

Enhanced Subtidal Infrastructure Assessment to Support Inland Finfish Aquaculture



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Enhanced Subtidal Infrastructure Assessment to Support Inland Finfish Aquaculture

Executive Summary

A section of coastline was surveyed on July 13, 2016 with a Leica Geosystems Chiroptera II topo-bathymetric lidar sensor for the purpose of collecting elevation data near Scotian Halibut's inland fish hatchery in Lower Woods Harbour, NS. The successful survey yielded high quality and high resolution lidar products which were used to delineate two submerged pipes extending from land into the nearshore adjacent to Scotian Halibut's facility. The lidar bathymetry at 1 m resolution revealed the full length of one pipe (the southern pipe) but only non-definitive evidence of the northern pipe in areas not exposed at low tide. However, the lidar intensity of the reflected green laser off the seabed revealed a linear pattern that is interpreted to be the northern pipe. Ground truth data collection occurred over three days and involved the collection of survey grade GPS points over land to validate the accuracy of the lidar products, as well as the collection of geolocated underwater video footage of transects over the suspected pipe locations. The videos were reviewed for visual evidence of the pipes, and GPS locations where the pipe is clearly seen were identified. Two buoys marking the ends of the pipes which were placed by divers independent of the survey could be seen at mid to low tide and these were used as confirmed pipe locations as well. In all, 13 GPS points confirmed the location of the southern pipes, and 2 GPS points – one at the beginning and one at the end – confirmed the location of the northern pipe. Although the northern pipe lacks confirmation GPS points along its length, the manner in which it was located in the lidar data, and the validation along the entire length of the southern pipe, lends confidence to the derived location of the northern pipe.

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1 Introduction

The nearshore coastal zone of Nova Scotia is an important area to many industries in the province, including both sea-based and land-based aquaculture companies. Scotian Halibut is one such company that uses nearshore coastal waters to fill its on shore halibut tanks in Lower Woods Harbour, Nova Scotia. Scotian Halibut has two pipes that extend approximately 250-300 m into Woods Harbour. The pipes intakes fresh salt water directly into Scotian Halibut's facility. However, the exact location of the pipes are not known, nor is the surrounding morphology of the seabed. Therefore, they are not sure if the pipes are in the ideal location. The project presented in this report is an NSERC-funded research effort to investigate if topo-bathy lidar could aid in identifying the location of the pipes, and to explore the possibility of moving, extending and/or enlarging the pipes for increased water volume intake. For this project, the Nova Scotia Community College (NSCC) Applied Geomatics Research Group (AGRG) used airborne topographic-bathymetric lidar to assist Scotian Halibut in determining the precise location of the pipes, and determining the general surrounding morphology of the seabed. The results from this study will assist Scotian Halibut and the other broader stakeholders in the onshore finfish community in providing them an avenue to remotely and precisely plan for and locate submerged infrastructure.

This report is comprised of four main sections. In the Introduction, the study area, the survey and field data collection, and the results. The details of the data collection and processing are covered in Section 2 - Methods, while the lidar validation and products are found in Section 3 - Results. The Discussion in Section 4 discusses the effectiveness of using topo-bathymetric lidar technology inside a Geographic Information System (GIS) to detect submerged infrastructure, and the report concludes in Section 5.

1.1 Study Area

Scotian Halibut's on-land halibut tanks are located in Lower Woods Harbour, in Southwest Nova Scotia. The tanks are housed adjacent to where the intake pipes come on shore, and the pipes extend roughly 250-300 m offshore. As the exact locations of the pipes were not known prior to the survey, an area much larger than the pipe extent was surveyed to ensure the pipes were within the area of data acquisition (Figure 1).

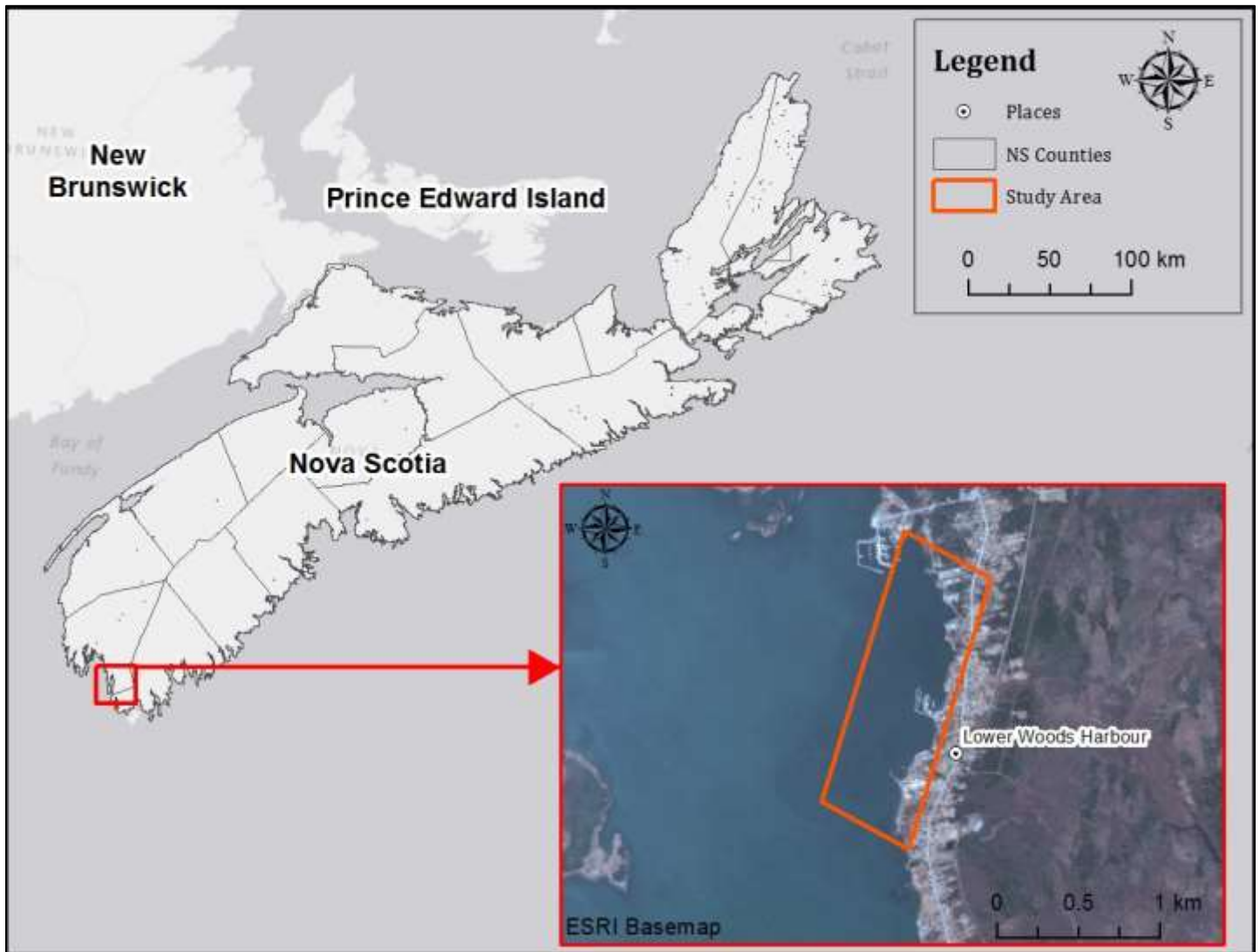


Figure 1. Lower Woods Harbour, NS (red box) is located on the South Shore along the Atlantic Ocean; the inset map (red outline) shows the study area (orange outline) for topo-bathy data acquisition.

2 Methods

2.1 Lidar Survey

2.1.1 Sensor Specifications and Installation

The lidar sensor used in this study is a Chiroptera II integrated topographic-bathymetric lidar sensor equipped with a 60 megapixel multispectral camera. The system incorporates a 1064 nm near-infrared laser for ground returns and sea surface and a green 515 nm laser for bathymetric returns (Figure 2). The lasers scan in an elliptical pattern, which enables coverage from many different angles on vertical faces, causes less shadow effects in the data, and is less sensitive to wave interaction. The bathymetric laser is limited by depth and clarity, and has a depth penetration rating of roughly 1.5 x the Secchi depth (a measure of turbidity or water clarity using a black and white disk). The Leica RCD30 camera (Figure 3) collects co-aligned RGB+NIR motion compensated photographs which can be mosaicked into a single image in post-processing, or analyzed frame by frame for maximum information extraction.

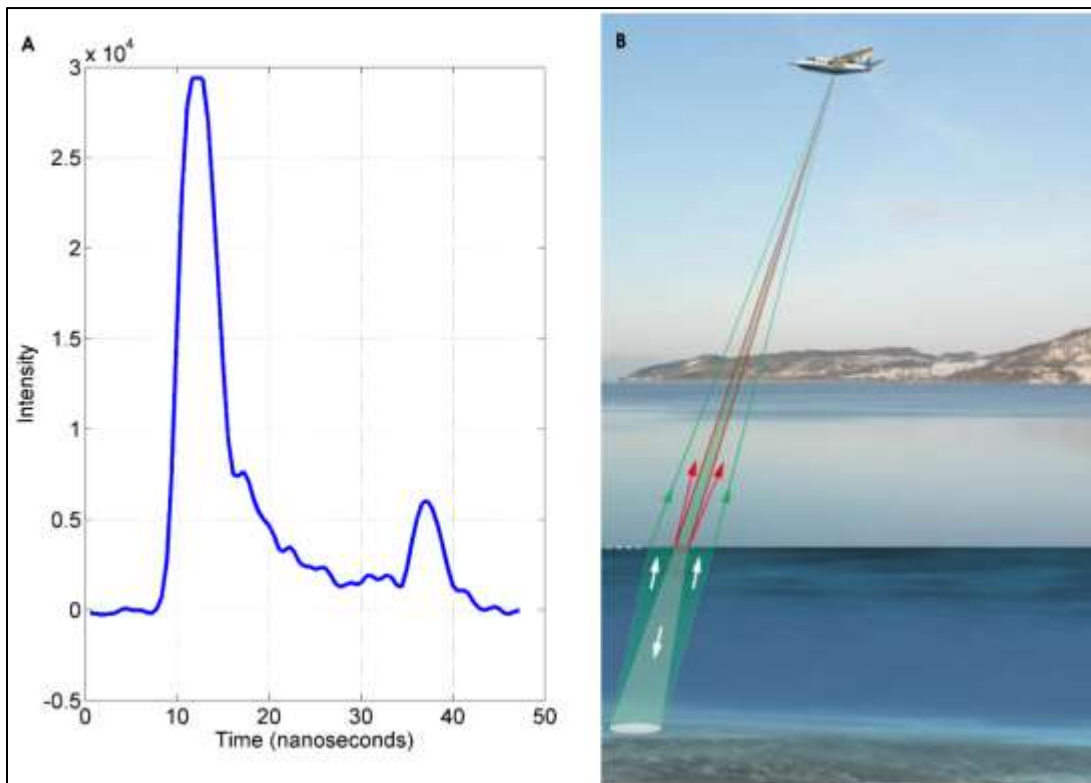


Figure 2. (A) Example of the Chiroptera II green laser waveform showing the large return from the sea surface and smaller return from the seabed. (B) Schematic of the Chiroptera II green and NIR lasers interaction with the sea surface and seabed (adapted from Leica Geosystems).

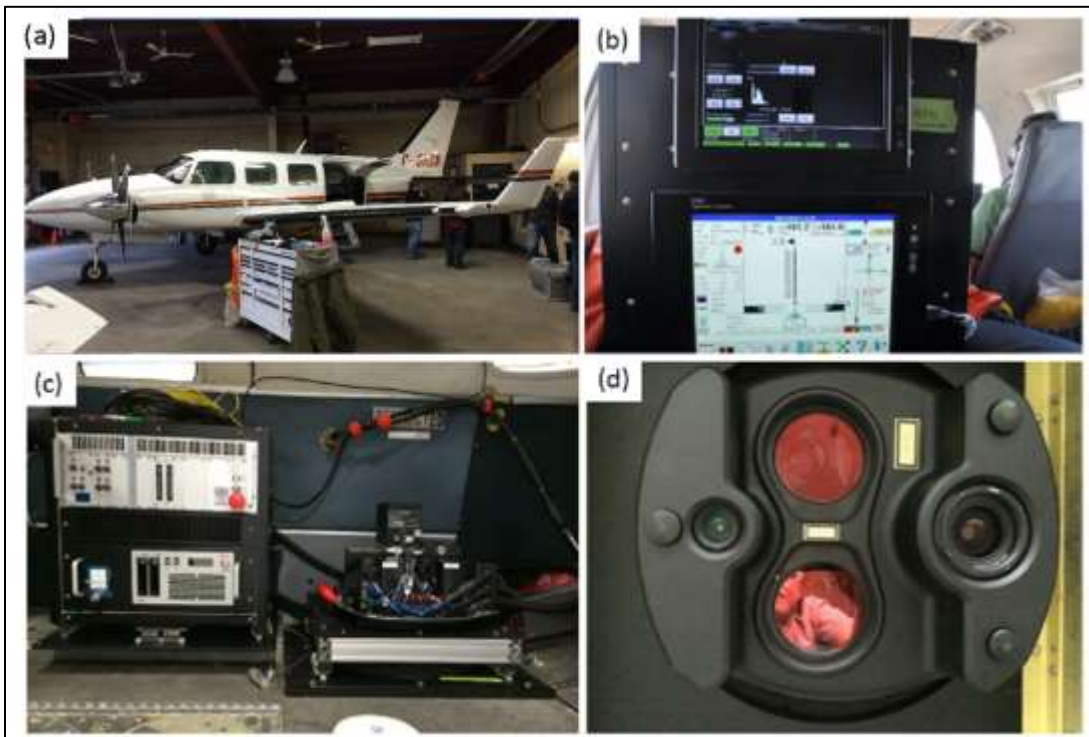


Figure 3. (a) Aircraft used for 2015 lidar survey; (b) display seen by lidar operator in-flight; (c) main body of sensor (right) and the data rack (left) during the 2014 sensor; (d) large red circles are the lasers; the RCD30 lens (right) and low resolution camera quality control (left).

2.1.2 Lidar Survey Details

The lidar survey was conducted on July 13, 2016. The survey was planned using Mission Pro software and flown at an altitude of 400 m above ground. The study area is shown in Figure 1 and a summary of survey details are found in Table 1. The aircraft required ground-based high precision GPS data to be collected during the lidar survey in order to provide accurate positional data for the aircraft trajectory. For this study data were retrieved from an active control station near Barrington Passage (Figure 4). The station is part of the NS Active Control Network which is part of the Canadian Active Control System of unattended tracking stations which continuously record carrier phase and pseudorange measurements for all GNSS satellites within station view (Natural Resources Canada, 2015).

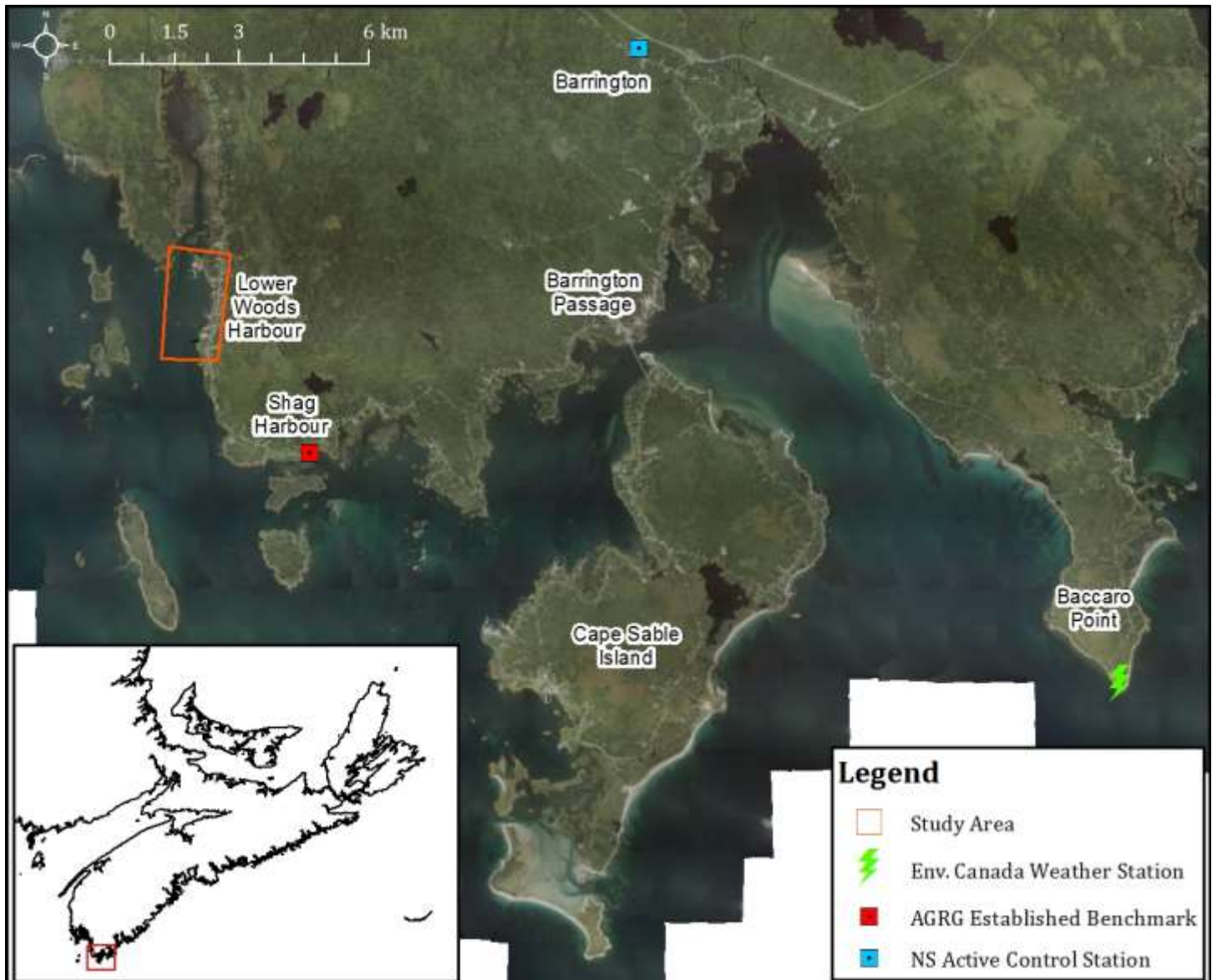


Figure 4. The Environment Canada weather station located at Baccaro Point (green bolt) was used to monitor weather in the area; an active control station in Barrington (blue square) was used as a reference during the flight, while an AGRG benchmark monument was used as a reference for 2 ground truth surveys (red square).

Table 1. Lidar survey details summary. Weather information is from the Environment Canada weather station at Baccaro Point (location shown in Figure 4; data shown in Figure 5); tidal information is from the University of South Carolina tide website (<http://tbone.biol.sc.edu/tide/>).

Study Area	Survey Date (mm/dd/yyyy)	Survey Time (UTC)	Tide	Wind Spd (km/hr)	Wind Dir
Lower Woods Harbour	07/13/2016	16:47 – 18:06	Mid Tide Rising	20	SW

Weather observations (Figure 5) are from the Environment Canada weather station at Baccaro Point and show that wind speeds leading up to the survey date were typically between 15 and 25 km/hr blowing from the northwest. The 24 hours prior to the lidar survey saw wind rotate counterclockwise from the SW, with winds during the survey blowing at roughly

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15-20 km/h. These winds were blowing in an onshore direction, both leading up and during the survey, though the water was not stirred up enough to negatively impact the survey significantly as the water quality was not reduced greatly.

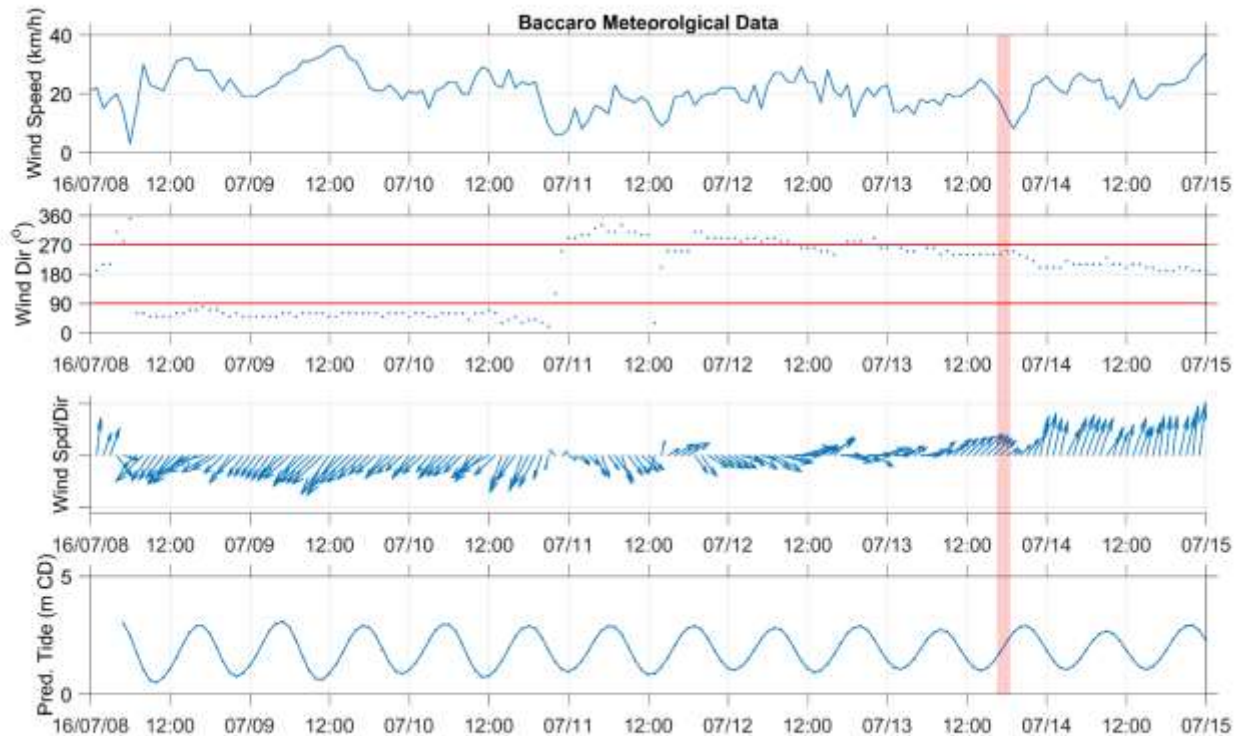


Figure 5. Wind speed (top panel) and direction (middle upper panel) collected at the EC weather station at Lower Woods Harbour (Baccaro Point) between July 8 and 15, 2016. The middle lower panel shows a vector plot of the wind, where the arrows point in the direction the wind is blowing, while the bottom panel shows the tidal stage in the area over the same timeframe. The narrow red rectangular box indicates the lidar survey duration.

2.2 Elevation Data Processing

2.2.1 Lidar processing

2.2.1.1 Point Cloud Processing

Once the GPS trajectory was processed for the aircraft utilizing the GPS base station and aircraft GPS observations and combined with the inertial measurement unit, the navigation data was linked to the laser returns and georeferenced. Lidar Survey Studio (LSS) software accompanies the Chiroptera II sensor and was used to process the lidar waveforms into discrete points. The data was then inspected to ensure there was sufficient overlap (30%) and no gaps existed in the lidar coverage.

One critical step in the processing of bathymetric lidar is the ability to map the water surface. This is critical for two components of georeferencing the final targets that the reflected laser pulse recorded: the refraction of the light when it passes from the medium of air to water, and the change in the speed of light from air to water. The LSS software computes the water surface from the lidar returns of both the topo and bathy lasers. In addition to classifying points as land, water surface or bathymetry, the system also computes a water surface that ensures the entire area of water surface is covered regardless of the original lidar point density. As mentioned, part of the processing involved converting the raw waveform lidar return time series into discrete classified points using LSS signal processing; points included ground, water surface, seabed, etc. Waveform processing may include algorithms specifically for classifying the seabed. The points were examined in LSS both in plan view and in cross-section view. The waveforms were then queried for each point so that the location of the waveform peak could be identified and the type of point defined, for example water surface and bathymetry.

Terrascan was utilized to further classify and filter the lidar point cloud. Because of the differences in the lidar footprint between the topographic and bathymetric sensors (topographic footprint has a 0.15 m and bathymetric footprint a 1.6 m diameter on the ground) it was decided that the bathymetric laser point returns were used to represent the water surface and bathymetry points and the topographic lidar points would be used to represent targets above ground. The total point cloud that utilized both sensors was processed in Terrascan where the ground was classified and erroneous points both above and below the ground were defined. Please see the Data Dictionary, which has been delivered as a separate document, for point classification codes.

2.2.1.2 Gridded Surface Models

There are three main data products derived from the lidar point cloud. The first two are based on the elevation and include the Digital Surface Model (DSM) which incorporates valid lidar returns from vegetation, buildings, ground and bathymetry returns, and the Digital Elevation Model (DEM) which incorporates ground returns above and below the water line. The third data product is the intensity of the lidar returns, or the reflectance of the bathy laser. The lidar reflectance, or the amplitude of the returning signal from the bathy laser, is influenced by several factors including water depth, the local

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angle of incidence with the target, the natural reflectivity of the target material, and the voltage or gain of the transmitted lidar pulse.

The original reflectance data are difficult to interpret because of variances as a result of water depth and loss of signal due to the attenuation of the laser pulse through the water column at different scan angles, as well as lack of bottom reflectivity.

2.2.1.3 *Aerial Photo Processing*

The low altitude and high resolution of the imagery required that the lidar data be processed first to produce bare-earth DEMs that were used in the orthorectification process. The RCD30 60 MPIX imagery was processed using the aircraft trajectory and direct georeferencing. The aircraft trajectory blends the GPS position and the IMU attitude information into a best estimate of the overall position and orientation of the aircraft during the survey. This trajectory, which is linked to the laser shots and photo events by GPS based time tags, was used to define the Exterior Orientation (EO) for each of the RCD30 aerial photos that were acquired. The EO, which has traditionally been calculated by selecting ground control point (x, y, and z) locations relative to the air photo frame and calculating a bundle adjustment, was calculated using direct georeferencing and by exploiting the high precision of the navigation system. The EO file defines the camera position (x, y, z) for every exposure as well as the various rotation angles about the x, y and z axis known as omega, phi and kappa. The EO file along with a DEM can be used with the aerial photo to produce a digital orthophoto. After the lidar data were processed and classified into ground points, the lidar-derived DEM (above and below the water line) was used in the orthorectification process in Erdas Imagine software and satisfactory results were produced.

The original elevation of any lidar products are referenced to the same elevation model as the GPS they were collected with. This model is a theoretical Earth surface known as the ellipsoid, and elevations referenced to this surface are in ellipsoidal height. To convert them to orthometric height (Oht), which is height relative to CGVD28, an offset must be applied. The conversions were calculated based on the geoid-ellipsoid separation model, HT2, from Natural Resources Canada.

2.2.1.4 *Depth Map Generation*

Depth maps were produced by subtracting valid bathymetric elevations from the measured water surface.

2.2.1.5 *Depth Normalization of the Green Laser*

The amplitude of the returning signal from the bathy laser provides a means of visualizing the seabed cover, and is influenced by several factors including water depth and clarity, the local angle of incidence with the target, the natural reflectivity of the target material, and the voltage or gain of the transmitted lidar pulse. The raw amplitude data are difficult to interpret because of variances because of signal loss due to the attenuation of the laser pulse through the water column at different scan angles. Gridding the amplitude value from the bathy laser results in an image with a wide range of values that are not compensated for depth and have significant differences for the same target depending on the

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local angle of incidence from flight line to flight line. As a result, these data are not suitable for quantitative analysis and are difficult to interpret for qualitative analysis. 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 (eg., 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 with the depth map to adjust the amplitude data so that they could be interpreted without the bias of depth. A depth normalized amplitude/intensity image (DNI) was created using this technique that can be more consistently interpreted for submerged features such as pipes. Note that this analysis considers only bathymetric lidar values and ignores any topographic elevation points.

2.3 Deriving Pipe Locations

The 1 m lidar topo-bathymetric DEM was visually assessed for evidence of any linear structures emanating from the shore near the Scotian Halibut facility into the nearshore. Several hillshaded models were constructed by introducing a sun angle to the lidar elevation data, which accentuates any patterns or features in the topography or bathymetry (Figure 6a&b). Features that appeared to be part or all of both pipes were identified and digitized into a line shapefile (Figure 6d). The pipes are hence referred to as the northern pipe and the southern pipe (as labeled in the figure). In addition, the depth normalized intensity (DNI) was visually investigated for signs of the pipes, and an additional section of the northern pipe was digitized (Figure 6c). The lines running north to south in the elevation maps (CSRs) are minor artifacts in seabed elevation resulting from the north-south flightlines during the survey.

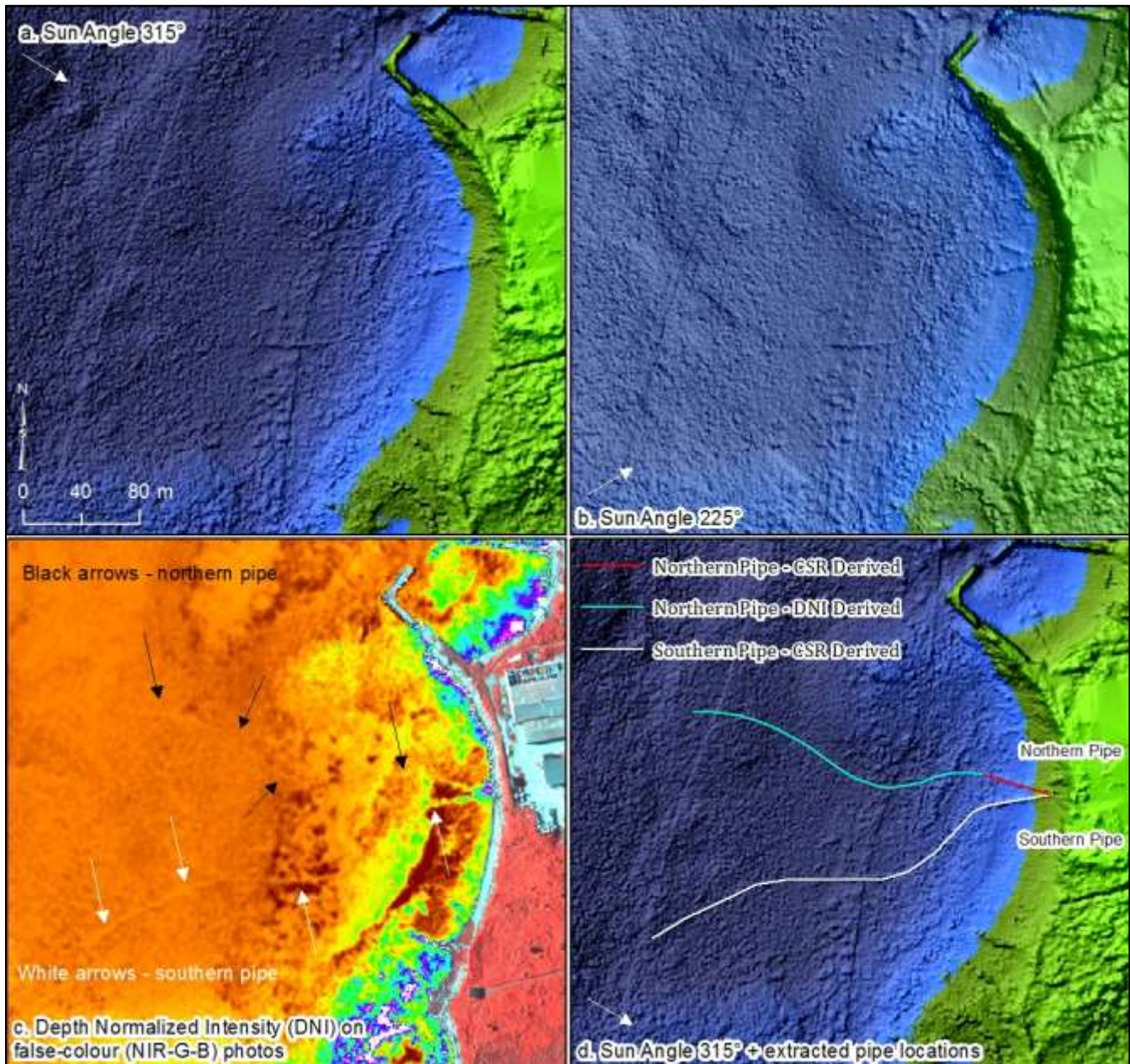


Figure 6. Colour shaded reliefs (CSR) using different superimposed sun angles - an angle of 315° (a) and 225° (b), as well as the depth-normalized intensity (DNI) (c), and with the derived pipe locations shown on the 315° CSR (d).

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2.4 Ground Truth Data Collection

Three missions were carried out to obtain geolocated ground truth data for the purposes of assessing the vertical quality of the lidar results, and to confirm the location of the submerged portion of the pipes using underwater video and survey grade GPS for high accuracy location. A summary of the ground truth missions can be found in Table 2.

Table 2. A summary table of the three data collection missions executed by AGRG. For all missions the GPS corrections were received from the SmartNet cellphone network using a Leica GS14 GPS system.

Date	Base station (id)	GPS System (GS14 or 530/1200)	Underwater Photos (see caption for options)	Hard Surface GPS (Y or -)
15-Aug	SmartNet	GS14	-	Y
22-Sep	SmartNet	GS14	GoPro	Y
3-Oct	SmartNet	GS14	SeaViewer Video	Y

On August 15, 2016, AGRG consulted with Scotian Halibut regarding the project on site at the Scotian Halibut facility in Lower Woods Harbour. At that time, GPS points were taken in the area on flat, hard surfaces around the facility to compare with the elevation of the resulting elevation models. Additionally, low tide that day exposed the pipes along the shore, so GPS points were collected of the exposed portion of the pipes (Figure 7). A Real-time Kinematic (RTK) GPS system referencing a nearby active control station was used to collect the GPS data. Two additional surveys – one on September 22 and one on October 3 - were conducted to collect additional hard surface RTK GPS points as well collect the underwater video from AGRG’s 14’ aluminum boat. On September 22, issues with power supply prevented the SeaViewer underwater video camera from being used for data collection, so in lieu a waterproof GoPro camera was attached to a large pole and set to record video. On October 3 the power supply issue was resolved and video was collected with the SeaViewer video camera. While the SeaViewer video camera was connected to a handheld GPS device that provided a latitude and longitude, an RTK GPS unit was used to track the movement of the boat for a more accurate location. The boat survey attempted to gain confirmation of the pipes by observing the location of the pipes on the seabed. Numerous transects were completed over the suspected locations of the pipes (Figure 9), and subsequently the underwater video was used to construct points where the pipe was located (more about this in Section 2.3).



Figure 7. The on-shore extent of the pipes to be surveyed. The picture is taken looking due southeast, thus the pipe on the right is the southern pipe, and the pipe on the left is the northern pipe. Picture taken on August 15, 2016.

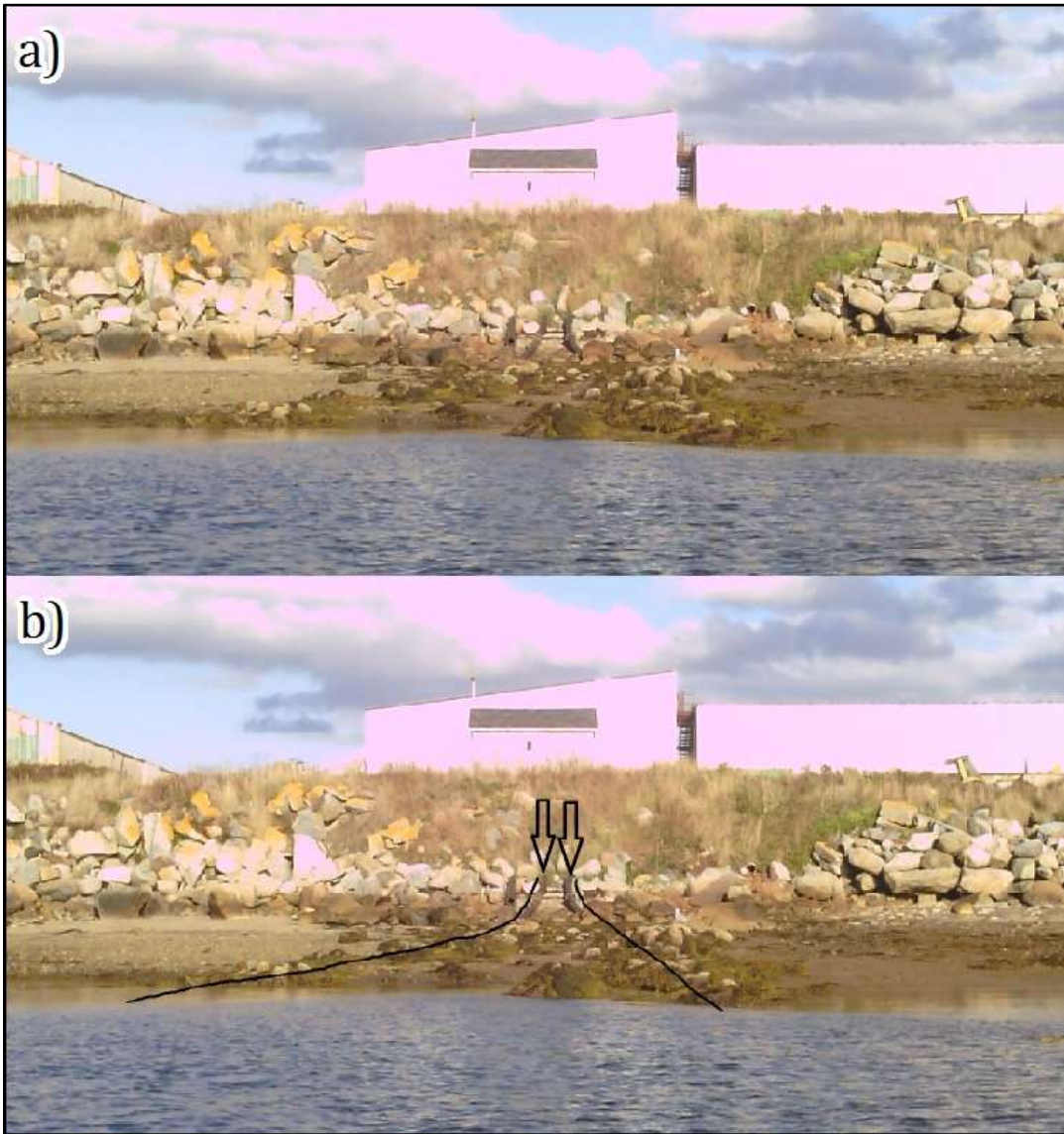


Figure 8. The pipes are exposed at low tide, as can be seen in this picture (a) and outlined (b) taken from the water on Oct 3. In these images the northern pipe is on the left and the southern pipe is on the right.

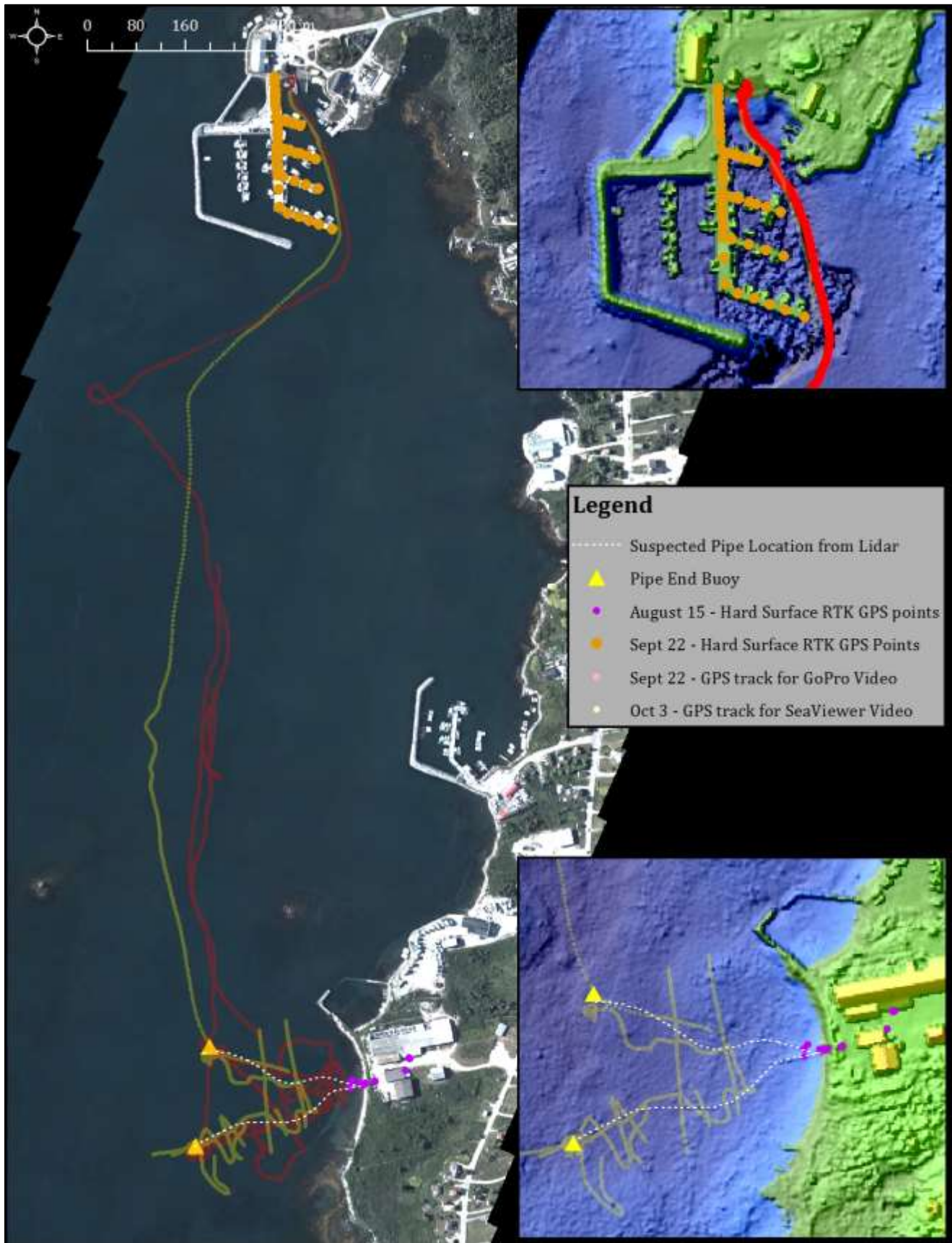


Figure 9. Ground truth data collected on Aug 15, Sept 22, and Oct 3. Hard surface validation was collected on Sept 22 at the Lower Woods Harbour Wharf (b) and at the Scotian Halibut facility on Aug 15 (c).

2.5 Pipe Confirmation from Ground Truth Data

Each video segment was watched and assessed visually for signs of the pipe. The moment the boat drove over the pipe, as evidenced in the video (Figure 10), the corresponding RTK GPS point was selected and treated as a confirmed location. As can be seen in this figure, the pipe is covered with a thick mat of fucus and other submerged aquatic vegetation.



Figure 10. A screenshot of the southern pipe taken from the underwater GoPro video collect done on September 22.

2.6 Validation

Hard surface validation RTK GPS data were collected on two separate dates – August 15 and September 22. On both days the base station corrections were being received from the SmartNet cell phone network. On August 15, RTK GPS points were taken adjacent to the Scotian Halibut facility in Lower Woods Harbour. The points were taken along the shore (since the tide was low and the pipes were exposed) and adjacent to the facility’s parking lot. On September 22, GPS points were taken along the Lower Woods Harbour wharf not far from the Scotian Halibut facility and still within the study area.

In addition to the hard surface validation points, nearshore bathymetric points were collected using RTK GPS to directly measure the bathymetry with a large metal pole. The offset of the pole was applied to each RTK GPS point to ensure the elevation being compared with the DEM is the elevation of the bathymetry.

All RTK GPS points were subject to a quality control assessment such that the standard deviations of the Easting, Northing, and elevation were required to be < 0.05 m. All RTK GPS points exceeding this quality were omitted from the validation results. The elevation of these RTK GPS points were compared with the elevation of the lidar DEM, such that:

$$\text{Difference } (\Delta z) = \text{RTK GPS elevation} - \text{lidar DEM elevation}$$

3 Results

3.1 Lidar Products

This section presents Colour Shaded Relief Models (CSRs) for the DEM (Figure 11) and DSM (Figure 12) for the whole study area. Figure 13 shows the 0.05 m true-colour composite imagery collected at the same time as the lidar survey using an RCD30 camera system. The lidar penetrated to -10.6763 m CGVD28 near the outer harbour and in the channel leading into the Lower Woods Harbour wharf, which is equivalent to -11.747 m in depth during the lidar survey (Figure 14). The DNI for the study area is shown in Figure 15.

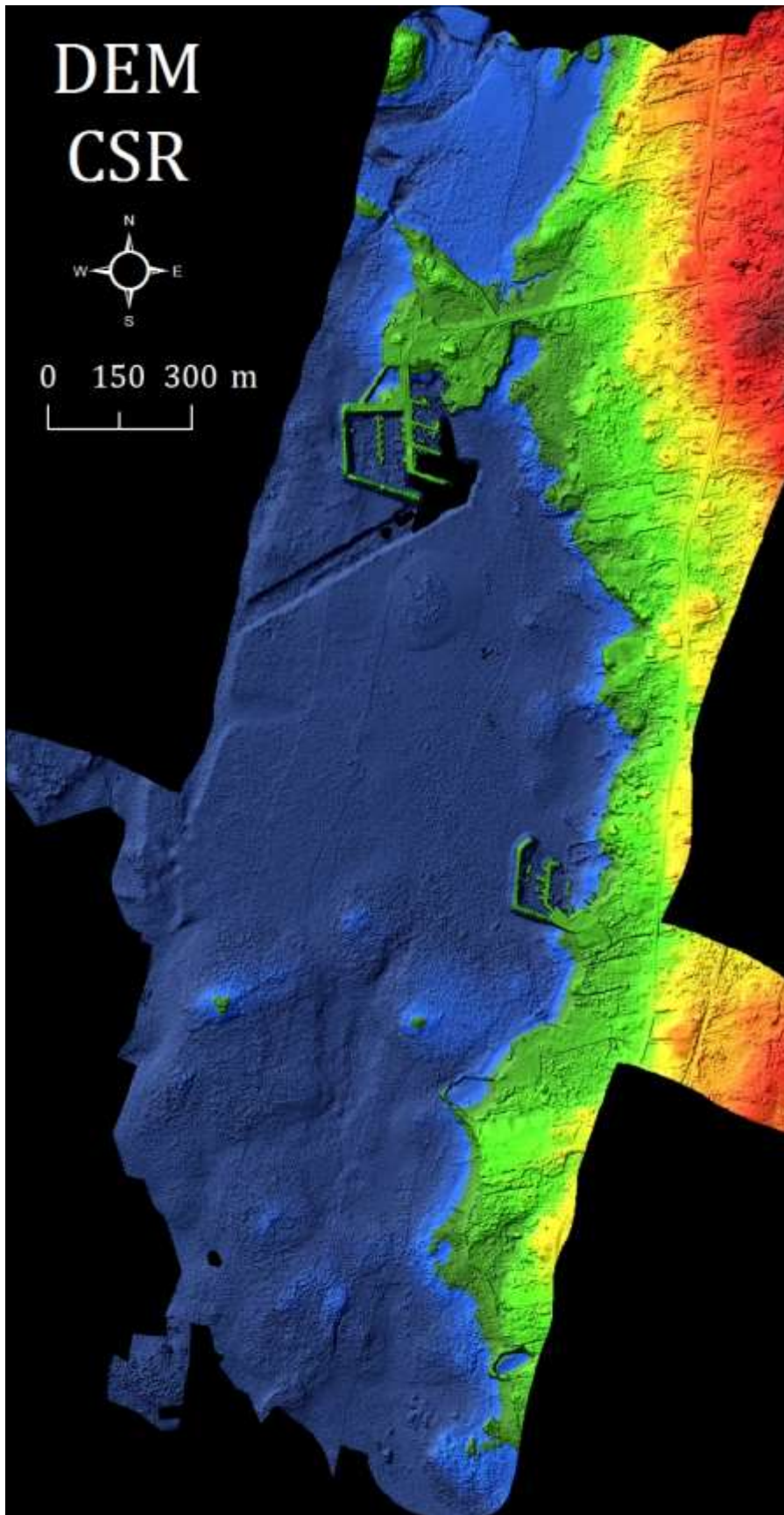


Figure 11. An elevation-coloured hillshaded relief of the digital elevation model.

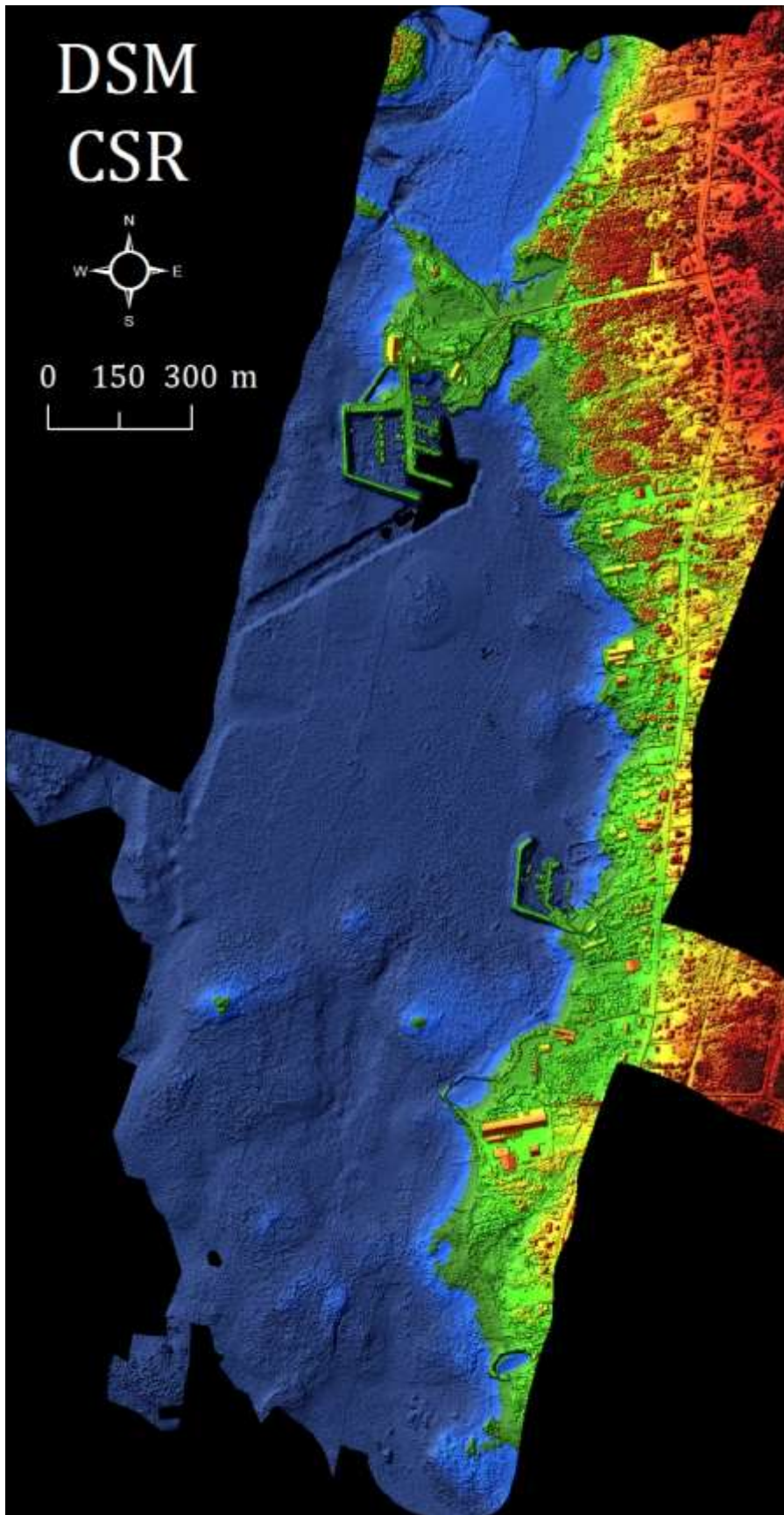


Figure 12. An elevation-coloured hillshaded relief of the digital surface model.



Figure 13. A true colour composite of the 0.05 m RCD30 aerial photo orthomosaic collected during the lidar survey on July 13, 2016.

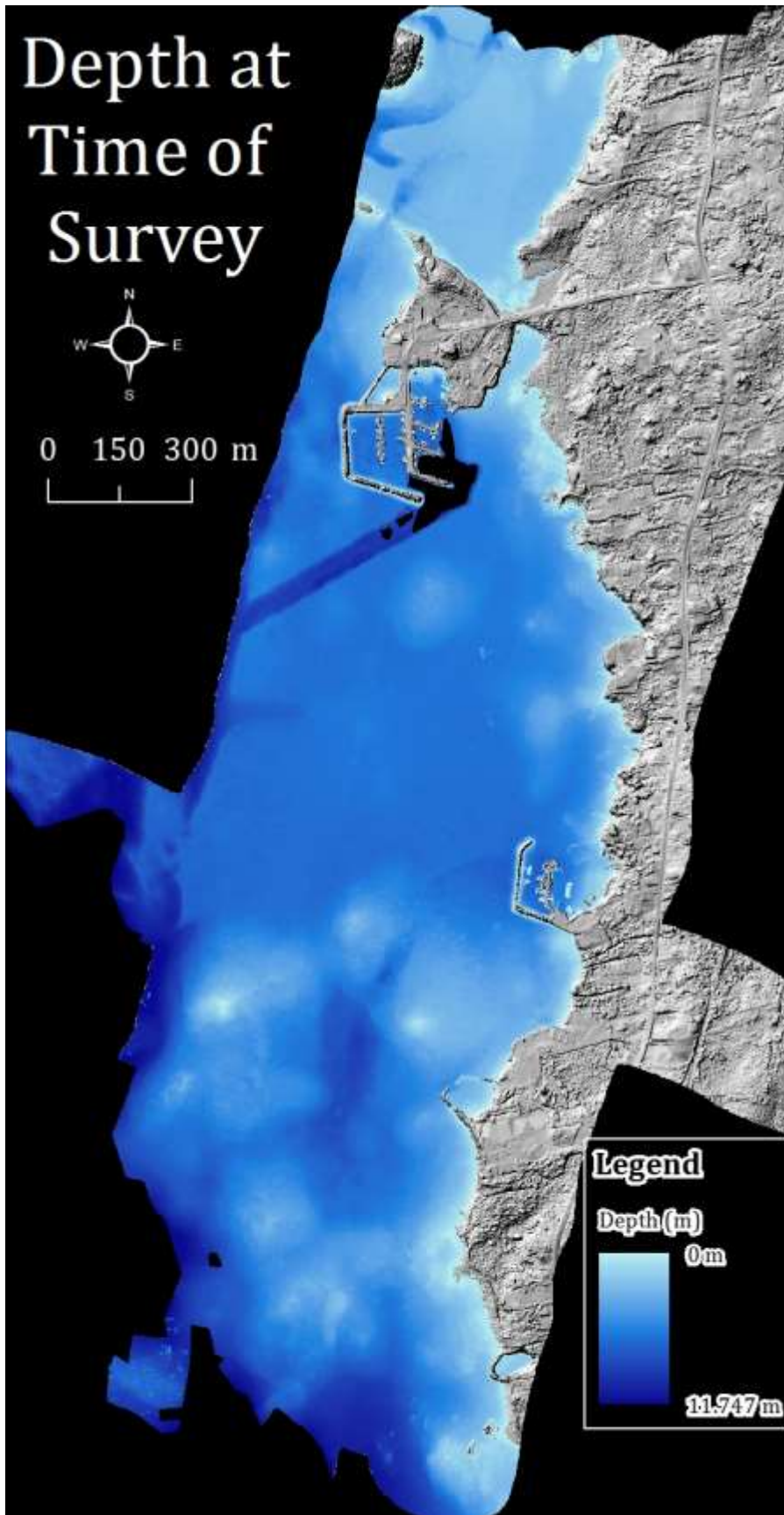


Figure 14. The depth of the water at the time of the lidar survey on July 13, 2016 shows the lidar penetrated a maximum of 11.747 m. The depth information here is shown on the greyscale hillshade of the DEM.

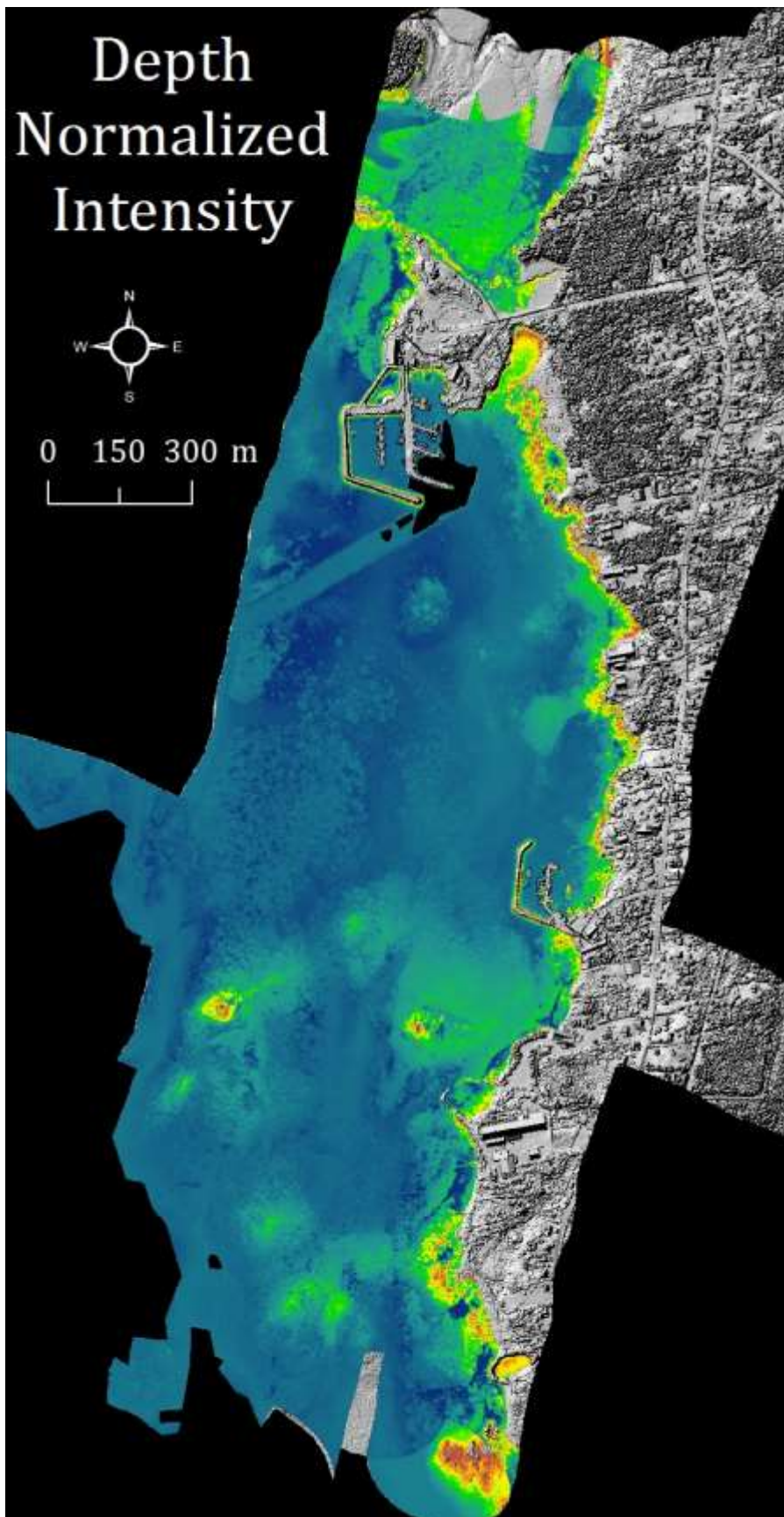


Figure 15. The depth normalized intensity for the study area. The depth information here is shown on the greyscale hillshade of the DSM.

3.2 Lidar Validation

There were 55 data points collected on hard surfaces to be used for topographic lidar validation; the mean difference (ΔZ) between the RTK points and the DEM was -0.0813 m with a standard deviation of 0.1098 m, well within the specifications of the lidar system (Figure 16). Since mean ΔZ is negative, this suggests that the DEM points are on average slightly higher than the RTK GPS values.

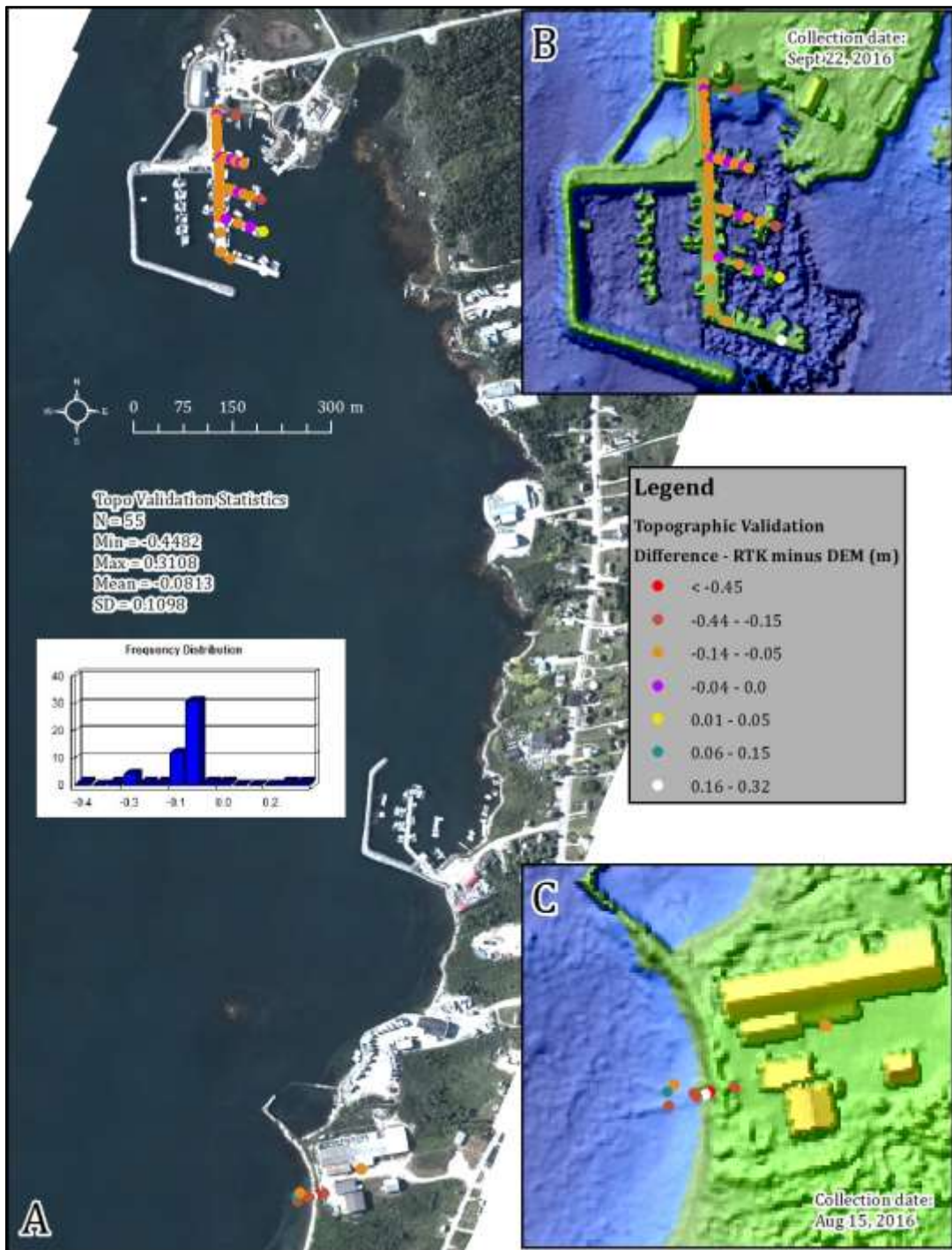


Figure 16. The overall topographic validation dataset (a), collected on September 22 (b) and August 15 (c), shows a mean difference from the lidar DEM of -0.08 m with a standard deviation of 0.11 m.

3.3 Ground Truth Results

In total, two videos were recorded – one on September 22 and one on October 3 – in which the pipes were detected and geolocated in both videos. In both videos the southern pipe was visible on the seabed as a long, linear feature mostly covered in vegetation while the northern pipe was not visible at any submerged location. Thus, numerous confirmed locations were collected for the southern pipe. Only two RTK GPS points confirmed the location of the northern pipe, which was the topographic GPS point taken on August 15 at low tide while at the facility and the GPS point of the buoy marking the end of the pipe taken on September 22. The confirmed locations relative to the suspected locations on the pipe is discussed more in the next section.

3.4 Pipe Location & Validation

Visual examination of CSRs constructed from various azimuth illumination angles revealed two linear features emanating from the exposed shoreline at the Scotian Halibut facility. One feature, the northern pipe, can be seen in the CSR only in the intertidal area, while the other feature, the southern pipe, can be seen curving and extending much deeper into the nearshore (Figure 17). Investigation of the DNI showed an additional section of the northern pipe which is not visible in the CSR (Figure 18), which connects the portion of pipe seen in the CSR (which is also visible in the DNI) and makes a curve before straightening out to extend further out.

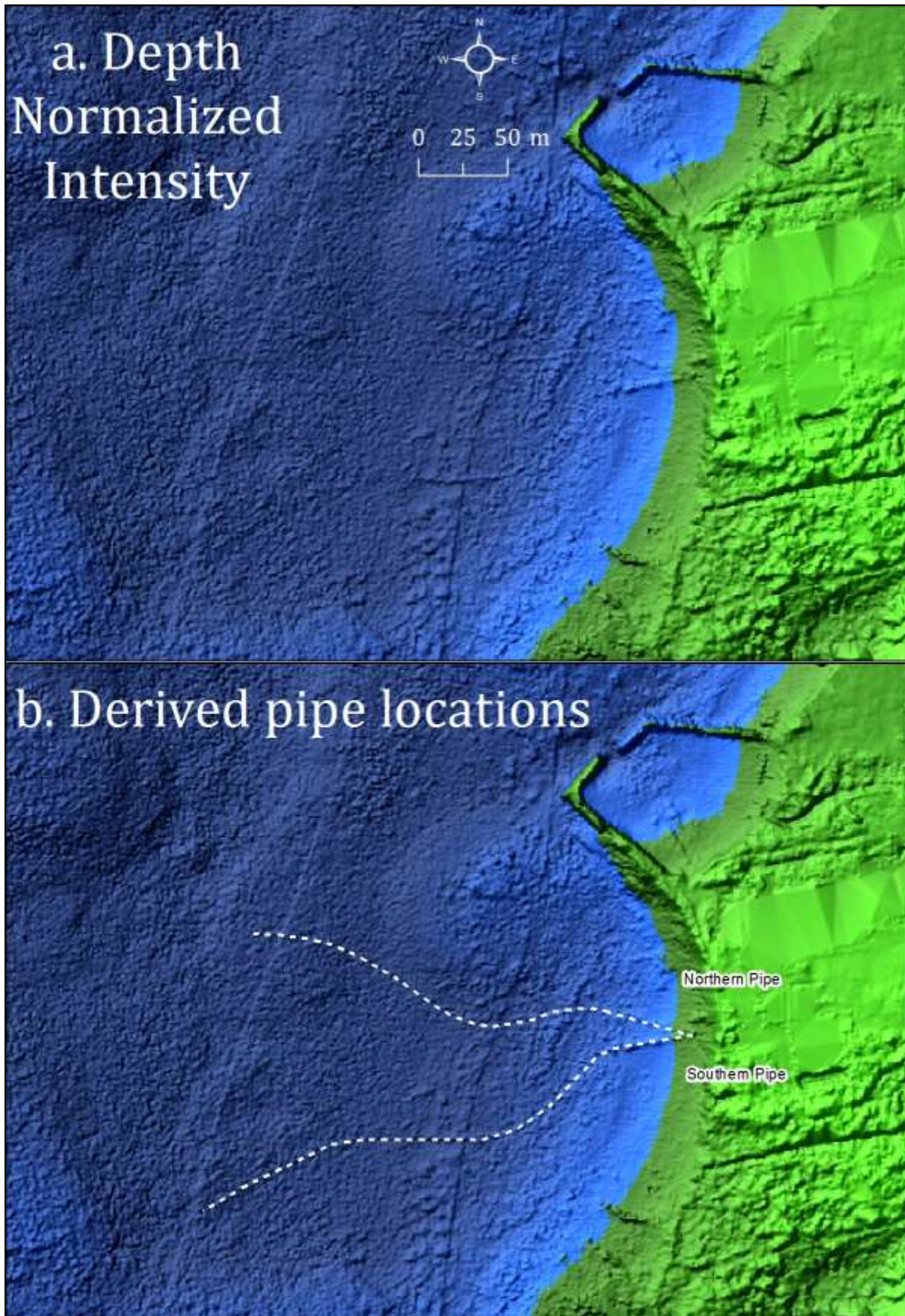


Figure 17. Visual analysis of a coloured, hill-shaded relief (315° sun angle) of the DEM (a) shows two linear features extending from the land into the nearshore (outlined in b).

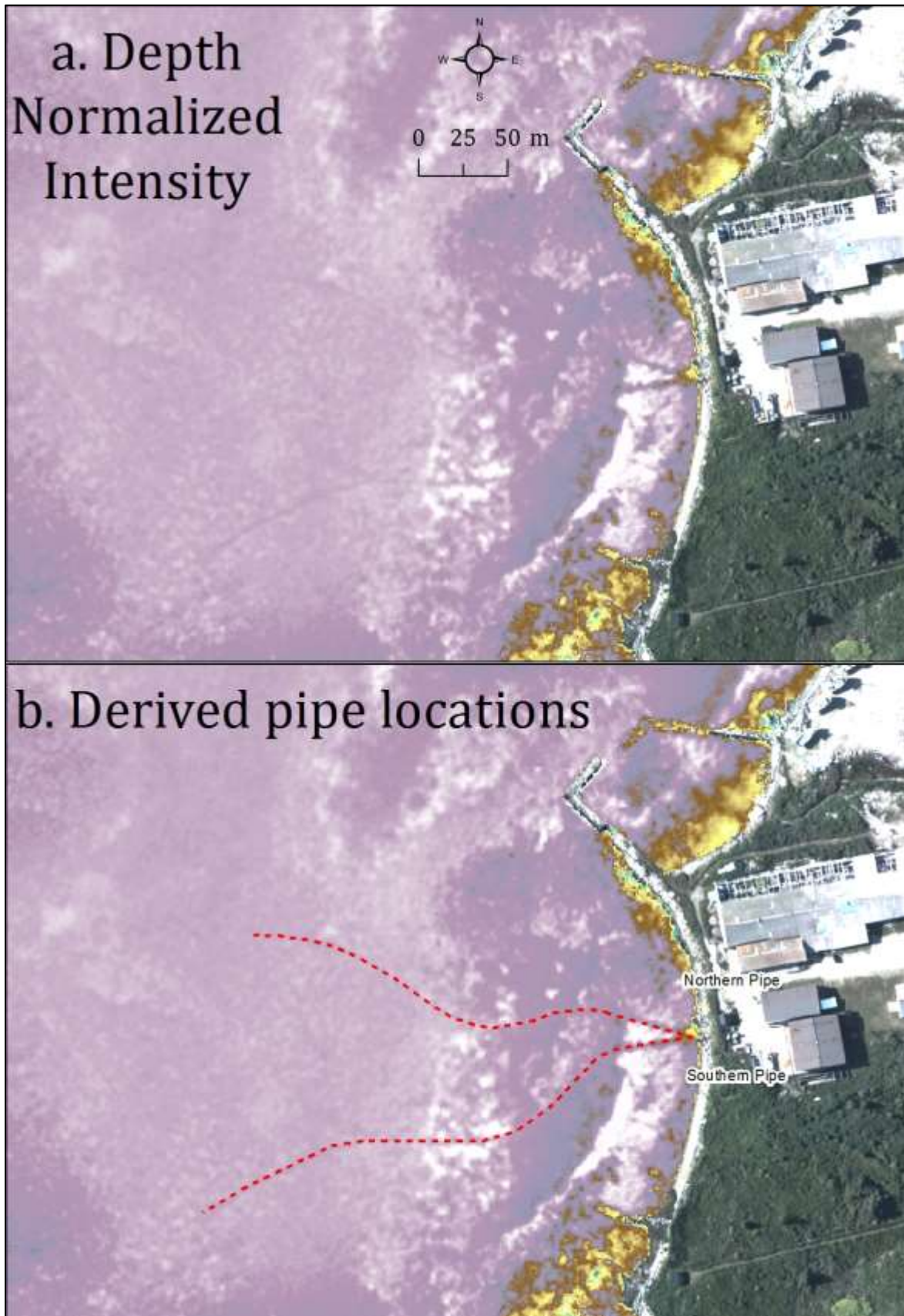


Figure 18. Visual analysis of the depth normalized intensity (a) shows two linear features extending from the land into the nearshore (outlined in b). Shown on true colour RCD30 imagery taken the day of the survey.

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To confirm the suspected location of the pipes, two videos were recorded – one on September 22 and one on October 3 – in which one of the pipes was detected and geolocated in both videos. In both videos the southern pipe was visible on the seabed as a long, linear feature mostly covered in vegetation (Figure 10) while the northern pipe was not visible at any submerged location. However, Thus, numerous confirmed locations were identified from the videos for the southern pipe while none were identified from the videos for the northern pipe. All visual confirmations of the southern pipe were screenshot and the GPS points recorded and compared with the suspected locations (Figure 19). In all, two RTK GPS points collected on land verify the suspected location of the pipes nearshore (Figure 19, 1-1 & 2-1); two points along the southern pipe were confirmed from the GoPro video; finally, nine points along the southern pipe were confirmed from SeaViewer video. Finally, two RTK GPS points collected at the marker buoys verify the end points of both suspected pipes (the line of the northern pipe marker buoy is shown in Figure 19, 2-13). Overall the 13 confirmed locations of the southern pipe agree very well, and the 2 confirmed locations for the northern pipe agree very well with the pipes derived from the lidar-derived products.

The depth of the water (at the time of the survey) over the deepest section of pipe was between 6-7 m (Figure 20). Finally, the length of the northern pipe remotely surveyed is 261 m while the length digitized for the southern pipe is 303 m (Figure 20).

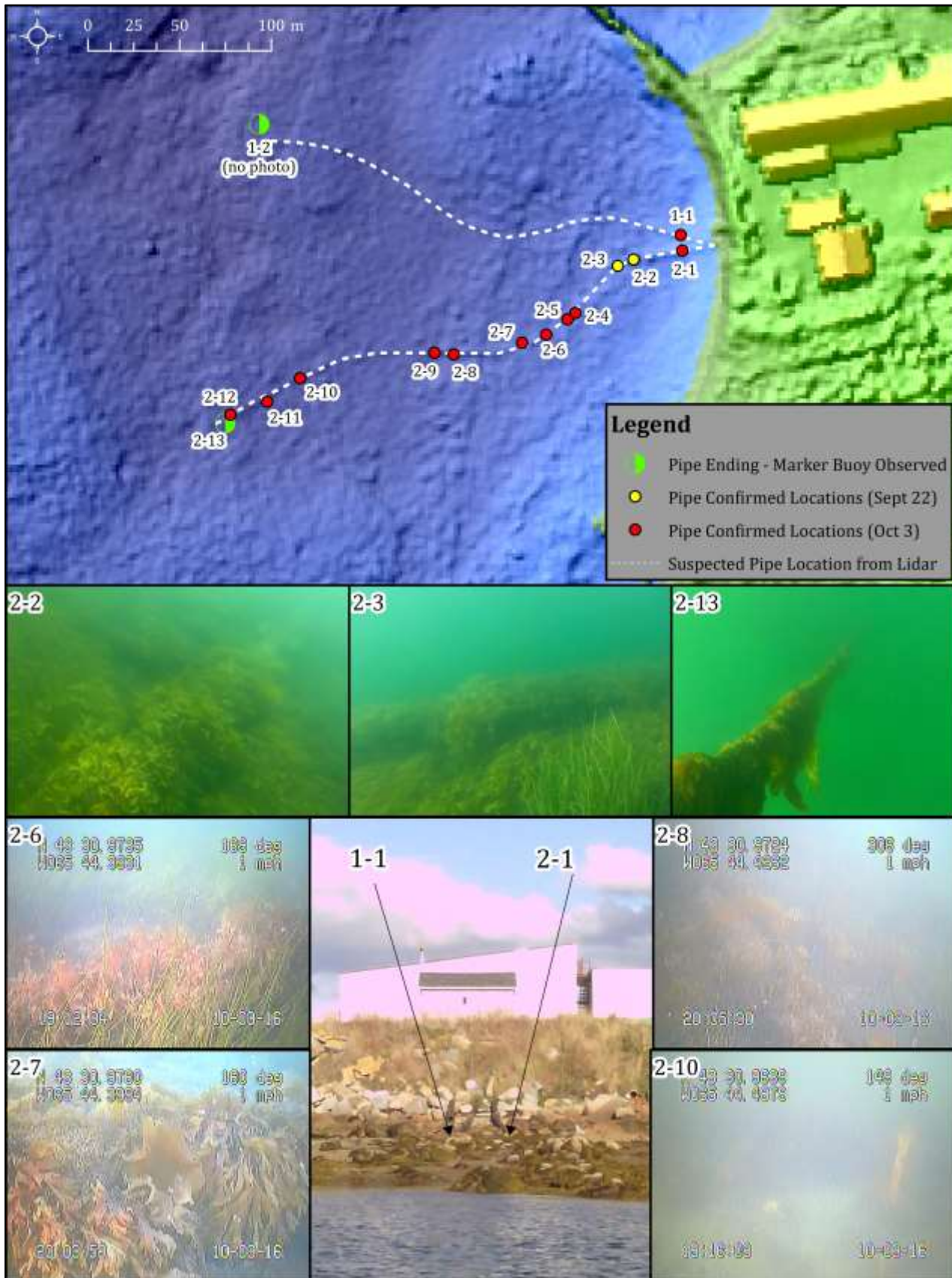


Figure 19. The suspected pipe locations (white line) and confirmed pipe locations (red and yellow dots). RTK GPS points for locations 1-1 and 2-1 were collected from land at low tide. Locations 1-2 and 2-13 (including image 2-13) were the GPS locations and picture of the buoy line marking the end of each pipe.

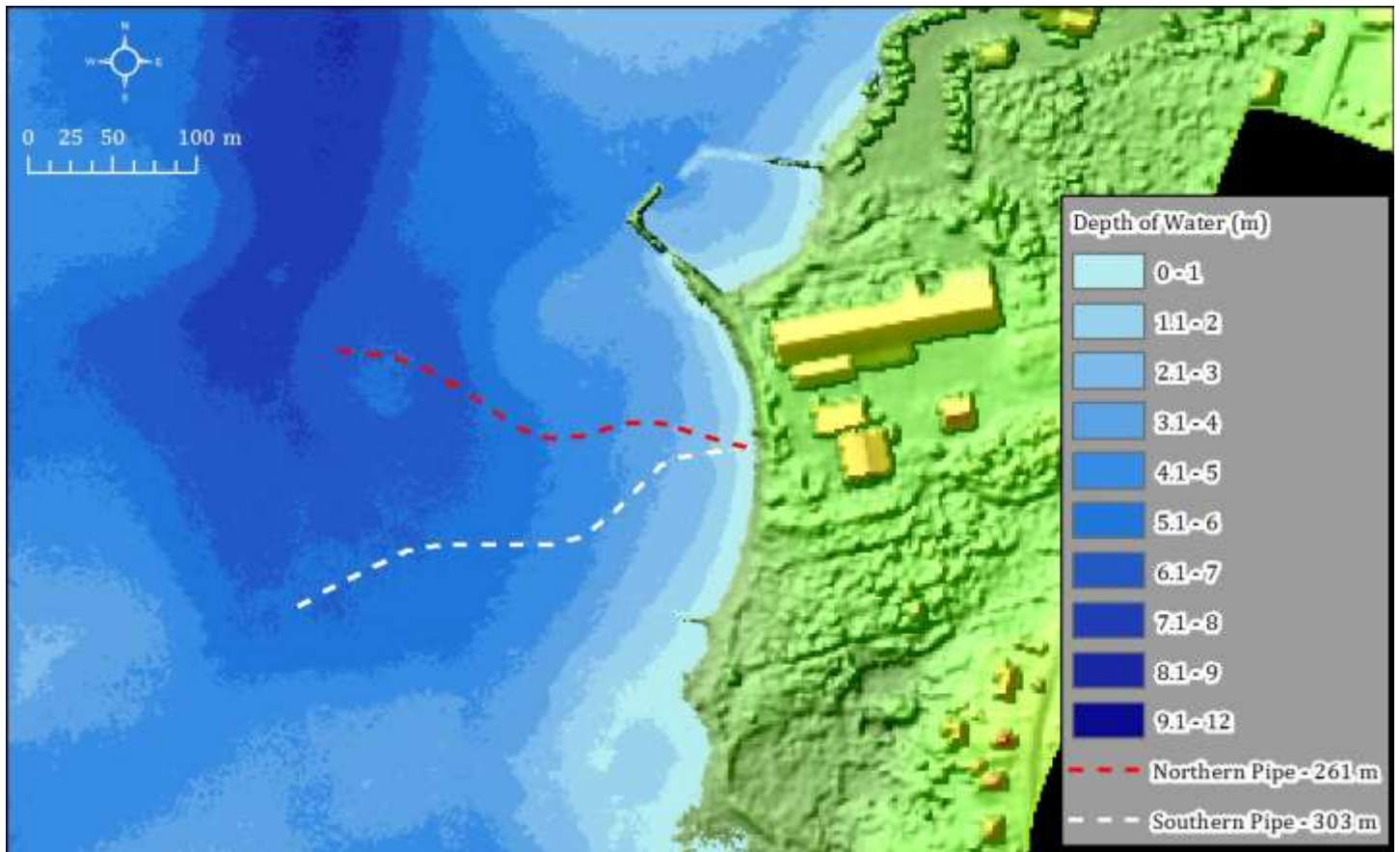


Figure 20. The depth of the water at the time of flight shows the pipe was detected even in up to 6-7 m of water.

4 Discussion

The topo-bathymetric lidar mission on July 13 was successful and various high quality, high resolution products were derived from the lidar data. Two pipes were located from the bathymetric lidar data – in one case the pipe extended to a depth of between 6-7 metres. Three ground truth missions were undertaken, with underwater video captured being more successful on October 3 than on September 22. The underwater video collection on October 3 was more successful than that on Sept 22 for two reasons. First, the water level was much lower (low tide on Oct 3 compared with high tide on Sept 22) so our video attachment could reach deeper into the water. Also, we had no power problems with the SeaViewer video camera on October 3rd like we did on September 22.

While transects were completed over both the northern and the southern pipes, only the southern pipe was able to be located in any video footage. Considering most of the northern pipe was not detected using the elevation data this would indicate that the pipe does not stick out vertically compared with its surroundings. Instead, the pipe was detected using the depth normalized intensity data, indicating that the composition of the vegetation or other seafloor materials appears different along the length of the pipe than it does directly adjacent to the pipe. Considering the pipe does not appear to have a strong topographic expression based on the lidar data, and is likely to be covered with vegetation, a linear strip of submerged vegetation surrounded by other vegetation would be very difficult to identify in a video with no vertical displacement of the pipe to suggest there is a feature of interest located there.

Despite the lack of confirmed GPS points to validate the location of the entire northern pipe, the full extent of the southern pipe was surveyed, mapped, and its location confirmed using underwater video and survey grade GPS. The southern pipe is also visible in the same manner as the northern pipe in the DNI. This fact, combined with the two confirmed GPS points for the northern pipe (one at each end), gives some confidence in the results of the location of the northern pipe despite lacking underwater video evidence.

Overall, the results show that topo-bathymetric lidar is a powerful tool that can be utilized to map submerged infrastructure. Topo-bathy lidar provides not just elevation data but also reflected intensity data which in this case was the only lidar dataset in which the northern pipe could be detected. Lidar's ability to penetrate the water column and survey the bathymetry at a high resolution holds a lot of potential for other submerged infrastructure mapping projects. However, a better way of confirming the location of submerged infrastructure that may be fully covered in vegetation and has no vertical relief should be investigated to provide more confidence in the results.

5 Conclusion

The lidar mission conducted in Lower Woods Harbour on July 13, 2016 resulted in high resolution elevation models (DEM and DSM), an orthophoto mosaic of the area, and a depth normalized intensity map of Woods Harbour. The seamless topographic-bathymetric DEM was validated for accuracy using survey grade RTK GPS and found to be within the specifications of the lidar sensor. Additional lidar products were produced, such as the elevation-coloured hillshaded reliefs and the depth normalized intensity image. These lidar products were used to successfully interpret the location of the full length of both of Scotian Halibut's pipes. Ground truth data collected over three dates confirmed the high quality of the elevation products and also confirmed the locations of the two pipes, with 2 RTK GPS points taken at marker buoys confirming the end points of both speculated pipes; 11 points along the southern line confirmed via recorded and geolocated underwater video; and 2 final RTK GPS points collected over both pipes on land at a very low tide.

This project demonstrates the potential for locating submerged infrastructure using topo-bathymetric lidar.

6 References

Webster, T.L., McGuigan, K., Crowell, N., Collins, K., and MacDonald, C. (2016). Optimization of data collection and refinement of post-processing techniques for Maritime Canada's first shallow water topographic-bathymetric lidar survey. *J. Coast. Res.*

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