CANADIAN CENTRE for Climate Change and Adaptation

UNIVERSITY of Prince Edward ISLAND

ANNUAL REPORT

RPAS Erosion-Mitigating Infrastructure Monitoring of 8 Sites on Prince Edward Island

2021-2022

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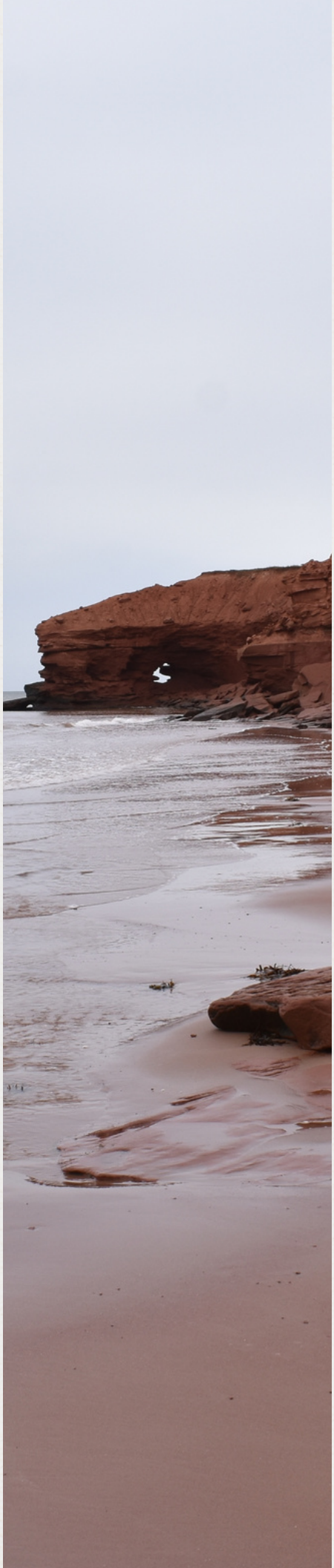
on behalf of Principal Investigator Dr. Adam Fenech



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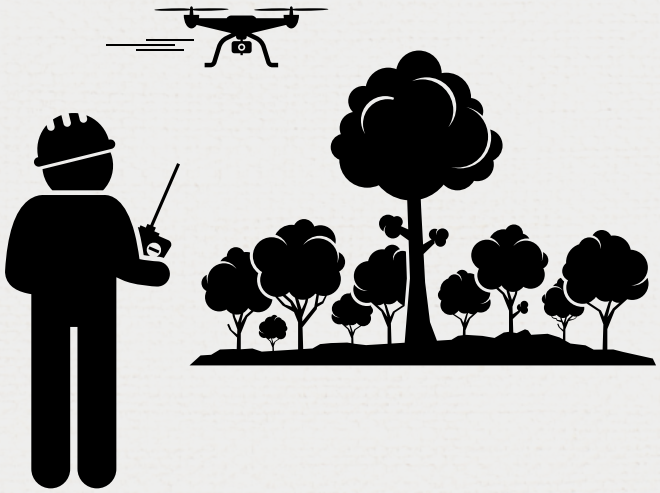


INTRODUCTION

The UPEI School of Climate Change and Adaptation, in collaboration with the Provincal goverment, has been collecting erosion-mitigating infrastrucutre data for 3 years. Monitoring takes place at 8 locations across PEI: Cape Traverse, Cedar Dunes & West Point Lighthouse, Crowbush golf course, Grand Tracadie beach, Jacques Cartier Provincial Park, Miminegash harbour, Panmure Island causeway, and Souris causeway.

During the 2022 data collection season, 14 flights took place between June 15th and November 25th. Spring/Summer and Fall flights took place for each of the 8 sites, except for Crowbush and Grand Tracadie which were only flown once (during the Fall) due to the golfing season and migratory bird restrictions in the National Park.

This was the first year to use a revised Methodology which included secondary areas of interest. The secondary areas of interest encompass a larger area and were flown, when feasible, during the Fall flights.

2022 was a unique flying year due to the arrival of Post Tropical Storm Fiona on September 23rd and 24th. All sites were flown Post-Fiona to document the coastal/infrastructure changes.

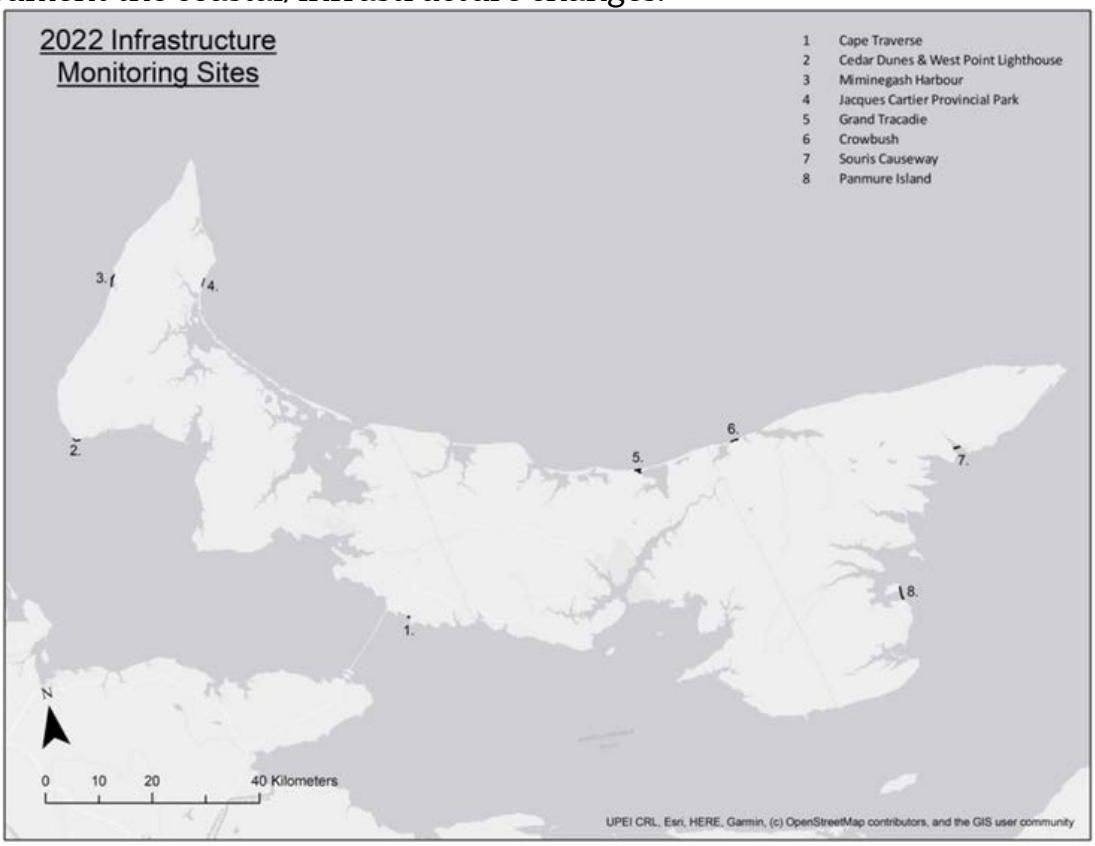


Fig 1. All current RPAS infrastructure monitoring locations

METHODS

Methods for the 2022 flying season were broken into 2 sections: Spring/Summer Flights and Fall Flights. The new methodology was provided in the summer, when Spring/Summer Flights were already underway using the original methodology, as such aspects of the new methodology was implemented during the Fall flights. The new Methodology is attached as an appendix to this report.

2.1 SPRING/SUMMER FLIGHTS

RPAS FLIGHT PROCEDURES

Between June 15th and August 22nd, RPAS flights were conducted at 6 of the 8 monitoring locations: Cape Traverse, Cedar Dunes & West Point Lighthouse, Jacques Cartier Provincial Park, Miminegash harbour, the Panmure Island causeway and Souris causeway. Crowbush could not be flown due to the golfing season, which created unsafe flying conditions (i.e. golfers were present within flight area, or there was risk of golf balls impacting RPAS), and Grand Tracadie could not be flown due to an RPAS restriction that was put in place by Parks Canada to protect migratory birds for the duration of the Spring/Summer.

Infrastructure Monitoring Locations	Date Flown
Cape Traverse	05-July-2022
Cedar Dunes and West Point Lighthouse	15-June-2022
Jacques Cartier Provincial Park	15-June-2022
Miminegash Harbour	22-August-2022
Panmure Island Causeway	16-June-2022
Souris Causeway	21-July-2022

Table 1. 2022 Spring/Summer RPAS flights

After programming the mission into the DJI Phantom 4 RTK, the weather forecast and the Notice to Airmen (NOTAMs) are checked to ensure the conditions are appropriate to fly. The DJI Phantom 4 RTK has a wind resistance of up to 36 km/hour - if the forecast calls for gusts above the 36 km/h, it is unsafe to fly. Additionally, if any NOTAMs restrict airspace for the area of the monitoring site, no flight is possible until the NOTAM is removed. For any flights within the National Park, permission must be coordinated beforehand.

RPAS pilots must assess whether a site is safe and legal to fly. Conditions that could pose problems include:

- damage to the RPAS;
- precipitation;
- high winds;
- issues with "line of sight" (i.e. obstacles blocking observer/pilot from seeing RPAS); or
- people present in the flight area.
- tide times (low tide is preferred)

Even with an Advanced RPAS Pilot Certificate, it is illegal to fly a DJI Phantom 4 RTK directly above someone. If it is safe and legal to fly, Ground Control Points (GCPs) are distributed throughout the site.

Fig 2. Danisha Saminathen using a Trimble Geo7x to mark the center point of a GCP

RPAS pilots make an effort to lay GCPs near the corners of the survey, at different elevations. At least 3 GCPs are required for data processing, but generally around 15-25 GCPS are used. Pilots measure and record the center points of these GCPs using a Trimble Geo7x survey-grade RTK unit connected to the Cansel network, which provides a horizontal accuracy of 1-4 cm, and a vertical accuracy of 2-8 cm. In areas with poor cellular connection these accuracies decrease. These points will eventually be used during the data processing stage to increase the accuracy of the final products (orthomosaic, digital surface model).

Once the GCPs are laid, the RPAS flight can begin. The DJI Phantom 4 RTK has on-board RTK, so if a strong cellular connection is available, a WiFi hot spot can be created using an available cell phone, to which the RPAS connects to and waits for the RTK to lock. Once connected, the RTK connection allows the RPAS to tag the resulting photos with accurate locations, generally within 2-4 cm accuracy. While on-board RTK can deliver excellent horizontal (X,Y) accuracy, the vertical accuracy (Z) is often less than desired, so GCPs are still used to improve vertical accuracy. In some areas of PEI, most notably areas along the Western coast and along the North shore of Kings County, cellular connection is often too poor to connect to RTK. Once RTK has been connected or turned off due to connection issues, the RPAS pilot uploads the flight plan and launches the RPAS. The RPAS flies the pre-programmed mission while the pilot monitors the remote controller screen and a visual observer keeps visual contact on the RPAS. The RPAS pilot and the visual observer communicate via walkie-talkies and stay connected throughout the flight to provide constant updates. Once the programmed flight finishes, the pilot then takes manual control and takes a series of oblique photos, which are photos taken at a 60-70 degree angle. Nadir photos are also taken during the mission, at around 90 degrees.

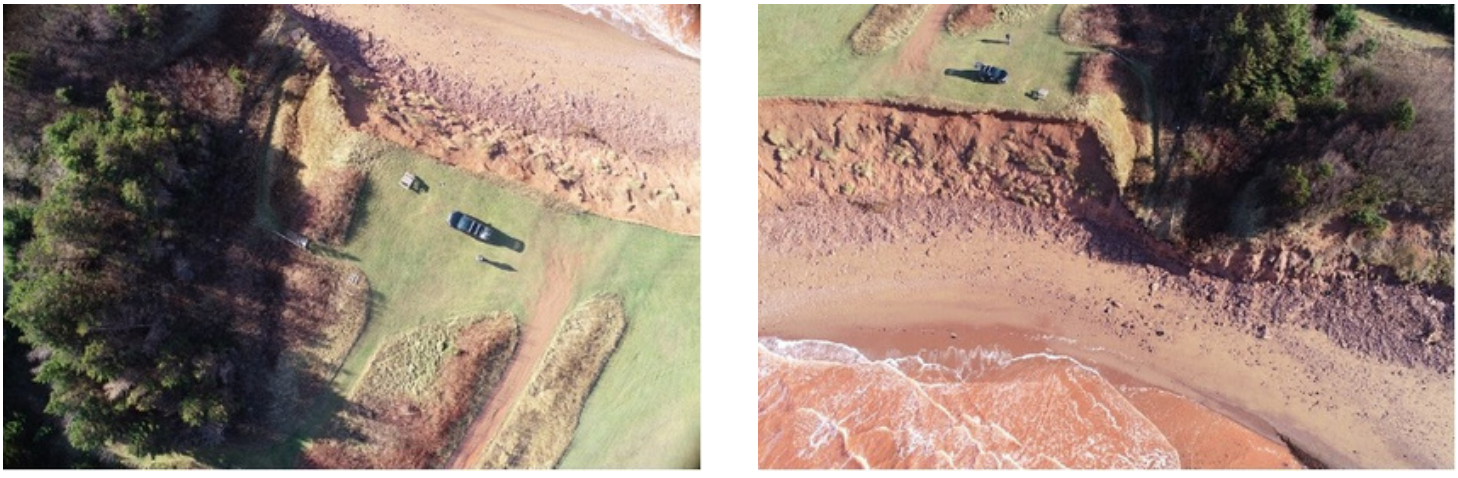


Fig 3. Nadir photo (left) vs. Oblique photo (right)

2.2 IMAGE PROCESSING

The captured imagery from an RPAS flight is stored on an onboard micro-SD card in the DJI Phantom 4 RTK. Once back in the office, imagery is downloaded from the SD card and organized. The GCP points taken by the Trimble Geo7x are then processed into the proper coordinate system (NAD 83 CSRS Prince Edward Island, Mean Sea Level) using Trimble Pathfinder Office software which exports the data as a Microsoft Excel CSV file. The imagery and the CSV file are then loaded into Pix4D Mapper photogrammetry software and processed using the 3D Maps option in order to generate a geo-referenced orthomosaic (high resolution stitched master image), a digital surface model (displays elevation), as well as other outputs such as point cloud and 3D mesh data. In order to incorporate the GCP data, the user must use the GCP Editor tool in Pix4D to manually mark the center of each GCP at least 10 times. Once processing finishes, a quality report is generated that shows the GCP accuracy.

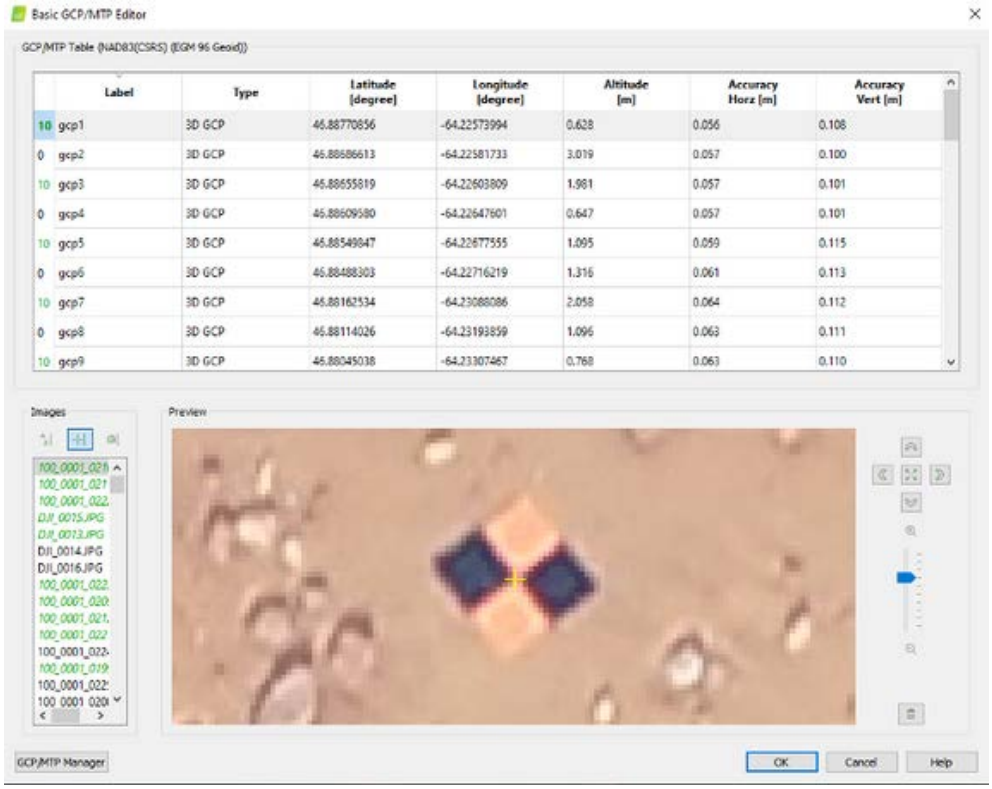


Fig 4. Marking GCPs using the GCP Editor tool in Pix4D Mapper

Quality Check

Images	median of 61706 keypoints per image	✓
Dataset	186 out of 186 images calibrated (100%), all images enabled	✓
Camera Optimization	0.31% relative difference between initial and optimized internal camera parameters	✓
Matching	median of 15407.3 matches per calibrated image	✓
Georeferencing	yes, 5 GCPs (5 3D), mean RMS error = 0.011 m	✓

Fig 5. Quality Check provided in Pix4D Quality Report

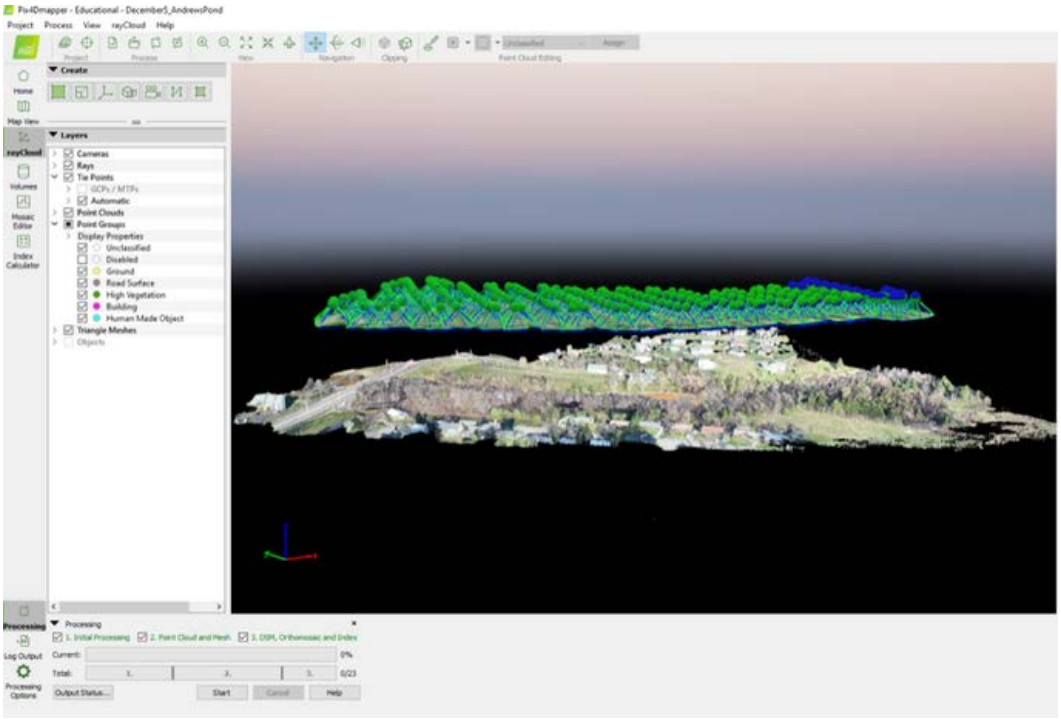


Fig 6. Pix4D Mapper software showing 3D model created from RPAS imagery

2.3 COASTLINE DELINEATION AND DSAS

Once the imagery processing is complete, coastlines must be manually delineated (traced) in GIS. Coastlines are created in the form of shapefiles and are drawn at a 1:40 ratio to ensure the delineator is properly zoomed in on the coast and that all coastlines are delineated at the same resolution. As the coastlines are delineated, the coastlines are assigned accuracies using a scale from 1-4, with 1 being high confidence and 4 being low confidence.

The classification scheme, which indicates the digitizer's confidence, is as follows:

1. **Obvious (discrete) erosion-induced boundaries between vegetation and Land** using orthomosaic. Cliff lines are usually distinct (within 3-5 image pixels) and easily identifiable. These coastline traces are given an accuracy of either 1 or 2 based on feature clarity.
2. **Fuzzy erosion-induced boundaries between short vegetation (non-treed) and Land** using orthomosaic and DSM. Cliff line trends are obvious but longer grass or smaller vegetated sinkholes not easily detectable in the DSM, which makes distinguishing the coastline more difficult. Coastline traces follow the trend in coastline as opposed to actual features, therefore protruding grass and inset potholes may sometimes be omitted. Generally, accuracy of the trace is typically 5-10 image pixels from the features omitted in the trace (grass/potholes). These coastline traces are given an accuracy of either 2 or 3 based on feature clarity.
3. **Fuzzy boundaries in vegetation along sand dunes** using orthomosaic and DSM. If vegetation is present, fuzzy erosion estimate is used where the coastline was traced along the trend of line separating sand from a mostly continuous vegetation layer. If no vegetation was observed but a definite erosion induced line was observed in combination of the orthomosaic and DSM, this line is used. Depending on the relief of the feature or the continuity of the vegetation-beach boundary, the accuracy of the coastline trace varies from 5-30 image pixels and is given an accuracy of 2-4.
4. **Fuzzy erosion-induced boundaries between large vegetation (treed) and Land** using orthomosaic. Coastline traces follow the trend in coastline as opposed to actual features, therefore entire trees or areas under tree foliage could be omitted or included. Accuracy generally is +20 image pixels from actual features (trees). These coastline traces are generally given an accuracy of 4.

Coastline Digitization Accuracy Estimation:

Acc = 1: Tracing error < 5 cm Acc = 2: Tracing error < 10 cm

Acc = 3: Tracing error 10 – 20 cm Acc = 4: Tracing error > 20 cm

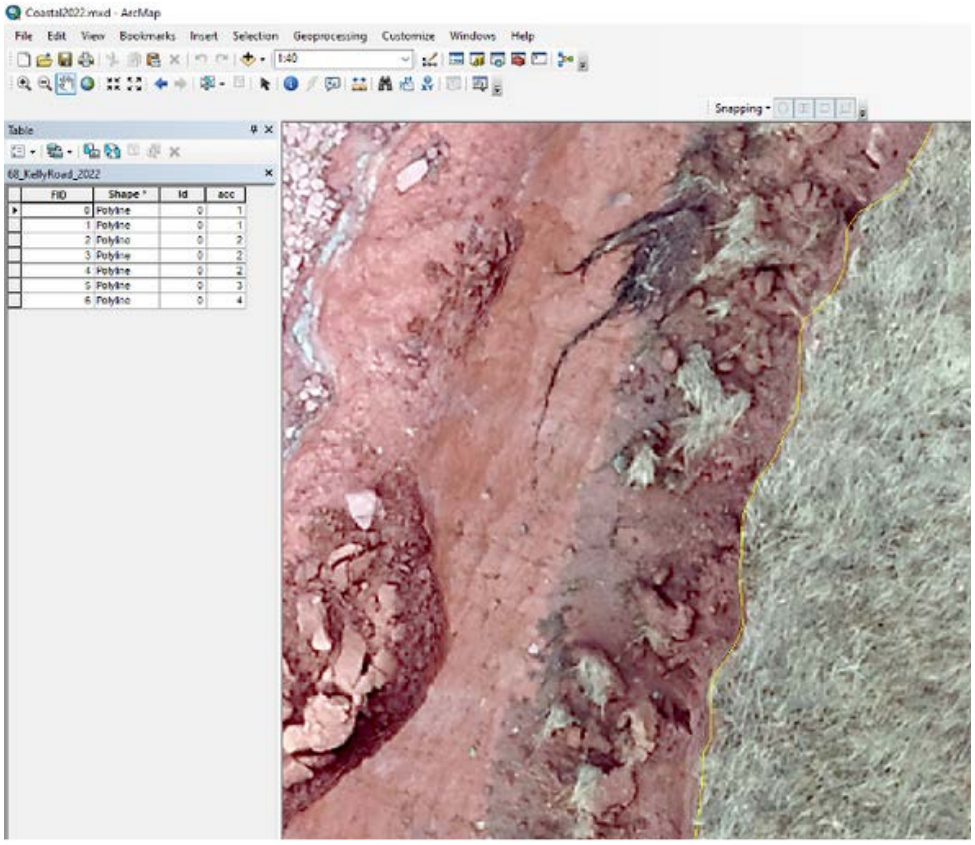


Fig 7. Delineating coastline within ArcGIS

Once all the coastlines are drawn, Digital Shoreline Analysis System (DSAS), a GIS tool, is used to perform an analysis on all delineated coastlines for a site. This process quantifies the Rate of Change (RoC) and Net Shoreline Movement (NSM) by creating and measuring transects that run between all delineated coastlines. Transects are created for every 2 meters of coastline, meaning an erosion measurement is taken every 2 meters.

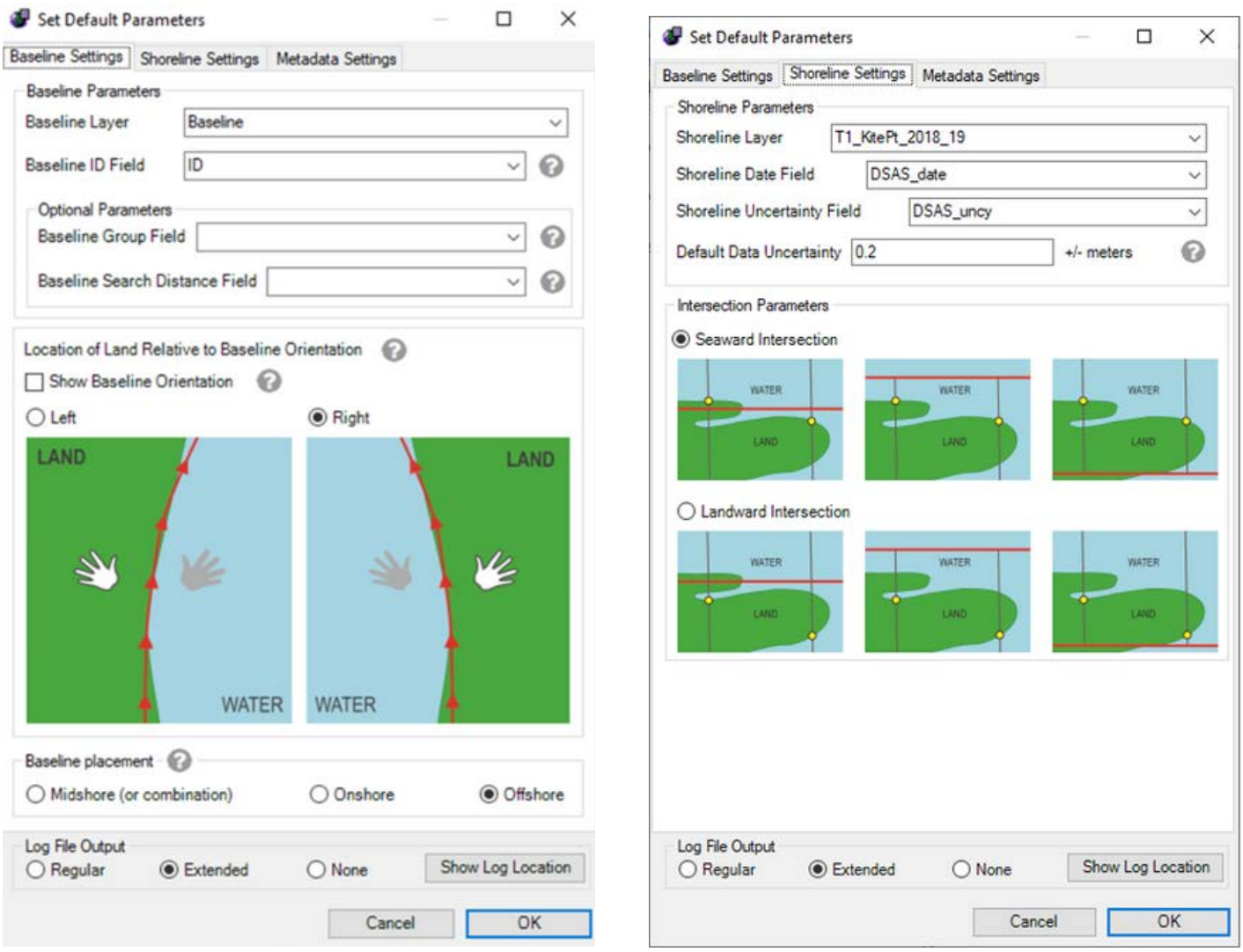
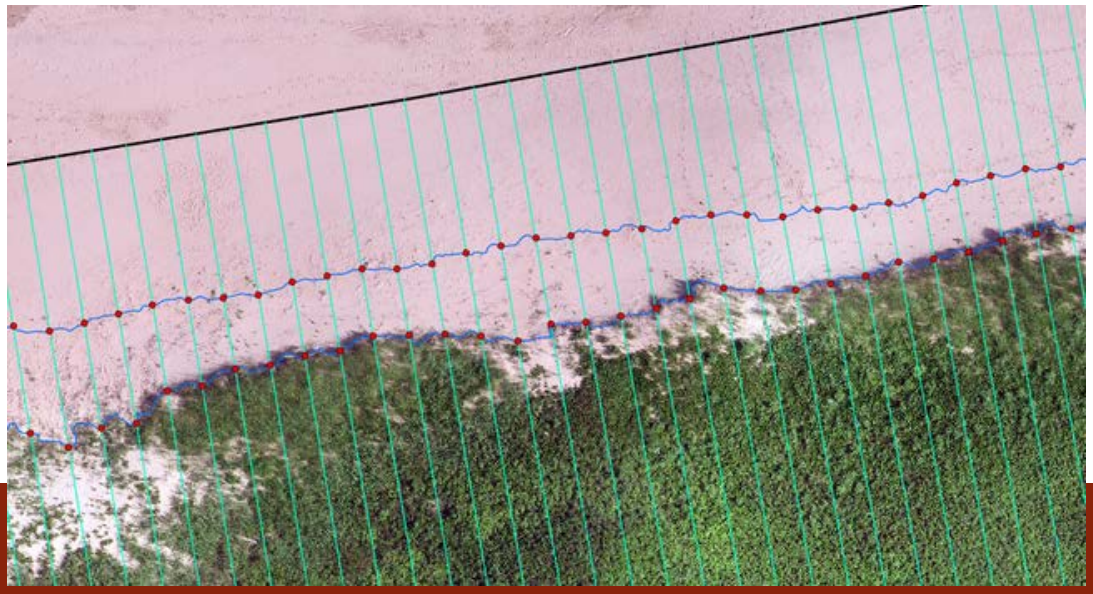


Fig 8. Setting parameters in DSAS (above) and creating transects (below)



2.2 FALL FLIGHTS

Between October 12th and November 25th, RPAS flights were conducted at all 8 infrastructure monitoring locations.

As per the Methodology, all Fall flights were processed at high resolution and used a GSD (Ground Sampling Distance) of 3 cm/pixel.

Deviations from the proposed Methodology are outlined in Section 4.2.

For a complete Methodology, please refer to the 2022 Infrastructure Monitoring Methodology document that is included as an appendix in this report.

Infrastructure Monitoring Locations	Date Flown
Cape Traverse	31-October-2022
Cedar Dunes and West Point Lighthouse	12-October-2022
Crowbush	11-November-2022
Grand Tracadie Beach	15-November-2022
Jacques Cartier Provincial Park	26-October-2022
Miminegash Harbour	25-November-2022
Panmure Island Causeway	20-October-2022
Souris Causeway	19-November-2022

Table 2. 2022 Fall RPAS flights

RESULTS

3.1 COASTAL CHANGE ANALYIS AND OUTPUT MAPS

Output maps are created using the imagery generated by Pix4D and the results generated by DSAS.

Output maps show all previous years' coastlines. All coastlines are viewable in the centre of the map, and each coastline is given its own colour, which is listed on the top left of the map. The transects are also shown on these maps and are colourized to reflect its Rate of Change (RoC). The colouring scheme for the transects is listed on the left side of the map, with Red indicating losses (erosion) over 1.5 meters and Blue indicating gains (accretion) over 1.5 meters, with a variety of colours/rates in between.

On the right side of the map, the site name, shore type, rate of change (per year), number of measurements (transects), site length and Net Shore Movement (NSM), are viewable. The NSM reflects the total amount of change over the site's history of RPAS monitoring.

Finally, low-resolution orthomosaics of each of the previous years' flights are shown at the bottom of the map.

As all sites were flown prior to and following Post Tropical Storm Fiona the main image on the the output map is of the site following the storm.

It is important to understand the difference between **EPR (End Point Rate)** and **NSM (Net Shoreline Movement)**. EPR is the annual rate of change (m/year) and is calculated through dividing the distance between coastlines by the time elapsed between aerial imagery. The NSM is simply the distance (in meters) between the two coastlines in question.

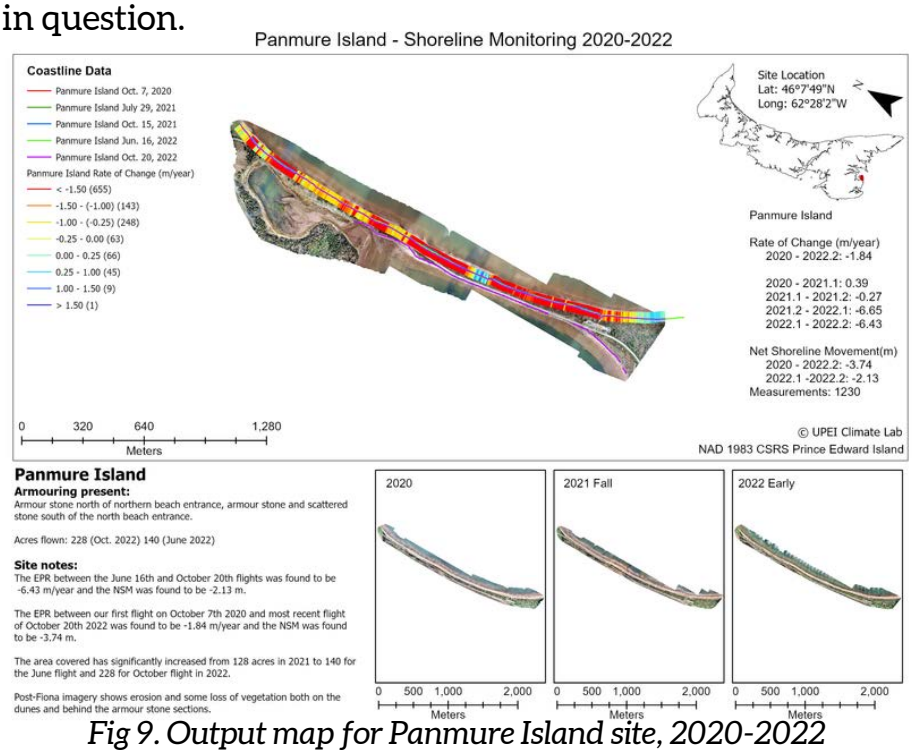


Fig 9. Output map for Panmure Island site, 2020-2022

CAPE TRAVERSE

Dates flown: July 5th, October 31st
Area flown: 22 acres (July), 260 acres (October)

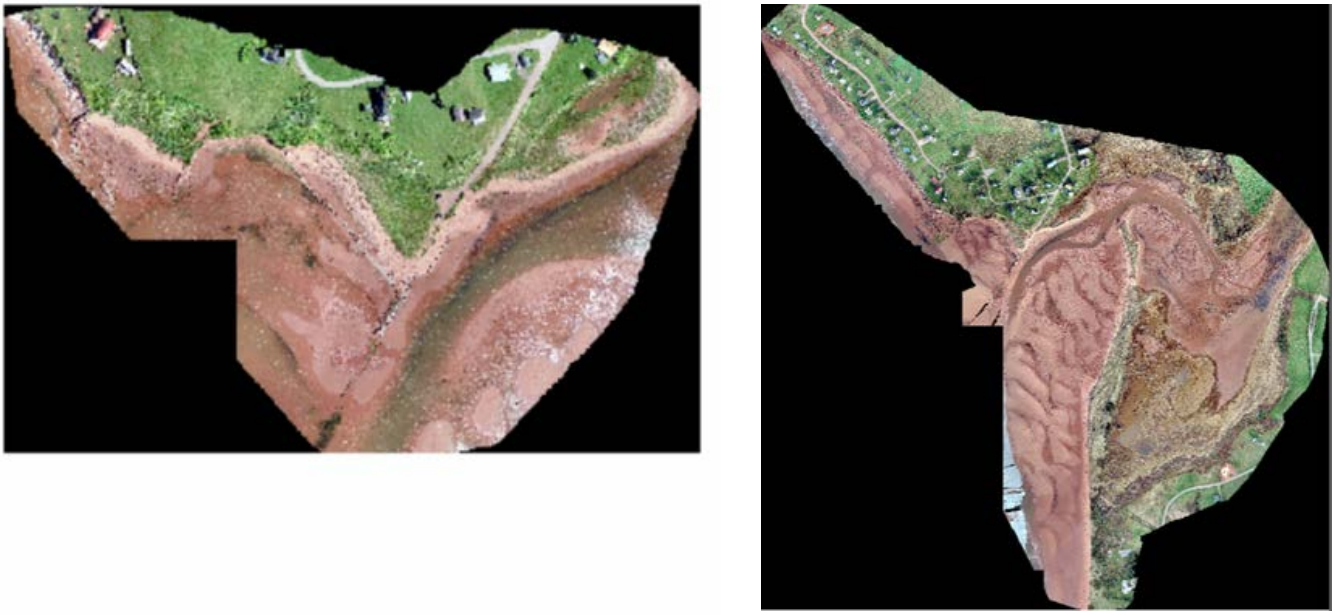


Fig 10. Othomosaics of Cape Traverse from July 5th and October 31st RPAS flights

Armouring present:
Cement blocks surrounding point and continuing west, scattered rip rap on eastern side of access road and on western end of site.

Site notes:

- A much larger area was flown and delineated Post-Fiona.
- The new area includes a wetland/saltmarsh - this could be a good area to monitor for coastal squeeze/saltmarsh migration.
- Erosion appears to be occurring behind the armour stone.
- Armour stone has scattered in some areas.

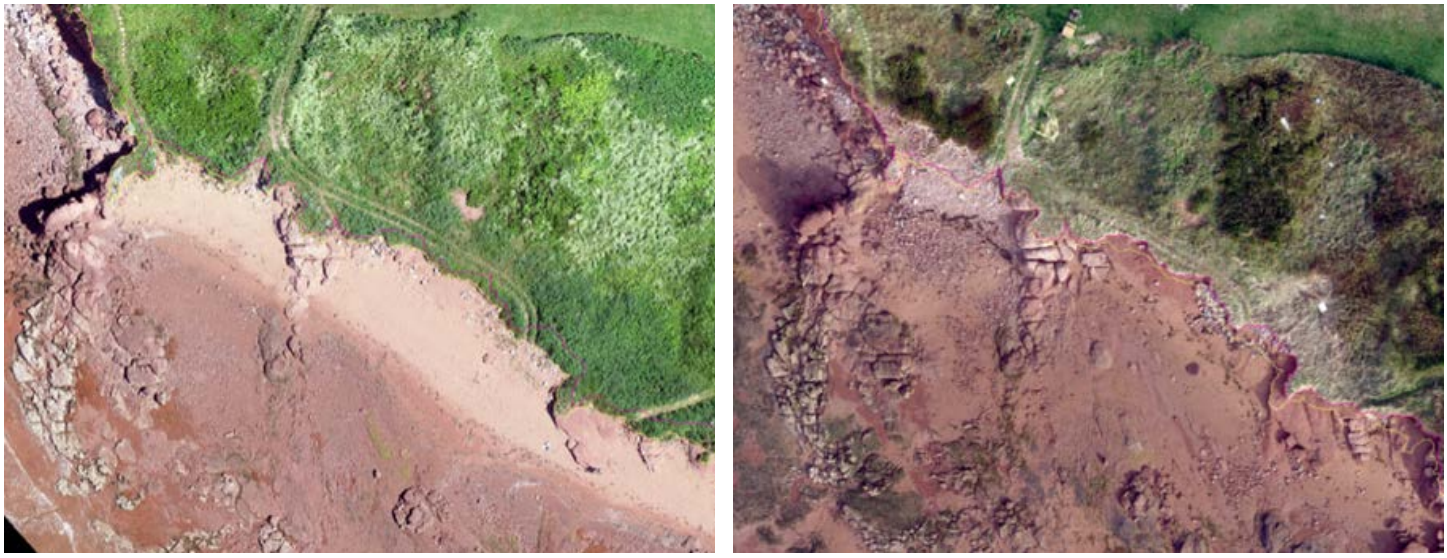


Fig 11. Section of Cape Traverse coastline from July (left) and October (right) showing coastal changes

DSAS Results/Output Map:

In 2022, the EPR between the July 5th and October 31st flights is -3.54 m/year and the NSM is -1.14 m.
The EPR between the first flight on October 5th 2020 and the most recent flight on October 31st 2022 is -0.92 m/year and the NSM is -1.91m.

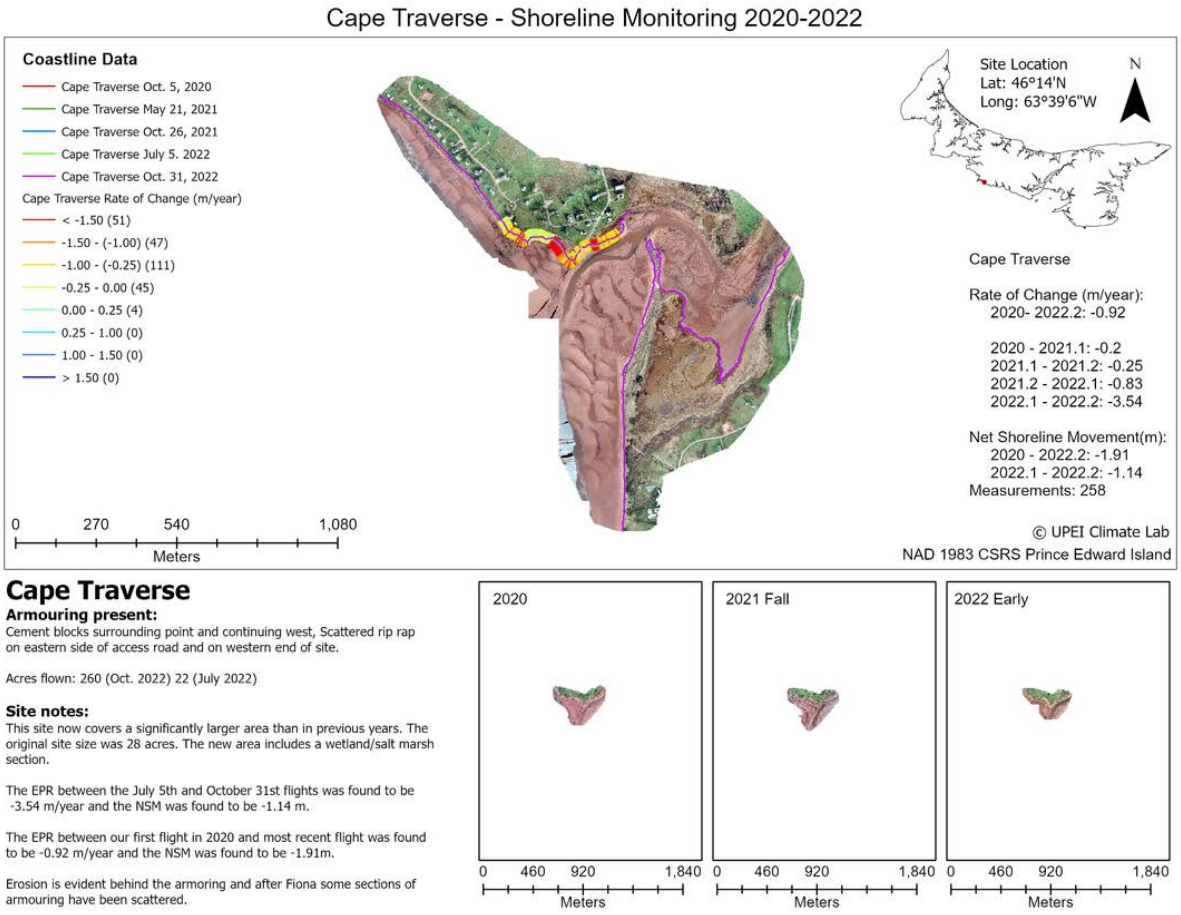


Fig 12. Output map for Cape Traverse site, from 2020-2022

CEDAR DUNES AND WEST POINT LIGHTHOUSE

Dates flown: June 15th, October 12th
Area flown: 68 acres (June), 117 acres (October)

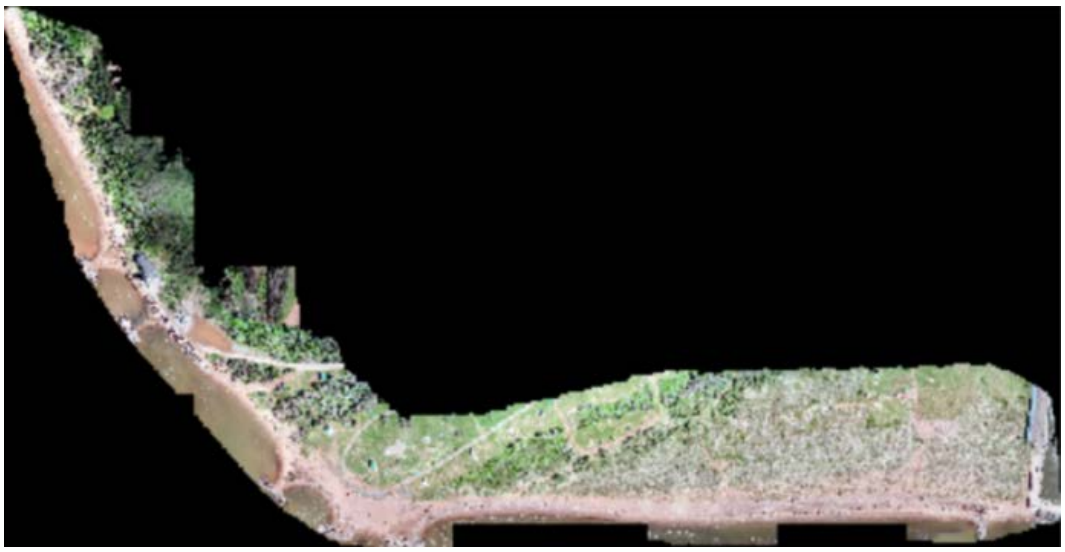


Fig 13. Orthomosaic of Cedar Dunes &West Point Lighthouse from June 15th RPAS flight

Fig 14. Orthomosaic of Cedar Dunes &West Point Lighthouse from October 12th RPAS flight

Armouring present:
Seawall with rip rap, armour stone immediately west of seawall, armour stone (with cement barricade) immediately west of seawall. 6 breakwaters (coastal reefs) were installed in 2021.

Site notes:

- A larger area was flown and delineated Post-Fiona, including the harbour.
- No significant changes from October 2021 - June 2022.
- Some marram grass growth from October 2021 – June 2022.
- There was significant erosion and loss of vegetation post-Fiona.
- Nearly 30m of change from June 2022 - October 2022 in some areas.
- There appears to be some sand accumulation near the coastal reefs (breakwaters).
- Significant erosion occurred around a facilities building which now appears to be on the new beach area and is located behind the coastal reef installation.

Fig 15. Section of Cedar Dunes coastline from June (left) and October (right) showing coastal changes

DSAS Results/Output Map:

In 2022, the EPR between the June 15th and October 12th flights is -16.01 m/year and the NSM is -5.22 m.
The EPR between the first flight on September 25th 2020 and the most recent flight on October 12th 2022 is -2.86 m/year and the NSM is -5.85 m.

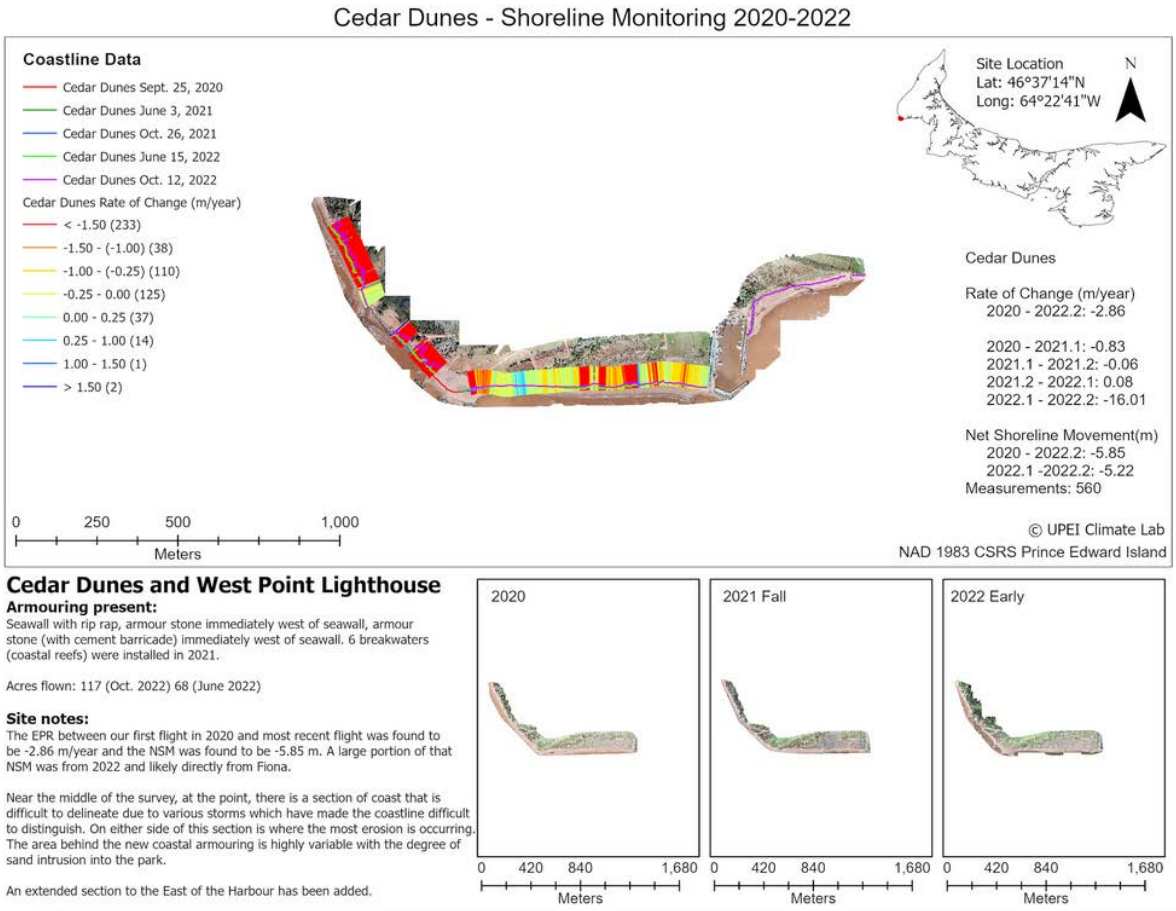


Fig 16. Output map for Cedar Dunes site, from 2020-2022

CROWBUSH

Dates flown: November 11th
Area flown: 145 acres

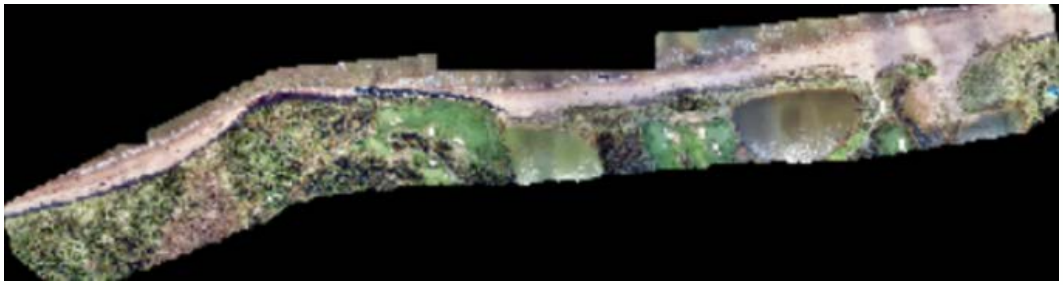


Fig 17. Orthomosaic of Crowbush from October 20th 2021 RPAS flight

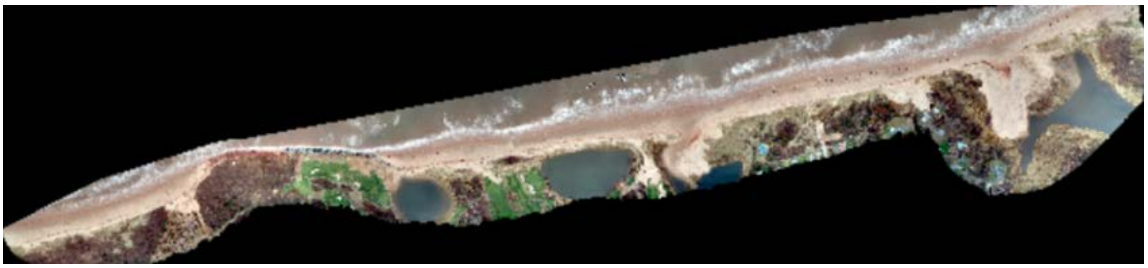


Fig 18. Orthomosaic of Crowbush from November 11th 2022 RPAS flight

Armouring present:
Armour stone protecting section of Crowbush golf course.

Site notes:

- A larger area was flown and delineated in 2022.
- Crowbush experienced significant erosion Post-Fiona.
- Erosion appears to have occurred behind the armour stone.
- Consistent significant erosion along the entire stretch of the coastline.
- The extended Western section requested within the new Methodology could not be flown due to lack of access (ie. road washout from Post Tropical Storm Fiona).
- The consistent presence of golfers makes this site difficult to fly before late Fall.

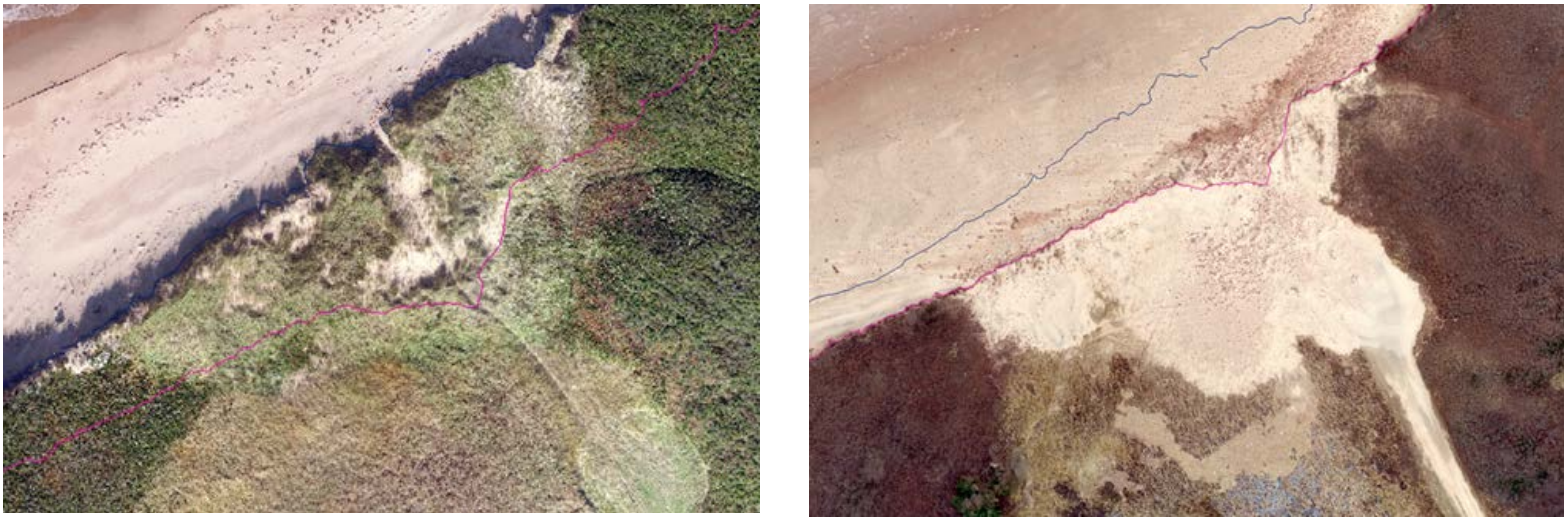


Fig 19. Section of Crowbush coastline from 2021 (left) and 2022 (right) showing coastal changes

DSAS Results/Output Map:

Between the October 20th 2021 flight and November 11th 2022 flight, the EPR is -9.04 m/year and the NSM is -9.27 m.

The EPR between the first flight on October 13th 2020 and most recent flight on November 11th 2022 is -4.24 m/year and the NSM is -8.81 m.

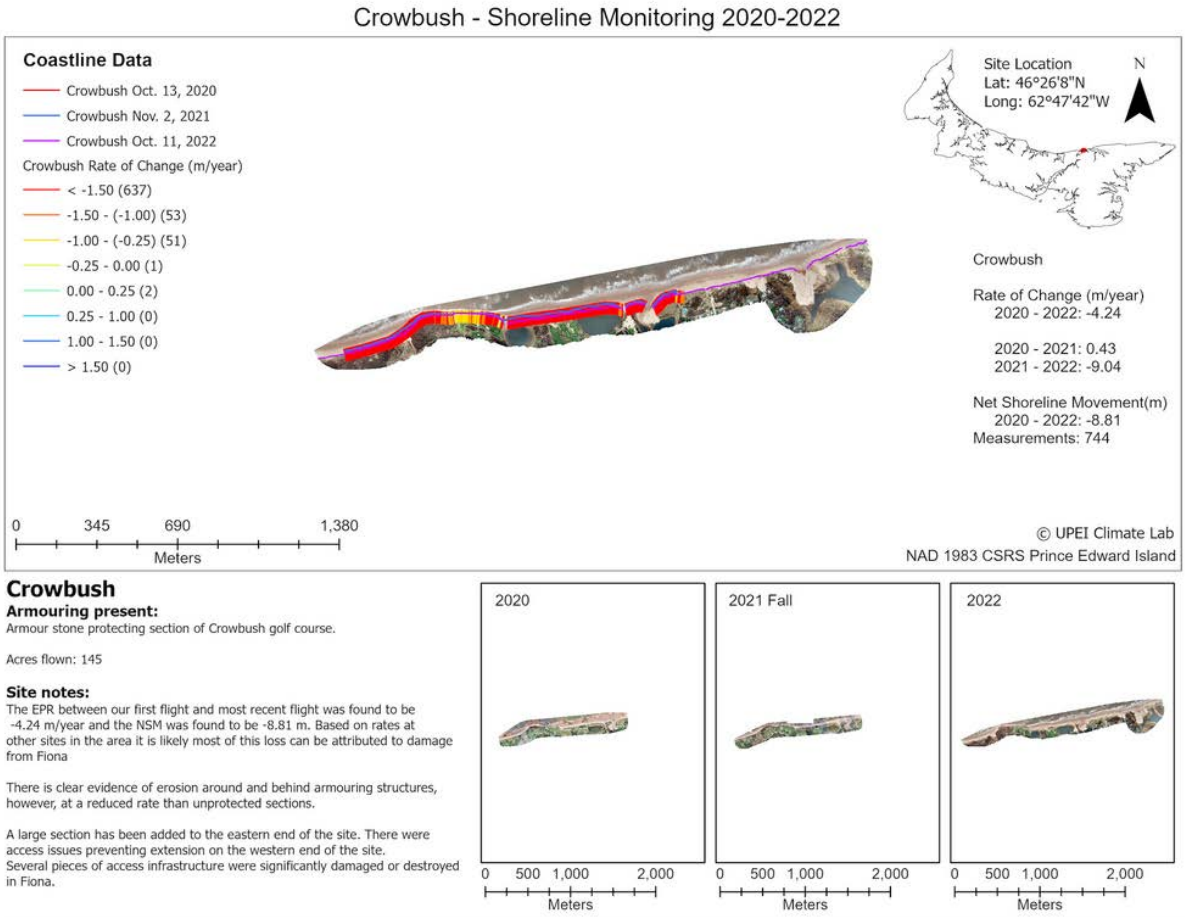


Fig 20. Output map for Crowbush site, from 2020-2022

GRAND TRACADIE

Dates flown: November 15th
Area flown: 214 acres

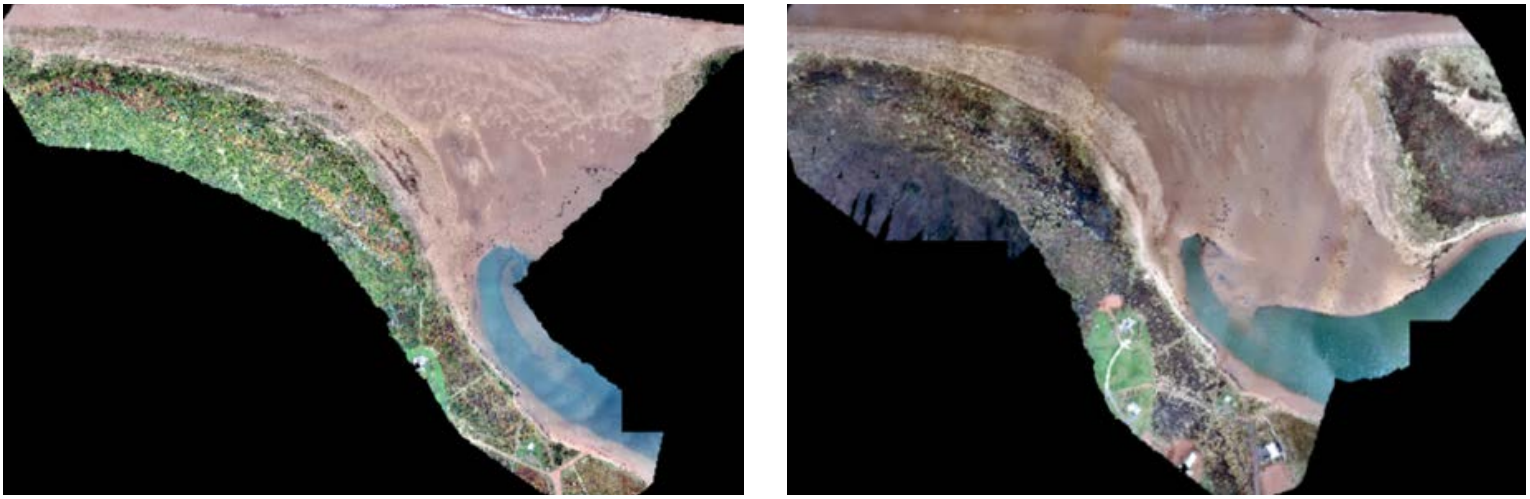


Fig 21. Orthomosaics of Grand Tracadie from October 19th 2021 (left) and November 15th 2022 (right)

Armouring present:
Armour stone sections (2) west of the main beach entrance.

Site notes:

- A larger area was flown and delineated in 2022
- The extended eastern section that was requested, including the harbour, was intended to be flown but unexpected precipitation caused the flight to end prematurely. This extended area will be flown in future years.
- This beach is very popular, so effort should be made to fly during the early Spring and late Fall to avoid beach-goers
- RPAS restrictions are often in place from Parks Canada for this site due to the presence of migratory birds
- Some erosion and vegetation loss behind the armouring

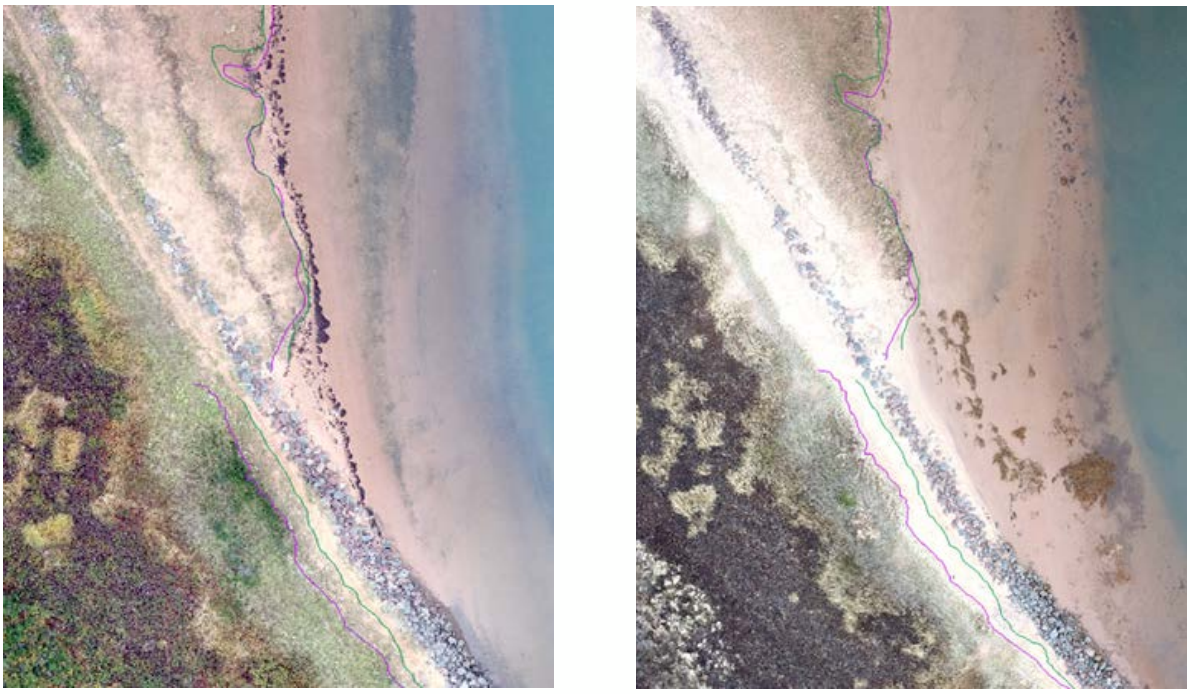


Fig 22. Sections of Tracadie coastline from 2021 (left) and 2022 (right) RPAS flights showing coastal changes

DSAS Results/Output Map:

Between our June 21st 2021 flight and our November 15th 2022 flight, the EPR is -2.21 m/year and the NSM is -2.37 m.

The EPR between our first flight on October 13th 2020 and most recent flight November 15th 2022 is -1.03 m/year and the NSM is -2.16 m.

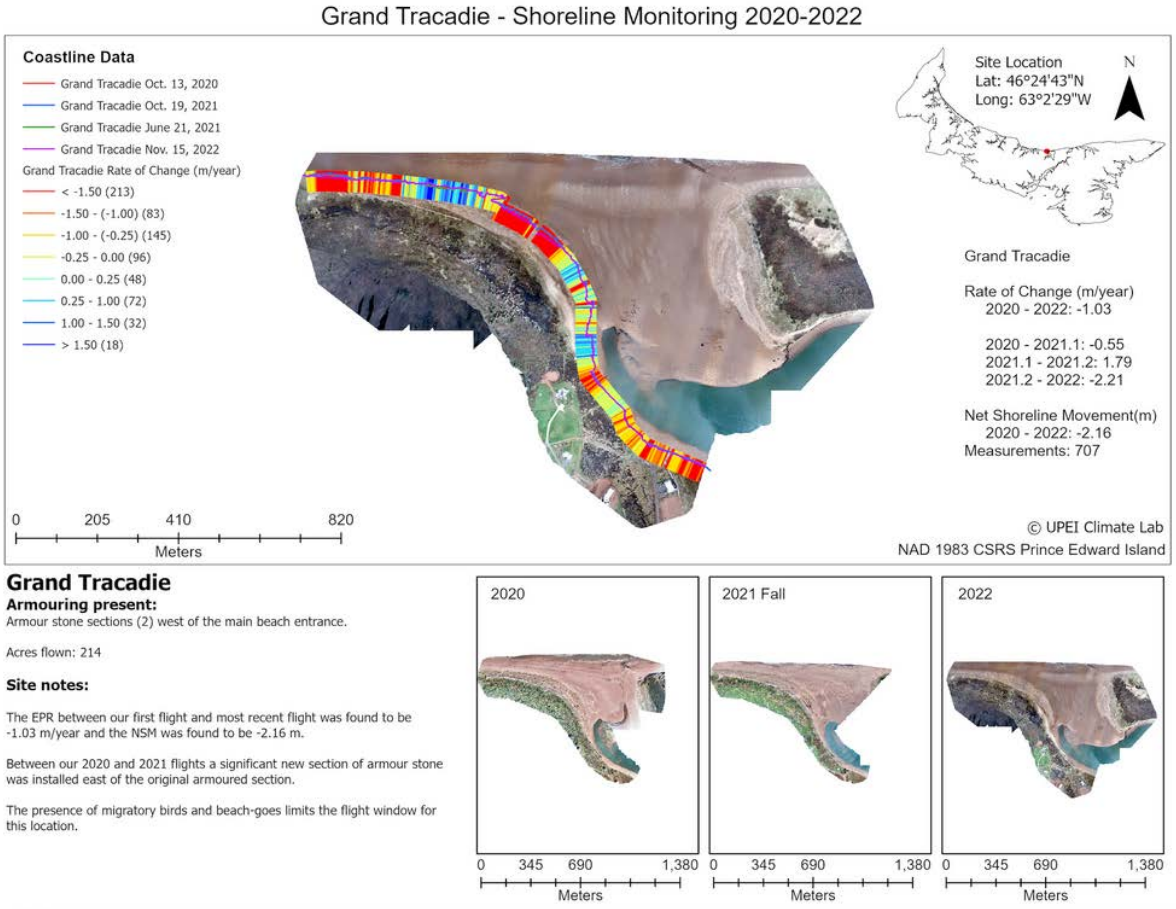


Fig 23. Output map for Grand Tracadie site, from 2020-2022

JACQUES CARTIER PROVINCIAL PARK

Dates flown: June 15th, October 26th
Area flown: 69 acres (June), 100 acres (October)

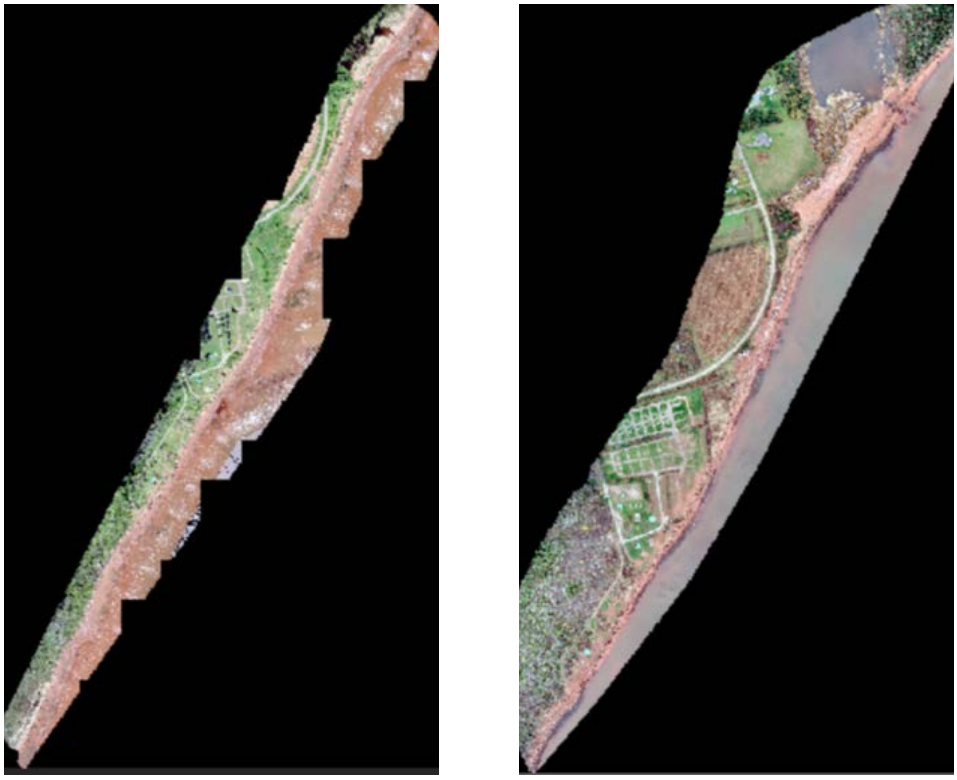


Fig 24. Orthomosaics of Jacques Cartier park from June 15th (left) and October 26th (right) RPAS flights

Armouring present:
Armour stone for the majority of the site, seawall at northern end of site with rip rap; scattered rip rap at southern end of site.

Site notes:

- A larger area was flown and delineated in 2022.
- Consistent erosion from October 2021 - June 2022.
- Significant erosion Post-Fiona, on the west side of the armouring.
- Significant vegetation loss Post-Fiona.
- Some armour stone moved Post-Fiona.
- New suggested study area has shortened the southern extent of the site, which should be restored to its original extent as this area has experienced significant erosion in previous years and is worth monitoring.
- A small facilities building and armour stone appear to have moved during the Post Tropical Storm Fiona.

Fig 25. Section of Jacques Cartier coastline from June 15th (left) and October 26th (right) showing movement of facilities building

DSAS Results/Output Map:

For our 2022 flights, the EPR between the June 15th and October 26th flights is -6.93 m/year and the NSM is -2.75 m.

The EPR between our first flight on October 2nd 2020 and most recent flight of October 26th 2022 is -1.59 m/year and the NSM is -3.29m.

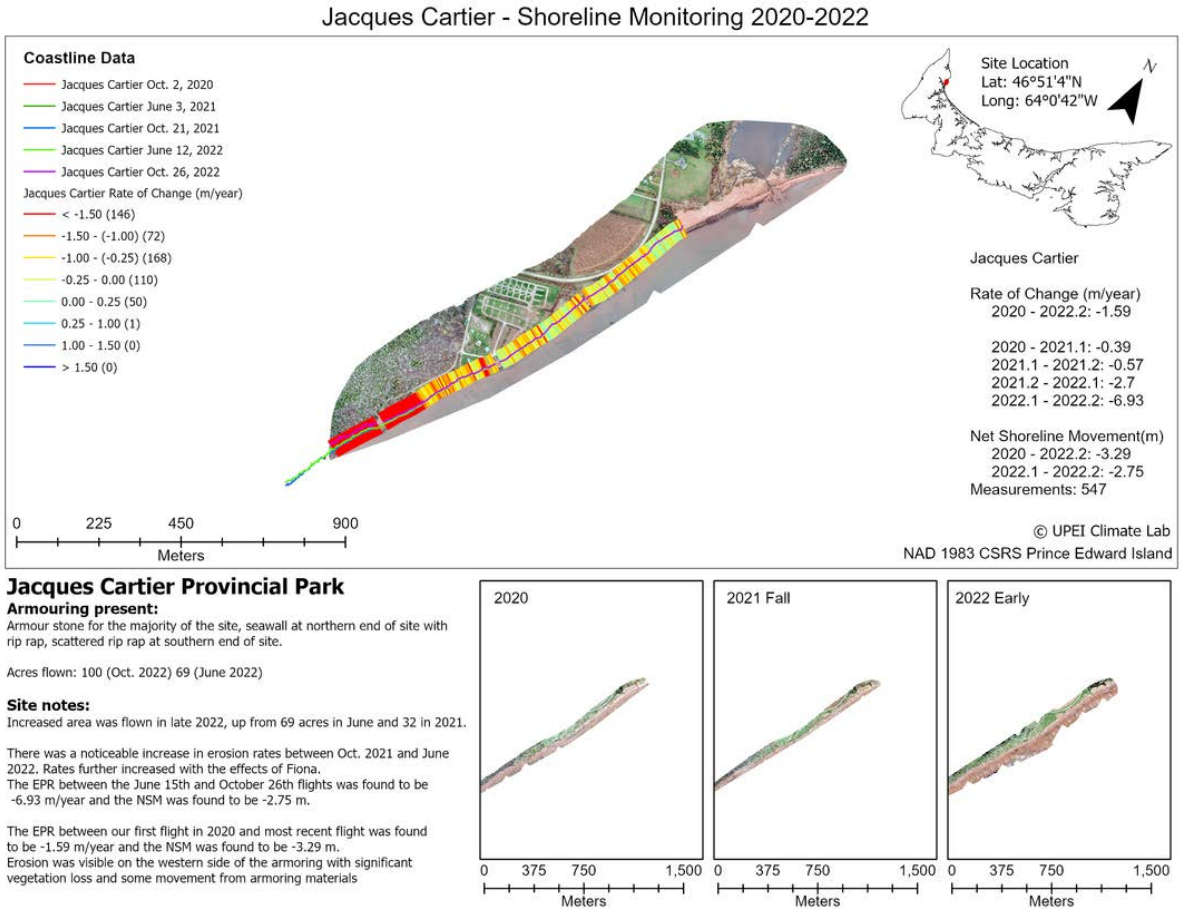


Fig 26. Output map for Jacques Cartier site, from 2020-2022

MIMINEGASH

Dates flown: August 22nd, November 25th
Area flown: 121 acres (August), 248 acres (November)

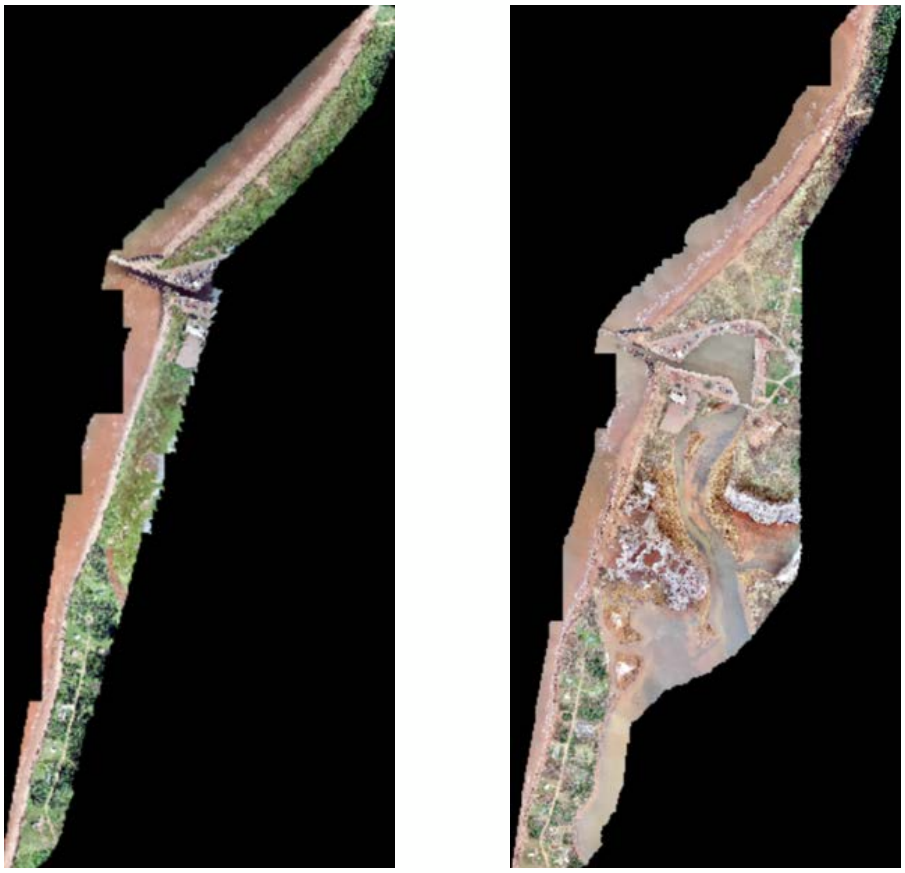


Fig 27. Orthomosaics of Miminegash from August 22nd (left) and November 25th (right) RPAS flights

Armouring present:
Armour stone at the northern beach entrance; armour stone sections (2) on either side of the channel leading out of the harbour; scattered stone and cement throughout middle/southern end of site; and armour stone protecting several private properties at southern end.

Site notes:

- Much larger area flown and delineated Post-Fiona.
- Due to the size of the area, this site is flown in 2 sections (North, South).
- Due to the amount of time required to fly this expanded area, shifting tides can create an issue with flying the entire area at low tide.
- Significant erosion appears to have occurred behind the armour stone (~9 meters in certain areas).
- Some movement and loss of armour stone was observed Post-Fiona.
- Consistent, significant erosion along the entire study area was observed Post-Fiona.

Fig 28. Section of Miminegash coastline from August (left) and November (right) RPAS flights showing coastal changes

DSAS Results/ Output Map:

For our 2022 flights, the EPR between the August 22nd and November 25th flights is -25.68 m/year and the NSM is -6.68 m.

The EPR between our first flight on October 2nd 2020 and most recent flight of November 25th 2022 is -3.0 m/year and the NSM is -6.44 m.

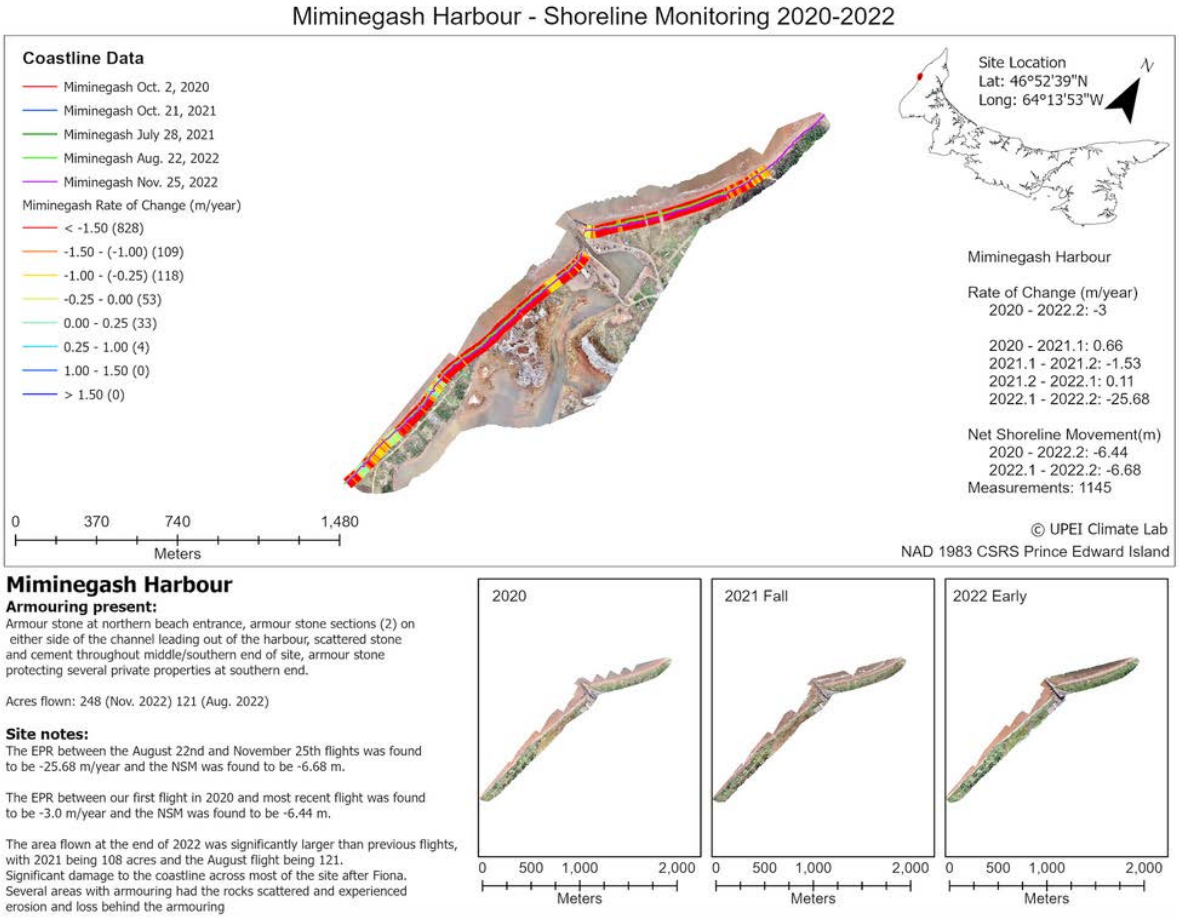


Fig 29. Output map for Miminegash site, from 2020-2022

PANMURE ISLAND

Dates flown: June 16th, October 20th
Area flown: 140 acres (June), 228 acres (October)

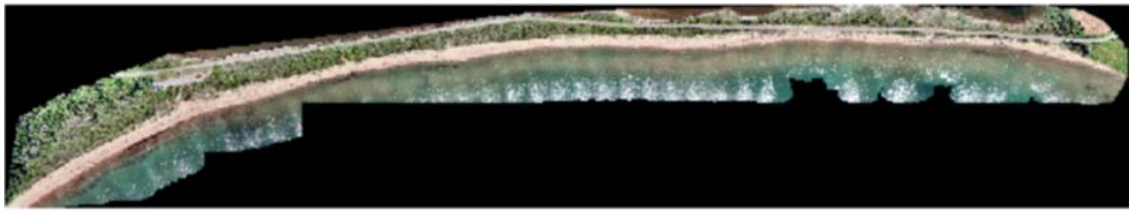


Fig 30. Orthomosaic of Panmure Island from June 16th RPAS flight

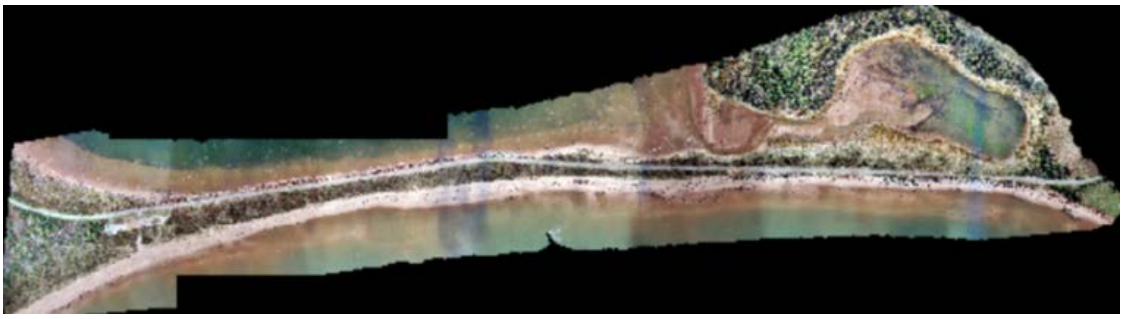


Fig 31. Orthomosaic of Panmure Island from October 20th RPAS flight

Armouring present:
Armour stone north of northern beach entrance, and armour stone and scattered stone south of the north beach entrance.
Site notes:

- A larger area was flown and delineated Post-Fiona.
- Newly suggested secondary areas could not be flown due to access issues, as the northern proposed area is private property and southern proposed area is a Provincial Park that was closed for the season.
- Both sides of Panmure causeway can now be delineated.
- Some erosion appears to have behind the armour stone Post-Fiona.
- Some vegetation loss and erosion of dunes was observed Post-Fiona.

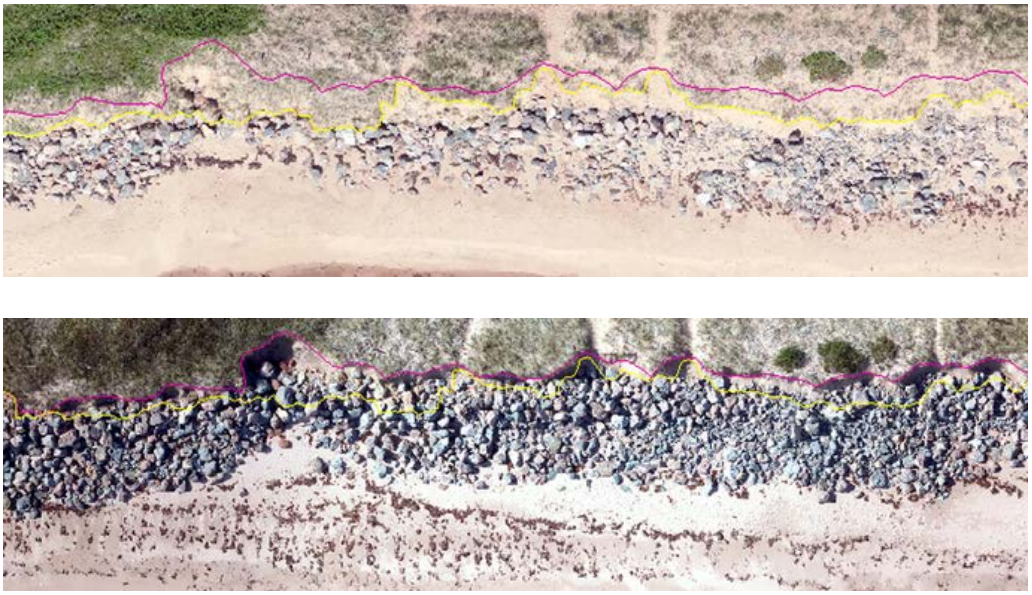


Fig 32. Section of Panmure Island coastline from June (top) and October (bottom) RPAS flights showing coastal changes

DSAS Results/ Output Map:

For our 2022 flights, the EPR between the June 16th and October 20th flights is -6.43 m/year and the NSM is -2.13 m.

The EPR between our first flight on October 7th 2020 and most recent flight of October 20th 2022 is -1.84 m/year and the NSM is -3.74 m.

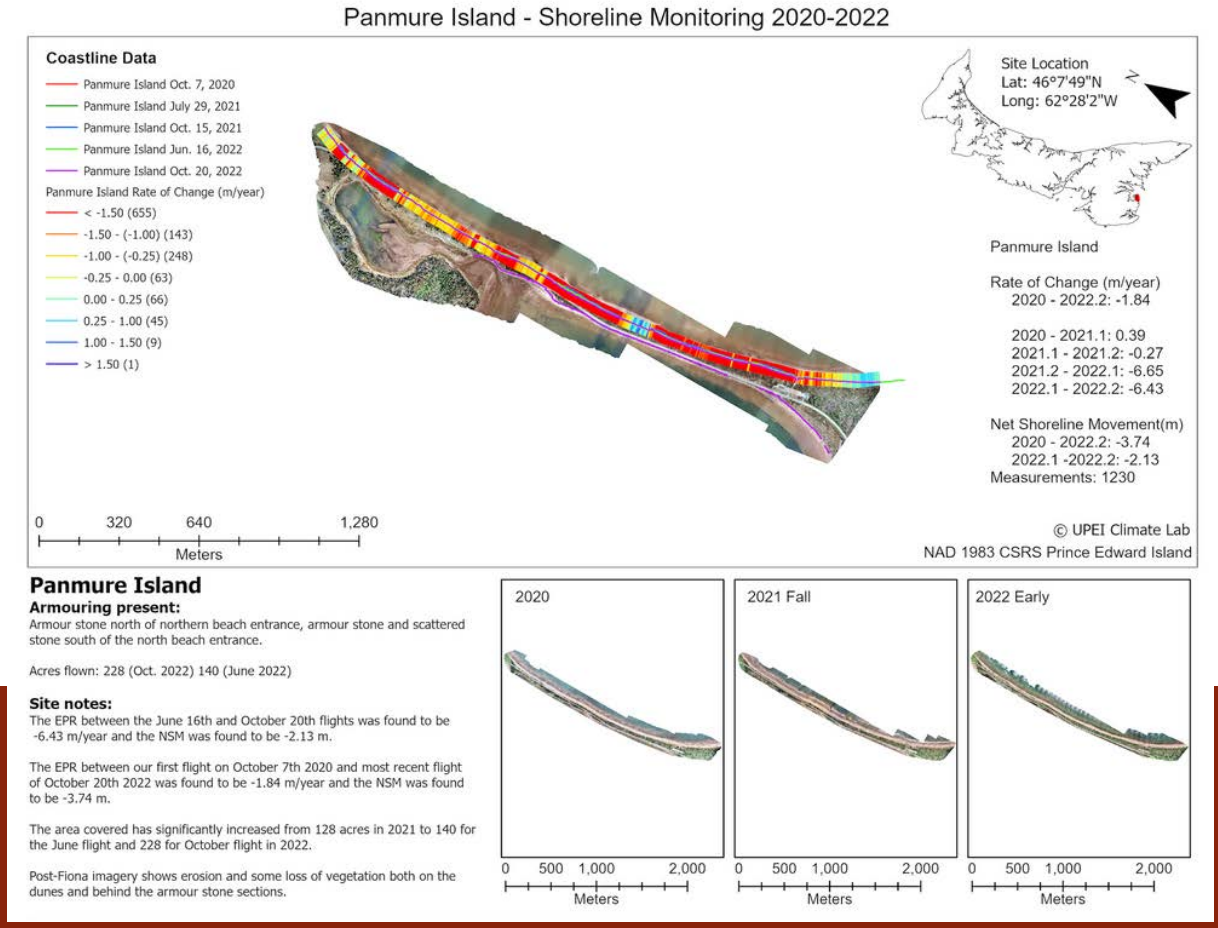


Fig 33. Output map forPanmure Island site, from 2020-2022

SOURIS CAUSEWAY

Dates flown: July 21st, November 19th
Area flown: 76 acres (July), 113 acres (November)

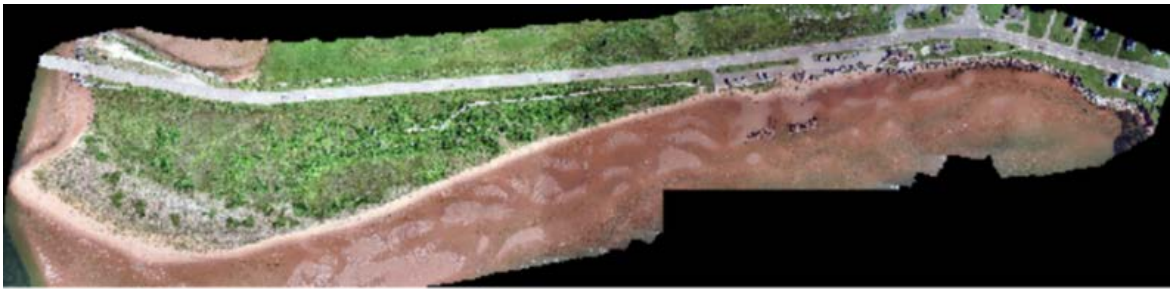


Fig 34. Orthomosaic from July 21st RPAS flight

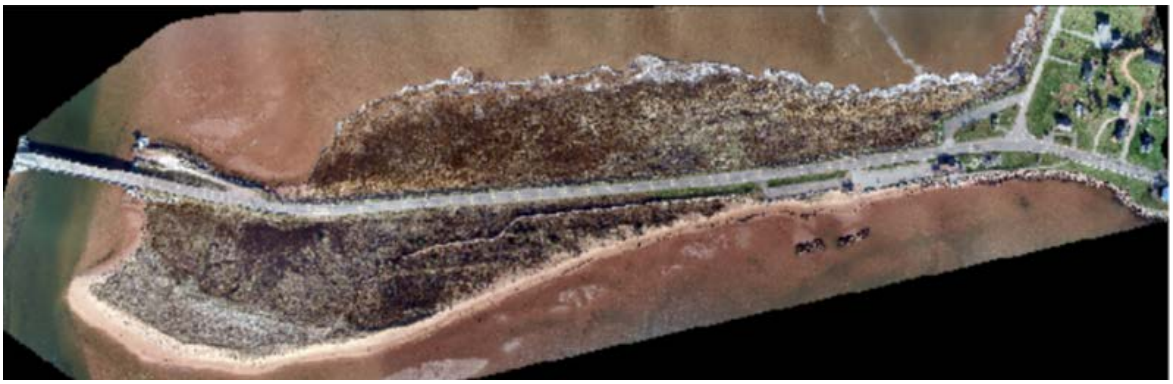


Fig 35. Orthomosaic from November 19th RPAS flight

Armouring present:
Breakwaters (2), and armour stone on east side of site.

Site notes:

- A larger area flown and delineated Post-Fiona.
- November flight ended prematurely due to minor damage to the RPAS. This means the angled (oblique) section of the flight was incomplete. However, the full area was still captured during the Nadir section of the flight and was still able to be processed.
- More sand appears to be building up on beach behind coastal reef.
- The unprotected shoreline experienced consistent erosion Post-Fiona.
- Most significant loss occurred in front of the board walk on either side of the stairs.

Fig 36. Section of Souris coastline from July (left) and November (right) RPAS flights showing erosion on either side of stairs

DSAS Results/ Output Map:

For our 2022 flights, the EPR between the July 21st and November 19th flights is -9.55 m/year and the NSM is -3.16 m.

The EPR between our first flight on October 1st 2020 and most recent flight of November 19th 2022 is -2.32 m/year and the NSM is -4.94 m.

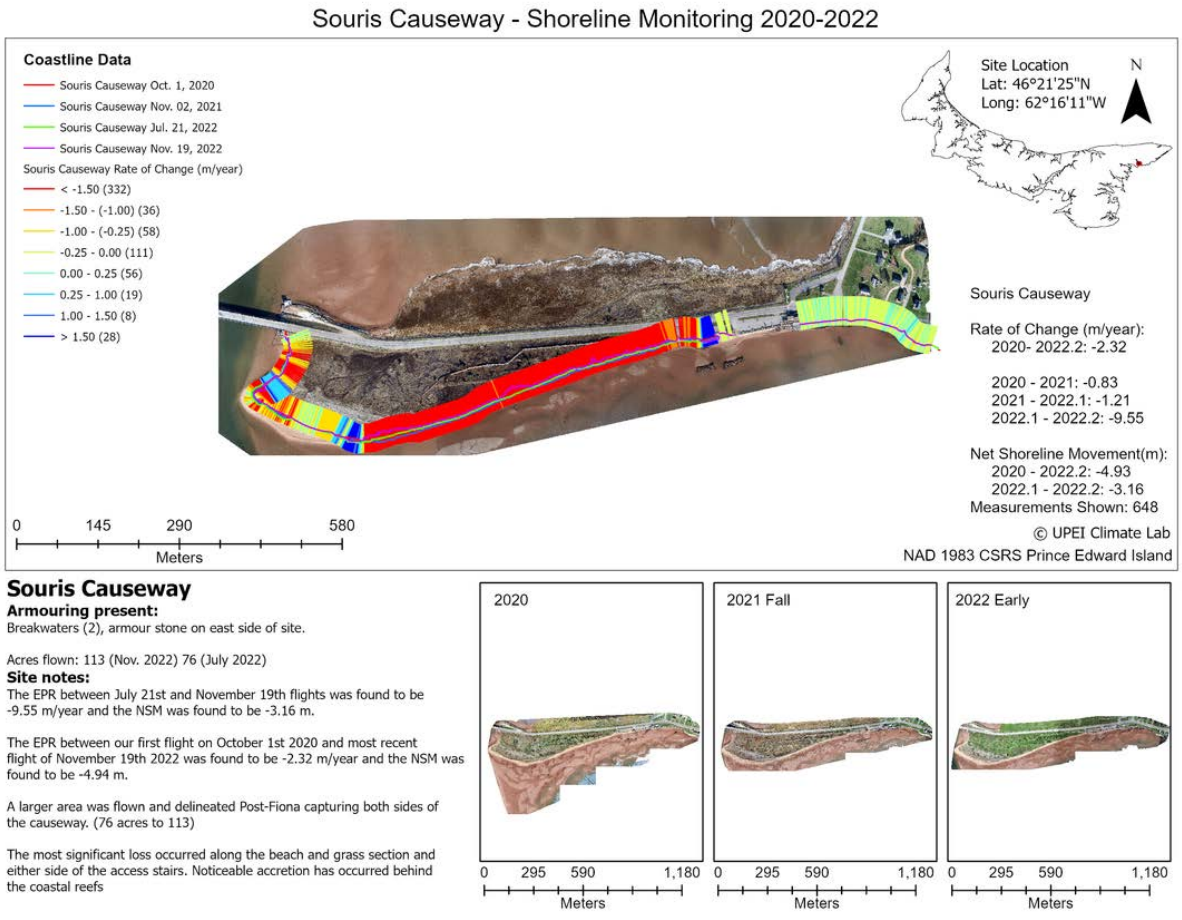


Fig 37. Output map for Souris Causeway site, from 2020-2022

3.4 ERROR ANALYSIS FOR FALL FLIGHTS

Monitoring location	Number of GCP checks	Number of processing GCPs	Average horizontal error (m)	Average vertical error (m)	Was differential correction needed?
Cape Traverse	9	10	0.034	0.030	No
Cedar Dunes and West Point	12	13	0.027	0.032	Yes
Crowbush	12	13	0.022	0.022	Yes
Grand Tracadie	7	7	0.032	0.018	No
Jacques Cartier	12	13	0.023	0.035	No
Miminegash	19	21	0.027	0.035	Yes
Panmure Island	10	10	0.019	0.031	No
Souris	12	12	0.025	0.04	No
Average	12	12	0.026	0.03	N/A

Table 3. Summary of error analysis for 8 monitoring sites during Fall flights

During Pix4D processing, approximately half of the GCPs are used to process the data, with the other half (checks) used after processing to analyze error. Excel tables are created using the Northing, Easting and Elevation values for all "checks" taken directly from the Trimble RTK unit, as well as the Northing, Easting and Elevation values measured within a GIS at the center of each GCP check. The differences between these values are calculated, followed by the averages. The Excel tables are included in the Appendices section at the end of the report.

The desired error for all sites is 3 cm in the horizontal and 5 cm in the vertical, with all sites meeting this threshold except for Cape Traverse which has an average horizontal error of 3.4 cm and Grand Tracadie which has an average horizontal error of 3.2 cm.

For Cape Traverse, one reason that the error may have been slightly high is due to the large size of the survey, combined with the large feature-less beach areas that are exposed at low tide which may cause processing issues. Also, several GCPs were taken or moved by citizens in the subdivision on the west end of the survey, meaning there were less GCPs than planned for processing. Additionally, the newly added southeastern section of the survey has poor access for laying GCPs due to private property, which may contribute to the increase in error. Finally, as is detailed in Section 4.2, Cape Traverse was not flown using the recommended cross-hatch and angled flight patterns, which may have contributed as well.

Regarding Grand Tracadie, approximately 10 additional GCPs were unusable due to unexpected precipitation, which caused the flight to end prematurely. This low number of GCPs, combined with the flight not finishing and poor weather/lighting conditions likely led to the slight increase in error.

3.5 ADDITIONAL DELIVERABLES

Additional flight details and requested deliverables for the fall flights are included in the Appendices section at this end of this report.

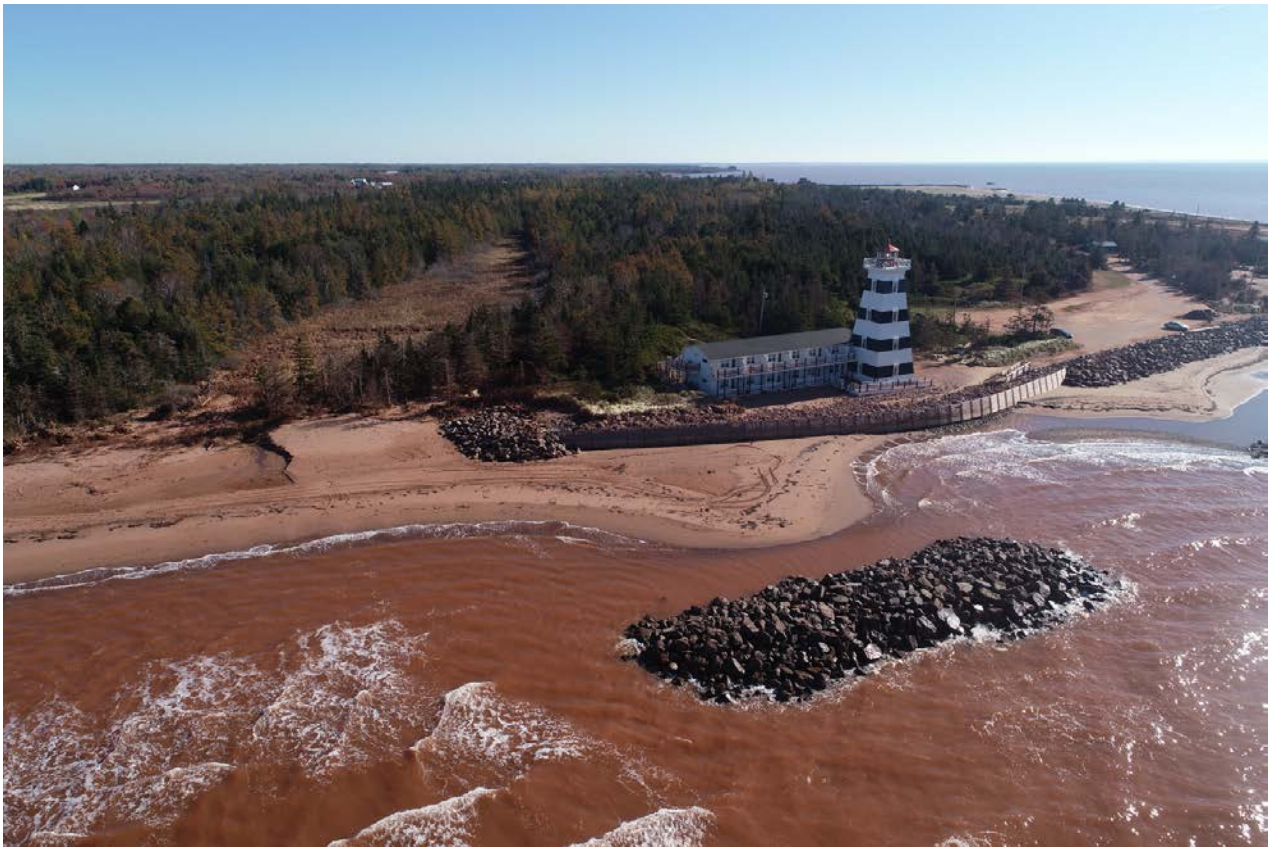


Fig 38. West Point Lighthouse and breakwater after Post Tropical Storm Fiona

DISCUSSION

4.1 DAMAGE CAUSED BY POST TROPICAL STORM FIONA

Due to the damage caused by Post Tropical Storm Fiona, all sites experienced greater than usual rates of coastal change in 2022. The North shore and West coast of Prince Edward Island were hit especially hard by the storm due to the wind direction, which means that the monitoring locations that saw the largest losses were Miminegash, Cedar Dunes & West Point Lighthouse and Crowbush. Similarly, the areas that experienced the least change, Cape Traverse and Panmure Island, are located on the south side of PEI.

While none of the 8 monitoring locations experienced significant infrastructure damage, numerous bridges and roads were closed on PEI in the aftermath of the storm, and many harbours had extensive damage.

Fig 39. Reuben's Lane bridge closed after Post Tropical Storm Fiona

4.2 IMPLEMENTATION OF NEW METHODOLOGY AND REASONS FOR DEVIATION

During the Fall flights at all 8 infrastructure monitoring sites, RPAS operators followed the proposed new Methodology, with some deviations (listed below).

1. Ground Control Points/Checks

A total of 40 GCPs (20 checks and 20 processing GCPs) were requested for all sites, however, this was too much of a burden for the visual observer as they were also responsible for carrying the Trimble RTK unit. The current GCPs are 43cm x 43 cm, which is the smallest possible size, as a smaller GCP would create difficulties within Pix4D processing (i.e. too pixelated to mark correctly). The length of these sites are walked by the visual observer to lay GCPs and then again to pick up the GCPs. This is very labour-intensive and often the job of a student assistant, so fewer GCPs were used (approximately 24 total GCPs/checks per site). For Miminegash, where the survey is broken into 2 sections due to its size, the 20 GCPs were redistributed for the second survey, so 40 GCPs/checks used in processing and analysis.

2. Panmure Island and Crowbush secondary areas

Due to access issues, the requested secondary areas of Panmure Island and the requested western secondary area of Crowbush were not flown. For Panmure Island, the requested northern section is comprised of private property which the pilots did not feel comfortable flying given that a resident in the area had reported a complaint during a past erosion monitoring RPAS flight. The requested southern section of Panmure Island is a provincial park which was closed and could not be accessed. In addition to access issues, these are very large areas and combined with the primary area of interest, it would likely require more than a single work day to fly. Unless essential, these secondary areas of interest should not be included.

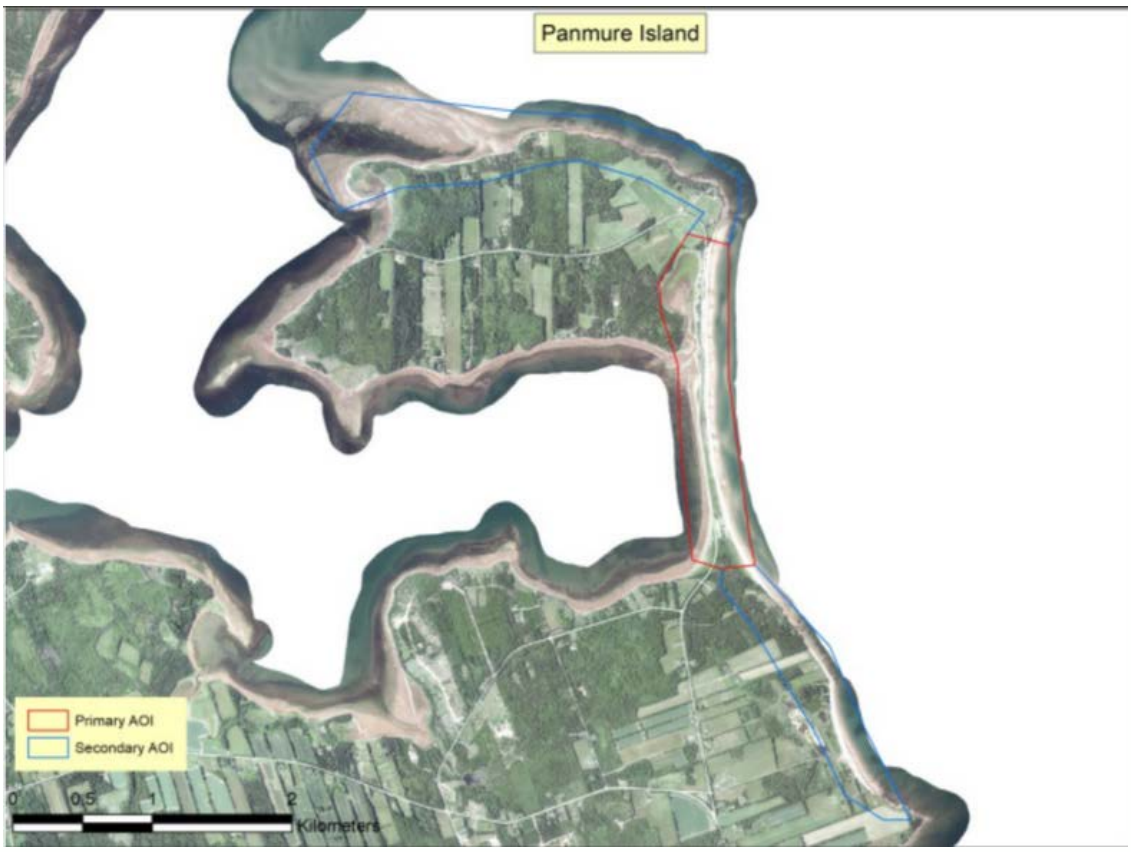


Fig 40. Primary (red) and secondary (blue) areas of interest at Panmure Island

At Crowbush, there was no access to the western secondary area of interest due to a road washout (MacAdam Road) just west of Crowbush's entrance. Without this road access, it is impossible to reach the requested area - even alternative routes such as walking around the armour stone section or scaling the cliff to get onto the western shore are no longer an option. Staff at Crowbush golf course indicated that MacAdam Road now goes through a resident's property, so it is unclear if it would be accessible moving forward. During the 2023 flying season, the availability of MacAdam Road should be explored further.

Fig 41. Primary (red) and secondary (blue) areas of interest at Crowbush

- **3. Flight Issues**
  - **Grand Tracadie** – Partway through the RPAS flight, unexpected precipitation forced the flight to end due to safety concerns. While the majority of the area was flown, the requested expanded eastern section of the survey, consisting of additional beach and harbour, could not be completed. This will be flown during the 2023 season.

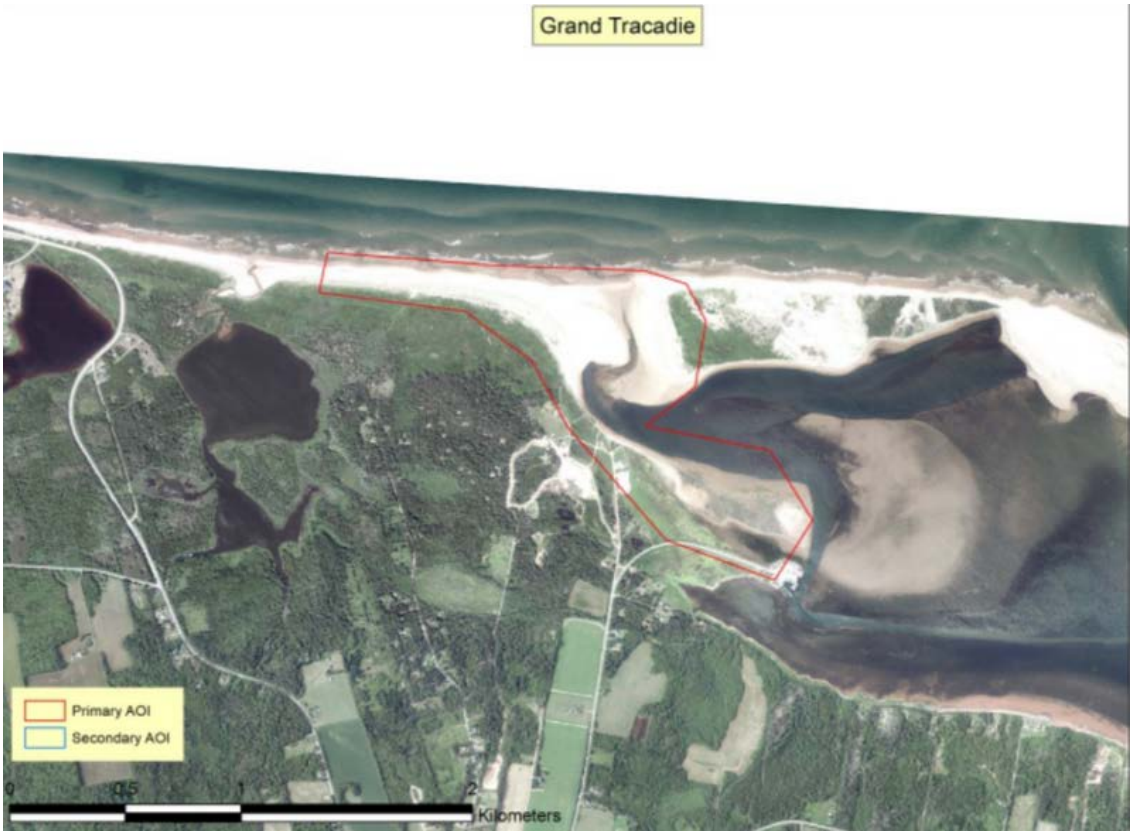


Fig 42. Primary area of interest at Grand Tracadie (red). The eastern bubble, including the harbour

  - **Miminegash** - In order to capture the new expanded area of Miminegash, setup and flight time takes approximately 5 hours. During this time, the tide can rise substantially, which means that by the time the southern end of the site is completed, beach area to lay GCPs and for the observer to stand is limited. During the November flight, a GCP almost washed away at the very end of the flight. Such a long flight and large area should not be required at this site, as the timing of the tides could provide less than ideal imagery.

Fig 43. GCP starting to float away at Miminegash as tide comes in at end of survey

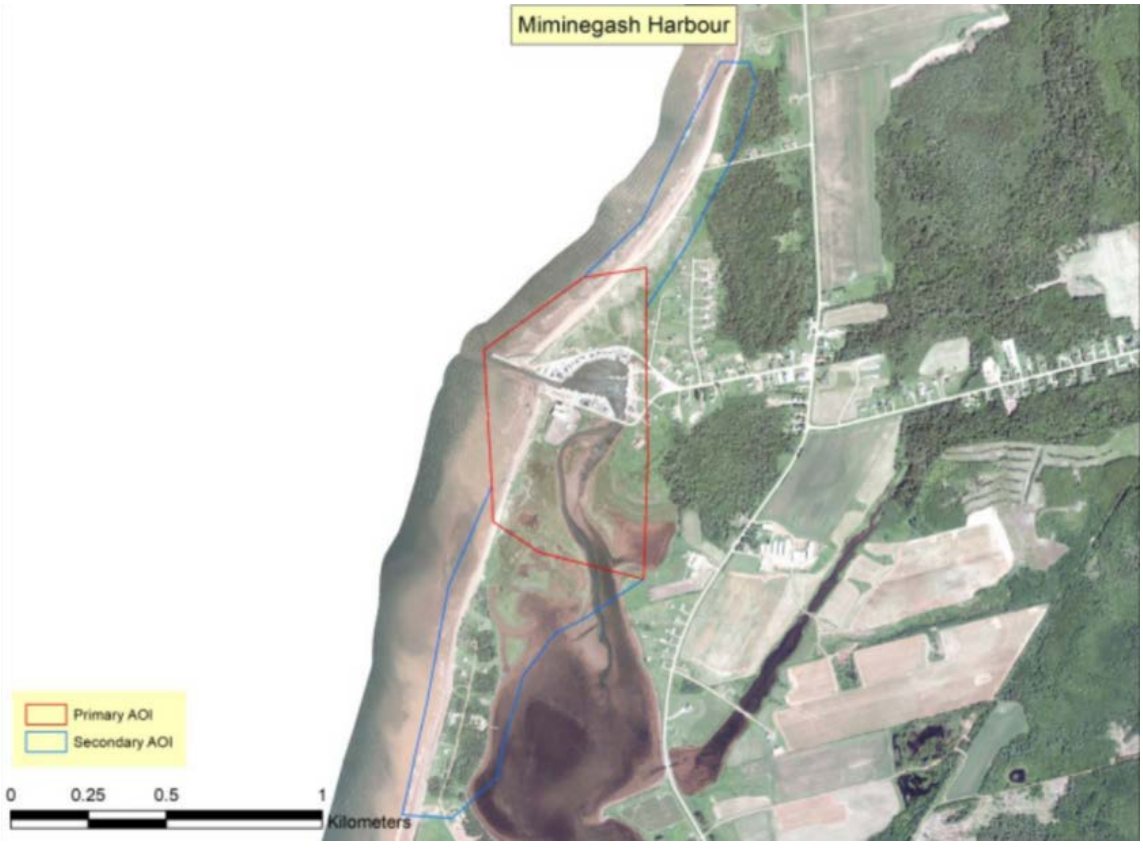


Fig 44. Primary and secondary areas of interest at Miminegash)

4. Cross-hatch and Angled Flights

As part of the new Methodology, cross-hatch and angled RPAS missions are requested at each monitoring location. This means that, in addition to the increased survey area requested at all sites, RPAS missions will be approximately 3 times longer than the previous approach of 1 automated 2D photogrammetry mission combined with manually taken oblique photos.

We experienced difficulty with this approach at Cape Traverse and Panmure Island, due to the amount of time required to spend in the air and uncertainty that the GCPs would be able to remain in place for the duration of the flight, as well as concern that rising tides would affect results and wash away GCPs. Using this Methodology, flight times for these sites could be up to 4 hours when flown at an altitude of 100 meters. Instead, the usual 2D Photogrammetry flights missions were created using the requested 80% overlaps and flown, with oblique photos taken to compensate for the lack of angled imagery.

Miminegash is another site with very large flight times, and an attempt was made to use the cross-hatch and angled approach. The flights were successful but as was referenced earlier, the tides had come in significantly by the end of the flights due to the amount of time required (approximately 5 hours).

One aspect of these much longer flight times to consider is the human element, wherein the RPAS pilot must maintain focused for a much longer period of time, generally in quite complex environments (ie. people present, vehicles, etc.). Similarly, the visual observer is required to keep visual contact on the RPAS for a much longer period of time.

4.3 LIMITATIONS OF CURRENT TECHNOLOGY AND RPAS REGULATIONS

There are several limitations of this study that should be considered.

- **RTK Connection/Accuracy:** To gather the most accurate results, the equipment in use must connect to RTK while in the field. Under ideal conditions the Trimble Geo7x surveying unit can usually register an accuracy of 1-2 cm in the horizontal (X,Y axes) and 3-4 cm in the vertical (Z axis) when taking GCP points. When cellular connectivity is low, the Trimble may not be able to connect to RTK. The Differential Correction option in the Trimble Pathfinder Office software can be used in this case, which allows users to post-process the points taken by the Trimble. However, points can be less accurate, at around 5-6m horizontally and at times over 10cm vertically.

- **GCP Distribution:** The locations of GCPs can impact accuracy. Ideally, GCPs are laid near the corners of the survey, with others scattered throughout the flight area at different elevations. However, this is not possible at many monitoring locations as access is limited (private property or no safe beach access, for example).

- **Flying Directly Above People:** The inability to legally fly directly over people remains a challenge for this project. Informing small groups of people present at monitoring sites of the RPAS flights has proven successful, however, larger concentrations of people make flying some sites illegal and unsafe. This means that areas prone to having large concentration of people are generally flown in the Spring and Fall when they are less likely to be populated. As regulations evolve and more RPAS models are exempted to allow for flights directly over people, this may no longer be a limitation.

- **Electric Vehicle Range/Charging:** In 2020 UPEI purchased 2 Hyundai KONA EVs. At full charge these vehicles can travel approximately 400 km under ideal conditions, which is generally sufficient. However, for longer trips, like travelling to Miminegash, charging is necessary during the day and overnight to be ensure there is sufficient range for the drive. During the 2022 field season there were no operational EV chargers on the main UPEI campus, which meant pilots were required to often charge on the Level 3 charger in Charlottetown, located on Babineau Avenue, for 30-60 minutes.

4.4 RECOMMENDATIONS AND QUESTIONS FOR 2023 FLIGHTS

As per comments made earlier in the report, these are some recommended changes for the 2023 flying season:

Use 20-25 Total GCPs Moving Forward

- With the exception of Miminegash, due to its size and the fact that it is broken into 2 surveys, all other sites should use 20-25 total GCPs moving forward. Using more GCPs would require a third person on the RPAS team and longer setup times.

Remove Panmure Island's Secondary Areas of Interest

- It would be beneficial to remove the secondary areas of interest from Panmure Island from this RPAS project due to size and lack of access.

Extend Jacques Cartier Area of Interest

- The Jacques Cartier southern extent should be expanded, as this area of interest has experienced significant erosion in the past and should be monitored.

The following questions would be helpful to have answered before 2023 flights begin:

Should other critical infrastructure sites be considered for this study?

- Potential options could be the Lennox Island causeway, new erosion-mitigating infrastructure within the National Park and roads/bridges/harbours that were damaged by Post Tropical Storm Fiona.

Can we reduce the area of very large surveys?

- Miminegash, Cape Traverse and Panmure Island all contain very large survey areas, which make implementation of the new Methodology difficult. Could these areas be trimmed to allow for less time in the air? This would decrease the risk of incidents and the amount of wear and tear on equipment.

Will vertical data be used in analysis?

- Will the vertical data (i.e. Digital Surface Model, 3D mesh, Point Cloud data) be used for analysis in this project and if not, why the need for such accurate vertical data (acquired through cross-hatch and angled flights) ?

CONCLUSION

In 2022, the UPEI RPAS team conducted 14 flights of the 8 infrastructure monitoring sites, with all sites flown twice except for Crowbush and Grand Tracadie which were only flown once.

The aerial imagery and resulting analysis from this year showed the greatest coastal change in the short history of this project, with Miminegash, Cedar Dunes & West Point Lighthouse and Crowbush showing the most significant change. These changes can be largely attributed to the arrival of Post Tropical Storm Fiona, which may be the most damaging storm on record for Prince Edward Island.

Moving into the 2023 flying season, all sites will be flown using a new Methodology which was first used in the Fall flights of 2022, with potential modifications outlined in this report.

Thank for your continued support of this project.

Fig 45. RPAS setup at Crowbush