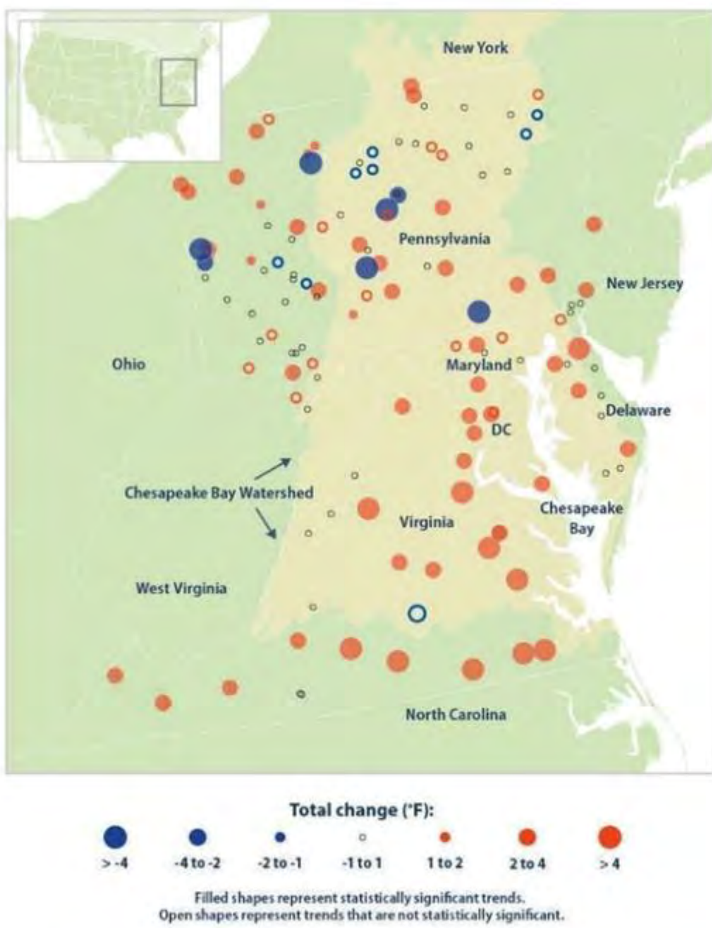
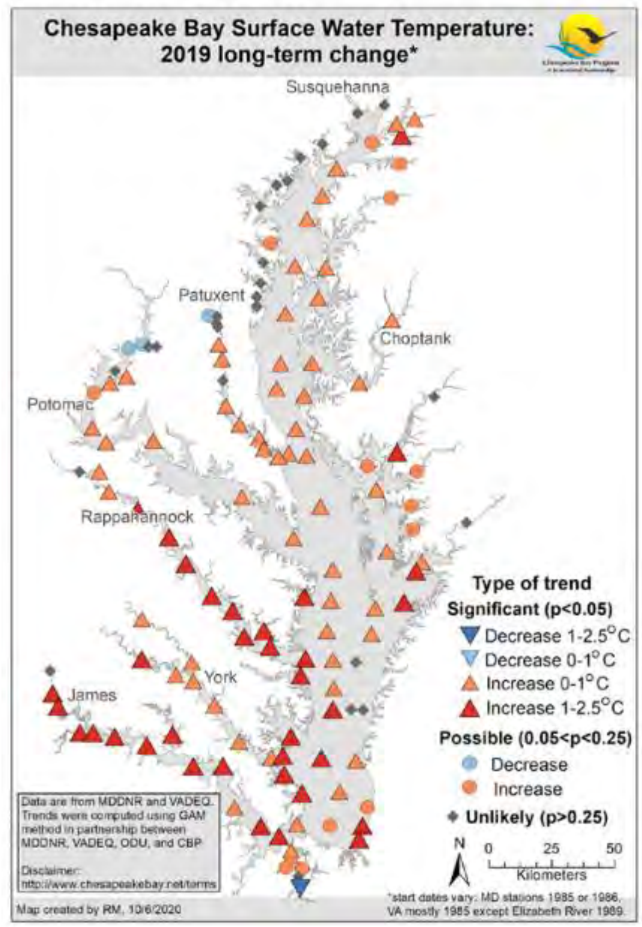
Rising Watershed and Bay Water Temperatures—Ecological Implications and Management Responses





A Scientific and Technical Advisory Committee Workshop Report

STAC Publication 23-001

About the Scientific and Technical Advisory Committee

The Scientific and Technical Advisory Committee (STAC) provides scientific and technical guidance to the Chesapeake Bay Program (CBP) on measures to restore and protect the Chesapeake Bay. Since its creation in 1984, STAC has worked to enhance scientific communication and outreach through the Chesapeake Bay watershed and beyond. STAC provides scientific and technical advice in various ways, including (1) technical reports and papers, (2) discussion groups, (3) assistance in organizing merit reviews of CBP programs and projects, (4) technical workshops, and (5) interaction between STAC members and the CBP. Through professional and academic contacts and organizational networks of its members, STAC ensures close cooperation among and between the various research institutions and management agencies represented in the watershed. For additional information about STAC, please visit the STAC website at www.chesapeake.org/stac.

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Cover graphic: Figure 1. Left. Changes in Stream Water Temperatures in the Chesapeake Bay Region, 1960–2014. Data source: Jastram and Rice, 2015. <https://www.epa.gov/climate-indicators/climate-change-indicators-stream-temperature> **Figure 2.** Right. Long term flow-adjusted trends in bottom water temperatures at the Chesapeake Bay Mainstem and Tidal Tributary Water Quality Monitoring Program stations through 2019 from the Integrated Trends Analysis Team (ITAT). <https://www.chesapeakebay.net/who/group/integrated-trends-analysis-team>

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Executive Summary

As atmospheric temperatures go up, water temperatures have been increasing in the Chesapeake Bay tidal waters and in streams and rivers across the Bay's watershed. Water temperatures are expected to continue rising, based on climate change projections.

Increases in water temperature have significant ecological implications for Bay and watershed natural resources and could undermine progress toward Chesapeake Bay Program (CBP) partnership goals for fisheries management, habitat restoration, water quality improvements, and protecting healthy watersheds. This STAC workshop examined current information on drivers and effects of rising water temperatures and sought answers to a critical question: what might the CBP partnership do now–within the scope of its current goals, policies and programs–to actively prevent, mitigate or adapt to some of the adverse consequences. Adapting to new water temperature conditions will have effects across the partnership.

Workshop preparation showed, from the outset, that the drivers, effects and likely management implications of water temperature increases are quite different between the Bay and the watershed. Therefore, both workshop days featured concurrent watershed and tidal sessions, and the findings and recommendations in the STAC report are organized in the same way.

Rising Water Temperatures in the Chesapeake Bay Watershed

* Water temperatures have been increasing in streams and rivers of the Chesapeake Bay watershed over the past several decades–even more than in the Bay's tidal waters. In many areas, water temperatures increased more than air temperatures, demonstrating that air temperature is not always the primary driver of water temperature in non-tidal waters.

* Land use has a significant impact on temperatures of stream flow and precipitation-induced runoff from land surfaces. Trees and riparian forests play a central role in stream temperature moderation, through shading, evapotranspiration and facilitating infiltration. Conversely, more developed areas with impervious surfaces contribute heated runoff to streams. Other landscape factors, like groundwater inputs, may help identify places that are more resilient to climate change to target for conservation, including healthy watersheds.

* Warmer water temperatures, including shorter-term extreme heat events, will negatively impact aquatic habitats and threaten many ecologically and economically important aquatic species. Stream temperature has direct and indirect effects on many biological, physical and chemical processes in the freshwater environment. Rising water temperatures may increase the occurrence or co-occurrence of known stressors (such as harmful algal blooms) that negatively impact aquatic species and habitats.

* "Cooling" best management practices (BMPs) such as riparian forest buffers, urban tree canopy and stormwater infiltration have the potential to mitigate rising water temperatures but overall, substantially more "heating" BMPs have been installed in the watershed. This suggests

that some practices implemented to improve water quality may be having unintended consequences for water temperature.

These findings and management implications led to the development of the following **recommendations** applicable to the lands within the Bay's watershed and its streams and rivers:

Coldwater Fisheries and Habitats: Chesapeake Bay Program partners need to accelerate conservation to protect the coldwater streams now supporting healthy aquatic life, especially native brook trout, which are extremely sensitive to rising water temperatures, and continue resiliency analyses and mapping to focus on coldwater habitat restoration efforts.

Rural Waters and Habitats: In rural areas, CBP partners should work to strategically restore forests and aquatic habitats while promoting good agricultural stewardship practices that can reduce the amount of heated runoff being generated by farms.

Urban Waters and Habitats: In urban areas, CBP partners should increase tree canopy, vegetation and practices favoring infiltration to reduce the amount of heated runoff entering waterways, paying attention to under-served urban areas which historically suffer the worst heating and human health outcomes.

Best Management Practices (BMPs): The CBP partners should work to minimize the extent to which water quality BMPs are further heating waterways, and strategically use cooling BMPs to counteract the warming effects of climate change and land use where possible.

State Temperature Water Quality Standards: Given the vital role of Clean Water Act water quality standards (WQS) in focusing federal, state, local and private actions to protect water quality and aquatic life. The Bay states and EPA should review and modernize the components of current WQS systems that would strengthen their capability to address climate-related rising water temperatures and drive area-targeted protection and restoration strategies.

Implementation actions and science needs are suggested in the report for each of these recommendations.

Rising Chesapeake Bay Tidal Waters Temperature

* Over the past three decades, the tidal water temperatures in the Chesapeake Bay have been increasing. These changes in tidal water temperatures are primarily driven by global atmospheric forcing (e.g., increasing surface air temperatures) and the warming ocean boundary.

* Rising water temperature in the Chesapeake Bay is already having an impact on many species and contributing to ecosystem regime shifts. Climate vulnerability scores and bay-specific research show a range of positive and negative responses of living resources to temperature and other climate change related factors.

* Positive impacts are likely for blue crab and some forage species (e.g. bay anchovy and menhaden), as warmer temperatures support higher productivity and increased habitat range as species move northward. However, shifts in predator distributions and diminishing seagrass habitat can have negative indirect effects on populations.

* Negative impacts are predicted for oysters due to their already depressed populations as a result of disease, overfishing, and habitat loss. While they can thrive in warmer temperatures, they are highly vulnerable to these stressors along with other climate-driven stressors, such as ocean acidification and changes in salinity driven by precipitation.

* Striped bass may experience both negative and positive effects from rising water temperatures at different life stages (larval to adult) and habitat use (rivers and estuaries to marine). While gradually rising water temperatures are important, other stressors (e.g., low water column dissolved oxygen that reduces the area of suitable habitat) and climate change consequences that exacerbate the exposure of species to heightened multiple stressors (e.g., increases in precipitation affecting nutrient loadings resulting in further decreases in dissolved oxygen, salinity fluctuations) and extreme events (e.g., increases in marine heat waves), are of great concern for maintaining populations in Chesapeake Bay.

* Without drastic improvements in water clarity or a reversal of warming trends, viable populations of eelgrass will likely be extirpated from Chesapeake Bay.

* Northward shifts in species ranges are being documented for several species. This is resulting in some Bay species shifting populations north while other species from the south are becoming more prevalent in the Bay. These shifts can result in changes to species abundance and distributions, food web dynamics, fishing behavior and the introduction of new fisheries.

* Likewise, habitats required by fish and shellfish species are shifting in range and experiencing impacts that lead to changes in fish abundance, distribution and reproduction success.

* Hardening of shorelines (use of bulkheads and rip rap) in response to shoreline erosion has negative impacts on fish communities and habitat, submerged aquatic vegetation (SAV), waterfowl, and water quality. Natural infrastructure provides ecosystem services in the face of climate change, including shoreline erosion protection, refuge of species from multiple stressors, including warmer temperatures, sedimentation mitigation, and improved water quality.

These findings and management implications led to the development of the following **recommendations** applicable to the Bay's tidal waters:

***Ecosystem-Based Management and New Temperature Regime*:**

- Establish Chesapeake Bay-wide striped bass fishing guidance based on temperature and dissolved oxygen thresholds to reduce catch and release mortality. Consider developing habitat condition thresholds and fishing guidance for other recreationally targeted species at risk during periods of poor habitat conditions.

- Develop and implement a strategy to improve communications between living resource managers, scientists and stakeholders on the new temperature regime, the impacts and management response/adaptation strategies.

- Hold a workshop with multiple fishery stakeholders to explore strategic, long-term ways to advance ecosystem approaches to fishery management in the Bay that incorporate climate change.

Multiple Stressors**:** An interdisciplinary team of scientists, resource managers, meteorologists, and communicators should collaborate to design and create a publicly available marine heat wave alert system. Consider a marine heat wave indicator that incorporates dissolved oxygen and links to habitat preferences of key species such as striped bass, blue crabs, oysters, and SAV.

Nearshore Habitat**:** Chesapeake Bay Program partners should develop common criteria and metrics to help target, site, design and implement tidal natural infrastructure projects in the nearshore where ecological and climate resilience benefits are highest.

Implementation actions and science needs are suggested in the report for each of these recommendations.

Across the Chesapeake Bay Watershed and the Bay's Tidal Waters…

There are significant gaps in understanding to be filled. The management recommendations are thus paired with recommendations for research, monitoring, modeling, and data analysis and interpretation. During the concurrent watershed and tidal sessions, the following common themes and linkages were identified:

- Modeling tool improvements: modeling at a finer scale, incorporating temperature change in our modeling systems, and improving the connections between models and monitoring of living resources is needed to better respond to rising water temperatures.

- Expanded monitoring: expanding monitoring networks to place more emphasis on tracking and better understanding water temperature change, and a focus on smaller streams, are necessary enhancements to the partnership's existing watershed monitoring network.

- Paired water and air temperature measurements: improving the ability to pair information about trends in water temperature with trends in air temperature at the appropriate scale will greatly improve understanding of the forces driving rising water temperatures and support management decisions.

- Nearshore research: improving understanding is needed on how and to what degree watershed BMPs can minimize warming for nearshore habitats of tidal tributaries in short to mid-term timeframes related to cooling benefits for SAV and fish.

- Thresholds: understanding threshold tolerance limits and communicating about the implications of thresholds to decision-makers and the public to improve understanding of why management tools and actions are needed to respond to rising water temperatures.

- Communication: communication with each other, with decision-makers, and with the public is key to ensuring that the implications of rising water temperatures are considered in decision making.

The CBP's management strategies and action plans for meeting the Program's goals in the 2014 Watershed Agreement need to take account of the fact that a critical, basic condition—water temperature—has been changing and will continue to do so. This STAC workshop was structured to initiate the full consideration of rising water temperatures in nearly every restoration, conservation, education and public communication decision—made individually as well as collectively—by the Chesapeake Bay Program partners. The recommendations include many actions which can be initiated in the near future, as well as actions in science, monitoring, modeling and program implementation which will help guide the Program in setting future goals.

1. INTRODUCTION

1.1 Workshop Goals, Objectives and Approach

Water temperature increases are occurring in Chesapeake Bay tidal waters and in streams and rivers across the Bay's watershed, and are expected to continue based on climate change projections. Water temperature increases have significant ecological implications for Bay and watershed natural resources, and could undermine progress toward Chesapeake Bay Program partnership goals for fisheries management, habitat restoration, water quality improvements, and protecting healthy watersheds. There is a critical need for insights into what the CBP partnership might do now–within the scope of its current goals, policies and programs–to prevent, mitigate or adapt to some of the adverse consequences. This STAC workshop was structured to help meet these needs through two primary objectives:

- Summarize major findings on the ecological impacts of rising water temperatures, including science-based linkages between causes and effects, on tidal and watershed living resources; and
- Develop recommendations on how to mitigate these impacts through existing management instruments, ranging from identifying best management practices to adapting policies and analytical approaches.

1.2 Management Relevance, Urgency and Outcomes

The impact of climate change on the restoration and protection of Chesapeake Bay and its watershed is being monitored, modeled and studied, and new knowledge is being gained. This workshop took advantage of available knowledge to determine how to better direct or redirect CBP partnership management instruments to help prevent, mitigate or adapt to harmful effects from water temperature increases. Examples of these management instruments include: (1) identification and better quantification of the benefits from temperature-lowering best BMPs for targeted implementation in the states' Phase III Watershed Implementation Plans (WIPs); (2) changes to habitat restoration strategies to mitigate or adapt to rising water temperatures; (3) adaptation of partnership and states to proactively respond to fisheries impacts associated with projected increases in watershed and Bay tidal water temperatures; and (4) enhancing the partnership's mapping and modeling tools to better evaluate where watersheds may be more vulnerable or resilient to stream temperature changes.

Previous STAC-sponsored and other scientific research and monitoring efforts have documented that water temperatures are rising and discussed their potential effects on the Bay and its watershed (for example, Najjar et al., 2010). However, for nearly four decades, the CBP partnership has largely based its restoration and protection goals and decisions on assumptions of constant air and water temperature regimes. Further, the partnership has focused on nitrogen, phosphorus and sediment pollutant load reductions as the means to restore water quality and aquatic ecological integrity, with limited consideration of water temperature. Recently, the partnership has placed emphasis on possible impacts of climate-related changes, such as how BMPs might function in light of changing precipitation patterns, but not increasing water temperatures. So, there was a critical need for a STAC workshop on better understanding the potential effects of rising water temperatures and developing options to mitigate these effects.

This STAC workshop provided the ideal forum for: (1) updating information on the potential effects of rising temperatures; (2) improving understanding of the science-based linkages between causes and effects; and (3) using the enhanced scientific and technical foundations for recommending changes in partnership priorities, policies, and management decision support systems and tools. The findings and recommendations from this STAC workshop have provided the needed credibility for the partnership to fully factor increasing water temperatures into its decision-making for achieving the partnership's shared fisheries, habitat, water quality and healthy watersheds goals. To influence the states' implementation of the Phase III WIPs through 2025, stronger linkages between rising water temperatures and decisions about the selection and placement of BMPs must be forged now to change basinwide, regional and local decision-making in 2023-2025 and beyond.

Several participants in the workshop asked about including human health impacts that might be associated with water temperature rises -- issues such as the impact of heat-promoted harmful algal blooms on recreational use of tidal and non-tidal water, or effects on drinking water source supplies. Questions about how water temperature increases could affect human health-related water uses are clearly important to citizens, local governments, organizations and agencies, but they were beyond the scope of this STAC workshop.

1.3 Workshop Preparation and Planning

We addressed the workshop outcomes in three sequential phases, leading to production of the final workshop report.

Phase 1 This workshop preparation phase began with in-depth compilations of the CBP partners' and stakeholders' current understanding about Bay watershed and tidal water temperature increases, their ecological implications, any recognized temperature change thresholds, and current understanding of actions being taken to actively prevent, mitigate or adapt to rising water temperatures. The workshop's sponsoring committees, goal implementation teams (GITs), and workgroups were also challenged to initiate work on identifying a range of possible actionable recommendations to be considered and discussed at the workshops. For the first step in preparation for the two one-day STAC workshops, a series of nine synthesis papers and an addendum were prepared by teams of co-authors documenting the current state of knowledge of each of the topic areas to be addressed in the workshops (see Appendices D-M). In addition, the CBP Climate Resiliency Workgroup hosted a one-day working session in June 2021 devoted to a cross-workgroup review of our current level of understanding about rising watershed and Bay water temperatures (see Appendix U).

Phase 2 The first workshop was a one full-day virtual meeting held on January 12, 2022. Concurrent tracks were designed to identify the ecological impacts and management implications of rising water temperatures on the watershed and tidal waters, respectively. This first workshop focused on building a more complete picture of interrelationships between the causes of increasing water temperature, the resultant ecological impacts, the range of management implications, and the relative scales of these causes and effects. For Day 1 plenary presentations, see Appendix Q; for links to recordings from Day 1, see Appendix R.

Phase 3 The third phase started with the STAC Workshop Steering Committee working from a synthesis of the first workshop to refine findings on the interrelationships and to develop draft recommendations for more effective use of the partnership's management instruments. The second workshop, one full-day virtual meeting held on March 15, 2022, focused on in-depth discussions to build consensus on the first workshop's findings and provide input on actions that the CBP partnership could take to address the impacts of rising water temperatures, capped off by a panel discussion among managers from across the partnership. Day 2 plenary presentations and links to session recordings can be found in Appendix Q and Appendix R, respectively.

1.4 Workshop Questions

The following questions drove the agendas for each of the one-day workshops based on parallel sessions focused on the watershed and the tidal waters issues, respectively:

Watershed Questions

- What do we know about what is driving rising water temperatures and what knowledge gaps do we need to fill before making management recommendations?
- What species and habitats are most vulnerable to the direct and indirect effects of rising water temperatures and what knowledge gaps do we need to fill before making management recommendations?
- What management actions are needed to address the known drivers and ecological impacts of rising water temperatures in coldwater, rural warmwater, and urban warmwater habitats across the watershed?
- How can state water quality standards be updated to better address rising water temperatures driven by land use and climate?
- Where are opportunities to better use or improve the Bay Program's existing monitoring programs and modeling tools to inform management decisions to address rising water temperatures?

Tidal Questions

- What are the direct and indirect positive and negative effects of rising water temperatures on the fishery and SAV resources?
- Are there certain effects more concerning than others from a resource management standpoint?
- What are the key factors to consider for the fishery/SAV resources to inform management action around these effects?

- How certain is our knowledge of temperature sensitivities on the fishery/SAV resources?
- What research gaps do we still need to fill to inform management action around temperature sensitivities (e.g., establishing temperature thresholds)?
- What temperature-specific analyses would be most useful for informing management actions for the fishery/SAV resource?
- Looking at the ecological effects, key factors to consider, and sensitivities related to rising water temperatures identified today, what are the management implications for the fishery/SAV resources?
- What management actions are agencies taking now or planning to address Bay water temperature change to the fishery/SAV resources?

1.5 Workshop Report

This workshop report is structured by focusing first on the effects of rising water temperatures up in Chesapeake Bay's watershed followed by effects in Chesapeake Bay tidal waters. Within this workshop report, references to "watershed" means all the lands which ultimately drain to Chesapeake Bay and its tidal tributaries and embayment as well as free flowing rivers and streams. References to "tidal" mean all tidally-influenced waters within the Chesapeake Bay and its tidal tributaries and embayments and the adjacent shorelines. The separate focus on watershed and then tidal waters reflects the very different nature of the drivers behind the observed increasing water temperatures as well as the resulting effects on the living resources which depend on these free-flowing and tidally-influenced aquatic and estuarine ecosystems, respectively. These two separate sets of storylines, management implications and recommendations are then brought together in the context of a management perspective and a drawing out of commonalities between these two different ecosystems.

2. WATERSHED RISING WATER TEMPERATURES

2.1 What We Know: Watershed Storyline

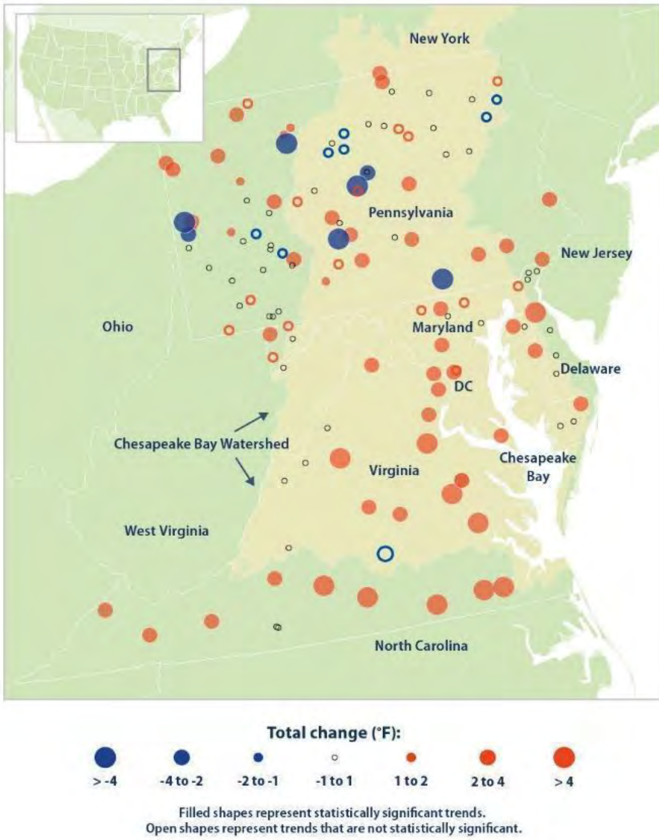

Figure 1: Changes in water temperatures in streams and rivers of the Chesapeake Bay watershed. Source: https://www.epa.gov/climate-indicators/climate-change-indicators-stream-temperature, based on data from Jastram and Rice, 2015

Water temperatures have been increasing in streams and rivers of the Chesapeake Bay watershed – even more than in the Bay's tidal waters. Furthermore, in many areas, water temperatures increased more than air temperatures from 1960 to 2010 in the Chesapeake Bay watershed (Rice and Jastram, 2015; Synthesis Element 5 Paper, Appendix I). This demonstrates that air temperature is not always the primary driver of water temperature in non-tidal areas (Figure 1). Air to water temperature ratios at sites show where land use or other factors are driving or buffering changes in water temperature.

Rising water temperatures can have major implications for stream ecosystems, local communities, as well as land and water management. Impacts on vulnerable coldwater species, such as the eastern brook trout, are of particular concern.

More robust data sets and methods should soon be available for evaluating annual and seasonal stream temperature trends (see for example Wagner et al. 2017). Stream ecosystems will likely be affected not only by longer-term stream warming trends, but also by shorter-term temperature events, including pulsed heat waves (see Tassone et al. 2022).

<u>Drivers of Changes in Water Temperature</u>

Changes in stream and river temperatures can be driven by rising air temperatures, but other drivers also have a strong influence. The workshop team developed a conceptual model summarizing the mechanistic drivers of non-tidal water temperature and their direction of influence (Figure 2). Negative arrows indicate drivers that can reduce water temperatures or provide a buffer against warming water temperatures. Positive arrows indicate drivers that can further exacerbate rising water temperatures. Many other interacting factors influence these broader drivers. A more detailed conceptual model is provided in the Synthesis Element 7/8 Paper, Appendix K. Land use, for example, has a significant impact on stream flow and runoff temperature, with riparian forest shade generally cooling streams relative to air temperature, while temperatures in streams receiving urban runoff from streets and other impervious surfaces may be higher than air temperature.

The relative importance of each driver will vary depending on the local landscape and the spatial and temporal scale of interest. Certain drivers will have a stronger influence either in the short or the long term, and certain drivers will have a more localized influence on water temperatures (i.e., channel buffering capacity), while others may have a broader influence on water temperature across the landscape (i.e., upstream land use). Additional work and site studies are needed to connect these mechanistic drivers with appropriate site- and area-specific information to inform management and land use decisions.

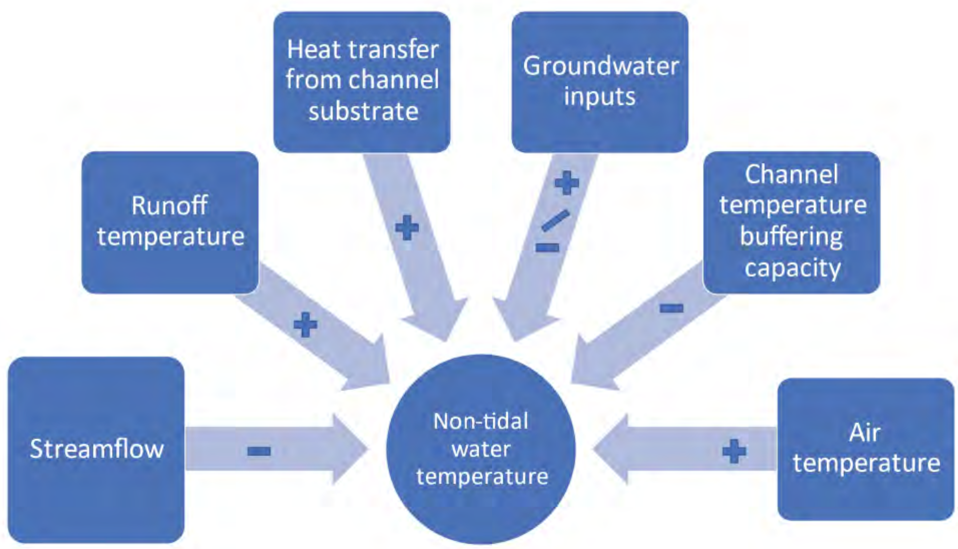

Figure 2: Major drivers of non-tidal water temperature and the direction of their influence. Source: Synthesis Element Paper 7/8, Appendix K.

During Day 1 of the workshop, participants were asked to rank the primary drivers in terms of their relative influence on water temperature and ability to influence the driver. Most of the drivers ranked highly in terms of their influence on water temperature (Figure 3). Runoff temperature, stream flow and channel buffering capacity were also identified as drivers that can be influenced through management. Other drivers, like groundwater inputs, may nonetheless be important to consider when identifying places and habitats that may be more resilient to climate change when targeting for conservation.

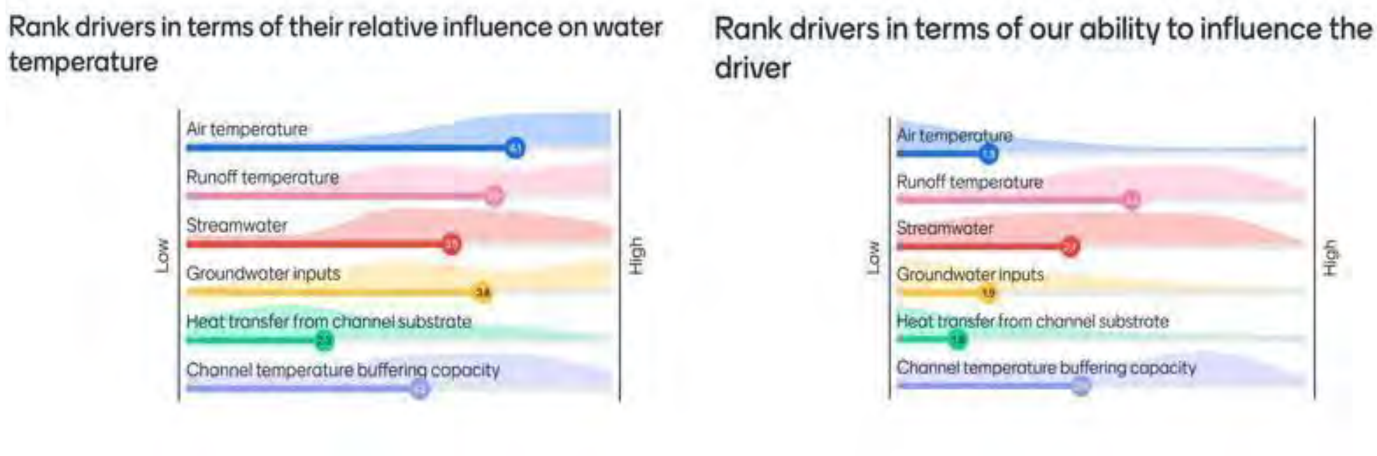

Figure 3: Left: Rankings from Workshop 1 participants (n=35) on the relative influence of each identified driver on water temperature. Rankings are on a scale from 0 (no influence) to 5 (very strong influence).
Right: Rankings from Workshop 1 participants (n=38) on our relative ability to influence each driver through management. Rankings are on a scale from 0 (no ability to influence) to 5 (very strong ability to influence).
For both figures: Circles represent the average ranking and the curves above each driver show the distribution of rankings.

Drivers of Rising Water Temperatures: Priority information needs

A key uncertainty is the degree to which various drivers and interactions between drivers influence water temperature in specific sub-watersheds. There is a need to invest in a strategically-designed stream temperature monitoring network that can answer the major questions about climate effects and other actions that influence water temperatures. Greater high-frequency or continuous water temperature monitoring is needed to better understand the relative local watershed/sub-watershed influence of various drivers as well as water temperature trends (including seasonal effects). State water quality standards monitoring strategies that focus on point source impacts may not be as useful for monitoring broader spatial and temporal trends. Additional monitoring is also needed at the air/water interface to identify hotspots where drivers are having a particularly large impact on water temperature as a way to target management. Finally, improved understanding of groundwater inputs is needed. Specific needs include better regional/sub-watershed models, more localized information about groundwater inputs, and a better understanding of how climate change could impact groundwater inputs.

Ecological Implications of Rising Water Temperatures

The workshop team adapted a high-level conceptual model of freshwater resource vulnerability from Foden et al. (2013) (Figure 4). This biophysical model does not include resource management considerations, such as the costs associated with protecting species or habitats. The

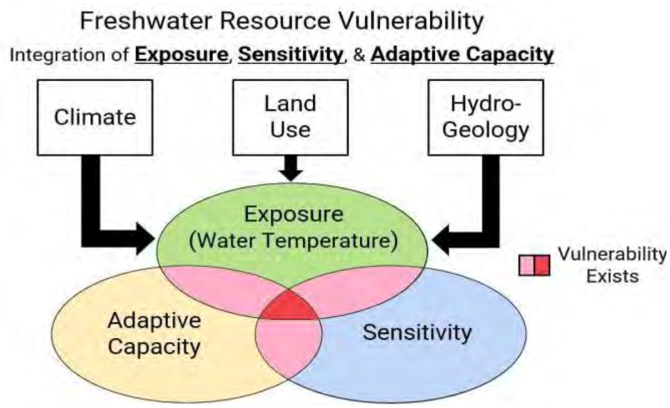

Figure 4: Conceptual model of freshwater resources vulnerability, Source: Foden et al. 2013.

model integrates a species or a habitat's vulnerability based on its **exposure** to rising water temperature, its **sensitivity**, as well as its **adaptive capacity**.

Warmer water temperatures will negatively impact aquatic habitats and threaten many ecologically and economically important species. Stream temperature has direct and indirect effects on many biological, physical and chemical processes in the freshwater environment, including significant impacts on fish metabolism, physiology and behavior, as referenced in the non-tidal fisheries and stream health paper, Synthesis Element 1Paper (Appendix D). It is expected that the strongest negative species-level impacts will be on coldwater species (e.g., eastern brook trout *Salvelinus fontinalis*) due to their exposure and sensitivity to rising water temperature. However, watershed-wide, warmwater aquatic species are most common. Although more tolerant to temperature increases, they are sensitive to extreme temperatures (see ORSANCO *Temperature Criteria Re-evaluation* 2005 in Synthesis Element 1 Addendum, Appendix E) and to indirect effects of higher temperatures, such as lower dissolved oxygen concentration and competition with non-native species.

Workshop participants were asked to rank eight species in terms of their relative exposure and sensitivity to rising water temperature. Participants perceived a positive relationship between a species' perceived exposure to rising temperature and a species' sensitivity to rising temperature. Brook trout and checkered sculpin (coldwater species) were ranked the most exposed and sensitive to rising water temperature.

Brook trout are an essential part of the headwater stream ecosystem, an important part of the upper watershed's heritage (the freshwater state fish of Virginia, West Virginia, Pennsylvania and New York), and a highly-prized recreational resource. Synthesis Element 1 reviews models developed to predict stream temperatures and brook trout occupancy, and first-cut predictions are dire for occupancy impact as water temperatures rise (Appendix D). However, the paper points out factors that can mitigate the impact and response of streams to increases in air temperature, such as land use, landform features and fine-scaled groundwater inputs. Cold groundwater input increases a stream's capacity for supporting coldwater fisheries.

Fine-scale analysis is required to identify patch/catchment characteristics and their interactions on thermal resiliency. Site-specific data are needed on local groundwater inputs to identify streams that may be particularly vulnerable or resilient to warming surface water temperatures. Protecting native brook trout habitat and the contributing watersheds/sub-watersheds thus requires protection/restoration strategies at the patch scale.

Spatial characteristics also influence exposure to rising water temperatures. These include cross-sectional features of the stream channel, aquatic connectivity, and landscape features, and whether there are accessible thermal refugia during extreme heat events, can also influence exposure to rising water temperatures. In general, waterways with low-forested watershed cover, sparse riparian cover, and heated urban runoff are particularly vulnerable to warming.

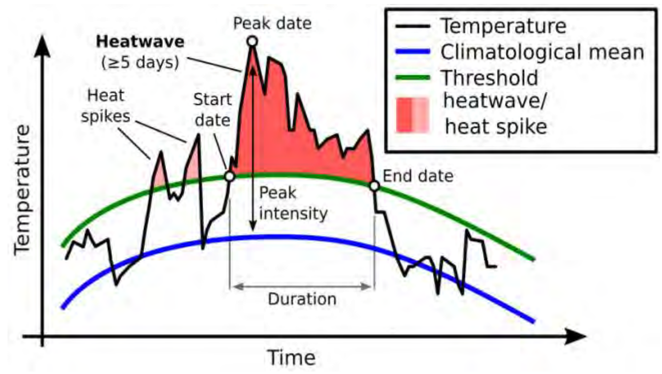

Figure 5: Characteristics of aquatic heatwaves. Source: Hobday and others 2016.

The ecological impacts of rising water temperature are influenced by specific ways in which temperature is warming. Shifts in seasonality (e.g., warmer winters, shift in season length) may impact spawning timing or migration which could influence exposure to rising water temperature. Pulsed extreme warmwater events (i.e., heatwaves) have a disproportionate impact on the environment relative to long-term changes in mean water temperature (Figure 5). Aspects of aquatic heat waves that are likely to affect vulnerable species include heat-wave frequency (i.e., the number of heatwaves per unit time), duration (i.e., the amount of time a heatwave lasts), intensity (i.e., how hot a heatwave gets), and onset rate (i.e., how quickly temperature reaches peak intensity).

Rising water temperatures may increase the occurrence or co-occurrence of known stressors that negatively impact aquatic species and habitats. Water temperature is a catalyst for biochemical reactions that negatively impact habitat quality at high water temperatures. Some known stressors that occur as temperature increases include:

- Low dissolved oxygen: gas solubility decreases with increasing water temperature (warm water holds less oxygen than cooler water).
- Invasive species: warmwater species have a longer time period in which to expand to inhabit new habitats to which they are not native.
- Algal blooms: cyanobacteria are known to perform well with elevated water temperatures and can develop into harmful algal blooms producing toxins.
- Bacterial/viral outbreaks: warm water increases physiological stress making it harder for species to fight off infection.
- Distribution and toxicity of other pollutants (e.g., heavy metals, pesticides, ammonia, etc.): rising water temperature mobilizes and increases the toxicity of other pollutants.

Increasing water temperatures will likely alter ecosystem structure and function. For example, aquatic ecosystems may move from diatom dominated to green-algae or cyanobacteria dominated. This alteration would represent a shift towards less nutritious food sources. In headwater streams, macroinvertebrates may also shift from coldwater sensitive fauna to more tolerant taxa and force changes in foraging behavior of fishes that rely on these communities as primary food sources.

Increasing water temperature will further isolate coldwater populations while expanding the range of warmwater and non-native species. As novel communities interact, there will be shifts in predator/prey interactions that are likely to alter energy and nutrient flow.

Priority information needs

Temperature effects on freshwater fish have been studied over many years, across a range of different aspects (e.g., lethality, reproduction, physiology), and these studies have been used to develop federal temperature criteria used in state water quality standards. Even so, there is more to study on impacts of elevated temperature, especially to non-trout species, including lower parts of the food web such as algae, biofilms, zooplankton, and macroinvertebrates. Management strategies would benefit from greater information on impacts of elevated temperature on species life stages, predator/prey interactions, and how these interact with multiple stressors. High-frequency (sub-daily) monitoring is needed to understand which places are most exposed and sensitive to pulsed heating events such as heatwaves.

2.2 Management Implications of Rising Water Temperatures

Multiple policies and practices could be considered to address the drivers of rising water temperature and ecological implications. These include policies that promote the protection and maintenance of natural lands that provide cooling benefits, including forests, wetlands and healthy watersheds. They also include BMPs included in jurisdictions' Watershed Implementation Plans (WIPs) and habitat restoration strategies.

Trees matter. By shading, cooling (evapotranspiration) and facilitating infiltration of rainwater, forests, riparian forest buffers and urban tree canopies play a central role in moderating the ecological risks of rising temperatures. CBP goals and practices for increasing riparian forest buffers, urban tree canopy and forest conservation are all relevant and could be reinforced.

Conserving existing healthy watersheds can help promote resiliency to rising water temperatures. Key factors of healthy watersheds that may moderate rising temperatures include:

- Land use/land cover: percent forest cover (catchment and riparian), percent natural land cover.
- Hydrology/flow alteration, including infiltration rates of land use/land cover types.
- Underlying geology/groundwater interaction.

Promoting practices that maintain or increase forest and natural land cover types, reduce flow alteration of streams, and are strategically sited based on an understanding of underlying geology and groundwater recharge can increase resiliency to rising water temperatures. Watershed characteristics and landscape factors that influence vulnerability and resilience to rising temperatures are reviewed in the watershed health paper, Synthesis Element 4 (Appendix H).

Some BMPs have the potential to mitigate rising water temperatures, but watershed-wide, there has been substantially greater implementation of "heater" BMPs as compared with "cooler" BMPs. BMPs can influence water temperature by impacting multiple drivers of water temperature identified in the conceptual model. The workshop team conducted a synthesis effort evaluating the temperature impacts of Bay Program BMPs and grouped BMPs based on the strength and direction of their impact on water temperature. **"Heaters"** include stormwater retention ponds, floating treatment wetlands and vegetated open channels. **"Coolers"** include riparian forest buffers, upstream tree planting, urban stormwater infiltration, and wetlands restoration, enhancement and rehabilitation. Many BMPs were classified as either "uncertain" or "thermally neutral".

In many years, there have been approximately three times (3x) as many heater BMPs as there were cooler BMPs implemented, suggesting that some of the practices being implemented to improve water quality may be having adverse, unintended consequences for water temperature (Figure 6).

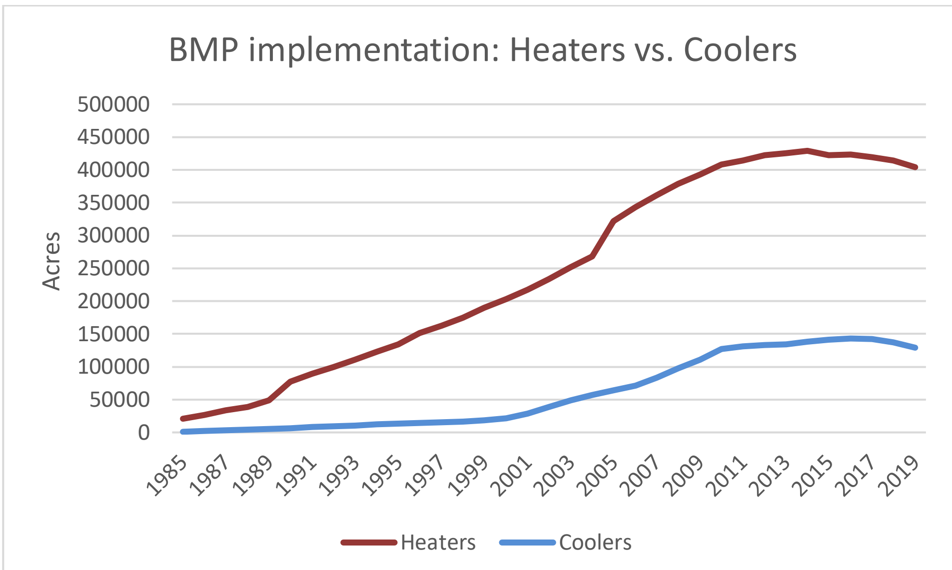

Figure 6: Trends in implementation of BMPs that may be having adverse impact on water temperature.

2.3 Management Recommendations

Initial management recommendations were drafted by the Workshop Steering Committee's watershed project team subgroup based on the Synthesis Papers and input received during Workshop 1. These initial recommendations were presented to Workshop 2 participants for discussion, and their input was solicited during breakout groups. The watershed project team then further refined the management recommendations based on the input received during Workshop 2.

The management recommendations, implementing actions and science needs below are grouped into three fisheries and habitat categories—Coldwater, Rural and Urban, and two cross-cutting subjects—Best Management Practices and Water Quality Standards. Why separate Coldwater from other Rural fisheries and habitats? It is to signal the differences in the types and intensity of measures required to sustain the highly temperature-sensitive, and treasured, coldwater species such as brook trout. Rural and Urban habitats have their own distinctive challenges and opportunities to address the aquatic ecosystem effects of rising temperatures.

<u>Coldwater Fisheries and Habitats Recommendation</u>

<u>Recommendation 1</u>: *Chesapeake Bay Program partners need to accelerate conservation to protect the coldwater streams now supporting healthy aquatic life, especially native brook trout, which are extremely sensitive to rising water temperatures, and continue resiliency analyses and mapping to focus coldwater habitat restoration efforts*

Rationale: Even though the CBP partnership is committed to brook trout stream protection and restoration, suitable brook trout habitat is still diminishing, due to development impacts such as heated stormwater runoff and especially loss of riparian forest. Stream temperature warming increases the urgency to identify the best habitat for land conservation and other restoration actions, and there are excellent mapping tools for habitat identification. More data are needed on local groundwater inputs to identify streams that may be particularly vulnerable or resilient to warming surface water temperatures.

Workshop participants were briefed on Maryland's "Conservation Framework for Increasing Resiliency for Maryland's Brook Trout". Success factors in the strategic framework included: (1) use of scientifically-valid, standardized survey and assessment techniques statewide; (2) choosing watersheds for resiliency and directing protection and restoration projects to those that provide the greatest opportunity for brook trout persistence into the future (including genetic diversity); and (3) working closely with partners to review stormwater infrastructure, construction and habitat projects that might impact coldwater resources (Goetz, 2022).

Workshop participants discussed opportunities to use conservation, restoration and BMPs to minimize stream warming in these important habitats. For example, where there are farms in these watersheds, partners should prioritize working with agricultural producers to minimize the potentially adverse impacts of agricultural practices to stream temperatures. Likewise, nonproductive agricultural lands and former minelands can be reforested to increase groundwater infiltration and forested cover in priority watersheds.

Based on years of study and coordination, e.g., through the CBP Brook Trout Workgroup, partner biologists and program leaders know what needs to be done and in what locations to protect coldwater habitats. Rising temperatures increase the urgency of connecting the science to the decision-makers at the federal, state and local levels so that effective conservation and restoration strategies can be coordinated across the relevant entities, adequately funded, and implemented.

Implementation Actions:

1. Partners should prioritize protecting currently forested watersheds containing high quality coldwater habitat, with land conservation practices (i.e., fee-simple purchase, conservation easements, open space programs, etc.).

2. Riparian forest buffers should be maximized in all coldwater watersheds. CBP partners should build on and intensify their existing strategies for conservation and riparian forest buffer restoration and find new public-private funding.

3. Each state should develop a strategy that pulls federal, state (e.g., departments of environment, transportation), private, non-governmental organization (NGO), and landowner resources together for coldwater conservation partnerships. State frameworks like Maryland's might be used to identify "best of the best" watersheds and incentives given to local governments to promote and maintain these watersheds as a historic, scenic and recreational priority.

4. Promote good agricultural stewardship, to include increased use of cooling BMPs, to minimize the impacts of agricultural land use in watersheds with high quality coldwater habitat. Enlist the federal and state partners in the CBP's Agriculture and Forestry Workgroups.

5. In priority coldwater habitat areas for conservation and restoration:
    a. Develop stronger engagement with private landowners, including working with agricultural agencies to promote cooling practices, and improving conservation easement programs and incentives.
    b. Work with local governments to improve land use planning and evaluation of development projects in high quality habitat areas and to better utilize new and existing programs for protecting their coldwater fisheries.

6. Within the strategic framework for identifying potentially resilient streams for restoring coldwater habitat, implement habitat restoration in degraded landscapes, including the reforestation of abandoned minelands and the restoration of degraded streams to improve connectivity and expand available habitat, while minimizing the loss of mature riparian trees

Science Needs to Support Implementation: Increased continuous, high-frequency surface water temperature monitoring in headwater (i.e., coldwater) streams will help to identify and prioritize waterways for restoration and conservation. Likewise, implementing sediment/benthic temperature monitoring along with groundwater mapping will help determine which waterways are most resilient to warming and provide the greatest opportunity for brook trout persistence in the future. Lastly, longer-term temperature and brook trout monitoring will provide richer insights into factors contributing to restoration and watershed conservation success.

Rural Waters and Habitats Recommendation

Recommendation 2: *In rural areas, CBP partners should work to strategically restore forests and aquatic habitats while promoting good agricultural stewardship practices that can reduce the amount of heated runoff being generated by farms.*

Rationale: Rural landscapes are highly variable, providing important lands and waters for agricultural production, habitat and communities. Given this variability, an equal level of effort won't always lead to equal outcomes for stream temperature in different landscapes. A strategic approach to conserving and restoring forests and aquatic habitats will ensure that resources are spent in the places and on the practices that will have the greatest benefits for cooling waterways. Riparian forest buffers are essential for cooling waterways. However, considering the width of affected streams and rivers and the potential for heated water flows to bypass buffers, riparian buffers will only accomplish so much, and other upstream practices are needed to minimize stream warming.

On agricultural lands, the CBP partners have generally focused on practices that reduce nutrient and sediment loads. Unfortunately, some management practices such as farm ponds can contribute to stream warming. Workshop participants discussed difficulties that farmers might have avoiding all use of practices that add to heated runoff, and concluded that strategic whole-farm planning could help ensure that sufficient cooling practices are utilized to minimize trade-offs between water quality and water temperature.

At the same time, the CBP partners should work to strategically restore aquatic habitats to minimize the impacts of warming temperatures on aquatic biota and ecosystems. For example, there are opportunities to improve aquatic connectivity between suitable habitat patches that could improve access to thermal refugia during peak summer water temperatures. Workshop participants were shown an example of a very "restorable" stream reach in Pennsylvania, just downstream from a forest-buffered coolwater stream area, where installing forest buffers could extend the healthy aquatic habitat conditions. Note that the aquatic habitat restoration concepts discussed in this part of the workshop were measures to prevent and offset thermal impacts on aquatic biota. Participants commented at several points of the workshop on the need for such measures (e.g., riparian shading, thermal refugia) to be incorporated into stream restoration BMPs now being implemented by the CBP partners for nutrient and sediment reduction.

Implementation Actions:

1. Improve and conserve forest cover throughout the landscape, ensuring rivers and streams are well buffered. Improving forest cover includes both reforesting upland areas as well as improving management of existing forests to encourage better infiltration and improve forest resiliency (for example, by increasing forest age class diversity). A strategic approach could prioritize areas where there is the greatest opportunity for conservation such as healthy coolwater streams, areas downstream of intact coldwater habitats, and streams that have a significant opportunity for ecosystem recovery based on restoration efforts. The Forestry Workgroup could work with the Chesapeake Conservation Partnership, the Chesapeake Bay Program Office (CBPO) GIS team and/or contractors to identify locations in need of reforestation or improved forest management to cool waterways.

2. Use the improved Bay watershed mapping capability to prioritize specific stream reaches where riparian buffer plantings can exert the greatest cooling impact in rural watersheds. The Forestry Workgroup could work with the CBPO GIS team and/or contractors to

develop a RFB priority map for stream cooling. The CBP promotes RFBs everywhere in the watershed because of their nutrient and sediment reduction benefits. Stream temperature regulation is an additional high value benefit.

3. Use aquatic habitat restoration to improve connectivity between suitable habitat patches and improve access to thermal refugia. The Stream Health Workgroup could help develop design guidance for restoration practitioners that would improve the benefits of restoration for buffering aquatic biota from the impacts of aquatic heatwaves.

4. Improve technical assistance and programs available to private landowners to support forest land conservation, tree planting, and better whole farm planning, including a focus on agroforestry, improving soil health and infiltration as well as other practices that prevent heated runoff from reaching the riparian corridor. Natural Resources Conservation Service (NRCS) and the Agriculture Workgroup could help support efforts to integrate considerations of rising water temperatures into USDA's work to support farmers in implementing climate-resilient farming practices.

5. Incorporate rising water temperatures in CBP partner strategies for working with local governments —for example, modification of codes and laws where appropriate to encourage conservation BMPs and cooling practices and the lessening of impervious surfaces where development of rural areas is proposed. The Local Leadership and Communications Workgroups at CBP could help develop tailored communications materials for local governments to help improve understanding of the implications of rising stream temperatures and examples of effective local actions that could help mitigate these impacts.

Science Needs to Support Implementation: In rural areas, there is a need for targeted research in small agricultural watersheds to measure temperature impacts of agricultural land and water management practices, including infiltration practices, when implemented on a large scale. There are also opportunities to further investigate the efficacy of other cooling mitigation strategies, including wetland creation, dam/pond removal, floodplain restoration, beaver analogue projects, and improved roadside ditch management. Finally, the CBP partners could use the new high-resolution land use data to determine the maximum rural stream mileage available for forestation and develop models to determine whether the installation of future stream "cooler" and "shader" practices will mitigate watershed warming factors.

Urban Waters and Habitats Recommendation

Recommendation 3: *In urban areas, CBP partners should increase tree canopy, vegetation and practices favoring infiltration to reduce the amount of heated runoff entering waterways, paying attention to under-served urban areas which historically suffer the worst heating and human health outcomes.*

Rationale: Urban rivers and streams tend to be particularly vulnerable to the effects of stream warming, as the loss of natural cover and prevalence of impervious surfaces increases the volume and temperature of runoff entering waterways. At the second workshop, participants mentioned several studies that documented increases in urban stream temperatures. One study–Nelson and Palmer (2007)–showed that after summer rainstorms in the Anacostia watershed, urban runoff resulted in increasing stream water temperatures by about 3-4 degrees Celsius. The pulses of warmer water lasted about three hours in the receiving stream system (Synthesis Element 7/8 Paper, Appendix K).

Workshop participants agreed that significant urban water temperature increases and impacts on stream biota are a predictable outcome of observed increases in urban heating, but as monitoring water temperature has not been a recent priority, site-specific information is lacking.

Heated impervious surfaces play the primary role in heating stormwater runoff, but some of the BMPs used to reduce nutrient and sediment loads in urban areas, such as stormwater detention ponds, can also warm surface runoff. To minimize these trade-offs between water quality BMPs and water temperature, the CBP partners should identify opportunities to further incentivize the use of BMPs that provide cooling benefits over the use of BMPs that add heat to waterways.

"Cooling" BMPs include tree planting to increase urban tree canopy, lawn conversion and forest buffers along urban waterways. Stormwater management practices that facilitate infiltration of rainwater into soil (bioretention, porous pavement, and infiltration practices without underdrains) are also cooling BMPs as infiltrated stormwater is not further heated by impervious surfaces. Stormwater infiltration BMPs are encouraged by EPA and the jurisdictions, and increasingly adopted. District of Columbia participants in the workshop pointed to (limited) research that has measured stormwater cooling in bioretention installations.

Stormwater infiltration BMPs are not "refrigerators," and generally cannot compensate for the effect of impervious surfaces on stream temperatures. Both stormwater management infiltration practices and expanded urban tree canopy have been promoted by the CBP partners for nutrient and sediment reduction, and it makes sense to couple these measures for urban cooling as well.

Practices that increase urban tree canopy also provide myriad other benefits to urban communities, including cooling air temperatures and improving air quality. Where possible, Bay Program partners should use existing environmental justice and equity mapping tools to identify locations where implementing these practices could be particularly beneficial to historically under-served populations. Bay watershed cities have already begun "tree equity" initiatives to cool hot neighborhoods, and these could be linked to stream cooling measures.

There is tremendous variability across developed areas in the Chesapeake Bay watershed, ranging from small townships to large metropolitan areas with varying hydrology, soil conditions, and proportions or types of impervious and pervious cover. For urban areas adjacent to wider rivers and waterways, it may be more difficult to directly cool these waterways with forest buffers. In these places, partners could identify opportunities to create thermal refugia or improve access to thermal refugia through in-stream and riparian habitat restoration work. Where stream restoration BMPs are installed for sediment and nutrient removal (bank and instream modifications), participants said that removal of existing riparian canopy coverage should be minimized so as to maintain cooling benefits already present.

Stormwater runoff for some areas will be captured by combined stormwater and sewage systems, while most areas have separate storm sewers and sanitary sewage lines. The cooling or heating impact of combined versus separate sanitary sewer systems was not studied but is worth further exploration. In areas with combined sewer systems, there are often initiatives to promote green stormwater infrastructure that can lower the volume and temperature of runoff that enters the system.

Another important factor that arose in workshop discussions was the intersection of human health impacts and rising water temperatures. Urbanized areas often have areas with legacies of toxic pollution from industrial or other sources, and these legacies can have lasting impacts on local soils or waterways depending on the pollutant and its ecotoxicity pathways. Bacteria and harmful algal blooms are also relevant human health concerns for numerous waterways. Water temperature can influence these pollutants, how they move through the ecosystem, and how they ultimately impact aquatic biota and human health. These human health concerns are doubly important when considering the disproportionate historical and continued impact of pollution on under-served communities of color.

Rising air and water temperatures increase the urgency of broadly implementing several goals and programs which the CBP partners have adopted – use of “green technology” infiltration methods for controlling stormwater from developed land uses, achieving a net gain in urban tree canopy, and promoting “Bay friendly” and native landscape planting in urban and suburban areas.

Implementation Actions:

1. Decrease the amount of turf in urban and suburban areas, using lawn conversion programs to increase rainwater infiltration capacity, shading trees and shrubs, and use of native plants.

2. Encourage the retention and expansion of urban tree cover (both in the riparian zone and upstream), especially in under-served urban areas which historically suffer the worst heating and human health outcomes. Strengthen implementation of the CBP’s Urban Tree Canopy strategy.

3. Use aquatic habitat restoration to improve connectivity between suitable habitat patches and improve access to thermal refugia. The CBP Urban Stormwater Workgroup could add guidance on how to consider water temperature effects and thermal refugia to its stream restoration BMP protocols.

4. Emphasize the multiple benefits of cooling BMPs such as urban trees (e.g., air quality, public health, urban livability) to better communicate about these practices with residents and local governments and to access additional sources of funding.

Science Needs to Support Implementation: For urban areas, the most significant science needs are to better understand how rising water temperatures interface with social science or public health issues, especially among under-served residents. Examples include evaluating the impacts of heated runoff and pollution concerns stemming from direct or indirect effects of elevated water temperature. An emphasis on improved understanding of locally relevant co-benefits for BMPs and restoration projects is also a priority science need.

Best Management Practices (BMPs) Recommendation

Recommendation 4: *The CBP partners should work to minimize the extent to which water quality BMPs are further heating waterways and strategically use cooling BMPs to counteract the warming effects of climate change and land use where possible.*

Rationale: Certain water quality BMPs are known to warm surface water temperature, including wet ponds, detention ponds, farm ponds and confined animal feeding operation (CAFO) lagoons. While these practices may be very effective and necessary to achieve nutrient and sediment load reductions, they may be having unintended consequences for water temperatures and stream ecosystems. There are other BMPs that can either directly cool waterways (i.e., riparian forest buffers) or can help minimize further stream warming (i.e., infiltration and bioretention practices).

The greater use of heating BMPs over cooling BMPs in the Bay watershed suggests a need to focus on incorporating temperature considerations into BMP selection and design.

The following actions are addressed to the CBP Goal Implementation Teams and workgroups responsible for providing guidance on BMPs, and to the multitude of local, regional, state and federal agencies and partners implementing them through the jurisdictions' WIPs.

Implementation Actions:

1. Work with local governments to avoid using "heater" BMPs near streams and identify opportunities to incentivize stacking multiple stormwater "cooler" BMPs over "heater" BMPs. Coldwater habitats are particularly sensitive and warrant extra protection.

2. For practices with the potential to exacerbate stream warming, develop specific design recommendations and criteria, taking landscape characteristics into account, to minimize warming impacts.

3. Relevant regulatory and stormwater permitting agencies should collaborate to review existing design criteria for new stormwater and restoration practices installed in cold and cool-water watersheds to avoid further stream warming.

4. For cooling practices whose efficacy is likely to be impacted by climate change, provide design recommendations to ensure these practices will remain resilient to likely future climate scenarios. This could include updating forestry BMP plant lists to make sure the appropriate species are being planted, accounting for local conditions, species

characteristics, and future hardiness zones in the warming watershed, and encouraging diversity in plant selection to hedge against potential losses to invasive pests and plants.

5. Where heating BMPs are needed to effectively address water quality concerns (no suitable cooling BMP alternatives are available), take a whole farm, whole property or whole landscape approach to ensure that enough cooling BMPs are implemented to offset any warming attributable to heating BMPs. Treatment trains should be used where possible to maximize infiltration and minimize heating.

Science Needs to Support Implementation: While the temperature effects of certain BMPs are well understood, at least in general terms, there are many BMPs where the CBP partners do not currently have a good understanding of temperature effects (for example, stream restoration, agricultural BMPs and wetlands BMPs). There is a need for a more robust assessment of which BMPs are heaters and coolers and to what extent. This could involve using a systematic expert elicitation process to better identify the BMPs likely to influence water temperature as well as the direction and magnitude of the temperature impact. Targeted research efforts should also further evaluate how various landscape characteristics, including groundwater, groundwater-surface water interactions, soil characteristics—both physical and chemical—underlying geology and land cover, mediate the temperature effects of BMPs and the scale at which various BMPs need to be implemented to have a measurable impact on water temperature.

State Temperature Water Quality Standards Recommendation

Recommendation 5: *Given the vital role of Clean Water Act water quality standards (WQS) in focusing federal, state, local and private actions to protect water quality and aquatic life, the states and EPA should review and modernize the components of current WQS systems that would strengthen their capability to address climate-related rising water temperatures and drive targeted protection and restoration strategies.*

Rationale: All CBP jurisdictions have a "water temperature policy" in their temperature WQS, but it needs to be updated to deal with climate-related water warming (Addendum, Appendix E). For decades, the standards (temperature criteria, monitoring schemes) have protected aquatic life and other water uses from heated discharges (e.g., power plants). Maryland officials showed the second workshop participants how they intend to use temperature WQS to drive better protection of trout streams from impairments caused by climate and land use impacts. The state added a forest buffer (shading) provision to its temperature criteria and is working on TMDL options. Workshop participants noted expert advice that current temperature criteria to protect aquatic life from heat discharges ("dots on the landscape") may not be protective for climate-related heating. Current monitoring regimes to detect impacts of discrete point sources need to be re-designed for climate-related heating. Participants had ideas for how to get started on the WQS modernization process. Just as the states' Chesapeake Bay WQS focused restoration action through the Chesapeake Bay TMDL and state WIPs, the states and EPA can work together to update the WQS mechanisms related to temperature, taking advantage of a large body of temperature-related fisheries research and advice from experts throughout the US.

Implementation Actions:

1. Convene EPA and jurisdiction WQS and 303(d) practitioners to explore how to make Chesapeake Bay watershed WQS effective to combat rising water temperatures. Evaluate accuracy of aquatic use zones (e.g., coldwater, coolwater, warmwater fisheries); refinement of temperature criteria for fisheries (e.g., to protect growth and reproduction) and corresponding biological criteria; monitoring/analysis methods and strategies adapted to climate-related temperature changes, taking into account land use influences and groundwater inputs. Evaluate TMDL options to spur restoration of temperature-impaired water uses. Can anti-degradation policies be leveraged to increase protection of current high-quality waters, especially healthy native trout streams? Aim to complete this evaluation in 12 months, building in advice from experiences elsewhere in the U.S.

2. Based on this evaluation, develop a plan to "modernize" these Clean Water Act tools to improve jurisdictions' capability to protect indigenous (and naturalized) populations of coldwater, coolwater and warmwater aquatic life from climate-related water temperature increases. The timing for making regulatory changes could be based on the regulatory WQS triennial review process.

3. Improve interstate cooperation and effectiveness by leveraging the CBP to promote information-sharing, problem-solving, and monitoring support.

4. Stronger anti-degradation measures could improve protection of temperature-threatened high-quality waters, e.g., native trout streams.

Science Needs to Support Implementation: As demonstrated by the ORSANCO compilation of temperature criteria (2005), there is a considerable body of research information on temperature effects on fisheries, and available information might support adoption of protective temperature criteria; however, information is more limited on growth/reproduction than lethality. Maryland's examples show the types of analysis and modeling associated with identifying those coldwater stream areas that are most amenable to conservation and restoration actions. Any action strategies will require site-specific information (e.g. species, benthic community, channel conditions, groundwater inputs). The highest priority is needed on building knowledge of where and why water temperatures are rising in the Chesapeake Bay watershed, and effects on fishery uses, through cost-effective monitoring strategies.

2.4 Scientific, Assessment and Monitoring Needs and Recommendations

<u>Overarching Research, Monitoring, and Modeling Needs</u>

There were specific science needs related to the recommendations in the previous section. The science recommendations to address these needs are grouped under three topics: research, monitoring and modeling. Each topic has an overarching recommendation, rationale, and proposed actions for the CBP partners to consider to address the recommendation. The topics are interrelated and a coordinated and intensive effort will be needed by the CBP partners to carry out the actions needed to address the recommendations.

Research

Recommendation 6: *The CBP partners should enhance and facilitate partnership efforts to collect data and develop tools needed to fill critical knowledge gaps, improve understanding of the impacts of rising temperatures on aquatic ecosystems, and inform management decisions.*

Rationale: The workshop participants agreed that there are critical knowledge gaps and science needs limiting our understanding of the ecological impacts of rising water temperatures, linkages between causes and effects, interactions with other stressors, and how best to mitigate detrimental impacts. Coldwater and coolwater fisheries are at high risk for habitat degradation and loss given their specific temperature thresholds; however, groundwater inputs were recognized as an important component that can mitigate temperature increases and provide thermal refugia. Information on coldwater species other than brook trout is quite limited. Given the many variables affecting the location and impact of groundwater inputs to streams (Snyder et al. 2015; Johnson et al. 2017; Briggs et al. 2018), additional research is needed to assist the CBP partners and relevant stakeholders in identifying streams with groundwater inputs and providing the data necessary to improve existing models and develop new models (see Modeling recommendations). While not as vulnerable as coldwater fisheries to rising temperatures, warmwater fish species are more widespread throughout the watershed, and there is little information on both the direct and indirect effects higher temperatures are having on these species.

Proposed actions to address the research recommendation:

1. Conduct climate vulnerability assessments to better understand both the exposure and sensitivity of species/habitats to rising temperatures, including indirect effects (e.g., invasive species), to better understand overall vulnerability. The assessments would consider various forecasts of land use, climate and hydrogeology in estimating exposure. The results would be useful in understanding the implications of restoration and protection plans and in targeting of resources. Federal agencies could concentrate on regional assessments, while state agencies, local governments, non-governmental organizations, universities and utilities could conduct more local assessments.

2. Collect additional data on the extent of deep and shallow groundwater to improve temperature-based estimates of climate refugia locations at finer spatial scales.

3. Determine how interactions between climate change and land use will affect brook trout and mussel populations including cumulative impacts.

4. Identify genetic metrics necessary to determine brook trout and mussel population resiliency to rising temperatures including adaptive variation to higher temperatures.

5. Conduct targeted research in smaller watersheds to improve understanding of temperature impacts of land use and water management practice; also research the efficacy of BMPs to mitigate temperature-related impacts in line with the science needs as outlined in the Best Management Practices section above.

6. Use an integrative approach combining information on flows, stream power, connectivity, and adaptive capacity to provide a more comprehensive approach for identifying climate refugia.

Monitoring and Analysis

Recommendation 7: *The CBP partners should increase monitoring of water temperature in smaller streams and further analyze existing data from larger streams and rivers to improve understanding of the effectiveness of restoration and conservation of stream communities and fisheries in the face of land-use and climate change.*

Rationale: Information on current temperature monitoring was described in Synthesis Element Paper 10 (Appendix M). A wide array of monitoring needs were identified during the workshop and in the previous section. Collectively they address several topics as described below.

One is stream temperature monitoring to assess if water temperatures are being sustained or ecological thresholds exceeded for sensitive populations of fish and stream communities. High-frequency (sub-daily) monitoring is needed to understand which places are most exposed and sensitive to pulsed heating events such as heatwaves. Additional monitoring is also needed to support state water quality temperature standards.

Documenting effects of different stressors on local stream temperatures is another key topic. Higher-frequency or continuous water temperature monitoring is needed to better understand the relative local influence of various drivers as well as water temperature trends (including seasonal effects). Additionally, a need was identified for monitoring to quantify the relationship between rising temperatures and other water quality constituents, including bacteria in urban areas.

A third topic is to improve and increase monitoring data to better target locations for restoration and conservation activities in the three primary landscapes (coldwater, rural and urban). Monitoring data are insufficient for assessing temperatures in streams draining all landscape areas. Smaller streams generally lack consistent monitoring for temperature and new temperature monitoring is needed in smaller streams important for coldwater fisheries. Additional monitoring is also needed at the air/water interface to identify hotspots where drivers are having a particularly large impact on water temperature to target management.

Finally, there is a need to assess the effects of selected management actions on stream temperature. The effects of selected BMPS on stream temperature is lacking and monitoring is needed to document these changes.

Proposed actions to address the monitoring and analysis recommendation:

1. Use monitoring data to assess changes and factors affecting stream temperatures. Status, trends, and correlations with land use types and changes in air temperature should be investigated. For example, the USGS could consider updating its analyses of changes in stream and air temperature (published by Rice and Jastram, 2015) with newer and more expansive temperature data from the watershed.

2. Evaluate monitoring approaches that have been previously used to assess important ecological thresholds and temperature criteria to protect fisheries. New approaches for temperature monitoring are needed to address watershed-wide effects of climate and land change. The existing data should also be explored for considering updated temperature standards for coldwater (and possibly cool- and warmwater) fisheries by the jurisdictions, similar to the effort by the Maryland Department of the Environment. The data collected by the jurisdictions could be supplemented by an inventory of temperature data compiled by the USGS. The USGS and the jurisdictions could collaborate to examine if multiple types of stream temperature data could be used to identify important ecological thresholds and be considered for improving water quality criteria to protect fisheries.

3. Establish a monitoring network of nested watershed (large to smaller streams) and landscape settings important for biological communities and coldwater fisheries. The CBP Scientific, Technical, Assessment, and Reporting (STAR) team could work with the Climate Resiliency Workgroup (CRWG) to design and implement a monitoring network to assess factors affecting stream temperatures in three landscape areas: coldwater, rural, and urban. One opportunity would be to expand the USEPA Regional Monitoring Networks to detect changing baselines in freshwater wadable streams. The new USGS monitoring effort in the Delaware River Basin should be examined as an approach for Chesapeake Bay watershed monitoring and potential collaboration.

4. Use monitoring and landscape information to help target locations for restoration and protection of areas from rising stream temperatures. Information from the healthy watersheds assessment could be coupled with remote sensing to detect groundwater discharge areas important for sustaining coldwater streams. Partners could include the Healthy Watersheds GIT, USGS, and NASA.

5. Understand temperature and biological response to BMPs in the three habitat settings of the watershed: coldwater, rural and urban. Where possible, take advantage of on-going studies of BMP effectiveness to assess changes to stream temperature. This expanded analysis could be done by academic institutions and other partners conducting small watershed studies.

Watershed Modeling

Recommendation 8: *The CBP partnership should develop new modeling tools and expand the use of CAST and the Chesapeake Healthy Watershed Assessment to better inform the management of watershed fisheries and ecosystems.*

Rationale: Current modeling tools used by the CBP partnership are not sufficient to meet the needs of freshwater fisheries managers. The most widely used CBP tools such as Chesapeake Analysis and Scenario Tool (CAST) and the Chesapeake Healthy Watershed Assessment (CHWA) are built to inform managers on nutrients and sediment, and general watershed health, respectively, at the large scale. They do not provide the types of information nor are they at an appropriate scale needed by fisheries managers making habitat protection and stocking decisions. New tools at the fine scale should be developed in selected areas for local management. New functionality should be added to existing tools to indicate how larger-scale land use and land management decisions would affect habitat.

Proposed actions to address the watershed modeling recommendation:

1. Develop fine-scale, process-based local models in selected areas that better simulate the influence of land use and groundwater on local steam temperatures. The model results would be useful to fishery managers in identifying areas that are in danger of exceeding temperature thresholds important for coldwater species. Improved groundwater simulation will be crucial. Similar efforts by USGS in the Delaware River Basin have developed promising new methods. USGS and other CBP partners may be able to identify resources to pursue development of fine-scale models.

2. The Healthy Watersheds GIT should better integrate the Chesapeake Healthy Watersheds Assessment with regional management models and with local habitat models. Local models may benefit from vulnerability indicators in the CHWA such as projected future development, wildfire risk, and climate change metrics. Findings from local habitat models can be used to improve the understanding of the linkage between vulnerability and habitat indicators in the CHWA. Regional models can share common data sets with the CHWA and can provide it with predictions such as stream temperature effects of climate change. The CHWA should be expanded to include stream temperature as a metric.

3. The Chesapeake Bay Program Office's CAST team should develop scenario outputs related to temperature, fisheries, and biota to inform managers on the aggregate effects of their land use and land management decisions related to the Chesapeake TMDL. This will require the USGS and academic partners to adapt habitat models to be responsive to inputs or outputs available in CAST.

3. TIDAL RISING WATER TEMPERATURES
3.1 What We Know Now: Tidal Storyline

Over the past three decades, the tidal water temperatures in the Chesapeake Bay have been increasing (Figure 7). These changes in tidal water temperatures are primarily driven by global atmospheric forcings (e.g., increasing surface air temperatures) and the warming ocean boundary (Hinson et al. 2021). Water temperature is a key factor influencing basic biological and ecological functions including the distribution and abundance of fishery resources, such as striped bass (*Morone saxatilis*), blue crab (*Callinectes sapidus*), and the eastern oyster (*Crassostrea virginica*) and their habitats, including marshes, submerged aquatic vegetation (SAV) beds, and oyster reefs.

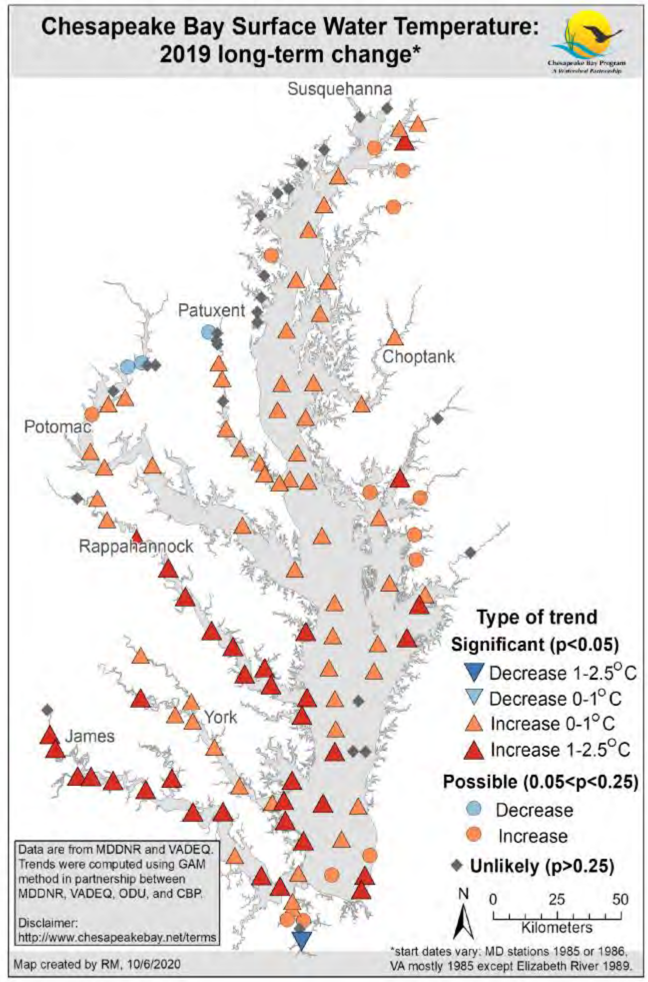

Figure 7: Long term trends in surface water temperatures at the Chesapeake Bay Mainstem and Tidal Tributary Water Quality Monitoring Program stations from a start date of 1985 or 1986 to an end date of 2019. Source: Chesapeake Bay Program Integrated Trends Analysis Team.

Rising water temperature in the Chesapeake Bay is already having an impact on many species and contributing to ecosystem regime shifts. Some examples of these shifts are declining eelgrass (*Zostera marina*) throughout the polyhaline southern region of the Bay, sub optimal summer temperatures for striped bass, fewer summer flounder (*Paralichthys dentatus*) and increases in species such as red drum (*Sciaenops ocellatus*) and white shrimp (*Litopenaeus setiferus*).

These regime shifts are a result of multiple system drivers (e.g., physical, chemical, biological, and anthropogenic factors) causing significant and persistent changes in the structure, function, and services of the ecosystem (National Marine Fisheries Service, 2022). There is an increased urgency for the scientific and management community to respond to these shifts by providing the information and tools to evaluate the risks and tradeoffs and to develop policies and frameworks to manage adaptively. Having the right monitoring and tidal water temperature change analyses in place to collect and organize data in response to management needs will be critical to inform improved decision-making under changing climate conditions.

Drivers Behind Warming Tidal Waters

Average annual tidal water temperatures in the Bay are estimated to increase by 1° C from 1995 to 2025 as a result of climate change (Shenk et al., 2021; Synthesis Element Paper 6, Appendix J). During this century, Bay waters are predicted to warm by 2 to 6° C, mirroring similar ocean surface water temperatures and global air temperatures, which are predicted to increase by 1.1 to 6.4° C and 3 to 4° C, respectively (Levitus et al. 2001; Meehl et al. 2007; Intergovernmental Panel on Climate Change [IPCC] 2014, 2021; Synthesis Element 3 Paper, Appendix G). Hinson et al. (2021) carried out a comprehensive evaluation of the extent and causes of water temperature change in the Chesapeake Bay over a 30-year timeframe (late 1980s-late 2010s). Major findings from Hinson et al. (2021) are summarized below.

In order of greatest influence, atmospheric forcings, the warming ocean boundary, sea level rise, and increasing river temperatures were identified as four principal mechanisms driving changes in the observed tidal water temperatures in Chesapeake Bay (Figure 8). Atmospheric forcings of increasing surface air temperatures and downwelling longwave radiation were determined to be the main drivers of rising water temperatures throughout the Bay's surface and bottom waters. For instance, atmospheric warming contributed to about 78% of the total change in bottom Chesapeake Bay water temperatures observed from May through October during the 30-year timeframe combined, equal to about a 0.6°C change (Figure 9) (Hinson et al. 2021; Synthesis Element 5 Paper, Appendix I). The role of atmospheric warming on the water temperatures in the Chesapeake Bay is also supported by the trends of increasing air and corresponding surface water temperatures across ~ 92% of the Chesapeake Bay based on more than 30 years of data (1980-2015) reported by Ding and Elmore (2015).

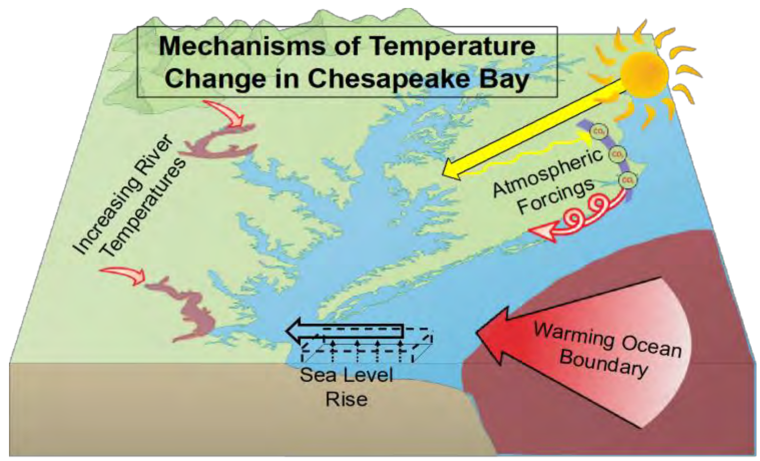

Figure 8: Illustration of the four major mechanisms driving changes in water temperature throughout the Chesapeake Bay's mainstem, tidal tributaries and embayments.
Source: Hinson et al. 2021

The warming of the adjacent Atlantic Ocean was identified as a secondary major driver that contributes to increasing Bay water temperatures, with about a 26% contribution to the overall changes in combined bottom water temperatures from May through October (Figure 9) during the 30-yr timeframe. Regional and seasonal differences were observed with the warming ocean boundary where water temperature increases occurred at the southern part of the Bay near the mouth the most, accounting for more than half of the combined summer warming (June-October) over the 30-yr timeframe. For the remaining months, the warming ocean boundary had a small overall effect on water temperatures (Hinson et al. 2021).

Overall, sea level rise was estimated to slightly cool Bay temperatures across the tidal waters, resulting in a 6% cooling contribution to the overall Bay bottom temperatures over the 30-yr timeframe, about 0.1°C difference (Figure 9) (Hinson et al. 2021; Synthesis Element 5 Paper, Appendix I). Seasonal differences related to sea level rise included an estimated overall cooling in the Bay's mainstem from April through September and slight warming in the winter months (November through February).

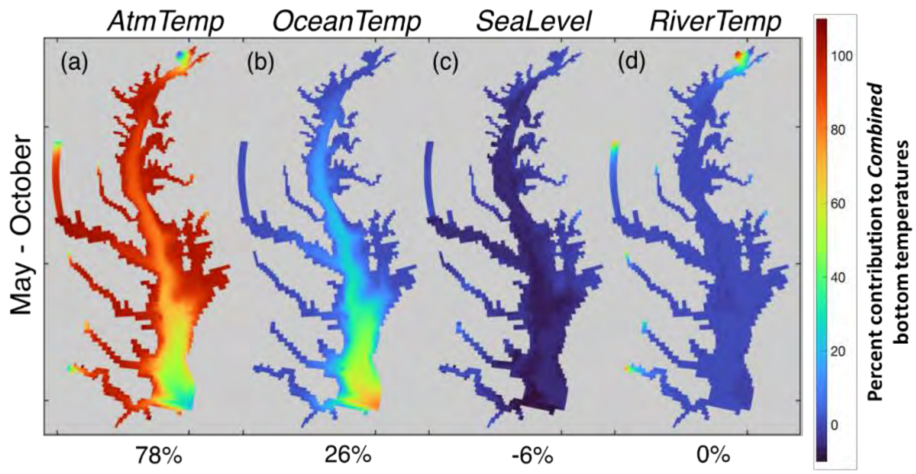

Figure 9: Percent contribution to the total change in main stem bottom temperatures from each sensitivity experiment for (a) atmospheric temperature, (b) ocean temperature, (c) sea level, and (d) river temperature May through October based on a 30-year timeframe (late 1980s-late 2010s). Average main stem percent contributions to total temperature change are denoted beneath each panel. Source: Hinson et al. 2021.

Both surface and bottom waters of the Bay and tidal tributaries exhibited similar temperature changes over the 30-year timeframe (Hinson et al. 2021). Some regional differences in temperature changes were reported, with higher temperature changes estimated for the Susquehanna Flats and adjoining upper Bay mainstem, the lower Bay and mouth of the Bay, and the tidal fresh reaches of the major tidal tributaries. The influence of increasing river temperatures on the warming of tidal waters has a small role in the upper tidal fresh reach of the major tidal tributaries (e.g., Susquehanna, Potomac, and James) and the upper Chesapeake Bay—Susquehanna Flats and the upper Bay mainstem reach down to about Back River on the western shore (Hinson et al. 2021; Synthesis Element 5 Paper, Appendix I). Ding and Elmore (2015) also found local spatial patterns of more rapid warming of surface water temperatures of western tidal tributaries (i.e., Patapsco, Patuxent, and Potomac) compared to the eastern tributaries and portions of the Bay's mainstem. Catchments influenced by high impervious areas in the watershed (i.e., urban heat centers) are particularly vulnerable to thermal pollution linked to riverine discharge (Boomer et al. 2019).

Ecological Implications of Rising Water Temperatures

To identify the ecological implications of rising water temperatures on tidal resources, the STAC Workshop Steering Committee decided on a two-fold approach: 1) recruit experts to develop synthesis papers that summarizes what is known regarding the effects of rising water temperatures on fisheries (Synthesis Element 2 Paper, Appendix F) and SAV (Synthesis Element 3 Paper, Appendix G) resources; and 2) get workshop participants' input on the influencing factors and sensitivities of these resources to rising water temperatures during Day 1 of the workshop. To support the development of the synthesis papers, the CBP's Climate Resiliency Workgroup held a special meeting on June 21, 2021 to get feedback on initial findings about existing knowledge on the effects of rising water temperatures on habitats and living resources. The agenda and meeting presentations can be found in Appendix A and Appendix G, respectively. To expand on the findings in the synthesis papers and further identify ecological implications of rising water temperatures, Day 1 of the workshop was organized into the following sessions (Day 1 agenda, Appendix B):

- Session 1: Identify key factors to consider to assess management implications related to rising water temperatures and ecological impacts
    - What are the direct and indirect positive and negative effects of rising water temperatures on the fishery or SAV resource?
    - What are key factors to consider for the fishery or SAV resource to inform management action around these effects?

- Session 2: Discuss ecological sensitivities to rising water temperatures and certainty of information
    - What do we know of temperature sensitivities on the fishery or SAV resource? What are the research gaps?
    - What temperature-specific analyses would be most useful for informing management for the resource, including temporal and spatial scales?

For each session, the tidal workshop participants were divided into resource-specific breakout groups: SAV (e.g., freshwater/oligohaline, mesohaline, and polyhaline species), oysters, blue crabs, forage (e.g., bay anchovy, menhaden, benthic organisms), and finfish predators (e.g., striped bass, summer flounder). Major findings from the synthesis papers and Day 1 workshop discussions are described below. Details of the Day 1 workshop participants' input can be found in the tidal briefing paper (Appendix P).

Tidal Fisheries Implications of Rising Water Temperatures

The effects of rising Chesapeake Bay water temperatures on living resources were discussed for five key fisheries species chosen on the basis of their economic, ecological, and cultural importance: blue crab, oysters, summer flounder, striped bass, and forage species (i.e., bay anchovy and menhaden). Climate vulnerability scores and bay-specific research, show a range of positive and negative responses of living resources to temperature and other climate change related factors. Positive impacts are likely for blue crab and some forage species (e.g., bay anchovy and menhaden), as warmer temperatures support higher productivity and increased habitat range as species move northward (Synthesis Element 2 Paper, Appendix F). Negative impacts are predicted for oysters due to their already depressed populations as a result of disease, overfishing, and habitat loss.

While oysters can thrive in higher temperature regimes and may experience an increase in habitat range, they are highly vulnerable to other climatic impacts such as ocean acidification and changes in salinity driven by precipitation. Striped bass and summer flounder may experience both negative and positive impacts at different stages of life (larval to adult) and habitat use (rivers and estuaries to marine). The range of responses and potential for localized impacts (e.g., changes in habitat quality and reproductive success within specific tributaries) lead to higher uncertainty in evaluating striped bass and summer flounder vulnerability.

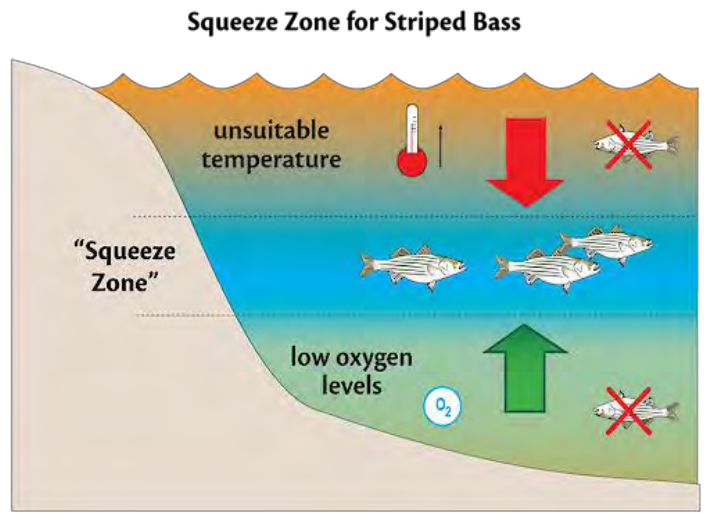

Figure 10: Conceptual diagram illustrating the compressed habitat of the striped bass from the low oxygen levels from the bottom, and the unsuitable temperatures from the surface. Diagram courtesy of the Integration and Application Network (ian.umces.edu), University of Maryland Center for Environmental Science. Source: Boesch 2008.

Workshop participants highlighted how rising water temperatures create a seasonal "habitat squeeze" where striped bass can only thrive in certain regions of the water column, as the higher portions of the water column are too warm, and the lower portions have low dissolved oxygen (DO) levels, compressing suitable habitat to the center (Figure 10) (Boesch, 2008). They also identified the possibility of predator-prey mismatches where rising water temperatures and seasonal shifts could cause unfavorable changes in spring-time spawning of striped bass and availability of food resources (e.g., zooplankton).

Northward shifts in species' ranges are being documented for several species. This is resulting in some Bay species shifting populations north while other species from the south are becoming more prevalent in the Bay. These shifts can result in changes to species abundance and distributions, food web dynamics, fishing behavior and the introduction of new fisheries. Likewise, habitats required by fish and shellfish species are shifting in range and experiencing impacts that lead to changes in fish abundance, distribution and reproduction success.

While rising temperatures are important and do affect species, other climate factors are equally, if not, more important. Existing fishery management approaches will need to adapt by better incorporating climate change impacts into their decision-making for currently managed Bay species as well as additional species that are moving north into the bay and increasing in abundance, such as brown shrimp.

Submerged Aquatic Vegetation Implications of Rising Water Temperatures

There are three primary symptoms of climate change that will directly affect Chesapeake Bay SAV: rising water temperatures, increased carbon dioxide (CO_2) concentrations, and sea level rise (Synthesis Element 3 Paper, Appendix G). Rising water temperatures will likely impact SAV species throughout the Bay in myriad ways, and along with other climate change stressors will complicate restoration efforts. In addition to rising water temperatures, CO_2 concentrations are predicted to increase by 50-160% and sea levels are predicted to rise by 0.7-1.6m.

Temperature impacts to eelgrass (*Zostera marina*) are well understood; warming alone is shown to negatively impact eelgrass, a dominant SAV species in the lower Bay. Chronic high summer temperatures and isolated heat events are associated with mass die offs; the Bay temperatures are already at the upper thermal limits for this cool-water species. Without drastic improvements in water clarity or a reversal of warming trends, viable populations of eelgrass will likely be extirpated from Chesapeake Bay. The Bay's most economically significant fishery–blue crabs (*Callinectus sapidus*)–is directly linked to eelgrass and the habitat it provides.

Temperature's impacts to other Chesapeake Bay SAV species are not as well studied but, based on available data, appear to be less dramatic than those to eelgrass. With that said, current research and preliminary results suggest that increasing temperatures do negatively impact all Chesapeake Bay SAV communities to some extent. The warming Bay temperatures are likely to favor more heat-tolerant species, including widgeon grass (*Ruppia maritima*), certain ecotypes of freshwater SAV, and possibly other subtropical seagrasses. The increasing CO_2 results in a CO_2 fertilization effect that may counterbalance some of the impacts from warming, but unknowns associated with invasive species, pathogens, cyanobacteria, etc. may set that balance awry. Finally, sea level rise affects SAV by increasing the water column depth in which SAV grows, decreasing the light available at SAV leaf blades. Stress from low light conditions can be alleviated by the shoreward migration of SAV in appropriate sediment and nearshore conditions but hardening along much of the Bay's shoreline will prevent that shoreward migration.

Management efforts (i.e., the Chesapeake Bay TMDL) that have reduced nitrogen and phosphorus in the Chesapeake Bay have facilitated recovery of SAV, and SAV are more resilient to all climate stressors (e.g., temperature, CO_2 concentrations, and sea-level rise) if water clarity is maximized. The single most effective action to protect Chesapeake Bay SAV is to sustain and accelerate improvements in water quality and clarity through nitrogen, phosphorus and total suspended solids load reductions. Additionally, SAV restoration efforts for diverse species may mitigate some of the loss of SAV from areas unable to recover without a seed source. The 2020 GIT-funded climate and SAV modeling project will be instrumental in answering many of our questions when complete.

3.2 Management Implications of Rising Water Temperatures

To identify the corresponding management implications of rising water temperatures on fisheries and SAV, Day 1 of the workshop was organized into the following sessions:

- Session 3: Identify management implications
    - Looking at the ecological effects, key factors to consider, and sensitivities related to rising water temperatures identified today, what are the management implications for the fishery/SAV resource related to rising water temperatures and when action is likely needed (e.g., within 5 years, 10 years, 20 years, 50 years, etc.)?

To identify commonalities and guide discussions on recommendations for Day 2 of the workshop, the identified resource-specific management implications related to rising water temperatures were organized under four main ecological themes: ecosystem-based management, new temperature regime, multiple stressors, and nearshore habitats, further described below.

- Ecosystem-based management strategies aimed to focus on changes in restoration locations and techniques; factoring in rising water temperatures in recruitment estimates, incorporating environmental conditions in fisheries management frameworks; efficacy of current stock surveys; and using nowcast and forecast models for forage species to manage predator stocks accordingly.

- New temperature regime management strategies aimed to focus on changes in spawning success, recruitment, and adult mortalities; monitoring threats from shifting predator distributions and new tropical parasites; and temperature-driven changes on oyster BMP effectiveness.

- Multiple stressors management strategies focused on maximizing improvements in water quality and clarity to build resilience; incorporating habitat squeeze considerations in fisheries management decisions; including shoreline development and other climate stressor effects when assessing SAV recovery; and building in buffers for ecosystem uncertainty in catch quotas.

- Nearshore habitat management strategies focused on co-locating oysters and SAV with one another and/or riparian forest buffers; limiting use of hardened shorelines that negatively affect nearshore resources; and promoting green infrastructure solutions for shoreline protection and habitat.

The management and policy implications of rising water temperatures for the fisheries and SAV resources that were identified by the tidal participants during Day 1 of the workshop are summarized below under the common themes.

1) **Ecosystem-Based Management**: Considerations related to seasonal shifts, prey availability, and habitat change and suitability.

   Management/Policy Implications:

   - <u>SAV</u>:
     - Loss of eelgrass in lower Bay may impact Bay-wide restoration goals; while widgeon grass may fill the niche in most areas, there will be ecological consequences (e.g., timing of emergence of spring habitat for crabs and fish).

   - <u>Oysters</u>:
     - Restoration locations and techniques may need to change to account for rising temperatures and impacts of other stressors.
     - Temperature and seasonal changes may affect growth rates and reproduction which in turn could require adjustments to harvest openings and limits.

- Blue crab:
  - Possible need for new harvest schedules and revised female-specific management to account for temperature change impacts; assess change in efficacy of current winter surveys and stock assessment strategies.
  - Incorporate environmental conditions like temperature and habitat when managing fishery; include monitoring of critical parameters influencing blue crab populations.

- Forage:
  - Support more research to evaluate the forage base and understudied species; aim for standardization of sampling methods and regional definitions for measuring restoration success.
  - Support development of nowcast and forecast models for forage species and establishment of forage indicators and thresholds for suitable habitats – manage predator stocks accordingly.
  - Minimize marsh and SAV habitat loss for forage populations in conservation strategies.
  - Consider changes in forage composition and abundance due to warming temps.

- Striped bass:
  - Collect more long-term fish and prey data to model carrying capacity of Chesapeake Bay in relation to temperature and DO conditions to improve model.
  - Factor in rising water temperatures in recruitment estimates under current management formula.
  - Quantify effects of ecosystem-based factors (e.g., change in food web structures and habitat availability) on striped bass populations and build into management strategies.
  - Incorporate considerations of seasonal change effects on spawning and migration timing/duration – possible predator-prey mismatch scenarios may occur.

2) **New Temperature Regime**: Considerations of the pros and cons of an ecosystem shift to a new temperature regime in Chesapeake Bay (e.g., changes in species distributions; new species moving in; new pathogens; BMP effectiveness).

   Management/Policy Implications:

   - SAV: whether to focus on species or genotypes that can thrive in future conditions (e.g., widgeon grass, heat-adapted eelgrass, or new sub-tropical species) that also provide ecosystem benefits.

   - Oysters: consideration of temp-driven changes on effectiveness of oyster BMPs to remove nutrients.

- Blue crab: increase monitoring for threats from shifting predator distributions and tropical parasites.

- Forage: consider potential competition for resources from invasives and new species moving into the Chesapeake Bay.

- Striped bass: consider changes in spawning success, recruitment and adult mortalities associated with temperature changes.

3) **Multiple Stressors**: Considerations related to co-occurring stressors (high temperatures, low dissolved oxygen, salinity fluctuations, increased disease prevalence, etc.) and extreme events (e.g., marine heat waves, increased precipitation).

   Management/Policy Implications:

   - SAV:
     - maximizing water clarity is key; SAV substantially more resilient to temperature stress in clear water; sustaining and accelerating improvements in water quality and clarity through N, P, and TSS load reductions and appropriate BMP implementation will be vital
     - shoreline development and other climate stressors (e.g., sea level rise) will affect SAV recovery – shoreline hardening negatively affects nearshore SAV and limits shoreward migration

   - Oysters:
     - fishery: may need more monitoring/management of diseases
     - aquaculture: more labor may be required due to increased fouling on cages, faster oyster growth rates, and longer growing season; increased movement of oysters away from areas with poor water quality

   - Forage:
     - continue to support water quality improvements as soft bottom mud is the predominant habitat for many benthic forage species

   - Striped bass:
     - consider habitat "squeeze"/compression (low bottom DO and warm surface water temperatures) when making management decisions (e.g., recreational fishing)
     - build in buffers for ecosystem uncertainty in catch quotas – rising temperatures and increases in other stressors could exacerbate already high mortality rates for striped bass

4) **Nearshore Habitats**: Considerations related to strategically co-locating certain restoration efforts or watershed BMPs to maximize resilience of nearshore habitats.

Management/Policy Implications:

- Oysters and SAV:
  - Consider co-locating oysters/freshwater mussels with SAV, and/or riparian forest buffers.
  - Strategic siting for shoreline and flood protection.

- Striped bass:
  - Consider land-based BMPs, conservation measures and nearshore restoration to increase resilience of key spawning areas (e.g., Susquehanna Flats, Choptank River, and Potomac River).

- SAV and Forage:
  - Limit use of hardened shorelines which negatively affect nearshore resources and promote green infrastructure solutions that provide shoreline protection and habitat.

3.3 Management Recommendations

The objectives for Day 2 of the workshop were to: 1) identify management and policy recommendations, and 2) identify the research, monitoring, or analysis needs to support these recommendations (Day 2 agenda, Appendix B). The management implications for the fisheries and SAV resources that were identified during Day 1 of the workshop were used to inform the Day 2 discussions based on four main themes: ecosystem-based management, new temperature regime, multiple stressors, nearshore habitats. Day 2 of the workshop aimed to answer two main questions: 1) how could current management or policy actions be adapted to address rising water temperatures, and are there entirely new management options that should be considered and 2) what additional science and/or information would you need to implement the management recommendations?

The tidal participants were randomly divided amongst three breakout groups during four sessions based on one of the four main themes to discuss management recommendations and corresponding science needs. The goal was to develop 1-2 management recommendations per group per session and identify science needs for those recommendations. At the end of the sessions, the tidal session workshop leadership convened to consolidate the recommendations, so that similar recommendations were combined to create one synthesized recommendation and to sort out those recommendations that were not as developed. The tidal session workshop leadership presented the final list of recommendations to the tidal project team subgroup, where recommendations were reviewed and assessed for feasibility to implement within the next 3 years and their impact on mitigation and/or resilience. The breakout group's individual management recommendations for each theme, the consolidated recommendations, and the feasibility and impact input can be found in Appendix R.

Post-workshop, the tidal session workshop leadership team selected five recommendations that generated the most interest from the tidal participants based on their feasibility and impact and were the most developed during the workshop sessions. While Day 2 of the workshop had separate sessions for the ecosystem-based management and the new temperature regime themes, the recommendations for these two themes were grouped together since the ecosystem-based management discussions carried over into the new temperature regime session resulting in the overlap of ideas. As a result, recommendations 1, 2, and 3 address both these themes. Recommendation 4 emerged from the Multiple Stressors session and recommendation 5 emerged from the Nearshore Habitats session. The five management recommendations and the themes that guided their development are described below.

Ecosystem-Based Management and New Temperature Regime Recommendations

Recommendation 1*: Establish Chesapeake Bay-wide striped bass fishing guidance based on temperature and dissolved oxygen thresholds to reduce catch and release mortality. Consider developing habitat condition thresholds and fishing guidance for other recreationally targeted species at risk during periods of poor habitat conditions.*

Rationale: Warm surface waters and low dissolved oxygen bottom waters outside the optimal ranges for fish survival minimizes usable habitat, commonly referred to as a "habitat squeeze." Fish experiencing this habitat squeeze are under stress and are more susceptible to mortality associated with catch and release recreational fishing. This stress can be minimized by notifying anglers of days when habitat conditions are poor and discourage fishing that could result in catch and release mortality.

Implementation Actions:

1. Host focused meetings with the joint Sustainable Fisheries and Habitat GITs, and the Fish Habitat Action Team (FHAT), to review existing science on temperature and oxygen thresholds, application of the science to develop bay-wide thresholds and guidance. The desired outcome of these meetings is to establish temperature and oxygen thresholds for striped bass and other key species based on best available science (e.g., number of days above a certain temperature in combination with hypoxic conditions to inform guidance sent to anglers and possibly other fishing restrictions).

2. Convene discussions at the Sustainable Fisheries GIT (SFGIT) with managers and invited anglers to a) consider the temperature and oxygen thresholds findings of the FHAT and develop and communicate guidance to anglers on the environmental thresholds and ways to modify fishing practices to reduce mortality when fish are most vulnerable, b) consider fishing restrictions in areas where conditions exceed thresholds to reduce fishing mortality, and c) develop options for how the thresholds could be built into fishery management plans at state and regional (Atlantic States Marine Fisheries Commission) levels.

There are current examples that apply threshold concepts and could be expanded Bay-wide. For instance, the Maryland Department of Natural Resources' Click Before You Cast simple yet informative approach to describing conditions for fishing could be merged with a temperature advisory system similar to Maryland DNR's system for anglers fishing striped bass. Maryland DNR's advisory system uses a stoplight approach based on temperature thresholds to inform fishing behaviors that minimize stress to striped bass (green = fishing conditions are normal; yellow = forecasted temperatures indicate extreme care encouraged – keep caught fish for later release in water; red = forecasted temperatures indicate not to fish for that species after a certain time in the morning or fish other less vulnerable species) (MD DNR, 1). Similar applications could be put in place for Virginia and Potomac tidal fishery programs. Additionally, established thresholds could be used to inform fishing decisions, particularly in the summer, when temperatures are high enough that would substantially, negatively affect the fish.

Science Needs to Support Implementation:

1. Synthesize existing science to determine temperature and DO habitat condition thresholds for striped bass and other key species. There may be a need for more information on how air and water temperatures interact and its effect on species-specific mortality risk that requires lab and field studies. However, several studies have been conducted on striped bass and these should serve as the starting point.

2. Conduct investigations to better understand behavior of anglers on the water (i.e., throwing back all fish, keeping some fish). This could include gathering additional information about behavior of the fishers when they are out on the water such as are they just going out to catch and release, do they catch their limit and head back to shore, or do they catch their limit and continue to fish and catch and release.

3. Develop habitat suitability models and indicators for key fishery resources. For example, NOAA and the CBP have funded several projects quantifying the impacts of temperature and other ecosystem drivers on forage (Fabrizio et al. 2020, Woodland et al. 2022), striped bass (Dixon et al. 2022) and summer flounder (Fabrizio et al. 2022, Schonfeld et al. 2022).

Recommendation 2*: Develop and implement a strategy to improve communications between living resource managers, scientists and stakeholders on the new temperature regime, the impacts and management response/adaptation strategies.*

Rationale: It is clear the Chesapeake Bay is undergoing an ecosystem regime shift driven by climate change and other factors. New species and new fisheries are emerging in the Bay, and existing species and fisheries are undergoing change. Some species and fisheries will be lost from the Bay entirely. There is a need to better communicate the impacts of rising water temperatures to manage the public's expectations of what the Bay will look like.

Implementation Actions:

1. Sustainable Fisheries and Habitat GIT representatives meet with the CBP communications team to scope out a communications strategy conveying that the shift to a new temperature regime in the Bay is already underway. Change has already occurred in the Bay's ecosystem, potentially bringing new species and fisheries, as well as impacting current species and fisheries. This strategy should be tailored to focus on various audiences–policy-makers, managers, and residents, as each stakeholder group has their own unique perspectives with regard to this changing system.

Science Needs to Support Implementation:

1. Understand where the gaps are in our current communication strategies
    a. Research communication strategies to target specific audiences

2. Social science research to help understand decision making (e.g., understanding behavior of anglers on the water when throwing back or keeping catches, understanding property owners' choice in SAV and shoreline protection)

3. Development of communication strategies for specific audiences (e.g., policy-makers, managers, residents, local partners)
    a. Examples: communication regarding shoreline protection decision-making, public health concerns regarding marine heat waves and state of the fisheries, the effect that the loss of eelgrass will potentially have on the blue-crab industry.

Recommendation 3***:*** *Hold a workshop with multiple fishery stakeholders to explore strategic, long-term ways to advance ecosystem approaches to fishery management in the Bay that incorporate climate change. These approaches would need to address current fisheries management practices that need to be reassessed based on current climate modeling, as well as developing new fisheries management practices that will address the new, potential fisheries that will develop as southern species move into the Bay. To better inform decision-makers, there is a need to develop climate scenarios and assess the risks of environmental drivers on fishery species and their habitats to inform fishery management planning and decisions.*

Rationale*:* Increasing air and water temperatures along with other climate change drivers are already leading to changes in the abundance and distribution of coastal and Chesapeake Bay fisheries as well as their habitat. At the same time, southern species are moving northward and showing up in greater abundances in the Chesapeake Bay and in some cases creating new fishery opportunities. The current fishery management framework is not considering these changes in a strategic, systematic, coordinated way.

Implementation Actions:

1. Hold a focused Sustainable Fisheries GIT forum to identify the changes that are occurring and develop scenarios for how the Bay and fisheries will change over the next 20 years.

2. Convene fishery survey experts to discuss if changes are needed on how we conduct fish stock surveys under changing climate conditions. Examples are:
    a. Blue crab winter dredge survey catchability estimates.
    b. Stock assessment surveys to better capture shifts in temperature ranges/seasons and response to emerging fisheries.

Science Needs to Support Implementation:

1. Improve environmental monitoring of surface and bottom temperature, dissolved oxygen and fish habitat condition. Pair fishery survey data and telemetry fish tag detections with data on changing environmental conditions to better understand impacts on fishery resources at temporal and spatial scales that can be used by managers.

2. Explore a state of ecosystem report level synthesis for the Chesapeake Bay to track how climate change is progressing and for use by managers to adapt actions addressing the changes appropriately. Determine the appropriate time frame for this report on an annual, 3-year, 5-year, or other basis.

3. Better understanding of physiological response of certain species (e.g., lower trophic organisms; need *in situ* monitoring to better assess change).

4. Explore assessments for emerging fisheries to facilitate management as climate change creates conditions for these fisheries to be economically viable.

5. Consider establishing monitoring stations where there are significant fisheries habitat and spawning grounds (long-term monitoring currently is more set up to characterize large bay segments). There are certain sentinel sites with continuous monitoring sites that could be considered (e.g., the National Estuarine Research Reserve System).

6. Evaluate need for zooplankton monitoring at spawning and nursery areas.
    a. The Chesapeake Bay is changing. While it is expected that improvements in habitat due to nutrient reductions and reduced fishing mortality rates will drive improvement in the Bay's living resources and fisheries, past monitoring (1984-2002 and 2011) indicated major negative shifts in phytoplankton, zooplankton, fish, and shellfish inconsistent with expectations from the Bay cleanup. Zooplankton are an important link in the food chain that transform nutrients to fish production by feeding fish larvae of many species and providing forage for forage fish. Zooplankton monitoring can be useful for understanding ecosystem changes associated with large-scale efforts to improve water quality in Chesapeake Bay and is currently a missing building block of the framework for ecosystem-based fisheries management in the Bay.

7. Improve information on drivers of natural mortality and recruitment success for key fishery species and build those drivers into ecosystem models. These improved models will then provide better information on how climate change will affect fisheries. Conduct research on and enhance the existing ecosystem models to better capture climate change drivers and impacts.

8. Better understanding of how the loss of late-winter/spring eelgrass habitat in the polyhaline region of the Bay has and will continue to impact the blue-crab fishery.

<u>Multiple Stressors Recommendation</u>

<u>Recommendation 4</u>*:* *An interdisciplinary team of scientists, resource managers, meteorologists, and communicators should collaborate to design and create a publicly available marine heat wave alert system and explore options to incorporate information on multiple stressors (e.g., low dissolved oxygen). The system would define estuarine marine heat wave conditions and send push notifications to stakeholders about safety and how to mitigate impacts on human health and living resources.*

Rationale: Marine heatwaves are defined as a short period of anomalous higher ocean temperatures and can be caused by ocean currents, air-sea heat flux, and warming through the ocean surface. Marine heat waves in the Chesapeake Bay are increasing in frequency, number of days per year and yearly cumulative intensity (Mazzini and Pianca, 2022). If trends persist, by 2100 the Chesapeake Bay will reach a semi-permanent marine heat wave state. Marine heat waves directly and indirectly negatively impact habitat, living resources, and human communities. Marine heat waves are associated with harmful algal blooms, increase in bacteria such as vibrio, mortality of SAV and other organisms, further decreases in bottom dissolved oxygen, shifts in species composition, increased risk during recreational activities and impacts to fishing and aquaculture. During a marine heat wave, it is important to change how/when/where fishing and aquatic recreation are occurring to minimize impact on both people and aquatic life.

Implementation Actions:

1. The Scientific and Technical Advisory Committee (STAC) and/or Scientific, Technical, Assessment and Reporting (STAR) team convene CBP partners and other relevant experts such as NOAA's weather service and Climate Program Office to review the state of the science and scope out a conceptual design for a heatwave alert system. During this workshop, participants will consider the degree of focus on human health and/or living resource risk, the scale (e.g. jurisdictional, Bay-wide, or tributary specific), alerts based on real-time monitoring data (retrospective) vs. forecast models (prospective), and which agency would issue alerts (e.g., MD DNR/VADEQ, NWS, etc.).

2. Review the following topics and issues in planning for the recommended workshop/meeting.
    a. Incorporate human health risks associated with marine heat waves and guidance on mitigating impacts.
    b. Design and develop a mobile application or incorporate into an existing application (such as Eyes on the Bay), including the impact and what the public should do to limit their impact (i.e., don't take fish out of the water).
    c. Test to ensure user-interface is easy and straightforward for end-users.
    d. Partner with the meteorological community and the media to incorporate into weather forecasts and warnings as a real time push notification.

   e. Examples of similar existing alert systems include:
      i. NCCOS developed a Gulf of Mexico Harmful Algal Bloom (HAB) Forecast system for Texas and Florida; end-users can sign up for HAB alerts through this tool, which can help inform any behavior when interacting with the Gulf.
      ii. NCCOS developed a Chesapeake Bay *Vibrio vulnificus* Forecast system with modeling for the previous six days, current day, and the next day. End-users can opt to receive forecast updates and breaking news on *Vibrio*.

3. If experts and stakeholders agree that such a product would be valuable to reducing risk to people and living resources and have developed a conceptual design, then consider GIT funding for product development.

Science Needs to Support Implementation:

1. Review current definitions of marine heat waves (e.g. Hobday et al. 2016, Mazzini and Pianca, 2022) and conduct research to determine an appropriate definition for Chesapeake Bay (or tributaries as appropriate).

2. Explore real time monitoring of marine heat waves and need for forecast products.

3. Consider a marine heat wave indicator that connects with living resource management and guidance to the public.
   a. Link marine heat waves to living resources by analyzing marine heat waves and fishery survey data such as ChesMMAP.
   b. Incorporate dissolved oxygen and links to habitat preferences of key species such as striped bass, blue crabs, oyster, and SAV.
   c. Synthesis Element 9 Paper (Appendix L) provides conceptual ideas and potential existing data sources that could inform a fisheries marine heat wave indicator.

4. Development of the warning system.

5. Outreach to the public and to partners during development to incorporate stakeholder needs.

Nearshore Habitat Recommendation

Recommendation 5*: Chesapeake Bay Program partners should develop common criteria and metrics to help target, site, design and implement tidal natural infrastructure projects in the nearshore where ecological and climate resilience benefits are highest. A priority should be placed on the use of natural infrastructure by conserving natural shorelines including marshes, wetlands, oyster reefs, and SAV and creating living shorelines in areas that incorporate multiple habitat types. Following targeting and prioritization of projects, emphasis should be placed on* *accelerating preferred designs, providing information on funding opportunities and providing technical drafting assistance for implementation proposals.*

Rationale: Shoreline hardening along the coastlines of the Bay continues despite regulations in Maryland and Virginia to promote natural infrastructure, including living shorelines, tidal wetlands, and other nearshore nature-based feature, where feasible and beneficial (e.g. The Living Shoreline Protection Act in Maryland and Virginia's Living Shoreline Requirement in SB776). Hardened shorelines adversely impact organisms and ecosystems including fish habitat, SAV, water fowl, and water quality. Natural infrastructure provides ecosystem services in the face of a changing climate, including shoreline erosion protection, refuge for many fish and shellfish species from multiple stressors, protection from rising water temperatures, sedimentation mitigation, and improved water quality. Natural infrastructure is an opportunity to create a link between protecting communities from flooding hazards while also enhancing habitat to benefit living resources and recreational activities. Evidence shows natural infrastructure provides multiple climate, ecological and social benefits (Sutton-Grier et al. 2015) and is a shoreline protection option that provides longer term resilience when compared to the hardened options (Currin 2019) NOAA defines "natural infrastructure" as healthy ecosystems–e.g., forests, wetlands, floodplains, dune systems, submerged aquatic vegetation, and reefs). These benefits and ecosystem services include storm protection through wave attenuation or flood storage capacity, enhanced water services and security, increased habitat for vertebrate and invertebrate species, improved water quality, and protection from shoreline erosion. While many terms exist for this infrastructure (e.g., living shorelines, nature-based infrastructure, green infrastructure, and natural/nature-based features), for the purpose of this report, natural infrastructure covers all these terms.

Implementation Actions:

1. Develop siting criteria and targeting tools to facilitate development of more project designs and project implementation proposals.
    a. Convene a meeting through Scientific, Technical Assessment and Reporting (STAR) team that includes key CBP experts and stakeholders working on nearshore restoration (wetlands, living shorelines, oysters, SAV) to compile existing criteria and targeting tools and look for ways to integrate information into the GIS team's Cross GIT mapping platform. Two current GIT funded projects will aid in targeting potential natural infrastructure projects and help identify regional partners and funding sources: "Synthesis of Shoreline, Sea Level Rise, and Marsh Migration Data for Wetland Restoration Targeting" and "Partnership-Building and Identification of Collaborative Tidal Marsh Adaptation Projects." A third GIT-funded project assessing the impacts of climate stressors on SAV may also provide siting information for SAV restoration and natural infrastructure solutions.
    b. Use Federal Emergency Management Agency (FEMA) hazard mitigation plans at community level for targeting. The plans are a good information source on hazard information and flood impacts which can be linked to habitat protection goals.

2. Conduct outreach to homeowners. Review current studies on behavioral drivers behind shoreline hardening decisions and summarize findings to develop effective communication strategies for homeowners to increase the use of living shorelines over hardened structures. Work with regional partners (e.g., Riverkeeper) to communicate with residents.
   a. Explore recent efforts such as MD Department of Natural Resources' (DNR) Social Marketing to Improve Shoreline Management Project, Virginia Institute of Marine Science's (VIMS) Shoreline Property Owner Motivations, Perceptions, and Drivers Project, and the CBP SAV and Communication Workgroup's Social Marketing Project on SAV: Barriers and Benefits with regard to shoreline property owners, and identify gaps in current communication strategies.

3. Develop a Chesapeake Bay specific guide for homeowners, city and town planners, and developers with a menu of living shoreline options, where they work best and how to integrate other habitats (SAV, oysters, etc.).

4. Hold discussion with members of the SAV Workgroup and FHAT to explore development of a funding proposal for a proof of concept project that integrates SAV and oysters.

Science Needs to Support Implementation:

1. Detailed analysis of costs of natural infrastructure versus hardened infrastructure (e.g., bulkhead, rip rap) including long term maintenance costs.

2. Threshold analysis to determine when ecological impacts or benefits occur from natural infrastructure implementation.

3. Development of criteria for targeting where multiple benefits and ecosystem services can be optimized.

4. Use of models to increase understanding of habitat change from sea level rise as to leverage change for different restoration efforts (subtidal oysters versus intertidal).

5. Development of pilot studies co-locating SAV and oysters to increase understanding of the synergistic benefits, such as the buffering capacity of SAV beds to minimize the effects of coastal ocean acidification on nearby vulnerable shelled organisms (e.g., oysters). Coastal ocean acidification refers to increases in carbon dioxide in the water column absorbed from the atmosphere resulting in decreases in pH and carbonate availability. This work would build on the current study by Rivest et al. (VIMS and Old Dominion University) assessing ocean acidification thresholds in Chesapeake Bay.

3.4 Scientific, Assessment and Monitoring Needs and Recommendations

<u>Overarching Research, Monitoring, and Modeling Needs</u>

Throughout this STAC workshop effort, a multitude of management recommendations and associated science needs were identified. Many of these science needs are cross-cutting and relevant to more than one management recommendation above. To make overall progress on addressing rising water temperatures on living resources, a coordinated effort will be needed by CBP partners on cross-cutting science needs. The overarching research, monitoring, and modeling needs are described below:

Research

The CBP partners should focus on reviewing and compiling current research related to social science and understanding the behavior of stakeholders interacting with the Chesapeake Bay, specifically as it pertains to shoreline protection and hardening, fishing activity, and communication about current and future Bay ecosystem status. The CBP should then identify and address gaps in current knowledge about these topics. Additionally, there is a need for research to better understand how and to what degree could watershed BMPs minimize warming for nearshore habitats within tidal tributaries in short to mid-term timeframes related to cooling benefits for SAV and fish.

Monitoring and Analysis

The CBP partners should focus on improvements to long-term monitoring networks surrounding water temperature, hypoxia, salinity, nutrients, and water clarity to help better assess change in habitat conditions for SAV and fisheries. The inclusion of *in situ* fish and plankton monitoring would allow for better assessment of seasonal shifts in temperatures and whether recruitment is affected due to unfavorable changes in spawning timing and prey resources. Furthermore, more habitat monitoring is needed to better understand how SAV community changes from seasonal temperature shifts and the timing differential of eelgrass and widgeon grass will affect habitat-use and productivity of blue crabs and other fisheries.

Modeling

The need exists for current modeling to aid in decision-making as it relates to rising water temperatures in the Chesapeake Bay. The CBP and partners should focus efforts on modeling improvements to help carry out the above identified implementation actions. In general, there is a need for greater habitat suitability modeling that integrates multiple climate stressors on SAV and fisheries, understanding and modeling of the linkages between environmental change and its impacts on living resources, and spatial analyses and modeling to help in nearshore project prioritization. To accomplish these goals, model improvements are needed in simulating shallow water parameters (e.g., dissolved oxygen) at finer scales and incorporating unstructured model grids to fit complicated shorelines. Additionally, forecasting models that project habitat (e.g., SAV, tidal wetlands) migration potential with sea level rise and shorter term changes (1 versus 5-10 years) to support fisheries-related decision-making are of interest to various stakeholders.

4. COMMONALITIES AND LINKAGES BETWEEN WATERSHED AND TIDAL RISING WATER TEMPERATURES

Through presentations and discussions held during the plenary sessions combining participants from the concurrent watershed and tidal sessions, the following common themes and linkages were identified:

- **Modeling tool improvements**: modeling at a finer scale, incorporating temperature change in our modeling systems, and improving the connections between the models we use and monitoring of living resources, are needed to enable us to better respond to rising water temperatures.

- **Expanded monitoring**: expanding the existing monitoring networks to place more emphasis on collecting the data necessary to track and better understand water temperature change, and a focus on smaller streams, are necessary enhancement to the partnership's existing watershed and tidal monitoring networks.

- **Paired water and air temperature measurements**: improving our ability to pair information about trends in water temperature with trends in air temperature at the appropriate scale will greatly improve our understanding of the forces driving the observed watershed and tidal rising water temperatures and support management decisions.

- **Targeting**: incorporating consideration of water temperatures into targeted implementation of practices and the co-location of practices, including different combinations of habitat restoration and land conservation activities, is absolutely necessary to ensure future implementation efforts account for continued rising water temperatures.

- **Land use planning**: making sure that planners and other people who make land use decisions are armed with essential information and science about the impacts of their decisions on rising water temperatures is key to mitigating future rises in water temperatures in the watershed and nearshore tidal environments. It is important to consider natural infrastructure strategies to maximize water quality, habitat, and living resources benefits that also build resilience to warming water temperatures and other climate change conditions (e.g., increased precipitation, sea level rise). While gray infrastructure and hardened shorelines are used to minimize climate change impacts related to watershed and coastal flooding and shoreline erosion, they also negatively affect water temperature and natural resources. Supporting research and enhancing knowledge on how best to implement land use strategies that maximize climate resilience, water quality, habitat, and living resources benefits will allow for better overall adaptation to future climate conditions.

- **Thresholds**: understanding thresholds and communicating about the implications of thresholds to decision-makers and the public would improve understanding of why management tools and actions are needed to respond to rising water temperatures.

- **Nature-based features**: restoration using natural resources both on the land and in the water is necessary to help with mitigation or to build additional resilience to rising water temperatures. Nature-based practices, such as forest buffers, wetland restoration, living shorelines, and SAV restoration provide multiple ecological and climate resilience benefits in addition to sequestering carbon from the atmosphere. Quantification of these benefits and increased understanding on the spatial and temporal shifts to nature-based features will be important for effective natural resource management under future climate conditions.

- **County comprehensive plans**: building tighter linkages between the growing scientific understanding of rising water temperatures and updating and implementing county comprehensive plans are essential to future planning to mitigate and adapt to rising water temperatures.

- **Communication**: communication with each other, communication with decision-makers, and communication with the public is key to ensuring we all start to directly consider the implication of rising water temperatures in our day-to-day management decision making.

5. MANAGEMENT PANEL INSIGHTS

A panel discussion among managers drawn from across the partnership was scheduled near the end of the second workshop held on March 15, 2022. Panel members provided the following series of insights for considering rising water temperatures within the partnership's shared decision-making efforts:

Stay focused. We need to recognize that protecting existing forest, promoting riparian buffers and promoting smart BMPs – that is, staying focused on implementation of the Chesapeake Bay TMDL – will help give the Bay and watershed ecosystems the resilience they need to stay the course in rapidly changing temperature regimes. Recognizing that many partners are feeling overwhelmed by taking on new things, we need to keep focused on incorporating consideration of rising stream temperature in the context of what the Chesapeake Bay Program partnership has already committed to and has existing goals in place to achieve.

Keep positive. We heard a lot about ongoing changes and projected future changes to the watershed and the Bay ecosystem due to rising water temperatures. How do we tell a compelling story which reflects such changes? We are already witnessing changes in our Bay fisheries due, in part, to increasing water temperatures throughout the Bay. We need to be telling those stories, realizing that continued changes are inevitable, and we will need to adapt to those changes through time.

Put More Attention on Smart BMPs. BMPs and natural infrastructure are all really important in this situation. We've been focused on water quality, but if there are water quality BMPs that are further heating waterways, we need to identify alternatives that could be implemented in multiple landscape contexts. Although it is not always possible to eliminate the use of heating BMPs, we can strive to use our continuing technological advances to reduce the heating of runoff from cities, farms and forests.

Increased integration of monitoring. Our monitoring programs need to better integrate considerations of smaller streams, groundwater, living resources and air temperatures in the context of rising water temperatures. We also need new monitoring approaches which will enable us to document the duration and impact of temperature shocks to receiving urban streams.

Communicate better and more often. To successfully cause behavior modification, people need to better understand the relationship between rising temperature and what they can do to correct it. This strategic communication is needed around a variety of topics, including fisheries and property maintenance. Communicating about rising water temperatures provides us with an additional means for communicating why taking these actions are so important.

It's about saving trees, not just replanting new ones. We need to quantify what we are losing when we cut down mature trees and forests and put these values in context with what we gain when we plant seedlings. The cost of losing mature forest needs to be better communicated.

Rethinking water quality standards. We need to challenge ourselves to update our states' water temperature standards and articulate what a state-of-the art standard might look like at the local scale.

Fisheries management will be different with rising water temperatures. Stay focused, keep positive, and recognize Bay fisheries are changing and will continue to change. We will likely have completely new fisheries in the future and lose fisheries which have been associated with Chesapeake Bay for decades over time. We must continue to manage our fisheries keeping in mind the entire life cycle of each fishery population, particularly for this species which spent part of their lives outside of Chesapeake Bay. We really need to make sure, before we approach our vast array of fishery stakeholders with new management approaches, that we are connecting the dots of what is happening inside and outside of the Bay. We need to take full advantage of the climate scenario planning initiative between the Atlantic States Marine Fisheries Commission and the Mid-Atlantic Fishery Management Council.

Use targeting to act smarter, not delay. We have a lot of targeting tools that can help us identify which lands to conserve and where to place the most effective BMP. We could use these tools more effectively to factor in consideration of rising water temperatures when identifying which practices should be implemented where. However, we shouldn't delay implementation of actions we know are needed now in the interest of further improving our existing targeting tools.

There are opportunities at the land-water interface. With new federal funding opportunities, we need to think through how we can best position ourselves in the Chesapeake Bay to better address strategies to maintain the natural systems we have along the shoreline. We need to carry out more restoration and more habitat protection at that near-shore interface to provide refuge to a number of species, such as blue crabs, oysters, and forage species in the face of rising water temperatures.