Tidal Briefing Paper

For March 15, 2022 Rising Water Temperature STAC Workshop

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Tidal Discussions for March 15th Breakout Groups & Identified Management/Policy Implications

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

   Management/Policy Implications:

   - SAV:
     - 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)
   - Oysters:
     - restoration: locations & techniques may need to change to account for rising temperatures & impacts of other stressors
     - fishery: temperature and seasonal changes may affect growth rates and reproduction which in turn could require adjustments to harvest openings & limits
   - Blue crab:
     - possible need for new harvest schedules & revised female-specific management to account for temperature change impacts; assess change in efficacy of current winter surveys & stock assessment strategies
     - incorporate environmental conditions like temperature & habitat when managing fishery; include monitoring of critical parameters influencing blue crab populations
   - Forage:
     - support more research to evaluate the forage base & understudied species; aim for standardization of sampling methods & regional definitions for measuring restoration success
     - support development of nowcast & forecast models for forage species & establishment of forage indicators & 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 temp and DO conditions to improve model
     - factor in rising water temps in recruitment estimates under current management formula
     - quantify effects of ecosystem-based factors (e.g., change in food web structures & habitat availability) on striped bass populations and build into management strategies
     - incorporate considerations of seasonal change effects on spawning & migration timing/duration – possible predator-prey mismatch scenarios may occur

2) **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 & clarity through N, P, and TSS load reductions & appropriate BMP implementation will be important
     - shoreline development & other climate stressors (e.g., sea level rise) will affect SAV recovery – shoreline hardening affects nearshore SAV & 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, & 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 dissolved oxygen and warm surface water temps) when making management decisions (e.g., recreational fishing)
    - build in buffers for ecosystem uncertainty in catch quotas – rising temps & increases in other stressors could exacerbate already high mortality rates for striped bass

3) **Nearshore Habitats**: Considerations related to strategically co-locating certain restoration efforts or watershed best management practices (BMPs) to maximize resilience of nearshore habitats

Management/Policy Implications:

- Oysters & SAV:
    - consider co-locating oysters/freshwater mussels with SAV, and/or riparian forest buffers
    - strategic siting for shoreline & flood protection
- Striped bass:
    - consider land based BMPs, conservation measures and nearshore restoration to increase resilience of key spawning areas (Susquehanna, Choptank, Potomac)
- SAV & forage:
    - limit use of hardened shorelines which negatively affect nearshore resources and promote green infrastructure solutions that provide shoreline protection and habitat

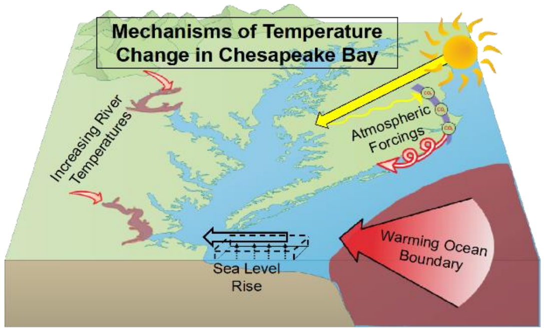
4) **New Temperature Regime**: Considerations of the pros and cons of an ecosystem shift to a new temperature regime in Chesapeake Bay (e.g., changes in species distributions; new species moving in; new pathogens; BMP effectiveness)

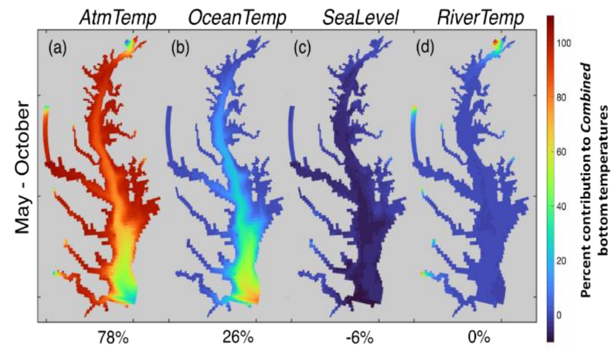
Management/Policy Implications:

- SAV: whether to focus on species or genotypes that can thrive in future conditions (e.g., widgeongrass, 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 & new species moving into the Bay
- Striped bass: consider changes in spawning success, recruitment and adult mortalities associated with temperature changes.

Tidal Storyline (DRAFT)

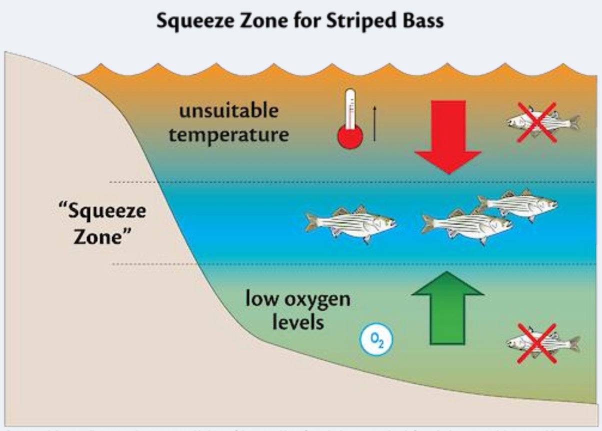
- Rising water temperatures in Chesapeake Bay are ***largely influenced by atmospheric and ocean temperatures***



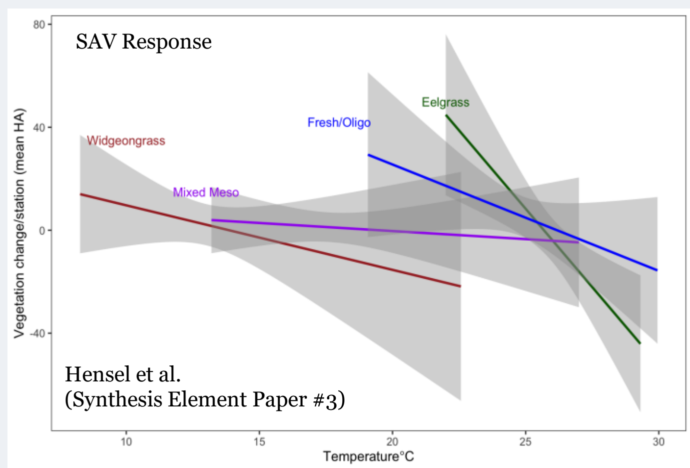


Source: Hinson et al. 2021

- Rising water temperatures influence physical, chemical, and biological processes and ecosystem responses – can cause ***direct and indirect positive and negative effects on the Bay's living resources*** given ***varying sensitivities*** of Bay's fish, crab, shellfish, benthic and pelagic forage, and SAV communities and habitats to temperature change



Conceptual diagram illustrating the compressed habitat of the striped bass from the low oxygen levels from the bottom, and the unsuitable unsuitiable tempatures on the top waters.
Diagram courtesy of the Integration and Application Network (ian.umces.edu), University of Maryland Center for Enviromental Science. Source: Boesch, D.F. (editor). 2008. Global Warming and the Free State: Comprehensive Assessment of Climate Change Impacts in Maryland. Report of the Scientific and Technical Working Group of the Maryland Commission on Climate Change. University of Maryland Center for Environmental Science, Cambridge, Maryland. This report is a component of the Plan of Action of the Maryland Commission on Climate Change, submitted to the Governor and General Assembly pursuant to Executive Order 01.10.2007.07.

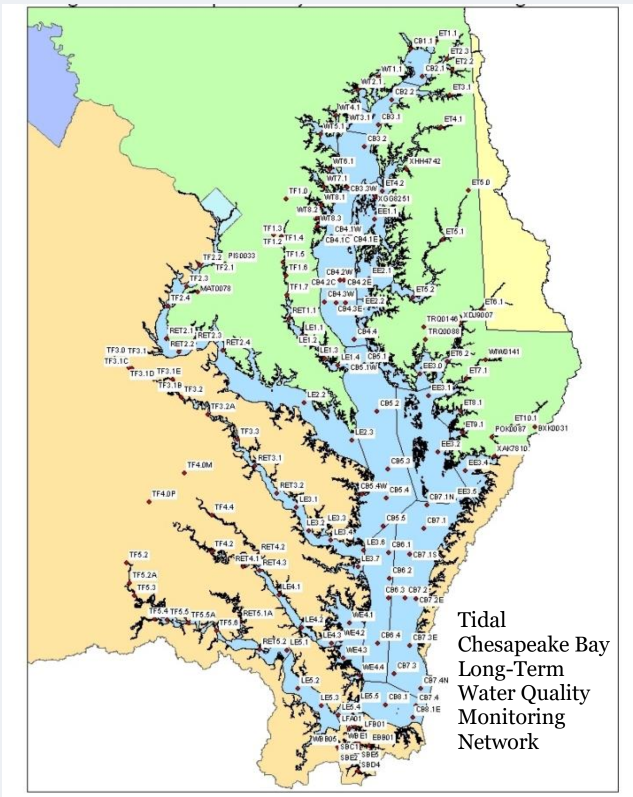


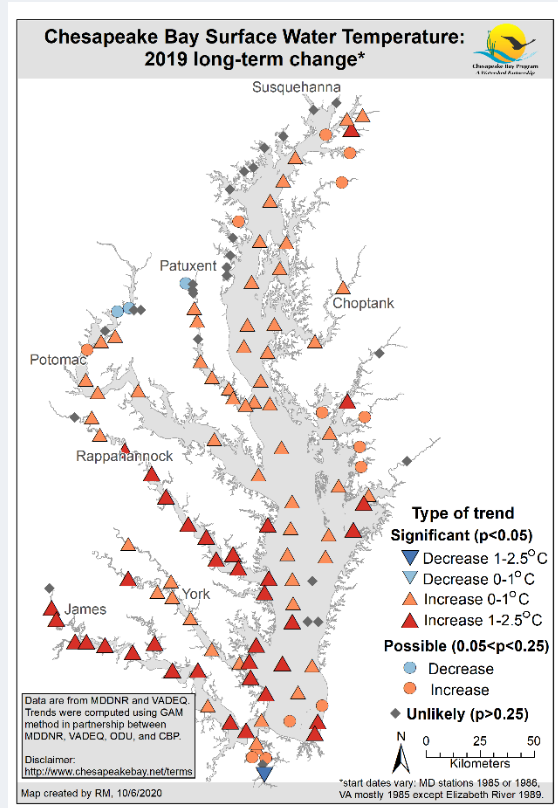
- Warming temperatures create ***new spatio-temporal habitat niches*** allowing species to extend their range into the Bay (e.g., cobia, red drum) and thrive (e.g., shrimp). Also allows for new warm water pathogens.

- ***Adjustments to fisheries management strategies*** (e.g., catch limits, seasonal openings) and ***submerged aquatic vegetation (SAV) community expectations*** likely needed to account for warming habitats given global drivers.

- ***Enhancements*** to the Partnership's current ***modeling tools*** are needed to better understand the influences of rising water temperatures on living resources and habitats.

- Having the ***right monitoring and tidal water temperature change analyses*** in place to collect and organize data in response to management needs is critical to inform ***improved decision-making***.





- ***Differing opinions on the effectiveness of watershed BMPs in reducing hot water plumes in tidal tributaries*** that could minimize exacerbated warming for some nearshore habitats in the short to mid-term timeframe (rural vs. urban vs. no substantial effect)

- Actions utilizing ***nature-based, habitat-forming, carbon sequestering BMPs*** (e.g., tidal wetlands, forest buffers) ***could mitigate or reduce vulnerabilities of global temperature increases*** within a mid to long-term timeframe (end of century).

Tidal storyline sources can be found in Synthesis Element Papers #2, #3, #5, #6, #9, and #10

The Rising Water Temperature Workshop Day 1 species-specific tidal findings are summarized below.

Submerged Aquatic Vegetation (SAV)

Ecological Impacts of Rising Water Temperatures

Positive	Negative
Potential increased productivity for freshwater & brackish species (“CO2 Fertilization Effect”)	Loss of eelgrass – extirpation of bay scallops; reduced habitat for finfish and crabs
Longer growing season – increased CO_2 fertilization (“Co2 Fertilization Effect”)	Reduced water quality from phytoplankton growth - decreased light availability
Better nursery habitat for tropical fish species (if subtropical SAV species migrate into Bay)	More thermal stress – increased disease susceptibility & sediment sulfide toxicity
	Decrease in SAV species and genetic diversity
	Loss in carbon sequestration

Key Factors to Consider

- **Timing**: temperature-induced changes in SAV communities & habitat-use by finfish & crabs
- **SAV recovery:** recovery rates & potential after thermal stress
- **Multiple stressors**: increased temperatures, turbidity, disease prevalence, sea level rise
- **Facilitated migration**: introduction of heat-tolerant eelgrass genotypes and/or subtropical species (will still require clear water/high light)

Management Implications

- Maximizing water clarity is key; SAV substantially more resilient to temperature stress in clear water
- Sustaining and accelerating improvements in water quality & clarity through N, P, and TSS load reductions & appropriate BMP implementation
- 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)
- Shoreline development & other climate stressors (e.g., sea level rise) will affect SAV recovery – shoreline hardening affects nearshore SAV & limits shoreward migration
- Whether to focus on species or genotypes that can thrive in future conditions (e.g., widgeongrass, heat-adapted eelgrass, or new sub-tropical species) that also provide ecosystem benefits

Current Knowledge

Known temperature ranges & thresholds for several SAV species (~17 commonly observed species); good biophysical model to predict eelgrass impacts; turbidity/water quality effects on SAV; different SAV species sensitivities (eelgrass more negatively affected than widgeongrass & other brackish & freshwater SAV)

Knowledge gaps

Temperature variability & extreme events (e.g., marine heat waves) on SAV reproductive success & survival; temperature change on stable vs. recovering beds vs. seedlings; temperature thresholds of fresh & brackish species; species-specific response curves to temperature changes

Suggested Research, Monitoring & Analyses

- Studies evaluating multiple stressors – there is a current GIT-funded modeling project
- Research to better understand cold winter & hot summer tolerances for various species – winter temps will limit survival of tropical species in Chesapeake Bay
- Research to better understand ecology and ecophysiology of widgeongrass
- More field studies on SAV species response; need more research on the competition among freshwater species in response to increasing temperatures

OYSTERS

Ecological Impacts of Rising Water Temperatures

Positive	Negative
Longer active feeding/filtering – possible increases in water quality improvements	Co-occurring stressors – ocean acidification (OA), increased hypoxia, increased precipitation/freshwater flow (low salinity, greater sedimentation)
Increased food availability (algae)	More harmful algal blooms (HABs), pathogens, & toxin exposure – human health consumption concern
Faster growth rate and earlier maturation	Alteration in food sources (greater abundance, lesser quality)
Longer growing season	Increased disease pressure
Lengthened spawning season	Reduced spawning activity at high temps
Reduced winter mortality	Non-native predators moving into Bay

Key Factors to Consider

- **Seasonal shifts/timing**: longer spawning season; more production in spring, but less favorable conditions in summer
- **Multiple stressors on survival**: other stressors (OA, low salinity, increased hypoxia) more concerning than temperature increases alone
- **Extreme events/anomalies**: how does long exposure to extreme temperatures affect vitality?
- **Disease prevalence**: increases in disease pressure; temperature-disease & human health interactions

Management Implications

- Restoration: locations & techniques may need to change to account for rising temperatures & impacts of other stressors; build in more resilience strategies (e.g., co-locating oysters with SAV or riparian forest buffers; siting for shoreline & flood protection)
- Fishery: temperature and seasonal changes may affect growth rates and reproduction which in turn could require adjustments to harvest openings & limits
- Aquaculture: more labor may be required due to increased fouling on cages, faster oyster growth rates, & longer growing season; increased movement of oysters away from areas with poor water quality
- Consideration of temp-driven changes on effectiveness of oyster BMPs to remove nutrients

Current Knowledge

Many studies on growth rates, fecundity, reproduction thresholds, spawning timing, & calcification rates

Knowledge Gaps

Maximum spawning temp; seasonal shifts & impact on growth rates, gender transition & time to first spawn; response to extreme events; temperature-disease interactions; temp effect on filtering & long-term survivability & adaptability

Suggested Research, Monitoring & Analyses

- Continue long-term temperature monitoring
- Modeling simulation studies to identify the impacts of temperature relative to other stressors;
- Forecasting - apply downscaled climate models to project shorter term changes (1 vs 5-10 years)
- Analyses to see if restoration techniques and locations are impacted by temperature change
- Relationship between temperature change, denitrification & ecosystem services

Blue Crab

Ecological Impacts of Rising Water Temperatures

Positive	Negative
Lower winter mortality	Increase in pathogens & vulnerability; potential new subtropical pathogens
Maturation size reached earlier	Loss in nursery & foraging SAV habitats
Improved juvenile growth & survival – longer growing season (assuming adequate prey availability)	Other climate stressors – increase in intense storms may affect larval transport & recruitment
	Increased predation from new predators moving into the Bay (e.g., red drum)

Key Factors to Consider

- **Seasonal shifts/timing**: delays in burrowing, winter food availability, earlier springs
- **Life stage & sex:** female maturation at smaller size
- **Geographic location**: greater effects in shallow tributaries compared to mainstem
- **Parasites & disease**: new tropical diseases and parasites enabled by warmer temperatures

Management Implications

- Possible need for new harvest schedules & revised female-specific management to account for temperature change impacts
- Change in efficacy of current winter surveys & stock assessment strategies (being assessed)
- Increase monitoring for threats from shifting predator distributions and tropical parasites
- Incorporate environmental conditions like temperature and habitat when managing fishery; include monitoring of critical parameters influencing blue crab populations

Current Knowledge

Higher crab survival rates in warmer winters; warmer water promotes rapid growth, faster molt to maturation, greater food consumption, reduced carapace thickness; well-established mortality thresholds, estimates of crab population, & hypoxia forecasts; smaller females at mating may lead to increased vulnerability to predation and diminished fecundity per brood; SAV density linked to juvenile survival

Knowledge gaps

Temperature change effect on female spawning migrations & mating; predator-prey dynamics related to seasonal shifts & new predators; impact of tropical parasites; marine heat wave effects; discard mortality rates for peeler industries under low dissolved oxygen and warmer temps; genetic capacity to adapt; spatial scales for blue crab forecasts, quantification of crab production by SAV types

Suggested Research, Monitoring & Analyses

- Correlation of blue crab productivity & nursery habitat availability
- Correlation of water temp & abundance estimates from winter survey/overwintering mortality
- Track the timing of spawning migration & predicted productivity
- Research on extreme events above/below thresholds on blue crab survival/abundance: relationship between storm events (i.e., wind currents) & recruitment success
- Assess temp effects during various life stages & locations in connection with recruitment & harvest
- Continuous monitoring of temp, dissolved oxygen, & salinity; connect abundance & environmental drivers for forecasting
- Quantify impacts of increased predation on blue crabs related to species distribution shifts

Forage (Bay Anchovy, Menhaden, Benthic Invertebrates)

Ecological Impacts of Rising Water Temperatures

Positive	Negative
Increased white shrimp populations in VA	Increased hypoxia/reduced bottom habitat
Increased growth rate of forage (assuming no food or water quality limitations)	Increased pollution affecting benthos
	Water quality degradation
	Changes to reproductive development
Unsure: changes in habitat availability, distributions, predator-prey overlap in space & time	

Key Factors to Consider

- **Changing habitat**: temperature stratification (distribution & abundance); effects of land use and development on abundance & diversity; availability of tidal marsh refugia relative to sea level rise; change in oyster reefs & SAV habitat availability on forage species
- **Predator-prey interactions:** multi-species stock assessments
- **Extreme events**: the frequency and duration of marine heat waves
- **Improved monitoring**: limitations of fishery surveys (sampling gear, coverage in space & time), need for better spatial coverage of bottom water temperature data

Management Implications

- Support more research to evaluate the forage base & understudied species; aim for standardization of sampling methods & regional definitions for measuring restoration success
- Support development of nowcast & forecast models for forage species & establishment of forage indicators & thresholds for suitable habitats & manage predator stocks accordingly
- Continue to support water quality improvements as soft bottom mud is the predominant habitat for many benthic forage species Minimize marsh and SAV habitat loss for forage populations in conservation strategies
- Consider changes in forage composition and abundance due to warming temps and potential competition for resources from invasives & new species moving into the Bay

Current Knowledge

Limited understanding of temperature effects on zooplankton distribution, benthic community composition, and bay anchovy distribution & abundance (bay-wide scale); spring time warming impacts on forage abundance

Knowledge Gaps

Temperature thresholds and sensitivities during various life stages (egg maturation, spawning); changes to reproduction & growth for key species; competition on forage by invasives; combined effects of stressors (temperature, salinity, etc.); genetic capacity to adapt to temperature changes; benthos distribution & abundance (infauna & epifauna)

Suggested Research, Monitoring & Analyses

- Temperature thresholds for species' sensitive life stages; establish forage indicators
- Studies on match-mismatch of forage species and food resources from temperature shifts
- Temperature impacts on anchovy reproduction
- Vertical/horizontal structure of marine heatwaves & persistent change to stratification
- Better understanding of the bay's heat exchange between the main stem and tributaries, and its impact on temperature variability
- Fisheries independent menhaden surveys that can help model habitat suitability
- Improved long-term monitoring of forage fish & benthic community

Predator-Finfish (Striped Bass)

Ecological Impacts of Rising Water Temperatures

Positive	Negative
Increased growth of larvae & age-0 juveniles	Poor survival due to increased temperature ranges & other stressors
	Reduced summer habitat for striped bass
	Reduced access to forage resources
	Decreased summer & fall presence in tributaries

Key Factors to Consider

- **Seasonal shifts**: spawning & migration timing/duration – predator-prey mismatch
- **Multiple stressors:** habitat "squeeze" from low bottom dissolved oxygen & warming surface waters; increased disease mortality
- **Fishing practices**: fishing effects on populations with spatial & temporal habitat compression (fish more concentrated due to less available habitat)
- **Prey composition & availability**: changes in zooplankton & benthic communities during early life stages
- **Extreme events/anomalies**: increase in extreme rain events along with marine heat wave timing could drastically diminish habitat; how are extreme events driving fish response?

Management Implications

- Build in buffers for ecosystem uncertainty in catch quotas – rising temps & increases in other stressors could exacerbate already high mortality rates for striped bass
- Quantify effects of ecosystem-based factors (e.g., change in food web structures & habitat availability) on striped bass populations and build into management strategies
- Consider habitat "squeeze"/compression (low bottom dissolved oxygen and warm surface water temps) when making management decisions (e.g., recreational fishing)
- Factor in rising water temps in recruitment estimates under current management formula
- Collect more long-term fish and prey data to model carrying capacity of Chesapeake Bay in relation to temp and DO conditions to improve models

Current Knowledge

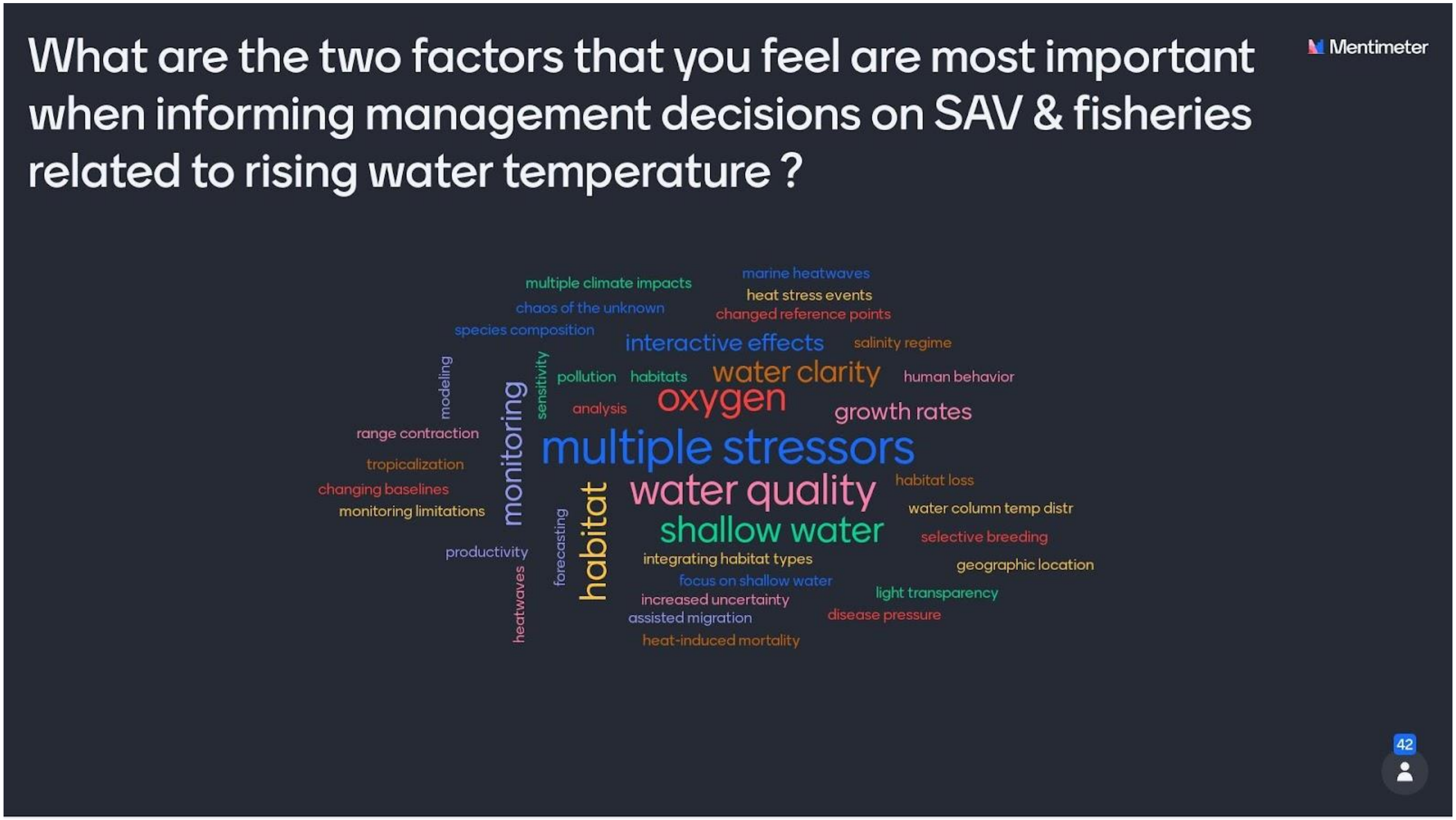
Spawning timing & larval survival and growth; good understanding of temperature thresholds & sensitivities of striped bass during different life stages

Knowledge Gaps

Effects of season-specific warming and extreme events (marine heat waves, high rainfall events) on early life stages and overall recruitment; adaptability and tipping points; suitable habitat and distribution of striped bass given multiple stressors; prey availability given effects on spawning timing

Suggested Research, Monitoring & Analyses

- Daily time series to identify marine heat wave effects in relation to optimal life stage temperatures
- Conceptual modeling of mechanisms related to temperature timing & lethal conditions to larvae; climate change simulations of early life processes & responses; larval fish & plankton monitoring
- *In situ* fish monitoring – sustained telemetry program that leverages Chesapeake Bay array to evaluate temperature influences on seasonal distributions by resident striped bass
- Revisit how we evaluate fish mortality – shorter timestep to better understand natural mortality rates versus fishing mortality
- Develop temperature indicator at finer temporal scale to understand changes in spawning timing in tidal tributaries
- Monitor multiple stressors (habitat "squeeze," intensity & duration of precipitation & wind)



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