IMPACTS OF HURRICANE ISABEL ON MARYLAND WATER QUALITY AND LIVING RESOURCES

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ABSTRACT

Spatially intensive, continuous, and fixed-station water quality monitoring data collected by the Maryland Department of Natural Resources provided an unprecedented opportunity to assess the impacts from Hurricane Isabel on Maryland's Chesapeake and Coastal Bays and tidal tributaries. Isabel made landfall on the Outer Banks of North Carolina on 18 September 2003; the storm's center traveled west of the Chesapeake Bay during much of 19 September. Isabel was noted for its extreme storm surge, but average rainfall statewide was only 3 to 4 in (7.6–10.2 cm) with an additional 2 to 3 in (5.1–7.6 cm) several days later. As a result, continuous monitoring data generally revealed short, one-day increases in salinity up to 7 ppt immediately following the storm, and rises in turbidity over 600 NTUs (nephelometric turbidity units). In many areas, salinities remained elevated by 1–2 ppt for weeks compared to pre-Isabel levels, but were not above average due to the extremely wet conditions of 2003. Turbidities in the shallow-water areas quickly returned to slightly above site-specific averages following Isabel's passage. Winds from Isabel mixed the water column and dissipated the Bay's "dead zone" several weeks earlier than normal. Several days after Isabel, continuous monitoring at 13 of 17 functioning shallow-water monitoring sites, along with baywide remote sensing, showed small ($5\ g \cdot L^{-1}$) to large (>25 $g \cdot L^{-1}$), one- to two-day increases in chlorophyll. Consequently, low dissolved oxygen (DO) resulted with subsequent algal die-offs. Following Isabel, fixed-station nutrient data illustrated that these blooms were most likely fueled by increased nutrient runoff. Hurricane Isabel's impact on living resources in Maryland appeared minimal. Benthic and non-tidal stream reference sites showed little change compared to conditions earlier in the year; impacts to submerged aquatic vegetation were mitigated by the late-summer timing of the storm and increased tidal heights that prevented scouring. Following Isabel, numerous record-low monthly DO levels were recorded for January, February, and March. High nutrient loads (mainly from a wet 2003 but in part due to Isabel), a ubiquitous *Heterocapsa rotundata* bloom, and a winter 2004 ice cover that reduced mixing in the upper Bay are believed to have caused these low DO levels.

INTRODUCTION

For those who study and manage the Chesapeake Bay, no single natural event looms larger in memory than Tropical Storm Agnes in June 1972. Delivering a 10-year or greater average load of sediment in a matter of days, Agnes had a devastating impact upon the Bay's submerged aquatic vegetation (SAV), as well as the oyster and soft shell clam populations—an impact still manifested today. At that time, the Chesapeake research community mounted a large effort, often without assurance of reimbursement or in conjunction with existing projects, to capture the immediate and long-term impacts to the Bay's water quality and living resources. The resulting synopsis, *The Effects of Tropical Storm Agnes on the Chesapeake Bay,* [1] compiled by the Chesapeake Research Consortium, provides a record of these events and a testimony to the great power that natural forces, in combination with anthropogenic influences, have upon ecosystems.

K.G. Sellner (ed.). 2005. Hurricane Isabel in Perspective. Chesapeake Research Consortium, CRC Publication 05-160, Edgewater, MD.

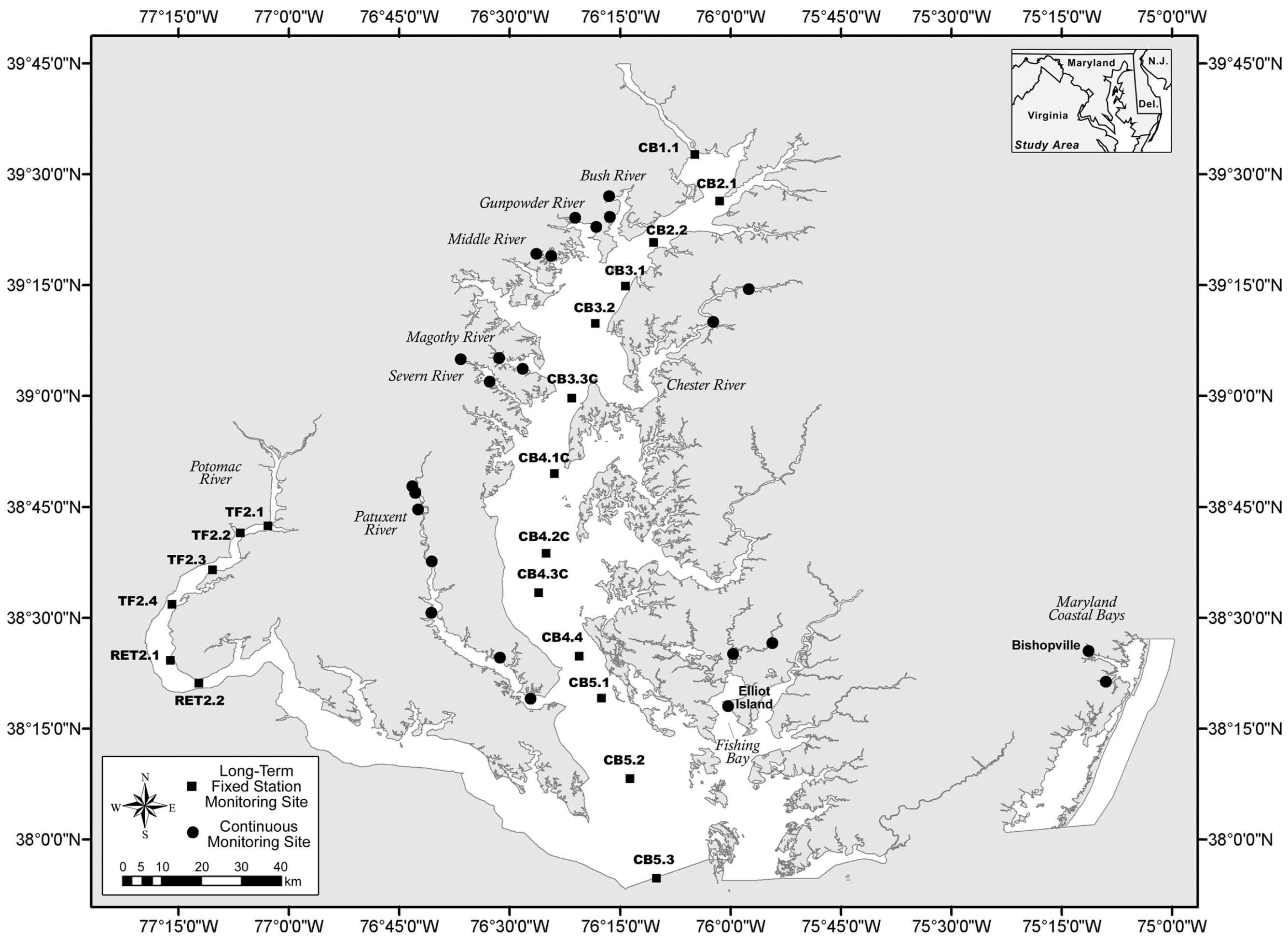

Figure 1. Map of long-term, fixed-station and continuous monitoring sites sampled pre- and post-Isabel.

In the week preceding Isabel, the Maryland Department of Natural Resources (MD DNR) recognized an opportunity to build upon the discoveries made during Agnes. A 20-year data record from fixed stations—many of which were based on locations sampled by the Chesapeake Bay Institute during Agnes—and a network of continuous monitors and spatially intensive sampling allowed an assessment of Isabel's impact on water quality baywide. Continuous monitors sampled ambient water quality at 15-minute intervals throughout the storm. The water quality mapping program provided spatially intensive maps that delineated the extent of water quality degradation.

METHODS

A full suite of ambient physical, chemical, and nutrient samples were collected from fixed stations on the mainstem Maryland Chesapeake Bay and Potomac River (Figure 1). Chesapeake Bay samples were collected on 15–17 September 2003 and 23–24 September 2003. Potomac River samples were collected on 15 and 22 September 2003.

During April through October 2003, 24 YSI-6600 continuous monitoring data sondes were deployed throughout Maryland's shallow tidal waters having depths of 2 m or less (Figure 1). Continuous monitors measured DO, turbidity, chlorophyll, water temperature, salinity, and pH at 15-minute intervals and were usually positioned floating 1 m below the water's surface. To map water quality, a YSI 6600 continuous monitor was also employed, which collected data every 4 seconds at a depth of approximately 0.5 m aboard a moving small boat. The resulting data from throughout each tributary allowed creation of

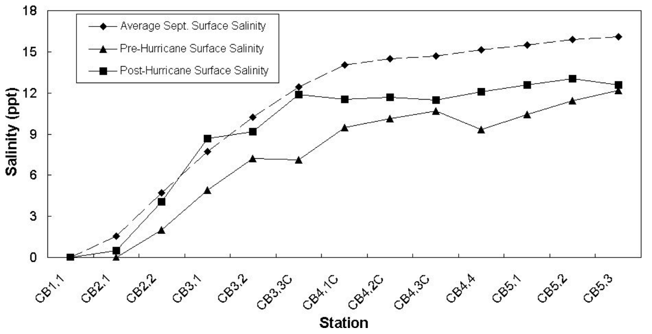

Figure 2. Comparison of long-term, mainstem Chesapeake Bay average September surface salinity (1986–2002) versus surface salinities pre- and post-Isabel. The below-average salinities before and after the storm reflect the extremely wet 2003 season.

spatially detailed maps of surface water quality. From April through October 2003, nine systems were sampled monthly (Severn, Magothy, Patuxent, Middle, Bush, Gunpowder, Chester, Fishing Bay/ Chicamacomico, and Coastal Bays) with special pre- and post-Isabel sampling on the Magothy (4 and 23 September 2003) and Middle (8 and 23 September 2003) rivers.

Complete records of continuous monitoring and water quality mapping data, and select fixed-station data, are available through DNR's Eyes on the Bay website *(www.eyesonthebay.net)*. Full fixed-station datasets are available through the Chesapeake Bay Program's data hub website *(www.chesapeakebay.net)*. Complete collection and analytical methodologies can be referenced in quality assurance project plans for fixed-station monitoring [2] and shallow-water monitoring [3].

RESULTS AND DISCUSSION

Salinity

Salinities along the main stem of the Chesapeake Bay prior to Isabel were well below the long-term (1985–2002) average for September (Figure 2) due to the high amount of precipitation the Bay region received in spring and summer 2003. The tidal surge associated with Isabel increased salinities along the Bay's main stem by up to 5 ppt, but even with this storm-associated increase, salinities remained below the long-term average for September (Figure 2). Water quality mapping of the Middle River pre- and post-Isabel demonstrated a similar slight increase in salinity several days and one month after the storm (Figure 3). Continuous monitors throughout the Bay generally recorded a substantial increase in salinity during and immediately after the storm, followed by a return to pre-storm (or slightly above) levels within approximately 24 hours (Figure 4). In general, salinity increases were more pronounced in tributaries along the Eastern Shore (Figure 5). One notable exception was at Bishopville in Maryland's Coastal Bays, where a large decrease in salinity was attributed to high upstream freshwater input (Figure 5). U.S. Geological Survey stream gauge data from nearby Birch Branch at Showell, Maryland indicated a maximum gauge height on 18 September 2003 exceeding 8 feet (2.4 m)—4 feet (1.2 m) above gauge levels in the days prior to Isabel.

Water Clarity

Hurricane Isabel decreased the water clarity (through increased turbidity) throughout the Chesapeake Bay and the Coastal Bays and their tributaries (Figure 6). This decreased water clarity following the storm was attributed to increased sediment input from upriver sources, shoreline erosion, and re-suspension of bottom sediments. The tidal surge associated with the storm caused extensive damage to waterfront property with localized areas of shore erosion.

The long-term (1985–2002) average September Secchi depths for the upper tidal Potomac River indicated that the wet 2003 spring and summer had resulted in *pre-storm* water clarity that was generally less than long-term averages. Hurricane Isabel further reduced water clarity in the upper tidal Potomac River (Figure 7). Results from 18 statewide continuous water quality monitors revealed water clarity declines in all monitored tributaries (Figure 6). Like the impacts to salinity, continuous monitors generally recorded a substantial decrease in water clarity during the hurricane, followed by a return to pre-storm or slightly poorer than pre-storm conditions within approximately 24 hours (Figure 8). As illustrated by water quality mapping data in the Middle River,

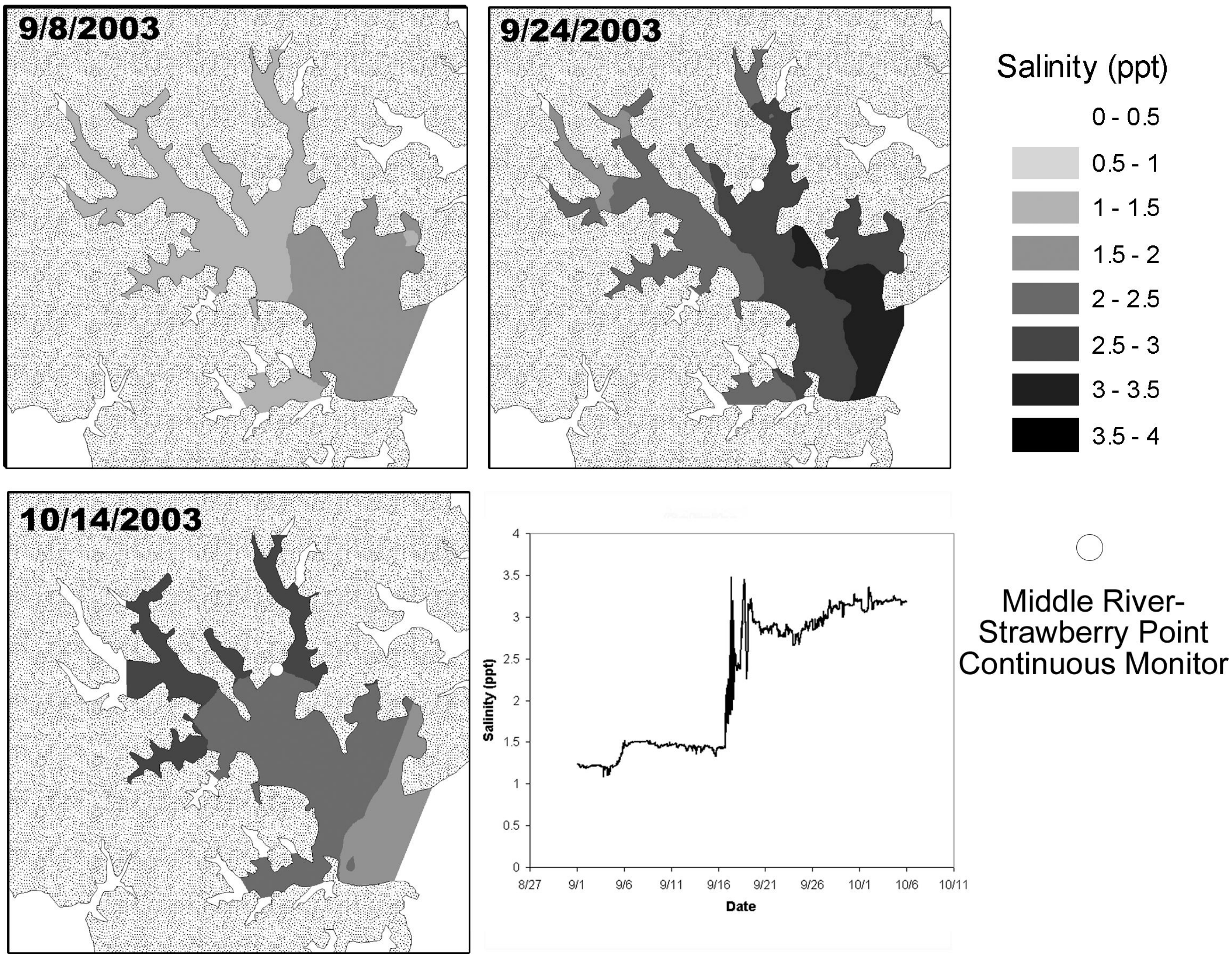

Figure 3. Water quality mapping of surface salinities on Middle River pre- and post-Isabel and continuous monitoring salinity data at Strawberry Point.

upriver locations may have received inputs of sediment after a one-week lag (Figure 9).

Dissolved Oxygen, Chlorophyll, and Nutrients

Post-storm bottom dissolved oxygen in the Bay's main stem increased at most stations over pre-storm and long-term average levels (Figure 10). This effect most likely resulted from water column mixing by winds and waves. Predictably, during the summer months, excessive anthropogenic nutrient additions to a stratified Bay fuel biological consumption of oxygen in unmixed bottom waters [4]. This reduction in dissolved oxygen produces a "dead zone" within which insufficient oxygen remains to support most aquatic life. A mixing of the Bay's waters typically occurs as water temperatures cool in late summer or early fall. The tidal surge and wind mixing from Hurricane Isabel, however, likely hastened this event by several weeks. Spatially interpolated maps of DNR fixed-station dissolved oxygen data, produced by the EPA Chesapeake Bay Program, illustrate the spatial extent of this overturn (Figure 11).

At many shallow-water continuous monitoring stations, higher oxygen levels following the storm were associated with algal production, followed by lower dissolved oxygen as algal blooms died off (Figure 12). The Chesapeake Bay Remote Sensing Program also documented baywide algal blooms following the hurricane (maps are on the website: *www.cbrsp.org*). In early November, a *Prorocentrum minimum* bloom of

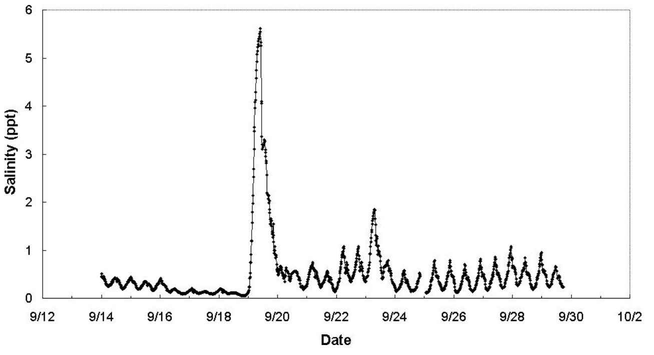

Figure 4. Continuous monitoring salinity data from Deep Landing on the Chester River during Isabel (18–19 September 2003).

over 100,000 cells·ml^{-1} was observed in Breton Bay on the Potomac River.

There was a positive note, however, as pervasive late-summer *Microcystis aeruoginosa* blooms on the Potomac River were dissipated during the hurricane. *Microcystis* is a cyanobacterium that blooms in the fresh and oligohaline, nutrient-enriched portions of the Chesapeake Bay, typically in late spring through fall. *Microcystis* is known to produce cyanotoxins [5]. Human health symptoms related to contact, ingestion, and inhalation of aerosols in bloom regions include itching and watery eyes, skin rashes, gastrointestinal discomfort, vomiting, diarrhea, headache, and fever [6]. Animal deaths have occurred from ingesting bloom-affected waters [6]. In the first week of September, the area near the Potomac River fixed station RET2.1 was the focus of a major *Microcystis* bloom (2 x 10^6 cells·ml^{-1}).

Chesapeake blooms are defined by abundances greater than 1 x 10^4 cells·ml^{-1} [7]. Bloom conditions were observed at lower but significant levels from Indian Head to Morgantown days before Isabel arrived. Initial post-hurricane sampling by the MD DNR and the Department of the Environment indicated that *Microcystis* was still

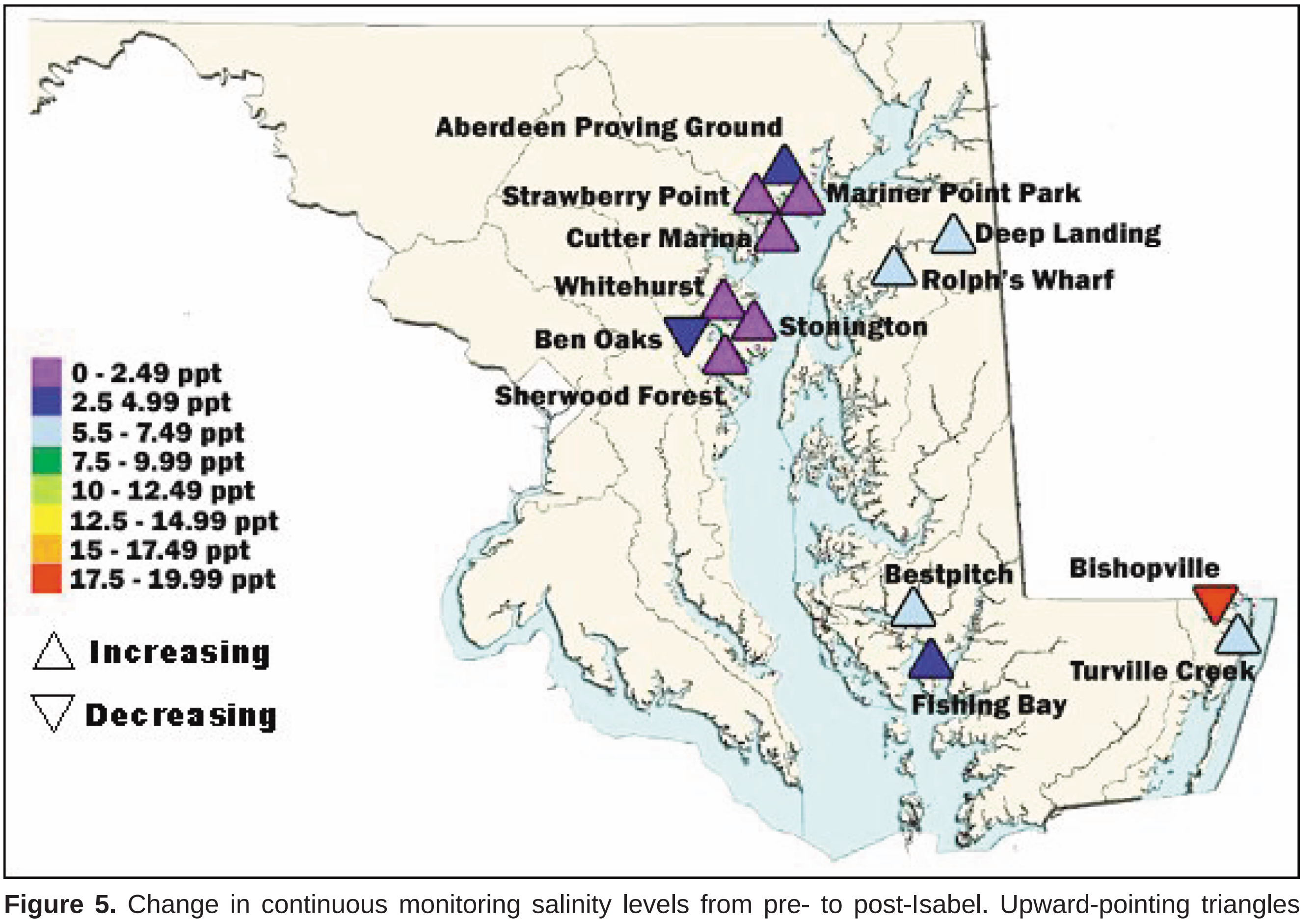

Figure 5. Change in continuous monitoring salinity levels from pre- to post-Isabel. Upward-pointing triangles indicate an increase in salinity; downward-pointing triangles indicate a decrease in salinity.

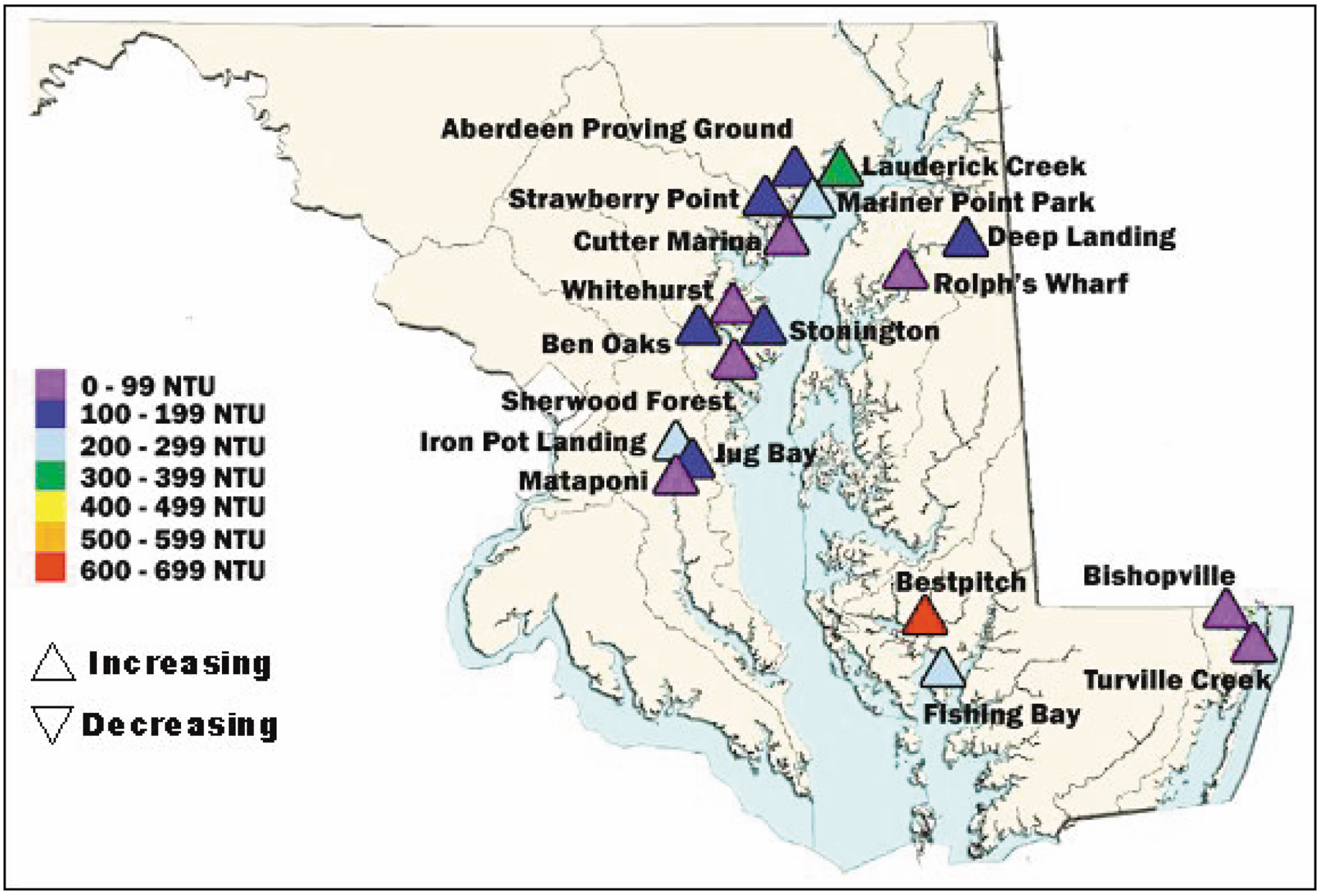

Figure 6. Maximum change in water clarity (turbidity) levels from pre- to post-Isabel from continuous monitoring data. Upward pointing triangles indicate a decrease in water clarity (increase in turbidity).

present on the river, but at significantly reduced levels [8]. *Microcystis* abundances ranging from 53–21,960 cells·ml^{-1}at Station RET2.1 and downstream were well below pre-hurricane levels. Some combination of intensive mixing related to wind effects, storm surge, and high river flows, as well as declines in water temperature to levels below optimal for *Microcystis*, may have caused its lower abundance [8].

In general, nutrient levels were elevated in the wet year of 2003 compared to the drought conditions in 2002, illustrated by average April to

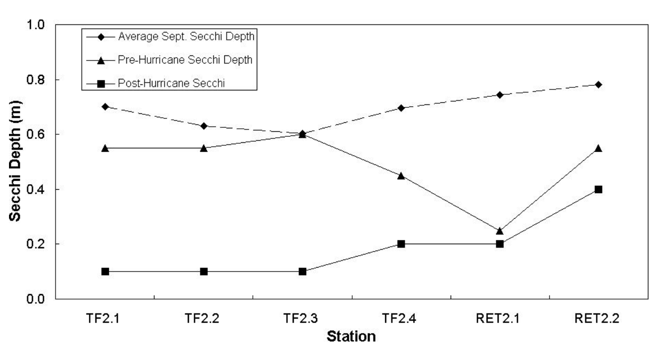

Figure 7. Comparison of long-term, mainstem Potomac River average September Secchi depths (1986–2002) versus Secchi depths pre- and post-Isabel.

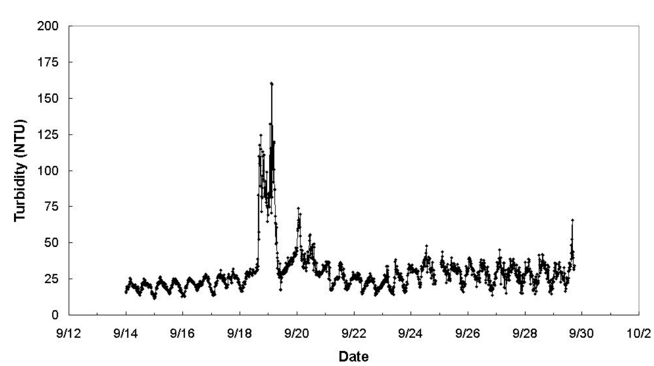

Figure 8. Continuous monitoring turbidity data from Deep Landing on the Chester River during Hurricane Isabel (18–19 September 2003). Higher turbidity values indicate lower water clarity.

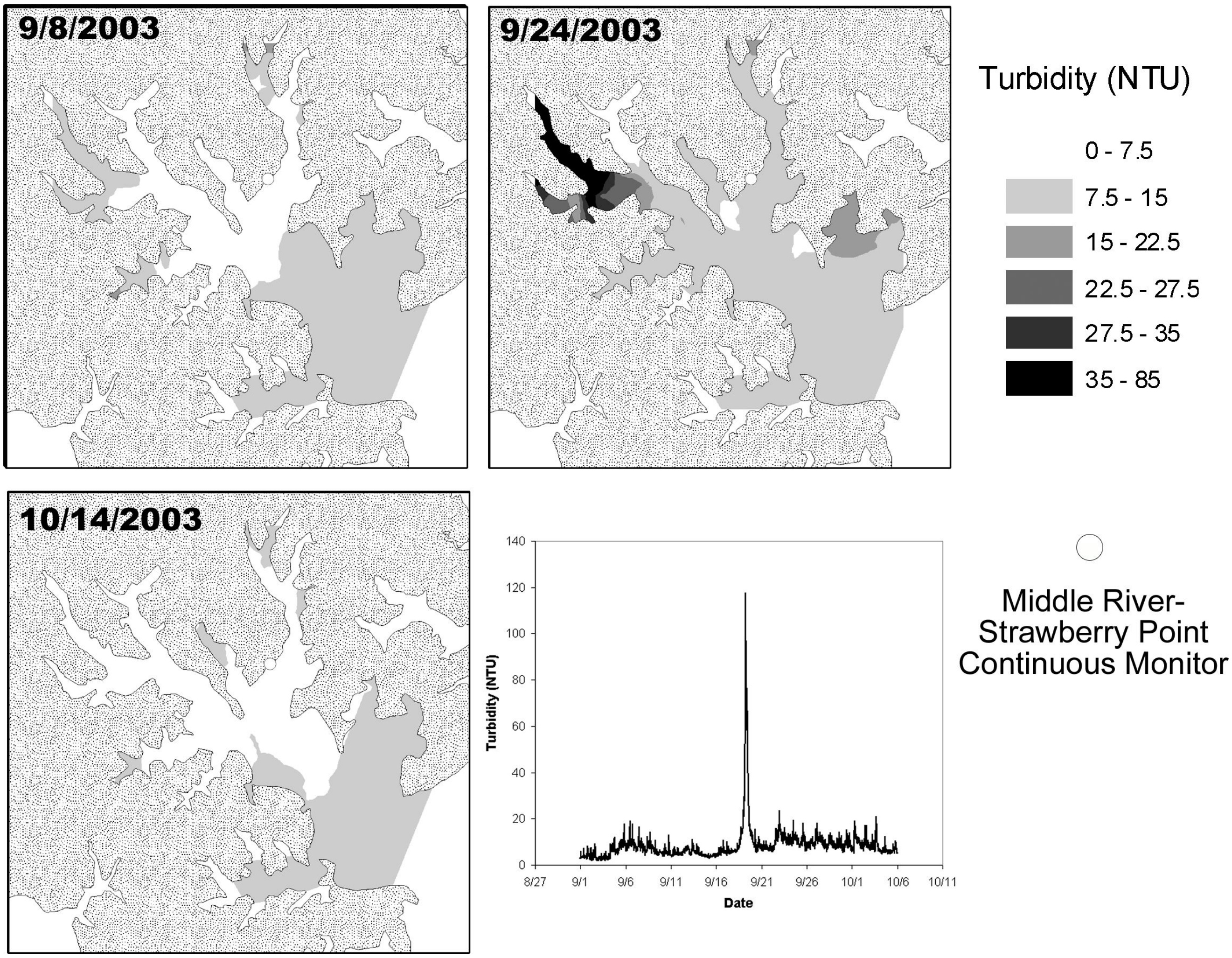

Figure 9. Water quality mapping of surface turbidity on the Middle River pre- and post-Isabel and continuous monitoring turbidity data at Strawberry Point.

October mainstem Bay total nitrogen plots (Figure 13). Pre-Isabel total nitrogen concentrations were already above long-term averages, but were further increased by Isabel in the upper Maryland portion of the Bay (Figure 14). A pulse of phosphate concentrations was also observed post-Isabel in the upper Bay; this pulse correlates well with data from September 2002, when increased rainfall began to alleviate drought conditions (Figure 15).

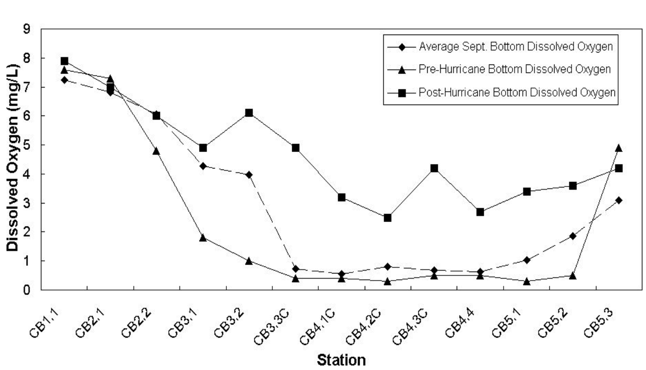

Figure 10. Comparison of long-term, mainstem Chesapeake Bay bottom dissolved oxygen for September with pre- and post-Isabel storm levels.

Ultimately, increased nutrients sent to the Chesapeake during a wet 2003 and during Isabel contributed to relatively low DO levels in the first quarter of 2004. A rather ubiquitous winter bloom of *Heterocapsa rotundata*, perhaps fueled by these nutrients and pervasive ice cover in the upper Bay that inhibited water column mixing, presumably contributed to all-time-low monthly bottom DO observations for January through March 2004 (Figure 16). The most extreme case was a reading of zero for the South River in January.

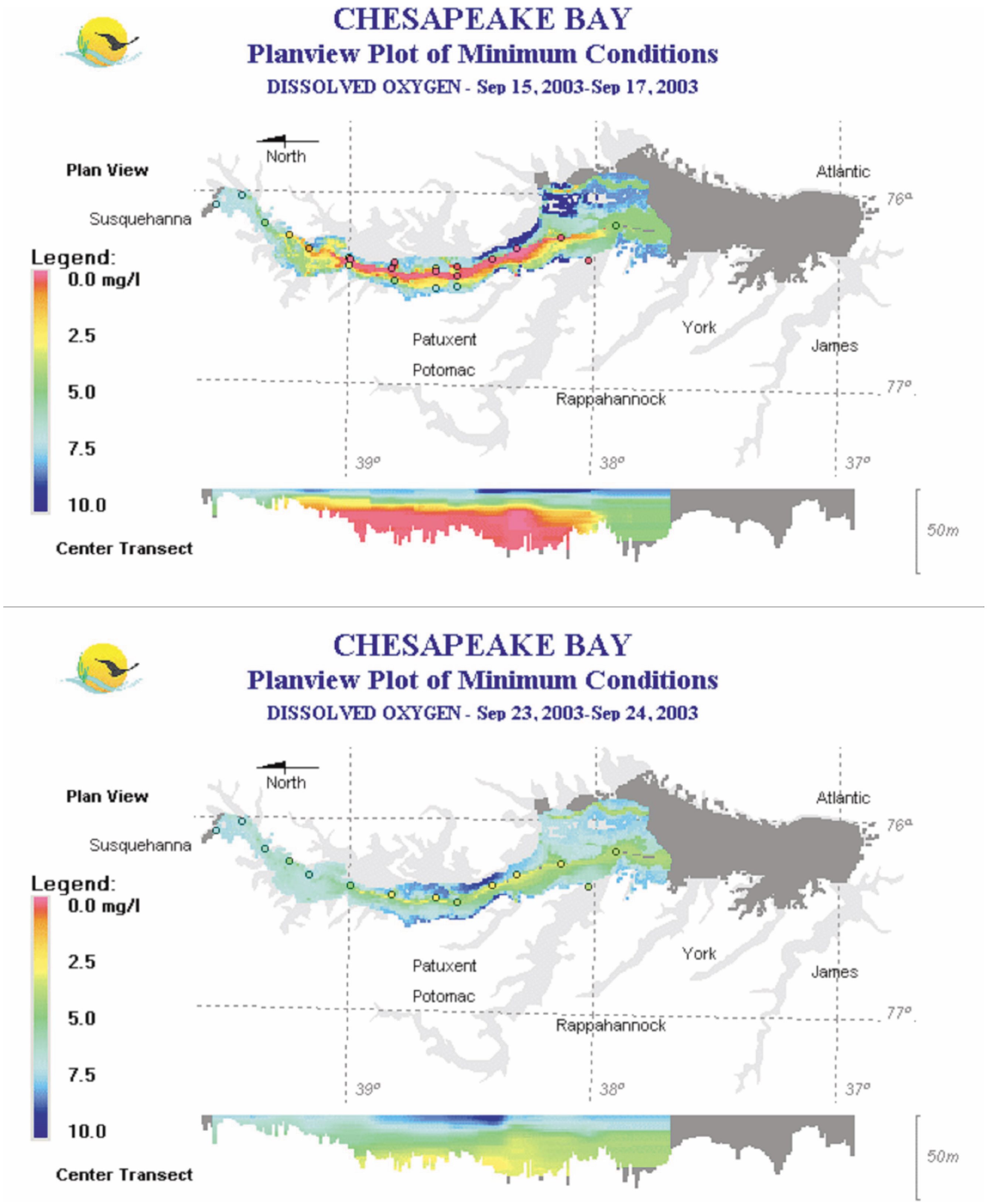

Figure 11. Interpolated plots of minimum dissolved oxygen conditions in the Chesapeake Bay before (top) and after (bottom) Isabel. Provided courtesy of the EPA Chesapeake Bay Program.

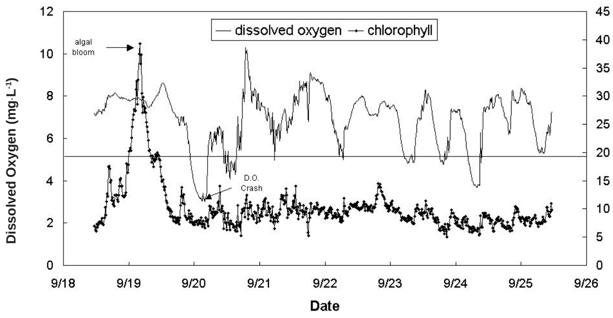

Figure 12. Chlorophyll and dissolved oxygen continuous monitoring data from Elliot Island on Fishing Bay following Hurricane Isabel. Data were collected 1 m below the surface.

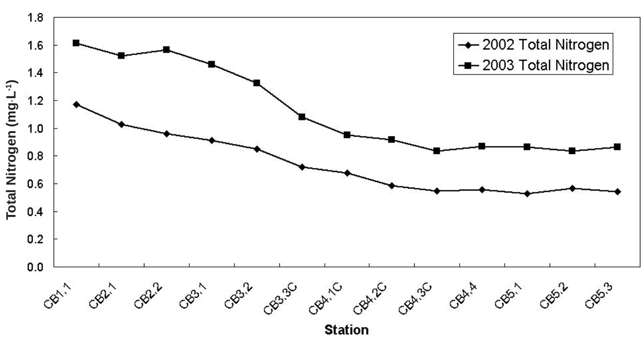

Figure 13. Mean mainstem Bay total nitrogen concentrations (April through October 2002 and 2003).

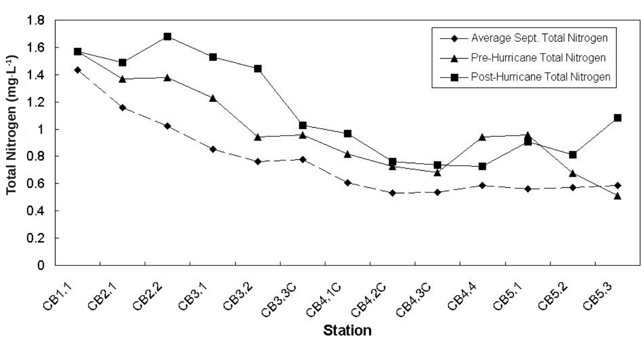

Figure 14. Mainstem Bay total nitrogen concentrations, pre- (15–17 September 2003) and post-Isabel (October) compared to the long-term September mean (1986–2002).

Living Resources

The DNR's Monitoring and Non-tidal Assessment (MANTA) division investigated possible impacts to five representative streams in the Coastal Plain, Piedmont, and Appalachian Plateau. It found no detectable changes in fish community assemblages and minor changes in physical habitat. Greater habitat perturbations occurred during significant rains in spring 2003.

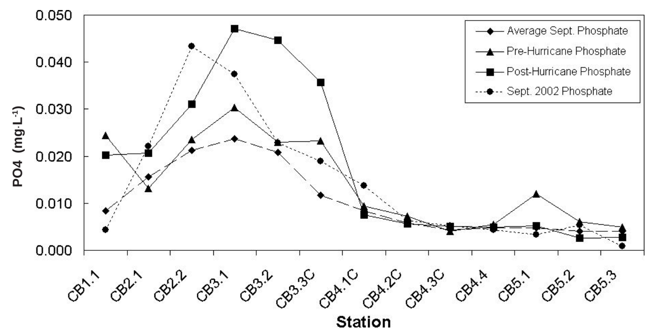

Figure 15. Mainstem Bay phosphate concentrations, pre- (15–17 September 2003) and post-Isabel (23–24 September 2003) compared to September 2002 and the long-term September mean (1986–2002).

Versar, Inc., a DNR consultant, re-examined several benthic reference sites in the Potomac River following Isabel [9]. No significant changes in a Benthic Index of Biotic Integrity (IBI) were observed. Impacts to SAV in Maryland appeared minimal [10]. Turbid conditions in 2003 likely had more impact on SAV than did Isabel. The timing of the storm at the end of the SAV growing season probably prevented the type of extensive damage that occurred during Agnes in June 1972. Also, increased water heights at the time of maximum wave energy prevented extensive scouring of shallow-water SAV beds. Some effects to SAV were observed in Virginia waters from Isabel and are contained in Orth et al. in this volume. Fish and shellfish impacts were not studied for this paper, but are also discussed elsewhere in this volume.

CONCLUSIONS

Advances in monitoring technology have provided the means to assess water quality on increasingly fine temporal and spatial scales. These improved capabilities, coupled with an existing long-term, fixed-station record, provide a greater understanding of the Bay's ecosystem and response to extreme meteorological events and anthropogenic influences. Hurricane Isabel's greatest impacts were the destruction of many human structures; ambient water quality and living resources appeared to escape relatively unscathed. The maintenance and expansion of monitoring technologies and networks in the Bay is, nonetheless,

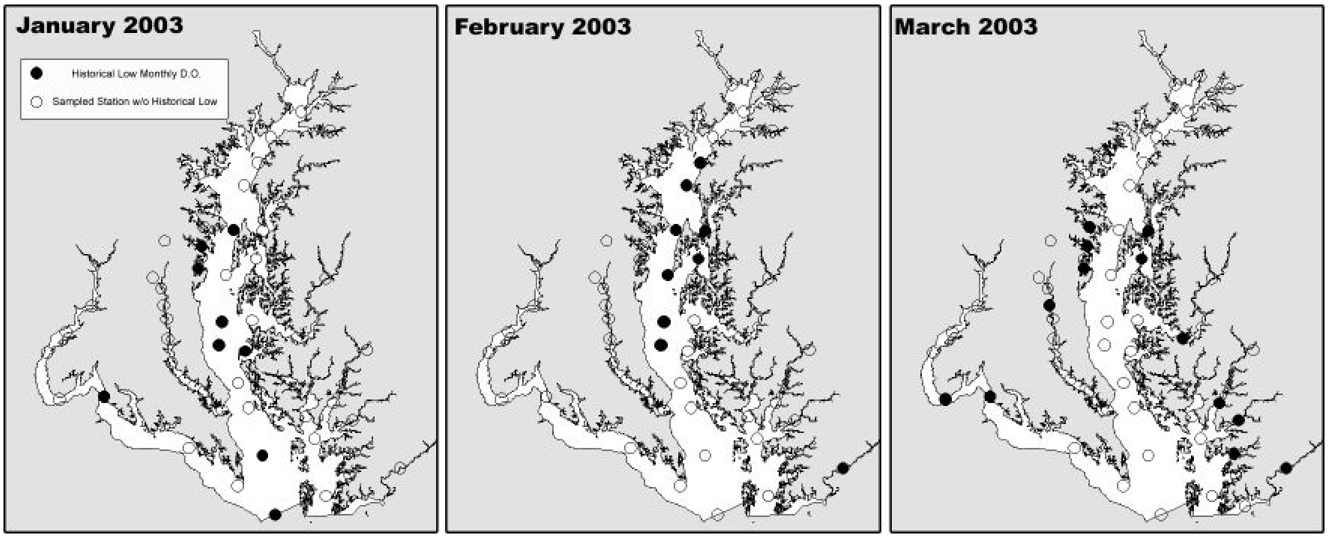

Figure 16. Record-low dissolved oxygen levels in 2003 for January, February, and March compared to monthly data from 1986 to 2002.

of great import and will increase our understanding of the Bay's response to extreme events and guide ecosystem management decisions.

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