Recommendations for Conducting Fish Habitat Assessments in Tidal Waters of the Chesapeake Bay

Prepared for

The Chesapeake Bay Program Fish Habitat Action Team,
a joint effort of the Sustainable Fisheries and the Vital Habitats
Goal Implementation Teams

By

A.K. Leight, Suzanne Skelley, John Christensen, Dan Dorfman*, Chris Jeffrey*

Marine Spatial Ecology Division
National Centers for Coastal Ocean Science
National Ocean Service
*CSS-Inc, under NOAA NCCOS Contract

David Bruce

NOAA Chesapeake Bay Office
Office of Habitat Conservation
National Marine Fisheries Service

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Executive Summary

In response to declines in fish habitat, the 2014 Chesapeake Bay Agreement set an objective to “continually improve the effectiveness of fish habit restoration and conservation efforts” (CBP, 2014). In order to address this objective a team of collaborators was established and a series of activities was initiated. These activities included a Bay Program sponsored workshop in 2018 which prompted an inventory of available datasets and led to initial scoping of Baywide fish habitat assessment efforts.

A review of previous fish habitat assessments that included the Chesapeake Bay was conducted. These assessments were largely limited to national datasets or specific funding objectives, but do lend insights into the conduct of fish habitat assessments. Key insights from these previous assessments include the importance of considering the spatial scale of the assessment structure as well as incorporating local data.

The collaborative Chesapeake Bay fish habitat assessment team divided pilot analytical assessment efforts between tidal and nontidal waters. For nontidal waters, the National Hydrography Dataset framework was chosen for the assessment framework. For tidal waters, a new two dimensional grid-lattice structure was developed for the entire Bay and was evaluated for utility by using the Choptank River as a pilot. Fifteen variables were integrated into the framework to explore and demonstrate options for inclusion of different data types, such as linear versus polygon data, and for different data summarization methods, such as average over time or proximity to other metrics. The framework was exercised to explore its utility for assessing aspects of fish habitat.

Subject matter experts were consulted through two virtual meetings in October 2020 to provide feedback on the pilot framework structure: the types of data to apply to the framework, methods to integrate various datasets into the framework, and the types of analysis feasible to conduct using the framework. A robust set of read-ahead materials was developed and delivered to participants prior to the meetings. During the workshops, a large amount of feedback was offered and catalogued. Key highlights of the feedback and recommendations follow:

- Management Application: Through both workshops and all topics discussed, the overarching element of feedback received was to clearly define the Baywide assessment’s intended management use. This is critically important as it informs technical decisions to conduct the assessment, implementation steps to reach end users and resource requirements for development and sustainment.
- Analytical Framework: The pilot’s analytical framework is suitable to extend Baywide. A grid-lattice of contiguous hexagons is recommended for its design.

- Data: While Chesapeake Bay enjoys rich data, it varies in temporal and spatial resolution and accessibility. Choices must be made to match available data to the intended management application. Choices must also be made regarding methods of integrating data and the use of modeled data. These choices will guide the technical conduct of the assessment and affect resources required.

- Time: The range of time for each variable and its treatment in the analytical framework ought to be clearly communicated and explained to the end user audience. Time periods must be considered as seasonal changes are important to fish life stages as are interannual variations. Including an analytical capability to assess climate time scale changes ought to be considered and decided upon during the design phase.

- Assessment Update Requirements and Temporal Relevance: Many fish habitat assessments represent conditions at a point in time. The richness of Chesapeake Bay monitoring programs offers the opportunity to routinely add data to an assessment tool, and some users may want a dynamic rather than static tool. During the design phase, an evaluation of intended lifespan, update strategies, and maintenance requirements should be conducted and weighed against utility for management decisions and resources required.

The Choptank River pilot assessment team provides the following recommended next steps based on the responses from subject matter experts, insights gained through exploration of the tidal pilot framework, and existing actions in the fish habitat management plan:

- Continued collaboration through assessment project team and others in scoping fish habitat assessments for the Chesapeake Bay, with the next immediate focus on identifying options for a headwaters-to-tributary mouth pilot assessment.

- Promote collaboration with data holders as a means of achieving habitat outcomes. Data holders, especially lead investigators of fisheries-independent fish and shellfish surveys, are also data generators. The use of biological information in fish habitat assessments adds to their value by making possible the identification of habitat influences not previously known.

- Address data gaps and data incompatibilities by promoting the expansion of monitoring programs, standardization of fish survey methods, and consider use of models.

- Continue to foster communication with likely assessment users to ensure content and application address their needs.

1.0 Introduction

The Choptank River Pilot fish habitat assessment is one activity of a series designed to improve the effectiveness of fish habitat conservation and preservation efforts in the Chesapeake Bay. This introduction provides a description of the Choptank Pilot's objectives; a brief review of the context in which the Choptank Pilot emerged; and a description of similar, contemporaneous fish habitat efforts.

1.1 Choptank Pilot Project Objectives

The objectives of this project were to 1) develop an example framework for assessing fish habitat in a tributary with tidal salt and tidal freshwater habitats, 2) obtain feedback from subject matter experts about the design and potential applications of the example framework, 3) conduct testing of the proposed framework, and 4) develop recommendations for extending the framework to Chesapeake Bay tidal areas.

1.2 Context for the Choptank River Pilot

The Chesapeake Bay forms the nation's largest estuary and serves as an essential ecological, economic, and social resource. The Chesapeake Bay watershed includes six states and the District of Columbia. Harvest of fish and shellfish from the Bay may exceed half a billion pounds per year (CBF, 2009). However, maintaining sustainable populations of commercially and recreationally important fish and shellfish remains challenging under the combined pressures of habitat loss and degradation, non-native and invasive species, and fishing pressure (CBP, 2014, Kennedy et al., 2020).

As part of the 2014 Chesapeake Bay Watershed Agreement (CBP, 2014), all Bay jurisdictions committed to improve the condition of the Bay, including a goal to achieve sustainable fisheries. An outcome under that goal is improved effectiveness of fish habitat conservation and preservation efforts; however, this outcome, as stated in the Bay Agreement, does not contain numeric metrics to measure progress:

> *Continually improve effectiveness of fish habitat conservation and restoration efforts by identifying and characterizing critical spawning, nursery and foraging areas within the Bay and tributaries for important fish and shellfish, and use existing and new tools to integrate information and conduct assessments to inform restoration and conservation efforts.*

To make progress towards Bay Agreement outcomes, actions are identified in outcome-specific biennial logic and action plans. Consistent with the Fish Habitat 2018-2019 Logic and Action Plan and in response to a request from the Sustainable Fisheries and Vital Habitat Goal Implementation Teams, the Chesapeake Bay Program Science and

Technical Advisory Committee sponsored a workshop in April 2018. The workshop's objective was to identify the necessary information and analytical approaches to assess the condition and vulnerability of fish habitat in the watershed.

Since a guiding principle for a Chesapeake Bay regional fish habitat assessment is to support planning and management decisions, a user-needs questionnaire was developed by the workshop steering committee and administered prior to the 2018 workshop. Responses were received from 148 individuals across all watershed jurisdictions. Of the respondents, 41% work in local government, with the remaining 59% composed of a wide-range of occupations including state, non-profit, federal, academic, and consulting individuals. The majority of respondents (70%) indicated that they would use a regional assessment to prioritize sites for restoration or conservation; although, they noted that it needs to complement tools or prioritization methods they already use. A detailed report of participants and questionnaire results may be found in Hunt et al. (2018). Lastly, in an effort to identify data available for the Chesapeake watershed which might not be available nationwide, scientists from NOAA and USGS compiled fisheries-independent fish survey data and environmental data for Chesapeake Bay tidal and non-tidal waters.

During the 2018 STAC workshop and using the compilation of fisheries-independent fish survey data and environmental data, participants applied their expert knowledge and identified 54 variables as having significant impact on fish habitat. The workshop resulted in 5 critical recommendations in the areas of data gathering; pilot assessment; assessment metrics; outreach and training to assessment users; and, research. The Choptank Pilot stems from the recommendation to conduct pilot assessments in waterways representative of the four Bay habitats: tidal salt, tidal fresh, warm non-tidal, and cold non-tidal waters.

Following the STAC workshop, a team of scientists from the National Oceanic Atmospheric Administration (NOAA), the United States Geological Survey (USGS), and the Chesapeake Bay Program coordinated with other on-going regional fish habitat assessments; conducted a further assessment of stakeholder needs as fishery managers and state agencies may have been under-represented in the workshop questionnaire (Leight et al, 2020); and, defined two pilot fish habitat assessments. Scientists from USGS Leetown Science Center are conducting a fish habitat assessment in warm and cold non-tidal waters. NOAA scientists conducted a pilot in the Choptank River watershed, encompassing tidal salt and tidal fresh habitats.

1.3 Existing Regional Fish Habitat Assessments

In 2015, NOAA and The Nature Conservancy launched the Chesapeake Bay Habitat Prioritization Tool, an online interactive website for prioritizing habitat (Martin, 2015). The goal of the tool was to allow managers and scientists to perform scenario-based assessments, primarily of tidal wetlands, by defining importance weights for a number of habitat related variables, with the emphasis on prioritizing areas for wetland conservation and restoration. Without a clear plan and resources for maintenance and updating, the Habitat Prioritization Tool lost support and is no longer accessible.

In preparation for the 2018 STAC workshop, a steering committee reviewed the methods and data or variables used in previous fish habitat assessments, including the 2010 and 2015 National Fish Habitat Partnership (NFHP) national assessments and the Gulf of Mexico and Pacific Coast regional assessments (Crawford et al, 2016). Several of the preceding fish habitat assessment efforts included the Chesapeake Bay within their geographic extent. For example, the National Fish Habitat Partnership habitat assessments included both estuarine and nontidal waters of the Chesapeake Bay (NFHB, 2010; Crawford et al, 2016). These assessments were conducted to better understand how human activities are impacting fish habitat. However, they could only broadly generalize habitat conditions in the Chesapeake Bay, since they were limited to national datasets and employed simple variable scoring methods based on expert opinion. The 2015 NFHP estuarine assessment used 18 metrics of anthropogenic disturbance, chosen by an expert panel, to evaluate habitat condition. These variables were combined to form a cumulative disturbance index for each estuarine segment. The assessment described poor habitat in large segments of the tidal Bay, principally due to nutrient concentrations in rural areas (e.g. the Choptank River) and impervious surfaces in urban watersheds (e.g. the Patapsco River). Importantly, the estuarine assessments classified some tributaries as being in very poor condition despite their support of productive spawning grounds.

The recent Atlantic Coast Fish Habitat Mapping and Prioritization Project (Martin et al, 2020) improved on the NFHP assessment by using a mesh-grid of 1km hexagons to categorize data for the Northeast US estuaries and coastal waters. For estuarine waters, the ACFHP Prioritization incorporated eight variables. For each of these variables, expert opinion was used to identify a measurement (e.g. percent of land use) that was then evaluated against a cut point (e.g. 10% within a given watershed) (ACFHP report). ACFHP developed this assessment primarily to identify and prioritize focus areas for ACFHP funding opportunities.

Leading up to framing the Choptank River pilot, many inputs about conducting a regional Chesapeake Bay fish habitat assessment were considered and shared these elements:

- Use a finer spatial scale;
- Use the rich and diverse fisheries independent and environmental data available;
- Provide a snapshot of current fish habitat status and threats;
- Such an assessment ought to be a resource to inform local planning and land use decisions, project designers and implementers; fishery managers and state agencies; and, federal agency project planners and those conducting essential fish habitat consultations

There are myriad implementation details to conduct a Baywide assessment spanning tidal salt, tidal fresh, warm non-tidal and cold non-tidal waters; hence, the practical need to conduct pilot assessments. The Choptank pilot was designed and conducted with the intention of testing the implementation viability of these elements Baywide.

2.0 Choptank Pilot Analytical Framework Approach

To address the first Choptank Pilot Project objective, an analytical framework was developed for the Choptank River. An analytical framework consists of a spatial structure, information and organizing principles. It is a construct to catalogue, curate, manage, and integrate data and information. Frameworks have been used to describe, prioritize and assess habitat in many coastal areas, including the Chesapeake Bay. The ACFHP approach, described earlier, also used an analytical framework approach.

The framework approach applied for the Choptank Pilot is inherently geographic as it is designed to identify conditions, such as habitats and stressors, in specific places. To reduce the complexity of geographic decisions, a spatial structure is applied to the representation of environmental information. By applying a spatial structure, the potential number of possible solutions to any given analysis using the framework is reduced.

2.1 Framework Design

For the spatial structure of the Choptank River pilot framework, we developed a contiguous surface of hexagons (Figure 1), with each hexagon measured 55km across and 2000m^2 in area. We first constructed this hexagon grid for all tidal waters of the Chesapeake Bay, extending 5km upstream of the tidal freshwater Chesapeake Bay segments (Chesapeake Bay Program segmentations scheme; USEPA, 2004) and 5km inland of the shoreline (using NOAA's Continually Updated Shoreline Product; NOAA, 2011). Each hexagon was assigned a unique identification number, to which any number of physical, biological, ecological or human use criteria can be linked. For our habitat assessment pilot effort, we then selected from this full extent, the hexagons within the Choptank River. This created a set of 263,945 hexagons for the Choptank framework.

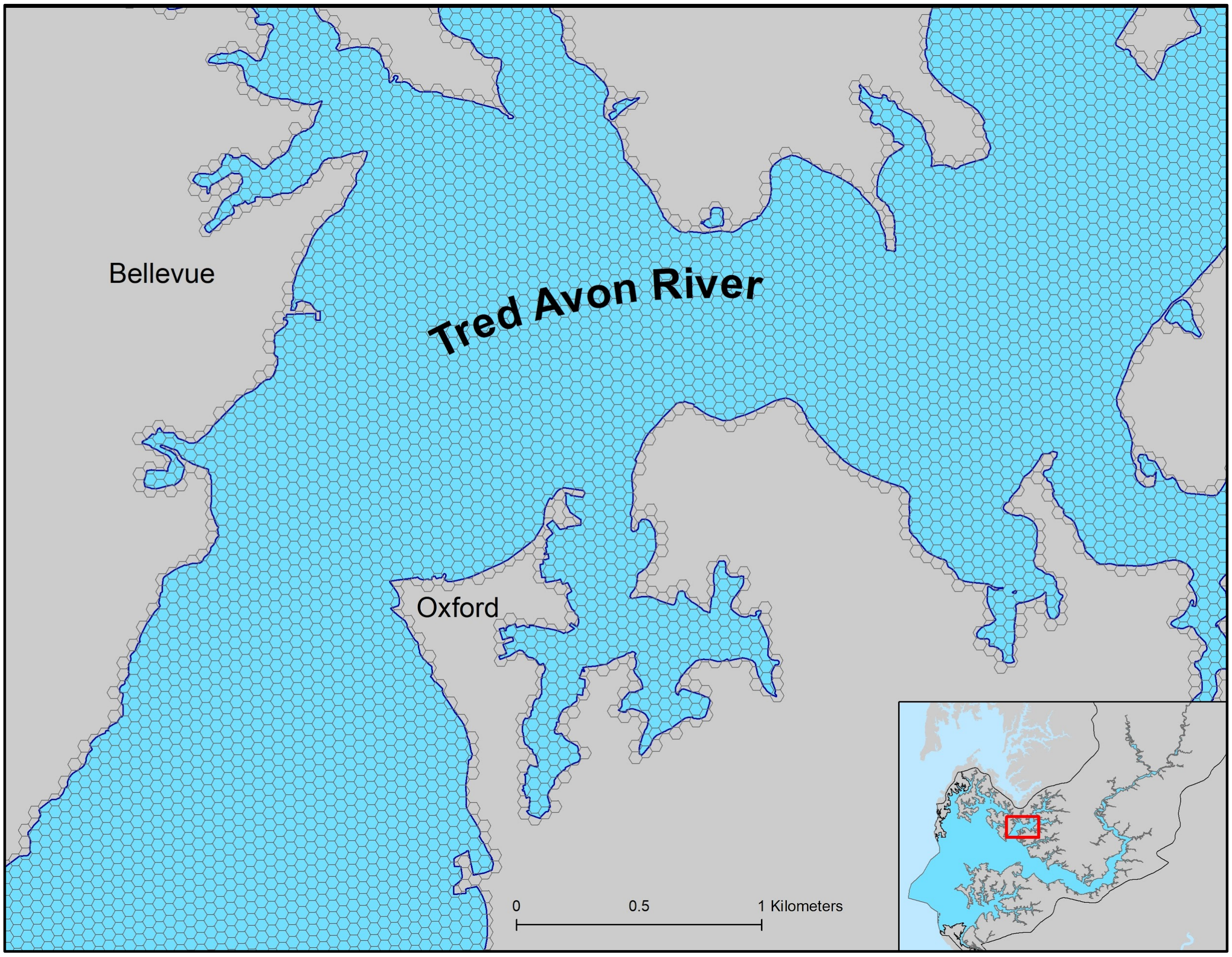

Figure 1. Hexagon framework consisting of 2,000 m^2 hexagons (shown at 1:24,000 scale).

2.2 Habitat Considerations

For the purposes of our Chesapeake Bay tidal waters pilot assessment, habitat refers to the geographic area or environment occupied by an animal, plant or other organism. Fish habitats can, therefore, be defined as the key places or environments where fish may be present. The framework structure detailed above provides a way to explore and evaluate the environmental parameters which may describe and influence fish habitat within our study area.

In order to explore with subject matter experts the types of data that might be applied to the framework, discover approaches for data integration, and to demonstrate the framework utility, a small suite of environmental parameters were selected (Table 1; Appendix A), some of which have been used in previous fish habitat projects (Crawford, 2016; Martin, 2015). Variables were chosen that are inherently geographic in scope and may be suspected to play a role in fish distributions. These variables included physical, chemical, ecological, and biological information. For each variable, at least one potential method for integration within the spatial analysis framework was conducted, providing examples of the environmental attributes of each hexagon.

Table 1. Variables integrated in the Choptank River pilot framework for initial scoping and expert feedback. Details about each variable are provided in Appendix C.

Benthic Habitat	Slope	Dissolved Oxygen
Shoreline Characteristics	Rugosity	Salinity
Tidal Wetlands	Subwatershed	Water Temperature
Water Column Depth	Proximity to Agriculture	Total Suspended Matter
Submerged Aquatic Vegetation	Proximity to Impervious Surfaces	Water Quality Monitoring Sites

2.3 Spatial Information Integration

While a small number of variables were selected and applied to the draft framework, there is a tremendous range of potential variables and ways in which those variables could be represented within the framework. There were several different approaches applied to integrating information into the spatial framework. The structure of the data played the most important role in how the data was integrated. For example, some data is collected and reported at single points in space, while other data sets include observations organized within discrete areas (Figure 2). The following examples describe some approaches to consider when integrating data of various spatial structures into a framework.

As an example of a dataset reported as a geographic area, benthic habitat information was obtained as a contiguous set of polygons with attributes defined by the Coastal and Marine Ecological Classification System (CMECS). To integrate this information in the spatial framework, we first recorded the area of each habitat type within each hexagon. Additionally, we recorded the habitat type with the largest area within each hexagon.
In contrast, shoreline Information was obtained from the NOAA CUSP as attributes of a linear feature. Within our pilot analysis, we recorded the length of each shoreline type

within each spatial analysis unit. Additionally, we recorded the length and % of man-made vs natural shoreline for each analysis unit.

Submerged Aquatic Vegetation (SAV) information was obtained as a non-contiguous set of polygons provided annually over a five year period. We represent the area of SAV coverage for each analysis unit for each of 5 years. Additionally, we represent the number of years over the five year period where SAV is present within an analysis unit.

Depth, slope, and rugosity (slope of slope) are all recorded from a raster dataset with a grid resolution of 10m X 10m. We obtained average values for each variable within each analysis unit. Additionally, we identify any analysis units where a slope of greater than 1 degree is present and where rugosity is greater than 1.

In-situ surveys such as water quality and fish were conducted at discrete locations and recorded as points.

Considerations for integrating different datasets into the framework were discussed extensively at the workshops. Summaries of the resulting recommendations and comments may be found in Appendix C.

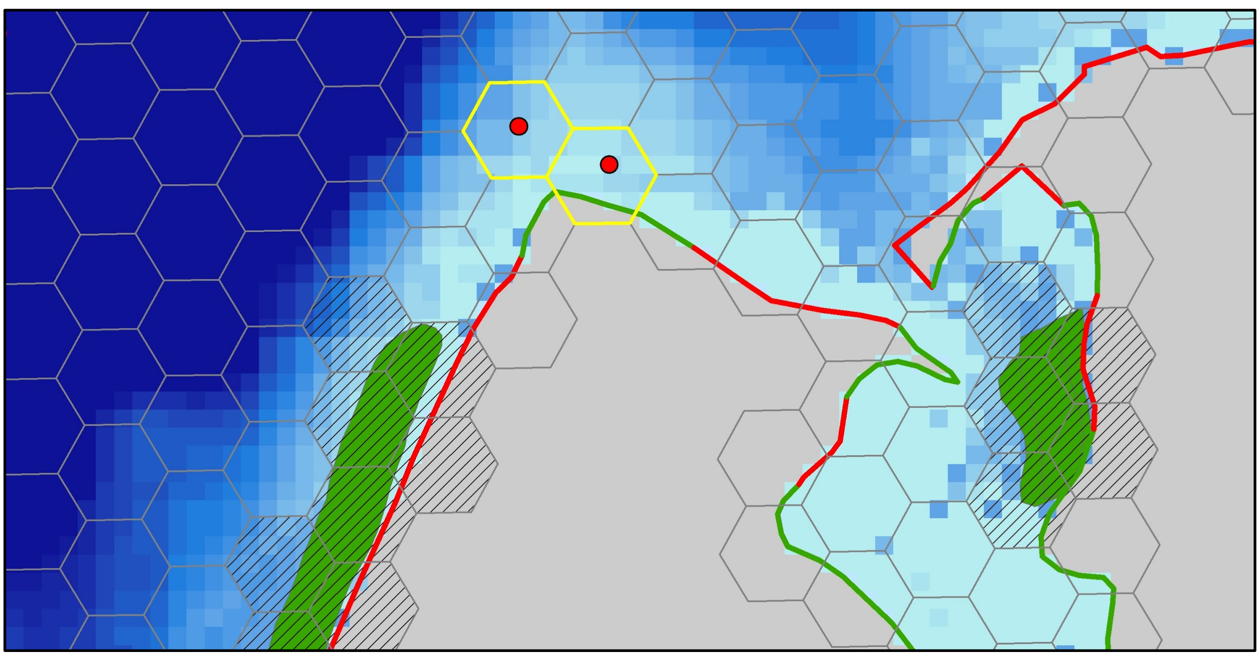

Figure 2. Information for a wide range of data types and sources were integrated into a standardized spatial analysis framework (2000 m^2 hexagons). Data sources were recorded in discrete locations (points), areas (polygons), along linear features (lines) and from “continuous” values (rasters).

3.0 Workshop Execution

Two expert panel workshops were conducted in October of 2020. Originally envisioned as one large, in-person meeting to be held in the summer of 2020, Covid-19 restrictions forced a restructuring of the effort towards two smaller virtual meetings. The pilot assessment team consulted with several experts in virtual meeting planning and execution. Key messages from these virtual-meeting experts included a thorough preparation prior to the meeting, a very clear set of objectives for the meeting, and the need for a team approach to managing the virtual meeting.

A robust set of read-ahead materials (Appendix B) was developed and distributed to the participants prior to each workshop. Some experts provided feedback via email prior to the workshop. A few experts shared the read-ahead materials with colleagues, who also provided feedback prior to the workshops.

Meeting tools included the use of a chat box, multiple choice and short answer polls, and speaker notes. One team member was assigned to monitor and assist with participant technology issues. Another was assigned to specifically capture notes throughout both workshops. A total of 24 subject matter experts participated in the workshops, not including the team of eight scientists and support personnel in the project team (Appendix B, page 42). Participants included representatives from federal agencies, state governments, the Potomac River Fisheries Commission, non-profits, and non-governmental organizations. Expertise within the group ranged from fish biologists, fisheries managers, habitat specialists, permitting consultants, and monitoring specialists.

Each workshop lasted three hours and generated substantial amounts of feedback. In addition to the feedback received by email prior to the workshops, feedback was collected during the workshops through verbal responses recorded by a team member, as well as in the chat box, and by using polls. Additional feedback was received after the workshops through email and phone conversations. A comprehensive list of feedback was collated by topic area and provided back to the participants for corrections and further refinement (Appendix C).

4.0 Discussion and Recommendations Based on Workshop Feedback

4.1 Management Application

An overarching comment received from both workshop days and across a variety of questions posed to the panels was that there needs to be a well-identified management application(s) for which a Chesapeake Bay watershed fish habitat assessment will be used. As the workshop participants made plain, the intended use is vitally important as it drives choices about assessment framework design, variables selected and methods of sampling the variables into the framework. Decisions made about these choices will vary depending on fish species, life stage and habitat type.

To date, the expressed desired uses of a Chesapeake Bay watershed fish habitat assessment in tidal waters span the following:

- A single, user-friendly tool which complements existing tools that local government planners may use to inform their decisions;
- One tool that provides habitat vulnerability/risk, degradation, condition of fish habitat, fish species utilization, and driving factors influencing habitat change;
- Justify the prioritization and allocation of limited funding to specific projects;
- Inform aquaculture and restoration siting decisions;
- Information source for protected habitat types and fish species used to inform regulatory consultations;
- Information resource for fish species distribution, abundance, and migration timing;
- Information about invasive species;
- Current habitat condition;
- Modeling, forecasting or anticipating interannual impacts caused by shifts in water temperature, changing water quality or increased variability of extreme flow events like drought and storms.

Given the range of management applications and the ever-declining cost of computing resources, it is tempting to pursue the technically feasible approach of including an unlimited number of variables and of methods to sample the variables into the framework. This would theoretically allow a user to select from a broad universe of variables to address their particular management issue. Doing so, however, results in a complex analytical framework, requiring a user knowledgeable of the underlying spatial and statistical tools as well as the science affecting the species or habitat types. It also has resource implications for maintaining and managing the tool.

Another approach, which addresses the concept of making the breadth and richness of Chesapeake Bay data discoverable to anyone via a user-friendly means, is to create a widely accessible information resource with the capability for users to select a geographic area and discover the data available. While this also has resource implications for its creation and maintenance, it is feasible to design the tool such that its use is intuitive, requiring little skill beyond customary use of on-line tools.

Recall that the availability of more data was a premise for a Chesapeake Bay regional fish habitat assessment yielding better results than one limited to data commonly available in all the Nation's estuaries. Adding more data leads to increased complexity, which drives the need for more data management, computing resources and elevated end-user skill. During the Choptank pilot SME workshop, a participant made an elegant point that more data is not always needed to inform management decisions. However, it is important to understand the factors most relevant to inform a particular decision. Hence, having a clear, narrow purpose for the assessment affords the opportunity to create a less complex assessment tool and potentially a lower level of skill for its use. Resource investment will be required.

Recommendation: *Given the strength and pervasiveness of feedback regarding the need to define the intended management application(s), before initiating a Chesapeake Bay watershed fish habitat assessment, the intended application(s) ought to be defined and informed by expected availability of initial and sustaining resource investment and suitability for the end user should be accounted for in the design.*

4.2 Extending the Analytical Framework

Feedback on the approach used in the Choptank River pilot was generally positive. Subject matter experts noted that the pilot was consistent with the intent of the Fish Habitat Action Team towards building a Baywide tool to address management targets. The approach was expected to be useful for conducting federal habitat consultations. There were, however, two cautionary types of feedback related to recommending to extend the framework approach Baywide. First, assessing fish habitat by definition calls for judging its value. Workshop participants emphasized that the value assigned to a particular habitat will vary depending on the targeted species and life stage for which the assessment is performed. The idea of identifying a narrow purpose of the habitat assessment as essential to the design of its implementation was a recurring theme and is further discussed in the recommendation about management application. Second, subject matter experts advised conducting additional pilots in multiple tributaries using the same approach and then to evaluate the results before reaching a conclusion about extending the analytical framework approach Baywide.

Recommendation: *The Choptank River pilot habitat assessment's analytical framework approach is suitable to extend Baywide with appropriate care first given to its intended use and possibly the evaluation of its utility through implementation in multiple tributaries.*

4.3 Analytical Framework Design

Feedback regarding the framework's design was generally positive with discussion around the choice of shape used and the use of a uniform size shape. For the Choptank framework, we implemented a grid-lattice of contiguous hexagons measuring approximately 55m across at their widest point and 2,000 m^2 in total area (Figure 3).

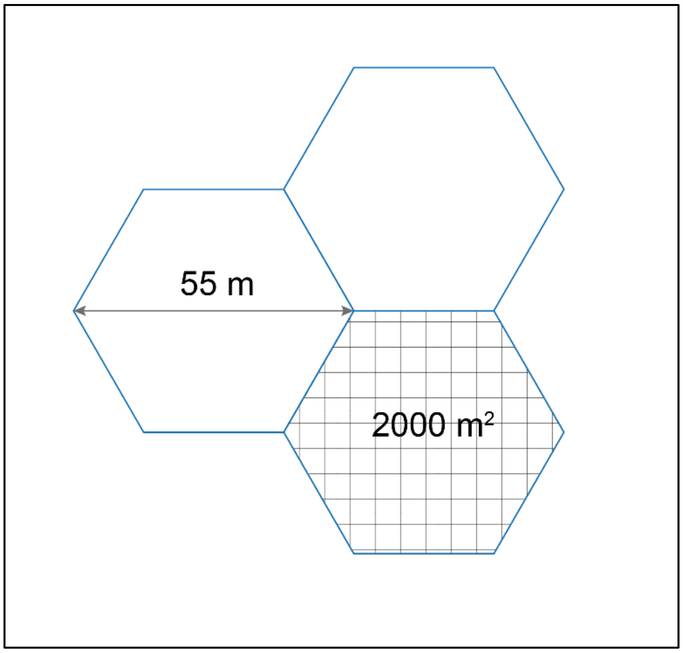

Figure 3. Basic dimensions of the Choptank River Pilot Framework hexagonal grid-lattice.

During the SME workshops, we discussed the choice of a hexagonal lattice over other commonly used shapes (e.g., triangles, rectangles, and other irregular quadrilaterals), and about the choice of a uniform grid scale throughout the watershed as opposed to a variable scale. The team provides the following insights after researching the options. A rectangular grid-lattice is commonly used because of its symmetrical, orthogonal coordinate system, and the frequent use of raster data sets in Geographic Information Systems (Birch et al., 2007). In contrast, a hexagonal lattice is often used when analysis boundaries are highly irregular, as was the case with the many kilometers of shoreline in the watershed. A hexagon also has the practical benefit of reducing sampling bias from edge effects of the lattice shape, which is related to high perimeter-to-area ratios. A circle has the lowest ratio, but cannot form a continuous grid, and hexagons are the closest uniform shape to a circle that can still form a grid. Additionally, when applying a lattice over a large area, a square grid will convey more geographic distortion due to curvature than a hexagon (DeSousa and Leitão, 2017; ArcGIS Pro Users Guide). Birch et al., 2007 provides rich analysis and comparison of the pros and cons of rectangular and hexagonal grids used for observation, experimentation and simulation in ecology, and ultimately recommend a hexagonal lattice when quantifying nearest neighborhood, movement, or connectivity.

As for scale, it is technically feasible to use a variably scaled grid-lattice (e.g., large hexagons in the Bay's main stem and ever-smaller hexagons in the rivers and upper tributaries), such variability presents choices and challenges for the framework end-user. While variably-scaled grids may have the advantage of generality in that they can be made to conform to nearly any desired geometry, they require considerable user interaction to produce grids with acceptable degrees of local resolution while at the same time having an acceptable spatial distortion. Variable scale grids can also require more information to be stored and recovered than uniform grids, increasing the computational demand of the system (Mavriplis, 1995). Lastly, and maybe most importantly, changing element shapes and sizes can increase numerical approximation errors. This challenge is known as the "Modifiable Area Unit Problem" (MAUP). The MAUP applies to two separate, but interrelated, problems with spatial data analysis. The first is the "scale problem", where the same set of areal data is aggregated into several sets of larger areal units, with each combination leading to different data values and inferences. The second aspect of the MAUP is the "zoning problem", where a given set of areal units is recombined into zones that are of the same size but located differently, again resulting in variation in data values and, consequently, different conclusions (Jelinski and Wu, 1996). While we will not present full implications of the MAUP here, the challenges to end users of the Choptank framework are vast when considering the range of analyses that might be performed using the proposed structure (Fotheringham and Wong, 1991; Perveen and James, 2009).

It is important to note that the proposed uniform hexagonal structure is designed to both organize and summarize existing data rather than solve Navier-Stokes equations most often used in hydrodynamic modeling. Such computations consist of a series of time-dependent equations for conservation of mass, momentum and energy (Pironneau, 1982). Here we seek only to estimate and store general statistics associated with pre-existing spatial data sets, and subsequently associate these estimations to primary observations of fish presence, abundance, and distribution within the framework. In the case of a variable grid-structure, the variation of statistics such as mean, median, range, majority and proximity have the real potential to make subsequent analysis more difficult. Because of these challenges, the team is proposing to implement a uniform spatial structure.

During the workshops, the potential for dividing each hexagon into different depth strata was also discussed. However, the proposed analytical framework utilizes a two dimensional spatial grid because most data sources that would be integrated into the framework are two dimensional, and the development of a three dimensional framework may be unnecessary since the management of fish habitat in three dimensions is extremely unlikely.

Recommendation: *Given the analytical framework approach, a grid pattern of hexagons is recommended. Regarding hexagon size, using a consistent size is recommended to limit complexity in applying the framework to address management issues. While the pilot framework hexagon size (55m) represents a useful scale as it can capture habitat conditions on a relatively small scale, an early decision in any new habitat assessment should be selection of the appropriate hexagon size.*

4.4 Data Richness for the Chesapeake Bay

As noted earlier, the richness of available Chesapeake Bay watershed data was a premise behind expectations that a regional fish habitat assessment will yield results reflective of expert knowledge and experience. This notion was partially supported by the inventory of habitat and environmental data that was generated for the 2018 Workshop (summarized in Hunt et al, 2018) and a recent inventory of fish and shellfish data for Chesapeake Bay tidal waters (Murphy et al, 2020). Choptank pilot workshop participants noted that while the watershed is data rich, much of the data is neither temporally nor spatially consistent. The relative richness of data also depends on the intended application of the fish habitat assessment, with data gaps existing for some questions. Decisions and strategies to fill those gaps are best made when the application is known.

To illustrate further, gaps in observed data may be filled by initiating or expanding monitoring programs, by extrapolating limited empirical data, or by using outputs from models. Each of these remedies has considerations. Initiating or expanding monitoring programs to achieve consistent spatial and temporal empirical data is expensive and may prove unnecessary depending on the assessment's management application(s). Extrapolating observed data is technically feasible though method selection carries inherent trade offs with some methods unacceptable for some uses and practically inconsequential for others. Workshop participants offered many opinions on the use of model output in lieu of, or in addition to, empirical data. The next section addresses this topic.

An additional aspect of data richness for the Chesapeake Bay is that some observations collected by different researchers are not easily integrated. A prominent example is fish community survey data collected by a range of government and nongovernment agencies. There are often differences in sampling gear between these surveys, with different catch efficiencies, resulting in unmeasured biases for particular species when combining fish datasets. Often these combined datasets must be reduced to the presence and absence of fish species, as a way to mitigate the impact of these biases.

Recommendation: *In order to achieve suitable results from assessing fish habitat in the watershed, the management application must be matched to data availability with choices made about filling data gaps. The choices made will affect resource investment required; hence, it is recommended to simultaneously consider the expected level of initial and sustained resource investment.*

4.5 Modeled Versus Empirical Data

The framework design is flexible and can be used to integrate a broad suite of data, including both empirical and modeled data. The primary utility of modeled data results from its ability to fill spatial and temporal gaps where empirical observations do not exist, often because the collection of empirical data at the desired resolution is impossible or impractical. For example, water quality measurements collected at discrete locations and points in time independent of fish surveys, will present limited utility for assessing habitat unless modeled over space and/or time. Modeled data also allows for scoping of monitoring programs and identification of data gaps.

A common approach for estimating water column parameters throughout an estuary is the use of a hydrodynamic model, which uses a series of differential equations to estimate values at unsampled locations, usually with an attempt to balance total mass of water within the estuary. Another closely related approach for addressing spatial gaps in data, mentioned by a workshop participant, is spatial interpolation, which creates a continual surface based on nearby values, but does not attempt to balance these values.

Several comments, however, were made during the workshop voicing some caution about the use of modeled data. The principle challenge with modeled data, as pointed out by the workshop participants, is that it may not accurately reflect real conditions. Therefore, an important consideration for use of modeled data is the ability of the model to predict empirical measurements, known as model skill. Many hydrodynamic models (e.g. ChesROMS; Brown et al, 2013) estimate a large number of variables, with differential skill in these estimates.

Another challenge with modeled data is that it is often very large, requiring both sufficient computer memory for storage and computer processing power for analysis.

Recommendation: *Whenever possible, empirical data should be used to assess fish habitat. The use of modeled data for assessing fish habitat will likely be necessary in many cases, but should only be employed where the model has been developed using empirical data, the skill of the model estimates is periodically evaluated, and the skill is acceptable to the assessment team. Any modeled variable with low accuracy should be avoided. In all cases, details about modeled data, such as accuracy and periodicity, should be explicitly provided to the audience.*

4.6 Treatment of Data

Considerations for data integration partially depend on data type (as discussed above). For example, a hexagon could easily be assigned the value of a single measurement collected within the hexagon. Some previous assessments, such as the ACFHP Habitat Prioritization Project (Martin et al, 2020), used expert opinion to decide threshold values for each variable. Other assessments, such as the Gulf of Mexico Fish Habitat Assessment (Miller et al, 2018) used summary statistics, such as total kilometers of hardened shoreline within an estuary. For the workshops, the Choptank pilot assessment team explored a range of examples for data integration. Workshop participants recommended that in the common case where multiple data values are available for a hexagon, the distribution of the data should drive decisions about integrations. The participants noted that the average value of the variable in question might be assigned to the coincident hexagon in the case of normally distributed data, whereas data with a skewed distribution might better be represented by using the median. The expert panel also suggested the use of measures of central tendency (e.g., mean, median) to represent chronic conditions and measures of variability (e.g., maximum values, range, standard variation) for extreme conditions. Related considerations, not explicitly discussed in the workshops, but used in the Gulf of Mexico Assessment (Miller et al, 2018), are data transformation and data normalization, which may be important for framework applications that involve statistical testing .

In addition to existing data variables, new measures may be calculated to fill data gaps or provide additional metrics for assessing habitat. For example, bathymetry data may include gaps, especially in nearshore areas, which may be approximated using spatial analysis tools. Bathymetry measures can also be used to calculate a host of other metrics, such as the slope and the roughness (a.k.a. rugosity) of the river bottom.

Other variables may be combined to produce a potentially important habitat metric. For example, salinity, depth, and water temperature can be used to calculate stratification of the water column. Similarly, the distance between variables may provide information about habitat. There was support from the workshop participants for considering spatial proximity as an important metric. The proximity of fish and benthic conditions within about 200m of tidal wetlands, and other natural shorelines. Likewise, the co-occurrence and proximity of habitats designated by the National Marine Fisheries Service (NMFS) as essential fish habitat, such as SAV and oyster beds, may provide important information about fish habitat.

While discussing the spatial scale of data aggregation, such as measures of land cover within a watershed, a workshop participant noted that assessing some variables at multiple spatial scales may provide different understanding of fish habitats. This suggestion was tempered, perhaps, by a note of caution on data complexity that was offered by the same workshop participant, saying that more data is not always beneficial in understanding fish habitat.

Recommendation: *As mentioned previously, the intended application of the framework should be the driving force behind data integration decisions. The framework allows for incorporation of a broad set of data types and integration choices, but these strategies need to be tempered by the management question being addressed. However, the treatment of data in the framework ought to be informed by its distribution and relative importance of spatial proximity to other variables.*

4.7 Time Is Important

Most fish habitat assessments do not explicitly account for changes in habitat variables over time. The NFHP and ACFHP assessments as well as the TNC Habitat Prioritization Tool, for example, were assessments of habitat using data aggregated over time and presented as a static set of conditions. During the expert panel workshops, a number of participants discussed the importance of considering time spans and windows of time when conducting fish habitat assessments. Some fish move into or within the estuary based on seasonal changes in water conditions. Some fish species rely on specific time-of-year water conditions for survival of early life stages or for life cycle transitions. For example, the amount of springtime rainfall, and subsequent low salinity waters, has been linked to greater survival of striped bass juveniles in the Chesapeake Bay (Martino and Houde, 2010). Similarly, the influence of changes in habitat conditions over longer periods of time (e.g., decades), driven by changes in climate, have been anticipated for many years (Kennedy, 1990) and are becoming more apparent nationally (NOAA-NMFS, 2015, Karnauskas, 2015).

If an assessment of habitat intends to account for these dynamics, a careful consideration of time must be conducted when integrating data into the framework. Several variables discussed during the expert workshops included elements of time. One example provided in the workshop read-ahead materials was the aggregation of SAV data from the last five years, which represents a methodological approach of calculating static values in time for a datasets collected over time. Another example discussed in the workshop was water quality information, such as water temperature and salinity, which are typically available as time series data of varying temporal frequency. One workshop participant noted that some variables might be summarized on different time scales. For example, temperature might be summarized by season, while salinity might be captured on a weekly scale.

In particular, experts at the workshops advocated for accounting for variation of water temperature and salinity by season and by season type across years. The idea of including an analytical capability to assess longer term, e.g. decadal, changes was also voiced. For example, one participant noted that there is evidence of fish communities moving north on a scale of miles per decade, a potential result of warming waters resulting from climate change.

Recommendation: *The range of time for each variable in a habitat assessment and the way that time was treated for each variable should be clearly communicated and explained to the audience. Time periods should be considered when integrating variables into fish habitat assessments. Whether to include an analytical capability to assess climate time scale changes in the Baywide fish habitat assessment ought to be considered and decided upon during the design phase.*

4.8 Assessment Update Requirements and Temporal Relevance

An important consequence of the aggregation of data over time for a habitat assessment, as discussed in the previous section, is that most assessments represent conditions at a point in time, as determined by the data available at the time of execution. New observations and modeling efforts, such as new fish surveys and updates to the Bay Watershed Model (CBP, 2020), will provide new information with which to assess fish habitat. Therefore, periodic updates may be desirable to incorporate these new data and research findings. These updates require sustained organizational interest and periodic investments of time and money, as well as some demonstrated applicability for real management decisions.

The maintenance of assessment tools and products demands commitment from a particular organization. Static products, such as the NFHP and ACFHP assessments, require a commitment for distribution of the product. Dynamic products that allow for user interaction and interrogation, such as the TNC Habitat Prioritization Tool, require ongoing curation and maintenance of the underlying datasets and online platform.

Recommendation: *Resource investment needs should be carefully considered when designing habitat assessments. An upfront evaluation of intended lifespan, maintenance requirements, and update strategies should be conducted and weighed against utility for management decisions and investment needed.*

5.0 Examples of Exercising the Framework

As discussed above (Recommendations, section 3), the experts consulted during the two workshops and associated communications generally agreed and clearly indicated that the intended use of the framework is important in deciding the types of variables integrated and the method of integration. The proposed framework purposely allows for flexibility in the types of questions possible to investigate. Below are four examples of applying the framework to address questions of fish habitat. These examples range from relatively simple combinations of a small number of variables chosen by experts, to complex analysis involving a wide range of metrics with potential influence on fish habitat.

5.1 Refine the NFHP Assessment

One potential application of the tidal framework would be to refine the approach taken by the 2015 NFHP estuarine assessment by using data types and datasets available for the Chesapeake Bay that were not available at the national scale, and use the finer spatial scale of the framework. The 22 unique variables chosen for the 2015 NFHP estuarine assessment were limited to datasets available at the national scale. The report (Crawford, 2016) states that although the datasets used "...represent many of the major sources of disturbance to estuary habitats, data on some habitat stressors was not available for analysis and will likely cause instances where condition is overestimated." Further, the framework structure for the assessment included relatively large segments of estuarine waters. These limitations resulted in an assessment which did not accurately reflect fish habitat condition in some tributaries. At the Chesapeake Bay scale, data is available for some of the 22 NFHP variables at a finer spatial scale and/or from more consistent data collection procedures. For example, six of the unique variables used for the 2015 NFHP estuarine assessment represent measures of land cover data, taken from the national Coastal Change Analysis Program (NOAA-OCM, 2011) at a resolution of $30m^2$. In the Chesapeake Bay watershed, land cover data at $1m^2$ resolution is available (Chesapeake Conservancy, 2016). However, the algorithms used to generate these land cover datasets, as well as the categories of land use, differ between the two programs.

5.2 Habitat Co-occurrence

Another potential analytical application of the tidal waters framework would be to discover areas where known fish habitats co-occur. For example, a set of physical habitats might be identified and their corresponding spatial data integrated into the framework to map where these habitats co-occur. In some cases, the benefits of a physical habitat to a fish community may extend for some distance from the outward edge of that habitat. During the expert workshops, a participant suggested considering the seaward space extending 200 meters from natural shoreline as habitat that is important for some fish populations. To account for this effect, a buffer of defined size may be applied to the habitat.

Figure 4 shows the co-occurrence of four physical habitats which may be considered important for fish, including tidal wetlands, SAV, oyster shell and natural shoreline. The footprint of each of the four physical habitats was expanded by 200m to account for scientific evidence of habitat benefits extending to nearby areas. These expanded footprints were then overlaid in space to look for the co-occurrence of the habitats as a measure of habitat complexity, with the hypothesis that greater complexity might be beneficial for some fish species. This particular example depicts habitat at a particular time, but other time periods could be represented in the framework as well. One feature of this approach is that relatively few considerations need to be made about how to integrate the data into the framework. Although the footprint of these habitats could be mapped without using the framework, integrating these variables into the framework provides a uniform structure for organizing, summarizing, and conducting spatial analyses on the multiple datasets. It also allows the integration of other dimensions, such as SAV density and proximity measurements to other habitats. One potential application of this analytical method would be to prioritize areas for restoration or conservation.

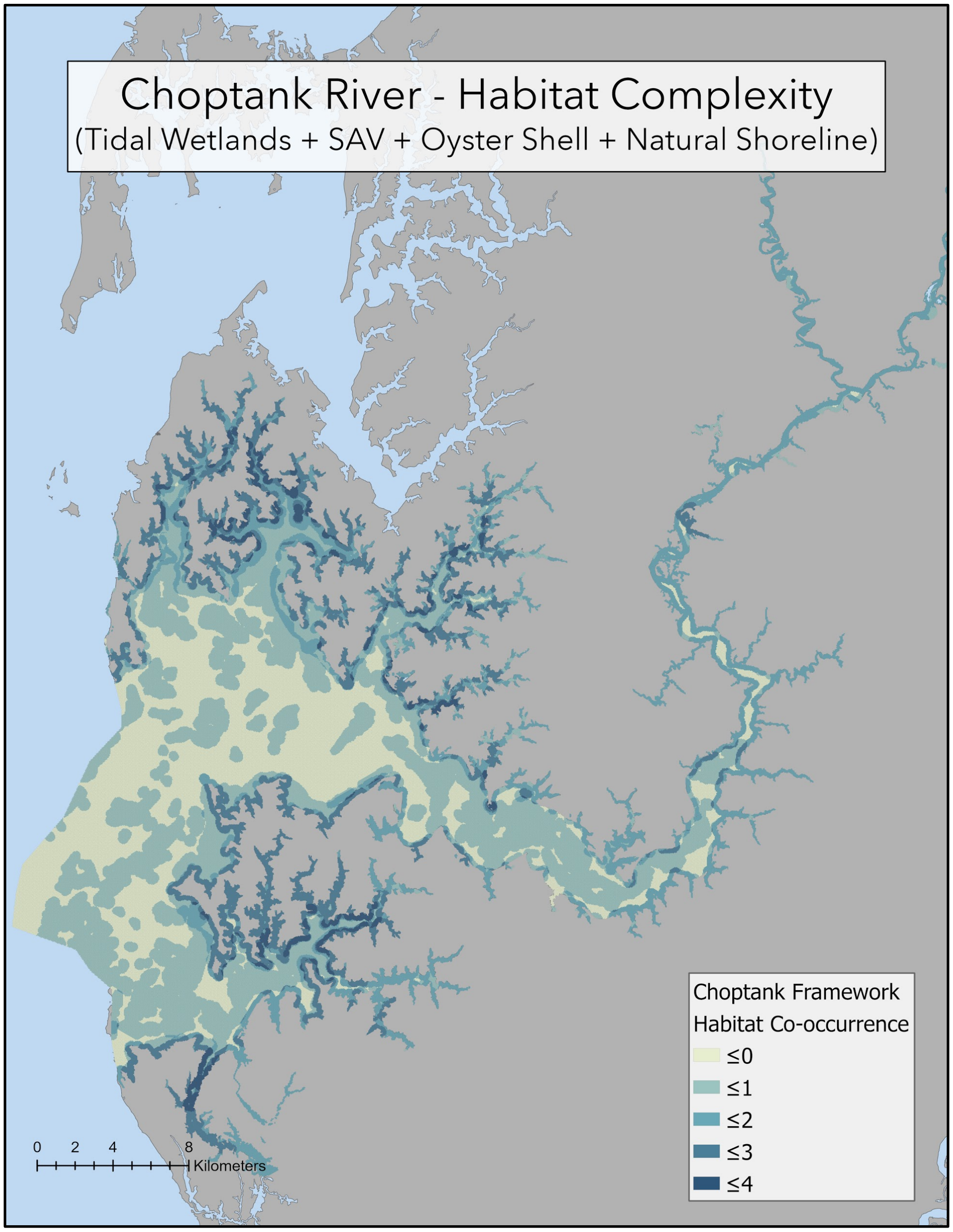

Figure 4. Habitat co-occurrence example, showing the locations of tidal wetlands, submerged aquatic vegetation (SAV), oyster shell, and natural shoreline.

5.3 Weighted Habitat Prioritization

This approach is similar to the habitat co-occurrence prioritization approach described above. The additional complexity of this approach would involve a weighting or scoring of the variables, based on reported thresholds or expert opinion. This is similar to the approach taken by the ACFHP assessment of Northeast US estuaries, where eight variables were scored by expert opinion (Table 2). A variation of this approach was also used by the TNC Habitat Prioritization Tool (Martin, 2015), where the relative importance of habitat variables could be weighted by the user. Using this approach, a few variables common to the Bay would be chosen and scored. For example, a threshold of 10% impervious surface for the survival of some juvenile fish in the Chesapeake Bay has been established and considered for land use management (Uphoff, 2011). Similarly, a threshold for armored shoreline as an indicator of fish habitat condition in Chesapeake Bay tributaries is supported by recent investigations (Kornis et al, 2017). Both the impervious surface and hardened shoreline thresholds could be integrated into the framework for assessment of habitat conditions.

Table 2. Example prioritization approach (recreated from ACFHP Assessment, Martin et al, 2020).

Variable	Measurement	Metric
Seagrass and oyster reef habitat	% of polygon covered by seagrass or oyster reef	10 points if the polygon is in the top 25% for coverage
Wetland habitat	% of polygon covered by wetlands	10 points if the polygon ranks in the top 25% for coverage
Water-vegetation edge	Length of estuarine-marsh-water edge in polygon	10 points if the polygon ranks in the top 25% for coverage
Proximity to protected habitat	Distance to a protected area	10 points if the polygon is within 1/2km of a protected area
Proximity to development	Distance from marinas and ports	10 points for the 25% of polygons farthest from marinas and ports
Water quality	303(d) sites	10 points for the 25% of polygons least associated with 303(d) sites
Hardened shoreline	Length of hardened shoreline within the polygon	10 points for the 25% of polygons with the least amount of hardened shoreline
Habitat fragmentation	Linear ft. of causeway within a polygon	10 points if the polygon has 0ft of causeways

5.4 Statistical Analysis

The power of organizing data in an analytical framework can be more fully realized by leveraging the framework to conduct statistical testing of the relationship between the variables integrated into the framework. To illustrate how the proposed framework can be used to evaluate fish-habitat interactions using a statistical approach, we integrated field observations of a species common to the Chesapeake Bay (hereafter, "species X") into the data structure using coordinates noted at the time of sampling. We used data from several local and available fish survey programs, including the Cooperative Oxford Laboratory Tred Avon ecological assessment surveys. In addition to noting the presence and abundance of species X, the survey data contained several additional environmental parameters commonly recorded at the point and time of sample: salinity, temperature, dissolved oxygen (D.O.) concentration and water depth. Important to this illustration, generalized estimations for these parameters also were sampled into the proposed framework (Figure 5).

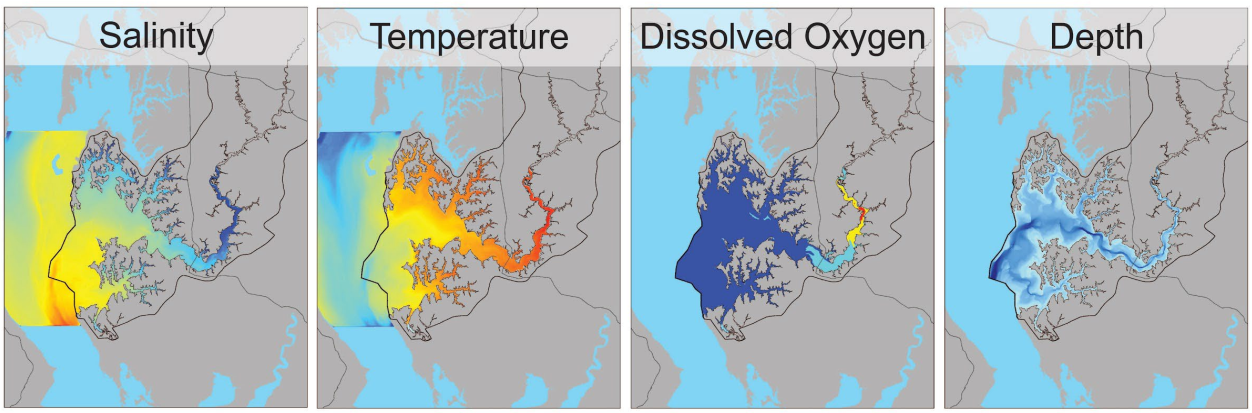

Figure 5. Generalized values for salinity, temperature, dissolved oxygen, and depth sampled into the analytical framework.

In this example, we chose to develop a statistically-based estimation of an "encounter probability" for species X. To accomplish this, we first identified individual sampling events across data sets (i.e., a unique seine/trawl tow), to summarize whether species X was present, and if so, how many were in the sample. The attending salinity, temperature, D.O., and sample depth at sample were promulgated. This derived data set allows one to explore the frequency of encounter through the range of conditions sampled across the survey programs. It is important to note that the number of individuals/tow was used to code a new variable as "present" (code: 1) where species X was recorded, and absent (code: 0) when not.

We then ran a forward-stepwise regression using this new data set to explore the relationship between multiple independent (predictor) variables and our dependent (criterion) variable. In this case, independent variables were salinity, temperature, D.O., and depth, while the dependent variable was presence/absence of species X. The dependent variable was modeled as a function of our independent variables with corresponding coefficients, along with a constant term. The generalized formula for multiple regression is:

$$\hat{y} = b_o + b_1x_1 + b_2X_2 + \ldots + b_px_p$$

where $\hat{y}$ is the predicted or expected value of the dependent variable; x_1 through x_p are p distinct predictor variables; b_o is the value of y when all of the independent variables (x_1 through x_p) are equal to zero; and b_1 through b_p are the estimated regression coefficients.

Model selection was based on the minimum Bayesian Information Criterion (BIC) to choose the best model in our stepwise procedure. When fitting models, it is possible to increase the "likelihood" by adding parameters, but doing so may result in overfitting. The BIC attempts to resolve this problem by introducing a penalty term for the number of parameters in the model (JMP, 2020).

In our species X example, the model selection process chose salinity, temperature and depth as significant predictors; leaving D.O. out of the resulting formula. Using the data stored in the framework for these three independent variables, we then propagated the prediction formula as a surface in the framework, and classified the resulting map as "low", "medium", and "high" encounter probability (40% - 64%, 65% – 74%, and >75%, respectively). Because of species X's ubiquity in the available samples, the minimum predicted encounter was 40% (Figure 6).

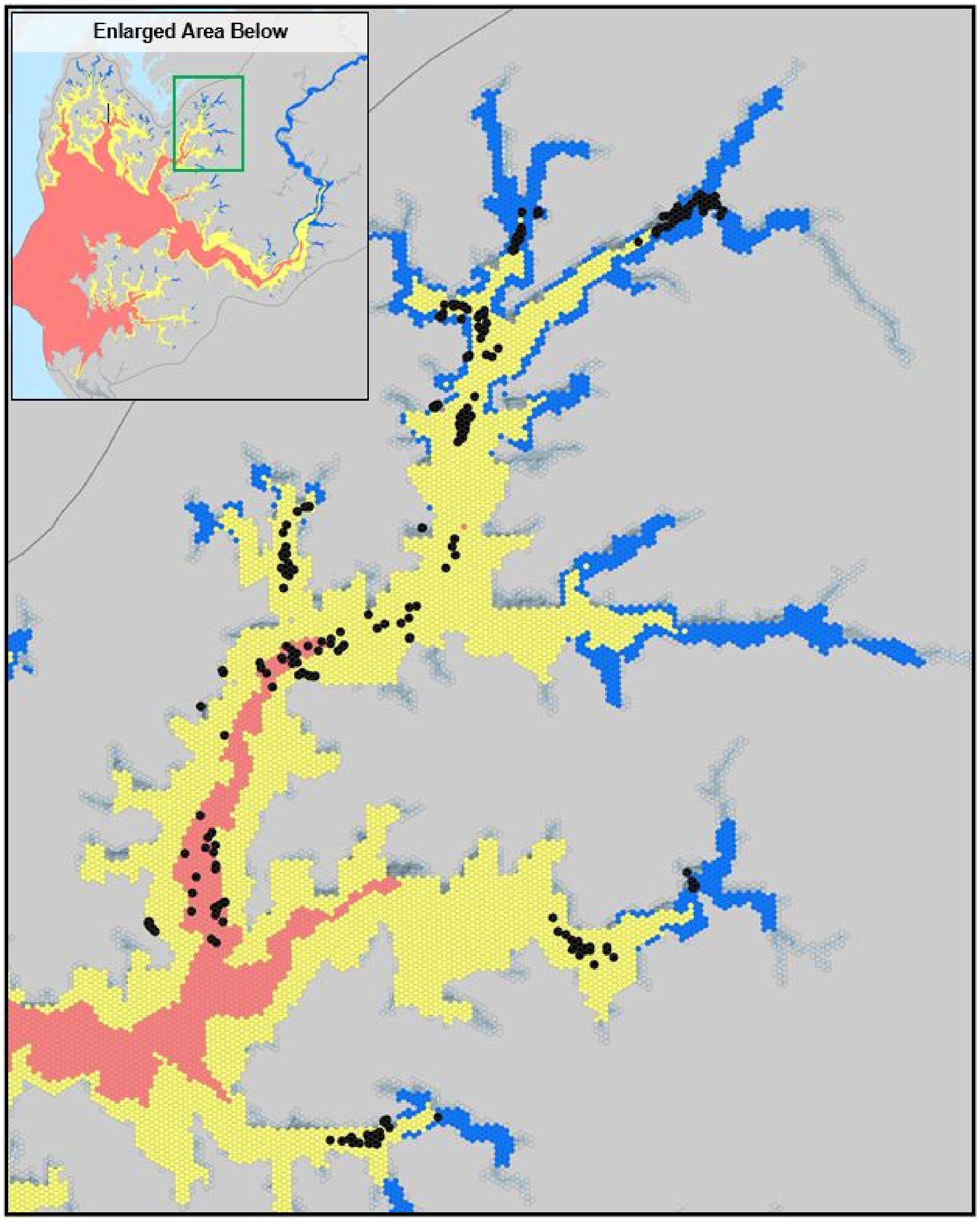

Figure 6. Mapped forward-stepwise prediction formula of encounter probability for species X. Blue areas were classified as high probability, yellow as medium, and red as low. Black symbols show locations of observations from the survey data sets used.

It is considered good practice to validate such a model with an independent data source before using it for decision-making. This step can inform the user of how well the model represents empirical data, and further provides a statistical measure of confidence in the model itself. To illustrate how one might test if the model is performing well, we used the framework to append the prediction class (low, medium, high) to the survey data set and applied a non-parametric variation of an analysis of variance (ANOVA) to test whether the observed median encounter frequencies in all prediction classes were equal, and the alternative that at least one population median of one group was different from the population median of at least one other group. Results indicate that encounter rates were indeed significantly different among all prediction classes, with lowest observed encounters in the "low" model class, and highest in the "high" model class (Figure 7, dark symbols). Additionally, we ran a standard ANOVA using the original counts (Log_{10} transformed abundance), grouped by model class. Again, results indicate that mean abundance was significantly different among all prediction classes, with lowest abundance in the "low" model class, and highest in the "high" model class (Figure 7, light gray symbols).

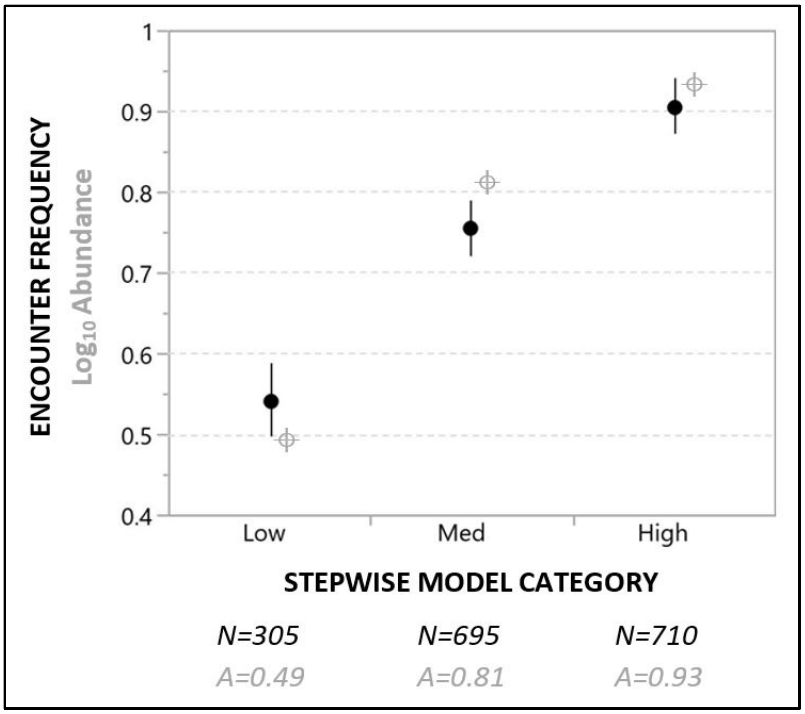

Figure 7. Comparison of encounter frequencies for species X among predicted probability classes (dark symbols with error bars), and mean log-transformed abundance among the same classes (gray symbols). N is the number of survey samples located in each class, A is the mean log-transformed abundance.

While this is just one example of how the framework can be put to use, a wide range of hypotheses may be tested using statistical testing of values integrated into the analytical framework. After establishing relationships, each analytical unit (i.e., hexagon) can be evaluated for the probability of containing the desired characteristics. In non-tidal waters, this approach has been used to assess the factors related to the distribution of brook trout (Kanno et al, 2015). Given sufficient survey data, an evaluation of fish community structure, such as diversity or richness, may also be conducted. Another approach for evaluating relationships between fish populations and communities is the integration of broad ranging and numerous datasets in the framework, including fish survey and environmental data, which allows for the discovery of unknown and/or interrelated relationships between fish and their environment. Relatively new machine learning techniques, such as random-forest and joint species distribution modeling, are computationally complex, but well-demonstrated statistical approaches for discovering such relationships.

6.0 Next Steps

Given the experience gained from developing and testing the framework, coupled with the recommendations received from subject matter experts, the following summary thoughts and next steps are offered:

- This recommendation report is one step in the Chesapeake Bay fish habitat assessment process. The NOAA team continues to collaborate with the USGS team and others in scoping fish habitat assessments for the Chesapeake Bay. The larger group now turns its focus to identifying options for a headwaters-to-tributary mouth pilot assessment.
- Promoting collaboration as a model of addressing outcomes will be a key to success. Data holders, especially the lead investigators of fisheries-independent fish and shellfish surveys, are also data generators. The use of biological information in fish habitat assessments adds to their value by making possible the identification of habitat relationships not previously known.
- Although the Chesapeake Bay is relatively data rich, data gaps persist. In some cases these result from resource demand, while in others they result from disparate and unconnected sampling surveys. These challenges may be mitigated by promoting the expansion of monitoring programs, standardization of fish survey methods, and use of models.
- Continue to foster communication with likely assessment users to ensure content and application address their needs.

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Appendix A: Geospatial Data Integrated in the Choptank Pilot

The following data sets were integrated into the example framework for the purposes of discussing with the expert panels during the two October workshops.

Bathymetry: The bathymetric surface we applied to this project was created for the purposes of this framework. It combines nearshore LIDAR with sonar readings to create a continuous surface from the deeper parts of the estuary into the shallow tributaries.

Depth (m): Depth was recorded in meters. Range was 0 – 26.41m

Slope (degrees): Slope was derived from the bathymetric surface created for this project. We addressed slope in two ways. First we identify the average slope value within each hexagon. Second, we identify any hexagons where slope exceeds 1 degree.

Water Temperature (°C): Water temperature values were derived from the ChopROMs hydrodynamic model using the average value for each hexagon.

Salinity (ppt): Salinity values were derived from the ChopROMs hydrodynamic model using average value for each hexagon.

Dissolved Oxygen (mg/l): Dissolved oxygen values were derived from the ChopROMs hydrodynamic model using average value for each hexagon.

Total Suspended Matter (g/m^3): Total suspended matter was derived from average summer condition from 2010-2019 using NESDIS STAR data.

Water Quality Monitoring Stations (various): We applied two data sources for water quality information to the framework. The first was the long term monitoring data from the Chesapeake Bay Program and the second was the ShoreKeepers data.

Submerged Aquatic Vegetation (m^2, persistence x/yrs): Data source VIMS SAV monitoring and restoration program. In the framework we track SAV distribution for 5 years (2014-2018) as well as persistence over the 5 year period. Persistent beds of SAV function as important fish habitat, and are therefore classed as a NMFS habitat of particular concern (HAPC).

Tidal Wetlands (m^2): Tidal wetlands were tracked using the Chesapeake Conservancy high resolution land use dataset.

Benthic Habitat Type (m^2, largest value): We tracked benthic habitats in two ways, first we recorded the amount of each habitat type within each hexagon. Second we recorded the single habitat type with the largest distribution within a given hexagon. Distribution of benthic habitat/materials was derived from sediment surveys (1970’s), oystershell surveys (1980’s), and sonar based surveys of oyster habitat (2010’s).

Impervious Surfaces (m^2, %): Impervious surfaces were determined using the Chesapeake Bay Conservancy’s High resolution land use dataset. They were tracked by subwatershed (12 digit HUC) using both area and % coverage.

Agriculture (m^2, %): Agriculture was determined using the Chesapeake Bay Conservancy’s high resolution land use dataset. They were tracked by subwatershed (12 digit HUC) using both area and % coverage.

Subwatersheds (name): Subwatersheds (12 digit HUCs) were included for reference within the framework.

Shoreline (m, % man-made): We tracked shoreline attributes based on the NOAA Continuously Updated Shoreline Product (CUSP). Length of each individual type was retained along with natural/man-made distinction.

Appendix B: Expert Workshop Read Ahead Document

READ AHEAD MATERIALS

Choptank River Fish Habitat Assessment Pilot

SUBJECT MATTER EXPERT WORKSHOP

October 2020

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WORKSHOP PARTICIPANTS

TUESDAY, OCTOBER 27

Donna Bilkovic	Virginia Institute of Marine Science
Michelle Canick	The Nature Conservancy
Sally Claggett	US Forest Service
Allison Colden	Chesapeake Bay Foundation
Tom Fisher	University of Maryland | Horn Point Laboratory
Jeni Keisman	US Geological Survey
David O'Brien	NOAA NMFS Greater Atlantic Regional Fisheries Office
Matt Pluta	ShoreRivers
Angela Sowers	US Army Corps of Engineers
David Sutherland	US Fish & Wildlife Service
Ronald Vogel	NOAA National Environmental Satellite, Data, and Information Service
Jonathan Watson	NOAA NMFS Greater Atlantic Regional Fisheries Office

THURSDAY, OCTOBER 29

Kristen Byler	National Fish and Wildlife Foundation
Mary Fabrizio	Virginia Institute of Marine Science
Martin Gary	Potomac River Fisheries Commission
Kelly Maloney	US Geological Survey
Margaret McGinty	Maryland Department of Natural Resources
Matthew Ogburn	Smithsonian Environmental Research Center
Tom Parham	Maryland Department of Natural Resources
Brian Richardson	Maryland Department of Natural Resources
Jim Uphoff	Maryland Department of Natural Resources
Ryan Woodland	University of Maryland | Chesapeake Bay Laboratory
John Young	US Geological Survey

Suzanne Skelley
Director
NCCOS Cooperative
Oxford Lab

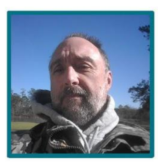
A.K. Leight
Marine Ecologist
NCCOS Cooperative
Oxford Lab

Dan Dorfman
Geospatial Analyst
NCCOS Biogeography
Branch

John Christensen
Chief
NCCOS Biogeography
Branch

Tracy Gill
Physical Scientist
NCCOS Biogeography
Branch

Eric Daniels
IT Specialist
NCCOS Cooperative
Oxford Lab



David Bruce
Ecologist
NMFS Chesapeake Bay
Office - Oxford Lab

Chris Jeffrey
Marine Ecologist
NCCOS Biogeography
Branch

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WORKSHOP PURPOSE

Solicit, assemble, and use your expertise to…

1. Guide development of an analytical framework to explore factors affecting fish distribution and abundance in the Bay; with specific examples presented for striped bass and white perch in the Choptank River,

   and

2. Develop recommendations for extending this analytical framework to Chesapeake Bay tidal waters.

A bit of context…

1. Development of this framework is part of a larger effort initiated through the Chesapeake Bay Program Fish Habitat Action Team ↗ (FHAT) to characterize fish and shellfish habitat in the Chesapeake Bay, and to determine highest priority data to inform restoration and conservation efforts.
2. It is envisioned that the Choptank pilot will inform recommendations to extend the framework to all tidal portions of Chesapeake Bay.
3. Recommendations are scheduled for delivery to FHAT in January 2021.

CHESAPEAKE WATERSHED AGREEMENT 2014

Fish Habitat 2020-2021 Logic & Action Plan (excerpt)

ACTIONS – 2020-2021			NOAA Implementation Tasks	
Action #	Description	Expected Timeline		
2.3	Build analytical framework for candidate tidal tributary	April 2020	Chose Choptank River for PILOT based on data availability.	Developed analytical framework for Choptank watershed.
	Obtain and incorporate feedback on framework and habitat factors from experts	July 2020	Conduct online discussions with groups of experts.	Listen to experts and apply feedback to Choptank PILOT framework.
2.4	Develop recommendations for extending framework to Chesapeake Bay tidal areas	January 2021	Develop recommendations using experts' feedback and experience with framework.	Deliver report of recommendations to FHAT in January 2021.

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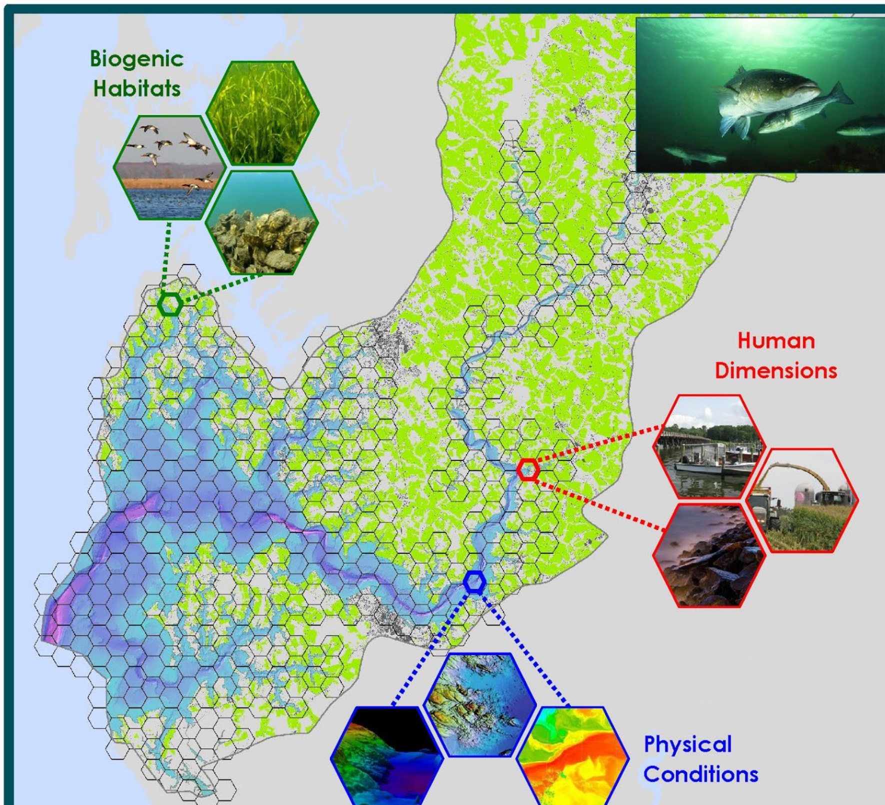
Framework Defined

For this workshop, we define framework as information and organizing principles that form the structure to allow assessment of fish habitat for fish in the geographic area being evaluated. It is a construct to catalogue, curate, manage, and integrate data and information.



Framework Concept || catalogue, curate, manage and integrate

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Our Requests of the Panel

Today we seek your expertise to provide us with:

1. Your opinions on using the proposed framework to explore factors affecting fish distribution and abundance;
2. Comments on the data and information that we have organized in a geographical information system (GIS) to date;
3. Suggestions of other data sources that are conspicuously absent;
4. Guidance on how these data sources shall be processed prior to ingestion;
5. Recommendations on methods to consider for habitat use and condition analyses.

Let's dive in…

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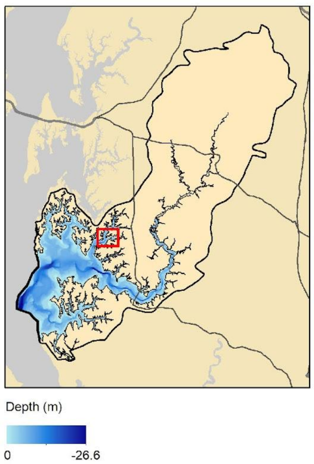
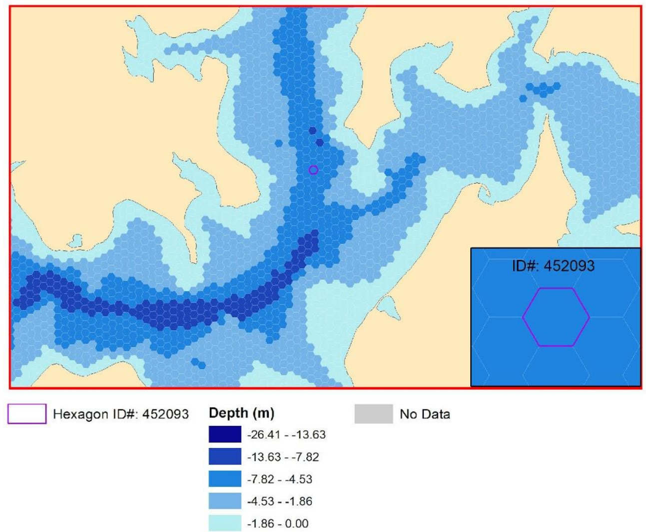
Bathymetry

Attribute: Depth (m) | Data Source Link: NOAA NGDC, 2017





Questions for the panel

1. The right-hand map depicts **average depth** in each framework hexagon; calculated from the source digital elevation model. Are you aware of a more comprehensive and better documented source of data that reaches into the Choptank tributary shallows?
2. We calculated average depth (m) for each hexagon in the framework, is there a more appropriate or additional measure of central tendency to use and/or include (e.g., median, mode)?
3. Do you have recommendations on how we might improve our method for filling "gaps" bathymetric estimates in these shallows? For reference, we used the ArcGIS elevation void fill function.
4. Do you have any general recommendations, thoughts, or concerns about using bathymetry in the framework?

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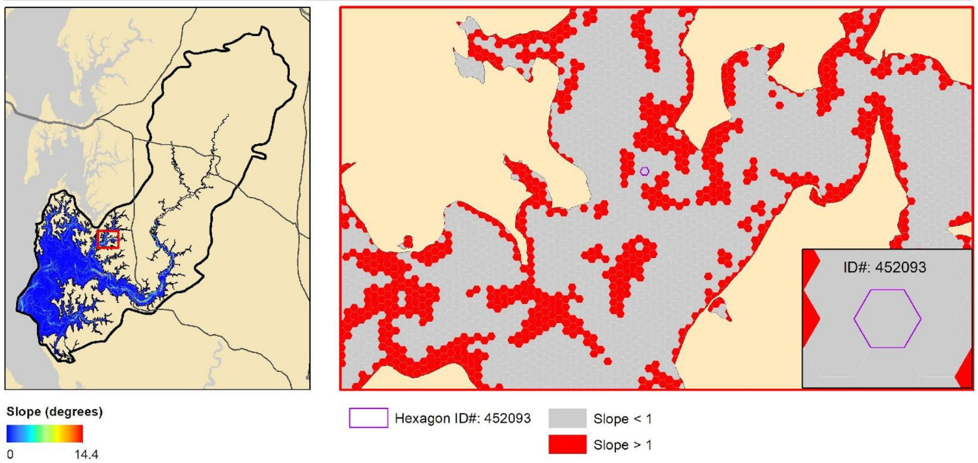
Bathymetric Slope

Attribute: Percent Rise (%) | Derived from NOAA NGDC, 2017 using SLOPE FUNCTION ↗



Questions for the panel

5. The right-hand map depicts **any hexagon wherein average slope exceeds 1% rise**. Slope was calculated from the source digital elevation model from the previous page. Do you think bathymetric slope may be important in understanding the abundance and distribution of fish in the Chesapeake Bay?
6. In developing predictive ecological models elsewhere, we found that benthic rugosity was often an important feature. This can be estimated at broad scales using the curvature function ↗ (i.e., second derivative of bathymetry). Do you think this is something we need to capture?
7. If so, do you have recommendations on how we might improve our method of estimating slope? For reference, we used the ArcGIS planar slope method↗, looking outward to 8 neighbors (e.g., wider neighborhood, steepness threshold, etc.).

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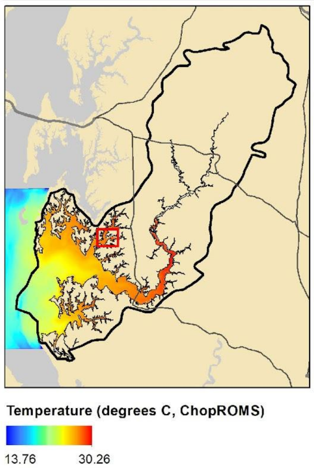
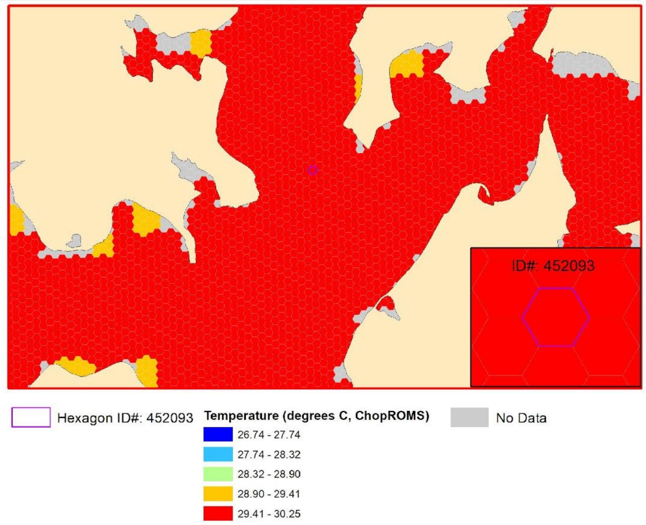
Water Temperature

Attribute: Temperature (°C) | Estimated from CHOPROMS hydrodynamic model





Questions for the panel

8. The right-hand map depicts **average mid-water temperature** in each framework hexagon; calculated from the source hydrodynamic model. Is there a more appropriate source of comprehensive water temperature data in the Choptank River?
9. How should we handle areas of no data (e.g. model estimates do not extend to area)? Are these important areas to capture (i.e. for nearshore habitat)?
10. The values displayed in this map are from August of 2010. For temperature specifically, should we account for variability over time (e.g., seasonally or inter-annually)? If so, what are the recommended time periods or divisions?
11. This map shows temperature at 'mid-water' depth. How should we account for changes with depth?

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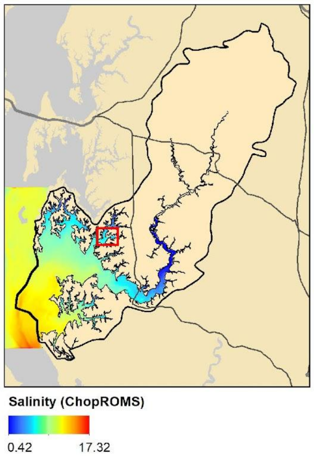
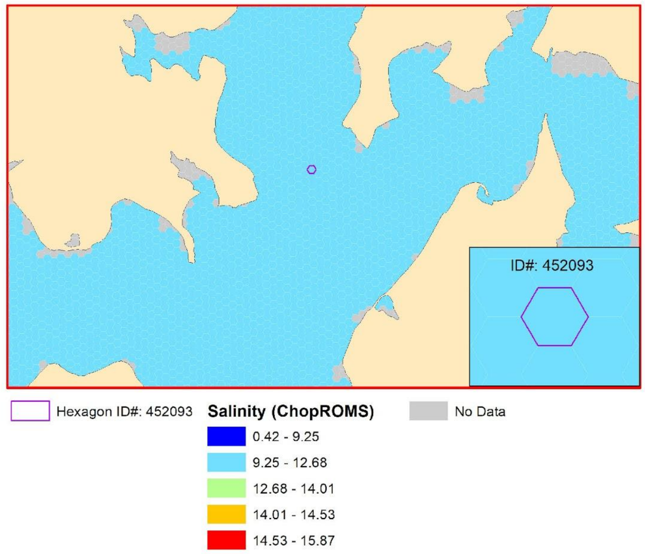
Salinity

Attribute: Salinity (ppt) | Estimated from CHOPROMS hydrodynamic model





Questions for the panel

12. The right-hand map depicts **average mid-water salinity** in each framework hexagon; calculated from the source hydrodynamic model. Are there more appropriate sources of comprehensive salinity data in the Choptank River?
13. The values for salinity in this map are from August of 2010. For salinity specifically, should we account for variability over time (e.g., seasonally or inter-annually)? If so, what are the recommended scales?
14. Would it be useful to include a more direct estimate of variability over time (e.g., coefficient of variation)?
15. This map shows salinity at 'mid-water' depth. How should we account for changes in salinity with depth?

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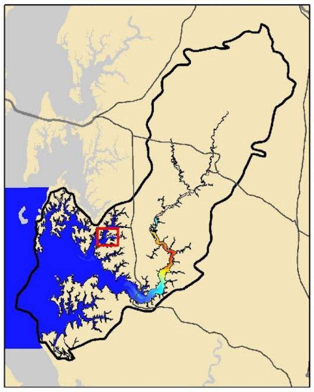
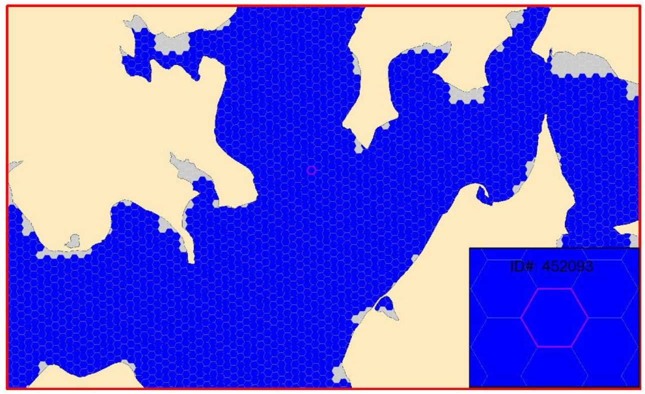
Dissolved Oxygen

Attribute: D.O. (mg/l) | Estimated from CHOPROMS ↗ hydrodynamic model





Questions for the panel

16. The right-hand map depicts **average dissolved oxygen** in each framework hexagon; calculated from the source hydrodynamic model. Are there more appropriate sources of comprehensive D.O. data in the Choptank River?
17. What are the appropriate time periods and/or time divisions (e.g. season, year) to represent dissolved oxygen?
18. Would it be useful to include an estimate of the frequency of threshold exceedance (e.g., how often D.O. < 3.0 mg/l)?
19. This map shows estimated dissolved oxygen at the bottom. Is this the correct depth for this variable? Should we account for dissolved oxygen variability with depth? If so, what are the relevant depths, thresholds?

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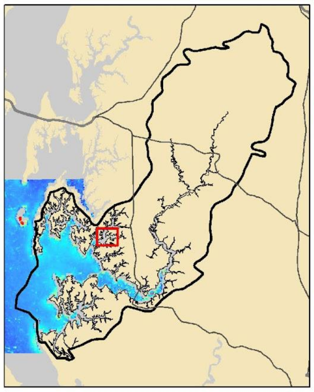
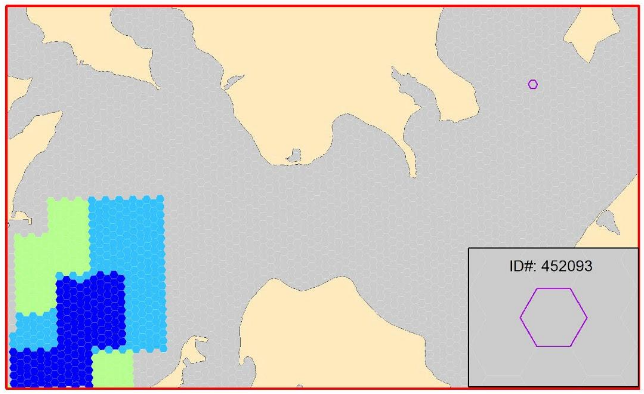
Total Suspended Matter

Attribute: TSM (g/m³) | Estimated from NESDIS STAR ↗





Questions for the panel

20. The right-hand map depicts **average total suspended matter** (TSM) in each framework hexagon; estimated from this satellite-derived predictive model ↗. Do you think predicted TSM may be important in understanding the abundance and distribution of fish in the Chesapeake Bay?
21. These data do not extend to the shoreline or to the headwaters. Are there other data sources available for aggregating and generalizing these data into these areas?
22. This map shows average conditions for summer 2010-2019. Are there other climatologies we should focus on? Is an average ('normal') climatology the correct summary, or would some other measure (e.g. extreme values) be better?

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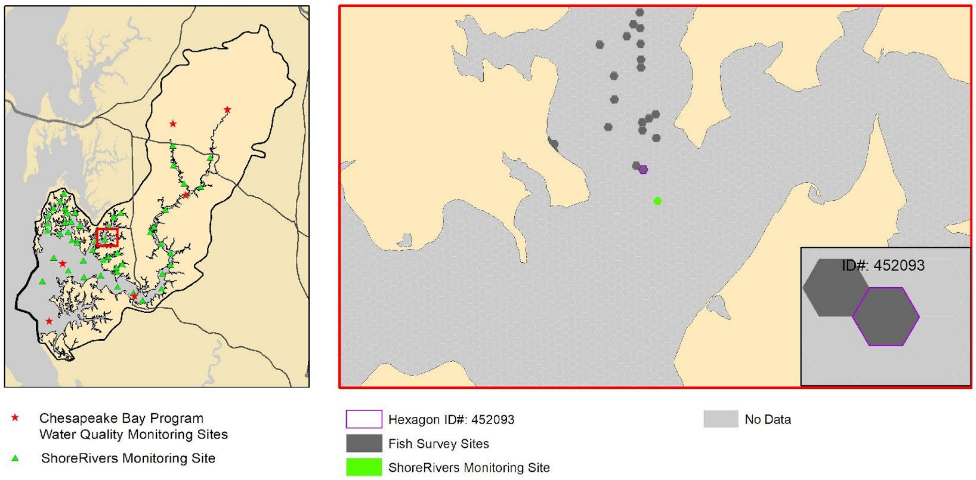
Water Quality Monitoring Programs

Attributes: Location | Chesapeake Bay Program ↗, Shore Rivers

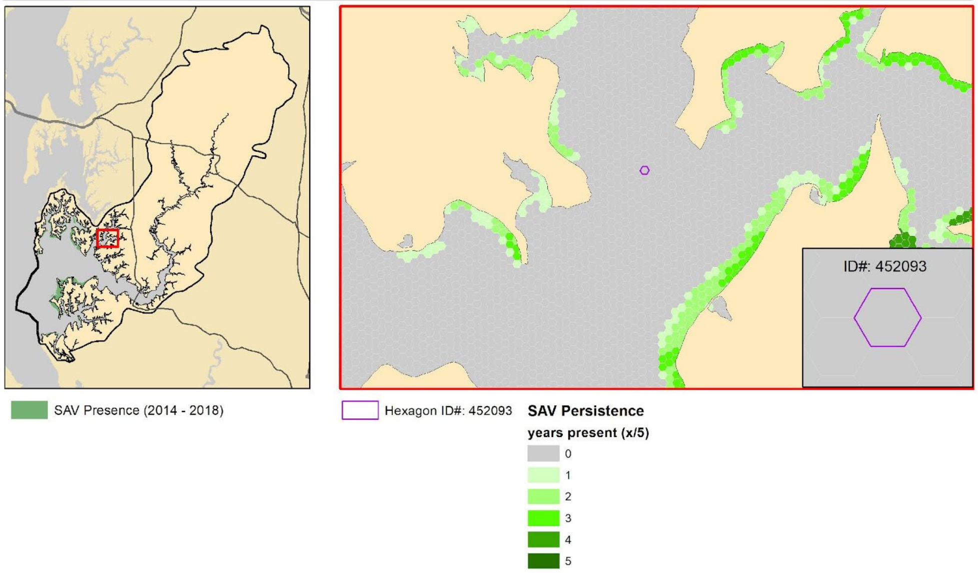


Questions for the panel

23. This map depicts **locations of the Chesapeake Bay Program and ShoreRivers water quality monitoring stations**. Routine measurements are taken at these locations; however, they are sparsely distributed throughout the study area. Is there value in capturing monitoring data from these programs in the framework?
24. If so, which of the water quality monitoring parameters ↗ shall we include in the framework?
25. Are there techniques to generalize these observations throughout the framework? If so, what are the most appropriate techniques for doing so, and for relating generalized observations to fish abundance and distribution data?

Submerged Aquatic Vegetation

Attribute: SAV persistence (years) | Data source link from VIMS SAV Monitoring & Restoration



Questions for the panel

26. The right-hand map depicts **the total number of years** (out of 5) where the VIMS SAV program found and mapped submerged aquatic vegetation. This metric was chosen to mimic the Bay Program approach to assessing SAV. Is there a more appropriate or additional measure of SAV presence and/or persistence to use?
27. Given the variability in the size and location of SAV beds, do you have recommendations on how we can quantify the influence they have on the surrounding waters?
28. Are there additional SAV metrics that we should capture in our framework and how (e.g., density)?

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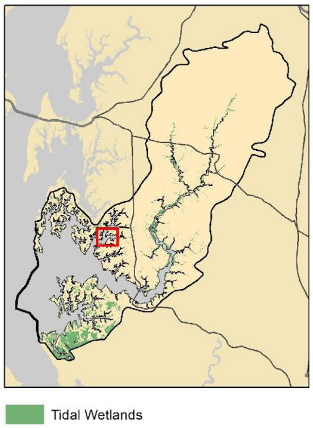
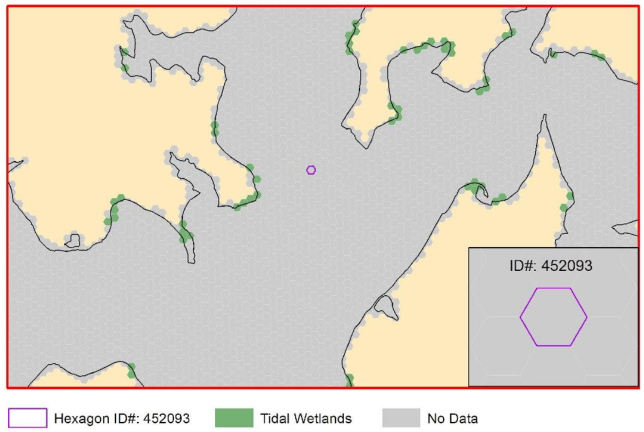
Tidal Wetlands

Attribute: Wetland presence (yes/no) | Data source link [Chesapeake Conservancy](#)





Questions for the panel

29. The right-hand map shows **hexagons where tidal wetlands are present along the shoreline** based on the Chesapeake Conservancy land cover data project (2013/14). Is this the best available tidal wetland dataset for the Choptank watershed?
30. How should we account for the influence of tidal wetlands in the nearby hexes and/or waterbody, and would wetland dimension/quantity be valuable to capture?
31. The Conservancy data include tidal wetlands, floodplain wetlands and other wetlands. The National Wetland Inventory contains different categories of wetlands. Is it important for us to capture different classes?
32. Are there additional wetland metrics that we should capture in our framework and how (e.g., density)?

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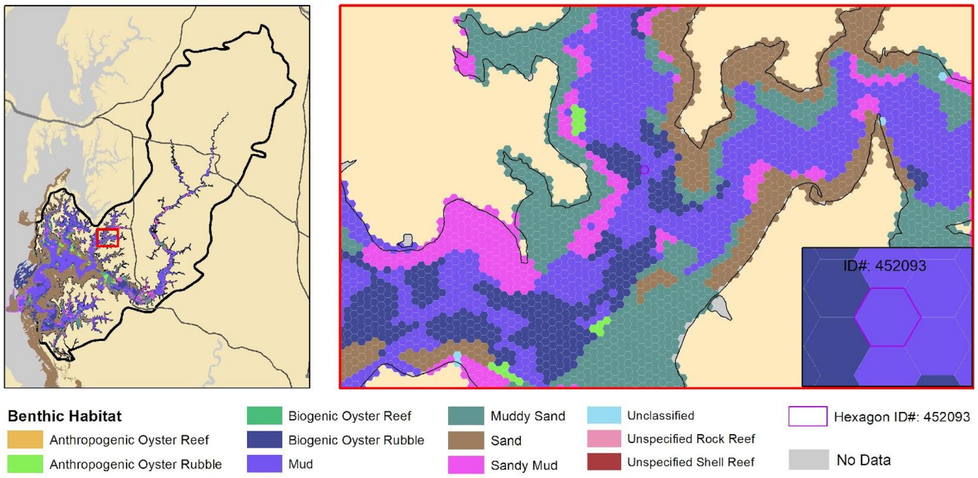
Benthic Habitat Type

Attribute: Seabed material (type) | Data source link [NCBO CMECS Habitat Classification](#)

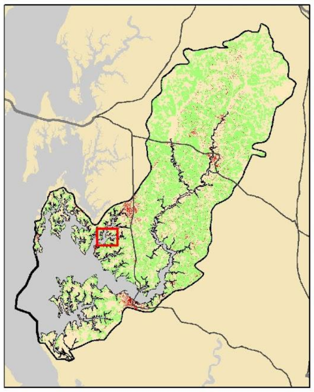


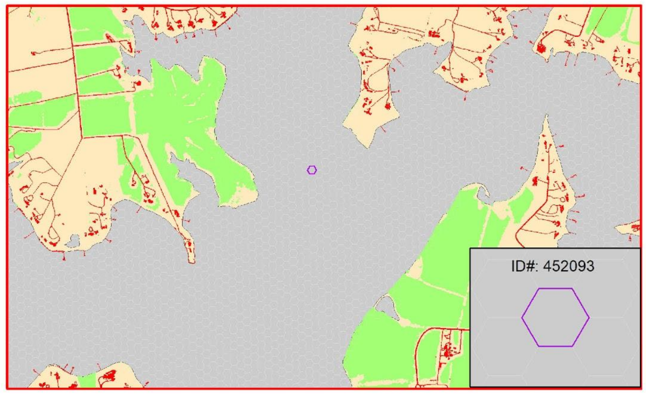
Questions for the panel

33. The right-hand map shows the **dominant (%) benthic class** that was aggregated from multiple sources to create a baywide record of seabed material in the Chesapeake Bay. Source habitat polygons are classified with an adaptation of the [Coastal and Marine Ecological Classification Standard](#) (CMECS) Substrate Component (SC). Is dominant class the most appropriate summary, or are there others to consider?
34. Are there additional datasets for us to consider?
35. Is the diversity of bottom type within a creek or river important to capture, or is the dominance of a particular bottom type more important?
36. Are there rare and/or critical habitats that need to be emphasized or treated differently in the framework?

Land use – Land Cover

Attribute: Land Use Class (type) | Data source link [Chesapeake Conservancy](#) ↗





Questions for the panel

37. These maps highlight data classified as "impervious surface" or "agricultural" from the Chesapeake Bay Conservancy **land use/cover data layer**. Do you think land use patterns may be important in understanding the abundance and distribution of fish in the Chesapeake Bay?
38. There are additional land use/cover types (e.g., shrubland, low vegetation, tree canopy, etc.). Shall we incorporate these into the framework?
39. Are there additional datasets for us to consider (e.g., USDA CropSCAPE ↗)?
40. If so, do you have recommendations on how we might best link in-water hexagons with land-based features (e.g., proximity to buffer, watershed metrics ↗, etc.)?

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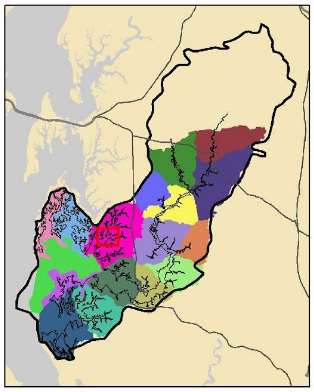
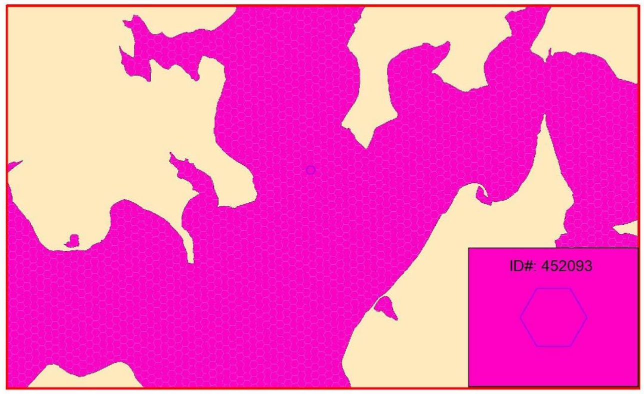
Watershed/Sub-watershed Metrics

Attribute: Percent Rise (%) | Data source link: USGS HUC 12



Subwatersheds



Hexagon ID#: 452093

Subwatershed

Tred Avon River-Choptank River

Questions for the panel

41. These maps depict **assigned USGS HUC-12 sub watershed classifications**. Do you think these geographic/watershed classifications may be important in understanding the abundance and distribution of fish in the Chesapeake Bay?
42. If so, do you have recommendations on how we might best link in-water hexagons with these geographies (e.g., transfer land-use composition, size, population, etc.)?
43. Do sub-watershed boundaries provide useful information for subsequent characterizations or trend analysis of fish abundance and distribution within the study area?

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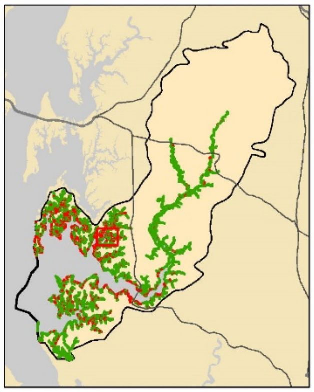
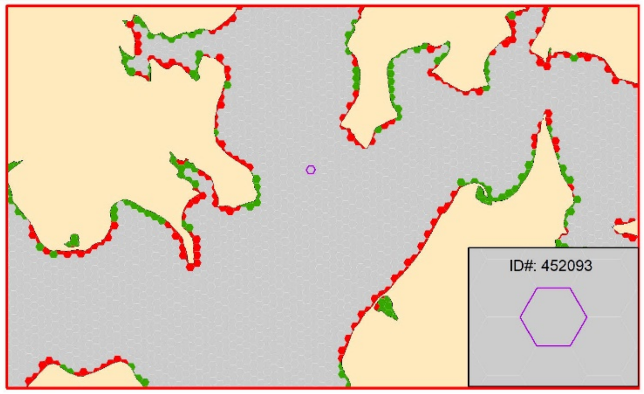
Shoreline

Attribute: Natural (yes/no) | [Data source link: NOAA Continuously Updated Shoreline](#)



CUSP Shoreline
Man-made
Natural



Hexagon ID#: 452093
CUSP Shoreline
Man-made
Natural
No Data

Questions for the panel

44. The right-hand map depicts the **majority classification of shoreline** (natural vs. man-made). Do you think that shoreline type may be important in understanding the abundance and distribution of fish in the Chesapeake Bay?
45. If so, do you have recommendations on how we might best link in-water hexagons with shoreline type?
46. This dataset includes additional sub-categories of shoreline type. Is it important to account for different types of man-made structure? If so, which ones?

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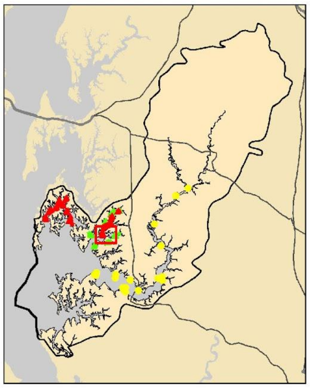
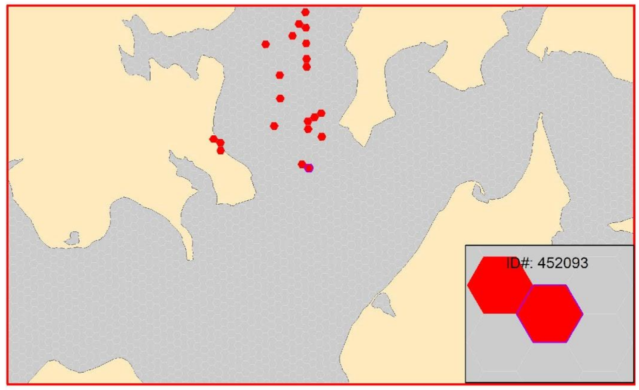
Exercising the Framework | A Few Examples





The next 3 pages provide examples of how the framework can be used to explore factors affecting fish distribution and abundance, with specific examples presented for striped bass and white perch in the Choptank River. In these examples, we have used data from the Maryland DNR juvenile striped bass seine survey, FHEP seine and trawl surveys, and the Cooperative Oxford Laboratory Tred Avon ecological assessment surveys. We present three types of analyses to illustrate potential uses of a thoughtfully constructed framework, including:

- Targeted characterization & assessment,
- Habitat suitability, and
- Statistical modeling & prediction.

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Example Analysis | Targeted Characterization & Assessment

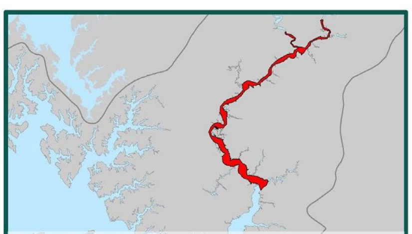
Striped bass spawning area characteristic summary & assessment of similar areas in the framework

To support the FHAT objective of characterizing fish and shellfish habitat and identifying important places for conservation and restoration, here we provide an example characterization using a partial list of physical features **inside** the Maryland DNR designated striped bass spawning habitat ***(1)*** in the upper Choptank and a companion assessment of areas demonstrating similar characteristics ***(2)***.

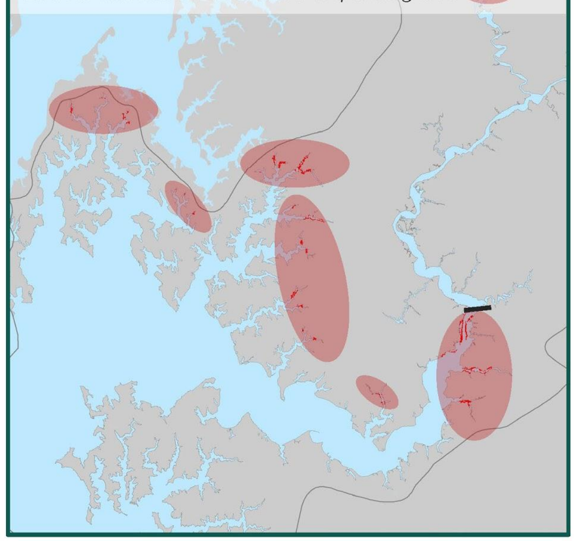
47. Do you think that this approach can be effectively applied to better understand such vital habitats, or for identifying areas with potential for consideration towards conservation and/or restoration of fish and shellfish habitat?

48. What are the most important characteristics to consider incorporating into the framework in order to serve this objective?

	Outside	Inside
Anthropogenic Oyster Rubble	1.8%	0%
Biogenic Oyster Reef	0.14%	0%
Biogenic Oyster Rubble	11.69%	0%
Mud	33.2%	57.8%
Muddy Sand	8.5%	12.4%
Sand	37.3%	2.7%
Sandy Mud	7.4%	27.2%
% Wetlands	1.2%	4.2%
% Natural Shore	84%	98%
Historical SAV Presence	12%	0.80%
Average Salinity	13.1 ppt	4.1 ppt
Average Temp	28.8 C	29.8 C
Average Depth	3.6 m	2.1 m
% Slope ≥ 1	13.90%	50%



1. *MD DNR striped bass spawning area*



2. *Areas with characteristics similar to spawning area*

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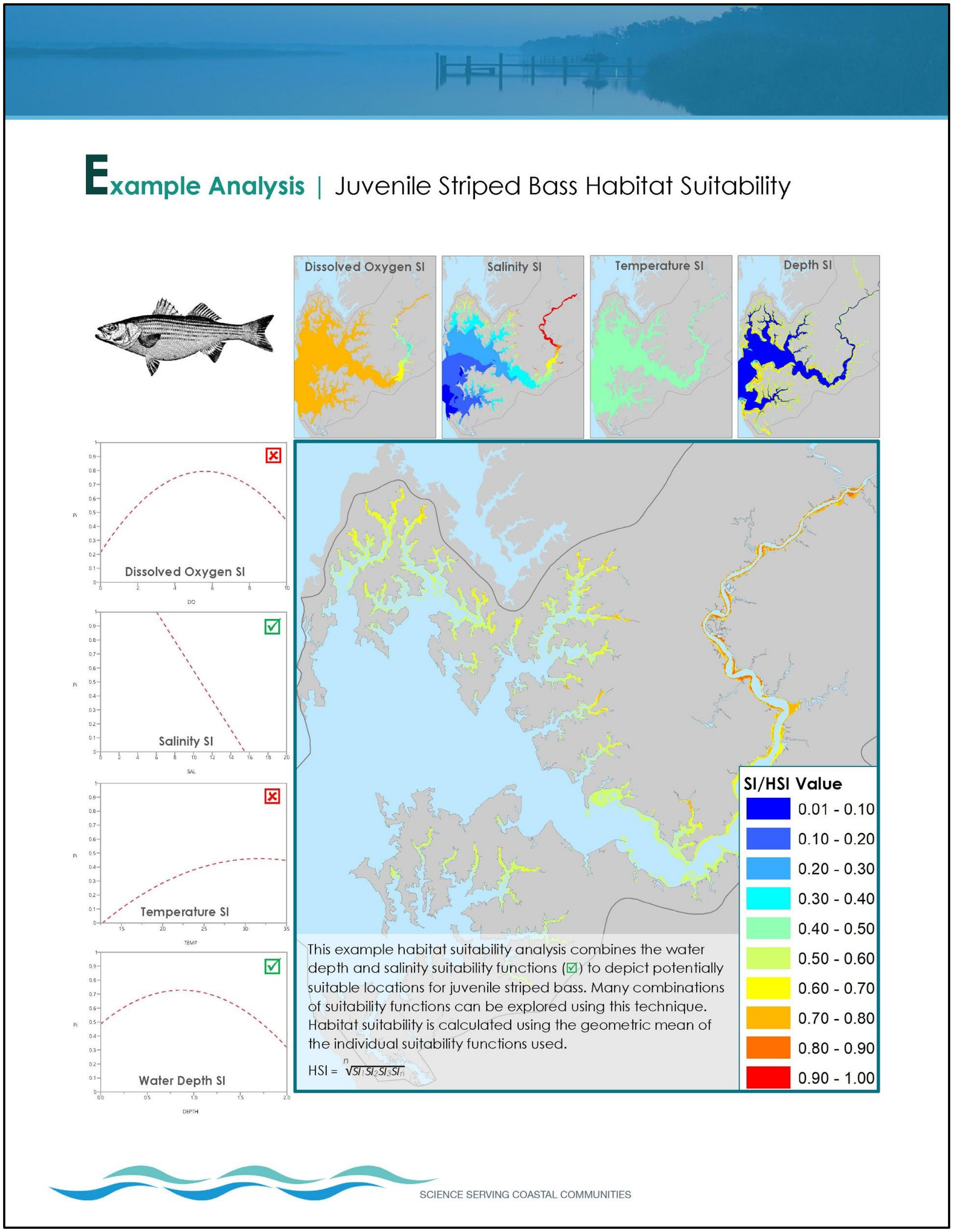
Example Analysis | Juvenile Striped Bass Habitat Suitability
Dissolved Oxygen SI
Salinity SI
Temperature SI
Depth SI
Dissolved Oxygen SI
Salinity SI
Temperature SI
Water Depth SI
SI/HSI Value
0.01 - 0.10
0.10 - 0.20
0.20 - 0.30
0.30 - 0.40
0.40 - 0.50
0.50 - 0.60
0.60 - 0.70
0.70 - 0.80
0.80 - 0.90
0.90 - 1.00
This example habitat suitability analysis combines the water depth and salinity suitability functions (☑) to depict potentially suitable locations for juvenile striped bass. Many combinations of suitability functions can be explored using this technique. Habitat suitability is calculated using the geometric mean of the individual suitability functions used.
HSI = $\sqrt[n]{SI_1 SI_2 SI_3 SI_n}$
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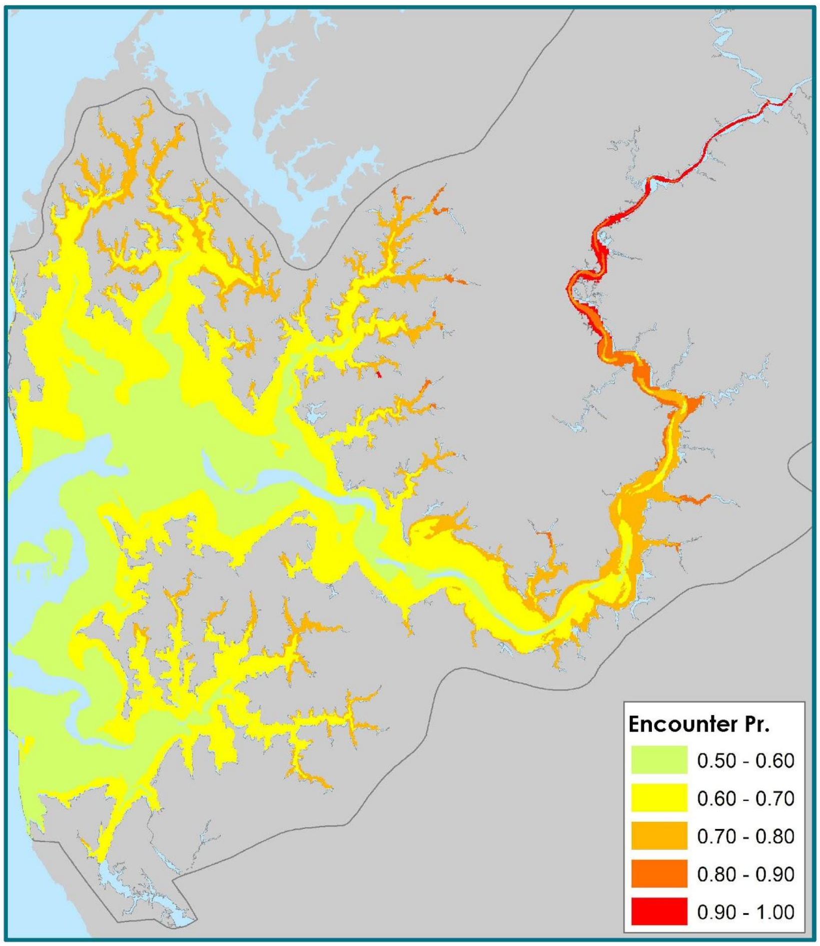
Example Analysis | Juvenile White Perch Statistical Model

This example map shows the predicted probability of encountering white perch in the Choptank tank. This example model uses a stepwise multiple regression to select parameters to include in the model. In this case, only statistically significant parameters were included: 1) salinity, 2) depth, and 3) temperature.



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WORKSHOP CONCLUSION

Before we conclude …

High level summary of comments

What to expect next:

1. Summary notes of workshop feedback by November 13;
2. Copy of recommendation report delivered to FHAT in late January 2021.

Our sincere thanks to each of you. To contact the team, please reach out to:

A.K. Leight
AK.Leight@noaa.gov

Suzanne Skelley
Suzanne.Skelley@noaa.gov

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Appendix C: Workshop Feedback Summary Notes

During our two workshops (October 27 and 29, 2020) and in emails, we received a large number of very helpful comments and suggestions. This document attempts to capture all of them. We have organized the feedback into several categories for simplicity. In most cases we captured the feedback verbatim. We attempted to associate each comment to the correct participant, but there may be some errors in attribution.

Framework Design Recommendations

This table captures comments and suggestions that we received about the framework design.

Item #	Recommendation	Suggested By:
1	Consider replacing hex grids with unstructured grid pattern used by CBP model	Michelle Canick, Peter Tango
2	While framework uses hexagons, other efforts use a triangle which reduces the number of interfaces per each polygon. Did you consider using other shapes like a triangle? Why was hexagon selected?	Tom Fisher
3	Hexagons are commonly used when boundaries are highly irregular such as shorelines and tributaries. 0.5 acre hexagon is reasonable except for smaller tributaries where this resolution may be too coarse for analyses.	Marek Topolski
4	Determine if there is a minimum number of variables available Bay-Wide that would be necessary to consider this framework 'valid'	Allison Colden
5	This type of approach will be useful for essential fish habitat consultations throughout the Chesapeake Bay. I would like to see more consideration for the effect of seasons. Also consider that habitat values will vary greatly among	Jonathan Watson

	species and life stages.	
6	Decisions about variables, to be most appropriate, need to be tuned to the species. Species are diverse, e.g. their life stages & metabolic responses.	Mary Fabrizio
7	The user's question is vital to understanding how to construct the framework	Ron Vogel
8	The hex framework is sufficiently resolved to illustrate horizontal salinity distributions. I can't tell how well it works for then possibly including vertical arrays of data. In our trend analyses of water quality parameters, we do see different trends with different depths so tracking parameters and the depth of the measurements in this framework seems important from the differences we see in our trend analyses.	Peter Tango
9	We see fish communities moving north at something like 10 miles per decade(?), we have seasonal shifts in habitat conditions of tens of miles in this highly variable estuarine environment, so my question is how fine does the resolution need to be to capture the important features of the phenomena associated with the scales of change influencing all species, knowing each species will have different sensitivities to the conditions. Food for thought on the size of the hexs or any other segment size considered.	Peter Tango
10	A challenge to such a tool is that data will have different time steps (e.g. daily through decadal). The data coverage in time and space should be explicit to help the user understand what they have to work with.	Peter Tango

Additional and Alternative Dataset Recommendations

This table captures comments and suggestions that we received about datasets that could be integrated into the framework that we either didn't consider or are alternatives to the datasets we presented.

Item #	Variable	Datasets	Suggested By:	Source
Alternative Datasets				
1	Bathymetry	USConEd TDEM	John Young, Donna Bilkovic, Michelle Canick	https://earthexplorer.usgs.gov/ https://topotools.cr.usgs.gov/topobathy_viewer/
2	Bathymetry	CBP or Versar Bay benthos data	Ryan Woodland	
3	Bathymetry	Other variables likely correlated to depth	David Bruce	
4	Bathymetry/Slope /Rugosity	Many measures of benthic heterogeneity and benthic indices - including standard deviation, rugosity, etc.; whether or not they are relevant to the biota is a good question, but to the degree that they inform habitat type and structure they are worth testing.	John Young	https://jblindsay.github.io/wbt_book/available_tools/geomorphometric_analysis.html
5	Slope	“bedform” = slope + topographic position	Michelle Canick	
6	Rugosity	Oyster habitat [oyster shell/mounds]	Angie Sowers	CMECS?

7	Density/ Stratification	Density gradients influence stratification of habitats vertically, and give you designated uses in the horizontal frame. Critical factor.	Peter Tango, Tom Fisher	Calculated from temp, salinity
8	Density/Stratification	Climate change (temperature) is influencing stratification in concert with salinity - see recent CBP Modeling Work group scenario assessments and how this will influence habitat distributions into the future which affects species community change expectations over time for example.	Peter Tango	Calculated from temp, salinity
9	Water Quality	State shellfish sanitation programs have additional data	Donna Bilkovic	VADEQ and MDE
10	Water Quality	High frequency profiler data from Tred Avon.	Tom Parham	
11	Water Quality	Noted availability of 35-yr monitor WQ program and NOAA/Vogel satellite derived datasets.	Peter Tango	https://datahub.chesapeakebay.net/ , https://eastcoast.coastwatch.noaa.gov/
12	Tidal Wetlands	NWI - better resolution in Ches Conserv, but better classifications in NWI	Donna Bilkovic, Marek Topolski	https://data.imap.maryland.gov/datasets/209f2ea6b146475d91bef53422a019fc_2 https://www.vims.edu/ccrm/research/inventory/virginia/i

				ndex.php
13	Tidal Wetlands	New product in development by TNC based on NWI and lidar "We are re-running the Sea Level Affecting Marshes Model (SLAMM), which creates a time-zero or current condition layer from NWI & tidal zone"	Michelle Canick	In development
14	Turbidity	CBP's Kd (diffuse attenuation) and satellite Kd (from NOAA NESDIS)	Ron Vogel	Ches Bay Program https://datahub.chesapeakebay.net/ NOAA NESDIS https://eastcoast.coastwatch.noaa.gov/
15	Benthic Habitat	QUESTION: Are there any clam bars remaining in the Choptank?	Angie Sowers	
16	Benthic Habitat	Include boundaries of protected areas - oyster sanctuaries, leases, historic and legal oyster bars.	Angie Sowers	MD DNR
17	Benthic Habitat	Percent of various sediment size classes (e.g. silt, sand, clay), although most sampling sites in relatively deep areas	Ryan Woodland	CBP benthic community survey
18	Benthic Habitat	Percent Mud	Michelle Canick	usSEABED and the CBP benthic community station data

19	Watersheds	HUC12 may be too big. Consider using NHD catchments	John Young	USGS, can get from Leetown team
20	Impervious Surface	MD Dept of Planning Tax Maps	Jim Uphoff	
21	Shoreline	Updated VIMS shoreline for Talbot County	Michelle Canick	VIMS
	Additional Datasets			
22	Water Clarity	Kd (light attenuation)	Ron Vogel	
23	Water Clarity	Secchi Depth	Jim Uphoff	Fish sampling programs
24	Biotic	Fish habitat preferences	Tom Fisher - content from final poll.	
25	Biotic	Benthic Community Data	Michelle Canick	CBP and Versar
26	Biotic	Secondary Production	Michelle Canick	Dan Dauer (ODU)
27	Biotic	Zooplankton Abundance	Michelle Canick	CBP data portal: BUT only at 2 stations in Choptank up to 2002
28	Protected area boundaries	Oyster sanctuaries, leases, historic and legal oyster bars	Angie Sowers	MD DNR
29	Oyster habitat	Oyster harvest regulations	Matt Ogburn	MDE and VADEQ

30	Contaminants(including endocrine disruptors)	Contaminants, including endocrine disruptors	Jim Uphoff	AK: Estimates are available for NHD catchments (StreamCat?)
31	Water Quality	Alkalinity, pH, and conductivity. Conductivity is useful to know in fresh-tidal areas and pH is useful when paired with DO to get more detail on blooms or other phenomena.	Jim Uphoff	CBP and ShoreRivers data
32	Climate Scenarios	E.g. expectations for wetland habitat to be inundated by tidal waters in next 10,20,30,50 yrs	Peter Tango	
33	Fishing locations	Recreational and Commercial fishing data	Jim Uphoff	MD DNR - Tom P
34	SAV Invasive vs Native	Invasive vs Native	Jim Uphoff	
35	Secondary Productivity	Secondary Productivity	Michelle Canick	Dr. Dan Dauer, Old Dominion University

Data Integration Recommendations

This table captures comments and suggestions that we received about the ways in which various and specific metrics might be integrated into a statistical analytical framework.

Item #	Variable	Recommendation	Suggested By:
1	All	Consider historical changes	Sally Claggett
2	All	Habitat variables should be matched as much as possible to fish behavior and distribution.	Jim Uphoff
3	All	Detail is not always your friend. What is your management application? It depends on how much "information" is gained or lost. What is your target audience? GIS geeks? Managers? Academics? Fishermen? Environmental groups? Who you target should tell you something about how much detail you consider.	Jim Uphoff
4	Bathymetry	Definitely important as shallow water is significant for some species. "We have used a metric of 'distance from shore to the 1m depth contour' to depict the relative availability of shallow waters, which are critical refuge areas for some juveniles and forage species."	Donna Bilkovic
5	Bathymetry	Consider integrating bathy data into zones (littoral, profundal, etc)	David Bruce
6	Bathymetry	1/3 arc-second is approximately 10x10m linear resolution which is reasonable for most areas being mapped. Vertical resolution is 1m which may be too coarse for shallow areas, estimating small changes in slope, and subtle changes in curvature. Deviates from actual shoreline in smaller tributaries.	Marek Topolski
7	Bathymetry	Re: central tendency, selected method may depend on the location. Recommend doing the statistics.	Tom Fisher

8	Bathymetry	Check to see if data are normally distributed to determine using mean versus median	Jim Uphoff, Marek Topolski
9	Bathymetry	Depth is useful. Might be good to know minimum and maximum depth	Tom Fisher
10	Bathymetry	Regarding filling gaps by using ArcGIS elevation void fill function, it depends on size of void. If void is large, best to sample and fill with measured data.	Tom Fisher
11	Bathymetry	I assume the database used to create this layer was sounding data. Fine for Ches Bay but for the Choptank, can you scale the changes as you move to smaller areas/tribs, e.g. Goldsborough Creek? 2,000 m2 hex works in Ches Bay, but in rivers, you will lose resolution. Can you use 1 or 2 m2 grid?	Tom Fisher
12	Bathymetry	Original data in Feet, now in Meters - maybe choose your gradient scale in . . start with metric units to keep more regular.	Tom Fisher
13	Bathymetry	Could you use depth for spp, that are less than 3? meters, bc that is 33%? Error?	Unknown
14	Slope	1% slope may be meaningless. Is there a way to let the user decide slope?	David O'Brien, Jim Uphoff
15	Slope	Fish might relate to slope change at a location as opposed to just slope itself. (slope change informs channel structure to me more than slope alone that fish often relate to.	Peter Tango
16	Slope	Curvature & rugosity should be explored, calculated from the DEM then aggregated for each hexagon.	Marek Topolski

		Check for spatial autocorrelation between slope and curvature	
17	Slope	Slope is important and questioned why 1% was used. Capturing steep slope changes is important	Unknown Tom Fisher
18	Slope	1% slope -- hard to know if it's important without info on species. You can match up these metrics to oyster bars or known fishing locations where you would some idea if these vars work on not.	Jim Uphoff
19	Slope	Cautioned about slope of 1% and associating with fish behavior. Also, if want to find a relationship, need to have a range of variables - said this in reference to all blue on p7.	Mary Fabrizio
20	Slope	Noted they have used distance to a certain point to capture a similar feature as slope.	Donna Bilkovic
21	Slope	Noted have used distance to depth to capture relative amount of shallows, to get to slope question. “We have used a metric of ‘distance from shore to the 1m depth contour’ to depict the relative availability of shallow waters, which are critical refuge areas for some juveniles and forage species.”	Donna Bilkovic
22	Slope	In marine tropics, there is a depth threshold at 10m. Are there similar slope breaks in CB? Noted SAV grows at depth less than 2m. Studies show this is critical refuge area for certain species.	Chris Jeffrey Allison Colden
23	Slope	Structure is important in summer. Fish orient to features such as sharp edges and lumps. These are different from slope or rugosity. Suggest plotting against oyster bars, fishing spots, survey catches, etc. Underlying fish distribution is the best indicator but sampling over uneven bottom makes it difficult to get fish data. Hard to say what type	Jim Uphoff

		of edges fish like to associate with. Jim U. and Margaret McGinty have mapped historic fishing locations.	
24	Bathy, Slope	Need both as changes in bathymetry are important. Having both variables will mitigate losing important info fish location.	Allison Colden
25	Rugosity	At scale of <1m, rugosity is important in structured habitats. This could provide landscape-scale idea of habitat diversity. Not certain if hex-grid scale provides same info	Allison Colden
26	Rugosity	Areas shaped by tidal currents and channels that are maintained by tides, meter scale and larger, where people go to fish.	Unknown
27	Water Quality	Use Fill Missing Values tool to fill data gaps Consider using field data to supplement (or even replace) missing data and constructing interpolations. It would seem to be useful for comparison with model predictions for shallow, nearshore, smaller tributaries. Consider geostatistical method like Empirical Bayesian Kriging or an interpolation with barriers (to account for shorelines).	Marek Topolski
28	Water Quality	Use of modeled data depends on accuracy of model compared to real data	Jim Uphoff
29	Water Quality	Central tendency should be informative for chronic conditions, while max and mins would represent the most acute conditions. You may want to consider some percentiles also (5 and 95% for example) to make sure your "extremes" aren't too extreme.	Jim Uphoff
30	Water Quality	Habitat variables should be matched as much as possible to fish behavior and distribution.	Multiple
31	Water Quality	Use of observations from fish sampling surveys, including bottom salinity and bottom temperature, to validate water quality models.	Mary Fabrizio

32	Water Quality	The interaction of water quality variables is important, e.g. the susceptibility of fish to certain DO levels may change in response to different temperature conditions	Ryan Woodland
33	Water Quality	Consider using the Bay Interpolator, though is a bit dated now	Michelle Canick, Jeni Keisman
34	Water Quality	Have flexibility to recalculate on time scale of user's interest	Ron Vogel
35	Water Quality	Consider using SPARROW model outputs [streamflow, sediment loads, total nitrogen, total phosphorus]	Michelle Canick
36	Water Quality	Consider reporting an uncertainty measure, This was done on a tributary basis by CBP	Peter Tango
37	Temp, Salinity, and Flow	Springtime values important for anadromous spawners	Donna Bilkovic
38	Temp, Salinity, and DO	Important drivers of fish distribution	Jim Uphoff
39	Temp, Salinity, and DO	When using model output, need to validate the model output results Noted skeptical of modeled output for DO in upper portion of Choptank as grad student studies showed this area is fairly well mixed. It's important to validate model output (model skill) It's often feasible to validate model output by using fisheries data. Important to note the skill of the model at particular ranges, as model performance isn't always the same over all ranges of output.	Tom Fisher Tom Fisher Unknown on 10/29 Mary Fabrizio

40	Temp, Salinity, and DO	Capture critical strata for specific species	Unknown
41	Temp and Salinity	Existing baywide models estimate these values (e.g. for sea nettle forecast and VIMS striped bass habitat suitability)	Peter Tango
42	Temp and Salinity	Temp might be captured on seasonal scale but salinity might be included on weekly scale	Ron Vogel
43	Temp	Temperature seasonality is becoming more important as temperature thresholds trigger many biology actions, e.g. migration, spawning, predator behavior.	Sally Claggett
44	Temp	Given warming trends over time, consider including excursions from certain thresholds instead of average mid-water temp	Jeni Keisman
45	Temp	Temp thresholds trigger migration, spawning, etc.	Donna Bilkovic
46	Temp	Temp thresholds trigger migration, spawning, etc. and their timing is changing with climate change	Peter Tango
47	Temp	Temp regimes are important & related to seasons per biologic need, e.g. spring, spawn.	Mary Fabrizio
48	Temp	Mid-water may not be optimal when have stratification. Animals are responding to water column changes hence important to capture more than mid-water temp.	Mary Fabrizio
49	Temp	I think that if there is a decision to use model-derived output for temp or other variables, it will be important to link the location in the water column over which it is calculated with the known habitat characteristics of the target species	Ryan Woodland
50	Temp	Might be hard to capture fine-scale, instead it might be useful to cross	Jonathan

		reference published values that have been cataloged in tools like "Fish Bioenergetics 4.0"	Watson
51	Temp, Salinity	Mean summer (Jun-Sep) bottom water temp and salinity important	Michelle Canick
52	Temp	For temperature if species specific models are generated there are a number of species that have literature looking into the particular time of the year that temperature may be most predictive but as you start looking at many species concurrently this can become cumbersome to test so many need to default for seasonal/water year averages or variability	Kevin Krause
53	Temp	Dates of certain temp thresholds (but would vary by species)	Allison Colden
54	Temp	Just for Choptank, DNR has profile TEMP data (hi frequency, bottom to surface); also have a Tred Avon profiler	Tom Parham
55	Salinity	Especially important for benthic species such as oysters	Matt Ogburn
56	Salinity	Yes, salinity is important to include.	Jim Uphoff
57	Salinity	Thresholds identified in Marine and Estuarine Finfish Ecological Habitat Investigations (2013)	Michelle Canick
58	Salinity	Include several salinity layers, which allows users to make selection suited to their purpose. Bottom layer important.	Unknown
59	Salinity	Noted she has been using tidal averages for salinity.	Mary Fabrizio
60	DO	Targets and threshold percentages are relevant to biology and for illustrating extent of conditions	Jim Uphoff
61	DO	If possible, capture daily minimum DO	Matt Ogburn

62	DO	Many fish not considered benthic orient to bottom structure in summer (striped bass for one). They don't hover in midwater. Volume affected is usually a metric, but that does not reflect loss of bottom available well.	Jim Uphoff
63	DO	Instead of avg, consider threshold exceedance, or lower 25th percentile	Michelle Canick
64	DO	Minimum DO and length of time < 2mg/L more important than avg	Allison Colden
65	DO	Surface temp over short frequencies might highlight when algal blooms occur	Matt Pluta
66	DO	If available, short-duration hypoxia in shallow waters might be included	Jeni Keisman
67	DO	Duration of low oxygen is important (scale of hours to month)	Peter Tango
68	DO	Suggest using TMDL and EPA Ambient Water Quality thresholds, as they are based on fish and shellfish habitat conditions	Peter Tango
69	DO	Bottom DO is not providing good info, it's the breakpoints that are important	Tom Parham
70	DO	Can get short term low DO in shallow waters during summer nights. Might be able to mine data for these cases.	Tom Parham
71	TSM	Although workshop handout indicates "predictive model" it is a satellite estimation based on an algorithm. It's not a prediction like in a hydrodynamic model. Ron suggests blocking values > 20 mg/L. Resolution of satellite data is 250m with limited data near the shoreline.	Ron Vogel
72	TSM	TSM variability can be both seasonal and episodic	Unknown
73	TSM	Including is useful as some species use suspended matter to hide.	Unknown

74	TSM	Cautioned about mixing course & fine scale data	John Young
75	TSM	Noted that the dataset used is a long-term climatology & flagged importance of time steps (weekly, monthly, seasonal, annual). Selection of time steps ought to depend on how the user will use the framework.	Ron Vogel
76	Turbidity	May be proxy [correlated] to SAV abundance	Sally Claggett, David Southerland
77	TSM	Might be useful if able to parse out the organic matter portion of TSM. Historical retrospective might be helpful.	Jim Uphoff
78	TSM	Turbidity max is important to fish early life history as that's generally when year class success is determined.	Jim Uphoff
79	TSM	All satellite values are surface estimates, but may not be good reflection of turbidity at depth	Tom Parham
80	Water Quality Monitor.Prgms	Yes, capture all of the available parameters.	Unknown
81	Water Quality Monitor.Prgms	Assess different ways to interpolate data. While there are issues, it's the best data we have, so use it.	Jeni Keisman
82	Water Quality Monitor.Prgms	Recommend sampling fish at WQ monitoring stations. Or, use CTD cast when sampling for fish.	Tom Fisher
83	Water Quality Monitor.Prgms	Most long-term fish sampling data sets collect WQ parameters esp. in VA.	Donna Bilkovic
84	Water Quality Monitor.Prgms	** applies to items above. Included here for use in our review & discussion.	** our team

85	Water Quality Monitor.Prgms	Identify key data gaps in recommendations.	Donna Bilkovic
86	Water Quality Monitor.Prgms	There are a lot of NOAA sites with high frequency data that could be used for model validation	Tom Parham
87	SAV	Persistence more important than presence	Sally Claggett, Angie Sowers, Michelle Canick
88	SAV	Consider weighting persistence by density	Jonathan Watson
89	SAV	Consider composite measure such as 5 year average crown density.	Marek Topolski
90	SAV	Include persistence. Data allows for identifying density of beds. Also, like measurement of distance btwn SAV bed and adjacent habitat like wetlands.	Donna Bilkovic
91	SAV	SAV is a NMFS habitat area of particular concern (HAPC) [and important to include]	David O'Brien
92	SAV	[To establish past locations of SAV] could use SAV photos from ~ 1930's. Suggested Renee Karrh at MDDNR as a point of contact for photos.	Tom Fisher?
93	SAV	For MD Coastal Resiliency Assessment, used 'areas with consistent coverage for at least 7 years	Unknown
94	SAV	Noted changes in species type and location presence is occurring. Tom	Peter Tango

		P indicated that this info is not available for all beds and that species abundances will change seasonally. Peter indicated that he is working with Brooke Landry to combine aerial survey with satellite data and this might provide info on succession	and Tom Parham
95	SAV	Referenced a STAC workshop on satellite based image assessment in future, which may lead to seasonal imagery of SAV presence. Technically, it looks feasible.	Peter Tango
96	SAV	VIMS study looked at persistence of SAV relative to fish habitat and might help decide period to choose	Tom Parham
97	Tidal Wetlands	Tidal wetlands provide landscape context, Consider using distance between habitat types (e.g. SAV, oyster reefs, tidal wetlands)	Allison Colden
98	Tidal Wetlands	Regarding the question about proximity, 200m is a good start. May be dependent upon species. 200m is reasonable for fish to safely swim during tidal change.	Donna Bilkovic
99	Tidal Wetlands	If available include differences in types of wetland. A *Spartan* marsh will have very different implications from a *Phragmites* marsh.	Ryan Woodland
100	Tidal Wetlands	Be consistent (in dataset used and processing) As long as consistent, not aware of reasons the choices would matter.	Jim Uphoff
101	Tidal Wetlands	Noted there are studies of distance to wetland and birds. References include DeLuca et al. 2004, DeLuca et al. 2008 and Prosser et al. 2016.	Peter Tango
102	Tidal Wetlands	Similar species may have similar ranges, which could be used to provide guidance on proximity estimates	Chris Jeffrey
103	Tidal Wetlands	Ches Bay Program is initiating a Wetlands working group.	Peter Tango
104	Tidal Wetlands	Instead of 200m distance, produce a variable of hex distance to	Ben Gressler

		wetland, allowing end user to tailor to their need	
105	Tidal Wetlands	For proximity, consult box models by Kemp and Boynton. Or look for effect within water quality variables	Jim Uphoff
106	Benthic Habitat	Would allow exploring the correlation between benthic habitat type and fine-scale benthic rugosity to ensure capturing complex benthic habitats in this classification scheme	Jonathan Watson
107	Benthic Habitat	Offered to share datasets used by TNC.	Michelle Canick
108	Benthic Habitat	Noted that over the years, he has heard that there’s a big difference in fisheries data whether it’s collected over a sandy bottom or not. Perhaps this is distinction that makes for a simpler dataset: sandy bottom or not. Jim U. noted that the sandy bottom versus not distinction may be about gear type and its ease of use over sandy bottom.	Peter Tango Jim Uphoff
109	Benthic Habitat	Diversity within hexagons may be important in narrower river reaches where there is high variability on small scales. Example is sturgeon and hard bottom habitat within a hex.	John Young
110	Land Use - Land Cover	Chesapeake Conservancy Land Use data is most precise for area of interest (1x1m resolution). Datasets such as USDA CropSCAPE are 30x30m resolution and not appropriate for such a localized study using 0.5 acre hexagons. Is there a particular reason for parsing out the type of agriculture crop or practice? If necessary, Soil Conservation District, Department of Agriculture, and/or Department of the Environment could be data resources.	Marek Topolski

111	Land Use - Land Cover	Include wastewater treatment plants.	Tom Fisher
112	Land Use - Land Cover	Include both positive & negative effect features of land on fish habitat.	Unknown
113	Land Use - Land Cover	Yes, have to include land based features, as they have big impact on fish habitat. Have done a lot of work to show that impervious surface is especially important in mesohaline and freshwater spawning areas. However, agriculture is negatively correlated to impervious surface so might be a confounding variable. Ag is far more compatible with fish and their habitat. Maintenance of forest and wetlands is a management consideration (no net loss policies).	Jim Uphoff
114	Land Use - Land Cover	Include wetland types and forest	Jim Uphoff
115	Land Use - Land Cover	Erosion and lack of shallow water habitat are big problems; hence including data that provides insight is useful.	Unknown
116	Land Use - Land Cover	Ches Conserv sometimes misclassifies ag as fractional turf. Can correct areas classified as fractional turf in CC by comparing to CropScape	Michelle Canick
117	Land Use - Land Cover	Accuracy depends on county. Dorchester has some ag areas classified as tidal wetlands	Michelle Canick
118	Watersheds	If using watershed area, be sure to remove open water area and recalculate the geometry prior to analysis. This is important when normalizing LULC by unit area.	Marek Toploski
119	Watersheds	Divide into subwatersheds to capture separate shorelines and land cover	Donna Bilkovic

120	Watersheds & Land Use - Land Cover	Noted Peter Claggett of CBP are doing work to get to finer differentiation of types of land cover.	Peter Tango
121	Watersheds & Land Use - Land Cover	See literature on impervious surface & ag impact on fish ecology (so important). Consider the cumulative effect of cascading subwatersheds. Yes, could use NHD catchments, or EcoShed framework, as sources.	John Young
122	Watersheds & Land Use - Land Cover	Different scales give different perspectives. They may help focus on hot spots for habitat or problems. Margaret has worked on this.	Jim Uphoff
123	Watersheds & Land Use - Land Cover	Very important up include. They are good proxies for nutrient loading and contamination	Ryan Woodland
124	Land Use/Land Cover	Agricultural land use in the watershed can be a good predictor of coarse vegetation indices in estuaries and juvenile demersal fish assemblages as well.	Ryan Woodland
125	Land Use/Land Cover	More resolved use classes have been developed by Peter Claggett at USGS	Peter Tango
126	Shoreline	Living shoreline should not be considered armored. For shoreline marshes with low stone sills, positive effect on fish assemblages (manuscript in draft)	Donna Bilkovic
127	Shoreline	Evidence that shoreline marsh provides different habitat value for different groups of species relative to hardened shoreline	Matt Ogburn
128	Shoreline	Consider prioritizing natural shoreline in areas where important fisheries are scarce	Sally Claggett
129	Shoreline	Did not lump living shorelines with natural shorelines, since many have	Jonathan

		rock that may be similar to a revetment	Watson
130	Shoreline	Ken Able at Rutgers Univ, funded by Hudson River Foundation, found that more vertical manmade shoreline is worse for fish.	Mary Fabrizio
131	Shoreline	Multiple studies have shown hardening shoreline effects on the quality of fish habitat, fish food, SAV recovery trajectories, turbidity and more	Peter Tango

Feedback About the Example Analyses

This table captures feedback about potential ways that a statistical framework like the one we presented could be used to explore fish habitat questions.

Item #	Recommendation	Suggested By:
1	Framework approach offers opportunity to explore questions and opportunity to test models against data - a powerful way to understand the importance of variables	Peter Tango (Mary Fabrizio agreed)
2	As much of the work that can be built upon existing, ongoing program [CBP?] outputs the better. That is balancing the need to start a new workload workflow for folks versus harnessing the power of outputs available.	Peter Tango
3	This is a good example of an intermediate step that this framework could be used for - namely, to use it to predict where we might expect to observe something, then confront those modeled conditions with empirical data. When the model falls apart, that tells us we may have fundamentally missed some key aspect of the ecology or biology of a target species	Ryan Woodland
4	To build on Ryan's point - the models should be calibrated or tested for accuracy with observed data.	Kelly Maloney

5	One other approach if you want to follow this path, is to generate a hypothesis about which environmental factors affect fish distribution/abundance. Then, based on the science, use the framework to demonstrate that it may be useful to project into other environments.	Mary Fabrizio
6	If the table was an actual CART analysis output that picked parameters in a statistical manner instead, applying the output of such an analysis like that might add some scientific basis for the illustration versus the approach shown here.	Peter Tango
7	HSI and statistical model projections may be useful but only if calibrated	Mary Fabrizio
8	Marsh edge is really important for fish and invertebrates.	Donna Bilkovic
9	Both types of statistical models would be of interest to fishery and habitat managers	Donna Bilkovic
10	Really like the logic/approach. Noted that the geometry of the area is missing, e.g. CURRENT which drives turbidity max. So, caution because if there's a critical element missing from the analysis, the result could be misguided.	Mary Fabrizio
11	Recommend doing pilots in multiple tributaries using same approach, then validate results before determining the utility/usefulness of approach.	Mary Fabrizio
12	Logic/approach doesn't work here for striped bass	Jim Uphoff
13	For anadromous fish life stage distribution maps by salinity for MD tributaries, see William Dovel, 1960s	Jim Uphoff
14	I think that what you have shown is consistent with what the FHAT is looking for to build a Bay wide tool for management targeting. The recommendation moving forward is to ground truth to be sure the habitat criteria are consistent with what is limiting.	Margaret McGinty