CHESAPEAKE BAY PROGRAM

LIVING RESOURCES
DATA ANALYSIS WORKSHOP

Proceedings of a workshop held in Waldorf, MD
March 28 and June 29, 2000

Sponsored by:
Scientific and Technical Advisory Committee (STAC)
and Co-organized with:
Living Resources Subcommittee

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The Chesapeake Bay management community has a great need for summarized information on living resources and habitat conditions within the Bay ecosystem, that is presented in ways that can be readily used to guide and support management decisions. This information must integrate different types of physical, chemical, and biological data, as well as synthesize knowledge from a variety of sources such as numerous independent monitoring programs and research studies. Our ultimate vision is to develop a suite of desktop management tools that meet these needs by combining spatial mapping technologies like GIS with data analysis methods like habitat suitability models. Such tools – often called spatial decision support systems (SDSS) – would provide summarized information in a spatially explicit, visual format which is easy to understand and apply in targeting and prioritization decisions.

This report summarizes the results of a workshop that was conceived as the first step toward that vision. Co-organized by STAC and the Living Resources Subcommittee (LRSc), the workshop was designed to:

1. Explore the potential uses of several methods for integrating and analyzing multi-disciplinary data on environmental conditions and living resources within Chesapeake Bay, including habitat suitability models;
2. Test the utility of existing CBP data sets in applying these methods to three pilot living resource groups – waterfowl, menhaden, and oysters; and
3. Recommend a general process that the LRSc could implement on a routine basis to encourage this type of data analysis and management tool development.

Overview of Habitat Suitability Models

Briefly, habitat suitability models (HSMs) are a method for integrating different types of physical, chemical, and biological data to assess habitat for a specific living resource group. These models combine data on water quality, food, or other habitat variables with data on species distributions and knowledge of habitat requirements. In developing an HSM, key habitat variables that influence the distribution and abundance of the target species or group of species are identified. For each habitat variable, a gradient of suitable to unsuitable values is identified based on field or laboratory research, information published in the scientific literature, or expert opinion. Monitoring data for each variable are then evaluated against the suitability gradient and mapped in a GIS "layer". The layers are used in the model to show where suitable conditions for individual environmental variables, or all variables combined, occur. The final product of an HSM is a spatially explicit, quantitative assessment in the form of a GIS map in which areas are numerically rated for suitability. Known distributions of the target species or group of species can be compared to the habitat suitability map, and past, present, and proposed changes in suitable habitat can be quantified.

Workshop Format

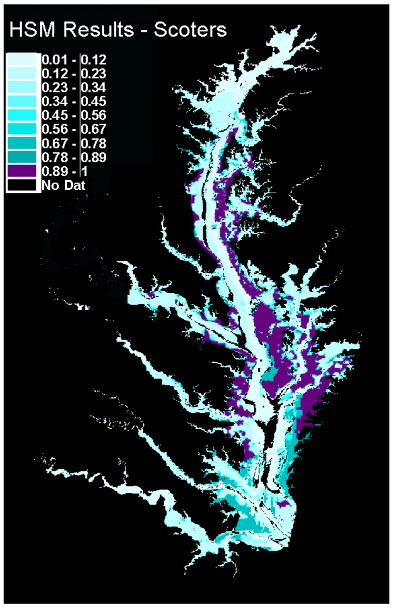
The first meeting of the workshop was held on March 28, 2000. During the meeting participants in each of the three sessions evaluated the extent to which existing data could be used to develop a habitat suitability model for each of the pilot living resource groups. Participants also suggested specific tasks such as compiling additional data, refining how existing data would be used (e.g., certain water quality variables should be averaged over seasons rather than years), and exploring potential relationships between species distributions and particular habitat variables. Many of these tasks were performed by CBP data analysts and session leaders prior to the second meeting of the workshop, which was held on June 29, 2000. During this second meeting participants reviewed the results of analyses performed since the March meeting, built upon this progress with additional discussions, and made recommendations for a general data analysis process.

Workshop Results

Sessions on the three pilot living resource groups came to vastly different conclusions regarding the adequacy of existing data for developing habitat suitability models. This disparity stems from the fact that the amount and quality of relevant data available, as well as the level of scientific understanding about ecological mechanisms affecting habitat suitability, varied among the three pilot groups. Thus, while each session ended up at a different point relative to the goal of developing a GIS-based habitat suitability model that could be used as a management tool, each was uniquely instructive as different lessons were learned from the three pilot groups.

Waterfowl Session

The waterfowl session focused on eight species of diving ducks. Of the three sessions, this one made the greatest progress in terms of integrating several different types of existing data to evaluate habitat and food conditions throughout the Bay.



Habitat suitability modeling software developed by NOAA was used to combine survey data of diving duck distributions, their benthic invertebrate prey, and physical habitat variables. The graphic to the right is an example of the kind of synthesized information produced. Colors represent different values of a suitability index for one species (Scoters). This type of map could be used by managers in several ways, such as determining which areas are currently most important to certain waterfowl species and identifying key areas for protection.

Another important achievement of this session was that it opened a dialog between waterfowl and benthic scientists. Several valuable ideas about potential linkages between these two living resource groups arose through the informal interaction and discussion of the data sets.

Menhaden Session

The menhaden session focused on habitat and food variables (e.g., phytoplankton and zooplankton) important to menhaden at different life stages. The goal of this session was to use existing data to determine if habitat and food conditions within Chesapeake Bay meet thresholds for normal menhaden growth.

CLAIRE, PLEASE FILL IN WITH ONE TO TWO PARAGRAPHS ABOUT RESULTS.

Oyster Session

The oyster session focused on physical and water chemistry variables that affect oyster recruitment, growth, and survival. The objective of this session was to use available monitoring data on water quality and benthic conditions to develop a habitat suitability model that would help target suitable locations for oyster reef restoration in Chesapeake Bay. Participants concluded that certain key data were inadequate for this purpose primarily because the spatial and temporal scales at which monitoring is currently conducted are far too coarse to be relevant to the site-specific conditions that affect individual restoration sites. Additionally, monitoring data do not include measures of important variables that are key determinants of reef success, such as factors influencing local hydraulic processes and larval recruitment.

Session participants felt strongly that bay-wide monitoring programs could not be expected to generate the appropriate data to guide oyster reef restoration. Rather, the necessary data for improving reef restoration techniques and identifying the key habitat variables that affect oyster reef success must be gathered at the scale of individual restoration projects. However, many different agencies and organizations are currently involved in reef restoration projects in Chesapeake Bay. Most projects do not incorporate monitoring into their project design, and there is no central repository for the data collected by projects that do perform some type of monitoring. Therefore, the group concluded that the greatest need at this time is to provide some monitoring guidance that would be sufficiently flexible to accommodate different project-specific goals, while at the same time promoting the consistency needed to combine information from multiple projects into a single database.

A guidance document that satisfies these criteria was produced at the second workshop meeting, and appears in the body of this report below. Additional work must be done to encourage and support agencies and organizations conducting reef restoration projects to 1) include monitoring in their project planning and budgeting, 2) implement the general data collection standards outlined in the guidance document, and 3) establish a central database into which all the data can be deposited. If these actions are taken, the result will be a database capable of answering many of the crucial questions about oyster reef restoration methods, key habitat variables, and factors that determine project success.

Conclusions and Recommendations:

From the results of this workshop there emerged two classes of general conclusions and accompanying recommendations. The first pertains to the *utility of existing data* which was tested for each of the three pilot groups. The second relates to the *process of data analysis* that could be implemented by the Living Resources Subcommittee in order to pursue the integration and synthesis of data on living resources and habitats on a routine basis.

Utility of Existing Data

4. The Chesapeake Bay Program's water quality and living resource datasets were generated by monitoring programs established to measure long-term changes, not to evaluate habitat suitability or trophic relationships. The data have traditionally been used for retrospective analysis of status and trends, rather than for predictive analyses that could help target and prioritize future management efforts. Integrating the physical, chemical, and biological data that have been collected by Chesapeake Bay monitoring programs into spatial explicit, quantitative assessments of habitat suitability (including food conditions) represents a new use for the data that goes beyond the original purposes for which the monitoring programs were designed. This new application is limited by spatial and temporal gaps and the scales at which monitoring data are typically collected. **The results of this workshop have shown that in some cases (e.g., waterfowl, menhaden) these limitations of the data can be overcome with integrative data analysis methods and supplementation with data from non-CBP datasets, while in others (e.g., oysters) the data limitations are too substantial to allow robust interpretations of habitat conditions.**

5. Data integration is easy to say, but more difficult to do. While specific methods for integrating data exist, their use has not been encouraged within the Chesapeake Bay Program. The habitat suitability modeling approach tested in this workshop is one example which has been successfully used by other agency offices (e.g., NOAA, Center for Coastal Monitoring and Assessment) to develop management tools for living resources and habitats in other estuaries. **To improve the utility of existing data, the Chesapeake Bay Program and its partners should become familiar with the available methods for data integration, and cultivate a willingness to apply them. This will require a commitment of time and effort in order to seek out the right methods suited to answering our questions with available data, get the training necessary to use them, and provide the manpower and time to conduct the analyses.**

6. The utility of CBP data can be greatly enhanced when combined with data from other sources. Although historically the Chesapeake Bay Program has focused almost exclusively on the data contained within its own monitoring datasets, there is a lot more data out there that can, and should be, utilized (e.g., satellite data, historical data, databases from state, Federal, and academic sources). Many times during the analyses for this workshop we had to locate additional data to fill specific gaps in the CBP datasets. This required a tremendous amount of time because databases were often not easily accessible or were not compiled/formatted for use.

   Surprisingly, even certain EPA databases were time consuming to obtain and compile (e.g., EMAP) and one EPA database was discovered to contain significant data errors that made it useless (i.e., incorrect lat/long coordinates for point sources). The bottom line is that if data are not available, they will not be used. **The Chesapeake Bay Program should make a concerted, ongoing effort to acquire and use datasets from these additional data sources. Although the Chesapeake Information Management System (CIMS) has promised to make these additional data sets more accessible, clearly a much greater effort must be made before that promise is delivered.**

Process of Data Analysis

1. Data analysis is a process not an event. Monitoring data are currently very underutilized within the Chesapeake Bay Program, and changing this situation will require a strong commitment to a long-term process of data analysis. There are three crucial elements that must be included in this commitment. **First, annual funding must be available for collaborative small-group meetings and workshops, including funds for both event hosting and participant compensation. Second, time must be reserved in the work plans of individuals to complete data analysis tasks, including CBP staff as well as staff from state and federal partner agencies. Third, the need for specific management tools that will be used once they are developed must be identified by managers within the CBP community.**
2. Multidisciplinary dialog within small groups charged with tackling a specific suite of questions will be the most effective format for data integration and problem-solving. **These data analysis teams should be spearheaded by principal investigators who are motivated and funded to complete the necessary tasks. It will often be beneficial to utilize "neutral" facilitators not aligned with any single agency or organization to coordinate and lead these teams. Teams should include individuals with different types of expertise and job functions in order to develop realistic assumptions and expectations.** Scientists with monitoring experience and data analysts (including GIS specialists) are particularly invaluable in the data analysis process. Input from the scientific community is also critical, and should be incorporated into the process through small, regional meetings that minimize the burden of time and travel for non-funded (e.g.,

academic) participants. When necessary, individual researchers with key knowledge or datasets should be compensated in exchange for active participation and data sharing. Finally, these small groups must be held accountable for progress on their assignment. Part of the group's job should be to document efforts, including stumbling blocks and blind alleys encountered, and produce products within an appropriate time frame.

3. An annual conference dedicated to fostering cross-disciplinary dialog on ecosystem topics, increasing awareness of new research and data analysis results, and stimulating interaction should be established. **The conference should be informal, and focused on a particular topic that the LRSc has identified as an area of management concern. Such annual data analysis conferences should be used as a starting point for the formation of data analysis teams, which would pursue the most promising avenues of data analysis to produce synthesized information with direct utility to managers on the particular topic.**

Waterfowl Session

Summary

This session focused on the relationships between diving ducks and their benthic invertebrate prey. Nine species of diving ducks – including greater and lesser scaup, buffleheads, ruddy ducks, common goldeneye, oldsquaw, and white-winged, black, and surf scoters – inhabit the Chesapeake Bay from December through March. Precise numbers of birds are unknown, but the combined population of these diving ducks is well over 500,000 individuals in winter. Additionally, several hundred thousand ducks probably use the Bay during migration. Each species of duck has a different shaped bill, different diving abilities, and different feeding habits. The foods of diving ducks ranges from small worms in muddy shallow oligohaline waters to large clams in sandy polyhaline deep waters.

The purpose of this session was two-fold: First, to bring together habitat data and try to model the distribution of diving ducks according to certain physical habitat variables, and secondly, to search for concordance between the distribution of birds and that of their benthic invertebrate prey. The specific goals were to:

- Use NOAA's habitat suitability modeling (HSM) software to model diving duck habitat areas based on depths, salinity, and bottom type, and to develop maps of the predicted distributions;
- Explore the distribution and abundance of diving ducks in relation to the distribution and abundance of their benthic invertebrate prey;
- Determine if benthic invertebrate distributions can be predicted based on modeling and patterns of predator (diving duck) distributions, and conversely, if diving duck distributions can be predicted based on modeling and patterns of prey (benthic invertebrate) distributions;
- Identify appropriate habitat indicators for diving ducks in terms of certain physical habitat parameters and benthic invertebrate indicators (specifically benthic IBI's).

Accomplishments:

This session resulted in tremendous progress toward integrating physical, chemical, and biological databases to better predict patterns of waterfowl habitat use, and understand potential trophic linkages between diving ducks and benthic invertebrate assemblages in Chesapeake Bay. Ultimately, this effort will lead to even more refined maps of habitat suitability that managers can use to identify areas that are currently most important for waterfowl, and identification of the key criteria that determine habitat quality for different waterfowl species.

There were three major accomplishments of this workshop session:

1. The habitat suitability modeling software developed by NOAA was tested and proved to be an excellent tool for modeling the Bay's resources for waterfowl. The model and GIS data layers developed during this workshop could be used in future efforts to integrate data sets to better understand linkages between birds, benthic invertebrates, and other living resource groups within the Bay ecosystem.
2. The Chesapeake Bay Program is now in possession of several GIS data layers that had been listed as "data needs" since 1995. In particular, benthic data from EMAP were acquired and combined with the CBP benthic monitoring database to provide a GIS layer with improved coverage of benthic invertebrate distribution and abundance for the Bay. Also significant is the fact that two data sets were found to have errors which made them unusable. This raises the question: *If these errors remained undetected until now, does that mean that incorrect data sets are being used or that no one has been using the data sets?*
3. Another important accomplishment of this session was the opening of dialog between waterfowl and benthic scientists. Several valuable ideas about potential linkages between these two living resource groups arose through the informal interaction and discussion of the data sets. The interaction that occurred as different GIS layers were examined together was extremely valuable, and was a refreshing change from workshops where everyone presents papers and little new thinking is accomplished.

Recommendations:

To continue and expand these kinds of analyses, the following recommendations should be implemented:

- Conduct systematic bird surveys of Chesapeake Bay on a regular basis.
- Locate and compile other benthic data sets, and make them available to CBP partners. Alternatively, fill in the spatial gaps through more directed benthic data sampling in areas where random samples have not provided coverage. Attention should also be paid to waters of less than 1 m depth.
- Develop GIS layers for 1) oyster beds/hard bottoms, and 2) anoxic areas.
- Correct errors in lat/long coordinates of NPDES discharges within the EPA Region III database.
- Obtain better substrate data for the tributaries. Compile any existing data sets that state partners already have, and conduct substrate surveys in those areas for which no data exist.
- Investigate spring blooms as food source for migrant ducks.

Participants:

Larry Eaton, Doug Forsell, Dave Jasinski, Jackie Johnson, Dennis Jorde, Patrick Nowlan, Monaca Noble, Bud Rodi, Vern Stotts

Review of Available Data:

Waterfowl data – Systematic aerial surveys of entire Bay (transects flown across open waters) with GPS positions from 1992 to 1994. Data were used to identify habitat affinities/preferences for the HSM.

Waterfowl concentration database – All concentration data and systematic survey data that have been computerized for the Chesapeake Bay from 1989-2000 (includes about 14,000 location data points for diving ducks). Data were used to generate a GIS map of bird distributions for overlay with benthic invertebrate distributions, and to verify the HSM.

Benthic data – Fixed and random sites from CBP benthic monitoring program studies (1990 to present). Fixed sites in MD started at 50 sites in 1985, but there are now only 25 fixed sites and random sites from 1990. In VA we have data from fixed sites from 1990, but random sites have been sampled only in the last 3 years. EMAP data were obtained after the March meeting to fill in areas not sampled by CBP monitoring. Data were used to produce a GIS map of 32 species or species groups of invertebrates for overlay with bird distributions.

Waterfowl food habits information – Matrix of bird species by benthic prey items, developed from a survey of literature. Used to determine what types of benthic invertebrates diving ducks might be eating in Chesapeake Bay.

Substrate data – Percent sand recorded from systematic sampling on 1 km grid of the mainstem of the Bay and extrapolated from the nearest benthic sites for the tidal tributaries. Data were used to assign substrate values to the waterfowl location data, and to create a 250 m^2 gridded substrate layer for the HSM.

Salinity data – Surface salinity for 1992-94 was used in the March meeting, but the group decided to use average 1990's summer bottom salinity for the final model because summer bottom salinity coincides best with when and where benthic sampling occurs. Data were used to assign values to the waterfowl location data, and to create a 250 m^2 gridded salinity layer for the HSM.

Depth data – Some tidal variance exists between CBP and NOAA data sets, so the best data layer available was generated by averaging CBP and NOAA values. Data were used to assign depth values to the waterfowl location data, and create a 250 m^2 gridded depth layer for the HSM.

New Layers Recommended for Analysis:

During the March meeting, session participants recommended that several other layers be incorporated into the exploration of the concordance between the distribution and abundance of diving ducks and the distribution and abundance of benthic invertebrates. If concordance is found, these additional layers should be incorporated into the HSM.

- Sewage outfalls as a surrogate for areas with high nutrient input.
- Power plants and other NPDES permit locations with thermal outflows because they may have high productivity of invertebrates in winter or cause inverts to reproduce earlier in the spring.
- Should have an anoxic layer to use in HSM and foods habits as an exclusion area with the assumption that viable food sources would not develop for waterfowl. Solution: We will plot an anoxic layer for evaluation at next session.
- A layer portraying oyster reefs would be helpful for some species of ducks such as oldsquaw. If an oyster reef habitat layer is not available a hard substrate layer should be developed to see if there is any concordance with waterfowl.

Discussion of Diving Duck Food Habits:

The following points were made during discussions of specific diving duck species and their habitat and food preferences. This discussion generated a matrix of birds and potential invertebrates they may be eating in Chesapeake Bay, for incorporation into the HSM.

Scoters (WWSC, BLSC, SUSC)

Food: *Mulinia lateralis, Mercenaria sp., Nereis sp.*

Habitat: moderate depths, moderate to high salinity, attracted to sandy areas

Common Goldeneye

Food: *Polychaetes, Oligochaetes, crustaceans (mud crabs), marsh insects (Chironomidae), Macoma sp.*

Habitat: edge species, may use oyster beds more than other species

Scaup

Food: *Rangia, Macoma mitchelli, Macoma baltica, Corbicula fluminea*

Habitat: low salinity species, more in MD than VA, info needed from Aberdeen Proving Grounds, large numbers in spring occurred in lower salinity waters than in winter.

Ruddy Ducks

Food: *Macoma mitchelli and M. baltica, oligochaetes, tubificoides sp., SAV, polychaetes, Heteromastus sp., Polydora sp., Streblospo benedicti)*

Habitat: possiblity of some clustering around power plants (more info needed), temp could be a factor; intermediate salinity; shallow waters; small sample sizes may cause problems.

Bufflehead

Food: *Macoma sp., mollusks, Mulinia sp., polychaetes, BENTHIC (generalist species)*

Habitat: close to shore at depths of 3 m or less, site loyal

Oldsquaw

Food: *no food habit diet data from the Bay, fish, polychaetes, amphipoda, opportunist feeders, mollusks*

Habitat: Offshore deep waters with high salinity and sandy or hard substrates (oyster beds?).

Data Analysis Problems and Suggested Solutions:

The following problems were encountered during development of data layers, during data analysis, or because of inherent limitations of the data available. Changes in the analysis or layers are suggested to understand the limitations of the HSM analysis:

Inadequate substrate layer – The substrate layer for the Bay was marginally adequate for this analysis. The mainstem has been systematically sampled on a 1 km^2 grid, but no systematic data set could be located for the tributaries. Additionally, substrate data are not classified consistently. Patrick Nowlan was able to develop a layer for the Bay based on percent sand, a feature common to most data sets. By combining substrate data from several benthic sampling sets a coverage was developed. Unfortunately the limited data in the tributaries must be extrapolated to larger areas than good data analysis would dictate. Systematic surveys should be conducted in the tributaries, so we do not have to depend on extrapolations from benthic samples.

Timing of bird and benthic sampling – Bird surveys are conducted in the winter while benthic samples are mostly taken in the summer. Solution: Can't do much about it because there are overriding considerations that dictate when bird and benthic sampling occurs, but this may not be a major problem because most invertebrates are sessile and don't move (although see item below about seasonal variation in invertebrates).

Biases in benthic data collection – Benthic data may have some biases related to sampling methods and gear limitations. For example, benthic sampling equipment is not standardized between MD and VA, the gear has difficulty sampling from hard substrates, and deep water sampling is limited. Under-represented sampling areas for benthic invertebrates are: oyster grounds, hard bottom, and the deep trench in MD. Also, all benthic samples are taken below the 1 m contour so there is no sampling in the intertidal which may be an important foraging area for some ducks. Solution: Can't do much about these biases, should be kept in mind during data analysis and interpretation.

Soft-bodied prey species – Polychaetes are the most prevalent benthic species in the Bay, however they are not well represented in the duck food habits studies. This could be because they are digested quickly, making them and other soft-bodied organisms absent in gut samples. Solution: Keep in mind in future analysis, polychaetes may be important, so look at their distribution even if they are not a large percentage of foods recorded.

Seasonal variation in invertebrates – Large abundances or "spring blooms" of invertebrates such as small worms (*Polydora*) or crustaceans (mysids) could be important to waterfowl during spring migration, but may not be present in great abundances in the summer when benthic sampling occurs. This kind of locally and seasonally abundant food source could be analogous to the horseshoe crab eggs and the thousands of shorebirds which feed on them in Delaware Bay. Perhaps some Chesapeake Bay areas are as important to the life cycle of scaup or ruddy ducks as the Delaware Bay is to the semi-palmated sandpipers and knots. Sampling invertebrates and waterfowl in the same areas in spring could determine if such areas and "spring blooms" are important to various species of waterfowl. Solution: Recommendation for research study.

Lumping benthic data – Should have used all benthic data rather than only 1992-94, because random sampling (as opposed to fixed point sampling) has been done only for the past 3 years in VA. Solution: We will use all CBP stations, plus EMAP stations in next analysis. Have to assume benthic communities are relatively consistent over last ten years.

Estimation of % sand – For the HSM we should lump percent sand into 5 percent categories, as data is not that precise. Solution: We will lump the sand.

Anoxic layer – Should have an anoxic layer to use as an exclusion area with the assumption that viable benthic food sources for waterfowl would not be present in anoxic areas. Solution: We will plot an anoxic layer for evaluation, however this layer is not currently available.

Nutrient and temperature variables – Should plot sewage outfalls (nutrients) and power plants (temperature) as possible areas with high benthic species abundance and thus more waterfowl. Solution: We attempted to plot these layers, but the latitudes and longitudes are not correct in the EPA Region III data sets. Will have to get corrected coordinates from EPA, then plot outfalls and power plants for evaluation.

No oyster bed maps – An oyster bed layer is not available in the CBP GIS database. Steve Jordan stated in the June meeting that MDNR has a layer for MD. Solution: We will try to acquire the MD oyster bed layer and otherwise plot hard substrate as well as possible to see if any concordance with waterfowl.

Population trends – Population trends should be incorporated in analysis, because oldsquaw and scoters are declining and their wintering grounds are an area of concern. Solution: We will look at population trends.

Results from June 29 meeting

This session did not reconvene for a second meeting because of many participants were not available, and the additional layers asked for in the March meeting were not yet available. Several of the invitees agreed to meet in smaller regional group meetings (one at VIMS and one in Maryland) when all of the layers are developed and schedules permit.

Menhaden Session

Summary

The goal of the menhaden session was to use existing data to determine if habitat and food conditions within Chesapeake Bay meet thresholds for normal menhaden growth. If the monitoring data indicate that present conditions are meeting the menhaden requirements, then menhaden management actions should focus on factors other than Chesapeake Bay habitat or food conditions.

Accomplishments:

Recommendations:

Results from March 28 Meeting

Participants:

INSERT LIST OF PEOPLE PRESENT

Session Overview:

Marcia Olson (NOAA, Chesapeake Bay Program) and Claire Buchanan (ICPRB) summarized the available CBP monitoring data available at the Chesapeake Bay Program Data Center that could potentially be used to evaluate menhaden habitat and food conditions. John Christiansen (NOAA, Silver Spring) gave a demonstration of the Habitat Suitability Modeling (HSM) approach being developed by NOAA, National Ocean Services, to integrate and interpret monitoring data habitat and food for important living resources. Robert Wood (VIMS) presented the results of his analyses of East Coast weather patterns and their impacts on fish recruitment in Chesapeake Bay. Session members discussed the spatial and temporal limitations of the monitoring data and how these might restrict use of the HSM approach. They identified some exploratory analyses that could be done for the second workshop.

Review of Available Information:

Menhaden first enter the Bay as late stage larvae in the Spring and metamorphose. Juveniles use the Bay as a nursery until Fall when they return to the ocean and join older menhaden in their seasonal migrations along the Atlantic coast. The older age classes inhabit the more brackish waters of the Bay in summer and fall. Menhaden larvae feed on zooplankton as larvae. They shift to smaller prey - phytoplankton and microzooplankton - after they metamorphose and gradually include larger plankton prey again as they age.

Available Habitat and Food Data

Measures of food availability at mid-channel monitoring stations (1984 - 1999)

- Phytoplankton biomass and abundance data categorized by taxonomic grouping (e.g. Cyanobacteria, Diatom) and size categories; vertical and horizontal profiles of chlorophyll; primary productivity
- Zooplankton biomass and abundance data categorized by taxonomic grouping (e.g. Rotifers, Copepods) and size categories
- Particulate organic carbon

Water quality parameters (1984 - 1999)

- Mid-channel water quality parameters important to menhaden (e.g. temperature, dissolved oxygen, salinity)
- Nearshore citizen's monitoring data (pH, temp, DO, salinity)
- Historical water quality data

Weather impacts

- Effect of freshwater inflow on various parameters, and “flow correction” approaches used by CBP Data Analysis workgroup

Special Statistical Tools

- Habitat Suitability Modeling approach (NOAA)
- 3D Interpolator for Chesapeake Bay (CBPO)

Discussion:

Below are the questions posed to session participants, and their responses.

1. Has the loss or degradation of critical menhaden habitats in the Chesapeake system exceeded thresholds for growth and survival of pre-juvenile, juvenile, and adult life-stages of menhaden? Do existing abundances and distributions of phytoplankton and zooplankton provide the sufficient and appropriate food quality and quantity for pre-juvenile, juvenile, and adult life-stages of menhaden?
    - Yes, recent changes in habitat and food could be important to menhaden. However, can the CBP monitoring data demonstrate this, i.e. is spatial and temporal coverage sufficient? The data have not been explored enough to determine if they will be useful.

2. Is there evidence that links menhaden abundance patterns either directly or indirectly to the habitat of food patterns in Chesapeake Bay? If so, are they linked only when habitat and food thresholds are exceeded?
    - This question might best be answered with research studies rather than analysis of monitoring data.
    - Exploratory analyses of the habitat and food conditions, and their degree of overlap with the distribution of Chesapeake Bay menhaden, might provide useful information. For example, the region of maximum slope in a cumulative frequency distribution graph of menhaden probability-of-encounter vs. [concentration of an environmental parameter] indicates the more frequented values of the parameter, e.g. preferred salinity. (These kinds of graphs can eventually be used in a HSM.)

3. Are there analysis methods that could be routinely applied to Chesapeake Bay monitoring data that would begin to distinguish the relative importance of habitat, food, predation (harvest, natural) and climate on menhaden life stages each year?

   - There was general agreement that approaches should move away from simple regression type analysis, towards principal component analysis, time series analysis, or other approaches.
   - The CBP is considering using the Habitat Suitability Modeling (HSM), currently being developed by NOAA, to integrate and interpret CBP monitoring data to evaluate juvenile menhaden habitat in Chesapeake Bay. Session members felt the HSM approach could be a great research tool, but might not be useful as a predictive management tool for menhaden because of the spatial and temporal characteristics of the monitoring data (e.g. focus on mid-channel rather than nearshore). There also is not enough process data available to satisfy the model or management needs. Before an HSM approach can be used to create a juvenile menhaden “habitat suitability index” for Chesapeake Bay, it should incorporate aspects of the “growth potential index” (Brandt). Some panel members proposed while parameters needed for the HSM model and the “growth potential index” are similar, “growth potential is the best measure of habitat suitability.” It was not clear if the existing/interpolated monitoring data is sufficient for use in the “growth potential index.” There still needs to be ground-truthing of the underlying relationships in the models. The models rely on correlations between menhaden and physical/chemical/biological parameters, and these correlations do not necessarily prove a cause and effect relationship. Session members contended that ground-truthing should be accomplished through research, not data analysis.
   - A Principal Component Analysis approach being developed by VIMS (Robert Wood and Herb Austin) could eventually be used to assess the likelihood of good larval recruitment into Chesapeake Bay from continental spawning areas. Specific configurations of the “Bermuda High” at critical times in the North Atlantic are associated with good menhaden year classes in Chesapeake Bay. Weather and North Atlantic current patterns play a large role in the success of larval migration into Chesapeake Bay from continental shelf spawning grounds. Eggs spawned from as far north as Long Island Sound area recruit to Chesapeake Bay. The influence of continental shelf winds, current patterns, water quality and food parameters on the egg and early larval life stages have been explored in a recent series of publications (SABRE project).

Information Needs:

Need to know what are the critical life stages in terms of the menhaden life cycle. (The SABRE project is indicating that late larval growth and mortality, followed by juvenile mortality and egg viability, are the most sensitive “lower-level” parameters - Quinlan and Crowder, 1999.) Need to identify critical geographic areas for each life stage as well as critical environmental parameters within those areas. Can we develop suitability curves and identify threshold values for these parameters based on the literature, existing models, and best judgements?

FOR LATE-STAGE LARVAE AND JUVENILES: Need monthly food data, monthly average size of each year class, and filtering efficiencies of each menhaden size category/life stage in order to calculate filterable food biomass for each menhaden size category/life stage over time. Need to identify times and locations where temperature and dissolved oxygen reduce growth potential (derived from habitat requirements of menhaden). Need to know extent of chlorophyll biomass measurements, 2D and 3D.

FOR ADULTS: Don't have enough data for the adult menhaden, but much of the work described for juveniles could be applied to adults. What are the food conditions like (large phytoplankton, microzooplankton, mesozooplankton)? What are the physical/chemical conditions like? How does this information coordinate with adult (expected) geography?

Next Steps

The next best steps for the CBP monitoring program are probably exploratory analysis of the monitoring data. These analyses could include:

- Locate the chlorophyll maximum in Chesapeake Bay tributaries and mainstem .
- Characterize recent changes in the phytoplankton food quality.
- Synthesize the juvenile menhaden data and determine its overlap with the chlorophyll maximum.
- Determine menhaden habitat preferences empirically from the monitoring data.

Results from June 29 Meeting

CLAIRE – PLEASE SEND ME TEXT FOR THIS PART

Oyster Session

Summary

Objectives:

The goal for this workshop session was to explore the potential for using existing water quality and phytoplankton data to evaluate physical, chemical, and food parameters that affect oyster recruitment, growth, and survival, and evaluate the influence of these parameters on oyster reef restoration. Habitat suitability models were suggested as one potential approach that could be used to assist in targeting specific sites which are suitable for oyster restoration work. There are currently no tools of this type that resource managers can use to identify where restoration projects should be placed. Most siting decisions are currently made based on historic oyster distributions (i.e., from the Winslow, Yates, and Baylor surveys), local knowledge, and expert opinion on a case-by-case basis.

Accomplishments:

Session participants concluded that the limitations of existing data preclude the development of a habitat suitability model that would serve as a useful management tool for targeting locations for oyster reef restoration in Chesapeake Bay. They further concluded that the needed data should be collected at the scale of individual restoration projects, and the greatest need at this time is to provide some monitoring guidance that would be sufficiently flexible to accommodate different project-specific goals, while at the same time promoting the consistency needed to combine information from multiple projects into a single database. The drafting of a guidance document that satisfies these criteria represents the major accomplishment of this session.

Recommendations:

Additional work must be done to encourage and support agencies and organizations conducting reef restoration projects to:

1. include pre- and post-restoration data collection in their project planning and budgeting;
2. implement the general data collection and reporting standards outlined in the guidance document; and
3. establish a central database into which all the data can be deposited.

If these actions are taken, the result will be a database capable of answering many of the crucial questions about oyster reef restoration methods, key habitat variables, and factors that determine project success.

Results of March 28 Meeting

Participants:

George Abbe, Lowell Bahner, Tim Battista, Caryn Boscoe, Jonathan Champion, Jamie King, Richard Lacouture, Don Merritt, Roger Newell, Pat Nowlan, Ken Paynter

Review of Available Data:

Prior to the workshop, potential parameters that might be incorporated into an Oyster HSI model for Chesapeake Bay were identified as:

- water quality – temperature/salinity/TSS/DO
- food availability – phytoplankton composition/abundance, chlorophyll density
- contaminants – concentration of toxics
- predation
- competition
- disease levels
- settling/post settling data (spatfall densities)

The CBP dataset includes data from 290 water quality monitoring stations. These data points can be interpolated across the entire Bay using the CBP's Interpolator program. Maps showing measured or interpolated values for the following parameters were presented:

- bottom DO
- salinity
- bottom substrate type
- current velocities
- chlorophyll and phytoplankton carbon

Discussion:

<u>Defining habitat suitability relative to management goals</u> – Participants pointed out that suitability is defined by the overall goal for managing the resource. Different habitat requirements will apply depending on whether the management goal is to restore ecological function or to improve opportunities for commercial harvest.

<u>Differences between MD and VA</u> – The physiological tolerance and habitat requirements of oysters differ between MD and Virginia waters due to drastic differences in recruitment of juvenile oysters and impact of disease in the upper Bay vs the lower Bay. This fact causes substantial differences in philosophy and goals for the agencies managing oysters in the two states.

<u>Location of monitoring sites</u> – The majority of the monitoring stations are in the mainstem, while the distribution of stations in the tributaries is much more sparse. Yet the tributaries and nearshore areas are where oyster reefs occur. Therefore, the existing monitoring stations do not cover the areas where data are needed to guide and assess oyster reef restoration.

<u>Spatial scale</u> – The mainstem monitoring program has a fairly coarse sampling network, while the interpolator makes it seem as though it is precise. It would be a mistake to put too much confidence in what the interpolator suggests is fine scale. This is particularly true for the tributaries, where parameter values are interpolated for the entire system from just one or a few sample sites located in the center of the tributary. In order to obtain water quality data that can be used to guide restoration, monitoring stations

must be located in areas that are more meaningful to oysters (i.e., over historical reef sites in near-shore areas, especially in the tributaries).

Temporal scale – The existing temporal coverage doesn't capture short-term, localized events that can significantly affect oyster restoration success. For example, the bottom DO data don't capture all of the elements of DO stress such as frequent, short-term events of low DO.

Disease and Recruitment – The two most important factors that will affect oyster restoration success are 1) prevalence of disease and oyster susceptibility to disease, and 2) level of oyster recruitment. These factors vary throughout the Bay as well as at local scales. The existing CBP dataset does not include data that can be used to incorporate these factors into a habitat suitability model, yet without parameters reflecting these factors any model for oyster habitat suitability would be fruitless.

The key question for recruitment is "what is driving high recruitment episodes?" The types of data and analyses needed to answer this question will involve relating spatfall with factors like salinity, primary productivity, and hydrodynamics. There is the possibility of using the CBP hydrodynamic model for this purpose, but it was not discussed further. Hydrodynamic modeling was viewed as a research need.

The group pointed out that it is possible to use larval monitoring as a management tool. This has been successfully done in other places (e.g., Dabob Bay, France) where substrates are placed in areas with high concentrations of larvae, and once the spat have settled the substrates are moved to other locations for growth. To employ such methods requires extensive understanding of the physical forces (e.g., tides, winds) that transport larvae, as well as extensive monitoring of those conditions so that substrates can be deployed at the proper time and place to catch the spatfall. Although we currently don't have this level of understanding for Chesapeake Bay, it was estimated that a 10-fold savings of shell material could be realized by such strategic placement of shell material as opposed to the current approach of putting shell down and hoping the larvae get there.

Phytoplankton/Chlorophyll as Oyster Food – The group strongly felt that oysters were not food limited. However, they suggested two analyses that might identify links between oysters and phytoplankton quality/quantity, if any correlations do exist. Because reproduction in one year is based on glycogen storage from the previous year, oyster nutrition is important and might warrant some data exploration such as oyster condition (fatness) index vs. phytoplankton composition. Because planktonic oyster larvae require sufficient phytoplankton food before they settle, another suggested analysis was spat settlement (spat/bushel) vs. phytoplankton composition.

Bottom Substrate – There is a desperate need for a better GIS layer of the bottom substrate throughout the Bay. New methods employing side scan sonar to detect buried historic reefs and soft vs. hard bottom should be used to thoroughly map the bottom nearshore areas in the mainstem and tributaries, especially in historic oyster bar areas. Once done, this kind of survey would only need to be repeated every decade or so.

Historic Abundance/Distribution – Historic data sets of oyster distributions and abundances would be very useful for determining good sites for restoration. However, the available maps are incomplete.

Overall Conclusion – *****Much higher spatial and temporal resolution is required of the water quality data in order to use this type of information to identify suitable areas for restoration efforts.**

Example of an HSI Model for Oysters:

An HSI model for oysters that has been developed for a portion of Chesapeake Bay was presented by Tim Battista.

Advantages of the HSI approach:

> Transferability between systems, spatially explicit, can address "what if?" scenarios, can resolve temporal components, allows for use of long-term water quality data sets, allows for use of fisheries independent monitoring data, can incorporate output into other models.

Disadvantages of the HSI approach:

> Independent variables have equal weighting, cumulative effects, doesn't count for life stage and species interactions, there is often insufficient data to validate the model, limited by spatial resolution of environmental data, limited by dated habitat data (i.e., conditions change), doesn't account for lag effects, doesn't account for disease intensity.

In responding to the oyster HSI model presented, the group reiterated that disease will play a huge role in defining and index for oyster habitat suitability. It would be possible to add parameters for disease to Tim Battista's model, but there is no work underway to do that.

*****Overall, the oyster biologists present felt strongly that it is not feasible to adopt an HSI modeling approach with the existing CBP dataset, given the data gaps and weaknesses mentioned earlier**. If attempted, such a model would be virtually useless in assisting resource managers decide where to place restoration reefs. Still, there is clearly an urgent need to understand the connection between water quality data and oyster restoration. It was suggested that the best we could do at the present time is use the existing dataset to identify and eliminate from consideration those areas that are *unsuitable* for restoration (i.e., a Habitat *Unsuitability* Index). To distinguish which areas would be *suitable*, however, would require more sophisticated analyses and data layers with better spatial and temporal resolution.

Information Needs:

With this conclusion, the focus of the discussion necessarily shifted from the utility of HSI modeling to questions about how to obtain the missing data that would allow a useful model of oyster habitat suitability to be developed. It was made clear that additional money and effort added to the existing water quality monitoring program would <u>not</u> provide the needed information on oyster habitat suitability. With the current level of knowledge, it is not possible to intelligently monitor oyster habitat quality in any systematic, baywide sense. Instead, funds should be directed toward collecting data on key parameters in specific locations that will improve our understanding of water quality and habitat conditions in relation to the dynamics of oyster recruitment, disease, and survival.

The following outline was developed by the group as an initial attempt to provide guidance on how and where data should be collected in order to answer the most important questions relating to oyster habitat suitability. The goals of this data collection, in order of priority, would be:

16. To measure the suitability of specific sites proposed for restoration and the success of those restoration projects.
17. To measure the contribution of oysters to local water quality improvements (i.e., within small systems).
18. To improve our knowledge of how and where to restore oyster reefs most effectively.

I. Oyster and Habitat Monitoring

To determine whether an area is suitable for oyster restoration, the following parameters should be measured at a site for a few years (i.e., these are not fixed-station site within a "long-term" monitoring program):

- Larval concentration in water column (weekly June-Aug.)
- Larval settlement (weekly June-Aug.)
- Spat recruitment (fall survey)
- Sedimentation/siltation
- Disease prevalence
- Local water quality (in the immediate vicinity of existing/proposed reef)
- Regionally based annual stock assessment

II. Pre-restoration Assessments

- Evaluate cultch conditions and bottom conditions
- Assess local oyster population (see number I above)

III. Post-restoration Assessments

- Measure survival rate
- Assess local oyster population (see number I above)
- Evaluate ecological functions (i.e., biodiversity, interstitial space, etc)

IV. Research Studies

- Linking larval distribution and physical/hydrographic processes
- Mechanisms for renovating natural cultch

Post-Workshop Thoughts:

Overall, this session exemplified the chasm between reality and wishful thinking in the Chesapeake Bay Program. Oysters were chosen as one of the 3 pilot groups for examining new approaches for analyzing living resource and habitat/food data in order to critically examine the question of whether sufficient and appropriate data relating to oysters are available for analysis. During the session, oyster biologists maintained that the necessary data do not exist within the CBP dataset, and they expressed justified frustration at being asked to answer questions that available data do not address. Additionally, there were strong sentiments against developing yet another list of monitoring recommendations that they believe will not get implemented. In fact, one participant pointed out that many of the data needs identified during the session had been outlined previously in the 1994 CBP Aquatic Reef Habitat Plan Agreement Commitment Report, but those recommendations have not been acted upon in the six years since.

In light of these realities, the workshop organizers adjusted the goals for the June oyster session in order to make the most productive use of participants' time. It is critical that the identified data needs be translated into action so that a useful database of information can begin to be amassed. Numerous agencies and organizations are currently conducting oyster restoration projects in various parts of the Bay (e.g., MD DNR, VMRC, CBF, Army Corps of Engineers, Oyster Recovery Partnership). A **technical guidance document** that describes a minimal set of data that should be collected pre- and post-restoration, and is sufficiently flexible to address project-specific goals and geographic differences, would serve two purposes:

1. Establish the consistency needed to compile a useful database over time.
2. Eliminate the need for a new and expensive "baywide monitoring program" that is unlikely to be funded.

The guidance document would integrate data collection with restoration implementation into an adaptive management framework. With this integration comes new opportunities, such as using state monitoring funds to leverage additional money for more restoration projects.

Finally, the new consensus document 'Chesapeake Bay Program Oyster Restoration: Workshop Proceedings and Agreement Statements' (March 2000) includes several agreement statements that pertain to the data needs discussed above (excerpted below). Before these recommendations also fall by the wayside, they should be incorporated into formal data collection guidelines that all partners of the oyster restoration effort will implement.

Sanctuaries

- Sanctuaries should exist as a network of sites. Larval dispersal should be a consideration when determining sites for sanctuaries.
- Sanctuaries should be placed in areas with high recruitment of should be stocked with hatchery seed in areas with good larval retention but low or infrequent recruitment.

Monitoring

- Monitoring should be spatially explicit, quantitative, and directed toward answering questions relevant for adaptive management, with an objective to improve restoration strategies.
- Monitoring at some sites should include assessments of the ecological functioning of reefs.

Disease Management

- The movement of disease should be minimized as much as possible.
- Managers should adopt a policy to "know what you move"; the infection rate and location of transplanted oysters should be tracked.
- In areas of low salinity and low recruitment only uninfected oysters should be seeded.

Research Priorities

- Develop hydrodynamic models and other necessary means to further understand larval dispersal.
- Define low-level disease. Better understand the threshold between infection and mortality.
- Understand the relationship between oyster population density and biological function.

Results of June 29 Meeting

Based on the re-scoped objectives of this oyster session, participants at the June meeting developed the content for a guidance document intended to help agencies and organizations involved in oyster restoration projects identify their project-specific data collection needs. Over time, the collection of data recommended by the guidance will provide the information necessary to evaluate the success of restoration efforts and improve our knowledge of how and where to restore oyster reefs most effectively. The current draft of this guidance document appears below.

ADVANCING THE SCIENCE
OF OYSTER RESTORATION:

Data Collection and Reporting Standards for Oyster Reef Restoration Projects in Chesapeake Bay

August 2000

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Foreword

This guidance document evolved from a workshop organized by the Living Resources Subcommittee and the Science and Technical Advisory Committee of the Chesapeake Bay Program in March and June, 2000. The purpose of the workshop was explore options for analyzing and integrating existing data on water quality, habitats, and living resources to better guide and gauge restoration efforts. The oyster session of this workshop focused on evaluating the potential to use water quality and benthic data to develop a habitat suitability model which could help target suitable locations for oyster reef restoration in Chesapeake Bay. Participants concluded that the available data were completely inadequate for this purpose, primarily because the spatial and temporal scales at which monitoring is currently conducted are far too coarse to be relevant to the site-specific conditions that affect individual restoration sites. Additionally, monitoring data do not include measures of important variables that are key determinants of reef success, such as factors influencing local hydraulic processes and larval recruitment.

Session participants felt strongly that bay-wide monitoring programs could not be expected to generate the appropriate data to guide oyster reef restoration. Rather, the necessary data for improving reef restoration techniques and identifying the key habitat variables that affect oyster reef success must be gathered at the scale of individual restoration projects. However, many different agencies and organizations are currently involved in reef restoration projects in Chesapeake Bay. Most projects do not incorporate monitoring into their project design, and there is no central repository for the data collected by projects that do perform some type of monitoring. Therefore, the group concluded that the greatest need at this time is to provide some monitoring guidance that would be sufficiently flexible to accommodate different project-specific goals, while at the same time promoting the consistency needed to combine information from multiple projects into a single database. In response to this determination, the present guidance document was drafted by participants at the June meeting of the workshop.

It is our hope that this guidance document will be actively used and improved upon by the agencies and organizations that are involved in oyster reef restoration in Chesapeake Bay. We have reason to believe it will be, given the enthusiasm expressed by managers and researchers alike in response to our original inquiries on this topic, as well as the (unusually) strong consensus that was reached during the workshop session where this document was developed. We thank all the contributors for their time and efforts.

Jamie King

Richard Lacouture

Introduction

The science of oyster restoration is in its infancy. Much remains to be learned about the results that can be expected from different restoration strategies and techniques. There are important questions to be answered, such as where to place restoration sites, the best size and structural topography of reefs, optimal seeding densities, and which techniques work best under different environmental conditions. These questions are especially difficult to answer because the factors affecting oyster populations and their abilities to form biogenic reef structures vary tremendously with salinity regime, temperature, disease levels, and harvest pressure. In light of this variation, oyster restoration must take an adaptive management approach in which the key questions are answered by evaluating the results of multiple restoration projects across a range of environmental conditions.

Numerous oyster reef restoration projects are currently ongoing or planned within Chesapeake Bay. In order to evaluate the results of these efforts and learn from them, information from individual projects must be combined and analyzed to identify they key factors that lead to successful restoration under different conditions. At the most basic level, this information will include documentation of the location and methods used, the source and disease levels of any oyster seed planted, and some indication of project success. More sophisticated types of information might include quantitative data on oyster populations or reef communities, collected according to a scientifically rigorous experimental design. Regardless of the type of information provided by any particular project, it is critical to begin constructing a combined database that will allow restoration managers to constantly improve and adaptively manage current and future oyster restoration projects.

This document provides some general and very flexible guidance on the types of data that should be collected within the context of individual oyster restoration projects. This guidance is intended to 1) encourage agencies and organizations conducting restoration projects to collect more pre- and post-restoration data than is currently typical of most projects, in order to both adequately measure project success and advance the science of oyster restoration; 2) assist project managers in identifying the information needs that match their specific project goals, so that data collection activities can be incorporated into project planning and budgeting; and 3) provide an element of consistency among different projects, so that a relatively standard set of information on pre- and post-restoration conditions can be compiled into a database for all project managers to use.

The recommendations presented below are not meant as strict requirements or regulating mechanisms, but rather have been compiled by agencies and organizations involved in oyster restoration with the idea that over the next few years we want to amass a combined dataset that allows us to:

- quantitatively improve our knowledge of how and where to restore oyster reefs most effectively, and
- demonstrate successful achievement of restoration goals on both a project-by-project and bay-wide basis.

Guidance

The three levels of information that an individual restoration project might generate and contribute to a combined database are described below. Our goals are:

- to have basic accounting information for every single project,
- to have sufficient data to evaluate the success of all projects with measurable goals, and
- to the greatest extent possible, obtain additional data that allows us to understand the causes for success or failure under different conditions.

IV. BASIC ACCOUNTING

This level of information is the most basic and includes data that should be gathered for every project. For example the policy of "know what you move" (referring to the source and disease levels of transplanted oyster stock) should be practiced universally and supported with documentation for every project. Basic accounting information includes: site location (lat/long or GPS coordinates); amount, source, and type of cultch deposited; amount, source, and disease status of stock planted; and general description of methods used. Compiled across all individual projects, this level of information provides a means for tracking where, when, and how restoration projects have been conducted. It will allow for better management of disease, and will provide managers with an overview of restoration efforts at any point in time.

V. MEASURING PROJECT SUCCESS

Some projects have stated goals, such as increasing the density of live oysters, establishing a diverse reef community, or improving habitat for fish. Whatever the stated goals of a specific project, success should be measured in terms of those goals. For example, if the goal of a project is to increase public awareness and participation, an appropriate measure of success would be the number of individuals involved in the project. However, if a stated project goal is to establish self-sustaining oyster populations or increase reef community biodiversity, then pre- and post-restoration data on these attributes must be collected in order to determine project success.

Thus, the data needed to evaluate project success will vary according to the specific goals of a given project. The attached table clarifies and organizes some common project goals and information needs. *The table is not exhaustive in its coverage of all the questions that might be addressed, and not everything listed in the table will be appropriate for a given restoration project*. Individual projects will tailor their pre- and post-restoration data collection activities according to their project-specific goals.

This level of information is critical for assessing achievement of restoration goals on a project-by-project basis. Compiled across all individual projects, this type of information will tell us what worked under different environmental conditions, and provide a means for tracking increases in the rate of success as we improve our knowledge and restoration abilities.

VI. UNDERSTANDING THE CAUSES FOR SUCCESS OR FAILURE

Beyond basic accounting and measures of project success, we need information that helps us understand the specific causes for success or failure – in other words, *why* a particular result was obtained by a given project. With the current level of knowledge, oyster restoration is necessarily experimental. By default, this great experiment has been approached largely in a trial-and-error fashion in the Chesapeake Bay. To more quickly advance the science of oyster restoration, individual restoration projects should explicitly recognize the experimental nature of their efforts. To the greatest extent possible, projects should be designed to test hypotheses about the performance of restoration methods (e.g., density of oysters planted, reef height) under different environmental conditions. This does not mean than every restoration project should be turned into an expensive scientific study. Simple and cost-effective methods can be used, but proper planning and data collection are essential.

	Management Objectives	Information Needs/ Measures of Success	Data to be Collected	Comments/ Resources Available
Site Selection	Select suitable sites for restoration	Appropriate substrate conditions?	**Pre-restoration:** *Ideal*: Survey on-site cultch and bottom conditions. *Alternative*: Consult existing substrate maps, and current/historic oyster bar maps.	Substrate maps exist for Maryland, and some parts of Virginia waters. Current and historic oyster bar maps are available. Consult MDDNR, VADEQ and VIMS.
		Pre-existing disease?	**Pre-restoration:** *Ideal*: Survey local population for disease. *Alternative*: Evaluate current or historical disease levels for the general area from existing information.	Information on current and historic disease levels for general areas is available through MDNR, VADEQ, and VIMS.
		Larvae present and competent to settle?	**Pre-restoration:** Measure larval concentration in water column, and larval settlement.	Weekly sampling June-Aug recommended.
		Natural recruitment level?	**Pre-restoration:** Measure spat recruitment.	Fall survey recommended.
		Water quality and hydrologic conditions favorable?	**Pre-restoration:** Measure local water quality parameters and on-site sedimentation/siltation rates.	Hydrological conditions in conjunction with sedimentation rates may influence optimal reef height to avoid burial.
Oyster Population	More oysters	Post-restoration oyster population larger than pre-restoration	**Pre- and Post-restoration:** Measure oyster numbers, density, or biomass.	
	Self-sustaining oyster population	Mean annual recruitment ≥ mean annual mortality	**Pre- and Post-restoration:** Measure annual spat recruitment and mortality; also oyster population properties such as oyster numbers, density, size distribution, biomass, and mortality.	Fall spat survey recommended. Surveys should continue for at least 3 years following restoration.
	Increase recruitment, both to restored area and to adjacent exploited areas	Post-restoration spatset on satellite reefs greater than pre-restoration	**Pre- and Post-restoration:** Measure spat recruitment and mortality.	Fall survey recommended. Surveys should continue for at least 3 years following restoration.
		Post-restoration harvest in adjacent areas higher than pre-restoration	**Pre- and Post-restoration:** Gather local catch data.	Harvest levels should be adjusted for level of effort, and tracked for at least 3 years following restoration
Disease	Know what you move	Disease levels of all transplanted stock documented and tracked	**Pre-restoration:** Document the source, history, disease levels, and quantity of all transplanted stock.	
	Maintain or decrease local disease prevalence	Post-restoration disease levels at or below pre-restoration levels	**Pre-restoration:** Measure disease levels in stock to be transplanted, and at restoration site. **Post-restoration:** Measure disease levels at restoration site.	
Ecosystem	Increase value of reef habitat for hard-bottom benthic communities	Community of reef organisms greater than pre-restoration levels	**Pre- and Post-restoration:** Measure properties such as community diversity, species richness, and biomass of benthic community.	Ideally, these measures will be quantitative. However, qualitative assessments are also useful and could be done using low-tech, cost-effective methods.
	Increase utilization of reef habitat by fish	Fish utilization of reef habitat greater than pre-restoration levels	**Pre- and Post-restoration:** Measure properties such as species richness and abundance of resident and/or transient fish using reef.	
	Contribute to improved water quality through increased filtration	Post-restoration improvments in local water quality	**Pre- and Post-restoration:** Measure local water quality parameters.	

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