Eelgrass Monitoring: Development of a Citizen Scientist Monitoring Method

A Pilot Study in Duxbury-Kingston-Plymouth Bay

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Summary

With funding from the Massachusetts Bays National Estuary Program (MassBays) and with input from local experts, the Massachusetts Division of Marine Fisheries (MA DMF) developed an eelgrass monitoring protocol to be implemented by trained citizen scientists to track changes in eelgrass extent and condition. The protocol will be tested in the Duxbury-Kingston-Plymouth embayment (DKP), where aerial monitoring programs and acoustic surveys have detected substantial declines in eelgrass extent and density over the last several decades. Data collected in this effort will supplement existing mapping programs and enhance our understanding of the embayment.

Background

Seagrasses are submerged, rooted and flowering marine plants found in shallow nearshore areas worldwide. Seagrass meadows enhance biodiversity (Hughes et al. 2002; Lubbers et al. 1990; Wyda et al. 2002), attenuate wave energy (Fonseca and Cahalan 1992; Koch 2001), stabilize sediments (Fonseca and Fisher 1986), sequester carbon and nutrients (Pedersen et al. 1999; Touchette and Burkholder 2000), oxygenate sediments and filter the water column (Short and Short 1984). Meadows and patches create important coastal habitats, providing shelter and forage for many marine fish species (Heck et al. 1989; Lubbers et al. 1990). As estuarine plants, seagrasses are useful indicators of estuarine health as they are subject to anthropogenic and environmental stresses. These stresses include light limitation caused by nutrient loading (Lee et al. 2007, Short et al. 1995, Dennison et al. 1993), development-related habitat loss (Short and Burdick 1996, Landry and Golden 2017), disease (Bull et al. 2012, Muehlstein 1989), and climate change (Thom et al. 2014, Echavarria-Heras et al. 2006). Seagrasses are used as an indicator of estuary health, therefore monitoring programs help to enhance the protection and management of seagrass beds (Orth et al. 2006).

Because of the importance and vulnerability of seagrasses, programs that monitor their extent or health have been increasing world-wide during the last two decades (Orth et al. 2006). The predominant seagrass in New England is *Zostera marina*, known commonly as eelgrass. Currently, the primary eelgrass survey effort in Massachusetts is a fixed-wing aerial photography survey conducted by the Massachusetts Department of Environmental Protection (DEP) (Costello and Kenworthy 2011). The DEP Eelgrass Mapping Project is conducted yearly in selected embayments and sections of the coastline, providing nearly coast-wide coverage approximately every five years. Their survey includes aerial photo interpretation along with groundtruthing with underwater video to spot-check the aerial imagery analysis. Since the DEP eelgrass survey only provides updates every five years, and the imagery is captured at a 1:20,000 scale, it is not well suited for tracking detailed spatial patterns within seagrass meadows, especially in patchy dynamic beds or in estuaries that are turbid. This can make it difficult to address specific environmental issues that may lead to uncertainty in the rate of change in eelgrass meadows and the causes of meadow decline (Neckles et al. 2012, Valle et al. 2015). Other mapping efforts include ad-hoc sidescan acoustic surveys conducted by MA DMF which also include underwater photo groundtruthing, and also have their limitations. In general, seagrass surveys can be divided into three scale categories:

1. Broad-scale remote sensing studies using fixed-wing aerial photography, Landsat satellite imagery (Hogrefe et al. 2014, O'Neill and Costa 2013), drone imagery (Duffy et al. 2018), or acoustic mapping are typically designed to assess regional changes in spatial distribution. See Appendix A for a literature review of broad-scale survey methods.
2. Meso-scale surveys are designed to assess single embayment and/or meadow-level changes in eelgrass spatial distribution and some can roughly track health-related changes like density, percent cover and canopy height. Examples of meso-scale monitoring include acoustic surveys (Vandermeulen 2014, Sonoki et al. 2016), randomized quadrat-based surveys (Neckles et al. 2012, Raposa and Bradley 2010), underwater camera and benthic grab surveys (McKenzie 2003), and towed video surveys (Berry et al. 2003). See Appendix B for a literature review of meso-scale survey methods.
3. Fine-scale surveys use high resolution monitoring to identify meadow and patch-level changes and responses to stressors to inform system-wide trends. These programs often require SCUBA or snorkel work at permanent monitoring sites, which cover a very small study area in comparison to broad and meso-scale surveys (Short et al. 2006, Neckles et al. 2012, McKenzie et al. 2003). See Appendix C for a literature review of fine-scale survey methods.

In the Duxbury-Kingston-Plymouth embayment (DKP), broad-scale surveys have detected large declines in eelgrass extent and density over the last several decades, with further losses documented using acoustic surveys done in between aerial survey time periods (Costello and Kenworthy 2011, Ford and Carr 2016). However, the cause and longevity of these losses are unclear, though likely associated with a mix of geomorphological processes, physical impacts, climate, and water quality. Therefore, in DKP more frequent meadow-level data collection is needed to supplement existing mapping programs and inform the overall understanding of the embayment.

Informed by extensive expert input, this protocol was developed to provide a methodology that can be applied by an engaged group of citizen scientists. Citizen science has recently expanded into the field of seagrass research, and volunteers can help collect, process and analyze data in a variety of ways (Jones et al. 2017). Marine benthic projects that rely on citizen scientists include Seagrass-Watch (McKenzie et al. 2003), Reef Life Survey (Stuart-Smith et al. 2017) and Seagrass Spotter (seagrassspotter.org). Monitoring methods include satellite photo analysis (blog.floatingforests.org), use of submersible cameras (Raoult et al. 2016, Wright et al. 2015) and data collection by divers (Stuart-Smith et al. 2017, McKenzie et al. 2003, Roelfsema et al. 2016, Sailing for Seagrass).

Goals

The overarching goal is to better understand and track changes to eelgrass bed extent and condition in DKP. When these datasets are considering alongside potential stressors, managers and stewards are in a better position to effectively manage and protect the resource. The specific goals of the citizen science monitoring protocol include documentation of eelgrass presence or absence and percent cover across the embayment, and assessment of eelgrass health in terms of canopy height, epiphyte coverage, and wasting disease presence at discrete indicator beds.

Quadrat-based Photo Monitoring

What?

This sampling protocol is focused on creating an annual assessment of eelgrass using underwater photo monitoring, and has been informed by Neckles et al. (2012). This protocol is designed to be used by volunteers and scientists, focusing on meso-scale survey data collection that provides a rapid assessment of eelgrass coverage and plant characteristics throughout the embayment, with more intensive sampling at indicator areas. A meeting convening eelgrass experts took place on 1/31/18 in Kingston to discuss monitoring methodology options in DKP (meeting notes in Appendix D). This protocol is based upon feedback received during that meeting, and the final document was reviewed by the expert group to ensure consensus with the methodology.

Who?

Monitoring will be conducted by trained volunteers with no previous data collection experience necessary. Volunteers will be solicited by the local watershed group, North & South Rivers Watershed Association (NSRWA), which also hosts the South Shore Regional Coordinator for MassBays. The first year of protocol implementation will be dedicated to training and testing the method while collecting data. Prior to sampling, an onsite training session will be provided by MA DMF and MassBays. Teams of 2-3 volunteers will work aboard watercraft under supervision and operation of MA DMF and MassBays in addition to any volunteer-provided watercraft. In future years, it is the intent that volunteer-provided watercraft can accommodate all sampling needs. Most powerboats and small engineless boats nine feet or greater can accommodate the sampling gear. Sampling from a kayak or small canoe is not recommended due to the lack of deck space and stability.

When?

Sampling will be conducted over a single sampling week (a blitz) to reduce environmental or other fluctuations as much as possible. In the first year, the blitz will be a multi-day effort where supervised volunteer teams are deployed to sample all of the designated monitoring stations. In order to ensure proper data collection and management, and since sampling is targeting a single point in time instead of season-wide, a blitz approach was determined to be the most efficient sampling scheme. The first year of sampling will inform the level of effort (e.g. number of people, boats and sea-days) needed for future years.

Monitoring should take place during the peak growing season for eelgrass when leaf biomass is at its highest, preferably in August. If possible, the same approximate dates should be targeted each year. While no designated tidal stage is required, it is important for samplers to consider depth at tidal stage in their sampling area, as some monitoring stations may be too shallow or too deep to access at certain tides. Time of day should also be considered, as water clarity monitoring via secchi disk must be done between 10am and 4pm. Monitoring of all stations should take place ideally annually but at least every other year to detect acute changes to eelgrass beds.

Where?

The DKP embayment was first divided into the two major sub-embayments of Duxbury and Plymouth Harbors as defined in the DEP 305b Integrated List of Waters layer (available on MassGIS). Within the two sub-embayments, a stratified random site selection was done using eelgrass persistence and sub-embayment as the strata. At the 1/31/2018 meeting, experts agreed that randomized site selection within suitable habitat areas would give a monitoring program the greatest statistical strength, and would help to answer the questions of where eelgrass still exists, if it returns to areas it has previously disappeared from, and if gross changes to coverage and condition are observable across the embayment.

Other site selection models were investigated including randomly located transects, sampling based on a tessellated or grid pattern, and simple random point sampling. These methods were ultimately disregarded because they required too many sampling locations, resulted in over- or under-sampling certain areas of interest, or were not conducive to a volunteer boat and camera based program. Stratified random sampling can provide population estimates for each of the strata, allowing comparison between them, and has the potential to increase precision due to lower standard errors (Levy and Lemeshow 2008).

We first looked at relevant layers pertaining to habitat suitability including bathymetry, sediment type, and presence of previously mapped eelgrass (Appendix E). Other datasets relevant to habitat suitability that were not incorporated due to lack of data include fetch and long-term water quality. All analyses were completed in ArcGIS 10.5. The stratification was focused by sub-embayment (Duxbury and Plymouth Harbors) and presence of previously mapped eelgrass. Bathymetry was used to limit the study area to depths suitable for eelgrass. Sediment type wasn't used since 95% of the embayment has the same sediment type (sand).

To limit the study area to depths suitable for eelgrass, USGS LIDAR data (downloaded from www.sciencebase.gov) were extracted as a raster and converted to points where eelgrass had been previously mapped by DEP's mapping program. Using these points, a histogram was generated to assess the minimum and maximum depths where eelgrass had been identified. Depth contours were then generated using the Create Contour tool at these minimum and maximum depths and used to clip the study area. Mapped aquaculture grant sites were removed from the study area, as were portions of the embayment that are particularly difficult to sample (e.g. very shallow innermost harbors). Manual smoothing of the boundary was done since some boundaries were excessively complicated as a result of the contour line drawing on the raster LIDAR surface.

Three strata were then delineated using an assessment of the frequency in which eelgrass had been identified at a location in the past. The DEP eelgrass polygons from 1995, 2001, 2006, 2012, and 2015 were used to generate raster layers at 27 m^2 cell resolution (all rasters were snapped to the 1995 base layer) and each layer had a cell value of "1" for an area with eelgrass and "NoData" for an area without eelgrass. These layers were then summed using the Cell Statistics tool. The resulting map indicated cells that had been identified as eelgrass once, twice, three times, four times, or five times by the DEP mapping program. This map was merged with the study area map, and all remaining areas were coded as "Never Identified." The three primary stratification units were defined where eelgrass was "Identified 4-5 Times", "Identified 1-3 Times", and "Never Identified". Because the "Identified 4-5 Times" stratum indicates high eelgrass persistence across DEP's survey, sampling stations selected in this stratum are categorized as "indicator sites", suggesting that changes at these stations may be indicative of changes to the greater meadow or embayment.

In order to distribute random samples into each of the six strata (the three eelgrass frequencies in both Plymouth and Duxbury Bays), it was decided to split the samples by each eelgrass frequency unit as follows:

% of all samples	# of samples	Stratum
20%	30	Never Identified
40%	60	Identified 1-3 Times
40%	60	Identified 4-5 Times (indicator beds)

The least degree of variation in eelgrass presence/absence is expected to occur in the stratum where eelgrass has never been identified but habitat may be suitable, therefore this stratum received the lowest proportion of samples (n=30, or 20% of the total samples). To populate the remaining strata, several different split options were explored. Ultimately, while variation has the potential to be highest in the beds of questionable persistence (identified 1-3 times), it is important to adequately sample the most persistent beds since they will act as indicators of change. Therefore, the remaining samples (n=120 or 80% of the total) were equally distributed between these two strata.

The samples were then distributed into Duxbury and Plymouth Bays based on the stratum area within each sub-embayment:

Sub-embayment	Eelgrass Persistence and Indicator Status	# of samples	% of stratum area	# samples
Duxbury Bay	Never Identified	30	80%	24
Plymouth Bay	Never Identified		20%	6
Duxbury Bay	Identified 4-5 Times (indicator beds)	60	80%	48
Plymouth Bay	Identified 4-5 Times (indicator beds)		20%	12
Duxbury Bay	Identified 1-3 Times	60	90%	54
Plymouth Bay	Identified 1-3 Times		10%	6

The ET GeoWizards tool Random Points in Polygons was used to distribute the samples with a minimum distance to the boundary of each polygon of 25 meters to account for unreliable edge data. The resulting sampling stations (n=150) appear well distributed and meet our goals for safety, access and randomness (Appendix F). The same stations will be sampled each survey year to detect changes in eelgrass presence or condition. In the first year, sampling will take place at up to an additional 100 locations to allow for a post-sampling power analysis that will help determine if a statistically suitable number of stations have been sampled.

The organizer may decide to assign specific stations to specific sampling teams based on the volunteer team's available resources (boat type, access, preferred launch site, etc). This approach may also serve to increase ownership of the stations and those eelgrass beds.

How?

Training will be provided prior to sampling, and all monitoring will be done in accordance with the Division of Marine Fisheries Standard Operating Procedures (SOP) for Citizen Science Eelgrass Monitoring (Appendix G). Volunteers (and organizers, in year one) will provide a stable vessel with standard safety equipment. Monitoring kits will be provided by MassBays/MA DMF to each volunteer team and will contain all equipment needed for sampling (Appendix H). Targeting the hours between 10 am and 4 pm during August, volunteers will navigate to each of the stations using provided GPS coordinates. Once anchored, volunteers will follow the SOP to record water clarity using a secchi disk, collect photos of the eelgrass in a quadrat placed on the seafloor, and record percent cover. The photo-sampling will be repeated at four corners of the boat to create replicates and improve statistical strength of the survey. At designated indicator stations, additional sampling will include conducting four plant grabs to record leaf measurements, collecting sample photos and assessing disease and epiphytes. See Appendix G for a detailed step-by-step field protocol with visual guides, and Appendix I for Field Datasheets.

Data obtained from the underwater photographs and eelgrass samples taken at indicator stations include presence/absence of eelgrass, percent cover, and canopy height, as well as presence or absence of wasting disease and epiphytes. Additional data to be collected include topside information (date, time, names of volunteers, and weather conditions), water depth and secchi depth readings. All data will be recorded on the paper data sheets provided, which will then be submitted along with photos to the appropriate location per the Data Management section below. To assist in the collection of these data, laminated SOPs for all methods, visual guides and equipment are available in the monitoring kit.

The protocol in Appendix G uses commonly measured parameters as indicators of eelgrass structure and function (Evans and Short 2005). Eelgrass canopy height changes seasonally and responds to water quality and periods of low light. Therefore, changes in canopy height may be indicative of stress in a system (Olesen and

Sand-Jensen 1993). Likewise, epiphyte coverage and wasting disease both limit photosynthesis and therefore can serve as a proxy for plant fitness (Broderson et al. 2015; Burdick et al. 1993). Tracking wasting disease coverage may help researchers understand certain trends in eelgrass loss. A secchi disk is used to measure water transparency, which is important as it relates to light available for plant growth. The secchi depth is the depth at which a weighted black and white disk is just visible through the water column, corresponding to the depth at which approximately 10% of the surface light remains (Wetzel 1983). The relationship between secchi depth and the light attenuation of Photosynthetically Active Radiation, the portion of the light spectrum used by plants, is nonlinear and dependent on particles and color in the water column that effects how light is absorbed or scattered (Holmes 1970). However, secchi depth commonly serves as an index of water quality. Light availability is recognized as the most important factor regulating eelgrass depth limits (Olsen and Sand-Jensen 1993) and eelgrass requires between 11 and 33% of surface light to thrive (Ochieng et al. 2009). Therefore, secchi depth measurements may help inform if changes in light conditions are taking place spatially or temporally. The use of a "view bucket" or "look box" in combination with the secchi disc helps to reduce glare and light refraction off the water leading to a more accurate and consistent secchi depth reading.

Data management

For the first year of sampling, data will be collected using the provided datasheets (Appendix I), provided in the monitoring kit. For future years, an app may be developed that will facilitate data collection via a tablet or smartphone. Photos are collected onto the SD card in the camera. The organizer will meet the sampling teams at the beginning of each day to provide kits and blank SD cards.

At the end of each sampling day, paper datasheets and camera SD cards will be turned in to the organizer (Sara Grady at NSRWA/MassBays). The organizer will scan and save the sheets and file the paper copies as soon as possible. The photos will be downloaded from the SD cards into a designated electronic folder. Photo file dates and times will be verified to be accurate. If they are not accurate, they must be placed in a subfolder named with the correct date and the sampling team (e.g. 08202018_team4) to minimize file confusion.

Other processing steps that should be done soon after sampling are as follows:

1. Data from the paper datasheets is entered in an Excel database and each entry checked for quality control (QC) by a second person.
2. Review the photos from each station. Delete extra photos (no more than two representative photos for each sample are recommended) and rename photos with the date, station and sample number (e.g.

Station5quad_Sample2_082018, or Station5anchor_Sample2_08202018). There will be at least four quadrat photos at every station plus an additional four anchor-collected sample photos taken at certain stations, so proper file organization is important to avoid confusion.

3. Back up all datasheets and photos to an online cloud storage service such as Dropbox, OneDrive, or Google Drive.

All of these tasks can be completed by the organizer or a volunteer specifically trained in the management of these files.

Another important form of QC is the periodic spot-checking of the collected data by visually comparing the eelgrass percent cover reported on the datasheet to the underwater photos collected during sampling. In the first year, QC should be done for all data collected at all stations. Subsequent years that involve repeat-volunteers might require less QC, at the organizer's discretion. If concerning mischaracterizations are found during QC, retraining should take place with the appropriate samplers, and the organizer should determine whether the images should be reprocessed and the data updated.

When all data are entered, analysis can take many forms: a spatial display of presence and absence across the embayment, analysis of variables by indicator bed, and integration with other mapping and water quality data. Neckles et al. (2012) ran an inverse distance-weighted spatial interpolation in ArcGIS to show bay-wide patterns, and used general linear models to quantitatively compare variables over time. While the data will be housed at NSRWA/MassBays, MA DMF recommends shared access and partnership in data analysis and distribution. The use of cloud storage backup will enable easy sharing.

As with all sampling, it is important to have a way to measure the success of an effort. In this project, success of the first year of sampling will be evaluated based on whether or not all stations were sampled as described and all parameters were able to be sampled. Volunteers will be solicited for feedback based on their experience. Following the first year, completion of a power analysis will help determine if an adequate number of stations were sampled. Protocol issues that may not be improved through experience will necessitate a re-evaluation of the methodology.

Other Recommendations

In addition to the citizen science protocol described above and in the appendices, we provide these additional recommendations regarding eelgrass monitoring in DKP:

Broad-scale recommendations: MA DMF recommend the continuation of the long-running, carefully standardized survey that DEP's eelgrass mapping program oversees for broad-scale surveying of eelgrass spatial extent in DKP. Other methods should continue to be experimentally explored (e.g. U.S. EPA satellite imagery studies). If a more efficient methodology is developed, it should be standardized to the DEP mapping methods.

Meso-scale recommendations: MA DMF recommends a meso-scale survey effort in DKP that combines periodic acoustic surveys and the quadrat-based photo survey described herein. Acoustic surveys should be performed biennially or as funding allows, following the MA DMF Guidelines (available upon request). It is likely that the quadrat-based survey can indicate areas of interest where the acoustic survey should be focused.

Fine-scale recommendations: The recommended fine-scale strategy for the DKP embayment is the establishment of a *SeagrassNet* site. *SeagrassNet* is a scientific global seagrass monitoring program that combines plant collection, underwater surveys, and photography into a standardized protocol (Short et al. 2006). By utilizing this standardized protocol, acute changes in specific beds of interest in DKP may be identified and compared to changes to other eelgrass beds monitored with the same methodology locally, regionally and internationally.

Closing Remarks & Acknowledgements

This document and its appendices are intended to guide the monitoring of eelgrass in the Duxbury, Kingston and Plymouth embayment. As this is a pilot study, this methodology may be amended over time to incorporate lessons learned. It is hoped that these methods can be easily applied to other embayments where eelgrass monitoring is needed and citizen scientists are actively engaged.

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Appendix A: Broad-scale Monitoring

Broad-scale monitoring is typically designed to answer questions about gross changes to eelgrass in an embayment or a region, such as presence/absence over time. Images collected by remote sensing or aerial photography methods are often used as a primary method to collect and interpret seagrass distribution and meadow size over a broad area over time. Aerial photographs taken at low altitude first captured by balloons in 1855 are now captured by airplanes and drones (Barrell and Grant 2015, Nahirnick et al. 2017). Remote sensing using satellites started in the 1960s by the military has expanded to methods also using aircrafts and drones. There are advantages and disadvantages to both aerial photographs and satellite imagery of subtidal habitats. While satellite imagery is more cost effective and time efficient for rapid, repeated observations over large regions, it typically provides lower resolution than aerial photographs (Larsen et al. 2004; Chandler et al. 2002) and there is less control over the ambient environmental conditions. The interpreter of satellite images has to account for atmospheric interferences, variability in water depth and bottom albedo, water column attenuation by scattering and absorption, and bottom reflectance variability (Cho et al. 2012; Haddad and Harris 1985; Ferguson et al. 1993; Jensen et al. 1987). Similarly the interpreter for aerial photography needs to account for environmental conditions such as low altitude atmospheric conditions, sea state, water clarity, and water depth (Dobson et al. 1995). Aerial photography lends itself to more flexibility in scheduling around the time of day, sensor altitude and flight line placement, unlike satellite imagery which is more opportunistic (Dobson et al. 1995).

Since 1995, DEP's Eelgrass Mapping Program has collected aerial photographs and field-groundtruthing data to map eelgrass coverage in coastal waters and therefore characterize overall eelgrass trends. DEP's survey is conducted yearly at select embayments on a rotating schedule, therefore individual embayments are revisited every 3 to 5 years. DEP standardizes image collection to ensure maximum eelgrass visibility, following the Coastal Change Analysis Program (C-CAP) standards for aerial photographic surveys for seagrasses (Costello and Kenworthy 2011; Dobson et al. 1995; Finkbeiner et al. 2001). True color aerial photography taken at a scale of 1:20,000 between May and early August requires specific environmental conditions including near to low tide, sun angle <25°, winds <5 mph, minimal cloud cover, no haze, fog, or rainfall or high winds within the previous 48 hours (Costello and Kenworthy, 2011). DEP collected aerial imagery in DKP in 1995, 2001, 2006, 2012, and 2015. Delineations based on the aerial photographs are groundtruthed with underwater video surveys. In addition, DEP utilized Massachusetts Department of Transportation (MassDOT) photos in an effort to establish an eelgrass baseline for 1951. The 1951 photos were not taken using the same specifications as applied by DEP, but were the earliest and best images available at that time (Ford and Carr 2016).

In Massachusetts, a mix of non-profit, Federal, and State agencies have collected aerial photographs to monitor eelgrass beds to provide supplemental perspective of areas of interest seen in DEP images and also help qualitatively assess specific beds between DEP mapping years (Ford and Carr 2016). These images are all taken with a variety of cameras aboard a variety of platforms, and methods are not standardized across different survey groups. The Center for Coastal Studies (CCS) in Provincetown has conducted aerial photo surveys at least three times per year since 2007 to collect eelgrass imagery over Cape Cod Bay embayments. Surveys are conducted during March/April (pre-growing season), July/August (peak growing season), and October/November (post-growing season). The United States Geological Survey (USGS) collected aerial photography in 2013/2014. MA DMF conducted qualitative aerial photo fly-overs of DKP and several Buzzards Bay and North Shore embayments in September 2014 using a volunteer pilot service. The U.S. EPA is currently investigating the use of satellite imagery for eelgrass mapping in select Massachusetts embayments on Cape Cod (Phil Colarusso, pers. comm.).

Other methods to monitor eelgrass include using satellite imagery, terrestrial oblique true color large-scale photography or optical imaging systems, and lightweight drones (Andrade and Ferreira 2011; Duffy et al. 2018). These methods are relatively low-cost alternative to aerial photography but have their own limitations. Satellite imagery methods involve the interpretation of satellite-acquired aerial imagery for eelgrass signatures. Available imagery has varied resolution ranging from 30m for Landsat Thematic Mapper, 4m for IKONOS, 2.44m for QuickBird multispectral data, and 1m or less for airborne hyperspectral data (Cho et al. 2012; Knudby et al. 2010; Lyons et al. 2015; Roelfsema et al. 2014). Resolution can be a potential hindrance, as can the timing of satellite fly-overs, cloud cover, waves, tidal conditions and other environmental factors. The terrestrial oblique method uses photographs taken monthly during low-water spring tides, from a fixed elevated point. Orthophotographs, with the metric qualities of a true map, are produced by correcting the oblique images that had distortions due to relief and photo-tilt and lens effects (Wolf 1980; Chandler et al. 2002). Finding an elevated point overlooking the area of interest is the main limitation for this method. A study by Duffy et al. (2018) used a drone and consumer grade cameras to produce very high spatial resolution (~4 mm $pixel^{-1}$) mosaics of intertidal sites in Wales, UK. Drones allow for higher resolution with additional flexibility in deployment capabilities and customization (Duffy et al. 2018). Limitations similar to satellite and aerial photography include turbidity, waves, cloud cover, weather (e.g. rain or fog) and water column height (Andrade and Ferreira 2011; Duffy et al. 2018). Also, drones typically have a short flight time and regulatory operational limitations, so can only be used over small areas.

Appendix B: Meso-scale Monitoring

Meso-scale monitoring usually involves ground-based assessment of a specific embayment or meadow. This level of monitoring can be used to estimate the coverage and quality of seagrass beds at a higher resolution and can include physical, chemical, or biological parameters of the bed (Brooks et al. 2004, Neckles et al. 2012, Hogrefe et al. 2014, Vandermeulen 2014). Detected changes might include density, percent cover, canopy height, sediment characteristics, or observation of changes to algae communities. The information can be used to monitor meadow-scale changes in extent, and to predict or explain changes in areal extent (Hogrefe et al. 2014, Johnson and Thedinga 2005). Examples of meso-scale surveys include acoustic remote sensing surveys (Ford and Carr 2016, Barrell et al. 2015, Vandermeulen 2014, Sonoki et al. 2016), randomized quadrat-based surveys

(Neckles et al. 2012, Raposa and Bradley 2010), systematic point sampling (Hogrefe et al. 2014), towed underwater video surveys (Berry et al. 2003, Fonseca et al. 2002, Vandermeulen 2014), unmanned surface vehicles (USV) equipped with sidescan sonar sensors (Klemens 2017), and benthic grab surveys (Short and Coles 2001, Norris et al. 2001, Moller and Martin 2007, McKenzie 2003).

Remote sensing methods that utilize active sonar (e.g. by emitting pulses of sound) can collect fine-scaled measurements of large seagrass regions, even in deep coastal water (Hossain et al. 2014), while remaining relatively cost-effective and easily repeatable (Barrell et al. 2015, Neckles et al. 2012). Numerous sonar arrangements are available including echosounders, side-scan sonar and seismic hydrophone systems, of various frequencies and beam counts. Acoustic methods are less affected by water clarity and turbidity compared to photo interpretation methods, and some researchers have been able to produce algorithms to compute canopy height of seagrass beds (Hossain et al. 2014). Generally though, acoustic methods require specialized equipment, trained staff to collect and process the data, and additional time and resources to groundtruth the survey area. Since 2014, MA DMF has conducted three acoustic surveys in DKP. The 2014 survey utilized both echosounder and sidescan sonar equipment and sampled at least one transect through every bed in DKP. Follow-up surveys in 2016 and 2017 utilized only side scan sonar and operated as more of a spot-checking effort, where certain beds of concern were targeted with one to two transects. Ideally, transects should be spaced so that adjacent image swaths overlap by at least 50%, and cover the entirety of the bed. A survey of this magnitude has not been conducted in DKP.

Quadrat-based assessments or systematic point sampling from a boat at permanent sampling stations provide an estimate of percent cover and canopy height within a bed and therefore allow users to establish trends in the health and condition of eelgrass beds over time (Neckles et al. 2012, Hogrefe et al. 2014). To measure percent cover an underwater camera takes a picture of a quadrat on the seafloor that is analyzed either in real-time or later in the lab for eelgrass coverage. To measure canopy height, a benthic grab survey is done in which a small anchor is used to collect samples to measure leaf length. The time and resources required for quadrat-based assessments depend on the size of the eelgrass meadow and number of sampling points. Underwater video surveys with 10cm scaling lasers provide accurately scaled images that can be used to estimate percent cover and health of the meadow (Vandermeulen 2014). Underwater videography is useful for deeper and/or larger beds and is better at discerning eelgrass from other vegetation than remote sensing or aerial imagery methods (Berry et al. 2003). However, it requires a trained observer to assess hours of video tape.

Appendix C: Fine-scale Monitoring

Fine-scale monitoring can include many approaches including plant collection, underwater surveys, and photography. Collecting data at this resolution can help identify stressors and their particular impacts on eelgrass. While these efforts cover a very small study area and often require SCUBA and other advanced training, repeated monitoring of plant and habitat parameters provides baseline information and a means of comparison to assess changes in eelgrass (Neckles et al. 2012). Through these approaches, detailed information related to potential impacts can be gathered such as morphological and reproductive condition of plants, presence of grazing, disease, and any other environmental variables (Short & Coles 2001).

SeagrassNet is a scientific global seagrass monitoring program that combines plant collection, underwater surveys, and photography into a standardized protocol (Short et al. 2006). By utilizing this standardized protocol, acute changes in specific beds of interest may be identified and compared to changes to other eelgrass beds monitored with the same methodology locally, regionally and internationally. A *SeagrassNet* site is made up of three 50-meter transects (deep, mid, and shallow depths) each with 12 predetermined randomized quadrats, where data collected include: percent cover, shoot density, canopy height, number of reproductive shoots, presence of invasive species, evidence of grazing, collection of a digital photograph, and collection of a biomass indicator. Transect level data collection includes water and sediment samples. Water samples are collected in a sealed vial from the canopy of the eelgrass at each transect, and are then processed with a refractometer to obtain salinity readings. Sediment samples are taken once at each transect to detect changes to the primary and secondary sediment types. Post-monitoring lab work involves processing the indicator samples taken at each quadrat to obtain the dried biomass of each shoot's leaves, stem, and root.

Site selection is a crucial component to the success of *SeagrassNet* monitoring. The ideal site lies within an eelgrass meadow that is representative of the location (Short et al. 2006). Because *SeagrassNet* sites are permanent, it is imperative that ease of access should be considered in the site selection process. Locating the permanent transects in a range of conditions from pristine to stressed within a single site is optimal to thoroughly monitor changes to the eelgrass bed. Targeted locations should have consistent eelgrass presence currently and historically.

Appendix D: Stakeholder/Expert Meeting Minutes (1/31/18)

Eelgrass Experts Monitoring Methodology Meeting

January 31, 2018, 12:30-3:30pm
Kingston Town Hall
Hosted by: NSRWA/MassBays, DMF

Attendance:
Alex Boeri, MassDMF
Susan Bryant, Cohasset Center for Student Coastal Research
Jill Carr, MassDMF
Phil Colarusso, EPA
Bill Doyle, MFAC, Plymouth Rock Oyster Growers
Tay Evans, MassDMF
Kate Frew, MassDMF
Joe Grady, Duxbury Conservation
Sara Grady, MassBays/NSRWA
Randall Hughes, Northeastern University (by Skype)
Raymond Kane, MFAC, Comm. ASMFC
Michael McHugh, MassDEP
Gregg Morris, Two Rocks Oyster Farm/fisheries researcher
Alyssa Novak, Boston University
Ann Priester, Island Creek Oysters
Forest Schenck, Northeastern University
Kaitlyn Shaw, Town of Nantucket (on phone)
Juliet Simpson, MIT Sea Grant
Dante Torio, Jackson Lab UNH
Kim Tower, Plymouth DMEA
Prassede Vella, MassBays/CZM

Sara Grady led introductions around the room and summarized the agenda. Susan Bryant recorded the meeting with audio and video equipment.

Eelgrass Trends
Jill Carr described 60 years of eelgrass trends in mapping data from DKP. Severe losses have been observed in aerial (DEP) and acoustic (DMF) mapping programs. Losses have occurred gradually and constantly, from both the shallow and deep edges, and across the embayment. Stressors were briefly discussed. The group was asked to identify questions they have about the embayment that can be answered through eelgrass monitoring. Over the course of the meeting, the group came up with the following:

- Where does suitable habitat exist? Consider identifying habitat suitability and use that to select monitoring sites. Define areas of historic eelgrass and add any areas where eelgrass could recruit into today where it wasn't in the past. Use this in monitoring site selection.
- How does system-wide health compare to specific bed health (and which is our goal?)
- Can sediment cores reveal changes in nitrogen over time and help describe losses? Maybe do a single-time deep coring, and then volunteers could collect surface sediment samples to create a bathymetry map of the embayment
- Can we track a rebound? Recent recoveries in Chesapeake Bay and Great Bay are encouraging
- Are changes in density predictive of loss, as it appears to be in remote sensing analysis?
- Is reproductive success changing or becoming a limiting factor? (fewer repro shoots, poor seed dispersal)
- How are plants responding to stressors (and what are those stressors? Need continued work on determining cause for loss and current stressors).
- When grass disappears, does it ever come back? (historic areas)

- Are light conditions favorable, and can monitoring incorporate light and other WQ? (put sensors on the drop frames)
- Can monitoring the wrack line tell us anything about the cause of loss? (e.g. roots present or clipped)
- Will dividing up the survey areas by volunteer group help increase stewardship and regularity of sampling at that site?

Discussion about eelgrass changes and stressors in DKP:

- In 2014, only 987 acres remained in an embayment that may have supported 3400ac (1951). 70% loss in 60 years, 50% loss in last 5 years.
- Aquaculturists noted a huge mussel set in all of DKP in 2015-2016 could be why mussels have moved in, as evident in the photo from Saquish Head. Spat comes from upper harbor and can be very episodic depending on weather.
- Interesting discussion: Can mussels be harvested and eelgrass planted in pockets within the mussel bed? Utilize the structure of the mussel bed to protect the eelgrass and dissipate the bottom sheer stress.
- Bill Doyle- Recent observations from locals around Clarks Island show heavy erosion at location of mussel beds, with previous sand bottoms now appearing to be hard clay. Super-hot summer days last year may have killed mussels and allowed for scour. Discussed how variable mussel beds can be, sometimes a lot – sometimes none.
- 1920s-1970s: Clarks Island was surrounded by mussel beds. Check for historic maps or DMP estuary reports showing mussels?
- Observations of increased Ulva and red/brown algae recently, and increased tunicates/sponges. Ulva is heavily fouling oyster gear. Especially last 10 years. Concerning given the water quality implications. Many observations of green crabs, but no historic data.
- Aquaculturist observation: Some of the flats that used to have eelgrass are now getting deeper due to scour. The grass is no longer binding the sediment. (specific to Duxbury beds)
- Potential increase of nutrients in bay (N +P)
    - Major increase of *Ulva* recently
    - Tunicates also covering a great deal of eelgrass – however Phil does not think it would be enough to cause major loss of eelgrass
    - K. Shaw - Water quality at the CCS monitoring site in 2012 was 0.5 mg/l total nitrogen and the eelgrass threshold is 0.37mg/l, so there may have been stress from increased nitrogen in the system – look into again, I think DMF found no significance.
- Kaitlyn Shaw: Could look at contaminants in the water (pharmaceuticals and others). We have also heard this in the past from aquaculturists – interest in looking into herbicides, pesticides, fertilizers.
    - CFCS looked at contaminants in Cape Cod Bay, but not DKP
- Weather (Bill Doyle):
    - Harbor had 18" of ice in 2014
    - Two 100 year storm events in the last few years (Hurricane Sandy, Blizzard'17)
    - Winds and storm surge caused increased water level for extended period of time and fast outgoing currents
    - When water receded, extreme currents may have removed sediment/grass
    - DMF: Wind direction has shifted over time: measurable in weather data, but needs more work
- Bathymetry
    - Dramatic shifts in sediment recently – some locations gaining 2-3 inches of sediment a year (per aquaculturists)
    - Scouring observed in some locations
    - Some areas of loss now appear to be exposed at mean low – could this have caused some loss?
    - Changes in bathymetry can occur rapidly when eelgrass/mussels leave an area
- Alyssa Novak: Ammonia production from oysters is toxic to eelgrass and could be a contributing factor to the eelgrass decline. No one has looked into this for DKP but we should

- Plausible that losses are a result of recruitment issues in the embayment. Should quantify reproductive shoots in monitoring. Maybe it didn't recover due to lack of seeding – Phil
- Loss might be due to all of the above – possibly storms knocked out the eelgrass and then it couldn't rebound due to changes in the habitat suitability, either because of poor water quality or changes in hydrodynamics or other.
- 80% daily flushing in the system, some think that means it is unlikely to be a nutrient loading issue
- Green crabs were noted as a nuisance – local aquaculturist comment
- Chlorophyll data are available from landsat analysis – viewed map of DKP showing hot spots (Dante Torio)

Mapping
Sara Grady presented various mapping approaches seen in the literature. Some studies identify DKP as a macro-scale site based on its size (around 39km^2), and monitoring in an embayment of this size should be limited to remote-sensing methods. However, we have observed large losses that have raised large questions, which may become elucidated with Tier 2 and 3 monitoring.

The tiered approach was presented as a goal, but the floor was opened to other monitoring strategies or methods. There was some discussion about doing multiple transects (using towable cameras or snorkelers) rather than point-locations. Tay Evans also suggested a protocol that would give flexibility to the samplers, for example the drop-frame camera would be the bare minimum, but if samplers were able and interested, they could expand to collect more data by doing snorkel work along transects.

There was discussion about installing acoustic mapping equipment on volunteer boats and having them run surveys during their normal operations. While this would collect more data, it would have a heavy training, QA/QC and data processing element, and may result in more sporadic data collection over various spatial and time scales, which would be difficult to interpret. Acoustic surveys require vessels to run around 3-4kts in calm weather conditions, and often multiple passes over the same area may be needed for adequate data – this can be challenging if volunteers are trying to tack the effort onto their other boating needs that day.

In general, there was good agreement around using the following tiered approach:
Tier 1 – continued DEP aerial mapping (every 5 yrs)
Tier 2 –Neckles (2012) hexagonal grid sampling method with drop-frame camera PLUS
continued DMF (or other) acoustic mapping (annually, biennially?)
Tier 3 – establish one SeagrassNet site (3 transects) at a relatively stable bed

Other Mapping Thoughts
- Fish finder sonar – could volunteers do it instead of DMF? (Juliet Simpson)
    - Issues with this include standardization of equipment, method of scan, areas scanned etc. see above
- Put HOBO's out in the Bay to observe temperature changes (Phil)
    - According to aquaculturists, Plymouth already has tidbit sensors deployed – collaborate with towns if possible
    - Check to see if towns would volunteer/contribute to the project at all
    - Mentioned that Providence Center for Coastal Studies monitors water temp
- Tier 3 sites – more than one necessary for best results?
    - One real SGN site would allow for results to be given to SGN
    - Two would allow for a healthy site and a stressed site to see changes over time (Phil)
- Volunteers can be used to look at eelgrass that has washed ashore for existence of roots etc. Would this be helpful to the monitoring effort?
- Connect with Jarrett Burns at UMB, doing citizen science with kelp

- Keep in mind that satellite imagery is constantly improving, and may become more of a tool for eelgrass in the future (Phil C is starting a new project on this)
- DEP (Mike McHugh) finds this info very helpful – ground efforts can help inform their aerial survey delineations (need more info on what format and what info would be helpful)
- Consider having volunteers use YSI's at each site, or have YSI data collection on a separate sampling day
- Consider incorporating coring and surface sediment collections. Coring in areas with existing AND historic eelgrass will be very telling. Don't core in bare areas since sediments may have shifted (Alyssa)
- Check in on dye study in Plymouth – hasn't happened yet
- Susan/Dante – consider ArcGIS online data entry form (but keep access and security in mind)
- Include in protocol how to deal with drifting vs anchoring at a site

Input provided post-meeting

2/1/18 phone call between J.Carr and Hilary Neckles:

- Perfectly OK to reduce total sampling area to eliminate channels and other unsuitable areas.
- The Neckles et al (2012) methodology was easier to conduct at Pleasant Bay than Great South Bay due to embayment size. The smaller, the easier. DKP is of similar size to Pleasant Bay.
- The method is working really well for them. It is tracking changes in the embayment.
- The method is repeated every 3 years. Adding in the index site was very helpful; it identified losses along the deep edge recently. Also ID'd ulva colonization.
- At first, it took 3 people about a week to sample 170 hexagons (about half of which were vegetated). Now, with more routine, it takes 2 people just 3 days. Hilary estimates it may be a 6 day task in DKP, to start.
- The method would vary depending on the tidal cycle and visibility. In shallow water, they could simply look over the side. Up around 1m deep, they used a view scope. Beyond that, underwater camera. They also incorporated some "drive-overs", which were quick checks of areas that were already known to be bare, and quickly confirmed without anchoring and conducting full sampling.
- Site selection involved overlaying 500m wide hexagons, and then randomly generating a sampling point within each cell. These sites are revisited with each sampling effort.
- For rake sampling, at least 3 terminal shoots were grabbed for canopy height measurements. At deeper sites (need more info – how deep is too deep?), the rake is challenging and the anchor could sometimes be helpful.
- Data can inform density changes, and can also produce a % cover map of the embayment.
- Target peak canopy height (July/Aug), and target the right tides for the site (ideal timing depends on what depth you are targeting).

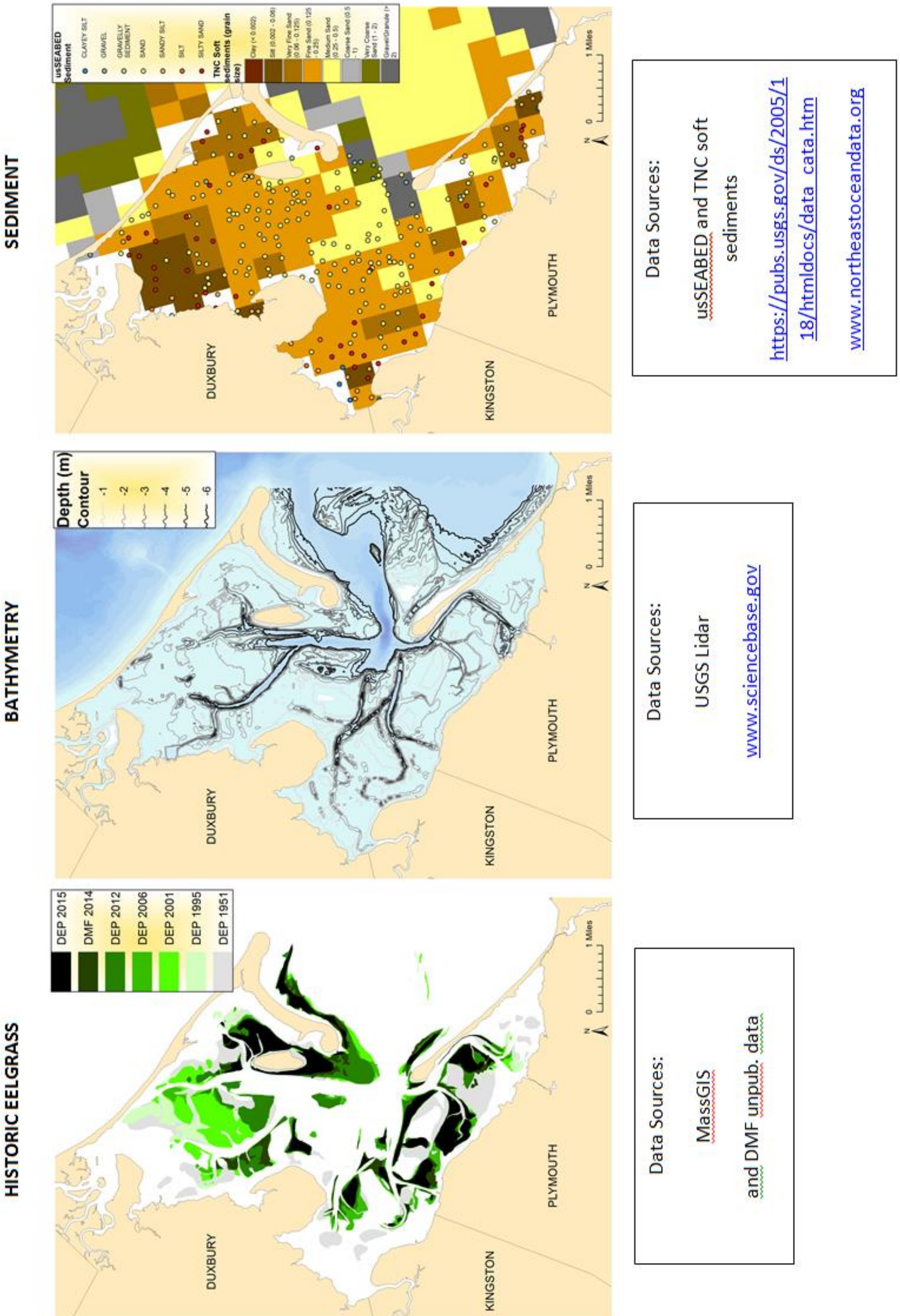
2/2/18 email from Forest Schenck to J.Carr

- Having citizens collect density data may be problematic due to accuracy and access, but the data could be really informative in understanding bed changes across the embayment
- Citizens doing presence/absence, depth and WQ testing along with other ongoing WQ work could help predict seagrass suitability. But are suitability models useful? It's not as though restoration is an immediate plan.
- Interesting idea to test suitability by doing test transplants throughout embayment, which may get at questions of habitat suitability as well as responses to stressors. Seeding could be an easy citizen program

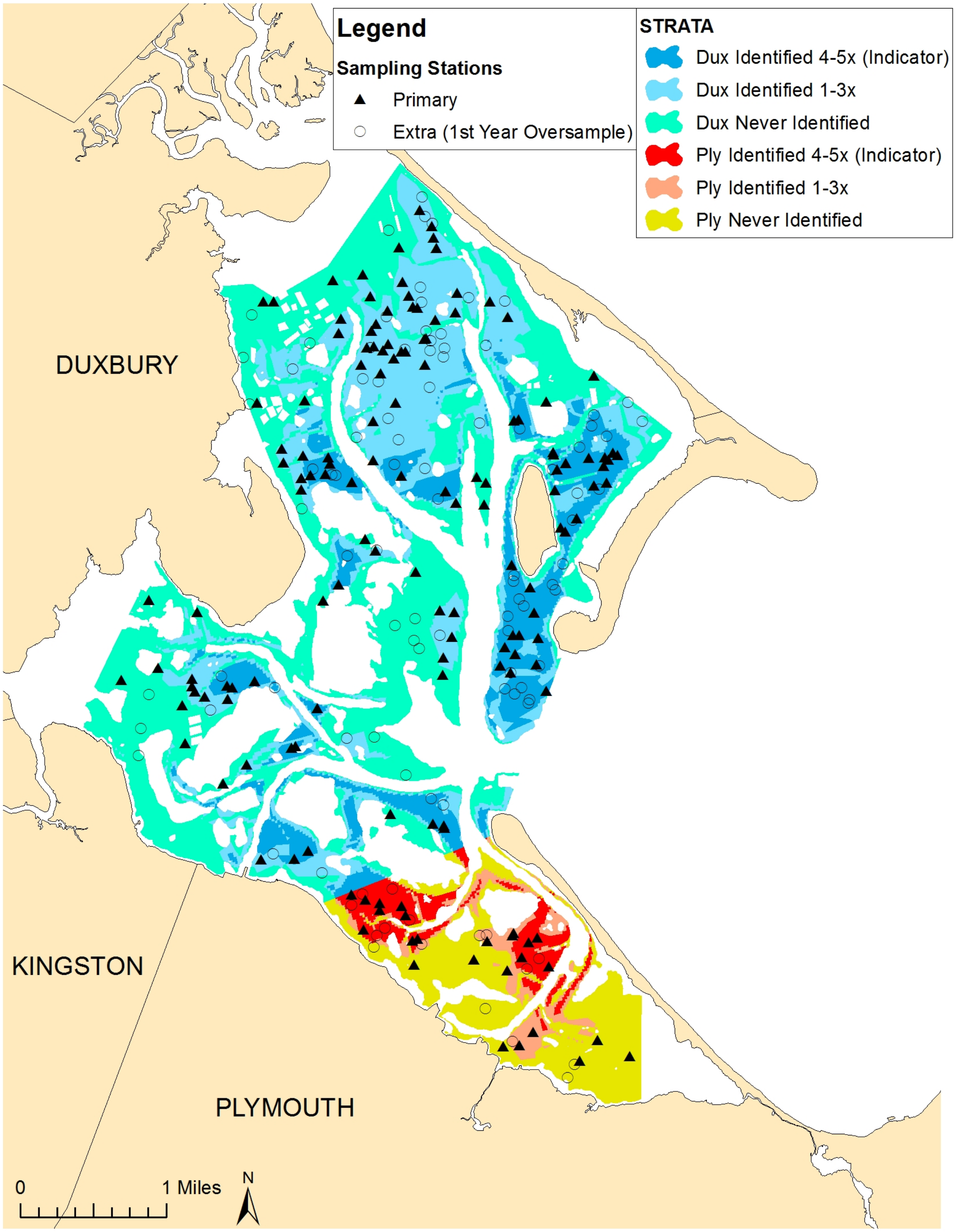
2/1/18 email from D. Torio to J.Carr

- Dante provided powerpoint of his citizen science protocol for monitoring eelgrass in Canada
- Shared chlorophyll, temperature, NIR (Near infrared/Red Reflectance, a vegetation index) data for GIS
- Use of ipads to collect data in the field, data go directly into a webmap

Appendix E: Habitat Suitability Maps



Appendix F: Site Selection Map



Appendix G: Standard Operating Procedure

Massachusetts Division of Marine Fisheries Standard Operating Procedure
Citizen Scientist Eelgrass Monitoring

Version 1, Created by T. Evans and J.Carr, 08/2018

Point of Contact:
Jillian.Carr@state.ma.us
MA DMF Annisquam River Field Station
30 Emerson Ave.
Gloucester, MA 01930
978-282-0308

OBJECTIVE: Volunteer monitoring of eelgrass extent and condition annually in DKP. Volunteers will take measurements at fixed stations assigned throughout the embayment using a stratified repeated random design, in accordance with the document titled "Eelgrass Monitoring: Development of a Citizen Scientist Monitoring Method - Pilot Study in Duxbury-Kingston-Plymouth Bay". Sampling will be performed at peak biomass in August according to the following procedure.

I. GEAR LIST:

Shallow draft vessel
Coast guard required safety gear
Boat anchor
GPS unit with accuracy of 4 m or better
Monitoring Kit contents:

- Clipboard, datasheets, pencils, laminated SOPs
- Underwater digital camera, reel, and case
- 0.25 m^2 PVC quadrat drop-frame, line
- SD card and charged battery for camera
- Secchi disk, line
- Measuring tape
- View Scope bucket
- Small Danforth anchor and small mushroom anchor, line
- Misc: zip ties, duct tape

II. SUMMARY

<u>At **all** stations:</u>

- Navigate to the station using GPS coordinates and anchor the boat, record actual coordinates and other topside information.
- Record secchi disk measurements at two locations on the sunny side of the boat using the view bucket.
- At four cardinal directions around the boat, use the drop-frame to take a sample picture and estimate the percent cover within the quadrat using the visual guides.
- Review data to ensure accuracy. If there are any changes, cross out the original and initial the change.
- If not an "indicator" station, raise the anchor and navigate to the next station.

<u>Additional sampling at **indicator** eelgrass stations</u>:

- At each of the four cardinal directions around the boat where eelgrass was observed, use the Danforth anchor to take a bottom grab sample, collecting at least three shoots per sample.
- Identify the longest leaf from each shoot. Measure the leaves and estimate coverage of wasting disease and epiphytes, and record.
- Lay the shoots on the tote cover and fan the leaves, collect photos of the sample using the underwater camera.
- Raise the anchor and navigate to the next station.

III. DETAILED METHODS:

1. Navigating to the station
    - Volunteers navigate using their boat's GPS (or a hand held unit if necessary) to get as close to the monitoring station as possible. Stations are defined as the area within a 10-m radius circle of the GPS location, accounting for boat swing and GPS error.
    - Once on station, turn the boat into the wind or current, whichever is strongest. Anchor the boat by lowering the anchor off of the bow. Let out the necessary scope.

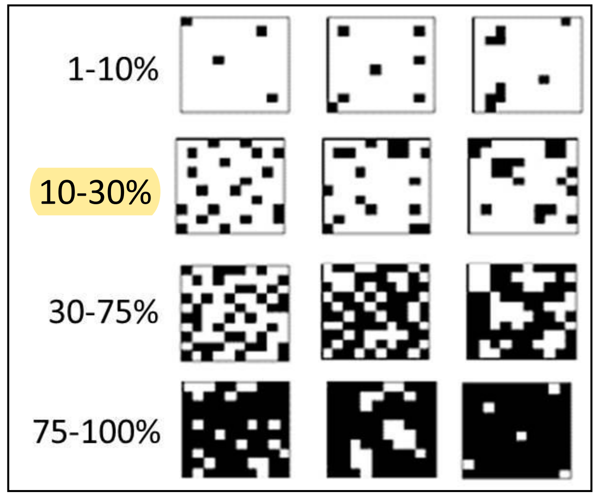
2. Data collection at all stations: Secchi disk

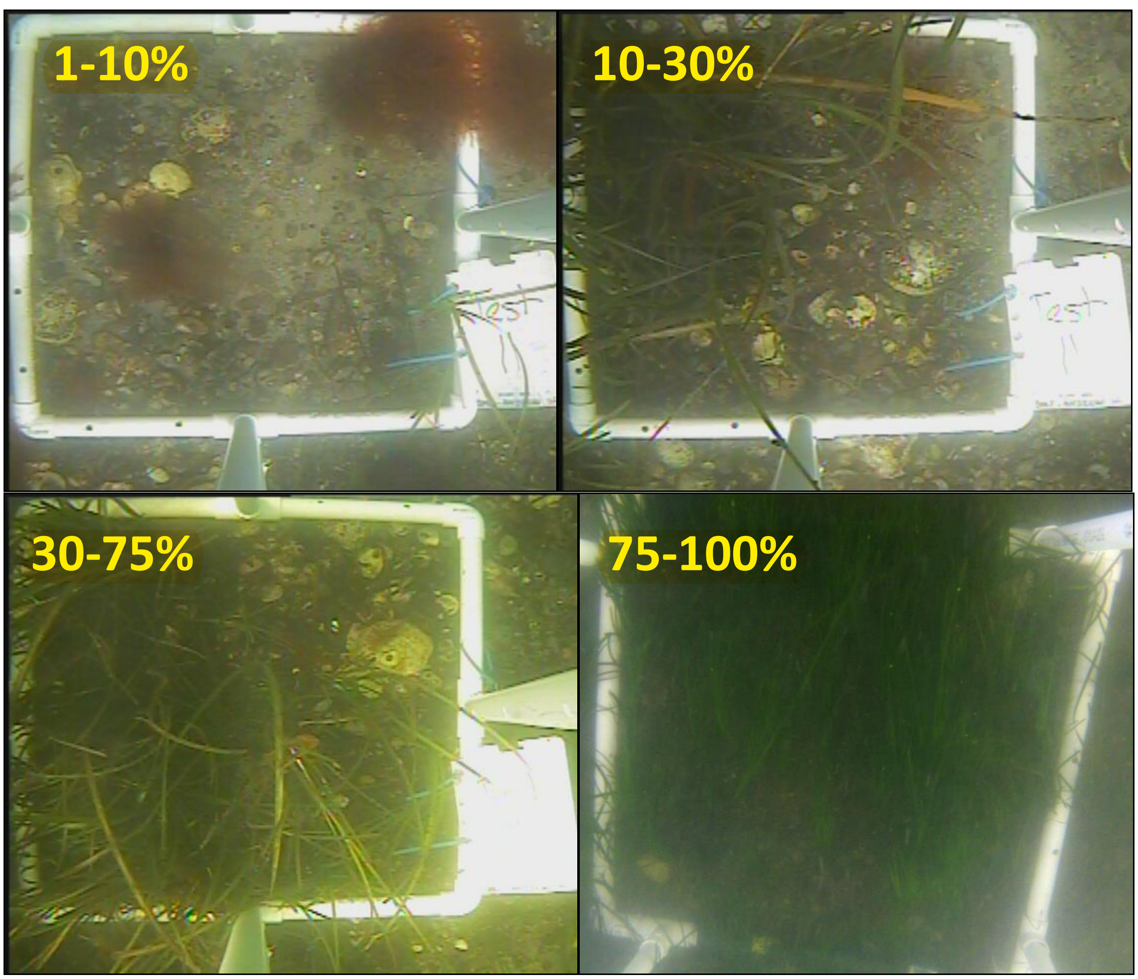
    A Secchi disk is a weighted 20 cm diameter disk painted black and white with an attached line. Ideal weather conditions for accurate secchi data collection include sunny or partly sunny skies; calm winds (≤10 knots) and little to no chop (waves on the water). Collect secchi measurements between 10 am and 4 pm. Ideally, water level should be about 50% greater than the secchi depth so that it is viewed through the water column rather than against bottom-reflected light. This may not always be possible in DKP. If the disk hits the bottom, record "bottom" under secchi depth with the water depth indicated.
    - Record the time, weather observations, water depth and other trip information on the datasheet.
    - Remove your sunglasses, as they will give you an inaccurate reading (but be sure to wear regular corrective lenses if you need them).
    - Unwind several meters of the Secchi disk rope from the holder.
    - Lean over the sunny side of the boat and submerge the bottom 1-2" of the view bucket into the water.
    - Another volunteer slowly lowers the secchi disk into the water until the viewer can no longer see it. Slowly raise the disk. When the secchi disk reappears, mark the rope at the surface of the water with a clothespin.
    - Bring the secchi disk back on board and measure the length of the line from the disk to the clothespin location with your measuring tape and record this measurement on your data sheet. Repeat from another location on the boat and record.
    - If you need to re-take a measurement, don't erase the old one, just cross out and initial the suspect data so that it can be used if needed to troubleshoot later.
    - If two different people will regularly be making secchi measurements, both should take the first few measurements to ensure that the results are similar.
    - Useful website with tips: http://www.secchidipin.org/?s=secchi+disk

3. Camera set up and operation: Follow the laminated camera guide included in the camera case.

4. Data collection at all stations: pictures and percent cover data
    - Four samples will be collected off the four corners of the boat.
    - Write the station number and sample ID on the frame labeler (e.g. "101_1" for the first sample at station 101).
    - Beginning on the windward and up-current side of the boat, with the camera on, gently lower the drop-frame over the side. Once it hits the bottom leave it there for 10 seconds to allow sediment to settle. View the camera screen to ensure the quadrat landed flat.

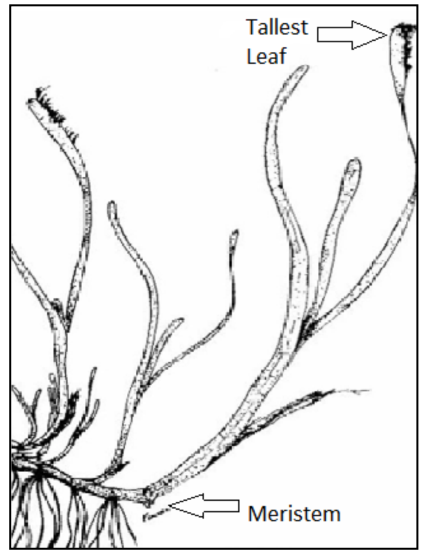
- Look at the monitor and ensure that the image is of the whole quadrat and the bottom (and/or eelgrass) is clearly visible. On the DVR unit, press the center "OK" button to take a picture. If you are unsure if a picture was taken, press the "Preview" button on the DVR unit to view the last image captured.
- Record the timestamp from the picture.
- Record sediment type as mud, clay, sand, gravel and/or cobble and note other benthic characteristics (mussels, debris, algae or other observation) on the datasheet.
- Estimate the percent cover of eelgrass using the following bins (**0%, 1-10%, 10-30%, 30-75%, 75-100%**) and the provided coverage guide (right).
- Repeat at the remaining 3 corners of the boat, be sure to update the labeler.
- If this is an indicator station, continue to step (5).

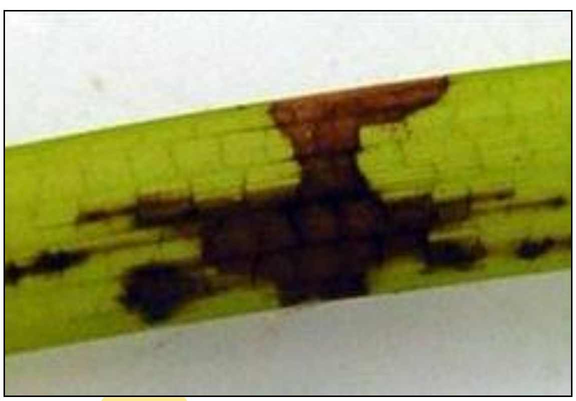




5. <u>Additional data collection at **indicator** stations: Eelgrass length and width anchor sample measurements</u>

- If eelgrass was present at a given sample location (e.g. corner of the boat), collect a sample by tossing the anchor out about 5 feet from the boat and gently dragging it several feet, attempting to collect at least three eelgrass shoots. Slowly pull it up, deploying again as necessary. This will be repeated at each of the four corners of the boat to generate four samples, each containing three shoots.
- From the sample, select three intact shoots and place the shoots on the white tote lid, fanning the leaves. Place the Station label in the field of view. Slide the lid under the frame and collect as many pictures as needed to capture the entire sample.
- Identify the longest leaf in each of the three sample plants. Measure the length and width of the leaf using the measuring tape. Length is measured from the meristem to the leaf tip (see below), and width is measured across the widest part of the leaf. If the tallest leaf is broken indicate this with an asterisk (*). Record the measurements on the datasheet.
- Estimate cover of epiphytes (encrusting algae or tunicates) on the three leaf samples by looking over all of the leaves for all of the shoots and assigning none, low, med. or high for the entire sample (see guide below).
- Estimate cover of wasting disease on the three leaf sample by looking over all of the leaves for all of the shoots and assigning a none, low, med. or high category for the entire sample (see below).
- Discard plants overboard and repeat at remaining corners. (Note: If colleagues or scientists request sampling collection, samples should be placed in clean, clearly labeled zip-lock bags and stored on ice in a cooler until transfer to the requester).





Wasting disease (left) and epiphyte coverage (right) on eelgrass. Photos from Cornell Cooperative Extension/SeagrassLI.org

INDEX FOR MEASURING COVERAGE OF WASTING DISEASE AND EPIPHYTES

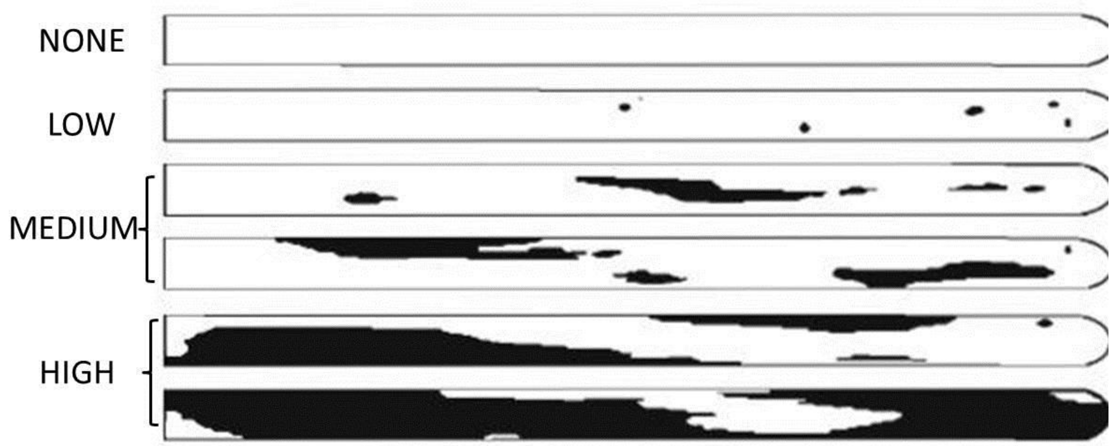


Image altered from Burdick et al. 1993.

6. Cleaning and storage
    - At the end of each field day, inspect all equipment to ensure everything is accounted for and in similar condition to when it was received at the beginning of the day. If any items are missing, damaged, or altered in any way, note the change(s) and inform the organizer.
    - Rinse all gear that came in contact with salt water, taking particular care with the camera and lowering frame. Soak the camera in a tub of warm water.
    - Be careful not to allow any cables, connections, or electronic equipment from the waterproof box to come into contact with water. The two plugs attached to the camera cable reel must also remain clean and dry at all times.
    - Inspect the camera case to make sure it has remained clean and dry after each use. If necessary, carefully clean that monitor screen with a paper towel. If water is present in the box, remove it as soon as possible with a dry paper towel and inspect all electronic equipment to ensure no damage occurred.
    - Allow all gear to dry and store in a cool, dry place.
    - Recharge batteries if needed, and give SD card and data sheets to the organizer.

Appendix H: Monitoring Kit Contents

Each monitoring kit is self-contained inside a clear plastic container and includes all equipment needed to complete volunteer monitoring (see table below). The operating instructions for each item, along with maintenance information, can be found in the Standard Operating Procedure document.

The drop camera frame is built entirely from PVC pipe and has predetermined specifications to ensure accurate data collection and correct field-of-view for the underwater camera. The base of the frame consists of a square with an inside measurement of 49.5cm (19.5”) x 49.5cm (19.5”). This base creates the 0.25 meter square (m^2) quadrat used to assess percent cover in a standardized area. The total height of the frame is about 93cm (36.5”), with four pipes extending vertically at a slight angle from each side of the base up to a smaller PVC square at the top of the frame where the underwater camera can be mounted. Instructions and materials for building the frame are below.

Monitoring Kit contents

Item	Model	Accessories
“Kit” Tote	Clear weathertight storage case	White Cover
Frame	PVC	25 ft. line with white buoy, label slate, washable markers for labelling
Camera	Splashcam Deep Blue Pro	Waterproof electronics box, 50 ft. cable, cable reel, cords
Secchi Disk	Fieldmaster Pre-Built	50 ft. line, circle weight
Viewscope	Pre-Built	5 gallon bucket with interior painted, Plexiglas view
Measuring Tape	Stanley LeverLock, meters	
Danforth Anchor	Seachoice 4lbs	30 ft. rope with white buoy
Mushroom Anchor	Seachoice 8lbs	30 ft. rope with white buoy
Paper datasheets, SOP	In clipboard	pencils
Clipboard	Black plastic	
Laminated list of contents	In tote	
Misc	In ziplock bag	Zip ties, Duct Tape

Drop Camera Frame Construction

Starting Components		
Equipment	Length	Quantity
3/4" PVC pipe	10'	2
1/4" rebar	10'	1
3/4" PVC T-bar		8
3/4" PVC 90° angle		8
3" PVC coupling		1
PVC cement		1

Cut Components		
Equipment	Length	Quantity
3/4" PVC pipe	36”	4
3/4" PVC pipe	9”	8
3/4" PVC pipe	1.25"	8
1/4" rebar	20"	4
3/4" PVC T-bar		8
3/4" PVC 90° angle		8
3" PVC coupling		1
PVC cement		1

Finished Product:

Appendix I: Field Datasheet

Eelgrass Monitoring Datasheet for All Stations

Trip Information

Date: ______ Crew Names: ______ Boat Name: ______

Sampling Station Number (i.e. #1-250, #9000): ______

Actual Lat.: ______ Actual Long: ______ GPS Device: ______

Wind Direction (circle one): N NE E SE S SW W NW

Wind Speed, kts (circle one): 0-5 5-10 10-15 15-20 20+

Sea State (circle one): glass-calm small ripples small waves moderate waves high waves

Cloud cover (circle one): 0% 1-25% 25- 50% 50-100%

Tide (circle one): flooding high slack high ebbing low slack low

Secchi Sampling

Water Depth (feet): ______ Time of Sampling: ______ Secchi Depth (meters) #1: ______

(meters): ______ Secchi Depth (meters) #2: ______

Drop-Frame Data Collection

	Picture taken	Picture Timestamp	Sediment (all that apply)	Eelgrass Percent cover	Notes
SAMPLE 1	Y / N		mud clay sand gravel cobble	0 1-10 11-30 30-75 75-100	
SAMPLE 2	Y / N		mud clay sand gravel cobble	0 1-10 11-30 30-75 75-100	
SAMPLE 3	Y / N		mud clay sand gravel cobble	0 1-10 11-30 30-75 75-100	
SAMPLE 4	Y / N		mud clay sand gravel cobble	0 1-10 11-30 30-75 75-100	

Additional Eelgrass Monitoring Datasheet for Indicator Stations

Station Number (i.e. #9000)

Sample 1

Shoot 1		Shoot 2		Shoot 3		Wasting disease	Epiphyte cover
length (cm)	*width (mm)*	*length (cm)*	*width (mm)*	*length (cm)*	*width (mm)*	*none, low, med., high*	

Sample 2

Shoot 1		Shoot 2		Shoot 3		Wasting disease	Epiphyte cover
length (cm)	*width (mm)*	*length (cm)*	*width (mm)*	*length (cm)*	*width (mm)*	*none, low, med., high*	

Sample 3

Shoot 1		Shoot 2		Shoot 3		Wasting disease	Epiphyte cover
length (cm)	*width (mm)*	*length (cm)*	*width (mm)*	*length (cm)*	*width (mm)*	*none, low, med., high*	

Sample 4

Shoot 1		Shoot 2		Shoot 3		Wasting disease	Epiphyte cover
length (cm)	*width (mm)*	*length (cm)*	*width (mm)*	*length (cm)*	*width (mm)*	*none, low, med., high*	

Notes: