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Eelgrass Distribution in the Great Bay Estuary and Piscataqua River for 2019: Final Project Report submitted to the Piscataqua Region Estuaries Partnership

Seth Barker

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Final Project Report submitted to the Piscataqua Region Estuaries Partnership

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Abstract

Eelgrass distribution in Great Bay, Little Bay, and the Piscataqua River Estuary was mapped from aerial photography acquired on August 2, 2019. The total area of eelgrass beds with 10% or greater cover and a polygon area equal to or greater than 100 square meters was 625.9 hectares or 1677.7 acres. Eelgrass polygons were coded for Assessment Zone (http://www.granit.unh.edu/data/search?dset=greatbayestuaryassessmentzones_current) location and the results reported for each zone. The largest concentration of eelgrass was found in Great Bay with lesser amounts in the vicinity of Portsmouth Harbor. The total area of eelgrass beds has increased by 131 acres which is approximately an 8.5% increase from 2017 and very nearly equal to that mapped in 2013. This number includes some areas where both eelgrass and widgeon grass were present. As noted, in addition to eelgrass, widgeon grass was mapped in areas where field work confirmed its presence. There were 257.4 acres of widgeon grass (and eelgrass combined) identified and this was found primarily in Great Bay.

Introduction

The report that follows provides details of the mapping of eelgrass distribution in Great Bay, Little Bay, the Piscataqua River, Portsmouth Harbor and a small portion of the Atlantic Coast for the year 2019. In addition to eelgrass, widgeon grass and a mix of widgeon grass and eelgrass was mapped in areas where field visits confirmed the presence of widgeon grass. Aerial photography was obtained on August 2, 2019 and was followed by field work in September and early October to establish signatures for photointerpretation and to aid in the accurate mapping of eelgrass distribution. At the time of this report, this mapping is the latest regional documentation of eelgrass beds in the area. The project area is described and illustrated in the Appendix A.1.

Methods

Procedures followed the guidelines articulated in the project Quality Assurance Project Plan (QAPP), which can be found at: https://scholars.unh.edu/prep/431/ Mapping of the distribution of eelgrass was based on photointerpretation of aerial photography obtained on August 2, 2019, under a contract with Cornerstone Mapping, Inc, Bangor, Maine. Preliminary, georeferenced images were made available at the end of August 2019 and were used for field logistics. This initial draft photography did not have the locational accuracy of the final photomosaic and had not been color balanced but provided sufficient detail to locate features of interest, conduct initial mapping, and to select stations to be visited. Stations were selected in Great Bay, Little Bay, the Piscataqua River, Portsmouth Harbor and the Atlantic Coast and field visits by boat were made in the September/October time period. The boat and operator were provided by PREP for assistance with field verification. Location of observations was recorded as track files using high accuracy Trimble GeoXT GPS equipped with an external antenna. Since there can be a variety of photographic signatures and signatures change from year to year and with conditions at the time, field stations are important for the understanding of the nature of the signatures. The water-based field visits were made on September 5,11,12,18,19, 23, and October 2. In addition, several stations were visited on foot on October 2.

A total of 165 numbered stations and several unnumbered stations were visited (Figure 1). Subsurface observations were made with a Seaviewer drop camera equipped with a surface monitor at most of these stations. In a few cases, the bottom could be clearly viewed without the use of the drop camera. Video recordings were made at most but not all stations. Observations were made and videos recorded as the boat either drifted or motored at low speed over a station and one or more observations were recorded on a field sheet (Appendix A.2). Observations included the presence of eelgrass, whether eelgrass cover was judged to be equal to or greater than 10 % (Appendix A.3), the presence and type of macroalgae (where possible), and in some cases, substrate. The time of the observation was recorded and used in conjunction with the time of GPS observations which were recorded as points in GPS files. In most locations, a video recording was made which was time stamped. This allowed for location specific review at a later date in a GIS with the GPS file providing a guide to the approximate location. A total of 380 unedited video files of a minute or less were recorded and are provided as part of the ancillary data.

The final photomosaics were received from Cornerstone Mapping in December, 2019. These were added to a GIS along with field information and other data layers to aid in photointerpretation. Eelgrass beds were first outlined and screen digitized using the GIS software package, QGIS, and saved to an ESRI shape file. Final digitizing was generally done at a screen scale of 1:1000 or less. The projection used was New Hampshire State Plane, NAD83, and the units were feet (EPSG:102710; https://epsg.io/102710).

During the initial digitizing process, all eelgrass that was easily discerned was digitized in a polygon file. After beds were outlined to form polygons, areas with less than 10% eelgrass coverage as visible from the aerial photography were then deleted from the GIS file leaving the polygons of 10 percent cover or greater. Also, polygons of less than 100 square meters were also deleted. Database file attributes for 2019 are as follows: “id”, a unique consecutive number; “Hectares”, the area of the polygon in hectares; “Acres”, the area of the polygon in acres; “Year”, equal to 2019, the year of the aerial photography, “Label” for the assessment zone, and “type” to distinguish between polygons mapped as eelgrass, widgeon grass, or both. Additional details are provided in the project metadata file.

The QAPP describes a process by which the accuracy of the digitized polygon boundary is verified in the field. To meet this requirement a total of 12 points were recorded using the Trimble Geo XT on 9-12-2019 and an additional 12 points were recorded on 9-23-2019 (Figure 3). These points represent the location were eelgrass was first observed using a drop camera as the boat traversed from the navigation channel to shallow depths. The distance from this point to the polygon boundary was measured with the “measure tool” in QGIS and reported in Table 1.

During the digitizing process and when the final file was produced, the topology of the shapefile was checked using the QGIS topology routine. The topology rules enforced were no gaps, no duplicates, no overlap, no invalid geometry, or no multi-part geometry.

Results and Discussion

The distribution of eelgrass for 2019 is shown in Figure 2 along with higher resolution maps at 1:24000 scale (Appendix A.4, Figures 1-3)

The total area of eelgrass mapped in the entire project area was 1677.7 acres. This has been broken down by Assessment Zone and shown in Table 2. As in past years, Great Bay had by far the greatest amount of eelgrass, 1450.6 acres. Little Bay had 20.3 acres. The Portsmouth Harbor zone had 87.1 acres. The Little Harbor and Back Channel zone had 41.9 acres. The Gerrish Island area had 58.4 acres with additional area for these beds reported in both the Atlantic Coast, Piscataqua River, and other Assessment Zones.

Widgeon grass was found in abundance at several locations in Great Bay. The densest concentrations were found in a swath from Woodman Point to Pierce Point. Large beds were also found extending from Strongs Landing to Shackford Point. The only other location where it was observed was the head of Spinney Creek. Though it very likely is present at low density throughout the estuary it was not found in sufficient density to map at other locations where field visits were carried out. The lack of a clear signature also contributed to limitations in mapping. Widgeon grass was found growing alongside macroalgae in shallow and intertidal areas and was mixed with eelgrass in other shallow locations. It is assumed but not know that freshwater input is one of the factors that favored widgeon grass growth in these locations. Though widgeon grass has been found repeatedly in the vicinity of the mouth of the Winnicut River, this is the first year that it has been included in this series of mapping efforts.

It is felt that areas of dense eelgrass that contained macroalgae could be adequately differentiated from dense stands of only macroalgae or macroalgae and widgeon grass. In locations where eelgrass was not dense (10-30% for example), it was often difficult to differentiate eelgrass from other vegetation and required field verification. In many locations macroalgae was found growing in dense concentrations around the stems of eelgrass plants. In this situation, dense eelgrass was visible in the aerial photography but the macroalgae was often much less evident or not detected.

As in past years, oysters provided another signature that was clearly detected in some locations. If a large number of oysters was present on the surface of a mud bottom, the signature was distinctive. If found in the presence of eelgrass but not macroalgae, the eelgrass signature was clear and to a lesser extent oysters could be detected. However, if oysters were present along with macroalgae and eelgrass, the signature was confounded such that only the predominate feature could be discerned. The hard bottom and different types of macroalgae also produced signatures that were difficult to separate from that of eelgrass and therefore required field verification.

The work done to provide information on the accuracy of mapping at polygon boundaries was productive but the procedure used can be improved upon. Table 2 contains measurements in meters of the difference between the observed and mapped edge. The mean and standard deviation of these measurements was within the QAPP specification of 5 meters. A graphic showing the location of points in Great Bay is shown in Figure 3. Depending on wind and tide the velocity of the boat varied at time during this exercise. The GPS antenna was not a constant distance from the camera location, a point that was not accounted for in the analysis and any delay in recording the point resulted in additional error in the recorded point as the boat drifted. These things combined make this estimate conservative at best. It also must be noted that the line drawn for the polygon boundary smooths the boundary and does not take into account the very irregular boundary that would be observed on the ground. This makes it an estimate at best and though the results of work carried out on these two days is encouraging there should be a review of this specification in the QAPP and possible revision.

Figure 1. Field stations and GPS track logs.

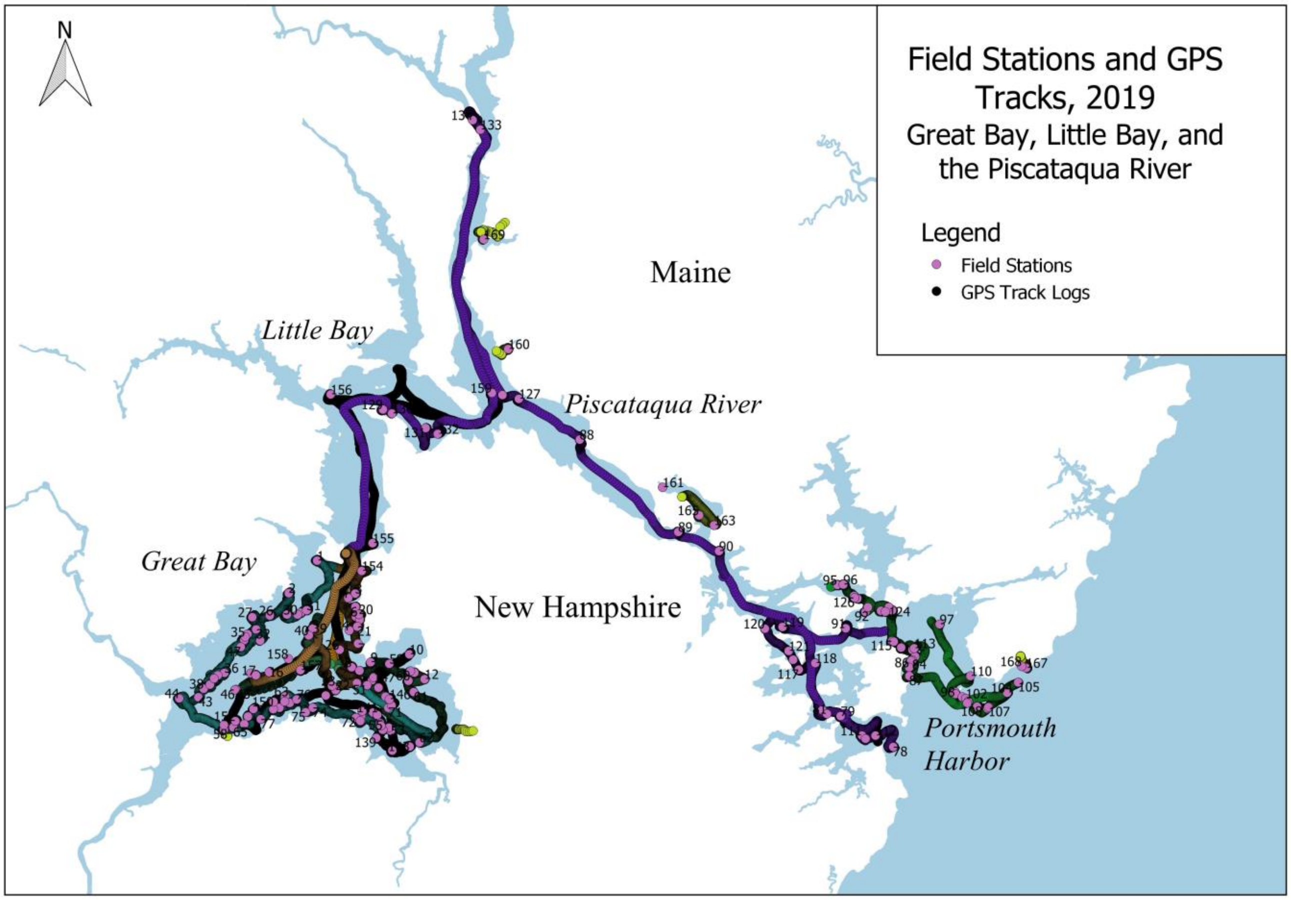


Figure 2. Distribution of eelgrass, 2019.

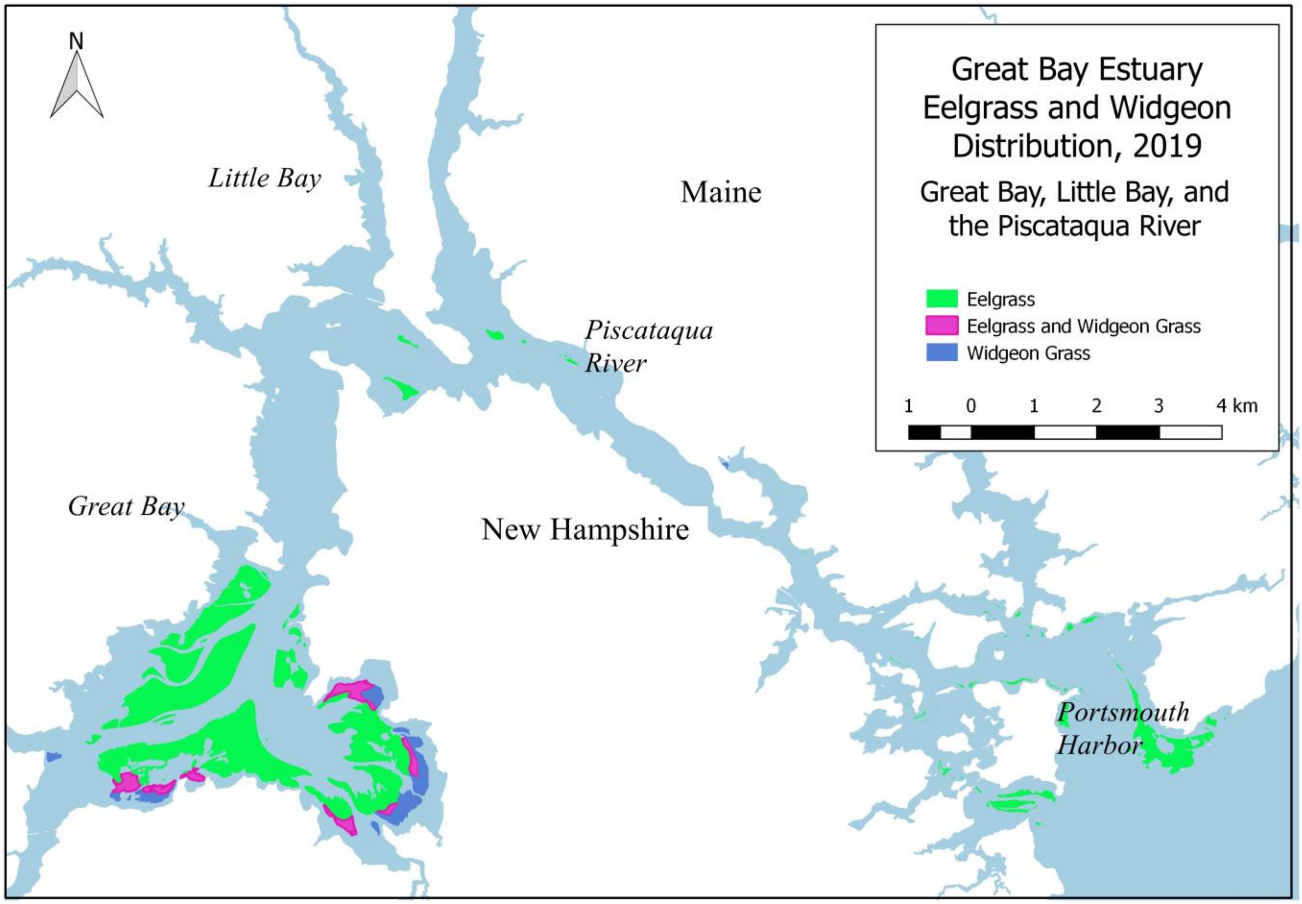


Figure 3. Screen shot showing location of edge check points

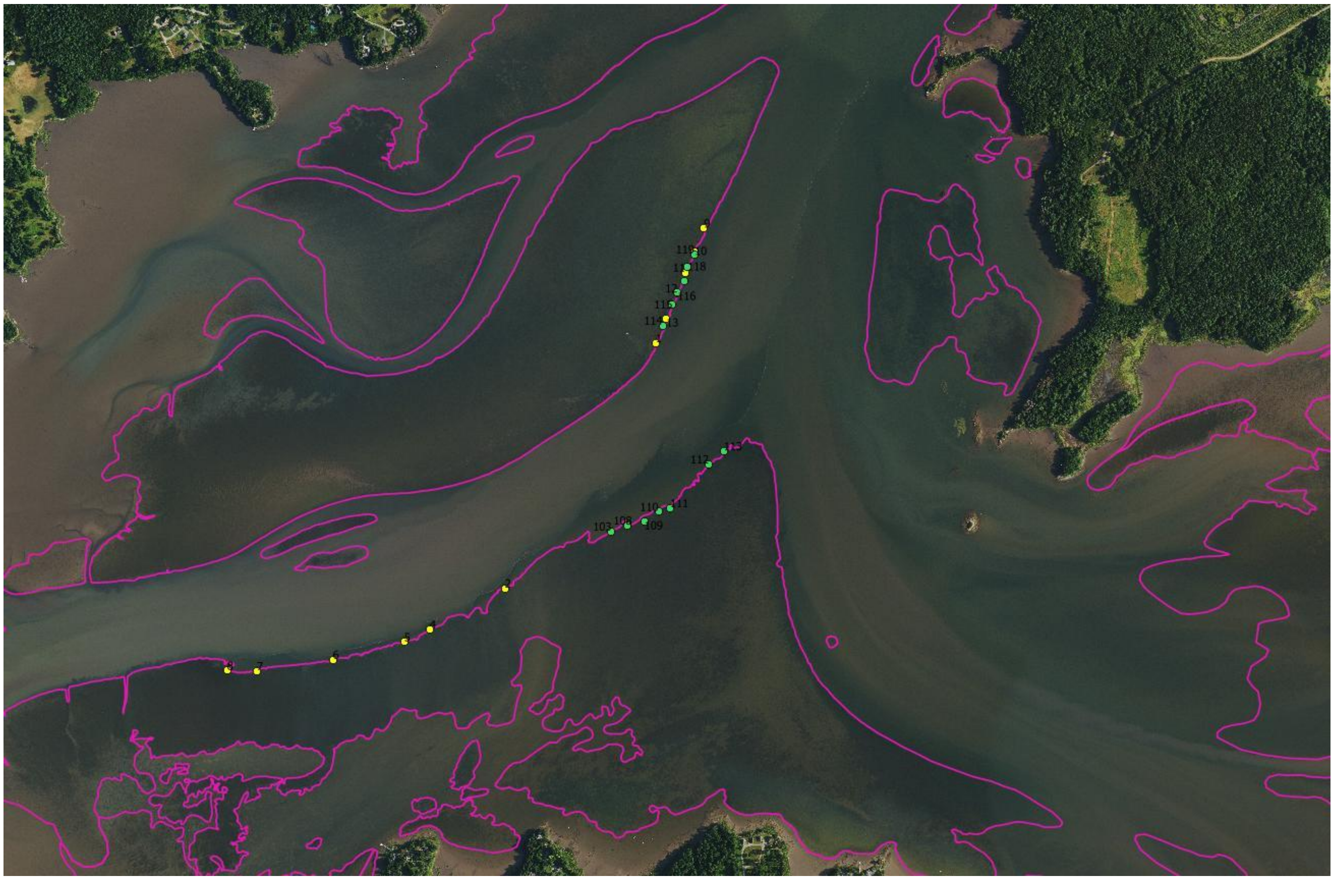


Table 1. Results of polygon edge check

9-12-2019, West Side of Channel					**9-23-2019, West Side of Channel**		
Point ID	**Distance(m)**	**Relative Position**			**Point ID**	**Distance(m)**	**Relative Position**
9	**7.4**	**inside**			**114**	**8.7**	**inside**
10	**2.9**	**inside**			**115**	**3.7**	**inside**
11	**2.6**	**inside**			**116**	**5.4**	**inside**
12	**4.7**	**inside**			**117**	**0.1**	**outside**
13	**5.7**	**inside**			**118**	**4.2**	**inside**
14	**6.3**	**inside**			**119**	**0.1**	**outside**
9-12-2019, East Side of Channel					**9-23-2019, East Side of Channel**		
Point ID	**Distance(m)**	**Relative Position**			**Point ID**	**Distance(m)**	**Relative Position**
2	**0.4**	**inside**			**105**	**3**	**inside**
4	**1.1**	**inside**			**108**	**4.3**	**inside**
5	**1**	**inside**			**110**	**8.7**	**inside**
6	**1**	**inside**			**111**	**6.9**	**inside**
7	**3.9**	**inside**			**112**	**4**	**outside**
8	**4.6**	**inside**			**113**	**1.4**	**outside**

Mean = 3.84 meters
SD = 2.545
95% Probability
3.84 ± 1.075 meters

Table 2. Area of polygons by Assessment Zone

Area in Acres – 2019					
Assessment Zone	Eelgrass (EG)	EG and WG	WG	**Total Eelgrass**	**Total**
Atlantic Coast	1.05			**1.05**	**1.05**
Gerrish Island Beds	58.43			**58.43**	**58.43**
Great Bay	1344.99	105.57	143.44	**1450.56**	**1594.01**
Little Bay	20.34			**20.34**	**20.34**
Little Harbor/Back Channel	41.89			**41.89**	**41.89**
Lower Piscataqua River North	8.57			**8.57**	**8.57**
Lower Piscataqua River South	3.55			**3.55**	**3.55**
Odiorne Point Beds	1.27			**1.27**	**1.27**
Portsmouth Harbor	87.08			**87.08**	**87.08**
Sagamore Creek	1.51			**1.51**	**1.51**
Spinney Creek			1.49		**1.49**
Upper Piscataqua River	2.18			**2.18**	**2.18**
Winnicut River		1.29	2.57	**1.29**	**3.87**
Total	**1570.87**	**106.87**	**147.50**	**1677.74**	**1825.24**

EG = Eelgrass
WG = Widgeon Grass

Appendix

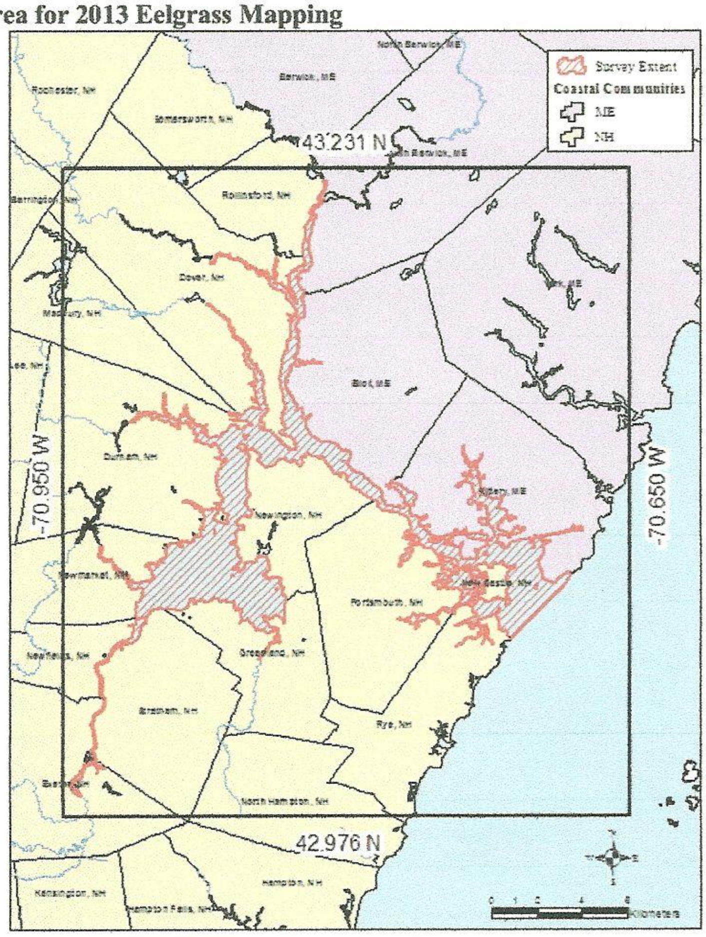
A.1 Description of study area.

The description from the 2019 QAPP is as follows:

A5 – Problem Definition/Background

Submerged aquatic vegetation (SAV), including seagrasses such as eelgrass (*Zostera marina*) and widgeon grass (*Ruppia maritima*) are essential to estuarine ecology because they filter nutrients and suspended particles from water, stabilizes sediments, provide food for wintering waterfowl, and provide habitat for juvenile fish and shellfish, as well as being the basis of an important estuarine food web. Healthy SAV both depends on and contributes to good water quality. Therefore, PREP tracks the presence of SAV in the Great Bay Estuary as an indicator of estuarine health. Note that seaweeds also provide some of these functions, but they are not considered SAVs as they are not vascular, rooted plants. The objective of this project is to map SAV habitat in the Great Bay Estuary during the summer growing period. The Great Bay Estuary is 21 square miles of tidal waters located in southeastern New Hampshire. The area for SAV mapping encompasses downstream portions of all tidal rivers and to the mouth of Portsmouth Harbor. The mouth of Portsmouth Harbor is defined by lines extending from Odiorne Point in Rye, NH to White Island to Horn Island to Sewards Point on Gerrish Island in Kittery, ME. The total area to be mapped is approximately 21 square miles. The study area in which SAV will be mapped for this project is shown in Figure 2. This is the same as the 2013 project area.

Figure 2: Study Area for 2013 Eelgrass Mapping



Appendix

A.2 Field sheet used for photointerpretation.

Station Number				Date (MMDDYY)						
Crew Chief				Crew Member 1						
Crew Member 2				Crew Member 3						
Purpose				GPS File						

Weather Condition				
Sea Condition				
Start Time			End Time	

Drop Camera Observation

Start Time	Observation	Depth	Offset	End Time	Notes

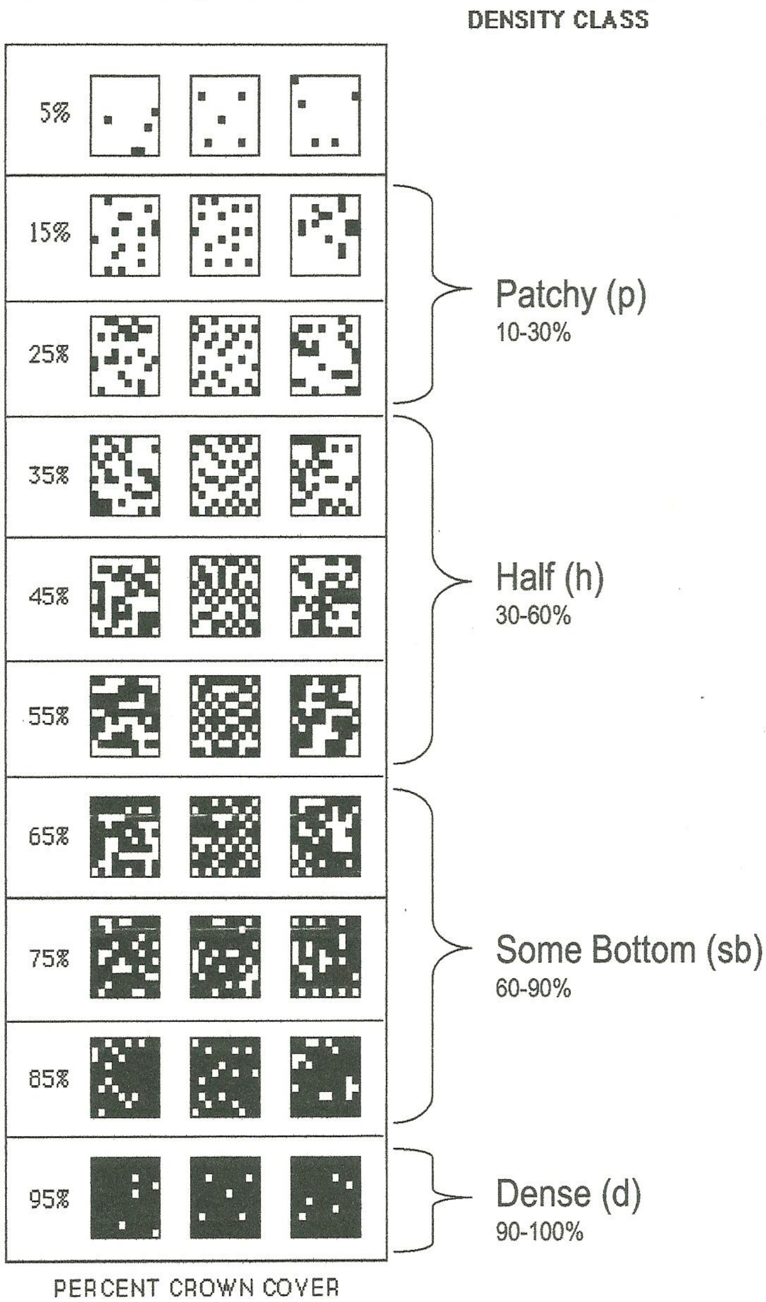
Appendix

A.3 Description of cover categories and photointerpretation aid (from QAPP).

Eelgrass cover greater that 10% as shown in the following density scale was mapped. Cover categories were not interpreted or coded.

Appendix F

Visual Guide for Eelgrass Percent Cover for Photointerpretation



Source: http://web.vims.edu/bio/sav/sav11/crown_density.html

A.4 1:24000 scale maps showing eelgrass beds in the Great Bay, Portsmouth Harbor, and the Piscataqua River area.

List of Maps:

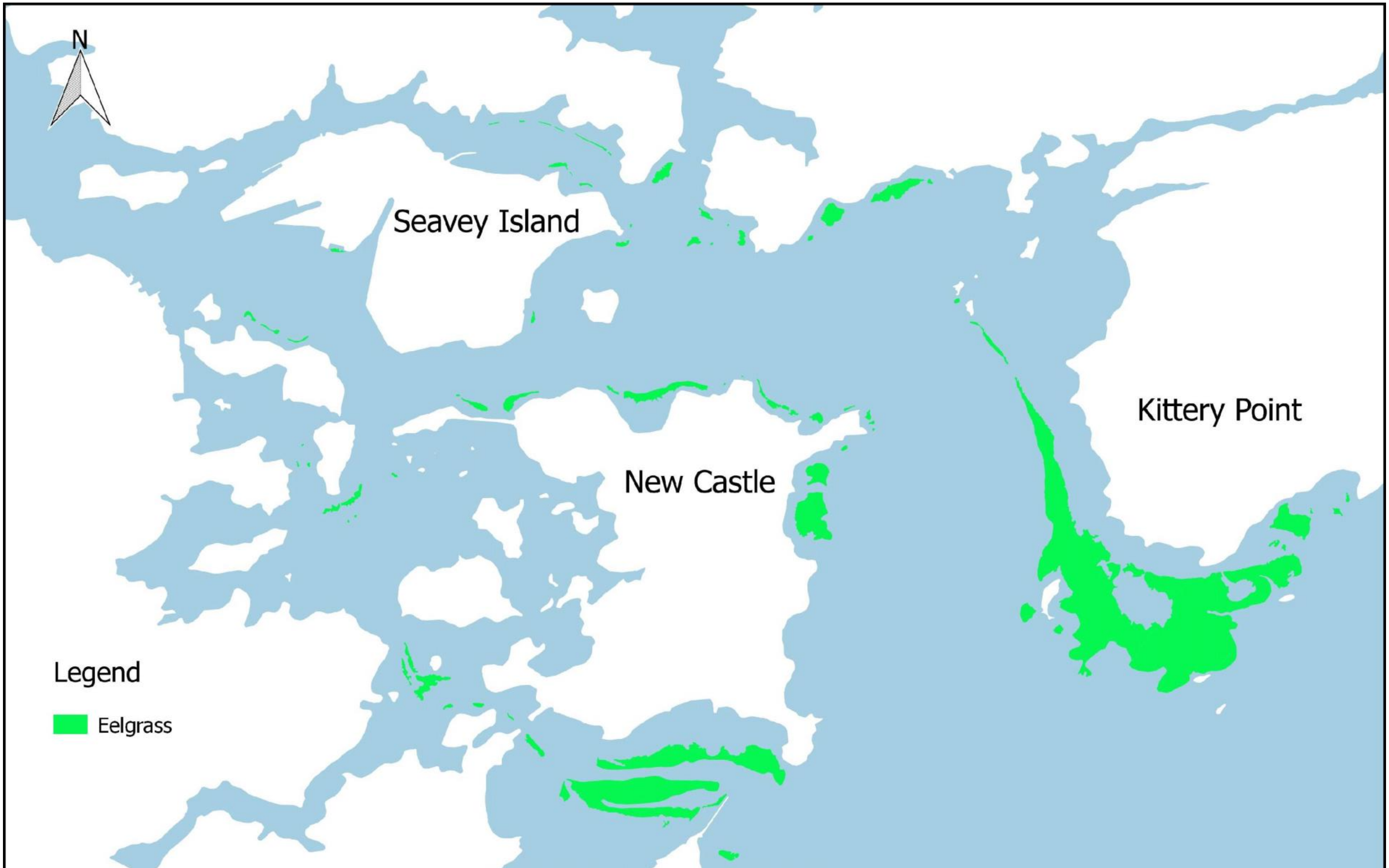


Figure 1. SAV Distribution - Portsmouth Harbor and Vicinity
Scale 1:24000

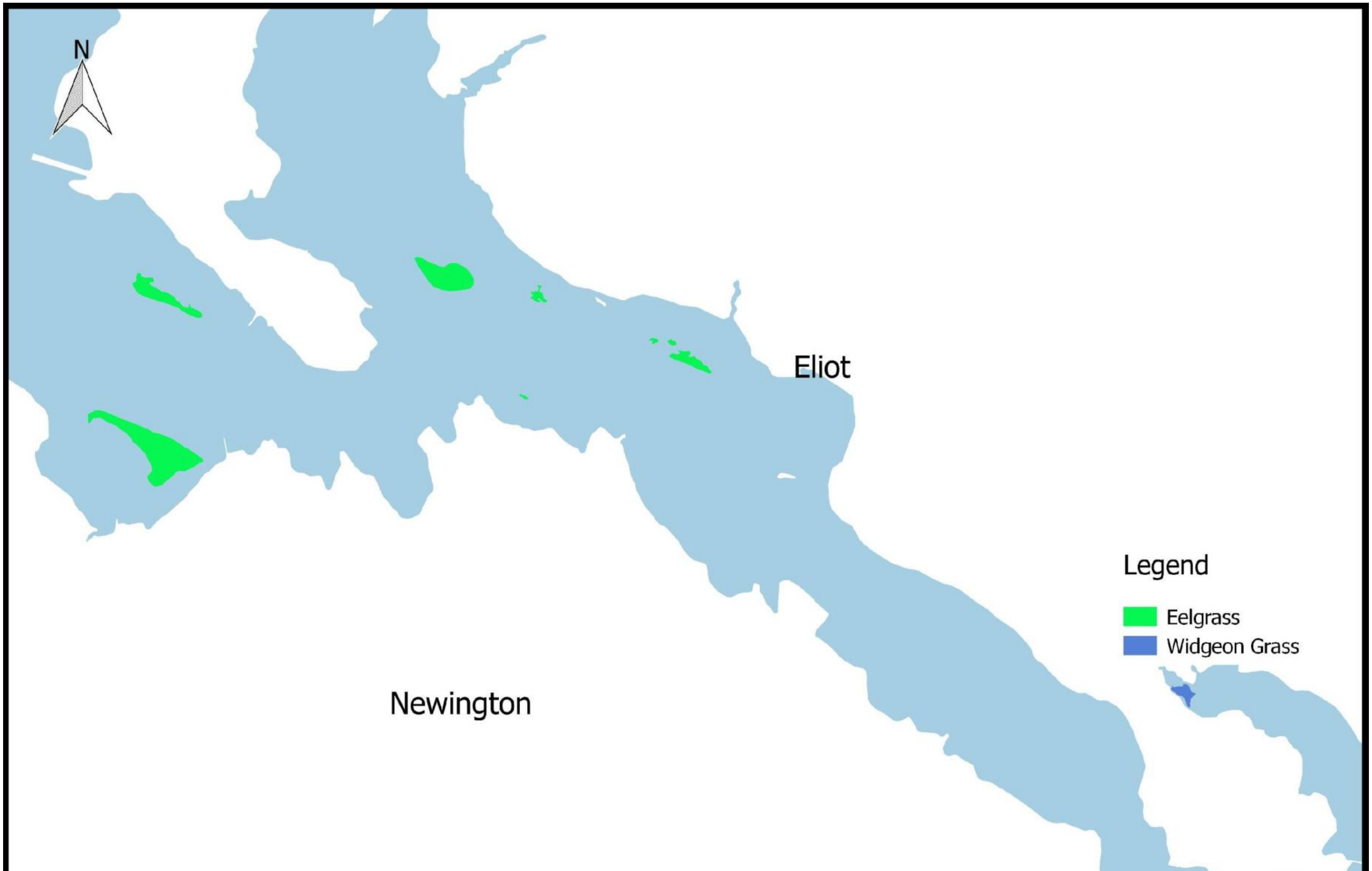


Figure 2. SAV Distribution - Piscataqua R. and Little Bay
Scale 1:24000

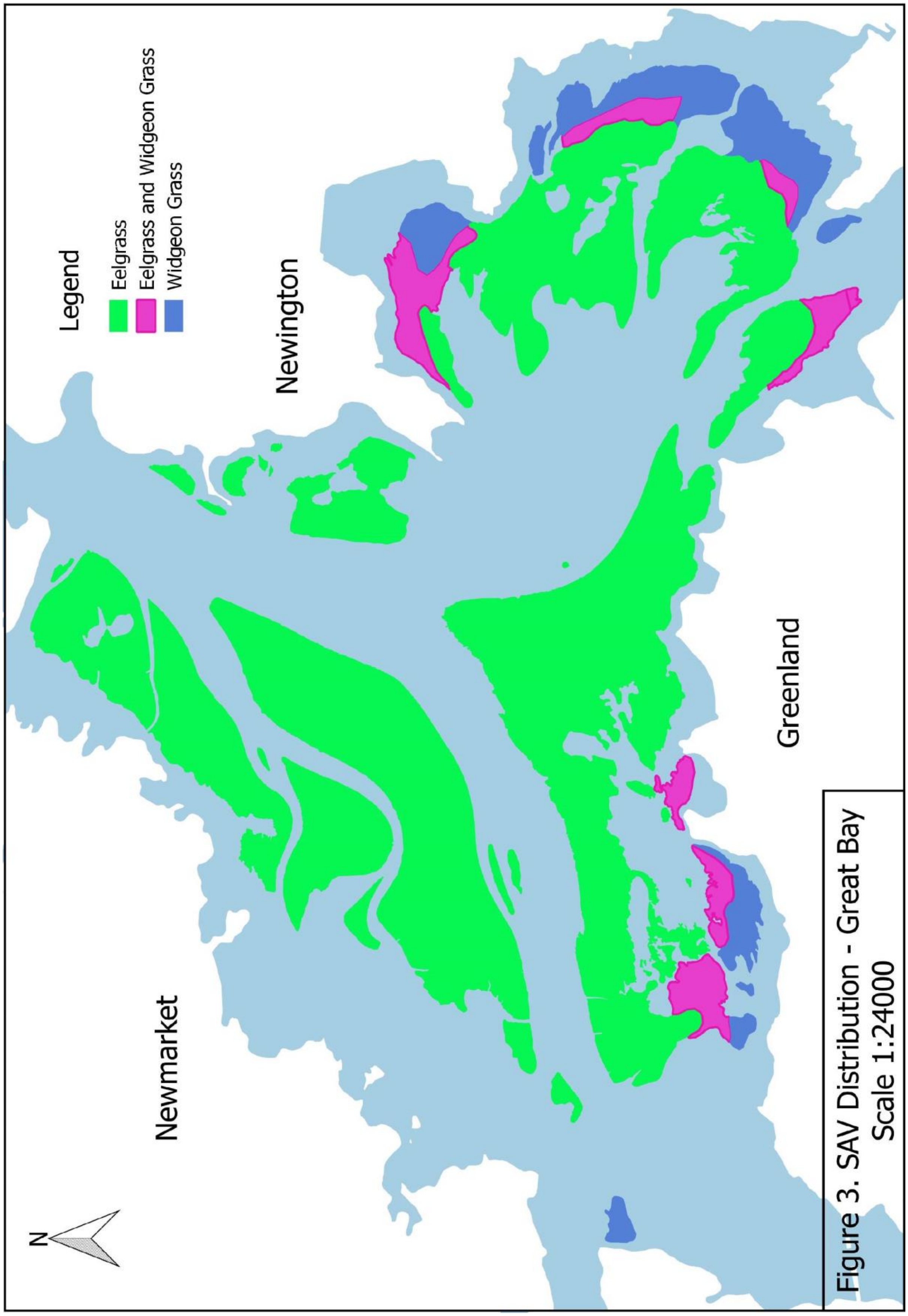


Figure 3. SAV Distribution - Great Bay
Scale 1:24000

Cornerstone
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AERIAL IMAGERY, MAPPING, & GIS

6 State Street, Suite 301 / Bangor ME 04401
207.942.5200, x350 / 866.836.8834 x350 toll free

Appendix B

Task 2: Quality Control Plan
For
Acquisition of Aerial Imagery
For Habitat Mapping for Summer 2019

Job #: TBD

May 9, 2019

I. Introduction

Our overall quality assurance plan starts at the project planning stage and ends with a customer satisfaction de-brief upon completion of the project. The general principle of "*Do it right the first time*" is followed throughout the project.

The key elements of a project are defined up front, when the contract is first negotiated. This ensures that the project is completed on time, within budget, and that the deliverables meet with the client's expectations.

A. Customer Satisfaction

The initial step of the project involves the contractual negotiations whereby the Project Team becomes more familiar with the client's project: specifications, final end use of any mapping products, time schedules, coordination with other projects or uses of products, contract terms, fee for services, change order procedures, specific technologies that will be used, QA/QC procedures that will be followed, etc. Having a thorough understanding of each of these components, and how they all relate to one another, results in no surprises during the project life cycle.

It is during this initial stage (Project Kickoff Meeting) that a complete project schedule and an allocation of labor hour requirements are finalized, to ensure that adequate resources are available to meet client needs and expectations.

B. Built-in Product Quality

On the technical side, a series of specific questions have been developed for each phase of a project. This ensures that the necessary elements of a project have been addressed not only by the customer, but also by the project team. This information, along with the specifications, is then passed directly to the technical/production people so that all project specific information has been transmitted to the appropriate individuals and that all production people are aware of upcoming projects and schedules. These instructions are provided to the team in writing and subsequently discussed in team and one on one meeting with the project leads.

Each technical task that the project team performs is structured with specific procedures to guarantee generation of a quality product. The QC process for mapping projects is linear in nature because the processes are linear in nature. Therefore, before each phase can be started, the previous phase has to pass certain QC criteria. This protocol is followed for each phase of the project.

At the start of each project, production procedures (checklists, progress charts, QC testing and reporting mechanisms) are developed. A portion of the project is then created and all production processes exercised, including QC procedures. This sample project data is then submitted to the customer for final approval. Any changes are noted and improvements to the production process implemented. At this point, production begins.

The next step in the production process is to complete the feedback loop by informing the production personnel of the QC analysis and results. Production personnel are given complete access to QC data so that they can improve their individual processes to conform to project standards.

After approximately 10-15% of the project has been completed, supervisory personnel meet with production staff members to identify bottlenecks or other challenges in the production process. This results in better, more highly automated routines to speed the process and improve the quality of the work product. Notable by-products of these meetings are the continued education and training of production staff, which leads to fewer human errors as production progresses.

II. Quality Assurance and Quality Control Procedures

Quality Assurance (QA) and Quality Control (QC) are two separate, but closely linked processes that ensure that the project deliverables meet the project specifications. Quality Assurance is a written plan of the procedures and processes that are to be followed for each task. These processes and procedures have been designed and proven to be effective in producing a quality product in a repeatable and sustainable fashion.

Quality Control is a process of evaluating, or testing, the final product to identify any defects. This process involves different people using different software/processes (than what was used to produce the product) to evaluate the product for conformance to specifications. QC involves using a structured and rigorous approach to the evaluation. Generally, if any part of the project specifications can be quantified, or measured, then it should be evaluated. Acceptance criteria are developed to provide a pass/fail analysis of each item. Both automated and manual review techniques are employed: automated routines for 100% review, and manual reviews for a random sample of products.

The linkage between QA and QC occurs after the results of the QC are known. If any defects are discovered, we determine why the QA plan did not prevent the defects and the plan is appropriately modified and implemented. This process is initiated after each QC cycle if defects are found. This method of constant and continual improvement results in highly consistent products with high quality. Both production and QC team members participate in the analysis and improvement of the process to make sure that all team members are up-to-date on the latest techniques and procedures for the entire project.

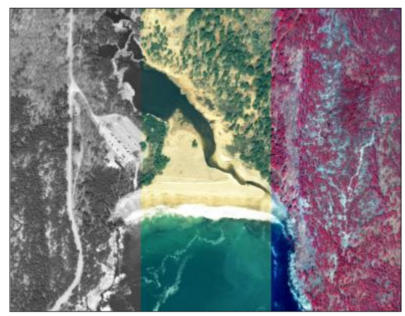
III. Tasks

A. TASK 1: Collect Aerial Imagery for the Piscataqua Region Estuaries

Task 1 involves the collection of digital 4-band imagery with a nominal 1 foot resolution. Also included is a preliminary set of orthophotographs produced using the ABGPS/IMU data and assuming an average elevation.

The mission will be flown using the Intergraph Digital Mapping Camera (DMC). The Cornerstone Project Team selected the DMC due to its superior accuracy, image clarity, and versatility. Flight lines and exposure stations for this project will have been pre-planned by Cornerstone according to the specifications listed in the RFP.

Multiple flights over the same area are not required because the DMC simultaneously captures panchromatic, color, and color infrared imagery in a single pass. The DMC system is a complete end-to-end digital imaging system. It has an integrated workflow, from mission planning and preparation to the creation of deliverable products. During a flight mission, a Global Positioning System supported navigation system interfaces with the camera control software, differential-GPS, and inertial measurement unit (IMU) sensors to capture positional data to the 0.62 meters (2 foot) accuracy required for the project.



The DMC captures imagery suitable for engineering-level planimetric and topographic mapping as well as superior ortho image products and it has been documented that the DMC's accuracy and image quality exceeds other digital imaging systems.

Cornerstone will work closely with both PREP Project Manager and the aerial survey firm, Geomni (formerly Richard Crouse & Associates/RCA), to schedule potential acquisition dates and times. We will continue to actively monitor the conditions along the coast so that everyone is kept up-to-date with the status of image acquisition and its specific parameters. The Cornerstone Project Team is very familiar with tracking tides and solar sun angles based on client criteria.

Geomni's Maine and New Hampshire flight operations are based out of Old Town Maine. ***This proximity to New Hampshire and southern Maine ensures that a decision to fly can be made quickly and early while acquisition conditions are optimal.***

The flightplan is shown below in Figure 1 and consists of 6 flight lines with 99 images flown at approximately 9,000 feet about ground level at a pixel resolution of 0.29 meters. The flightplan is based on mapping limits provided by PREP.

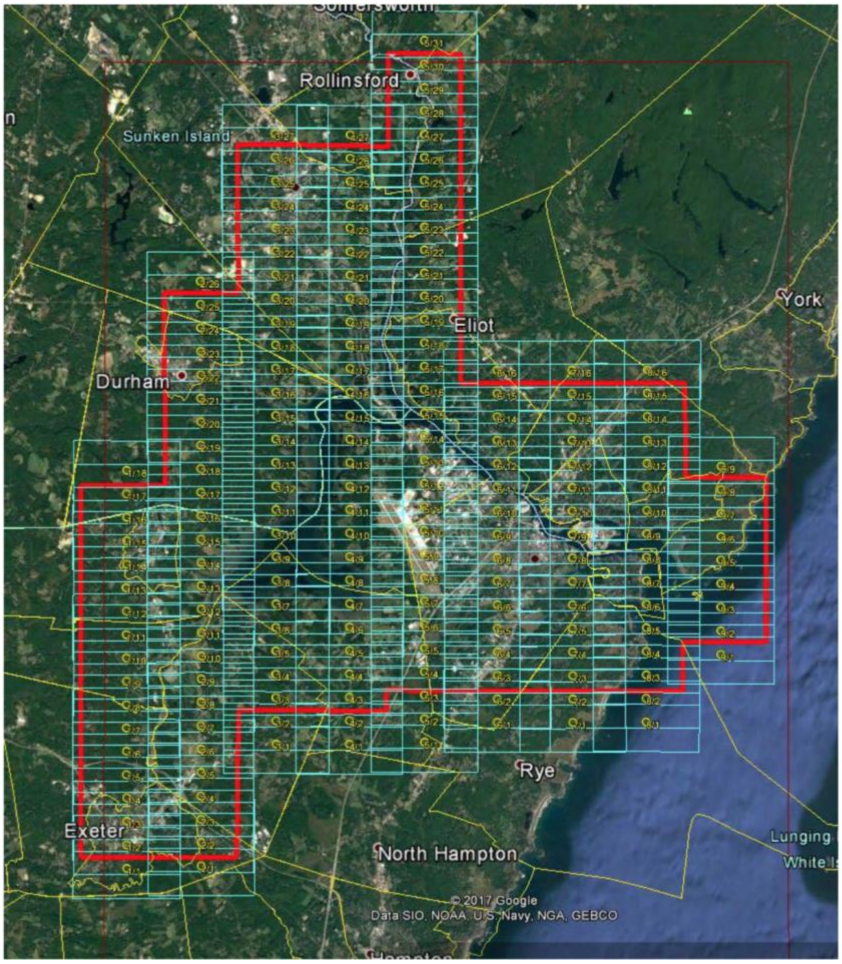


Figure 1. Flightplan layout consisting of 9 flightlines and 186 images. The yellow line is the project boundary, cyan lines are overlapping images lines, and red circles/line are image centers and flightline. Ground sample resolution for the raw imagery is 0.29 meters.

<u>Quality Assurance</u>

Project specifications for not only the flight, but also the derivative project deliverables, will be conducted with the flight crew and staff so that they have a complete understanding of this important project.

Geomni, working closely with Cornerstone and PREP, will collect aerial imagery that meets or exceeds the following specifications.

- Mapping location: The Great Bay Estuary, Little Harbor, and the New Hampshire Coastline. See attached description and map.

- 4-band source imagery (red, green, blue, and near infrared) and will be of sufficient resolution to support production of digital orthorectified images to a ground pixel resolution of 0.30 meters (nominal 1 foot).
- Orientation: Vertical.
- Ground Pixel Resolution: 0.30 meters (1 foot).
- Spatial accuracy: Digital orthorectified imagery shall have a horizontal positional accuracy not to exceed 0.62 meters (2 feet) Root Mean Squared Error. A digital elevation model of sufficient accuracy and resolution shall be used in the orthorectification process to ensure compliance with the accuracy specification for the final imagery product.
- Overlap: The extent of image coverage over the project area shall be sufficient to ensure void areas do not exist within the defined project area.
- Camera Station Control: Camera position shall be recorded at the instant of exposure for each image using airborne, differential GPS. Camera attitude shall be recorded at the instant of exposure for each image.
- Sensor Calibration: A current Product Characterization Report will be provided.
- Environmental Conditions:
  - June 15 to September 9, 20191,
  - Early morning (7:00 am – 10:00 am)
  - Low spring tide (+/-2 hours of low tide at Adams Point in Great Bay)
  - Low sun angle (>30 degrees ideal, >50 degrees unacceptable. Flight window was extended to >22 degrees, to accommodate ideal tide conditions. Flight lines shall be planned, and imagery acquired, in such a way so as to minimize sun glint over areas of interest.)
  - Low cloud cover (>10% cover is unacceptable)
  - Calm winds (<10 mph)
  - No preceding rain events (TBD by PREP Project Manager)
  - Low turbidity / good water clarity (TBD by PREP Project Manager).

Flight maps will be prepared using a well established and trusted flight planning software. Project limits furnished by the client will be used to determine the area coverage. Digital output from the flight planning software is transferred electronically into the flight navigation and the DMC image capture system.

The Flight Contractor, Geomni, will obtain prior authorization from the PREP Project Manager for the date of the aerial survey. The Flight Contractor will also coordinate with Pease International Tradeport regarding flight restrictions near the Portsmouth International Airport.

A contacts list was generated to discuss status of water, ground, tide, sun angle, and weather conditions prior to flight:

Contact List:

Name	Organization	Work Phone	Mobile Phone	Email	Role
Kalle Matson	PREP / NH Dept. of Environmental Services	(603) 781-6591	(603) 781-6591	Kalle.Matso@unh.edu	Project Manager
Claire Kiedrowski	Cornerstone Energy Services	(207) 942-5200, x350	(207) 266-7087	ckiedrowski@Cornerstoneenergyinc.com	Project Manager, Mapping Director
Jeremy Whittemore	Cornerstone Energy Services	(207) 942-5200, x356	(207) 465-6828	jwhittemore@Cornerstoneenergyinc.com	Mapping Coordinator
Seth Barker	Independent Contractor	(207) 633-3735	(207) 315-1924	seth.l.barker@gmail.com	Aerial Interpreter
Vilia Bates	Geomni	(207) 827-5979	(207)323-4366	vbates@verisk.com	Flight Contractor Contact

QC for Aerial Imagery and AGPS/IMU capture

- Pre-flight
  - The digital flight maps will be checked for proper coverage, sidelap, overlap, and flight height by Cornerstone personnel.
  - Teleconference meetings to discuss appropriate flight conditions will be documented by Cornerstone and distributed to each party.
  - Images will be automatically inspected to verify that it is in the 4-band format, with a nominal ground resolution exceeding 1 foot ground resolution. Performed by Geomni.
- Post-flight
  - Flight logs will be inspected to verify that all environmental conditions have been met along with proper time considerations. Performed by Geomni.
  - When the flying mission has been successfully completed and the images have been processed suitable to work with them as individual images, they will be imported into ArcMap and inspected for cloud shadow, density, clarity and image consistency. Images will also be checked for acceptable overlap, and sidelap. Tilt, and crab angle will be reviewed by inspecting the IMU rotational angles. Performed by Cornerstone.
  - The AGPS/IMU data will be verified post-flight by importing photo center positions into ArcMap and checked for proper coverage, overlap and sidelap. Performed by Cornerstone.

- Again, the images will be visually inspected to verify that it is in the 4-band format, with a nominal ground resolution exceeding 1 foot ground resolution. Performed by Cornerstone.

There are two sets of deliverables with Task 1: the first is a preliminary set of raw and rectified images and the second is the final orthorectified images along with photo center information and supporting documents.

Preliminary Deliverables:

Raw Images, AGPS/IMU data, and preliminary orthophotos. Within 21 days or sooner (the intent is as soon as possible) of acquiring the imagery, Cornerstone will provide PREP and Aerial Interpreter with raw images, AGPS/IMU data, and preliminary orthophotos for the study area to be used in the ground truth survey. We will use AGPS/IMU for geo-positioning and an average elevation terrain model (the same across all images) will be used to generate 4-band orthophotographs with a 1 foot resolution. They will not be mosaicked.These images are not to be distributed but are meant solely for the aerial interpreter.

The images shall be in a JPEG format with JGW world file and will be geo-referenced using direct geo-referencing from the airborne GPS (AGPS) and inertial measurement unit (IMU) used in the aerial acquisition phase.

Quality Control Checks and Procedures for Digital Raw Images and Preliminary Orthophotographs

- Check that imagery covers project area.
- Preliminary check on quality of imagery.
- Check for proper image format(s).
- Check coordinate system and units.
- If applicable, check that all images were orthorectified and are readable with at least two software packages.

Delivery Materials

- Raw images. Within 21 days of image acquisition, deliver raw images with AGPS/IMU only as the geo-referencing in TIF and/or JPEG formats.
- Deliver preliminary images orthophotographs in SID and/or JPEG formats using direct geo-referencing.

Final Deliverable Materials

The final deliverables will be will be verified for completeness prior to shipping.

- Digital Camera Product Characterization Report.
- ArcGIS shapefile(s) showing photo centers and times of all photographs.
- Raw imagery data with camera station control data in the New Hampshire State Plane Coordinate System referenced to NAD83. Elevations will be referenced to NAVD88 via NAD83 ellipsoid heights, and geoid modeling. Units will be US Survey Feet.
- Raw images on external disk drive.
- QC summary report.

B. TASK 3: Prepare and Deliver Digital Files to PREP

Task 3 involves the preparation of orthorectified multi-band imagery and RGB composite true color imagery mosaicked in uncompressed GeoTiff format.

1. Direct geo-referencing or AT

Quality Assurance

Cornerstone proposes to use direct geo-referencing for the positioning of the imagery. In this scenario, ground control points are not used because the aircraft is equipped with integrated Airborne GPS (AGPS) and IMU systems. The AGPS calculates the exposure centers for each photo. The IMU unit provides the roll, tip, and yaw of the aircraft at the instance of exposure. In essence, each photo center is a control point with this approach.

To verify the geo-positioning, Cornerstone proposes to obtain scaled ground control check points surrounding the project area. We will scale a minimum of 20 coordinates from photo-identifiable points from New Hampshire's GRANIT Statewide GIS Clearinghouse and the Maine GIS Geolibrary such as the recent 2012 and 2016 orthophotographs in York County. We will compare scaled coordinates with the directly geo-referenced coordinates to ensure that we meet the 0.62 RMSE as specified for the horizontal accuracy. Points will be well distributed over the entire project area: points will enclose the project area as well as a number of them will be sprinkled throughout the middle. Points will be selected <u>after</u> Cornerstone receives the imagery.

If we do not meet the positional accuracy requirements, then we are prepared to follow a traditional workflow of running the aerotriangulation (AT) process. Typically, the aerotriangulation (also called bridging) process is used to densify the ground control network and the AGPS, and to extend the limited control into every frame of photography. The process involves measuring points on each stereo model, tying the stereo models into strips, and then tying the strips into a block. The block is then transformed to fit the existing scaled ground control. A sophisticated least squares algorithm is then used to adjust all of the measurement values simultaneously to achieve a best fit solution.

The above bridging process would be used to the extent possible on this project. However, water photos cannot be bridged in the above manner unless sufficient land features are present. Where typical bridging is not possible, we will rely on the AGPS exposure center coordinates, and the photo rotations derived from the inertial measurement unit (IMU). On land features that are present, we will scale coordinates of photo-identifiable points from New Hampshire's GRANIT Clearinghouse, and will add such points to the aerotriangulation solution for that area. This process is discussed in the "*Guidance for Benthic Habitat Mapping*" in the section Alternative Sources of Control.

Quality Control Checks

- If Direct georeferencing
  - Check points from scaled imagery
- If Aerotriangulating (AT)
  - Check model ties
  - Check flight ties for blunders.
  - Check ground control residuals.
  - Check RMSE of final block adjustment

Delivery Materials

The final deliverables will be will be verified for completeness prior to shipping.

- If Direct geo-referencing
  - Exterior orientation parameters (X, Y, Z, Omega, Phi, Kappa).
  - Listing of check points and their coordinates
- If Aerotriangulation (AT)
  - Report and listing of the refined plate coordinates; pass point and flight tie residuals, final coordinates of all pass points, flight ties, and ground control, and exterior orientation parameters (X, Y, Z, Omega, Phi, Kappa).
- ArcGIS shapefile(s) showing photo centers and times of all photographs.

2. Digital Elevation Model

Quality Assurance

Digital Elevation Models (DEM) are a necessary element to create digital orthophotographs. Cornerstone will obtain the best, freely available LiDAR data or USGS DEMs that cover the project area and use these in the orthorectification process. We propose to use the following composite data: a new composite DEM will consist of LiDAR data compiled from Coastal NH (2011, NOAA), FEMA 2006, and NRCS 2013 datasets and will be obtained from New Hampshire's GRANIT website.

The DEM will be imported into our softcopy system and edge matching will be verified in stereo using photogrammetric software and hardware. In areas of gaps or overlaps, Cornerstone will correct the area in stereo using our softcopy system. The Digital Elevation Model will be of sufficient accuracy and resolution for the orthorectification process to ensure compliance to the spatial accuracy of the RFP.

QC of Digital Elevation Model

- Stereo visual inspection and correction, if necessary.

Delivery Materials

- None

3. Orthophotography & Mosaicking

Quality Assurance

Ortho-rectified multi-band (red, green, blue, and near infrared) imagery will be created from the following raw data sources: aerial imagery from the digital camera, exterior orientations from either direct geo-referencing or aerotriangulation, and the Digital Elevation Model (DEM).

The individual images will be orthorectified using specialized orthorectification software. The orthorectification process will use a bi-cubic convolution algorithm, which produces a quality orthophotograph. Output pixel resolution for each image will be 1 foot (0.30 meters) and the projection will be the New Hampshire State Plane Coordinate System with horizontal datum of NAD83.

Images will be mosaicked into a seamless database using OrthoVista software. This software package also provides tools for radiometrically balancing of the images, to ensure image consistency and enhancement across flight lines. We will review the radiometric balance options with PREP to ensure optimal viewing of the eelgrass and salt marshes. Changes in color balance across the project will be gradual (if at all). It is understood that abrupt tonal variations are not acceptable.

Once the images are color corrected and mosaicked, they will be tiled to a layout suitable for PREP. The geo-referenced mosaic images will be in uncompressed

GeoTIFF format. As the images are loaded into your GIS package, they will automatically be placed in the correct geographic position.

Deliverables will also include a 3-band (red, green, blue) true-color composite.

QC for Orthophotography

- DEM will be verified before the orthorectification process.
- Imagery locations will be checked against checkpoints and existing vector data. A minimum of 20 check points that are distributed throughout the project area will be evaluated to determine the accuracy of the final product. Existing data sets (vector maps, high resolution/quality digital orthophotographs, etc) as well as the initial points used to verify the quality of the direct georeferencing or AT will be used to extract suitable points. RMSE's for both the x and y component of the check points will be computed assuming that the RMSE of the x and y components are roughly equal. The 95% confidence level using the circular map accuracy standard (Accuracy = 1.7308 * $RMSE_r$) will be applied. The results will be reported in the standard NSSDA report format showing all computations. This step is in addition to the step checking the horizontal accuracy in Task 3, Subtask 1 (Direct Georeferencing or AT).
- Individual inspection of the imagery for pleasing and consistent color balancing suitable for eelgrass habitat monitoring.

The final deliverables will be will be verified for completeness prior to shipping.

Delivery Materials

- Digital media on hard drive
- Ortho images in uncompressed GeoTIF/TFW format
- Index of tile layout in ArcGIS format
- Composite image in SID format
- Orthophoto metadata meeting FGDC standards
- Clearly stated materials to deliver to GRANIT clearinghouse.

C. TASK 4: Quality Control Report

Task 3 involves the preparation of the Quality Control Report that demonstrates that the imagery meets or exceeds the specifications from Task 1 according to the procedures specified in the Quality Control Plan from Task 2.

Quality Assurance

The QC reports and check lists from the previous tasks will be assembled.

Quality Control

The assembled reports will be reviewed to make sure all required items are a “pass”.

Cornerstone
Energy Services
AERIAL IMAGERY, MAPPING, & GIS

Appendix C

Task 3: National Standard for Spatial Data Accuracy (NSSDA) Report For PREP Orthophotography

Cornerstone Energy Services, Inc. Project # 19114.00

November 11, 2019

Submitted by:

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I. The Project

The objective of this phase of the project was to obtain aerial imagery in the Piscataqua Region for the purpose of mapping estuarine habitats. Four-band imagery was collected during the summer of 2019 during peak growing periods and the mission was flown using the Intergraph Digital Mapping Camera (DMC). During the flight mission, a Global Positioning System supported the navigation system interfaced with the camera control software, differential-GPS, and inertial measurement unit (IMU) sensors to capture positional data to the 0.62 meters (2 foot) accuracy required for the project.

The flightplan consisted of 9 flight lines with 113 images at a pixel resolution of 0.29 meters.

Images were obtained on August 2, 2019 and followed the flight plan.

II. Tested Data Set

KAPPA generated 1.0 foot orthophotography from the digital imagery, AT results, and Digital Elevation Model.

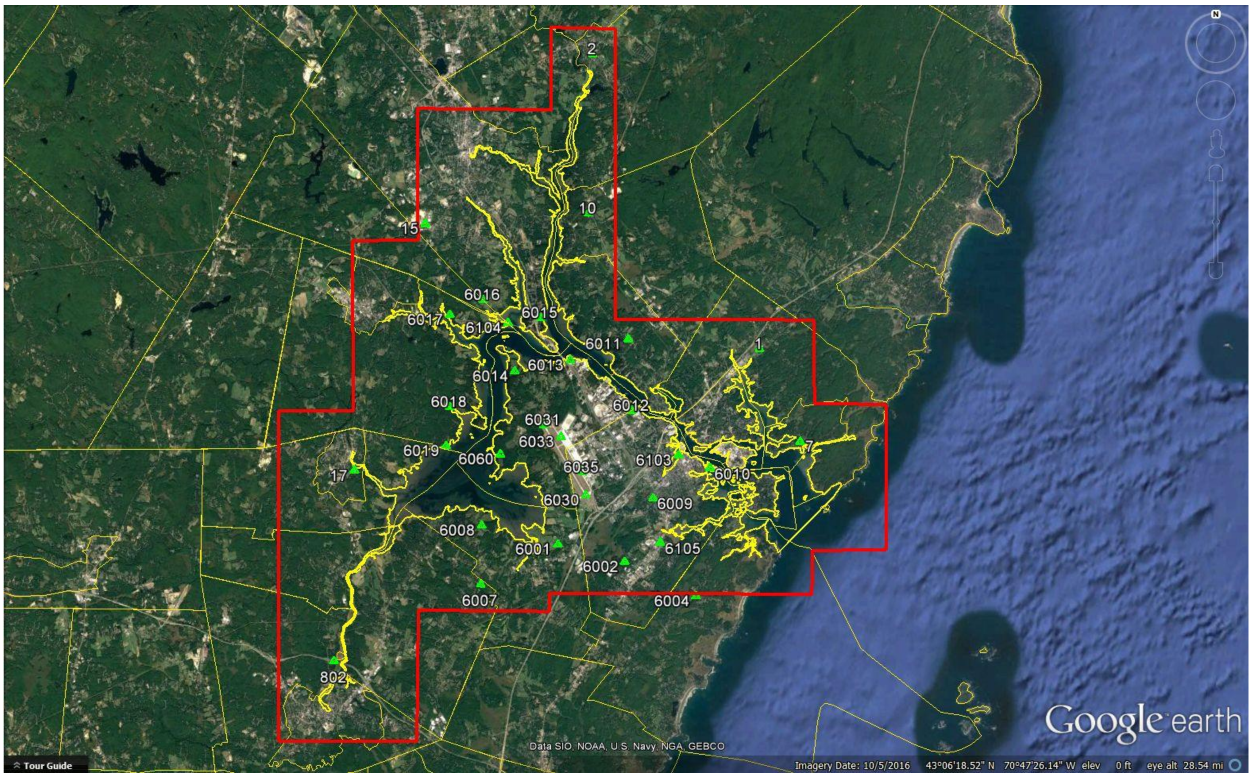
Coordinates of 26 well-distributed check points were selected throughout the project area. These were photo-identifiable points such as road intersections, corner of parking lots, sidewalks, etc.

III. Independent Data Sets

Three datasets were used as an independent check against the PREP orthophotography. The first dataset was from the State of Maine orthophotography program. York County was flown in the spring of April 2012 (under leaf-off conditions) with pixel resolutions of 0.5 foot (http://mapserver.maine.gov/basemap/index.html. This imagery and metadata are available from the Maine Office of GIS / Maine GeoLibrary (http://mapserver.maine.gov/basemap/index.html). Coordinates were scaled from the corresponding images from the Maine orthophotography program. These are labeled **2012**.

The second dataset is GRANIT's Coastal New Hampshire Point Cloud Data (http://lidar.unh.edu/map/), which consists of all the LiDAR data, not just the bare earth classification. This LiDAR dataset was collected in the Winter and Spring of 2011 at a 2 meter or better nominal post spacing for approximately 902 square miles of New Hampshire. Coordinates were scaled from the corresponding LiDAR dataset from feature identifiable points. These are labeled **PSM_XX**.

The third dataset used to perform an independent check was from an in-house Cornerstone project for end client Pease International Airport (PSM). This project objective is to conduct an airports GIS survey with obstruction mapping to support planning and procedure development. This control is accurate to +/- 3 cm, which meets our objective of having a better quality dataset to use in our NSSDA testing. All of these points are labeled **PSM OBS - 2017**, and consist of photo-identifiable points. See graphic below.



IV. IV. Worksheet

PREP Horizontal Accuracy Statistic Worksheet - 2019

Point No.	DESC	x (CHK)	x (TEST)	diff in x	(diff in x)²	y (CHK)	y (TEST)	diff in y	(diff in y)²	(diff in x)² + (diff in y)²
1	2012 - ME corner box	1223036.6444	1223037.6099	-0.97	0.93	200448.4614	200447.8099	0.65	0.42	1.36
2	2012 - ME sidewalk corner	1177592.7071	1177593.0799	-0.37	0.14	183440.5314	183440.8999	-0.37	0.14	0.27
802	2011 - NH LidarDEM Inter paint-joint	1212866.8679	1212865.8299	1.04	1.08	268380.0429	268380.0699	-0.03	0.00	1.08
6004	PSM OBS - 2017, stripe	1228110.3740	1228111.3399	-0.97	0.93	192993.5666	192992.9099	0.66	0.43	1.36
6007	PSM OBS - 2017, drive corner	1198019.6652	1198018.0699	1.60	2.54	194335.9347	194335.7899	0.14	0.02	2.57
6009	PSM OBS - 2017, drive corner	1221986.1829	1221985.5999	0.58	0.34	206593.852	206594.8999	-1.05	1.10	1.44
6011	PSM OBS - 2017, stripe	1209019.8298	1209021.4199	-1.59	2.53	214992.8912	214992.4399	0.45	0.20	2.73
6013	PSM OBS - 2017, stop bar middle	1206595.6757	1206596.3199	-0.64	0.42	216642.8546	216643.0399	-0.19	0.03	0.45
6017	PSM OBS - 2017, parking stripe	1212019.4991	1212020.1899	-0.69	0.48	210083.5395	210083.0999	0.44	0.19	0.67
6019	PSM OBS - 2017, corner of drive	1212576.0990	1212576.8299	-0.73	0.53	206886.1205	206885.6599	0.46	0.21	0.75
6030	PSM OBS - 2017, paint corner	1210222.3497	1210223.2499	-0.90	0.81	225661.5058	225661.8699	-0.36	0.13	0.94
6031	PSM OBS - 2017, paint corner	1218286.8898	1218287.4199	-0.53	0.28	228710.7225	228711.3399	-0.62	0.38	0.66
6033	PSM OBS - 2017, paint corner	1193317.1654	1193317.7399	-0.57	0.33	231840.958	231840.9399	0.02	0.00	0.33
6035	PSM OBS - 2017, paint corner	1192953.9726	1192953.5199	0.45	0.20	213582.1732	213581.9999	0.17	0.03	0.23
6104	PSM OBS - 2017, parking stripe	1201437.2159	1201437.3799	-0.16	0.03	230790.8965	230790.8699	0.03	0.00	0.03
6105	PSM OBS - 2017, crosswalk stripe	1236632.9850	1236632.5199	0.47	0.22	227523.2053	227524.4699	-1.26	1.60	1.82
PSM_01	Inside corner paint	1204001.6709	1204002.4853	-0.81	0.66	236395.2923	236394.8093	0.48	0.23	0.90
PSM_02	intersect crosswlk paint/conc. Sidewalk	1207029.2100	1207028.9170	0.29	0.09	195914.1819	195912.2352	1.95	3.79	3.88
PSM_03	w'ly corner driveway	1195497.8071	1195497.5614	0.25	0.06	199484.9217	199484.5329	0.39	0.15	0.21
PSM_04	intersect stop mark/side road paint line	1198256.0488	1198256.3878	-0.34	0.11	216862.782	216862.9506	-0.17	0.03	0.14
PSM_05	corner stop mark at yellow road cl	1192978.5591	1192978.9034	-0.34	0.12	229050.2039	229050.4581	-0.25	0.06	0.18
PSM_06	intersect roads in cemetery	1220519.1133	1220520.0140	-0.90	0.81	185688.8158	185687.7935	1.02	1.05	1.86
PSM_07	intersect crosswalk/conc. Sidewalk	1206552.4235	1206551.5181	0.91	0.82	195485.1264	195484.4287	0.70	0.49	1.31
PSM_08	nw'ly cor conc parking area	1227970.1200	1227970.6450	-0.52	0.28	201252.1146	201251.5186	0.60	0.36	0.63
PSM_09	se'ly cor parking area	1226765.4579	1226765.8346	-0.38	0.14	205458.9216	205459.5458	-0.62	0.39	0.53
PSM_10	center nw'ly end stop mark	1229168.1403	1229168.5602	-0.42	0.18	215416.4021	215415.6129	0.79	0.62	0.80
									sum	27.12
									average	1.04
									RMSE	1.02
									NSSDA	1.77

Using the National Standard for Spatial Data Accuracy, this data set tested **1.77** foot horizontal accuracy at the 95% confidence level.

V. Positional Accuracy Statistic

The horizontal root mean square value is the sum error squared in both X and Y directions divided by the number of check points (in this case 26 check points). The RMSE calculated value is **1.02** feet. This Root Mean Square Error is then multiplied by 1.7308 which gives a value of **1.77** feet horizontal accuracy at the 95% confidence level.

VI. Comments

Horizontal positional accuracy statement:
Using the National Standard for Spatial Data Accuracy, this data set tested **1.77**-foot horizontal accuracy at the 95% confidence level.

Vertical positional accuracy statement: Not applicable.

APPENDIX D

MEMORANDUM

From: Kalle Matso, PREP

Date: March 2019

Re: Quality Assurance of 2019 Great Bay Estuary Eelgrass Mapping

PURPOSE

The purpose of this memorandum is to document the results of quality assurance checks on the 2019 Great Bay Estuary Eelgrass Mapping conducted by Seth Barker (photo interpretation) and Cornerstone Energy Services (image acquisition and ortho-rectification).

The project consisted of photointerpretation of the aerial imagery to delineate and classify presence/absence of eelgrass beds in the Great Bay Estuary.

The following table contains assessments of the data quality objectives of the project. Supporting tables and figures are also provided.

For more information on data quality objectives, please contact: Kalle Matso at (kalle.matso@unh.edu)

DATA QUALITY OBJECTIVE ASSESSMENTS

Aerial Survey Objectives

Data Quality Objective	Criteria	Protocol	Assessment of Criteria	Data Quality Objective Status
Imagery completeness	4-band source imagery obtained for 100% of study area	Extent of mapped eelgrass will be compared to study area.	All of the eelgrass mapped was within the defined mapping extent (see Figure 1 in Appendix B). Additionally, all of the eelgrass mapped was within one of DES's existing Eelgrass Assessment Zones.	**Achieved**
Ground Pixel Resolution	Less than or equal to 0.30 meters (1 foot)	Pixel size of imagery will be compared to criteria.	Post-flight report shows that pixel size was 0.29 meters.	**Achieved**
Spatial Accuracy	Horizontal positional accuracy less than or equal to 0.62 meters (2 feet) Root Mean Square Error following guidance from NSSDA*	The positions of 20 known locations in the orthorectified imagery will be checked against the known coordinates.	Post-flight report shows that horizontal positional accuracy was 0.54 meters at the 95% confidence interval.	**Achieved**
Environmental and Timing Considerations	Environmental & timing conditions during flight - 7/1/17 to 9/30/17 - 7 AM to 10 AM - Low spring tide (+/- 2 hrs) - Low sun angle (22-50$_o$) - Low cloud cover (<10%) - Calm winds (<10 mph) - No preceding rain events - Good water (Secchi disk depth > 2 meters is ideal, but < 2 meters is allowable, especially in Great Bay	Environmental & timing conditions during flight will be compared to criteria.	Environmental & timing conditions met during actual flight - Date = 8/2/2019 - 7:40 to 8:38 a.m. - Low spring tide (+/- 2 hrs) - Sun angle = 12.5 to 24 degrees - Cloud Cover = 0% - Wind speed = 3 to 5 mph - Slight rain July 31; No rain Aug 1 - Water Clarity (Secchi disk visual depth of at least 2 meters is ideal, but less than 2 meters is allowable. On Aug. 2, Portsmouth Harbor Secchi Disk reading was 2.6 meters and reading at Cedar Pt was 1.2 meters and Adams Pt was 1.0 meters. It was decided that this was sufficient water clarity for mapping purposes. Later, photointerpretation work verified this decision, although there were some isolated areas where turbidity was too high for image-based mapping. These areas were mapped via field verification instead.	**Achieved*** **(Before the flight, it was determined that 12 degree sun angle would be sufficient and maybe preferable for glare issues. This turned out to be true.)**

*Root Mean Square Error (RMSE). A measure of the difference between locations that are known and locations that have been interpolated or digitized. RMSE is derived by squaring the differences between known and unknown points, adding those together, dividing that by the number of test points, and then taking the square root of that result. Following guidance from the National Standard for Spatial Data Accuracy (NSSDA), the spatial accuracy will be calculated as the 95% confidence level using the circular map accuracy standard (Accuracy = 1.7308 * RMSE). See http://www.fgdc.gov/standards/projects/FGDC-standards-projects/accuracy/part3/chapter3 for methods.

Field Verification Objectives

Data Quality Objective	Criteria	Protocol	Assessment of Criteria	Data Quality Objective Status
Spatial Accuracy	Field GPS units should have a reported accuracy less than or equal to 3 meters using NAD83 datum	Check reported accuracy of field GPS units.	Checked reported accuracy of the equipment used; reported accuracy meets criteria.	**Achieved**
Comparability	Field observations should be collected using a standardized protocol.	Check that protocols from the QAPP were used for field observations.	Protocols in the QAPP were used. The QAPP for 2017 is based on previous QAPPs so the data are considered comparable. For a copy of the QAPP, please contact Kalle Matso at: kalle.matso@unh.edu	**Achieved**
Completeness	Field observations should be made at planned locations and should ideally represent various conditions in SAV beds. At least 80% of the field verification stations should be visited.	Check field verification observation locations against planned locations. Check that 80% of field verification stations were visited.	165 (nearly all) pre-chosen numbered stations were visited. These stations represent a variety of locations and SAV conditions. In addition, several unplanned sites were visited. Therefore, in total, over 170 stations were visited.	**Achieved**

Photointerpretation Objectives

Data Quality Objective	Criteria	Protocol	Assessment of Criteria	Data Quality Objective Status
Imagery completeness	4-band source imagery obtained for 100% of study area	Extent of mapped eelgrass will be compared to study area.	All of the eelgrass mapped was within the defined mapping extent (see Figure 1 in Appendix B). Additionally, all of the eelgrass mapped was within one of DES's existing Eelgrass Assessment Zones.	**Achieved**
Minimum Mapping Unit	100 square meters	The area of the smallest delineated SAV beds will be compared to the criteria. If SAV beds smaller than 100 sq meters can be clearly discerned, they will be mapped but flagged as being below the MMU.	The minimum mapping unit is the theoretical minimum size technically possible for delineating an eelgrass bed based upon the image data that the land cover is being derived from.	**Achieved**
Spatial Accuracy	Less than or equal to 5 meters	The bed edge measured at 10 ground truth locations will be compared to mapped edge.	Defining edges can be difficult to do in a way that is not arbitrary. These edge checks were implemented at channel margins. For a high-accuracy comparison between field and aerial imagery, transects would be required.	**Achieved**