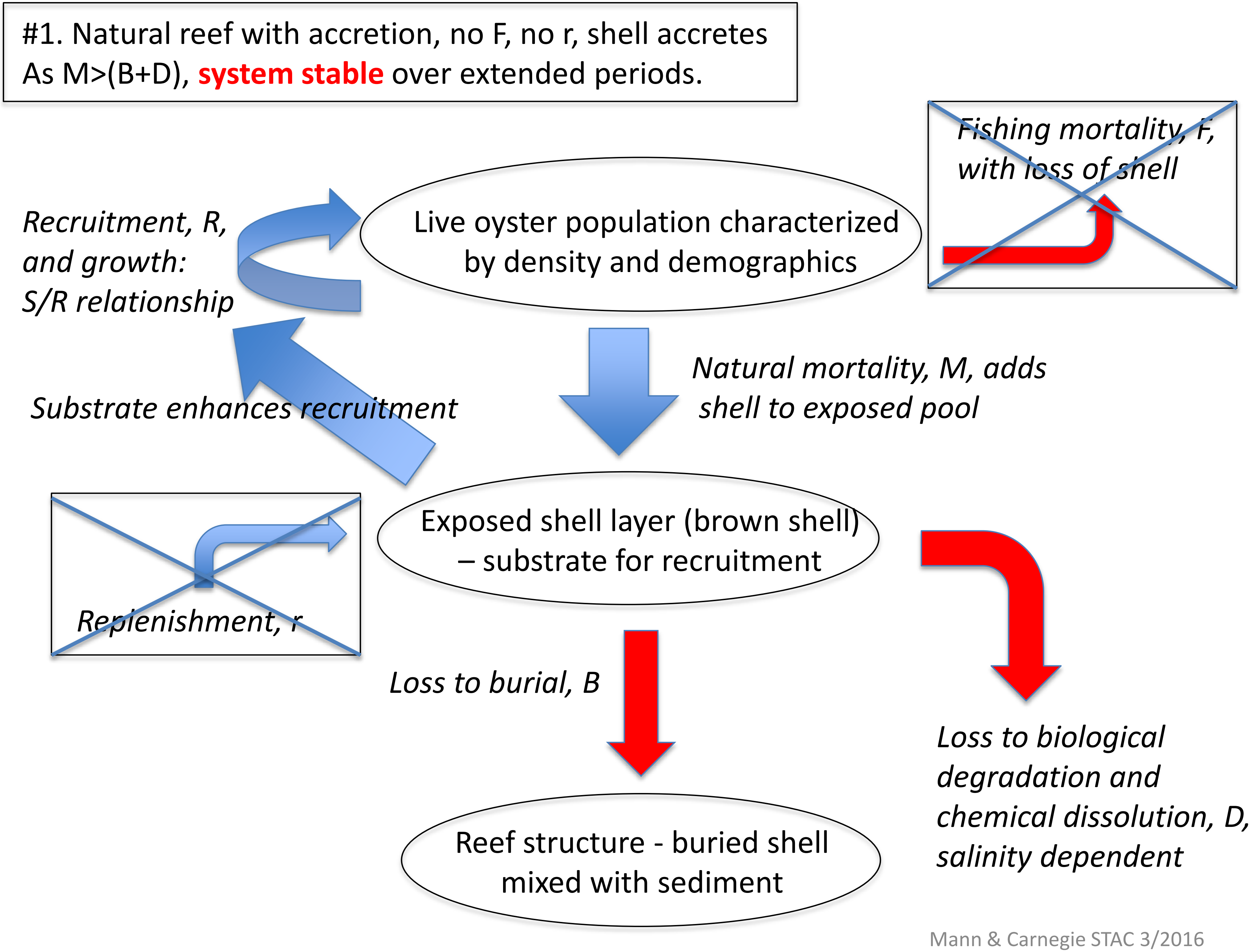
#1. Natural reef with accretion, no F, no r, shell accretes
As M>(B+D), system stable over extended periods.
Fishing mortality, F, with loss of shell
Recruitment, R, and growth: S/R relationship
Live oyster population characterized by density and demographics
Natural mortality, M, adds shell to exposed pool
Substrate enhances recruitment
Exposed shell layer (brown shell) – substrate for recruitment
Replenishment, r
Loss to burial, B
Loss to biological degradation and chemical dissolution, D, salinity dependent
Reef structure - buried shell mixed with sediment
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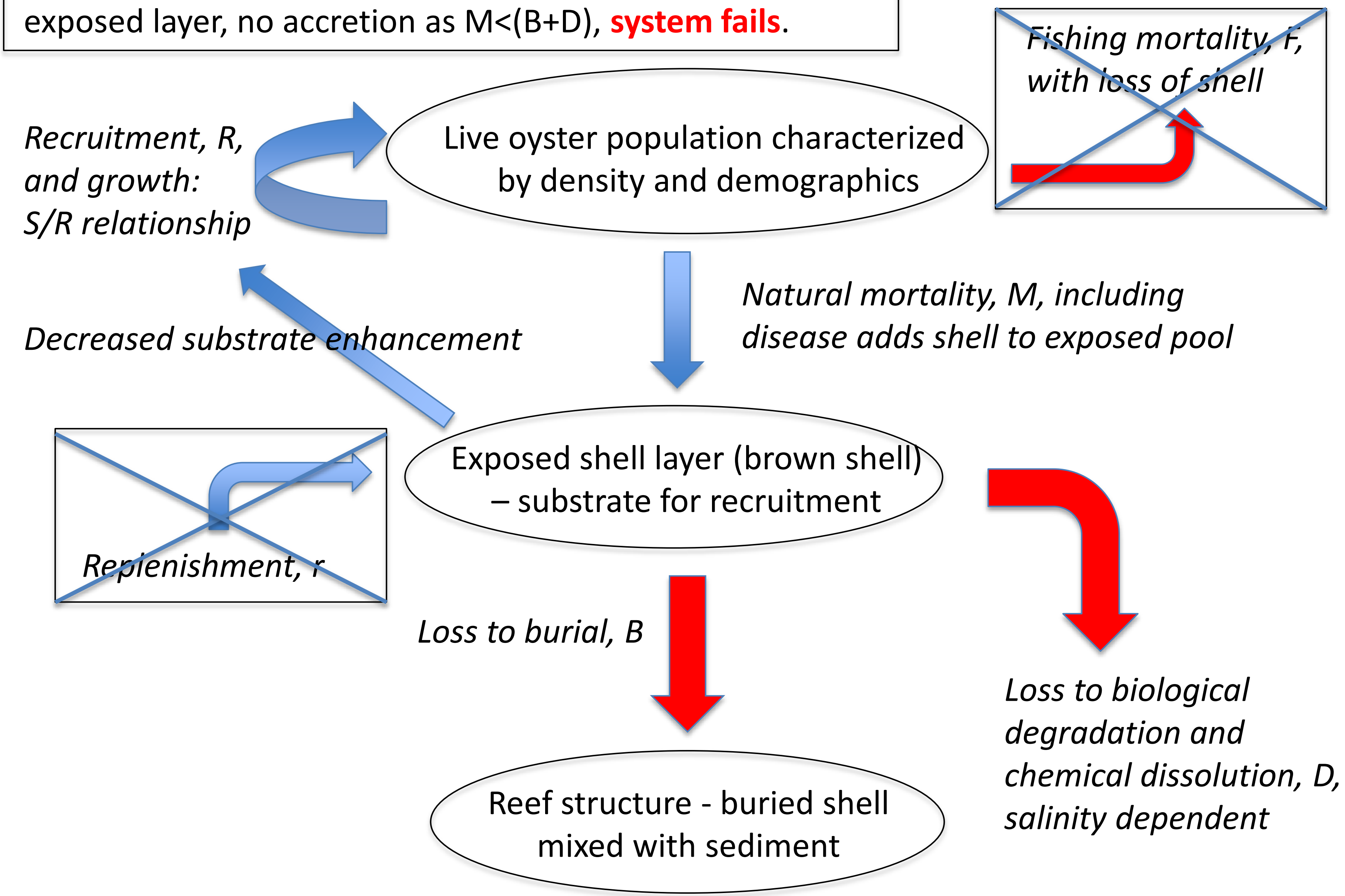
#2. Natural reef, no F, no r, but increased M due to disease. Decreased oyster longevity, lower shell addition rate to exposed layer, no accretion as M<(B+D), **system fails**.



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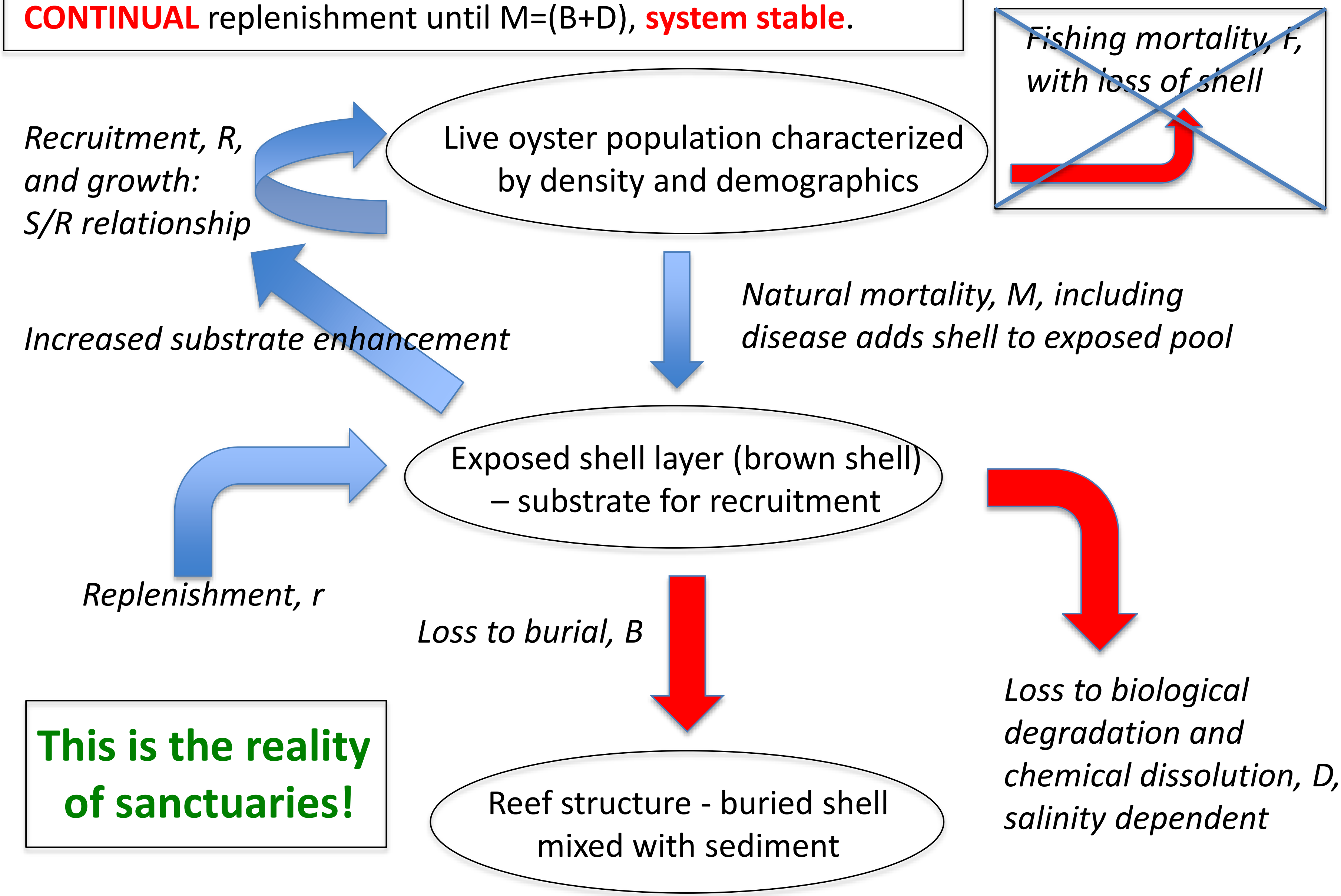
#3. Natural reef, no F, increased M (disease). Decreased oyster longevity, lower shell addition rate to exposed layer, offset by **CONTINUAL** replenishment until M=(B+D), **system stable**.



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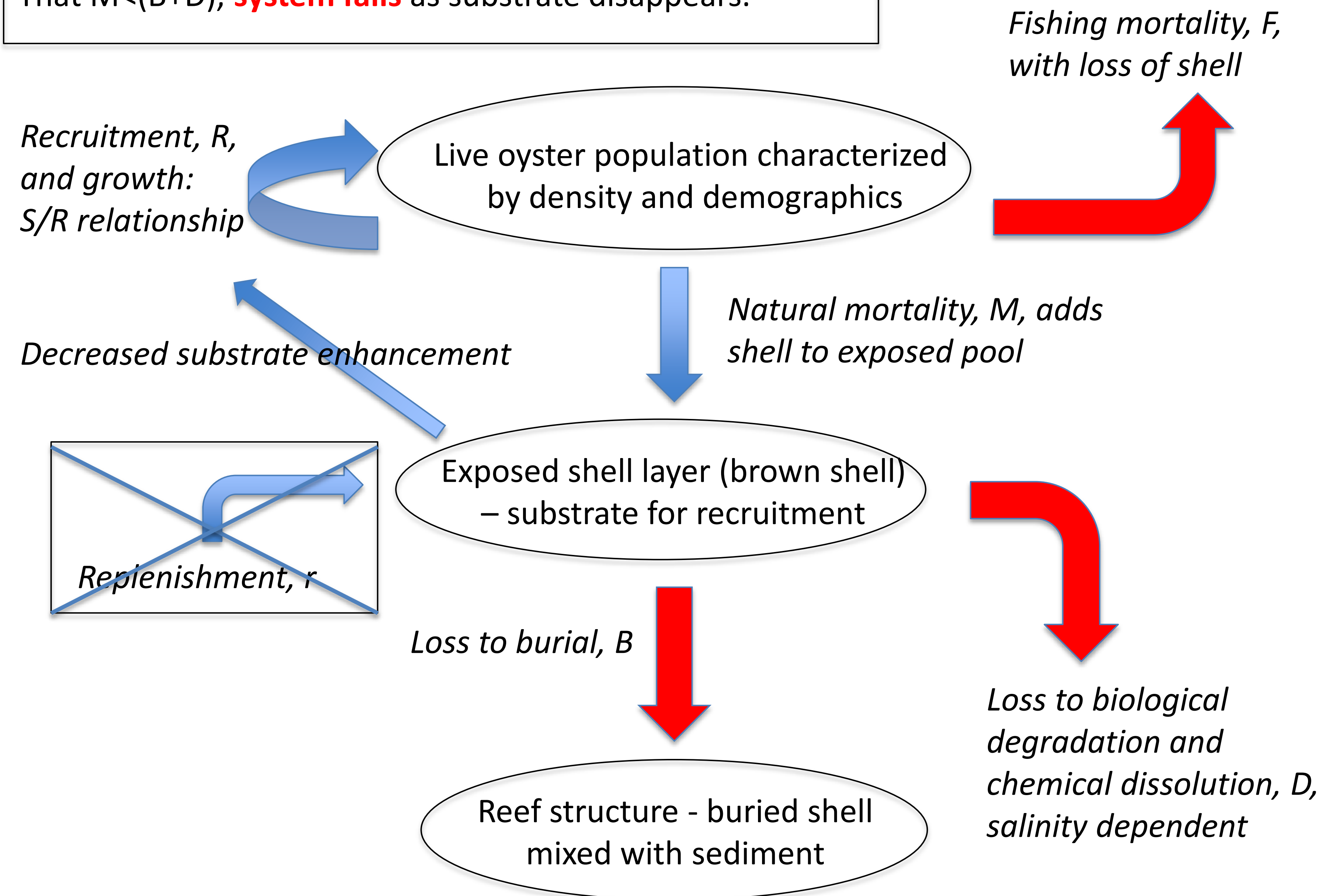
#4. Overfishing, no disease, no r, but F removes shell such That M<(B+D), **system fails** as substrate disappears.



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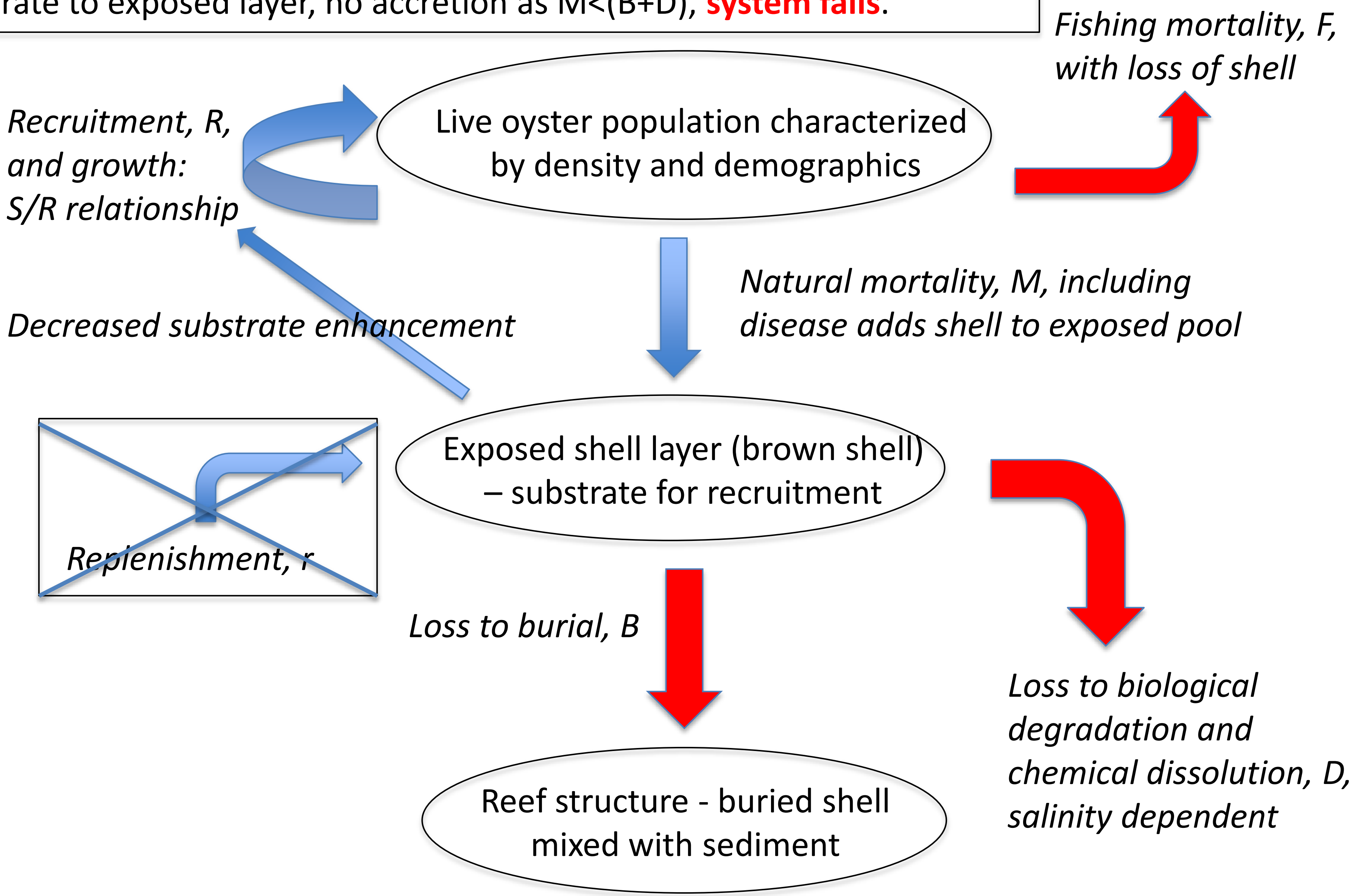
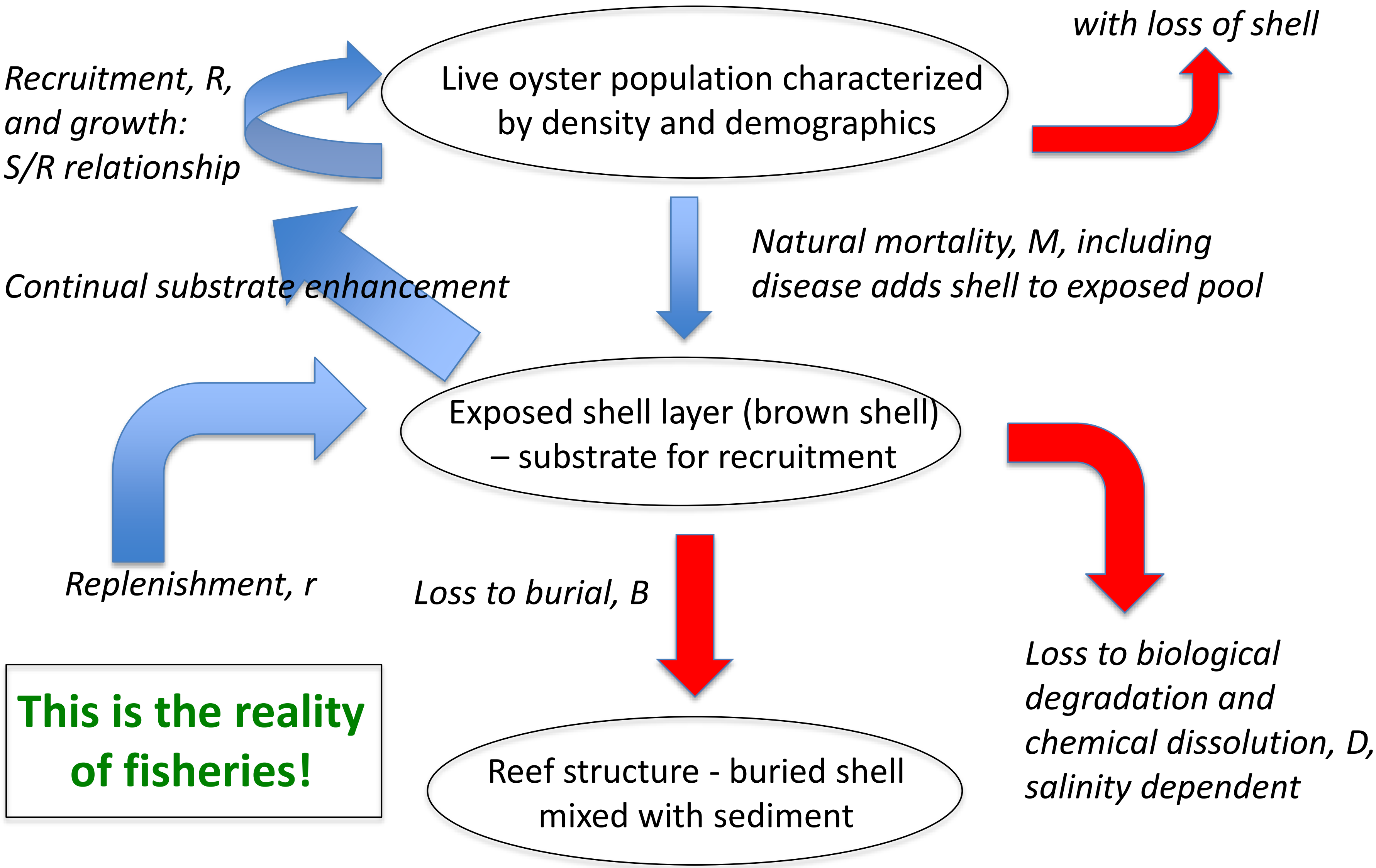
#5. Natural reef, no r, but with fishing, F, and increased M (disease). Decreased oyster longevity in those not fished, lower shell addition rate to exposed layer, no accretion as M<(B+D), **system fails**.



#6. Natural reef, limited fishing, F, and increased M (disease). Decreased oyster longevity, lower shell addition rate to exposed layer balanced by **CONTINUAL** replenishment until M=(B+D), **system stable**.



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Shell budget scenarios: long term observations in VA.

Scenario #	1	2	3	4	5	6
Disease	-	+	+	-	+	+
Overfishing	-	-	-	+	-	-
Fishing	-	-	-	-	+	+
Repletion	-	-	+	-	-	+
Stable?*	Y	N	Y	N	N	Y

* Stability Y or N dependent on an improved understanding of population dynamics in a climate driven moving baseline scenario, which, as we can see, is a moving target!

Scenario #6 applies <u>everywhere in VA except a limited number of reefs in James River</u> which exhibit very high recruitment to offset impact of reduced longevity on shell supply. All other systems require varying levels of shell replenishment to maintain substrate cover.
(http://www.vims.edu/research/units/labgroups/molluscan_ecology/vorhf/shell/status_shell_substrate/index.php.)

Concluding thoughts and future needs

- While the effects of warming in isolation are of modest concern, the effects of warming and/or as yet undefined changes in salinity and/or changing environment (anthropogenic toxins, chemistry, HAB, microbiota and more) on the dynamic oyster-parasite system of Chesapeake Bay are uncertain.
- ***The baselines*** of an equilibrium situation with respect to recruitment, growth and mortality of live oysters, and the fate of shell as a substrate, chemical moderator, structural component of epifaunal habitat, and foundation of reefs in general ***are all moving, not necessarily in a linear manner***.
- We do not know which of the complex climate drivers versus non climate drivers dominate the observed movement, and we are unable, at this time, to predict where this movement will end.