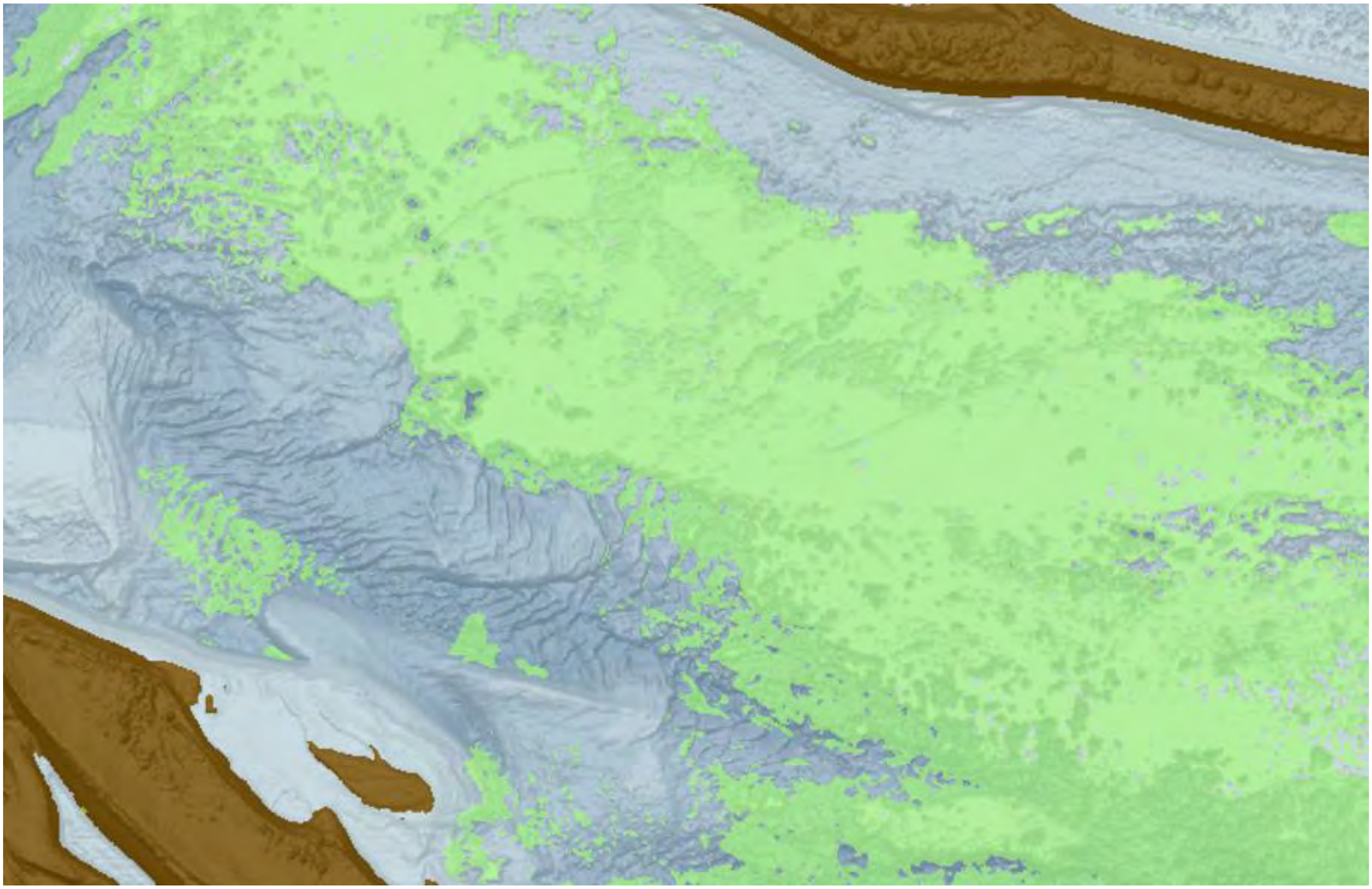
Using Topo-Bathymetric Lidar to Map Eelgrass in Tabusintac, NB



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Executive Summary

NSCC-AGRG surveyed a coastal area of Tabusintac, NB on July 29, 2021, and produced high resolution lidar and image data that were suitable for mapping coastal eelgrass. The results of this project demonstrate how topo-bathymetric lidar can be used to map underwater vegetation. Eelgrass distribution was prominent throughout the main channel and surrounding shallow waters. The sensor collected data up to 5.5 m water depth and was only unable to map a small area in the deepest northern portion of the channel. While no data were collected in this small area, this did not inhibit NSCC-AGRG's mapping efforts as the water was considered too deep to support the growth of eelgrass. The water clarity throughout the Tabusintac Bay was highly variable and introduced variability in the developed eelgrass confidence maps. To mitigate potential impact, a skilled technician performed comparative assessments between survey products to identify the 2.44 km^2 of eelgrass throughout the AOI.

Data delivery consisted of an eelgrass location map, high-resolution lidar digital elevation model, depth normalized lidar intensity image, a lidar colour-shaded relief model, and a 0.05 m multispectral air photo mosaic.

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1 Introduction

Eelgrass (*Zostera marina*) is the most dominant seagrass species in the northern hemisphere, and contributes to a wide range of ecosystem parameters, such as sediment stabilization, improvement of water clarity, and enhanced biodiversity (Olesen et al. 2015). In Canada, it is widespread on both the Pacific and Atlantic coasts, as well as the Hudson Bay (Environment and Climate Change Canada 2020). Seagrasses create one of the most productive yet highly threatened ecosystems on earth (van Katwijk et al. 2016). Global coverage of seagrass has been declining over the past century, with almost 30% of global coverage lost (Wong et al., 2013). Causes of decline have been attributed to anthropogenic influences, such as physical disturbances and changes in water parameters due to climate change.

Bathymetric lidar is an effective method for estimating water depth in coastal environments (Pan et al. 2016). Bathymetry data for shallow coastal waters is increasingly important to policy makers for science, resource management, and defense. It is considered vital to the management of disaster risk and toward guiding investment (Moffitt & Kumar 2018). Topo-bathymetric lidar also provides a tool to assess and map coastal and benthic habitat (Parrish et al. 2016). This method of seagrass mapping is cost effective and can cover a much larger area compared to traditional methods. The Nova Scotia Community College – Applied Geomatics Research Group (NSCC-AGRG) own and operate a Leica Chiroptera 4X (CH4X) high-resolution topo-bathymetric lidar scanner equipped with an ancillary Leica RCD30 60-megapixel multispectral (RGB-Nir) camera that can survey seabed morphology and habitat, including submerged vegetation (Webster et al., 2019).

2 Methods

Methods on survey preparation, sensor management, and data processing are detailed in the following sections. Additional details can be requested from NSCC-AGRG if required.

2.1 Sensor Specifications and Installation

The lidar sensor used in this survey was the Leica Chiroptera 4X integrated topographic-bathymetric lidar sensor equipped with a 60-megapixel Leica RCD30 multispectral (RGB-Nir) camera. The lidar uses a 1064 nm near-infrared laser to survey ground and sea surface positions at 500 kHz and a green 515 nm laser to survey bathymetric positions at 35 kHz. The lasers scan in an elliptical pattern, which facilitates coverage from many different angles on vertical faces, produces fewer shadow effects in the data, and is less sensitive to wave interaction when compared to lateral 'saw tooth' scanners. The ability of the bathymetric laser to penetrate the water column is limited by water clarity. The system has a depth penetration rating of roughly 1.5 x visible extinction (Secchi depth). The Leica RCD30 camera collects coincident multispectral motion compensated imagery. NSCC-AGRG partnered with Leading Edge Geomatics (LEG) to charter a Piper Navajo twin engine aircraft capable of housing the lidar unit. The CH4 was installed in the aircraft in Debert, NS on July 27, 2021, and calibrated on July 28, 2021, over a ground control site established by NSCC-AGRG in Truro.

2.2 Data Collection

Survey lines were planned using Leica Mission Pro at 400 m altitude at a speed of 65 m/s with 30% lateral overlap to ensure that no data gaps were present within the 3.8 km^2 area of interest (Figure 1). Data collection parameters supported full coverage for the AOI in five lines with a topo point density of >10 ppm, a bathy density of >5 ppm and aerial imagery with a ground pixel resolution of better than 5 cm. The Tabusintac lidar survey was successfully completed on July 29, 2021, from 1500 to 1545 UTC. In-situ weather and GNSS constellation conditions were deemed suitable to support optimal data collection. Control for the survey was established by flying flat and level over two active control points proximal to the AOI in Miramichi, NB (MIRA 3485) (Figure 2).

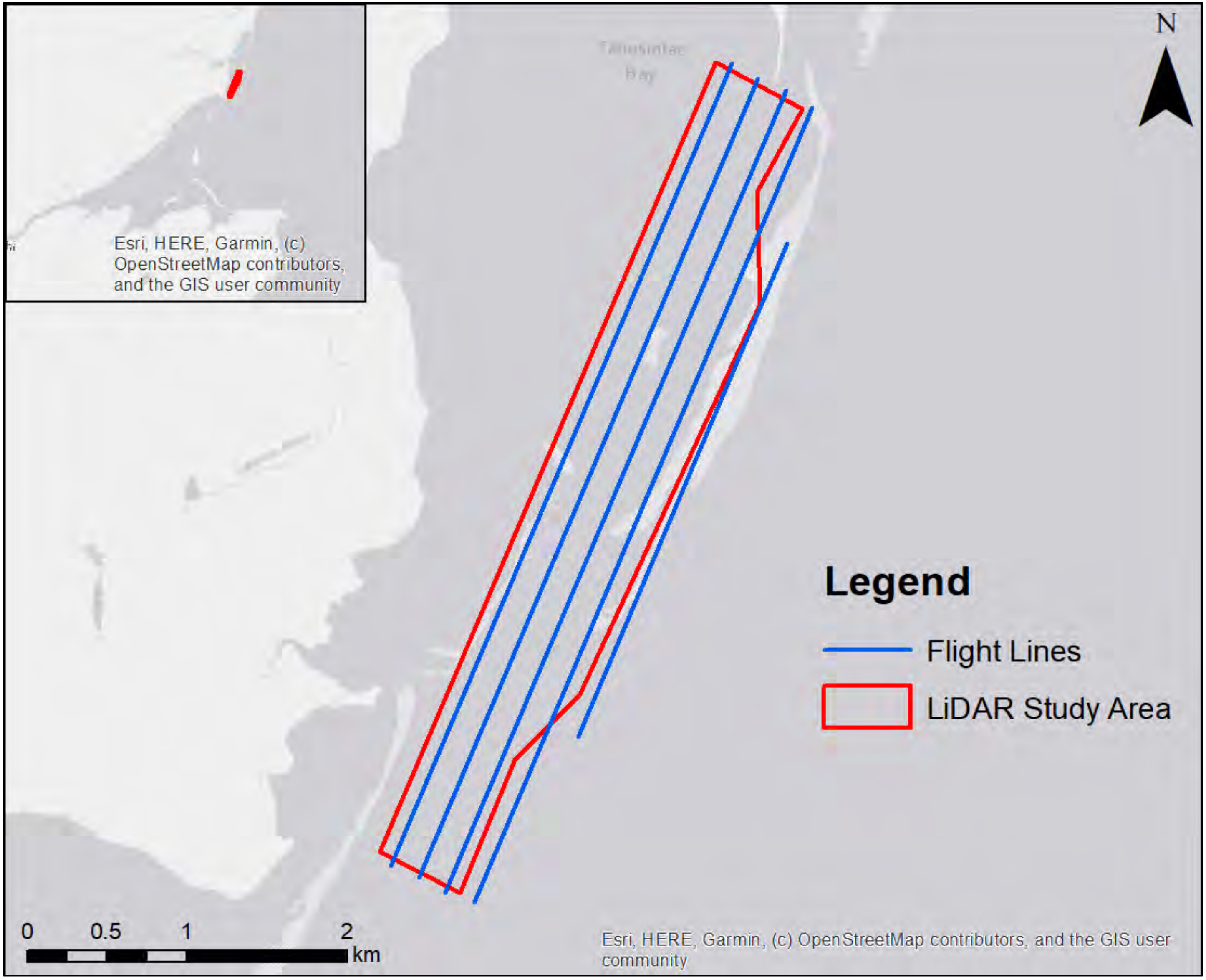

Figure 1. Englobe study area and planned flight lines over Tabusintac, NB.

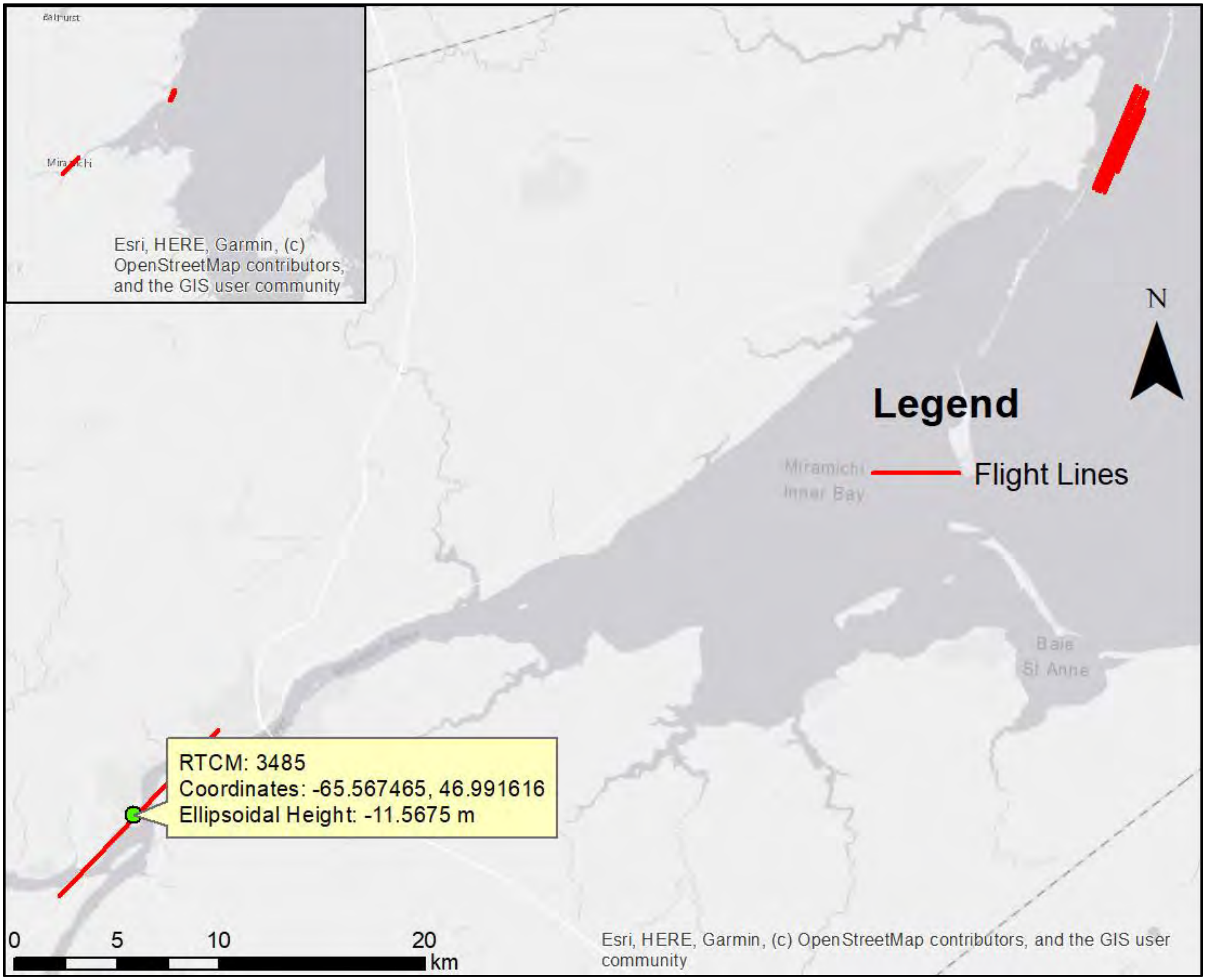

Figure 2. Locations of the RTCM reference stations used during calibration flights for the LiDAR survey in Tabusintac, NB.

2.3 Meteorological Condition Monitoring

Meteorological conditions during and prior to topo-bathy lidar data collection are an important factor in successful data quality because the bathy lidar sensor is limited by water clarity. Windy weather has the potential to stir up any fine sediment in the water and prevent good laser penetration, rain is not suitable for lidar collection, and sun angle can produce problematic glint in aerial imagery. Forecasted, current, and past weather conditions were monitored prior to data collection using the Summerside and Stanhope weather stations operated by Environment and Climate Change Canada (Figure 3). Conditions were deemed suitable to support optimal data collection at the time of survey.

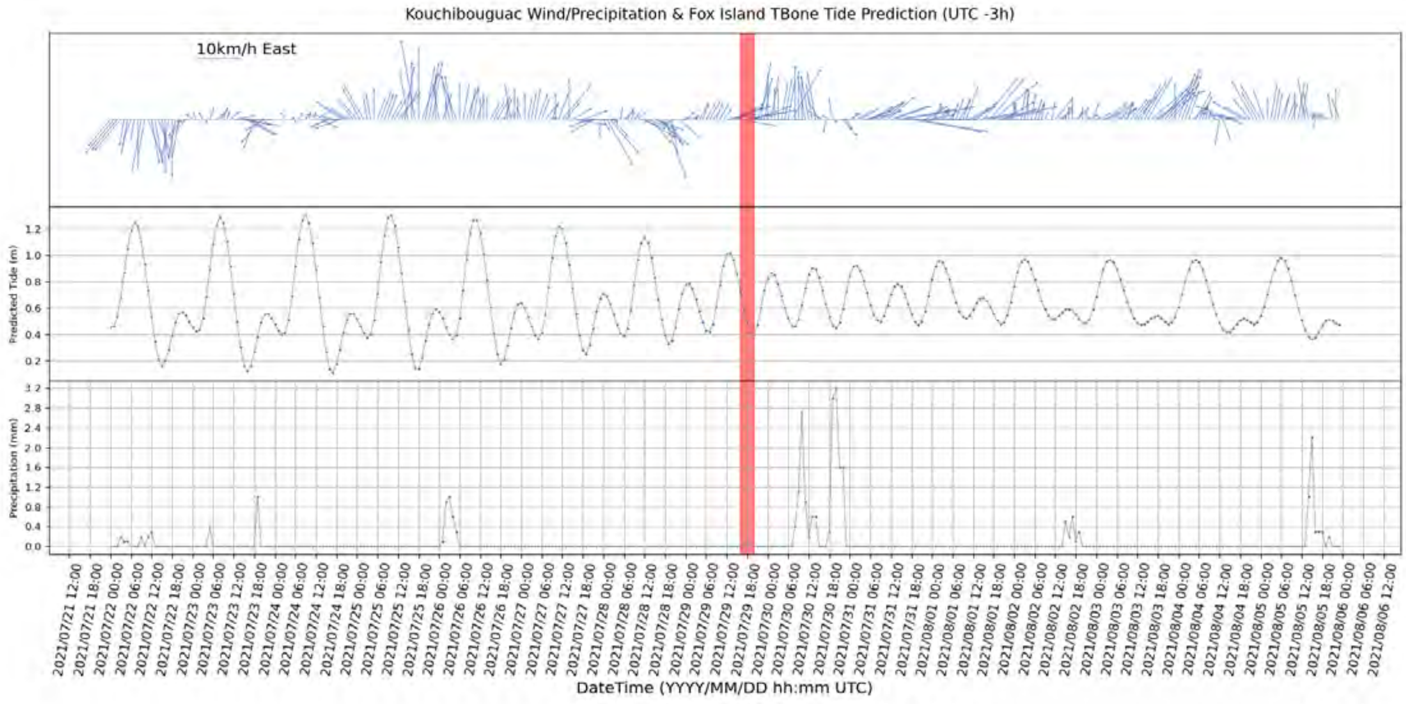

Figure 3. Wind speed (km/h), precipitation (mm) and predicted tide (m) for the Tabusintac Bay area. Flight times are highlighted in red.

2.4 Lidar Data Processing

A smoothed trajectory of the lidar and camera positions was calculated by linking system GNSS positions and IMU attitude with the control data from nearby stations using NovAtel Inertial Explorer. Leica Lidar Survey Studio (LSS) was used to process Chiroptera 4X waveforms to discrete georeferenced (NAD83 CSRSv7) points by linking laser returns to the processed aircraft trajectory to produce point clouds in the LAS format. The data were inspected to ensure there was sufficient overlap (30%) and the AOI was fully covered by lidar returns. LAS files were read into Bentley TerraScan to analyze and further refine point metrics. Points were classified into discrete classes based on their physical characteristics including relative geometry and reflective properties (Table 1).

Table 1. Lidar point classification values and descriptions

Classification Value	Meaning
1	Unclassified
2	Ground
4	Medium vegetation
7	Low point (noise)
9	Topographic water surface
18	High noise
40	Bathymetric point
41	Bathymetric water surface
42	Derived water surface
80	Bathymetric vegetation

Two data products were derived directly from the lidar point cloud, 1) a rasterized digital elevation model (DEM) that included only returns that were classified as ground above and below the water line, and 2) a rasterized model of laser return intensities. Lidar return intensity is influenced by several factors including the local angle of incidence with the target, the natural reflectivity of the target material, the voltage or gain of the transmitted lidar pulse, and attenuation of the energy within the water column. Raw reflectance data are difficult to interpret due to these covariances and normalized values are needed to isolate the natural reflectivity of the target. A process has been developed to normalize the amplitude data for signal loss in a recent publication (Webster et al., 2016). The process involved sampling the amplitude data from a location with homogeneous seabed cover (e.g., sand or eelgrass) over a range of depths. These data were used to establish a relationship between depth and the logarithm of the amplitude value. The inverse of this relationship was used to adjust the amplitude data so that they could be interpreted without the bias of depth. A depth normalized amplitude/intensity raster (DNI) was created that can be used to interpret seabed cover material more consistently throughout the AOI. Note that this analysis considers only bathymetric lidar returns and ignores any topographic elevation points.

2.5 Image Processing

Multispectral RCD30 imagery was processed using Agisoft Metashape Professional. The processed smooth trajectory was linked to image events based on system time tags. This linkage was used to define the exterior orientation (EO) for each of the RCD30 images where camera position (x, y, z) and attitude (yaw, pitch, roll; omega, phi, kappa) were recorded for every exposure with positional accuracies better than 0.01 m and rotational accuracies better than 0.004 degrees. Any ambiguity between relief displacement and lens distortion was solved using by generating a well-defined internal orientation (IO) of the engineered zero distortion RCD30 lens and CCD during the camera boresight process at the Truro calibration site. Captured imagery was positioned using an aerial triangulation model where possible to generate the best relief map for subsequent orthorectification. Where photo positions were unable to be resolved, such as deep open water with few image tie-points, imagery was directly georeferenced using the EO and IO. In both cases imagery was georeferenced to within 5 cm.

2.6 Submerged Aquatic Vegetation Mapping

Submerged Aquatic Vegetation (SAV) has been successfully mapped in several CH4X data collections by combining aerial imagery, normalized lidar reflectance values, and accurate depth models derived from lidar (Figure 4). In relatively clear water conditions this technique can produce a clear image of SAV. The SAV prediction logic is based on the understanding that vegetation absorbs more energy, and appear darker, relative to surrounding sands. This interaction becomes apparent when depth normalization and has been applied to the lidar (Figure 5) and imagery (Figure 6). The image derived product was computed using a normalized difference technique which included red, green, and blue image values. As with the lidar, image radiometric signatures were normalized by depth using the lidar depth model described in the equation below:

$$\mathrm{SAV}_{RGB} = \left[\frac{Red - Green}{Red + Green} + \frac{Green - Blue}{Green + Blue} + 0.1\right] * \frac{1}{0.2}$$

$$\mathrm{SAV}_{515nm} = [-6.8\,] * \frac{1}{4.3}$$

$$\mathrm{DS}_{depth} = depth * \frac{1}{-5.5}$$

Many band ratios in the visible light spectrum illustrate a linear relationship with respect to water depth while lidar reflectance exhibits an exponential rate of decay. Therefore, the relationship of the natural logarithm of the lidar reflectance to depth is linear. Each image derivative was appropriately scaled such that the resulting range would align with the lidar depth image from 0 m up to a maximum depth of 5.5 m such that the linear depth compensation could be performed directly.

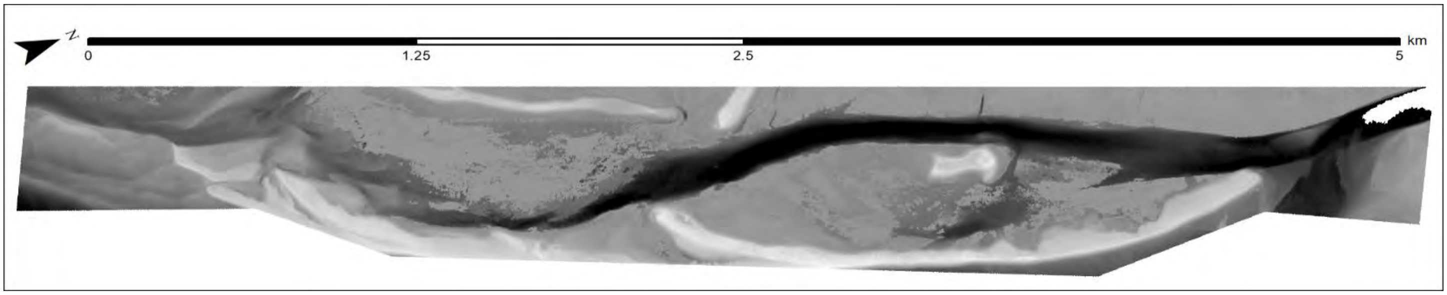

Figure 4. Lidar depth map showing a gradient of water depths from 0 m (white) to 5.5 m depth (black).

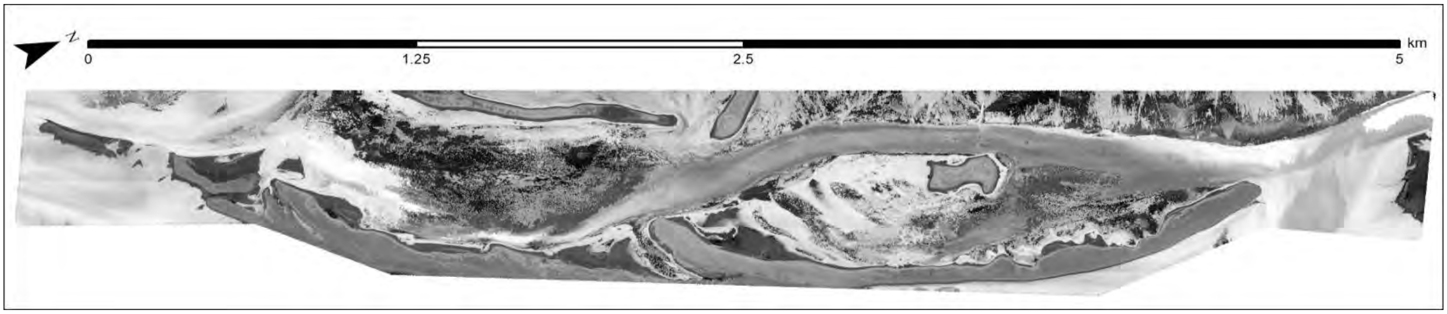

Figure 5. Lidar intensity map which separates less reflective materials, like eelgrass (dark), from highly reflective materials, such as sand (bright).

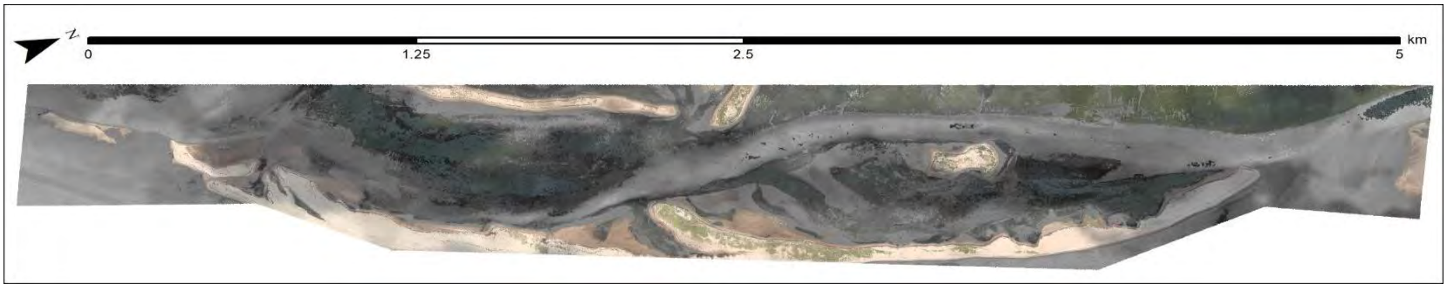

Figure 6. RCD30 derived normalized difference map which minimizes wave and glint artifacts while separating dark eelgrass from sand. This technique breaks down in deeper water in the north of the AOI.

A principal reason for building SAV indexes for each sensor is that they each have various benefits and limitations. The SAV model derived from the camera sensor performed better in very shallow waters, less than 1 m depth, where the lidar reflectance was susceptible to peaking and exhibited noise due to complex water surface interactions. The lidar showed a stronger sea floor reflectance up to a much greater depth (>5 m) compared to the camera. Both sensors had various technical artifacts which diminished the result of their individual SAV products including sea surface glint, sediment plumes, water characteristics, signal loss due to incident angle, and changing light conditions. These problems were inconsistent between the sensors and a fusion of their SAV products helped to produce a superior model. Various approaches have been experimented with to amalgamate these models and based on the extent of the various technical aspects which affect each sensor the maximum returning value from both models was used to map SAV in the Tabusintac AOI (Figure 7):

$$SAV_{index} = \max\left[(\mathrm{SAV}_{RGB} + \mathrm{DS}_{depth}), (\mathrm{SAV}_{515nm} + \mathrm{DS}_{depth})\right]$$

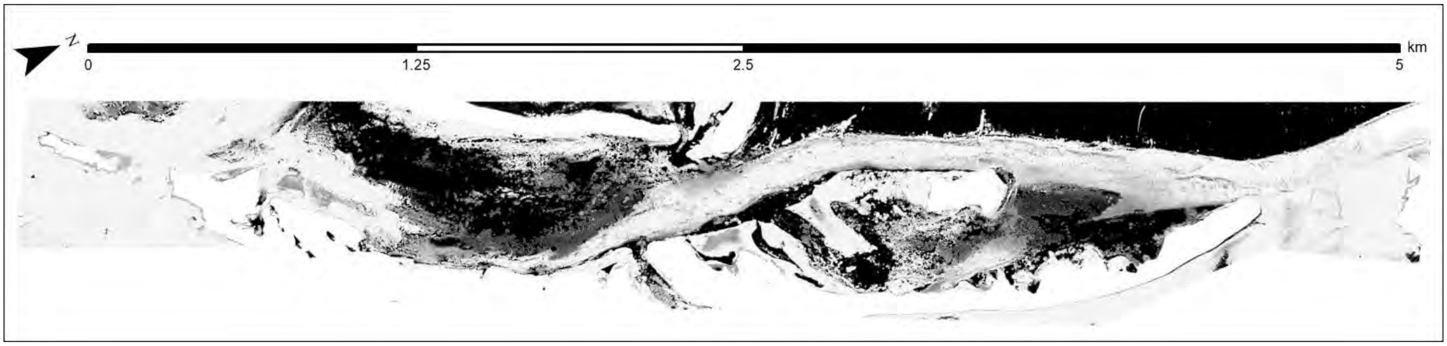

Figure 7. Eelgrass confidence map generated using the image based SAV map, the lidar based SAV map, and depth. Eelgrass appears darker than surrounding bottom materials.

These confidence values were used to determine the qualitative density estimates for the mapped eelgrass beds (Figure 8).

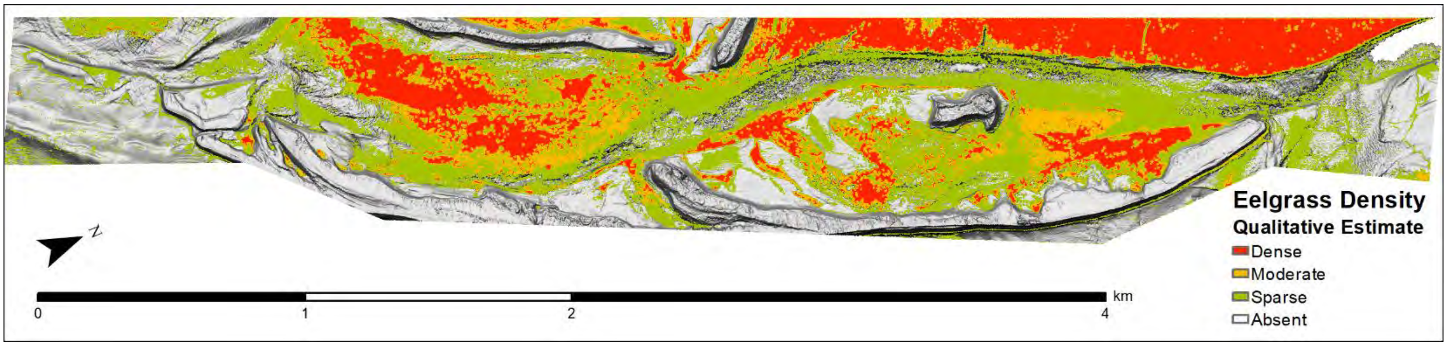

Figure 8. Qualitative estimate of eelgrass density based on confidence mapping.

The water clarity throughout the Tabusintac AOI was highly variable. As a result, the confidence map could not be converted to a presence absence product using a single threshold value. A skilled technician performed comparative assessments between survey products to identify the presence of eelgrass throughout the AOI.

3 Results

The AOI was over-collected to ensure the area was fully scanned by the CH4X. The total area scanned was approximately 3.8 km^2. All products met or exceeded project goals. Topo lidar was collected at a density of >10 ppm, bathymetric lidar was collected at a density of >5 ppm to a depth of >5 m and imagery was collected at a native resolution of < 0.05 m. There were no gaps in coverage, though extinction of the bathymetric signal did occur in the northern section of the AOI. Both the laser and image products were suitable for generating an eelgrass map and several additional deliverables discussed within the following section. For delivery, map data have been projected to the Universal Transverse Mercator Zone 20 North, following the North American Datum of 1983 Canadian Spatial Reference System Version 7 horizontal coordinate system, and the Canadian Geodetic Vertical Datum of 2013 vertical coordinate system (prjUTM20N_hcsNAD83CSRSv7_vcsCGVD2013).

3.1 Image Products

The orthophoto mosaic product was generated at a resolution of 0.05 m resolution with pixel perfect alignment between frames and covered the entire extent of the AOI. The quality of the imagery was suitable for assisting with the interpretation of the DEM and eelgrass coverage though context-based contrast and brightness enhancements (Figure 9). False colour composite imagery which incorporated the near-infrared band was found to be suitable for mapping floating vegetation in the region (Figure 10).

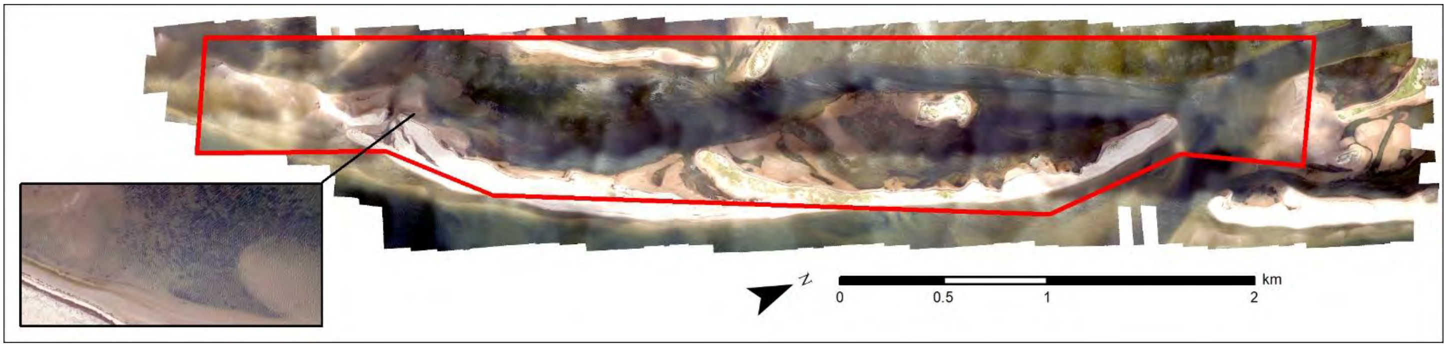

Figure 9. True colour orthomosaic of Tabusintac Bay, PEI created using Agisoft Metashape Professional 1.7.2.

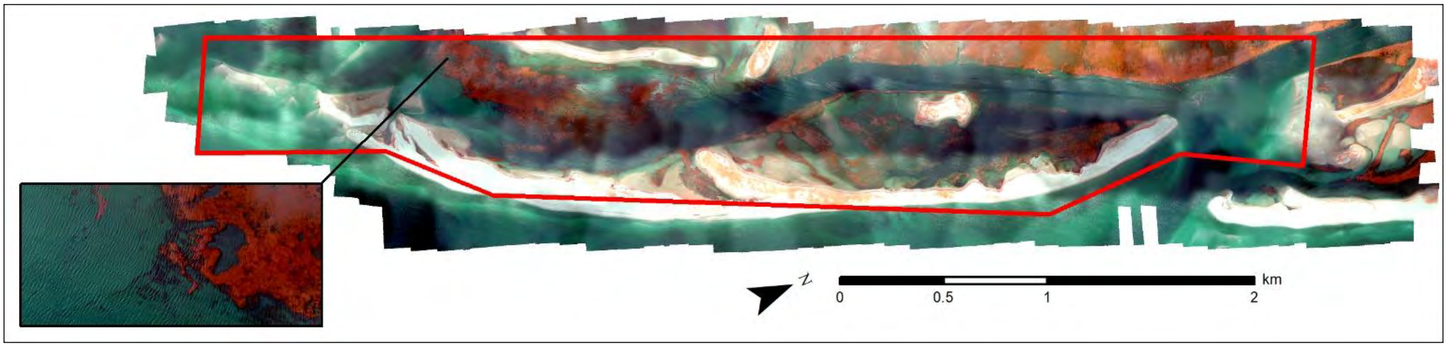

Figure 10. False colour composite (near-infrared, green, blue) highlights vegetation in red, including vegetation floating on the water surface.

3.2 Lidar Products

The bathy lidar penetrated to roughly 5 m depth but was unable to map the seafloor in a small portion of the northern channel. While no data were collected in these deep waters, this did not inhibit NSCC-AGRG's mapping efforts as these areas were considered too deep to support the growth of eelgrass. Topographic and bathymetric data were of high quality and exhibited very little noise which resulted in smooth elevation models (Figure 11) and colour shaded relief models that combine elevation information from the DEM with a colour ramp to highlight differences in elevation (Figure 12). The normalized bathymetric intensity model compensated for the variation in depth and the impact on the amplitude of the reflected green laser pulses in Tabusintac Bay (Figure 13). Depth contour maps were generated for the highly dynamic bay to further highlight variations in depth (Figure 14).

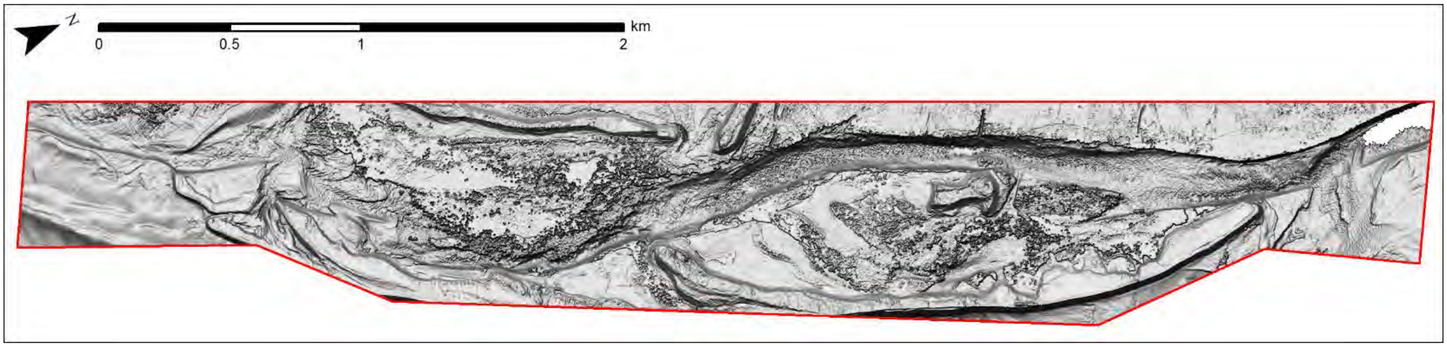

Figure 11. Seamless topo-bathy digital elevation model of Tabusintac Bay, NB with 50 times vertical exaggeration.

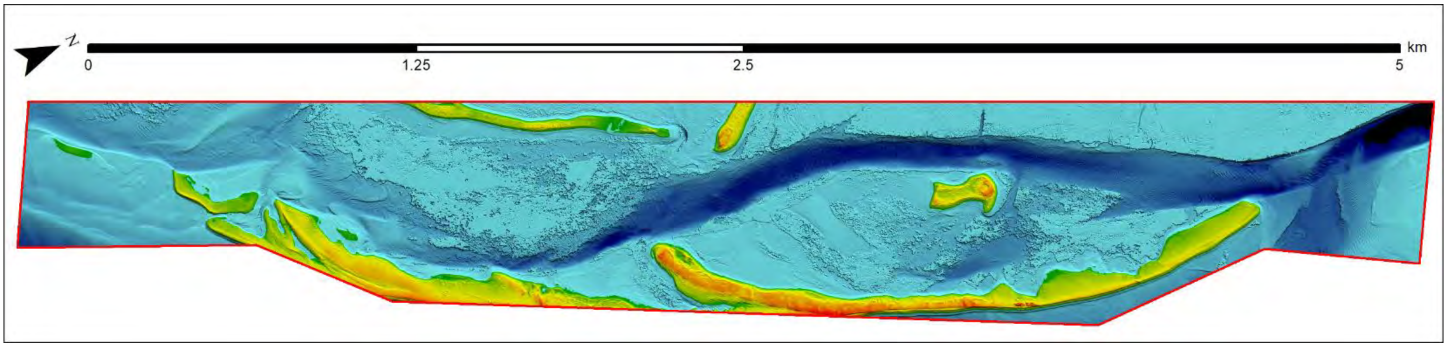

Figure 12. Colour shaded relief model of the study area. The DEM CSR shows the separation of land and water at 0 m CGVD2013 at the blue-green boundary.

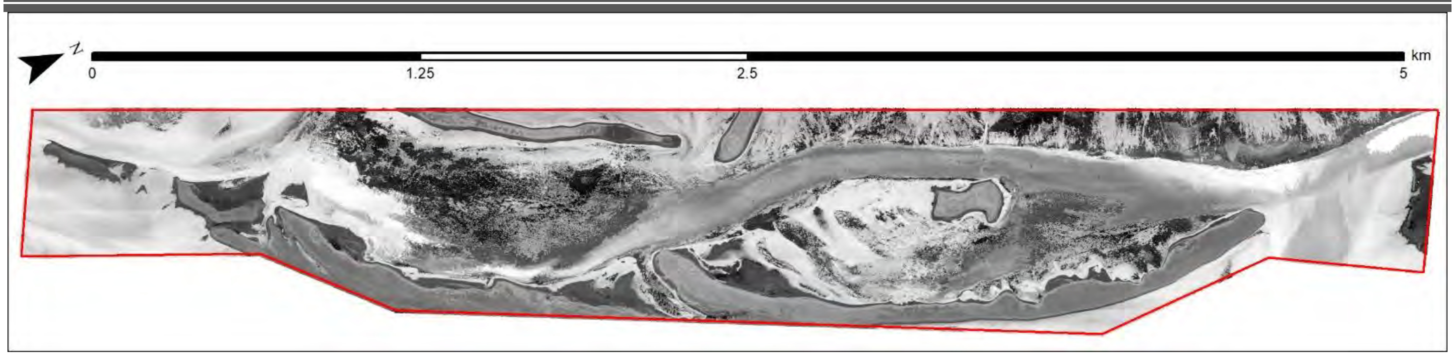

Figure 13. Depth normalized intensity map which separates highly absorbent materials, like eelgrass, from highly reflective materials, such as sand, regardless of depth.

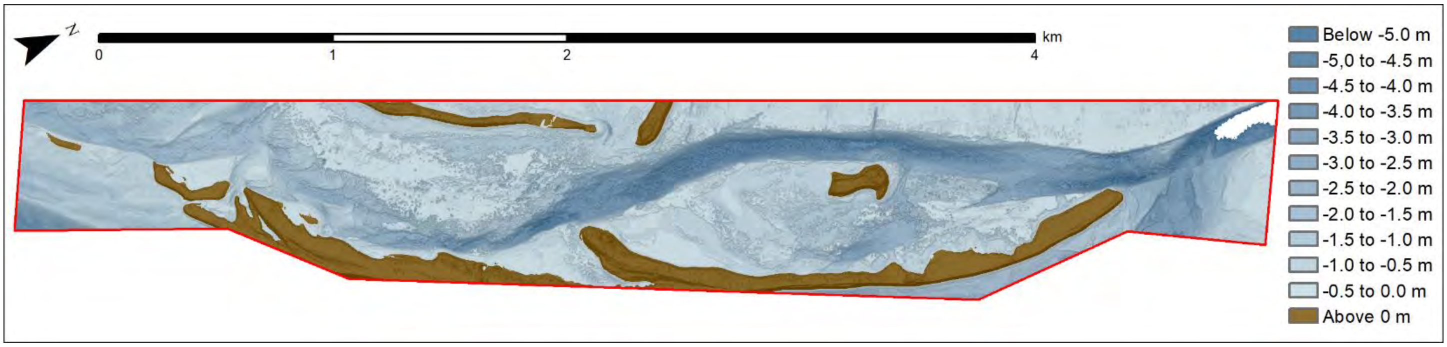

Figure 14. Depth contour map showing depth contours every 0.5 m to a depth of 5 m.

3.3 Submerged Aquatic Vegetation Map

Eelgrass and other seagrasses were successfully mapped were found to be prominent throughout the main Tabusintac channel and surrounding shallows with 2.44 km^2 of coverage within the 3.8 km^2 AOI (Figure 15).

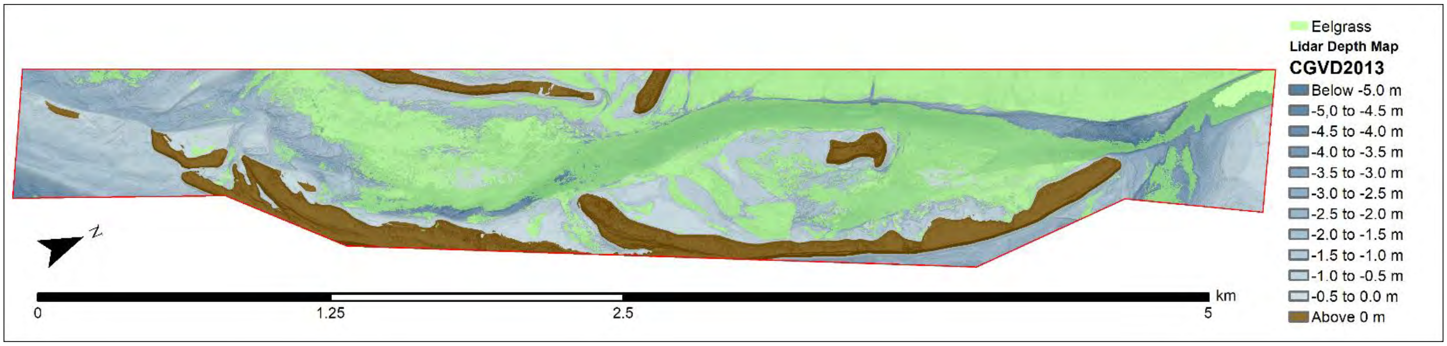

Figure 15. Submerged aquatic vegetation presence absence map with a threshold set to display high confidence eelgrass location within the study area.

4 Discussion

Three separate approaches were examined for mapping eelgrass and other seagrasses in the Tabusintac Bay area: a localized roughness approach, a lidar reflectance approach, and a multispectral imagery approach. Each method had benefits and unique challenges. Image band-ratio composites successfully indicated dark seafloor features such as vegetation while reducing the impact of sun angle and water surface. The lidar reflectance approach was valuable as the green laser penetrated deeper in the water than any of the camera bands. It will be important to create up to date eelgrass maps for the Tabusintac Bay area if continued dredging is being considered.

5 Conclusion

NSCC-AGRG surveyed the nearshore area in Tabusintac Bay, NB on July 29, 2021, and produced high resolution lidar and image data suitable for mapping coastal eelgrass. The results of this project demonstrate how topo-bathymetric lidar can be used to map eelgrass in shallow water coastal areas. It was estimated that eelgrass was present in 64% of the surveyed AOI, 2.44 km^2 of the 3.80 km^2. While eelgrass was mapped in the channel as well as shallow water areas, it was found that eelgrass density was much higher throughout the shallow water areas.

This project has demonstrated the multiple uses of data derived from a single topo-bathymetric lidar survey to support eelgrass conservation efforts. Several key datasets were derived from the lidar seamless land-sea elevation data including the digital elevation model (DEM), the depth normalized intensity (DNI) model, the colour shaded relief (CSR), and the depth contour map with seagrass presence. The methods developed in this project can be used to monitor changes in eelgrass distribution in Tabusintac Bay and map eelgrass beds elsewhere. As seagrasses worldwide are highly threatened (van Katwijk et al. 2016), it is more important than ever to have monitoring procedures in place.

6 Acknowledgements

We like to thank Jeff Barrell of DFO for providing expert advice on eelgrass distribution characteristics. Thanks to staff from Leica Airborne Hydrography and Leica Geosystems for operational support, Leading Edge Geomatics for their flexible hours and piloting skills, and additional NSCC staff for administrative support and data processing efforts.

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