Mapping Areas of Interest for Coastal Enhancement related to Capelin Spawning in Conception Bay, Newfoundland and Labrador

by © Brandon Tilley

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Abstract

Capelin is a forage fish species that plays a key role in Newfoundland and Labrador (NL) marine ecosystems. The species tends to spawn on beaches possessing specific environmental characteristics, such as gentle slopes and granular sediment sizes. Many beaches on the island of Newfoundland have been modified by humans and are no longer suitable for capelin spawning. Coastal enhancement work, which could help increase the suitability of beaches for capelin spawning, requires an understanding of beach dynamics and geomorphology to identify suitable sites for enhancement and long-term effectiveness. Three beaches along Conception Bay, NL were examined to inform potential future coastal enhancement work: Lance Cove, Chapel's Cove, and Harbour Main. Aerial photos and digital surface models (DSM) of the beaches were acquired at different times throughout 2019 using an uncrewed aerial vehicle, complemented by field observations. A multi-criteria decision analysis (MCDA) approach was then used to provide a systematic way to prioritize these beaches for enhancement suitability. The MCDA prioritization accounts for key components of capelin spawning, wind direction, beach protection, sediment grain size, slope, and anthropogenic footprint.

Key components were addressed both in terms of capelin spawning suitability and coastal stability. DSM and geomorphological data indicate that beaches experience different changes throughout a season, although they present somewhat similar physical characteristics. Adjacent beaches can exhibit very different responses to the same weather event, indicated by the geomorphic dynamics of Lance Cove, Chapel's Cove, and Harbour Main. Of the three sites, Chapel's Cove is most suitable for coastal enhancements to make the beach more suitable for capelin spawning. Chapel's Cove is more dynamically stable than Lance Cove, and is much less anthropogenically influenced than is Harbour Main. Findings demonstrate the key factors

influencing beach geomorphology and how it pertains to planning species-specific enhancement projects, building on the idea that enhancement projects require a multi-dimensional approach.

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Table of Contents:

Abstract ii

Acknowledgments iv

Table of Contents: v

List of Figures: ix

List of Tables: xiv

List of Appendices: xiv

List of Abbreviations xv

1. Chapter 1 – Introduction 1

1.1 Background 1

1.1.1 Coastal Intervention 1

1.1.2 Capelin 3

1.2 Research Gap 8

1.3 Research Questions 8

1.4 Research Objectives 9

1.5 Thesis Outline 9

2. Chapter 2 – Materials and Methods 10

2.1 Previous Work 10

2.1.1 Restoration and Enhancement 10

2.1.2 Use of UAV and other tools for ecological intervention practices 13

2.1.3 Gravel Beaches 14

2.2 Study Area and Settings 16

2.2.1 Study Area 16

2.2.2 Regional Climate and Weather 19

2.2.3 Regional Geology 20

2.2.4 Quaternary History 21

2.2.5 Anthropogenic Influences... 23

2.3 Data Collection.. 26

2.4 Processing of Digital Models and Land-Cover Mapping................................... 28

2.5 Multi-criteria Enhancement Prioritization 28

3. Chapter 3 – Results 30

3.1 Study Sites Surveys.. 30

3.2 Beach Geomorphology.. 31

3.2.1 Lance Cove 31

3.2.2 Chapel's Cove.. 39

3.2.3 Harbour Main 47

3.3 Map and Processing Accuracy 57

3.4 Observing Sediment Dynamics through DSMs 58

3.4.1 Lance Cove 58

3.4.2 Chapel's Cove... 68

3.4.3 Harbour Main ... 70

3.5 MCDA Scoring and Weighting ... 71

4. Chapter 4 – Discussion ... 76

4.1 Validation of the MCDA and Individual Parameters ... 76

4.2 Recommendations ... 84

5. Chapter 5 – Conclusion ... 91

5.1 Major Findings ... 91

5.2 Implications ... 92

5.2.1 Chapel's Cove ... 92

5.2.2 MCDA ... 93

5.2.3 Habitat Intervention ... 93

5.3 Limitations ... 95

5.4 Future Research ... 97

5.5 Final Remarks ... 99

References ... 100

Appendices ... 117

Appendix A: Field Survey ... 117

Appendix B: Transect Data ... 120

Lance Cove: ... 120

Chapel Cove: ... 125

Harbour Main: 132

Appendix C: Orthomosaics 143

Appendix D: Digital Surface Model Errors 149

Appendix E: Parameter Scoring Legend and Associated References 150

Appendix F: Final Weighted Scores for Sites External to this Study 152

List of Figures:

Figure 2.1: Study site locations, southern Conception Bay, Newfoundland and Labrador. 18

Figure 2.2: Bedrock Geology Map of Southern Conception Bay. Modified from King (1998) 21

Figure 2.3: Quaternary Geology Map of Conception Bay. Modified from Liverman & Taylor (1994) 23

Figure 2.4: General MCDA prioritization approach 29

Figure 3.1: Lance Cove orthomosaic with transect and GCP locations in June 2019. Transect associated sections separated by blue lines. 32

Figure 3.2: Buried pipe outflow on the southwest part of Lance Cove Beach aerial view, (A) 14 June 2019, (B) 11 September 2019, and (C) 28 November 2019. 33

Figure 3.3: Buried pipe outflow on the southwest part of Lance Cove Beach ground view. Red circles are representing the same drainage pipe feature. (A) 14 June 2019 camera orientation South, and (B) 15 November 2019 camera orientation West. 35

Figure 3.4: Furthest backshore slope for T3-T4, central beach. (A) 11 September 2019 and (B) 15 November 2019. 36

Figure 3.5: Central area of Lance Cove Beach. Red is representing ground transect location (dotted was the location of the transect that was uncompleted). (A) NE oriented photo - 14 June 2019, (B) SW oriented photo - 28 November 2019. 37

Figure 3.6: Northern Lance Cove transect. (A) Aerial photo with the camera oriented southwest on 15 June 2019. (B) Aerial photo with the camera oriented east on 28 November 2019. (C) Area directly southwest of transect on 15 June 2019, transect line directly left of the picture. 38

Figure 3.7: Chapel's Cove orthomosaic with transect and GCP locations in June 2019. 40

Figure 3.8: Eastern transect line on Chapel's Cove Beach. (A) Ground photo from intertidal zone - 19 June 2019, (B) Ground Photo from intertidal zone - 17 October 2019, (C) Aerial photo - 19 June 2019, (D) Aerial Photo – 17 October 2019. 42

Figure 3.9: Main beach part (central) of Chapel's Cove beach, (A) westward oriented aerial photo - 29 July 2019, (B) eastward oriented aerial photo - 17 October 2019. 43

Figure 3.10: Central transect, T3-T4, for Chapel's Cove Beach. (A) & (B) Lead up to mechanical flatten part of the backshore on 19 June 2019 and 17 October 2019, respectively. (C) Alternating sand pebble patches on 19 June 2019. (D) Intertidal zone ~1 hour before a 0 m low tide. 44

Figure 3.11: Western flank of Chapel's Cove beach, (A) Aerial with a south camera orientation on 29 July 2019. (B) North oriented photo from transect line on 29 July 2019. (C) North oriented photo from transect line on 17 October 2019. 46

Figure 3.12: Harbour Main orthomosaic with transect and GCP locations in June 2019 48

Figure 3.13: East section of Harbour Main primary beach. (A, B) 12 November 2019, (C) 27 June 2019. 50

Figure 3.14: Primary beach, east, in Harbour Main. (A) Ground photo mid beach, oriented east toward transect T1-T2 on 27 June 2019. (B) T1-T2 on 12 November 2019. (C) Three small berms and sediment texture for T3-T4 on 27 June 2019. (D) Sediment texture midway of T3-T4. 52

Figure 3.15: West section of Harbour Main primary beach. (A) 27 June 2019. (B) Freshwater outflow on 12 November 2019. (B) The rock wall on 12 November 2019. 54

Figure 3.16: Primary beach, west, in Harbour main looking east from the freshwater outflow. (A) 27 June 2019. (B) The base of the wooden structure, 12 November 2019. 55

Figure 3.17: Secondary beach at Harbour Main, (A) 27 June 2019 and (B) 12 November 2019. 56

Figure 3.18: Secondary beach in Harbour Main. (A) Eastside of the beach looking westward at transect T7-T8 on 27 June 2019. (B) Taken from transect line T7-T8 looking south on 12 November 2019. 57

Figure 3.19: DSM differences for Lance Cove between June 2019 and September 2019 61

Figure 3.20: Enlarged DSM differences for the west section of Lance Cove between June 2019 and September 2019. 62

Figure 3.21: Enlarged DSM differences for the central section of Lance Cove between June 2019 and September 2019. 63

Figure 3.22: Enlarged DSM differences for the east section of Lance Cove between June 2019 and September 2019 64

Figure 3.23: DSM differences for Lance Cove between September 2019 and November 2019. 65

Figure 3.24: Enlarged DSM differences for the west section of Lance Cove between September 2019 and November 2019. 66

Figure 3.25: Enlarged DSM differences for the central section of Lance Cove between September 2019 and November 2019. 67

Figure 3.26: Enlarged DSM differences for the east section of Lance Cove between September 2019 and November 2019. 68

Figure 3.27: DSM differences for Lance Cove between June 2019 and November 2019 69

Figure 3.28: Enlarged DSM differences for the west section of Lance Cove between June 2019 and November 2019 70

Figure 3.29: Enlarged DSM differences for the central section of Lance Cove between June 2019 and November 2019. 71

Figure 3.30: Enlarged DSM differences for the east section of Lance Cove between June 2019 and November 2019 72

Figure 3.31: DSM differences for Chapel’s Cove between June 2019 and October 2019 69

Figure 3.32: DSM differences for Chapel's Cove between June 2019 and October 2019, with the gravel beach enlarged. 70

Figure 3.33: Enhancement suitability placement chart for capelin spawning beaches in Newfoundland and Labrador. 75

Figure 4.1: Enhancement suitability placement chart for capelin spawning beaches in Newfoundland and Labrador and additional reference sites. Circles representing sites assessed in this study; squares represent known successful spawning beaches; triangles represent unsuitable coastal spawning locations. 79

Figure 4.2: (A) Ship Cove Beach pre-enhancement, pebble to cobble sediment, photo orientation North – September 2011 (Photo Credit: Melanie Irvine); (B) Ship Cove post enhancement, granule to fine pebble sediment, photo orientation North – Feb. 2018 (Photo Credit: Victoria Neville), (C) Chapel's Cove, sand patches in the intertidal zone and pebble to cobble sediment, photo orientation Southeast - October 2019. Chapel's Cove (C) and Ship Cove, before enhancement (A) both, outside of the sand patches at Chapel's Cove, have a similar pebble to cobble texture and cusping features. A proposed enhancement for Chapel's Cove would fall in line with Ship Cove post enhancements (B), where the beach is a well-mixed granule-small pebble texture. 88

List of Tables:

Table 3.1: Importance level of each factor provided by capelin fisheries experts. (-) represents an absence of a response from the expert. 72

Table 3.2: Importance level of each factor provided by Coastal geomorphology experts. (-) represents an absence of a response from the expert. 72

Table 3.3: Weight factors assigned for capelin beach parameters. 72

Table 3.4: Weight factors assigned for coastal geomorphology parameters. 73

Table 3.5: Final weighted scores for each study site. 74

Table 4.1: Chapel's Cove field observations compared to previous observations. 85

Table 4.2: Chapel's Cove field observations compared to Ship Cove post degradation but pre-enhancements. 85

List of Appendices:

Appendix A: Field Survey 117

Appendix B: Transect Data 120

Appendix C: Orthomosaics 143

Appendix D: Digital Surface Model Errors 149

Appendix E: Parameter Scoring Legend and Associated References 150

Appendix F: Final Weighted Scores for Sites External to this Study 152

List of Abbreviations

°C	Degrees Celsius
AHP	Analytical Hierarchy Process
CEI	Coastal Erosion Index
CRF	Coastal Restoration Fund
CSI	Coastal erosion and sensitivity to Sea-level rise Index
DFO	Fisheries and Oceans Canada
DJI	Da-Jiang Innovations
DSM	Digital Surface Model
GCP	Ground Control Points
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
iOS	iPhone Operating System
km/h	Kilometers per Hour
km	Kilometer
MCDA	Multi-Criteria Decision Analyses
m	Meter
NL	Newfoundland and Labrador
ROV	Remotely Operated Vehicle
RTK	Real-Time Kinematic
SER	Society for Ecological Restoration
SfM	Structure from Motion
UAV	Uncrewed/Unmanned/Unpiloted Aerial Vehicle
WWF	World Wildlife Fund

1. Chapter 1 – Introduction

1.1 Background

1.1.1 Coastal Intervention

The people of Newfoundland and Labrador (NL) on Canada's eastern coast have strong connections with coastal areas. For hundreds of years, the NL economy has primarily relied on fishing (Castañeda *et al.*, 2020; Hutchings & Myers, 1995), and humans have altered the coast to better suit the needs of fish harvesters and other users (Catto & Catto, 2012). In the Northeast Avalon Peninsula, the most populated region of the Island of Newfoundland, population growth has put increasing pressure on coastal ecosystems (Catto, 2020; Catto *et al.*, 1999). Together, NL's physical and social systems contribute to coastal change that can impact coastal habitats and species.

Coastal ecosystems are at the interface of two drastically different environments, terrestrial and marine (Short & Woodroffe, 2009), and are therefore impacted by natural and anthropogenic processes taking place in both. As a result, coastal systems are very dynamic and vulnerable areas that are at risk of undergoing extensive changes due to anthropogenic pressures and climate change (Olsson *et al.*, 2019). Preventing damage to coastal environments is necessary for protecting ecosystems and the services they provide (Menz, Dixon, & Hobbs, 2013; Roni & Beechie, 2013). However, where coasts have already been degraded, interventions may help enhance or restore coastal areas to help revitalize ecosystem services.

For this thesis, the term intervention is used as an umbrella term to cover any and all types of active or passive actions taken to influence the desired outcome of a habitat or environment.

Interventions such as habitat rehabilitation, ecological improvement, and reclamation may involve different actions than those required for the true restoration of a site to an earlier state. In many cases, true restoration is not possible because the original "unaltered" state is unknown due to the extensive impacts and developments through time and a lack of baseline data (Barker *et al.*, 2017; Catto & Catto, 2012). Furthermore, even if the unaltered state was known, past environmental conditions may differ from present and future conditions (Chazdon, 2014; Higgs, 2003; Hobbs *et al.*, 2011) and may not allow changes that revert the environment to the original condition. For those reasons, I will refer to these potential changes as coastal "enhancement" rather than coastal "restoration" in this thesis. Enhancement of a coastal system has a similar goal to restoration while acknowledging changes to natural and anthropogenic factors (Liversage & Chapman, 2018). Whether by improving an environment that has degraded, helping to enhance its recovery (Menz *et al.*, 2013; SER Group, 2004), or minimizing degrading pressures through infrastructure (Palmer & Ruhl, 2015), the goal of enhancement is, in this context, to improve coastal environments for the benefit of biodiversity.

Successful interventions in natural processes often require understanding complex processes. All coastal enhancement projects do not bring the expected benefits (Thom *et al.*, 2005; 2011). Bayraktarov *et al.* (2016) argued that coastal restoration projects' failures often result from inadequate attention to environmental and habitat influences during site selection. Failures can stem from individual factors or combinations of insufficient understanding of the physical environment, biological needs, and anthropogenic stressors in the enhancement site. Furthermore, gaps in understanding the relationships between biota and their natural and anthropogenic environments contribute to restoration failures (Vaughn *et al.*, 2010). Conducting enhancement projects requires a comprehensive understanding of the unique and changing geomorphic, environmental, and anthropogenic characteristics of an area. The natural variability of coastal regions further emphasizes the need to understand the system's current state and past patterns, which will better inform any attempt at enhancing coastal areas.

Coastal enhancement projects are not guaranteed to be successful in the medium to long term, particularly when a specific site's physical conditions do not allow the enhancement measures to remain in place over time. Globally, coastal erosion is occurring at accelerating rates, and can be directly tied not only to natural changes but anthropogenic as well. As a result, viewing a shoreline from a shortsighted mindset as an object of rigidity and unchangability obscures the relationship between land and water (Yincan *et al.*, 2017). Wind and wave action shape shorelines by eroding, transporting, reworking, and depositing sediments (Catto, 2012). Furthermore, extreme weather events have the capability of modifying and reshaping coastal areas and transporting sediment (Harley *et al.*, 2017). Although southern Conception Bay is currenty not one of the sites of greatest concern for erosion, weather and wave action on coastal areas is projected to increase (Mentaschi *et al.*, 2017). Southern Conception Bay should not be excluded from rigorous site selection processes, to give enhancement projects the best chance for long-term sustainability.

1.1.2 Capelin

Changes to coastal environments can impact those environments' suitability to meet the need of specific species and habitats that depend on them. For instance, many species use the subaerial parts of coastal areas during their reproductive cycles, including turtles (Lohmann & Lohmann, 2019) and sea birds (Kolb, Ekholm, & Hambäck, 2010). While less common, some marine fish species utilize beaches at some point in their life cycle for behavioural or biological reasons, including reproduction (Ishimatsu *et al.*, 2013; Martin & Swiderskif, 2001; Martin *et al.*, 2004). Most species that return to beaches to spawn never emerge from the water, remaining within the tidal range (Ishimatsu *et al.*, 2018; Martin & Swiderskif, 2001). Capelin (*Mallotus villosus*) is one of the few marine fish that fully emerge from the water, although only briefly, for spawning. Only two other species of forage fish are known to do this: the California grunion (*Leuresthes tenuis*) and the Gulf grunion (*Leuresthes sardinas*) (Martin & Swiderskif, 2001). Although marine fish spawning on the terrestrial part of a beach may seem to expose them to danger, it does come with reproductive advantages, as burial or adherence to substrates keeps eggs moist and away from most predators until hatching (Fridgeirsson, 1976; Jeffers, 1931; Templeman, 1948). It also offers higher incubation temperatures and available oxygen levels than exist in marine water (Ishimatsu *et al.*, 2018; Martin *et al.*, 2004; Murphy *et al.*, 2018; Ressel *et al.*, 2020).

Located in North American and European waters, capelin are integral to northern ocean ecosystems (Bone & Davoren, 2018; Martin & Swiderskif, 2001). Much like other types of forage fish, fluctuations in capelin populations have been shown to cause cascading effects on many other species through trophic interactions (Carscadden & Vilhjálmsson, 2002). As with other commercial fishery species in the Northwest Atlantic, capelin population numbers are still well below pre-1990s levels, the result of population collapse in NL coastal waters (Buren *et al.*, 2014; Murphy *et al.*, 2018). Unlike grunion, which spawn on sand in response to tidal influence (Griem & Martin, 2000; Ishimatsu *et al.*, 2018; Thomson & Muench, 1976), capelin spawning is more complex and less predictable. Capelin spawns both offshore (Martin & Swiderskif, 2001; Muus & Nielsen, 1999) and on subaerial gravel beach surfaces (Nakashima & Taggart, 2002; Neville, 2020). The type of spawning method appears to be associated with different capelin population locations. Northeast Pacific populations spawn on beaches, while almost all Icelandic and Barents

Sea populations are bottom spawners (Dodson *et al.*, 1991). Capelin spawning may be driven less by nature of the species and more by circumstance of the environment (Dodson *et al.*, 1991; Templeman, 1948), with the warmer temperatures of the northeast Pacific leading to beach spawning and the colder temperature of the Icelandic and Barents Sea resulting in bottom spawning (Penton *et al.*, 2012; Præbel *et al.*, 2009). The physical and ecological conditions in NL are suitable for beach spawning (Carscadden & Vilhjálmsson, 2002). A small percentage of the NL capelin population, those of the southeast shoal – Grand Banks, are deep water bottom spawners, supporting observations that capelin are environmentally adaptive spawners. The southeast shoal was a beach above relative sea level ca. 18,000 years ago during the last glacial period (Lambeck *et al.*, 2014). Capelin possibly spawned surfically on the shoal at that time, and a fraction of the popluation likely continued to do so on the ideal substrate as relative sea level rose and the shoal became submerged (Dodson *et al.*, 1991).

Capelin spawning in NL takes place once a year, for a short period. Factors initiating capelin beach spawning are poorly known, although it is believed that the spawning process is driven mainly by shifts in dominant wind direction (Martin *et al.*, 2004). The seasonal switch to onshore winds in spring allows pooling of warmer water, preferred for spawning and egg development (Jackson, 1991). Once the spawning process begins, females head toward the shore and join with one to two males, riding waves into the swash zone's furthest extent where they stay as the wave recedes. Then, in rapid succession, the eggs are deposited by the female, then fertilized and buried in the beach substrate by the male(s). Subsequent waves either reach the spawning group, and the backwash offers the group, or part thereof, the opportunity to return seaward or remain stranded above the swash zone limit (Carscadden, Frank, & Leggett, 2001; Leggett & Frank, 1990). Females that manage to return to sea then move offshore, as their reproduction cycle for the season is complete. Males that manage their way back to sea remain near the coast and participate in following runs, or "roll(s)". It is believed that females can often participate in multiple spawning seasons. Males, however, have a higher mortality rate due to trauma and exhaustion inflicted throughout numerous runs through the intertidal zone. The mortality rate is high enough that some researchers go as far as considering male capelin as semelparous, i.e., participating in a single spawning season before dying (Huse, 1998; Jackson, 1991; Martin *et al.*, 2004).

While the switch to onshore winds may play a role in the spawning process initiation by pooling warmer water on beach fronts, it is also believed to play a role in the incubation and larval stage. Onshore winds contribute to egg survival through wave action aiding the emergence process (Leggett, 1984) and food availability of zooplankton associated with the pooling of warm water after emergence (Frank & Leggett, 1982). Capelin that spawn on beaches also exhibit preferences for specific environmental conditions and sediment characteristics (Nakashima & Taggart, 2002). Sediment texture is a habitat factor influencing spawning occurrence and reproductive success. The spawning process for capelin can occur on a range of substrates, but they appear to prefer texture sizes ranging from coarse sand and granules to fine pebbles (0.5 mm – 16 mm) (Nakashima & Taggart, 2002; Neville, 2020). Though not definitively clear, the preference of surface spawning substrate texture is assumed to be related to porosity, offering an optimal balance between moisture retention and oxygen exchange for the given species and environment (Martin & Swiderskif, 2001).

Beach slope may have a minor influence on capelin spawning and egg development. Some observers have noticed spawning preference for gentle slopes, less than approxmately 15 degrees. Gentle slopes are associated with wider intertidal zones which generally display more eggs

(Nakashima & Taggart, 2002). Catto *et al.* (2003) add that the slopes capelin prefer tend to be planar or slightly concave, with pebbles showing a generally seaward imbrication. Though precisely stated slope angles are not cited in the literature, it seems the most appropriate means to describe an ideal slope is that it is low enough to offer a reasonably sized subaerial area in which to spawn, but high enough to reduce the risk of desiccation (Catto & Catto, 2012; Martin *et al.*, 2004; Nakashima & Taggart, 2002). The prefered spawning slope angle may be a geomorphic control, as gravel beaches with steeper slopes generally consist of coarser sediment (boulders-cobbles-pebbles), with gentler slopes involving finer sediment (pebbles-granules-sand). Capelin adults, and even more so eggs and larvae, are known to be very tolerant to salinity differences (Præbel *et al.*, 2009). The ability of less saline water sources to maintain egg moisture is possible without mortality or development risks (Davenport & Stene, 1986).

Morphological changes and erosion, natural or anthropogenically induced, of traditional spawning beaches can negatively affect the species' reproductive success. Beaches in NL where capelin have historically spawned now see inconsistent, reduced, or even an absence of spawning (Rose, 2007; Neville, 2020). In contrast, the enhancement of gravel beaches can protect and sustain suitable habitats for capelin spawning. Ship Cove (Placentia Bay, southern Avalon Peninsula), is a recent example of a successful beach enhancement project for capelin spawning. Historically a successful capelin spawning site, Ship Cove was altered due to extensive gravel extraction. In 2017, the site was nourished with fine pebbles and coarse sand and has since seen robust spawning results in the years that have followed (Neville, 2020). Due to the beach's very recent enhancement, the long-term suitability for capelin spawning is yet to be demonstrated.

1.2 Research Gap

Capelin population dynamics are clearly complex, and spawning success cannot be attributed to one defining factor. However, spawning behaviour is a key part of the capelin lifecycle and potentially significant for the conservation of the species. There is available literature on capelin, their spawning habits, and spawning habitats. Also available is literature on coastal intervention projects and suggested approaches to achieve the highest chances of success. However, studies linking these two subjects, which could allow better assessment of capelin spawning, are less common, with only one known work detailing the monitoring phase (Neville, 2020).

This thesis aims to address the research gap by assessing historic capelin spawning beaches in Conception Bay, Newfoundland and Labrador. As part of the assessment of beaches, there is a need to develop a new prioritization method for ecological enhancements that incorporates both the target species needs and the local areas' natural and anthropogenic stability. In this case, the focus is on the needs of capelin during beach spawning and fine gravel beaches.

1.3 Research Questions

In this thesis, I address this knowledge gap by seeking answers to the following questions:

1. What are the geomorphic, sedimentologic, and anthropogenic characteristics of the gravel beach systems in this study?
2. How do those gravel beaches' natural characteristics and human modifications influence their suitability as capelin spawning habitat?

3. Are any of those beaches suitable for making enhancements? If so, what types of enhancements would the beach benefit from to improve capelin spawning habitat?

1.4 Research Objectives

The thesis aims to use uncrewed aerial vehicle (UAV) mapping techniques and field observations to describe the characteristics and changes of the study sites to identify the suitability of those sites for enhancement measures for capelin spawning habitat improvements. This goal and the research questions asked are to be achieved through the following objectives:

1. Describe the system stresses through characterization of the physical environment and its changes on the coastal sites;
2. Access the suitability of the coastal sites for enhancement measures to improve the capelin spawning habitat for each location; and
3. Suggest whether enhancements are suitable and what type of enhancement measure is recommended for each coastal site.

1.5 Thesis Outline

This thesis follows a traditional format. Following the introduction is Chapter 2, presenting methods related to beach geomorphology assessments, processing procedures, and a newly adapted prioritization method. Results are found in Chapter 3, including observations of physical characteristics, anthropogenic influence, and geomorphological and elevation changes. Chapter 3 also contains the data used to create and implement a prioritization method to rank the beach sites for potential enhancements. Chapter 4 includes discussion of observations, consideration of implications, and assessment of limitations. Chapter 5 is the conclusion.

2. Chapter 2 – Materials and Methods

2.1 Previous Work

2.1.1 Restoration and Enhancement

Marine and coastal intervention ecology is a growing field of study (Hobbs *et al.*, 2011; Basconi *et al.*, 2020). Removing negative pressures on areas or regions through enacting protective measures has been a standard passive intervention tool (Halpern & Warner, 2003; Lester *et al.*, 2009). However, passive approaches alone are not always enough (Cox *et al.*, 2017) and more active approaches are necessary.

Concepts of human ecological interventions can easily be based on what an intervention does rather than why it is needed. Most recognized definitions of various types of intervention focus on aiding ecosystems that have been altered by some means (SER Group, 2004). Adjusting characteristics of a habitat is not the goal of intervention: it is a step towards remediating why intervention was needed in the first place (Martin, 2017). By focusing on why intervention is needed, evaluations of true success can be made and, in turn, contribute to the best practices process for human ecological interventions.

The Society for Ecological Restoration (SER) is an internationally recognized non-government organization that has identified six main concepts underpinning the best practices behind intervention. In general, the concepts have consistent themes. Human intervention aims for improvement to a fully functional ecosystem but recognizes the importance of letting this happen as naturally as possible. A key concept is that the ecosystem at some time must do the work itself. Intervention is a means of creating conditions to benefit the initiation of that self-reliance. Another recurring theme is the importance of knowledge before action. Baseline data, referencing sites to others in the regional area, and using local knowledge, and biological knowledge, all contribute to planning and, therefore, greater chance of successful intervention. The final theme is communication. Ecological intervention aims at long-term solutions, which involve the project funders, planners, the local community, and many others. Transparency between all involved and all who may be impacted is necessary to have a chance for long-term success (Mcdonald *et al.*, 2016).

Underpinning concepts, like those recognized by the SER outlined above, are ecological intervention frameworks. Therefore, following or ignoring those concepts can set the stage for success or failure, respectively. Mangrove replanting projects in Sri Lanka are a prime example of where enhancements can go wrong, with over an 80% fatality rate in the approximately 1200 hectares planted since 2004 (Kodikara *et al.*, 2017). Many of the issues with failures found in Sri Lanka planting projects stem from lack of knowledge of basic enhancement concepts and the themes of intervention. Site selection was among the issues noted by Kodikara *et al.* (2017). Poor site selection originates from inadequate knowledge. The mangrove planting site failures largely resulted from negligible consideration of species' needs with respect to the local physical and environmental conditions.

Minimal intervention to acquire full functionality is another theme of the SER. Minimal intervention is not a known constant. Instead, it can change from project to project, determined through preliminary investigations. Nor is minimal intervention rigidly set within a project. It needs to be open-ended and flexible in order to adjust to the unforeseen, continuously tailoring support to reach full self-sustaining functionality (Mcdonald *et al.*, 2016). Of the few planting projects in Sri Lanka that, purposely or unknowingly, selected suitable site locations for mangrove planting, some still showed little success for this reason. In many cases, minimal effort was not made to monitor and care for the Sri Lanka mangrove plantings, and influences that could have been manageable cascaded with devastating results. Communication, the last SER theme, is yet another failing issue in the Sri Lanka mangrove planting projects. Kodikara *et al.* (2017) found that only a six of the 23 projects studied reported using any type of guidelines or consultation of ecological mangrove restoration. Such numbers clearly show a lack of communication between knowledge holders and stakeholders. Coordination of resources and knowledge may not guarantee success, but it is fundamental to increase the chances thereof greatly.

In contrast to the example above, intervention project success can be achieved by following basic concepts. The response to mass aquatic vegetation losses in Chesapeake Bay in the mid- to late 20th century exemplifies the value of ecological intervention concepts. The Chesapeake Bay project has been ongoing for over 30 years and has coordinated an interwoven web of multiple governments, private, and scientific organizations that are involved in monitoring, collecting data, and intervention as necessary to achieve the maximum ecological function (Lefcheck *et al.*, 2018). As a result of the efforts in Chesapeake Bay, over 17,000 hectares of aquatic vegetation have returned. It has become a leading global example to draw from, inspiring more projects including seagrass restoration in Australia, to follow similar concepts (Sinclair *et al.*, 2021). These projects have the framework of ecological intervention concepts built into their core. Though such concepts cannot guarantee success, they, at the very least, lay the foundation for it (Mcdonald *et al.*, 2016).

Most active restoration work focuses on improving the habitat of vegetation, with a secondary focus on other species. Any active intervention follows similarly to the traditional definition of restoration, which is aiding damaged, degraded or destroyed ecosystems (SER Group, 2004). Vegetation holds the primary role in an ecosystem's trophic level. Whether there will be a disconnect between the application of basic restoration and enhancement principles to situations sidestepping primary producers (vegetation) is unclear.

In Newfoundland and Labrador, an ongoing project, the first known of its kind, aims to restore capelin habitat (Neville, 2020). Neville (2020) and World Wildlife Fund (WWF) Canada identified the fish's unique beach surface spawning as the most accessible means of directly aiding capelin populations by enhancing degraded beach geomorphology to pre-existing suitable conditions for spawning. Thus, enhancement in this instance does not involve modification of the vegetation assemblage.

2.1.2 Use of UAV and other tools for ecological intervention practices

Uncrewed Aerial Vehicles (UAV) have been increasingly utilized in scientific research (Doukari *et al.*, 2019). If appropriately used, UAVs bring an inexpensive yet highly detailed means of remote sensing to the realms of ecological and environmental assessments. However, UAV's are only a tool and, if not used correctly to their fullest potential, are nothing more than a means of taking "pretty pictures" (Joyce *et al.*, 2019). It is not uncommon to see documents reporting little to no information of the method, planning, or procedures behind the use of UAVs (Singh & Frazier, 2018). Generally, widely accepted underpinning concepts of use for new technology comes after its introduction, and it is only in recent years that some interlocking agreement between conceptual use of UAV literature has developed (Doukari *et al.*, 2019; Joyce *et al.*, 2019; Tmušić *et al.*, 2020).

Tmušić *et al.* (2020) represents one of the most recent attempts to present the basic framework necessities to using UAVs in the field of ecological and environmental sciences. They stress five underpinning concepts that are collectively important to the success of the project: study design, pre-flight, flight mission, data processing, and quality. The study design is a fundamental starting point incorporating what the project is intended to achieve, which in turn informs requirements on environmental factors, legalities, equipment and others. Pre-flight and flight mission concepts are centered on the need for site reconnaissance, georeferencing, assessment of atmospheric conditions, flight plan, and how these are essential to obtaining usable and reliable data. Tmušić *et al.* (2020) take the basic concepts a step further than simply data collection by also stating that data processing is an integral step in using UAVs for science. Very similar themes are presented throughout Doukari *et al.* (2019) through overarching concepts of area morphology, environmental conditions, and study design. However, Doukari *et al.* (2019) do not incorporate the importance of data processing and quality control. Though not as detailed or elaborate, Joyce *et al.* (2019) describe the principles used in the particular form of marine science and share many principles with other works mentioned. A conceptual framework for UAVs in science is currently solidifying.

2.1.3 Gravel Beaches

Gravel beaches are one of many natural types of coastal modification. Gravel beaches can absorb and reflect the ocean's immense power and at the same time, unlike rugged cliff faces that stand fast, maintain a dynamic structural equilibrium (Buscombe & Masselink, 2006). Such gravel beaches are a staple of Newfoundland and Labrador and have their share of interest for research and professional study, particularly on the Avalon Peninsula and Conception Bay.

Catto *et al.* (2003) assessed the coastline of eastern Newfoundland, and through a classification system, concluded that gravel beaches backed by rock cliffs were typical around most of the Avalon Peninsula. Sediment dynamics with these types of beaches are often largely restricted within a cove flanked by headlands, with wave and storm action being the leading factor in moving and reworking the locally supplied sediments. However, much of the Conception Bay South to Holyrood coastline includes gravel or gravel and sand flats or beaches, predominately consisting of pebble to cobble-sized sediments. The morphology of such beaches is mainly dependent on storm events. As a result, slope, physical features, and sediment clast size distributions can be highly dynamic. Wave activity is the dominant contributor to morphodynamics of gravel beaches, and as wave action is directly connected to prolonged wind direction and strength, the orientation of a beach face with respect to dominant storm direction will have immense impact on beach stability.

Although wave action may be the leading factor to beach dynamics on any gravel beach, localized factors of an individual beach such as sediment clast size plays a large role in gravel beach development. Sediment clasts interact with each other and respond differently to wave action depending on size, influencing and restricting parameters influencing sediment movements and beach slope (Bujan, Cox, & Masselink, 2019; Buscombe & Masselink, 2006).

Pittman (2004) developed knowledge specifically of the dynamics of Conception Bay South gravel beaches. Approaching the more anthropogenic-influenced area of Long Pond, Pittman (2004) addressed the impact of human changes on barachois dynamics. Beach armouring of bluffs in the region has slowed bluff erosion, but caused the down-drift barachois to back step beyond the adjacent mainland, stretch, and create inlets. In addition, when an industrial port was created in the lagoon and the inlet opening was permanently maintained, it improved the tidal exchange between the Bay and the lagoon. A permanent roadway led to further narrowing of the barachois. This research shows that even varying degrees of anthropogenic influence can have long lasting impacts and can be an important factor when considering gravel beach dynamics.

Paone (2003) focused on the coastline from Conception Bay South to Holyrood. The research incorporated gravel beach dynamics and their relation to hazard sensitivity, with climate change implications. One finding was the degree of gravel barachois sensitivity to relative sea level changes. Long-term changes to morphology are a direct response to the rise or fall of relative sea level and sediment availability. Rapid change will adversely influence a barachois' ability to respond.

2.2 Study Area and Settings

2.2.1 Study Area

This study was conducted in the coastal zone of the southern part of Conception Bay, in the eastern part of the island of Newfoundland (Figure 2.1). In response to ongoing threats to marine species and coastal habitats, Fisheries and Oceans Canada launched the Coastal Restoration Fund for the purpose of planning, restoring, and monitoring (Fisheries and Oceans Canada, 2019). During the past three decades, the WWF Canada, recognizing the decline in Newfoundland capelin populations (Buren *et al.*, 2019), acquired funding to restore capelin spawning beaches throughout the province. WWF contracted Feaver's Lane, a geographic information systems consulting company, for a province-wide site identification analytical prioritization for fish habitat enhancements. The identification process took into account broad-scale issues such as area disturbance, future threats, ecology, and community feedback (Greene, 2019). As a result, Lance Cove and Harbour Main were identified as potential candidates for enhancements, and were suggested as sites to be observed in greater detail for this thesis. Chapel's Cove was also selected for this study as a beach with geomorphic and sedimentologic characteristics intermediate between Lance Cove and Harbour Main.

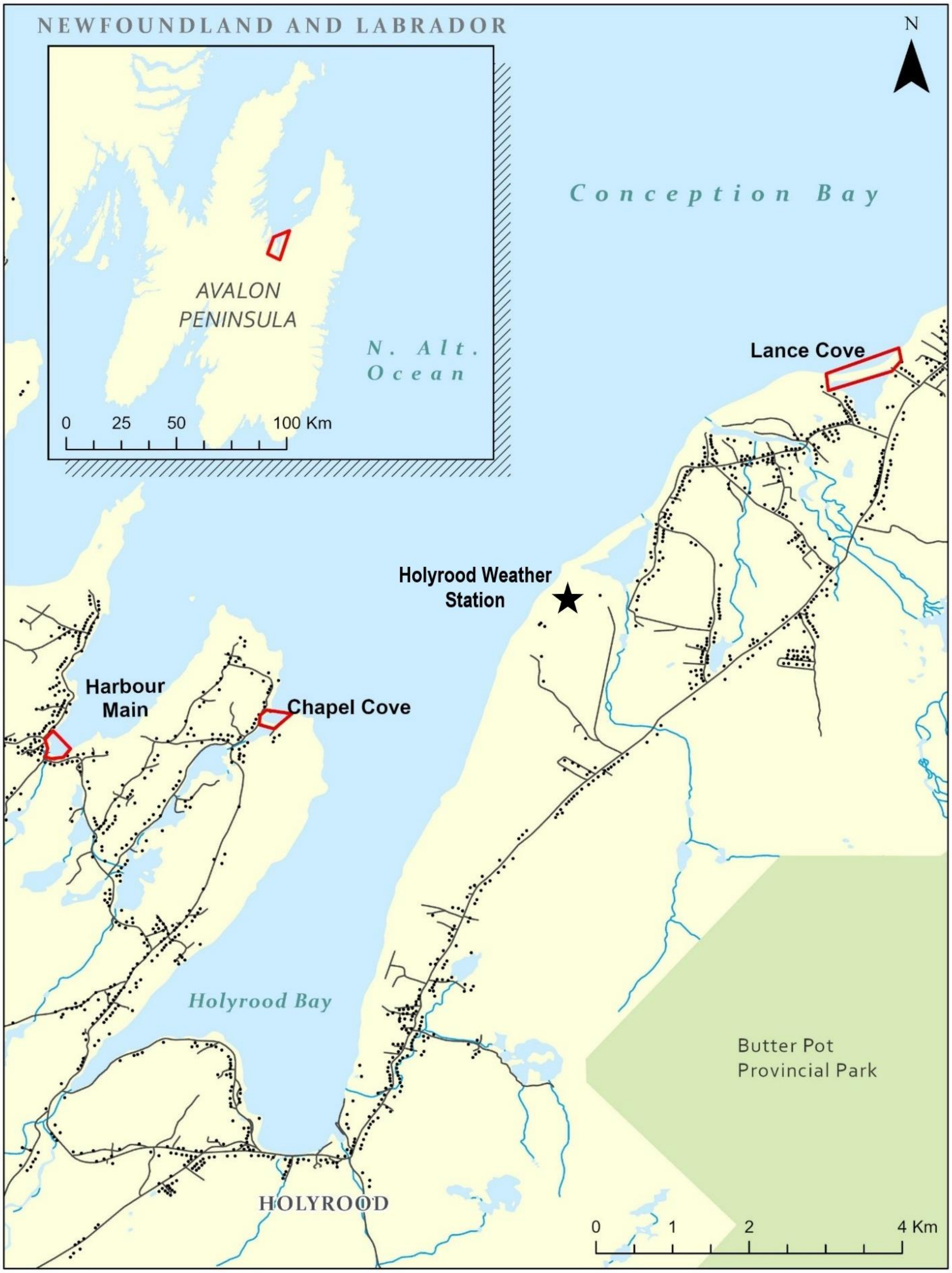

Figure 2.1: Study site locations, southern Conception Bay, Newfoundland and Labrador.

2.2.2 Regional Climate and Weather

The ocean particularly influences the island of Newfoundland's weather and climate. The Avalon Peninsula is entirely a coastal region, with no point being farther than 30 km from the sea. The study sites are all located within 8 km of the Holyrood Generator Plant weather station (Figure 2.1) and within 40 km of the nearest World Meteorological Organization recognized station at St. John's International Airport. The Holyrood station is located near the head of Conception Bay at an elevation of 6 m. In comparison, the airport station is located further northeast at an elevation of 140.5 m, closer to the open North Atlantic Ocean.

According to the Holyrood climate normals for 1981-2010, the study area mean temperature is 6.3 °C, ranging from -3.6 °C in February to 17.2 °C in August (Environment Canada, 2020). The station did not have a record for the mean wind speed but did record the most frequent direction from the south to the southwest for all months, with calm conditions commonly occurring. However, the maximum wind directions tend to occur most commonly from the north, ranging from northwest to northeast, with some from the southeast. A slightly lower mean annual temperature of 5 °C was seen at St. John's International, ranging from -4.9 °C in February to 16.1 °C in August. The wind speed mean here is 21.9 km/h from the west, while the maximum hourly speed reached 137 km/h. The maximum wind directions showed a broader range than Holyrood, ranging 270°, from northwest through east to southwest.

Conception Bay is mixed semidiurnal microtidal with a mean range of 1.4 m (Canadian Tide and Current Tables, 2019). Mean significant wave height can often exceed 7 m (Paone, 2003). Historically, ice in Conception Bay is a yearly occurrence, with nearshore ice intensity varying annually (Hill & Clarke, 1999), ice foot development lasting from approximately December to March in some winters (Catto, 2012). However, with climate change, Avalon Peninsula winters are becoming more variable and generally milder (Finnis, 2012). These climate trends lead to inconsistent spatial and temporal ice development, particularly in southern Conception Bay, that can be easily influenced by weather and wave events. The lack of consistent systematic monitoring of coastal ice in the area makes confirming trends of ice foot formation on southern Conception Bay beaches difficult. The high levels of precipitation generally result in snow and ice cover above mean high tide. Ice generally offers coastal protection through physical resistance onshore (ice foot, beach cover) so future changes in onshore and nearshore ice may influence coastal stability.

2.2.3 Regional Geology

The southern region of Conception Bay comprises approximately 30 km of cliff and gravel beach shoreline between Harbour Main (north, western shore) and Lance Cove (eastern shore). The bedrock is Ediacaran to early Paleozoic. The oldest unit, exposed at Harbour Main, is the Harbour Main Group, including clastic sedimentary and volcaniclastic rocks. Ediacaran gabbroic rocks of the Holyrood Intrusive Suite intrude the Harbour Main Group at several locations, including Chapel's Cove. The overlying Cambrian Adeyton and Harcourt Groups consist of red, green, and pink shales and carbonates. Lance Cove is underlain by the Manuels River Formation of the Harcourt Group, although this shale is not exposed on the surface (Figure 2.2) (Catto, 2020; King, 1988).

The bedrock material and structural geology play a role in forming the regional landscape. In general, the Cambrian Adeyton and Harcourt Group shale and carbonates are less resistant to erosion in comparison to the clastic sedimentary and volcaniclastic bedrock of the Ediacaran Harbour Main Group and Holyrood Intrusive Suite. Additionally, the tectonic history of these groups on the Avalon resulted in folds oriented northeast-southwest, along with similarly, aligned major fault lines ranging from north-northwest—south-southeast to north-northeast—south-southwest (King, 1988). The faults and folds control much of Conception Bay's western coastline north of Holyrood. Not only are these structural weak points, but the faulted areas are usually associated with less resistant rock material (Catto, 2020). The combination of structure and lithology allowed erosional processes to create a coastline of alternating coves and headlands.

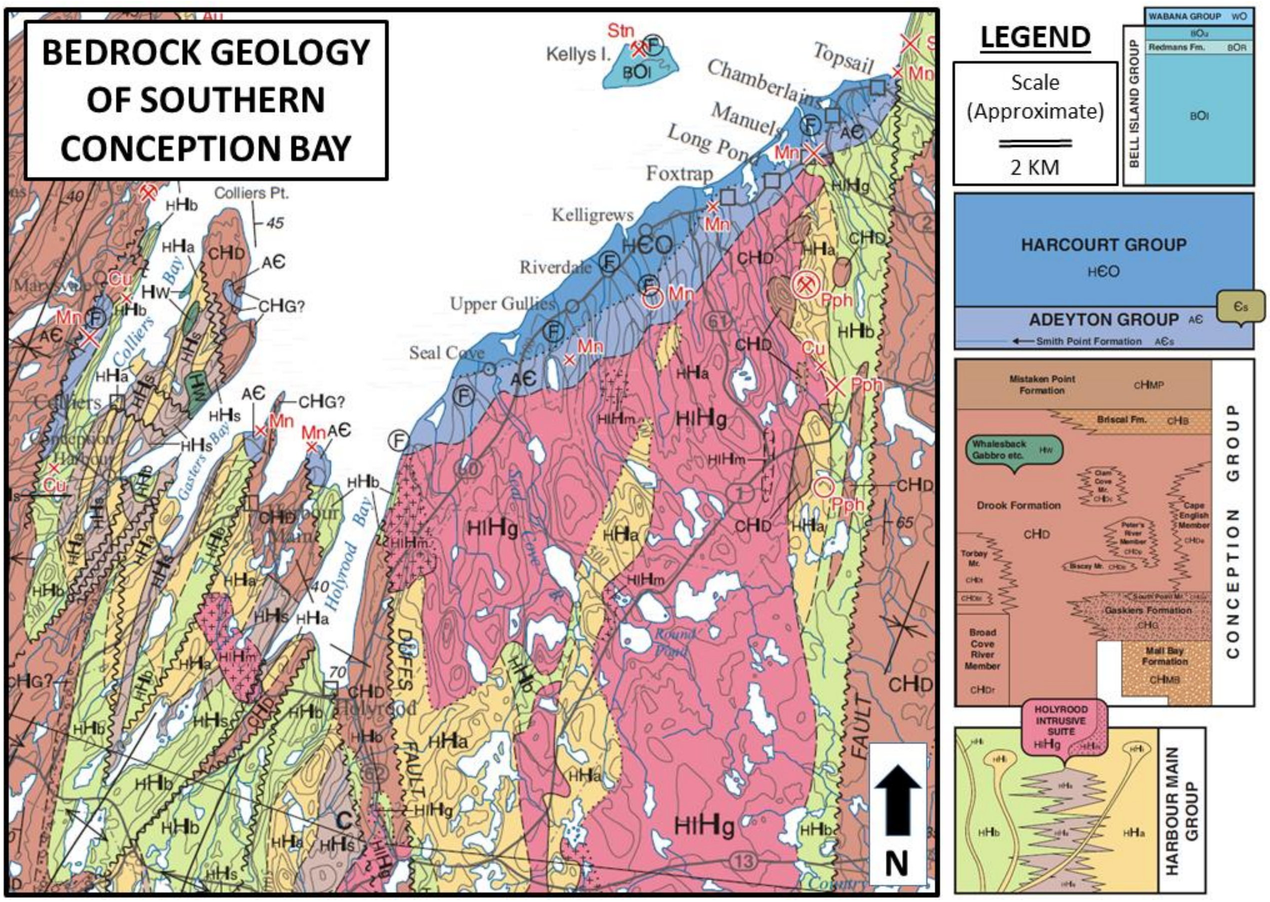

Figure 2.2: Bedrock Geology Map of Southern Conception Bay. Modified from King (1988)

2.2.4 Quaternary History

Several glaciations over the area have also shaped the coastal geomorphology. Much of the Conception Bay South to Harbour Main area is covered in a discontinuous diamicton (till) veneer (<1.5 m), with other parts receiving thicker deposits as a till blanket (1.5 m to 3 m) (Figure 2.3)

(Catto & Taylor, 1998; Liverman & Taylor, 1994). Quaternary glacifluvial outwash deposits primarily consisting of gravel, ranging from granules to boulders, are present along much of the Conception Bay South to Holyrood coastline (Catto, 2012; Paone, 2003; Pittman, 2004). Areas where the finer material has been washed away have pebble-cobble-dominated beaches with high permeability.

Sea-level is directly linked to glacial history. On the Avalon Peninsula, glaciation is the largest influence on relative sea-level change (Batterson & Liverman, 2010). Currently, all the Avalon is under the influence of isostatic subsidence of ~2 mm/year (Batterson & Liverman, 2010; Paone, 2003). Including both subsidence and ongoing increasing ocean volume, the current relative sea-level rise for the Conception Bay region is approximately 3.0-3.5 mm/year (Catto *et al.*, 2003; Catto, 2020). Nevertheless, the pattern of relative sea level change has varied since the last glacial maximum 20,000 years ago. Raised beaches and other features in the southern Conception Bay area suggest that postglacial relative sea level was approximately 10 m higher in these areas compared to today (Catto, 2012, 2020; Catto *et al.*, 2003). The relative sea level maximum in Conception Bay is associated with initial deglaciation, approximately 12,000 years ago. During the early Holocene, minimum relative sea level dropped to approximately 10 m below present, associated with the overcompensation from isostatic rebound. Ongoing subsidence since approximately 8,000 years ago is largely responsible for the current rise in relative sea level (Catto, 2020).

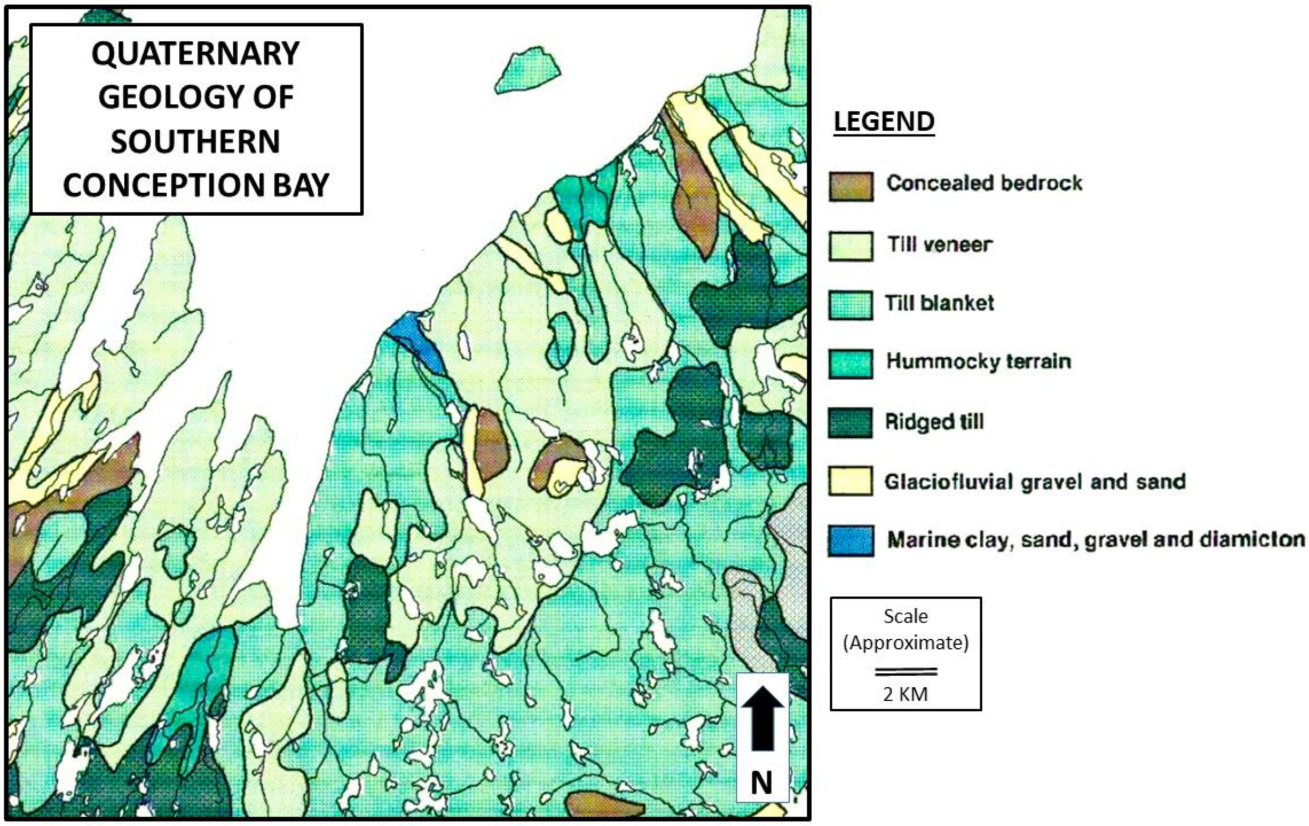

Figure 2.3: Quaternary Geology Map of Conception Bay. Modified from Liverman & Taylor (1994)

2.2.5 Anthropogenic Influences

Human-induced modification in the Conception Bay region involves construction near shorelines associated with initial European settlements in the late 17th to early 18th centuries (Prowse, 1896). Locally, larger-scale modification began with the construction of the Newfoundland Railway. The railbed required substantial alteration to accommodate heavy locomotive operation directly along the shoreline between Holyrood and Kelligrews. The process continued from the initial construction of the railway (1881) to the final dismantlement (1990) (Railway Coastal Museum, 2011). This railway disturbance represents a direct and ongoing impact on the Lance Cove site explored in this study, as the former rail bed was placed on the gravel barrier. In 2016, the Conception Bay South part of this retired railbed was modified into the T'Railway, part of an expansion of walking trails in association with the Grand Concourse Authority. Furthermore, a rock wall in the intertidal zone also directly influences the northeastern part of Lance Cove, as its placement is to protect the developed walking trail directly landward of the wall. An extractive sand and gravel pit is located along the shoreline directly southwest of Lance Cove.

Harbour Main also has other notable developments which alter and influence the beach. A rock wall was built in 2012 to protect an outdoor swimming hole and picnic area for public use. Dredging of the lagoon (most recently in 2017) and maintenance of the barrier (most recently 2020) have continued. The Conception Bay Highway, a major roadway, passes at its closest point within 10 m of the beach area in Harbour Main. A concrete barrier was constructed to support the cliffside along one section of the road. In another location, rock rubble (large cobble to boulder size) was placed on the beach in 2018-2020 to prevent the roadway's erosion. Other structures around the cove's head include residential dwellings directly east of the swimming hole and a wharf, boat launch, and dockside warehouses along the west shoreline of the cove near Conception Bay Highway and Harbour Drive.

Chapel's Cove is not without human impact, related primarily to small boat use. A roadway extends the entirety of the beach bar to allow access to a few residences and a boat launch located on the eastern side of the cove. A rock boulder breakwater on the east side of the cove offers protection to the boat launch. On the western side of the beach, boulders and concrete debris have been dumped to protect Point Road from erosion. Many of these features are associated with the former nearshore cod fishery. Until 1992, Chapel's Cove was a prevalent local harbour for livelihood fisheries, small boats docked in the lagoon, and the channel was dredged regularly for access (Catto, 2020). Now, only some run-down remnants of the past remain, such as rotting wooden retaining walls. The post-1992 constructed structures were built as easily maintained replacements better suited for the amount of modern usage.

All three beaches are used recreationally. Usage should be considered relative to their location, as Harbour Main and Chapel's Cove are outside the St. John's region, and Lance Cove is located near the southwestern border of Conception Bay South. Lance Cove is in Conception Bay South (population 27,618; (Statistics Canada, 2021), while the town of Harbour Main-Chapel's Cove-Lakeview is much less populated (1,065). Lance Cove is used by walkers, cyclists, and all-terrain vehicle users. However, these activities are usually restricted to the T'Railway on the landward part of the barachois. The seaward trudge to the intertidal zone is often quite challenging due to the loosely packed steep grade of the beach face, making it generally unappealing to foot or wheeled traffic.

Harbour Main's infrastructure is purposed to invite recreational use. However, the largest attraction, the swimming hole, is already behind a protective boulder wall. Therefore, the impact behind the boulder wall should easily accumulate, whether that be from recreational activities, tidal action, or rare breaching by storm action. The other nearby parts of the beach seaward of any rock wall have a small beach width of 5 to 10 m. Though less appealing, they likely receive reasonable amounts of foot traffic due to their association with the swimming hole.

Local residents commonly visit Chapel's Cove, and those that live there or who look to take up residence view the beach as a centerpiece of the community (Mooney, 2021).The beach is generally low-sloping with easy access all the way to the waterline for foot or wheeled usage. The layout out of the beach makes for easy access to all parts, enticing regular usage for fires, fishing, and walks or browsing.

2.3 Data Collection

Data collection occurred in two phases. The first phase entailed data acquisition from Lance Cove, Chapel's Cove, and Harbour Main that helped map and identify beach characteristics and changes. The second phase assessed what those characteristics and changes mean in terms of completing capelin spawning habitat enhancements.

For the first phase, the study used Uncrewed Aerial Vehicle (UAV) technology to measure and map physical land-based characteristics, a method that has been used in coastal areas (Irvine, Roberts, & Oldham, 2018; Mancini *et al.*, 2013; Papakonstantinou, Topouzelis, & Pavlogeorgatos, 2016). The UAV, when used with a Real-Time Kinematic (RTK) Global Navigation Satellite System (GNSS), collected elevation data that can help assess sediment changes. The UAV approach allows for complete data coverage of the area.

Digital images of each site were collected using a DJI Mavic Pro 2 UAV, supplemented by ground transect surveys. Ground control points (GCP) were first collected to help georeference the imagery. Thirteen GCP along with transect start and endpoints were distributed throughout the site area during each site visit. GCP was acquired using a Trimble R8s Integrated GNSS System, offering centimetre geospatial positioning required for the UAV imagery post-processing. Collecting aerial images involved UAV flight planning software, *Map Pilot for DJI* (IOS Application, version 4.0.8). The application was used to run pre-programmed flight paths automatically, under a trained pilot's supervision in case of an emergency. The flight paths followed an "S" pattern over the designated area, with images taken perpendicular to the ground at an overlap rate of 75% in both the forward and lateral directions. The pre-programmed flight plans were made individually for each site and encompassed the entirety of the gravel beach and parts of the adjacent backshore and coast. Methods were consistent across sites and site visits, with minor exceptions for Lance Cove and Chapel's Cove's first surveys. UAV flights were conducted during the first two field visits, Lance Cove on 14 June 2019 and Chapel's Cove on 19 June 2019, at an altitude of 60 m. All other flights were conducted at an altitude of 40 m, helping reach a higher spatial resolution. The flight plan areas for each beach remained consistent between the initial and repeated surveys.

To complement the UAV imagery, physical and biotic environmental data were collected through transect sampling at each site. Transect length and spacing depended on the spatial configuration of each site. Transects were designed to be feasibly completed in conjunction with the aerial survey in one field day in an effort to control for weather conditions across data sources. For this study, transects did not have to be evenly distributed along the coast, although each transect was normal to the shoreline and representative of critical points on the beach. Critical points were considered as any freshwater outflows, flanks of the beaches, and areas where sediment could enter or leave the beach site. While UAV surveys were operated at low tide to maximize the mapped area, transects were performed on the same days during higher tide periods. Biological and sediment characteristics were observed and recorded through visual interpretation along each transect. Each transect described vegetation changes by classifying observations, generally as trees, shrubs, grass/weeds, eelgrass, and seaweed. For sediment characteristics, observations followed the Wentworth Scale of sediment size (Wentworth, 1922), roundness guidelines of Powers (1953), and shape based on the Zingg (1935) classification of shape. For the area between transect lines, notes were made of significant characteristics differing from the transects.

2.4 Processing of Digital Models and Land-Cover Mapping

Processing the UAV images was performed using the photogrammetric software Agisoft Metashape (version 1.5.4, Agisoft LLC). The software was used to generate orthomosaics and digital surface models (DSM) of each site, using the structure from motion [SfM] method (Kaimaris, Patias, & Sifnaiou, 2017). The software, previously known as Photoscan, has proven useful in creating high-resolution DSM in other coastal studies (Mancini *et al.*, 2013; Papakonstantinou, Topouzelis, & Pavlogeorgatos, 2016).

DSM were used to interpret changes on gravel beaches. The ArcGIS (version 10.7, Esri) Raster Calculator tool was used to create maps showing elevation changes for each study site between two surveys. Additionally, ArcGIS tools combined with the DSMs and orthomosaics were used to calculate distances, areas, and volumetric changes of land features or resulting changes.

2.5 Multi-criteria Enhancement Prioritization

For the second phase of the project, I used a multi-criteria decision analysis (MCDA) approach to prioritize the three study sites, based on data collected from the first phase of this project and on other existing information available for those sites. MCDA has been commonly employed in prioritizing coastal restoration sites (Diefenderfer *et al.*, 2009; Kauffman, 2007; Kauffman-Axelrod and Steinberg, 2010; Kunert, 2005; Rahman *et al.*, 2014; Widis *et al.*, 2015). Here, I used an analytical hierarchy process (AHP) MCDA method. For the AHP, each parameter was selected based on its ability to describe two objectives (Figure 2.4). First, I assessed the suitability of each study site in terms of capelin spawning habitat. Second, I assessed the extent of the changes observed at each site to favour sites that are less dynamic in terms of sediment movement.

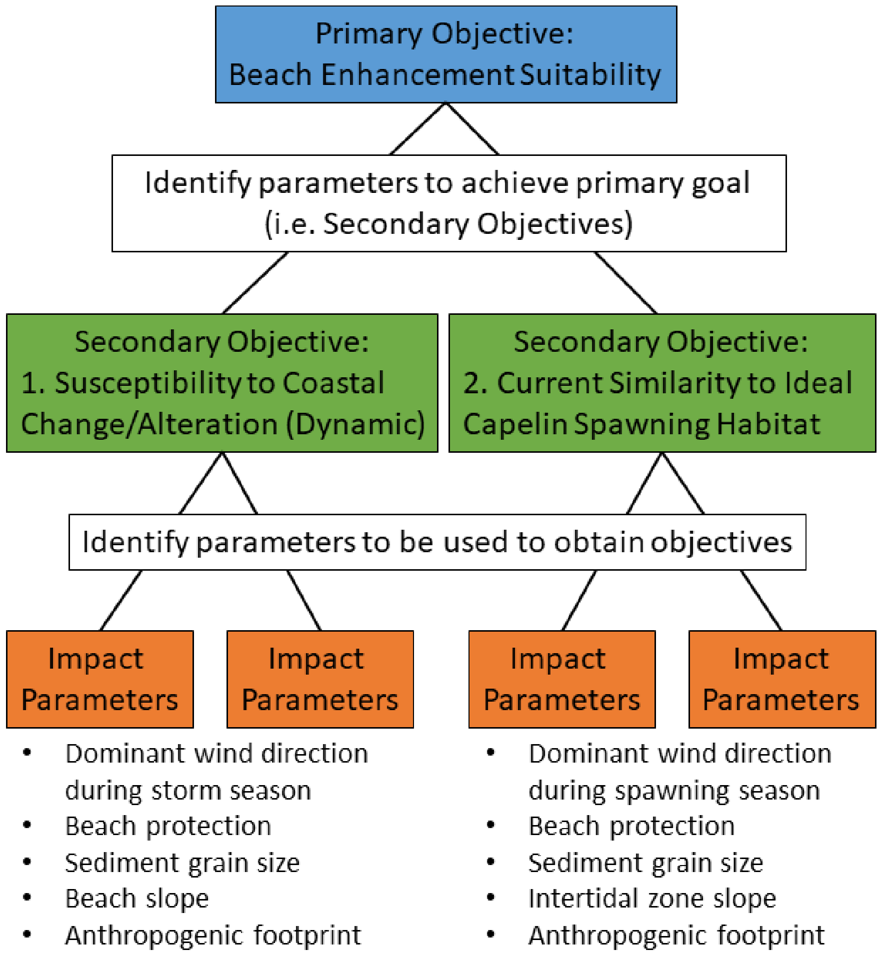

Figure 2.4: General MCDA prioritization approach

The multi-criteria approach took place in three stages. First, capelin spawning and coastal geomorphology literature were reviewed to identify sedimentologic, geomorphic, climate, and anthropogenic parameters known to influence spawning habitat and susceptibility to coastal change. Second, the parameters were assigned a score based on each beach's characteristics, where the similarity to the most ideal situation was scored highest, and the least ideal scored lowest.

Third, fisheries and coastal experts were consulted individually to offer insight into the selected factors' importance.

The fisheries and coastal area experts provided a level of importance (high, medium, low, and none) for each parameter. By assigning a quantitative value for each possible answer (high=3, medium=2, low=1, none=0) (Horta e Costa *et al.*, 2016; Kincaid *et al.*, 2017), weights for each parameter were derived. Parameters' weights were obtained using the 'rating' MCDA weighting method (Greene *et al.*, 2011; Malczewski & Rinner, 2015).

3. Chapter 3 – Results

3.1 Study Sites Surveys

Each of the three study sites was visited a minimum of two times in 2019 to capture the beach's temporal changes. Field survey procedures and detailed operations for each visit can be found in "Appendix A: Field Survey".

Lance Cove (Figure 3.1) was visited four times: on 14 June, 11 September, 15 November, and 28 November, 2019. The 15 November survey was incomplete due to technical difficulties. Chapel's Cove was visited twice, on 19 June and 17 October, 2019. Harbour Main was visited twice, on 27 June and 12 November, 2019. A data recording malfunction with the UAV resulted in the last survey missing data for the southwestern part of the mapping area. The majority of the Harbour Main beach was captured in the aerial survey, but a small gap in the data coverage was created on the backshore and hinterland.

3.2 Beach Geomorphology

Sediment characteristics were described along transect lines (Appendix B: Transect Data), and general observations of morphologic changes were acquired using UAV oblique imagery and standard field photos. Transect line surveys completed ranged from 2 to 4 lines per study site, depending on the local context. However, transect lines for return visits were placed as close as reasonably possible in the same locations as for previous visits. The original placement of transect lines were initially selected to best represent the beach in question, areas of sediment influx or outflux, freshwater outflows, and impacts of human-placed structures.

3.2.1 Lance Cove

Lance Cove beach (Figure 3.1) is a gravel beach bar or barachois. It is mainly composed of granitic and clastic sedimentary pebbles and cobbles and has clasts ranging from boulders to sand. Much of the pebble material can be found on or near the old railway bed, a path that runs across the barachois, and near or in the intertidal zone, usually mixed with cobbles. There is a rock wall on the northeastern part of the beach protecting the Grand Concourse T'Railway hiking trail. During low tide, this section of the subaerial beach is shorter in width, 15 m or less, relative to the remainder of the beach to the southwest of the rock wall that is 25 m or greater. Southwest of the rock wall, the beach transitions into another section where the intertidal zone has a slope of approximately 10 degrees. The intertidal zone includes multiple lower berms, extending to the near backshore area. The backshore area is a large berm approximately 3 m in height with a slope in excess of 20 degrees. At the crest of the slope, the beach is relatively flat landward to the edge of the T'Railway. The landward margin dips sharply into the lagoon.

Further east, a transition is seen in a third section that closely resembles the second. However, there is a distinct separation between the old railway bed, which has a rock wall reinforcing its seaward side, and the berm's crest with the steepest slope. The area between the two is also marked by the remains of upright rails pounded vertically into the beach. Three transect lines were chosen to represent these three sections and were surveyed four times each on 14 June (Figure 3.1), 11 September, 15 November, and 28 November (Appendix C: Orthomosaics).

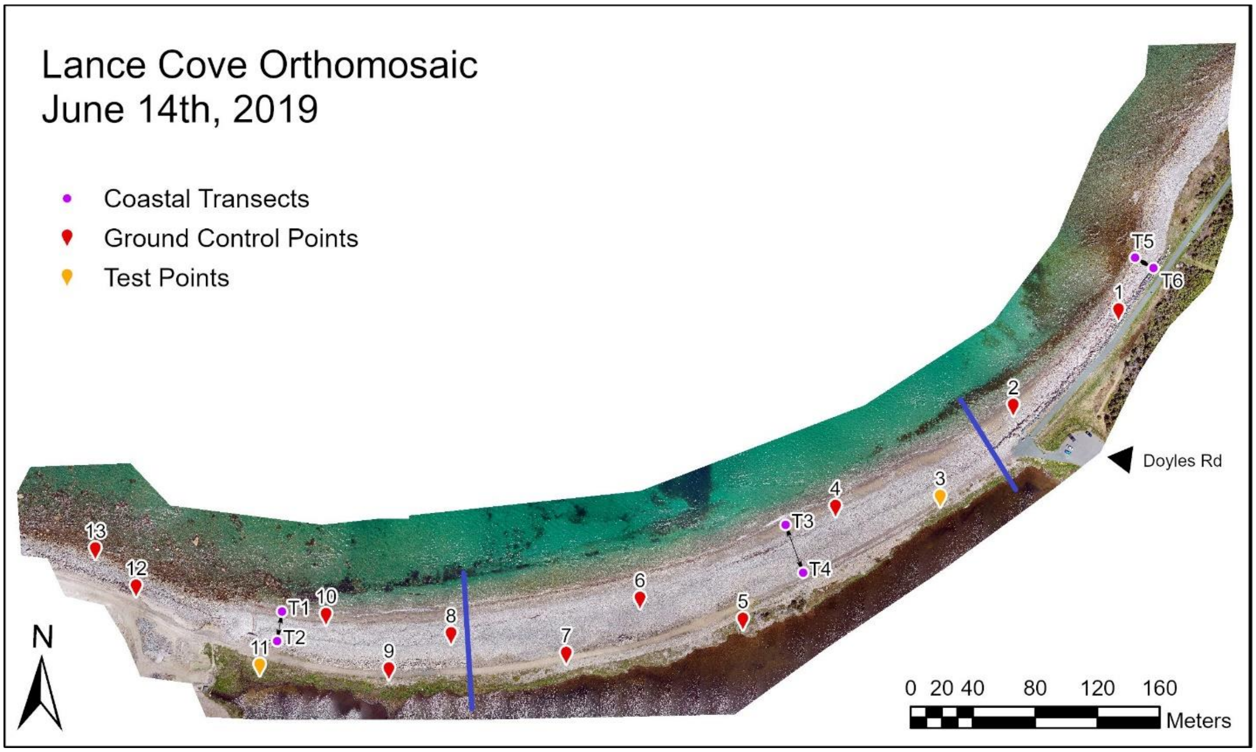

Figure 3.1: Lance Cove orthomosaic *with transect and GCP locations in June 2019. Transect associated sections separated by blue lines.*

The T1-T2 transect (Figure 3.1 & Figure 3.2) was located on the beach's southern edge, with a drainage pipe approximately 15 m due west (Figure 3.2 & Figure 3.3). The intertidal zone directly adjacent to the shoreline consisted of <99% medium pebbles during the June visit. Landward pebbles still dominated the texture ranging from 50-90% but were much coarser.

Cobbles formed the remaining sediment, with a well-sorted texture overall. A change near the low tide shoreline area was observed in September to ~90% coarse pebbles, while November characteristics in the same area were similar to those in June. Little noticeable change between visits was observed in sediment texture characteristics landward of the intertidal zone to the rock wall.

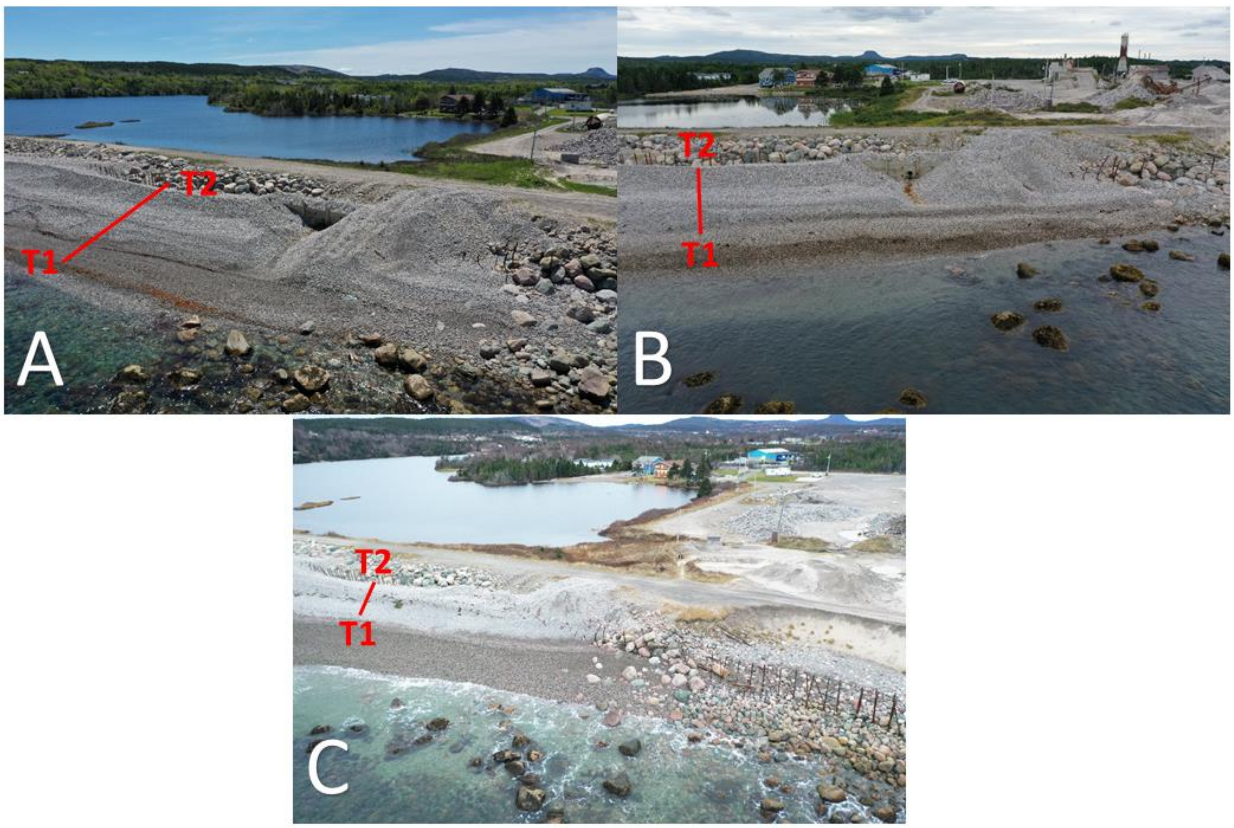

Figure 3.2: Buried pipe outflow on the southwest part of Lance Cove Beach aerial view, (A) 14 June 2019, (B) 11 September 2019, and (C) 28 November 2019.

The area directly surrounding the drainage pipe, west of the transect, was characterized by a high amount of sediment movement, possibly due to human repositioning. During the initial visit in June, a distinct drainage path to the intertidal zone with minimal discharge from the drainage pipe was observed. Sediment characteristics flanking the ditch, normal to the shoreline, were similar to the transect 15 m east. The ditch had no noticeable buildup of fine material deposits from the pipe discharge. Additionally, during this visit, the mound of gravel directly west of the drainage area shows signs of heavy equipment tracks, suggesting the drainage ditch has been mechanically created or cleared since the last time the beach has been naturally reformed. During the second visit in September, the drainage pipe and ditch remained relatively unobstructed. However, the drainage path showed small amounts of infill from the surrounding beach pebbles and cobbles. Where the ditch met the intertidal zone, there was a noticeable mound of gravel stretching across the entirety of the drainage route. During the final visit in November, there was complete infilling of the previously existing drainage ditch. The pipe was only recognizable based on three vertically placed wooden posts from the pipe's support structure that remained above the beach gravel infill's surface (Figure 3.3). The posts were distinguished as part of the pipe's support structure from previous visits.

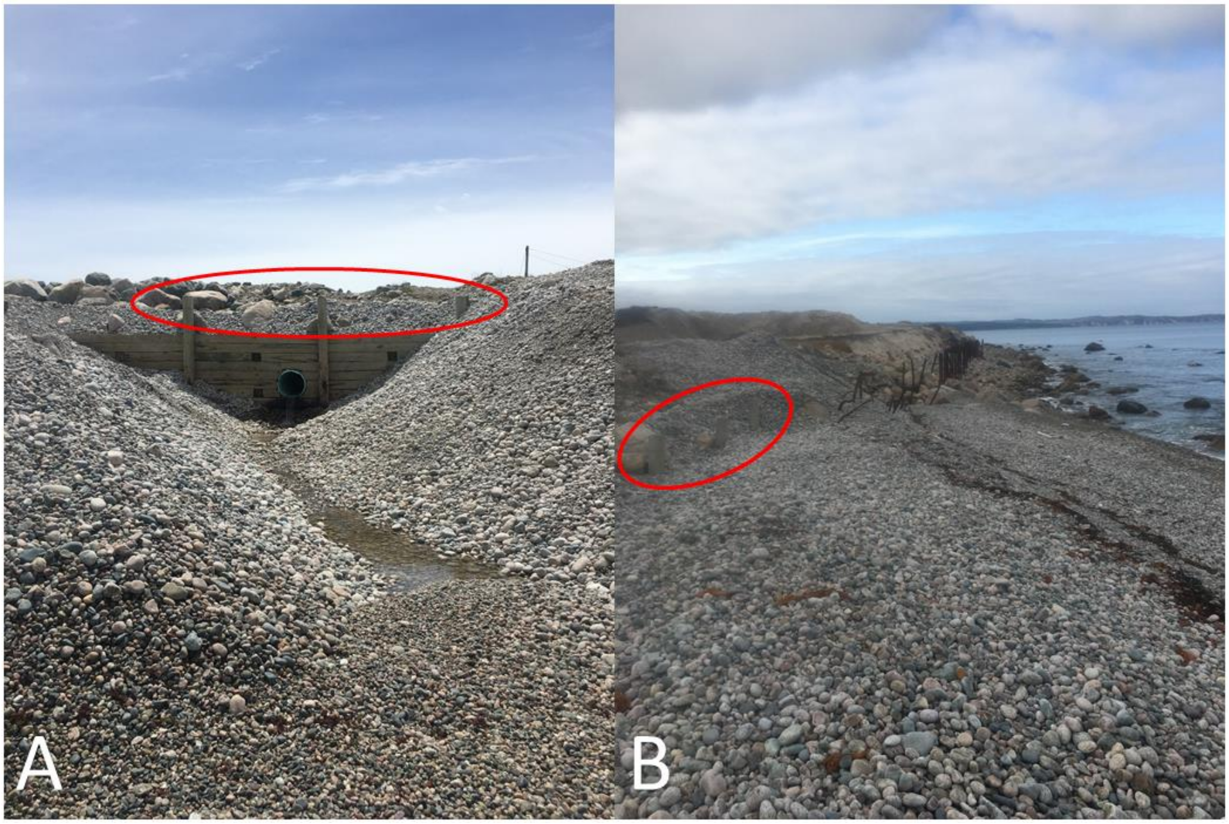

Figure 3.3: Buried pipe outflow on the southwest part of Lance Cove Beach ground view. Red circles are representing the same drainage pipe feature. (A) 14 June 2019 camera orientation South, and (B) 15 November 2019 camera orientation West.

The second transect, T3-T4 (Figure 3.1, Figure 3.4, & Figure 3.5), was placed more central on the beach, approximately 200 m west from the end of Doyles Road. For the first site visit in June, no data was collected because a bypasser removed the marker flag indicating the transect location. The intertidal zone showed much textural change throughout the study period. Though no transect was completed in June, based on area photos and observations, there was a ~5 m band width of 99% sand in the intertidal zone in front of Doyles Road, stretching along the beach's length ~150 m southwest. In September, the exposed intertidal zone next to the water line was ~60/20/20 pebbles, cobbles, and sand. From there to ~15 m back from the shoreline to the steepest slope, there were ~70% cobbles, transitioning to pebbles and back to cobbles at the bottom of the slope. The cobble zone at the base of the backshore's steepest slope transitions to ~70% coarse pebbles towards the crest (Figure 3.4).

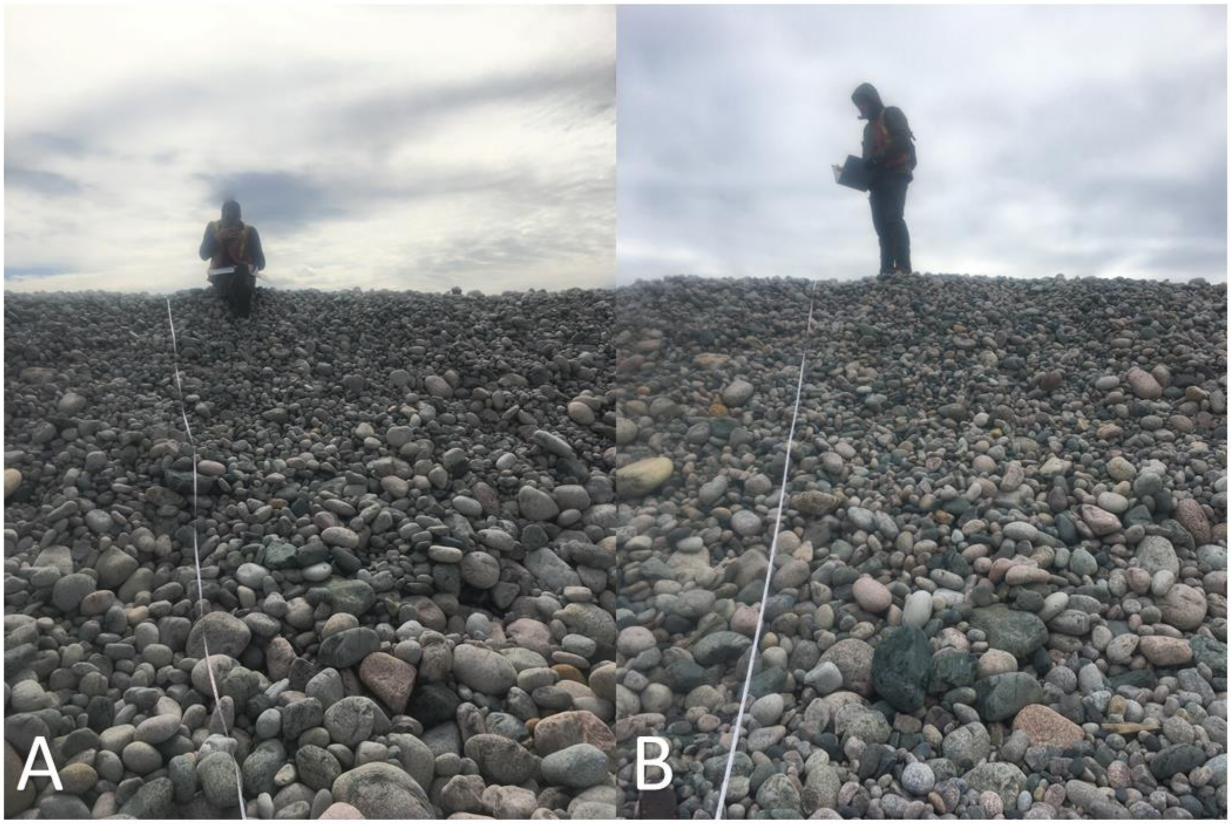

Figure 3.4: Furthest backshore slope for T3-T4, central beach. (A) 11 September 2019 and (B) 15 November 2019.

Above this zone to the T'Railway is approximately a 60/40 split of coarse pebbles and cobbles. At the crest of the last landward slope, the beach plateaus, followed by a landward slope into the lagoon. The crest is marked by a remnant of the old railway, with pebble and cobble clasts from the beach. Where the transect intersects the trail, beach material covers approximately 80% of the T'Railway, and other parts of the trail have coverage ranging from 10-90%. In November, the swash area of low tide remained 95% sand as it did in September. However, the intertidal zone consisted of ~70/20/10% cobbles, pebbles, and sand up to the steepest slope ~15 m back from the shoreline. From there, landward, there were no noticeable changes.

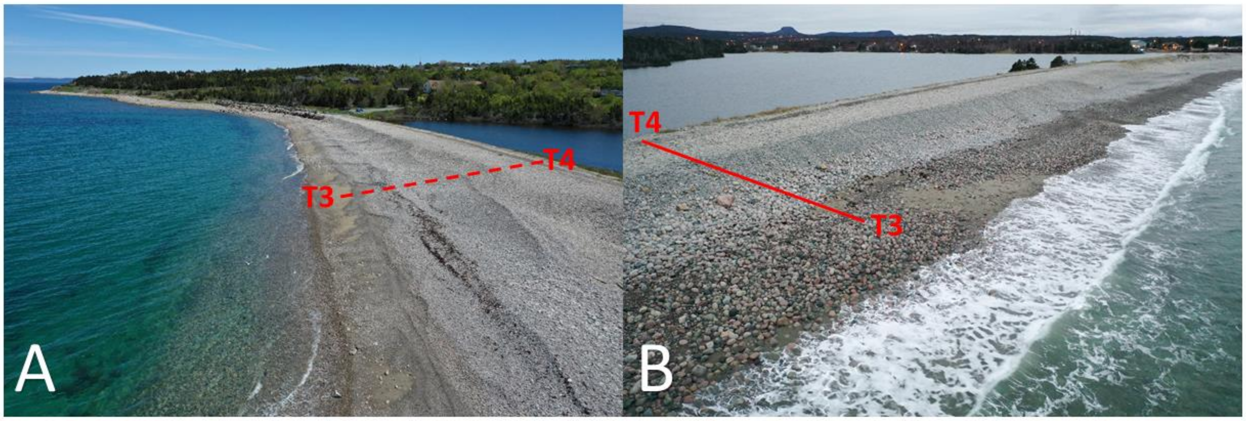

Figure 3.5: Central area of Lance Cove Beach. Red is representing ground transect location (dotted was the location of the transect that was uncompleted). (A) NE oriented photo - 14 June 2019, (B) SW oriented photo - 28 November 2019.

The third transect, T5-T6 (Figure 3.1 & Figure 3.6), was located in the northeastern part of the survey area, 120 m north-northeast of the end of Doyles Road. The area is influenced by a ~170 m long rock wall that protects the Grand Concourse trail directly behind it. This northern section of the beach, influenced by the rock wall in the backshore, is narrow with a width of approximately 15 m or less from rock wall to low tide and has a slope ranging around 10-12 degrees. The intertidal zone spans almost all of the ~15 m between low tide and the rock wall for this transect. In June, the shoreline consisted of 90% boulders, with the remaining 10% of sediment interspersed cobbles or pebbles. The beach texture steadily transitions to smaller material landward. Directly seaward of the rock wall, the texture is 90% pebbles. This texture was consistent throughout the visits, although it is not fully representative of the entire beach seaward of the rock wall. The rock wall is compromised at some points, and the distance between low tide and the wall reaches a minimum of 10 m, leading to greater variability in this section of the beach.

Figure 3.6: Northern Lance Cove transect. (A) Aerial photo with the camera oriented southwest on 15 June 2019. (B) Aerial photo with the camera oriented east on 28 November 2019. (C) Area directly southwest of transect on 15 June 2019, transect line directly left of the picture.

3.2.2 Chapel's Cove

Chapel's Cove beach (Figure 3.7) is best described as a mid-bay bar beach. It primarily consists of pebbles and cobbles on a slope <10 degrees, with minimal boulders mainly located on either the beach's flank and sporadic sand patches in the intertidal zone. There is a maintained dirt road across the beach to grant access to a small number of residences that are accessible by other means. Along the eastern flank is a small rock wall protecting a roadway leading to an ill-maintained boat launch. A rock breakwater was also established to shelter the boat launch. The rock wall is made up of smaller boulders, while the breakwater includes larger boulders. A freshwater output from the lagoon separates the main beach from the eastern rock wall, with remnants of wooden walls designed to support the outlet's maintenance before storm damage in October 1992. On the western flank is a profoundly damaged wooden wall, many small boulders, and scattered pieces of large rubble concrete. The texture change is reasonably defined in the western corner between the main beach and western flank, with a distinct transition of mainly pebbles and cobbles to larger cobble and boulders. The transition occurs relatively parallel to and approximately 20 m east of Point Road. Three transects were chosen to represent both corners of the beach and a more central location and were surveyed on two separate occasions: on 19 June (Figure 3.7) and 17 October 2019 (Appendix C: Orthomosaics).

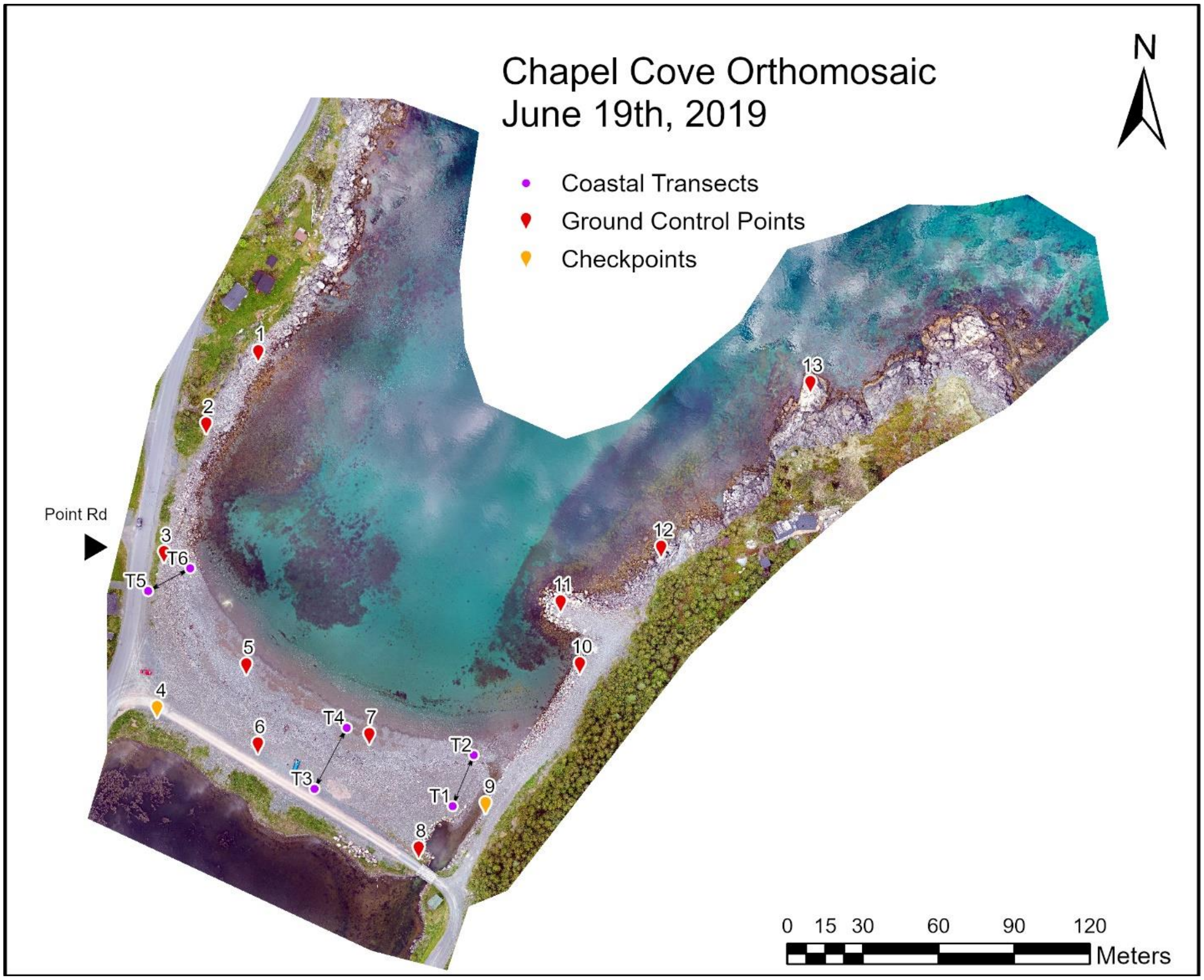

Figure 3.7: Chapel's Cove orthomosaic with transect and GCP locations in June 2019.

The first transect was located on the gravel beach's eastern corner, T1-T2 (Figure 3.7 & Figure 3.8), alongside the freshwater outflow from behind the barachois. The freshwater outflow was constructed and maintained until 1992 to access a wharf on the lagoon (Catto *et al.*, 2003). Between visits to the beach, the intertidal zone showed some extent of change. In June, the sand to pebble ratio near the shoreline of the transect was approximately one, with sporadic cobble clasts. However, the pebbles and sand were patchily distributed. Further landward in front of the slope, indicating where the beach is mechanically flattened, about 10 m from the low tide shoreline, the intertidal zone transitioned to 80/20 pebble-fine cobble mix. The slope is ~60% sand, with pebbles and lesser cobbles composing the rest. The mechanically flattened texture ranges from sand to cobbles, with pebbles dominating the texture (~80%) and the other clast sizes evenly distributed. In October, 80% of the intertidal zone closest to the shoreline was dominated by sand, with other clasts ranging from coarse pebbles to fine boulders. Landward before the mechanically flattened slope, the sand transitions to a 60/40% pebble-cobble mix. The slope during this time had changed to ~90% pebbles, but the flattened backshore showed no noticeable change.

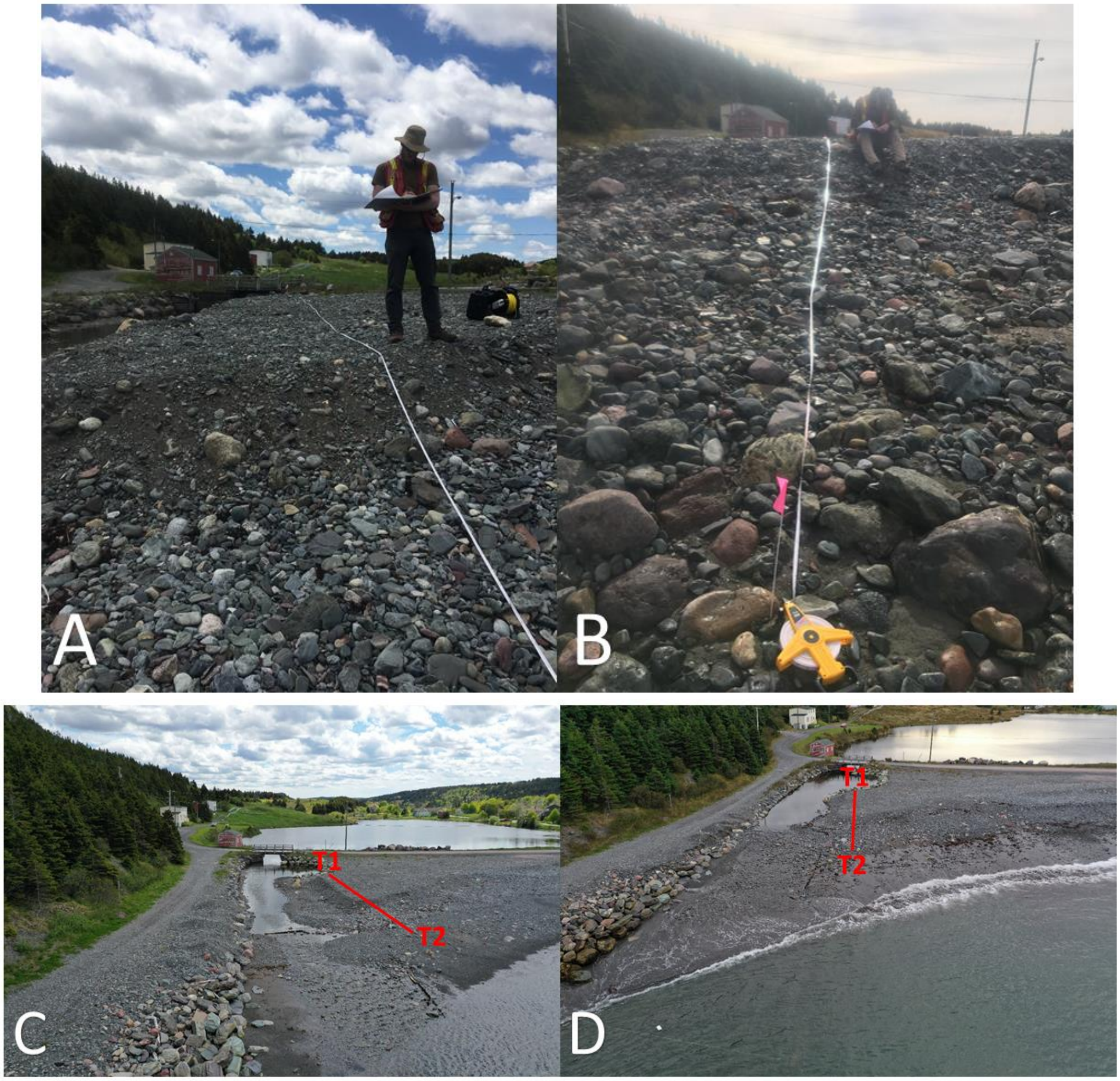

Figure 3.8: Eastern transect line on Chapel's Cove Beach. (A) Ground photo from intertidal zone - 19 June 2019, (B) Ground Photo from intertidal zone - 17 October 2019, (C) Aerial photo - 19 June 2019, (D) Aerial Photo – 17 October 2019.

The second transect was centrally located on the beach approximately 100 m southwest of Point Road, T3-T4 (Figure 3.7, Figure 3.9, & Figure 3.10). During the June visit, the intertidal zone towards the low tide shoreline had an alternating pattern between 90% pebble to 90% sand, repeated in four zones within 20 m landward width of the beach. Above the last zone of sand, a transition begins to a 60/40% cobble-pebble split that continues for 3 m. The remainder of the beach is mechanically flattened, with 80% pebbles and other clasts distributed from sand to fine cobbles (Figure 3.10). In October, the swash zone's directly landward was a 1 m width of >90% sand along the transect. Landward for 2-3 m, this shifted to a 60/40% pebble-cobble mix. Landward of that zone is a >90% pebble zone extending to 10 m from the shoreline, where a patch of 80% sand with pebbles and cobbles was recorded. The landward zone showed the same texture as in June (Figure 3.10).

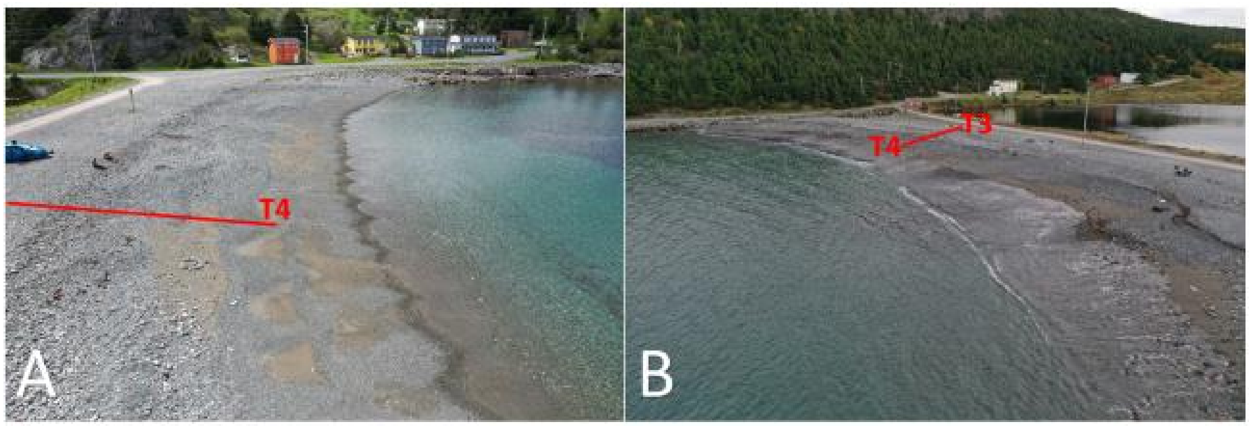

Figure 3.9: Main beach part (central) of Chapel's Cove beach, (A) westward oriented aerial photo - 29 July 2019, (B) eastward oriented aerial photo - 17 October 2019.

During June, this section of the beach had a fire pit created out of cobbles on a sand patch about 10 m landward of the shoreline (Figure 3.9). In October, the created feature could not be recognized. Additionally, during the October visit, the beach had picnic tables and cast iron fireplaces in the backshore area, removed by a backhoe tractor during the field day's conclusion to be stored away for the winter season. The backhoe tractor drove further seaward onto the beach than most vehicles.

Figure 3.10: Central transect, T3-T4, for Chapel's Cove Beach. (A) & (B) Lead up to mechanical flatten part of the backshore on 19 June 2019 and 17 October 2019, respectively. (C) Alternating sand pebble patches on 19 June 2019. (D) Intertidal zone ~1 hour before a 0 m low tide.

The third transect line, T5-T6 (Figure 3.7 & Figure 3.11), was placed on the beach's west side, starting directly adjacent to Point Road. Approximately 15 m north of the transect is the southern end of an old wooden wall in the intertidal zone, extending approximately 50 m north-northwest (Figure 3.11). During June, in the first 5 m from the shoreline, the texture was 70% boulders and coarse cobbles, with the rest comprised of pebbles. Landward of that zone for 3 m was 80% pebbles, with the remainder being larger clasts, transitioning to 80% cobbles and fine boulders with infilling pebbles. The cobble-boulder texture continued landward to the zone of finer material used for road construction.

October showed only two textural differences. Directly next to the shoreline was an exposed ~1 m band of 90% sand. The pebble-dominated section that was present in June had changed to an equal distribution of pebbles, cobbles, and boulders.

Much of the material in this section of the beach differs from the remainder of the beach, with large concrete clasts and boulders of granitic igneous composition similar to the rock wall on the eastern side of the beach. The material was likely brought in for purposes of building or protecting Point Road.

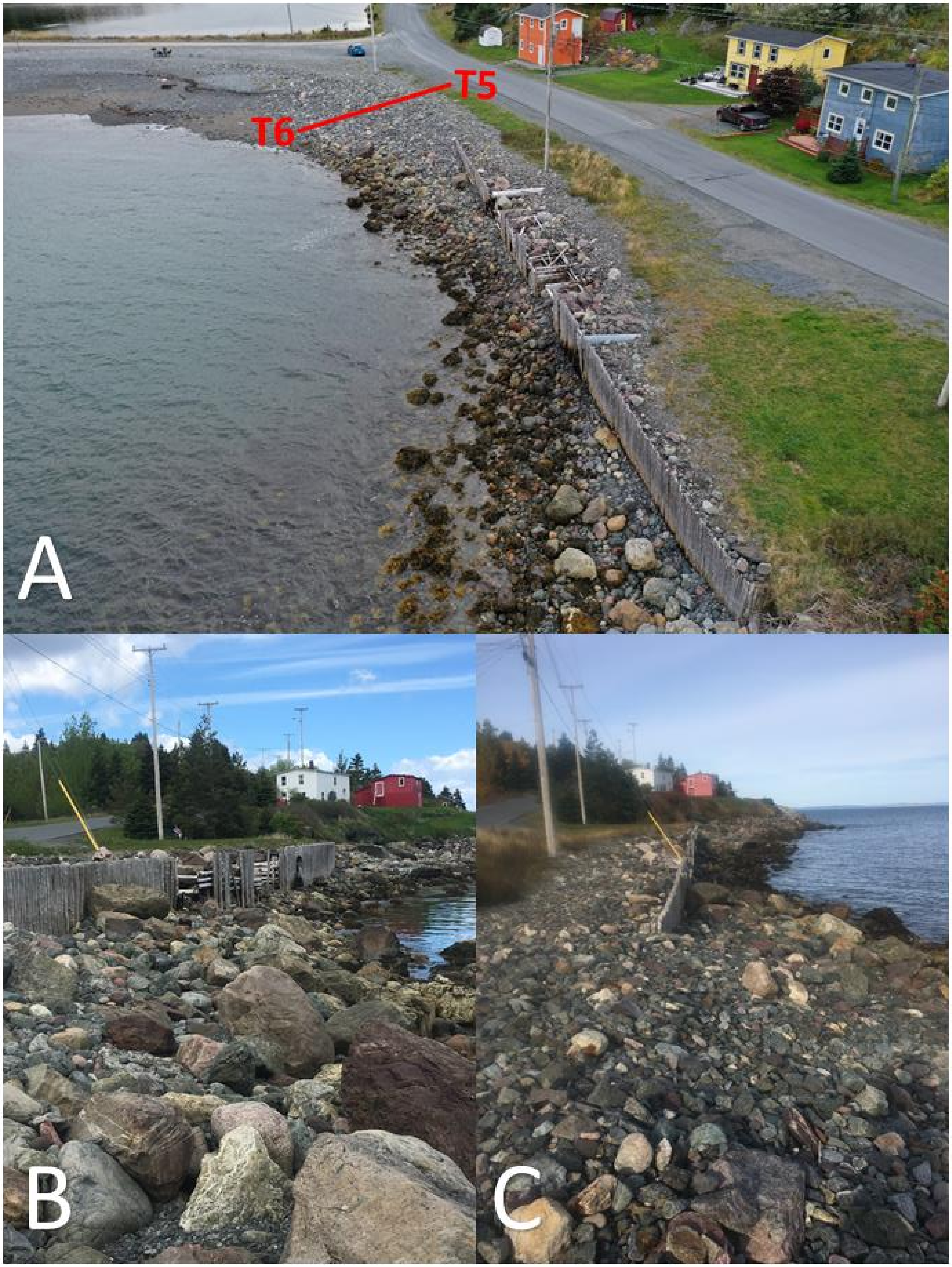

Figure 3.11: Western flank of Chapel's Cove beach, (A) Aerial with a south camera orientation on 29 July 2019. (B) North oriented photo from transect line on 29 July 2019. (C) North oriented photo from transect line on 17 October 2019.

3.2.3 Harbour Main

Harbour Main (Figure 3.12) includes two bayhead beach bars of more mafic rock composition, generally consisting primarily of pebbles and cobbles. Natural bedrock barriers segment the beach area of Harbour Main. The main beach has eastern and western parts separated by a small outcrop of bedrock, approximately 15 m in length. The east part is a pebble/cobble beach, whereas the west side is an approximately 75 m long rock wall. A third section is a secondary gravel beach, separated from the main beach to the northwest by a larger amount of exposed bedrock. Both of the gravel beaches are 10-15 m in width and slope at ~10 degrees. The east section of the main beach has a boardwalk along the backshore from a gravel parking lot to the mechanically flattened beach and swimming hole behind the west part of the main beach's rock wall. Four transects were chosen to represent the Harbour Main beach area, two on each corner of the eastern part of the main beach, one next to the freshwater outflow, and one across the secondary beach to the northwest (Figure 3.12). Each transect was surveyed twice: on 27 June 2019 and 12 November 2019.

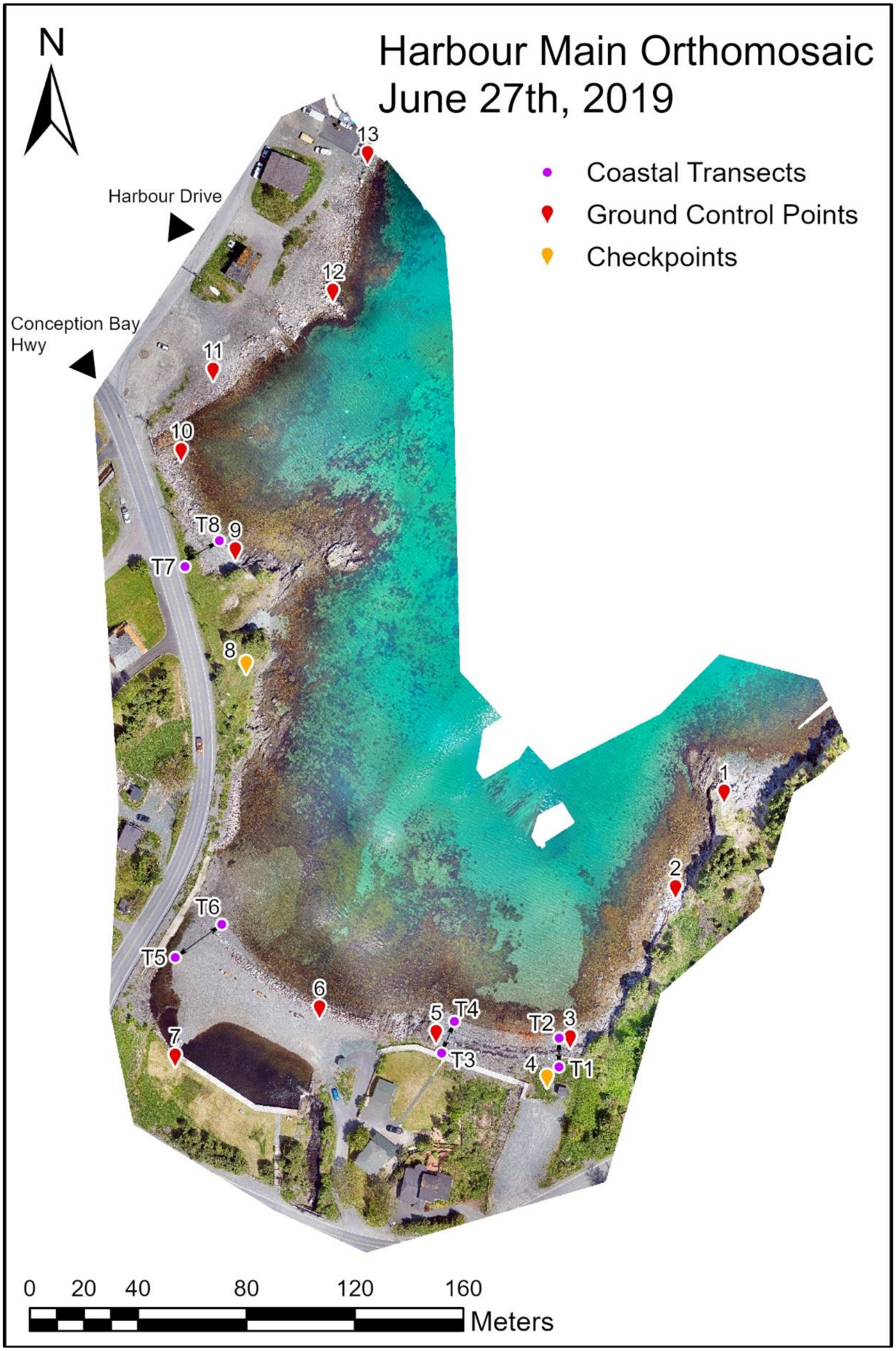

Figure 3.12: Harbour Main orthomosaic with transect and GCP locations in June 2019.

Two transects were placed east of the rock outcrop on the main beach, T1-T2 and T3-T4 (Figure 3.12, Figure 3.13, & Figure 3.14), one on each extremity of the section. This section of the beach has a 50 m rock wall parallel to the shoreline in the backshore area. The wall is made of boulders and looks to have been initially placed to separate beach sediments from the grass vegetated backshore. However, the wall has been overtopped, and many of the boulders are, to some degree, buried in beach gravel.

During the June visit, the first transect, T1-T2 (Figure 3.12, & Figure 3.13), the seaward half of the intertidal zone was 60/40% cobble-coarse pebble. However, east of the transect for approximately 10 m in the intertidal zone, there was exposed sand ranging from 20-80% cover with cobbles to small boulders, distinct from the rest of the beach. Landward, the sediments transition to a coarse pebble cover (80%) with fewer cobbles, extending to the boulder rock wall. Landward of the rock wall for 1-2 m grass vegetation covers 80% of the terrain, along with pebbles and cobbles from overtopping. During the November visit, the zone directly next to the shoreline was >90% sand over a width of 2-3 m, confined to the transect. On either side of this patch of sand were zones of approximately 60/40% cobbles-pebbles. Landward for 5 m was a zone with 90% pebbles, followed by a transition to a ~1 m wide zone of 60% sand cover with pebbles and cobbles. Further landward, the sediment appeared to be similar to the June visit, but dense seaweed cover made it difficult to make observations.

Figure 3.13: East section of Harbour Main primary beach. (A, B) 12 November 2019, (C) 27 June 2019.

The second transect, T3-T4 (Figure 3.12 & Figure 3.14), during the June visit, showed a texture transition of 60% pebbles at the shoreline to 80% at the boardwalk in the backshore, with cobbles comprising the rest. There were three distinguishable berms during this visit, one between the boardwalk and the rock wall, one directly seaward of the rock wall, and one in the middle of the beach width (Figure 3.14). In November, the seaward berm had been redistributed by wave action, and the berm directly in front of the rock wall seemed to have changed. A large amount of seaweed deposits, ~90% in front of the rock wall with some in the wall itself, support wave action landward into the beach. November also showed this transect to have an increase in pebble texture, with the shoreline consisting of 60% pebbles transitioning to 90% towards the rock wall with cobbles consisting of the rest. The zone landward of the rock wall appeared to show consistency with the June visit. There was a noticeable consistency of texture differences between the two visits, even within texture classes. However, the beach consisted of pebbles in June and November (Figure 3.14), coarse pebbles dominated in June. In contrast, in November, the pebbles were consistently finer.

Figure 3.14: Primary beach, east, in Harbour Main. (A) Ground photo mid beach, oriented east toward transect T1-T2 on 27 June 2019. (B) T1-T2 on 12 November 2019. (C) Three small berms and sediment texture for T3-T4 on 27 June 2019. (D) Sediment texture midway of T3-T4.

The third transect was placed on the western side of the main beach, T5-T6 (Figure 3.12, Figure 3.15, & Figure 3.16), directly adjacent to the freshwater outflow. This part of the beach has a nearly continuous intact rock wall about 75 m in length. The western end had some structural failure. The freshwater outflow is connected to the ocean directly at the west end of the rock wall. This area contained the greatest amount of exposed gravel in front of the rock wall at approximately 15 m width, but the gravel beach's width in front of the rock wall tapers away to 0 m eastward (Figure 3.15 & Figure 3.16). The eastern part of the rock wall had no intertidal zone, as the low tide shoreline was in contact with the rock wall. During both visits, a small part of the upper intertidal area bordering the swash zone included higher proportions of cobbles and fine boulders. These were concentrated in the vicinity of the base frame remain of a wooden structure (Figure 3.16).

The transect along the western edge was 90% pebbles in June, both in the intertidal area in front of the rock wall and the mechanically flattened landward of the wall. In November, the intertidal zone appeared to be dominated by pebbles as in June, but the zone 5 m landward of the rock wall contained patches where sand/granules comprised up to 60% of the texture. This zone also contained seaweed detritus not present in June, suggesting wave action can overtop the rock wall. Additionally, the rock wall directly adjacent to the water outflow had become noticeably more exposed between the two visits suggesting sediment loss and further supporting overtopping.

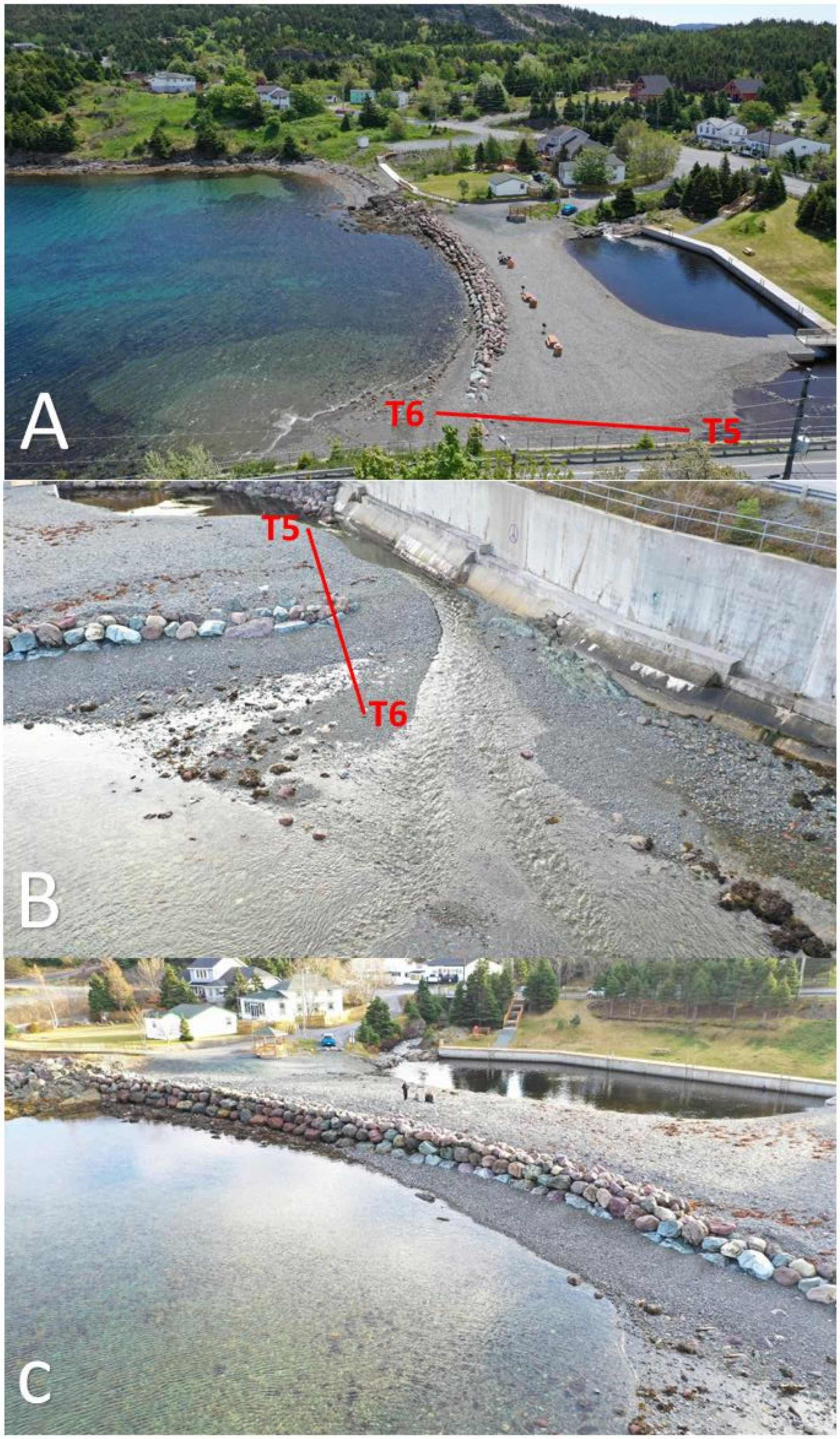

Figure 3.15: West section of Harbour Main primary beach. (A) 27 June 2019. (B) Freshwater outflow on 12 November 2019. (B) The rock wall on 12 November 2019.

Figure 3.16: Primary beach, west, in Harbour main looking east from the freshwater outflow. (A) 27 June 2019. (B) The base of the wooden structure, 12 November 2019.

Harbour Main has a secondary pocket beach less than 200 m to the northwest of the main beach, where the fourth transect was placed, T7-T8 (Figure 3.12, Figure 3.17, & Figure 3.18). This smaller beach, approximately 50 m in length, consists of pebble/cobble gravel to the east with a sharp transition approximately in the middle to boulders and concrete rubble westward extending to a freshwater outflow at the western flank of the harbour (Figure 3.17). The boulders and rubble on the western part appeared to be placed to protect Conception Bay Highway from erosion, as the roadway here is 10 m horizontally from low tide. The transect was placed on the gravel segment of the beach.

In June, the zone closest to the low tide shoreline was dominated by 80% finer cobbles, with pebbles covering the remainder. Around the midpoint of the beach's width, the texture transitions into an 80% pebble-dominated area with isolated cobbles. The beach gravel is replaced by soil, vegetation, and construction grade gravels in the Conception Bay Highway 15 m from the low tide shoreline. Coarse cobbles and boulders have been placed at this boundary to protect the road by slowing further erosion, but some of the soil has collapsed upon the clasts. In November, the intertidal zone directly adjacent to the low tide shoreline textural dominance contained pebbles, finer than June, with a 60/40% ratio with fine cobbles. Landward within a ~3 m wide zone, a transition to ~90% pebbles occurs, extending to the limit of the beach gravel (Figure 3.18).

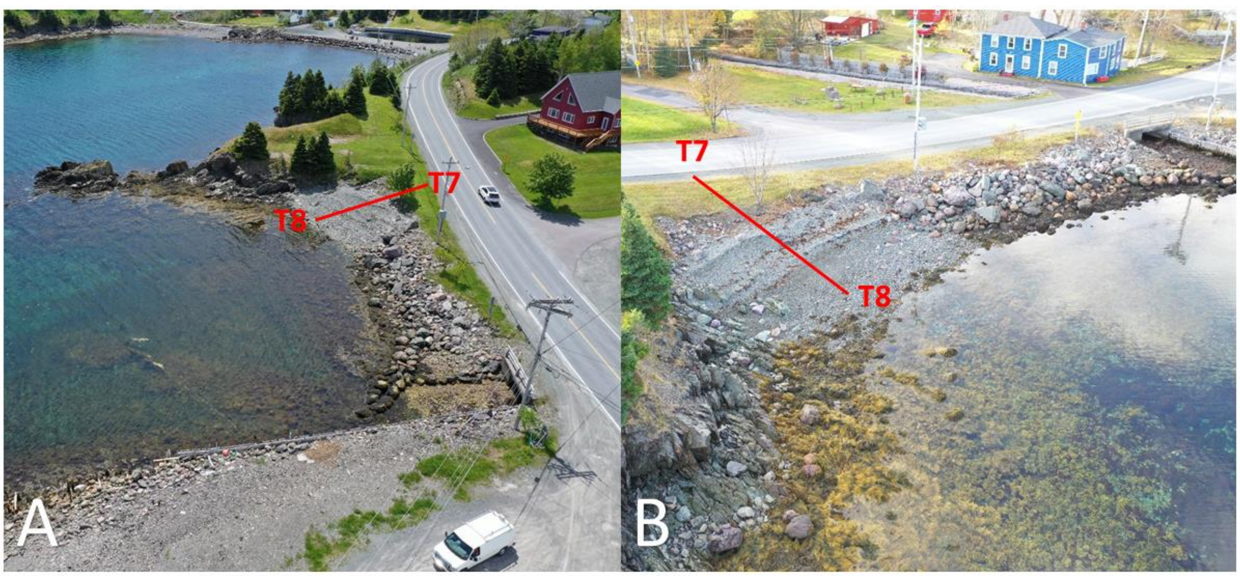

Figure 3.17: Secondary beach at Harbour Main, (A) 27 June 2019 and (B) 12 November 2019.

Figure 3.18: Secondary beach in Harbour Main. (A) Eastside of the beach looking westward at transect T7-T8 on 27 June 2019. (B) Taken from transect line T7-T8 looking south on 12 November 2019.

3.3 Map and Processing Accuracy

Aerial images and the resulting DSM were georeferenced by matching aerial images to location data. While the images were first georeferenced using the UAV onboard GPS, positional accuracy was improved in post-processing using the ground control points (GCP) positions located by the RTK system. Image processing for each site excluded two GCP (i.e., checkpoints) used to assess the resulting positional accuracy of the orthomosaic.

Technical difficulties in the field and the resulting uncertainties with the data collected on 12 November 2019 in Harbour Main resulted in the exclusion of this survey from further analysis. The remaining errors for each site's model are presented in "

Appendix D: Digital Surface Model Errors", ranging from 3.13 cm to 34.29 cm (total error), with an average total error of 13.52 cm. Errors in elevation (z) were smaller, ranging from 0.33 cm to 14.51 cm, averaging 2.57 cm. All elevation comparison maps show the differences between the DSM from two different survey dates at one single study site. Data were classified as displaying a positive, negative, or no change in elevation. A threshold of 25 cm was used for classifying data as a change. This threshold was determined by adding the two largest vertical DSM error values of each site's survey dates (i.e., 14.5 cm from Chapel's Cove on June 19th and 10.5 cm on October 17th at the same site). Using this method, all remaining elevation comparison maps have combined errors within the model's change detection capabilities.

3.4 Observing Sediment Dynamics through DSMs

3.4.1 Lance Cove

Three elevation change maps were produced for Lance Cove: June vs. September (Figure 3.19, Figure 3.20, Figure 3.21, & Figure 3.22), September vs. November (Figure 3.23, Figure 3.24, Figure 3.25, & Figure 3.26), and June vs. November (Figure 3.27, Figure 3.28, Figure 3.29, & Figure 3.30).

The elevation change for June vs. September ranged from 1.9 m maximum gain to 2.2 m maximum loss. However, the mean change was a 1 cm gain, with a 4 cm standard deviation. High elevation changes are rare, located around larger boulders and the rock walls and possibly resulting from slight shifts in georeferenced between survey dates. In zones with exposed cobbles and finer clasts, few monitored changes were noted. Some small patches of elevation gain along the beach's intertidal zone and some patches of elevation loss were observed. For all parts of the beach, excluding the drainage pipe area, the largest gain patch is approximately 17.5 m^2 with a minimal volumetric change of ~1.4 m^3. The elevation loss patches were equal to or less than in size compared to the areas marked by gain.

On the western extremity of the beach, seaward of the drainage pipe, was a larger patch of elevation gain with an area of ~70 m^2 and a patch of elevation loss of ~6 m^2. Both patches were larger than any other on the beach. The gain patch had a volumetric change of at least 10 m^3, with a higher volume of the change occurring in the drainage ditch's mouth and lessening westward. The patch of elevation loss had a volumetric change of ~0.1 m^3. Additional changes were seen further landward where numerous patches of ~0.1 m^2 area size are seen, centralized around larger boulders, mainly the rock walls. The most noticeable patches indicated elevation loss, but there were a few that indicated elevation gain.

Lance Cove elevation differences between 11 September and 28 November 2019 are seen in (Figure 3.23), enlarged by section in (Figure 3.24, Figure 3.25, Figure 3.26). The elevation changes ranged from 2.2 m maximum gain to 1.8 m maximum loss. The mean elevation change for this timeframe was 0 cm change, with a standard deviation of 8 cm.

Almost all of the 15-20 m area from the low tide mark at Lance Cove beach appears to have been reworked at least once during the time between visits. The easternmost section of the beach intertidal zone indicated elevation loss as a whole, while the middle section showed consistent loss parallel to the low tide shoreline and elevation gain paired with and directly landward. Near the western part of the beach, elevation change transitioned primarily from loss into gain. For the eastern part of the beach, elevation loss mainly ranged from 0-25cm and encompassed almost all the area between low tide and the rock wall, ~1250 m^2. Most zones showed between 0-30 cm gain or loss in the middle section of the beach, with few locations registering

~100 cm gain or loss. The westernmost end of the beach was where the more consistently large, 30cm+, changes of both gain and loss were concentrated.

Near the western extremity of the beach, at the drainage pipe's location, was the zone with maximum gain, where the drainage ditch had been infilled between visits. The drainage ditch was filled with a minimum of 50 m^3 of beach gravel between visits. Additional changes were observed further landward, with ~0.1 m^2 patches, though far less numerous than June-September (Figure 3.19). The patches were mainly located around larger boulders and rock walls. These patches most noticeably indicated elevation loss, but few indicate elevation gain.

Lance Cove elevation differences between 14 June and 28 November 2019 are seen in (Figure 3.27), enlarged by section in (Figure 3.28, Figure 3.29, & Figure 3.30). However, the changes that occurred after 11 September 2019 were such a magnitude larger than the changes that occurred before, making the DSM differences for 14 June to 28 November 2019 (Figure 3.27, Figure 3.28, Figure 3.29, & Figure 3.30) and 11 September to 28 November 2019 (Figure 3.23, Figure 3.24, Figure 3.25, & Figure 3.26) similar in presentation.

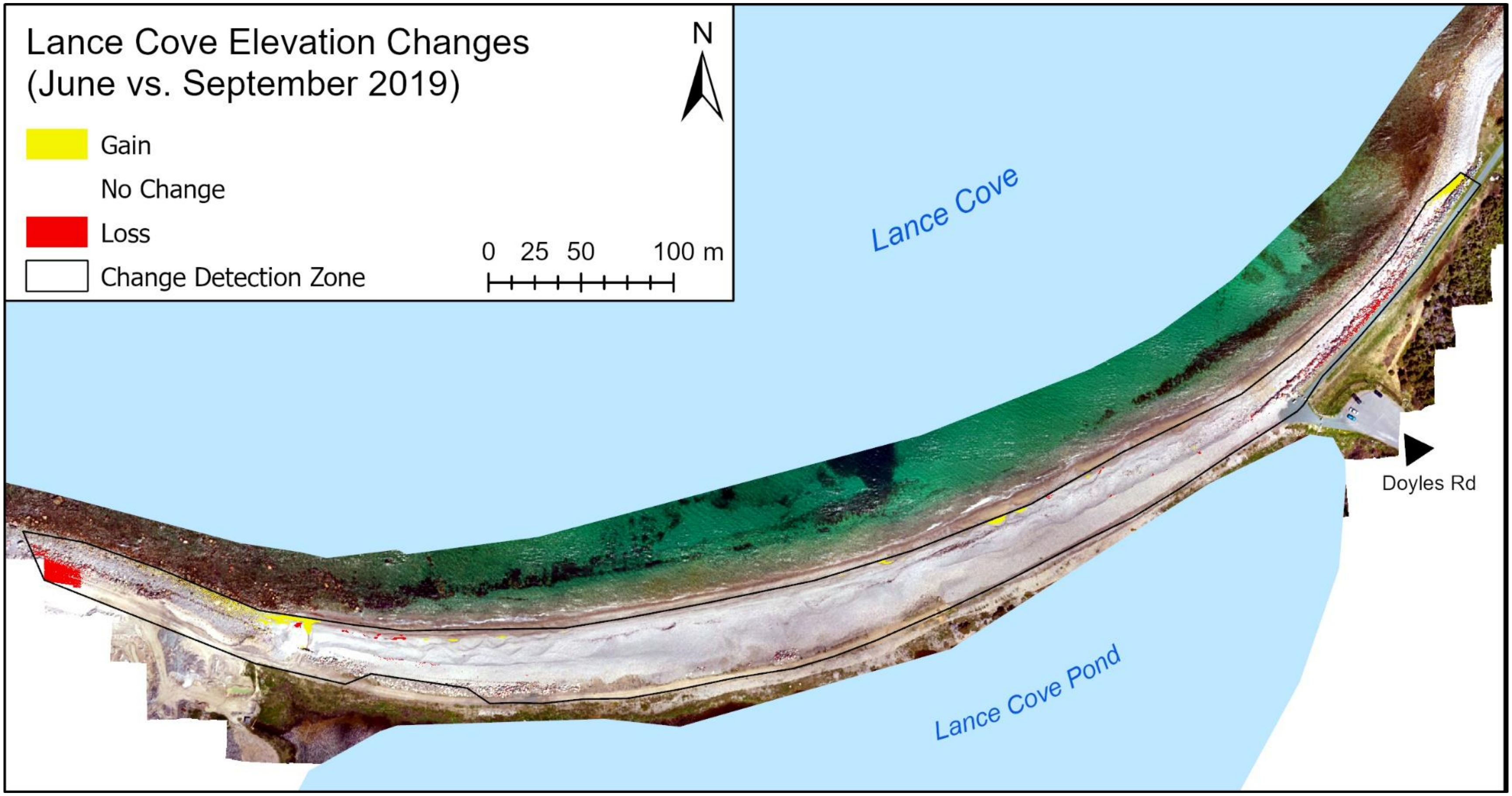

Figure 3.19: DSM differences for Lance Cove between June 2019 and September 2019.

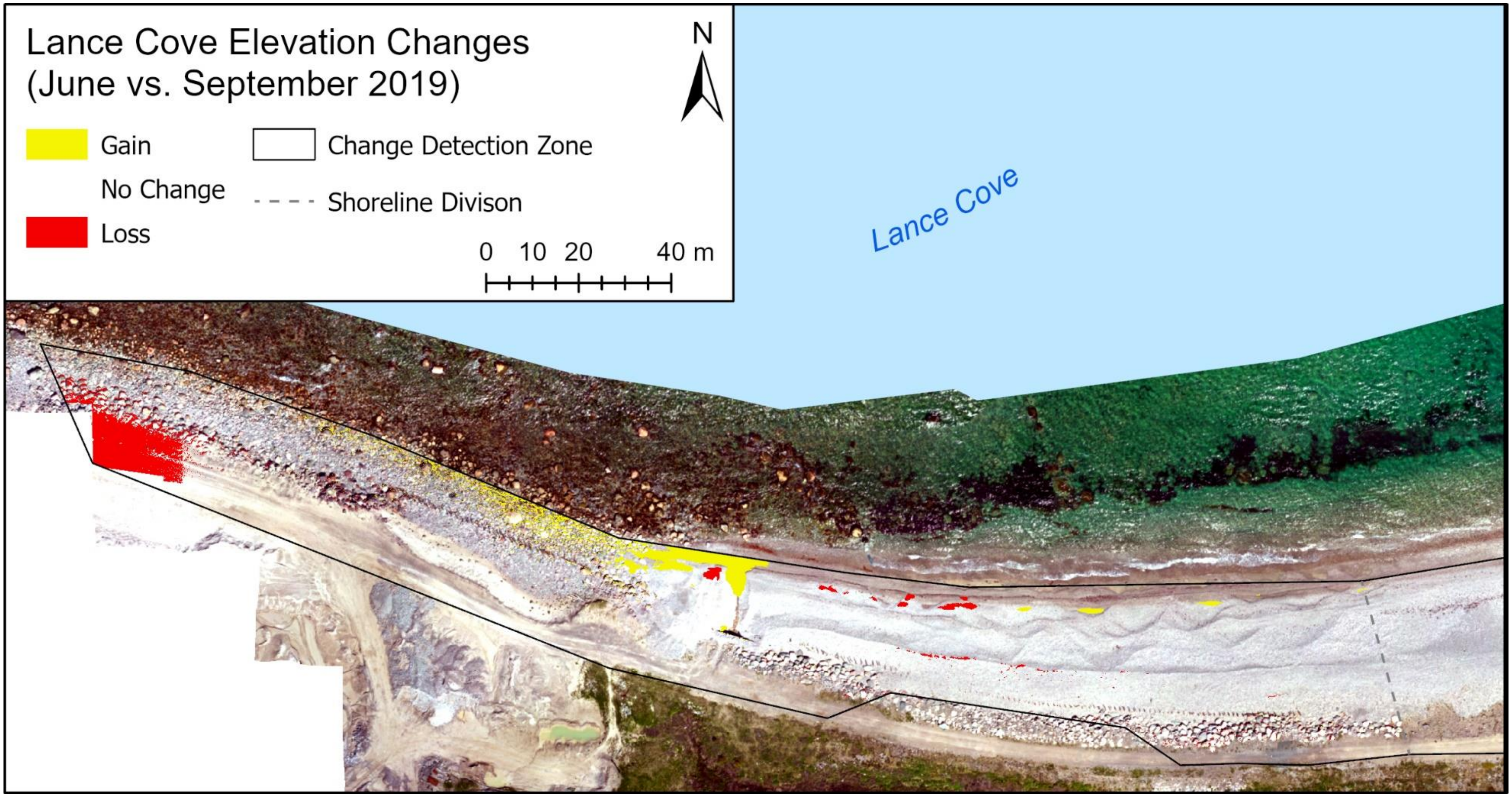

Figure 3.20: Enlarged DSM differences for the west section of Lance Cove between June 2019 and September 2019.

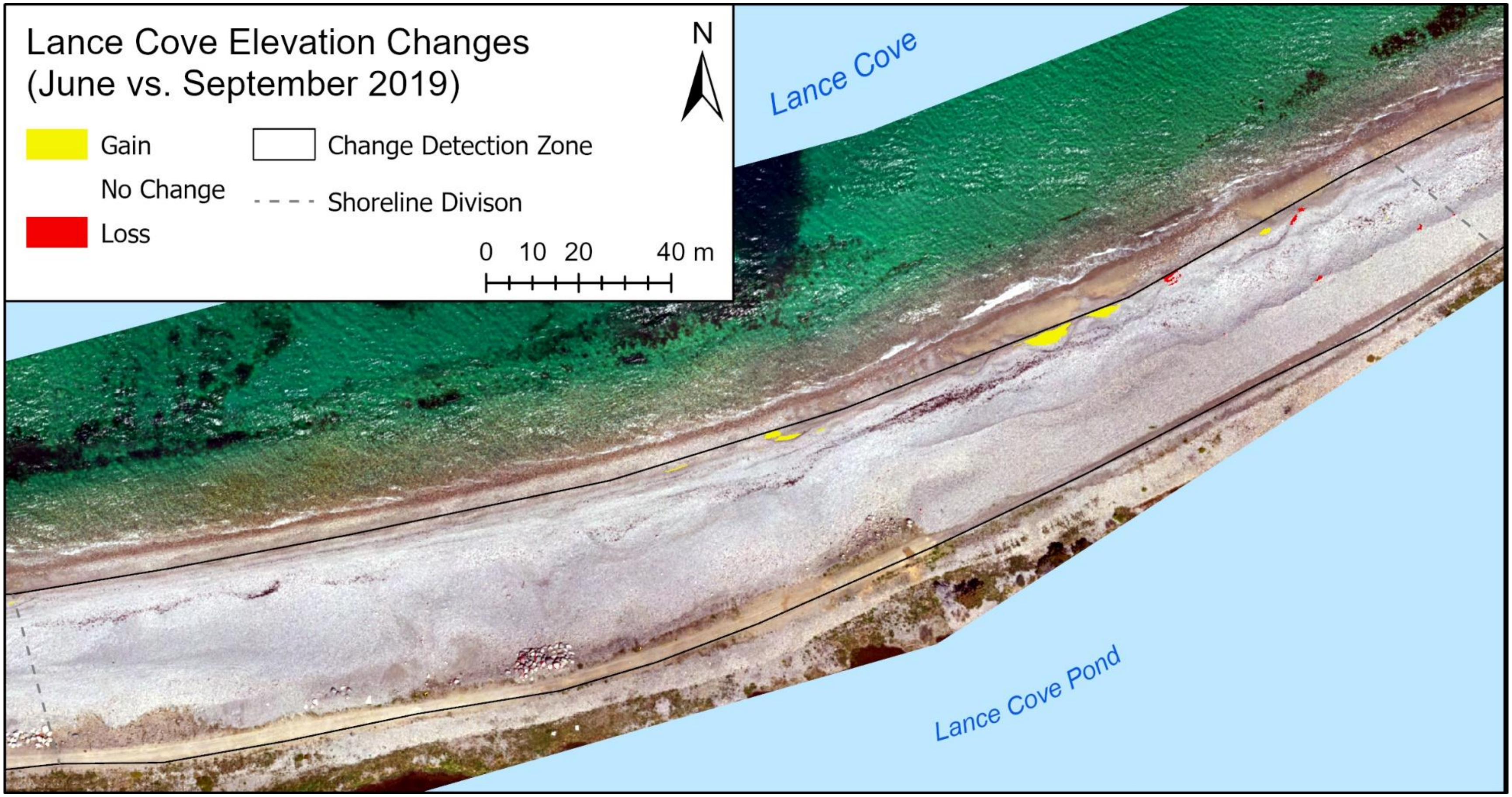

Figure 3.21: Enlarged DSM differences for the central section of Lance Cove between June 2019 and September 2019.

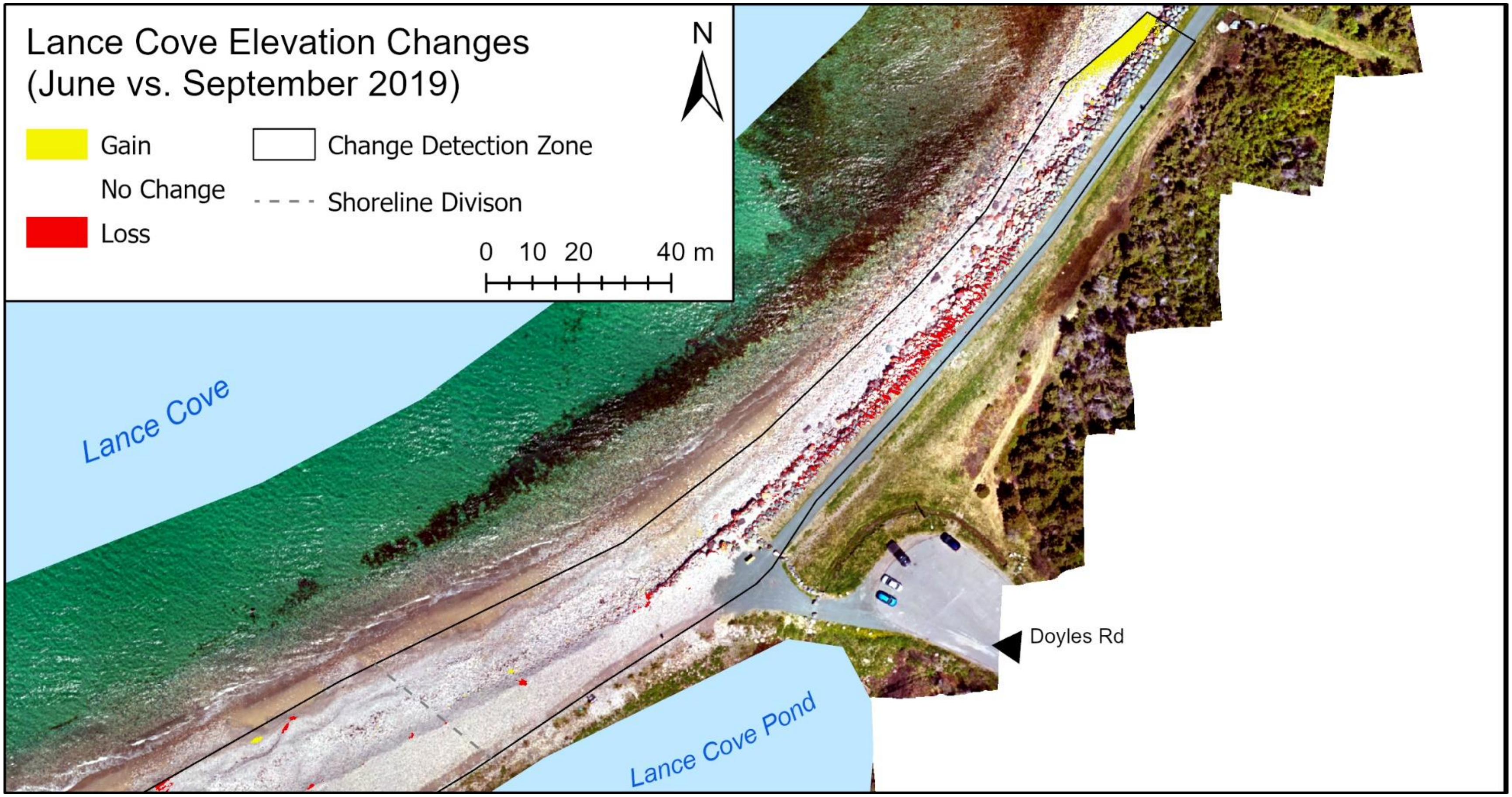

Figure 3.22: Enlarged DSM differences for the east section of Lance Cove between June 2019 and September 2019

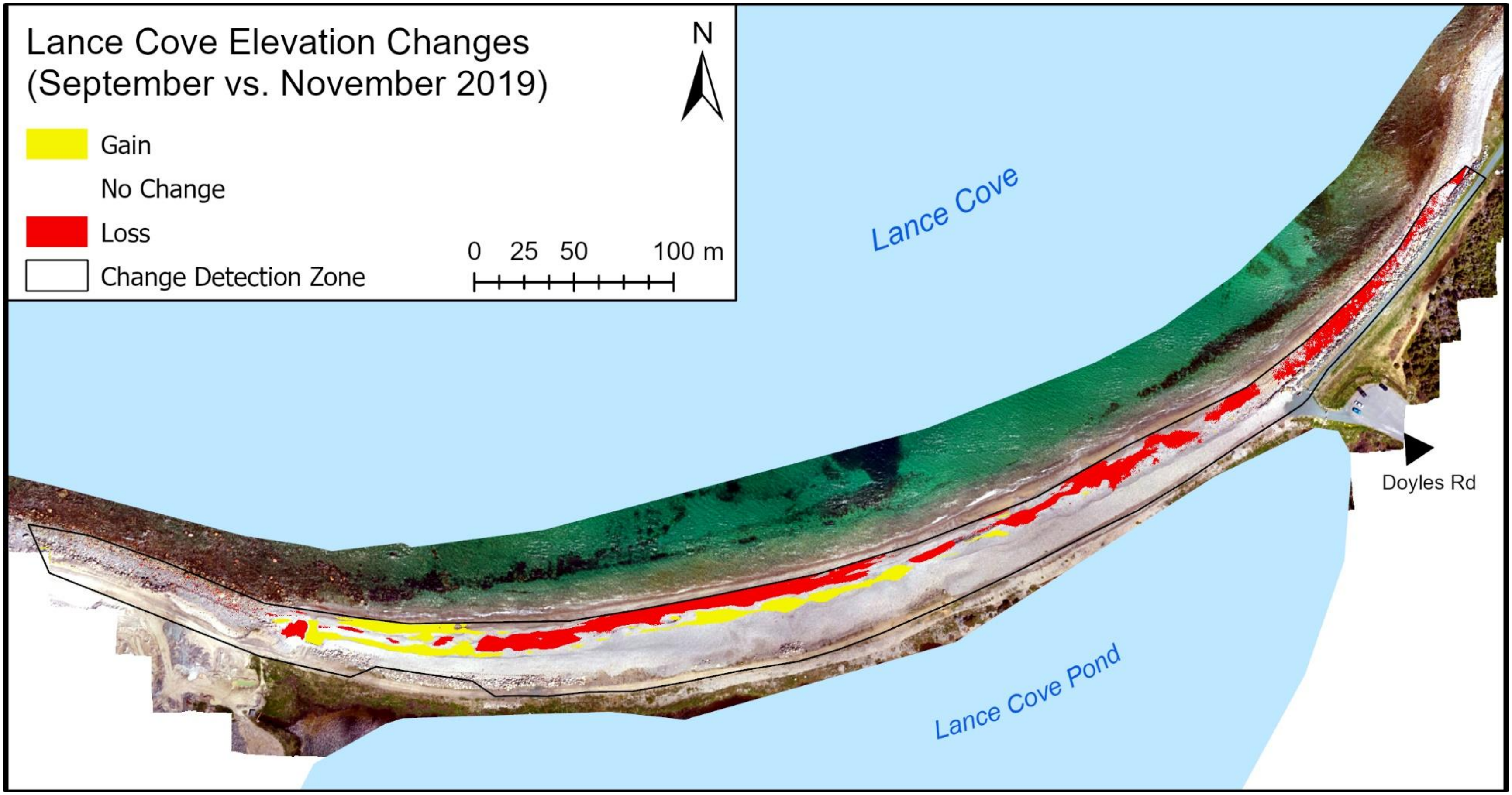

Figure 3.23: DSM differences for Lance Cove between September 2019 and November 2019.

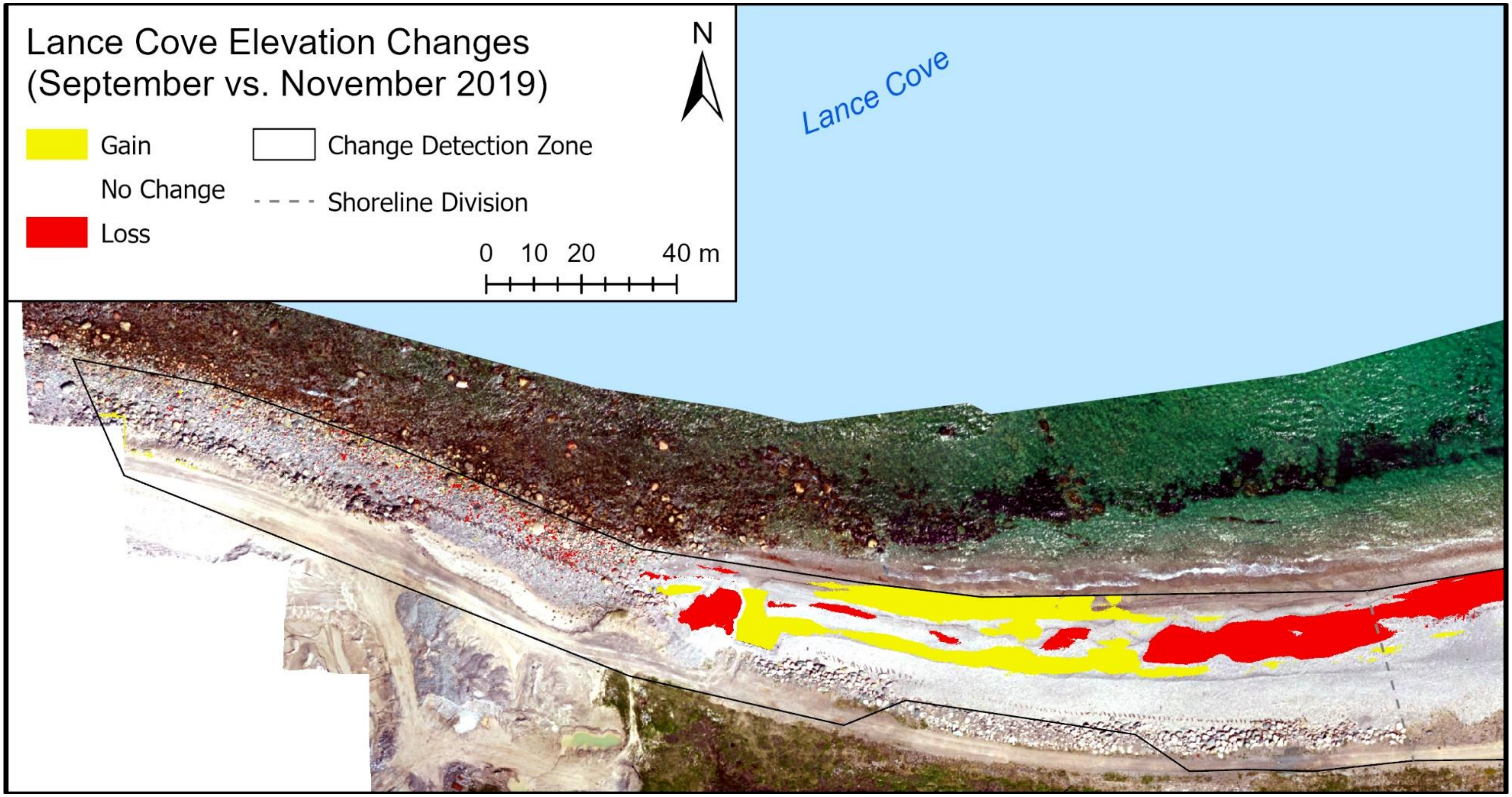

Figure 3.24: Enlarged DSM differences for the west section of Lance Cove between September 2019 and November 2019.

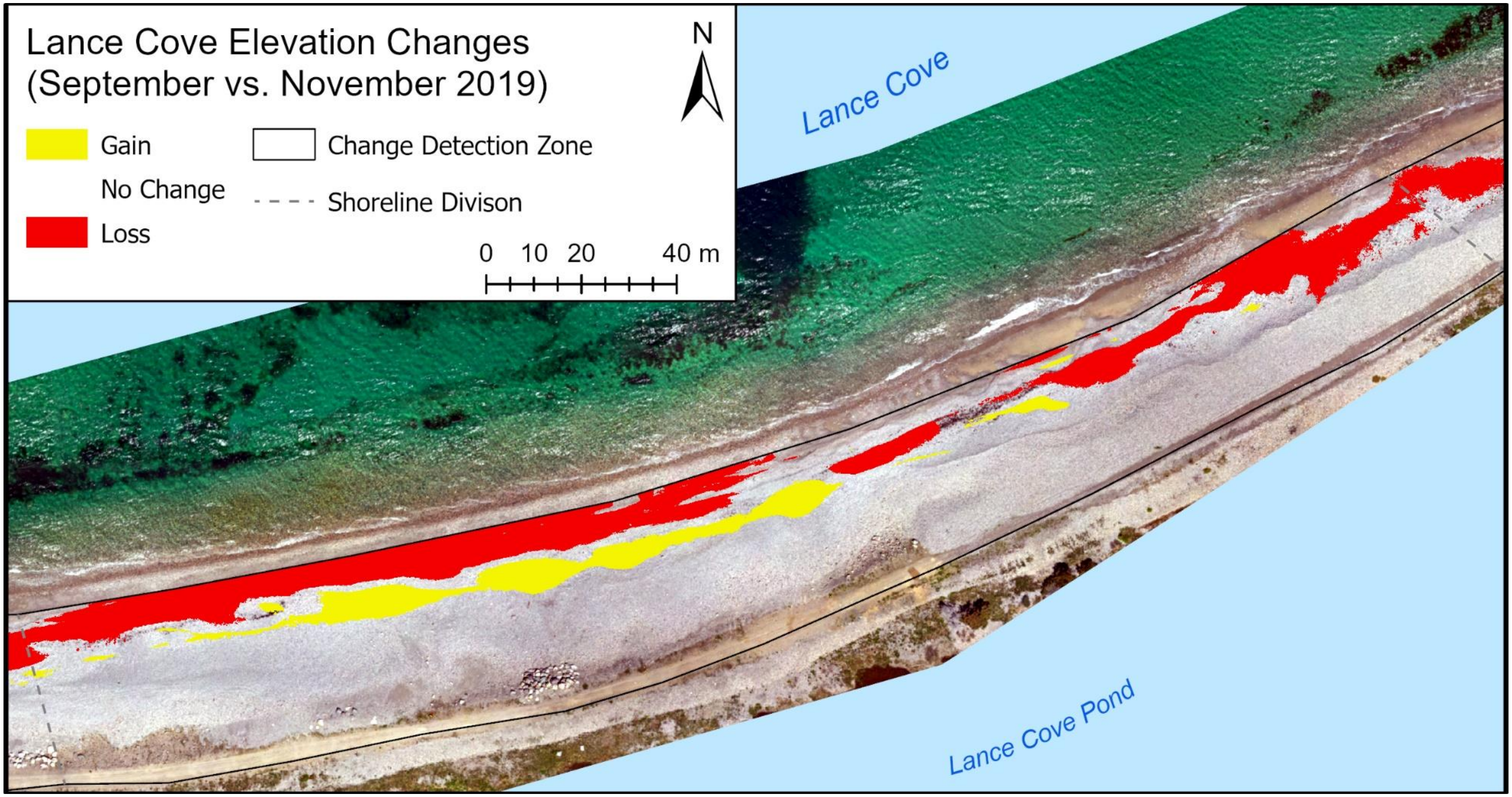

Figure 3.25: Enlarged DSM differences for the central section of Lance Cove between September 2019 and November 2019.

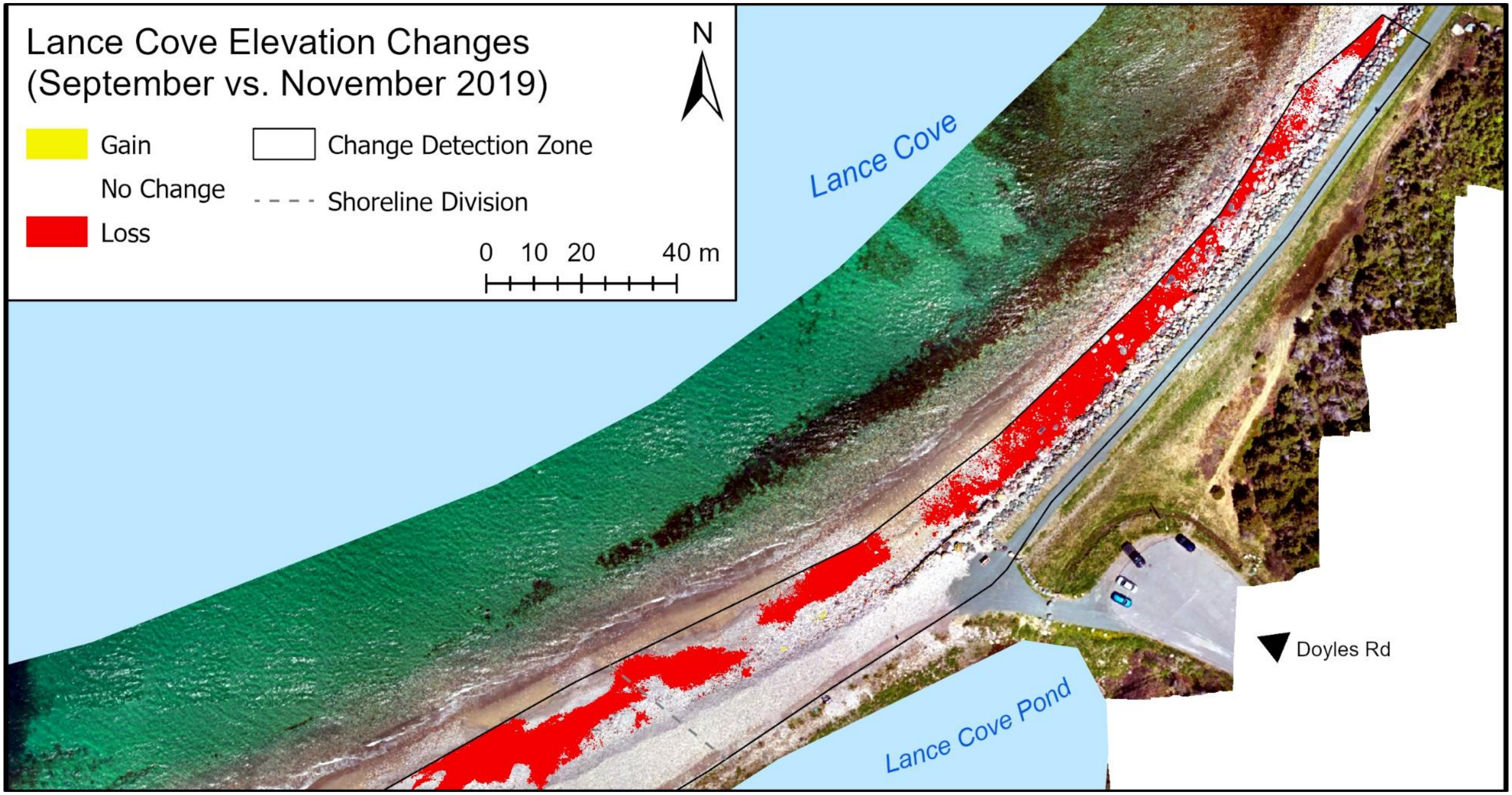

Figure 3.26: Enlarged DSM differences for the east section of Lance Cove between September 2019 and November 2019.

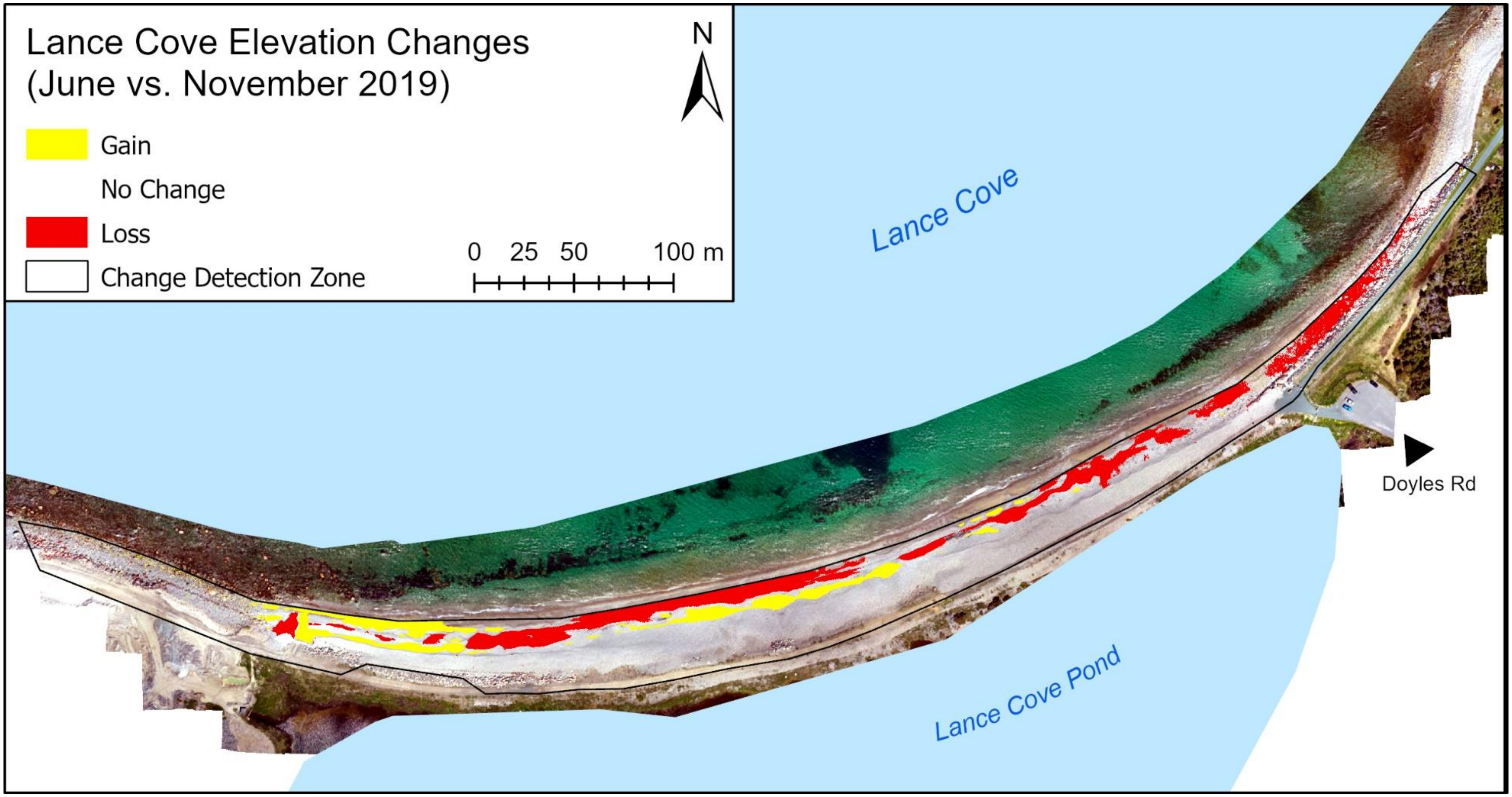

Figure 3.27: DSM differences for Lance Cove between June 2019 and November 2019.

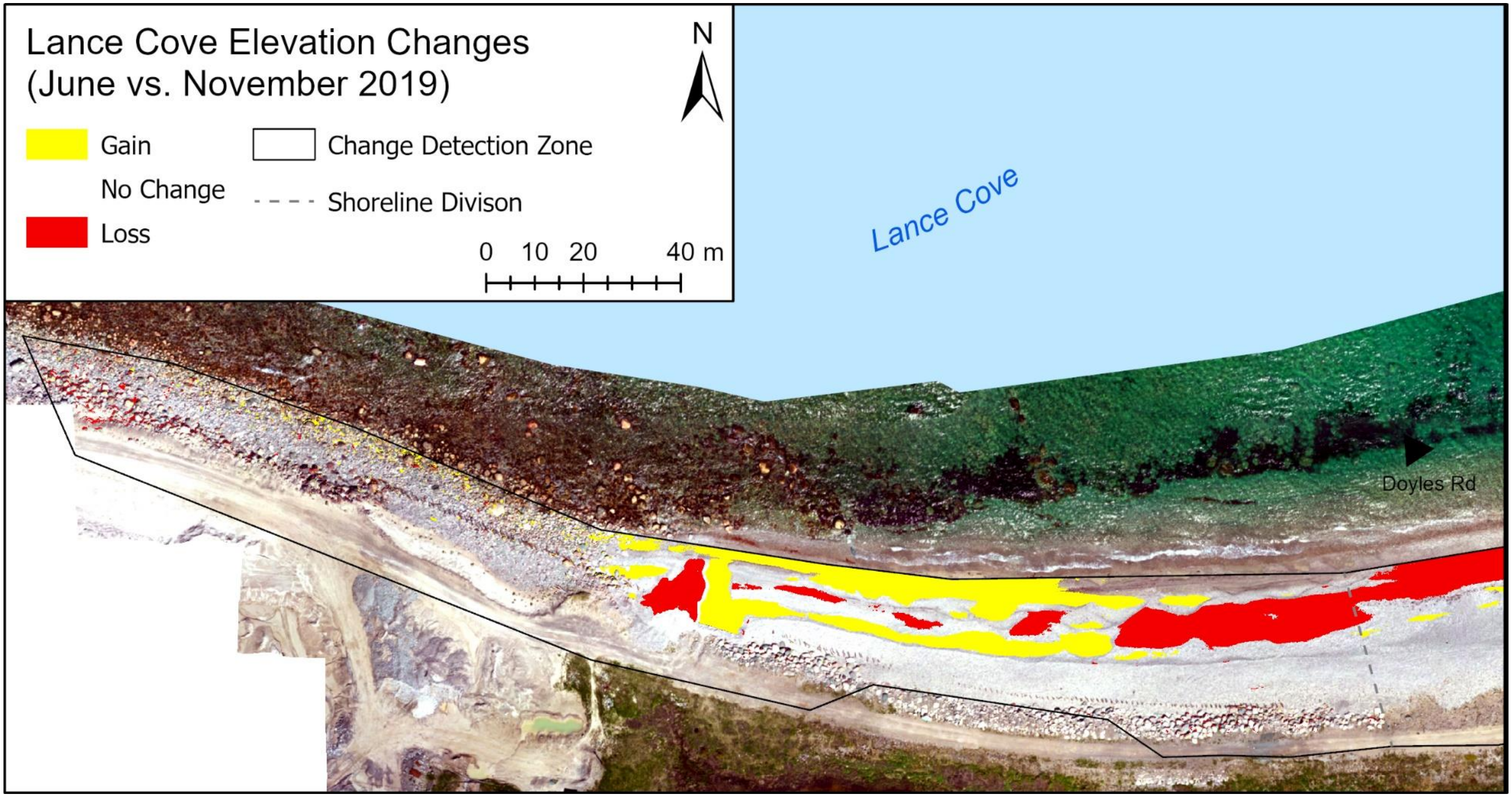

Figure 3.28: Enlarged DSM differences for the west section of Lance Cove between June 2019 and November 2019.

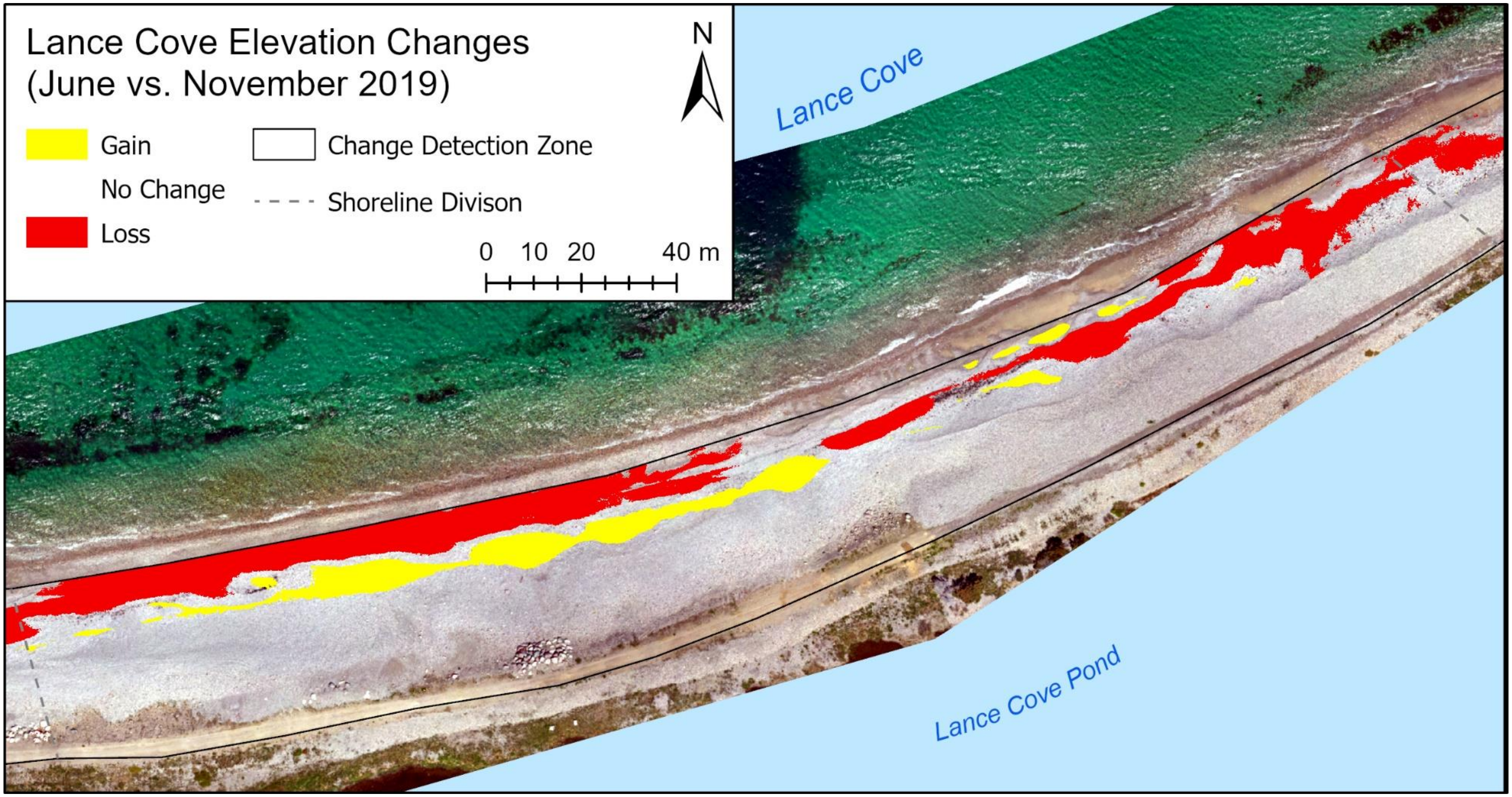

Figure 3.29: Enlarged DSM differences for the central section of Lance Cove between June 2019 and November 2019.

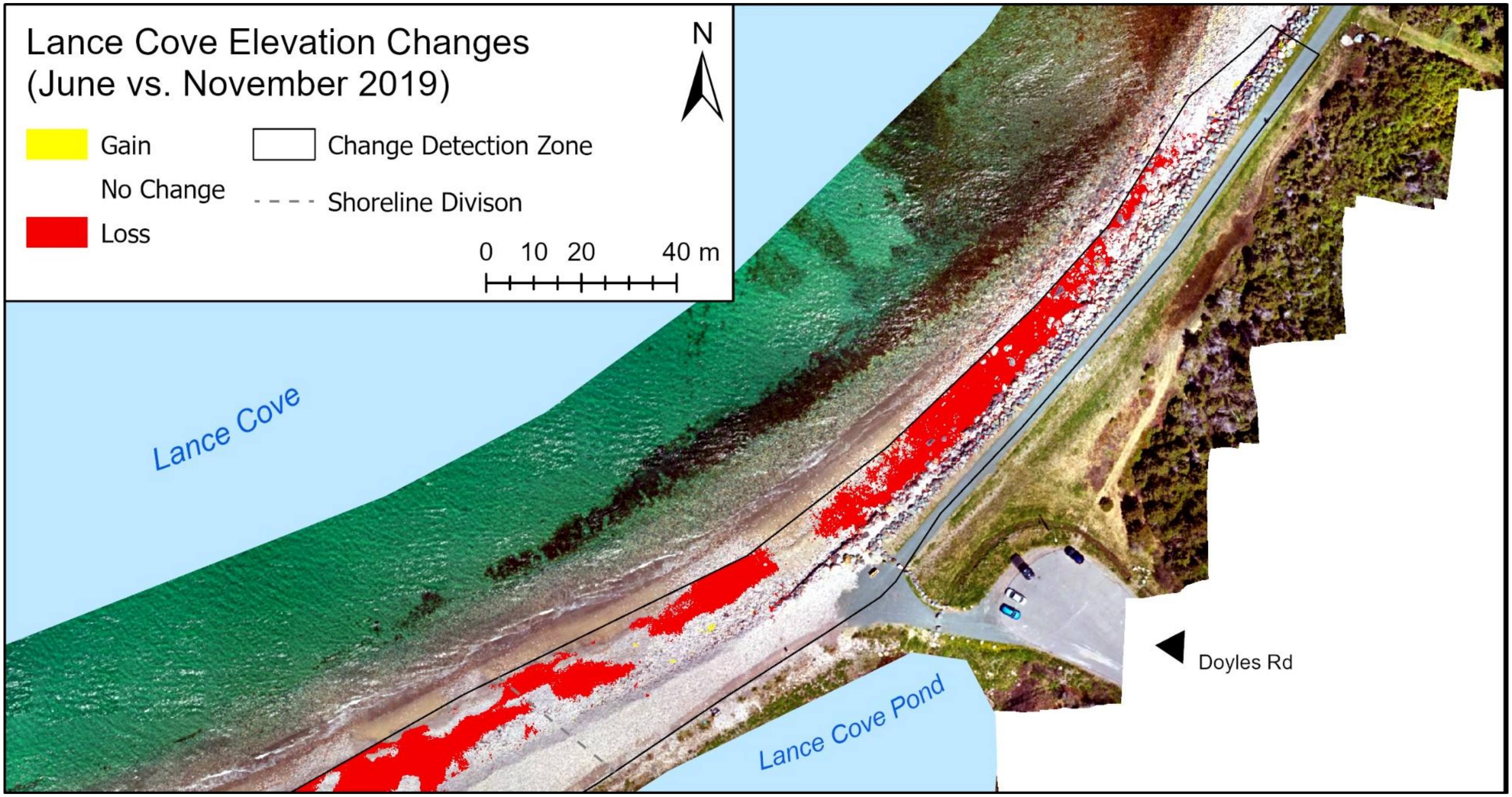

Figure 3.30: Enlarged DSM differences for the east section of Lance Cove between June 2019 and November 2019.

3.4.2 Chapel’s Cove

Chapel’s Cove was surveyed on two occasions, and a single elevation change map was produced comparing 19 June with 17 October 2019 (Figure 3.31). The elevation changes ranged between 3.1 m gain and loss, a mean elevation change of 1 cm gain with a 5 cm standard deviation. The range maximums were similar to Lance Cove, tending to be located around the edges of larger boulders or bedrock areas. On the east side of the primary beach (Figure 3.32), dominated by cobbles and pebbles, monitored changes were few and primarily contained within 20 m from low tide. There were sporadic patches of both gain and loss, up to 15 m^2 in area, with most of the vertical change less than 25 cm.

Beyond 20 m landward, on the beach's mechanically altered part, were changes associated with known human use. Three equally spaced picnic tables and associated accessories placed ~15 m seaward of the road crossing the beach appeared on the DSM as elevation gain locations because they were on the beach during the October 2019 survey but not in June 2019. A car parked near the middle of the mechanically flattened beach in June but not in October was indicated as elevation loss.

The western and eastern flanks of the beach showed changes that differ from the centre. The western flank was backed by a wooden wall between the water and Point Road. Between the wall and the shoreline were multiple small, closely packed patches of elevation gain. The larger of the patches were ~0.5 m^2 in size, and almost all indicate vertical changes less than 10 cm. On the eastern flank, the changes near the bridge were water noise, as processing software is incapable of penetrating water and results in odd returns. However, 40 m due northeast of the bridge, there was a larger patch of gain in the freshwater outflow path, along with multiple smaller patches of gain and loss. The large gain patch in the outflow was ~10 m^2, while the others were ~2 m^2 and less.

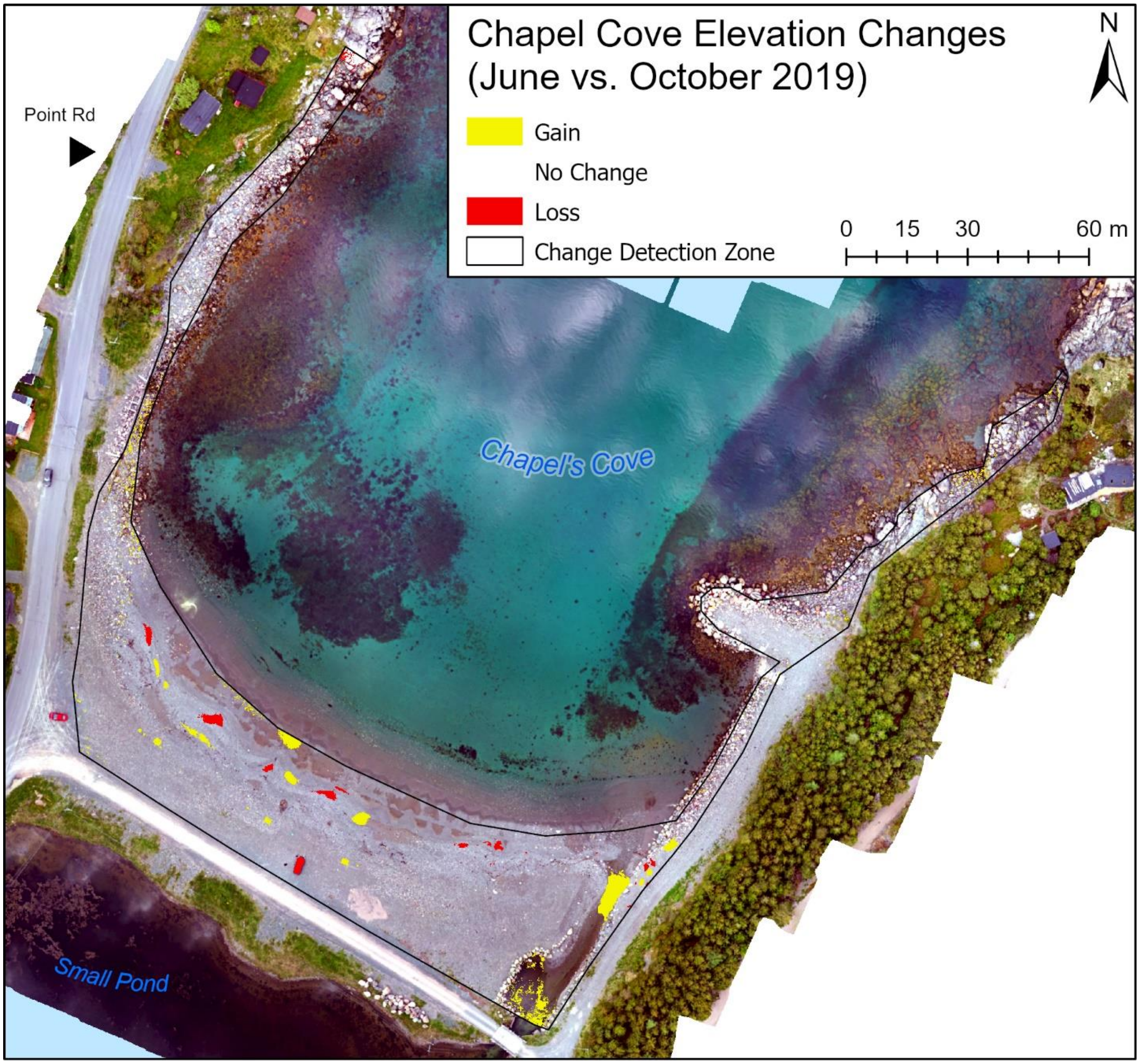

Figure 3.31: DSM differences for Chapel's Cove between June 2019 and October 2019.

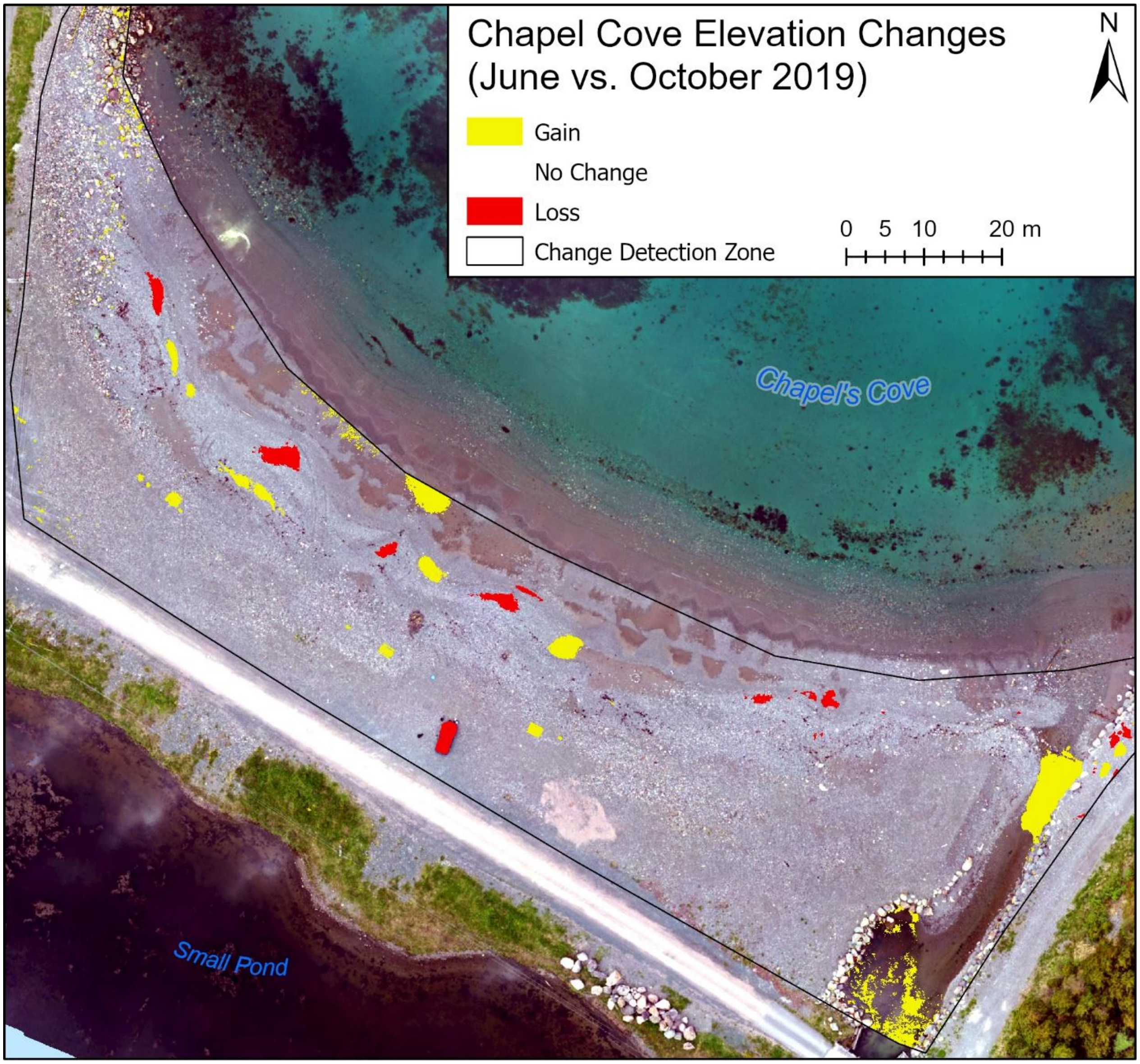

Figure 3.32: DSM differences for Chapel's Cove between June 2019 and October 2019, with the gravel beach enlarged.

3.4.3 Harbour Main

Harbour Main was excluded from DSM comparisons due to issues encountered in the field during the second visit, 12 November 2019, that did not provide data suitable for this analysis. Although quantifiable elevation change results for Harbour Main are unavailable, field observations indicate noticeable changes on the main beach area. Changes that occurred include berm destruction, overwash fans, and sediment erosion.

The area directly east of the bedrock outcrop in the center of the primary beach saw the noticeable removal of a berm between visits (3.2.3 Harbour Main). This part of the beach had three clear berms in June. During the second visit to Harbour Main, observations indicate that the area seaward of the June middle berm location showed a slightly seaward inclining smooth gravel surface.

The swimming hole behind the large rock wall and mechanically flattened beach had sediment deposits that appeared to be small overwash fans during the second visit, which were not present during the first. The deposits occurred on the swimming hole's seaward side, with the largest protruding 1-1.5 m from the mean shoreline with an area of ~4 m^2. Also, the rock wall on the west side of the primary beach was much more exposed on its western extremity and directly landward part of the wall.

3.5 MCDA Scoring and Weighting

The MCDA approach produced three main types of results: a) weighting of the parameters, b) scoring of the parameters, and c) the combined weighted score for each study site. First, three experts in each of the two fields of expertise (capelin fisheries and coastal geomorphology) were consulted and asked to weigh the parameters by assigning an ordinal level of importance to predetermined parameters (Table 3.1, & Table 3.2). By assigning numerical values to an associated ordinal variable, high=3, medium=2, low=1, and none=0, weights per parameter were obtained (Table 3.3, & Table 3.4).

Table 3.1: Importance level of each factor provided by capelin fisheries experts. (-) represents an absence of a response from the expert.

Parameter	Fisheries Expert 1	Fisheries Expert 2	Fisheries Expert 3
Wind/Beach Orientation	High	High	High
Beach Protection	Medium	-	Medium
Sediment Grain Size	High	Medium	High
Beach Slope	Medium	High	Medium
Anthropogenic Footprint	Medium	Low	Low

Table 3.2: Importance level of each factor provided by Coastal geomorphology experts. (-) represents an absence of a response from the expert.

Parameter	Coastal Expert 1	Coastal Expert 2	Coastal Expert 3
Wind/Beach Orientation	High	Medium	High
Beach Protection	Medium	High	Medium
Sediment Grain Size	Medium	-	High
Beach Slope	High	-	High
Anthropogenic Footprint	High	High	High

Table 3.3: Weight factors assigned for capelin beach parameters.

Parameter	Fisheries Expert 1	Fisheries Expert 2	Fisheries Expert 3	Avg./Expert	Weight/ Parameter
Wind/Beach Orientation	3	3	3	3	0.26
Beach Protection	2	-	2	2	0.18
Sediment Grain Size	3	2	3	2.66	0.23
Beach Slope	2	3	2	2.33	0.21
Anthropogenic Footprint	2	1	1	1.33	0.12

Table 3.4: Weight factors assigned for coastal geomorphology parameters.

Parameter	Coastal Expert 1	Coastal Expert 2	Coastal Expert 3	Avg./Expert	Weight/ Parameter
Wind/Beach Orientation	3	2	3	2.67	0.20
Beach Protection	2	3	2	2.33	0.17
Sediment Grain Size	2	-	3	2.5	0.19
Beach Slope	3	-	3	3	0.22
Anthropogenic Footprint	3	3	3	3	0.22

Second, each site's parameter scores were assigned by reference to a scoring legend (Appendix E: Parameter Scoring Legend and Associated References). The scoring legend was developed involving only capelin spawning beaches of NL. The scoring legend assigns a numerical value for characterizing each parameter's alternatives where the most favourable condition for the objective is rated highest and less suitable conditions lower.

Third, multiplying the weights determined by the first stage by the parameter scores of the second stage produced a weighted score comparison between the two objectives, similarity to an ideal capelin spawning habitat and the likelihood of coastal stability (Table 3.5 & Figure 3.33).

Table 3.5: Final weighted scores for each study site.

Lance Cove							
Similarity to Ideal Capelin Spawning Habitat				**Likelihood of Coastal Stability**			
Factor	Factor Score	Weight/Factor	Weighted Score	**Factor**	Factor Score	Weight/Factor	Weighted Score
A	0	0.26	0	**A'**	1	0.20	0.20
B	0.5	0.18	0.09	**B'**	0.66	0.17	0.11
C	0.25	0.23	0.06	**C'**	0.66	0.19	0.13
D	0.5	0.21	0.11	**D'**	0.33	0.22	0.07
E	1	0.12	0.12	**E'**	0	0.22	0
		Total:	**0.37**			**Total:**	**0.51**
Chapel's Cove							
Similarity to Ideal Capelin Spawning Habitat				**Likelihood of Coastal Stability**			
Factor	Factor Score	Weight/Factor	Weighted Score	**Factor**	Factor Score	Weight/Factor	Weighted Score
A	0	0.26	0	**A'**	0	0.20	0
B	0.5	0.18	0.09	**B'**	1	0.17	0.17
C	0.5	0.23	0.12	**C'**	0.66	0.19	0.13
D	1	0.21	0.21	**D'**	0.66	0.22	0.15
E	0.5	0.12	0.06	**E'**	0.5	0.22	0.11
		Total:	**0.48**			**Total:**	**0.55**
Harbour Main							
Similarity to Ideal Capelin Spawning Habitat				**Likelihood of Coastal Stability**			
Factor	Factor Score	Weight/Factor	Weighted Score	**Factor**	Factor Score	Weight/Factor	Weighted Score
A	0	0.26	0	**A'**	0	0.20	0
B	0.5	0.18	0.09	**B'**	1	0.17	0.17
C	0.5	0.23	0.12	**C'**	0.66	0.19	0.13
D	0.5	0.20	0.11	**D'**	0.33	0.22	0.07
E	1	0.129	0.12	**E'**	0	0.22	0
		Total:	**0.43**			**Total:**	**0.37**

A = Wind/Beach orientation during spawning season	**A' = Wind/Beach orientation during storm season**
B = Level of protection	**B' = Level of protection**
C = Grain Size	**C' = Grain Size**
D = Slope (intertidal zone)	**D' = Slope**
E = Anthropogenic Footprint on the intertidal zone	**E' = Anthropogenic Footprint**

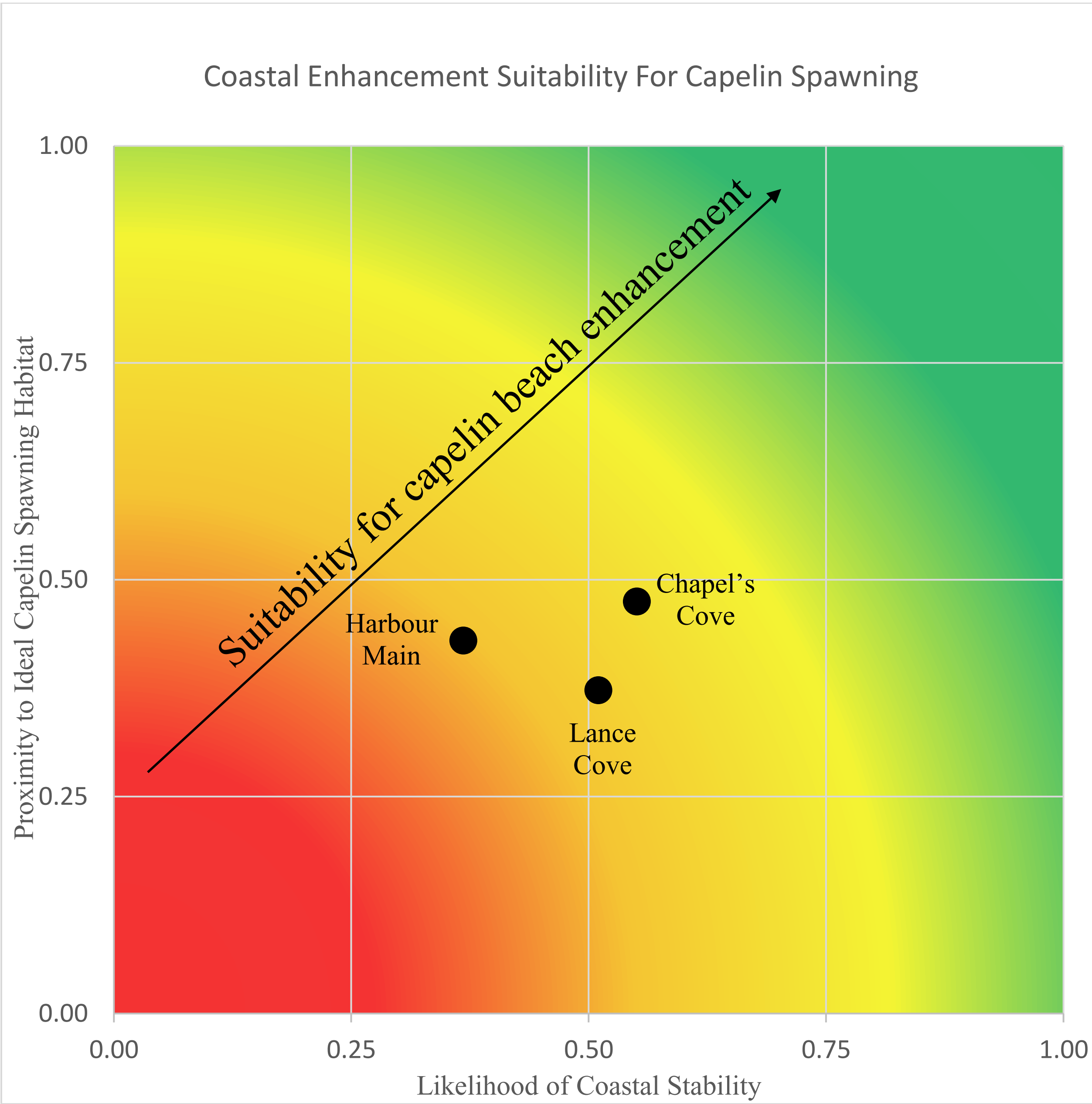

Figure 3.33: Enhancement suitability placement chart for capelin spawning beaches in Newfoundland and Labrador. Arbitrary coloring red to green associated to less ideal to more ideal respectively.

4. Chapter 4 – Discussion

4.1 Validation of the MCDA and Individual Parameters

My analyses identified Chapel's Cove as the most suitable site for potential coastal enhancements, followed closely by Lance Cove and Harbour Main. The MCDA approach shows small differences between the three beaches overall, suggesting relatively similar suitability based on the experts' assessment. There are two possible reasons for the similarities in the MCDA. First, the beaches could indeed be fairly similar or, second, the method developed may be unable to differentiate the three sites further. Lance Cove and Harbour Main were selected based on an earlier assessment process (Greene, 2019) to become potential candidates for this project, and Chapel's Cove was selected for its geographic proximity to the other sites. Therefore, similarities in the three sites were to be expected as, being in the same geographic areas, they share many similarities in terms of environmental variables.

However, the MCDA approach was developed using five parameters per objective and few alternatives for each parameter. The limited number of parameters and their alternatives could have restricted the MCDA from distinguishing more subtle differences between beaches. In an effort at comparison, six sites not examined in detail for this study were also assessed using the same approach. Two of the sites, Bellevue Beach and Middle Cove, are known for successful capelin spawning over many years. Two others, Cape Spear and St. John's Harbour, are coastal sites from the Avalon Peninsula known to be unsuitable for capelin spawning. Finally, Ship Cove is the only known example of enhancing a gravel beach for promoting capelin spawning. Therefore, it was assessed as two separate sites, once in its pre-enhanced state and the other from its post-enhanced state (See Appendix F: Final Weighted Scores for Sites External to this Study). Adding these sites allows assessment of the ability of the approach to identify suitable sites from a broader range of possibilities. The Ship Cove sites give two additional benefits: first, the ability to assess relative importance of the objectives, proximity to ideal habitat and coastal stability, with respect to each other. Second, as the only available location with temporal before and after data, it can be useful in predicting future suitability with other assessed beaches based on pre-enhancement similarities.

Adding the six additional sites to my assessment of the suitability of the three original sites (Figure 4.1) illustrates that Bellevue and Middle Cove both score high in terms of suitability for the capelin spawning objective. Wind orientation during spawning season was the only thing preventing Bellevue from achieving a perfect score. Cape Spear and St. John's Harbour scored well below all other sites, with St. John's Harbour receiving a score of zero. The lack of anthropogenic footprint in the intertidal zone is the only reason Cape Spear did not receive a similar score. Ship Cove pre-enhancement scored in a similar range as the study sites, while post-enhancement scored the highest of all assessed sites. Scores for suitability for capelin spawning habitat suggest that the approach is effective at discriminating a range of sites. Additionally, the temporal results of Ship Cove suggest that the MCDA method can indeed differentiate individual changes made to a beach with respect to capelin spawning habitat suitability.

Distinguishing differences becomes more complex when assessing the coastal stability objective (Figure 4.1). While most sites are within a fairly narrow range of values, Middle Cove has the lowest score in terms of coastal stability, and Ship Cove post-enhancements has the highest. Middle Cove is a very dynamic beach, both spatially and temporally, where texture can range from medium sands to coarse cobbles and slopes from nearly flat to >20 degrees (Catto, 2012, 2020). Nevertheless, Middle Cove's geomorphology is usually suitable, at least along some part of the beach, for capelin spawning before the season begins. Short-term variations in geomorphology and sedimentology are not accurately accounted for in the current iteration of the MCDA. Ship Cove post-enhancement, like Middle Cove, is considered as a known successful capelin spawning beach. However, unlike Middle Cove, Ship Cove post-enhancement scores high in stability relative to the rest of the beaches. Ship Cove pre-enhancement has the next highest score, largely due to it being the only southward facing beach. A southward facing beach has a large advantage over the other sites when it comes to protection from strong north-easterly storm winds.

MDCA assessments of the other reference sites are generally relatable to the three study sites. Bellevue shows resemblance to Chapel's Cove, with the only differences being related to sediment texture. Cape Spear and St. John's may have lower than expected scores, due to the high stability of bedrock-dominated coasts. Ship Cove pre-enhancement, aside from dominant wind direction, shows much resemblance to Lance Cove and Harbour Main.

As it stands, it appears the proximity to ideal capelin spawning habitat is the objective of greater importance compared to coastal stability. The three "known" successful capelin beaches display the broadest range in coastal stability scoring (Figure 4.1). Proximity to ideal capelin spawning habitat was assessed in a singular moment when spawning occurs. In contrast, coastal stability was attempted to be scored over a longer period to account for variations in the beach. Middle Cove is an example indicating that the assessed stability can indeed vary over time. Perhaps future work could start by better defining coastal "stability" of gravel beaches, such as indicating a range of dynamic and morphological changes that is not exceeded and results in similar seasonal states annually.

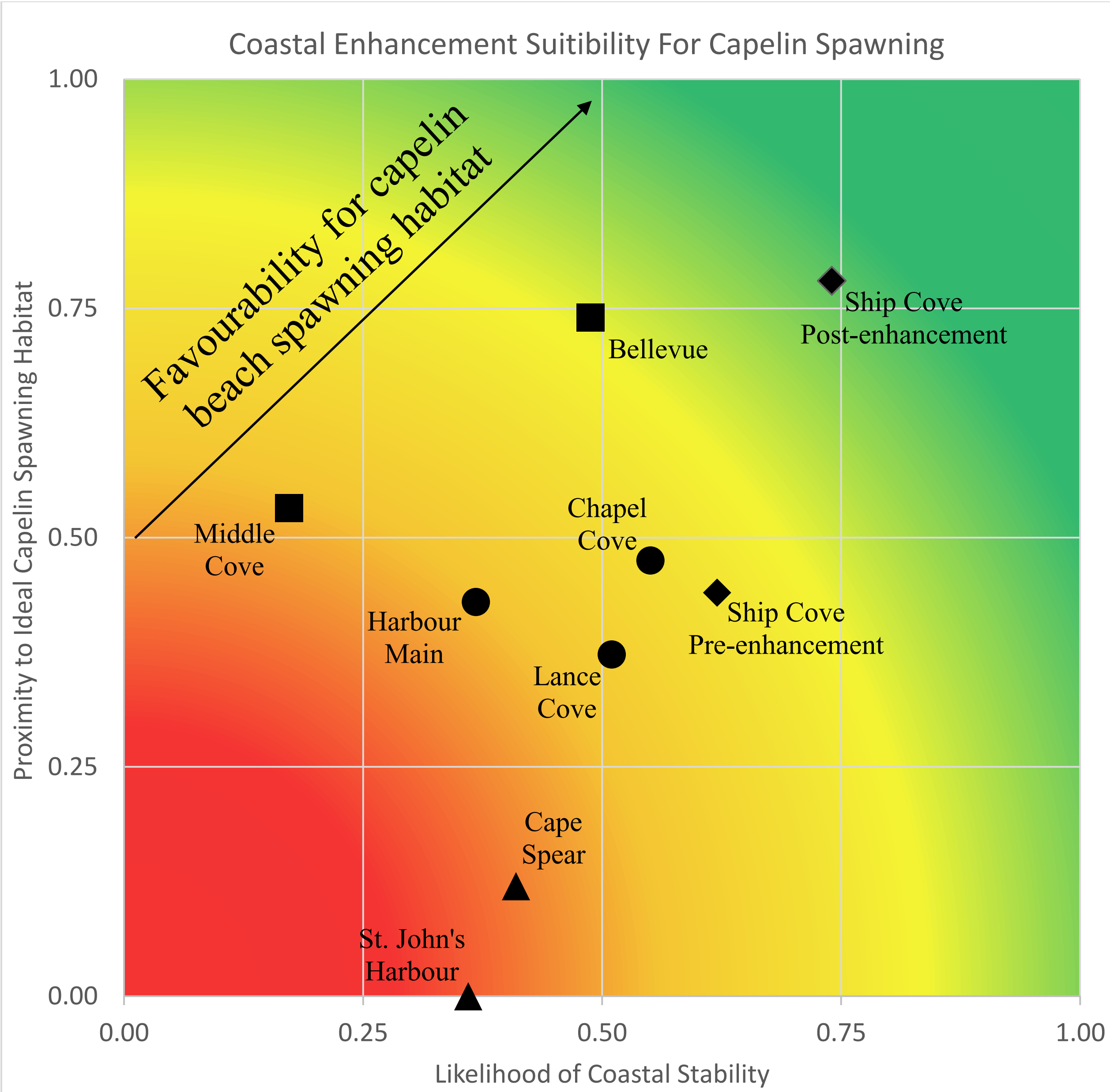

Figure 4.1: Enhancement suitability placement chart for capelin spawning beaches in Newfoundland and Labrador and additional reference sites. Circles representing sites assessed in this study; squares represent known successful spawning beaches; triangles represent unsuitable coastal spawning locations.

As seen in the six reference sites added to test the approach, the method can distinguish different coastlines based on their suitability for capelin spawning habitat enhancements. The three studied beaches, although different at the local scale, generally share several similar characteristics. The study sites generally share similar orientations and dominant sediment size, explaining their relative similarity in the MCDA analyses.

The difference of angle between wind direction and the beach orientations was considered to be the most important factor for the suitability for capelin spawning enhancements by both capelin and coastal experts. Since the groundfish fisheries' collapse in the early 1990s, capelin have been spawning later in the year, shifting from late spring to early or even mid-summer (Murphy *et al.*, 2018). While onshore northeasterlies prevail in the spring, southwesterlies winds dominate in the summer, blowing offshore at north-facing beaches. Due to the beach orientations, the overall southwesterly wind direction characterizing all three study sites during the spawning season is not ideal for capelin spawning. The three study sites may have been more appropriate for capelin spawning during the northeasterlies associated with historic spawning times. There has been no major shift in prevailing wind patterns since the 1980s. Changes in the suitability for capelin spawning regarding wind direction are related to the later time of species spawning. Chapel's Cove, Lance Cove, and Harbour Main are hence less likely to benefit from an optimal onshore wind that could assist with the incubation and release stages of capelin spawning.

However, although wind direction plays a key role in defining an ideal capelin spawning beach, other criteria are important. Capelin continue to spawn on north-facing beaches since the groundfish fisheries collapse. Since 2013, the online tracking platform *ecapelin.ca* has been used for recording capelin spawning events. Data collected in this platform have consistently confirmed spawning events at Middle Cove beach, which faces northeast. Capelin spawning events were also recorded at other beaches along the Avalon Peninsula with similar geographic settings, such as Holyrood (north-facing), located between Lance Cove and Chapel's Cove, and Bellevue (northwest-facing).

Both Lance Cove and Chapel's Cove show a sediment reworking pattern mainly restricted to a distance of ~20 m inland from mean low tide (Figure 3.19 & Figure 3.32). The limited changes indicated at Lance Cove between June and mid-September (summer) were restricted to ~10 m inland of mean low tide (Figure 3.19, Figure 3.20, Figure 3.21, & Figure 3.22). The limited change at Lance Cove during the 2019 summer is likely associated with the unusually calm conditions. Environment Canada recorded only five days between the end of June and mid-September 2019 where winds in St. John's were in excess of 40 km/h, and only one of those days had winds reaching 50 km/h. A typical summer has an average of approximately five days of >50 km/h winds (Environment Canada, 2020). Even in the intertidal zone, the limited elevation changes at Lance Cove indicate that the southwesterly dominant wind direction may not have produced enough wave action that could rework sediment and benefit capelin spawning.

Noticeable reworking of sediments at Lance Cove between mid-September and late November did occur, with potential implications for future enhancement projects. The completely infilled drainage ditch indicates the scale of change that can happen at Lance Cove without any major storm events (Figure 3.2, Figure 3.3, & Figure 3.20). Driftwood and seaweed debris suggest wave action in the fall 2019 reached 15 m inland from mean low tide. The drainage ditch required over 50 m^3 of sediment to be filled in. The degree of erosion to the T'Railway indicates that previous extreme weather events caused wave action to extend further inland than in 2019.

Changes at Chapel's Cove do not resemble those of Lance Cove. It is impossible to determine if the changes observed at Chapel's Cove (Figure 3.32) were synchronous with those observed at Lance Cove, as there were only two visits to the Chapel's Cove site. Adjacent beaches can react substantially differently over the same period due to differing physical and hydrological conditions (Catto *et al.*, 2003). The final observation of Lance Cove also took place later in the fall than at Chapel's Cove, so that Lance Cove changes may have occurred after the last visit made to the Chapel's Cove site.

Some apparent changes are thought to be misleading due to conditions during field surveys. While UAV flight scheduling placed priority on surveying at low tide, other weather conditions varied between visits. Cloud cover and sun angle differed greatly between visits, producing various glares and shadowing on the images. To a small degree, shadows were shown to impact the creation of elevation models (Guisado-Pintado & Jackson, 2018). Additional apparent changes are associated with areas of steep sloping angles, such as edges of large boulders. Errors in horizontal positioning exceeding the image resolution (lowest DSM resolution 2.85 cm) can have sizable repercussions on elevation errors at positions of more extensive slopes (Hodgson & Bresnahan, 2013; Tinkham *et al.*, 2012). Hence, a slight shift in the horizontal positioning of two DSMs can be perceived as vertical changes that do not exist in practice. At both Lance Cove and Chapel's Cove, larger boulders and other features with larger near-vertical edges showed such apparent changes but are known from field observations to have not changed over the study period.

Data on beach geomorphology and elevation were collected to supplement the MCDA approach and prioritize potential enhancement sites. None of the three beaches displayed an ideal granule to medium pebble-dominated surface during any visit (Nakashima & Taggart, 2002). All were dominated by larger grain sizes (coarse pebbles and cobbles), with sporadic patches of finer sand in some instances, less than ideal spawning substrates (Nakashima & Taggart, 2002; Neville, 2020). However, Harbour Main displayed on 12 November 2019 a finer pebble composition on the east part of the primary and secondary beach compared to the coarser pebbles and fine cobbles observed on the previous visit. Under the limited energy conditions, in combination with gravity, it is possible that net seaward movement of coarser clasts occurred, observations that have been documented elsewhere (Bertoni *et al.*, 2013; Grottoli *et al.*, 2019). It is also possible that the sediments were kinetically sieved or passively settled vertically. More frequent observations would be required to determine which of the two processes occurred at Harbour Main or any other sites. However, a beach's transition to finer sediments in the swash zone throughout the summer season may offer a more suitable spawning substrate - a potential side benefit to the later spawning of capelin since the 1990s (Murphy *et al.*, 2018).

Within this study's limited temporal scope, Chapel's Cove appears to be the most suitable of the three locations for capelin spawning beach enhancements. Previous observations of the beach (Catto *et al.*, 1999, 2003) indicate very strong similarities to observations made in this study. Further monitoring could provide a better assessment of long-term conditions on the beaches and their suitability for enhancements (e.g., beach nourishment) that could persist.

Harbour Main also appears to have similarities to Chapel's Cove, both in the MCDA prioritization and physical settings. However, anthropogenic disturbance involves primarily human use and maintenance at Chapel's Cove rather than physical rigid structures at Harbour Main. Harbour Main has rock walls, concrete walls, boardwalks, and roadways bordering or within a few meters of mean high tide. The community of Harbour Main also constructed the swimming hole with full intention to promote usage of the beach, combined with the addition of picnic tables, fire pits, and garbage bins during the summer months. Such influence by the local community to control the beach's layout and surrounding area for recreational and commercial will likely hinder any enhancement work.

In contrast, Chapel's Cove has a dirt road and a small wooden bridge for access to four dwellings and a small boat launch that is actively used. The dirt road access across the beach is more than 20 m inland from the shoreline at the minimum point. Therefore, the dirt road should have little influence on the beach area seaward of it. With cooperation from the local community, the beach's anthropogenic usage could be easily confined to non-mechanical activity. However, as at Harbour Main, picnic tables are added to the beach during the summer months, and users construct fire pits. Any enhancements will need to consider the continuance of such recreational use. Additionally, the mid-bay barachois is largely protected from wave action, and sediment is primarily locally derived and transported (Catto, 2012). Sediment added to Chapel's Cove for nourishment should theoretically be largely contained within the system.

4.2 Recommendations

Chapel's Cove was found to be the most suitable site to conduct capelin spawning habitat enhancements among the three study sites. The MCDA approach identified a number of general properties that make it more suitable. Field observations have confirmed that Chapel's Cove shows minimal change throughout the study period, increasing the chances that beach enhancement work will last longer. As a wave-dominated, swash-aligned, shore-normal, mid-bay barachois, most of its sediment is locally sourced from erosion of local bedrock, with little distal transport of sediment (Catto, 2012). Observations of beach geomorphology at Chapel's Cove for over 20 years (Table 4.1) indicate consistent beach characteristics. There are, however, some changes, including a slight increase in mean sediment size and a gradually decreasing slope. Both related to the magnitude and frequency of northeasterly storm weather events in the 1990s and early 2000s (Catto *et al.*, 2003). Strong northeasterly storm winds did not impact Chapel's Cove to the same extent within the 2010-2019 decade. The indicators considered by coastal and capelin experts support the likelihood of sustaining enhancements at Chapel's Cove beach.

Table 4.1: Chapel's Cove field observations compared to previous observations.

	(Catto *et al.*, 1999)	(Catto *et al.*, 2003)	Catto (2004-2018) personal communication *	Field Observations 2019
Mean Sediment Size	Medium Pebble	Medium Pebble	Medium pebble to fine cobble	Pebble / Fine Cobble
Slope Range of specific place measurements	14°-27°	14°-27°	5-20°	5-15°
Profile Spring	Planar	Planar	Planar	Planar
Profile Autumn	Concave	Concave	Moderately to strongly concave	Concave
Cusps	1 tier	1 tier	1-2 tiers	1-2 tiers

**Personal communication based on repeat observation made from 2004 through 2018*

Table 4.2: Chapel's Cove field observations compared to Ship Cove post degradation but pre-enhancements.

Beach	Chapel's Cove		Ship Cove (South)	Ship Cove (Central)	Ship Cove (North)
Reference	Catto (2004-2018) personal communication *	Field Observations 2019	(Boger, 1998)	(Boger, 1998)	(Boger, 1998)
Mean Sediment Size	Medium pebble to fine cobble	Pebble to fine cobble	Sand to granule	Boulders with pebble infill	Pebble to cobble
Slope Range of specific place measurements	5-20°	5-15°	5-13°	5-18°	5-18°
Profile Spring	Planar	Planar	Convex	Convex	Convex
Profile Autumn	Moderately to strongly concave	Concave	Concave	Concave	Concave
Cusps	1-2 tiers	1-2 tiers	1 tier	Nil	1-4 tiers

**Personal communication based on repeat observation made from 2004 through 2018*

Chapel's Cove bears similarities to Ship Cove, NL. The closest overall scoring sites from the MCDA (Figure 4.1) are Chapel's Cove and Ship Cove pre-enhanced, suggesting a closer investigation presented in Table 4.2. Ship Cove is a beach recently enhanced to make it more suitable for capelin spawning and thus far appears to be a successful intervention (Figure 4.2) (Neville, 2020). Before enhancements, Ship Cove comprised of granules and sand on the southern part, boulders with pebble infill centrally, and pebbles to cobbles on the northern section of the beach (Figure 4.2 – 1A) (Boger, 1998). Post-enhancement, much of Ship Cove displays granule to pebble texture (Figure 4.2 – 1B). Since completion of the enhancements before the 2018 capelin spawning season, the Ship Cove, NL project has shown continuously positive results in terms of both the stability of introduced fine pebble and granule sediments and capelin spawning. Both Ship Cove and Chapel's Cove include flanking headlands on either side of the beach that offer a degree of protection and reduce the likely occurrence of any distal transportation of sediments.

The only suggested enhancement for Chapel's Cove would entail nourishing the beach with granules (2 mm diameter) to medium pebbles (16 mm diameter), the range of ideal substrate for capelin spawning (Nakashima & Taggart, 2002; Neville, 2020). The nourishment should be applied to the beach's central part, between the wooden wall and boulder rubble to the northwest adjacent to Point Road, the freshwater input to the southeast. Outside of the central area of the beach transitions to boulders placed for protective measures before the Cove shifts into bedrock northeastwards. Given the similarities between Chapel's Cove and Ship Cove pre-enhancment from the MCDA result and a more detailed comparision (Table 4.2), it would be expected that there would be a similar measurable improvement to Chapel's Cove post-enhancment as recorded at Ship Cove.

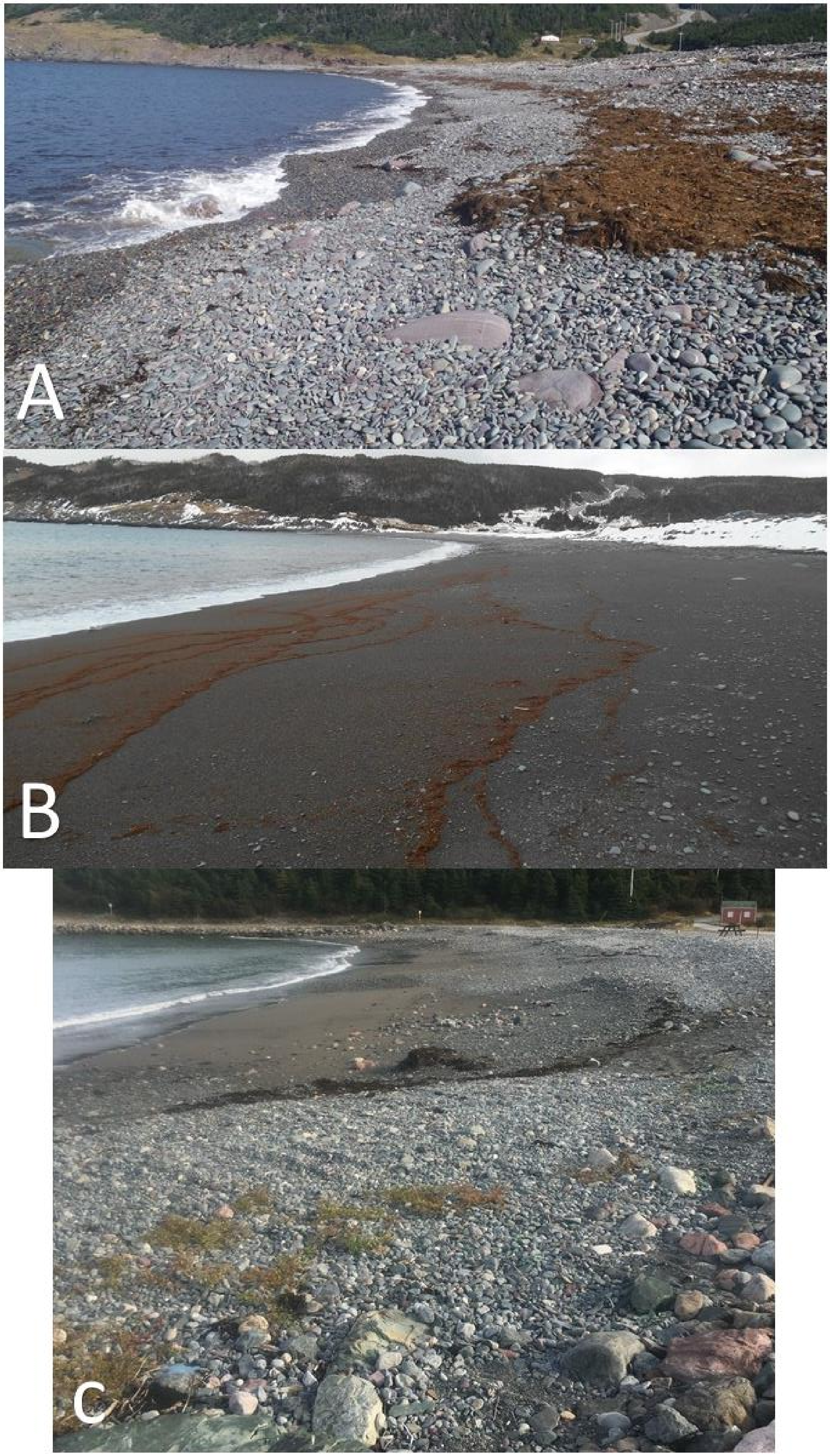
A
B
C

Figure 4.2: (A) Ship Cove Beach pre-enhancement, pebble to cobble sediment, photo orientation North – September 2011 (Photo Credit: Melanie Irvine); (B) Ship Cove post enhancement, granule to fine pebble sediment, photo orientation North – Feb. 2018 (Photo Credit: Victoria Neville), (C) Chapel's Cove, sand patches in the intertidal zone and pebble to cobble sediment, photo orientation Southeast - October 2019. Chapel's Cove (C) and Ship Cove, before enhancement (A) both, outside of the sand patches at Chapel's Cove, have a similar pebble to cobble texture and cusping features. A proposed enhancement for Chapel's Cove would fall in line with Ship Cove post enhancements (B), where the beach is a well-mixed granule-small pebble texture.

Lance Cove was not found to be a suitable beach for enhancement work. Analyses indicate slightly lower suitability for enhancement, and field observations suggest a much more dynamic beach than the two other studied sites. The claim that Lance Cove is unsuitable for enhancements is also supported by previous studies such as the sensitivity to coastal erosion index (CEI Index), a short-term evaluation of coastal sensitivity, and the coastal erosion and sensitivity to sea-level rise index (CSI index), a long-term evaluation of sensitivity (Catto, 2012). The CEI index considers five factors in creating a total score: sediment type, shoreline classification, sediment flux, aspect, and the influence of seasonal ice. Meanwhile, the CSI index is evaluated through sea-level change and tidal range, but also mean annual maximum significant wave height, rock and/or sediment exposed along the shore, landform type, and shoreline displacement. Catto (2012) locally applied both CEI and CSI indices as tools to evaluate coastal erosion for the island of Newfoundland's coastal beaches. The indices' local application gives a greater detailed evaluation of coastal erosion and sensitivity to the change of coastal Newfoundland, which helps further inform coastal enhancement planning in the province.

Lance Cove's CEI index indicates a high sensitivity, similar to the moderate to high scores of Chapel's Cove, Harbour Main, and Ship Cove. A very narrow range separates the total scores of which the four beaches above received. Ship Cove's geographical location limits ice influence. However, Lance Cove is separated from the other beaches in its higher sensitive score in the CSI Index, the longer-term erosion index (Catto, 2012). Harbour Main, Chapel's Cove, and Ship Cove range from low to moderate to the CSI index. Short and long-term sustainability should be both considered for enhancement projects, making the CEI and CSI indices good tools to consider, as they address a beach's stability and, therefore, its likelihood of sustaining enhancements. Lance Cove is more sensitive in both erosion indices, setting it apart from Harbour Main and Chapel's Cove, and from Ship Cove, a successful example of beach enhancements for capelin spawning. With the study sites in the same geographical region, the CSI input factors of sea-level change and tidal range are identical. Therefore, the higher CSI results must stem from the remainder of the input factors, relief, wave height, sediment type, landform type, and shoreline displacement. Furthermore, the input factor sediment type and landform type are likely lesser influencers on Lance Cove's higher CSI result because they are the same or similar to input factors considered in the CEI evaluation where all beaches resulted in similar scores. Hence, the most likely contributing factors to Lance Cove's higher sensitivity in the CSI are lower relief, wave height, and shoreline displacement. Though Ship Cove belongs to a separate region, Placentia Bay still maintains a similar relative sea-level rise and tidal regime to the three study sites in Conception Bay. Therefore, the input factors isolated above as the main contributors to the CSI differences likely apply to Ship Cove as well.

Additional concerns with Lance Cove revolve around the Grand Concourse. Currently, the beautified portion of the T'Railway (The Grand Concourse) ends at Doyle's Road, directly northeast of the barachois, but the old rail bed extends to Holyrood before moving inland. If plans to develop the Lance Cove-Holyrood retired rail bed to the Grand Concourse proceed, alteration to the Lance Cove barachois could be expected. A greater degree of anthropogenic influence and control would make retention of added sediment to Lance Cove less predictable and stable than at Chapel's Cove. However, the T'Railway is a designated walking path that recreational users are more likely to be confined to using. The steep gravel slopes separating the T'Railway from the shoreline result in low actual usage of the intertidal beach area in Lance Cove.

Harbour Main is also not recommended for enhancement. Although Harbour Main shows similarities to Chapel's Cove, notably in terms of its physical setting, the extent of anthropogenic influences makes it a poor choice for enhancing beach habitat. Harbour Main's infrastructure is adjacent to the beach. Removal of the rock wall and sediment nourishment on the western side of the main beach could potentially increase capelin spawning. However, behind the rock wall is a popular picnic and swimming area, which would not exist without the maintained rock wall. This structure was installed and is maintained by the community. The infrastructure behind the other sections of the beach may be protected as a result of the modification. Both the east section of the main beach and the secondary beach have infrastructure ~10 m landward from mean high tide. The installment of any coastal defence structures in these two areas would require a large horizontal area between the structures and high mean tide. A smaller landward distance between defence structures and mean high tide results in more occasions when the defence structure is needed. The beach seaward would be altered by both swash and backwash. Current climate change and associated sea-level changes create concerns that any alterations that work with the local community would, in the long term, be more rigid defence focused on protecting infrastructure, which would not result in beneficial and sustainable capelin spawning habitat enhancement.

5. Chapter 5 – Conclusion

5.1 Major Findings

With increasing concern over prolonged reduced capelin population in Newfoundland and Labrador, this research devised a means to investigate capelin spawning habitat as a way to stimulate population growth. The identification of capelin spawning characteristics, collection of geomorphic baseline data, examination, and interpretation were used to prioritize through a MCDA approach for beach enhancements of three study sites in the order of Chapel's Cove, Lance Cove, and Harbour Main. Chapel's Cove is the only site to be recommended as suitable for enhancements with further analysis and interpretation of available information.

Chapel's Cove shows suitability from both the main objectives considered in the research, those being suitability from the perspective of capelin spawning needs and coastal stability. It already has some characteristic that are advantageous for promoting capelin spawning, while its geomorphic characteristics support sustaining beach enhancements that could further support spawning. Meanwhile, Lance Cove and Harbour Main, though still prioritized by the MCDA approach, were eliminated from enhancement suitability recommendations based on further investigations of available information. Lance Cove's relatively high energy dynamics along with results from other coastal investigations ultimately led to its assessed unsuitability for enhancement. Harbour Main's unsuitability for enhancement stems from the intensive anthropogenic influence in the waterline area.

5.2 Implications

5.2.1 Chapel's Cove

Locally, enhancements to Chapel’s Cove can change the physical characteristics of the beach and disrupt the current equilibrium. No matter how thorough the research, sustainable results from enhancements are not guaranteed and the beach could revert to its current setting. Then, there is the considerations of social interactions. Chapel’s Cove, unlike Ship Cove with a local population of nearly zero, is frequently visited and used recreationally by the local community. The implications are unknown as to the effect that enhancements would have on human interactions with the beach. With proximity to St. John’s and Conception Bay South, immediate curiosity could increase visits and usage of Chapel’s Cove. However, whether the number of visits would continue at higher than pre-enhancement rates is a harder question to answer. The type of beach usage post-enhancement would also be very important when considering implications. Middle Cove is a very successful capelin spawning beach even though it gets used very heavily for bonfires, walks, and beachcombing. Lance Cove and Harbour Main, and Ship Cove prior to enhancements, are much less known for capelin spawning, but also show anthropogenic influences.

Even though enhancements to Chapel’s Cove may be expected to draw more attention from denser populations of St. John’s, Conception Bay South, and surrounding areas, it is unanticipated that these newly found tourists would be a source of concern. A demographic that is interested enough to go out of their way to visit an enhanced habitat are also unlikely candidates to negatively disturb such an environment. Furthermore, walking and beachcombing by “enhancement tourists” will have almost no impact. Bonfires are currently rare at Chapel Cove, and there are already frequented beaches near St. John’s, Conception Bay South, and surrounding areas that are quickly and easily accessible to those larger populations including Middle Cove and Topsail Beach. Hence, the community members of Chapel's Cove would be the most important population that could influence an impactful change of usage on the beach. Therefore, if enhancements were to move forward, it is of the utmost importance to include the community and have them onboard.

5.2.2 MCDA

It is important to consider the implications this research has in the field of habitat enhancement. The development of an analytical hierarchy process type of MCDA method and applying to the unique environment-species relationship focus of this study is a new frontier for the field. The MCDA from this study demonstrates the techniques' ability to collect and present semi-quantitative data for large complex systems by breaking them into small manageable pieces. The various MCDA method types are adaptable and useful in the field of habitat intervention. The foundations may be the same, and this research supports existing work in the field. The directions MCDA methods can be taken and uniquely modified for the study environment, equipment available, and questions asked, are endless.

5.2.3 Habitat Intervention

In the overall larger focus of habitat intervention such enhancement or restoration, this research project moves in supporting a change in perspective: moving away from what intervention does, or addressing the symptom, to why we need intervention, solving the underlying problem (Martin, 2017). The study sites selected for this project did not have intervention methods thrown at them without thought. They once were capelin spawning sites, but are now much less successful or even inactive. Instead, the research focused on why spawning has diminished at historically successful locations. It is acknowledged that the issue could be as straightforward as a capelin population size problem, with numbers much lower than prior to 1992. Overall capelin population was not assessed in this research. Beach characteristics and dynamics are evaluable factors in capelin spawning habit that were quantifiable and usable as a basis to ask why capelin no longer successfully spawn in those locations.

Precipitous intervention is not the intended outcome of this research. This study places itself in the field of habitat intervention by supporting the need for and following underpinning concepts. Whether enhancements ultimately are made or not made at any of the study sites does not influence the conclusions, as the themes of appropriate intervention have already succeeded in influencing the choice between action or non-action. The three themes (Mcdonald *et al.*, 2016) are pillars to this study: knowledge before action; keep things as natural as possible; and communication. Knowledge before action is the first and foremost theme for all research questions. The study objectives were constructed around knowledge and guided towards answering the suitability for habitat enhancements. In obtaining knowledge on intervention, assessing suitability of gravel beach systems by understanding characteristics and natural dynamics seamlessly flowed into what types of enhancements to consider. This unsurprisingly forced consideration of what would naturally work with the surrounding environment. Although the final theme, communication, may not seem to be directly demonstrated by the study, it is supported none the less. The MCDA communicated with working professionals with differing interests, biological and physical, to create an interdisciplinary approach to assessing capelin spawning habitat. The completed research methods and results have been communicated to the initial stakeholder, the

WWF. However, it will be up to the stakeholder to determine their future course of action, communicate with local communities, and to engage partners for enhancement if desired.

5.3 Limitations

A key limitation of this project was the relatively short study period, something that could not be avoided in the context of a graduate project with one field season. Field observations during 2020 were not possible due to COVID restrictions on travel and field research imposed by the Government of Newfoundland and Labrador and by Memorial University. More prolonged monitoring of the sites would have improved insight into coastal changes in the three study sites. Although large geomorphic changes to gravel beaches are typically associated with storm events (Catto, 2012; Grottoli, Bertoni, & Ciavola, 2017) no major storm occurred during the study period (June to November 2019). To help understand coastal changes, future studies could gather data year-round and over several consecutive years to account for annual differences in weather and observe the impacts of various storm events. This approach has been useful in studies of other beaches on the Avalon Peninsula.

This study also relied very heavily on terrestrial data, while subtidal marine aspects were less investigated. Capelin is a marine species, and coastal areas are the intersection point of terrestrial and marine environments. Future studies with available time and appropriate resources collecting applicable marine data would supplement terrestrial data collected in this study. Observations could include water temperature, dissolved oxygen, and salinity (Ressel *et al.*, 2020), which could be compared to those at other successful spawning beaches and be used to help identify the likelihood of successful enhancement.

The MCDA prioritization approach developed for this project was restricted to five parameters. Parameter selection was based on the information available, which applied to both preferred capelin beach spawning conditions and geomorphology of gravel beaches. An effort was made to evaluate each parameter as an independent factor. In reality, species-habitat relationships and coastal geomorphology are both influenced by closely intertwined parameters. For example, beach slope is a product of wave characteristics and sediment properties (Buscombe & Masselink, 2006). For a truly accurate depiction of the slope, consideration must be given to all the factors that contribute to slope and how they interact. The MCDA approach does not include multi-parameter relationships. Regardless of how many additional parameters could potentially be included, for example the ability to respond to sea level change, the MDCA should be considered one of several tools to assist the decision-making process.

By testing the validity of the MCDA method with additional coastlines, it appears the similarity to the ideal capelin spawning habitat can effectively be distinguished for beaches. At the same time, the likelihood of coastal stability is a somewhat more difficult question to answer, although it is believed the results accurately represent the sites. Cape Spear, for instance, though it may be a resilient cliff face with no human influence, is also completely unsheltered, open to dominant storm waves, and steeply sloping. Such approaches to the problem explain how lower stability results for locations that may have been predicted as more stable.

Finally, though not considered a limitation in this study, it is impossible to receive a perfect score in the MCDA approach. A coastal location can receive a perfect score in one of the two main objectives: proximity to the ideal capelin spawning habitat or the likelihood of coastal stability. However, for some parameters, the highest possible scoring alternative for one objective may be the lowest scoring alternative for the same parameter under the other objective. For example, bedrock for the parameter sediment texture is the highest scoring alternative in the likelihood for coastal stability objective but at the same time is the lowest scoring alternative for the same parameter in the proximity to ideal capelin spawning habitat objective. This is not considered a limitation but rather a means of accurately describing a coastline. Although this is due to each objective's contrasting requirements, future studies could mitigate the contrast by adjusting the MCDA method for evaluating gravel coastlines only. However, in this study there was insufficient time or resources available to collect information from other gravel beaches on the Avalon Peninsula. WWF Canada and partners had previously eliminated less suitable coastlines for that very purpose, therefore making this project much more manageable. As a final point, the method appears to work, but requires future application to other potential gravel coastline.

5.4 Future Research

This research is step forward for the field of restorative and ecological enhancement sciences, filling a niche knowledge gap of species-specific ecological intervention for capelin. However, there is always room to expand in new fronts of research. Considering the limitations of this study, any future research would benefit from an extended observation period. One observation season is limited in its ability to obtain climate influences on beach dynamics, or even weather influences of differing seasons. Hence, a longer observation period would offer the ability to solidify observations in this study with respect to longer term impacts.

To further develop the work in this thesis, I recommend that advancement in the field include subtidal to nearshore spatial and temporal dynamics. As the coastal zone is a unique transition from terrestrial to marine environment, it would be beneficial to integrate all of its individual parts. The failed method of observing subtidal dynamics in this study during the field season indicates that caution is required in rigorously identifying methods and equipment that have been tested in the specific environment. Even the lightest wave action in the subtidal zone of a gravel beach can create havoc for submersible remotely operated vehicles (ROV). If wave conditions allow for ROV deployment, consideration must also be given to biophysical barriers such as kelp beds or rockweed mats that can quickly become entangled in the propellers of smaller devices.

Kelp and seaweed mats are biophysical barriers that can make observation of subtidal beach dynamics problematic, but also influence both coastal dynamics and capelin spawning. Through the field season of this study, the presence of kelp and rockweed were noticed. No literature was found that directly related capelin spawning process and ultimate spawning and larval success to kelp or rockweed presence. The presence of displaced kelp and rockweed on a beach also can influence sediment accumulation and distribution, as well as beach slope.

Finally, this research was driven more by geomorphology than it is by biology. If a particular beach is enhanced with a focus on capelin spawning habitat, it would be invaluable to have biological monitoring completed for multiple years both pre- and post-intervention. Attempting enhancement to gravel beaches to promote capelin spawning is a new frontier, but without before and after production comparisons there is no way to calculate any level of success. Assessment of both egg density and resultant number and percentage of larvae emergence would be a good means of approaching such a problem, as it has been observed that the amount of spawn does not necessarily correlate to a proportionate emergence of larvae.

5.5 Final Remarks

Coastal zones play a large role in the social, cultural, and economic making of the Newfoundland and Labrador we see today. Historically, the inshore fisheries drove initial settlement on the shoreline of the province. The social and cultural identity of the province today still encompasses those traditional roots and has become a tourism attraction in itself. With a declining fishery and more intensive human encroachment on coastal areas, the time to act is now. Intervention to restore, enhance, or preferably conserve capelin spawning grounds is one method in which action can be taken to promote capelin population, in addition to other fishes and marine mammals.

Capelin are and have always been vital to play a role in that identity. Capelin were regarded largely as a food source for more valued fish when settlement first occurred, but now are utilized as a local food source and a commercial fishery, and as an attraction for both locals and tourists when they roll on the beaches. Although they may be less recognized for the value they hold, numbers alone could never quantify the value of capelin to Newfoundland and Labrador.

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Appendices

Appendix A: Field Survey

Lance Cove, Conception Bay South, NL				
Visit	1st	2nd	3rd	4th
Date	14 June 2019	11 September 2019	15 November 2019	28 November 2019
Survey Start Time	09:15	08:15	09:40	09:40
Survey End Time	15:15	15:30	N/A	17:00
GCP's Deployed	13	13	13	13
Transect Surveys Deployed	3	3	3	3
Transect Surveys Completed	2	3	3	3
UAV Flight Start Time	11:45	13:04	14:15	14:30
UAV Flight End Time	12:45	14:38	16:15*	16:30
UAV Mapping Altitude	60 m	40 m	40 m	40 m
Side Overlap	75%	75%	75%	75 %
Front Overlap	75%	75%	75%	75%
Low Tide	0.2 m	0.3 m	0.1 m	0
Low Tide Time	11:59	13:04	15:31	15:56
Wind Speed	N - 20 kph	W – 15 kph	S – 15 kph	NE – 10 kph
Weather Conditions	11°C No precipitation	16°C No precipitation	4°C No precipitation	4°C No precipitation
Additional Comments	One transect was not completed due to removal of marker by pedestrian	Available control monument located approximately 15cm below ground level, the contrast between excessive sunlight glare and the shadow of the pit on this morning made set up of RTK challenging	*Weather conditions checked before take off, but temperatures dropped to near zero. Systems and software failures made it unsafe to fly and cancellation of survey	Large tide difference of 0.0 m – 1.3 m

Chapel Cove Beach, Chapel Cove, NL		
Visit	1st	2nd
Date	19 June 2019	17 October 2019
Survey Start Time	09:45	10:15

Survey End Time	15:45	17:30
GCP's Deployed	13	13
Transect Surveys Deployed	3	3
Transect Surveys Completed	3	3
UAV Flight Start Time	14:55	15:49
UAV Flight End Time	15:35	17:20
UAV Mapping Altitude	60 m	40 m
Side Overlap	75%	75%
Front Overlap	75%	75%
Low Tide	0.2 m	0.2 m
Low Tide Time	15:42	16:39
Wind speed	W - 11 kph	ESE – 20 kph
Weather Conditions	19°C No precipitation	11°C No precipitation
Additional Comments		Mapping software malfunction occurred during flight with the second battery; the UAV was moving but not recording or recognized by mapping program. After landing and re-uploading flight plan, UAV continued mapping from pre-malfunction location morning made set up of RTK challenging

Harbour Main Beach, Harbour Main, NL		
Visit	1st	2nd
Date	27 June 2019	12 November 2019
Survey Start Time	09:15	10:00
Survey End Time	15:15	16:15
GCP's Deployed	13	13
Transect Surveys Deployed	4	4
Transect Surveys Completed	4	4
UAV Flight Start Time	10:35	13:30
UAV Flight End Time	11:55	15:00
UAV Mapping Altitude	40 m	40 m
Side Overlap	75%	75%
Front Overlap	75%	75%
Low Tide	0.3 m	0.2 m
Low Tide Time	09:50	16:39
Wind speed	NNE - 10 kph	ESE – 20 kph
Weather Conditions	18°C No precipitation	5°C No precipitation

Additional Comments	Rescue helicopter passed by the area, immediate emergency landing was required mid flight	Battery draining occurs more quickly with cooler temperatures

Appendix B: Transect Data

Lance Cove:

LANCE COVE 14 June 2019

Control Monument 96G6111

Northing 5259884.966 Easting 344820.551

Field Notes for Survey Site:

- Flight altitude 60 m

Trimble Point/marker: LCT2-LCT1

Southwest Transect

LCT2: Northing 5260185.098 Easting 344195.989

LCT1: Northing 5260204.053 Easting 344199.081

Bearing: 20° North

20.1 m in length

Transect 0 m to 5.9 m

- Starting point at base of rock wall with boulders that are 1 m or larger in size, landward
- Composition includes mainly small cobble with some large pebble, rounded to well-rounded in shape, mostly sphere shape with some disk
- Other composition includes driftwood and non-functioning upright railway structures

Transect 5.9 m to 12.8 m 1:17 pm

- Top of berm
- Composition includes mainly pebble with some small cobble, rounded to well-rounded in shape, sphere in shape
- Other composition includes small amounts of dry seaweed, sea urchin test shells, and devil's purses (mermaid purses)

Transect 12.8 m to 20.1 m 1:20 pm

- Top of next berm, with multiple smaller berms
- 12.8 -15 m composition is mainly cobble that is well rounded in shape and sphere in shape
- At 15 m, composition turns into mainly pebbles that are subrounded to rounded shape and sphere in shape
- Increased abundance of seaweed
- 20.1 m is the shoreline

Notes: Combination of wave and seaweed made it impossible to use at this transect. Wind and waves picked up into the afternoon. Shoreline bearing was 100°, and Wave bearing was 110°.

Trimble Point/marker: LCT4-LCT3

Central Transect

Member of the public removed marker flag; therefore, this transect was not completed.

Trimble Point/marker: LCT6-LCT7

Northeast Transect

LCT6: Northing 5260431.358 Easting: 344747.449

LCT7: Northing: 5260424.732 Easting: 344759.267

Bearing: N/A

14.2 m in length

Transect 0 m to 5.0 m 2:23 pm

- Starting point at railway track/wooden wall with boulder wall
- Composition mainly cobbles with a few boulders and pebbles, sub-rounded to rounded in shape. Sphere in shape
- Other composition is very minimal with very small amounts of driftwood and seaweed

Transect 5.0 m to 8.4 m

- Transaction zone of small cobble to small boulders
- Composition mainly small boulders, well rounded in shape, sphere in shape
- No other Composition to include

Transect 8.4 m to 14.2 m 2:25 pm

- Composition of mainly small boulders to large cobble, well rounded in shape, sphere in shape
- No other Composition to include

Notes: Northeast Transect more sheltered from wave action compared to the southwest. Shoreline bearing was 50°, and wave angle was 80°

**General Note 3:10 pm: Sand and gravel areas on shoreline (patches in cusp-like shapes) for 30 m in both direction of GCP/Marker LC4

LANCE COVE September 11 2019

Control Monument 96G6111

Northing: 5259884.966 Easting: 344820.551

Field Notes for Survey Site:

- Lab arrival at 7 am
- Arrived on site at 8:15 am
- Started GCP distribution at 9:15 am
- Transects started at 11:15 am
- Issues setting up RTK base and satellite connection was a little unreliable at first, but then steadied out
- Weather was cloudy with a slight wind/breeze
- Neighbours in area shared some local knowledge
    - Hurricane Leslie caused the massive berm in survey site; before, it was a relatively gentle berm
    - There had been washouts at some point
    - Beach rocks never use to be on walking trail part
- Black beach spiders everywhere (type of wolf spider?)

Trimble Point/marker: 2LCT6-2LCT5

Northeast Transect

2LCT6: Northing: 5260427.103 Easting: 344760.533

2LCT5: Northing: 5260432.235 Easting: 344751.054

Bearing: 135°W

11 m in length

Transect 0 m to 3.3 m 11:15am

- Composition is cobble and pebble (with slightly more pebble), angular to sub-rounded in shape, mainly sphere and blade in shape
- Other composition includes few twigs and no seaweed.

- Found lost ruler from last time on-site in June

Transect 3.3 m to 4.9 m 11:32am

- Composition is mainly pebbles with some granules and cobble, angular to sub-rounded in shape, primarily sphere and blade in shape
- Other composition includes a few shells, very little wood, and no seaweed

Transect 4.9 m to 6.9 m

- Composition is a wide range of cobble, some pebbles and some boulders, sub-rounded to well-rounded in shape, sphere and blade in shape
- Other composition includes minimal amounts of dry seaweed and trash, as well as a few shells and sea urchin tests

Transect 6.9 m to 11 m 11:39am

- Composition is small boulders infilled with cobble and a small number of pebbles rounded to well-rounded in shape, mainly sphere in shape
- Other composition includes moderate amounts of wet seaweed mostly attached to rock, as well as some crab and mussel shells

Notes: This area included a rock wall, as well as a fire pit. Shoreline angle was 196°S, and wave angle was 222°W. Trident dive was unsuccessful as boulders were too slippery to get trident to shoreline and waves were too strong.

Trimble Point/marker: 2LCT4-2LCT3

Central transect

2LCT4: Northing: 5260277.076 Easting: 344630.828

2LCT3: Northing: 5260299.97 Easting: 344618.595

Bearing: NA

26.7 m in length

Transect 0 m to 3.9 m (12:05 pm)

- Composition is mostly a even mix of large cobble to sand, rounded in shape, mainly sphere and blade in shape
- Resembles a well-used path
- Other composition includes sporadically dispersed grass and weeds

Transect 3.9 m to 11.4 m

- Composition is cobble, rounded in shape, sphere with some blade in shape,

- No other composition to include

Transect 11.4 m to 17 m

- Top of berm (This does not seem to be a natural berm)
- Composition is cobble and some pebble, rounded in shape, sphere and blade in shape,
- Other composition includes some dry seaweed

Transect 17 m to 21.6 m (12:20 pm)

- Bottom of berm slope
- Composition is pebble and cobble (a little more pebble), rounded to well-rounded in shape, sphere and blade in shape
- Other composition includes a very small amount of seaweed

Transect 21.6 m to 24.1 m

- Composition is sand with very sparse cobble and pebble, rounded in shape, sphere and blade in shape
- Other composition includes small amounts of dry seaweed

Transect 24.1 m to 26.7 m

- Composition is mainly granule to coarse sand with pebble, cobble, and a few boulders mixed in, sub-angular to well-rounded in shape
- Other composition includes wet-ish dry seaweed

Transect 26.7 m

- Endpoint
- Up to the shoreline stays same as above but transitions to more sand

Notes: Shoreline angle was 270° and wave angle was parallel to shoreline (waves had died down). Trident dive attempted at 12:36 pm and maintaining a 0° angle was unachievable as Trident veered a lot to the West. This might have been due to the seaweed tangled in the propellers.

Trimble Point/marker: LCT2-LCT1

Southwest Transect

LCT2: Northing: 5260184.64 Easting: 344199.529

LCT1: Northing: 5260199.984 Easting: 344201.624

Bearing:

16.4 m in length

Transect 0 m to 5.8 m 1:08 pm

- Rockwall is approximately 0 m
- Composition is pebbles and cobble, rounded in shape, sphere and blades in shape
- Other composition includes driftwood, sea urchin tests and garbage

Transect 5.8 m to 8.7 m

- Top of berm
- Composition is pebbles and cobble, rounded in shape, sphere and blade in shape while getting more pebbly towards 8.7 m
- Other composition includes driftwood, sea urchin tests, garbage, and dry seaweed

Transect 8.7 m to 12 m

- Slope ends, noticeably flat surface (excavator possibly? No visible tire tracks however)
- Composition is pebbles and cobble, rounded in shape, sphere and blade in shape
- Other composition includes driftwood, sea urchin tests, garbage, and dry seaweed

Transect 12 m to 16.4 m

- Composition is pebbles and cobble, rounded in shape, sphere and blade in shape
- Other composition includes wet and dry seaweed and sea urchin tests

Transect 16.4 m

- No change between the last transect marker and shoreline

Notes: Shoreline angle was 219° W and Wave angle was 219°. Waves were very calm and parallel to shoreline. Trident dive attempted at 3:24 pm, but too much seaweed clogging the propellers

Chapel Cove:

CHAPEL COVE 19 June 2019

Control Monument 87G4225

Northing: 5256171.865 Easting: 339044.77

Field Notes for Survey Site:

- Chapel Cove is small but still aiming for three transects (CCT1-CCT2, CCT3-CCT4, CCT5-CCT6). Each transect starts landward and heads seaward
- GCP: CC1 through CC13
- Flight altitude 60 m

- UAV take-off time 2:55 pm
-
- Local knowledge from unknown resident:
  - CC used to be a heavy capelin spawning beach, sparse in recent years
  - Last year, capelin rolled on and off for a week. The year before, they rolled only 6 hours
- General notes from beach:
  - Rockwall protecting boat launch Southeast side of cove
  - Wooden wall with drainage system Northwest side of cove
  - Roadway surrounding all sides but mouth of cove
  - Heavy motorized traffic on beach, noticeably flattened by vehicles
  - Old fire pit remains
  - Beach glass sporadic about beach
- Air photos range from #DJI_0658 to DJI_0825
  - All photos transferred off of SD and phone onto "Storage_1."
- Phone photos range from #IMG_653 to IMG_0709
- Ends of each transect are before the shoreline as set up occurs before low tide. Hence the water recedes from originally placed transect markers

Trimble Point/marker: CCT1- CCT2

East Transect

CCT1: Northing 5255774.319 Easting 339126.508

CCT2: Northing 5255794.57 Easting 339134.888

Bearing: 45° Northeast

22.1 m in length

Transect 0 m to 15.5 m 11:50am

- Composition is sand to very large cobble, angular to rounded in shape, blade, sphere, disk, and rod in shape
  - vast assortment, very unsorted
  - looks as if it was placed mechanically
- Other composition includes very few sporadic shrubs/weeds
- At 14.5 m, there is an unnatural looking berm, sand is concentrated so likely not a berm

Transect 15.5 m to 19.9 m 12:03 pm

- Composition is mainly cobble, some sand, pebbles, and small boulders, sub-angular to well-rounded in shape, mainly spheres with some disks and blades
- Other composition includes some dry seaweed
- Beginning to look more like a natural beach

Transect 19.9 m to 22.1 m

- Composition is a combination of sand and pebbles, subrounded to well-rounded, mainly sphere and few blades
    - a lot less cobble
    - more exposed smaller boulders

Transect 22.1 m

- Composition stays consistent to shoreline

Notes: Completed 100 m ROV Trident video on bearing 45°, video "June19_12:18:18."

Trimble Point/marker: CCT3- CCT4

Central Transect

CCT3: Northing 5255781.185 Easting 339071.715

CCT4: Northing 5255805.38 Easting 339084.514

Bearing: 42° Northeast

27.8 m in length

Transect 0 m to 12.5 m 12:39 pm

- Slight upwards slope
- Very compacted from traffic
- Composition mainly cobble with some pebble, granules, and coarse sand, angular to rounded in shape, spheres with some blades and even less disk in shape
- No other composition to include

Transect 12.5 m to 21.4 m 12:50 pm

- Firepit present a few m to the northwest
- Composition is a transition of cobble and pebble dominant, to sand, and back to cobble and pebble, subrounded to rounded in shape, mainly sphere and blade with some disk and rod in shape
- Other composition includes dry seaweed, devil's purses, and some driftwood

Transect 21.4 m to 23.9 m

- Composition is pretty much all sand

Transect 23.9 m to 27.8 m 1:00 pm

- Observing a lot of sand and pebble alternating cusp features at this Level of beach continuing to shoreline
- Composition is a steady transition from small cobble/pebble to sand going seaward, subrounded to rounded in shape, blades and spheres in shape

Notes: Completed 100 m ROV Trident video on bearing 42°, video "June19_13:07:35."

Trimble Point/marker: CCT5- CCT6

West Transect

CCT5: Northing 5255859.602 Easting 339005.72

CCT6: Northing 5255868.589 Easting 339022.398

Bearing: 77° East

19.3 m in length

Transect 0 m to 3.0 m 2:01 pm

- Start point is on roadway
- Composition is roadway sand
- Other composition is weeds

Transect 3.0 m to 6.0 m

- Composition is mainly cobble, and some pebble, angular to subrounded in shape, spheres, blades and some disks in shape
- No other composition to include

Transect 6.0 m to 13.7 m

- Composition is mainly small boulders and large cobble with some pebbles, subangular to rounded in shape, sphere and blade in shape
- Other composition includes very little dry seaweed, and concrete pieces

Transect 13.7 m to 19.3 m

- Composition is a transition to dominant pebble and small cobble with few boulders popping through, generally rounded in shape, blades and sphere in shape
- Other composition includes some seaweed
- There is a large piece of concrete base structure at 14.6 m

Transect 19.3 m

- Endpoint
- To shoreline, boulders and large cobble dominate, filled by smaller clasts, subrounded to rounded in shape, sphere and blade in shape

Notes: Completed 100 m ROV Trident video on bearing 77°, video "June19_14:21:07". Picture was taken of possible algae bloom

CHAPEL COVE 17 OCTOBER 2019

Control Monument 87G4225

Northing: 5256171.865 Easting: 339044.77

Field Notes for Survey Site:

- Arrived on site at 10:15 am
- Started GCP distribution at 12:00 pm
- Upon arrival, waves were rather large and frequent
    - ROV use in such wave condition did not seem reasonable or achievable
    - Waves breaking at about 1-2 feet
- Initial Observations
    - Westside of beach seemed to have some noticeable differences compared to before
    - Eastside did not seem to have any observable differences besides the gully mouth seemed to be wider with more water flowing through
- Noticed a species of bird resembling a piper on site
- Picnic tables and garbage bins were new to site compared to last site visit, and possibly fire pits are new as well.
    - Town worker was actually removing garbage bins in a front loader (drove right onto beach)
    - Town worker claimed the bins are only there during summer months

Trimble Point/marker: CCT1- CCT2

East Transect

CCT1: Northing: 5255774.396 Easting: 339126.694

CCT2: Northing: 5255794.013 Easting: 339134.198

Bearing: NA

18.6 m in length

Transect 0 m to 15.5 m 1:33 pm

- Composition is sand to cobble (less so on cobble side), subangular to rounded in shape, blade and sphere in shape, some disk shale pieces
- Other composition includes some sort of shrubs, picture taken (0133-0134)
- At 14 m, there is a slope seaward

Transect 15.5 m to 18.6 m 1:48 pm

- Composition is large pebbles to cobbles with some larger cobble, subangular to subrounded in shape, blade and sphere in shape with some disks (shale)
- Other composition included plenty of seaweed that was damp but not fresh and wet, bird feathers, smaller driftwood

Transect 18.6 m 1:54 pm

- Composition is big pebbles to cobbles with scattered boulders and intermittent sand, subangular to subrounded in shape, blade and sphere with some disk (shale) in shape

Trimble Point/marker: CCT3- CCT4

Central Transect

CCT3: Northing: 5255781.125 Easting: 339072.102

CCT4: Northing: 5255801.766 Easting: 339082.762

Bearing: NA

23.4 m in length

Transect 0 m to 1.1 m 2:11 pm

- Composition is road gravel, pebble in size, angular in shape, sphere and blade in shape
- No other composition to include

Transect 1.1 m to 2.3 m 2:16 pm

- Area of heavy vegetation patch, clover, grass, dandelion
- Composition is granule to cobble, angular to rounded in shape, blade and sphere in shape

Transect 2.3 m to 3.5 m 2:18 pm

- Composition is cobble, subrounded in shape, blades and sphere in shape
- No other composition to include

Transect 3.5 m to 9.7 m

- Composition is sand to cobble, subangular to rounded in shape, blades and sphere in shape
- No other composition to include

Transect 9.7 m to 12.9 m 2:23 pm

- Composition is granule to cobble (heavier on the cobble), subangular to well-rounded in shape, blade and sphere in shape (few potential rods)
- Other composition includes a picnic table and fire pit area

Transect 12.9 m to 14.7 m

- Slope seawards
- Composition is granule to cobble (heavier on the cobble), subangular to well-rounded in shape, blade and sphere in shape (few potential rods)

Transect 14.7 m to 17.6 m 2:28 pm

- Same green vegetation as before (sparse)
- Composition is sand with pieces of pebble/cobble, subrounded in shape, sphere and blade in shape
- Other composition includes dry and soft seaweed and mystery white honeycomb/cone item

Transect 17.6 m to 23.4 m 2:33

- Composition is pebbles with few cobbles, subrounded to rounded in shape, mainly sphere with blades
- Other composition includes very wet seaweed, nearly fully intact dead crabs and crab pieces (seemed to be entangled in seaweed), and some driftwood

Transect 23.4 m 2:40 pm

- Waves and lowering tide exposed cobble and then sand

Trimble Point/marker: CCT5- CCT6

West Transect

CCT5: Northing: 5255859.522 Easting: 339005.706

CCT6: Northing: 5255861.279 Easting: 339023.374

Bearing: NA

17.5 m in length

Transect 0 m to 3.2 m 2:51 pm

- Composition is road gravel (granule to pebble), angular in shape
- Other composition includes vegetation growing on-road gravel (grass, dandelion, other weeds, and thistle?)

Transect 3.2 m to 5.6 m

- Composition is pebble to large cobble, subangular to subrounded in shape, sphere and blades in shape (maybe some rods and disk)
- Other composition includes sparse vegetation (dandelion or maybe thistle?)

Transect 5.6 m to 11.9 m 2:51 pm

- Composition is boulders and larger cobble infilled by smaller material (cobble/pebble), angular to subrounded in shape, sphere and blade in shape (maybe some rods and disk but very sparse)
- Other composition includes sparse vegetation (dandelion or maybe thistle?)

Transect 11.9 m to 17.5 m 3:01 pm

- Composition is boulders and larger cobble with intermittent granule/pebble/small cobble patches, subangular to rounded in shape, sphere and blade in shape
- Other composition includes tiny amounts of soft seaweed and devil's purses

Transect 17.5 m

- Sand with scattered boulders to shoreline

Harbour Main:

HARBOUR MAIN 27 June 2019

Control Monument 87G4221

Northing: 5255920.443 Easting: 337203.243

Field Notes for Survey Site:

- Harbour Main has two gravelly beaches, both small
- GCP's are HM1-HM13
- Heavy anthropogenic influence
  - Swimming hole, rock walls, docking area, road on ocean (concrete wall)
- UAV take-off time: 10:35 am flying at 40 m

Trimble Point/marker: HMT1- HMT2

East Transect

HMT1: Northing: 5255432.329 Easting: 337250.807

HMT2: Northing: 5255442.971 Easting: 337250.861

Bearing: 43° NE

11.1 m in length

Transect 0 m to 0.4 m 12:35 pm

- Start point, landwards
- Composition is entirely vegetation such as weeds

Transect 0.4 m to 4.1 m

- Combination of rocks and vegetation
- Composition is cobble and pebble, subrounded to rounded in shape, a bit of everything (disk, rod, sphere, blade)
- Other composition includes some dry seaweed, much garbage, pine cones, driftwood (processed and unprocessed)
- At 3.3 m, there looks to be a rundown, smaller boulder barrier (landscaping, function?)

Transect 4.1 m to 8.0 m

- Composition is pebble with cobble and some granule and sand, many disks, rods, and blades in shape, subrounded to well-rounded in shape
- Other composition includes much dry seaweed, garbage and shellfish remains

Transect 8.0 m to 11.1 m

- Composition is cobble with small amounts of pebble, subrounded to well-rounded in shape, sphere and blade in shape.
- Other composition includes a little seaweed and some shellfish remains

Notes: ROV survey attempted at 1:03 pm, but seaweed was too thick to get through, propellers kept getting blocked up (Video # June27_13:02:49). Wave incident angle was 16°

Trimble Point/marker: HMT3- HMT4

Central Transect

HMT3: Northing: 5255437.419 Easting: 337207.477

HMT4: Northing: 5255449.11 Easting: 337212.199

Bearing: 38° NE

13.0 m in length

Note: Start point is at boardwalk, but beach rock does continue under it with personal property starting on the other side of boardwalk

Transect 0 m to 2.8 m 1:17 pm

- Start point at boardwalk
- Composition is even amount of cobble and pebble, rounded to well-rounded in shape, mainly blade and sphere in shape
- Other composition includes driftwood, dry seaweed, some vegetation and weeds

Transect 2.8 m to 6.5 m

- Berm
- Smaller boulder barrier still exists like the last transect, but here it is more covered than other transect
- Composition is mainly pebble, rounded to well-rounded in shape, blade and sphere in shape with a few rods
- Other composition includes garbage, dry seaweed, and driftwood

Transect 6.5 m to 9.5 m

- Start of another berm
- Boulder barrier no longer present
- Composition is the same as above but larger pebbles and smaller cobble
- Other composition includes shellfish remains and dry seaweed

Transect 9.5 m to 13.0 m 1:33 pm

- Start of another berm
- Tiny spiders
- Composition is pebble and small cobble dominant with little granule, rounded to well-rounded in shape, blade and sphere in shape
- Other composition includes lots of dry seaweed, and shellfish remains (crab)

Note: No ROV attempts made, seaweed thicker than last transect

Trimble Point/marker: HMT5- HMT6

West Transect

HMT5: Northing: 5255472.727 Easting: 337109.149

HMT6: Northing: 5255484.949 Easting: 337126.311

Bearing: 68° E

21.4 m in length

Note: Waves mainly at 20° angle but a very refractive area of beach. This area includes a stream entrance, concrete wall and larger rock wall. The larger rock wall is more organized and in better condition than the previous smaller boulder barrier. This larger rock wall is only between this transect and the last hmt3-hmt4. See aerial photos for differences.

Transect 0 m to 12.6 m

- Starting point at stream edge
- Bulldozed flat for human use/recreation. Area flattened for swimming hole and picnic area
- Composition is mainly pebble, some granule, and few cobble, sphere and rod in shape, rounded in shape
- No other composition to include

Transect 12.6 m to 17.3 m

- Composition is same as above but with some slightly exposed boulders (part of rock wall? Damaged? Purposefully placed?
- No other composition to include

Transect 17.3 m to 21.4 m

- Gravel covered rock wall? Damaged
- Composition is similar as above but with smaller pebbles and disk-shaped than before
- Other composition includes little dry seaweed

Note: ROV survey complete with some difficulty, 100 m done on a bearing of approx. 65°. Video # June27_14:09:19

Trimble Point/marker: HMT7- HMT8

Northwest Pocket Transect

HMT7: Northing: 5255616.984 Easting: 337112.774

HMT8: Northing: 5255626.575 Easting: 337125.441

Bearing: 66° ENE

16.3 m in length

Note: Transect is in the side beach area next to main beach

Transect 0 m to 4.3 m

- Start point next to main road
- Composition is town grass

Transect 4.3 m to 5.9 m

- Composition is placed gravel for grass to grow but left exposed

Transect 5.9 m to 6.3 m

- Small boulder wall to hold back the roadway gravel (asphalt in wall)

Transect 6.3 m to 8.9 m

- Composition is mostly large pebble, few cobble, and granule, subrounded to rounded in shape, sphere and blade in shape with some disk and rods
- Other composition includes shells (crab, mussel, sea urchins, periwinkles), driftwood, dry seaweed, leaf litter, and pine cones

Transect 8.9 m to 12 m

- Berm
- Composition is similar to last stretch with possibly more granule, and smaller pebbles
- Other composition includes fewer organics than above stretch

Transect 12 m to 12.7 m

- Composition is very small pebbles, ranging in shape (sphere, disk, rod, blade) subrounded to well-rounded in shape

Transect 12.7 m to 16.3 m

- Composition is cobbles and large pebbles, subrounded to rounded in shape, sphere and blade in shape
- Other composition includes lots of dry seaweed and lots of crab shells

Note: ROV attempt was made at 3:05 pm, but there was too much seaweed

General Notes:

Secondary beach next to main beach changes drastically to large boulders and concrete waste (parallel to shoreline). This is likely to prevent further erosion towards road. There is also a small stream in this area.There is also a wooden wall, rock breakwater, and rock wall to protect boat launch. All of this is on northeast side of the cove.

HARBOUR MAIN 12 November 2019

Control Monument 87G4221

Northing: 5255920.443 Easting: 337203.243

Field Notes for Survey Site:

- Arrived on site at 10:10 am. Had to stop to see Shelly at the Marine Institute Holyrood Station to get the RTK equipment
- Upon arrival, it was sunny with much glare on the water. There was hardly any wind but fairly large gusts every so often
- Site potentially has less garbage than last time, maybe more seaweed
- Handheld GPS would be useful in the future to guide back to previous GCP's and transects used before

Trimble Point/marker: HMT1- HMT2

East Transect

HMT1: Northing: 5255435.242 Easting: 337252.006

HMT2: Northing: 5255444.554 Easting: 337251.235

Bearing: 12° N

9.6 m in length

Transect 0 m to 0.2 m 12:23 pm

- Composition is pebbles with some cobble, subrounded to rounded in shape, blade and sphere in shape
- Other composition includes lots of vegetation (grass and weeds?), and seaweed mixed into area

Transect 0.2 m to 4.0 m 12:26 pm

- One big boulder, part of a semi consumed boulder barrier at the start of this area
- Composition is pebble (more so) and cobble, subrounded to well-rounded in shape, blade in shape with some sphere and disk
- Other composition includes lots of seaweed. Some seaweed had 1-inch diameter stipe that looked to be ripped from ground/sediment. Possibly from a kelp bed?

Transect 4.0 m to 5.0 m 12:33 pm

- Composition is a sand matrix with cobble and pebbles, subrounded to rounded in shape, blade and sphere in shape
- Other composition includes little seaweed

Transect 5.0 m to 6.9 m 12:36 pm

- Composition is a thin matrix of pebble covering sand with some sporadic cobble, rounded in shape, sphere and blade in shape with a few rods
- No other composition to include

Transect 6.9 m to 9.6 m 12:40 pm

- Composition is the same as above, just an increase in amount of cobble
- Other composition includes a bit of seaweed

Transect 9.6 m

- Sand and seaweed to the shoreline

Note: No waves to tell incident angle but looks to be pretty well parallel to shore. There were ducks feeding between this transect and the next.

Trimble Point/marker: HMT3- HMT4

Central Transect

HMT3: Northing: 5255437.467 Easting: 337207.796

HMT4: Northing: 5255449.317 Easting: 337212.885

Bearing: 47° NE

13.1 m in length

Transect 0 m to 3.3 m 12:28 pm

- Start point is at wooden boardwalk
- Composition is well mixed between cobble and pebble, subrounded to well-rounded in shape, mostly blade in shape with some spheres, disks, and rods
- Other composition includes organic debris (plant and animal), seaweed is relatively dry but not crunchy, also garbage
- Berm crest is at 2.3 m

Transect 3.3 m to 5.4 m 12:59 pm

- Continued presence of boulder barrier from last transect which is taken over by below composition
- Composition is mainly pebble with a few small cobbles, rounded to well-rounded in shape, blade in shape with some rods and spheres
- Other composition includes plenty of seaweed with garbage mixed in

Transect 5.4 m to 6.6 m 1:04 pm

- Composition is mainly pebble with a few small cobbles, rounded to well-rounded in shape, blade in shape with some rods and spheres
- Other composition includes lots of seaweed
- Berm crest is at 6.2 m

Transect 6.6 m to 9.4 m

- Composition is pebbles, subrounded to well-rounded in shape, all shapes but mainly blade and sphere
- Other composition includes lots of seaweed
- Small berm crest at 8.1 m

Transect 9.4 m to 13.1 m

- Composition is a range of granule to cobble, subangular to rounded in shape, mainly sphere and blade in shape
- Other composition includes plenty of seaweed

Transect 13.1 m

- To shoreline is same as above

Note: Hardly any waves to tell incident angle but looks like it would be parallel to shoreline. There were multiple ducks feeding

Trimble Point/marker: HMT5- HMT6

West Transect

HMT5: Northing: 5255467.055 Easting: 337106.951

HMT6: Northing: 5255491.8 Easting: 337126.988

Bearing: 50° NE

32.2 m in length

Transect 0 m to 19.7 m

- Start point at stream
- Composition is granule to cobble, subrounded to well-rounded in shape, all shapes but mainly blade and sphere in shape
- Other composition includes bits of seaweed all over, twigs, feathers, and garbage

Transect 19.7 m to 21.1 m 1:25 pm

- Composition is sand matrix with everything up to small cobble, rounded to well-rounded in shape, all shapes but mainly blade and sphere in shape
- Other composition includes some seaweed

Transect 21.1 m to 23.5 m 1:31 pm

- Boulder wall (NW side of wall more eroded)
- Composition in between boulder wall is filled with same as above
- No other composition to include

Transect 23.5 m to 25.5 m 1:34 pm

- Composition is granule/pebble with few cobbles, rounded to well-rounded in shape, sphere and blade in shape
- No other composition to include

Transect 25.5 m to 29.7 m

- Composition is pebbles with cobble, rounded to well-rounded in shape, blade and sphere in shape with a few rods and disk
- Other composition includes old bags sticking out of gravel?

Transect 29.7 m to 32.2 m

- Composition is granule/pebble with very few cobbles to small boulder, well rounded in shape, sphere and blade in shape with very few rods
- Other composition includes seaweed

Notes: No waves at all, so cannot tell wave incident angle. Stream entering ocean at this transect site

Trimble Point/marker: HMT7- HMT8

Northwest Pocket Transect

HMT7: Northing: 5255615.19 Easting: 337111.767

HMT8: Northing: 5255626.439 Easting: 337126.615

Bearing: 68° ENE

18.9 m in length

Transect 0 m to 0.9 m 3:47 pm

- Composition is road gravel
- No other composition to include

Transect 0.9 m to 6.4 m

- Composition is grass
- No other composition to include

Transect 6.4 m to 7.7 m 3:52 pm

- Area of dirt gravel?
- Topsoil is covered in grade A gravel?
- Composition of gravel is pebble/granule size and very angular in shape

Transect 7.7 m to 8.1 m

- Small boulder wall infilled by the same composition as above

Transect 8.1 m to 11 m

- Composition is cobble and pebble, subrounded to rounded in shape, blade and sphere in shape with quite a few rods and disks
- Other composition includes lots of organic litter (leaves, twigs, shells, seaweed)

Transect 11 m to 12.9 m 4:00 pm

- Berm crest
- Composition is granule dominant with pebble and cobble, subrounded to rounded in shape, blade and sphere in shape with a few disks and rods
- Other composition includes seaweed, periwinkle shells and leaves

Transect 12.9 m to 14 m

- Composition is pebble, subrounded to rounded in shape, sphere and blade in shape
- Other composition includes seaweed

Transect 14.8 m to 18.9 m

- Composition is granule with pebbles, subrounded to rounded in shape, sphere and blade in shape
- Other composition includes very little seaweed

Transect 18.9 m

- To shoreline, composition transitions into cobble, rounded in shape, blade and sphere in shape

Notes: No waves at all, so cannot tell wave incident angle.

Appendix C: Orthomosaics

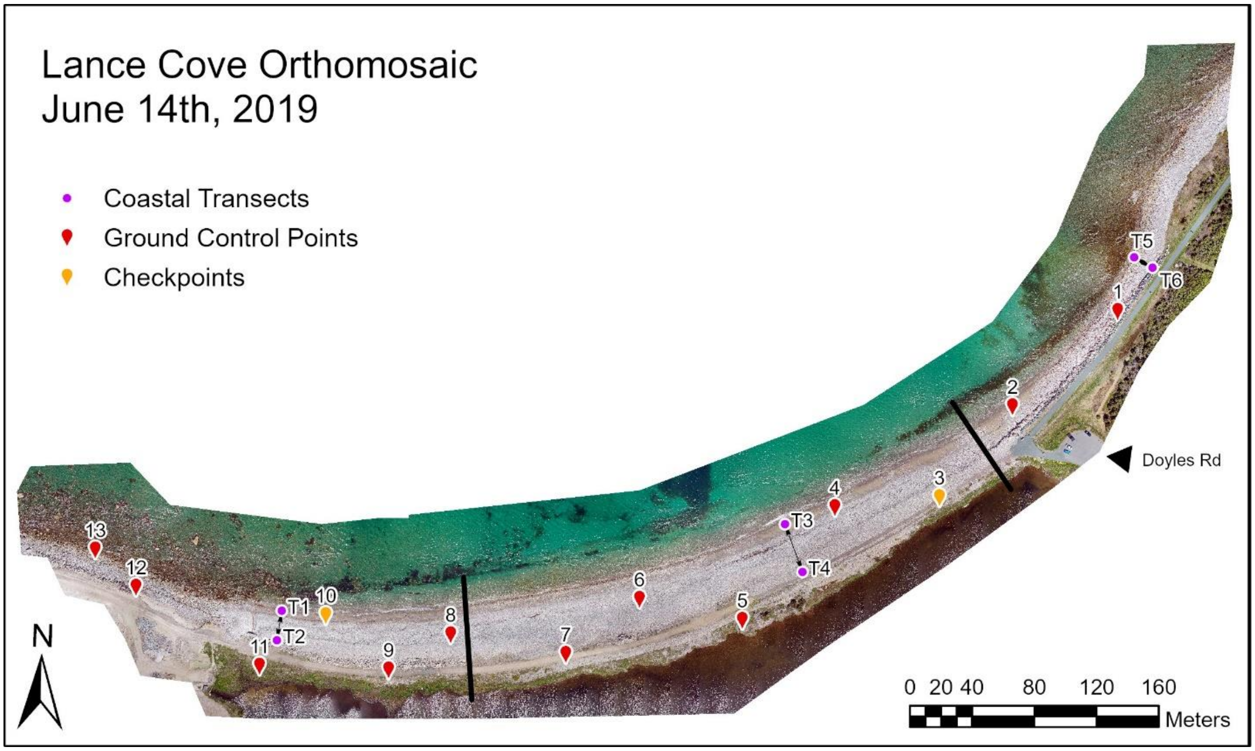

Plate 1: Lance Cove orthomosaic for 14 June 2019

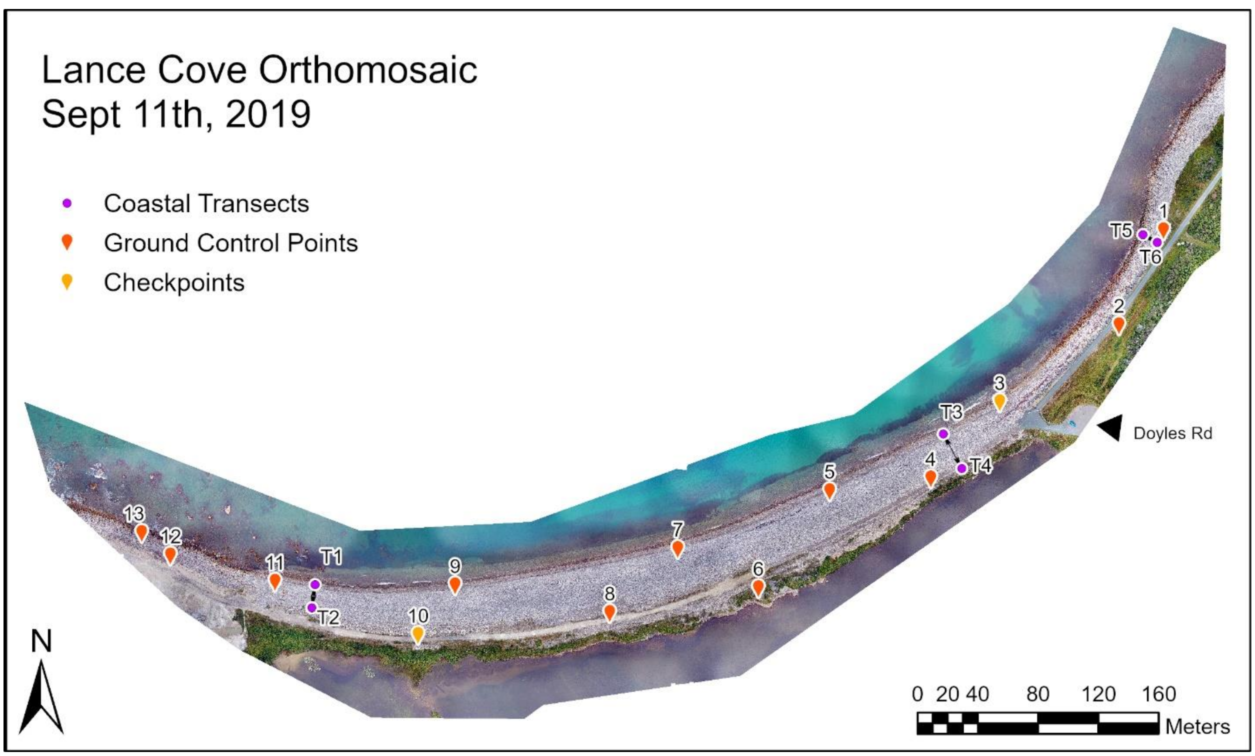

Plate 2: Lance Cove orthomosaic for 11 September 2019

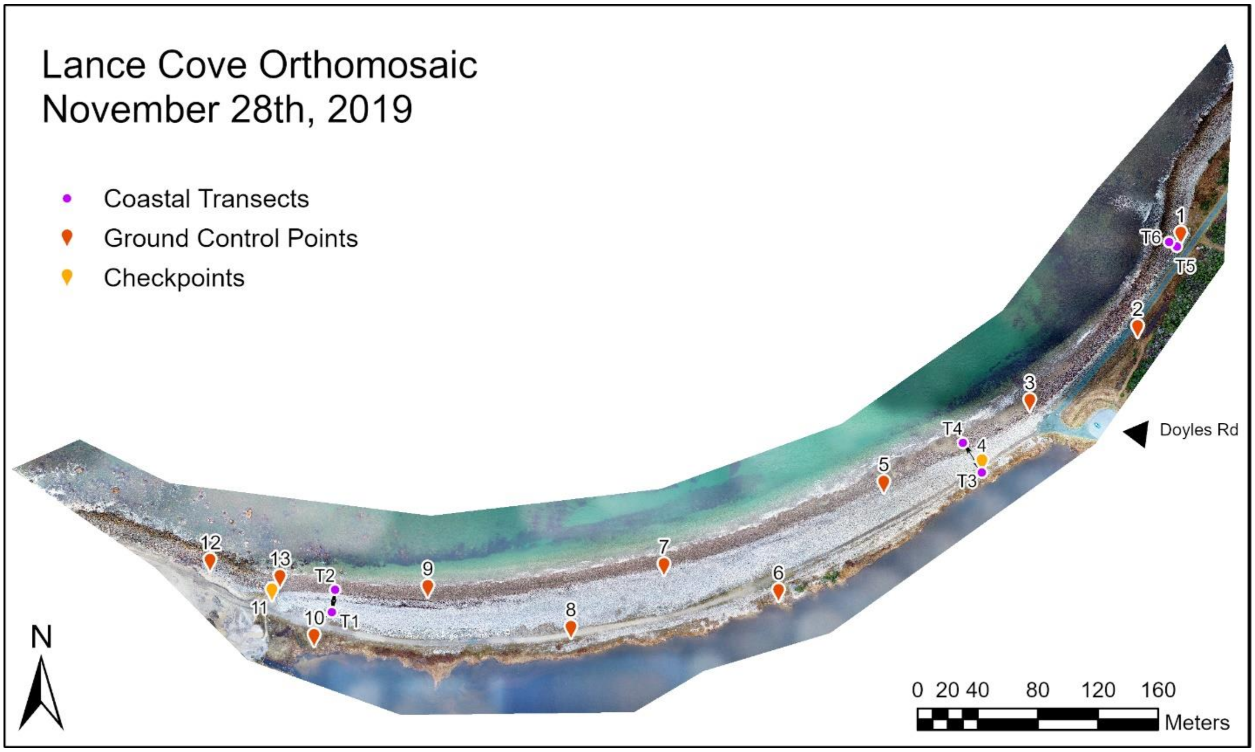

Plate 3: Lance Cove orthomosaic for 28 November 2019

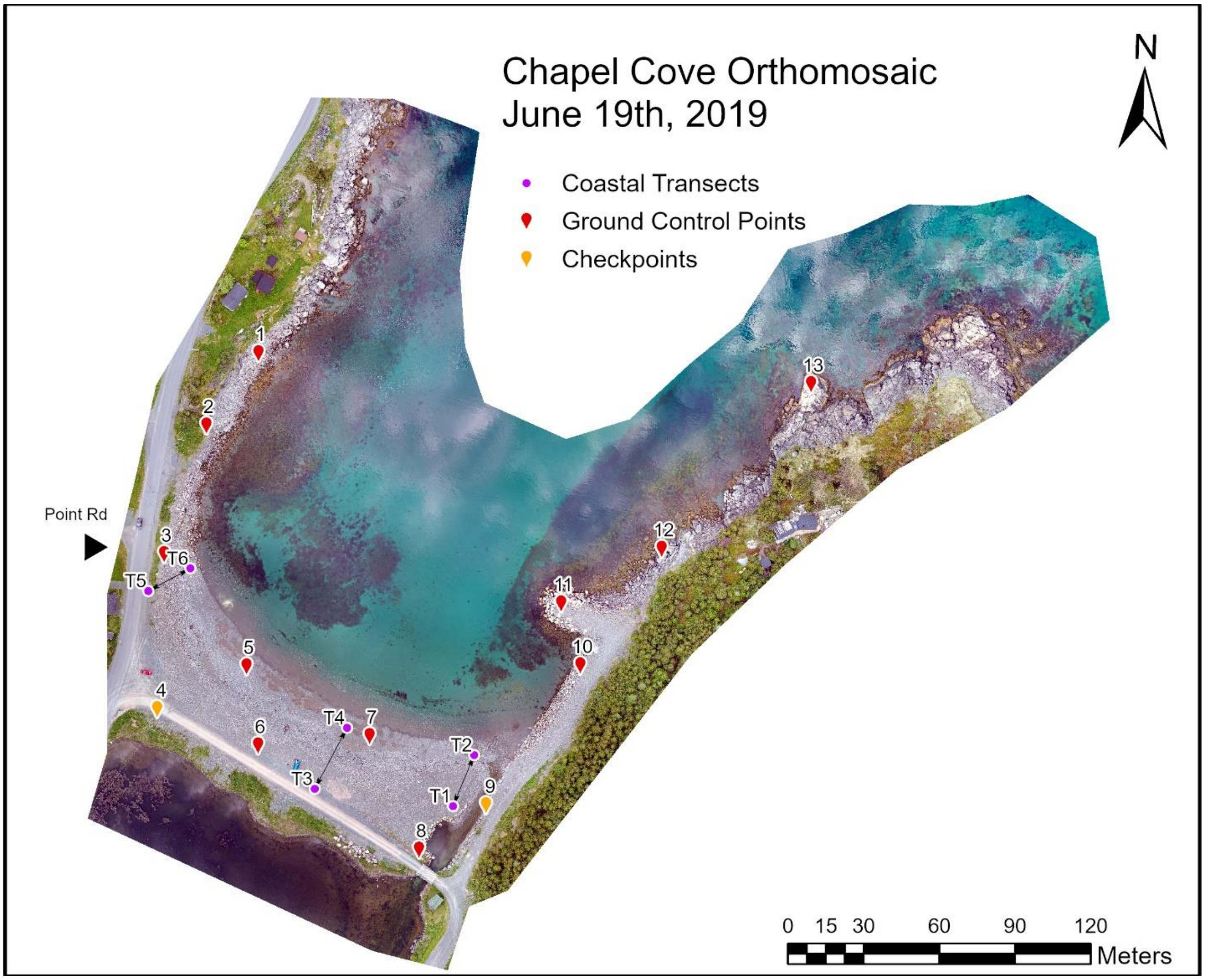

Plate 4: Chapel Cove orthomosaic for 19 June 2019

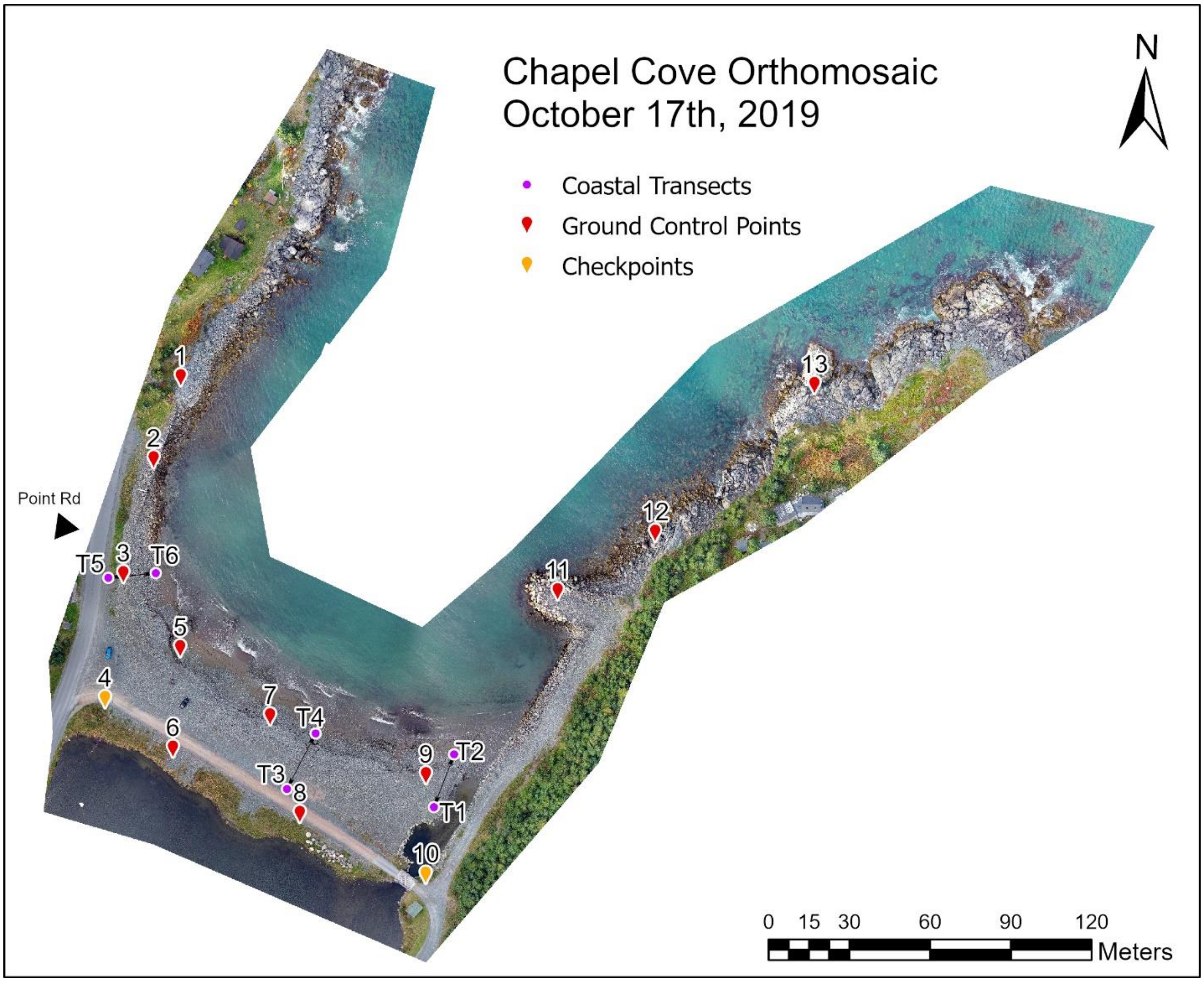

Plate 5: Chapel Cove orthomosaic for 17 October 2019

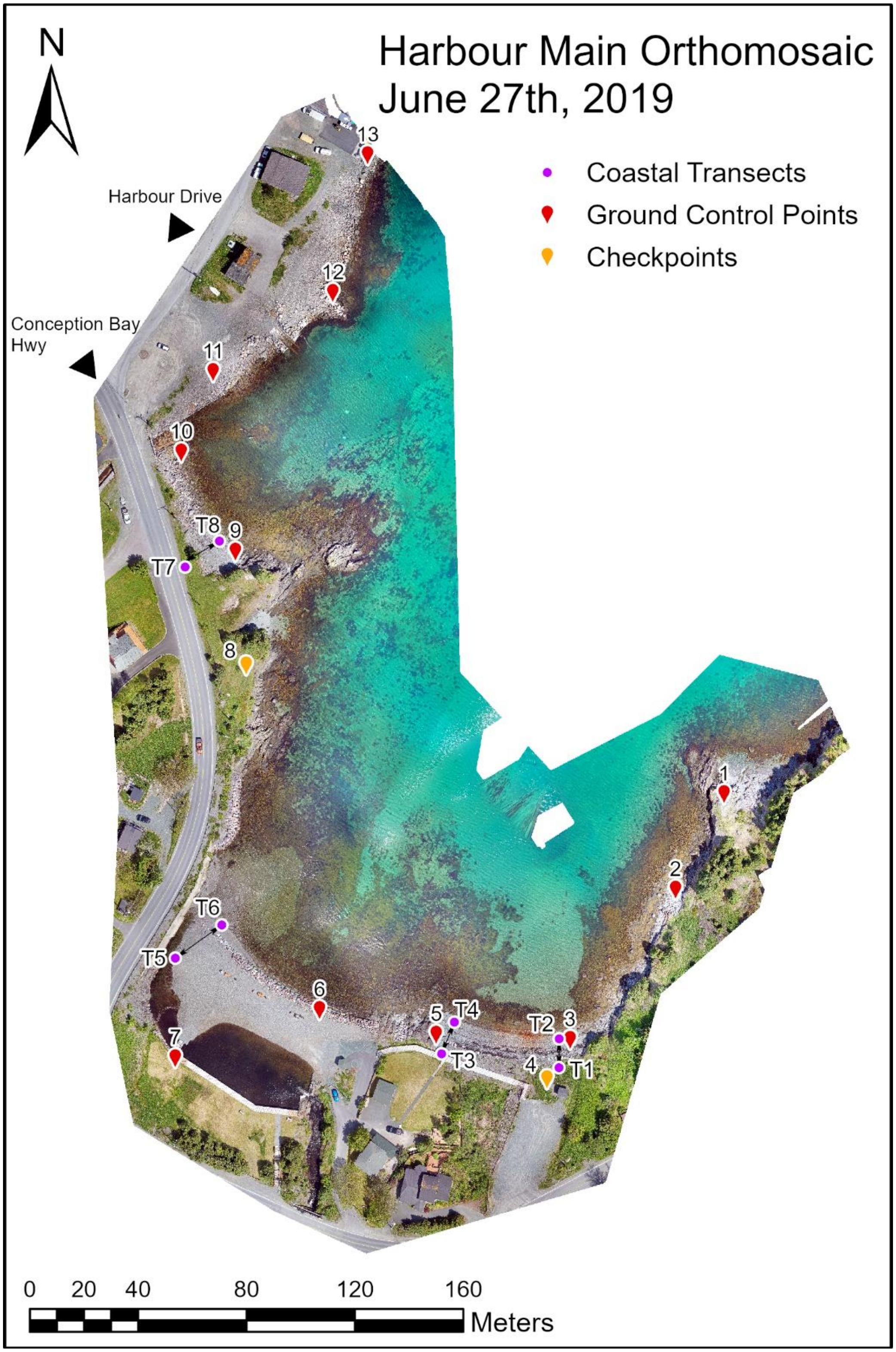

Plate 6: Harbour Main orthomosaic for 27 June 2019

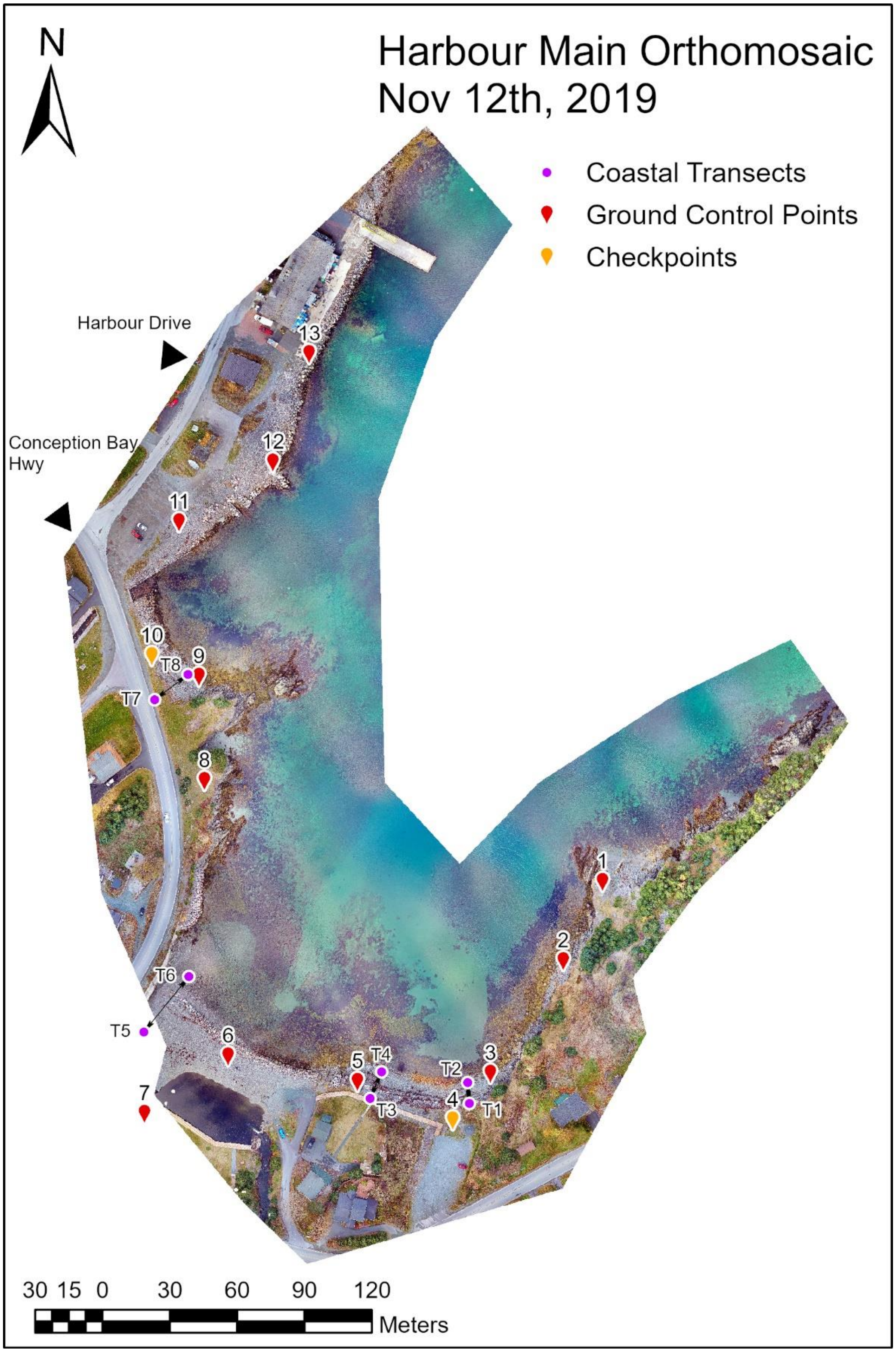

Plate 7: Harbour Main orthomosaic for 12 November 2019

Appendix D: Digital Surface Model Errors

Lance Cove: 14 June 2019				
Checkpoint	Error (cm)			
GCP #	X	Y	Z	Total
lc3	4.62455	5.18839	0.42979	6.96351
lc10	0.980344	-10.5658	3.24136	11.0952
Lance Cove: 11 September 2019				
2lc3	2.78956	-6.78663	3.71508	8.22447
2lc10	-0.863978	12.1967	-7.64397	14.42
Lance Cove: 28 November 2019				
4lc4	4.11545	3.97446	9.73115	11.2884
4lc11	-1.35802	-1.00336	6.37675	6.59651
Chapel Cove: 19 June 2019				
cc4	-6.92421	26.4065	-10.1694	29.1319
cc9	15.2069	-0.569913	14.5138	21.0291
Chapel Cove: 17 October 2019				
2cc4	-4.93846	10.0669	-0.334281	11.2179
2cc10	30.9904	-10.2582	10.51	34.2943
Harbour Main: 27 June 2019				
hm3	-1.49377	-2.674	-0.667975	3.13493
hm10	1.54964	4.38394	1.1227	4.78338
Harbour Main: 12 November 2019				
N/A	N/A	N/A	N/A	N/A

Appendix E: Parameter Scoring Legend and Associated References

Proximity to Ideal Capelin Spawning Habitat				Likelihood of Coastal Stability			
Para-meter	**Alternatives**	**Value**	**Model developed from**	**Para-meter**	**Alternatives**	**Value**	**Model developed from**
A	Landward	1	Murphy et al., (2018); Nakashima & Taggart, (2002)	**A'**	Seaward	1	Catto (2012); Davidson-Arnott (2010)
	Parallel	0.5			Landward	0	
	Seaward	0					
B	Long open beach face	0.5	In comparison to Bellevue beach, a heavily studied "ideal" beach	**B'**	Sheltered from the open ocean	1	Catto (2012); Davidson-Arnott (2010)
	A long beach protected by small headlands	1			Partially Sheltered	0.66	
	A short beach protected by small headlands	0.5			Open to the ocean but not dominant storm direction	0.33	
	A short beach protected by deep headlands	0			Exposed to dominant storm direction	0	
C	Boulder/ Bedrock	0	Nakashima & Taggart (2002)	**C'**	Boulder/ Bedrock	1	Catto (2012); Davidson-Arnott (2010)
	Cobble/ Boulder	0.25			Mixed pebble-cobble	0.66	
	Pebble/ Cobble	0.5			Mixed sand-granule-pebble	0.33	
	Granules/ pebbles	0.75			Fine Sand/ Organics	0	
	Coarse Sand/ Granules	1					
	Fine Sand/ Organics	0					

D	Steep Grade (>20 °)	0	Catto (2012); Nakashima & Taggart (2002)	**D'**	Steep Grade (>20°)	0	Catto (2012); Davidson-Arnott (2010)
	Mild grade (10-20°)	0.5			Mild grade (10-20°)	0.33	
	Low grade (1-10°)	1			Low grade (1-10°)	0.66	
	Near flat (<1°)	0.5			Near flat (<1°)	1	
E	Mechanical/structure Influence	0		**D'**	Mechanical/structure Influence	0	
	Non-Mechanical usage	0.5			Non-Mechanical usage	0.5	
	Little to no influence	1			Little to no influence	1	
A = Wind/Beach orientation during spawning season				**A' = Wind/Beach orientation during storm season**			
B = Level of protection				**B' = Level of protection**			
C = Grain Size				**C' = Grain Size**			
D = Slope (intertidal zone)				**D' = Slope**			
E = Anthropogenic Footprint on the intertidal zone				**E' = Anthropogenic Footprint**			

Appendix F: Final Weighted Scores for Sites External to this Study

Bellevue							
Similarity to Ideal Capelin Spawning Habitat				**Likelihood of Coastal Stability**			
Factor	Factor Score	Weight/Factor	Weighted Score	**Factor**	Factor Score	Weight/Factor	Weighted Score
A	0.00	0.26	0.00	**A'**	0.00	0.20	0.00
B	1.00	0.18	0.18	**B'**	1.00	0.17	0.17
C	1.00	0.23	0.23	**C'**	0.33	0.19	0.06
D	1.00	0.21	0.21	**D'**	0.66	0.22	0.15
E	1.00	0.12	0.12	**E'**	0.50	0.22	0.11
		Total:	**0.74**			**Total:**	**0.49**

Middle Cove							
Similarity to Ideal Capelin Spawning Habitat				**Likelihood of Coastal Stability**			
Factor	Factor Score	Weight/Factor	Weighted Score	**Factor**	Factor Score	Weight/Factor	Weighted Score
A	0.00	0.26	0.00	**A'**	0.00	0.20	0.00
B	0.50	0.18	0.09	**B'**	0.00	0.17	0.00
C	0.75	0.23	0.17	**C'**	0.33	0.19	0.06
D	1.00	0.21	0.21	**D'**	0.00	0.22	0.00
E	0.50	0.12	0.06	**E'**	0.50	0.22	0.11
		Total:	**0.53**			**Total:**	**0.17**

Cape Spear							
Similarity to Ideal Capelin Spawning Habitat				**Likelihood of Coastal Stability**			
Factor	Factor Score	Weight/Factor	Weighted Score	**Factor**	Factor Score	Weight/Factor	Weighted Score
A	0.00	0.26	0.00	**A'**	0.00	0.20	0.00
B	0.00	0.18	0.00	**B'**	0.00	0.17	0.00
C	0.00	0.23	0.00	**C'**	1.00	0.19	0.19
D	0.00	0.20	0.00	**D'**	0.00	0.22	0.00
E	1.00	0.129	0.12	**E'**	1.00	0.22	0.22
		Total:	**0.12**			**Total:**	**0.41**

St. John's Harbour							
Similarity to Ideal Capelin Spawning Habitat				**Likelihood of Coastal Stability**			
Factor	Factor Score	Weight/Factor	Weighted Score	**Factor**	Factor Score	Weight/Factor	Weighted Score
A	0.00	0.26	0.00	**A'**	0.00	0.20	0.00
B	0.00	0.18	0.00	**B'**	1.00	0.17	0.17
C	0.00	0.23	0.00	**C'**	1.00	0.19	0.19
D	0.00	0.20	0.00	**D'**	0.00	0.22	0.00
E	0.00	0.129	0.00	**E'**	0.00	0.22	0.00
		Total:	**0.00**			**Total:**	**0.36**

Ship Cove (Pre-enhancement)							
Similarity to Ideal Capelin Spawning Habitat				**Likelihood of Coastal Stability**			
Factor	Factor Score	Weight/Factor	Weighted Score	**Factor**	Factor Score	Weight/Factor	Weighted Score
A	0.00	0.26	0.13	**A'**	0.00	0.20	0.20
B	0.00	0.18	0.09	**B'**	1.00	0.17	0.11
C	0.00	0.23	0.12	**C'**	1.00	0.19	0.13
D	0.00	0.21	0.11	**D'**	0.00	0.22	0.07
E	0.00	0.12	0.00	**E'**	0.00	0.22	0.11
		Total:	**0.44**			**Total:**	**0.62**

Ship Cove (Post-enhancement)							
Similarity to Ideal Capelin Spawning Habitat				**Likelihood of Coastal Stability**			
Factor	Factor Score	Weight/Factor	Weighted Score	**Factor**	Factor Score	Weight/Factor	Weighted Score
A	0.00	0.26	0.13	**A'**	0.00	0.20	0.20
B	0.00	0.18	0.09	**B'**	1.00	0.17	0.11
C	0.00	0.23	0.23	**C'**	1.00	0.19	0.06
D	0.00	0.21	0.21	**D'**	0.00	0.22	0.15
E	0.00	0.12	0.12	**E'**	0.00	0.22	0.22
		Total:	**0.78**			**Total:**	**0.74**

A = Wind/Beach orientation during spawning season	**A' = Wind/Beach orientation during storm season**
B = Level of protection	**B' = Level of protection**
C = Grain Size	**C' = Grain Size**
D = Slope (intertidal zone)	**D' = Slope**
E = Anthropogenic Footprint on the intertidal zone	**E' = Anthropogenic Footprint**