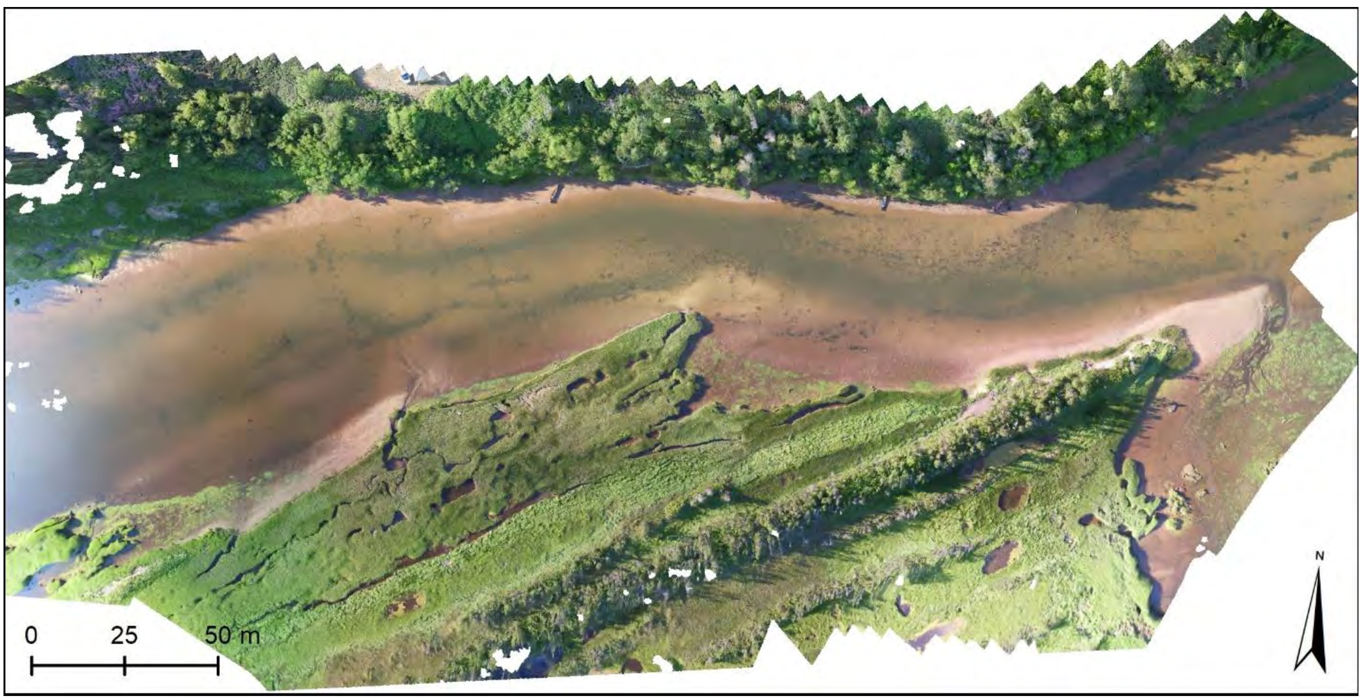
# Remote sensing mapping of Irish moss in Basin Head Marine Protected Area, PEI: Final Report

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# Executive Summary

The Nova Scotia Community College (NSCC) – Applied Geomatics Research Group (AGRG) provided Fisheries and Oceans Canada (DFO) with unmanned aerial vehicle (UAV) mapping and monitoring of Irish moss in the Basin Head Marine Protected Area (MPA), Prince Edward Island. NSCC-AGRG completed ten UAV surveys at Basin Head over three days, from August 10 to August 12, 2018. Collections were focused on the three identified Irish moss beds within Basin Head tidal inlet: Fireweed, Main, and Corduroy. Two UAVs were used for the surveys: a DJI Mavic Pro Platinum and a DJI Matrice 100 equipped with a Zenmuse X5 camera. The 2018 survey conditions were not ideal and imagery collected by NSCC-AGRG was plagued with variable light levels and glint which negatively impacted the results of photogrammetric processing. UAV survey data from DFO collected in 2017 by David Cairns were found to contain fewer spectral issues and were provided to NSCC-AGRG to test the capabilities of photogrammetric processing over the Main bed area of interest. UAV data were classified using two supervised classification techniques: a pixel-based maximum likelihood classification using ESRI ArcMap, and an object-oriented image segmentation classification using Definiens eCognition Developer. Both classification techniques were demonstrated to have strengths and weaknesses when used to classify Irish moss, which generally stemmed from variable light levels due to water depth, and atmospheric conditions during survey periods. Analysis of classification results demonstrated that the ESRI ArcMap classification was superior at generating an accurate Irish moss coverage estimate when using high quality imagery (31.6 $m^2$) compared to DFO provided field measurements (47.8 $m^2$). eCognition classification results may have suffered from the level of spectral variability in the large Main bed area of interest; additional training areas and refinement of the eCognition classifier are likely to improve results.

To maximize the success of future UAV survey activities in the Basin Head MPA several environmental conditions should be considered. The most important environmental factor for successful classification is the homogeneity of light conditions during the survey period. Surveys should be executed during periods of flat-light (overcast conditions) and low wind (< 5 km/h) to reduce image hot-spots, shadows, and glint. Second, surveys should be conducted during slack low tides to reduce light scattering within the water column and allow for sediment deposition to minimize the impact of water clarity on Irish moss visibility. Finally, UAV equipment and flight paths should be optimized to capture data below the water surface by using cameras that minimize spectral noise (Zenmuse x5, Hasselblad HDR) and operate at the minimum safe altitude allowable (~5 to 10 m).

UAV platforms have the unique capability to be deployed rapidly and collect data efficiently during short periods of ideal weather conditions. Future monitoring should exploit these capabilities to ensure suitable data are collected for Irish moss classification and quantification efforts.

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# 1 Introduction

Fisheries and Oceans Canada (DFO) required assistance mapping and monitoring Irish moss in the Basin Head Marine Protected Area, Prince Edward Island. The rare giant Irish moss found in the estuary is threatened by the presence of invasive green crabs, sediment loading, and *Ulva*. DFO has been planting Irish moss in the Northwest arm of Basin Head and mapping the spatial distribution of the moss using a combination of ground fieldwork and unmanned aerial vehicle (UAV) work. The success of the planting program has led to the requirement for a long-term monitoring and mapping strategy that is more efficient than the traditional manual measurements used in the early stages of the program.

The Nova Scotia Community College – Applied Geomatics Research Group (NSCC- AGRG) was contracted to develop a Long-Term Monitoring Strategy for mapping Irish moss using remote sensing for implementation by DFO. Section 2 of this document describes the field activities undertaken at Basin Head in August of 2018, methods employed for photogrammetric processing, Irish moss classification and coverage estimation, and data validation. Data products, classification results and coverage estimation results are presented in Section 3, with a Discussion including limitations following in Section 4. The Long-Term Monitoring Strategy, along with cost estimate for DFO implementation, is presented in Section 5.

# 2 Methods

## 2.1 Study Area

The Basin Head Marine Protected Area (MPA) is located near the Northeastern tip of PEI. The MPA was subdivided into three major Irish moss beds: Fireweed, Main, and Corduroy, as identified by DFO (Figure 2.1). The study areas were protected by a high relief hill and overhanging trees along the north bank which presented challenges for UAV and GPS data collection. The inlet is sheltered by a wide dune system and opens to the Southern Gulf of St. Lawrence via a narrow (~10 m) inlet. Predicted tides are best represented by the Canadian Hydrographic Service (CHS) at Souris, PEI, ~10 km southwest of Basin Head, but tidal stage at Basin Head is known to lag tidal stage at Souris by between 1 to 2 hours. Water depth at low tide is ~1 m and slack tide is brief.

As the Basin Head estuary is known to have poor water clarity due to suspended sediment, Irish moss detection surveys were planned to occur during the lowest annual tides. DFO identified two optimal survey times for the summer of 2018 based on the lowest tides that occurred during daylight hours: June 11 – 18, and August 7 – 14 (Figure 2.2).

Past efforts to monitor Irish moss using remote sensing in Basin Head were challenged by the presence of *Ulva,* a genus of algae that blooms during early summer and floats throughout the estuary, obscuring Irish moss clumps on the seabed. The August low tide period was selected for the Irish moss survey, as *Ulva* would be in decline during that phase of the season.


**Figure 2.1: Basin Head, located near the Northeastern tip of PEI. The inset shows the locations of the three Irish moss bed study areas: Main, Fireweed, and Corduroy. The CHS station at Souris and the weather station at East Point are shown.**

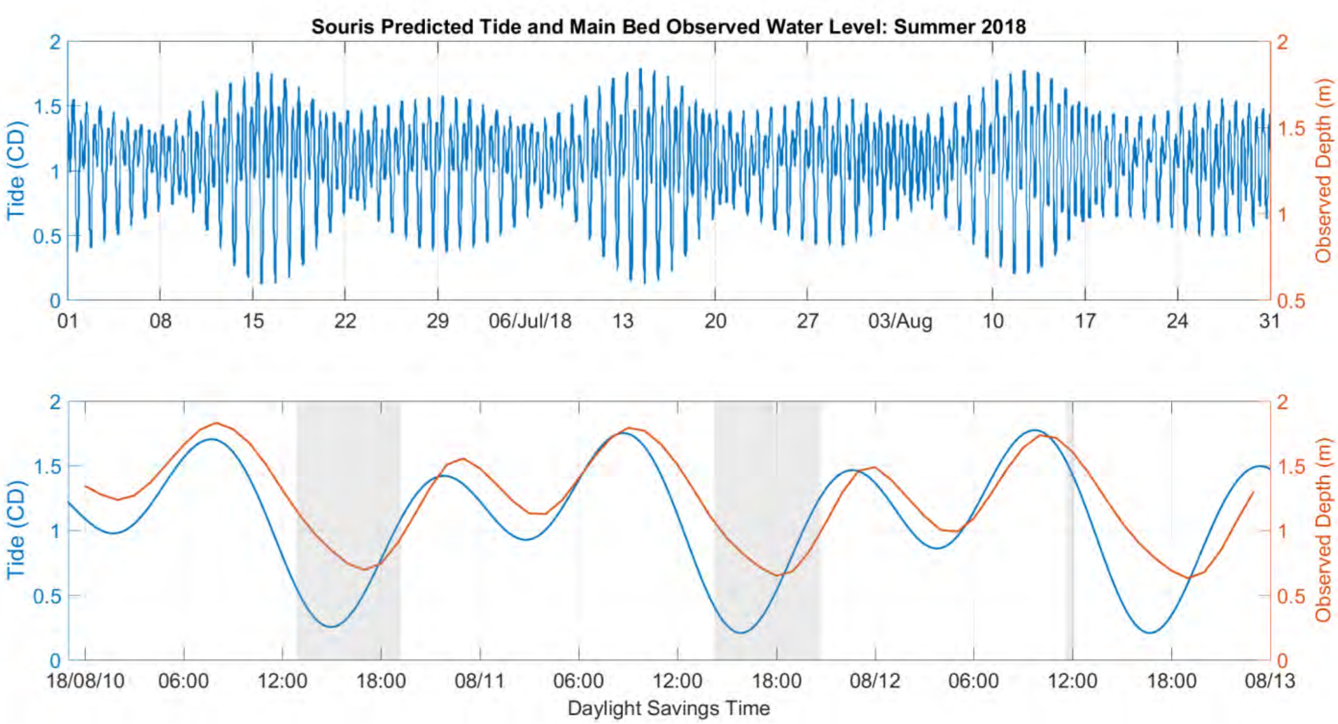



**Figure 2.2: CHS predicted tide for summer 2018 at Souris, PE (top panel). Lowest low tides occurred between June 11 – 18 and August 7 – 14. The lower panel shows predicted tide (blue, left axis) and water depth measured by the DFO pressure sensor from Aug 10 – 13 (orange, right axis). Grey bars represent the duration of the UAV surveys.**

## 2.2 Experimental Procedures

### 2.2.1 Data Collection

NSCC-AGRG completed ten UAV surveys at Basin Head, PEI over three days, from August 10 to August 12, 2018. Collections were focused on the three identified Irish moss beds within Basin Head tidal inlet: Fireweed, Main, and Corduroy. Two UAVs were used for the surveys: a DJI Mavic Pro Platinum and a DJI Matrice 100 (Table 2.1). The Matrice 100 was outfitted with a Zenmuse X5 red, green, blue camera (ZX5), and a MicaSense RedEdge camera that was used to collect RGB, near infrared (NIR), and red edge bands for a large overview survey. The Mavic Pro was equipped with an RGB visible spectrum camera.

**Table 2.1: Summary of UAVs and sensors used in Irish moss survey.**

| UAV Model | Camera | Video | Stills | Bands |
|---|---|---|---|---|
| Matrice 100 | Zenmuse X5 | 4k | 16 MP | 3: R, G, B |
| | MicaSense RedEdge | N/A | 12 MP | 5: R, G, B, red-edge, near-IR |
| Mavic Pro | DJI camera | 4k | 12 MP | 3: R, G, B |

UAV surveys were planned using two free software packages: DroneDeploy was used to plan Mavic flights, and DJI Ground Station Pro was used to plan flights for the Matrice 100. Both software packages were free for standard use (including flight planning) and offered in app purchases for value added product generation. While these flight-planning solutions were virtually the same, both were required due to UAV and controller compatibility limitations. DJI Ground Station Pro was only available for download on an iPad from the iOS App Store and only supported flight planning for DJI Phantom, Matrice, and Inspire Series UAVs. DroneDeploy was available for download from the iOS App Store and Google Play and supported all DJI Phantom, Inspire, Matrice, and Mavic Series UAVs. DroneDeploy was not used to plan the Matrice flights due to an inefficiency in data collection caused by the way the software handles UAV speed adjustments while capturing photos. In general, DroneDeploy required 20-30% more battery power compared to DJI Ground Station Pro when collecting over the same extent. Both software packages used the same collection principle when planning UAV flights where the user was instructed to draw a polygon area of interest (AOI) on a basemap, specify the survey altitude, and enter basic collection parameters including speed, overlap, and line direction.

Ten UAV surveys were completed under a variety of conditions to assess best practices for future collections (Table 2.2). Three overview surveys were completed for the entire Basin Head site, and each sub-area was surveyed in detail multiple times: Fireweed (n=2), Main (n=3), and Corduroy (n=2). Weather observations were obtained from Environment and Climate Change Canada's (ECCC) East Point, PE, weather station located ~10 km Northeast of Basin Head for August 8 -13, showing UAV surveys as vertical grey bars (Figure 2.3). The East Point station recorded daily rainfall, and hourly wind speed, direction, and temperature.

**Table 2.2: Information for each UAV flight completed at Basin Head, PEI. Altitude values were measured as approximate height from ground. Tidal stage is represented by the following acronyms: HT = High Tide, LT = Low Tide, MT = Mid-tide and F = Falling, R = Rising, S = Slack. Tidal stage at Basin head was extracted from measured water depth in Main Bed, collected with a DFO pressure sensor. Cloud conditions were noted on location during each survey, and average wind speed was taken from ECCC hourly data at East Point, PEI. Duration (min) is the approximate total flying time taken to complete each survey. Rows in green highlight surveys that were flown after *Ulva* cleaning had been completed.**

| Area | Sensor | Alt. (m) | Tidal stage (Basin Head) | Cloud Conditions | Wind Speed (km/h) | Photo Targets | Date/Start Time (ADT) | Duration (min) |
|---|---|---|---|---|---|---|---|---|
| Fireweed | Mavic | 40 | LTR | Variable cloud/light | 7 | Plywood, Cinder | 2018/8/10 18:27 | 21 |
| Fireweed | ZX5 | 50 | LTS | Variable cloud/light | 15 | Plywood, Cinder, Posts | 2018/8/10 17:17 | 21 |
| Main | Mavic | 40 | MTF | Clear | 28 | Plywood | 2018/8/11 14:13 | 22 |
| Main | Mavic | 30 | LTR | Clear, shadows | 3 | Plywood, Cinder | 2018/8/11 19:06 | 18 |
| Main | ZX5 | 40 | LTS | Clear | 3 | Plywood, Cinder | 2018/8/11 18:31 | 21 |
| Corduroy | Mavic | 95 | MTF | Overcast | 21 | Plywood, Cinder | 2018/8/10 12:51 | 28 |
| Corduroy | ZX5 | 50 | LTF | Variable cloud/light | 23 | Plywood, Cinder, Posts | 2018/8/10 14:55 | 12 |
| Entire Site | Mavic | 50 | MTF - LTR | Overcast | 14 - 22 | Plywood, Cinder | 2018/8/10 13:39 | 55 |
| Entire Site | Mavic | 70 | LTR | Clear, shadows | 6 | Plywood, Cinder | 2018/8/11 19:33 | 23 |
| Entire Site | RedEdge | 130 | MTR | Clear, shadows | 8 | N/A | 2018/8/11 19:54 | 29 |

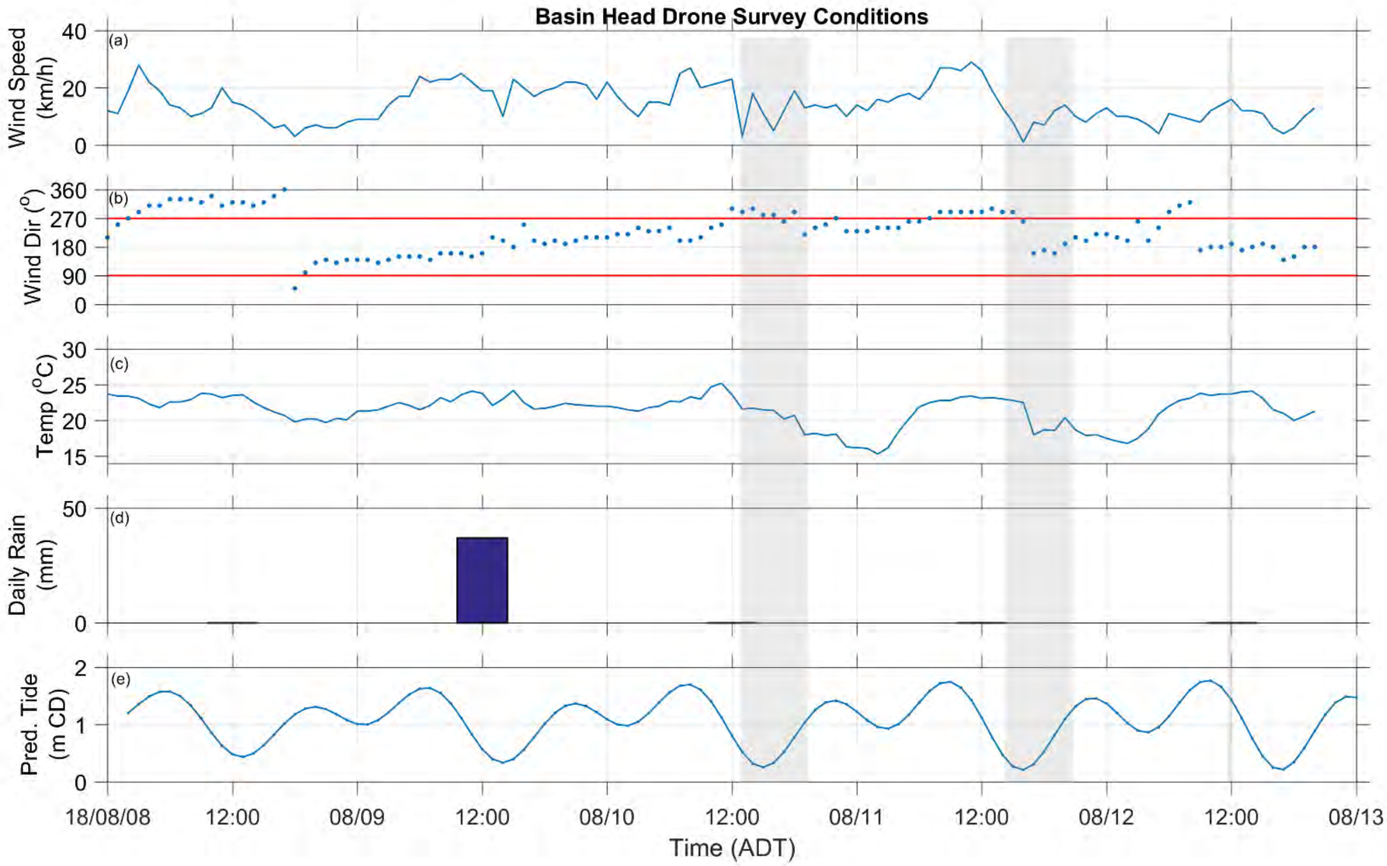



**Figure 2.3: Weather and tidal conditions for August 8 to 13, preceding and during UAV surveys. Hourly data from ECCC East Point: (a) wind speed, (b) wind direction, (c) temperature. ECCC daily data from East Point: (d) rainfall. (e) CHS predicted tide at Souris (Basin Head lag time is not included). Grey blocks represent periods of UAV flights on each day of collection, August 10, and 11.**

### 2.2.2 Ground Truth Data Collection

Ground truth GPS data were collected to assess the positional accuracy of the collected imagery and to validate the results of classification routines (Figure 2.4). GPS points of photo targets were collected throughout the study areas to use in aerial imagery georeferencing procedures discussed in detail in the following sections (Figure 2.5, Figure 2.6, and Figure 2.7). Varying photo target types were used throughout the surveys to assess best practices (Table 2.2). Several 0.5 $m^2$ black and white plywood targets were positioned on land along the edges of each survey area and yellow and pink painted cinder blocks were placed within the channel. Smaller cardboard targets were placed on posts within the channel, on the seabed for the Corduroy surveys, and floating on top of the water for the Fireweed surveys.

**Figure 2.4: Fieldwork activities including GPS point collection of photo targets. Yellow and pink cinder block target is visible in the middle of the photo, below the water surface. *Ulva* cleaning activities are being completed by DFO team members in the background.**


**Figure 2.5: Photo target locations around the Fireweed bed. Three types of targets were used: plywood checkerboards on the shore, underwater cinder blocks, and posts extending out of the water from the seabed.**

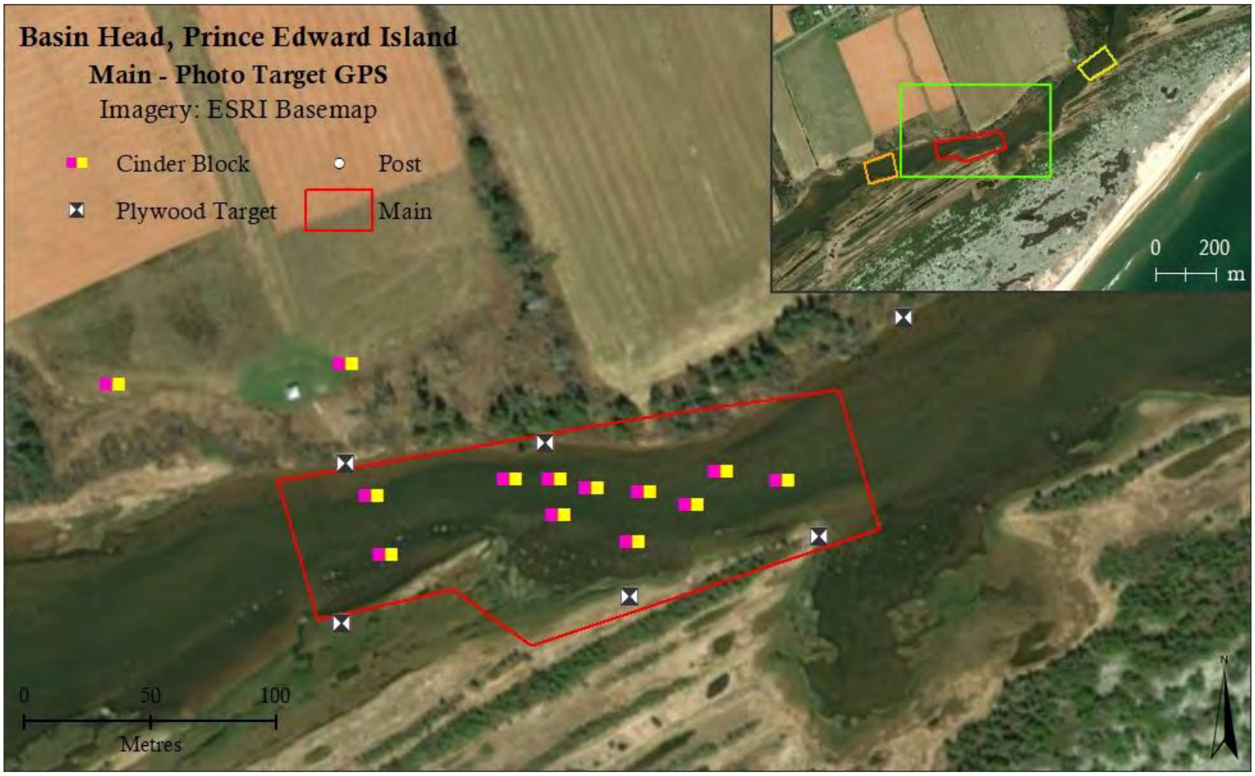



**Figure 2.6: Photo target locations around the Main bed. Two types of targets were used: plywood checkerboards on the shore and underwater cinder blocks.**

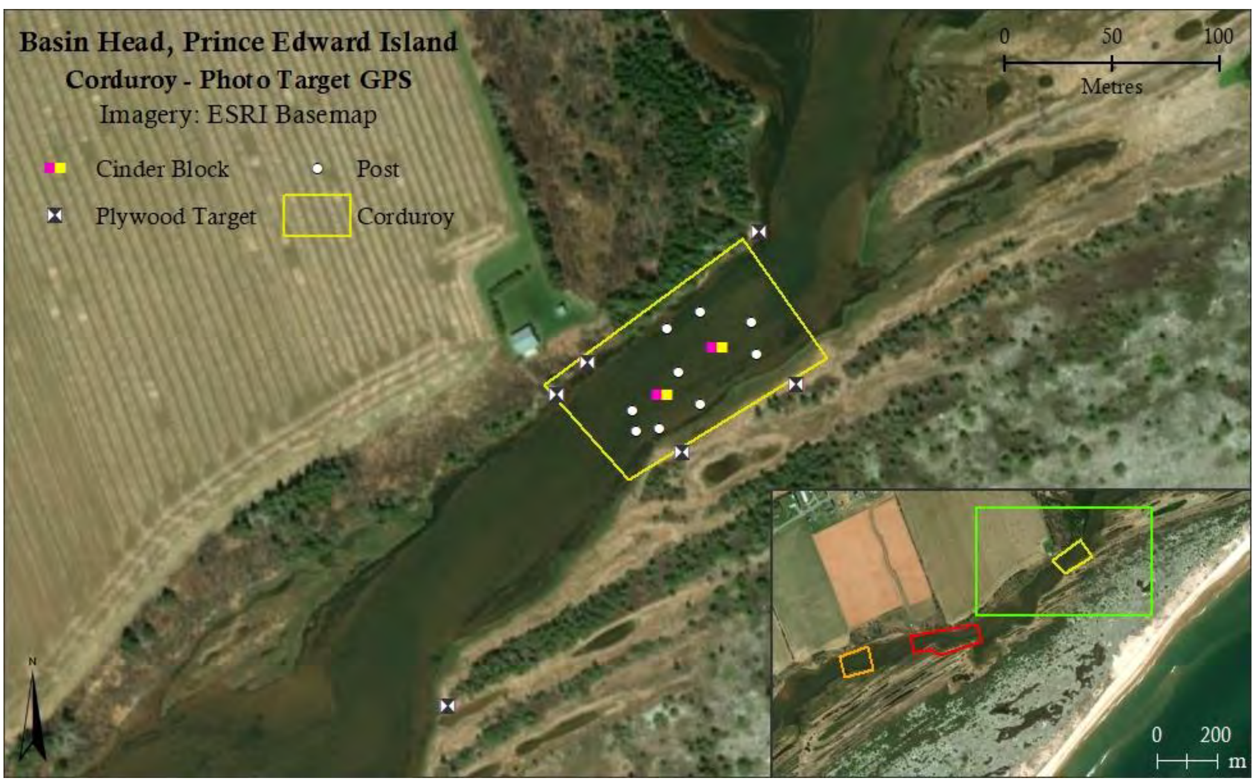



**Figure 2.7: Photo target locations around the Corduroy bed. Three types of targets were used: plywood checkerboards on the shore, underwater cinder blocks, and posts extending out of the water from the seabed.**

The survey plan was to use the Leica SmartNet active control network to obtain real-time kinematic GPS corrections, but due to lack of cellular service, Leica SmartNet was not obtainable and post processing of target locations was required to achieve survey grade accuracy. Survey grade GPS accuracy was unattainable in Corduroy due to poor satellite coverage caused by high relief and overhanging trees. Collected points and their accuracies are outlined in Table 2.3.

**Table 2.3: Summary of photo target GPS points and their achieved accuracies with post processing.**

| Area of Interest | Points Collected (#) | Avg. Standard Deviation X (m) | Avg. Standard Deviation Y (m) | Avg. Standard Deviation Z (m) |
|---|---|---|---|---|
| Fireweed | 15 | 0.003 | 0.005 | 0.009 |
| Main | 16 | 0.004 | 0.006 | 0.012 |
| Corduroy | 16 | 1.287 | 1.972 | 3.490 |

## 2.3 Photogrammetric Processing

Agisoft PhotoScan Professional v1.4.4 was used for photogrammetry and georeferencing of the imagery. For a detailed description of how to use Agisoft software to import drone imagery and generate orthomosaic and Digital Surface Model (DSM) products please refer to the ancillary report: *Agisoft PhotoScan Professional Step-by-Step Guide*. Following the methods described in the Agisoft Guide, each UAV flight was processed separately to produce ten sets of orthomosaic and DSM products. Table 2.2 outlines which photo targets were used for each survey to use in georeferencing. Note that the MicaSense RedEdge camera overview was not flown with photo target control; in this case, control was established by selecting photo identifiable points from overlapping high-resolution surveys. Orthomosaics and DSMs were exported from Agisoft for each survey in North American Datum of 1983 (NAD83), Canadian Spatial Reference System (CSRS) Epoch 2010, UTM Zone 20N and Canadian Geodetic Vertical Datum of 1928 (CGVD28).

## 2.4 Irish Moss Classification

Automated processes were developed to classify Irish moss using UAV survey data. These techniques were applied to imagery collected by NSCC-AGRG as well as DFO (Cairns, 2018) using both Trimble eCognition and ESRI ArcMap software suites. Orthomosaics were selected for classification based on data quality, and additional elevation products were constructed before classification took place in eCognition and ArcMap, as described below.

### 2.4.1 Orthomosaic Selection

Images in which Irish moss was clearly visible were required so that training areas for the classification could be drawn with confidence. In most cases, Irish moss was not easily identified due to poor water clarity, distortion of light with depth, and water surface disturbances that caused sun glint. Colour degradation at increasing depths and colour variation due to shifting light levels increased the difficulty of classification using only spectral data. To address these issues, elevation data were incorporated into the classification when possible in the form of normalized height models.

### 2.4.2 Normalized Height Model Construction

Normalized Height Models (NHM) were created to quantify the lumpy nature of Irish moss clumps. Standard DSMs capture the absolute elevations of objects in an area, where NHMs capture the height above ground objects extend by normalizing for the elevation of ground points surrounding the object. NHMs were developed by generating several DSM outputs from Agisoft at varying resolutions and smoothing factors. A native resolution DSM was produced to capture the full relief detail within the AOI. A second DSM was produced at a resolution ten times coarser than the native resolution using a minimum cell value binning schema. This process effectively smoothed the finer elevation features on the surface to represent the base terrain topography. The coarse surface model was smoothed further using kernel filters to remove larger elevated features still present within the model. Filtering was a two-step process where a circular 2x2 minimum filter was passed over the raster to flatten the remaining features, then a larger circular 3x3 mean filter was passed over the raster to correct any unnatural looking terrain artifacts that the first filter may have created. The coarse DSM was resampled to match the native resolution of fine DSM surface model and subtracted to produce the final NHM.

### 2.4.3 ArcMap Classification

General image classification techniques in ArcGIS Desktop 10.6.1 for the purpose of this project are outlined in Image Classification Using the ArcGIS Spatial Analyst Extension (ESRI, 2018). Additional techniques relevant to the classification of Irish moss in UAV imagery are described below.

Pixel-based classification of imagery and elevation data was completed in ArcMap using the Image Classification toolbar. Imagery and elevation data were combined for the classification process. Elevation rasters were stretched to match the bit depth of the imagery (8-bit unsigned) using the ArcMap Copy Raster tool and were then merged to their respective RGB orthomosaics using the ArcMap Composite Bands tool. Each 8-bit multiband raster was then selected in the Image Classification toolbar for training area selection and classification. Training areas were selected for Irish moss features only and separate groups of training areas were required for every spectral variation of the feature. For example, Irish moss had a different spectral response in shallow water than in deep water and training areas were constructed for each of these circumstances. Imagery with highly variable light levels required many training area sets. Since Irish moss (and *Ulva* in some cases) were the only classes of interest, a confidence rejection fraction was used to ensure pixels with poor class membership certainties were classified as null. If the confidence rejection fraction was not implemented, or set too low, there would be no null values in the output and the entire scene would have been classified as Irish moss or *Ulva*. Once all appropriate training areas had been delineated and saved, the standard ArcMap supervised maximum likelihood classification algorithm was run. Results of the ArcMap classification were exported as raster layers for further analysis.

#### 2.4.4 eCognition

The object-based image classification techniques used in Trimble eCognition for this project are outlined in a step-by-step guide in an ancillary report: *Trimble eCognition Developer Step-by-Step Guide*. Imagery and elevation data were imported into eCognition where a rule set was developed to segment the data into homogeneous features. The NHM was segmented using a 2 cm elevation threshold where objects that were 2 cm or more above the ground were identified as 'clumps'. Imagery was segmented using the Multiresolution Segmentation algorithm to create homogenous segments based on spectral values. These segments were restricted to minimum and maximum sizes based on image scales using minimum pixel coverage (4 $cm^2$) and compactness coefficient which limited the maximum segment size to roughly 0.5 $m^2$. Classes were created for Irish moss and *Ulva* and a training set of segmented inputs were sorted into the appropriate class by a technician to train the object-based classification routine. The statistical attributes of the segmented inputs were then calculated using the Feature Space Optimization function with a nearest neighbour technique. The object-based classification was executed once sufficient training data and segmentation statistics were computed. Results of the classification were exported from eCognition as polygon features for further analysis.

## 2.5 Irish Moss Coverage Estimates

Classification results were quantified as coverage estimates by calculating the area each class covered within the three major areas of interest. Area calculations were done within ArcMap using the Calculate Geometry tool for eCognition polygon products, and number of classified pixels multiplied by the pixel area for ArcMap Maximum Likelihood raster products.

## 2.6 Data Validation

To validate the image classification results, quadrat photos and GPS points of their locations were collected at representative vegetation/ground types within the Main and Corduroy beds (Figure 2.8 and Figure 2.9). The Fireweed bed did not have points collected due to time limitations. Points were collected to identify Irish moss, *Ulva*, and mud. GPS survey points previously collected by DFO to monitor Irish moss and mussel clump locations throughout the study area were provided to validate classification results.

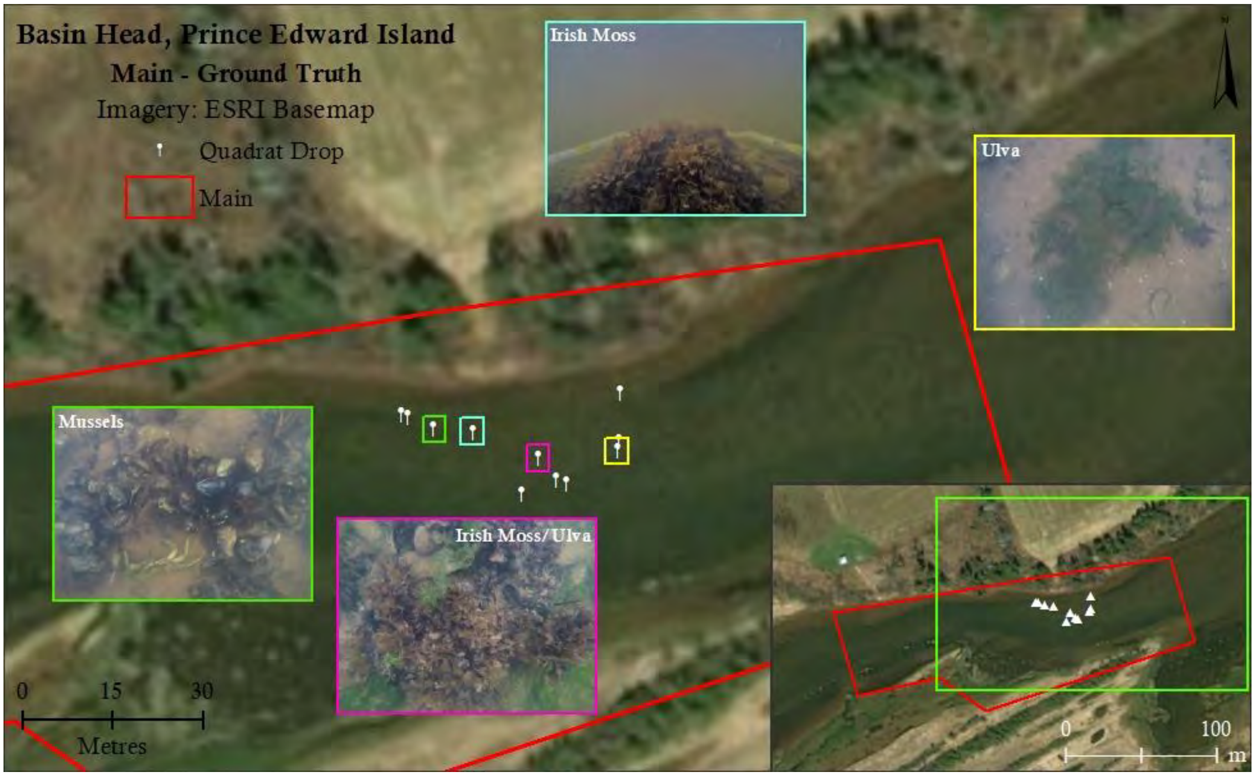



**Figure 2.8: Location of quadrat samples within the Main bed study area.**


**Figure 2.9: Location of quadrat samples within the Corduroy study area.**

# 3 Results

## 3.1 Data Products

Orthophoto mosaics and DSMs were successfully created for all drone flights and were stored in TIFF format. In the majority of cases, imagery suffered from high spectral variance due to water surface effects and shading. DSM products suffered from poor triangulation in deep channels and areas with poor surface conditions (Figure 3.1 to Figure 3.10). Poor elevation model results appear as smooth gaps where interpolation has occurred, or a series of rough spikes where photogrammetric triangulation became unstable.

### 3.1.1 Accuracy Evaluation

Total error for each survey was recorded from the Agisoft processing reports for each flight and was calculated using Ground Control Point (GCP) error values. Total error is an assessment of spatial accuracy and represents how much each product (image or DSM) differs from the GCPs. Product resolution was calculated by Agisoft using flight altitude, sensor, and platform.

**Table 3.1. Overview of photogrammetric product (orthomosaics and elevation models) accuracy and resolution for each survey. Resolution refers to the image and model pixel size (ground sample distance in meters).**

| Area | Sensor | Alt. (m) | Resolution (m) | Photo Targets | Total Error (m) |
|---|---|---|---|---|---|
| Fireweed | Mavic | 40 | 0.015 | Plywood, Cinder | 0.12 |
| Fireweed | ZX5 | 50 | 0.015 | Plywood, Cinder, Posts | 0.28 |
| Main | Mavic | 40 | 0.015 | Plywood | 0.07 |
| Main | Mavic | 30 | 0.010 | Plywood, Cinder | 0.49 |
| Main | ZX5 | 40 | 0.015 | Plywood, Cinder | 0.29 |
| Corduroy | Mavic | 95 | 0.035 | Plywood, Cinder | 0.54 |
| Corduroy | ZX5 | 50 | 0.015 | Plywood, Cinder, Posts | 2.20 |
| Entire Site | Mavic | 50 | 0.020 | Plywood, Cinder | 7.57 |
| Entire Site | Mavic | 70 | 0.025 | Plywood, Cinder | 2.37 |
| Entire Site | RedEdge | 130 | 0.10 | N/A | 1.95 |

### 3.1.2 Overview Surveys

Surveys of the entire study area, including all three beds were completed using the DJI Mavic and DJI Matrice (outfitted with the RedEdge camera) UAVs. Variable cloud conditions during the August 10$^{th}$ Mavic survey caused significant light level variations within the mosaic, and the presence of wind/waves resulted in areas of glint (Figure 3.1). Lack of quality in the imagery resulted in a poorly resolved elevation model, especially in areas of deeper water. This survey had the highest total residual error as reported by Agisoft PhotoScan (7.57 meters).

Although flown at a higher altitude resulting in a slightly lower image resolution of 25 mm, the second survey of the entire study area with the Mavic produced higher quality imagery with regard to light level variation and water clarity/seabed visualization. The DSM was also of higher quality, with less noise in deeper areas of the channel, and total residual error of both products (2.37 m) was improved compared to the first survey. Skies were clear during the flight, but significant shadows were present due to evening solar angle and can be seen in the image mosaic shown in Figure 3.2.

Figure 3.3 shows the results of the overview survey completed with the Matrice 100 UAV and MicaSense RedEdge multispectral camera. Due to the lower resolution capabilities of the camera, and high flight altitude, this survey had the lowest resolution at 10 cm. Skies were clear during the flight, but automatic radiation normalization of the camera system resulted in some uneven light levels throughout the imagery. Possibly due to lower resolution of the imagery, the elevation model did not resolve in the channel, resulting in a noisy DSM that was unsuitable for further analysis. The products had a reported total residual error of 1.95 m.

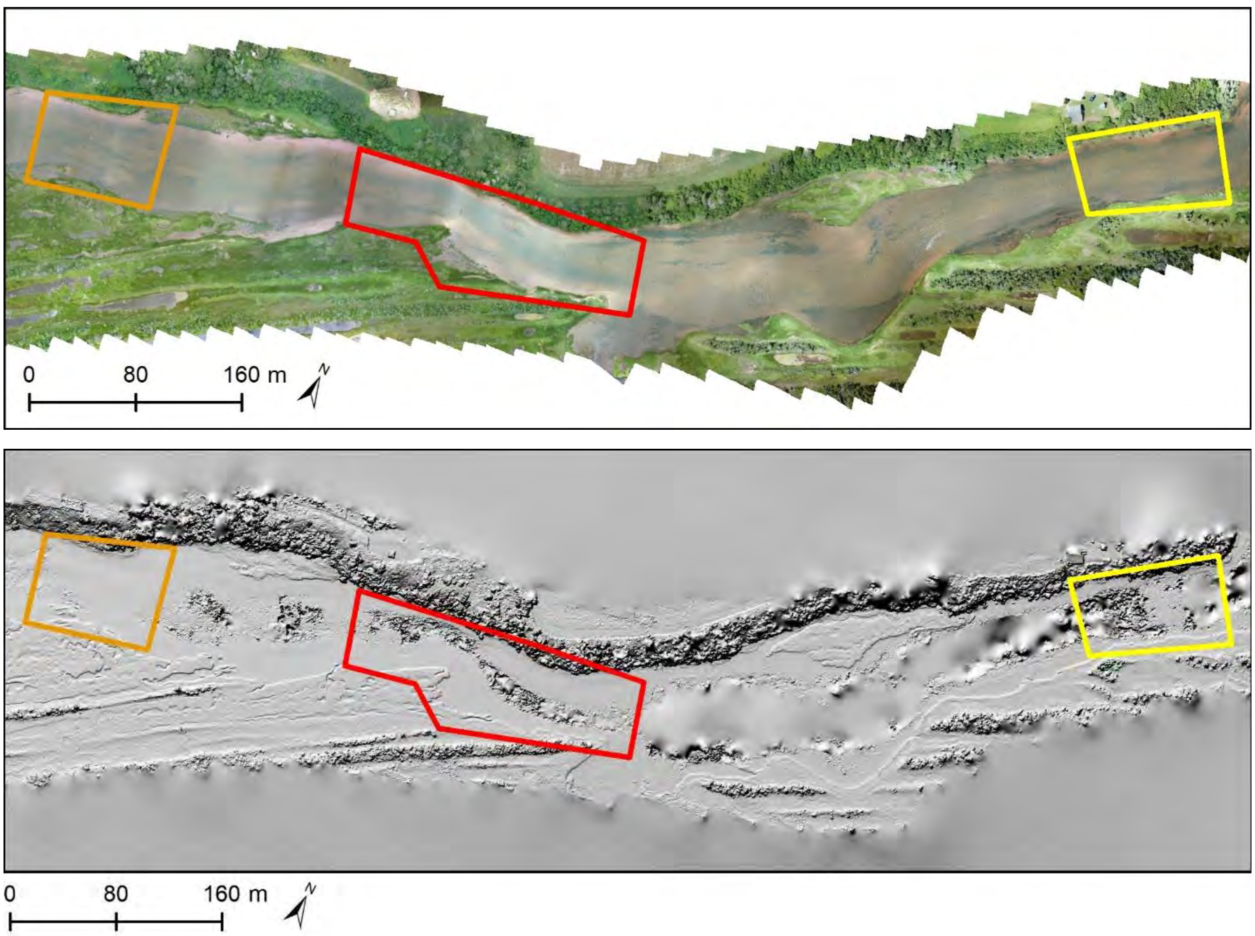



**Figure 3.1: Mavic Orthomosaic (A) and DSM hillshade (B) of the entire study area, 20 mm resolution. Survey was completed on August 10, 2018 at 13:39 (ADT) during a falling mid tide with a flight altitude of 50 m. Orange polygon represents Fireweed study area boundaries, red represents Main and yellow represents Corduroy.**

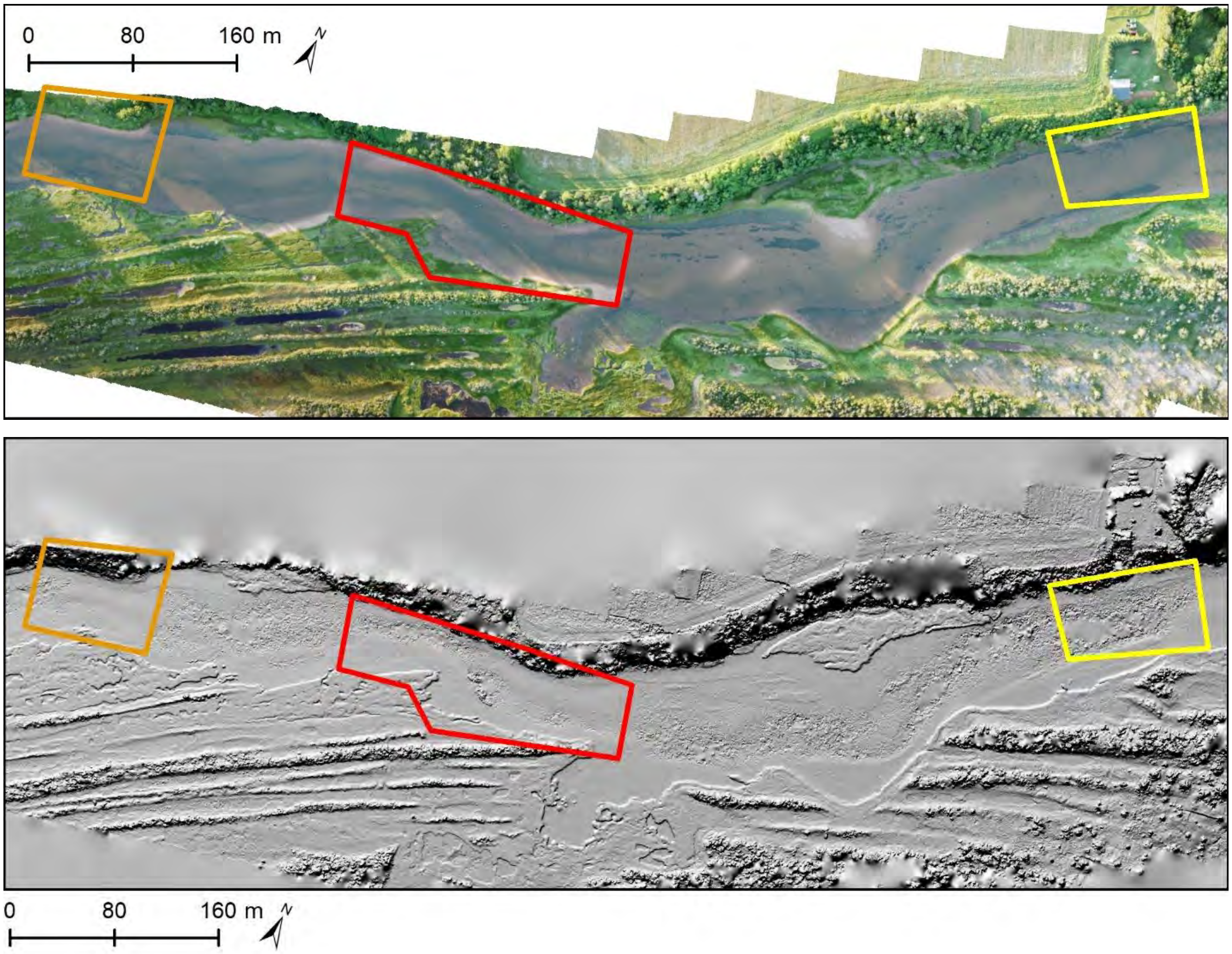



**Figure 3.2: Mavic Orthomosaic (A) and DSM hillshade (B) of the entire study area, 25 mm resolution. Survey was completed on August 11, 2018 at 19:33 (ADT) during a rising mid tide with a flight altitude of 70 m. Orange polygon represents Fireweed study area boundaries, red represents Main and yellow represents Corduroy.**

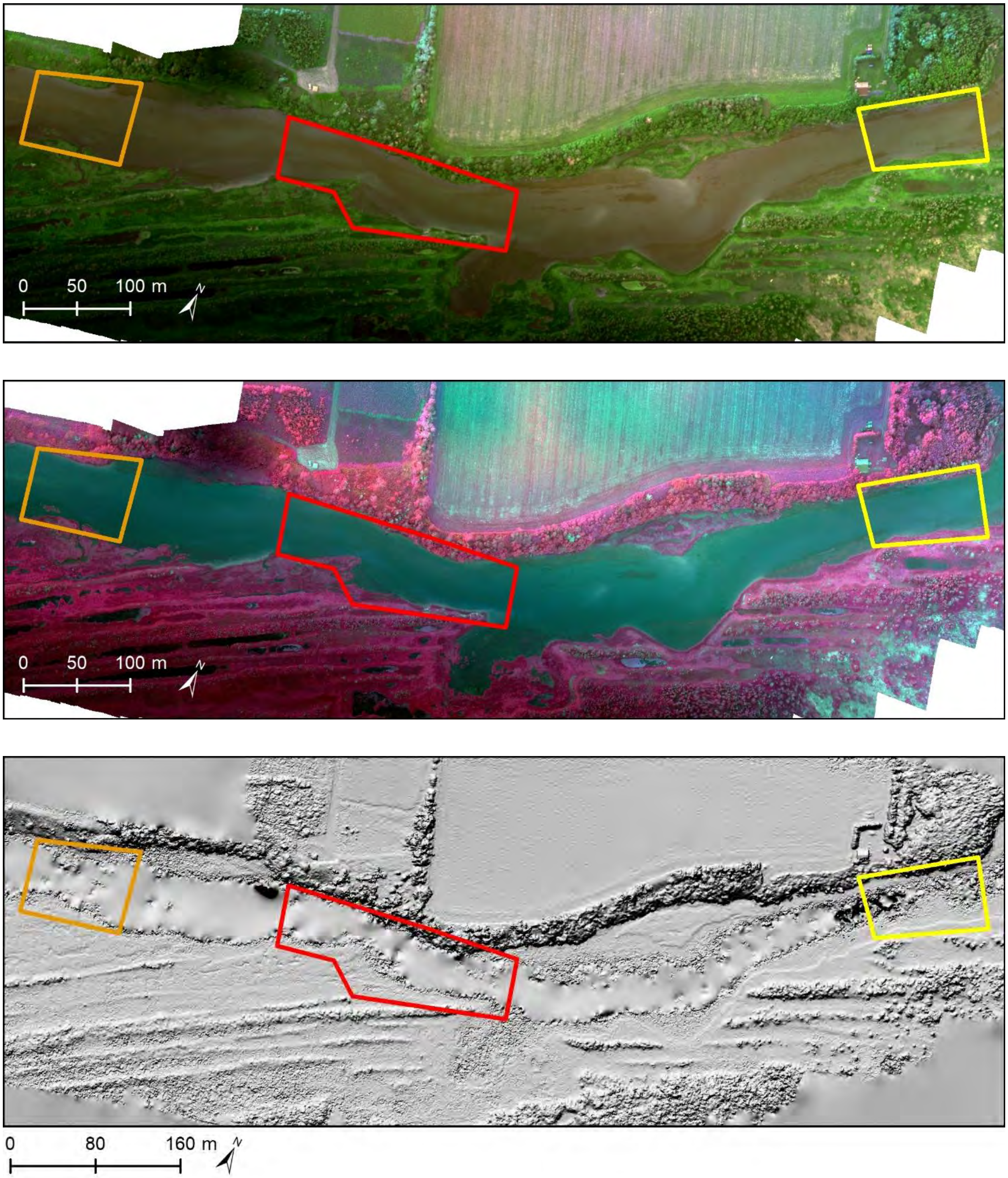



**Figure 3.3: Red Edge RGB Orthomosaic (A), Red Edge, Red, Green colours composite (B) and DSM hillshade (C) of the entire study area, 10 cm resolution. Survey was completed on August 11, 2018 at 19:54 (ADT) during a rising mid tide with a flight altitude of 130 m. Orange polygon represents Fireweed study area boundaries, red represents Main and yellow represents Corduroy.**

### 3.1.3 Fireweed

Fireweed was surveyed on August 10th with the Mavic (Figure 3.4) and with the Matrice and Zenmuse X5 camera (Figure 3.5). The presence of glint in both surveys caused poor visualization of the seabed, resulting in very poor quality DSMs in the channel area. Variable cloudiness caused light level variations in the Zenmuse X5 imagery, and cloud reflections on the water surface in the Mavic imagery. Both of these surveys had high spatial accuracy, but the Zenmuse X5 survey was slightly lower with a reported total error of 0.28 m compared to 0.12 m from the Mavic survey.

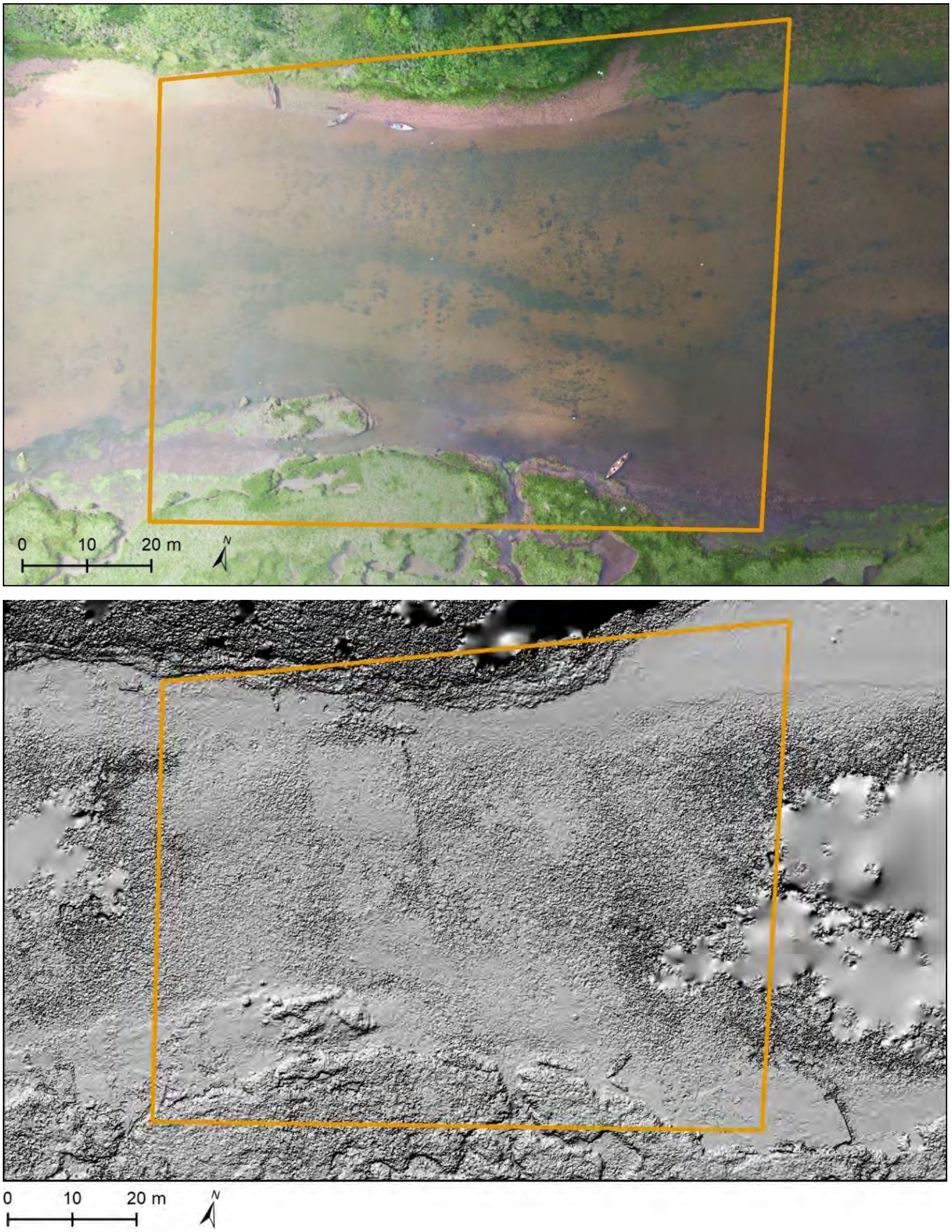



**Figure 3.4: Zenmuse X5 Orthomosaic (A) and DSM hillshade (B) of the Fireweed Irish moss bed, 15 mm resolution. Survey was completed on August 10, 2018 at 17:17 (ADT) during a slack low tide with a flight altitude of 50 m. Orange polygon represents the Fireweed study area boundaries.**

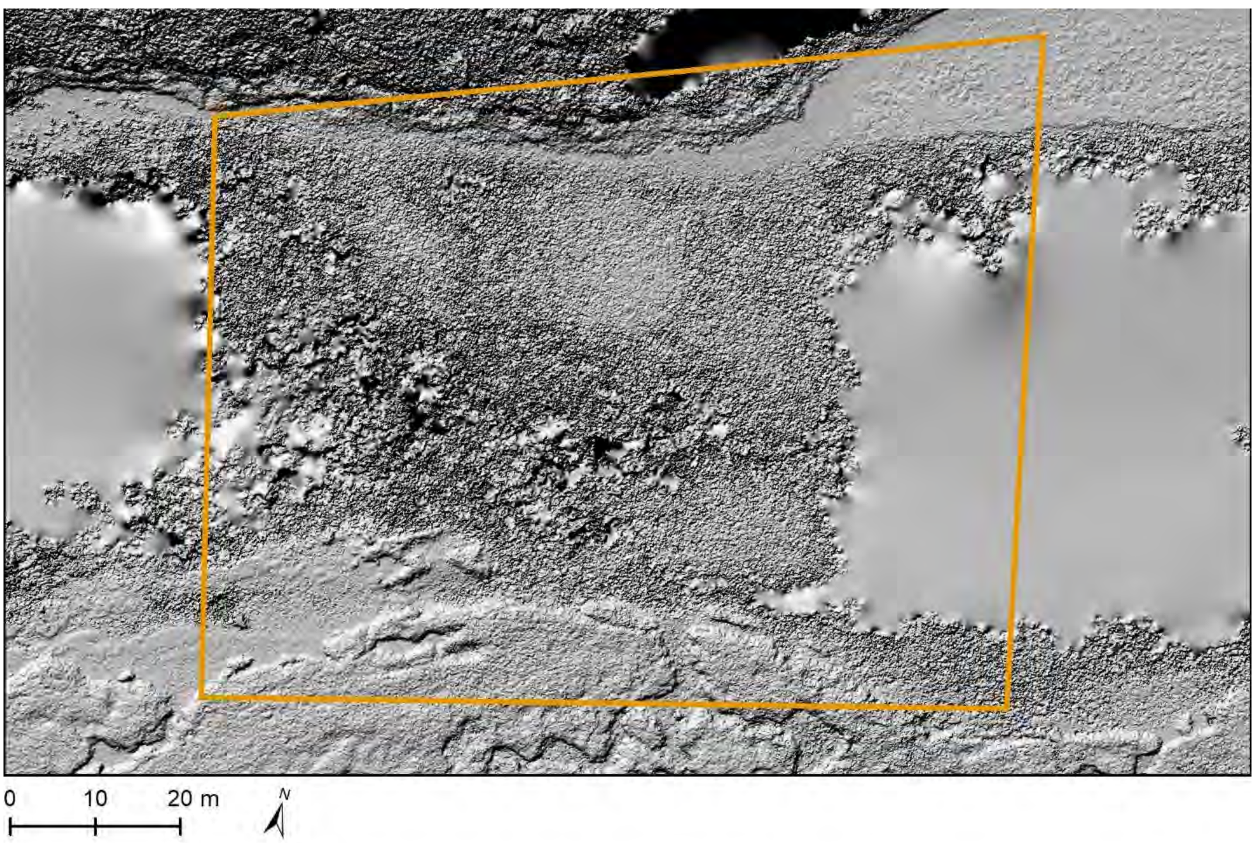




**Figure 3.5: Mavic Orthomosaic (A) and DSM hillshade (B) of the Fireweed Irish moss bed, 15 mm resolution. Survey was completed on August 10, 2018 at 18:27 (ADT) during a rising mid tide with a flight altitude of 40 m. Orange polygon represents the Fireweed study area boundaries.**

### 3.1.4 Main

Main bed was surveyed on August 11th, once with the Matrice and Zenmuse X5 camera, and twice with the Mavic at varying altitudes. Spatial accuracy was comparable between the three flights, with a reported total error of 0.29 m for the ZX5 survey, 0.07 for the 40 m Mavic survey and 0.49 for the 30 m Mavic survey.

The ZX5 survey resulted in high quality imagery, with little to no glint from surface disturbances, and good visualization of the seabed (Figure 3.6). Some shadows were present along the Northern bank due to evening solar angle and tree cover. The DSM was resolved in the majority of the channel, however some signal breakdown in deeper areas caused noise and erroneous data.

The first Mavic survey of Main bed was flown at 40 m altitude (Figure 3.7). This was the least successful survey of Main bed, due to wind and sun glint, and produced a very noisy DSM that did not resolve the majority of the channel. Alternatively, the second survey of Main bed, flown at 30 m altitude, resulted in very high quality imagery with a resolution of 10 mm (Figure 3.8). Unfortunately, evening solar angle and tree cover caused significant shadowing and loss of spectral information around the Northern bank. This survey produced the highest quality elevation model that highlighted Irish moss clumps, aside from a deep area in the Northeastern portion of the channel.

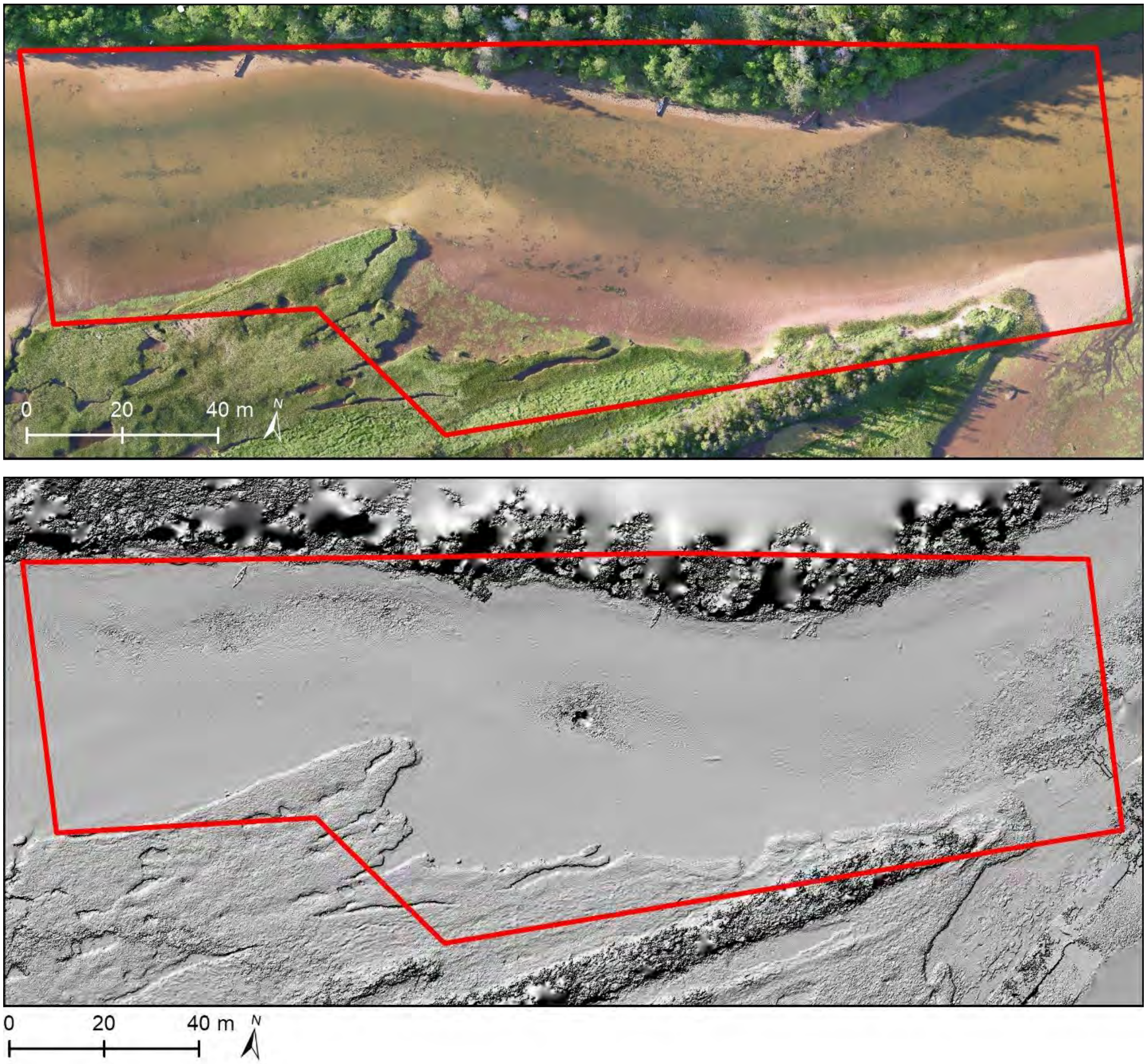



**Figure 3.6: Zenmuse X5 Orthomosaic (A) and DSM hillshade (B) of the Main Irish moss bed, 15 mm resolution. Survey was completed on August 11, 2018 at 18:31 (ADT) during a rising low tide with a flight altitude of 40 m. Red polygon represents the Main study area boundaries.**

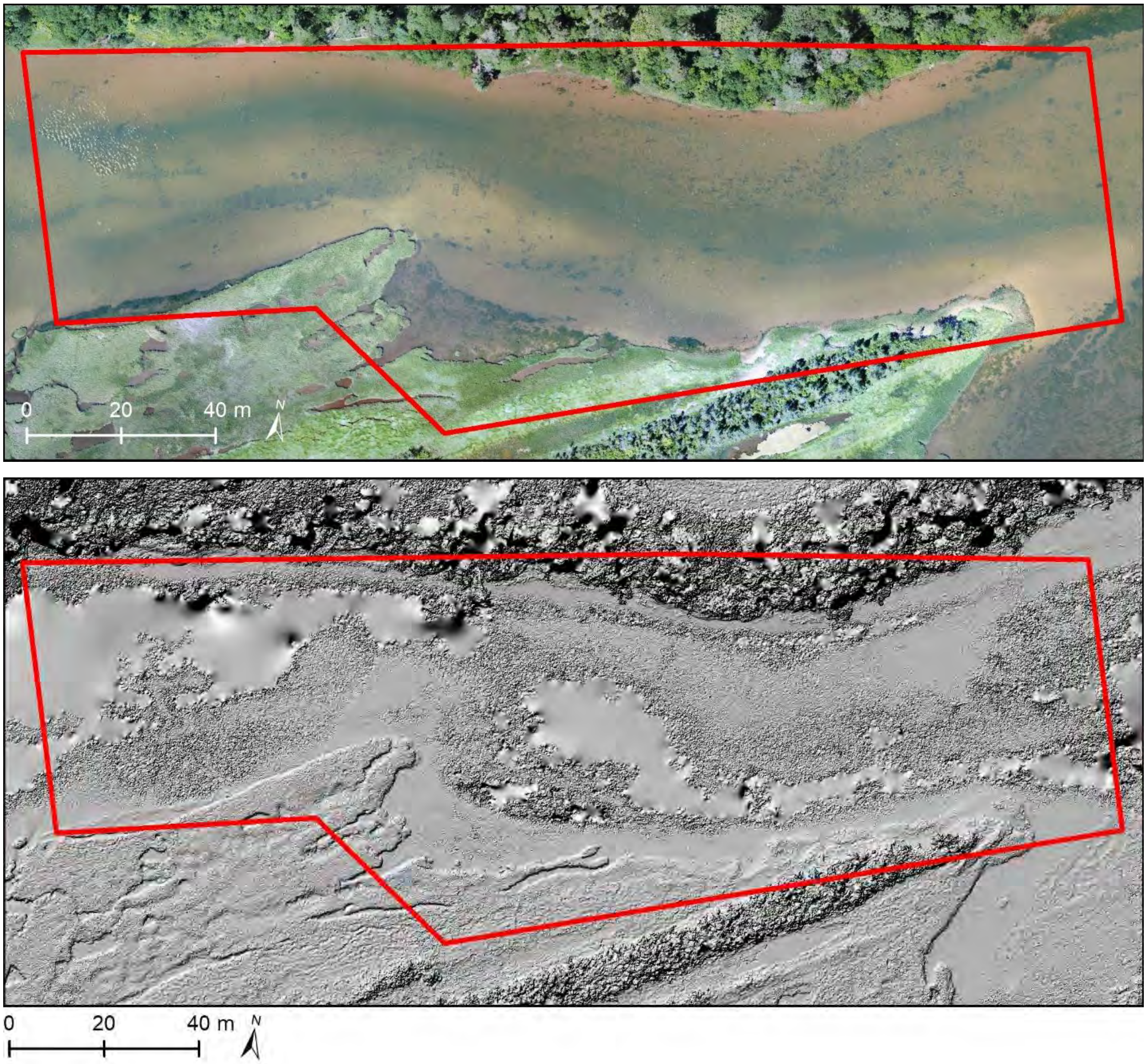



**Figure 3.7: Mavic Orthomosaic (A) and DSM hillshade (B) of the Main Irish moss bed, 15 mm resolution. Survey was completed on August 11, 2018 at 14:13 (ADT) during a falling low tide with a flight altitude of 40 m. Red polygon represents the Main study area boundaries.**

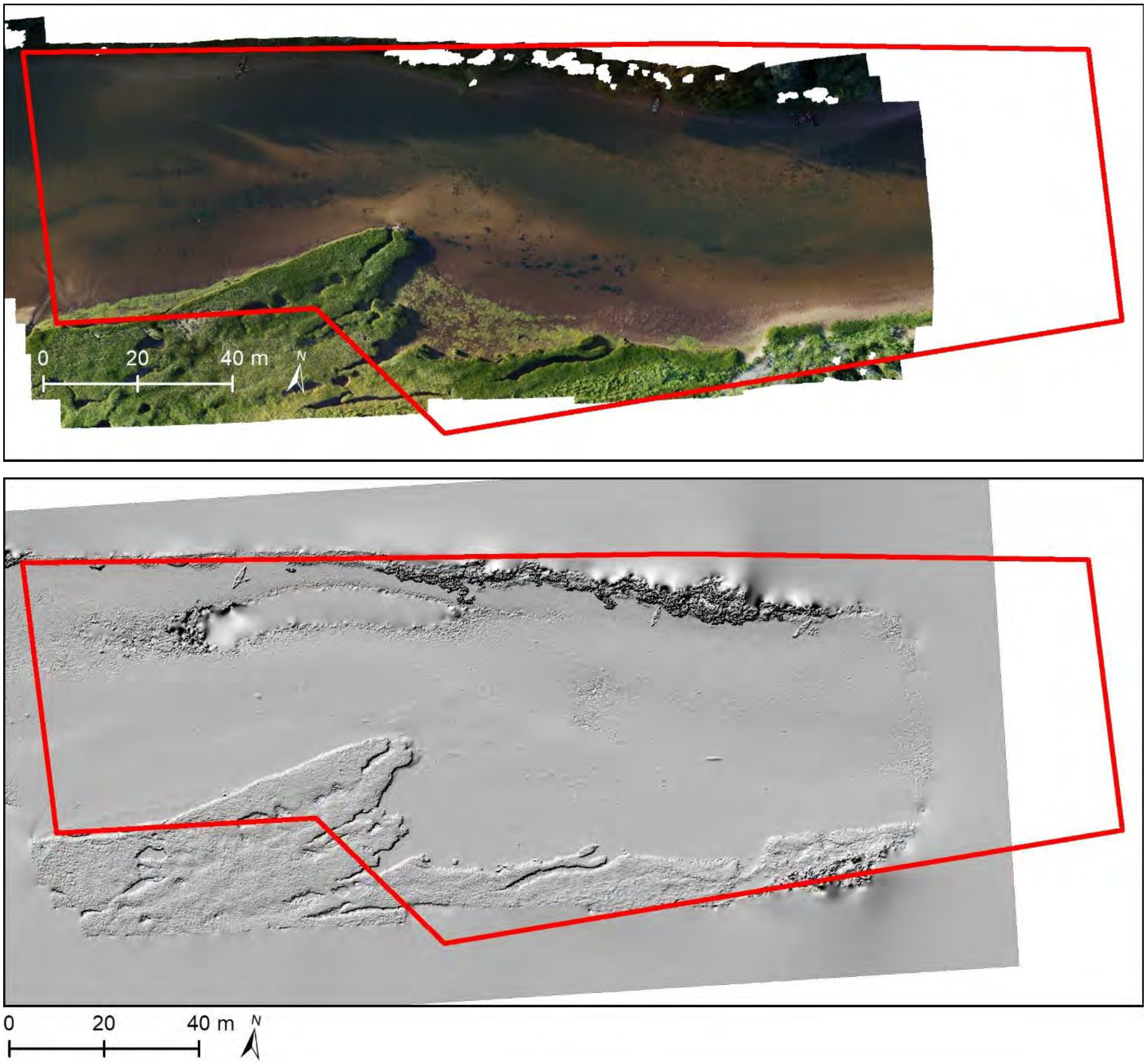



**Figure 3.8: Mavic Orthomosaic (A) and DSM hillshade (B) of the Main Irish moss bed, 10 mm resolution. Survey was completed on August 11, 2018 at 19:06 (ADT) during a rising mid tide with a flight altitude of 30 m. Red polygon represents the Main study area boundaries.**

### 3.1.5 Corduroy

Corduroy bed was surveyed on August $10^{th}$ with the Matrice and Zenmuse X5 (Figure 3.9) and with the Mavic (Figure Figure 3.10). Both surveys had significant wave action and glint issues, as well as poor seabed visualization due to water clarity and/or depth. Due to the issues in image quality, DSMs did not resolve in the channel and the elevation models were unsuitable for analysis. Spatial accuracy was also relatively poor for these products: the ZX5 survey had a reported total residual error of 2.20 m and the Mavic had 0.54 m.

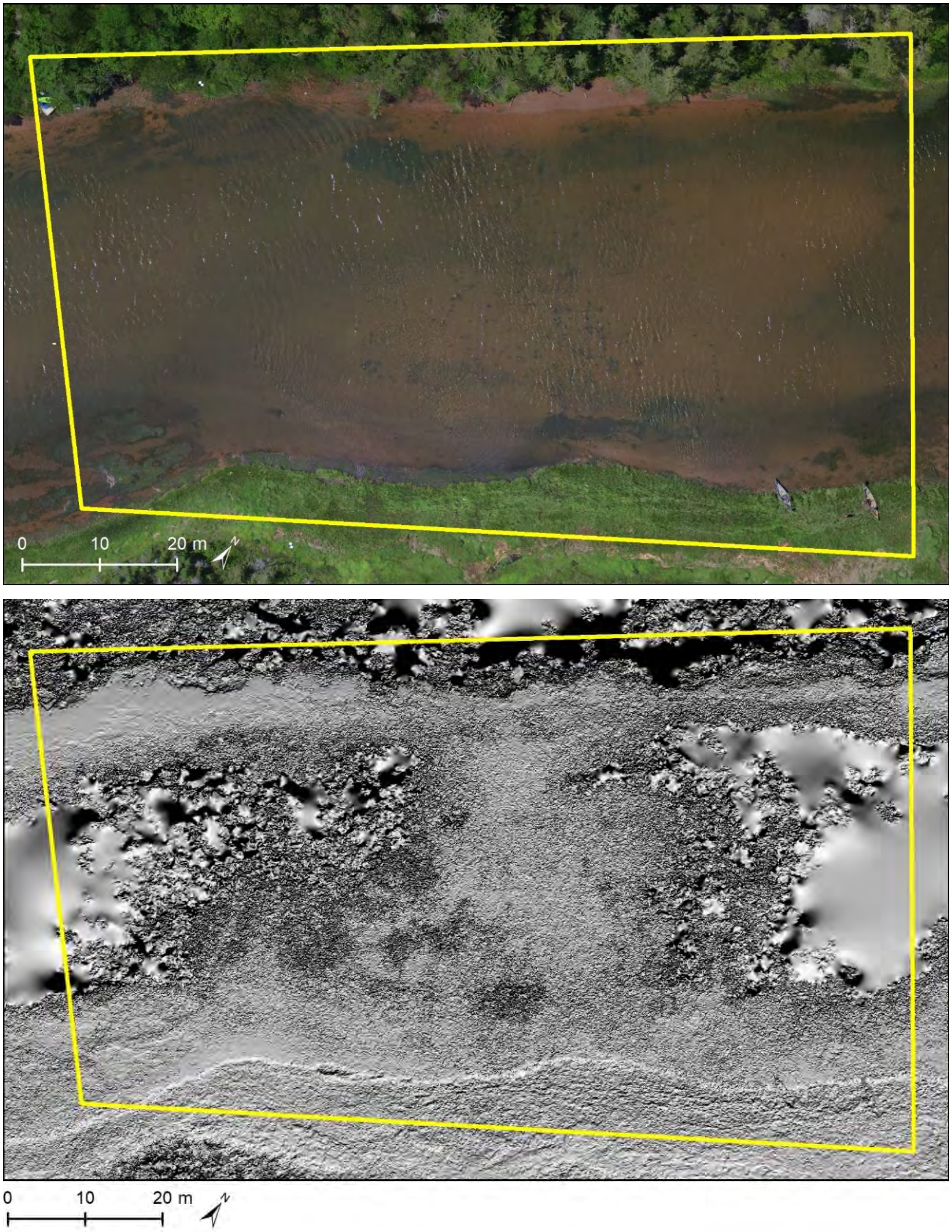



**Figure 3.9: Zenmuse X5 Orthomosaic (A) and DSM hillshade (B) of the Corduroy Irish moss bed, 15 mm resolution. Survey was completed on August 10, 2018 at 14:55 (ADT) during a falling low tide with a flight altitude of 50 m. Yellow polygon represents the Corduroy study area boundaries.**

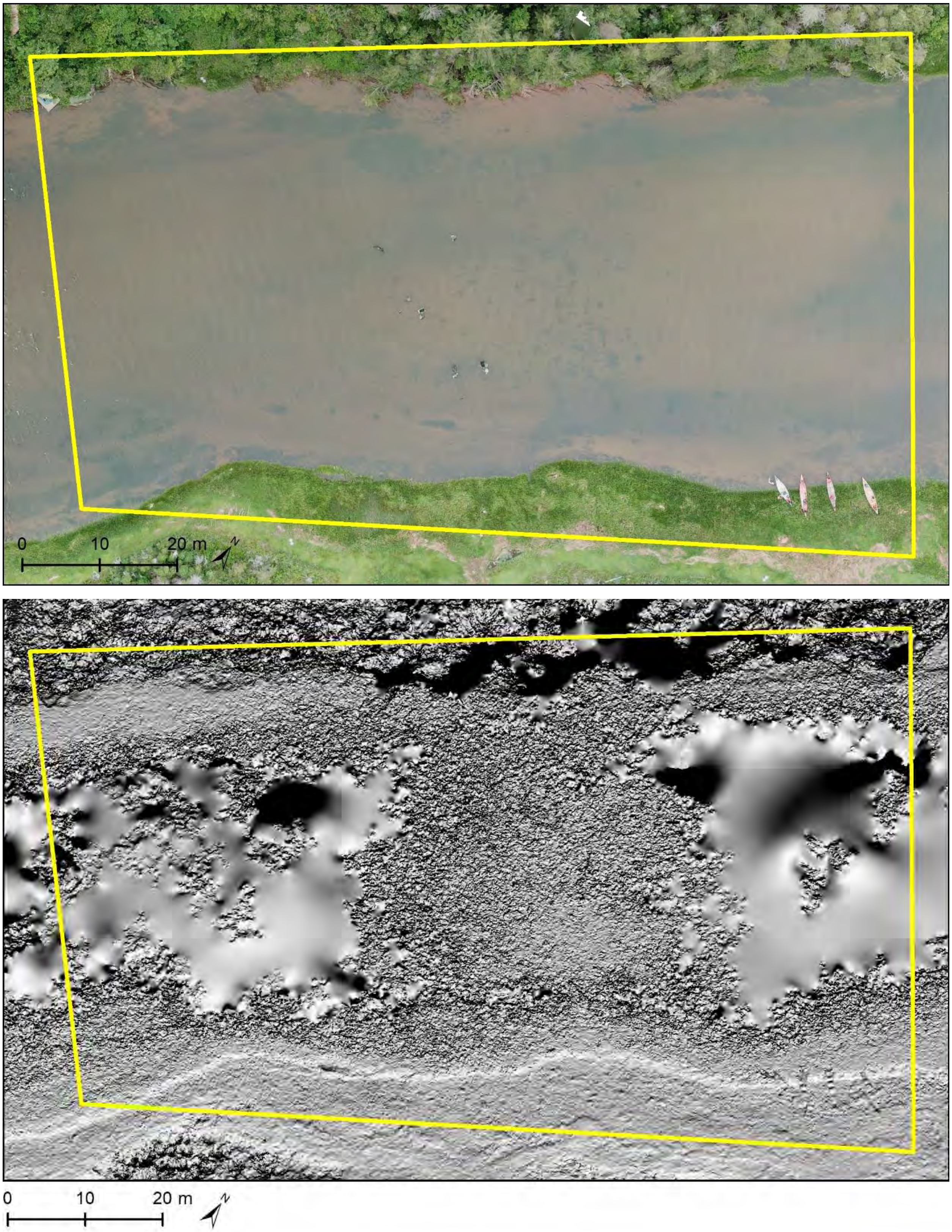



**Figure 3.10: Mavic Orthomosaic (A) and DSM hillshade (B) of the Corduroy Irish moss bed, 35 mm resolution. Survey was completed on August 10, 2018 at 12:51 (ADT) during a falling mid tide with a flight altitude of 95 m. Yellow polygon represents the Corduroy study area boundaries.**

## 3.2 DSM Validation

Elevation transects were collected across the channel at Main bed to validate UAV survey elevations. Validation of survey results were constrained to the best Mavic and Matrice triangulation results for the Main bed because they did not exhibit large interpolation artifacts. Elevation comparisons were found to be accurate within ± 0.2 m in the majority of cases (Figure 3.11 to Figure 3.15).


**Figure 3.11: Location of PPK GPS point cross sections collected in Main bed on Aug 11, 2018.**

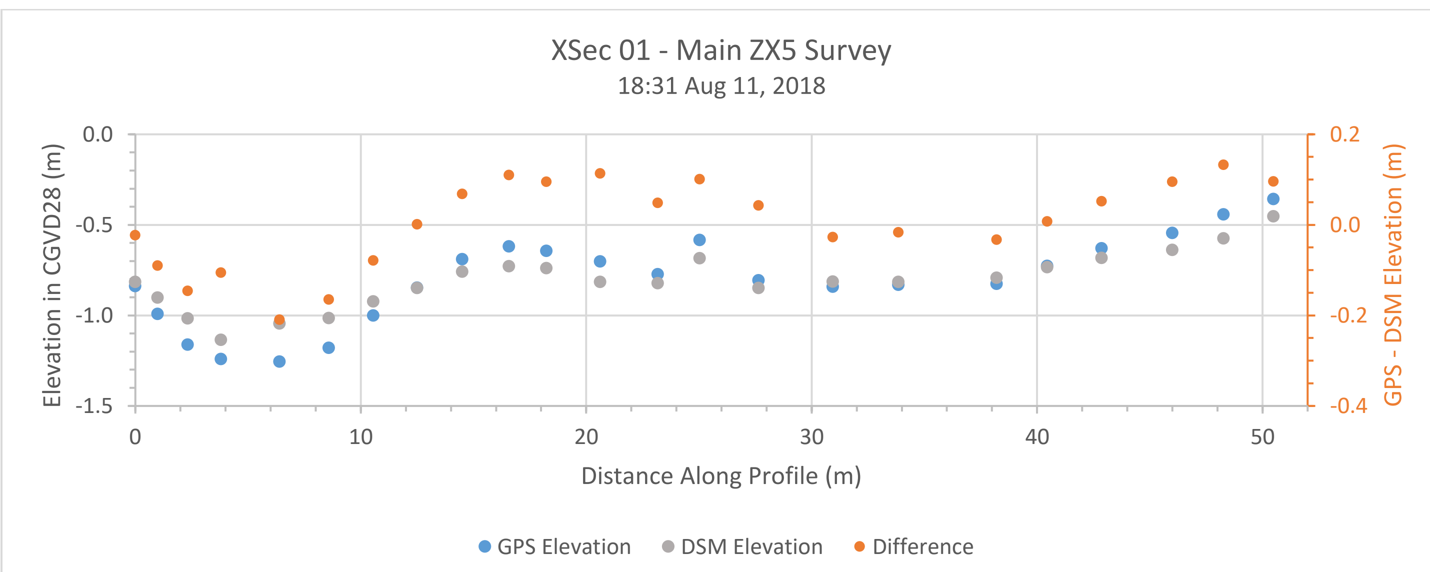



**Figure 3.12: Comparison along cross section 01 of GPS point elevations in CDVD28 orthometric height to DSM elevations for the Zenmuse X5 survey of Main bed on Aug 11, 2018 with an altitude of 40 m. The difference between the elevation values at each point is represented in orange on the secondary vertical axis.**

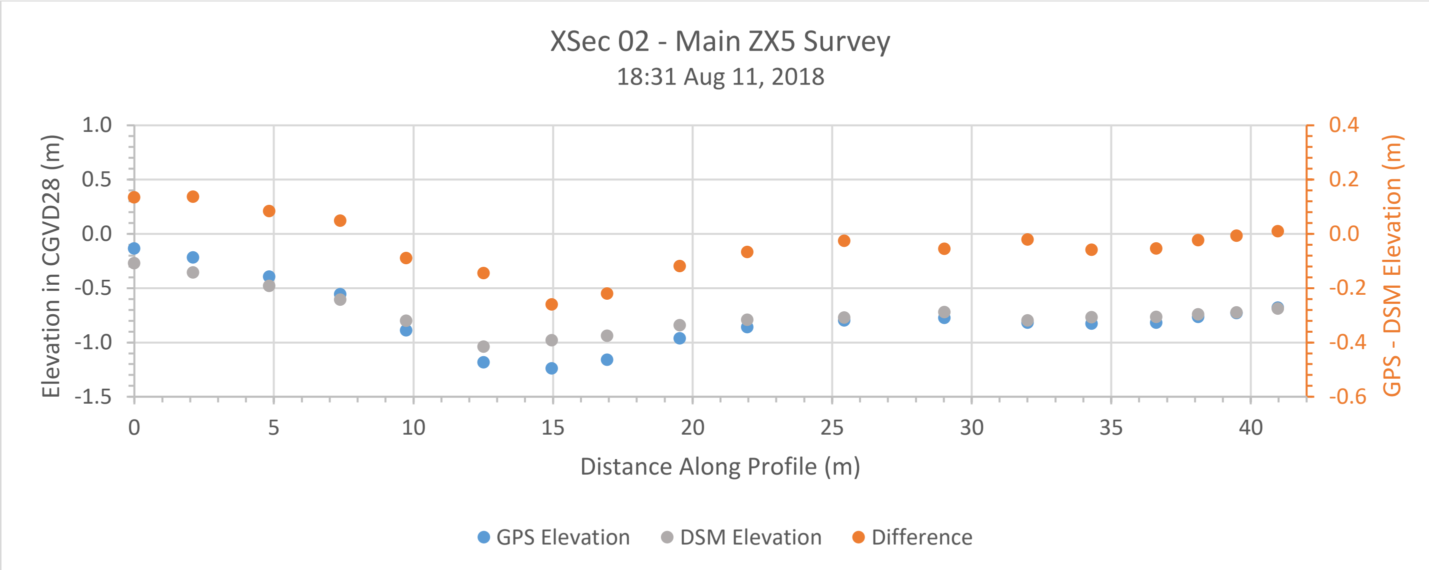



**Figure 3.13. Comparison along cross section 02 of GPS point elevations in CDVD28 orthometric height to DSM elevations for the Zenmuse X5 survey of Main bed on Aug 11, 2018 with an altitude of 40 m. The difference between the elevation values at each point is represented in orange on the secondary vertical axis.**

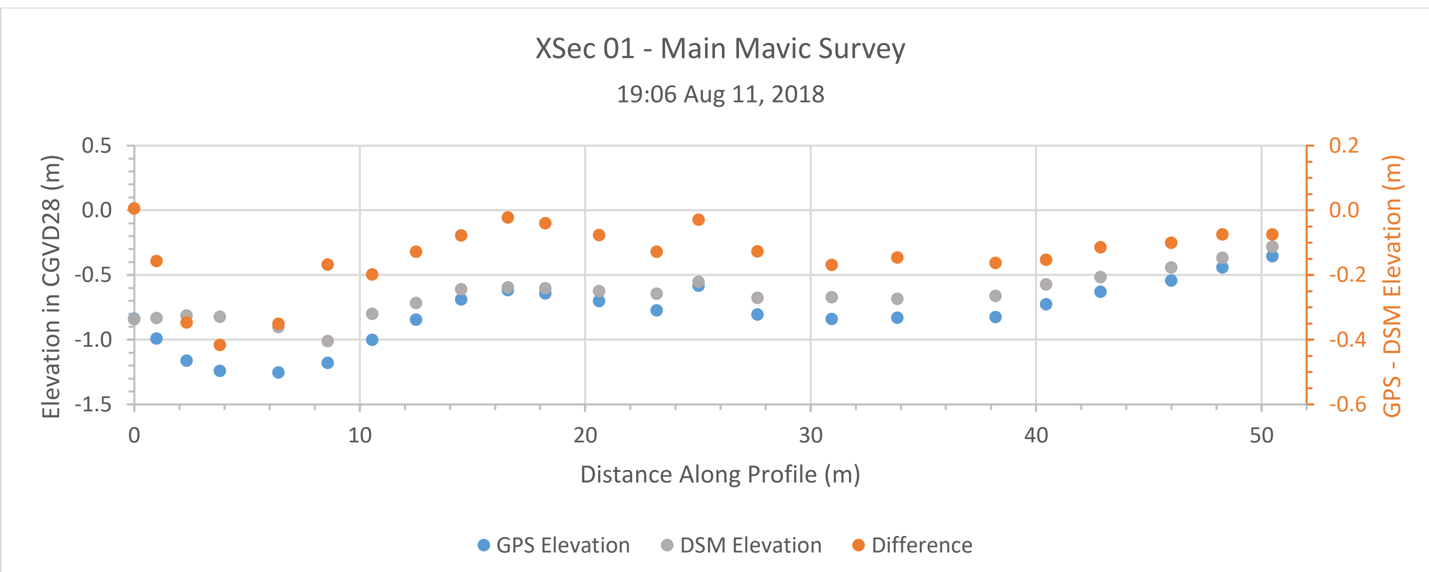



**Figure 3.14: Comparison along cross section 01 of GPS point elevations in CDVD28 orthometric height to DSM elevations for the Mavic survey of Main bed on Aug 11, 2018 with an altitude of 30 m. The difference between the elevation values at each point is represented in orange on the secondary vertical axis.**

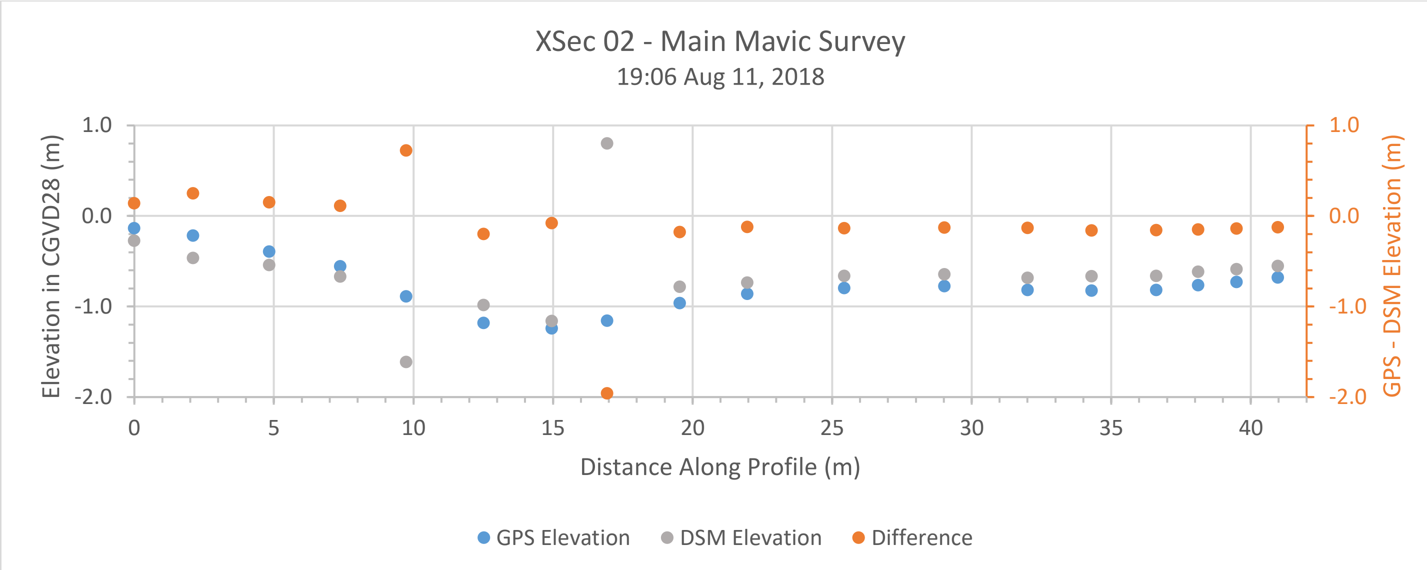



**Figure 3.15: Comparison along cross section 02 of GPS point elevations in CDVD28 orthometric height to DSM elevations for the Mavic survey of Main bed on Aug 11, 2018 with an altitude of 30 m. The difference between the elevation values at each point is represented in orange on the secondary vertical axis.**

## 3.3 Irish Moss Classification

Irish moss classification was possible only in areas with acceptable spectral variation and where NHM construction was successful. In most cases, due to models not resolving in deeper water, DSMs were not of high enough quality for NHM construction. Unfortunately, these limitations constrained classification to three drone flights over the Main bed: NSCC-AGRG Matrice ZX5, NSCC-AGRG Mavic, and DFO Phantom 3. The results of ArcMap and eCognition classification routines are presented below.

### 3.3.1 ArcMap

ArcMap classification was performed for all three viable surveys of Main bed. ZX5 imagery was captured at a 40 m altitude and produced a 15 mm resolution product. The classification of ZX5 imagery contained several false positives where deep water was falsely classified as *Ulva* and shallow shadows were falsely classified as Irish moss (Figure 3.16). Mavic imagery was captured at a 30 m altitude and produced a 10 mm resolution product. The classification of the Mavic imagery did not include *Ulva* but had similar false positive classification issues with Irish moss in deep water and shadow edges. (Figure 3.17). Finally, DFO Phantom 3 imagery was collected at an unknown altitude and produced a 10 mm resolution product. DFO imagery was classified using the same ArcMap technique, but was found to produced superior results, with significantly fewer false positive classifications of Irish moss (Figure 3.18).

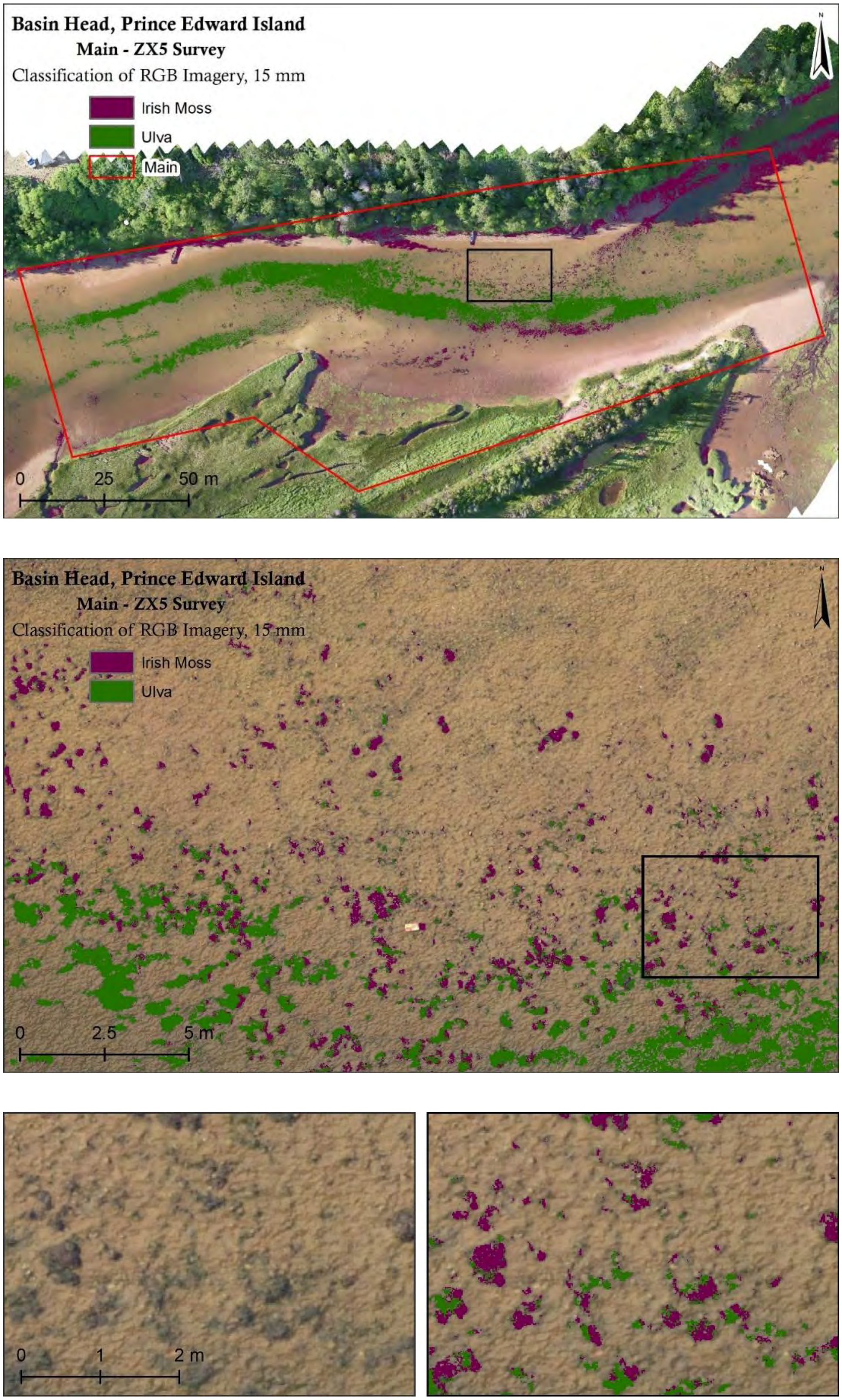



**Figure 3.16: Classification of 15 mm orthomosaic (RGB bands) using a supervised maximum likelihood classifier in ArcMap v10.6. A hillshade is draped below the orthophoto in the lower three panels. Survey was completed with the Zenmuse X5 camera on August 11, 2018 at 18:31 (ADT) during a rising low tide with a flight altitude of 40 meters. Red polygon represents Main Bed study area boundaries, black polygons represent subsequent close-ups of the imagery/classification.**

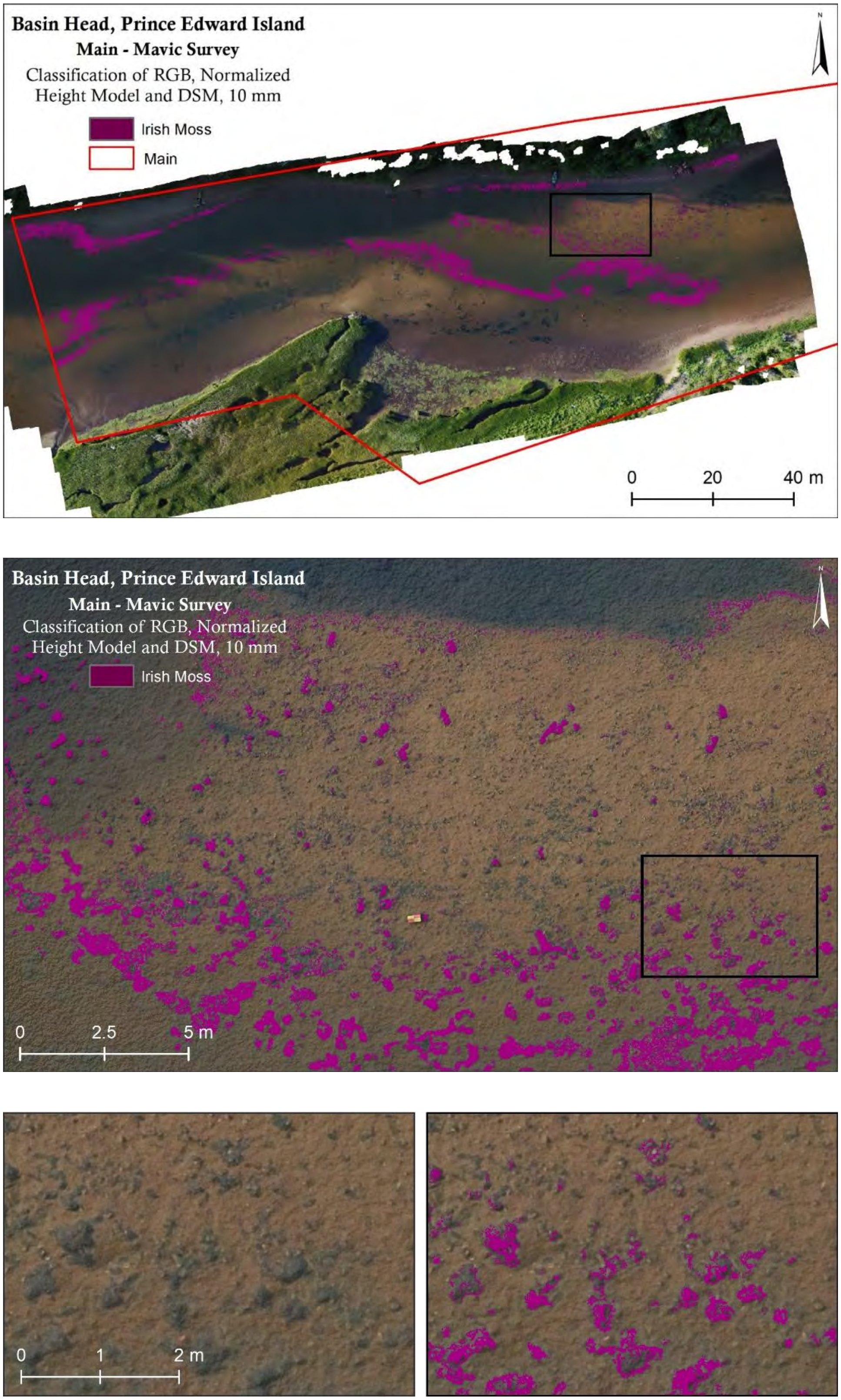
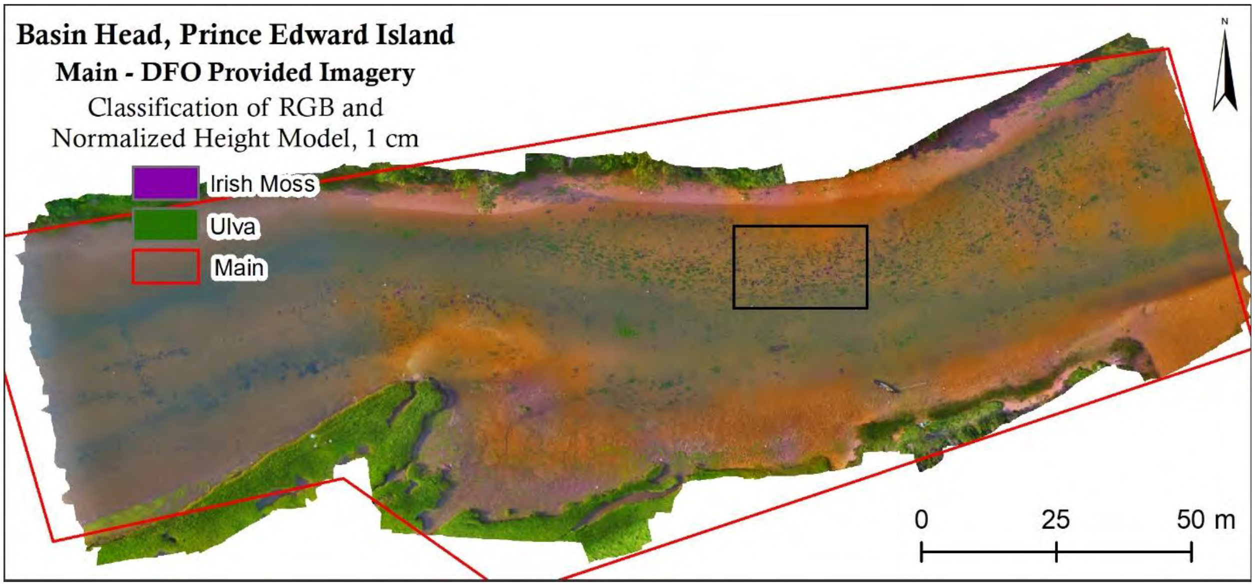
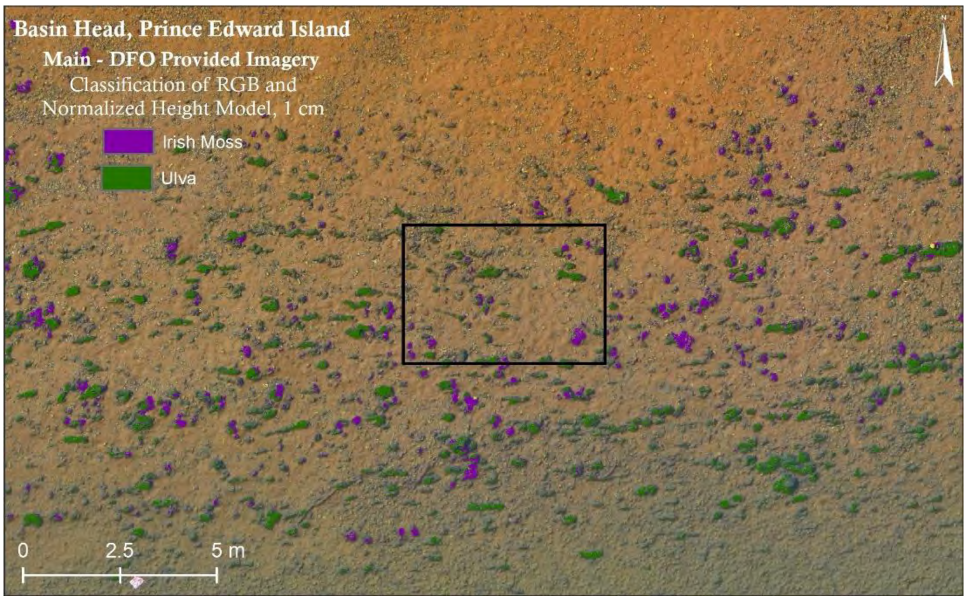



**Figure 3.17. Classification of 10 mm orthomosaic and elevation models (RGB, NHM, DSM) using a supervised maximum likelihood classifier in ArcMap v10.6. A hillshade is draped below the orthophoto in the lower three panels. Survey was completed with the Mavic camera on August 11, 2018 at 19:06 (ADT) during a rising mid tide with a flight altitude of 30 meters. Red polygon represents Main Bed study area boundaries, black polygons represent subsequent close-ups of the imagery/classification.**



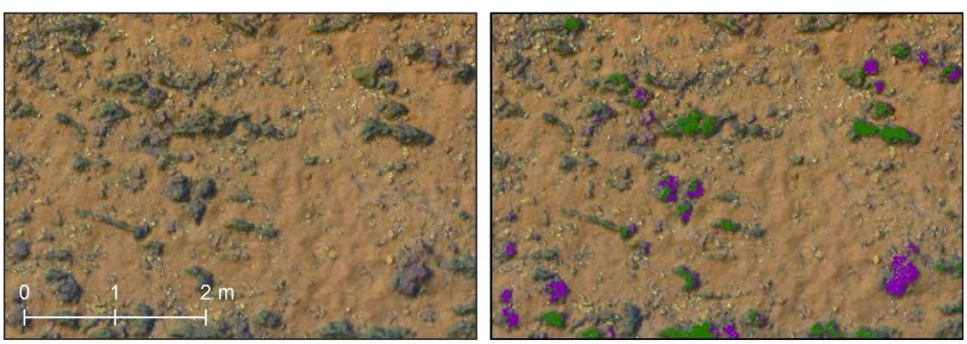




**Figure 3.18. Classification of 1 cm orthomosaic and elevation model (RGB, NHM) using a supervised maximum likelihood classifier in ArcMap v10.6. A hillshade is draped below the orthophoto in the lower three panels. Imagery data was provided by DFO. Red polygon represents Main Bed study area boundaries, black polygons represent subsequent close-ups of the imagery/classification.**

### 3.3.2 eCognition

An initial classification was performed using eCognition on a sub-section of the Main bed NSCC-AGRG Mavic survey due to processing limitations. Results from this classification were found to have fewer false positives than results from ArcMap, most likely due to the avoidance of intense shadows and deep water (Figure 3.19). An initial classification was also performed on data provided by DFO for a constrained sub-section of the Main bed. This sub-section was later expanded to cover the entire Main bed area following discussions with DFO. The resulting eCognition classification product developed using the provided 5 mm Phantom 3 imagery showed significant issues with false classification of both Irish moss and *Ulva* in both shallow and deep areas of the channel (Figure 3.20).

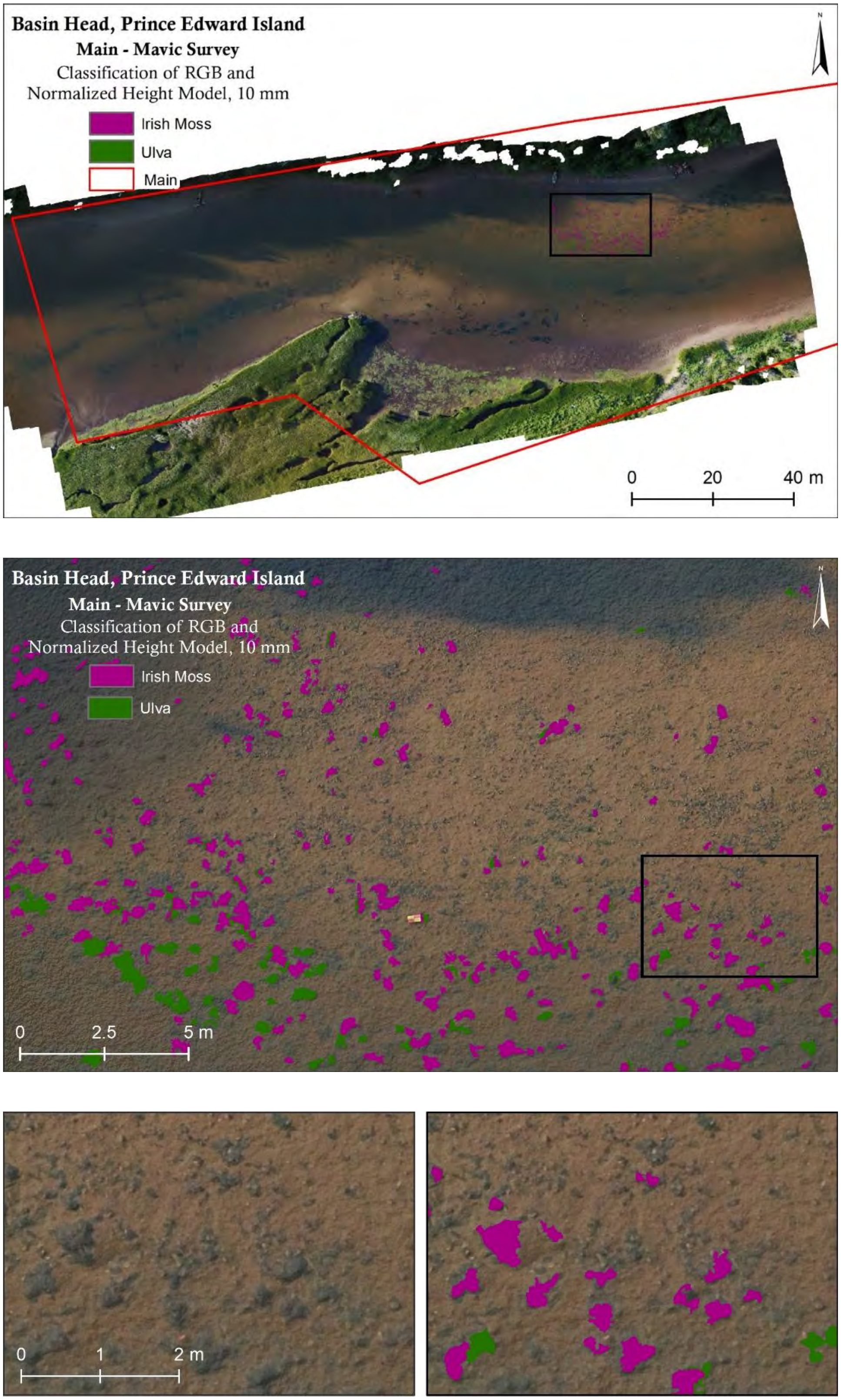



**Figure 3.19: Classification of 10 mm orthomosaic and elevation model (RGB, NHM) using an object-based classification in eCognition. Survey was completed with the Mavic camera on August 11, 2018 at 19:06 (ADT) during a rising mid tide with a flight altitude of 30 meters. Red polygon represents Main Bed study area boundaries, black polygons represent subsequent close-ups of the imagery/classification.**

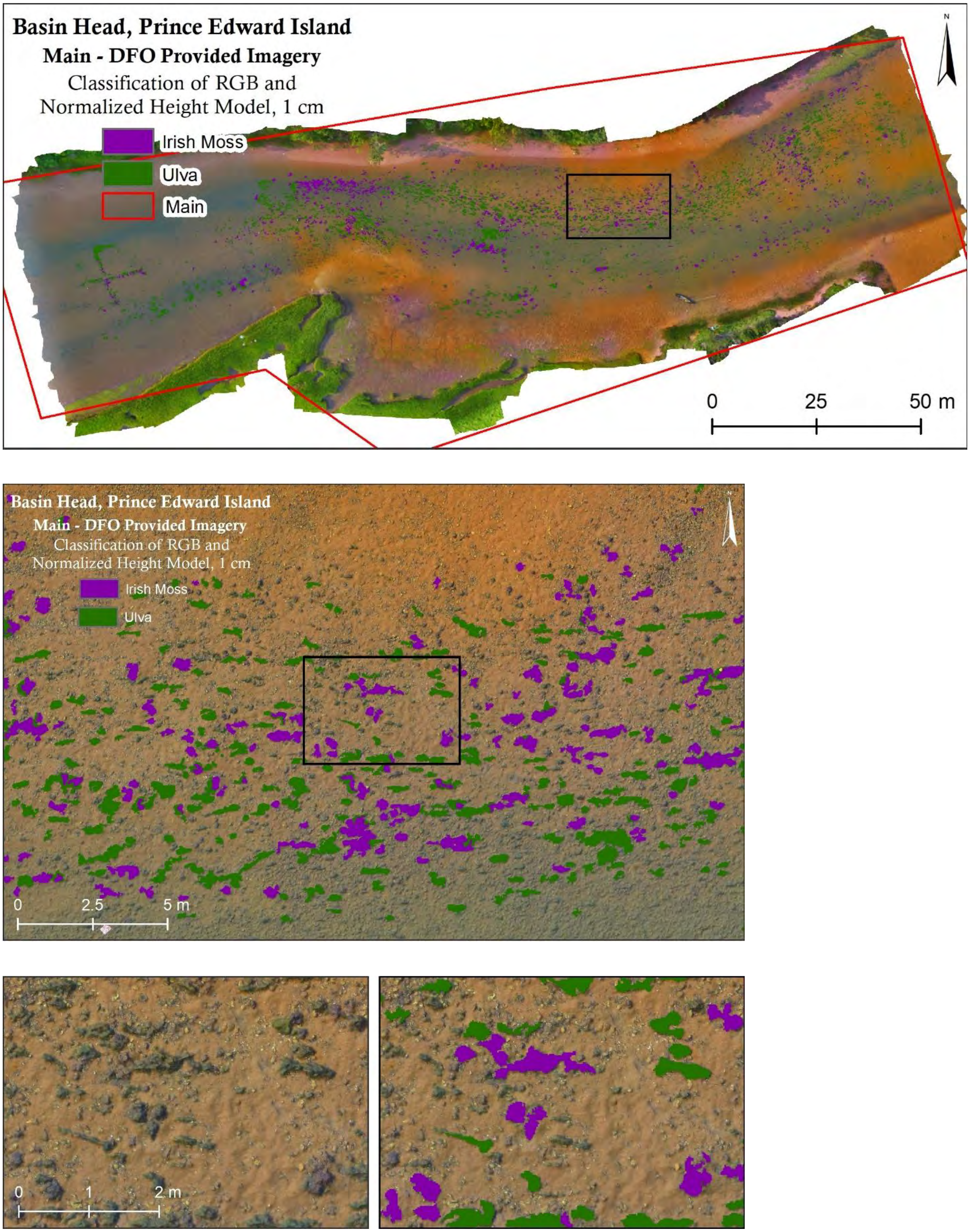



**Figure 3.20: Classification of 5 mm orthomosaic and elevation model (RGB, NHM) using an object-based classification in eCognition. Imagery data was provided by DFO. Red polygon represents Main Bed study area boundaries, black polygons represent subsequent close-ups of the imagery/classification.**

## 3.4 Irish Moss Classification Validation

Preliminary validation was based on visual inspection of classified results compared to input NHM and spectral data. DFO ground truth data from previous years were examined, but found to be of limited use due both to the mobile and interspersed nature of the Irish moss clumps, and positioning errors that caused DFO data to be shifted by roughly 3 to 5 m. Although NSCC-AGRG survey data positional errors were lower (0.3 to 0.5 m) the dataset was also rejected and not used for validation.

## 3.5 Irish Moss Coverage Estimation

**Irish moss coverage estimates from the three Main bed UAV surveys were compared in an area of coincident overlap (Figure 3.21). Resulting estimations of Irish moss coverage were different for each of the three surveys; these differences can be accounted for by the differences in imagery resulting from the different survey conditions (e.g. camera resolution, flight altitude, variable light, wind). Irish moss coverage estimations also varied depending on the classification technique used (**

Table 3.2). Note that there was no eCognition classification for the Zenmuse X5 because the survey produced insufficient elevation data to support the classification process.

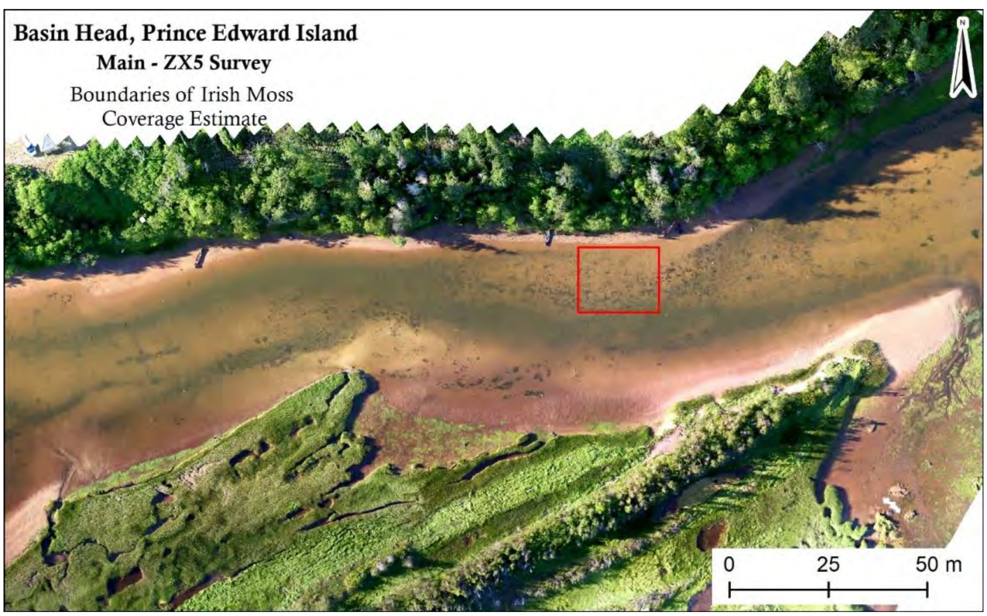



**Figure 3.21: Location of the coverage estimate area in Main bed.**

**Table 3.2: Irish moss coverage estimations for the overlap area (red box) referenced in Figure 3.21. Note that were insufficient Zenmuse X5 elevation data to support the eCognition classification process.**

| | Irish Moss Coverage Estimates ($m^2$) | | |
|---|---|---|---|
| **Classification Method** | Mavic | Zenmuse X5 | Phantom 3 |
| ArcMap Maximum Likelihood | 19.2 | 9.8 | 3.1 |
| eCognition Object Based | 12.8 | | 9.2 |

Coverage estimates for the entire Main bed area were also completed using ArcMap and eCognition classification results from the DFO Phantom 3 imagery. ArcMap classification results showed good agreement with a manual survey of the same area conducted by DFO, while the eCognition Irish moss coverage estimate was very high. During the manual survey, Irish moss clumps were counted, then multiplied by the average clump coverage area to calculate a total coverage (Table 3.3).

**Table 3.3. Irish moss coverage estimates for the full Main bed area of interest, from both a manual survey of the area, and results of an object-based image classification using eCognition.**

| Method | Main Bed Irish Moss Coverage Estimates ($m^2$) |
|---|---|
| Manual Survey | 47.8 |
| eCognition Classification | 174.3 |
| ArcMap Classification | 31.6 |

# 4 Discussion

## 4.1 Data Collection Limitations

The interaction of poor water clarity and water surface disturbances resulted in photo products that were not ideal for aerial triangulation and classification. Survey activities were planned around brief slack tides at astronomical low tide periods while paying less attention to wind, cloud, and rain conditions. The 2018 Basin Head UAV surveys were conducted during a variety of meteorological and tidal conditions. Wind speed and direction, cloud coverage, water depth, and solar angle conditions were variable between flights. Survey activities began near low tide on August 10$^{th}$ and 11$^{th}$ and were completed near high tide on both days (Figure 2.1e). Wind speeds during the surveys varied between 3 -19 km/hr blowing mainly from the west on August 10$^{th}$, and between 1 -14 km/hr blowing mainly from the south on August 11$^{th}$. Cloud conditions varied throughout each survey day, and the distribution of survey activities ensured data was collected during different solar angles. In addition to tidal state, it was important to consider weather conditions preceding and throughout UAV survey activities as strong winds and heavy rainfall may have worsened water clarity conditions. Wind speed at East Point was ~20 km/hr between August 9$^{th}$ and 10$^{th}$ (Figure 2.3a), and a 37 mm rain event occurred on the Aug. 9 (Figure 2.3d). Water clarity conditions may have also been poorly impacted by the observed tidal extremes as these events may have resulted in high flows that suspended additional sediment and *Ulva* when compared to normal low tides.

Wind conditions had a significant effect on photo quality. Surface disturbances such as waves cause glint and distortion in clear and overcast conditions (Figure 4.1) while flying during low wind conditions greatly improved the appearance of submerged features (Figure 4.2). Glint and uneven surface reflectance also reduced ability of Agisoft PhotoScan Professional to define photo tie points in the photogrammetric process, resulting in lower quality DSMs and orthomosaics. Finally, flying during high wind conditions greatly diminished the battery life of the UAVs.

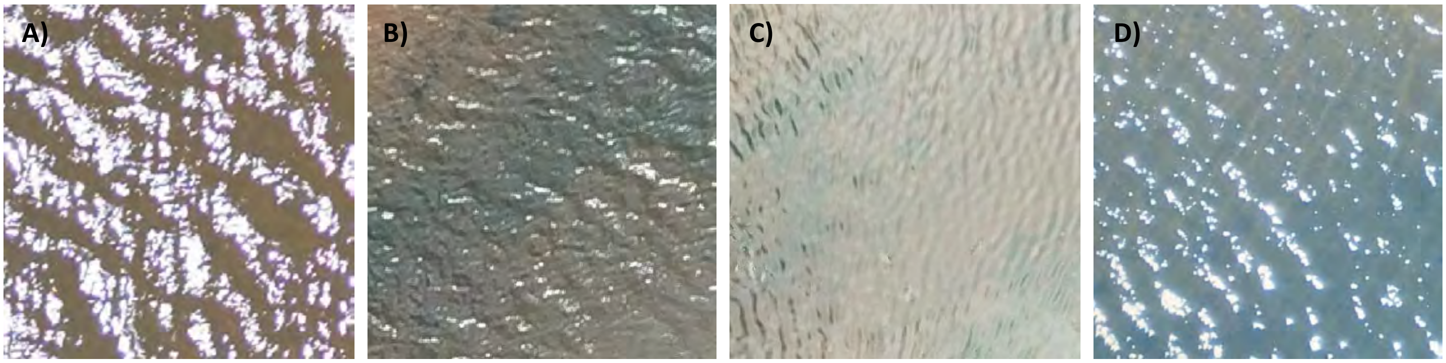



**Figure 4.1: Examples of severe/visibility-reducing glint in various surveys and conditions. (A) Aug 10, 2018 survey of Corduroy bed with Zenmuse X5 camera, variable cloud cover, 23 km/h wind, falling low tide, 50 m altitude. (B) Aug 10, 2018 survey of Corduroy bed with Mavic camera, overcast, 21 km/h wind speed, falling mid tide, 95 m altitude. (C) Aug 10, 2018 survey of Fireweed bed with Mavic camera, variable cloud cover, 7 km/h wind speed, rising mid tide, 40 m altitude. (D) Aug 11, 2018 survey of Main bed with Mavic camera, clear sky, 28 km/h wind speed, falling mid tide, 40 m altitude.**

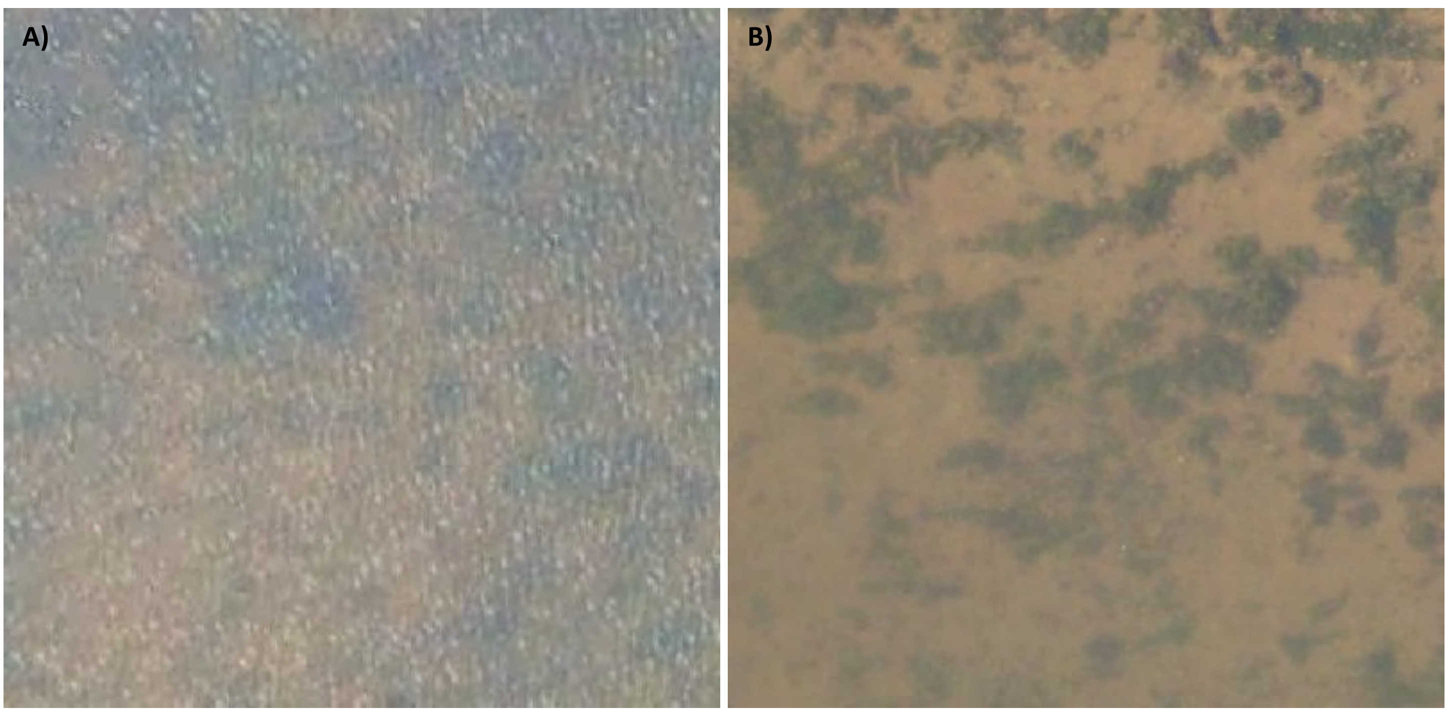



**Figure 4.2: Comparison of reduced visibility of seabed features due to the presence of water surface disturbances and clear visibility of seabed features in calm water conditions. (A) Survey completed on Aug 10, 2018 of Fireweed bed with Zenmuse X5 camera. Variable cloud conditions, 15 km/h wind speed, slack low tide, 50 m altitude flight, 15 mm resolution. (B) Survey completed on Aug 11, 2018 of Main bed with Zenmuse X5 camera. Clear sky conditions, 3 km/hour wind speed, rising low tide, 40 m altitude flight, 15 mm resolution.**

Variable light levels from cloud movement during data collection resulted in an uneven mosaic product. Colour calibration in Agisoft reduced this issue but did not remove it completely (Figure 4.3). The spectral variation was a significant limitation on colour-based image pixel classification methods due to variable spectral responses for single classes.

**Figure 4.3: (A) Original 15 mm orthomosaic product from Agisoft PhotoScan, (B) 15 mm orthomosaic product after colour calibration in Agisoft PhotoScan. Survey completed on Aug 10, 2018 of Fireweed bed with Zenmuse X5 camera. Variable cloud conditions, 15 mm resolution.**

Four different photo target arrangements were used during the 2018 surveys. Large (0.6 x 0.6 m) black and white plywood targets were used above water on the survey AOI edges, yellow and pink painted cinderblocks were submerged in the channel, and posts were set up in the channel to hold small cardboard targets, either submerged with rebar posts on the channel bottom or floating on the surface (Figure 4.4). Small cardboard targets were difficult to identify when submerged, and although visible when floating, markings on the target showing the center point (where GPS point was taken) were not visible. Cinder blocks were visible, as were the plywood targets. Cinder blocks were found to be the best targets to establish control in submerged areas but added logistical difficulty as they are heavy and difficult to carry around in canoes. The cinder blocks are at risk of becoming covered with *Ulva* and sediment if left in the channel for a long period of time before completing the aerial survey (Figure 4.5). This has the potential to make target center identification difficult during photogrammetric processing but was not found to be an issue for short survey turnaround times.


**Figure 4.4: Examples of target visibility in multiple surveys. (A) Plywood photo target from Zenmuse X5 survey of Corduroy bed on Aug 10, 2018, 50 m altitude, 15 mm resolution. (B) Submerged cinder block target from Zenmuse X5 survey of Fireweed bed on Aug 10, 2018, 50 m altitude, 15 mm resolution. (C) Submerged cardboard target from Zenmuse X5 survey of Corduroy bed on Aug 10, 2018, 50 m altitude, 15 mm resolution. (D) Floating cardboard target from Zenmuse X5 survey of Fireweed bed on Aug 10, 2018, 50 m altitude, 15 mm resolution.**

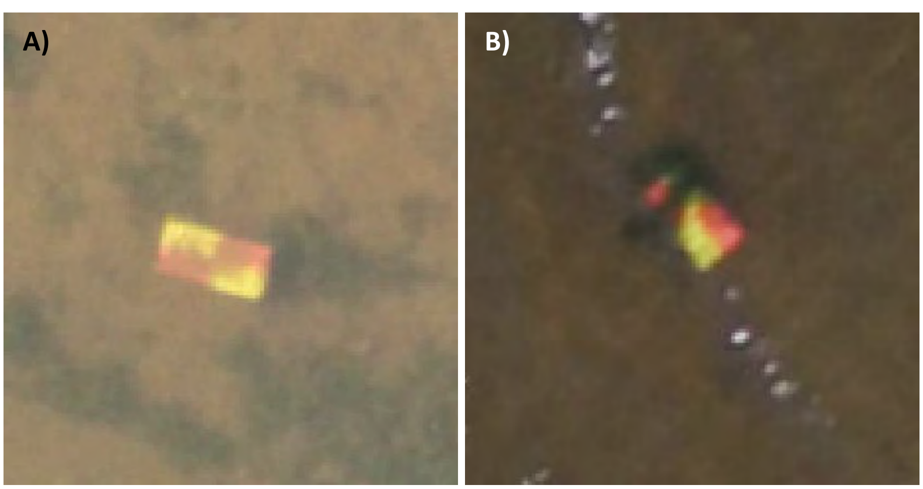



**Figure 4.5: (A) Sediment deposition on cinderblock target in Zenmuse X5 survey of Main bed on Aug 11, 2018. (B) *Ulva* cover on cinderblock target in Zenmuse X5 survey of Corduroy bed on Aug 10, 2018, 15 mm resolution.**

Caustics on the seabed, caused by reflected light rays, reduced the ability of Agisoft PhotoScan Professional to construct accurate elevation models when waves and surface ripples were present in bright conditions. Imagery without this distortion produced higher quality DSMs. Examples of both conditions and their resulting DSMs are shown in Figure 4.6. Water clarity and depth also greatly affected the ability of Agisoft to construct accurate elevation models. Greater visibility of the seabed resulted in higher quality DSMs (Figure 4.7).

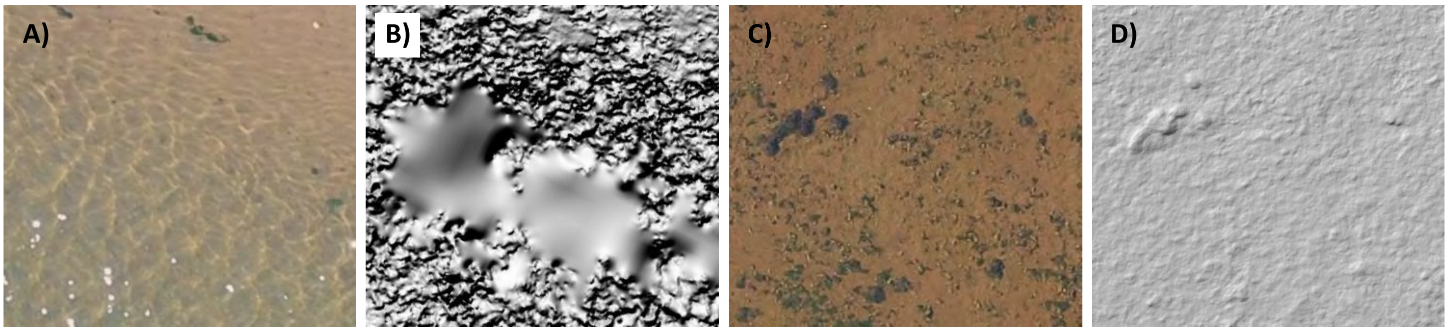



**Figure 4.6: (A) 15 mm imagery showing caustics on the seabed from bright sunlight and ripples in the water surface. Mavic survey of Main bed on Aug 11, 2018, clear sky, 28 km/h wind speeds. (B) Hillshade of poor-quality DSM created from imagery in (A). (C) 15 mm imagery showing how lack of undulation in the water surface results in a clear view of the seabed. Zenmuse X5 survey of main bed on Aug 11, 2018, clear sky, 3 km/h wind speeds. (D) Hillshade of high-quality DSM created from imagery in (C).**

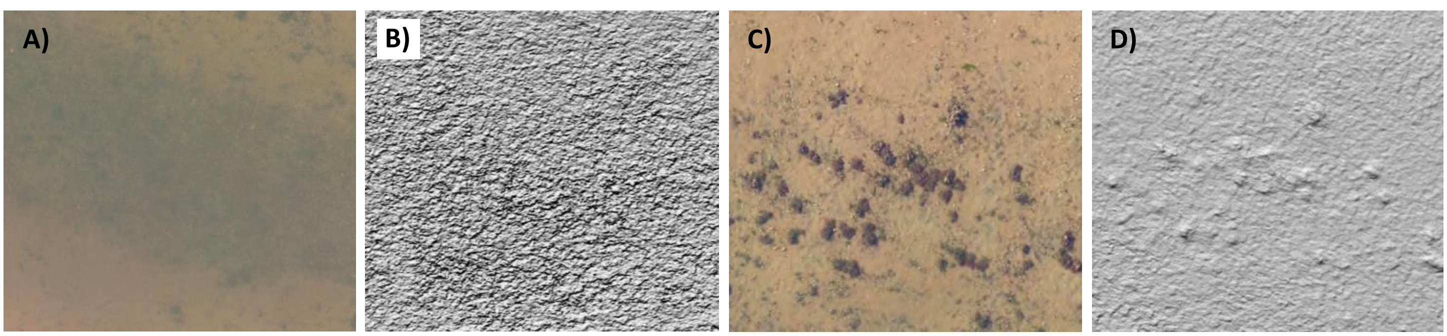



**Figure 4.7. (A) Depth and poor water quality reduced visibility of seabed substrate including Irish moss, mussel shells and *Ulva*. (B) Hillshade of poor-quality DSM created from imagery in (A). (C) Shallow/clear water resulted in improved visibility of Irish moss clumps and substrate in the orthomosaic. (D) Hillshade of high-quality DSM created from imagery in (C).**

The Matrice UAV experienced a technical issue where the camera gimbal (used to keep the camera pointing straight down) seemed to lose voltage and failed to keep the ZX5 camera steady. This problem was detectable by the operator and could be remedied by landing and power-cycling the UAV if time permitted. It was found that surveys around the main areas of interest were approximately 30 minutes in length. Due to the abundance of *Ulva*, several researchers were required to clean the sites prior to survey activities. Cleaning activities limited the NSCC-AGRG ground crew's ability to perform quadrat and GPS collection work and it is suggested that these activities be separate in future data collections. If it is vital to fly at slack low tide, cleaning activities must be completed before low tide to limit the abundance of *Ulva* present, but allow enough time for sediment suspended by researchers during the cleaning activity to dissipate before the UAV collection can begin. Due to these limitations, only one area should be flown during a single low tide event.

## 4.2 Data Processing

### 4.2.1 Positioning and Alignment

The high relief of the Basin Head northern bank resulted in a poor GPS satellite constellation while collecting ground control data in the channel. The poor GPS signal resulted periods of non-survey grade GPS data collection which impacted the Corduroy collections and resulted in poorly aligned orthophoto mosaics, elevation models, and ground truth data. The issues with UAV data were mostly resolved by aligning poor quality GPS points to photo-identifiable objects identifiable in well aligned orthomosaic products surrounding the problematic area at the cost of additional processing time.

Despite achieving the best possible alignments, there were slight shifts between survey products due to accuracy limitations inherent in the photogrammetric process in complex areas with few ground control targets. Products from each survey were not easily compared or interchangeable because of these shifts between models. For example, the most successful elevation model output was generated from the Mavic and could only be incorporated with the coincident low quality RGB data and not the best RGB data produced by Zenmuse X5 orthomosaic for the same area (Figure 4.8).

GPS cross-section comparisons to validate elevation demonstrated that the majority DSM products generated using photogrammetric processing were within 20 cm vertical accuracy. These results are similar to cross-section comparisons made on land in areas distant from control points. This result indicated that UAV photogrammetry was suitable method for obtaining seabed elevation in shallow water areas within a margin of acceptable error.

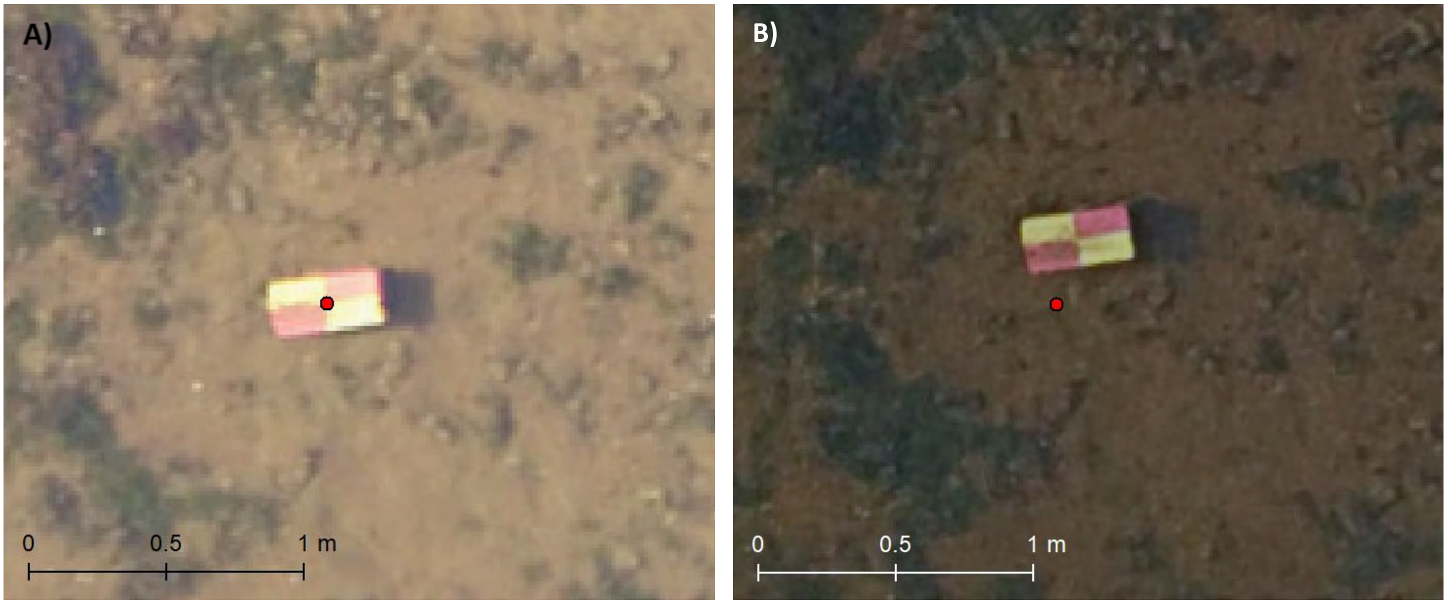



**Figure 4.8: Imagery from the Zenmuse X5 survey (A) and 30 m altitude Mavic survey (B) of Main bed. A red marker has been added to show the shift between the two surveys.**

### 4.2.2 Image Classification

The primary limitation of image classification was the confusion caused by similar spectral responses that spanned multiple features. When completing a classification with only spectral information, such as the red, green, and blue bands of an orthomosaic, if two individual features appeared to be the same colour, the classifier had difficulty differentiating between them. This issue was prominent in ArcMap supervised maximum likelihood classification using Zenmuse X5 imagery of Main bed. For example, Figure 4.9 illustrates that shadows over the seabed from high relief objects, such as trees, had similar spectral responses to shallow water Irish moss and were misclassified for that reason. Similarly, the shallow water *Ulva* class in this imagery had a similar spectral response as the murky channel which caused most of the channel to be misclassified as *Ulva* (see Figure 4.10).

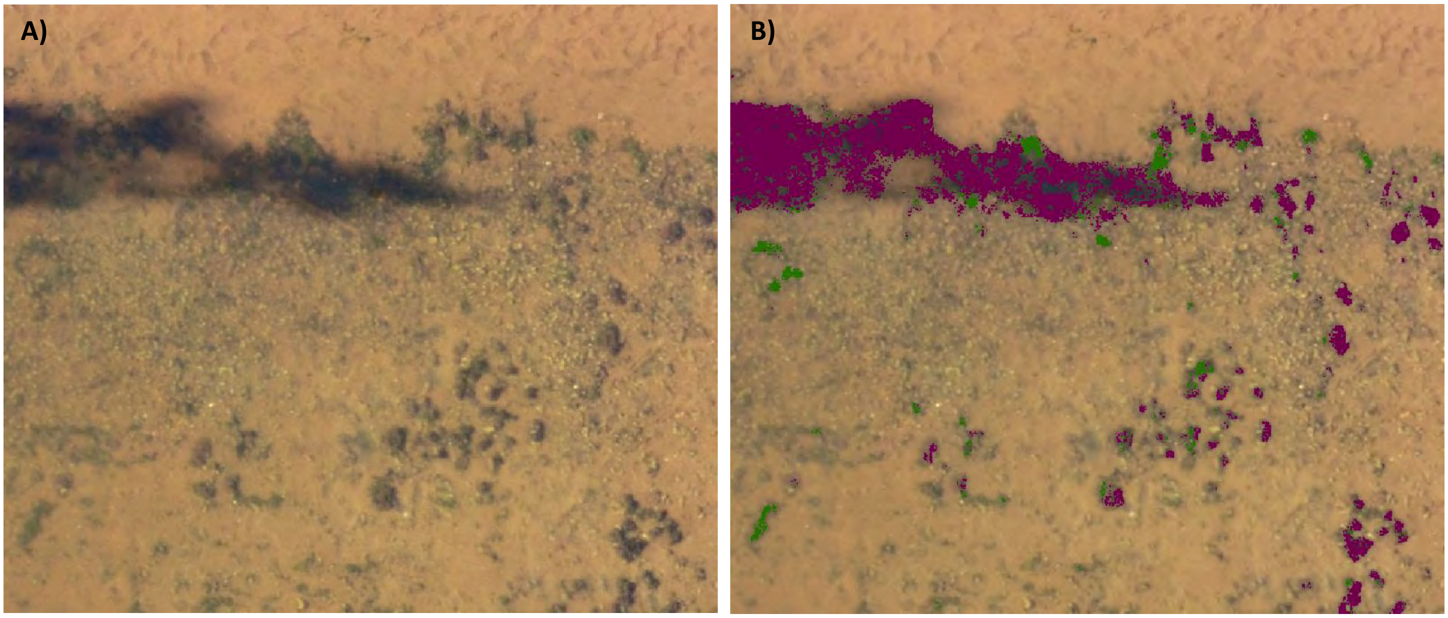



**Figure 4.9: Orthomosaic from the Zenmuse X5 survey of Main bed on Aug 11, 2018 with a 40 m altitude (A) and the results of a supervised maximum likelihood classification of the imagery in ArcMap (B). Irish moss class is displayed in purple, *Ulva* class is displayed in green.**

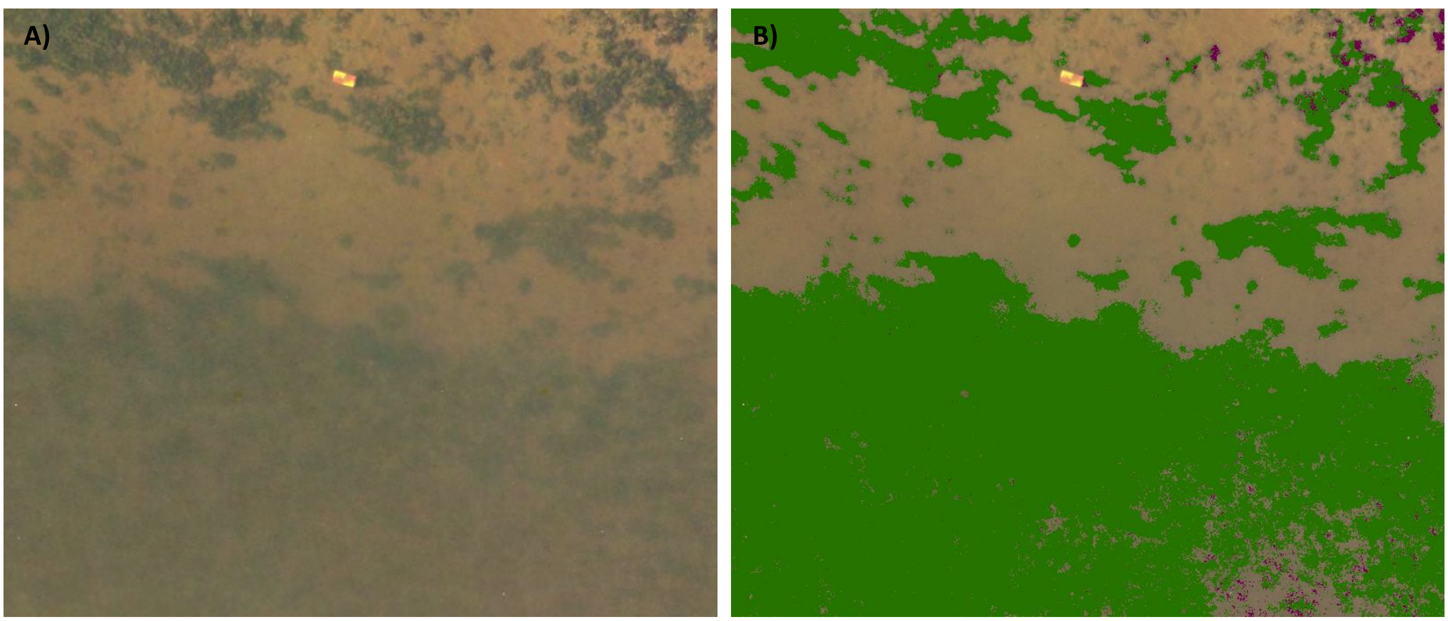



**Figure 4.10: Orthomosaic from the Zenmuse X5 survey of Main bed on Aug 11, 2018 with a 40 m altitude (A) and the results of a supervised maximum likelihood classification of the imagery in ArcMap (B). Irish moss class is displayed in purple, *Ulva* class is displayed in green.**

Misclassification due to spectral confusion between features was minimized by creating several very specific training areas for every class variation. Training areas were created for all spectral variations for classes, caused mostly by changes in light levels and water depth. A limitation of this technique was that features of interest must be identifiable by a technician to create accurate and appropriate training areas. In every survey, there were areas of the imagery where Irish moss was indistinguishable from surrounding features (Figure 4.11). Without the ability to create training areas for these Irish moss clumps, they were not accurately classified with supervised classifications.

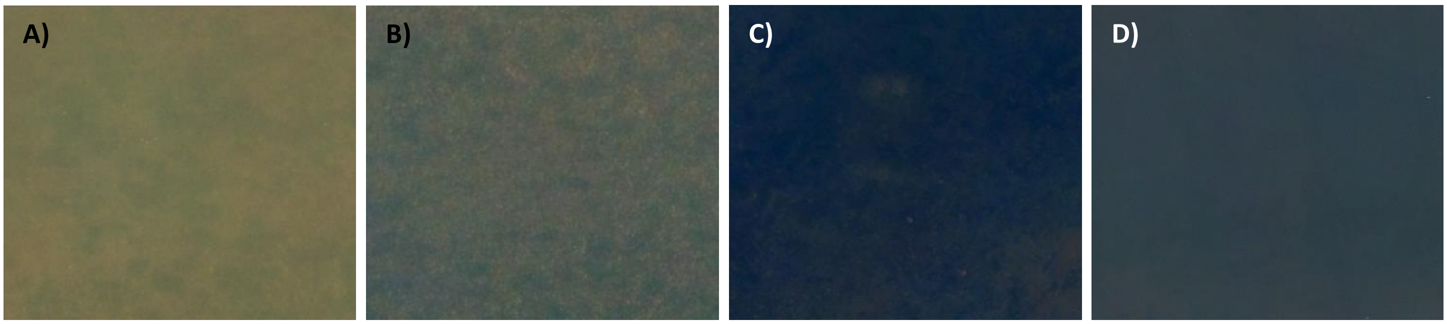



**Figure 4.11: Deep/murky water reduces the visibility of Irish moss in the Zenmuse X5 survey (A) and 30 m altitude Mavic survey (B) of Main bed. Shadows from trees also greatly reduce visibility of Irish moss in both the Zenmuse X5 survey (C) and Mavic survey (D) of Main bed.**

Where spectral characteristics were not found to be adequate for a robust classification, it was necessary to utilize other types of data. In the case of this project, elevation data from Agisoft PhotoScan products were incorporated where possible. The Mavic survey of Main bed on Aug 11, 2018 with a 10 mm resolution produced the highest quality elevation raster, which was therefore incorporated into the supervised maximum likelihood classification in ArcMap. Unfortunately, murky/deep water areas were not resolved in Agisoft as well as shallow water areas, and clumps of Irish moss were not apparent in those sections of the NHM. These poorly resolved areas did not add value to the classification process, and ultimately resulted in a lack of valid classification outside of clear, shallow waters due to a combination of both poor spectral differentiation and lack of accurate elevation data (see Figure 4.12).

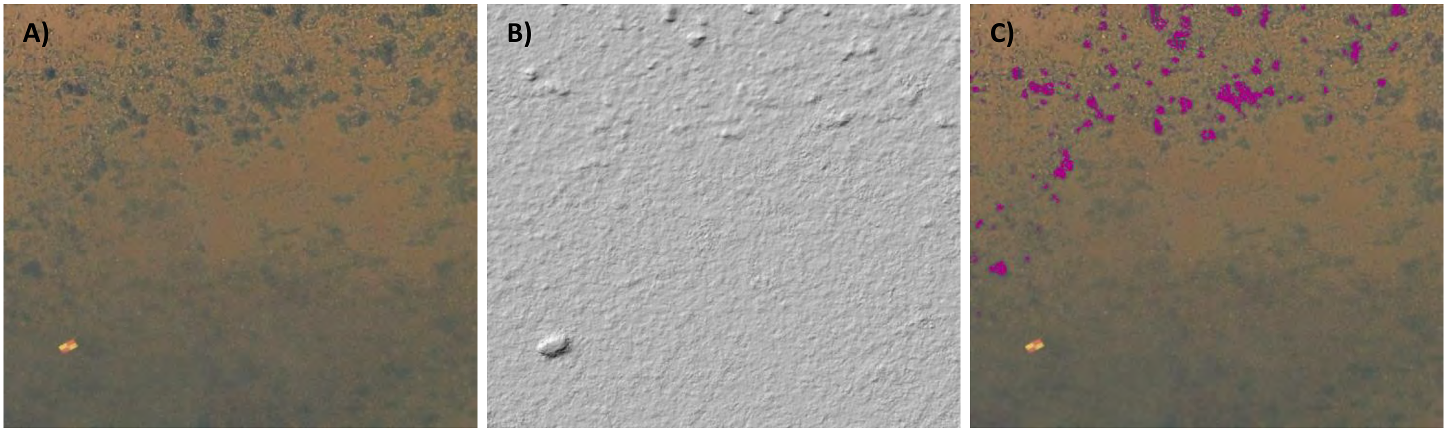



**Figure 4.12: RGB orthomosaic (A), hillshade NHM (B) and ArcMap classification (C) of the 30 m altitude Mavic survey of Main bed on Aug 11, 2018, 10 mm resolution. Upper areas of the scene have clear/shallow water resulting in a better spectral response from the Irish moss and a more detailed NHM that highlights Irish moss clumps. Classification in this area was more successful.**

Visibility of Irish moss was improved in the 3 mm imagery collected by DFO in 2017. A supervised maximum likelihood classification of RGB bands and NHM from the DFO provided data was completed in ArcMap. To account for changes in spectral response due to depth, training areas were created for two classes; shallow water Irish moss and deep water Irish moss. Classification results were promising, but routinely misclassified shadows within *Ulva* as Irish moss because the spectral characteristics of both required features were similar (Figure 4.13).

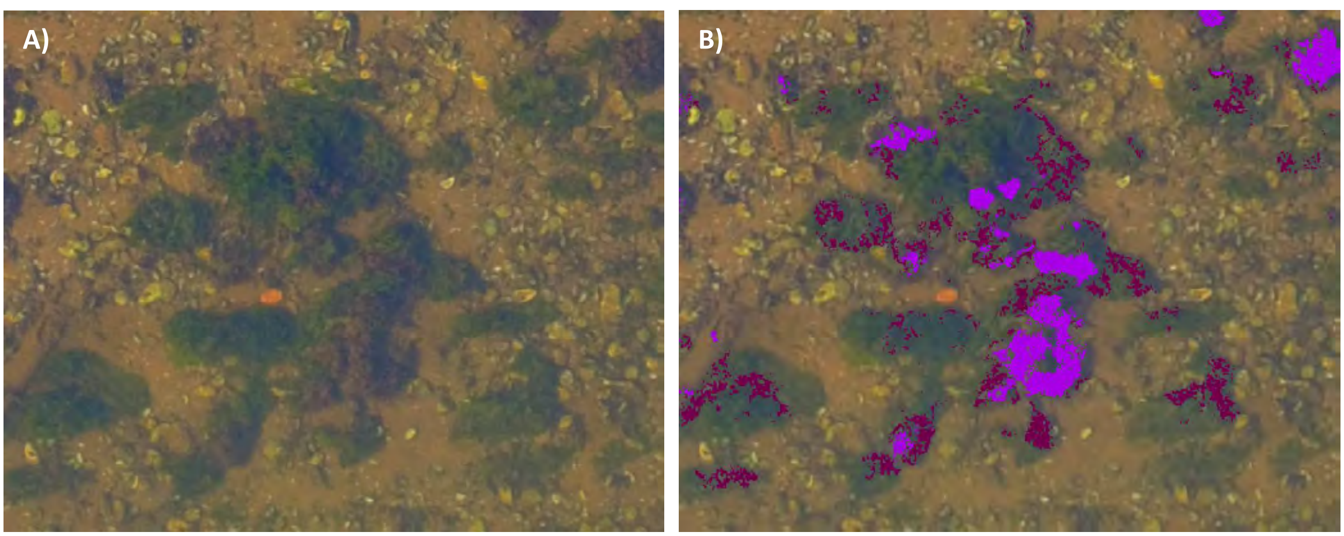



**Figure 4.13: DFO imagery of Main bed (A) and the resulting ArcMap classification (B). Shallow water Irish moss class is shown in light purple, deep water Irish moss class is shown in dark purple.**

Attempts were made to improve classification through dehazing techniques as described in Cairns, 2018. The intent of this technique was to: improve the visibility and spectral signature of Irish moss in deep water areas, allow technicians to define training areas more easily, and improve the classification algorithm by enhancing spectral variation. While these techniques produced more visually appealing products, the adjustments to pixel values in the enhanced imagery were not found to improve classification results. A second classification of the imagery was completed using newly derived training areas which resulted in a classification with fewer false positive classifications of shadows but suffered from an increased false positive classification of other features such as bright shells and sediment, and false negative classifications of Irish moss in dark areas.

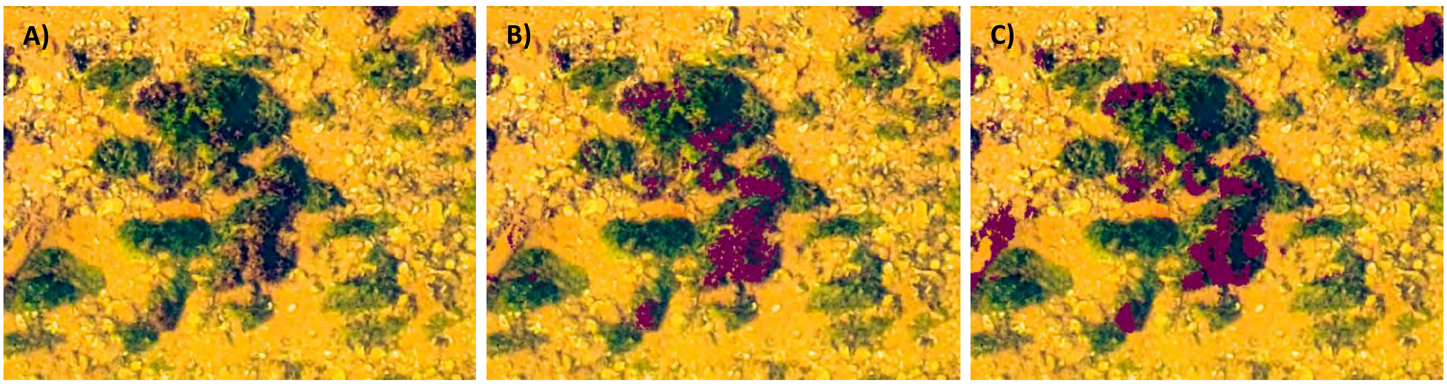



**Figure 4.14: Dehazed and enhanced DFO imagery of Main bed (A), classification results using all training areas (B) and classification results using only bright Irish moss training areas (C). Irish moss class is shown in purple.**

The use of Definiens eCognition Developer was investigated as an improved classification technique for identifying and quantifying Irish moss. Classification in eCognition uses an object-based approach, the benefits of which include reducing pixel noise in classification outputs and allowing the use of object characteristics like size and shape as classification parameters. Object-based classifications with eCognition were completed on the Mavic 10 mm imagery and NHM, as well as the DFO provided imagery and NHM of Main bed. The results of these classification attempts contained numerous cases of false positive classification of Irish moss (Figure 4.15 and Figure 4.16). In the DFO data classification, there was a significant breakdown of classification in deep water areas due to loss of spectral signature, which caused additional false positive misclassifications for both Irish moss and *Ulva* (Figure 4.17). eCognition classification results were found to contain few false negative classifications in Mavic data (Figure 4.18), and an increased number of false negatives in the DFO data where small Irish moss clumps were not classified (Figure 4.19). It is possible that the full-scale classification of Main bed with eCognition was more inaccurate and erroneous compared to the restricted overlap area classification due to the larger extent. There were more variations in spectral characteristics of Irish moss and Ulva present in the full-scale classification area. The increase in area and variation required a complex training dataset, and even with a large number of training samples, the classification was found to be less accurate due to the abundance of spectral variation which resulted in confusion between features and classes.

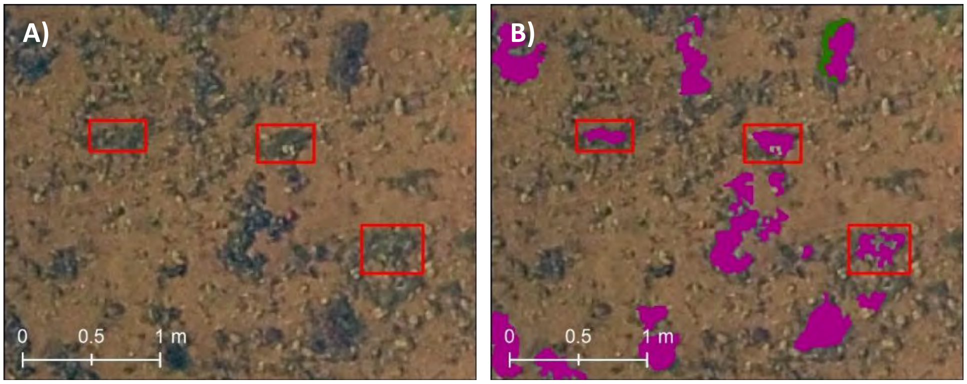



**Figure 4.15. 10 mm Mavic Imagery of Main bed (A) and the resulting object-based classification in eCognition (B). Red rectangles highlight examples of false positive classification of *Ulva* and shellfish/debris as Irish moss. Irish moss class is shown in purple.**

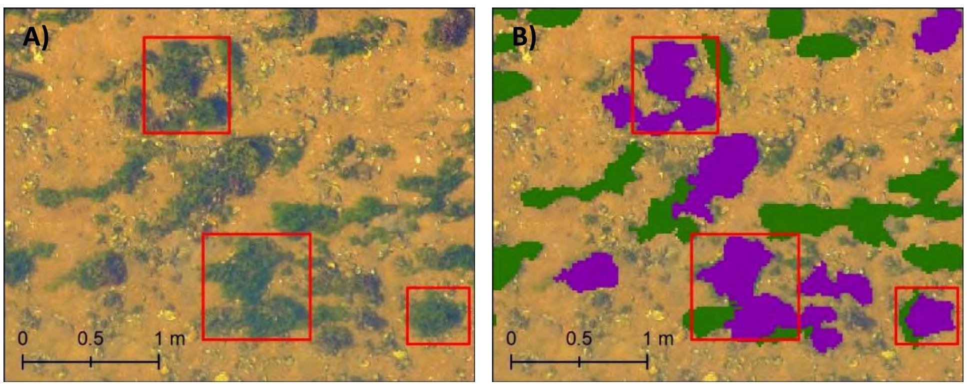



**Figure 4.16. DFO Imagery of Main bed (A) and the resulting object-based classification in eCognition (B). Red rectangles highlight examples of false positive classification of *Ulva* as Irish moss. Irish moss class is shown in purple, *Ulva* is green.**

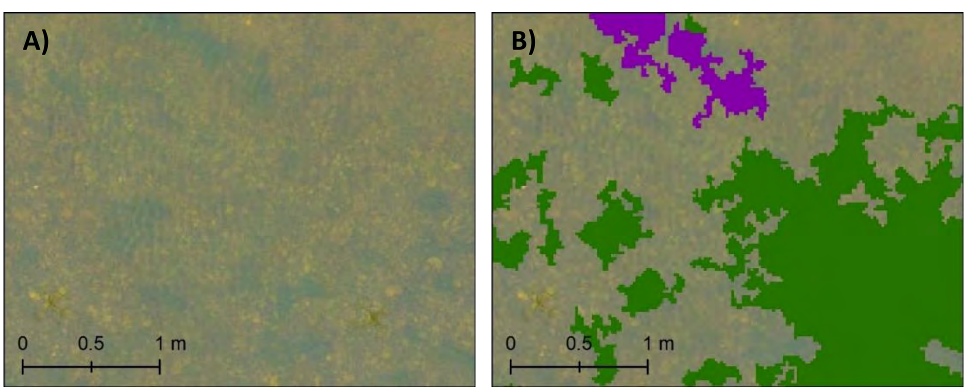



**Figure 4.17. DFO Imagery of Main bed (A) and the resulting object-based classification in eCognition (B). Significant breakdown in spectral signal results in false positive classification of Irish moss and *Ulva*. Irish moss class is shown in purple, *Ulva* is green.**

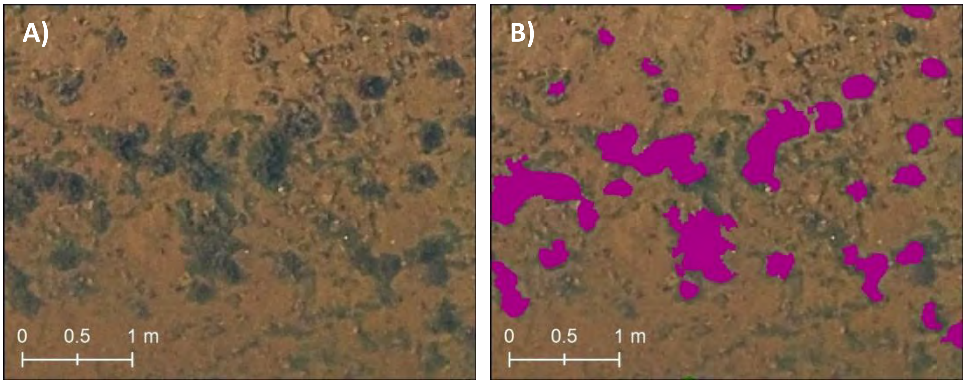



**Figure 4.18. 10 mm Mavic Imagery of Main bed (A) and the resulting object-based classification in eCognition (B) that demonstrates very few false negative classification of Irish moss. Irish moss class is shown in purple.**

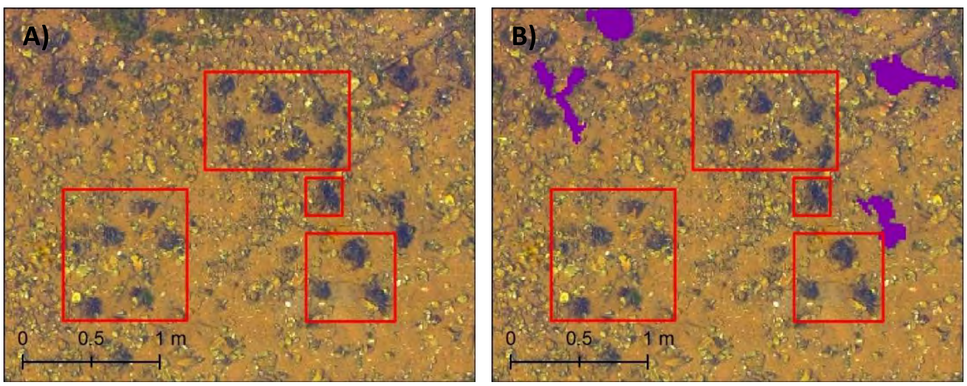



**Figure 4.19. DFO Imagery of Main bed (A) and the resulting object-based classification in eCognition. Red rectangles highlight examples of false negative classification of Irish moss. Irish moss class is shown in purple.**

In general, both ArcMap and eCognition classifications required high quality imagery with a clear view of the seabed, and high resolution, accurate elevation data. In areas lacking either of these conditions such as prominent shadowing, glint, clouds, and deep/opaque water, classification quality was poor. Both classification techniques were found to benefit from many specific training sample types, especially when dealing with such a complex and spectrally variable environment such as the Basin Head MPA. In both cases Irish moss was generally distinguishable from bare mussel clumps within a margin of error.

The pixel based classification in ArcMap resulted in a “salt-and-pepper” effect (pixel noise) within classes and had a high number of false negatives when Irish moss clumps were spectrally variable, but produced fewer false positives in the clear, shallow water areas of the DFO survey data. While the eCognition results reduced pixel noise and gave a more clump-like result, there was an increase in false positive classifications of Irish moss.

## 4.3 Irish Moss Coverage Estimation

The eCognition classification method was found to be the most accurate when classifying the NSCC-AGRG Mavic 10 mm imagery. The ArcMap method produced more visibly erroneous classifications of sediment and *Ulva* as Irish moss in the deeper water areas (Figure 4.20). ArcMap also produced more erroneous classification of shadow edges as Irish moss when compared to eCognition (Figure 4.21). ArcMap pixel-based classification resulted in an abundance of noisy pixels classified as Irish moss, and less complete classification of all Irish moss clumps where pixels within Irish moss clump boundaries were not classified (Figure 4.22).

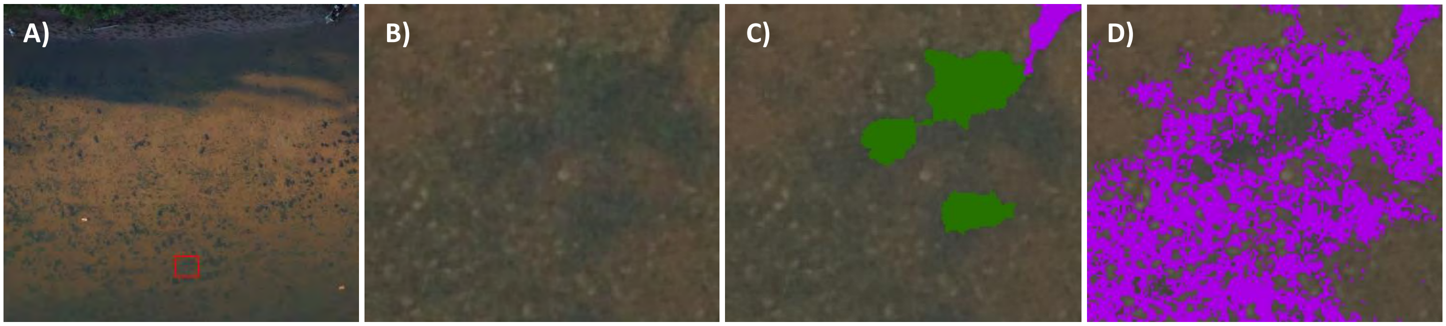



**Figure 4.20: (A) Mavic 10 mm imagery from the 30 m altitude survey of Main bed on Aug 11, 2018. Red box shows location of the following three images. (B) Close up of imagery. (C) Results of object based classification in eCognition. (D) Results of supervised maximum likelihood classification in ArcMap.**

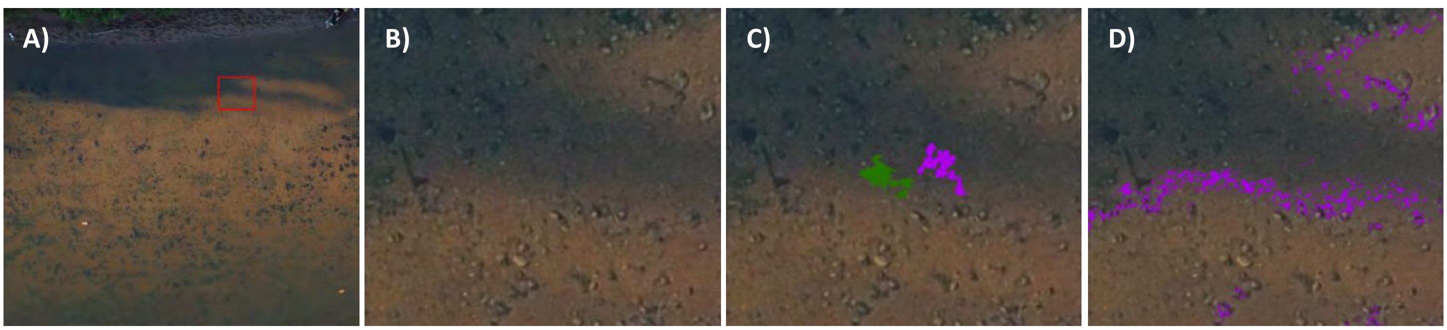



**Figure 4.21: (A) Mavic 10 mm imagery from the 30 m altitude survey of Main bed on Aug 11, 2018. Red box shows location of the following three images. (B) Close up of imagery. (C) Results of object based classification in eCognition. (D) Results of supervised maximum likelihood classification in ArcMap.**

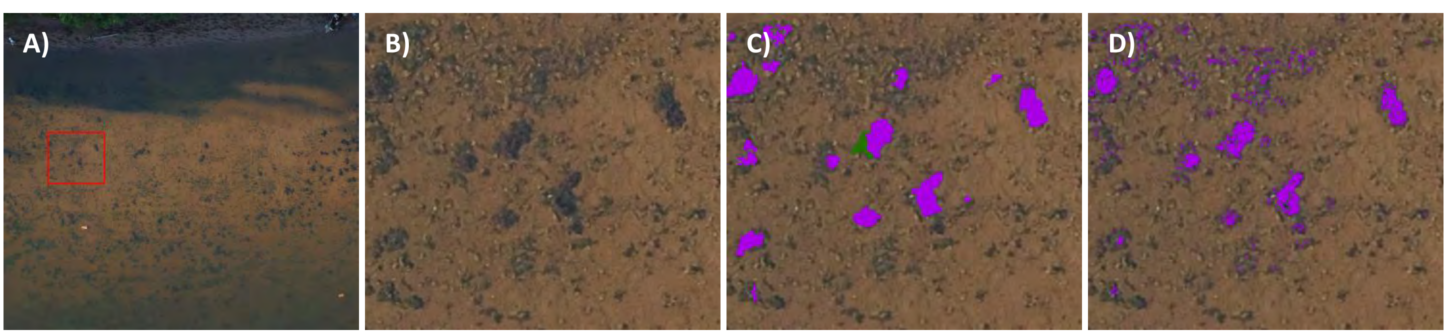



**Figure 4.22: (A) Mavic 10 mm imagery from the 30 m altitude survey of Main bed on Aug 11, 2018. Red box shows location of the following three images. (B) Close up of imagery. (C) Results of object based classification in eCognition. (D) Results of supervised maximum likelihood classification in ArcMap.**

When classifying the 2017 DFO imagery, eCognition was found to over classify Irish moss by extending classified polygons beyond the extent of Irish moss when compared to ArcMap classification. This over-classification resulted in a large disparity between coverage values for both the subsample of Main bed and the entire survey area (Figure 4.23). Contrary to the classification of the Mavic imagery, eCognition classification results of the DFO imagery had significantly more misclassification in deeper water areas of the channel (Figure 4.24). This, combined with the numerous false positive classifications in shallow water, resulted in the supervised maximum likelihood classification in ArcMap being much more accurate when compared to the manual survey coverage results as reported in Table 3.3.

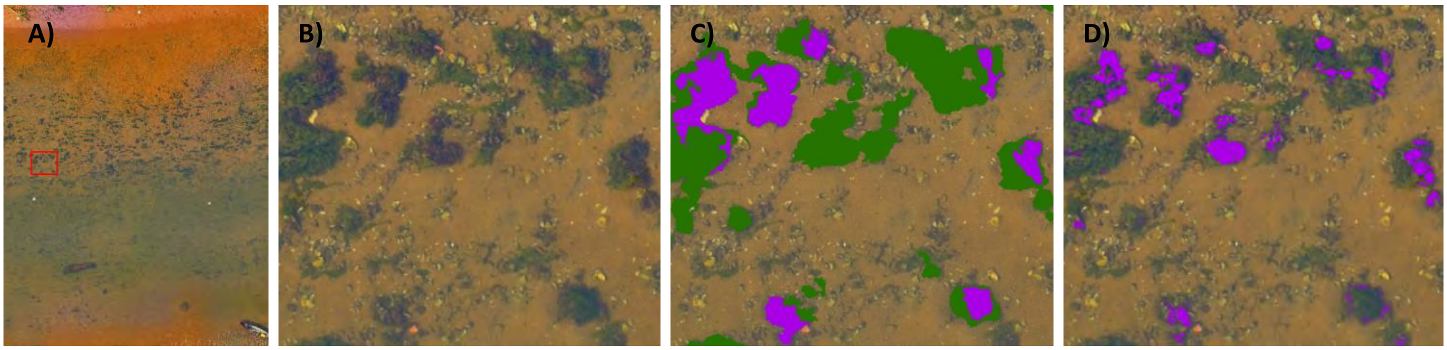



**Figure 4.23: (A) DFO provided imagery of Main bed. Red box shows location of the following three images. (B) Close up of imagery. (C) Results of object based classification in eCognition. (D) Results of supervised maximum likelihood classification in ArcMap.**

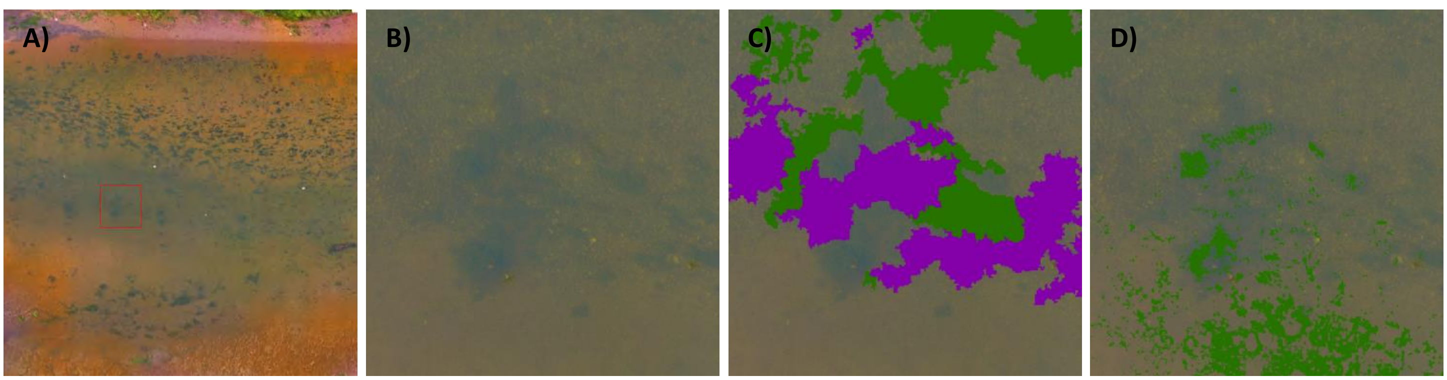



**Figure 4.24. (A) DFO provided imagery of Main bed. Red box shows location of the following three images. (B) Close up of imagery. (C) Results of object based classification in eCognition. (D) Results of supervised maximum likelihood classification in ArcMap.**

# 5 Long Term Monitoring Strategy

The results of this study show that using UAV survey techniques and image classification methods for long term monitoring of Irish moss can be effective if the recommendation in this section are taken into consideration. The following section will detail recommendations by NSCC-AGRG to optimize collection and maximize the probability of success. The strategies presented here are relevant for Irish moss at Basin Head and are also applicable to any UAV data collection projects.

## 5.1 UAV Survey Considerations

The most important component of the UAV data collection process is understanding the challenges presented by the collection environment and how these challenges can limit the ability to quantify the subject of examination. If these interactions are understood, mitigation actions can be established through camera selection, flying altitude, and mission planning to optimize the data collection process.

### 5.1.1 Environmental Conditions

UAV data quality is impacted by several factors, and this is especially true when measuring submerged objects. The most important consideration when collecting data for use in spectral classification is the homogeneity of light conditions. Any variation in light during data collection will require additional training and processing to produce classified products. To minimize the impact of variable light, surveys should be executed during overcast periods. This may seem counter intuitive since the seabed will appear brighter during sunny periods, however these bright periods also greatly increase the amount of light scattered by particles suspended in the water column and will result in hazy imagery. The best solution to maximize the capability of the UAV is to lower the camera shutter speed to maximize the exposure of the subject during a brief test flight. Once the camera exposure settings are established, they should be locked for the duration of the UAV flight, as variable exposure settings will create artificial differences in recorded light levels. To minimize the effects of light scattering within the water column, survey activities should be planned during slack low tides, after sediments have had time to fully precipitate. In practice, this is difficult to judge as field crews are often present to establish ground control, or clean the survey areas, and these activities suspend additional sediment. To minimize the impact of the field crews it is recommended that these activities are completed in advance of slack tide. Wind is a critical factor in the success of UAV data collection as it can produce several simultaneous deleterious effects, such as: i) reduced UAV battery life, ii) sun glint (image blowout) on the water surface, iii) seabed occlusion through specular reflection of the water surface, iv) bright caustics on the seabed, and v) increased particle suspension in the water column. To minimize these effects UAV survey activities should be restricted to periods where the observed wind speed is less than 5 km/hr. Finally, antecedent conditions should be considered when planning a flight in any area of interest. For example, if a heavy rainfall was observed before a scheduled flight a check should be made to ensure that water clarity conditions were not impacted by freshwater runoff.

The optimal environmental conditions for a UAV flight are during an overcast period, at slack low tide, where wind speed is less than 5 km/hr. The seasonal variations of confounding factors, such as *Ulva*, should steer the overall project planning windows.

### 5.1.2 UAV Platform and Camera Selection

NSCC-AGRG has assessed several DJI UAVs and noted key elements that are pertinent to successful data collection for photogrammetric processing and classification processes (Table 5.1). This assessment was limited to DJI platforms because NSCC-AGRG has found their products, service, and troubleshooting to be superior to other manufacturers such as 3DR, Swellpro, and SenseFly. Additionally, NSCC-AGRG has provided a breakdown of functional UAV resolutions for our products at various resolutions in an ancillary report: *NSCC UAV Resolution Assessments*. Advances in UAV technology have produced several unique options for data collection. NSCC-AGRG has identified two platforms that are expected to optimize the collection of high quality data in marine environments. The first option is the DJI Mavic 2 Pro, an affordable option that is compact, boasts a long battery life, and is equipped with a high-resolution Hasselblad HDR camera which is expected to perform well in seabed collections by capturing subtle differences in spectral reflection. The second option is the higher priced DJI Phantom 4 RTK that comes outfitted with real-time kinematic survey grade GPS which eliminates the need for ground control targets. The DJI Mavic 2 Pro is recommended for optimal data collection in areas that extend into marine environments. A backup UAV should be available to reduce the risk of equipment failure.

**Table 5.1: UAV characteristics highlighting survey capabilities. Includes additional models that were not used in the project. Approximate cost is in Canadian Dollars, and referenced from the Manufacturer's website. Weight value includes propellers and battery (but can vary with interchangeable batteries/cameras), and flight time is approximate (can vary with interchangeable batteries/cameras and survey conditions) in no wind conditions.**

| Model | Approx. Cost ($) | Weight (kg) | Compact Carry? | Flight Time (min/ batt) | Interchangeable Camera | Camera (MP) | Notes |
|---|---|---|---|---|---|---|---|
| DJI Mavic Pro Platinum | 1,300-1,700 | 0.743 | Yes | 30 | No | 12.35 | |
| DJI Mavic Air | 1,100-1,350 | 0.430 | Yes | 21 | No | 12 | |
| DJI Mavic 2 Pro | 2,000-2,550 | 0.907 | Yes | 31 | No | 20 | High Dynamic Range |
| DJI Mavic 2 Zoom | 1,650-2,225 | 0.905 | Yes | 31 | No | 12 | 2x optical zoom |
| DJI Matrice 100 | 4,500-8,000 | 2.3- 3.6 | No | 20 | Yes (Zenmuse Z3 base) | 12.4 | Developer platform |
| DJI Spark | 525-750 | 0.300 | Yes | 16 | No | 12 | |
| DJI Phantom 4 Adv. | 1,600-2,700 | 1.368 | No | 30 | No | 20 | |
| DJI Phantom 4 RTK | 10,000 | 1.391 | No | 30 | No | 20 | RTK Positioning |
| Inspire 1 Pro | 4,500-5,500 | 3.400 | No | 15 | Yes (Zenmuse X5 base) | 16 | |
| Inspire 2 | 4,000-26,800 | 3.440 | No | 23-27 | Yes | 20 - 24 | |

### 5.1.3 Signal Loss

Irish moss classification has proven to be difficult due to the complexity of the environment in which it exists. Irish moss has a distinctive purple hue comprised of red and blue components. This is a particularly difficult spectral signature to map in the Basin Head study area because the sediment throughout PEI is highly reflective in the red portion of the visible spectrum. The red spectral response of the seabed becomes increasingly similar to Irish moss as light travels through the water column scattering blue light that increases with depth. For this reason, classification of Irish moss within the channel presents additional data requirements and processing considerations. It has been stated that 90% of the Irish moss in the area occurs within the shallow water areas closer to shore. It is recommended that future data collections focus solely on shallow water moss and ignore the 10% of moss within the channel. This procedural change will give GIS technicians more time to focus on relevant classification training areas while avoiding confounding data, such as deep water purple signatures. Focusing on Shallow water areas will also reduce the reliance on elevation data when performing classification. NSCC-AGRG has shown that elevation data, and normalized height models, can be used to resolve confounding spectral signatures to a degree of success. However, reliance on elevation data can produce problems if inadequate ground control measures are taken during UAV data collection that result in erroneous computed elevations. To focus the consideration of depth, NSCC-AGRG has determined the extinction depths of distinct spectral signatures and photogrammetric elevation derivation for each UAV survey over the Main Bed area of interest (Table 5.2). It is evident that there is a complex interaction between environmental conditions, camera sensitivity, and UAV altitude when considering signal extinction. Since these interactions are largely unknown it is logical to choose a mitigation strategy that focuses on controllable components first, such as camera quality, followed by platform elevation, then attempt to optimize data collection during a good weather window.

To optimize classification efforts UAV missions should be planned at a minimum safe operating altitude, as low as 5 m above ground level, while avoiding obstructions such as trees and areas of high relief. This operating altitude maximize the spectral signal while ensuring that a moderately sized area of interest can be covered on a single 20-30 minute battery life. If an allowable proportion of Irish moss exists in the shallow water area, the scope of classification should be restricted to areas that are ~ 40 cm below the water surface at low tide.

**Table 5.2: Approximate depths at which signal is lost/unusable for each survey of Main bed. Both the spectral signature and break down of digital surface models are considered. Values are variable with light levels, water clarity and image quality, however, signal loss depths are fairly consistent between areas with similar light levels in each single survey.**

| | **Approximate Depth at which Signal is Lost** | | |
|---|---|---|---|
| | ZX5 | Mavic | Phantom |
| **UAV Collection Component** | (40 m ALT; 15 mm Pixel) | (30 m ALT; 10 mm Pixel) | (3 m ALT; 5 mm Pixel) |
| Spectral Response | 20 cm | 15 cm | 40 cm |
| Elevation Model | 50 cm | 30 cm | 75 cm |

## 5.2 Data Processing and Classification

Several software packages and workflows are required to collect, position, and classify UAV data. NSCC-AGRG has provided detailed methods on flight planning, photogrammetric processing, ground control, classification, and coverage calculations. The purchase prices of the software required to perform the work are listed in Table 5.3 (note that ESRI ArcMap is not included in the pricing, as they would not provide a standard quote).

**Table 5.3: Approximate software purchase costs (single license, perpetual).**

| Software | Cost (CAD) |
|---|---|
| Agisoft PhotoScan Professional | $3,499.00 |
| Pix4D Mapper | $6,680.00 |
| eCognition Developer | $25,050.00 |

NSCC-AGRG project results have demonstrated that the ESRI ArcMap maximum likelihood classification performs well when classifying Irish moss in imagery that was collected during acceptable atmospheric conditions. While it is the case that eCognition object-based classification produced inferior products, these products can be improved with additional training areas and refinement to rule parameters that could not be addressed within the scope of this project.

Classification validation was found to be difficult, as little validation data exist. NSCC-AGRG compared project results to field data collected within the Main bed area of interest in 2017 (n = 1). Ground truth data could not be compared to classification results on an observation by observation basis due to the mobility of the moss between monitoring activities, coupled with patchy nature of Irish moss distribution and accuracy limitations of the georeferencing approach. To support classification validation it is recommended that additional instruments are used to quantify Irish moss during a trial period to establish the viability of UAV data as a classification tool. Implementation of RTK enabled marine devices, such as the Biosonics MX singlebeam sonar habitat mapper, or the Teledyne RiverRay ADCP and camera system would provided valuable data to validate or disprove UAV results. It is also recommended that DFO consider using expert analysis to manually classify images in addition to using the automated techniques presented in this report. These manual classification datasets would provide valuable metrics on classification accuracies and would serve to validate or disprove classification algorithms during an assessment period.

## 5.3 Project Planning

The long term monitoring of Irish moss requires a sustainable data collection and product generation plan. While UAV data collection can be complex, NSCC-AGRG has presented several consideration and recommendations to maximize the likelihood of success. In addition to these general recommendations, there are several practical limitations to consider when monitoring Irish moss in the Basin Head MPA.

UAV regulations are rapidly changing and it is difficult to remain up-to-date on training and certification requirements. NSCC-AGRG has an active special flight operation certificate (SFOC) that allows the use of UAV platforms for commercial and research purposes. All of the NSCC owned UAVs are insured and certified to fly under the SFOC. NSCC-AGRG has several certified pilots that are able to legally operate the UAVs and understand restrictions and regulations enforced by Transport Canada. If it is the intention of DFO to have their staff conduct UAV surveys they will need to ensure that these items are addressed.

The time required to perform a single UAV survey is much longer than the planned flight time. Ground control must be established, the study area must be cleaned if Ulva is inhibitory to data collection, and the flight may take longer than expected due to technical issues and battery limitations. The minimum field time to conduct a survey in the Basin Head MPA is estimated to be 7 hours for an area roughly the size of Main bed. This window allows for four hours of ground control layout, flight planning, and site cleaning, two hours for UAV collection, and one hour for cleanup. It is standard practice to expect downtime due to weather during planned flights (200%) which increase the collection time for an area the size of main bed to 21 hours total. At the request of DFO, a data collection and processing estimate has been generated to evaluate the time and cost required to survey and process data for an area the size of Main bed (Table 5.4). Please note that these prices do not constitute a quotation and do not include tax, administrative overhead, or travel costs.

**Table 5.4: Estimates are for the processing of one UAV survey of one study area the size of Main bed (approximately 15,000 m$^2$). Values are highly variable depending on data resolution, survey area size, computer processing capabilities, processing settings, and user knowledge.**

| Processing Steps | Analysist Input (hrs) | Computer Processing (hrs) | NSCC-AGRG Cost ($) |
|---|---|---|---|
| UAV Data Collection | 21 | NA | $1,500 |
| Agisoft PhotoScan (Photogrammetry, Georeferencing, DSM and Orthomosaic creation) | 14 | 7 – 28 | $500 |
| Intermediate Products, NHM creation | 7 | 7 | $250 |
| eCognition Classification | 35 | 3 – 7 | $1,250 |
| ArcMap Classification | 14 | 1 – 2 | $500 |
| | | **Total:** | **$5,000** |

## 5.4 Summary

The following section summarizes the recommendations presented by NSCC-AGRG as they pertain to successful UAV data collection and Irish moss classification:

**Data Collection**

While local factors, such as *Ulva*, should steer the overall project planning window, the optimal environmental conditions for a UAV flight are during an overcast period, at slack low tide, where wind speed is less than 5 km/hr. Based on a review of available technology, the DJI Mavic 2 Pro is recommended for data collection in coastal marine environments.

Areas of interest should be established that do not exceed 15,000 $m^2$ and focus on Irish moss in shallow water areas while ignoring less abundant moss in deeper channels. UAV flights should be planned at a minimum safe operating altitude, as low as 5 m above ground level, while avoiding obstructions such as trees and areas of high relief.

**Processing and validation**

ESRI ArcMap maximum likelihood classification performs well when classifying Irish moss in imagery that was collected during acceptable atmospheric conditions. eCognition should continue to be considered as a viable classification tool, but requires additional research.

A trial assessment period should be established where additional equipment and experts are allocated to produce high-quality validation data to thoroughly assess the capacity of UAV data to provide Irish moss coverage estimates.

**Project Planning**

Transport Canada UAV regulations are changing rapidly and there are several requirements to legally operate a UAV for commercial or research purposes. NSCC-AGRG possess the required certification and follow Transport Canada restrictions as applicable to the NSCC SFOC. NSCC-AGRG can provide collection and processing services for roughly $5,000 (plus tax, administrative overhead, and travel) to cover an area the size of Main bed (15,000 $m^2$).

# 6 Acknowledgements

We would like to thank DFO Moncton for funding, DFO PEI for scientific guidance, and all students and volunteers for fieldwork support of this project. We would also like to acknowledge NSCC for administrative support of this project.

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