Severn Riverkeeper Water Quality Monitoring Program

2012 Report

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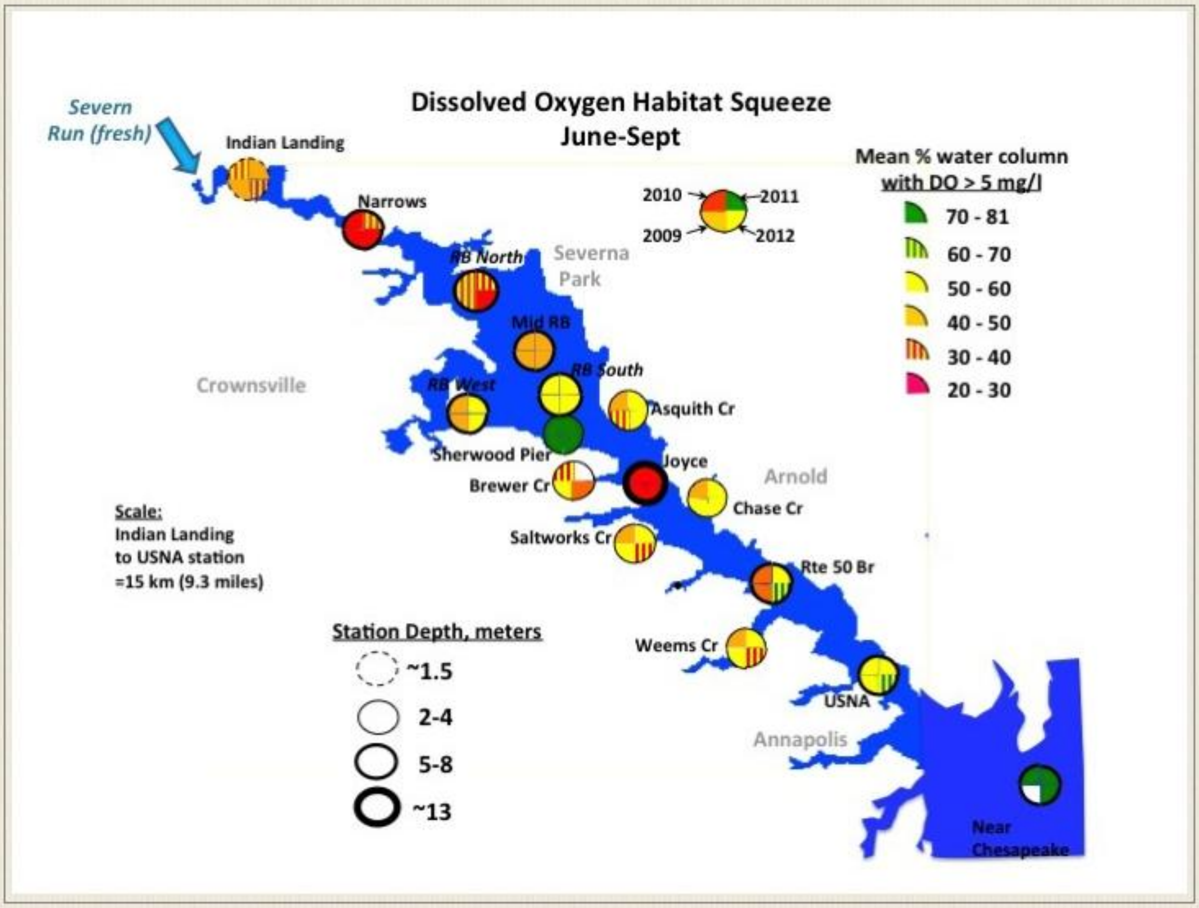


Summary

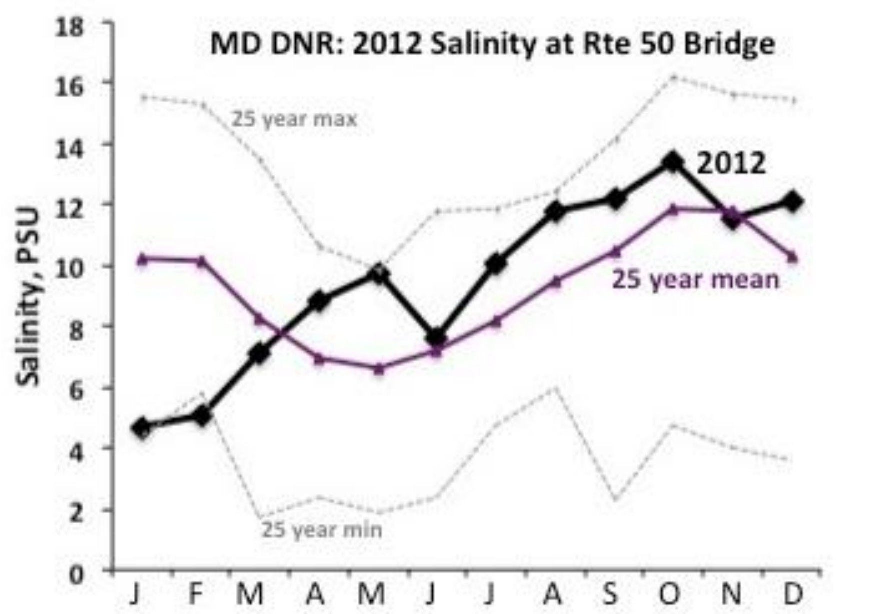
The Severn Riverkeeper Water Quality Monitoring Program has conducted weekly water quality monitoring at 16 stations throughout the tidal Severn during the summer months for each year since 2006, concentrating on dissolved oxygen measurements. Monitoring in 2012 began in mid-May and continued to mid-September. This period was one of low rainfall, giving rise to higher-than-normal salinity throughout the monitoring period. Bottom anoxia (dissolved oxygen <0.2 mg/liter) was found in northern Round Bay by the end of May, although this moderated dramatically in early June. However, by July bottom anoxia returned to Round Bay and persisted until mid-August when it was replaced by milder bottom hypoxia. 2012 was unusual in that anoxia occurred in May and resolved in mid-August. Other areas of the Severn showed the typically variable bottom hypoxic conditions observed in previous years. Overall water column hypoxia throughout the Severn mainstem and tributaries was generally similar to previous years, with stations closer to the Chesapeake showing higher oxygen levels throughout the water column. Based on Secchi measurements, water clarity throughout the Severn in 2012 improved compared to 2011, but was only slightly higher than our 6 year average. As shown by chlorophyll readings from our newly acquired monitoring instrument, phytoplankton levels were often high, consistent with the model of hypoxia driven by excess phytoplankton growth in turn driven by excess nutrients.

Introduction

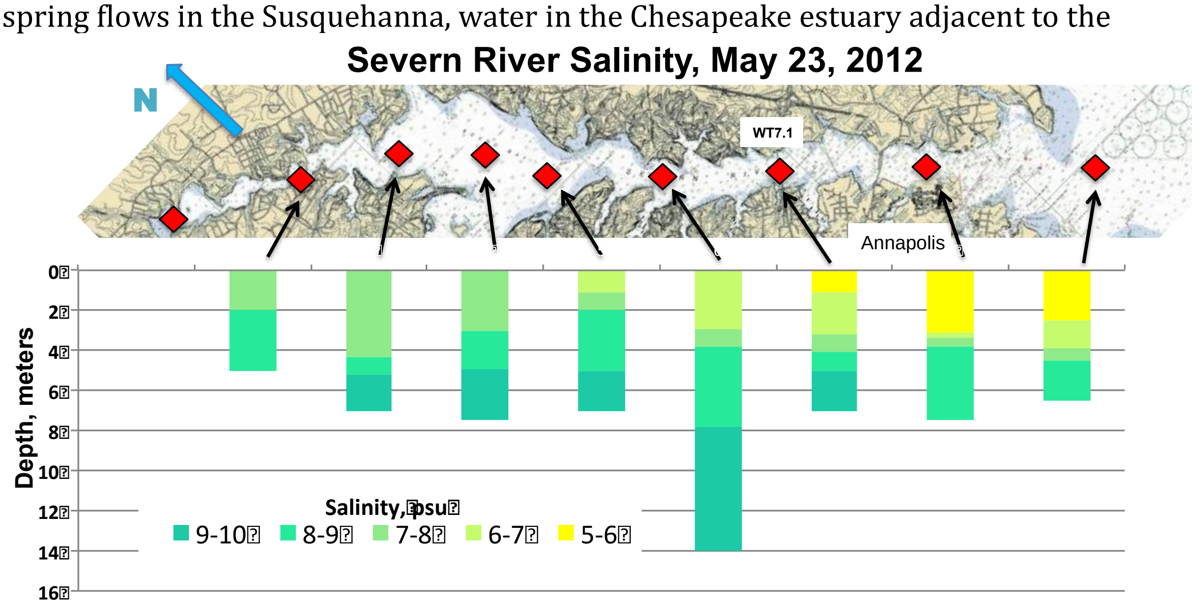
The Severn Riverkeeper Monitoring Program has conducted water quality monitoring measurements throughout the tidal Severn River during the summer months since 2006. Our objective has been to acquire data that would help provide a scientific understanding of the Severn's widely perceived decline in aquatic resources including fish, crabs and oysters. Our initial year's findings showed that the Severn suffered from severe oxygen deprivation along the bottom of upper Round Bay and adjacent areas during July and August, and subsequent years have confirmed these observations. The extent and intensity of the Severn "dead zone" is unusual in that it occurs in relatively shallow water (~7 meters) and similar persistent anoxia has not been reported in other Chesapeake tributaries. While hypoxia clearly stresses life in benthic habitats in many areas of the Chesapeake, the levels of anoxia we find in the upper Severn are incompatible with the survival of any multicellular organisms. We have therefore continued our summer monitoring program focussing on understanding the factors causing the Severn's low bottom dissolved oxygen levels. One such prominent element is the lack of effective vertical mixing to replenish depleted oxygen in bottom water, driven by the salinity and temperature density gradients in the Severn. Thus we will discuss these before presenting our oxygen results.

Salinity and Temperature

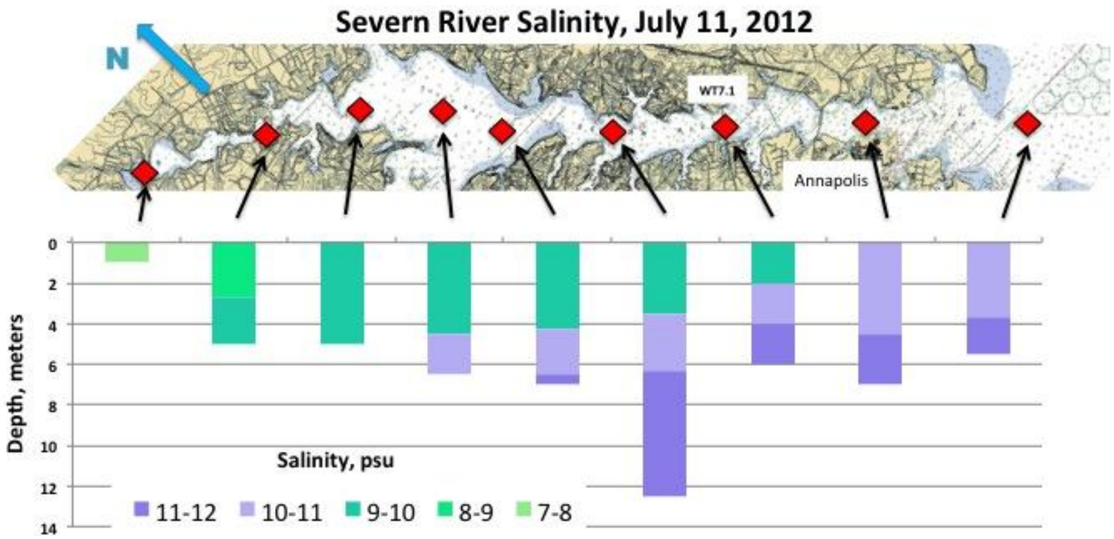
2012 was a year of below-average local rainfall in most months of the year, with a major storm in late October providing a catch-up boost to the yearly total. Since 2011 was a wet year, the Severn's salinity started 2012 at near record low levels, as shown in this figure summarizing the Maryland DNR's 2012 salinity monitoring at the Route 50 bridge. January and February salinity levels were close to the 25-year low levels, and the normal salinity decrease seen between February and May was replaced by a pronounced increase, so that by April the Severn's salinity was considerably higher than normal. The continuing dry weather gave rise to higher-than-normal salinity in most of the following months.



Our monitoring began in May, which can be seen from the above data as an exceptional month of decreasing Severn salinity. Our data in the figure below shows clearly that the source of the fresh water influx was the Chesapeake. Although contrary to the expectations of some people, we have seen a similar "reverse" salinity profile during the May-June period in several previous Severn monitoring years. Due to high spring flows in the Susquehanna, water in the Chesapeake estuary adjacent to the



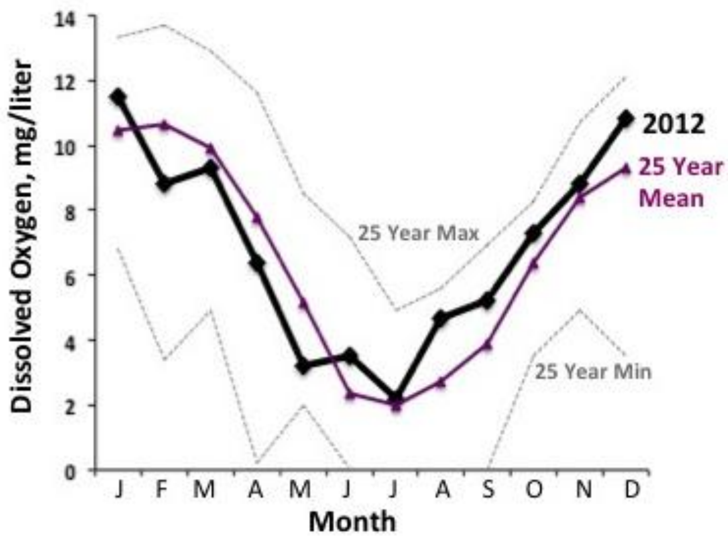
Severn becomes much fresher than the water in the Severn, which has only modest freshwater inflow compared to the Susquehanna. The result is a period of mixing, lowering the Severn's salinity to match that of the adjacent Chesapeake. The "reverse" salinity profile seen on May 23 occurs only during periods of high Susquehanna flows; during most of the summer the salinity pattern is more like that shown for July 11.



These figures show the salinity gradients throughout the Severn, with denser, saltier water layered underneath upper layers of fresher water. Another factor influencing density is temperature, which we also measure. In May and June, Severn water is warming due to increasing air temperatures, and bottom waters are generally about one degree C cooler than surface waters. However, by August the bottom waters have warmed, and we find only small temperature differences between top and bottom. The combined top-to-bottom differences in salinity and temperature create vertical density gradients that resist re-oxygenation of bottom waters, giving rise to the Severn's hypoxia and anoxia discussed in the next section.

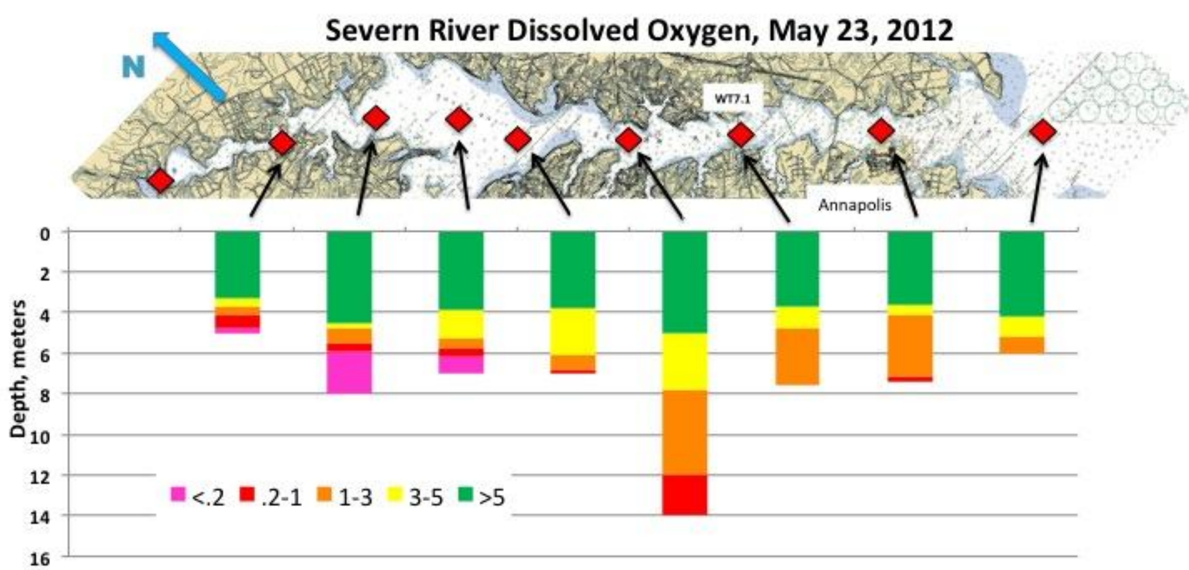
Dissolved Oxygen and Density

Our findings of consistent anoxic bottom water in northern Round Bay and Asquith Creek in the summer of 2006 have stimulated our annual return to monitor these areas. We have found that anoxic bottom water forms in northern Round Bay every year by July and persists into August or September, and every year also in Asquith Creek, but with a more variable pattern. We are unaware of other Chesapeake tributaries that develop such substantial areas of anoxic bottom water for such prolonged periods at the depths (15-25 feet) we see them in the Severn. This anoxia clearly devastates the Severn's benthic habitat, greatly compromising local crabbing and fishing. Efforts to understand how this unusual anoxic bottom water forms lead to attempts to characterize the patterns of vertical mixing in the Severn. Such mixing is required to replenish oxygen-depleted bottom water with well-oxygenated surface waters, and in summer is largely driven by surface waves we have no means of analyzing.



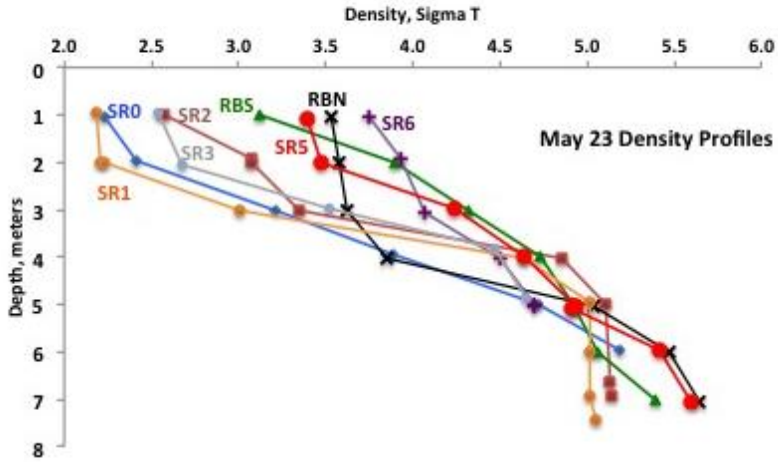
This figure shows the bottom dissolved oxygen concentrations at the Severn's Route 50 bridge (WT7.1) as measured by the DNR's year-round monthly monitoring program. As typically found, oxygen concentrations were minimal in the summer, and 2012 was a fairly typical year.

Our monitoring began in May and measured full depth profiles at each of 16 stations, giving a much more complete picture of the Severn's dissolved oxygen status over the course of the summer. An example of DO data from an early monitoring run is shown in the figure below:



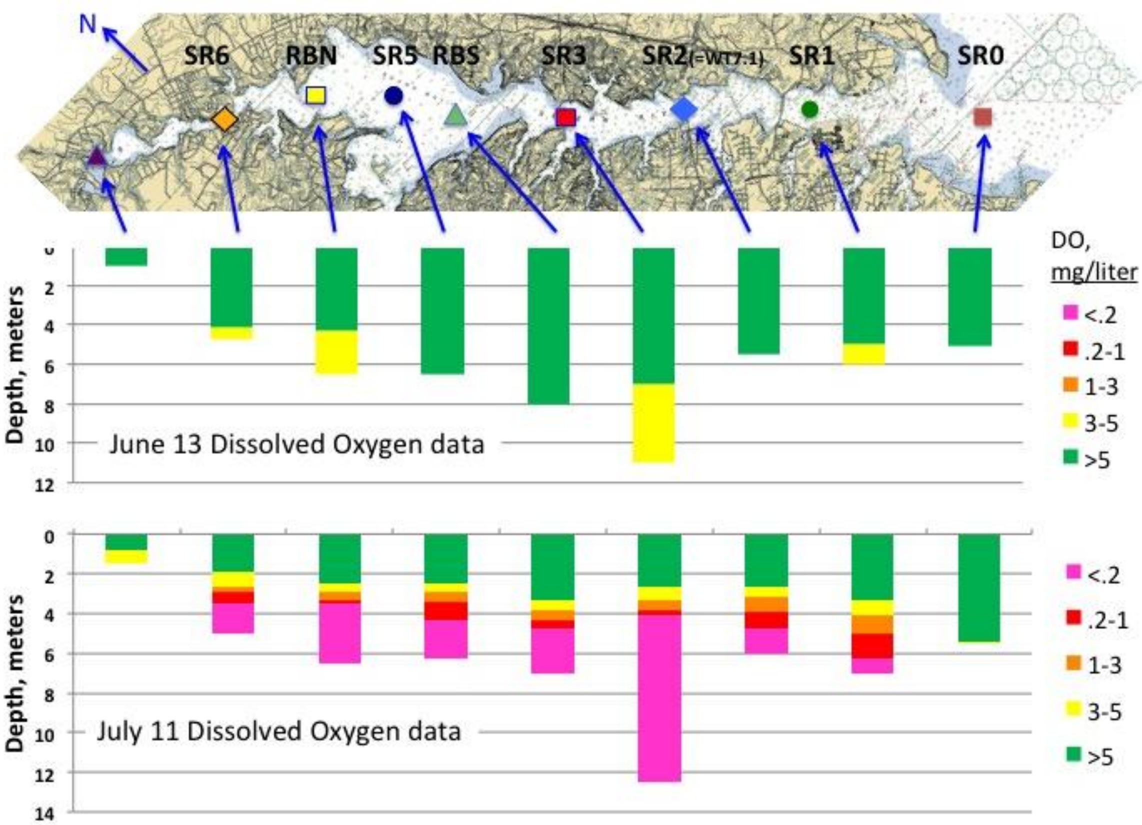
These results show that upper Round Bay had already developed anoxia in its bottom water, although the upper half of the water column was well oxygenated, and hypoxia was clear in the bottom water at all stations. More pronounced hypoxia/anoxia was observed a week later. This level of early hypoxic stress had not been seen in previous years of monitoring, when we had never observed anoxia in Round Bay in May. Complete Severn summer mainstem oxygen and salinity results can be found at: http://www.slideshare.net/henkartp/2012-severn-oxygen-salinity

One possibility to explain the May 23 result above is that vertical mixing/re-oxygenation of bottom water in Round Bay was suppressed by stronger density gradients than was present in the less hypoxic stations near the Chesapeake. We thus calculated density profiles using the UNESCO polynomial from our salinity and temperature data, with the resulting plots shown on the next page.

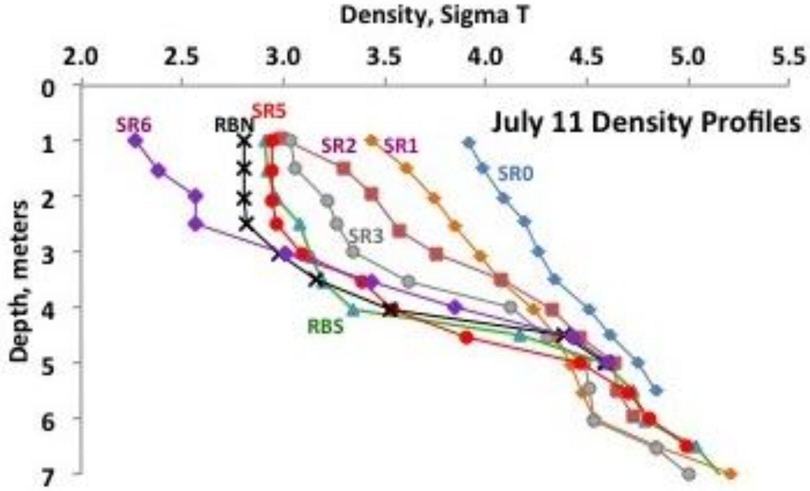


These plots indicate that the near-Chesapeake stations (SR0, SR1, SR2) have steeper density profiles than the Round Bay stations (SR5, SR6, RBN), compatible with the May 23 salinity data. Thus at this time, the greater Round Bay hypoxia/ anoxia was due to either a higher rate of bottom oxygen consumption, or weaker vertical mixing compared to the near Chesapeake stations (or a combination of these).

By early June the Severn's hypoxia largely disappeared, but then returned with a vengeance in July, as shown in the following figure:



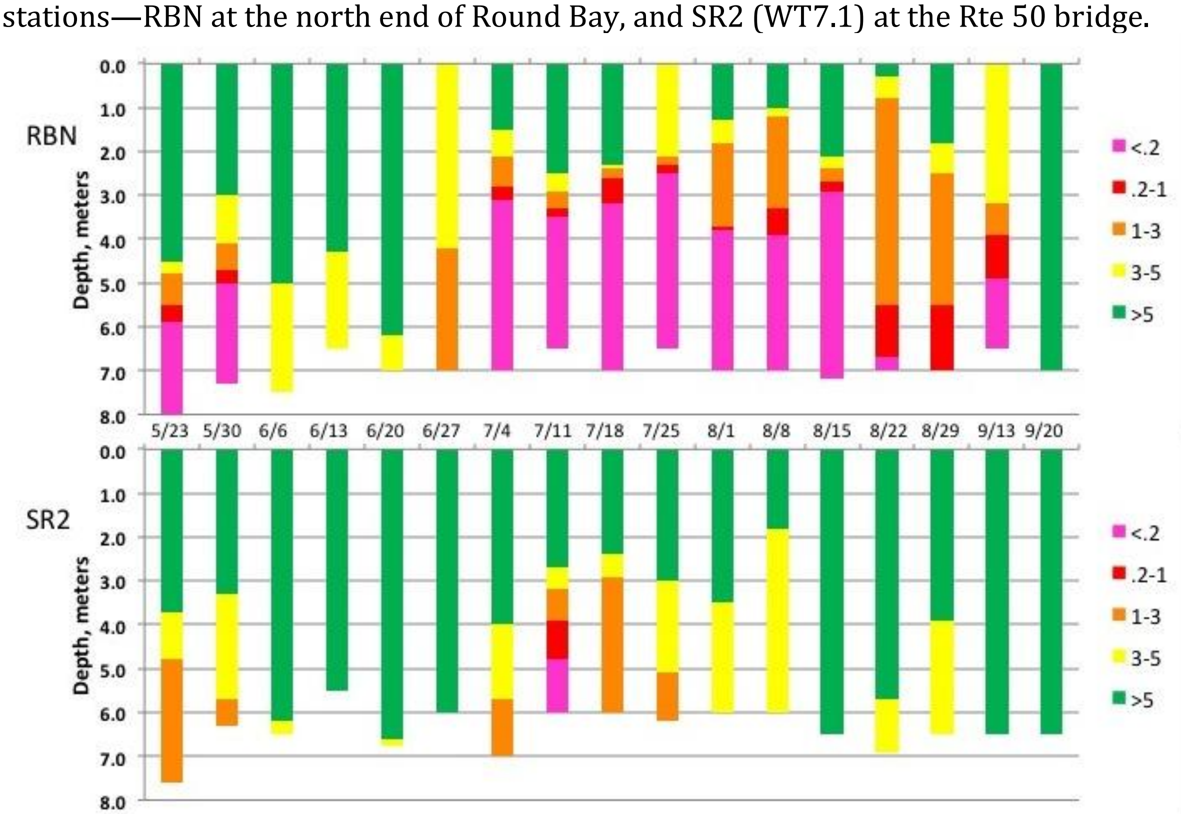
Thus on July 11, a sizable fraction of the water in the Severn was anoxic, including bottom water in the near-Chesapeake stations. These profiles represent the extremes of 2012 summer oxygen results, and the July 11 levels of hypoxia/anoxia are the worst we have found in 7 years of monitoring the Severn.



As described above, by July 11, the Severn's salinity pattern had resumed its "normal" sub-estuary like pattern, which resulted in steeper density profiles in the upper Severn as shown by the figure here. In this case the density gradients are steeper in upper Round Bay than in the lower Severn, but bottom anoxia was present at all these stations except SR0. Here again, differences in the degree of hypoxia/anoxia do not seem directly related to differences in the density profiles.

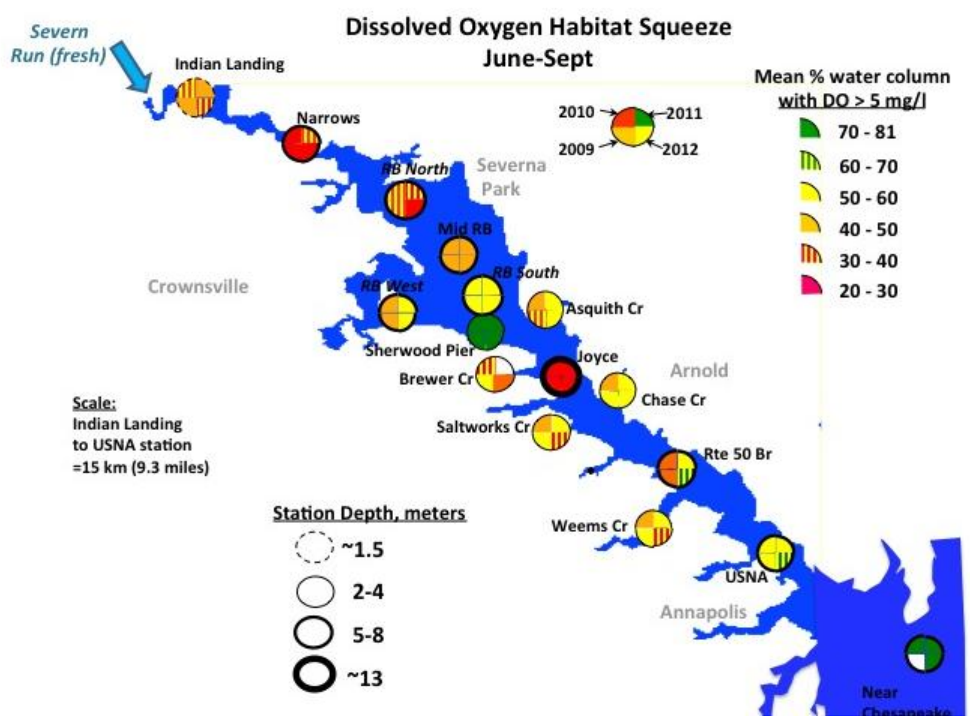
It should be emphasized that our 2012 oxygen results are derived from two different oxygen probes (based on luminescence quenching and Clark electrode) in two different instruments (Hydrolab DS-5 and YSI Pro2030, respectively), with no significant differences in resulting profiles.

To show the week-to-week variability in the Severn's DO depth profiles, the figure below shows the progression of DO results throughout the summer at two stations—RBN at the north end of Round Bay, and SR2 (WT7.1) at the Rte 50 bridge.

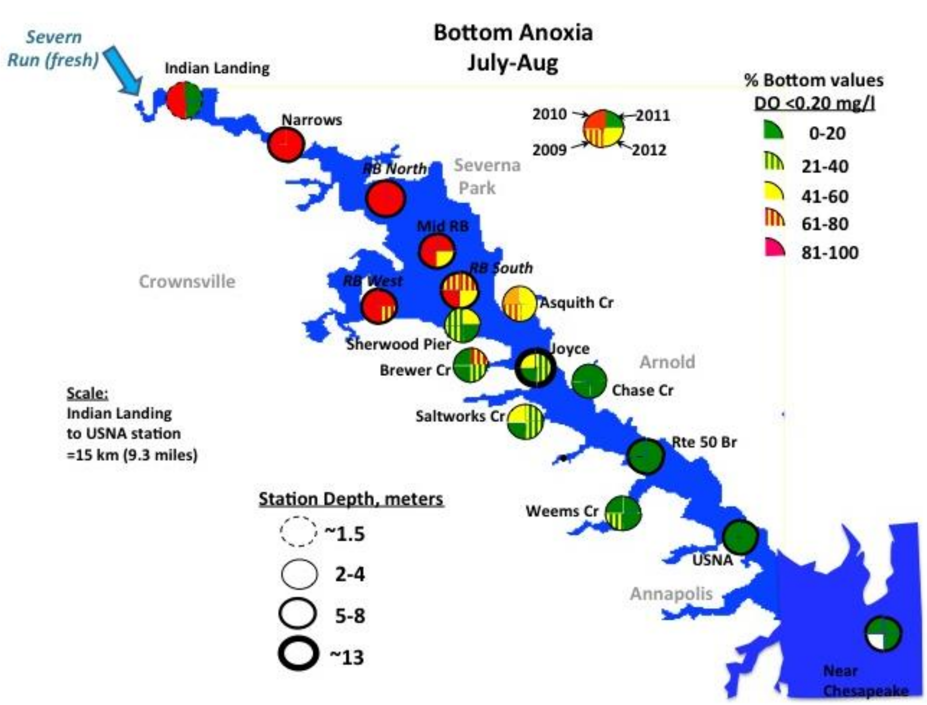


It can be seen that the progression of Round Bay hypoxia/anoxia correlates with a weaker hypoxia in the lower Severn.

Since oxygen is required at various levels for all multicellular organisms, the hypoxia we see will have different impacts on different organisms. For free-swimming fish, one way of comparing different DO depth profiles is to calculate the percentage of the water column with oxygen levels greater than 5 mg/liter, a level thought to be required by some fast-swimming fish. These numbers can be considered as indicative of the degree of hypoxic squeeze, forcing fish into the shallower portion of the water column. As shown in this chart, the lower Severn has less hypoxic squeeze than the mid-Severn, and the stations above Round Bay are most heavily impacted by hypoxia, even the shallow uppermost station. Compared to the previous three years, the hypoxic squeeze in 2012 was worse in the upper Severn, but better in the lower Severn.



Hypoxic stress for the benthic habitat is different in that although the worms, clams, and oysters are more resistant to hypoxia, they cannot respond by moving to more favorable locations. Thus the anoxic bottom water we find in the Severn every summer



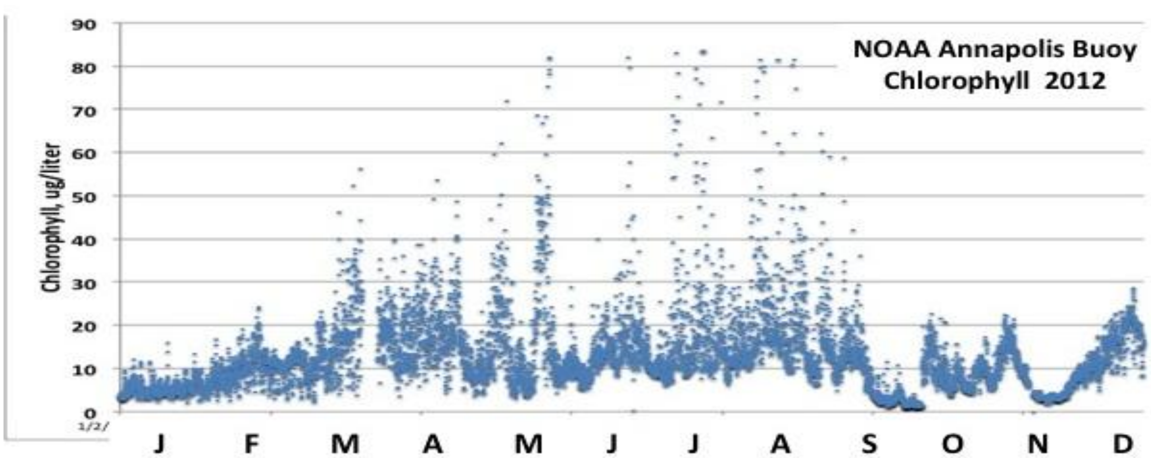
totally wipes out these benthic organisms, depriving crabs and some fish of a major food source. To allow comparisons between different regions of the Severn and different years, we have calculated the percentages of bottom anoxia in July and August, the worst months, as shown in this figure. It is clear that bottom anoxia occurs only occasionally in the Severn below Round Bay, but its frequency of occurrence rises dramatically as one proceeds further up the tributary. Bottom anoxia was significantly less frequent in our central, southern, and western Round Bay stations in 2012 compared to previous years, but the overall pattern remained similar.

In 2012 we again monitored 5 of the Severn's tidal creeks, with dissolved oxygen results generally comparable to previous years. Our most interesting creek is Asquith Creek, which is different from the others in that it has a shallow bar over its entrance, with boat access via a long channel ~2 meter deep parallel to the shoreline. Our monitoring station is in mid-creek with a depth of 4.5 meters. Similar to previous observations, from May 23 until June 6 Asquith Creek had a distinct layer of cooler salty anoxic bottom water underlying fresher well-oxygenated surface water. However, by mid-June, the Severn's increasingly salty water had penetrated into Asquith Creek, destabilizing the layering and re-oxygenating the bottom water. Anoxic bottom water was observed again in Asquith several times in July and August, but was not as persistent as we had observed in 2009 and 2010. Complete oxygen monitoring data can be found at: http://www.slideshare.net/henkartp/severn-hypoxia-2012-the-edge

Chlorophyll

2012 marked the first year we were able to measure chlorophyll, using the luminescence probe on our Hydrolab DS-5 instrument. This is a measurement of phytoplankton density, although the various species of phytoplankton differ in their contribution to probe output, and bacterioplankton do not contribute at all. We presume the dominant chlorophyll signal in the Severn is from dinoflagellates, e.g., Prorocentrum minimum, which we have observed microscopically in several Severn blooms. Although some varieties of dinoflagellate can be toxic, the Chesapeake has not experienced major "harmful algae" blooms, and we are not aware of any in the Severn. We measure chlorophyll to obtain a general read-out of nutrient loading.

NOAA's Annapolis water quality monitoring buoy gives continuous readings of a number of parameters including chlorophyll at a fixed depth of 1 meter as shown here.

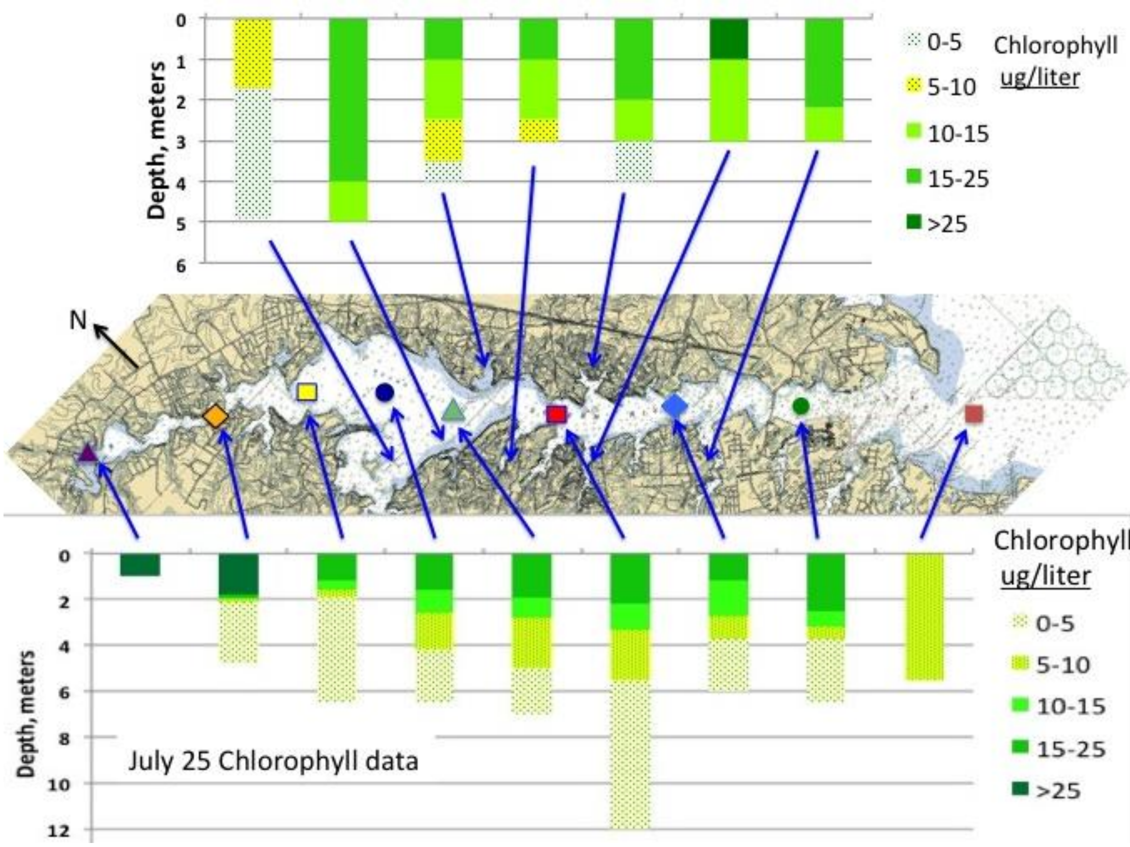


This buoy is close to our near-Chesapeake station SR0 and serves as reference data to compare our readings with.

Phytoplankton growth builds gradually in January and February, but begins to increase significantly in March as sunlight increases and the water warms. Throughout the spring and summer, surface chlorophyll levels are generally above 10 ug/liter, with frequent spikes reflecting blooms. These spikes make it difficult to draw conclusions from monitoring data based on single weekly sampling events such as ours.

Our weekly monitoring measured chlorophyll depth profiles, which generally showed the highest chlorophyll levels near the top of the water column. However, there were exceptions to this pattern. In some creek profiles we found more chlorophyll near the bottom, and in other cases we found a chlorophyll maximum in the midst of a pycnocline midway down the water column. Since dinoflagellates are highly mobile and migrate in response to conditions, some of the spikes seen in the above plot could be attributed to vertically moving organisms.

Our 2012 Severn results show that summer phytoplankton levels throughout Severn are likely to be fairly similar to the above Annapolis buoy results, although we found only a few examples of the bloom level spikes at the NOAA Annapolis buoy. Most stations showed chlorophyll levels somewhat greater than10 ug/liter at 1 meter below the surface. Our stations above Round Bay tended to have the highest chlorophyll levels, and the tidal creeks tended to have higher levels than the mid-Severn stations. Typical chlorophyll results from mid-summer are shown in the figure on the next page.

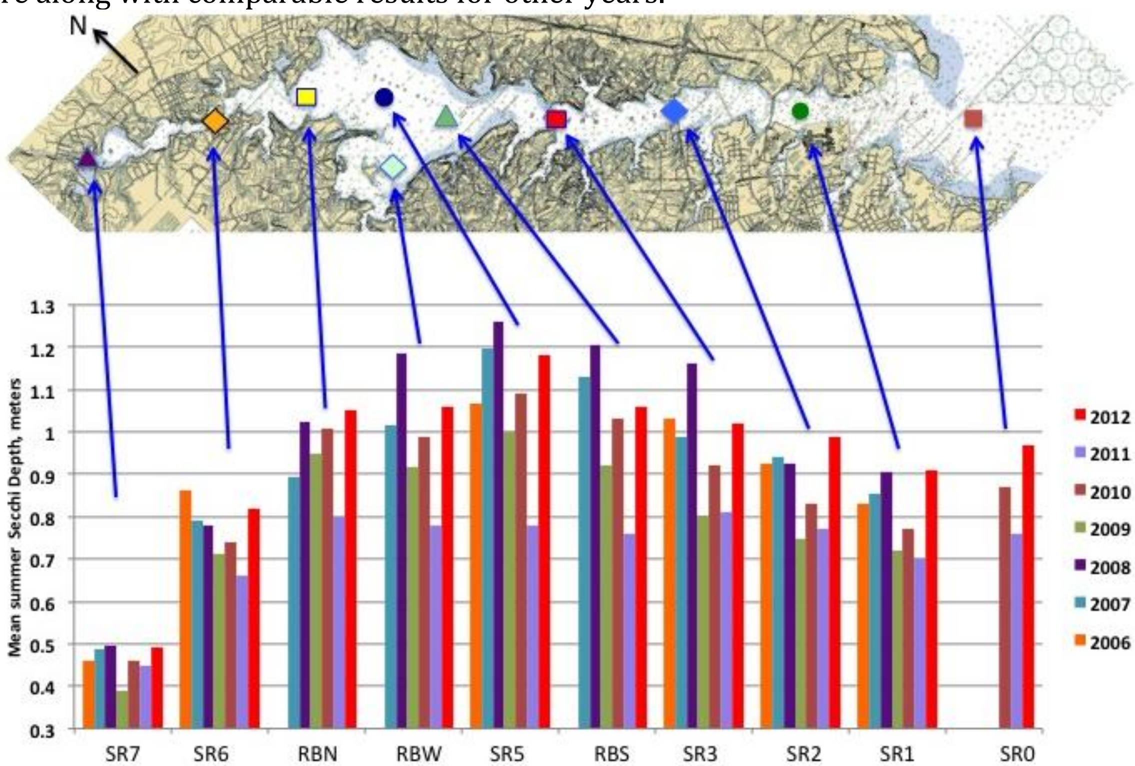


Although the July 25 data showed lower chlorophyll levels at our near-Chesapeake station, this was not generally the case. If we calculate total chlorophyll in the water column, the summer mean level at the near-Chesapeake station is only slightly smaller than the level at the uppermost station. And the stations below Round Bay have higher levels than the Round Bay stations. The most straightforward conclusion from our chlorophyll data is that phytoplankton growth is widely distributed throughout the Severn, and both the Chesapeake and the local watershed provide the critical nutrients.

Water clarity

Our monitoring program has measured surface water clarity by the traditional Secchi disk method since 2006, so it is useful for assessing historical changes in water clarity. However, it only measures surface water clarity, and in 2012 we acquired additional turbidity data using a probe that measures light scattering on our Hydrolab DS-5 instrument. Because the visual vs instrumental assessments of water clarity depend on different physical and chemical properties of water we first analyzed the correlation between Secchi depth and surface turbidity in 2012. We found a statistically significant but weak (negative) correlation between these two measurements, leaving us to analyze these results separately.

The 2012 season average results for the Severn mainstem stations are shown here along with comparable results for other years.

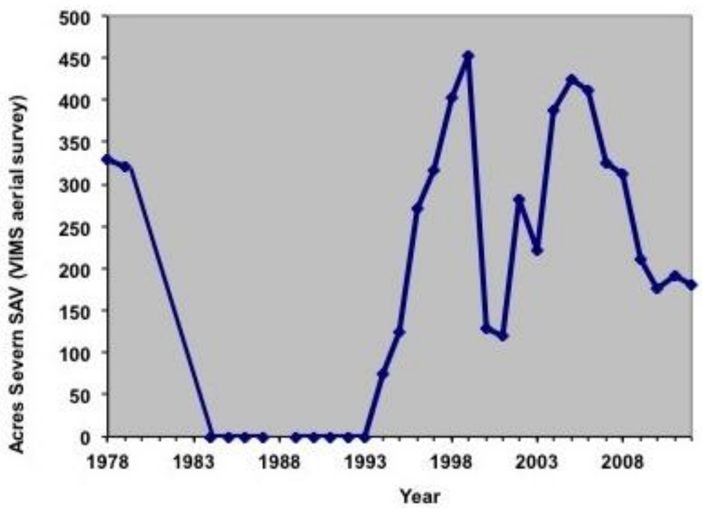


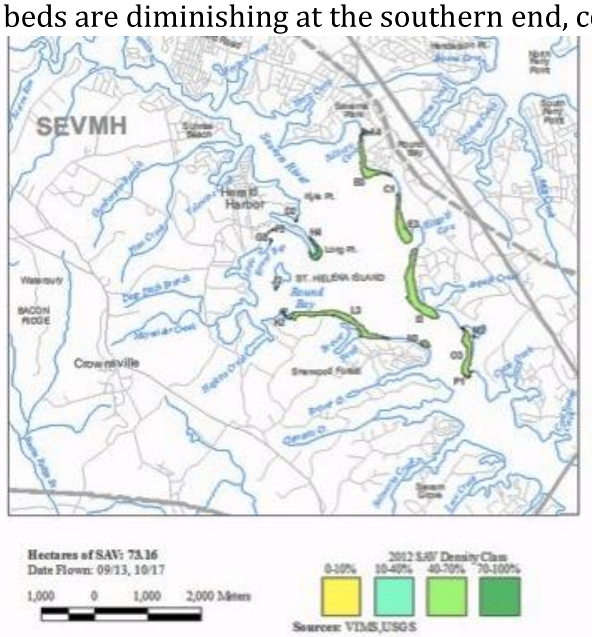
At every station, the 2012 average Secchi depths are greater than 2011, and in most cases the 2012 water clarity was the best in several years. As found in previous years, Round Bay stations had better water clarity than stations above or below them, and once again, the shallow uppermost station had markedly lower clarity.

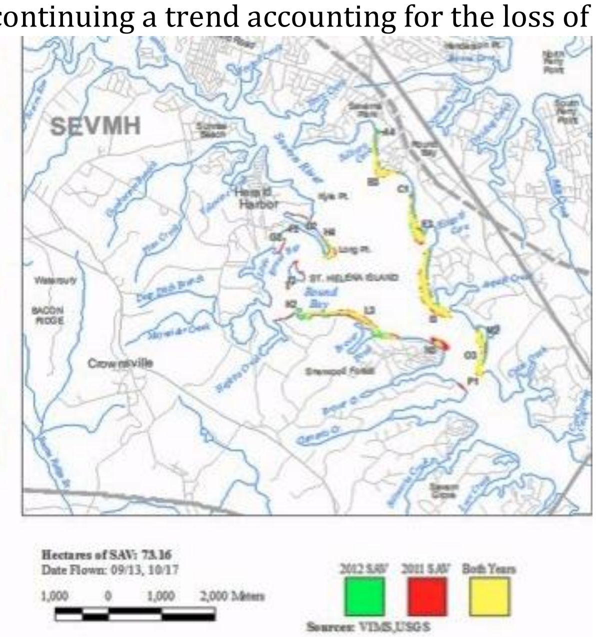
Turbidity data has been difficult to interpret. NOAA Annapolis buoy data shows variable NTU values between 3 and 8 for most of the year, with occasional higher single values that seem likely to be artifactual. Our depth profiles showed several patterns of NTU values in the 3-8 range. One of these was a increasing turbidity near the bottom which could be due to sediment resuspension as chlorophyll did not increase, but since many types of particles scatter light, we cannot currently make meaningful conclusions from our turbidity data.

Submerged Aquatic Vegetation

For decades, the Severn has stood out among Western shore tributaries for its acreage of submerged aquatic vegetation. These rooted flowering plants grow along the edges of Round Bay and provide excellent habitat for fish and crabs. After being decimated by Hurricane Agnes, the Severn's SAV regrew in the 1990s and has variably persisted since then, as shown in this figure. SAV growth throughout the Chesapeake is monitored by aerial surveillance in the late summer through a program at the Virginia Institute of Marine Science. Our water quality monitoring program does not monitor SAV, but water clarity as measured by Secchi depth is traditionally regarded as an indicator of light availability for these plants. Severn SAV has been comprised by a mixture of several species, and our 2012 casual observations suggested a lack of one of these (redhead grass) compared to previous years. The SAV area mapped by the VIMS program in the Severn has remained relatively constant for the last 3 years, and, as can be seen in these maps, is all in Round Bay. The map on the right shows the slight loss of SAV growth since 2011 in red, indicating that the Severn's SAV beds are diminishing at the southern end, continuing a trend accounting for the loss of







SAV area since 2005.

The reasons for the recent loss in SAV area in the Severn are not clear, but do not seem attributable of a reduction in water clarity given our Secchi observations showing a general improvement in 2012 (discussed above). However, our Secchi data comes from our mid-Severn stations, and it is possible that the near-shore water clarity in regions of SAV growth could be different. Nevertheless, other factors besides water clarity (e.g. epiphytic algal growth and viruses) can limit SAV growth, and it seems likely that such factors could explain the selective loss in redhead grass.

pH

In the 2012 season we had the opportunity to measure pH along with the other water quality parameters, as our Hydrolab DS-5 was equipped with an appropriate glass electrode. All measurements fell between 8.4 and 6.9. with the great majority between 7 and 8. In general, we found higher pH readings at the top of the water column with bottom readings close to 7. The higher pH values generally correlated with higher chlorophyll and DO levels, which is reasonable since photosynthesis consumes CO_2, equivalent to carbonic acid. Bottom pH levels similar to what we found in the Severn are considered to be healthy for oysters, and it appears that overall the Severn's pH is in a "healthy" range.

Discussion/Conclusions

The Severn's dead zone. In 2012 our Severn water quality monitoring program documented the continuing hypoxia we have seen throughout the tidal Severn River every summer since 2006. The Severn appears unique amongst Chesapeake tributaries in the formation of a layer of anoxic bottom water in a portion of Round Bay encompassing several square miles. At a depth 20-25 feet, this "dead zone" is not connected with the much deeper and better known Chesapeake dead zone which also forms every summer. Much of our motivation for continuing this project for seven years has been the hope that we can gain some insights into how this Severn dead zone forms every summer and why we have it in the Severn but not in other Chesapeake tributaries. Recent monitoring efforts in the South River show that it also suffers from episodes of bottom anoxia, but they are not as persistent or widespread as we have in the Severn.

One issue that we have clarified is whether the anoxia we find is due to the daily cycle of phytoplankton-based oxygen generation and consumption. Because this transient anoxia occasionally causes fish kills (none documented in the Severn in 2012), there is sometimes confusion between this phenomenon and the long-term anoxia characterizing "dead zones" like that in the Chesapeake mainstem and in Round Bay. The most dramatic evidence of persistent anoxia is the presence of hydrogen sulfide in the water column. This odoriferous gas is produced by anaerobic bacteria only after more favorable oxidative metabolic pathways are not available, and is unstable in the presence of oxygen. Using classic oceanographic water sampling devices, we have consistently detected hydrogen sulfide in the Severn's bottom water after our monitoring instruments have indicated anoxia at a site for more than two weeks.

As discussed above, in 2012 bottom anoxia in the Severn was detectable on our first monitoring run in May, which is earlier than we had previously found. This lasted for only two weeks before moderating to hypoxia in June, which was similar to previous years. However, once again by early July the Round Bay dead zone had formed, continuing for seven weeks before moderating to severe hypoxia in late August. This August weakening of the Round Bay dead zone was unusual, as it normally persists until sometime in September.

Is the Severn the only Chesapeake tributary with it's own dead zone? Maryland's Department of Natural Resources monitors Chesapeake tidal tributaries like the Severn and its neighbors monthly at a single station, and also has a "shallow water" monitoring program with more extensive area coverage. These programs provide excellent data but have not found the Severn's dead zone because no measurements were made in the relevant water. The Chesapeake Bay Program's benthic monitoring program has a random sampling strategy which every few years samples the Severn dead zone and finds no living organisms in the bottom substrate. This never led to a "dead zone" characterization of any part of the Severn's benthic habitat, suggesting that this program lacks the capability to identify local tributary dead zones. Thus it would appear that more intense monitoring by local groups are most likely to do so. Recent monitoring efforts by South Riverkeeper Diana Muller in the South River show that it also suffers from episodes of bottom anoxia, but they are not as persistent or widespread as we have in the Severn. The many similarities between the neighboring South and Severn mean it is no surprise that they suffer from similar problems, but we would like to understand why the Severn's more intense anoxia. Interestingly, going south a bit further, extensive bottom water oxygen monitoring by the West/Rhode Riverkeeper program has shown no bottom anoxia and only modest bottom hypoxia (www.westrhoderiverkeeper.org). Unfortunately, our northern neighbors in the Magothy have had only a spotty monitoring effort focusing on oyster restoration efforts, and while no anoxia has been reported, we cannot exclude the possibility of summer bottom anoxia in that tributary. Similarly, it is possible that other more distant Chesapeake tributaries experience summer bottom anoxia, but we are unaware of any data supporting such possibilities.

Why doesn't atmospheric oxygen get down 25 feet to the Severn dead zone? Aqueous oxygen concentrations are determined by a balance between local oxygen consumption on one hand and oxygen generation and transport on the other. At the bottom, oxygen is depleted by bacterial metabolism fueled by deposition of organic matter, most classically dead phytoplankton from the water column above. In principle oxygen can be generated within this bottom layer by photosynthesis, but our bad water clarity in the Severn blocks most sunlight, preventing photosynthesis. The major route of replenishing depleted oxygen in the water column is by mixing with well oxygenated surface water, which exchanges gases with atmospheric oxygen. Diffusion of gases like oxygen is negligible at distances of inches, so vertical mixing is the critical component for re-oxygenation of depleted bottom water in the Severn. Thus the Severn's bottom anoxia must result from excessive oxygen depletion driven by high phytoplankton loads or by limited vertical mixing. Since our chlorophyll measurements do not suggest higher phytoplankton loads in the area where we see Round Bay bottom anoxia, we have favored the hypothesis that this area has restricted vertical mixing compared to the lower Severn and other tributaries.

Estuaries classically resist vertical mixing because lighter fresher water flowing seaward layers on top of heavier, saltier water moving up-estuary. The density layering resulting from this vertical salinity gradient is reinforced in summer by solar heating of the surface layers, and the resulting density gradient resists vertical mixing. Several examples of the Severn's density gradients are shown above, and there is no doubt that they are a major factor in limiting vertical mixing. However, the magnitude and intensity of these density gradients do not correlate with bottom anoxia when we compare the various Severn stations (although density gradients appear to be the major factor controlling bottom anoxia in Asquith Creek).

We thus need to consider the forces that promote vertical mixing, which are waves, and turbulence induced by lateral flows (tidal and wind-driven surges). The Severn has the lowest tides in the Chesapeake (about 1 foot), and surge-driven flows are generally slow, so we detect current flows on our monitoring trips only occasionally, and then only below Round Bay. We unfortunately have no data on wave intensity within the Severn. In particular, long-period waves arising from distant wind events are most effective in promoting vertical mixing at depths like the bottom of Round Bay. However, we speculate that such waves could enter the Severn from the Chesapeake and progress upwards towards Round Bay, where they would then lose intensity as they radiate into the much wider water body there. The most plausible explanation for the selective anoxia in northern Round Bay is the limited vertical mixing caused by a combination of 1) the often-steeper and longer density gradients; 2) reduced long-period wave induced mixing compared to other portions of the Severn and other tributaries; and 3) the reduced power of wave-induced vertical mixing at the significantly greater depth of Round Bay compared to neighboring Chesapeake tributaries.

Can the Severn's regular summer bottom anoxia be prevented? Re-oxygenation of hypoxic/anoxic ponds and lakes has been successful using power-driven air injection devices. However the scale of the Severn's anoxia imposes power and accessibility requirements that rule out a parallel approach here. We are unaware of precedents of mechanical approaches to promote vertical mixing that could be adopted locally.

The only factors driving the Severn's anoxia/hypoxia problem that can potentially be controlled are the nutrient inputs driving phytoplankton growth in the affected areas. Unfortunately, current efforts to limit such nutrient inputs have not achieved significant reductions. Although nutrient inputs from the local watershed seem to be the most obvious candidates, it is possible that significant nutrients arrive in Round Bay from the Chesapeake via estuarine flow. It is also not completely clear whether the critical Severn phytoplankton growth is limited by nitrogen or phosphorous, which have significantly different abatement policies. Even if one of these nutrients is identified as critical, the most effective (cost and political) approach towards reducing it is also unclear. Generalizations developed from Chesapeake-wide studies may or may not be relevant when applied to the interesting local conditions we have in the Severn.

Appendix – On-line components

1. Week by week summer Severn mainstem oxygen and salinity profiles are available online at:
http://www.slideshare.net/henkartp/2012-severn-oxygen-salinity
Similar week-by-week oxygen profiles for Severn tributaries are online at:
http://www.slideshare.net/henkartp/severn-hypoxia-2012-the-edge

2. A short video showing monitoring instruments and activities on the monitoring boat can be found at:
http://www.youtube.com/watch?v=bBrAL71D1SM

Acknowledgments

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