Report to the Joint Standing Committee on Environment and Natural Resources 131st Legislature, Second Session

Marine Vegetation Mapping Program Report

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Introduction

The Marine Vegetation Mapping Program (MVMP) was established by P.L. 2021, ch. 424, an Act to Restore Eelgrass Mapping and Enhance Salt Marsh Vegetation Mapping in the State, by the 130th Legislature in 2021. The MVMP is now defined by 38 M.R.S. §1805, which mandates that the mapping schedule begins in 2023 and the first biennial report to the Joint Standing Committee on Environment and Natural Resources be submitted by March 1, 2024. This final report for the 2023 mapping survey is organized into an Introduction, Executive Summary, and the following main sections:

1. Background
2. Aerial Photography Survey Coordination
3. Seagrass Delineation and Mapping
4. Tidal Marsh Delineation and Mapping

The full report is available on the DEP website at:
https://www.maine.gov/dep/water/monitoring/coastal/index.html

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Sarah Gladu, Coastal Rivers Conservation Trust, Director of Education and Community Science

Acronyms

2DRMS	2x root mean square (95% precision)
BRLT	Boothbay Region Land Trust
CDOM	colored dissolved organic matter
DD	decimal degrees
DEP	Department of Environmental Protection
DMC	Darling Marine Center
DMR	Department of Marine Resources
DQI	data quality indicators
DQO	data quality objectives
GIS	geographic information system
GNSS	global navigation satellite system
GPS	global positioning system
GSD	ground sample distance
IMU	inertial measurement unit
KELT	Kennebec Estuary Land Trust
MCOA	Maine Coastal Observing Alliance
MEGIS	Maine Office of GIS
MEMP	Marine Environmental Monitoring Program
MLLW	mean lower low water
MMU	minimum mapping unit
MNAP	Maine Natural Areas Program
MVMP	Marine Vegetation Mapping Program
NAD	North Atlantic datum
UTM	universal transverse mercator
NHDES	New Hampshire Department of Environmental Services
NAIP	National Agriculture Imagery Program
NIR	near infrared
NOAA	National Oceanic and Atmospheric Administration
QA/QC	quality assurance/quality control
RGB	red, green, blue
SAV	submerged aquatic vegetation
SOP	standard operating procedure
TNC	The Nature Conservancy
WAAS	wide area augmentation system

Executive Summary

Background

The Maine Department of Environmental Protection's (DEP) Marine Vegetation Mapping Program (MVMP) is responsible for implementing 38 M.R.S. §1805 to delineate eelgrass (*Zostera marina)* and salt marsh extent coastwide with a 5-year rotating regional survey. The program is located in the Marine Unit within the Division of Environmental Assessment and Bureau of Water Quality. Coastal vegetation provides critical habitat, nursery grounds, storm surge protection, carbon sequestration, and water quality benefits to the nearshore environment, and requires routine mapping to detect changes in extent and condition. In 2023, the MVMP surveyed the Midcoast Region (Phippsburg to Port Clyde) through the acquisition of high-resolution, low tide, true color aerial orthoimagery followed by targeted field-validation and photointerpretation of aerial signatures. The Midcoast Region was last surveyed for eelgrass in 2005 by the Department of Marine Resources (DMR). Existing state tidal marsh maps were not derived from tidally coordinated imagery and are limited by landowner permission for field validation efforts. Although the statute only mandates the mapping of eelgrass and salt marsh distribution, an additional seagrass species (widgeon grass, *Ruppia maritima*) and tidal marsh habitat type (Freshwater Tidal Marsh) were included in the survey to maintain consistency with previous methodology and existing databases. Additional funding of $12,000 was obtained from The Nature Conservancy (TNC) to expand the survey area.

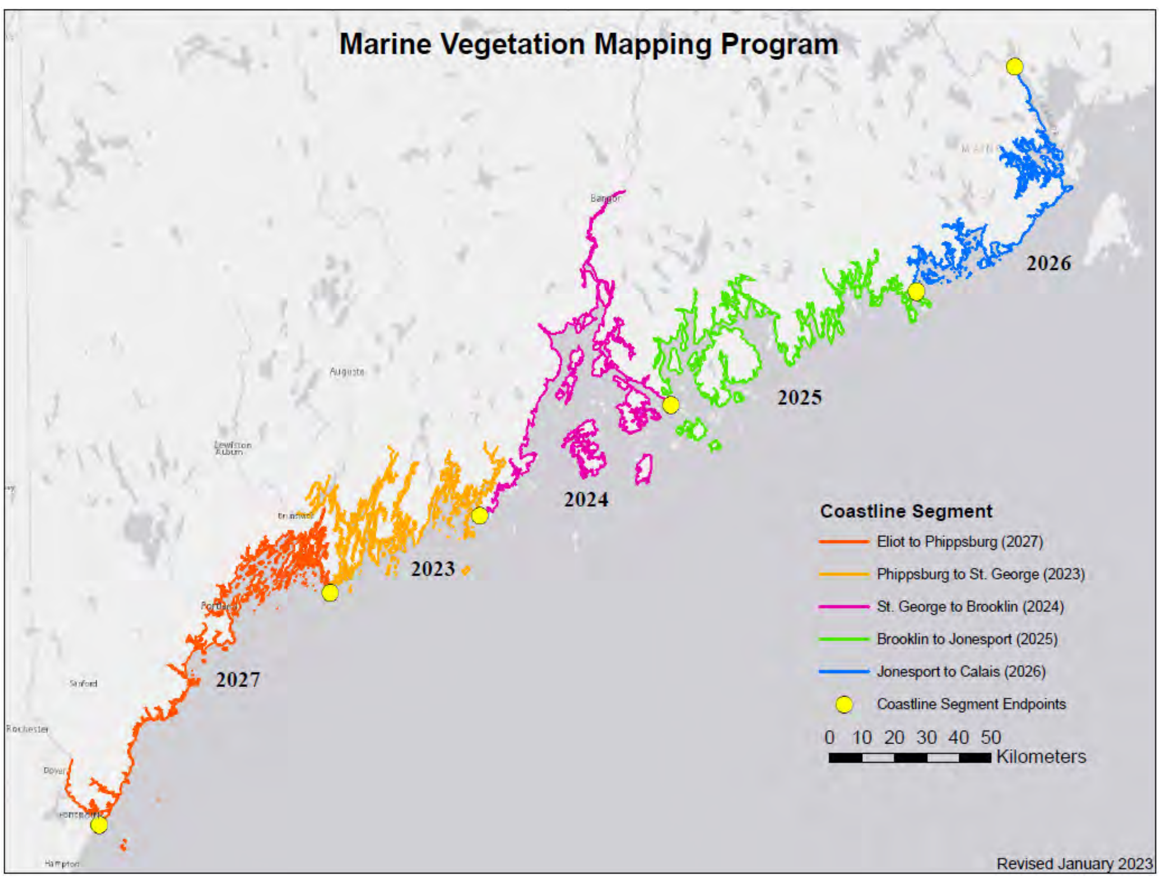

Figure 1. Marine Vegetation Mapping Program 5-year survey rotation schedule.

Aerial Photography Survey Coordination

True color, 6-inch resolution, low tide aerial imagery with 1-foot accuracy was acquired by Bluesky Geospatial Ltd. under subcontract with James W. Sewall Co. on July 7, August 2, August 3, and August 6. Target flight conditions included survey within 2 hours of a spring low tide, a sun angle of 20-50 degrees above the horizon, less than 10% cloud cover, and less than 10 knots maximum predicted wind velocity. No precipitation within the preceding 48 hours and a Secchi disk depth ≥1.5 meters were also desirable, but a few minor exceptions were considered acceptable to ensure the acquisition of imagery for 100% of the survey area. The 2023 project area was approximately 510,309 acres in size, and the aerial photography survey consisted of approximately 2,781 images over 28 flight lines with 60% forelap and 30% sidelap acquired at an elevation of approximately 9,500 feet. The draft imagery was delivered to DEP by August 24, 2023, and the revised final imagery and other deliverables (e.g., flight reports, metadata, and QA/QC checklist) by January 17, 2024. The revised final imagery and associated metadata are available on the Maine Office of GIS (MEGIS) data catalog as an imagery service layer (https://maine.hub.arcgis.com/datasets/fb96713c40034cca917e230a2bd7b452/explore).

Seagrass Delineation and Mapping

Aerial orthoimagery was photointerpreted to determine seagrass extent and assigned one of four percent cover classifications (0-10%, 10-40%, 40-70%, 70-100%) as per Orth et al. (1996). Since seagrass has many aerial signatures which vary depending on factors such as water depth, substrate type, bed density, and cohabitation with macroalgae, targeted field validation efforts are critical to accurate delineation. Due to the tight window for field efforts between delivery of draft aerial imagery and the expected time of seasonal senescence of seagrass beds, digitization of seagrass beds was completed following the collection of field observation waypoints and underwater video files. Field data collection began on August 14 and was completed by October 11 over the course of 21 days on the water and resulted in the completion of 716 transects. Slightly more than half of all mapped seagrass beds (393/692) were visited in the field, and 272 of the unverified beds have been mapped previously in the same or nearly the same location.
Key findings from the survey included:

- Approximately 1,022.9 acres of eelgrass and 0.4 acres of widgeon grass were mapped in 2023, which represents a **59.9% decline** since the Midcoast Region was last surveyed in 2005. Widgeon grass was observed in a tributary to Great Salt Bay, upstream of a culvert that likely restricts tidal flow.

- The seagrass resource in the Midcoast Region was defined by a patchy distribution, with the majority of mapped seagrass polygons being under 1 acre in size.

- The largest documented eelgrass beds were located in Great Salt Bay near the head of the Damariscotta River (three large beds totaling 148.2 acres, not including smaller beds in Great Salt Bay), and along the western shore of Louds Island (84.3 acres), the northeastern shore of Morse Island (32.23 acres), and in Hatchet Cove (26.7 acres) in Muscongus Bay.

- Although not included in historical DMR surveys in 1994/1995 and 2005, the project area was extended to include Monhegan Island in 2023 which resulted in the novel documentation and delineation of a 7.6-acre eelgrass bed near the ferry terminal.

- Areas with the most significant losses include the historically extensive eelgrass beds to the west of Westport Island in the Back River (161.7 acres in 2005, 0 acres in 2023), in the Medomak River (533.4 acres in 2005, 0 acres in 2023), and in Great Salt Bay (416.9 acres in 2005, 151.7 acres in 2023).

- Seagrass was largely absent from the upper reaches of estuaries, which may be attributable to light limitation from precipitation-derived turbidity in the water column. European green crabs (*Carcinus maenus)* and epiphytic growth can also lead to seagrass decline, although relatively low abundance of both were observed throughout the survey. However, whether high levels of rainfall in the spring and summer of 2023, epiphytes, or green crabs may have been related to any recent seagrass losses or growth limitations cannot be clearly established since the Midcoast Region had not been mapped since 2005, and changes in seagrass distribution could have occurred at any time since the prior survey.

The final GIS map of seagrass beds (polygon shapefile) and associated metadata are available on the MEGIS data catalog as a service layer (https://hub.arcgis.com/maps/maine::mainedep-mid-coast-seagrass-2023/explore).

Tidal Marsh Delineation and Mapping

Aerial orthoimagery was photointerpreted to refine polygon boundaries and improve acreage accuracy within the Midcoast Region of the existing coastwide tidal marsh GIS map (polygon shapefile). The Maine Natural Areas Program[1] (MNAP) provided DEP with the most recent, 2021 version of the tidal marsh shapefile, and will incorporate edits made by DEP in a future update to the shapefile that is currently hosted on the MEGIS data catalog (MNAP 2014). Sites that were visited in the field were further refined based on waypoints and track logs. Tidal marsh natural community types (Salt-hay Salt Marsh, Mixed Graminoid-Forb Salt Marsh, Brackish Tidal Marsh, and Freshwater Tidal Marsh) were previously assigned to each site by MNAP according to Gawler and Cutko (2010) and were unchanged during the photointerpretation process. Tidal marsh sites larger than 2.5 acres are considered Element Occurrences by MNAP and are tracked in their georeferenced database, Biotics. Biotics is the official state record of tidal marsh sites, as well as other rare and exemplary natural communities and rare plant populations, that is made publicly available for conservation, development, and management planning. Tidal marsh field verification occurred following the seagrass field verification survey due to the tight time window for seagrass field observations as described above. The season for tidal marsh field verification is approximately July through November, when there is sufficient aboveground biomass for the majority of characteristic plant species, and fieldwork occurred on July 17, October 17, and October 19.

[1] The Maine Natural Areas Program (part of the Department of Agriculture, Conservation and Forestry) facilitates conservation of Maine's biodiversity by providing comprehensive information and scientific expertise on at-risk species, natural ecosystems, wildlife habitats, ecological reserves, and invasive plants to landowners, developers, resource managers, towns, and other conservation partners (https://www.maine.gov/dacf/mnap/).

Six d*e novo* sites that are not currently included in the Biotics database due to lack of field verification, or sites that required an update, were selected for field verification by MNAP staff based on landowner permission and property boundaries. Only sites where landowners provide permission for a field survey were visited. **Key findings from this survey included:**

- The Midcoast Region hosts the greatest extent of tidal marshes compared to all other MVMP regions, approximately 8,865.9 out of 22,175.2 coastwide acres. This includes approximately 4,205.8 acres of the state's 4,288.9 acres of freshwater tidal marshes, which are largely concentrated in Merrymeeting Bay.
- Four sites were found to be tidal marsh communities and were added to Biotics either as updates or new Element Occurrences. One site was found to be a tidal marsh community but was too small to be considered an Element Occurrence (<2.5 acres), and one site was found to not host a tidal marsh. Both sites were added to Biotics as negative surveys to avoid duplicate effort in future surveys.
- Additionally, the rare plants marsh-elder (*Iva frutescens)* and saltmarsh false-foxglove (*Agalinis maritima)* were documented at Hall Bay marsh and Hockomock marsh, respectively. **Marsh-elder is a state endangered species** and saltmarsh false-foxglove is a species of special concern.
- Of the four sites that were added to or updated in Biotics, three are Salt-hay Salt Marshes (Back River, Hall Bay, and Hockomock Bay), and one is a Brackish Tidal Marsh (Hubbard Point).
- In total within the Midcoast Region, approximately 41 acres of tidal marshes were added, updated, or otherwise improved in the Biotics database. Additionally, the 2021 version of the existing coastwide tidal marsh shapefile was refined by approximately 223.5 acres within the Midcoast Region through more accurate delineation of the seaward edge of marshes and removing open water stream and river channels.

These changes were reviewed by MNAP staff and will be incorporated into the GIS map of coastwide tidal marshes (polygon shapefile) that is currently hosted on the MEGIS data catalog during the next scheduled update in 2024 (https://maine.hub.arcgis.com/datasets/948b222d1f644410a74ba7499e1484d9/explore).

1. Background

1.1 Program Overview

The Marine Vegetation Mapping Program (MVMP) was established in 2021 by the Maine State Legislature (38 M.R.S. §1805) to restore regular eelgrass mapping and enhance salt marsh mapping within the state. The bill (Legislative Document 593) included General Fund appropriations for one Biologist II and one Environmental Technician position. In January of 2023, the Biologist II position was filled by Cheyenne Adams to coordinate, oversee, and otherwise manage the MVMP. In April of 2023, the Environmental Technician position was filled by Eric Rainey to captain watercraft vessels, provide technical field assistance, and otherwise support the MVMP. Additionally, the program acquired the necessary field instrumentation, including underwater videography equipment (SeaViewer Admiral Pro with 6000 SeaDrop Camera), high-accuracy GPS equipment (Juniper Systems Geode GNS3S Global Navigation Satellite System [GNSS] Receiver), field ruggedized tablets (Samsung Tab Active3), and a marine chartplotter with sonar (GPSMAP 1243xsv). The MVMP follows a 5-year rotating regional survey approach to coastwide mapping of the target coastal vegetation (Figure 1). In 2023, seagrasses and tidal marshes between Small Point, Phippsburg and Marshall Point, Port Clyde were mapped (Figure 2). The survey area covered the supratidal, intertidal, and shallow subtidal from the exposed oceanic coast through the head-of-tide. This area is referred to as the Midcoast Region throughout this report. Although the statute only mandates the mapping of eelgrass (*Zostera marina*) and salt marsh distribution, an additional seagrass species (widgeon grass, *Ruppia maritima*) and tidal marsh habitat type (Freshwater Tidal Marsh) were included in the survey to maintain consistency with previous seagrass mapping efforts and the MNAP datasets, respectively. Additional funding of $12,000 was obtained from The Nature Conservancy (TNC) to expand the survey area.

1.2 Seagrass and Salt Marsh Benefits and Threats

Coastal vegetation, including seagrasses and tidal marshes, provides critical habitat and water quality benefits in the nearshore environment globally. In Maine, the predominant seagrass is eelgrass, which is a flowering perennial plant that grows in soft substrates of the shallow subtidal and low intertidal marine environments and forms extensive beds through both the spread of rhizomes and seed distribution (Figure 3). Several factors impact the distribution of eelgrass in Maine, including light availability, temperature, and disturbance regimes. This species faces several threats that can impact populations, including reduction of light (through suspended algae or sediment, or shading by structures), physical disturbance (by dredging, mooring tackle abrasion, propeller strikes, or pile installation), disease, and impact by invasive species such as the European green crab (*Carcinus maenus*)(Wippelhauser 1996; Neckles 2015). Eelgrass also serves as an indicator species for nutrient enrichment and, for this reason, can be a factor in determining the attainment status of Maine’s marine waters based on their respective statutory classification. Eelgrass is an important gauge of marine life support and knowledge of changes in bed extent and percent cover have led to impairment designations in the Piscataqua River estuary and Portsmouth Harbor. Although there are currently no established numeric criteria for eelgrass in Maine’s Water Quality Standards (38 M.R.S. §§464-470), understanding change in eelgrass beds can inform narrative interpretation of water quality standards.

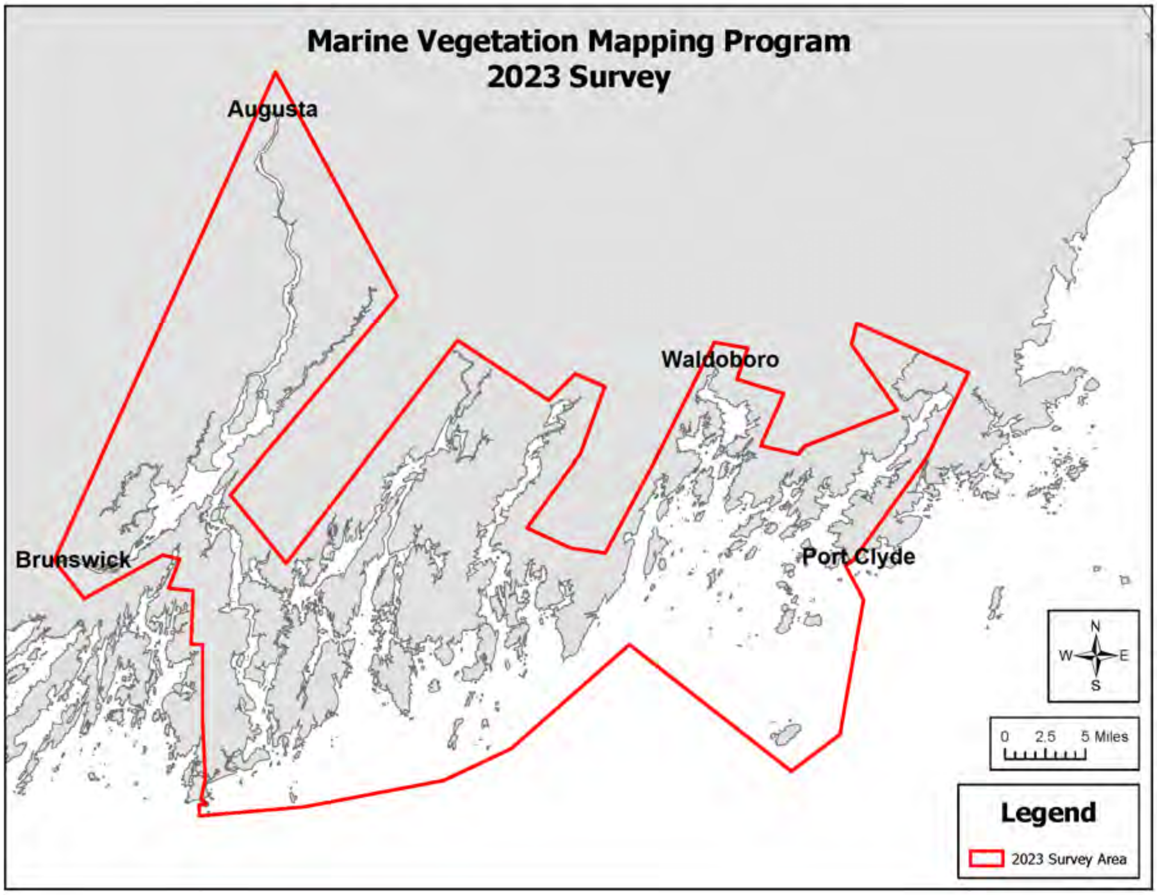

Figure 2. Marine Vegetation Mapping Program 2023 Survey Area.

Figure 3. Novel documentation of eelgrass bed near Monhegan Island (September, 2023).

Maine has over 22,000 acres of tidal marshes that occupy significant portions of the intertidal zone, generally from mean tide level to the highest annual tide level. Salinity, watershed position, sediment supply, and tidal range gradients dictate the type of vegetation present; the predominant types are various cordgrasses, rushes, sedges, and forbs. Sediment deposition and subsequent colonization by marsh vegetation leads to the creation of high organic matter sediment known as peat, which can store large quantities of carbon over long time-periods. Using the Maine Natural Areas Program (MNAP) classification system, tidal marshes in Maine are categorized into four natural community types: Salt-hay Salt Marsh, Mixed Graminoid-Forb Salt Marsh, Brackish Tidal Marsh, and Freshwater Tidal Marsh (Figure 4).

Both seagrass beds and tidal marshes are widely recognized as key habitat, nursery grounds, food sources, and refuge for a host of commercially important marine and estuarine animals, particularly during larval and juvenile life stages. Nearshore water quality benefits are provided in the form of nutrient uptake, sediment stabilization, and pH buffering. Carbon sequestration via belowground biomass and sediment accretion is an additional and critical climate resiliency contribution of these ecosystems, as is storm surge protection. Seagrass beds wax and wane on relatively short timescales due to a variety of stressors and coastal processes, and tidal marshes are increasingly subject to the impacts of erosion and inundation from sea level rise. Therefore, both ecosystems are in flux and require ongoing mapping surveys to inform permitting decisions (e.g., wastewater licensing, mooring and dock installation, aquaculture siting), restoration efforts, conservation planning, and carbon stock assessments.

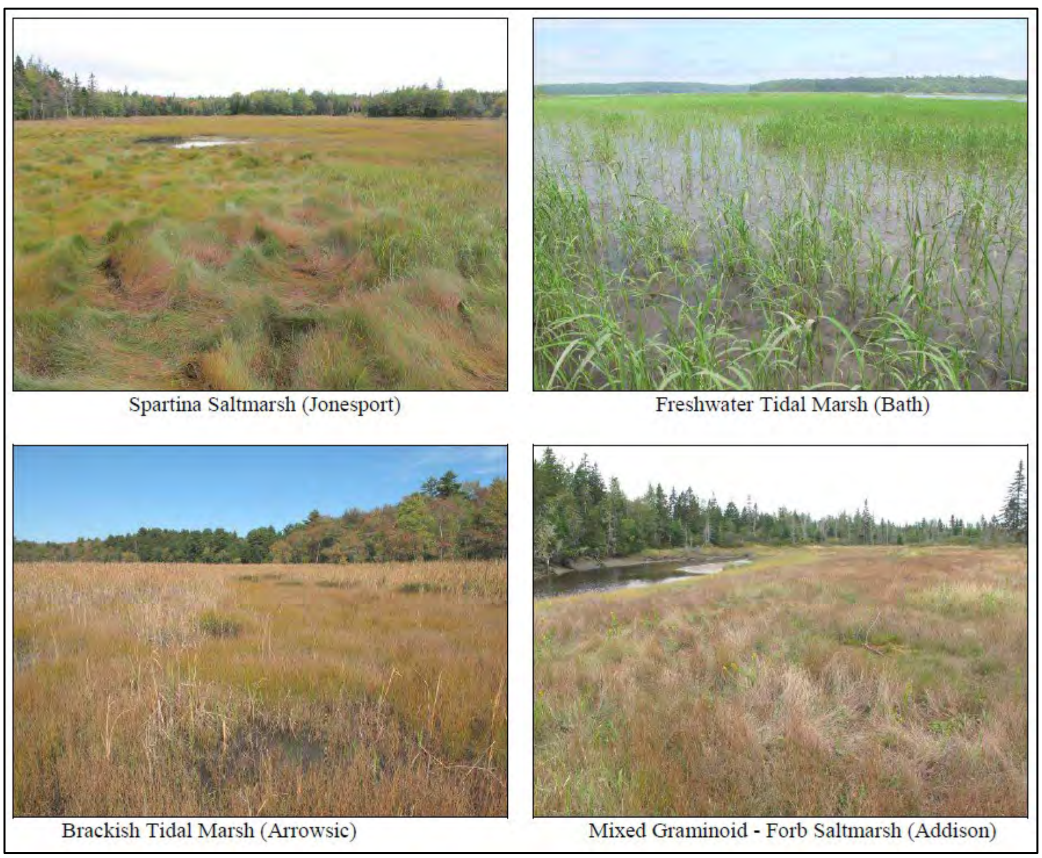

Figure 4. Tidal marsh natural community types recognized in Maine (photo courtesy of MNAP).

1.3 Past Surveys

Eelgrass was historically mapped by the Department of Marine Resources (DMR) in two rounds of coastwide surveys, one in the 1990s (1992-1997) and one in the 2000s (2001-2010). Eelgrass maps along much of the coastline have not been updated since DMR's 2000s survey, although the Department of Environmental Protection's (DEP) Marine Environmental Monitoring Program (MEMP) has produced more recent maps of both eelgrass (Casco Bay Region in 2013 and 2018) and eelgrass and widgeon grass (South Coast Region in 2021, Casco Bay Region in 2022), collectively referred to as seagrass, in select areas. All mapping efforts produced orthorectified, tidally coordinated coastal imagery and GIS maps. The DEP surveys produced high resolution (at least 0.30 meter pixel resolution) 4-band digital orthoimagery and GIS maps of eelgrass and beginning in 2021, eelgrass and widgeon grass, with a minimum mapping unit of 0.5 acres. All historical GIS maps (polygon shapefiles) can be accessed through the Maine Office of GIS (MEGIS) data catalog.

MNAP maintains both a GIS map (MNAP 2014) and georeferenced database (Biotics) of tidal marshes, which includes freshwater tidal marshes in addition to the salt-tolerant marsh community types. Biotics is the official state record of tidal marsh sites, as well as other rare and exemplary natural communities and rare plant populations, that is made publicly available for conservation, development, and management planning. The GIS map was produced using the best available aerial imagery from 2013/2014 and was updated using National Agriculture Imagery Program (NAIP) imagery from 2021. It should be noted that 'the best available aerial imagery' and NAIP imagery are not necessarily tidally coordinated. The GIS map includes some marshes smaller than 2.5 acres and those that have not been field verified, although these sites are not included in Biotics. The GIS polygon shapefile titled 'MaineNAP – Current Tidal Marshes' is available through the MEGIS data catalog and currently reflects the 2013/2014 data, although it will be updated in 2024 to reflect the 2021 revisions (https://maine.hub.arcgis.com/datasets/948b222d1f644410a74ba7499e1484d9/explore).

2. Aerial Photography Survey Coordination

2.1 Specifications

The use of low-tide, high-resolution aerial orthophotography as a raster base image is the standard method for seagrass delineation at a regional scale and has been employed in all historic seagrass mapping efforts in the state (DOC 1995; NOAA 2001). The extent of tidal marshes can be delineated from the same imagery with higher accuracy than non-tidally coordinated imagery, as was used to develop and update the current MNAP tidal marshes GIS map. In 2023, DEP contracted with James W. Sewall Co. to obtain tidally coordinated aerial imagery within the survey area, who in turn subcontracted with Bluesky Geospatial Ltd. for flight operations and orthophoto processing and development. The photographs are true color, 4-band (RGB-NIR) images captured by a Vexcel Eagle 80-mm Mark 3 digital aerial sensor mounted aboard a fixed-wing aircraft at 14.5 centimeters Ground Sample Distance (GSD) and processed to produce 6-inch orthorectified imagery with 1-foot accuracy. Digital ortho-rectified imagery was created using the raw digital aerial imagery, ground control, aerotriangulation, and the best available digital elevation model. A total of 21 new ground control points were installed and 6 existing points were verified by James W. Sewall Co. to within 2 centimeters of the actual ground coordinates. Airborne GPS and an Inertial Measurement Unit (IMU) were utilized during photograph capture to improve the aerotriangulation solution. The 2023 project area was approximately 510,309 acres in size, and the aerial photography survey consisted of approximately 2,781 images over 28 flight lines with 60% forelap and 30% sidelap acquired at an elevation of approximately 9,500 feet (Figure 5). Exceptionally wet and cloudy conditions persisted throughout the spring and summer of 2023, which resulted in multiple smaller flight windows across 4 separate days on July 7, August 2, August 3, and August 6.

Flight windows occurred within 2 hours of low spring tides and required atmospheric conditions including flying between a sun angle of 20 and 50 degrees, no more than 10% cloud cover, and less than 10 knots maximum predicted wind velocity. Additionally, water quality conditions were monitored by Secchi disk for suitable water column clarity to enable visualization of the benthos in the imagery at 8 sites within the survey area during late ebb tidal stage prior to each flight window (Table 1). Water clarity readings collected by DEP staff followed an established SOP (DEP SOP No. 5: Transparency Data Collection and Processing) which includes triplicate estimates of disk disappear and reappear depths, selecting the shaded side of the dock when possible, and taking measurements between 9:00 AM and 3:00 PM. These controls account for some variability in Secchi disk data due to changes in light or water surface conditions that could possibly affect the observer’s accuracy. Several partner organizations also contributed water quality monitoring data or observations from across the project area to inform the aerial photography survey timing (see Acknowledgements). Factors that can contribute to loss of water column clarity include turbidity from recent precipitation events, wind wave sediment resuspension, and phytoplankton blooms.

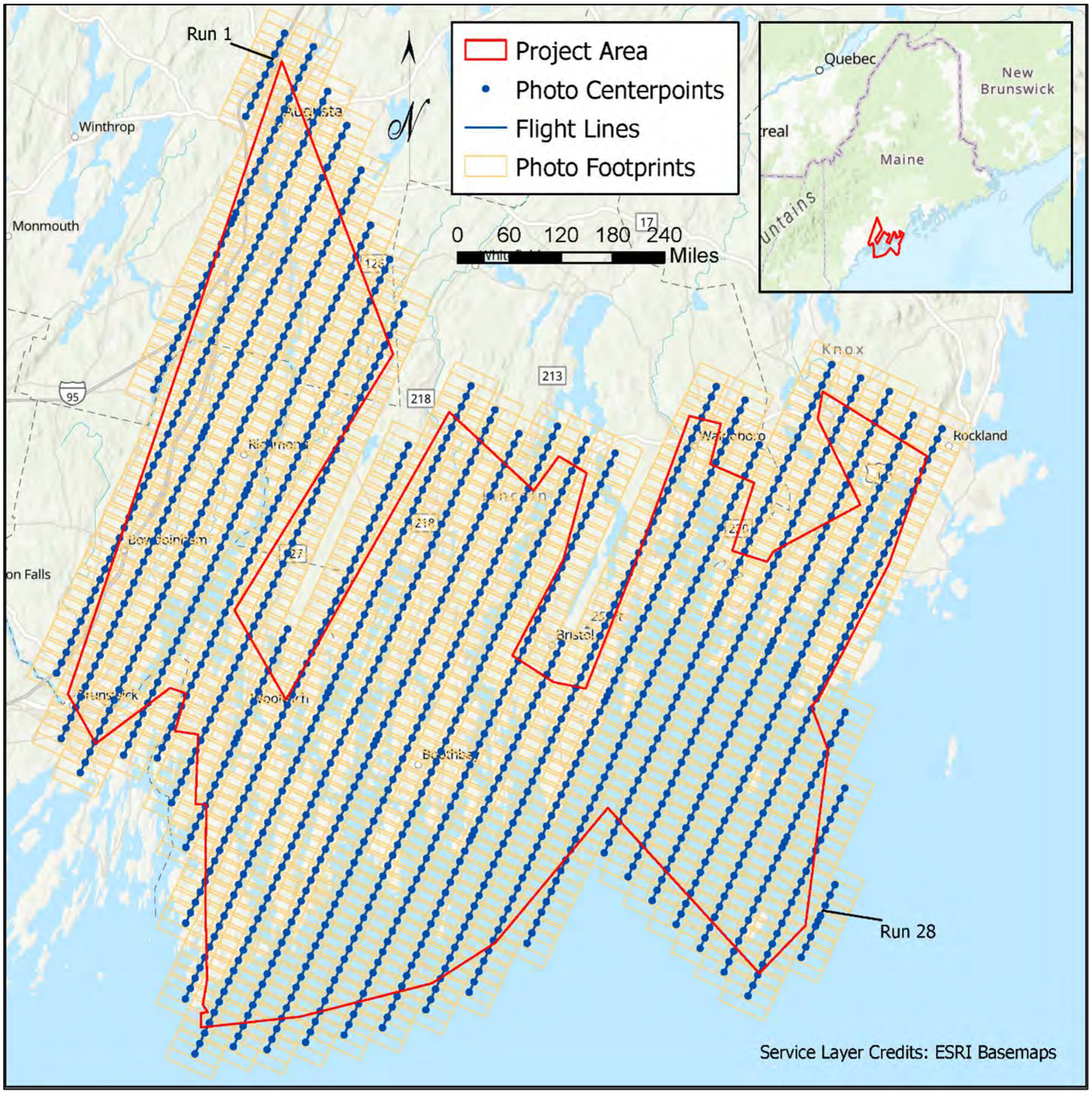

Figure 1. Flight lines, photo center points, and photo footprints for aerial flight photographs.

Table 1. Water column clarity observation locations (NAD 1983 UTM Zone 19N).

Site Name	Municipality	Latitude (DD)	Longitude (DD)
Friendship Lobster Co-op	Friendship	43.970758	-69.339632
Bremen Town Landing	New Harbor	43.997716	-69.400651
Damariscotta Town Landing	Damariscotta	44.032232	-69.533623
Bigelow Lab for Ocean Sciences	East Boothbay	43.860507	-69.578172
DMR Dock	West Boothbay Harbor	43.844518	-69.641042
Wiscasset Town Dock	Wiscasset	43.999498	-69.664324
Wright Landing Boat Launch	Wiscasset	43.95808	-69.68405
Fort Popham	Phippsburg	43.754966	-69.78463

2.2 Flight Reports

On July 7, 2023, Bluesky Geospatial Ltd. flew a portion of the project area, capturing 1,489 photos across 13 flight lines (runs 3-15). This flight began recording at approximately 7:41 AM and concluded at approximately 9:51 AM, which was within the required two-hour window of the low spring tide as predicted by the tide station nearest to each flight line for flight lines 6-15. Due to extreme tidal delays in Merrymeeting Bay and the upper reaches of the Kennebec and Androscoggin Rivers caused by high river flows and the constriction at the Chops Passage, 358 images from flight lines 3-5 were flown outside of the required two-hour window of the low spring tide as predicted by the nearest tide stations, and were therefore flown again on August 2. See Table 2 for tide height, time and date, and station for each flight line and Figure 6 for location of tide stations within the project area. The flight report stated "fairly hazy conditions initially – improving as the sun angle increased" and noted a few small clouds. Flight and ground conditions were monitored the week leading up to the flight to capture the best conditions. Actual conditions included clear skies with SW winds of approximately 6 mph, according to the National Oceanic and Atmospheric Administration (NOAA) weather station closest to the project area (Wiscasset Airport). In the 48 hours prior to the survey, there were no precipitation events reported by the Wiscasset Airport. Water column clarity was checked by the DEP staff on 7/3 and 7/5 with the use of a Secchi disk, and although the upper Damariscotta River and Sheepscot River were turbid (average 1.0 meter and 1.4 meters, respectively), the remainder of the project area was acceptable. Although the Secchi disk was still visible while resting on the sediment at two sampling locations on a total of three occasions, the average Secchi disk depth for all locations the week prior to the survey was greater than 1.9 meters. Secchi depth data and water quality observations from partner organizations were also utilized to inform water clarity at additional locations.

On August 2, 2023, Bluesky Geospatial Ltd. flew a portion of the project area, capturing 443 photos across 5 flight lines (runs 1-5)(Table 2; Figure 6). This flight began recording at approximately 7:49 AM and concluded at approximately 9:11 AM, which was within the required two-hour window of the low spring tide as predicted by the tide station nearest to each flight line. The flight report notes the conditions were "calm and clear." Flight and ground conditions were monitored the week leading up to the flight to capture the best conditions. Actual conditions included clear skies with variable winds of approximately 5 mph, according to the NOAA weather station closest to the project area (Wiscasset Airport). In the 48 hours prior to the survey, there was a precipitation event on 7/31 totaling 0.07 inches, as reported by the Wiscasset Airport. Water column clarity was checked by the DEP staff on 7/31 and 8/1 with the use of a Secchi disk, and only the Medomak River was slightly more turbid than preferable (1.4 meters), which was not within the area covered by the flight lines flown on August 2. Although the Secchi disk was still visible while resting on the sediment at two sampling locations on a total of two occasions, the average Secchi disk depth for all locations the week prior to the survey was greater than 2.1 meters. Secchi depth data and water quality observations from partner organizations were also utilized to inform water clarity at additional locations.

On August 3, 2023, Bluesky Geospatial Ltd. flew a portion of the project area, capturing 688 photos across 6 flight lines (runs 16-21)(Table 2; Figure 6). This flight began recording at approximately 6:38 AM and concluded at approximately 8:56 AM, which was within the required two-hour window of the low spring tide as predicted by the tide station nearest to each flight line. Approximately 98 photos from flight line 21 were recaptured on August 6 due to sun glare. The flight report notes state "calm and clear through out – some light high cloud shadow at end of window." Flight and ground conditions were monitored the week leading up to the flight to capture the best conditions. The location of the flight lines captured on August 3 is approximately equidistant between the NOAA weather stations at the Wiscasset Airport and the Knox County Regional Airport in Rockland. Actual conditions included clear skies with variable winds up to approximately 6 mph according to the Wiscasset Airport weather station, and clear skies with variable winds up to approximately 8 mph according to the Knox County Regional Airport in Rockland. In the 48 hours prior to the survey, there were two small precipitation events on 8/1 and 8/2, each totaling less than 0.03 inches, as reported by the Knox County Regional Airport. Water column clarity data was the same as 8/2, which was within preferred specifications at all sites except the Medomak River.

On August 6, 2023, Bluesky Geospatial Ltd. flew a portion of the project area, capturing 617 photos across 8 flight lines (runs 21-28)(Table 2; Figure 6). This flight began recording at approximately 7:37 AM and concluded at approximately 9:27 AM, which was within the required two-hour window of the low spring tide as predicted by the tide station nearest to each flight line. The flight report notes state "calm and clear through out – Wiscasset 0 knots – Rockland 7 knots" and indicate that flight line 21 was recaptured due to sun glare in the imagery captured on August 3. Flight and ground conditions were monitored the week leading up to the flight to capture the best conditions. Actual conditions included clear skies with west winds up to approximately 10 mph, according to the NOAA weather station closest to the project area (Knox County Regional Airport, Rockland). In the 48 hours prior to the survey, there were two small precipitation events on 8/4 and 8/5 totaling 0.01 and 0.1 inches, respectively, as reported by the Knox County Regional Airport. Water column clarity data was the same as 8/2, which was within preferred specifications at all sites except the Medomak River.

2.3 Draft and Final Orthoimagery

The draft imagery for July 7, August 2, August 3, and August 6 were delivered to DEP on July 30, August 14, August 22, and August 23, respectively. Additionally, a small gap spanning the imagery acquired on July 7 and August 3 was initially missed and the draft imagery was delivered on August 24. The draft imagery had the image frame assembly, color balancing, and radiometry completed with the software program Ultramap by Vexcel, and the final mosaicking routine completed with the software program Inpho by Trimble. DEP provided written comments on the draft imagery to Bluesky Geospatial Ltd. on August 14 and a shapefile with examples of seagrass signature, high-quality imagery, and imagery issues (e.g., sun glare and artifacts) on August 25. The first version of final imagery was delivered to DEP on October 23 and other deliverables from Bluesky Geospatial Ltd. (e.g., flight reports, aerotriangulation report, and camera calibration report) on October 30.

The first version of final imagery was processed as true orthoimagery entirely with the software program Ultramap, which applied a water mask to the shoreline areas that obscured subtidal signatures. On October 31, DEP provided written comment and screenshots of issues with the first version of final imagery, including loss of seagrass signature compared to the draft imagery and numerous distortions, which was followed up with a list of coordinates for examples of issues within a subset of the imagery files on November 29. In response to the issues, Bluesky Geospatial Ltd. Reprocessed the final imagery as standard orthoimagery, which allowed the water mask to be turned off in the same software program. The revised final imagery was delivered to DEP on December 29 (photography captured on August 2, August 3, and August 6) and January 17, 2024 (photography captured on July 7). James W. Sewall Co. provided the imagery metadata and Verified QC Checklist on January 16. The revised final imagery and associated metadata are available on the MEGIS data catalog as an imagery service layer (https://maine.hub.arcgis.com/datasets/fb96713c40034cca917e230a2bd7b452/explore).

Table 2. Tide time, height, and station for each flight line.

Flight Line	Date Captured	MLLW Time	MLLW Height (feet)	NOAA Tide Station Name	NOAA Tide Station ID
1	August 2	10:05 AM	-0.12	Gardiner	8417134
2	August 2	10:05 AM	-0.12	Gardiner	8417134
3	August 2	10:05 AM & 10:33 AM	-0.12 & -0.52	Gardiner & Brunswick	8417134 & 8417527
4	August 2	10:05 AM & 10:33 AM	-0.12 & -0.52	Gardiner & Brunswick	8417134 & 8417527
5	August 2	9:09 AM	-0.31	Richmond	8417208
6	July 7	9:50 AM	-1.03	Bath	8417227
7	July 7	9:50 AM	-1.03	Bath	8417227
8	July 7	9:50 AM	-1.03	Bath	8417227
9	July 7	9:50 AM	-1.03	Bath	8417227
10	July 7	8:55 AM	-1.23	Hunniwell Point	8417177
11	July 7	8:55 AM	-1.23	Hunniwell Point	8417177
12	July 7	8:55 AM	-1.23	Hunniwell Point	8417177
13	July 7	8:55 AM	-1.23	Hunniwell Point	8417177
14	July 7	8:44 AM	-1.10	Boothbay Harbor	8416828
15	July 7	8:44 AM & 9:06 AM	-1.10 & -0.97	Boothbay Harbor & Walpole	8416828 & 8416731
16	August 3	7:04 AM	-1.29	Walpole	8416731
17	August 3	7:04 AM	-1.29	Walpole	8416731
18	August 3	7:04 AM	-1.29	Walpole	8416731
19	August 3	7:04 AM	-1.29	Walpole	8416731
20	August 3	7:04 AM	-1.29	Walpole	8416731
21	August 6	9:16 AM	-0.78	Thomaston	8415709
22	August 6	9:16 AM	-0.78	Thomaston	8415709
23	August 6	9:16 AM	-0.78	Thomaston	8415709
24	August 6	9:16 AM	-0.78	Thomaston	8415709
25	August 6	9:12 AM	-0.78	Monhegan	8416092
26	August 6	9:12 AM	-0.78	Monhegan	8416092
27	August 6	9:12 AM	-0.78	Monhegan	8416092
28	August 6	9:12 AM	-0.78	Monhegan	8416092

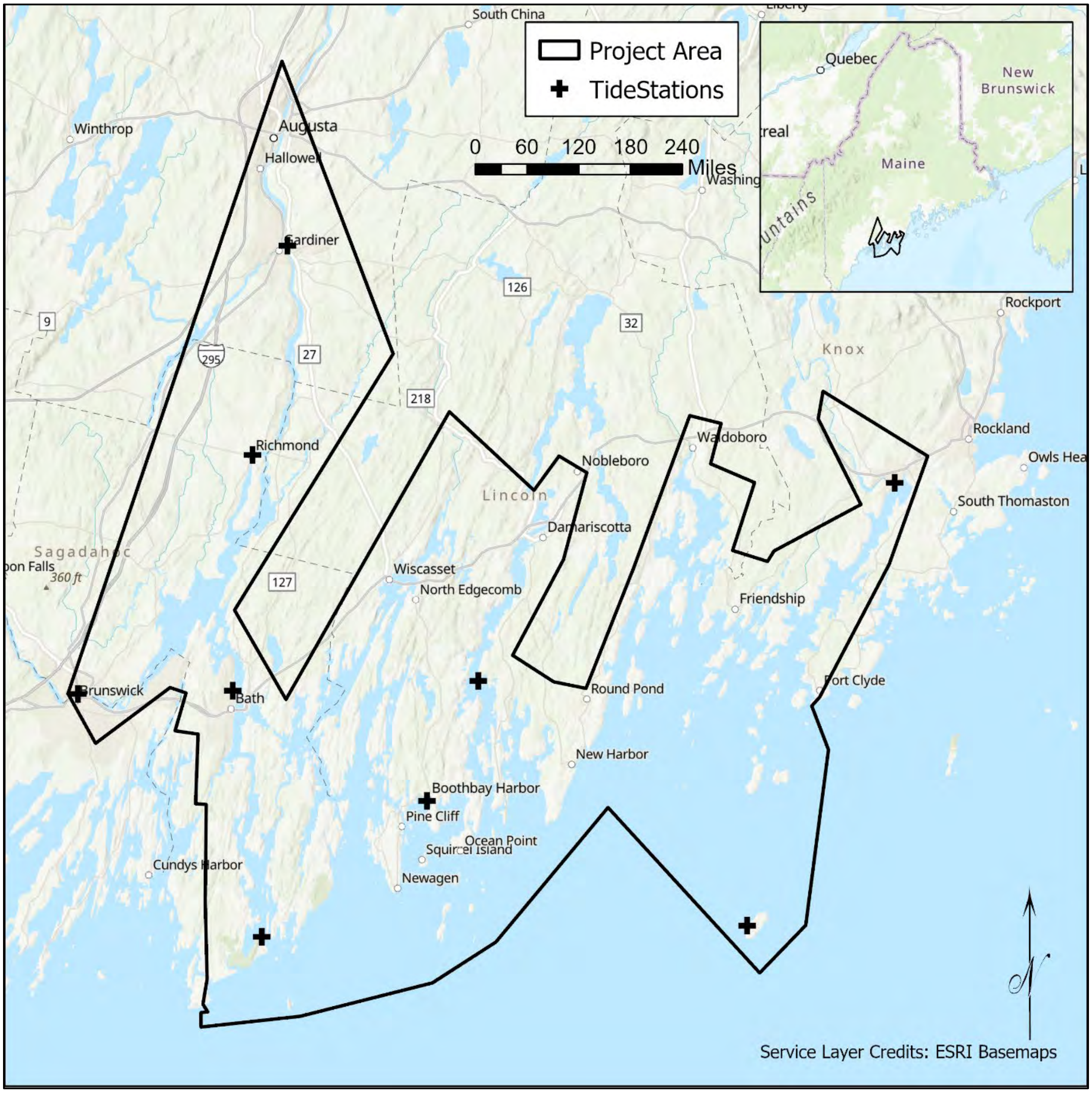

Figure 2. NOAA tide stations within the project area.

3. Seagrass Delineation and Mapping

3.1 Methods

3.1.1 Photointerpretation

Aerial orthoimagery was photointerpreted using methods from NOAA (DOC 1995; NOAA 2001). Seagrass has many aerial signatures which vary depending on factors such as water depth, substrate type, bed density, and cohabitation with macroalgae. The consistent identification of seagrass signature within a given area is critical to the production of accurate maps. Some characteristics of seagrass signature include a clumpy growth pattern, a pointillism appearance, dark color that contrasts against sediment, a green tint to the color, and a varied/inconsistent tone within a bed. Seagrass beds also tend to have a tapered signature at the edges, particularly the deep edge, as opposed to a more clearly defined edge for similar signatures such as macroalgae.

Historical eelgrass (*Zostera marina)* signatures from previous mapping efforts within the Midcoast Region (DMR 2010), as well as seagrass signature from more recent mapping efforts in other parts of the state (Casco Bay 2013, 2018, 2022 and South Coast 2021), were reviewed for calibration and to reinforce the seagrass signature and other common features (ledge, macroalgae). The DMR shapefile from the 1990s (DMR 1997) was used as a reference for historical bed extent only since associated imagery is not currently available. The above referenced seagrass map polygon shapefiles, along with associated aerial orthoimagery for all but the DMR 1990s shapefile, are publicly available through the MEGIS data catalog (https://www.maine.gov/geolib/catalog.html) and are described in more detail in Appendix C.

The Midcoast Region survey area was subdivided into eight geographic sections for the purpose of organizing field efforts and photointerpretation. These geographic sections are Merrymeeting Bay, Kennebec River, Sheepscot River, Boothbay Harbor, Damariscotta River, Johns River, Muscongus Bay, and St. George River (Figure 7). The size of each geographic section varies, along with the seagrass habitat type and quality within each section.

Once draft aerial imagery was delivered to DEP, priority sites for targeted field verification were identified and a transect shapefile developed. Normandeau Associates Inc., the mapping provider for South Coast 2021 and Casco Bay 2022, also identified field transects for approximately 50% of the survey area and provided DEP with a shapefile as part of the on-call services provided in the contract (for more information, see Section 3.1.3 Quality Assurance/Quality Control). The DEP shapefile was compared to the Normandeau Associates Inc. shapefile and augmented as necessary to ensure thorough field verification efforts and to calibrate the interpretation of aerial signatures across different photointerpreters, survey years, and project areas. Transects were established in areas of unclear signatures, to delineate the deep edge of beds, for general confirmation of seagrass presence, and as quality control checks in historical eelgrass beds that lacked a visible aerial signature in the 2023 imagery. To the extent practicable, transects were also selected at locations representative of all substrate types, water depths, and overlapping signatures (macroalgae, ledge, etc.) present within the survey region.

Seagrass bed digitization was completed following field verification due to the tight window for field efforts, which necessarily must occur after the aerial photography survey and before seasonal dieback of seagrass beds. In addition to photointerpretation of the aerial signature, bed boundaries were refined with the use of field waypoints, vessel track logs, and georeferenced underwater video files. Contiguous seagrass beds were split into estimated percent cover classifications (0-10%, 10-40%, 40-70%, 70-100%, see Figure 8) per Orth et al. (1996) based on the aerial signature, field waypoints, and georeferenced underwater video files. This is a useful framework since percent cover, unlike density, can be estimated by photointerpretation of aerial imagery and accounts for patchiness while allowing delineation of non-continuous seagrass distribution. Eelgrass and widgeon grass (*Ruppia maritima)* were distinguished where possible based on field verification data. Distinguishing between these two species of seagrass cannot be achieved based on aerial signature alone and therefore, seagrass beds without field verification were not identified to the species level. In general, however, eelgrass is the predominant seagrass species in Maine and prefers full oceanic salinity, whereas widgeon grass may grow in more brackish waters and has been mapped in areas upstream of tidal restrictions both in previous mapping efforts (South Coast 2021 and Casco Bay 2022) and in the Midcoast Region in 2023. Due to the delay in delivery of final imagery from the provider, seagrass beds were partially delineated with draft imagery and then checked against the final imagery. Draft imagery was fully orthorectified with 1-foot accuracy, but lacked full color balancing for a seamless mosaic between each flight lift and exhibited some artifacts.

Delineations were completed according to the following specifications:

- For both transect and polygon development, a percent clip stretch was applied to the orthophotography tiles in most locations to enhance the seagrass signature. Additionally, up to 25 percent contrast and 20 percent brightness was applied in some locations in response to varying types of substrate, water depth, bed density, and lighting.
- A minimum mapping unit (MMU) of 100 square meters (0.02 acres) was employed, but seagrass beds as small as 39 square feet (0.0009 acres) were mapped where conditions, such as water depth and clarity, allowed.
- Beds less than 0.07 acres in size were typically combined with nearby beds when possible, which is consistent with both NOAA guidance (DOC 1995; NOAA 2001) and the most recent mapping efforts in the state (South Coast 2021, Casco Bay 2022). Individual seagrass shoots or isolated clumps from individual plants with no aerial signature were not mapped, with the exception of areas with density greater than 10%, which were mapped as a 3-m radius circle to account for GPS error (i.e., boat movement, GNSS receiver accuracy, etc.) but not overestimate bed size.
- In cases of ambiguous signature or diffuse beds, mapping was adjusted to be consistent with the DMR 2010 shapefile.
- Photointerpretation was done at a scale ranging from 1:250-1:2,000 depending on bed size and other landscape features, and beds that were mapped at a scale at or close to 1:2,000 were reviewed at a larger scale after initial polygon development to ensure boundary accuracy.
- Void areas (interior to a seagrass polygon but with zero percent cover of seagrass, such as rocks or bare substrate) were clipped, or removed, from the features. This approach is consistent with the most recent mapping efforts in the state (South Coast 2021, Casco

Bay 2022), but it should be noted that some historical maps (e.g., DMR 1997) retained the void areas within eelgrass polygons and assigned a 0% cover category.

- In the final attribute table, polygons were numbered sequentially from west to east along the coast, and contiguous seagrass beds (which often consist of multiple percent cover polygons) were numbered sequentially approximately west to east along the coast.
- Normandeau Associates Inc. reviewed seagrass polygons in approximately 25% of the survey area and provided DEP with comments as part of the on-call services provided in the contract, and the final shapefile was checked for accuracy and errors as described below in Section 3.1.3 Quality Assurance/Quality Control.
- ArcGIS Pro v. 2.9.9 was used for all desktop GIS workflows.

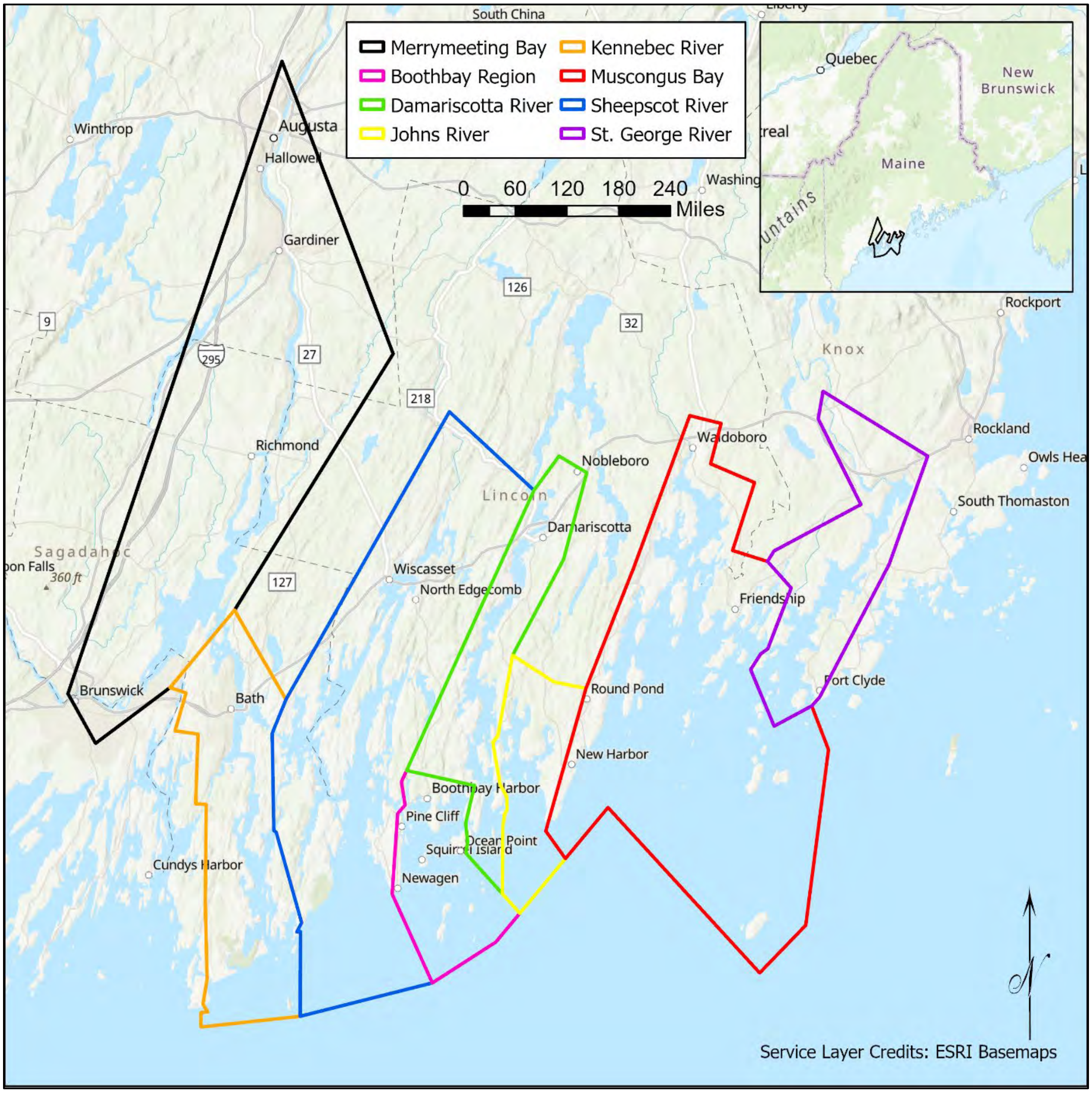

Figure 3. Geographic sections within the survey area.

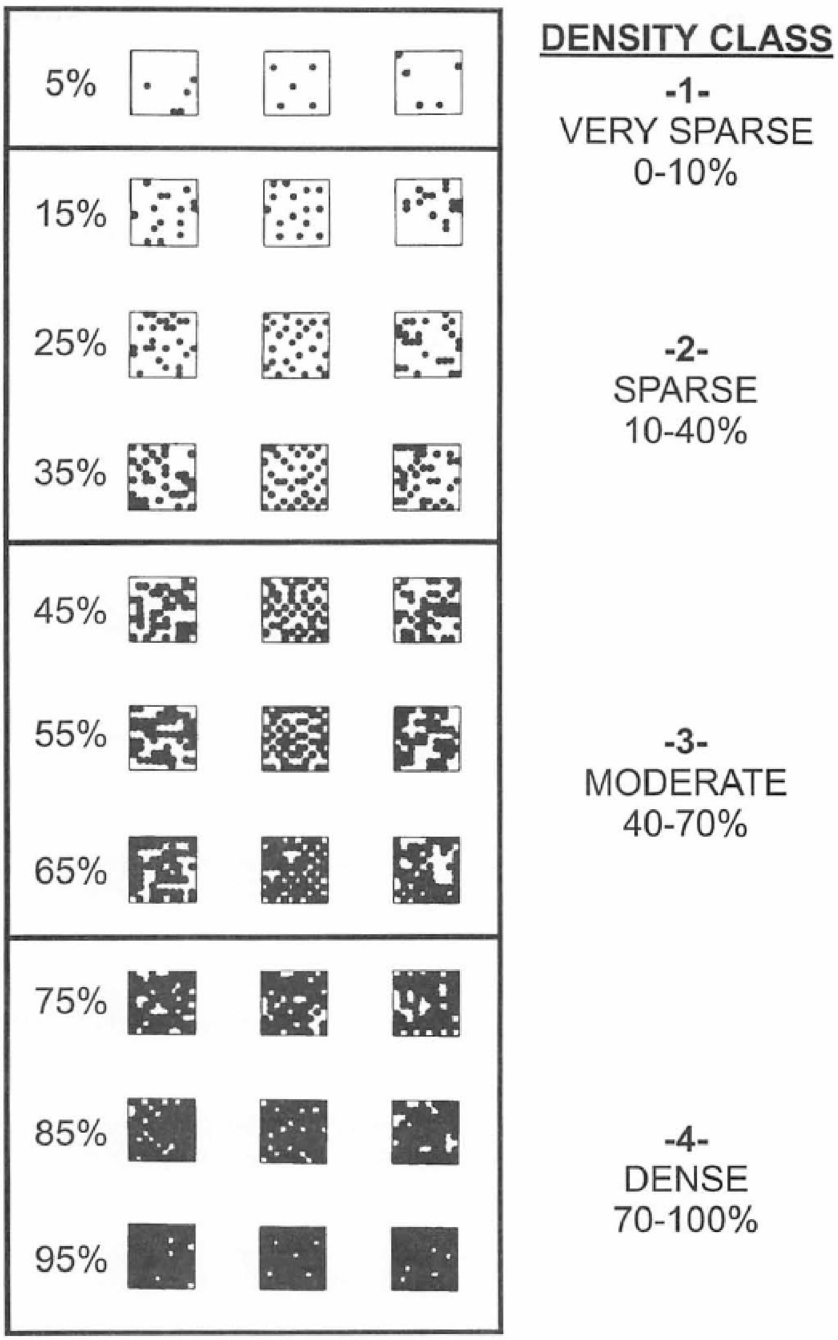

Figure 4. Seagrass percent cover categories (Orth et al. 1996).

3.1.2 Field Verification

The seagrass field verification survey occurred following transect development based on the draft orthoimagery tiles. Due to the tight time window for field verification, which should be completed prior to seasonal senescence of seagrass beds, the survey occurred prior to draft seagrass polygon development. The objectives of the field investigation are, in order of priority, to confirm presence/absence of seagrass beds, locate bed boundary, collect percent cover data, and document other features along a transect that may produce a similar aerial signature (e.g., macroalgae, ledge). Field verification to locate bed boundaries is of paramount importance at the deep edges of seagrass beds, in particular. The field survey entailed the use of an underwater video camera system, high-accuracy GNSS receiver, and field ruggedized tablet. Field verification occurred primarily by boat, but some efforts were carried out by foot and by canoe where motorboat access was restricted or otherwise impractical. In some instances, the sea floor could be visualized without the use of the underwater video camera system and logistics (i.e., canoe operation) prevented the deployment of the camera. In those cases, the GNSS receiver and tablet were utilized to record the GPS location of observations, but no recorded video file was produced. On most days, the crew consisted of three personnel: camera operator, vessel captain, and video observer/waypoint recorder. To maintain consistency, the video observation and waypoint collection was completed by either MVMP Manager Cheyenne Adams or MVMP Environmental Technician Eric Rainey.

On most days, the DEP Marine Unit’s 20-foot Maritime Skiff, powered by a 115-horsepower outboard, was launched to support field efforts. Occasionally, when the size of the Maritime Skiff was prohibitive in accessing the necessary field sites, field verification was carried out aboard a smaller motorized DEP vessel (12-foot Tracker jon boat with 5-horsepower outboard) or canoe. Field equipment included a SeaViewer High-Definition Admiral Pro underwater video system with digital video recording capabilities and 6000 SeaDrop Camera, AccuView 21.5-inch high-brightness, sunlight-readable monitor mounted inside a Display Shield weatherproof display enclosure, Juniper Systems Geode GNS3S GNSS receiver with real-time Wide Area Augmentation System (WAAS) corrections and capable of submeter accuracy, and Samsung Tab Active3 tablet (Figure 9). The SeaViewer underwater camera system was cabled to the Geode GNSS receiver to enable high-accuracy GPS coordinate overlay, along with date and time stamp, to be recorded in the video files. The Geode GNSS receiver was additionally wirelessly paired to the Samsung Tab Active3 tablet, which has an 8-inch, high-brightness, sunlight-readable screen and is field-ruggedized, for the collection of vessel track logs, observation waypoints, and high-accuracy GPS metadata.

Transect locations were loaded onto the vessel chartplotter to enable navigation to and along each transect by the vessel captain. Once the vessel was on site of a transect, the underwater camera was lowered over the vessel gunwale by rope with an 8-lb downrigger weight and fin attached to achieve an approximately 45-degree orientation relative to the sea floor. Depth of the camera above the sea floor varied with conditions (e.g., turbidity, seagrass canopy height), but was typically 0.3 to 2 meters. The external monitor displayed the video feed in real time and allowed the camera operator to make necessary adjustments to maintain optimal positioning of the camera. The georeferenced and timestamped video feed was also recorded for future reference. Tow speeds were approximately 2.5 knots in most conditions. Esri ArcGIS Field Maps and QuickCapture applications were installed on the field tablet. QuickCapture was used for high-speed data collection of new waypoints with field observations, GPS coordinates, and associated high-accuracy metadata. The QuickCapture application also recorded vessel track logs and had an offline map which displayed vessel location relative to transects and historical eelgrass maps (DMR 1997, 2010). Field Maps was required to visualize previously collected waypoints and vessel track logs. Waypoints were collected for the following observation types: seagrass absent, seagrass present, macroalgae, shell hash, ledge, epiphytes, 0-10% seagrass cover, 10%-40% seagrass cover, 40%-70% seagrass cover, 70%-100% seagrass cover, and notes/other. At the beginning of each field day, QuickCapture was used to record the geographic section, crew members, and weather conditions. At the end of each field day, data were uploaded from the field tablet to cloud storage on an ArcGIS Online hosted feature layer.

Due to the limited timeframe to conduct field investigations after draft aerial imagery was received and before seasonal loss of seagrass biomass, some field efforts were conducted during mist or light rain conditions, but no field efforts were conducted immediately following large wind or rain events that significantly reduced underwater visibility. To adequately document the diverse seagrass signatures across various localized conditions, numerous locations were visited in each geographic section with suitable habitat to support seagrass populations. The salinity in Merrymeeting Bay is too low to facilitate seagrass growth, but field verification was conducted in the upper reaches of the Kennebec River to confirm the aerial signature of freshwater submerged aquatic vegetation (SAV) (*Vallisneria americana*), which was not included the final seagrass GIS map. The exact transect location was often modified in the field based on the presence of obstacles (e.g., lobster trap buoys, other vessels), environmental conditions (e.g., wind, waves, current), personnel safety considerations, and underwater observations. Transects were labeled with two to three letters corresponding to the geographic section (i.e., KR for Kennebec River and SGR for the St. George River) followed by a numeric value. The underwater video files are named by transect name and provided in the “Video” column of the seagrass polygon shapefile attribute table.

Figure 5. Field verification equipment aboard the 20-foot Maritime Skiff.

3.1.3 Quality Assurance/Quality Control

Data quality objectives (DQOs) assess the adequacy of data collected relative to their intended uses and present the specifications necessary to support the qualitative and quantitative data collection effort. These specifications address the acceptable probability of error, define the type of data needed to support the decision, and identify the conditions under which the data should be collected. To ensure that DQOs were met, all field crew members were adequately trained on survey methodology. Performance criteria are presented in quantitative terms as data quality indicators (DQIs) for those parameters most important to accurately delineating seagrass (Table 3). Although Secchi disk depth was less than 1.5 meters on a few occasions and small precipitation events occurred in the 48 hours preceding some flights, all DQIs established as requirements for seagrass delineation were met during the 2023 survey.

To inform evaluation of quality control for the aerial orthoimagery, Bluesky Geospatial Ltd. provided flight reports for all four lifts, the latest camera/sensor calibration report, documentation of the GSD for imagery acquisition, horizontal positional accuracy verification, and an aerotriangulation report. James W. Sewall Co. additionally provided a Verified QC Checklist and installed 21 new ground control points to improve aerotriangulation and ensure spatial accuracy of the final imagery.

The GPS accuracy for all field observation waypoints was ≤0.6 meters 2DRMS (2x Distance Root Mean Square, 95% precision). Due to occasionally beginning vessel track logging during a cold start of the GNSS receiver when satellite fix and WAAS correction was still limited, the accuracy of vessel track logs was rarely greater than 0.6 meters 2DRMS (0.17% of vessel track log points collected), and even more rarely greater than 1 meter 2DRMS (0.11% of vessel track log points collected). Instances of vessel track logging with accuracy greater than 1 meter 2DRMS were not used during seagrass digitization. A total of 48% of polygons and 57% of contiguous seagrass beds were field verified. Underwater video files were reviewed as needed during photointerpretation for polygon development, but particularly to confirm percent cover estimates and to calibrate those estimates with the aerial signature. In addition to review of aerial signature, field observation waypoints, vessel track logs, and video files, seagrass delineation was informed by historical imagery from 2005. Finally, seagrass bed edge as determined by photointerpretation was compared to the field-verified bed edge at 12 Quality Assurance/Quality Control (QA/QC) points approximately evenly distributed throughout the survey area with at least one QA/QC point in each geographic section. All QA/QC photointerpreted bed edge points were within 3.6 meters of field-verified bed edges with an average distance of 2.0 meters.

Normandeau Associates Inc. was contracted by DEP in 2021-2022 to complete the field verification and seagrass delineation for the South Coast and Casco Bay Regions, and again in 2023 to produce a detailed Standard Operating Procedure (SOP) document and provide on-call services throughout the year. Both the seagrass mapping SOP and on-call services were critical to maintaining consistency between mapping providers (Normandeau vs. DEP) and survey areas. As part of the on-call services, Normandeau Associates Inc. senior delineator and 2021-2022 project manager, Jamie O'Brien, developed field verification transects for approximately 50% of the survey area and reviewed seagrass polygon delineations for approximately 25% of the survey area. The provided transect shapefile was compared to that developed by DEP and any differences were reconciled. Comments provided on digitized seagrass beds were likewise reviewed and incorporated into the final shapefile.

The final digitized seagrass bed shapefile was evaluated for completeness and correctness. First, the associated attribute table was filtered and sorted to identify any omissions or errors and all polygons smaller than the MMU were reviewed as potentially erroneous sliver polygons. The ‘Dissolve Boundary’ geoprocessing tool was used to confirm the accuracy of the contiguous seagrass bed naming system and the ‘Check Geometry’ geoprocessing tool was run to identify any invalid geometry in the dataset. Finally, attribute rules and a topology were created to check for polygon overlaps, duplicate features, gap slivers, unclosed polygons, and unnecessary boundaries. Vertex snapping was used as appropriate throughout seagrass polygon development to reduce topology errors.

Table 3. Data quality indicators for seagrass delineation.

Work Stage	DQI	Criteria
Aerial Survey	Imagery Completeness	Imagery obtained for 100% of annual survey area with ≥60% forelap and ≥30% sidelap
	Imagery Spatial Resolution	Ground Sample Distance (GSD) ≤0.15 meters
	Imagery Spectral Resolution	At least 4-band (RGB and NIR)
	Imagery Spatial Accuracy	Horizontal positional accuracy of ≤1 meter
	Season	June-August
	Tidal Coordination	Imagery obtained within ± 2 hours of low spring tide
	Environmental Conditions	Sun angle: 20-50° Cloud cover: 0-10% Wind: 0-10 knots Precipitation events: generally, none in past 48 hours Water Clarity: generally, ≥1.5 meter Secchi depth
Field verification Survey	Spatial Accuracy	GNSS receiver reported accuracy ≤1 meter 2DRMS
	Survey Completeness	Field transects completed for ≥50% of all mapped beds
	Season	June-October
	Underwater Videography Equipment	GPS coordinates overlay with horizontal spatial accuracy of ≤2.5 meter 2DRMS
	Representativeness	Field observations made at planned locations representative of diverse environmental and bed conditions throughout the survey area
Photointerpretation	Mapping completeness	Seagrass presence/absence mapped for 100% of annual survey area
	Minimum Mapping Unit	100 square meters
	Spatial Accuracy	Vegetation edge measured during field verification is within ≤5 meters of bed vegetation determined by photointerpretation

3.2 Results

3.2.1 Field Verification

Field data collection began on August 14 and was completed by October 11 over the course of 21 days on the water. No seasonal senescence or decline of seagrass biomass was noted during field activity. Targeted field observations were used to verify seagrass extent and percent cover, and a total of 716 transects were completed. The total number of transects, and thus amount of time required to complete the field-validation survey, is dependent on the amount of target vegetation present in the survey area, water clarity, sediment type, overlapping signatures, and the quality of the aerial imagery. Clear water and dense eelgrass beds on sandy substrate require less field-validation effort than turbid water and patchy or sparse eelgrass beds intermixed with macroalgae, for example. A useful metric for evaluating field effort is the proportion of seagrass beds that were visited, which was slightly more than half (393/692). However, this value may not be the best metric of field effort since some large seagrass beds were visited at multiple locations to determine the bed boundary, while other beds are in close proximity to field verified beds with visibly similar signature. Of the beds that were not visited in the field, only 27 had not been previously mapped in the same or nearly the same location in either the DMR 1997 or 2010 shapefile. Many of these beds are nearby beds that were field verified and display a similar aerial signature. Field verification was paramount for accurate digitization of seagrass beds, particularly for areas of unclear imagery, or that had overlapping signature with macroalgae or deep water (Figure 10).

Figure 6. Look-a-like and overlapping signatures observed in the field. Green circles indicate seagrass presence, red circles indicate seagrass absence, yellow circles indicate macroalgae, pink lines are field transects, and the green line is the delineated seagrass bed. (Left: Look-a-like aerial signature of macroalgae, Right: seagrass signature overlapping with deep water signature).

3.2.2 Final Maps

Seagrass beds were delineated and digitized for a total of 692 beds and 1,023.4 acres within the Midcoast Region. Of this total acreage, 251.5 acres were classified as Orth percent cover category 1 (0%-10%), 162.7 acres were classified as Orth percent cover category 2 (10%-40%), 231.2 acres were classified as Orth percent cover category 3 (40%-70%), and 378.1 acres were classified as Orth percent cover category 4 (70%-100%) (Figure 11). As noted above, populations of eelgrass and widgeon grass are impossible to distinguish by aerial signature alone. Therefore, only seagrass beds that were observed in the field are assigned a species in the shapefile attribute table, and the species identification is based on visual analysis only. However, since eelgrass is the dominant seagrass species along the Maine coastline, most non-speciated seagrass beds are assumed to be eelgrass for the purpose of this report but should be field-verified in future survey years. Widgeon grass was only documented in a 0.4-acre area in a tributary to Great Salt Bay, upstream of a culvert that likely restricts tidal flow.

The seagrass resource in the Midcoast Region was defined by a patchy distribution, with the majority of mapped seagrass polygons being under 1 acre in size. A relatively low abundance of epiphytes were observed and were a mixed composition of primarily filamentous macroalgal, tunicate, bryozoan, and hydroid species. A small herbivorous snail, *Lacuna vincta*, was commonly observed residing on eelgrass blades. Water column clarity was generally poor in the upper reaches of estuaries, declining rapidly beyond the landward extent of observed seagrass beds, which may be attributed to record levels of precipitation in the spring and summer of 2023. Several overlapping signatures were present within and nearby mapped seagrass beds, most commonly sugar kelp (*Saccharina latissima),* but also including fucoid (e.g., *Ascophyllum nodosum* and *Fucus vesiculosus)* and other macroalgal species (e.g., *Ulva lactuca* and *Codium fragile*), ledge, shell rubble, and general detrital drift.

The final GIS map of seagrass beds (polygon shapefile) and associated metadata are available on the MEGIS data catalog as a service layer (https://hub.arcgis.com/datasets/maine::mainedep-mid-coast-seagrass-2023/explore).

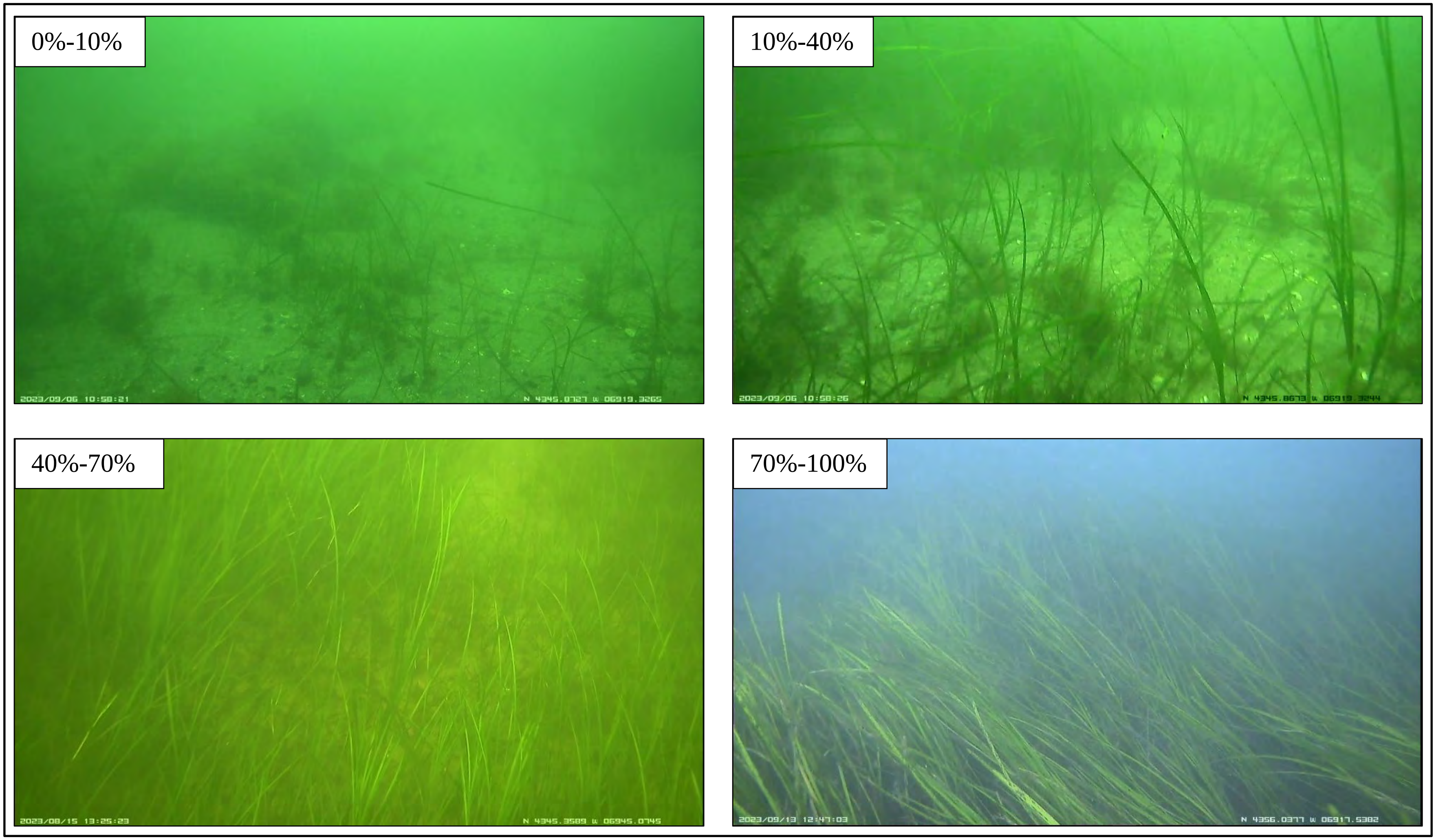

Figure 7. Seagrass percent cover categories observed in the field.

3.3 Discussion

3.3.1 Distribution and Coverage of Seagrass

Seagrass extent and percent cover were both assessed as part of the 2023 Midcoast Region survey. In general, the seagrass in this region was characterized by patchy distribution with many small beds throughout the project area. Most beds (527/692) were under 1 acre in size and the average bed size was 1.48 acres. This was contrasted by a relatively few large beds that were documented along the western shore of Louds Island in Muscongus Bay (84.3 acres), in Great Salt Bay near the head of the Damariscotta River (68.62, 50.5, and 29.0 acres), along the northeastern shore of Morse Island in Muscongus Bay (32.23 acres), and in Hatchet Cove in Muscongus Bay (26.7 acres), which were all the beds greater than 25 acres in size. It is noteworthy that three of the six largest beds mapped in the Midcoast Region were located within Great Salt Bay, which also hosted two of the five largest high-density (category 4, 70%-100% cover) polygons (34.7 and 20.5 acres). Other large, high-density polygons were located along the northwestern shore of Gay Island (21.0 acres), the western shore of Louds Island (18.8 acres), and in Hatchet Cove (16.8 acres) in Muscongus Bay.

Seagrass populations were largely absent from the upper reaches of estuaries where there is likely less suitable habitat. In the Kennebec River, a declining salinity gradient toward Merrymeeting Bay from large riverine (i.e., freshwater) inputs likely limits seagrass distribution. This is corroborated by the presence of freshwater SAV beds (*Vallisneria americana)* near the northern extent of the Kennebec River geographic section that were documented during field investigations but not included in the seagrass shapefile. Other estuaries may be light-limited toward the landward end. Light is required by seagrass for photosynthesis, and eelgrass is more sensitive to light limitation than many other marine macrophytes such as macroalgae (Larkum et al. 2006). Light transmission through the water column can be reduced by colored dissolved organic matter (CDOM) or suspended particulates such as sediment or phytoplankton cells, and light penetration to eelgrass shoots can be further affected by the presence of epiphytic growth such as filamentous macroalgae. Although epiphytes were observed on occasion throughout the field verification survey, eelgrass leaves were generally healthy and free of impediments to light absorption.

The DEP MEMP monitored the Sheepscot, Medomak (within the Muscongus Bay geographic section), and St. George Rivers for several water quality parameters every three weeks from May to October, 2023, including the light attenuation coefficient (K_d, m^{-1}), which is a measure of water clarity or light transmission through the water column. The upper and mid-estuaries generally experience high levels of turbidity and phytoplankton productivity, with elevated K_d values toward the landward end of these systems. Based on the New Hampshire Department of Environmental Services (NHDES) established K_d threshold of $\leq 0.75\ m^{-1}$ for eelgrass restoration to a depth of 2 meters (NHDES 2009), the upper Sheepscot, Medomak, and St. George Rivers were likely too turbid to support eelgrass beds, and no seagrass beds were observed up-estuary of measured median K_d values above $0.75\ m^{-1}$ (Figure 12). Low light levels may be attributable to record precipitation in the spring and summer, totaling 17.23 inches from June to August, which is the 7th wettest summer since 1871 according to the National Weather Service Portland station.

Rain events can increase freshwater runoff leading to elevated nutrients, suspended sediments, and CDOM in estuarine systems. However, whether the rainfall was related to any seagrass loss or growth limitations cannot be clearly established since seagrass in the Midcoast Region had not been mapped since 2005, and changes in seagrass distribution could therefore have occurred at any time since the prior survey. DEP did not collect water quality measurements in the Damariscotta River in 2023, and relatively little seagrass was mapped outside of Great Salt Bay (74.6 acres), but this is consistent with previous mapping years (119.7 acres in 1994, 92.4 acres in 2005).

European green crabs (*Carcinus maenus)*, an invasive species, have also been implicated in loss of eelgrass density and extent in Maine, particularly in Casco Bay (Neckles 2015). Green crabs feed on benthic pray such as shellfish and worms, but the foraging activity of green crabs within eelgrass beds involves uprooting and clipping off eelgrass shoots. Green crabs were observed sporadically throughout the field verification survey, and occasionally within eelgrass beds. Although there was no direct evidence of green crab disturbance to eelgrass beds in the Midcoast Region in 2023, the length of time since the last eelgrass mapping survey and lack of empirical studies to provide quantitative data on the matter cannot rule out the possibility.

Several potential sources of error can affect the accuracy of seagrass extent and percent cover maps, including the level of effort (field effort, in particular, is largely limited by environmental conditions and season length), differences between photointerpreters, GPS accuracy (e.g., data post-processing or real-time corrections, coordinate system and projections used, boat movement, and changes in camera scope with water depth), the use of mapping topology rules, and programmatic QA/QC protocols. The MVMP 2023 survey utilized high-accuracy GPS equipment with real-time WAAS corrections and all data are in NAD 1983 UTM Zone 19N meter projection. Mapping topology rules were employed to validate the seagrass shapefile accuracy, as well as several QA/QC checks as described above in section 3.1.3 Quality Assurance/Quality Control. Likely the largest source of error is differences between photointerpreters since seagrass digitization is at least somewhat subjective. This source of error was addressed by contracting with the 2021-2022 seagrass mapping provider, Normandeau Associates Inc., for a review of digitized seagrass beds in approximately 25% of the 2023 project area by the 2021-2022 seagrass mapping project manager and senior delineator, Jamie O’Brien.

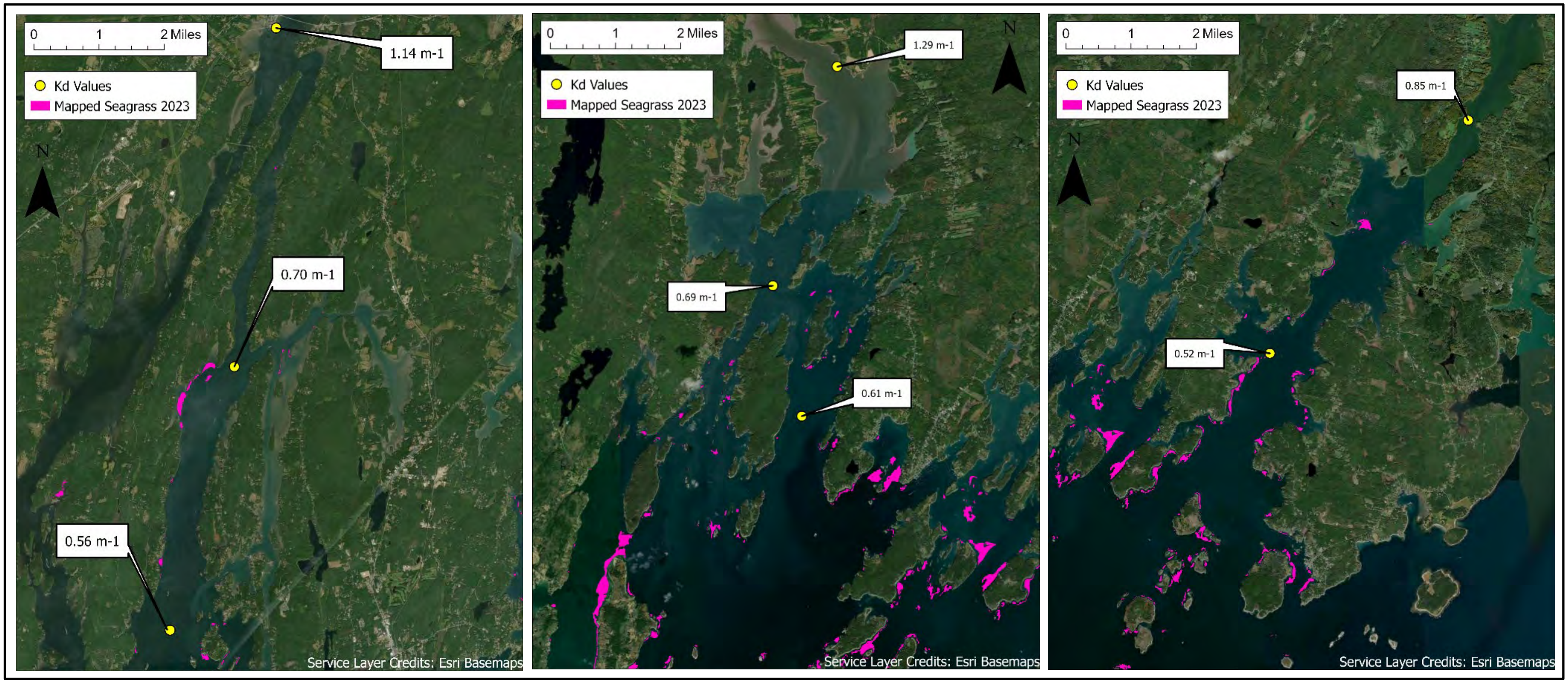

Figure 8. Upper extent of seagrass distribution and light suitability in three estuaries (left: Sheepscot River; middle: Muscongus Bay; right: St. George River). Reported K_d values are seasonal medians, and values ≤0.75 m-1 has been established as a threshold to restore eelgrass to a depth of 2 meters (NHDES 2009).

3.3.2 Comparison with Previous Years

Differences in delineated beds between seagrass surveys may arise from variation in methods, field observation interpretation, aerial signature interpretation, or equipment and data accuracy. Although the results from this survey are comparable to previous seagrass maps, the DMR eelgrass digitization and field verification methodology is not documented in a detailed manner. The DMR personnel responsible for eelgrass mapping produced a protocol document for mapping eelgrass in Maine (Barker 2015), which outlines a generalized survey approach that the MVMP 2023 survey was largely modelled after.

Compared to the most recent previous seagrass survey in 2005 (DMR 2010), the Midcoast Region lost 59.9% of total seagrass bed extent, or 1,530.1 acres (Table 4). Areas with the most significant losses include the historically extensive beds to the west of Westport Island in the Sheepscot River geographic section (161.7 acres in 2005, 0 acres in 2023), in the Medomak River in the Muscongus Bay geographic section (533.4 acres in 2005, 0 acres in 2023), and Great Salt Bay in the Damariscotta River geographic section (416.9 acres in 2005, 151.7 acres in 2023). For the purposes of this report, the Great Salt Bay area is considered to be the area north of Route 1, exclusive of the tributary to the east which becomes Oyster Creek. Combined, these three areas account for 960.3 acres of the 1530.1-acre decline since 2005 in the Midcoast Region. Many small and/or fringing beds have also declined since 2005, primarily in Muscongus Bay. The most stable geographic sections relative to the 2005 survey are Johns River, St. George River, and Kennebec River, while Boothbay Harbor saw a moderate increase in total seagrass acreage relative to 2005, although the region supports a relatively small seagrass population in total.

In addition to loss of seagrass extent, there was also a slight decline in density with the lowest percent cover category (0%-10%) comprising a slightly larger proportion of the total mapped acreage in 2023 relative to 2005 (Table 5). New seagrass resource was documented most notably in a 23.1-acre expansion of the eelgrass beds to the east of Westport Island in the Sheepscot River geographic section relative to 2005, and also throughout the project area in small, patchy beds. Although not included in the historical DMR survey in 2005, and likely not included in the historical DMR survey in 1994/1995, the Muscongus Bay geographic section was extended to include Monhegan Island in 2023 and a 7.6-acre eelgrass bed near the ferry terminal was documented and delineated for the first time.

Table 4. Seagrass acreage by geographic section and survey year.

Geographic Section	Year		
	1994/1995	**2005**	**2023**
Kennebec River	21.6	38.4	27.0
Sheepscot River	506.3	253.2	79.7
Boothbay Harbor	13.0	27.8	39.5
Damariscotta River	465.1	476.9	186.7
Johns River	32.4	46.5	40.0
Muscongus Bay	1,859.1	1,464.0	473.1
St. George River	256.1	246.7	177.3
Total	3,153.6	2,553.5	1,023.4

Table 5. Seagrass acreage by percent cover and survey year.

Percent Cover	Year		
	1994/1995	**2005**	**2023**
0-10	506.8	336.1	251.5
10-40	614.3	514.7	162.7
40-70	917.6	704.1	231.2
70-100	1,114.9	998.6	378.1
Total	3,153.6	2,553.5	1,023.4

4. Tidal Marsh Delineation and Mapping

4.1 Methods

4.1.1 Photointerpretation

Aerial orthoimagery was photointerpreted to refine polygon boundaries within the Midcoast Region in the existing tidal marsh polygon shapefile. MNAP provided DEP with the most recent, 2021 version of the tidal marsh shapefile, and will incorporate edits made by DEP in a future update to the shapefile that is currently hosted on the MEGIS data catalog (MNAP 2014). The tidal marsh aerial signature can be relatively clearly distinguished along the seaward edge in low tide imagery, which often transitions to mudflat or other habitat types along a visually distinct edge.

The Midcoast Region survey area was subdivided into eight geographic sections for the purpose of organizing field efforts and photointerpretation. These geographic sections are Merrymeeting Bay, Kennebec River, Sheepscot River, Boothbay Harbor, Damariscotta River, Johns River, Muscongus Bay, and St. George River (Figure 7). The size of each geographic section varies, along with the tidal marsh habitat type and quality within each section.

Changes made to the tidal marsh shapefile based on the 2023 low tide imagery primarily included refining the seaward edge of marsh polygons and removing open water stream and river channels to improve acreage accuracy. Sites that were visited in the field were further refined based on waypoints and track logs. Natural community types (Salt-hay Salt Marsh, Mixed Graminoid-Forb Salt Marsh, Brackish Tidal Marsh, and Freshwater Tidal Marsh) were previously assigned to each site by MNAP according to Gawler and Cutko (2010) and were unchanged during the photointerpretation process. An MMU of 2.5 acres was employed by MNAP in the development of the tidal marsh shapefile, but marshes as small as 0.08 acres were previously mapped in the Midcoast Region where conditions and context allowed, such as more extensive but multi-parted tidal marsh areas. Tidal marsh sites larger than 2.5 acres are considered Element Occurrences by MNAP and are tracked in their georeferenced database, Biotics.

Photointerpretation was done at a scale ranging from 1:1,000-1:2,500 depending on marsh or channel size and other landscape features. Marshes and channels that were mapped at a scale at or close to 1:2,500 were reviewed at a larger scale after initial edits to ensure boundary accuracy. Void areas (interior to a marsh polygon but not marsh habitat, such as mudflats or uplands) were clipped, or removed, from the features. This approach is consistent with the existing tidal marsh shapefile. No stretch, brightness, or contrast was applied to the imagery during polygon refinement. Due to the delay in delivery of final imagery from the provider, marshes were partially refined with draft imagery and then checked against the final imagery. Draft imagery was fully orthorectified with 1-foot accuracy, but lacked full color balancing for a seamless mosaic between each flight and exhibited some artifacts. The final shapefile was checked for accuracy and errors as described below in Section 4.1.4 Quality Assurance/Quality Control. ArcGIS Pro v. 2.9.9 was used for all desktop GIS workflows.

4.1.2 Field Verification

Tidal marsh field visits were performed by both DEP and MNAP staff. Tidal marsh field verification occurred following the seagrass field verification survey due to the tight time window for seagrass field observations as described above. The season for tidal marsh field verification is approximately July through November, when there is sufficient aboveground biomass for the majority of characteristic plant species. *De novo* sites that are not currently included in the Biotics database due to lack of field verification, or sites that required an update, were selected for field verification by MNAP staff based on landowner permission and property boundaries. Only sites where landowner permission was acquired were field surveyed. The objectives of field visits included walking the upland edge to create a GPS track line, collecting waypoints for any notable features (i.e., rare species, upland 'islands'), and completing an MNAP Natural Community Survey form. Information was collected regarding plant species composition, including rare or invasive species, relevant landscape features, including hydrology and land use in the general area, and disturbance history. Based on the results of the Natural Community Survey form, MNAP staff ranked each site from A (Excellent) to D (Poor) based on condition, landscape context, and size. Field verification entailed the use of a Bad Elf GNSS Surveyor high-accuracy GNSS receiver capable of submeter accuracy and a field notebook and occurred on foot. The crew consisted of two to four individuals, with an MNAP staff member present for five of the six sites.

4.1.3 Database Updates

Biotics is the database maintained by MNAP that is the official geo-referenced tracking system of rare plants and rare or exemplary natural communities, including tidal marshes which are considered vulnerable in Maine. Biotics data is provided annually to the NatureServe program, which hosts data from all state natural heritage programs to track species, communities, and biodiversity across state lines with comparable methodology. MNAP's database serves as a valuable tool for conservation planning, among other uses, and is available to municipalities, state, and federal agencies, as well as the general public. All tidal marshes greater than 2.5 acres in size are considered Element Occurrences of a rare natural community type and are tracked in Biotics following field confirmation. *De novo* sites and site updates were added to Biotics following field visits, completion of MNAP's Natural Community Survey form and Site Survey form, finalization of the site delineation polygon in GIS, and creation of a site map (see Appendix B for Biotics submission maps, courtesy of MNAP staff Emily Carty).

4.1.4 Quality Assurance/Quality Control

Data quality objectives (DQOs) assess the adequacy of data collected relative to their intended uses and present the specifications necessary to support the qualitative and quantitative data collection effort. These specifications address the acceptable probability of error, define the type of data needed to support the decision, and identify the conditions under which the data should be collected. To ensure that DQOs were met, all field crew members were adequately trained on survey methodology. Performance criteria are presented in quantitative terms as data quality indicators (DQIs) for those parameters most important to accurately delineating tidal marshes (Table 6). All DQIs established for tidal marsh delineation were met during the 2023 survey.

To inform evaluation of quality control for the aerial orthoimagery, Bluesky Geospatial Ltd. provided flight reports for all four lifts, the latest camera/sensor calibration report, documentation of the GSD for imagery acquisition, horizontal positional accuracy verification, and an aerotriangulation report. James W. Sewall Co. additionally provided a Verified QC Checklist and installed 21 new ground control points to improve aerotriangulation and ensure spatial accuracy of the final imagery.

The accuracy of GPS for all field observations waypoints was ≤2.5 meters. Due to occasionally beginning track logging during a cold start of the GNSS receiver when satellite fix and WAAS correction was still limited, and due to occasional obstruction of satellite signal by forest canopy, the accuracy of track logs was occasionally greater than 2.5 meters. Field staff paused walking the upland edge in those instances until greater accuracy could be achieved. All six sites within the Midcoast Region that were identified by MNAP were visited by DEP staff, and an MNAP staff member was present for five sites. Natural Community Survey forms were completed in the field and used to verify the natural community type of each site. In addition to review of aerial signature, field observation waypoints, track logs, field notes, and Natural Community Survey forms, tidal marsh delineation was informed by historical NAIP imagery from 2021. To maintain consistency between previous and current mapping efforts, refined tidal marsh delineation polygons were reviewed by MNAP Community Ecologist Kristen Puryear.

The final digitized tidal marsh shapefile was evaluated for completeness and correctness within the Midcoast Region. First, the associated attribute table was sorted and all polygons smaller than the MMU were reviewed as potentially erroneous sliver polygons. The ‘Check Geometry’ geoprocessing tool was run to identify any invalid geometry in the dataset. Finally, attribute rules and a topology were created to check for polygon overlaps, duplicate features, gap slivers, unclosed polygons, and unnecessary boundaries. Vertex snapping was used as appropriate throughout tidal marsh polygon refinement to reduce topology errors.

Table 6. Data quality indicators for tidal marsh delineation.

Work Stage	DQI	Criteria
Aerial Survey	Imagery Completeness	Imagery obtained for 100% of annual survey area with ≥60% forelap and ≥30% sidelap
	Imagery Spatial Resolution	Ground Sample Distance (GSD) ≤0.15 meters
	Imagery Spectral Resolution	At least 4-band (RGB and NIR)
	Imagery Spatial Accuracy	Horizontal positional accuracy of ≤1 meter
	Season	June-September
	Tidal Coordination	Imagery obtained within ± 2 hours of low spring tide
	Environmental Conditions	Cloud cover: 0-10%
Field verification Survey	Spatial Accuracy	GNSS receiver reported accuracy ≤2.5 meters 2DRMS
	Survey Completeness	Field visits completed for all *de novo* sites with sufficient landowner access permission
	Season	July-November
Photointerpretation	Mapping completeness	Tidal marsh polygon boundaries refined for 100% of annual survey area
	Minimum Mapping Unit	2.5 acres

4.2 Results

4.2.1 Field Verification, Database Updates, and Final Maps

Field data collection occurred on July 17, October 17, and October 19. No seasonal senescence or decline of vegetation biomass of characteristic plant species was noted during field activity. Field visits were used to verify tidal marsh presence and community type for *de novo* sites that were not previously included in Biotics, or sites that required an update, and a total of six sites were visited by DEP staff. The number of sites that can be visited depends largely on the ability to obtain landowner permission to access the site. Four sites were found to be tidal marsh communities and were added to Biotics as either updates or new Element Occurrences. One site was found to be a tidal marsh community but was too small to be considered an Element Occurrence (<2.5 acres, South Back River), and one site was found to not host a tidal marsh (Sewall Creek). Both were added to Biotics as negative surveys to avoid duplicate effort in the future. Additionally, the rare plants marsh-elder (*Iva frutescens)* and saltmarsh false-foxglove (*Agalinis maritima)* were documented at Hall Bay marsh and Hockomock marsh, respectively. Marsh-elder is a state endangered species and saltmarsh false-foxglove is a species of special concern. In total within the Midcoast Region, approximately 41 acres of tidal marshes were updated, added to, or improved in the Biotics database across six field sites. Of the four sites that were added to or updated in Biotics, three are Salt-hay Salt Marshes (Back River, Hall Bay, and Hockomock Bay), and one is a brackish tidal marsh (Hubbard Point). The sites were ranked in quality by MNAP Community Ecologist Kristen Puryear in accordance with the standard ranking system employed for all Element Occurrences and are as follows:

- Back River Marsh – Rank D (small size)
- Hubbard Point Marsh – Rank C (small size)
- Hockomock Marsh – Rank C (landscape context and risk of the invasive reed *Phragmites australis*)
- Hall Bay Marsh – C (small size and natural fragmentation from larger marsh system)

Additionally, the 2021 version of the tidal marsh shapefile was refined by approximately 223.5 acres within the Midcoast Region through more accurate delineation of the seaward edge of marshes and removing open water stream and river channels. These changes will be incorporated into the GIS map of statewide tidal marshes (polygon shapefile) that is currently hosted on the MEGIS data catalog during the next scheduled update in 2024 (https://maine.hub.arcgis.com/datasets/948b222d1f644410a74ba7499e1484d9/explore).

4.3 Discussion

Most of Maine's 22,000+ acres of tidal marsh have been mapped with a remote landscape analysis using the best available aerial orthoimagery, but accuracy improvements have been made in the Midcoast Region based on high-resolution low tide aerial orthoimagery with this 2023 survey. Accurate baseline maps could function to inform future assessments of marsh migration due to sea level rise at a regional or coastwide scale. Additionally, a subset of these marsh sites have been the subject of field inventory and added to the MNAP database, Biotics, which serves as the official state record of tidal marsh sites. The ability to field verify and add new sites to Biotics is limited by access to the sites, which is in turn dictated by landowner permission and property boundaries, as many tidal marsh sites exist across multiple private parcels and, therefore, only partial access permission is granted in some cases.

The Midcoast Region hosts the greatest extent of tidal marshes compared to all other MVMP regions. Based on the 2023 adjustment to the existing tidal marsh shapefile within the Midcoast Region, approximately 8,865.9 out of 22,175.2 acres of coastwide tidal marsh reside within the Midcoast Region. This includes approximately 4,205.8 acres of the state's 4,288.9 acres of freshwater tidal marshes, which are largely concentrated in Merrymeeting Bay due to unique hydrology of the area at the confluence of the Kennebec and Androscoggin Rivers.

Several potential sources of error may exist in the tidal marsh shapefile within the Midcoast Region, including GPS accuracy (e.g., data post-processing or real-time corrections, coordinate system and projections used, and the presence of overhead obstructions such as forest cover) and the best professional judgement employed in deciding when to remove a channel from a marsh polygon in the GIS shapefile. The MVMP 2023 survey utilized high-accuracy GPS equipment with real-time WAAS corrections and all data are in NAD 1983 UTM Zone 19N meter projection. Mapping topology rules were employed to validate the tidal marsh shapefile accuracy, as well as several QA/QC checks as described above in section 4.1.4 Quality Assurance/Quality Control. All revisions to the tidal marsh shapefile were reviewer by MNAP Community Ecologist to ensure consistency with previous tidal marsh delineations and other coastal regions.

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6. Appendices

Appendix A. Seagrass Distribution and Percent Cover Maps

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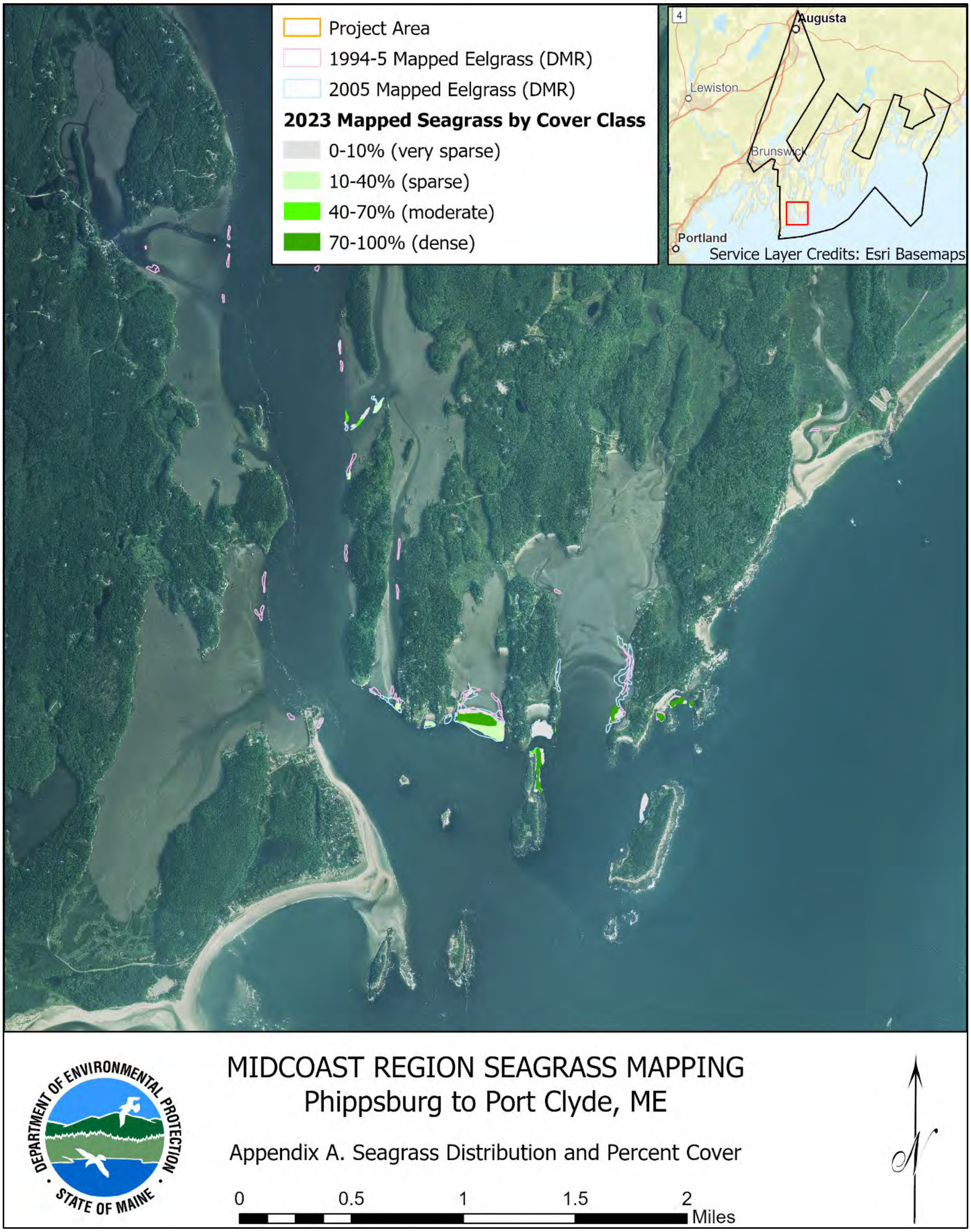
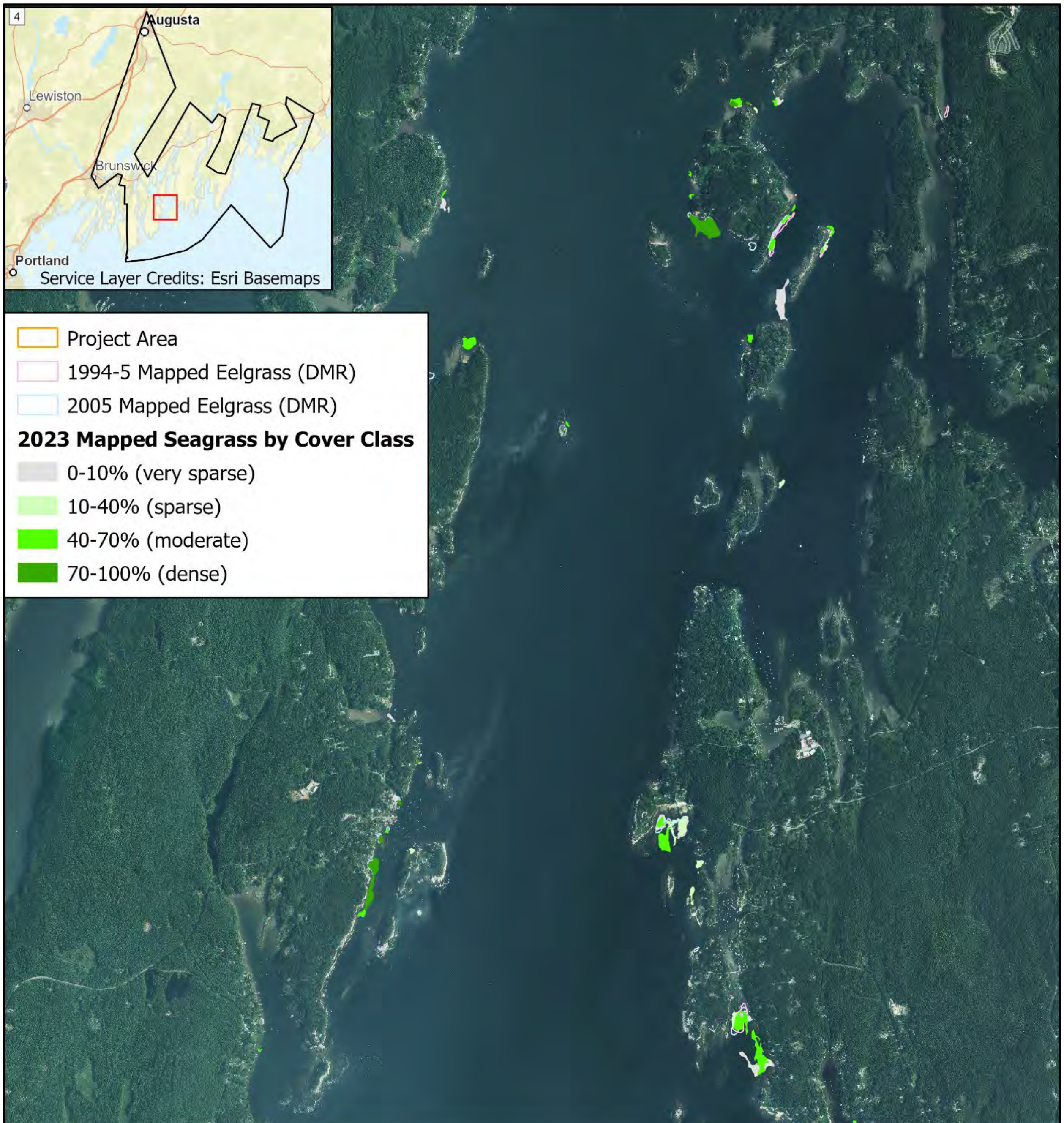
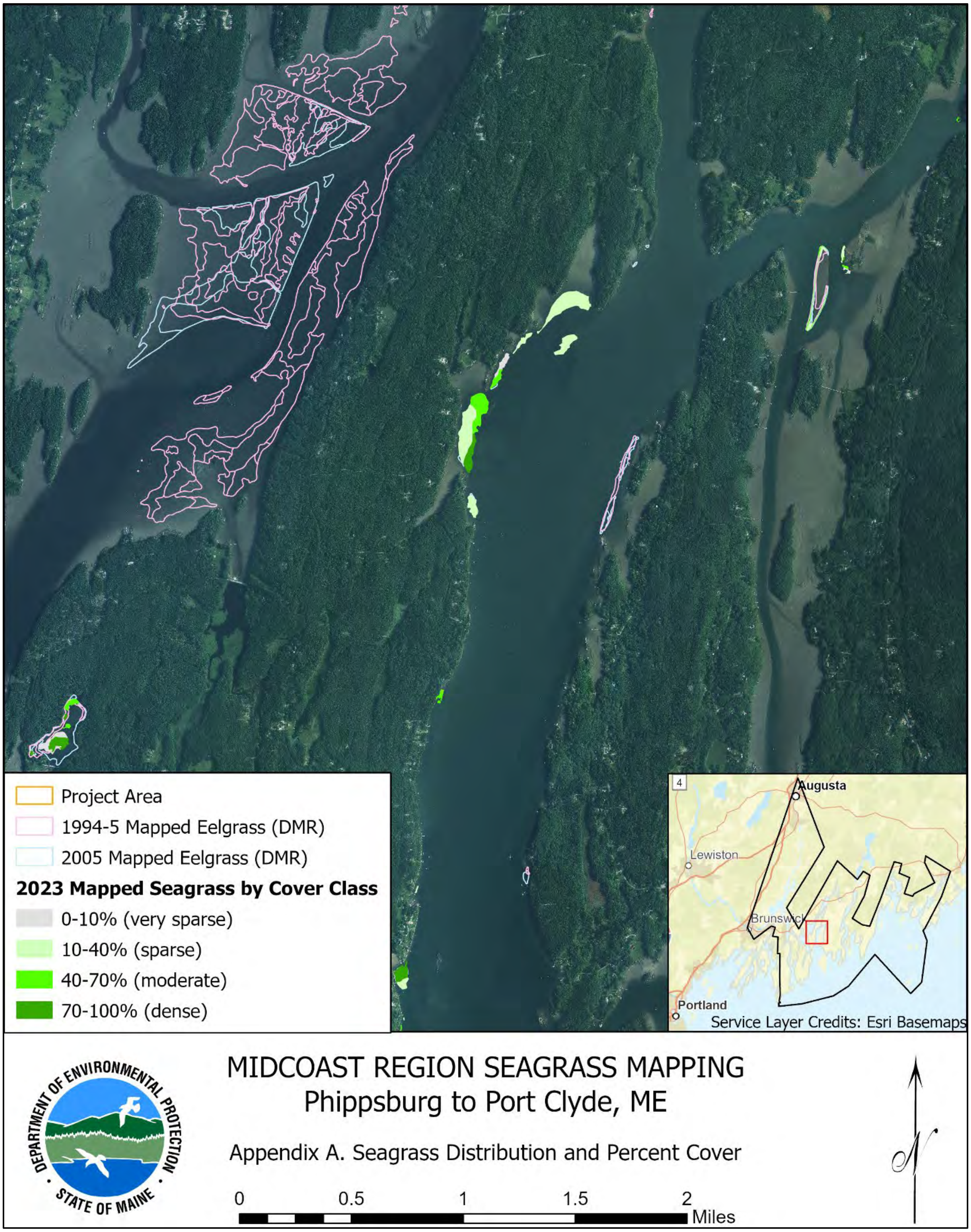

Project Area
1994-5 Mapped Eelgrass (DMR)
2005 Mapped Eelgrass (DMR)
2023 Mapped Seagrass by Cover Class
0-10% (very sparse)
10-40% (sparse)
40-70% (moderate)
70-100% (dense)
Augusta
Lewiston
Brunswick
Portland
Service Layer Credits: Esri Basemaps
MIDCOAST REGION SEAGRASS MAPPING
Phippsburg to Port Clyde, ME
Appendix A. Seagrass Distribution and Percent Cover
0
0.5
1
1.5
2
Miles



MIDCOAST REGION SEAGRASS MAPPING
Phippsburg to Port Clyde, ME

Appendix A. Seagrass Distribution and Percent Cover

0 0.5 1 1.5 2 Miles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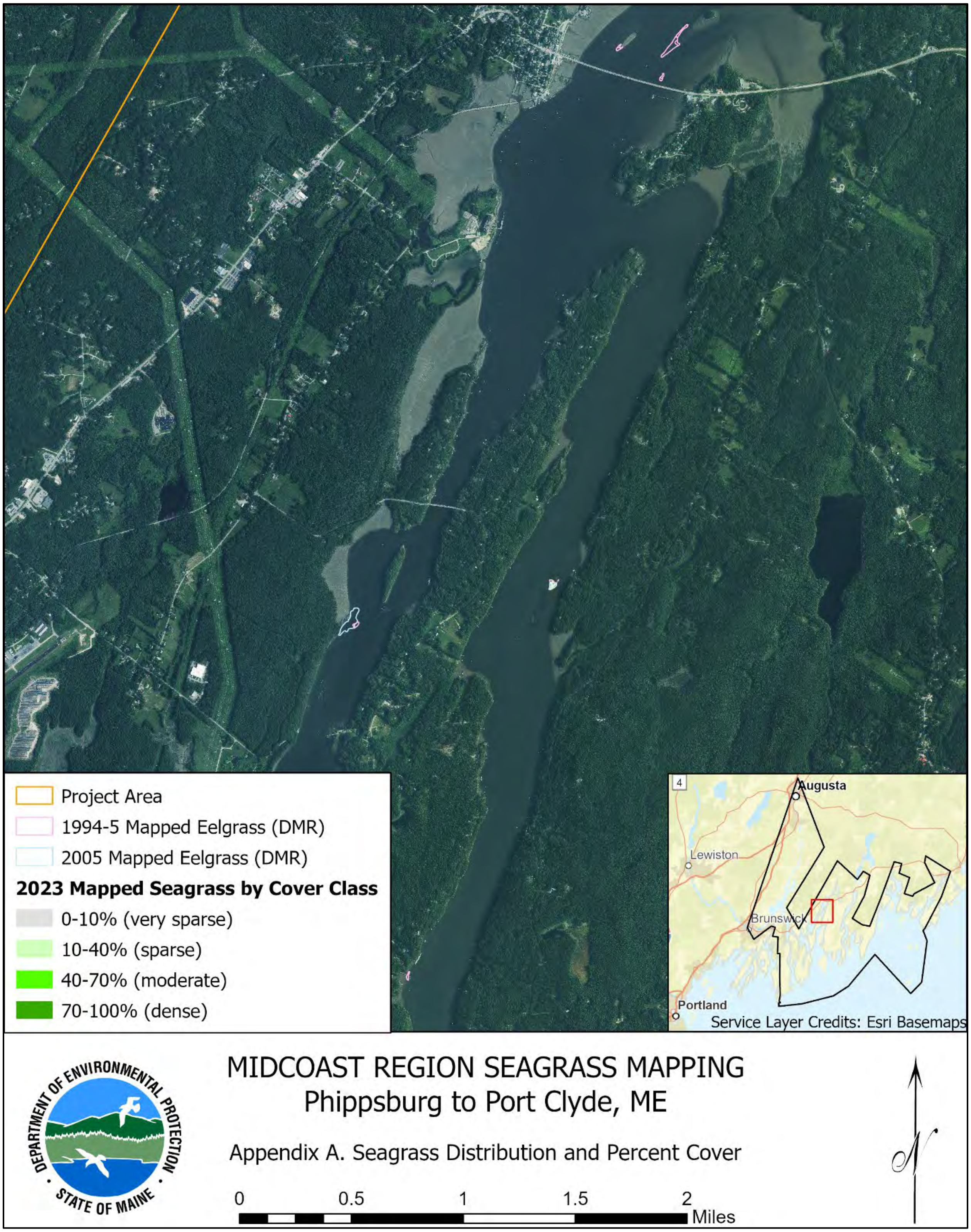
2005 Mapped Eelgrass (DMR)
2023 Mapped Seagrass by Cover Class
0-10% (very sparse)
10-40% (sparse)
40-70% (moderate)
70-100% (dense)
Augusta
Lewiston
Brunswick
Portland
Service Layer Credits: Esri Basemaps
DEPARTMENT OF ENVIRONMENTAL PROTECTION
STATE OF MAINE
MIDCOAST REGION SEAGRASS MAPPING
Phippsburg to Port Clyde, ME
Appendix A. Seagrass Distribution and Percent Cover
0 0.5 1 1.5 2
Miles



Project Area
1994-5 Mapped Eelgrass (DMR)
2005 Mapped Eelgrass (DMR)
2023 Mapped Seagrass by Cover Class
0-10% (very sparse)
10-40% (sparse)
40-70% (moderate)
70-100% (dense)
Augusta
Lewiston
Brunswick
Portland
Service Layer Credits: Esri Basemaps
DEPARTMENT OF ENVIRONMENTAL PROTECTION
STATE OF MAINE
MIDCOAST REGION SEAGRASS MAPPING
Phippsburg to Port Clyde, ME
Appendix A. Seagrass Distribution and Percent Cover
0 0.5 1 1.5 2
Miles
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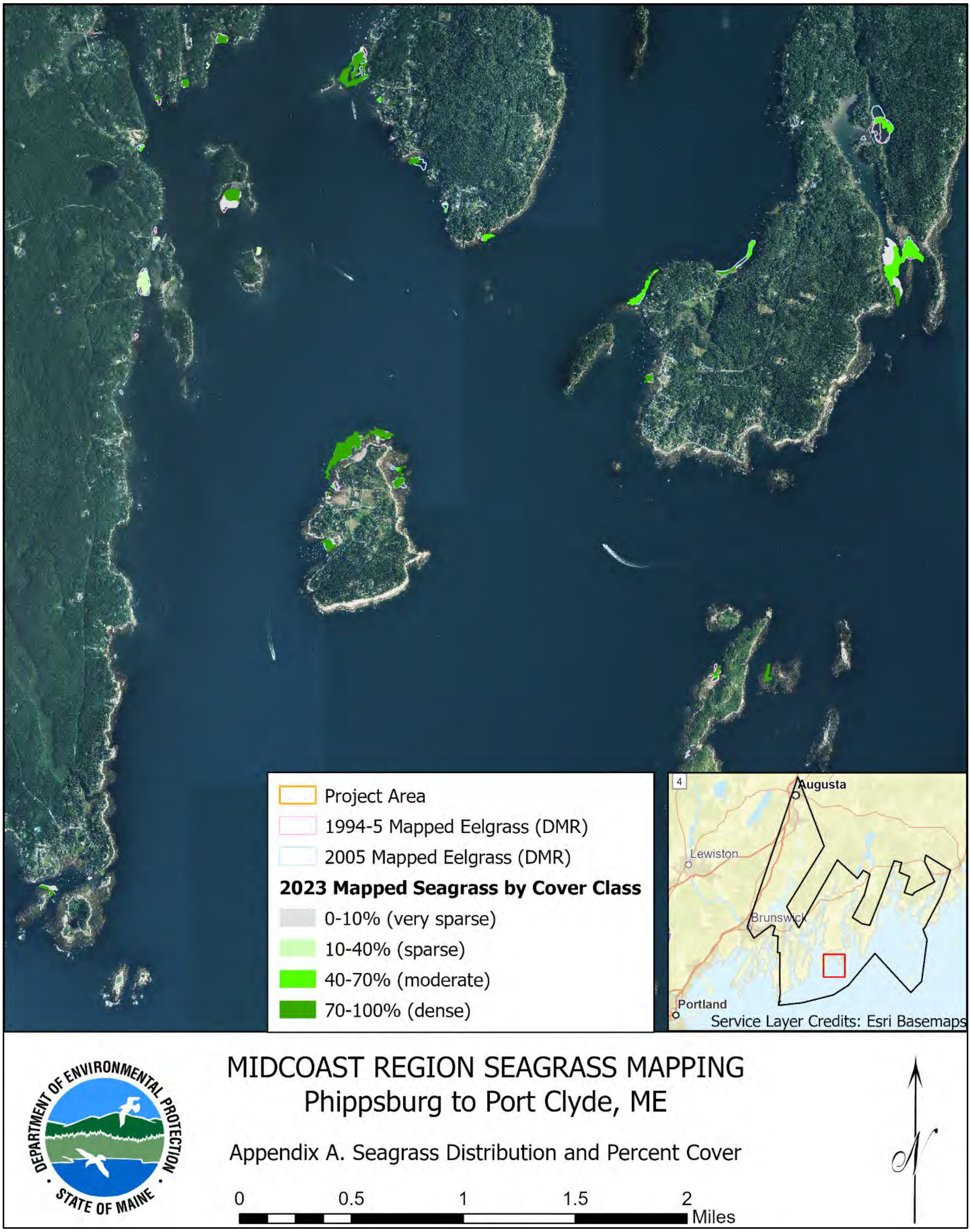
Project Area
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2005 Mapped Eelgrass (DMR)
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0-10% (very sparse)
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Augusta
Lewiston
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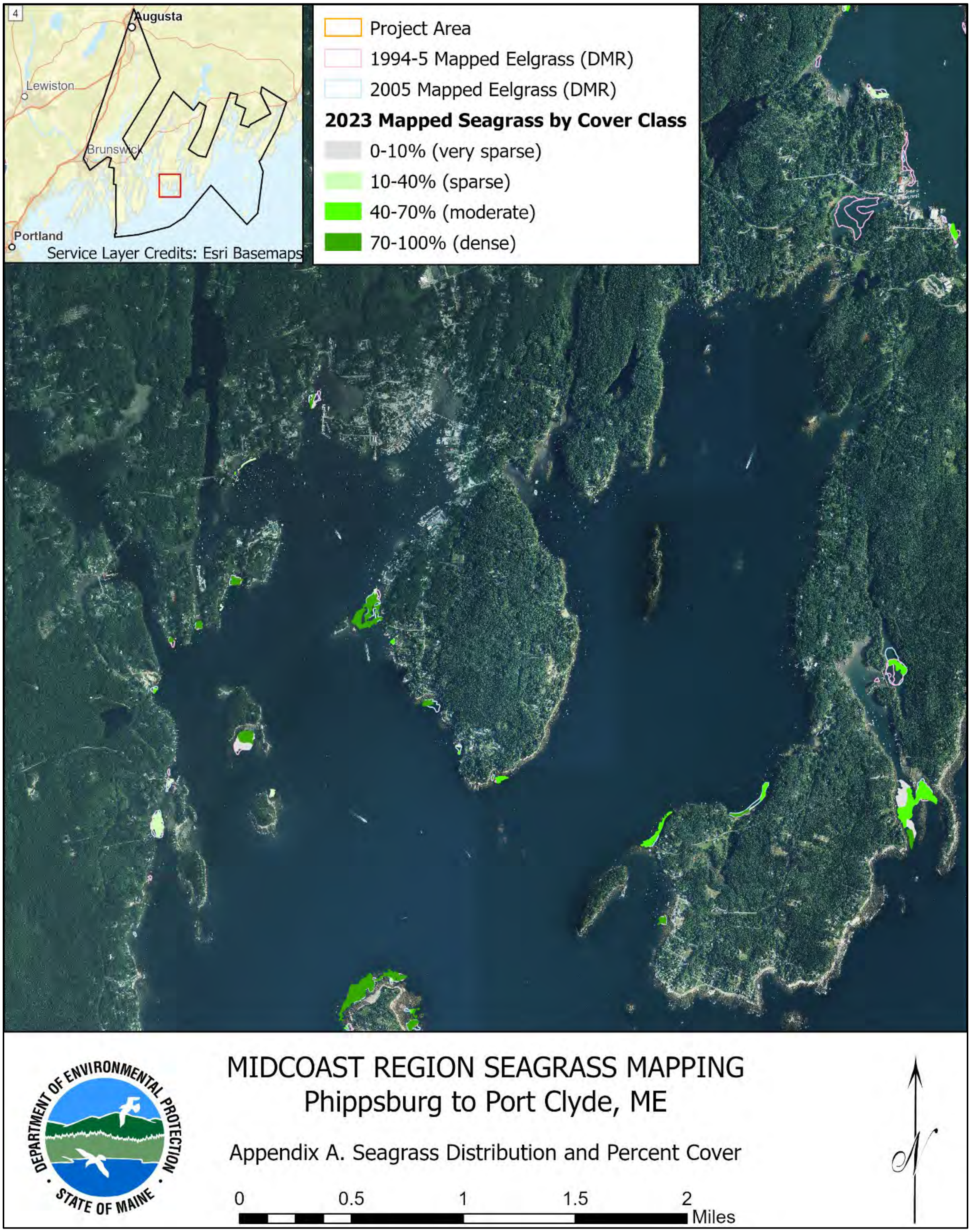
Portland
Service Layer Credits: Esri Basemaps
DEPARTMENT OF ENVIRONMENTAL PROTECTION
STATE OF MAINE
MIDCOAST REGION SEAGRASS MAPPING
Phippsburg to Port Clyde, ME
Appendix A. Seagrass Distribution and Percent Cover
0
0.5
1
1.5
2
Miles
N


Augusta
Lewiston
Brunswick
Portland
Service Layer Credits: Esri Basemaps
Project Area
1994-5 Mapped Eelgrass (DMR)
2005 Mapped Eelgrass (DMR)
2023 Mapped Seagrass by Cover Class
0-10% (very sparse)
10-40% (sparse)
40-70% (moderate)
70-100% (dense)
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0.5
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2
Miles
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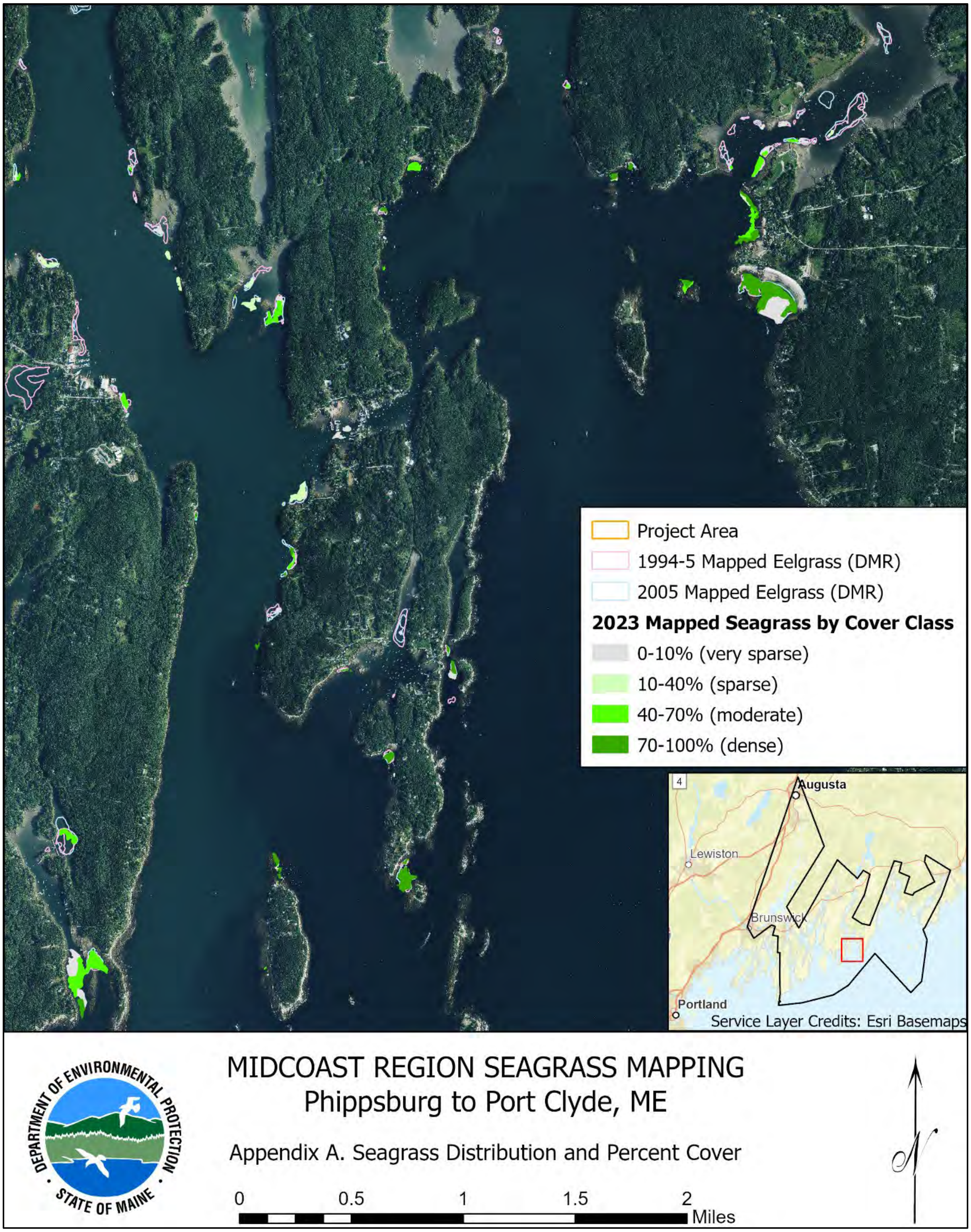
STATE OF MAINE



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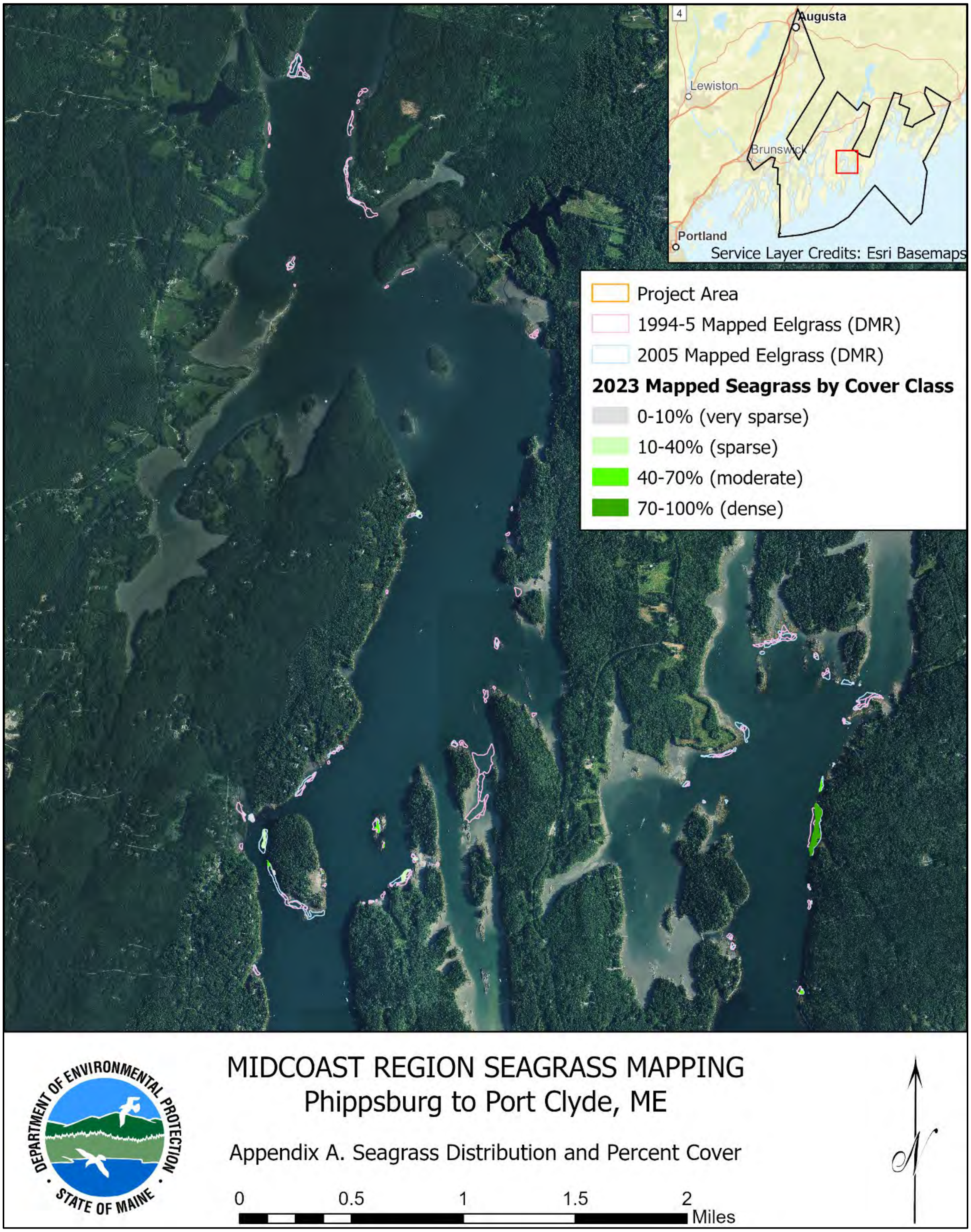
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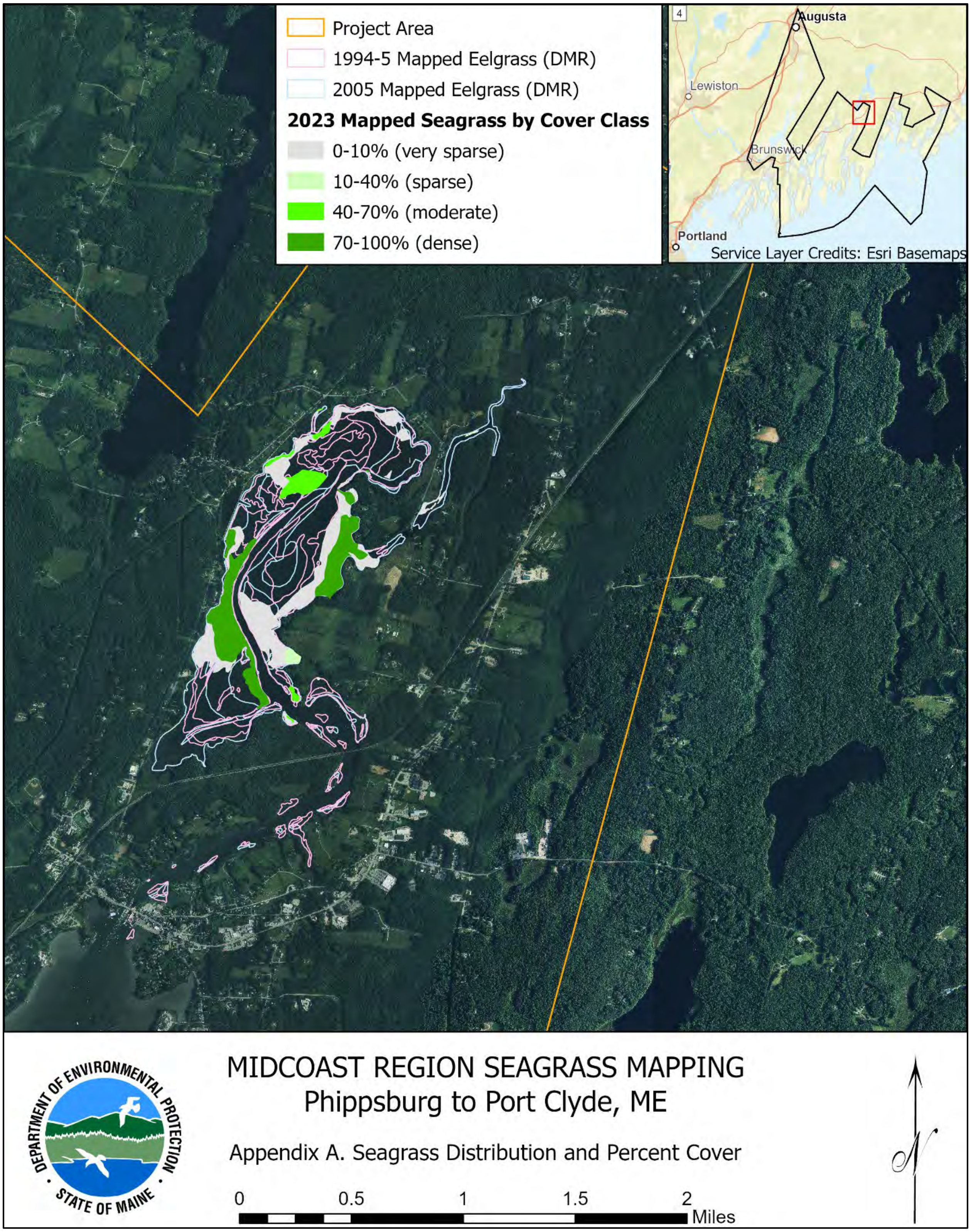
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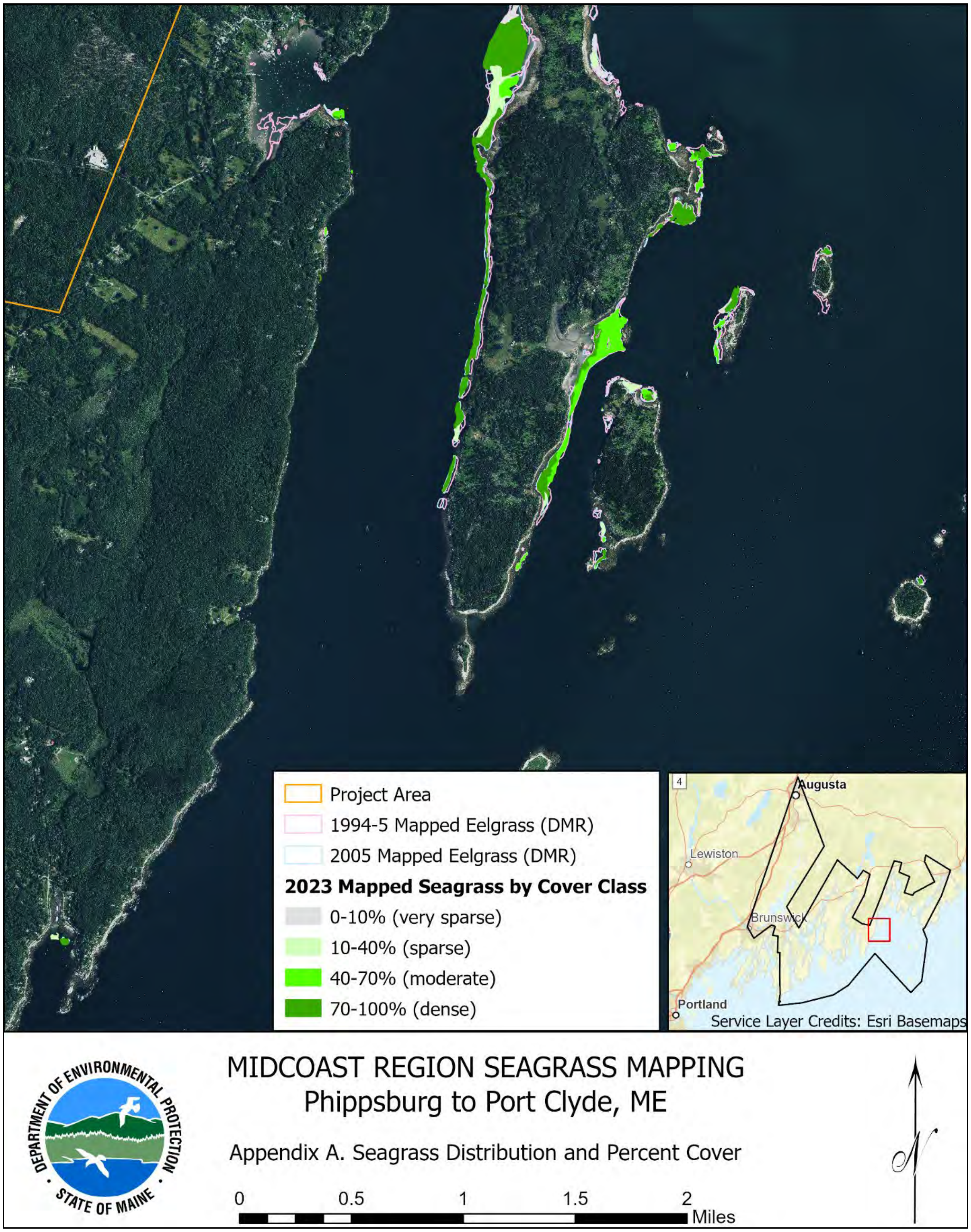
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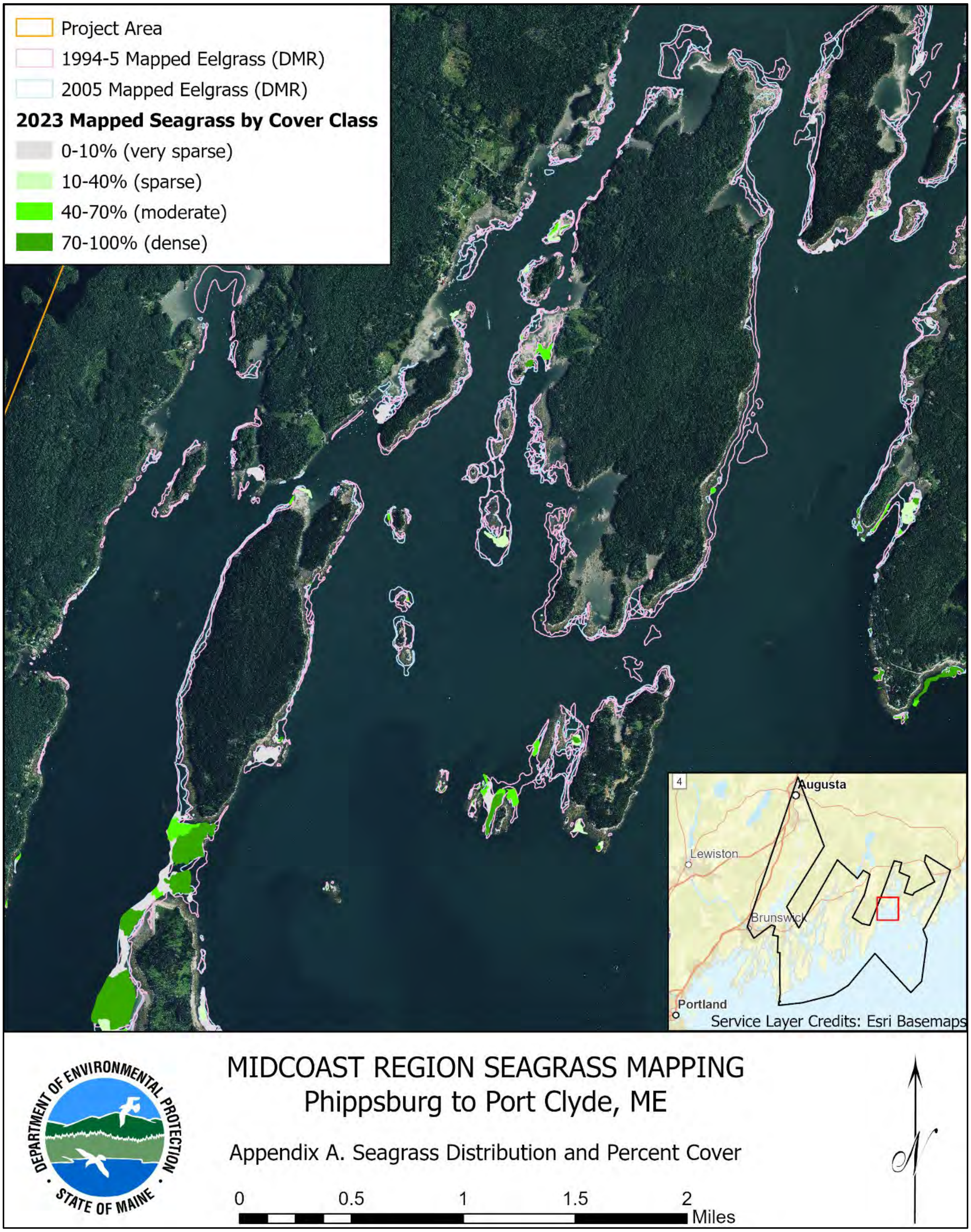

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Phippsburg to Port Clyde, ME
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0 0.5 1 1.5 2 Miles
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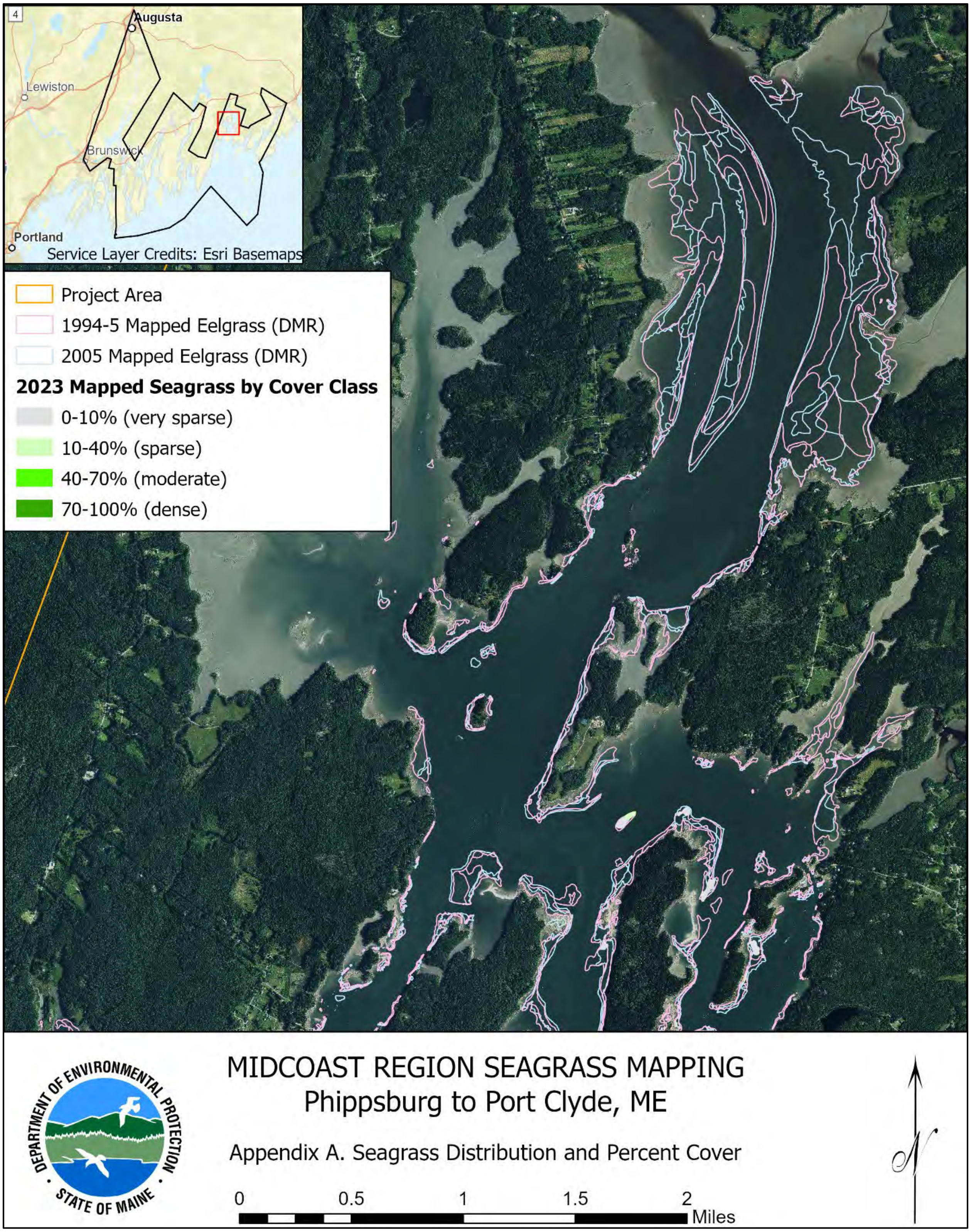
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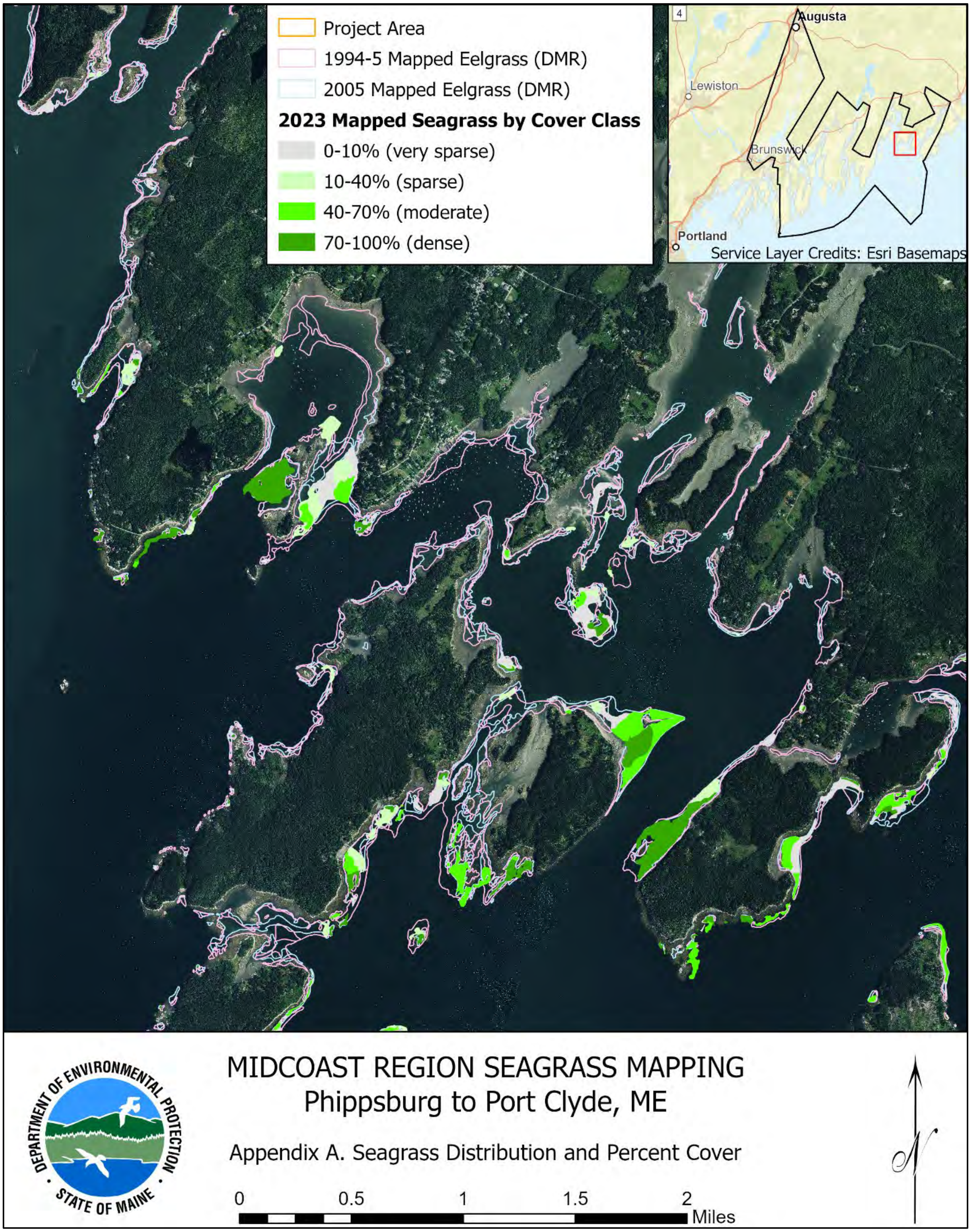
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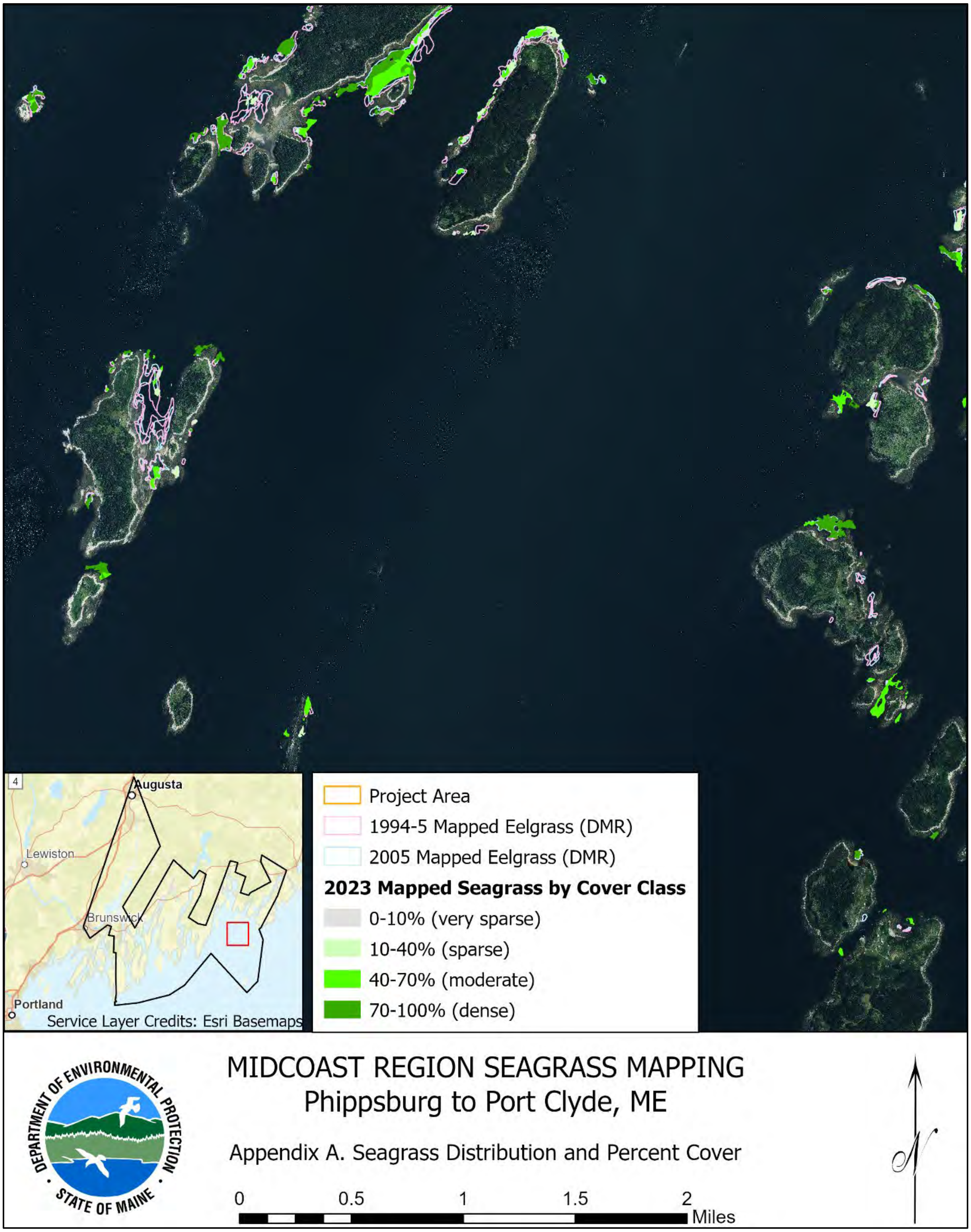

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Lewiston
Brunswick
Portland
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Miles
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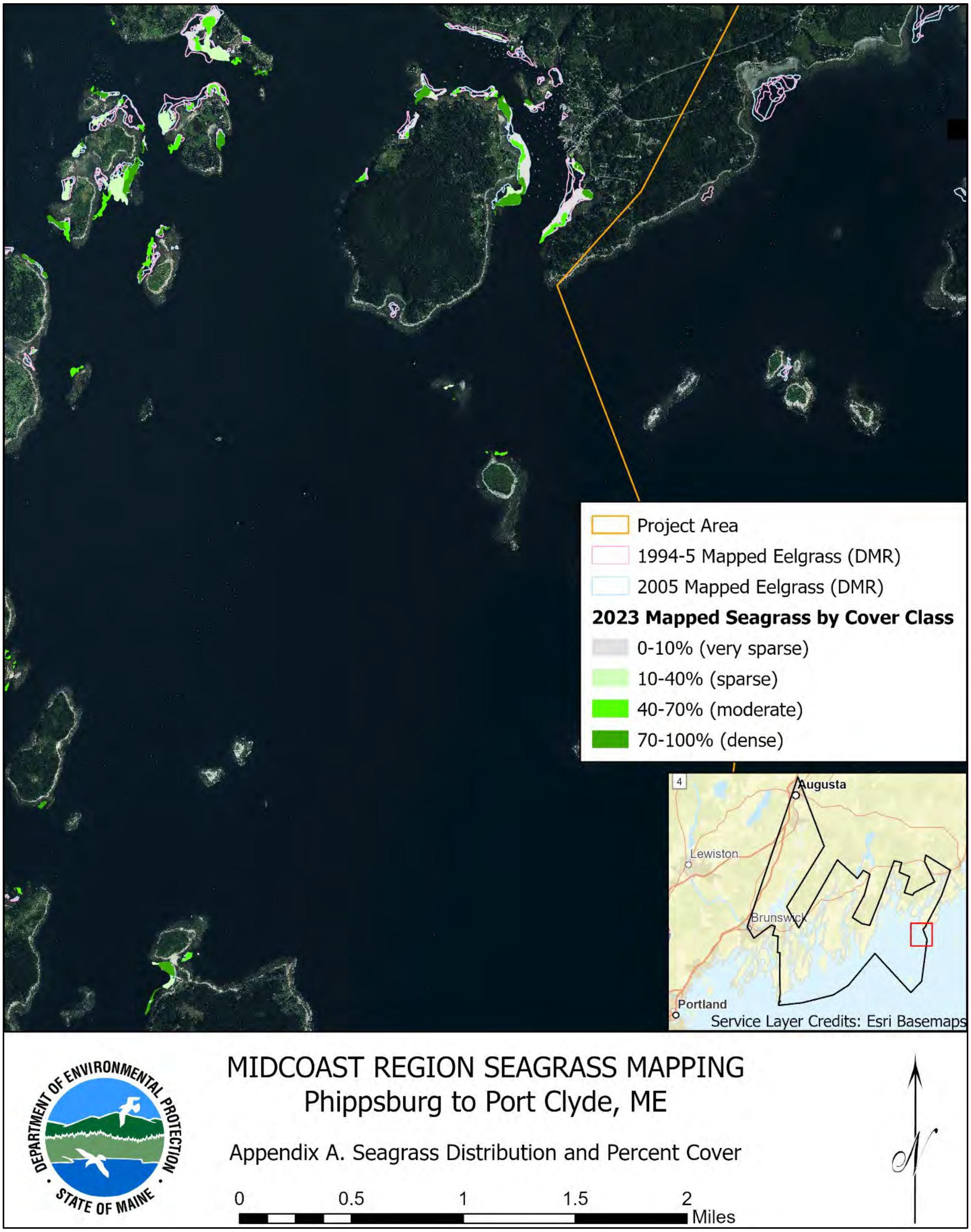
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Miles
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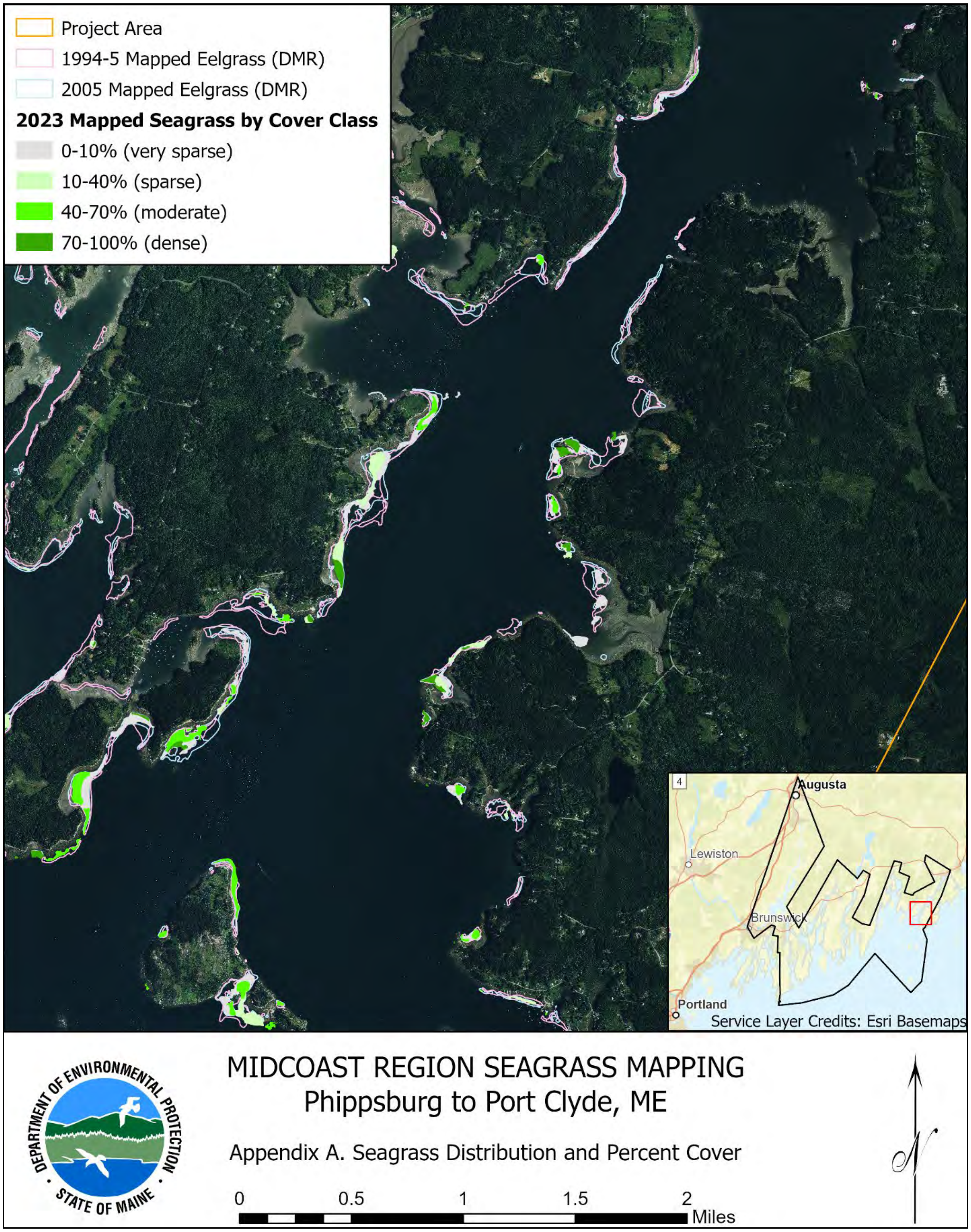
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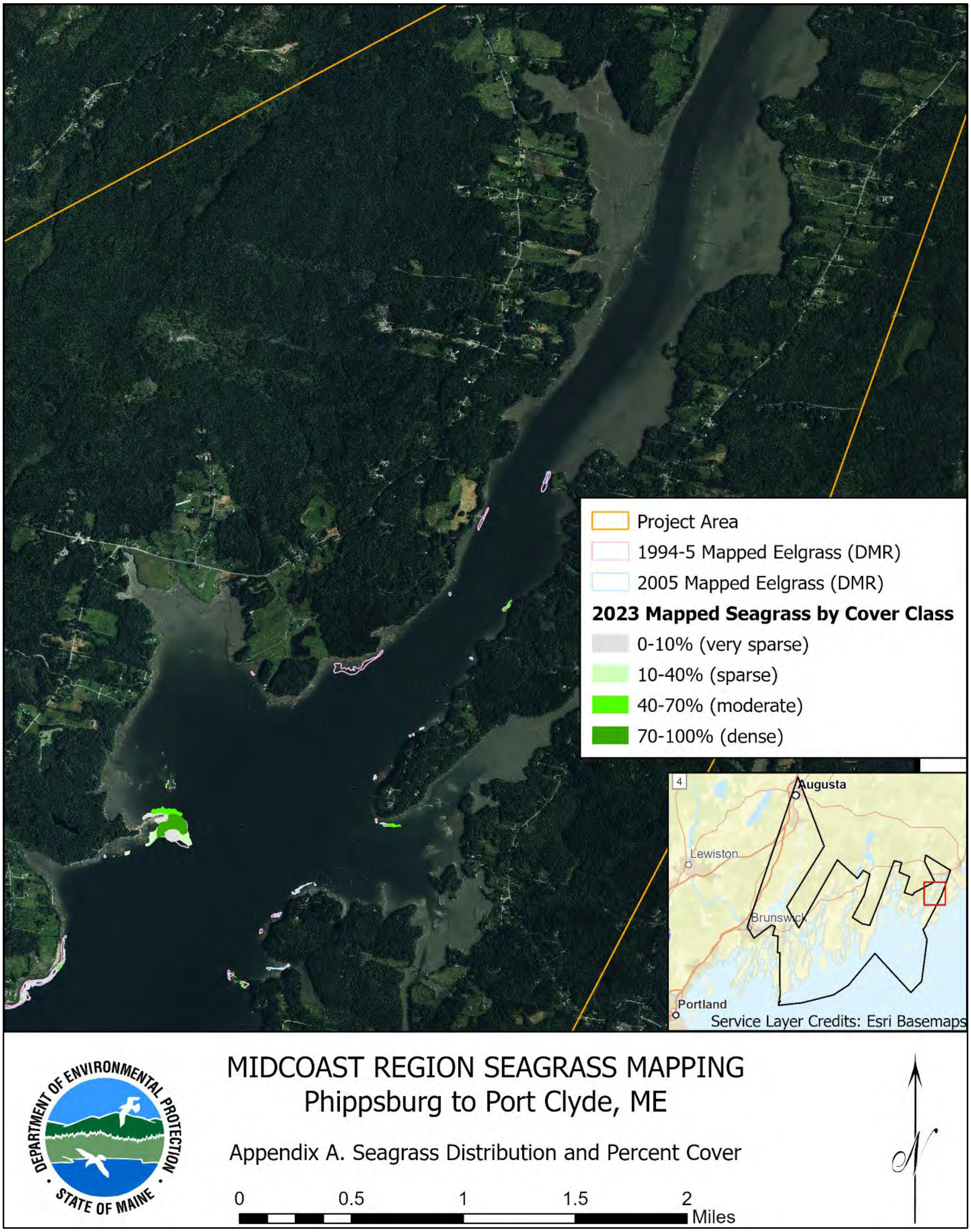
Phippsburg to Port Clyde, ME
Appendix A. Seagrass Distribution and Percent Cover
0 0.5 1 1.5 2
Miles
DEPARTMENT OF ENVIRONMENTAL PROTECTION
STATE OF MAINE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4
Augusta
Lewiston
Brunswick
Portland
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STATE OF MAINE
MIDCOAST REGION SEAGRASS MAPPING
Phippsburg to Port Clyde, ME
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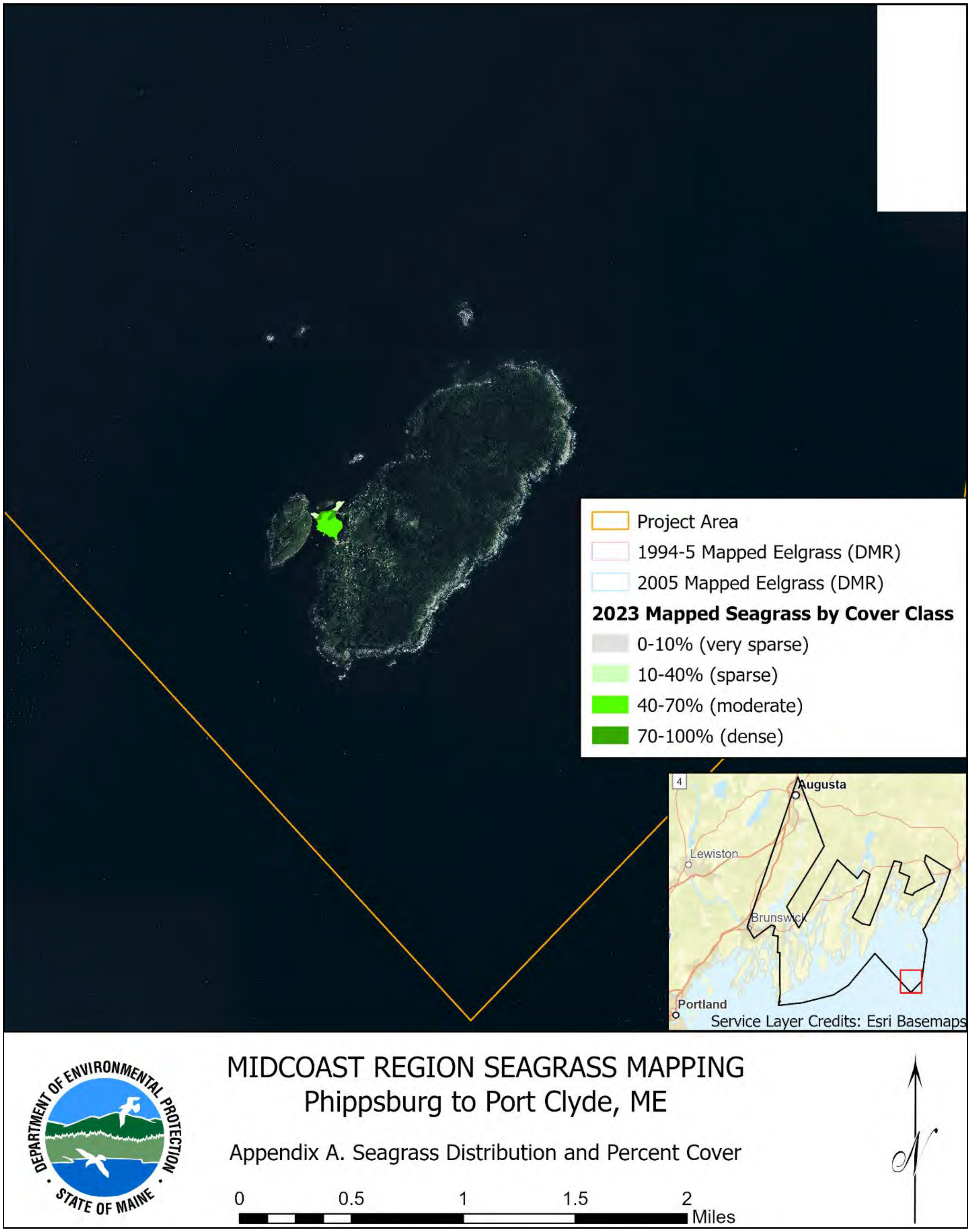
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MIDCOAST REGION SEAGRASS MAPPING
Phippsburg to Port Clyde, ME
Appendix A. Seagrass Distribution and Percent Cover
0
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1.5
2
Miles
N

Appendix B. Tidal Marsh Biotics Submission Maps

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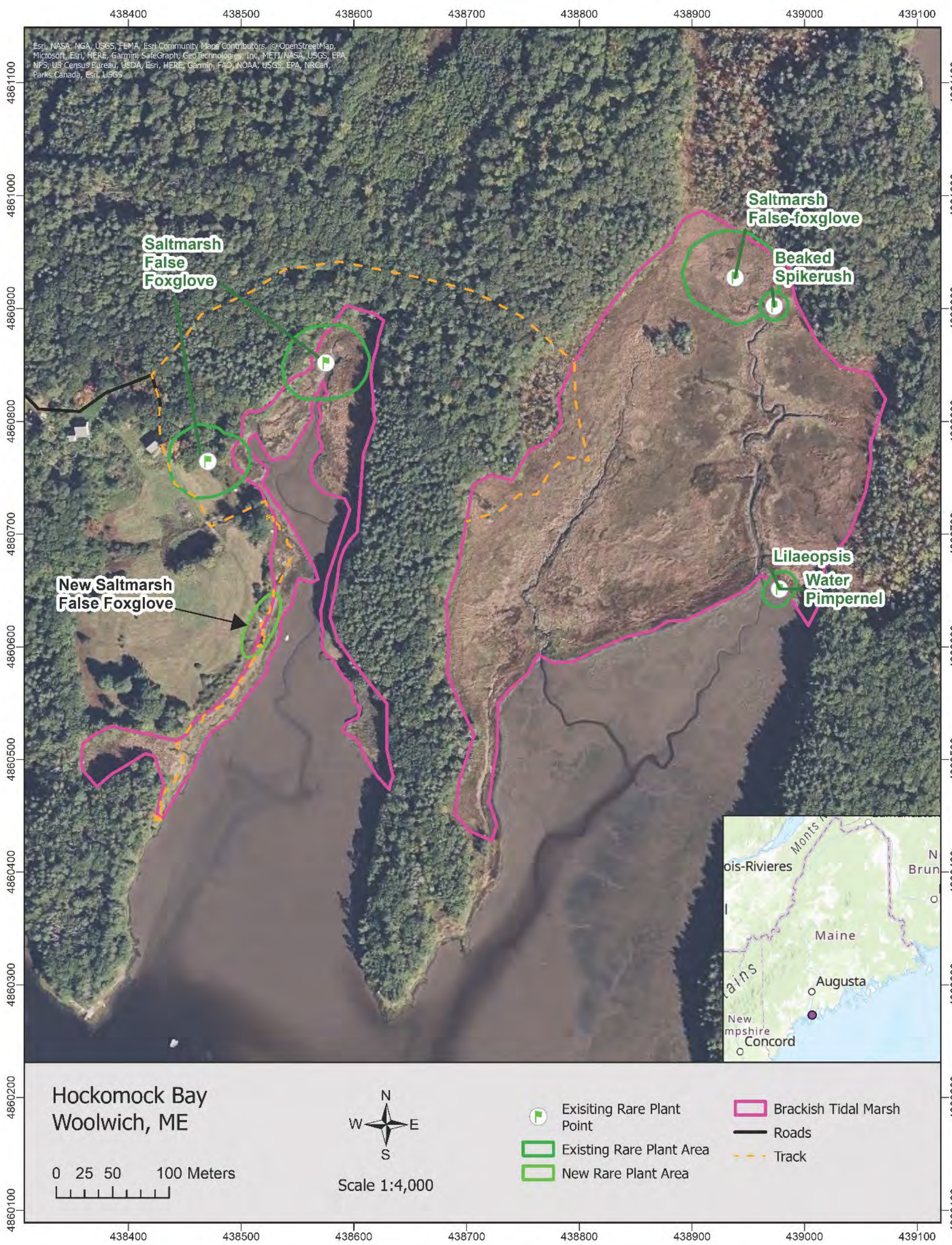
Back River Marsh
Arrowsic, ME
0 25 50 100 Meters
N
W
E
S
Scale 1:2,000
Spartina Saltmarsh
Roads
Track
Maine
Augusta
Concord
New
mpshire
ois-Rivieres
437500
437550
437600
437650
437700
437750
437800
437850
4853450
4853400
4853350
4853300
4853250
4853200
4853150
4853100
4853050
4853000
4852950

Marsh Elder
Hall Bay
Georgetown, ME
0 25 50 100 Meters
Scale 1:2,000
N
W
E
S
New Rare Plant Area
Spartina Saltmarsh
Roads
Track
Maine
Augusta
Concord
ois-Rivieres


Saltmarsh
False-foxglove
Beaked
Spikerush
Saltmarsh
False
Foxglove
New Saltmarsh
False Foxglove
Lilaeopsis
Water
Pimpernel
Maine
Augusta
Concord
Hockomock Bay
Woolwich, ME
0 25 50 100 Meters
Scale 1:4,000
Exisiting Rare Plant Point
Existing Rare Plant Area
New Rare Plant Area
Brackish Tidal Marsh
Roads
Track


Hubbard Point
Westport Island, ME
0 25 50 100 Meters
Scale 1:2,000
N
W
E
S
Roads
Spartina Saltmarsh
Track
Maine
Augusta
New
mpshire
Concord
ois-Rivieres
440750
440800
440850
440900
440950
441000
441050
441100
441150
4860900
4860850
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4860750
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4860450
4860400


437700
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4851750
4851700
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ois-Rivieres
Maine
Augusta
New
mpshire
Concord
South Back River Marsh
Georgetown, ME
0
12.5
25
50 Meters
N
W
E
S
Scale 1:1,000
Spartina Saltmarsh
Roads
Track

Appendix C. Historical Seagrass Map Polygon Layers

MaineDMR – Eelgrass 1997: This shapefile (DMR 1997) is a coast-wide eelgrass survey completed by DMR over the course of several years. Mapping efforts from 1993 to 1997 are included in this compilation. The Midcoast Region was surveyed in 1994 and 1995, but the survey area likely did not extend to Monhegan Island. Corresponding low tide imagery was collected between July and October for each survey year at times of low wind velocity and good water clarity. Polygons were screen digitized and assigned an Orth percent cover (Figure 8) and field verified by boat, on foot, and by plane. The MMU is conservatively estimated at 150 square meters. The corresponding aerial imagery files are maintained by DMR but are not currently available digitally.

MaineDMR – Eelgrass 2010: This shapefile (DMR 2010) is a coast-wide eelgrass survey completed by DMR over the course of several years. Mapping efforts from 2001 to 2010 are included in this compilation. The Midcoast Region was surveyed in 2005, but the survey area did not extend to Monhegan Island. Corresponding low tide imagery was collected between June and September for each survey year at times of low wind velocity and good water clarity. Polygons were screen digitized and assigned an Orth percent cover (Figure 8) and field verified by boat, on foot, and by plane. The MMU is conservatively estimated at 150 square meters. The corresponding aerial imagery can be viewed either as an imagery service layer or the tiles can be downloaded from the MEGIS data catalog (for the Midcoast Region: Maine Orthoimagery Coastal Central Coast 2003 and 2005).

MaineDEP Casco Bay Eelgrass 2013: This shapefile (Casco Bay 2013) is an eelgrass survey completed by DEP in 2013 for Casco Bay only. Corresponding low tide imagery was collected on August 11 and 12 at a time of low wind velocity and good water clarity. Polygons were screen digitized and assigned an Orth percent cover (Figure 8) and field verified by boat, on foot, and by plane. The MMU is conservatively estimated at 150 square meters. The corresponding aerial imagery is 0.15 meter resolution and can be viewed either as an imagery service layer or the tiles can be downloaded from the MEGIS data catalog (Maine Orthoimagery Coastal Casco Bay 2013).

MaineDEP Casco Bay Eelgrass 2018: This shapefile (Casco Bay 2018) is an eelgrass survey completed by DEP in 2018 for Casco Bay only. Corresponding low tide imagery was collected on June 16 and 17 at a time of low wind velocity and good water clarity. Polygons were screen digitized and assigned an Orth percent cover (Figure 8) and field verified by boat, on foot, and by plane. The MMU is conservatively estimated at 150 square meters. The corresponding aerial imagery is 0.30 meter resolution and can be viewed either as an imagery service layer or the tiles can be downloaded from the MEGIS data catalog (Maine Orthoimagery Coastal Casco Bay 2018).

MaineDEP Seagrass 2021 (South Coast – Elliot to Cape Elizabeth): This shapefile (South Coast 2021) is a seagrass survey completed by DEP in 2021 for the South Coast only. Widgeon grass (*Ruppia maritima)* was included in the survey, in addition to eelgrass (*Zostera marina*). Corresponding low tide imagery was collected on June 29 within 2 hours of low tide and at a sun angle of 25-50 degrees. Additional environmental considerations included no more than 10% cloud cover, less than 10 knots maximum predicted wind velocity, and a 48-hour precipitation-free period preceding the flight. Polygons were screen digitized and assigned an Orth percent cover (Figure 8) and field verified by boat, on foot, and with view tubes and an SAV rake. Field GPS equipment was capable of submeter accuracy. The MMU was assumed to be 0.5 acres, but areas as small as 55 square feet were delineated. The corresponding aerial imagery is approximately 0.15 meter resolution and can be viewed either as an imagery service layer or the tiles can be downloaded from the MEGIS data catalog (Maine Orthoimagery Coastal South Coast 2021).

MaineDEP Casco Bay Seagrass 2022: This shapefile (Casco Bay 2022) is a seagrass survey completed by DEP in 2022 for Casco Bay only. Widgeon grass (*R. maritima)* was included in the survey, in addition to eelgrass (*Z. marina*). Corresponding low tide imagery was collected on July 16 within 2 hours of low tide and at a sun angle of 25-50 degrees. Additional environmental considerations included no more than 10% cloud cover, less than 10 knots maximum predicted wind velocity, and a 48-hour precipitation-free period preceding the flight. Polygons were screen digitized and assigned an Orth percent cover (Figure 8) and field verified by boat and on foot. Field GPS equipment was capable of submeter accuracy. The MMU was assumed to be 0.5 acres, but areas as small as 444 square feet were delineated. The corresponding aerial imagery is approximately 0.15 meter resolution and can be viewed either as an imagery service layer or the tiles can be downloaded from the MEGIS data catalog (Maine Orthoimagery Coastal Casco Bay 2022).