Evaluation of the Effectiveness of SAV Restoration Approaches in the Chesapeake Bay

A program review requested by the
Chesapeake Bay Program's SAV Workgroup and conducted by the
Chesapeake Bay Program's Scientific and Technical Advisory Committee (STAC)

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The Scientific and Technical Advisory Committee (STAC) provides scientific and technical guidance to the Chesapeake Bay Program on measures to restore and protect the Chesapeake Bay. As an advisory committee, STAC reports periodically to the Implementation Committee and annually to the Executive Council. Since its creation in December 1984, STAC has worked to enhance scientific communication and outreach throughout the Chesapeake Bay watershed and beyond. STAC provides scientific and technical advice in various ways, including (1) technical reports and papers, (2) discussion groups, (3) assistance in organizing merit reviews of CBP programs and projects, (4) technical conferences and workshops, and (5) service by STAC members on CBP subcommittees and workgroups. In addition, STAC has the mechanisms in place that will allow STAC to hold meetings, workshops, and reviews in rapid response to CBP subcommittee and workgroup requests for scientific and technical input. This will allow STAC to provide the CBP subcommittees and workgroups with information and support needed as specific issues arise while working towards meeting the goals outlined in the Chesapeake 2000 agreement. STAC also acts proactively to bring the most recent scientific information to the Bay Program and its partners. For additional information about STAC, please visit the STAC website at www.chesapeake.org/stac.

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EXECUTIVE SUMMARY

Submerged aquatic vegetation (SAV) has declined dramatically in the Chesapeake Bay and worldwide, largely as a result of stress from poor water quality. In response, the Chesapeake Bay Program established a goal of achieving 185,000 acres of SAV bay wide, recognizing that this level of restoration would be dependent upon improved water quality. As part of this restoration strategy, the Bay Program set a goal of "direct restoration" of 1000 acres of SAV via planting of whole plants or seeds in areas of historic beds, with the expectation that these restored beds would help to "kick-start" broader expansion of SAV beds. Years after establishing these goals, results have fallen far short of the original targets. Consequently, STAC was requested to conduct a review of the effectiveness of direct SAV restoration efforts, evaluate the efficacy of the direct restoration strategy for accelerating broader SAV recovery and, if appropriate, provide guidance on how to improve the restoration efforts.

To accomplish these tasks a committee comprised of STAC members and SAV experts from outside the region reviewed published and unpublished data provided by the Bay's SAV Workgroup. The committee considered the success of these restoration efforts on several levels: (*i*) operational success (progress towards 1000-acre goal), (*ii*) functional success (persistence and spread of planted beds and performance of SAV ecosystem functions), and (*iii*) programmatic success (knowledge gained towards achieving restoration goals). The review committee evaluated program techniques, such as site selection, planting, monitoring and the implementation of adaptive management. It also considered the overall effectiveness of the direct restoration approach towards meeting the larger goal of restoring 185,000 acres of SAV. Finally, the committee made recommendations related to techniques, program evaluation and the need for more integration of research and adaptive management approaches towards restoring SAV to Chesapeake Bay.

The initial estimate of the cost to plant and monitor 1000 acres of SAV was $31,386,000 (CBP 2003) of which only $5,063,000 was provided. Within this context, the program was operationally successful in planting 150 acres, a proportion of the 1000-acre target that approximates the level of funding received. Nevertheless, the large funding shortfall limited the program's ability to achieve its goal. Functional success was not generally achieved since the majority of beds planted did not persist beyond one year and did not spread beyond the original planting area. However, some important exceptions to this pattern were beds in the York and James rivers that persisted and expanded far beyond their initial planting areas. The restoration effort has shown modest programmatic success, employing adaptive management as new knowledge has been gained. Site selection tools and planting techniques were improved over time and some lessons learned from successes and failures were applied to improve restoration choices.

Our review generally supports the techniques used for planting and monitoring SAV. Evidence from the York and James rivers and from Virginia's Coastal Bays supports the premise that SAV beds can be successfully restored using these techniques where water quality is sufficient. The majority of direct SAV restoration efforts were undertaken with eelgrass *Zostera marina*. The rationale for focusing most of the effort on this species—its wide distribution, established restoration techniques and historic low levels—was sound. However, if more resources had been available to develop techniques, direct restoration with other species would have been desirable.

The primary means of selecting restoration sites was a GIS-based decision tool, which incorporated information on water quality, water depth, current and historical SAV distribution, important fisheries habitat, and potential disturbance from clam fisheries. Though this site selection model was arguably state-of-the-art at the time it was developed, it fell short in meeting its intended use. A review of the

model's effectiveness revealed that it was adequate for predicting sites where germination of SAV seeds would occur, but not for predicting persistence of beds beyond one year. Shortcomings of the model include (*i*) limitations on the data available to parameterize it, (*ii*) failure to include temperature as a stressor, and (*iii*) perhaps most importantly, reliance on multi-year average water quality, rather than variances and even extremes. This latter limitation was evident in numerous instances when data used to select restoration sites were collected in dry or average rainfall years and restoration was then followed by high rainfall (and thus poor water quality) years. The need to incorporate longer-term data sets, multiple stressors and environmental extremes into the site selection model is now apparent.

This report is organized into four sections: 1. Charge to the Committee 2. Review of SAV Workgroup Efforts and 3. Summary and Conclusions. 4. Specific recommendations for any future program are provided at the end of the report.

1. Background and Charge to the Review Committee

The Bay Program set the following **Restoration Goals** for the program

- Short-term goal of restoring 1,000 acres of SAV by direct planting
- Long-term goal of achieving 185,000 acres of SAV Bay wide.

The Bay Program has fallen far short of its proximate SAV goal of direct restoration of 1,000 acres of SAV. Further, it is unclear whether or not direct restoration has or could advance the overall goal of achieving 185,000 acres of SAV bay wide. Direct restoration was originally proposed as a strategy for increasing SAV abundance because new beds were thought to have the potential to "kick-start" seagrass restoration by providing seed sources and improving physical conditions for seagrass recruitment. Past SAV restoration has shown mixed results in terms of generating persistent beds and inducing new bed development, raising the question of whether or not current restoration techniques are generating sufficient returns on investment.

Continued implementation of the SAV restoration strategy is contingent upon an independent assessment of its effectiveness. A recent review (Orth et al 2010) examined SAV restoration efforts and suggested that efforts "have failed to significantly influence the overall abundance of eelgrass at most locations." However, the study also cited some notable exceptions such as success in the York and James rivers and in Virginia's coastal bays. Inconsistency of past restoration results raises several questions:

1. What lessons can be drawn from past successes and failures?
2. Have lessons learned been applied to restoration choices of sites and techniques?
3. Have relevant new research findings and key ecological principles been used to enhance likelihood of success?
4. Are there data, logistical, or other limitations to improving cost-effectiveness?
5. What are priority research topics that need to be addressed to enhance long-term restoration success?

The STAC concluded that a review would serve to address these and other questions by bringing together subject area experts (Review Committee: RC) from both within and outside of the Chesapeake Bay community to objectively review the evidence regarding the past effectiveness of SAV restoration to achieve goals and the potential for enhancing future performance. STAC is the logical entity to provide this independent review.

The following needs were defined by the STAC and accepted by the review committee:

1. Develop criteria to define *successful* direct SAV restoration over short- and long-timeframes. For example, short-term criteria may include germination success and survival for >1 year. Longer-term criteria may include persistence for many years and a trend of bed expansion (either contiguous with or adjacent to planted beds).
2. Evaluate the effectiveness of direct restoration to accelerate SAV recovery and protection through activities like seeding and transplanting. Specifically, evaluate:
    - Where and when have viable beds been produced?
    - Is there evidence that SAV beds have expanded beyond the immediate restoration site?; and

    - Has restoration promoted scientific understanding needed to support broad restoration goals for the Bay?
3. Provide guidance on the desirability of continuing to employ direct SAV restoration and, if appropriate, how to improve its cost-effectiveness, probability of success, and potential for improved scientific understanding through changes in the following Focus Areas:
    - Site selection criteria,
    - Restoration techniques, and
    - Monitoring requirements
    - Program management

The STAC and Non-STAC members of the RC worked together through several conference calls and extensive electronic communication to address the charge to evaluate the success of the restoration program. The RC developed questions to address different aspects of the program operation and outcomes. Many of the questions were directed to the SAV workgroup to understand what had been done and how. The workgroup then used those responses to analyze the program and provide suggestions for future efforts.

2. Evaluation of Restoration Program

To evaluate the restoration program, the RC first created a multi-part definition of success and then used that definition to evaluate different aspects of the program. This evaluation section first provides the definitions and then presents information gathered to address each of the three types of success identified. Much of the analysis is presented as a series of questions and answers to reflect the RC analysis approach. Responses from the SAV workgroup to questions posed by the RC are presented in italics and are followed by RC analysis.

2.1. Definitions of successful direct SAV restoration over short- and long- timeframes

The SAV Workgroup provided the RC with their definition of a successful restoration project:

- *one that persists over time (at least one annual cycle) and*
- *has as many of the attributes of natural SAV beds as possible, including:*
    - *sustainability,*
    - *plant density,*
    - *species diversity,*
    - *high quality fish and shellfish habitats,*
    - *reproduction and dispersal of SAV propagules,*
    - *water quality improvement capacity (by the restored seagrass acting as a filter), and*
    - *wave attenuation.*

The RC agrees that the various metrics listed by the SAV Workgroup are relevant for evaluating the development of seagrass beds and their contribution to the Bay Program Goals. However, the RC saw a need to define success for the SAV restoration program in broader terms that included not only biological success but also operational and programmatic success to reflect the multi-faceted contributions of the program to long-term SAV restoration success. The RC distinguished three types of success: operational, functional, and programmatic. *Operational success* considers whether program outputs were consistent with resources provided. *Functional success* includes biological outcomes such as those defined by the workgroup. *Programmatic success* is evaluated in terms of whether the program helped to build knowledge.

More detailed definitions follow:

Operational success is defined as the program's implementation of the desired number of acres planted and is one of two factors that measure progress towards effective SAV restoration. It is distinguished from *functional success* because it examines whether implementation met program targets and was sufficient considering the reasonableness of the goals and resources provided.

Functional success is defined as the outcomes of planting in terms of persistence and spread of planted beds and the characteristics of beds that indicate the performance of SAV ecosystem functions. This encompasses the characteristics of a successful restoration project identified above by the SAV Workgroup, including sustainability, SAV reproduction, provision of fish and shellfish habitat, water quality improvement capacity (e.g., filtering by seagrass) , and wave attenuation. Functional success is best evaluated by comparing the attributes between planted and natural, reference SAV beds. Persistence over one annual cycle would generally be considered the minimum requirement for functional success. Persistence for three to five years is desirable to ensure ecosystem sustainability and development of primary production, habitat structure, and faunal community functions equivalent to reference beds (Fonseca et al. 1998; Evans and Short 2005).

Programmatic success is defined as the successful implementation of adaptive management to promote the accumulation of scientific knowledge that can be applied to improve management. The two critical components of programmatic success are the knowledge gained from monitoring management outcomes and the implementation of an iterative process that feeds this knowledge back into management decisions.

More generally, adaptive management is defined as a systematic approach for improving resource management by learning from management outcomes. Through this process, the knowledge gained by careful monitoring of results following management interventions is used to adjust future management decisions. Adaptive management is most useful when actions must be taken to achieve management goals in the face of uncertain outcomes. Successful implementation includes not only progress towards environmental goals but also increases in scientific knowledge (National Research Council 2004). Although restoration of SAV in Chesapeake Bay was not formalized within an adaptive management context, restoration actions have implicitly followed the adaptive management sequence of exploring alternative options for meeting restoration targets, using models to predict the consequences of restoration actions, monitoring restoration results, and using these results to adjust restoration approaches (e.g. Williams et al. 2009).

2.2. Evaluation of Operational Success

What was planted?

The SAV Workgroup provided the following information about operational undertakings of the restoration program:

During the period 2003 through 2008 a total of ~150 acres were planted. Plantings occurred in:

- *Long Creek (Baltimore County, MD,* Valisneria americana*),*
- *Shallow Creek (Baltimore County, MD,* Valisneria americana, Potamogeton perfoliatus, Stuckenia pectinata*),*
- *Eastern Bay (Queen Anne's County, MD* Ruppia maritima, Potamogeton perfoliatus*),*
- *Choptank River (Talbot County, MD,* Potamogeton pefoliatus*),*
- *Little Choptank River (Dorchester County, MD,* Zostera marina*),*
- *Patuxent River (Calvert County, MD,* Zostera marina*),*
- *St. Mary's and Potomac Rivers (St. Mary's County, MD,* Zostera marina*),*
- *Piankatank River (Mathews and Middlesex counties, VA,* Zostera marina*), and*
- *York River (Gloucester and York counties, VA,* Zostera marina*).*

Were resources adequate to achieve the goal?

Clearly, the program did not meet the target of 1000 acres. However, the 150 acres planted between 2003 and 2008 comprised 15% of the 1,000 acre target. Because the program received only about 16% of the total funds estimated to be needed for full implementation ($5,063,000[1] out of an estimated requirement of $31,386,000 [CBP 2003]), this seemingly low implementation level was consistent with the level of funding. Thus, within the context of the funds provided the SAV restoration efforts, the 150 acres were judged to be an operational success that generated progress towards the restoration goal.

Was the 1000 acre short-term goal appropriate?

The planting target was developed in consultation with academic researchers, SAV restoration practitioners, program managers, and others. According to the SAV workgroup, the goal was based largely on the limitations of the volume of seed collection and processing that would be possible using protocols developed by VIMS, subject to further limitations of infrastructure, partnering agencies, and institutions and funding/personnel resources.

Assumptions made in developing the goal:

- Field yields of restoration materials could be duplicated in time and space from the VIMS experience prior to 2003.
- Product yields would be similar between facilities and species.
- Funding levels would be sufficient for planned effort.
- High partner "buy-in" and support" would lead to cooperation and resource sharing necessary to achieve goals.

[1] Federal funds: $4,148.000; state funds: $770.000; NGO funds:$145,000.

The developers of the goal generally considered the 1000 acres as reasonable because it represented a relatively small percentage of the original acreage in the Bay and because facilities and other operational capacity could be developed to meet this goal. Moreover, given the success in the Virginia coastal bays where >1000 acres have been created, the scale of this goal seems tractable, if pursued where proper environmental conditions exist.

2.3. Evaluation of Functional Success

Was there evidence of bed persistence and expansion?

To be considered functionally successful, planted seagrass beds must self-propagate and persist. The SAV workgroup reports the following:

> *Monitoring data show that the majority of planted SAV beds have either not persisted beyond one year or have not expanded beyond the original area planted. Notable exceptions are the York River and James River seeded plots (collective expansion from 15.5 acres seeded to 170 acres of coverage) and the James River whole-plant plots (total of 1.4 acres planted in three sites in the 1990's expanded to a total of 233 acres coverage in 2010).*

The SAV Workgroup further presented us with a narrative which indicated that many sites survived initially, established at high density and in a few instances, spread beyond the original planting area. These results demonstrate that initial planting of seagrass was effective at establishing plants in the ground. However, a recent review of SAV restoration outcomes from this and related programs (Ort et al. 2010) showed that the vast majority of planted sites did not persist longer than five years. Again, the coastal bays of Virginia provide an exception to this general situation. Restored eelgrass beds there have persisted and spread over the past 12 years, apparently as a result of a combination of adequate water quality and cooler seawater temperatures relative to Chesapeake Bay.

We compared this result to guidance provided by Fonseca et al. 1998 (Figure 4.1, pg 133: http://www.cop.noaa.gov/pubs/das/das12.pdf) that five years is the minimum time required for documenting planting success. Although self-propagation was evident across sites, they did not persist for five years. Fonseca et al. remark that the five year goal is an initial target that needs further refinement, but the RC considered this an acceptable criterion. Using these standards, the RC concludes that *the program did not achieve functional success*. The RC then considered the various reasons for this lack of success.

In light of program outcomes, was the restoration goal realistic?

One of the first issues regarding program success is whether the original goal of restoring 1000 acres of seagrass needs to be revisited. The lack of improving water clarity in the Bay has restricted eelgrass beds to the shallowest waters. Because of rising temperatures in the mid-Atlantic, shallow eelgrass beds are becoming extremely vulnerable to temperature stress (Moore and Jarvis 2008). This seems to be the most likely reason for the lack of substantial success in the recent restoration efforts. In addition, when compared to average temperatures from the period 1971 through 2000, average temperatures in the Bay region are expected to rise approximately 1-2 degrees C for the period 2010 to 2039 under a medium-high CO_2emission scenario and by 4.7 degrees C for the period 2070 to 2099 (Najjar et al. 2009). If correct, such increasing temperatures will severely threaten eelgrass populations in Chesapeake Bay and are likely to make future attempts at eelgrass restoration difficult and risky.

Was the restoration approach appropriate?

The persistence of SAV at some locations suggests that the seed selection and planting techniques were as effective as could be expected. On the other hand, the site screening tool was not uniformly effective at predicting areas where SAV could persist. Given that open system restoration faces significant obstacles to predicting water quality conditions in any given time and place, the expectation for successful SAV restoration in the short-term should be moderated. Restoration techniques have improved significantly as a result of this program and these represent important scientific contributions by the program. Historically, however, problems associated with methods and problems with the larger issues of project planning (such as site selection) have not always been clearly differentiated with the result that restoration has generally failed. What has emerged from the Bay effort is that the current methodology of seagrass restoration is directed largely at recruitment limitation and has never been intended as a water quality remediation strategy. Site quality, including water quality, has emerged in this review as a primary challenge for restoring SAV coverage in the Bay. Thus, SAV restoration has been applied in an instance where it probably could not succeed. This does not mean that SAV restoration is a failed option because it did not work in much of the Chesapeake proper, it was simply applied beyond its capacity. This is an important distinction because managers should not transfer results from the Chesapeake context to the practice as a whole. SAV restoration using techniques developed under this program is clearly highly effective in suitable areas nearby (like the coastal bays).

Were state-of-the-art field techniques applied?

We note the response given to us by the SAV Workgroup:

> *Workgroup members developed the first large-scale seed collection, storage, processing, and adult plant culture techniques (for eelgrass, widgeon grass, redhead grass, and wild celery) to promote seed viability and enhance availability of restoration materials. The research evaluated the relative effectiveness of alternative methods of field propagation (timing, seeds vs. plants, and various seeding/planting techniques) based on input from subject area experts and available literature. The program has not had the opportunity to incorporate some of the most recent findings on SAV physical habitat needs (e.g., Koch et al. 2010), because those results came at the end of the program or because appropriate data were not available to implement those findings. These findings are further described under "what was learned."*

It appears that a solid effort was made to apply current techniques and build on past successes of SAV plantings. One other possible approach to consider is the planting of sods of SAV (but only in limited areas) in an attempt to separate recruitment failure by the seeding technique from wholesale inability of sites to support any SAV.

Were appropriate planting methods used?

We note the response provided to us by the SAV Workgroup:

Several different planting methods have used over the course of the SAV restoration program. For adult plant eelgrass transplants (for test plots), methods based on Fonseca et al. (1998) and Davis and Short (1997) were used. Seeds of eelgrass, widgeon grass and redhead grass were primarily dispersed through hand broadcasts (Orth et al. 1992, Busch et al. 2010) or the use of a modified BuDS system (Pickerell et al. 2005; Busch et al. 2010). Wild celery plantings at Long Creek (Maryland) were done by planting 9" x 13" sods grown in culture and a similar technique was used in Shallow Creek (Maryland) for wild celery and redhead grass (unpublished data).

If conditions were more favorable for the survival of eelgrass, the planting methods used would seem to have been adequate for establishing both adult shoots and seedlings in the Bay system. However, the choice of planting methods appears to have had little bearing on the success or failure of restoration efforts to date. The limiting factor to successful long-term plant establishment would seem to be site selection, especially in the context of changing temperature regimes. It has become apparent that multiple stressors including increasing water temperatures combined with poor water clarity and possibly low salinity have made much of the Bay unsuitable for the growth of eelgrass or at least too stressful for relatively small-scale restoration plantings to survive. Under existing conditions it appears that restoration of eelgrass can be successful in only a limited number of places within Chesapeake Bay.

If and when site selection methods can be refined or conditions in the bay improve to the point where suitable sites are found, there may be opportunity for advances in eelgrass seeding methods. Even at the most favorable sites, seedling recruitment is fairly low and it is not clear whether this is the result of poor germination or some post germination factor (e.g., bioturbation, erosion, burial, etc.) that leads to loss of seedlings. However, before this is pursued, the more important issue of the overall suitability of the bay for the growth of eelgrass should be addressed.

Under what conditions is direct seeding most likely to be effective?
We note the response provided to us by the SAV Workgroup:

The SAV workgroup suggests that for eelgrass, sufficient shallow (<1m) shoals with above average water quality and good substrate (a thick (>10 cm) layer of fine sand), and proper hydrodynamic conditions (low to medium wave and current energy). Also, field yield of seed is critical. . For wild celery, one of the biggest limitations is finding freshwater locations with adequate water quality that are NOT already colonized by wild celery. For other SAV species, the requirements are largely unknown.

While seeding has been effective in establishing eelgrass plantings at sites such as the VA coastal bays, the exact set of conditions that allow for this establishment are not well defined. Given the general unsuitability of the Chesapeake Bay system for the growth of eelgrass, this question may not be relevant for the Bay (see above).

If we ignore the fact that much of the Chesapeake is unsuited for the growth of eelgrass or if we focus on the Coastal Bay system, then there are numerous factors that should be considered because they have a bearing on seedling recruitment. This process can be separated into two phases: initial seed retention and entrainment, followed by germination and growth. Sediment texture and the amount of organic matter can help to predict whether seeds will be retained where released or transported off site. It may also be possible to relate sediment texture to overall hydrodynamic conditions within an area, thereby helping to predict the likelihood of physical disturbance that could lead to scouring of seeds or seedlings.

What techniques are working best?

We note the response given to us by the SAV Workgroup*:*

> *All techniques used worked to varying degrees and in varying locations. With eelgrass seeding, higher initial densities were found by holding the seeds through the summer and broadcasting in the fall (Busch et al., 2010; Golden et al., 2010), though the adaptation of the BuDS system (Pickerell, 2005) is significantly less expensive with very satisfactory results in terms of seedling establishment and long-term survival. Whole plant and sods also had some success with other species (wild celery, redhead, and widgeon), but the enhanced success was not enough to warrant the higher labor and infrastructure needs compared to working with the seeds of these species for large scale (>1 acre) restoration.*

The fact that the planting techniques employed by the SAV Workgroup resulted in the establishment of seagrass beds within the Chesapeake Bay and elsewhere indicates that these techniques worked well. The limited success in persistence of beds appears largely due to water quality conditions, not planting techniques.

Is eelgrass the right species to target in CB? Has there been success with other species?

We note the response given to us by the SAV Workgroup:

> *Tidal fresh and oligohaline species are currently not in need of major restoration. Mesohaline species have been in decline for over a decade; however, habitat conditions (water quality) in most areas are not suitable for restoration. Eelgrass was chosen for large-scale restoration due to previous transplanting efforts and lack of natural populations to fuel recovery, particularly in the Western Shore tributaries. Other species still have populations throughout their historic ranges and seed banks to aid in natural recovery.*
>
> *Smaller scale restoration projects have been attempted with other species (transplants and seeds). Seed processing and storage techniques to maximize germination have been developed and implemented for sago pondweed, redhead grass, widgeon grass, and horned pondweed (Ailstock et al., 2010). Kemp and Murray have some mesohaline restoration sites sago pondweed, widgeon grass, redhead grass) in the Choptank (Kemp's presentation at first webinar, Hengst et al., 2010). USFWS planted redhead, sago, and wild celery at Shallow Creek (a small tributary between the Patapsco and Back Rivers in Maryland) in 1999, 2000, 2001 and 2003. A survey in August 2010 identified that redhead and wild celery (the latter is the dominant) are still present in the planting area and have expanded from the original footprint (Bergstrom, 2006). It is difficult to estimate the amount of expansion, because several smaller, natural beds of milfoil have merged with the restored beds over time.*

> *From 1999 through 2005, Maryland DNR performed several small-scale restorations (50 to 200m^2 per year) at Rocky Point Park (Long Creek between Back and Middle Rivers) with adult wild celery grown in culture (http://www.dnr.state.md.us/bay/sav/bgic/). No SAV had been mapped by the VIMS aerial survey in the creek prior to the plantings, though field surveys indicated very patchy milfoil. In 2003, a small bed was mapped for the first time. In 2009, there were approximately 9.5 acres were mapped. Wild celery was the dominant species in the creek, though the upper reaches were dominated by milfoil. We assume that most of the wild celery originated from our plantings, it is unclear whether the expansion of the milfoil is due to local water quality improvements by the wild celery or to some other mechanism.*

It appears there has been some success with plantings of other macrophytes, but only within small areas. Eelgrass would appear to be among the strongest candidate species for restoration given its past extensive distribution throughout the Bay and the critical ecosystem services that it provides. However, inadequate water quality throughout much of Chesapeake Bay has limited eelgrass restoration success thus far and climate change may further limit success with *Zostera*. Therefore, further research into this question is warranted.

SITE SELECTION CRITERIA

Was state-of-the-art site screening applied?

We note the response given to us by the SAV Workgroup:

> ***Creation of a Site selection tool*** *– SAV working group developed a site targeting tool for evaluating sites for direct restoration. This GIS-based tool was used to pre-screen areas of interest for restoration. The basic targeting layers were interpolations of water quality data (three year medians of secchi or Kd, dissolved inorganic nitrogen and phosphorous, chlorophyll a and total suspended solids) on a 100 meter grid. The water quality data were analyzed as "pass/fail" based on the Batiuk et al. (1992) habitat requirements. Additional layers used included bathymetry, historic (pre-1984 and 1984 through 2001) and recent (2002 through 2004) SAV distributions. As the project progressed, water quality mapping data were used, when available, to provide high spatial resolution water quality data. An additional data layer describing important areas for hydraulic fishing of clams was incorporated into the tool. This tool was then used to examine SAV habitat suitability in all tributaries based on information including water quality, depth, SAV occurrence (current and historical), and hydraulic clamming areas by computing the following index.*

$$\left[(Depth) X \begin{pmatrix} Hydraulic \\ Escalator \\ DredgingArea \end{pmatrix} X \begin{pmatrix} ExistingSAV\,Area \\ +1/4 milebuffer \end{pmatrix} X \begin{pmatrix} Kd + CHLa + DIN + DIP + TSS \\ + YellowPerchHabitat \\ + BlueCrabPostLarvalArea \\ + HistoricSAVarea \end{pmatrix} \right] = \mathrm{Re}\,storationPotential$$

where each of the components were parameterized as follows:.

Depth *- The areas deeper than two meters were given a habitat multiplier value of 0 while the areas shallower than two meters were given a value of 1. This multiplier would exclude areas deeper than two meters from SAV restoration consideration.*

Hydraulic Clamming Area *- The areas open to clamming were assigned a multiplier value of 0 and those areas closed to clamming a multiplier value of 1. Therefore, an area open to clamming would have a habitat quality of 0, indicating that this area is not suitable for restoration because there is the risk of physical disruption of transplants by hydraulic clamming activity.*

Existing SAV + Buffer *- All areas currently vegetated with SAV (most recent coverage) were surrounded with a 1/4 mile buffer and assigned a value of 0. This multiplier would prevent restoration activities occurring near (1/4 mile radius) or in areas currently vegetated. The 1/4 mile buffer was added to allow for natural SAV bed expansion through the growing season. For an area to be considered for restoration, the above three conditions (shallow water, no fisheries conflict, and no existing SAV) must all be met. If any have these three parameters failed in a given GIS polygon, that polygon would be assigned a "Restoration Potential Index" value of zero, indicating that it was unsuitable for restoration activities.*

Water Quality – *Using all available water quality data, areas that met the habitat requirement for each parameter (Batiuk et al, 1992) were assigned a value of 1, and those that failed the habitat requirement criteria were assigned a value of 0. The exception was Kd, which was assigned a value of 2 to give more weight to this factor, which has a larger impact on the growth and survival of SAV. The value assigned to each parameter was then summed to provide a overall water quality score, ranging from 0 (all parameters fail) to 6 (all parameters pass). This process yielded a water quality score for all areas of the Chesapeake Bay. In later versions of the model, "Percent Light through the Water" (PLW) and "Percent Light at Leaf" (PLL) were added, as well as water quality mapping data to provide higher spatial resolution.*

Habitat *- The important fishery habitat areas of the Chesapeake Bay (blue crab postlarvae and yellow perch) were each assigned a habitat value of 0.2 to indicate that these areas should received special attention in SAV restoration work. Areas not containing important fishery habitat were assigned a value of 0.*

Historical SAV - *Areas that historically contained SAV beds (1981-1995) were given a value of 1. Because these areas previously contained SAV, they might be more suitable* *than areas never showing recorded SAV distributions. In later versions of the model, a data layer containing "the single best year" coverage was used, reaching back to the 1930s in some cases.*

Scores for the resulting SAV Restoration Potential were interpreted as shown in Table 1.

Table 1. Restoration index scores and corresponding restoration potential categorization

Score Range	***Restoration Potential***
0 – 3.4	Poor
3.4 – 4.4	Marginal
4.41 – 5.4	Fair
5.41 – 7.4	Good

For those sites with high restoration potential scores, specific regions within areas known to have supported SAV species were identified, and field surveys were then conducted to select specific sites for restoration, either by wading at sites with shore access or via boat. Crews considered actual bathymetry, potential impediments to restoration (debris, herbivores, sufficient area to restore, etc.), access, land-use adjacent to the sites, and a qualitative assessment of sediments.

A value of 0 was assigned as a deliberate "kill switch".

In an evaluation of the site selection targeting model, Golden et al. (2010) concluded that the model was adequate for identifying locations where seedlings would germinate, but the model was not useful for predicting long-term survival.

It appears that factors thought to be important for choosing suitable sites for restoration were included in a systematic index that was used to identify the restoration potential of candidate areas. This comprehensive index allowed for a ranking of sites, although the most important features remain water quality and depth.

However, it is not clear whether the inclusion of other parameters was helpful in the process of site selection (i.e., how well did this work?). A major concern is that the ranking process may provide an accurate assessment only for early survival of seagrass. Moreover, this index had no temporal consideration, that is, what is the effect of extreme, aperiodic events applied to these habitats, especially with short return intervals?

Innovative work has been done by members of the workgroup to understand how system dynamics limit SAV persistence (Moore et al. 1997 founded in work by Gaines, and Denny 1993), yet that understanding is absent from the site selection approach. This omission appears to represent a fundamental weakness in the approach taken and it is unclear to the committee how effective the site selection tool has been. We are not aware of attempts to compare forecasts of site suitability to restoration outcomes other than what is implied in Orth et al. (2010, Fig. 1). It would have been useful to apply statistical techniques, such as Information Theoretic (Uhrin et al. 2011) or other non-parametric techniques effective for categorical data, to formally analyze the relationships between model forecasts and restoration outcomes.

Did program collect and apply the most useful data (at appropriate temporal and spatial scales) for site screening?

We note the response provided to us by the SAV Workgroup:

> *Highly detailed historical data were not available for most sites, but additional monitoring data were added after sites were selected, including continuous monitoring data (ConMon), http://mddnr.chesapeakebay.net/newmontech/contmon/index.cfm) and spatially detailed (DataFlow) data http://mddnr.chesapeakebay.net/sim/index.cfm). These systems came on line in support of the large-scale restoration, but would have been more useful prior to restoration attempts. Additional datasets such as high resolution bathymetry and sediment data would have been useful as well, particularly to understand the high variability between successful and failed sites.*

The group used a site selection process that attempted to incorporate locally important stressors, but many of the selected sites failed to support long-term survival of eelgrass. This suggests that there are one or more factors such as water temperature and possibly light that may not react as predicted by existing models. Until these stressors can be accurately modeled, it may be impossible to select successful planting sites using the tool. Enhanced bathymetry data combined with sediment texture and percent organic matter measures may be useful in helping to better define planting sites, especially for seeding efforts, but until the water temperature and water clarity are understood, this information will not likely lead to greater planting success.

Do we have the knowledge to identify propagule-limited areas?

We note the response provided to us by the SAV Workgroup:

> *Identifying seed limited areas has not been done. The workgroup has raised the possibility of adapting Elizabeth North's oyster larval dispersion model (North et al., 2008) for evaluating seagrass seed transport, however, no funding is available to pursue this work.*

The work group and RC believe that *Zostera* seed limitation is widespread throughout the Chesapeake Bay region given the lack of extant populations that can serve as donor sites. Although it has been shown that seeds can travel great distances within floating reproductive shoots, this method of distribution is not reliable in the absence of natural meadows. Given that much of the Chesapeake appears to be unsuitable for the growth of eelgrass at this time, identification of seed limited areas would appear to be unnecessary. It may be useful to identify areas that are propagule-limited for other species in the portions of the Bay where water quality is not a limiting factor.

Were Bay water quality conditions supportive of success during the period of planting?
We note the response given to us by the SAV Workgroup:

> *After several years of relatively good water clarity, clarity dropped sharply as the restoration project began. Long-term trends suggest a degrading trend in the Bay's water clarity. Water years 2003 and 2004 were above average for stream flow entering the Bay. Several heavy precipitation events occurred during the spring (2005 and 2008) and summer (2006), critical times for SAV growth. Also, record-high summer water temperatures occurred during the project (2005) (Golden, personal communication).*
>
> *Several sites had intensive monitoring allowing the workgroup to evaluate potential causes of success and failure.*
>
> *1) In 2003, the U. S. Geological Survey (USGS) measured sedimentation and erosion, shoot height, shoot burial, and water quality during the growing season (March to November) at the VDOT and Potomac Crossing Consultants (PCC) transplant site (eelgrass) and at a naturally-vegetated reference site. These data were used to evaluate the factors affecting the complete lack of survival of SAV at these sites. We concluded that the median water clarity measurements met habitat requirements, but eelgrass transplant failure may have been due to above average precipitation during both years (Schenk and Rybicki 2006). The increased precipitation drove salinity below eelgrass tolerance limits (10 ppt) for 54 percent of the time at the transplant site and 11 percent of the time at the reference site during the combined 2003 and 2004 growing seasons. The periods when salinity was high enough for eelgrass often occurred late in the growing season (July, August, or September). Eelgrass growth and survival could have also been limited by low sediment nutrient concentrations and poor substrate at the transplant site (relative to the reference site) (Schenk and Rybicki, 2006).*
>
> *2) Experimental plantings of Vallisneria americana were conducted in the Anacostia River. U. S. The objectives of the Anacostia transplant were to explore and explain the potential for SAV restoration at two site: , a low velocity, restored tidal marsh and a relatively high velocity, urban stream with flood control structures (manmade levy, riprap banks, and wing bars). The US Geological Survey (USGS) conducted test transplants and continuously recorded turbidity and water depth. We used time interval photography and found that waterfowl grazers are a potential hindrance to SAV survival at the NPS site in Kenilworth Park, Washington D.C. Transplants were successful (>20% survival) in the spring and summer but not in the fall at the tidal site and in the summer only at the nontidal site. Grazing by resident waterfowl and periods of high turbidity and high flow hindered survival. We provided a report to the NPS (Rybicki et al. 2009).*

It appears that over the time period of the restoration effort, anomalous events of high rainfall and one summer of extremely high temperatures may have worked synergistically with limitations of water quality to increase mortality of seagrass seedlings. If so, water quality may have been supportive of restoration, but only if additional sources of stress to seagrass are alleviated. Again, the predictive capacity of the site selection index may have been exceeded given absence of a temporal component in the assessment protocol.

2.4 Evaluation of Programmatic Success

Programmatic success is covered by two overarching issues: 1) whether programmatic knowledge was gained and 2) whether adaptive management was used to guide program implementation and adaptation to new knowledge. Several specific questions were used to address each aspect of programmatic success.

2.4.1 Programmatic Knowledge Gained

What has been learned?

The SAV Workgroup provided the following information:

> *Several specific research questions were listed in the SAV Strategy to Accelerate the Protection and Restoration of Submerged Aquatic Vegetation in the Chesapeake Bay (Chesapeake Bay Executive Council [of the Chesapeake Bay Program], 2003) document; and many of these questions were addressed. MDNR and VIMS* [members of the SAV workgroup] *identified, evaluated and recommended techniques and facilities capable of producing adequate quantities of eelgrass seeds for planting (Action 4.2 CBP 2003). They also developed and published restoration protocols that included species selection, production schedules, transport and planting methods, acclimation needs of plants (to restoration site conditions), and follow-up monitoring templates (Action 4.3 CBP 2003, Restoration Ecology Special Issue, 2010). Additionally, they developed, implemented, and disseminated results from the Chesapeake Bay SAV protection and restoration research agenda, including developing cost-effective, efficient restoration methods. Specific research questions answered included succession, species diversity, propagule choice, size, density, pattern and exclosures (Action 7.1.2 CBP 2003).*
>
> *SAV restoration served as a platform for specific research questions developed with stakeholders and included issues of reproductive ecology and suitable habitat conditions for restored SAV. Limitations of existing habitat requirements were elucidated and new concepts of what water quality and physical condition requirements for SAV restoration were developed (see Restoration Ecology, vol. 18, Special Issue, July 2010).*

Other specific knowledge gained included:

1- *Physical habitat needs of various species were determined (Ailstock et al., 2010; Koch et al., 2010)*
2- *Spatial and temporal variability in water quality and substrate conditions was revealed to be the major controls of restoration "success" (germination and long-term survival, Golden et al., 2010). Therefore, the findings suggest that plant and habitat condition monitoring is important prior to, during, and after restoration projects. The work also suggests that habitat requirements for restoration may need to be more stringent than the published values (Batiuk et al. 1992, 2000; Moore personal communication) and that more spatially explicit physical information is needed (surficial and sub-bottom*

sediments, waves, currents, etc.) for proposed restoration work (Koch et al., in prep; Karrh and VanRyswick, in prep).

3- *SAV appear to be more wave limited in the upper Bay than in the mid and lower Bay. This seems to be due to the morphology of the SAV species found in these regions: mostly strap-like, meadow forming, low-drag species (*Zostera, Ruppia*, and* Stuckenia*) in the mid and lower Bay and mostly complex, canopy forming, high-drag species (*Myriophyllum, Hydrilla, Potamogeton*, etc.) in the upper Bay. This finding was not applied as restoration was being done mainly with low-drag species (*Zostera, Ruppia, *and* Vallisneria*) (Koch et al. 2010).*

4- *The work suggests that SAV habitat cannot be created by simply building breakwaters. Although breakwaters may initially favor the growth of SAV, in the long term breakwaters are detrimental to SAV especially in areas where a high load of fine particles is found in suspension or where a large source of shoreline sediment is available.*

5- *The research revealed that SAV seeds settle rapidly and need relatively strong currents and waves to be dispersed, but seeds of some SAV species are more mobile than others. When currents resemble those of SAV beds (< 10 cm s-1), seeds tend to remain in the area of the parent population, especially in the presence of microtopographic features like ripples, mounds, and SAV shoots. In the absence of vegetation, only moving ripples led to the burial of seeds.*

These statements are supported by scientific evidence, but they do not appear to supply the full story behind the lack of SAV persistence nor to fulfill all the needs for a long-term strategy to maintain the species. In addition to this long list of biological and ecological lessons learned, the numerous lessons about the sequence of management decisions, funding, and implementation of adaptive management need to be specified to inform future efforts. It would also be beneficial to consider biological and ecological findings relevant to population-level support of the population. For example, the role of SAV genetic structure in the persistence of the species has been studied by members of the program (Williams and Orth 1998) who concluded, "*These data provide a basis for developing a management plan for conserving eelgrass genetic diversity …and for guiding estuary-wide restoration efforts.*" However, population-level strategies do not appear to have been applied as part of this program.

<u>What lessons were applied?</u>

The SAV Workgroup responded to this question with:

> *Restoration site selection is the most important step in the restoration process. Later restoration plantings were focused in areas with previous germination and survival "success." Improved collection, culturing and processing of restoration material was implemented as knowledge was gained.*

While past successes and failures were used to guide future planting, this approach did not promote significant gains in our collective knowledge. It does not appear to have significantly increased the total acreage, nor have successes and failures been part of a systematic effort to reveal the drivers of bed success. A systematic approach to evaluating failures could have identified the weak link or links in the restoration chain in order to allocate effort where it could be applied to best enhance learning and restoration success.

What lessons were not applied? Why not?
The SAV Workgroup responded to this question with:

> *New understanding of the hydrodynamic conditions conducive for seed incorporation and initial establishment (Ailstock et al., 2010; Koch et al., 2010) were not applied as this research was concurrent with restoration activities.*
>
> *The importance of micro-scale (10s of cm) differences in bathymetry was not applied, as high spatial resolution bathymetry was not available during the restoration program. These data remain unavailable, but the capability exists to collect data using advanced hydro-acoustic gear mounted on small vessels, (as described in Karrh and Van Ryswick in prep).*
>
> *New understanding of the importance of surficial (top 10cm) sediments and the role that sub-bottom profiles can play in SAV establishment, growth, and survival (Karrh and Van Ryswick, in prep) was not applied because this work was finished after the large-scale restoration programs wound down.*
>
> *Enhanced understanding of the impact of inter-annual weather variability could not be applied because of the inability to forecast future conditions*.

The evidence provided by the SAV workgroup suggests that the program's short duration did not allow some of the research results to be incorporated into the restoration techniques. However, it appears that a broader perspective is needed regarding what information is most important to apply to have the greatest impact on restoration results. Some specific research done by this group and others does not appear to have been applied, such as optical water quality modeling (e.g., Gallegos 2001) and genetic considerations (Williams and Orth 1998). The SAV workgroup said that it was aware of such work but could not apply it due to data or time constraints. Perhaps more importantly, it is not clear that the water quality monitoring was used in a quantitative manner to evaluate the strengths and weaknesses of the site selection model.

Has restoration promoted scientific understanding needed to support broad restoration goals for the Bay?
The physico-chemical monitoring efforts that were conducted as part of the restoration program made clear that light levels in the Bay have not improved sufficiently in many places to support SAV. Marginal light levels; in combination with increasing numbers of warm, stressful summer days; likely explain the poor persistence of SAV after one year in many Bay locations. What this recent restoration work has strongly suggested is that unexpected combination of conditions (specifically, chronically poor light availability, co-occurring with increasing summer water temperatures and potentially sub-optimal salinity levels) makes large scale SAV restoration a very uncertain proposition in the Bay. Thus, this work has shown that novel conditions exist and previous research may be inadequate to predict success under this new environmental regime in the Bay.

2.4.2 Adaptive Management

Did monitoring resources and program duration promote adaptive management?

The SAV Workgroup provided information on program monitoring:

Monitoring - Each jurisdiction used similar techniques for monitoring eelgrass growth and survival. Counts of total number of shoots in a one meter wide path along the length of the transect were made in restoration plots. The number of shoots was divided by the length of the transect to yield shoots/m^2 (Golden et al. 2010). Additional data such as shoot height, water depth, and biomass where collected in some locations. In Maryland, the most successful eelgrass plots also were fully mapped by divers finding the outer edge of the bed in multiple locations and marking a waypoint with a GPS unit in a waterproof housing.

For seedlings of widgeon grass and redhead grass, similar methods were used as for eelgrass. For the whole plant sods of wild celery and redhead grass, simple "presence/absence" observations either from a vessel or by wading were made.

In conjunction with most large-scale restoration locations, intensive water quality monitoring (continuous monitoring, fixed station monitoring, and water quality mapping) was performed (Golden et al. 2010). Where sufficient resources were not available to initiate new water quality monitoring stations or cruises, restoration locations were partially selected based on proximity to existing monitoring resources.

It appears from our review of the monitoring data that insufficient resources were expended in monitoring water quality and other physical conditions to enable a full interpretation of the reasons for bed success and failure. The Golden et al. (2010) article describes the likely reasons for bed failure using published literature but does not *demonstrate* the relationship between monitored variables and SAV outcomes. The SAV workgroup acknowledges that not every site was monitored at high spatial and temporal resolution, but consistent and strategic monitoring across a range of successful and unsuccessful sites is required to provide evidence for the drivers of bed success or failure. Monitoring is crucial to an adaptive management framework, and the deployment of monitoring resources can itself be usefully evaluated as part of adaptive management. However, it does not appear from the information provided that monitoring resources were moved or re-allocated to gain better knowledge of why beds failed or succeeded.

Was there a process for engaging the scientific community in restoration choices?
The SAV Workgroup provided the following information:

Each year (winter/spring), the SAV workgroup hosts a meeting to specifically discuss the previous year's effort and to brain-storm ideas for the upcoming season. Most of the regional experts attend this meeting.

This appears to be a useful forum, but the material outcomes of these meetings are not clear. If meaningful actions arose from these meetings, then we would conclude that this was a meaningful component of adaptive management process. However, one limitation was the lack of substantial input from experts outside of the Chesapeake Bay region, who could have contributed knowledge gained in other regions or in other programs.

Were there institutional barriers to adaptively changing program activities? If so, what were they and how can they be overcome?
The SAV Workgroup responded:

Funding for research, most importantly site-selection research and research with multiple species, arrived at the same time as funds for large-scale restoration. A sequential process would have been much better, but the Chesapeake Bay Program goal time-frame was too short to allow for a sequence. Seven years is not a lot of time to experiment, analyze, report, and then implement.

For the Patuxent River, contract amendments to move effort to the more productive Potomac took a long time to implement.

Very critical and short timeframe evaluations by higher level management prevented comprehensive adaptive management from being fully utilized before funding was eliminated. At the start of the project, much work remained to be done to develop propagule production techniques for these wild plants, which cannot be grown as predictably as corn. Therefore, initial planting efforts did not implement later advances in propagule viability.

Initial field results suggested a critical issue of propagule viability, and the timetable and design of the restoration project did not allow for additional effort to be directed at this topic. This appears to have been a general approach in restoration projects that look to "get plants in the ground" and do not allow redirection of effort to research projects that might allow for a "midcourse correction." With buy-in from executive leadership and stakeholders, this type of flexibility could be employed. This was not the framework applied, and such redirection of effort would require great flexibility on the part of the funding agency in addition to a reassessment of project goals.

How was adaptive management used in managing program effort?

The SAV workgroup provided the following information:

Results of planting were evaluated by upper level management two to three years after program initiation, and then managers made precipitous decisions to de-fund the restoration efforts. At the practitioner level, interim decisions to shift locations were made on the basis of successes or failures rather than based on systematic data collection. These decisions limited the ability to test alternative techniques to overcome failure. For example, it was apparent that eelgrass work in the Patuxent River wasn't fruitful, so the effort was eliminated there and placed instead in the St. Mary's River where long-term survival was evident (Golden et al., 2010; Busch et al., 2010). Additionally, seed processing and storage experiments were simultaneous with restoration projects (Marion and Orth, 2010), so advances in seed viability could only be incorporated in subsequent years and not from the beginning of the effort.

Based on this response and the other information provided about lessons applied, the SAV restoration program showed some evidence of programmatic success as well as room for improvement. Successful elements included the way that sites were selected, and restoration methods were chosen based on a combination of local conditions that were thought to be of primary importance to planting success. In addition, monitoring of progress towards operational and functional success yielded new scientific insights, and this information was used to refine and focus some of the subsequent restoration efforts. However, successful adaptive management includes refining a range of goals and objectives as understanding accumulates and not just refining the management approaches (Williams et al. 2009). It appears that the program could have benefited from a more structured approach to incorporating monitoring results into ongoing decision making. It is not clear that institutional structures and management decisions supported a systematic approach to adaptive management.

3. Summary of Program Review

Our review evaluated the following program components:

1. Restoration techniques
2. Site selection criteria
3. Monitoring requirements
4. Adaptive management, and
5. Evaluation approaches

Restoration Techniques: This program has developed the most successful large-scale eelgrass (*Z. marina*) restoration methods in history. Fine-tuning and transfer of research approaches to other species is strongly recommended to capitalize on this achievement. Resources should be directed towards those SAV species for which sufficiently large areas of habitat exist within the Chesapeake Bay.

Site Selection: The strength of the site selection tool appeared to be one of the major impediments to successful SAV restoration. This limitation extends to SAV restoration efforts worldwide and is not just a problem for the Chesapeake Bay. For the restoration program in the Bay, the primary means of selecting restoration sites was a GIS-based decision tool, which incorporated information on water quality, water depth, current and historical SAV distribution, important fisheries habitat, and potential disturbance from clam fisheries. Though this site selection model was arguably state-of-the-art at the time it was developed, it fell short in meeting its intended use. A review of the model's effectiveness revealed that it was adequate for predicting sites where germination of SAV seeds would occur, but not for predicting persistence of beds beyond one year. Shortcomings of the model include (*i*) limitations on the data available to parameterize it, (*ii*) failure to include temperature as a stressor, and (*iii*) perhaps most importantly, relying only on multi-year average water quality and not considering the variation in water quality, especially the extremes. This latter limitation was evident in numerous instances when data used to select restoration sites were collected in dry or average rainfall years and restoration was then followed by high rainfall (and thus poor water quality) years. The need to incorporate longer-term data sets, multiple stressors, and environmental extremes into the site selection model is now apparent. In particular, it may be critical to consider the temporal dynamics and sequencing of these limiting factors (*sensu* Gaines and Denny 1993, Moore and Jarvis 2008, Jarvis and Moore 2010).

Monitoring requirements: These were fully adequate for evaluating SAV outcomes but showed some limitations for explaining why some sites failed and others succeeded. Monitoring of outcomes might be reasonably reduced to simpler, binary terms, except in the case of manipulative studies. The site selection model fell short, in part, because of limitations on the data available to parameterize the model. The need to incorporate longer-term data sets, multiple stressors, and environmental extremes into the site selection model is now apparent and carefully gathered monitoring data can help meet this need.

Adaptive management: Adaptive management was applied informally and could have benefited from a more structured approach to ensure that program outcomes were used to effectively guide ongoing decisions. For example, the site selection tool should have been thoroughly revisited once SAV die-offs were recorded. Targeted studies could have been designed to evaluate which of the factors included in the selection model might need to be modified by altering their weighting factors. Furthermore, adaptive management could have been applied at different levels of management to evaluate and adjust goals, techniques, and site choices as warranted by program outcomes.

Evaluation approaches: Evaluation of the planting results was fully adequate. However, if many aspects of functional success of beds (as listed by the SAV Workgroup) are adopted, then monitoring would need to be modified and expanded to include assessment of a broad set of process-based metrics. Evaluation of the entire management program was not possible because of a lack of information about what actions were taken as the result of the various working group meetings.

4. Conclusions and Recommendations

To conclude this review, we summarize our main findings regarding the success of the program and discuss recommendations for future efforts aimed at direct SAV restoration.

Main findings:

1. Given that the 150 acres that were planted were consistent with the proportion of funding provided (15% of the total estimated to be required for 1000 acres), the SAV restoration program was judged to be **an operational success**.
2. Using the standard that the majority of SAV beds must persist beyond 5 years and self-propagate, the RC concludes that the program **did not achieve functional success** even though considerable progress was made in preparation and planting techniques.
3. The program showed **moderate programmatic success** since substantial knowledge was gained and applied through informal approaches to adaptive management; however, the RC also found substantial room for improvement in adaptive management.

The techniques used for preparing and deploying seeds and plant material were state-of-the art, and workgroup members advanced this area of restoration science. Successful bed development in the York and James rivers and Virginia's Coastal Bays supports the premise that SAV beds can be successfully restored using the SAV workgroup's techniques, where water quality is sufficient.

The response to the failures of the site selection model were deficient, both in the program and in the adaptive management effort. Once it became apparent that beds were not surviving in areas that were predicted to have sufficient water quality, it would have been appropriate to reorient the restoration program towards understanding the limitations of the site selection model rather than continuing to plant. Although monitoring of water quality is unusually thorough in the Bay, it would have been appropriate to redeploy monitoring resources to more quantitatively address the question of why beds were or were not persisting.

Perhaps the most important finding is that this recent restoration work has strongly suggested that an unexpected combination of conditions – specifically, chronically poor light availability co-occurring with increasing summer water temperatures – makes large-scale SAV restoration a highly uncertain proposition in the Bay. Although seed limitation for the target species *Zostera marina* appears widespread in the Bay (which suggests that direct seeding is a useful restoration strategy), methods for identifying the areas that can support adult SAV are not well-developed. Further, the RC notes that physico-chemical stressors on *Zostera marina* are expected to worsen if predictions for warming waters come true. This expectation suggests there is a need to develop restoration techniques for other species of SAV that may be able to tolerate future conditions in order to maintain important structure and ecological functions in the Bay.

The apparent failure of the site selection process to screen out areas unsuitable for eelgrass persistence represents a significant shortcoming of the program. As detailed above, this failure likely resulted from data limitations, the interaction of temperature with other stressors, and an underappreciated role of interannual variability and extremes in environmental conditions.

Based on this evaluation of the programs successes and failures, the RC makes the following recommendations:

1. **Discontinue efforts aimed at widespread direct restoration of SAV until environmental conditions improve.** Work in the Virginia Coastal Bays clearly reveals that techniques developed under the SAV restoration program are viable for overcoming apparent recruitment limitation for the target species, *Zostera marina,* and can generate sustainable beds over large regions where water quality and summertime temperatures are supportive. However, without water quality improvements in the Chesapeake Bay, SAV seeding and planting is not a viable strategy for widespread restoration because SAV restoration techniques only address recruitment limitation and not other habitat quality limitations. Therefore, the apparent failure of large-scale restoration of SAV within the Chesapeake Bay is not a methodological limitation but an environmental limitation. Until such time as optical water quality is improved, summertime temperatures moderate, or the site selection criteria are vastly improved; only limited direct SAV restoration efforts in the Chesapeake Bay are warranted.

2. **Continue targeted restoration efforts, both to establish viable beds and to further understand site selection criteria.** Restoration is still appropriate in areas with high probability of success, if such areas can be identified. Efforts should be made to improve site selection criteria for *Zostera* through additional analysis of monitoring data that includes:
    a. Evaluating extremes of temperature and clarity rather than just average conditions;
    b. Considering the interacting effects of multiple stressors (particularly temperature, clarity, and salinity) and temporal dynamics and sequencing, such as high temperatures that follow months with high chlorophyll a or low dissolved oxygen concentrations.

The focus should be on establishing a few beds with a high probability of success as opposed to setting an arbitrary goal of a specified number of acres.

3. **Develop SAV restoration strategies that are responsive to climate change.** The effects of warming waters on *Zostera* should be evaluated and applied to site selection criteria and other strategies, because warming is expected to limit the range of this species in the future. Although the species occurs in North Carolina, which has warmer average water temperatures, the species' ability to tolerate warmer waters may be dependent upon sufficient water clarity. Therefore, the interaction of multiple stressors will be an important consideration for projecting future *Zostera* viability.

4. **Incorporate full adaptive management into restoration decision making.** Future restoration programs could be improved through the use of a thorough adaptive management (AM) framework that engages researchers and managers and applies lessons learned from successes and failures. Many elements of AM were applied in the current effort, such as engaging a broad range of stakeholders in initial goal-setting and applying monitoring results to inform strategies. However, the process did not always explore the full implications of monitoring results to inform subsequent actions or to re-evaluate targets. Therefore, the approach could be improved by:
   a. Developing deliberate and sequential implementation strategies with sufficient opportunity to evaluate restoration responses and to apply improved understanding of causal relationships to refine restoration approaches;
   b. Conducting additional research (possibly using lab and mesocosm studies) to fill gaps in understanding; and
   c. Incorporating flexibility in adaptive decision-making so that policy-makers, managers, researchers, and restoration practitioners can provide appropriate input for adjusting targets, techniques, and allocation of effort and funds, as knowledge is gained.

5. **Build on the successful research into restoration techniques**. The innovations developed for seeding and planting *Zostera* should be transferred to other native species that have potential for large-scale restoration and to enlarge the set of restoration options available to the Chesapeake Bay Program.

Without water quality improvements, SAV restoration in the Bay proper is not yet a viable, large-scale alternative. Work in the coastal bays clearly reveals that large-scale SAV restoration techniques developed under this program are viable for overcoming apparent recruitment limitation for the key SAV in question, *Zostera marina,* when conditions are appropriate. This means that it is highly likely that the failure of SAV restoration in the Chesapeake Bay on the whole is not a methodological limitation, but an environmental limitation. Until optical water quality is improved or the site selection criteria vastly improved, only limited SAV restoration efforts in the Chesapeake Bay are warranted. Small-scale restoration may be appropriate in areas where there has been a demonstrated track record of sustained seagrass following restoration.

The lack of improving water clarity in the Bay has restricted eelgrass beds to the shallowest waters. Furthermore, because of rising temperatures in the mid-Atlantic, shallow eelgrass beds are becoming extremely vulnerable to temperature stress (Moore and Jarvis 2008). when compared to average temperatures from the period 1971 through 2000, average temperatures in the Bay region are expected to rise approximately 1-2 degrees C for the period 2010 to 2039 under a medium-high CO_2emission scenario and by 4.7 degrees C for the period 2070 to 2099 (Najjar et al. 2009). If correct, such increasing temperatures alone will threaten eelgrass populations in Chesapeake Bay. Because shallow waters where light availability is optimal are also areas prone to higher temperatures, future attempts at eelgrass restoration may become yet more difficult and risky.

What is needed now is additional research to understand how interactions among the most important stressors of eelgrass – light, temperature, and salinity – affect survival of newly restored eelgrass plots. Given the decreasing light levels and the increasing temperatures, it is not possible to draw on previous research to allow accurate predictions of what will occur as temperature increases interact with potentially stressful light levels and other critical factors. Thus, research on the separate and interacting effects of multiple stressors as well as their temporal sequencing (*sensu* Gaines and Denny 1993) is needed before future large-scale restoration efforts should be attempted. More powerful statistical techniques should also be applied to discern the limiting capacity of the various stressors.

4.1 Make use of adaptive management framework

We recommend full implementation of adaptive management, including:

1. Collaboration among managers, scientists, policy makers, and other stakeholders in setting restoration targets;
2. Use of science-based models to predict restoration outcomes;
3. Monitoring responses to restoration actions;
4. Use of monitoring data to evaluate restoration progress, improve understanding of system dynamics, identify research needs, and inform future actions; and
5. Long-term commitment of executive leadership to iterative learning-based restoration.

Within such an adaptive management framework, there are key considerations for improving the likelihood of restoration success in Chesapeake Bay:

1. Implementation should be deliberate and sequential, with ample and sufficient opportunity to evaluate restoration responses, improve understanding of causal relationships, and use this information to refine restoration approaches.
2. Field activities should be monitored and evaluated to inform actions. Lab and mesocosm studies may also be needed.
3. Executive leadership and institutional structures should support iterations of restoration, evaluation, and learning that include flexibility to adjust restoration targets and reallocate efforts and funds as knowledge is gained.
4. Long-term evaluation is used to put inter-annual variability and unforeseen circumstances in perspective.

One theme that seems to emerge is that even in a system which is among the best studied and for which there is a good deal of historical information, successful restoration remains a challenge. Some of underlying processes producing these challenges will likely not be apparent even to the scientists who design restoration with the best information available. Thus, decision makers must be warned that setting acreage of cover as a goal is laudable but likely futile. On the other hand, scientists should be prepared to discuss with decision makers a set of alternative scenarios to which effort could be re-directed as necessary when the results of the restoration become evident. Future studies should create opportunities for scientists to adjust allocation of effort and funds and to refine and re-evaluate program design as it is being implemented. The duration of evaluation should be sufficient to detect statistically valid changes.

Setting realistic expectations is critical. Restoration of open systems is risky work. Extreme events (e.g., hurricanes) can undo successes in a very short period of time, and chronic stressors are not easily predicted at a local scale. A recent review by Fonseca (2011) notes that seagrass (SAV) restoration is held to inappropriate standards of success. However, this is not widely recognized, which fuels the perception that seagrass restoration is 'experimental' rather than just inherently risky.

4.2 Guide implementation with focused research

We suggest the program consider annual plantings in select locations along with detailed studies of temperature, salinity, and light. These studies should be monitored over long time scales (5-10 years). Metrics of success by year could be noted and a genetic component could also be added, with appropriate experimentation, to link genomic information with responses. These kinds of long term observations, while very descriptive, are among the most critical to assess whether there are in fact any "good" years for planting that can be identified using evolving statistical techniques and special attention to temporal patterns. A long-term perspective, although unattractive to decision makers, is prudent before restoration is ruled a success or failure.

Comparisons of predicted and observed restoration responses can effectively guide research focused on maximizing restoration success. Long-term increases in restoration success will be contingent on understanding how SAV recruitment and growth respond to the interaction of multiple stressors, including water quality, water temperature, and sediment parameters; and to variations in these and other environmental parameters. Research to inform restoration efforts should be at appropriate scales and may involve combinations of field, mesocosm, and laboratory studies targeting specific restoration needs including identifying sites with high probabilities of restoration success.

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