Oysters – A Bit of History

- We developed the oyster model circa 2000 – 2005, on the 12,000-cell grid, to assess the impact of a ten-fold increase in oyster population.
- We moved the oyster model to the 50,000-cell grid in 2008.
- We ceased all activity shortly thereafter.
- We are renewing our interest in oysters with an emphasis on management implications of aquaculture.

New Factors to Consider

- Estimates of the current natural population vs. estimates completed circa 2000.
- Designation of oyster sanctuaries.
- Development of aquaculture.
- Credits for nutrient removal:
  - Biomass removal
  - Denitrification

Three Oyster Populations

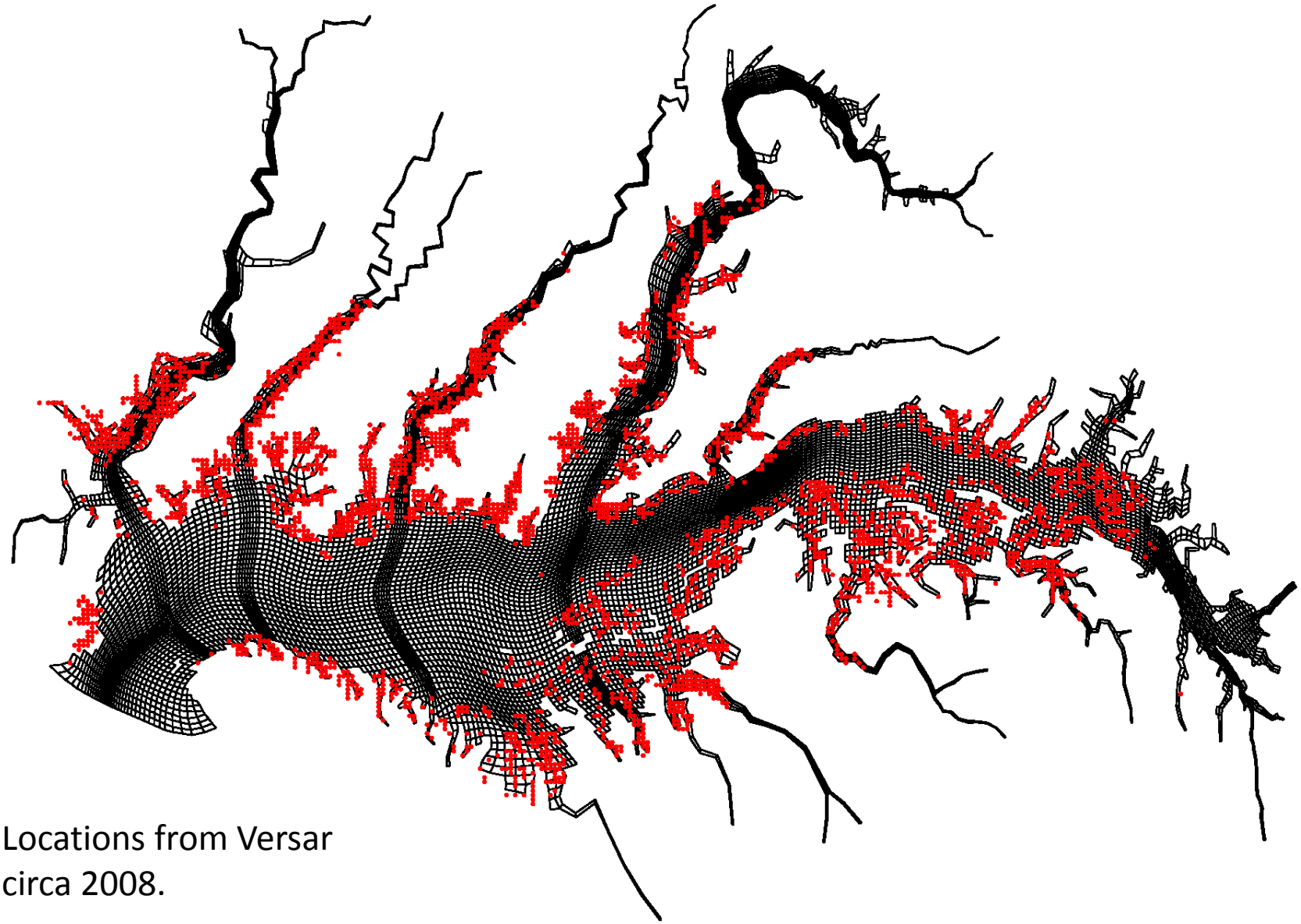
We're modeling three groups or populations of oysters:

1. Reefs subject to predation, disease, and harvest.
2. Sanctuaries subject to predation and disease but no harvest.
3. Aquaculture. Limited predation, 100% of the biomass is harvested each year.

What Do We Have to Do?

- Locate oysters on the present grid.
  - Oyster Bars
  - Sanctuaries
  - Aquaculture
- Obtain biomass estimates.
- Tune our model to represent current biomass in each group.
- Execute scenarios.

Oyster bars mapped to 50,000-cell grid.



Locations from Versar circa 2008.

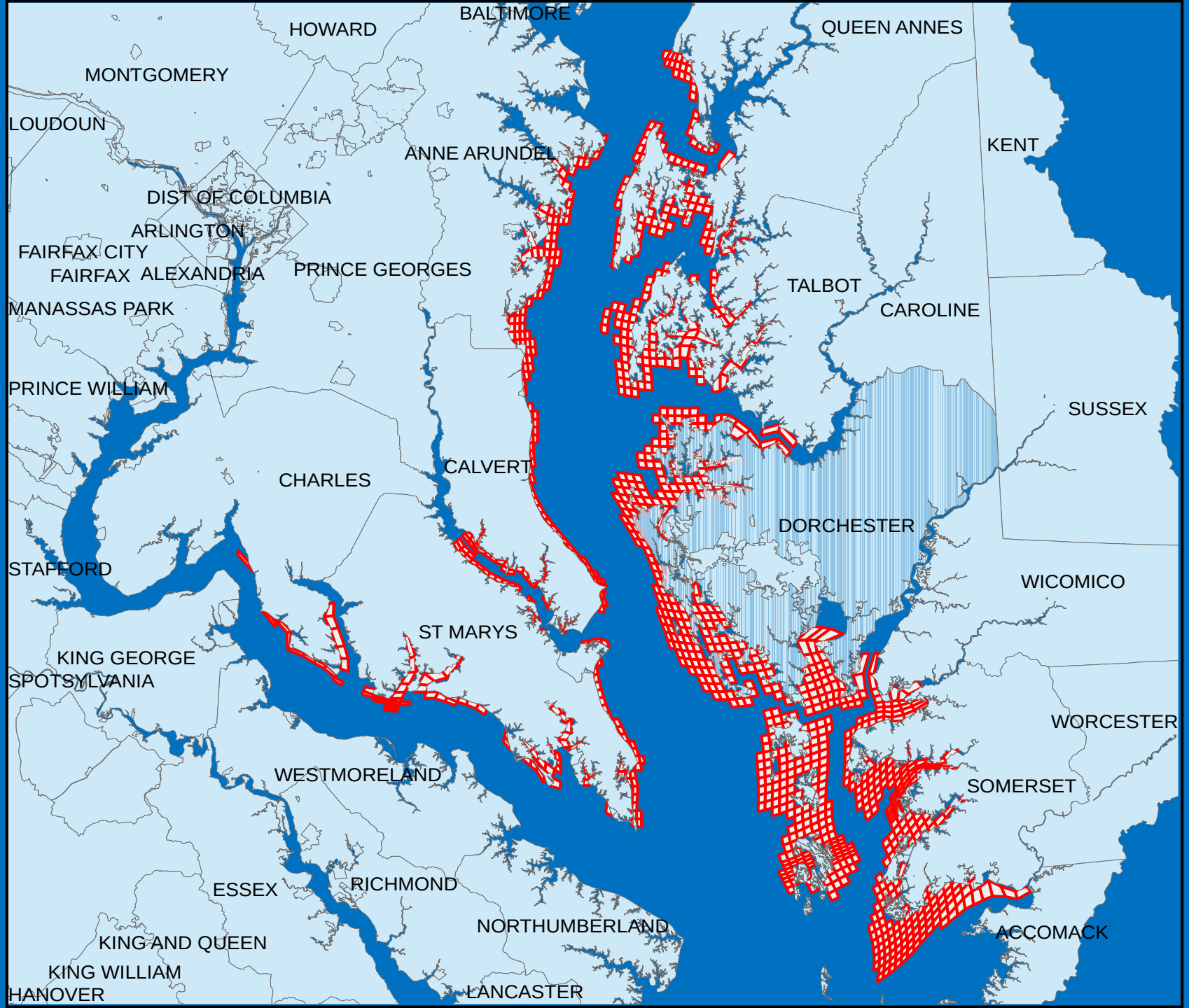
Maryland oyster leases by county, October 2015

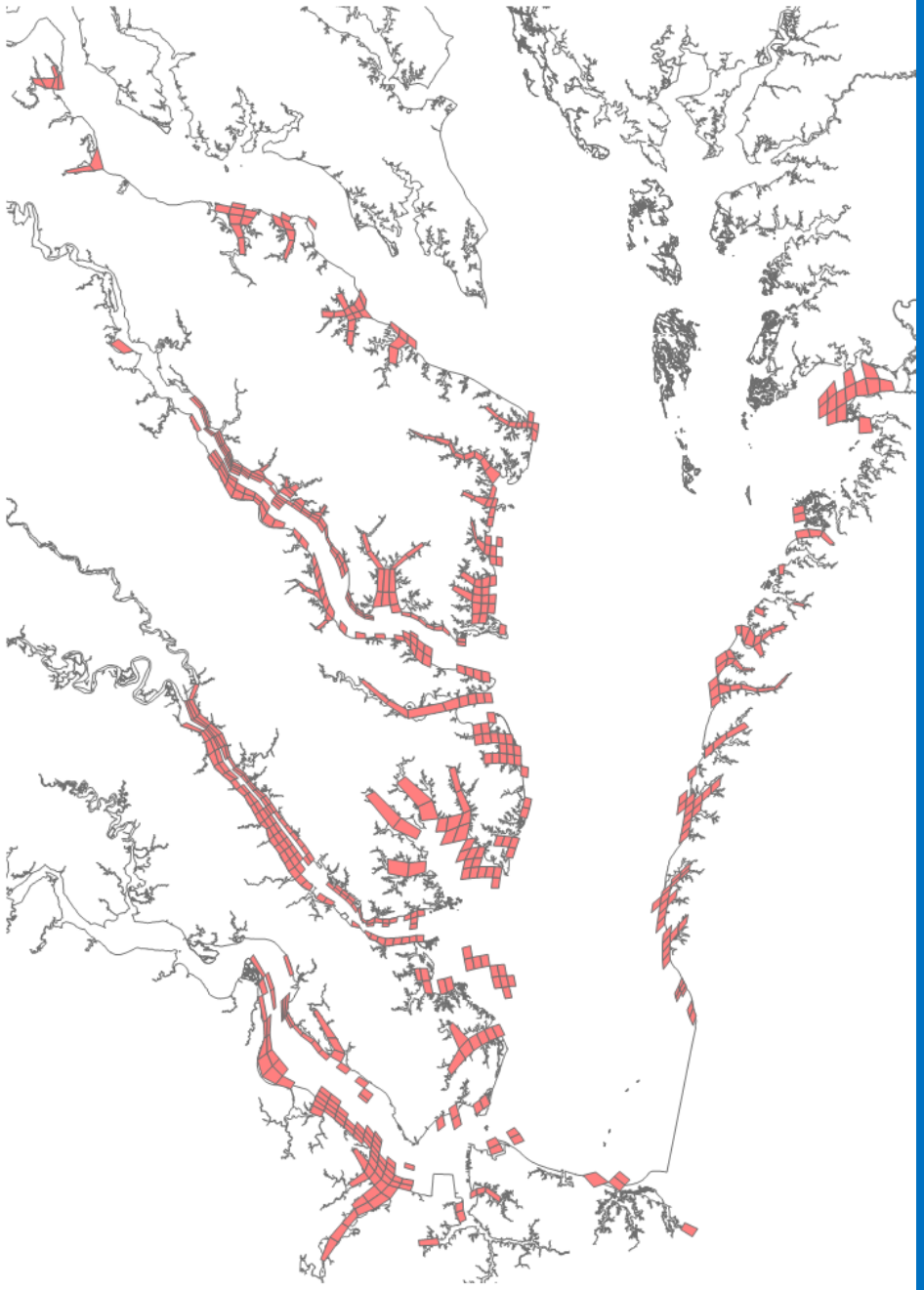
Lease type	Anne Arundel	Calvert	Charles	Dorchester	Kent	Queen Anne	St. Mary's	Somerset	Talbot	Wicomico	Worcester	Total
Submerged land (SL)	24	11	1	57	1	5	64	24	52	40	10	289
Water column (WC)	2	2	0	19	1	2	22	6	1	0	8	63
Total	26	13	1	76	2	7	86	30	53	40	18	352

Oyster farmers are trying a variety of high-tech and low-tech *approaches to growing this bivalve in Maryland waters, but the state Department of Natural Resources classifies them in only two categories: Submerged Land Leases (SL) and Water Column Leases (WC). The first category primarily covers on-bottom techniques that feature loose shell to catch natural spat set or plantings of spat-on-shell. The second category covers cages, bags, floats, and any other device that holds oysters off the bottom. As the map shows, the busiest centers for both styles of aquaculture are Dorchester County on the Eastern Shore and St. Mary's County on the western side of the Bay.* TABLE SOURCE: KARL ROSCHER; MAP, CREATED BY SANDY RODGERS ON A BASE MAP FROM VECTORSTOCK.COM

Aquaculture

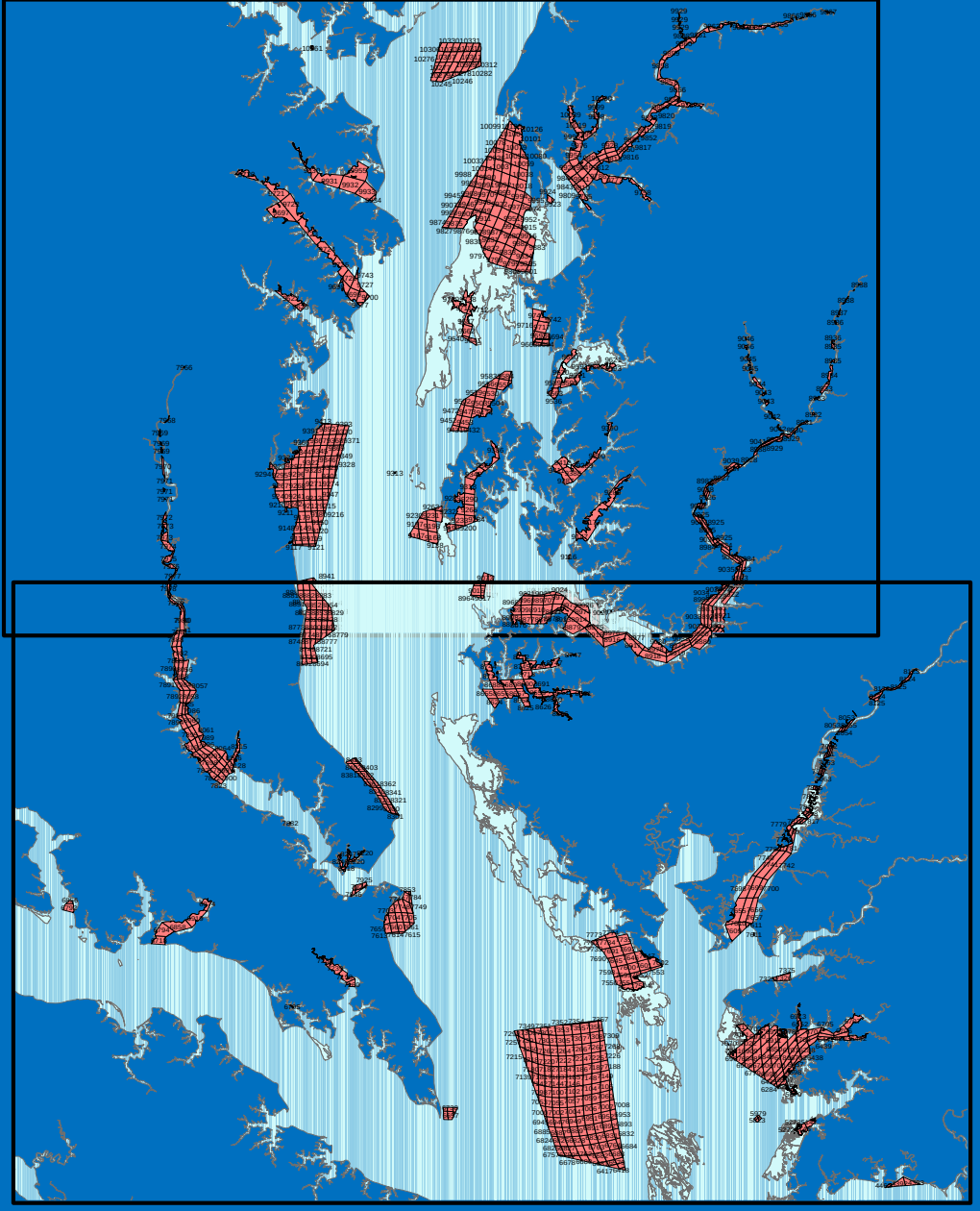
- We have Maryland harvest by county.
- We do not have location of aquaculture facilities.
- As a start, we are allowing aquaculture activity in Maryland waters with salinity > 7 and depth < 12 feet.


HOWARD
BALTIMORE
QUEEN ANNES
MONTGOMERY
LOUDOUN
ANNE ARUNDEL
KENT
DIST OF COLUMBIA
ARLINGTON
FAIRFAX CITY
FAIRFAX
ALEXANDRIA
PRINCE GEORGES
TALBOT
CAROLINE
MANASSAS PARK
PRINCE WILLIAM
SUSSEX
CALVERT
CHARLES
DORCHESTER
STAFFORD
WICOMICO
ST MARYS
KING GEORGE
SPOTSYLVANIA
WORCESTER
WESTMORELAND
SOMERSET
ESSEX
RICHMOND
NORTHUMBERLAND
ACCOMACK
KING AND QUEEN
KING WILLIAM
HANOVER
LANCASTER



Aquaculture

- We have a GIS file of Virginia lease areas.
- We do not have specific location of aquaculture facilities.
- As a start, we are allowing aquaculture activity in lease areas with salinity > 7 and depth < 12 feet.



Sanctuaries

- We have Maryland oyster sanctuaries mapped to the grid.
- We have overlap with the oyster bar data from 2008.
- If a sanctuary and a bar coincide, we assume that bar is now a sanctuary.
- We lack information on location of Virginia sanctuaries.

CBOPE

Chesapeake Bay Oyster Population Estimate

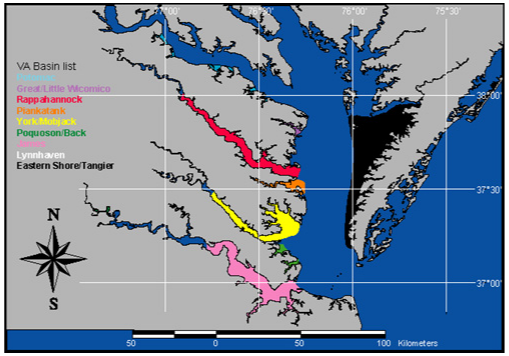
- A web site maintained by VIMS originally intended to measure progress towards the planned ten-fold population increase.
- Extends from 1994 to 2002 (MD), 2008 (VA).
- Contains “fishery-independent data” (standing stock) for two states. Little locational information.
- Contains “fishery dependent” data, separated into “public” and “private” effort, by state.

.vims.edu/mollusc/cbope/vabasin.htm

Chesapeake Bay Oyster Population Estimation (CBOPE)

Virginia Basin Estimates

Chesapeake Bay tributaries in Virginia waters were assigned to the following basin categories: Potomac tributaries (includes Nomini Creek, Coan River, Yeocomico River), Great/Little Wicomico, Rappahannock (includes Corrotoman River), Piankatank, York/Mobjack Bay (includes East, North, Ware, Severn, and Perrin River), Poquoson/Back, James (includes Elizabeth, Lafayette, and Nansemond Rivers), Lynnhaven, and Eastern Shore/Tangier (includes Tangier and Pocomoke Sounds as well as all Bay side tributaries of Virginia's Eastern Shore). These basins are shown on the map below.



Basin estimates are available for Virginia oyster populations from 1994 through 2008. These basin estimates rely on a variety of different data types that are collected by diff institutions. All data used in Virginia oyster population estimates fall into one of 4 categories: fishery independent, fishery dependent, restoration, or oyster aquaculture. Each is described briefly below.

A. Fishery Independent data - These data are collected during annual patent tong surveys conducted by the Virginia Institute of Marine Science and the Virginia Marine Res These surveys use a hydraulic patent tong deployed from the research vessel *J.B. Baylor* which samples 1 square meter of bottom at each sample. 2005 data also reflect th of the Lynnhaven River system completed by Dr. Mark Luckenbach and colleagues at the VIMS Eastern Shore Laboratory for the NORM program.

B. Fishery Dependent data

B1. Public/Commercial fishery - These data are based on the oyster landings as reported to the Virginia Marine Resources Commission by commercial fishermen. The data exercise by the Virginia Marine Resources Commission Fishery Statistics Department.
B2. Private fishery - These data are based on the oyster landings as reported to the Virginia Marine Resources Commission by private leaseholders. The data are provided the Virginia Marine Resources Commission Fishery Statistics Department.

C. Restoration Efforts

C1. Reefs - unexploited sanctuaries - since the early 1990s, the Virginia Marine Resources Commission Shellfish Replenishment program in collaboration with the Virginia In Science, the Virginia Department of Environmental Quality, and other state and federal agencies has been actively building three dimensional reefs in an effort to restore so habitat that was historically dominant in the lower Chesapeake Bay. These reefs are sanctuaries for oysters in that the oysters are neither fished nor disturbed and these ree of oyster larvae for the surrounding waters. The Virginia Marine Resources Commission Shellfish Replenishment program conducts annual surveys of the oyster populations These data are provided courtesy of the Virginia Marine Resources Commission Shellfish Replenishment Program.

C2. Replenishment areas - exploited shellplants and reefs - each year the Virginia Marine Resources Commission Shellfish Replenishment program plants shell and oyster in Virginia's tributaries to enhance fishery production and restoration activities. The data on the number of oysters planted by location were obtained from the annual Virginia Commission Shellfish Replenishment program Repletion reports.

Chesapeake Bay Oyster Population Estimation - Basins

State: VIRGINIA Year: 1994

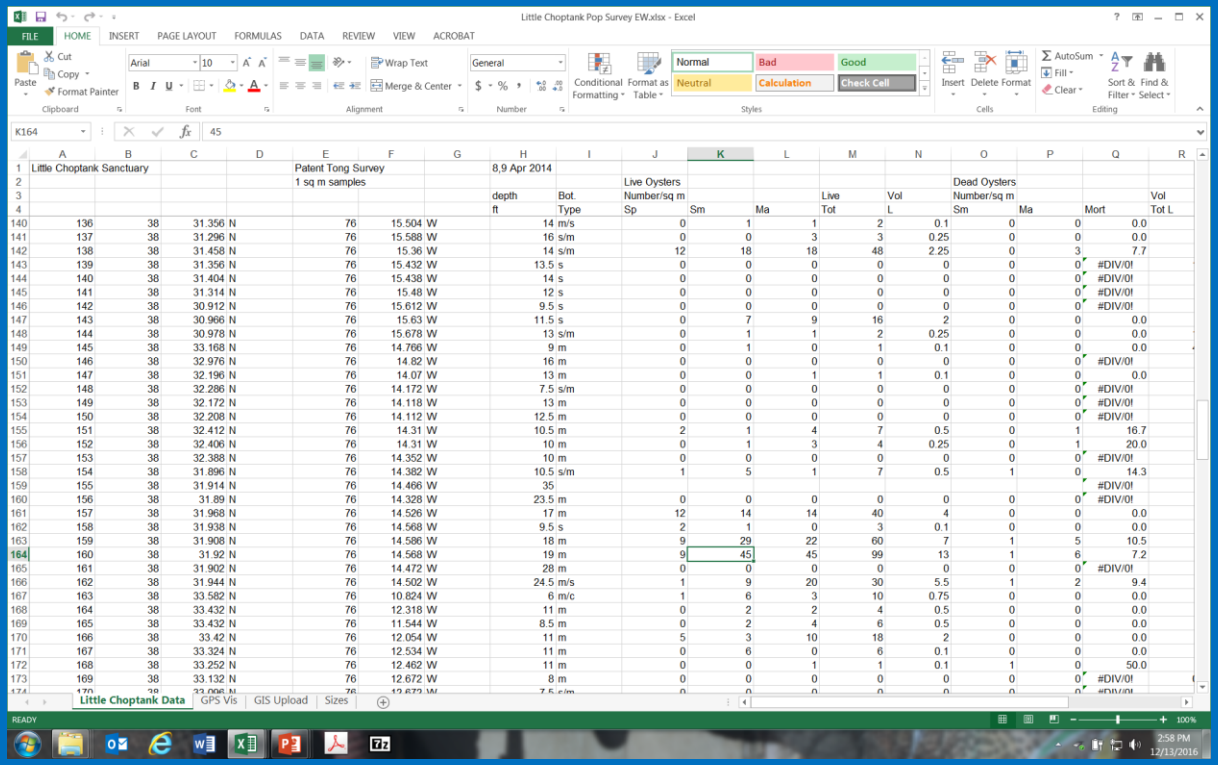
	Potomac	Great/Little Wicomico	Rappahannock	Piankatank	York/Mobjack Bay	Poquoson/Back	James	Lynnhaven	Eastern Shore/Tangier	Total number of oysters	Total oyster biomass
A. Fishery Independent survey											
Average number of oysters/m2			2.1				56.8				
Average oyster biomass/m2			1.7				20.2				
Number of reefs surveyed			7				23				
Acres surveyed			214				5955.6				
Number of samples			193				800			1.37E +09	4.89E+08
B. Fishery Dependent survey											
B1. Public/Commercial effort											
Public VA landings (bushels x 1000)	18.6									9.29E+06	7.91E+06
B2. Private effort											
Private VA landings (bushels x 1000)	36.8									1.84E+07	1.57E+07
C. Restoration efforts											
C1. Reefs/unexploited sanctuaries											
Average number of oysters/m2	The VMRC Dive survey was started in 1997. No data are available for 1994.										
Average oyster biomass/m2											
Number of reefs surveyed											
Acres surveyed										0.00E+00	0.00E+00
C2. Replenishment/exploited ground											
Average number of oysters/m2	55.5		58.9								
Average oyster biomass/m2	14		14.9								
Number of reefs surveyed	1		2								
Acres surveyed	5		20							5.89E+06	1.49E+06
D. Oyster Aquaculture											
D1. Oyster gardening via CBF											
Total number of oysters/m2	The Chesapeake Bay Foundation did not start planting oysters on restored reefs until 1996. No data are available for 1994.										
Total oyster biomass/m2											
Number of reefs surveyed											
Acres surveyed										0.00E+00	0.00E+00
Grand total number of oysters										1.40E+09	
Grand total oyster biomass											5.14E+08

Aquaculture Biomass

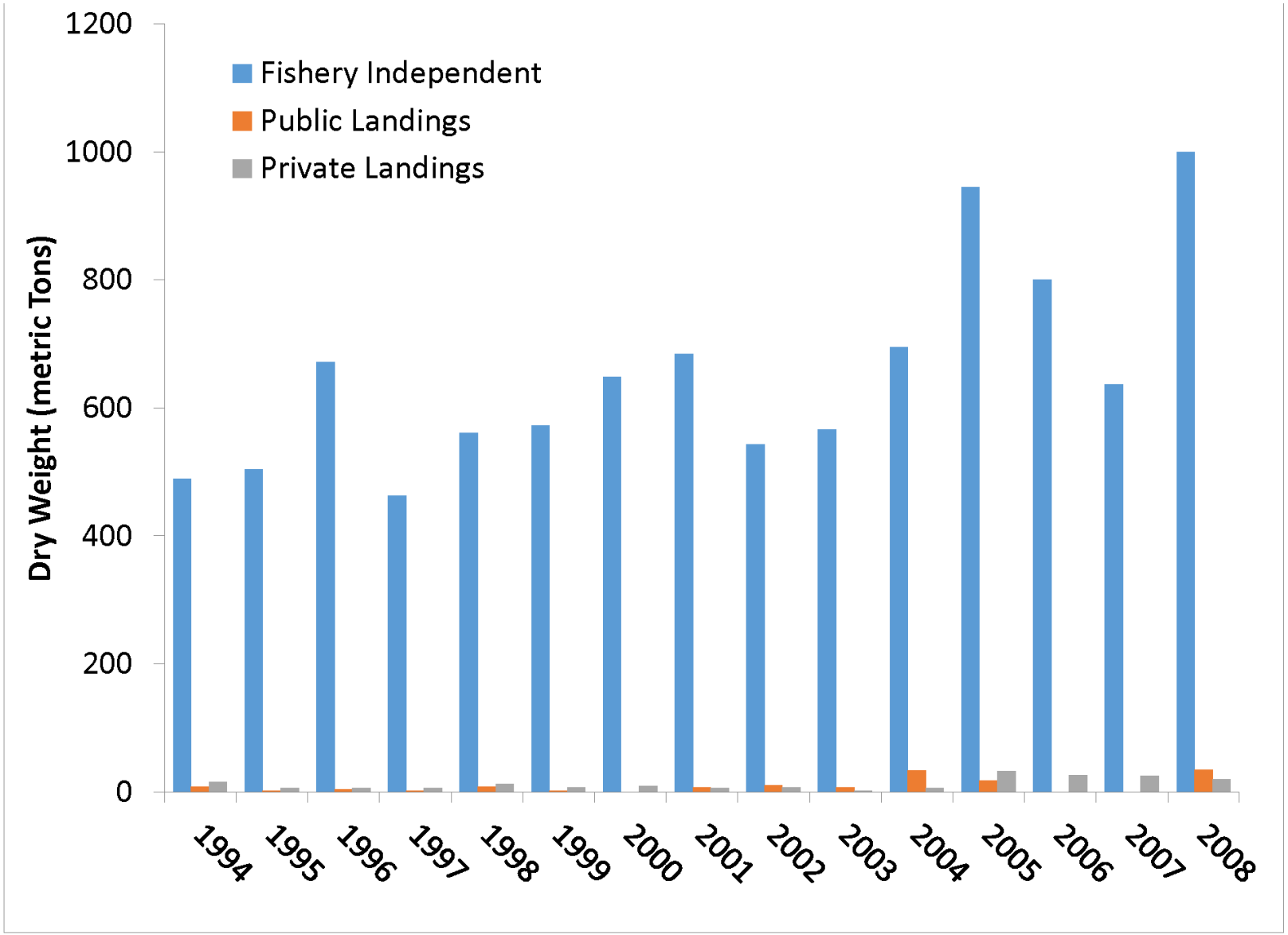
- Assume the biomass is equivalent to the harvest. The farmer plants the seeds and harvests the crop. This activity is continuous year-round.
- Maryland – We have 2014-2016 data from Julie Riechert (Oyster Recoveries Partnership, Annapolis MD)
- Virginia – We have 2005 – 2015 results from VIMS surveys. We have 1985 – 2015 fishery landings from private grounds (CBOPE and VMRC). We've been advised aquaculture accounts for roughly half of private landings.

Sanctuaries

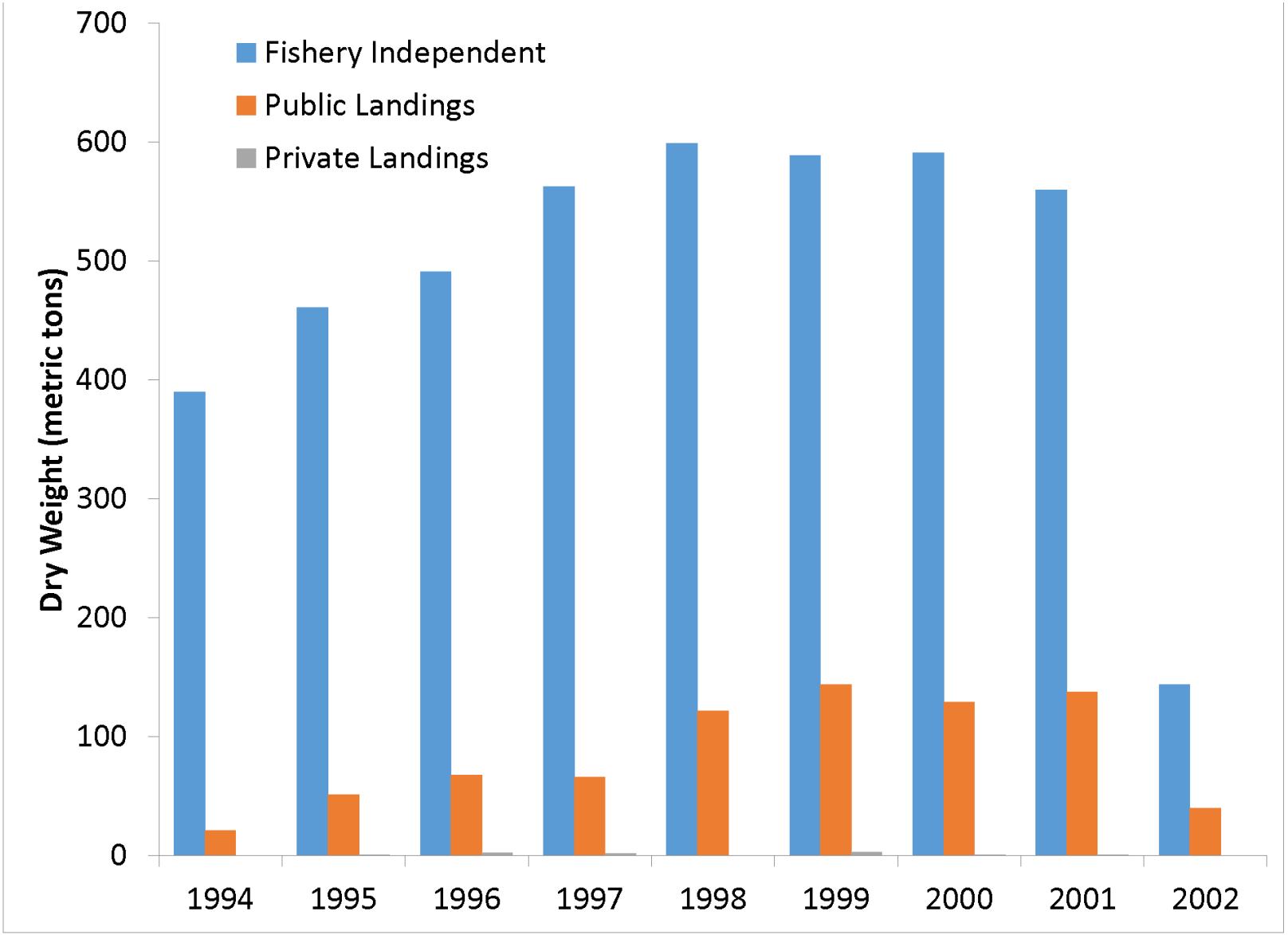
- We have the area of each Maryland sanctuary and some measure of density (quantity per unit area) for each sanctuary.
- It's going to be extraordinarily difficult to work up this data for each sanctuary and impossible to individually represent each sanctuary in the model.
- Modeled reef and sanctuary populations will be combined and compared with fishery-independent population estimates.



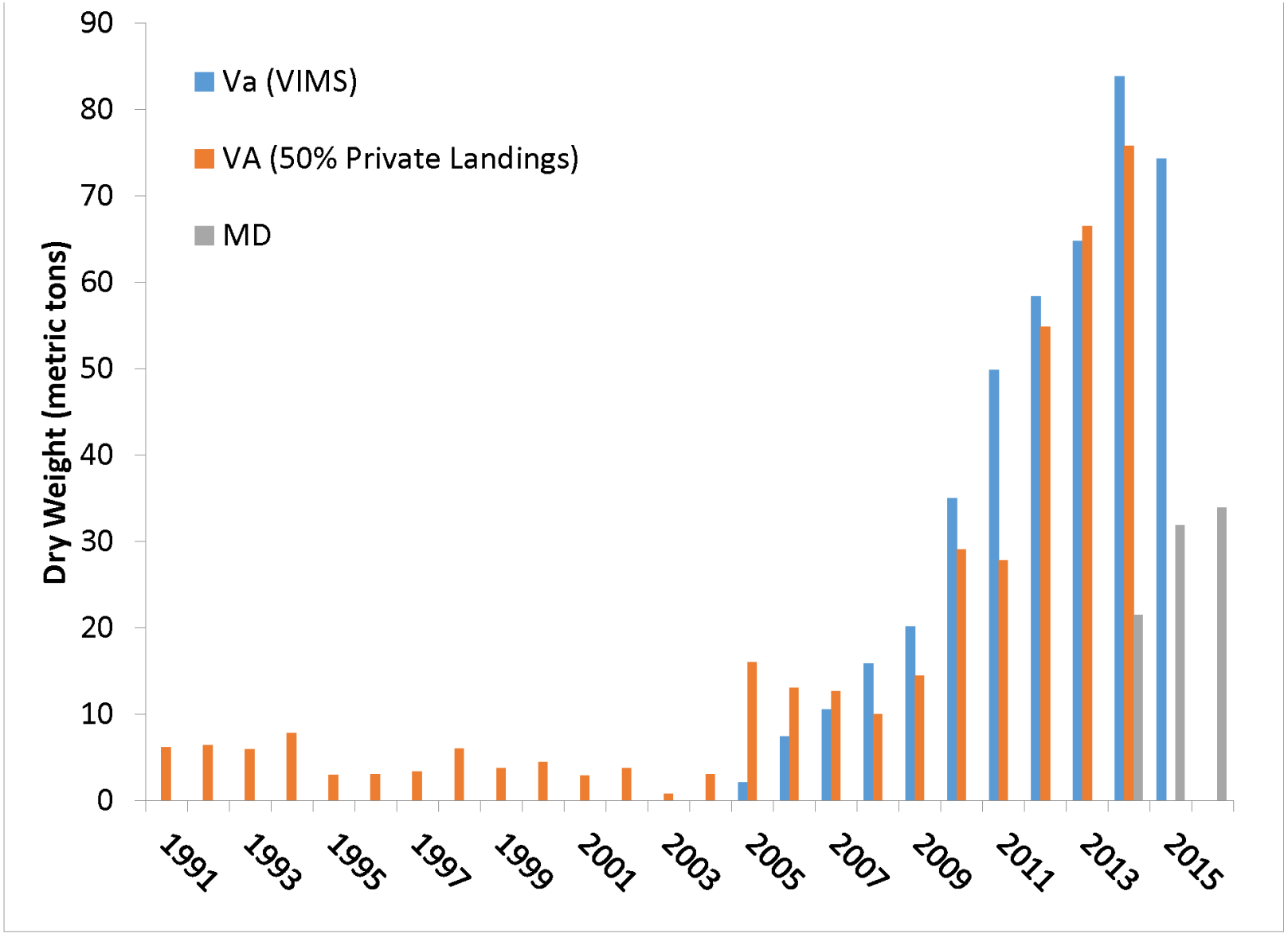
Virginia Biomass from CBOPE



Maryland Biomass from CBOPE

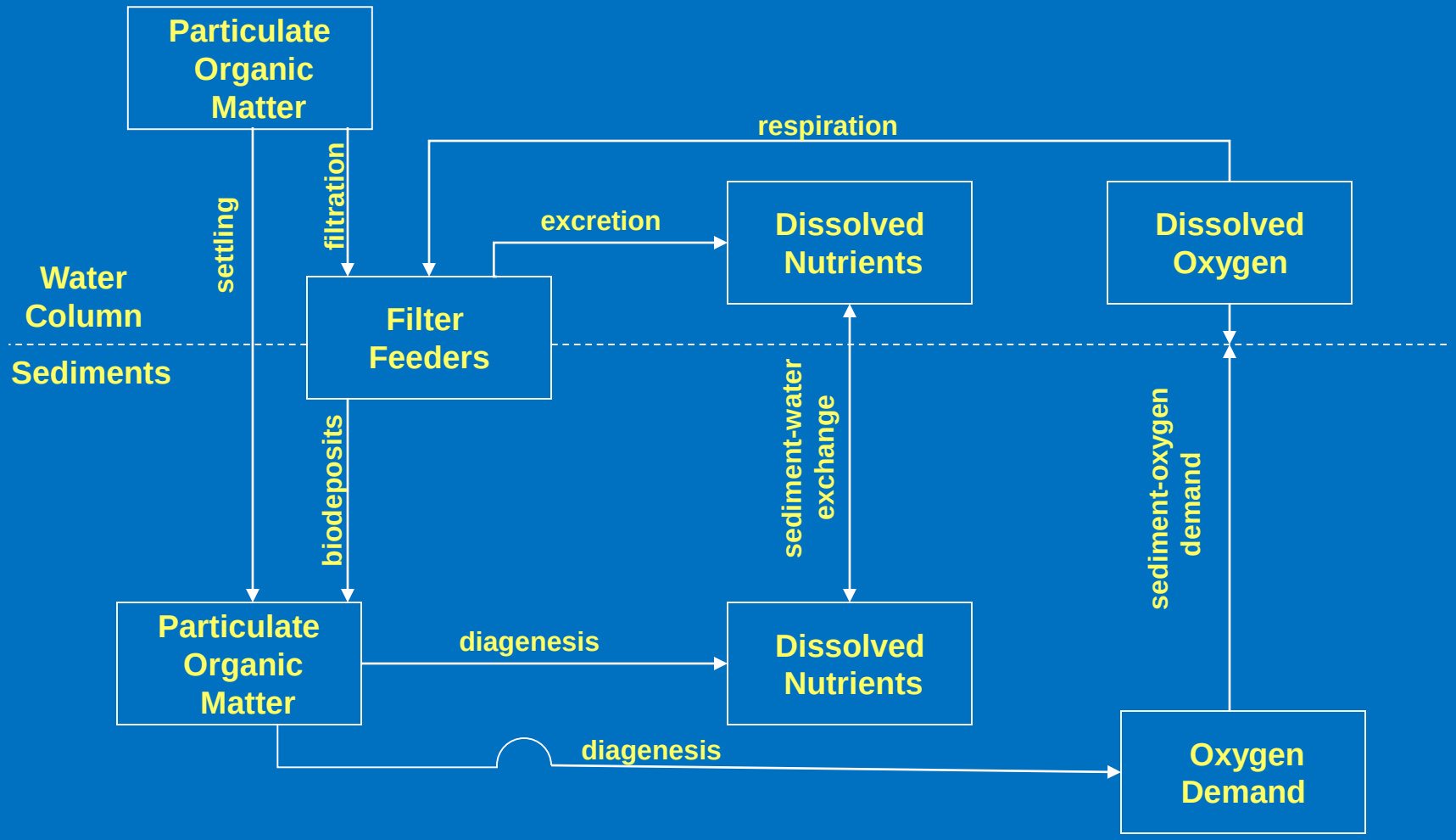


Aquaculture from Various Sources



Issues with Aquaculture

- The VIMS surveys indicate little or no aquaculture in Virginia prior to 2005. We need to investigate further. May be insignificant in any event.
- No Maryland data prior to 2014. We've been advised our early data on private takings (1994 – 2002) does not reflect aquaculture. We need some consultation on when significant aquaculture commenced.



Diagenesis Model with Benthos

Basic Equation

$$\frac{dO}{dt} = \propto \cdot Fr \cdot POC \cdot IF \cdot (1 - RF) \cdot O - BM \cdot O - \beta \cdot O$$

In which:

O = oyster biomass (g C m^{-2})

α = assimilation efficiency ($0 < \alpha < 1$)

Fr = filtration rate (m^3 g^{-1} C d^{-1})

POC = particulate organic carbon (g m^{-3})

IF = ingestion fraction ($0 < IF < 1$)

RF = respiration fraction ($0 < RF < 1$)

BM = basal metabolism (d^{-1})

β = mortality (d^{-1})

The Approach

- Adapt most parameters from 2005 oyster model.
- The mortality term includes predation, disease, and harvest. Tune the mortality term until computed reef and sanctuary biomass is consistent with observations.
- We let the oysters locate themselves on reefs with appropriate conditions.

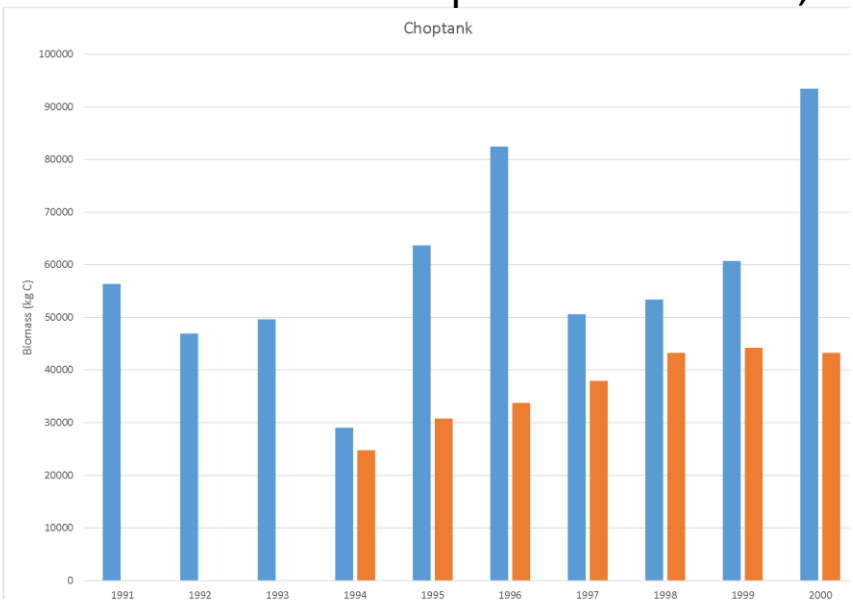
Model – Data Comparisons

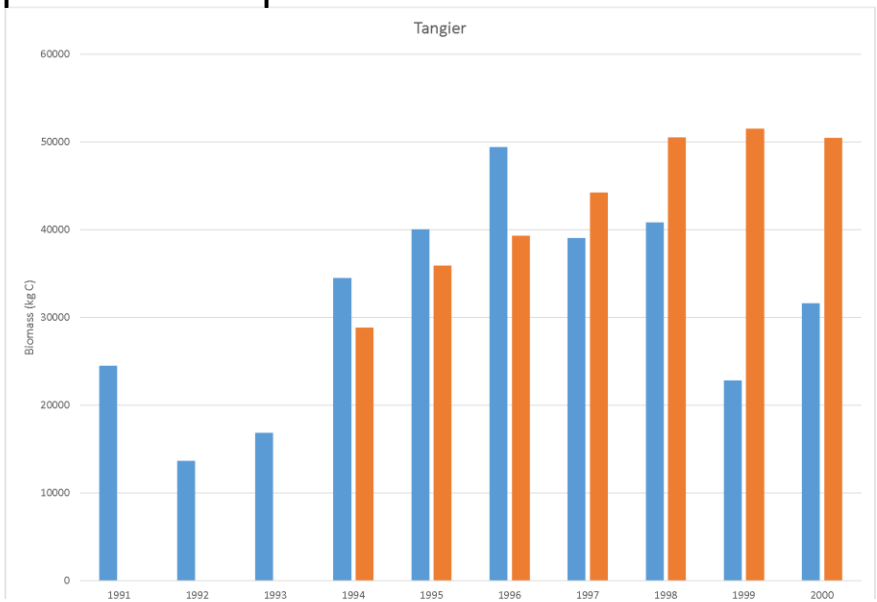
- We have biomass estimates by state.
- Apportion the Virginia biomass to basins in proportion to landings. Assume biomass is related to landings.
- Apportion the Maryland biomass to basins according to proportions determined by Greenhawk and O'Connell (2007).

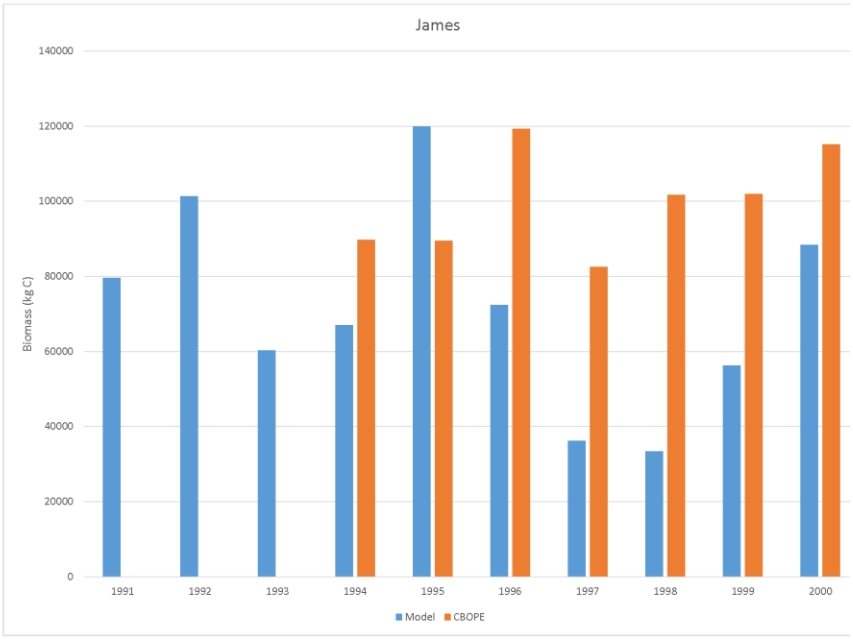
	2014-2015	
System	Public	Private
Chesapeake	80,978	78,548
James	112,082	117,205
York	32,372	34,800
Rappahannock	57,681	17,987
Potomac	1,316	62,688
Misc Bay	9,873	36,179
Totals	294,302	347,407

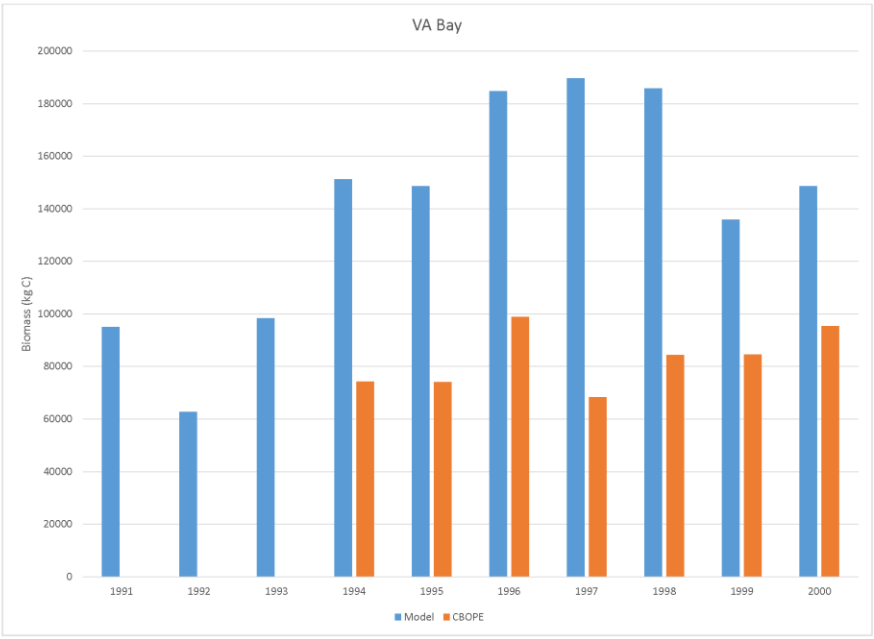
Greenhawk K and O'Connell T. 2007. Oyster Population Estimates for the Maryland Portion of Chesapeake Bay 1994–2006. Maryland Department of Natural Resources, Annapolis, MD, USA. Appendix A in US Army Corps of Engineers, Norfolk District. Final Programmatic Environmental Impact Statement for Oyster Restoration in Chesapeake Bay Including the Use of a Native and/or Nonnative Oyster. Available at http://www.nao.usace.army.mil/Missions/CivilWorks/Oysters.aspx (accessed May 10, 2013).

Example Model Results, Computed and Reported Biomass









Aquaculture

- The aquaculture biomass is roughly constant. Oysters are continuously planted and harvested.
- We want the ability to specify biomass, either existing biomass or a scenario biomass.
- We can do this in the existing framework by specifying dO/dt = 0. In that case the initial conditions will remain constant.

Aquaculture

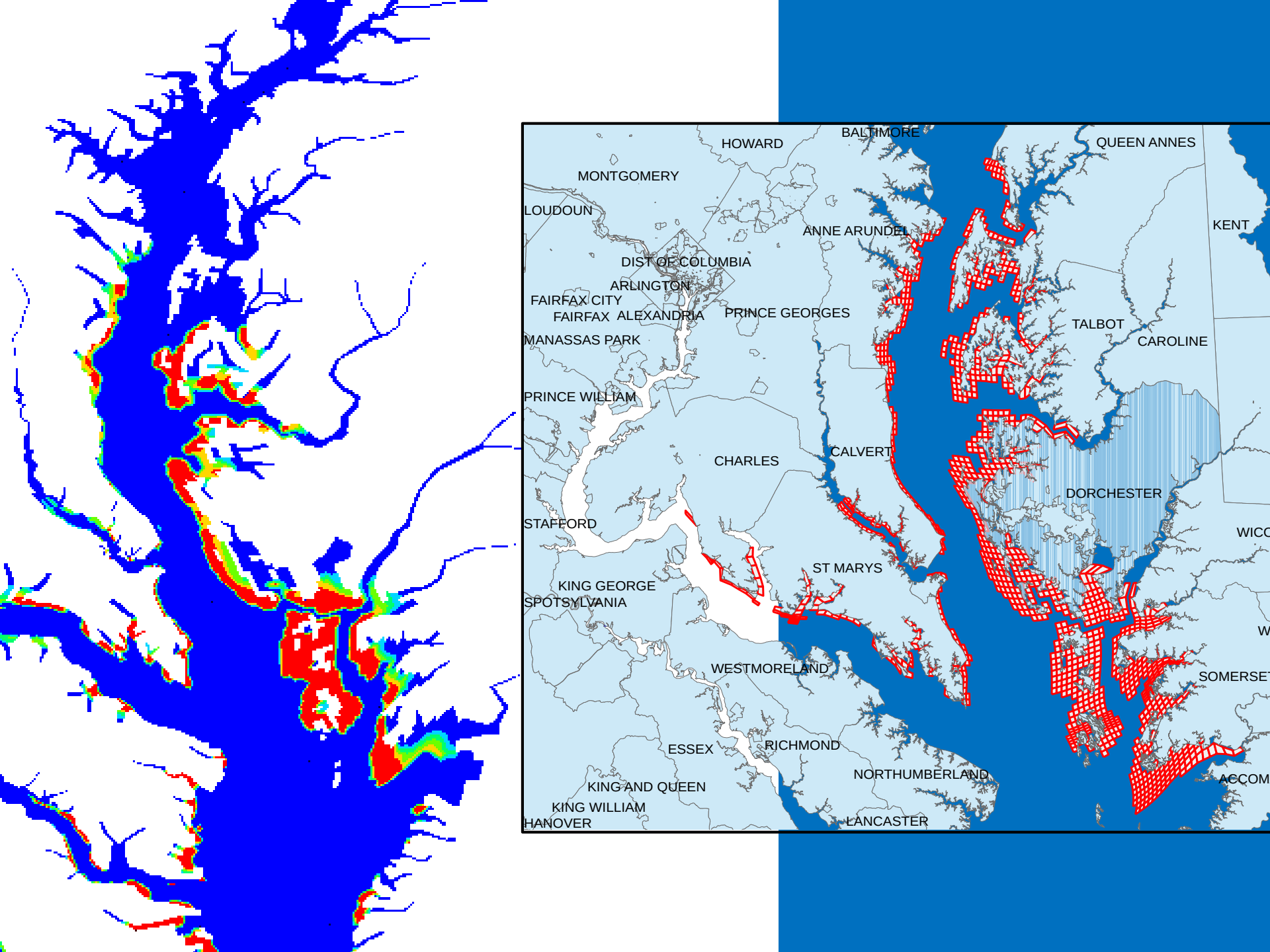
- We encounter some problems if we place aquaculture biomass where conditions are not sufficient to maintain the biomass.
- We can “overfilter” the water column, create negative concentrations and other problems.
- We can implement various “hardwires” but if we force aquaculture where conditions won’t support it, we get unrealistic scenarios.
- We need to implement aquaculture in the right amount in the right locations.

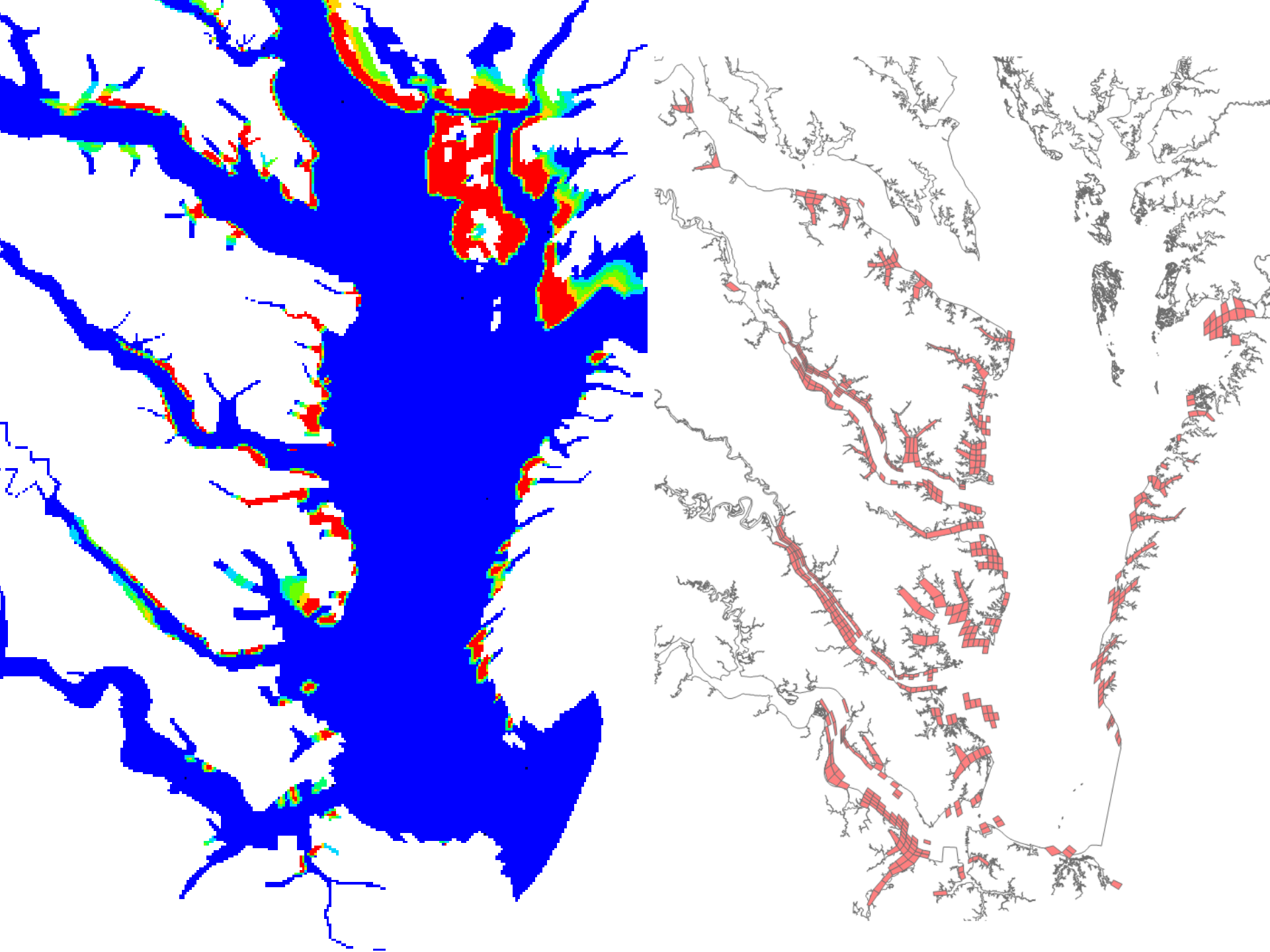
Locating Aquaculture Operations

- Not all cells in our aquaculture regions will support aquaculture. Cells that support present levels will not support a ten-fold increase.
- With the reef population, we let the oysters self-locate. For scenarios, we allow a ten-fold increase globally, not in each cell.
- We are exploring a similar process for aquaculture.
- Otherwise, we can treat aquaculture the same as natural populations ($dO/dt \neq 0$). It will be difficult to exactly match reported biomass.

Locating Aquaculture Operations

- If we let aquaculture self locate, what are the locations with high biomass?
- How do these compare to our allowed areas?


BALTIMORE
HOWARD
QUEEN ANNES
MONTGOMERY
LOUDOUN
ANNE ARUNDEL
KENT
DIST OF COLUMBIA
ARLINGTON
FAIRFAX CITY
FAIRFAX
ALEXANDRIA
PRINCE GEORGES
TALBOT
CAROLINE
MANASSAS PARK
PRINCE WILLIAM
CALVERT
CHARLES
DORCHESTER
STAFFORD
ST MARYS
KING GEORGE
SPOTSYLVANIA
WESTMORELAND
ESSEX
RICHMOND
NORTHUMBERLAND
KING AND QUEEN
KING WILLIAM
HANOVER
LANCASTER



Next Steps

- Assign aquaculture to favorable locations.
- Test model results with existing and scenario populations.
- Determine if our present approach is feasible.