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CRD Pilot
Harbours Ecological Inventory

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Contents

1 Background

The Capital Regional District (CRD) identified the need to update the ecological inventory and classification of the shoreline of the Esquimalt and Victoria Harbours and sponsored a project to conduct a pilot study to evaluate a variety of methodologies to collect new spatial data.

The original survey information was collected in 1997, when the Victoria and Esquimalt Harbours Environmental Action Program (VEHEAP) began the Harbours Ecological Inventory and Rating (HEIR) program (HEIR 1997). An inventory of backshore, intertidal, and subtidal biological and physical features was undertaken using ground and boat-based field surveys throughout the five harbour areas (Victoria Harbour, the Gorge Waterway, Portage Inlet, Esquimalt Harbour and Esquimalt Lagoon).

Observations included data from terrestrial land-use planners and terrestrial ecologists for the backshore areas. Intertidal zone features were observed from boat-based surveys and data were compiled within the framework of the existing BC ShoreZone mapping that had been completed by the Province of BC a few years prior (BC ShoreZone 2019). Subtidal areas were surveyed by underwater towed video, which was then reviewed to classify and map biophysical features. Key sites identified during the review of the video were checked by divers to confirm the classifications.

Inventory data were collected to help inform a process for assigning an ecological rating to shoreline segments. Criteria for ratings were developed and included a score for ecological value, vulnerability to development and priority for action. The rating system was applied to each individual shoreline segment within all five harbour areas for the backshore and intertidal zone. The VEHEAP and HEIR datasets were subsequently integrated into the CRD Harbour Atlas and later made available for viewing as layers within the online CRD Regional Community Atlas.

The objectives of the new pilot project were to:

1. Assess the suitability of three types of remote sensing imagery for inventory, mapping and classification of the biophysical features of the five harbour areas and to recommend the best option to use across the whole study area.
2. Identify suitable biophysical features and attributes to use for the update of the ecological inventory of the backshore, intertidal and shallow subtidal zones to be included in the new inventory.
3. Test a supervised classification of imagery to assess application to the whole study area.
4. Ensure that new inventory is comparable to and compatible with the original HEIR dataset.
5. Conduct a user/stakeholder workshop to poll user needs for the new inventory and mapping attributes.

6. Provide scoping outline of tasks required to complete new ecological inventory and classification of spatial data for the whole Harbours study area[1].

[1] Draft scope of work presented to client along with this draft final report as a stand-alone report.

2 Methods

2.1 Pilot study sites

Six locations were selected for the pilot project, chosen to represent a cross-section of intertidal shoreline types and ecological ratings as well as geographic extent of the study area (Table 1 and Figure 1).

Table 1. Pilot study site locations, showing HEIR habitat types, ecological ratings, and key indicators (with input from HEIR 1997).

Harbour Area	Location (length of HEIR shore unit)	Intertidal Shoreline HEIR Habitat Type	HEIR Ecological Value Rating	Key Subtidal Indicator	2019 Ground Survey Date
Victoria Harbour	Coast Harbourside (257 m)	• Pilings and wharves • Sea wall • Rip rap	Very Low	n/a	July 4, 2019
	Rose Bay (151 m)	• Sand and gravel pocket beach • Bedrock	Medium	Bladed kelp	August 28, 2019
Esquimalt Harbour	Inside of Smart Island (248 m)	• Bedrock • Pocket beach (mixed rock/sediment) • Tidal flat	High	n/a	August 29, 2019
Esquimalt Lagoon	Esquimalt Lagoon (177 m)	• Mud/sand flats	Very high	Eelgrass	July 3, 2019
Portage Inlet	Portage Inlet Linear Park (892 m)	• Beach • Riprap	Low	Eelgrass	July 19, 2019
The Gorge	The Gorge Park (168 m)	• Bedrock • Beach (mixed rock/sediment) • Sea wall	Medium	Eelgrass	July 5, 2019

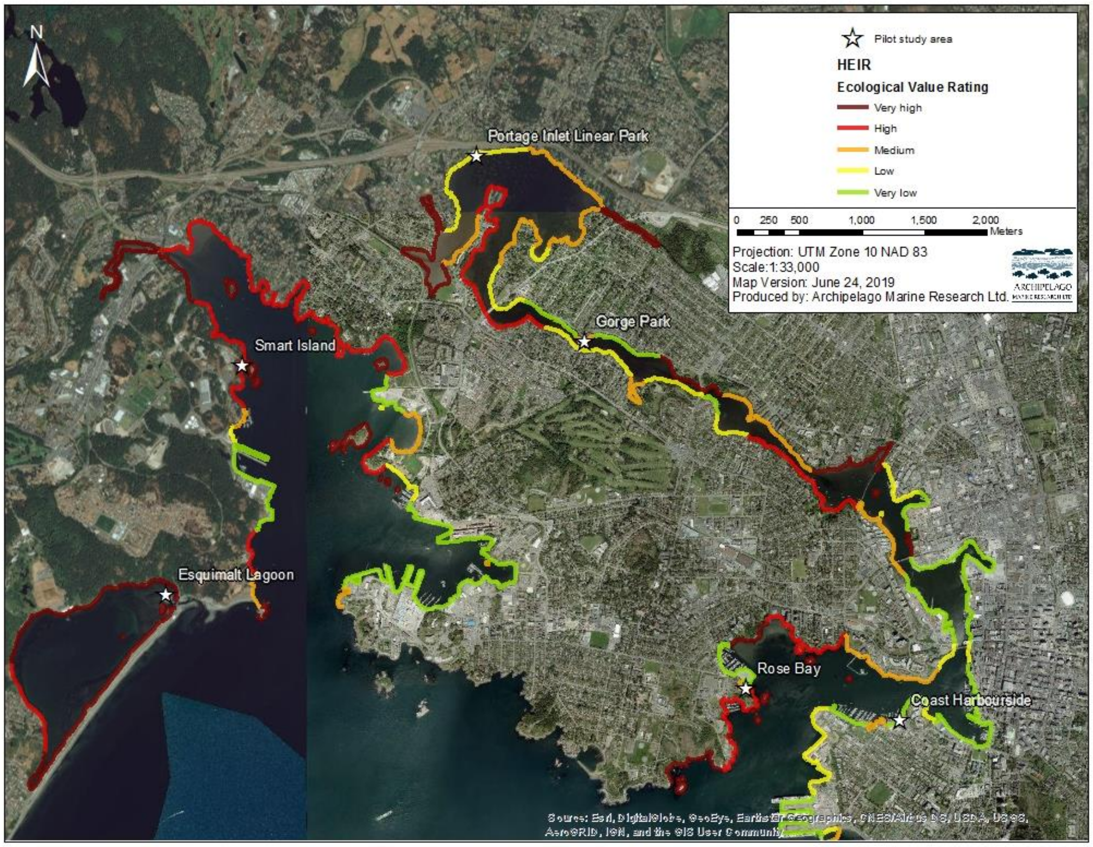


Figure 1. Pilot study site locations. Shoreline mapping shows the Ecological Value Rating from HEIR (1997).

2.2 Remote sensing imagery types

Three different remotely sensed imagery types were collected for the pilot study, to assess which method (or combination of methods) was best suited to provide accurate, economically efficient and easily repeatable data collection of inventory and mapping information in the Harbours region. Details for each of the three aerial imagery types which include Unmanned Aerial Vehicle (UAV) imagery, orthophoto imagery and satellite imagery are shown in Table 2. All imagery was acquired by McElhanney and provided to Archipelago.

<u>Drone Survey Permits and Logistics</u>

All pilot study sites were within the Victoria Harbour aerodrome-controlled air space and required permission from NavCanada. All UAV pilots flying in controlled air space are required to be certified as Transport Canada advanced pilots. UAV pilots are unable to fly when air traffic is in the vicinity and UAVs must always remain within the line of sight.

Site access for the UAV survey was variable. Rose Bay and Smart Island are on Department of National Defense (DND) property and required approval from the Base Operations Officer and commissionaire escort during the flights. All other sites were readily accessible to the public.

Table 2. Remote sensing imagery used in the CRD Pilot Study

Imagery Type	Resolution	Imagery Date	# of Bands	Bands	Note
Pléiades Multispectral, [2] High-spatial resolution Satellite	50 cm/ 2m	July 25, 2018 and April 20, 2019[3]	4	• Red • Green • Blue • Near Infrared	The derived Normalized Difference Vegetation Index (NDVI) was available
Aerial Orthophoto	10 cm	June 13, 2019	4	• Red • Green • Blue • Near Infrared	NDVI was available
Unmanned Aerial Vehicle (UAV) (aka Drone)	4 cm	August 1 & 2, 2019	3	• Red • Green • Blue	-3D imagery available -NIR camera was not available on the UAV used for the pilot study

2.3 Ground survey

Observations of on-the-ground features at each pilot site were collected during lower low tides, with one site surveyed per field day (Table 1)[4]. A Commissionaire escort was required at Rose Bay and the Smart Island sites as they were located on DND property. To remain consistent with the original HEIR data, pilot sites were selected to align with a Shore Unit described in the original HEIR program. Pilot sites varied in shoreline length and intertidal zone area, ranging from 100 to 400 m in alongshore length, and a perimeter boundary for each pilot site was drawn to define the footprint of the site in the imagery for the ground crew.

Physical and biological features were delineated using ESRI's mobile ArcCollector application and a sub metre accuracy Trimble R1 receiver by walking the perimeter of each feature. Physical and biological features were mapped independently. A pre-defined list of feature names was used to name the features according to the dominant biological or physical feature being mapped (e.g. eelgrass; bedrock, seawall) (Table 3). Backshore feature names were adapted from the original HEIR categories and similarly a list of anticipated intertidal and nearshore subtidal zone features was compiled. All feature names were setup in the ArcCollector form for use in the field. Features not included in the predefined feature list were documented and added to list afterwards.

If logistical constraints including steep banks and access did not allow for features to be delineated, they were document in field notes and photographs.

[2]Pléiades imagery has 50 cm panchromatic resolution and 2 m multispectral resolution. WorldView 2 high-resolution Satellite imagery, with 40 cm panchromatic resolution and 1.8 m multispectral resolution with 8 bands, was also collected however only the Pléiades imagery was classified for the pilot study as the imagery was received after classification had been initiated.

[3] Only the April 2019 imagery was used for imagery interpretation as it covered all study areas.

[4] Three of the six sites were visited a second time to remap features with Y-axis coordinates enabled to allow for more accurate area calculations.

Backshore features were delineated up to ~50 m from the HHW mark or to the nearest road (Table 3). Attributes recorded for backshore features include species of vegetation (if known), comments about site access, and estimated data quality. Perimeter of tree canopy as was surveyed if possible.

Table 3. Biological and physical features compiled for field and image classification for CRD Pilot Study

Backshore features	Intertidal physical features	Intertidal and nearshore subtidal biological features
Coniferous trees	Bedrock	Eelgrass
Deciduous trees	Mud	Bladed kelp
Mixed deciduous and coniferous trees	Sand	Canopy Kelp
Shrub	Pebble	Red algae
Invasive plants	Cobble	Green algae
Grass	Boulder	Rockweed
Marsh	Rip rap	Saltmarsh
Bare ground	Concrete	Barnacles
Landscaped	Pilings/Wharves/ Boardwalk	Mussels
Paved/road/parking lot	Shell Hash	Oysters
	Dock	Vegetated (algae)
	Organics	Black Lichen
	Unknown	

Most features observed in the field were mapped as polygons to allow for area comparisons with the results from the three types of remotely sensed image interpretation. However, if features could not be mapped as polygons they were mapped as linear (e.g., seawall, upper extent of eelgrass bed in nearshore, edge of shoreline at marine limit) or point features (e.g., pilings, location of across-shore profiles, small man-made features, small biological features).

For each physical feature mapped, up to three substrate types and associated percent cover classes were recorded as attributes in the associated database. Similarly, for the biological features, both the total percent cover of biota and names and cover categories for up to three dominant taxa of vegetation and/or sessile invertebrates (if applicable) could also be entered within each feature (Table 4). Biota observed were listed in order from greatest to least cover. Nearshore subtidal features that were within wading distance were delineated when possible, following the same feature naming protocols and cover class categories.

All features were documented with example photos, from different aspects, both within ArcCollector and with additional overview photos. Space for additional notes on observations was provided in the form for all features and attributes to assist in comparison between the field observations and the image classifications.

A qualitative estimate of data quality was recorded for each feature to help inform comparisons with the results from the three types of remotely sensed imagery interpretation (Table 5). If conditions indicated that delineated polygons were of moderate quality, which occurred on steep slopes, intertidal survey profiles were conducted. If conditions indicated that delineated polygons were of low quality, which occurred on vertical structures like seawalls, pilings and wharves, vertical elevations of biophysical features were collected. On-the-ground access to backshore areas of the pilot sites was also scored in the field, following the categories in Table 6.

Table 4. Percent cover categories for vegetation and substrate subcomponent

Cover Category	Vegetation	Substrate
Low	<5% - 25%	<5% - 25%
Moderate	25 – 75%	25-75%
High	>75%	>75 %

Table 5. Qualitative measure for data quality of each delineated feature

Feature Delineation Quality	Definition
Excellent	• High confidence in feature delineation in both area and perimeter
Good	• Mostly high confidence in feature delineation with some areas with moderate confidence in feature boundaries
Moderate	• Delineated features on a vertical or steep slope are not anticipated to be accurate • Boundaries based on colour and texture are unclear
Low	• Unable to delineate polygons in 2D space (e.g. seawalls) • Viewing in NIR, vegetated and unvegetated substrate is distinguishable • Can distinguish between beach, rip rap and bedrock, unable to determine sediment type (sand, pebble, cobble, boulder) • Features obscured by water

Table 6. Backshore access score

Backshore Access Level	Description
Full	Backshore up to 50 m from HWM or to nearest road is fully accessible
Limited	Some portions of the backshore are accessible, and some are prohibited
Prohibited	None of the backshore is accessible

2.4 Image classification by biologist

Biophysical features within each of the six pilot study areas were delineated by a biologist, with separate review for each of the three image types: satellite imagery, orthophoto, and UAV imagery. The perimeter boundary for each pilot site was included as a layer within ArcGIS.

Image interpretation to digitize and classify features visible in the imagery was conducted by a biologist familiar with image classification of biophysical features. The biologist conducting the image classification did not participate in the field surveys and had no prior knowledge of which features were present at the pilot sites. Following those initial classifications, another experienced aerial imagery classifier reviewed all six pilot study areas and did QAQC revisions. Changes were made and documented for future training purposes.

The imagery classification started with the lowest resolution imagery at each site, where the least detail was discernable (the satellite imagery), the ortho imagery second and the highest resolution UAV imagery third. Physical and biological features were classified as separate layers with biological features often overlapping physical features. Most features were mapped as polygons, however line and point features were also classified if necessary. Trees were mapped by delineating the perimeter of the tree canopy and as such often overlapped other features. Three dimensional models of the UAV imagery were available to determine if biophysical features could be observed on sea walls and beneath overhanging trees.

Line features were delineated when a polygon was not possible (i.e. top of seawall, upper extent of eelgrass bed if the lower boundary of bed underwater is not visible). Point features were mapped to mark small features (i.e., pilings and other notable features too small to be mapped as polygon). Point and line features also included the feature name, attribute data and comment fields.

The definitions for features, attributes and cover classes were consistent between the image classification and the ground surveys, with an option for the mapper to add notes and/or new feature types as needed (Table 3). The same cover classes as were recorded for the features mapped in the ground surveys were used during the image classification (Table 4). Backshore features were delineated in the coastal fringe from the higher-high water (HHW) line back ~ 50 m or to the nearest road.

Attributes within each feature recorded in the database included description of form (e.g., ramp, cliff, beach, tidal flat); type and percent cover of the substrate (e.g., cobble, boulder, bedrock); biota present and percent cover class (e.g., dune grass, green algae, eelgrass).

2.5 Comparing features classified, by image types

Features delineated and classified by the biologist in each of the three image types were systematically compared with the ground observations at each site, where the features observed/surveyed on the ground were deemed to be 'correct' identification. Attributes in the database associated with each feature and other comments and photographs collected by the ground survey crew were also reviewed for scoring these comparisons.

A ranked system was defined to score 'match -- partial match -- no match' between each feature, for all three image types, as compared to how the features were classified on the ground (Table 7). Matches (or mismatches) were assigned based on the entire pilot study area. Therefore, if for a given feature, a match occurred in one area and a partial match was assigned in another, both scores were included in the rating system using a colour gradient. Areas calculated for polygon features were also compared, and comments on discrepancies (if any) were noted to explain the scoring. Area values of 'n/a' indicate when a feature was observed on the ground but not delineated due to logistics[5] or when a feature was combined with another feature during classification (Table 7).

Table 7. Scoring system for comparing features mapped on-the-ground to those mapped from imagery, for intertidal, nearshore subtidal and backshore zones

Match Score	Definition
1	Perfect match -- Feature identified and area of extent the same as identified on the ground.
2	Match – Feature classification match but mapped extent differs due to variable tide heights or imagery covers subtidal or backshore areas not surveyed during ground survey.
3	Partial Match - Matched feature but mismatched elevation/ zone.
4	Partial Match - Mismatched feature but correct zone/elevation
5	No match - Detected during ground survey but not classified in imagery (omission)
6	No match - Mapped from imagery and not observed from ground survey (error)
Colour gradient	Feature delineated correctly in one location of the site, but same feature incorrectly mapped in another location of the site.
n/a	Feature present but not delineated on the ground; or feature present but not mapped separately in imagery.
	Imagery not available or submerged physical feature

Based on observations from the imagery interpretation (including ubiquitous low cover of mixed algae, and challenges in estimating cover of larger gravels throughout a shoreline), feature categories listed in Table 3 were 'rolled up' into categories shown in Table 8 to compare and rank the match scores of the classifications from the three imagery types across all sites. For example, for backshore features of 'coniferous trees', 'deciduous trees' and 'mixed deciduous and coniferous trees' categories were combined into a 'deciduous and/or coniferous trees'. Substrate was also combined into more general classes (e.g., 'pebble', 'cobble', 'boulder' features were combined as 'coarse sediment'; and 'mud' and 'sand' combined as 'fine

[5] Including site access or steep slopes.

sediment'). Intertidal turf algae were combined into 'rockweed, green and/or red algae' and subtidal turf algae were combined into 'subtidal green, red and/or brown algae' (Table 3 and Table 8).

Table 8. Rolled up features compared in assessing the image interpretation of different image sources

Backshore features	Intertidal physical features	Intertidal and nearshore subtidal biological features
Deciduous and/or coniferous trees	Bedrock	Salt marsh
Grass	Shell hash	Rockweed, green or red algae (intertidal)
Bare ground/parking lot/paths	Fine sediments	Green, red and or brown algae (shallow subtidal)
Buildings	Coarse sediments	Bladed kelp
Shrubs (including invasive plants)	Mixed fine and coarse sediments	Subtidal eelgrass
Rip rap	Rip rap	
Storm drain	Concrete debris	
	Wood platform	
	Sea wall	

Rank per feature at each site

For each pilot study area, imagery type, and rolled up feature, the rank described in Table 7 was converted to a numeric score such that a ranked positive (+) score would indicate a partial match to perfect match; and ranked negative (-) score would describe mismatches (omissions and errors). Numeric match scores were assigned based on the ranking system shown in Table 9.

Rank per feature across all sites

An 'interpretation accuracy' rank was then applied to rolled up features for each imagery type across all pilot study sites. Ranking match scores for each feature were added across all pilot study areas and divided by the number of pilot study areas they occurred in. The overall rank per feature and imagery type was assigned an 'interpretation accuracy' rank based on the categories shown in Table 10. Because accuracy ranking was applied to the rolled-up features, the initial match comparisons may have different feature names than the final accuracy scores discussed below.

Table 9. Ranking match scores of features classified from image sources

Matching Rank	Definition
-2	Error
-1	Omission
0	Match and error or omission
0.5	Partial match with omission
1	Partial match
1.5	Match and partial match
2	Perfect match or match
n/a	Not included in imagery

Table 10. Interpretation accuracy ranking feature match scores

Feature Score	Rankings
High	1.5-2
Moderate	1-1.49
Low	0-0.99
Omission	-1.0--0.00
Error	-2- -1.01

2.6 Supervised image classification

Supervised classification is an image classification technique whereby an image analyst or user 'supervises' classification of an image done by a computer algorithm. In supervised classifications the user specifies the pixel values or spectral signatures to be used for each classification by selecting representative sample 'training sites' to train a computer algorithm. The spectral signatures identified from the training sites are then applied by the algorithm to classify an entire image.

To evaluate the potential of using this method to detect and map backshore, intertidal, and shallow subtidal features in the study area, supervised classifications were conducted over all six pilot study areas using each of the three image types: satellite imagery, orthophoto, and drone imagery (See Appendix E for the supervised classification report). In addition to the remotely sensed imagery, the user was provided with site photos and GIS geodatabases that were collected during the ground surveys of each site. These were used to further inform land cover classes. The results of the supervised classifications were then visually compared with the 'features' identified during the ground survey and by the human image classifier.

After initial review of the imagery and spatial data, the image analyst concluded that because the image types were acquired on several different dates and at different times of the day, each pilot site would require an independent set of training sites with which to perform a supervised classification. The image analyst also determined that the imagery could not support detailed vegetation extraction such as kelp, algae, or eelgrass, but was better suited to broad classes including trees, grass/herb, or intertidal vegetation.

Based on the initial findings, a set of potential land cover classes that could be reasonably extracted from the imagery was created (Table 11). Classes that had two divisions within a class were based on the identification of different spectral signatures of vegetation. The sub-classes could be rolled-up into one parent class if the separation of classes could not be resolved to species or species groupings.

Note that due to the inherent differences between the six pilot sites surveyed, not all classes were present at any one site. In addition, the number of classes identified at each site may vary due to several factors:

- Sensor limits what is separable (primarily UAV);
- Extent of the image (UAV) may not encompass areas of all classes;
- Acquisition date/timing meant that some intertidal classes were not present in all imagery.

Table 11. List of Cover Classes from Supervised Classification.

Unclassified
Water
Shadow
Rock/Rubble
Fine Sediments
Mixed Fine/Coarse Sediments
Mud: Mixed sediments with direct water influence
Man-Made1: Concrete, asphalt, tar-roof
Man-made 2: Metal, Canvas, Plastics, Vinyl, other Synthetic materials
Tree – trees greater than ~ 2 m in height
Shrub
Grass/Herb – stressed
Grass/Herb – healthy
Submerged/Emergent Vegetation – visible water influence 1
Submerged/Emergent Vegetation – visible water influence 2
Intertidal Vegetation – no visible water influence 1
Intertidal Vegetation – no visible water influence 2

3 Results and Interpretation

3.1 Comparing features classified at each site, by image types

Biophysical features delineated during the ground survey and classification of the three imagery types within the six pilot study areas are described below followed by an assessment of the ability to delineate features using each imagery type. Figures for features mapped during the ground survey and summary field notes for all six pilot sites are included in Appendix A. Maps showing the classification of each imagery type at all sites are shown in Appendix B. Comparison tables for all six pilot study sites are included in Appendix C.

3.1.1 The Gorge Waterway Park

Intertidal physical features observed during the ground survey at the Gorge Waterway include mixed gravel and fine sediment beaches, mud, sea walls and bedrock. Intertidal biological features include saltmarsh and subtidal eelgrass. Backshore features include parking lots and paths, grass, mixed coniferous and deciduous trees and shrubs (See Appendix A for further details from the ground survey).

- The interpretation of the satellite imagery was poor with correct delineation of features limited to parking lots and paths, grass and trees in the backshore zone (See Appendix B and C).
- The interpretation of the orthophoto imagery included the correct classification of saltmarsh, mixed substrate beaches and one stretch of seawall. The western sea wall within the study area was not delineated during the orthophoto imagery classification. The subtidal eelgrass was mapped as green algae, likely due to the dark image provided in the orthophoto. Polygons delineated as trees were in some cases partial matches as they included shrubs. Mud was not classified as it occurred beneath overhanging trees and bedrock was not classified as it occurred within a shadow (See Appendix B and C).
- Interpretation of the UAV Imagery correctly captured most features, including subtidal eelgrass, except for the intertidal mud as it was obscured by overhanging trees. The sea wall was considered a partial match as it was classified as a fence. The 3D models available did not facilitate viewing biophysical features below the overhanging trees or biological features present on the sea wall (See Appendix B and C).

3.1.2 Smart Island

Intertidal physical features observed during the Smart Island ground survey included shell hash, various gravel or mixed fine and coarse substrate beaches, and bedrock. Intertidal biological features included subtidal green algae, black lichen and mixed intertidal algae. Backshore features included mixed deciduous and coniferous trees, grass, roads, a parking lot and deciduous trees (See Appendix A for further details from the ground survey).

- The interpretation of the satellite imagery was poor in the intertidal zone with no biological features being correctly identified. Intertidal physical features correctly identified were limited to bedrock. The satellite imagery performed well for backshore features with all features except deciduous trees correctly classified (See Appendix B and C).

- Classification of the orthophoto captured biophysical features well. The orthophoto classification captured all features except for intertidal shell hash and deciduous trees in the backshore zone. A boulder/sand beach was considered a partial match from the orthophoto interpretation as it was classified as a boulder beach (See Appendix B and C).
- Classification of the UAV imagery resulted in the delineation of all features identified during the ground survey except for shell hash (See Appendix B and C).

3.1.3 Esquimalt Lagoon

Physical features observed during the Esquimalt lagoon ground survey include intertidal bedrock, a pebble beach, tidal flat and sand and shell. Intertidal biological features include saltmarsh and green algae. Subtidal green algae was observed in the subtidal zone. Backshore observations include invasive plants, a parking lot and rip rap (See Appendix A for further details from the ground survey).

- The interpretation of the satellite imagery was poor. Correct interpretation of features was limited to the pebble beach, intertidal green algae and the parking lot (See Appendix B and C).
- The interpretation of the orthophoto imagery captured all intertidal physical features. The salt marsh vegetation was partially classified as an intertidal feature and partially classified as terrestrial grass. Intertidal green algae was not captured likely due to imagery capture dates. Invasive plants were not delineated, and the rip rap was obscured by a shadow from the bridge (See Appendix B and C).
- The interpretation of the drone imagery included the correct interpretation of all features except for backshore invasive plants and intertidal green algae. The intertidal algae may have been absent due to seasonal differences between the ground survey and imagery capture date (See Appendix B and C).

3.1.4 Coast Harbourside

Physical features observed during the ground survey at Coast Harbourside include a mudflat (with boulder and sand), rip rap, concrete remnants, a raised wood platform, docks and boats, a rock wall and a boulder beach. Intertidal and nearshore subtidal biological features include green algae, bladed kelp and barnacle/rockweed. Backshore features include concrete walkways, buildings, coniferous and deciduous trees, grass and shrubs (See Appendix A for further details from the ground survey).

- The classification of the satellite imagery correctly identified rip rap and docks and boats. No intertidal or nearshore subtidal biological features were classified. The backshore features were a combination of matches and partial matches as trees, shrubs and grasses were combined in some areas. Buildings and paved areas were also combined[6] (See Appendix B and C).

- Using the orthophoto imagery, correct classification of intertidal and nearshore subtidal biological features was limited to green algae. The bladed kelp area was submerged and in the shadow of the sea wall in the orthophoto. Correctly classified intertidal physical features included the rip rank bank and docks and boats (like in the satellite imagery interpretation). The mudflat and the boulder beach were submerged and therefore not captured. The concrete remnants, wood platform and sea wall were not classified. All backshore features were correctly classified using the orthophoto imagery (See Appendix B and C).
- The available UAV imagery was limited to the intertidal and nearshore subtidal zones as the pilot did not fly the drone due to: the requirement of the drone remaining in the line of sight as well as difficulties presented by low flying aircraft, wind, numerous individuals from the public and a relatively busy marina. The pilot collected photos using the drone camera in handheld mode and walked around the site. All intertidal and nearshore subtidal biological features were correctly classified using the UAV imagery. Physical features that were correctly classified include the mudflat, rip rap and boulder beach (See Appendix B and C).

3.1.5 Rose Bay

Physical features observed during the ground survey at Rose Bay include a concrete footing, bedrock, mixed fine and coarse sediment beaches, a coarse sediment beach with bricks, a mudflat, a concrete wall, a rip rap bank and a brick structure. Intertidal and nearshore subtidal biological features include green algae, rockweed/barnacle and black lichen. Backshore features include mixed coniferous and deciduous trees, parking lots, grass, buildings, deciduous trees and shrubs (See Appendix A for further details from the ground survey).

- Correct classification of intertidal physical features using the satellite imagery was limited to bedrock however the rock wall was below overhanging trees and the mudflat was submerged. No biological features were classified. All backshore features were correctly classified except for the deciduous trees which were combined with mixed trees (See Appendix B and C).
- The orthophoto imagery interpretation correctly classified bedrock and rip rap. However as with the satellite imagery, the rock wall was below overhanging trees and the mudflat was submerged. Green algae and rockweed/barnacle were correctly classified. All backshore features were correctly classified (See Appendix B and C).
- The drone imagery classification correctly classified all physical intertidal features apart from the concrete footing, mixed fine sediment and gravel beach, rock concrete wall (under overhanging trees) and a brick structure. All intertidal and nearshore subtidal biological features were correctly classified. The drone imagery did not cover most of the backshore included within the pilot study area due to the requirement for the drone

[6] Should be resolved with training.

to remain within the line of sight. Of the areas covered, all were correctly classified (See Appendix B and C).

- Anthropogenic features observed on the beach including bricks and concrete footings were not classified by any of the three imagery types.

3.1.6 Portage Inlet

Physical intertidal features observed during the ground survey at Portage Inlet include a pebble beach, mudflat and rip rap. Intertidal and nearshore subtidal biological features include salt marsh, subtidal green algae and subtidal eelgrass. Backshore features include pathways, invasive plants/shrubs, grass, mixed coniferous and deciduous trees and a storm drain (See Appendix A for further details from the ground survey).

- The interpretation of the satellite imagery was poor with correct classifications limited to grass, portions of the trees and portions of the mudflat (See Appendix B and C).
- The interpretation of the orthophoto imagery correctly classified the western portion of the rip rap bank however the eastern rip rap bank was combined into a boulder, sand beach polygon and therefore both features were considered a partial match. All biological features were correctly classified including salt marsh and eelgrass. Most of the backshore features were correctly classified however, shrubs were often included in the tree polygons (See Appendix B and C).
- The interpretation of the drone imagery correctly captured the rip rap bank as well as part of the mudflat. The pebble beach was classified as cobble/sand. All biological features were correctly classified including salt marsh and subtidal eelgrass. Most of the backshore features were correctly classified however as with for the orthophoto imagery, shrubs were often included in the tree polygons (See Appendix B and C).

3.2 Comparing accuracy of features mapped, across all sites

The results of the analysis of the classification of the satellite, orthophoto and UAV imagery are presented in Table 12. A summary of results per feature category (backshore, intertidal physical and intertidal biological features) are presented below in section 3.2.1 through 3.2.3.

Colour key for interpretation accuracy
High
Moderate
Low
Omission
Error

Table 12. Feature interpretation accuracy ranking, by image type, all sites combined.

Features	Imagery Source		
Backshore Features	**Satellite**	**Ortho**	**UAV/Drone**
Deciduous and/or coniferous trees	1.70	1.80	1.88
Grass	2.00	2.00	2.00
Bare ground/parking lot/paths	1.00	2.00	2.00
Buildings	1.75	2.00	n/a
Shrubs (including invasive plants)	-0.38	0.70	1.17
Rip rap	-1.00*	1.00*	2.00*
Storm drain	-1.00*	-1.00*	-1.00*
Physical Features			
Bedrock	0.50	1.25	2.00
Shell hash	n/a	-1.00*	-1.00*
Fine sediments	0.00	0.83	1.30
Coarse sediments	0.88	1.25	1.63
Mixed fine and coarse sediments	0.83	1.50	1.67
Rip rap	0.67	1.83	2.00
Concrete debris	-1.00	-1.00	-1.00
Wood platform	-1.00*	-1.00*	-1.00*
Sea wall	-1.00	0.25	-1.00
Biological Features			
Salt marsh	-0.33	1.83	2.00
Rockweed, green or red algae (intertidal)	-1.00	2.00	1.90
Green, red and or brown algae (shallow subtidal)	0.00	2.00	2.00
Bladed kelp	-1.00*	-1.00*	2.00*
Subtidal eelgrass	-1.00	1.00	2.00

* feature observed at a single site

3.2.1 Backshore features

- All three imagery types functioned well for the interpretation of backshore features when using rolled up categories (Table 8 and Table 12).
- Shrubs were not easily classified as they were often combined with trees in interpretations of all imagery types.
- Small backshore features were limited to a storm drain observed during the Portage Inlet ground survey which was not delineated during the classification of any of the three imagery types. The inclusion of similarly small features in the Harbour Atlas is not appropriate if relying predominantly on remote sensing imaging to delineate features.

3.2.2 Intertidal physical features

- Classification of intertidal physical features using satellite imagery was poor for all physical features considered.
- Classification of the orthophoto imagery had a high to moderate accuracy score for bedrock, coarse sediments, mixed fine and coarse sediments and rip rap. Fine sediments and sea walls had a low accuracy score. Shell hash, concrete debris and a wood platform were not classified (omission).
- The highest resolution imagery from the UAV survey had the best accuracy scores with moderate to high accuracy scores for the classification of bedrock, fine sediments, coarse sediments, mixed fine and coarse sediments and rip rap. Shell hash, concrete debris, a wood platform and sea walls were not classified (omission) (Table 12).
- Small anthropogenic features observed on the beach including bricks and concrete footings were not identified using any of the three imagery types.

3.2.3 Intertidal and nearshore subtidal biological features

- Classification of intertidal and nearshore subtidal biological features was poor for all features considered using the satellite imagery.
- Salt marsh, intertidal turf (rockweed, red and/or green algae) algae and subtidal turf algae (green, red and/or brown) and subtidal eelgrass[7] had a moderate to high accuracy score using the orthophoto imagery. Bladed kelp, which was only observed at the Coast Harbourside site was not classified using the orthophoto imagery as the tidal height was higher than that of the ground and UAV survey.
- All biological features within the rolled-up categories were correctly classified using the drone imagery.
- No 'false positive' (error) mismatches were observed; that is, there were no instances where a feature was mapped from imagery which was not observed from ground survey.

[7] Eelgrass had a moderate rating as the interpretation of the dark orthophoto imagery at the Gorge Waterway site resulted in the subtidal eelgrass to be mapped as green algae.

3.2.4 Overhanging structures and sea walls

The 3D models produced from the drone imagery were unable to capture biological features on sea walls at the Gorge Park Waterway or at Coast Harbourside; nor did they 'see' areas under overhanging trees along the shorelines.

3.3 Supervised classification comparisons

Eighteen sets of training data were collected for the study sites and were used to create land cover classification maps. No accuracy assessments were performed on the results due to the quality and limited number of ground-truth data points.

Although no feature by feature match comparisons were done on the results of the supervised classification, coastal features were delineated quite well using this method. A visual assessment indicates that boundaries were delineated with more precision than what the human classifier accomplished. However, the features were often classified incorrectly, or in more general categories than what the human classifier used (i.e., where the supervised classification identified the feature as 'grass/herb – stressed', the human classifier was able to classify the feature correctly as 'salt marsh vegetation'). We expect that the classification for the features detected in the supervised classification would likely be improved with further training, however, due to the complex spectral signatures of the spatially heterogeneous features present in the Harbours area, QAQC with human classifier will be required for best results.

Supervised classification results for the Esquimalt Lagoon site are shown in Figure 2, and results for all other sites are included in the Vertex Report which is attached in Appendix E.

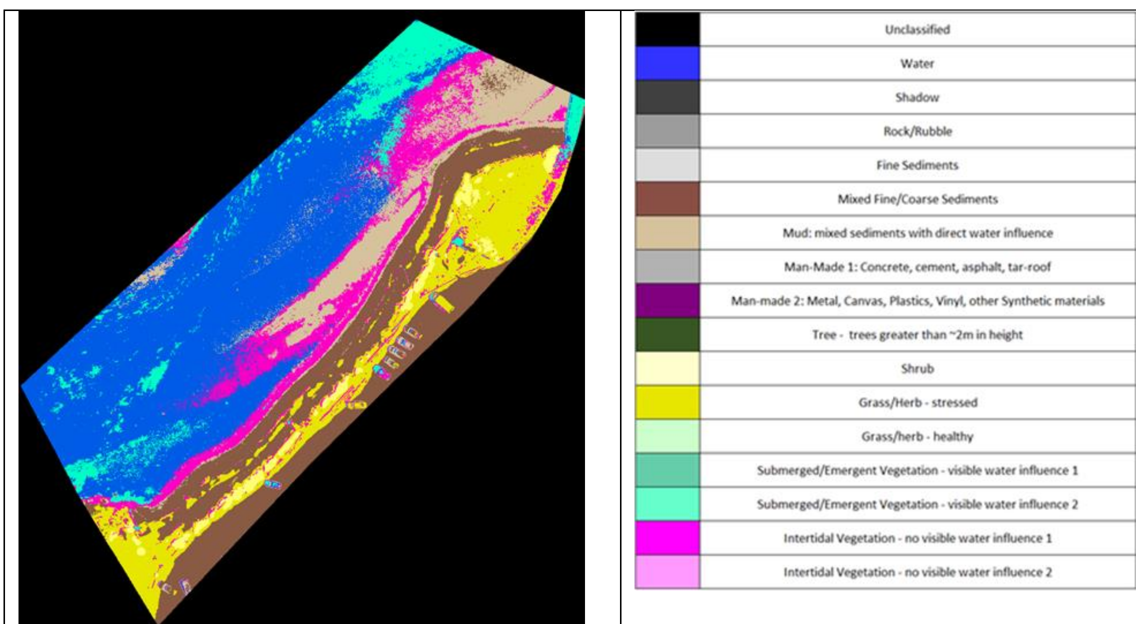


Figure 2. Example of supervised classification for the Esquimalt Lagoon pilot site

4 Discussion of Pilot Study Results

The pilot study has demonstrated that orthophoto and UAV imagery can be used to inventory and map many of the physical and biological features found in Victoria and Esquimalt Harbours. Of all three image types trialed in the Pilot Study, aerial orthophotos are the best option for a future classification of the CRD shoreline. The orthophotography option was the most economical, allowed for the classification of general biophysical features, can be planned to fly during low tide windows, and can include additional spectral bands and/or higher resolution imagery as options if needed. The 50 cm resolution of satellite imagery is clearly too coarse to adequately identify features of interest at the scale required for an updated Harbour Atlas. Furthermore, the tide height captured in the imagery was higher than that obtained from the UAV and the orthophoto imagery. Although the highest resolution imagery was collected using the UAV (which resulted in higher interpretation accuracy), the cost as well as logistical constraints (i.e., not being conducive to larger areas, requiring line of sight at all times, limited access, complaints from the public, interfering with sea plane traffic, permitting requirements etc.) associated with flying the drone in a populated area near a seaplane airport made this method unfeasible to survey the whole study area. The UAV imagery used for the pilot study also lacked near infrared (NIR) bands[8] which facilitates distinguishing classes of vegetation, however, the 3D aspect of oblique view could potentially be useful to inventory features not visible in the other two birds-eye view image types at certain sites.

The results of the supervised classification indicate that despite inconsistencies in classification due to factors such as seasonality, shadows, and solar illumination, the classification was able to delineate the shape of features better than the human classifier. Therefore, supervised classification could be used to complete the delineation of biophysical features followed by a review of the categories assigned to each feature by a human classifier. This would then be followed up by a ground survey to verify a subset of the classified features. One constraint of the use of a supervised classification is that it would be challenging to map overlapping biological and physical features separately as the algorithm used views the image as one flat surface.

The following sections provide further discussions regarding the use of orthophoto or drone imagery for the CRD Harbours Atlas[9] including:

1. Suitable biophysical features identified for mapping using orthophoto or drone imagery.
2. Benefits of using aerial imagery for mapping coastal features.
3. Limitations of using aerial imagery for mapping coastal features.

[8] NIR cameras can be available on UAV, however McElhanney did not have one available.

[9] The satellite imagery interpretation is not further discussed as results indicate that it is unsuitable for mapping at the scale required for the CRD Harbour Atlas.

4.1 Suitable Biophysical Features

4.1.1 Intertidal and shallow subtidal biological features

Most of the study area has low to very low wave energies which tend to have the least diverse intertidal biota; and as is typical of protected shorelines elsewhere in the Salish Sea, the intertidal zone has generally sparse cover of attached biota throughout. Places in the harbour which are more influenced by the open marine environment of the Strait of Juan de Fuca and have more wave energy (i.e., those which are close to the mouths of the harbours) tend to have more diverse species assemblages.

The habitats and associated biota of the intertidal zone are naturally strongly influenced by across-shore elevation. A few centimeters difference in elevation can change which biota can live there, resulting in spatial heterogeneity of a fine scale, making these features even more challenging to show on a map. For these reasons, it was difficult to differentiate between algal species or species groups in the intertidal zone using the three imagery types. Combining the 'turf' algae groups into one intertidal or subtidal turf algae category resolved this issue.

Both orthophoto and drone imagery can be used to detect the upper limit of subtidal eelgrass and possibly bladed kelps[10], however delineation of subtidal eelgrass beds not visible in remotely sensed imagery will require alternative subtidal survey methodologies.

Intertidal or nearshore subtidal biological features that can be mapped using the methods demonstrated in this pilot study using orthophoto or UAV imagery include:

- Salt Marsh
- Intertidal turf algae (rockweed, red and or green algae)
- Subtidal turf algae (green, red and/or brown algae)
- Intertidal or shallow subtidal eelgrass[11]
- Bladed kelp[12]

Due to the variability in classification results, ground surveys to verify classified biological features will be important.

4.1.2 Intertidal physical features

The methodologies explored showed variable results for correct identification of substrates. For this reason, substrates types were combined into 'fine substrate' and 'coarse substrates' which

[10] Bladed kelps were only observed at one pilot study site and were submerged in the orthophoto imagery. We are therefore unable to determine the ability of orthophoto and drone imagery to capture the upper limit of bladed kelp beds.
[11] The ability to map subtidal eelgrass would be limited in most cases (except for very shallow areas including Portage Inlet) to delineating the upper limit of the eelgrass bed.
[12] The ability to delineate the upper limit of bladed kelp was not verified using orthophoto imagery as the bladed kelp was both submerged and in the shadow of a sea wall. As with eelgrass, the ability to map bladed kelps using aerial imagery would for the most part be limited to delineating the upper limit of the bladed kelp bed.

improved the classification accuracy[13] for drone and orthophoto imagery interpretation. Bedrock was always classified correctly using drone imagery and had a moderate level of accuracy in orthophoto imagery interpretation.

Much of the harbours shoreline has been modified by human activity, including areas of fill, pilings, docks and piers. The previous HEIR inventory showed that about half of the total shoreline length was not natural shoreline (HEIR 1997). Rip rap had a high level of accuracy in both drone and orthophoto imagery interpretation. Sea walls did not tend to be included in the classification however this should be resolved with further training. Docks and piers are readily identifiable from remotely sensed imagery however it is difficult to differentiate piled structures from structures on fill without high quality 3D models.

Intertidal physical features that can be mapped using the methods demonstrated in this pilot study using orthophoto or UAV imagery include:

- Bedrock
- Coarse sediments
- Mixed fine and coarse sediments
- Rip rap
- Fine sediments[14]

Due to the variability in classification results, ground surveys to verify classification of physical features will be important.

4.1.3 Backshore features

All imagery types performed well in the backshore zone at the level of classification used in this pilot study. Backshore features are often included in other mapping inventories, including ecological inventory and municipal infrastructure; however, few programs include synoptic inventory of intertidal or subtidal zone biophysical features.

Backshore features that can be mapped using the methods demonstrated in this pilot study include:

- Deciduous and/or coniferous trees
- Grass
- Bare ground/parking lots/paths
- Buildings
- Shrubs[15]
- Rip rap

[13] The feature accuracy score was assessed on the rolled-up categories.
[14] Fine sediments had a low to moderate accuracy rating.
[15] Shrubs had a low accuracy rating using orthophoto imagery as they were often combined with trees.

4.2 Benefits of using aerial imagery for mapping coastal features

Some of the benefits of using aerial imagery interpretation for mapping coastal features include:

- Large area coverage, which allows for regional-scale surveys.
- Potential streamlining of spatial mapping by using supervised image classification to automate the digitizing of polygon features.
- Reduction the amount of field survey time needed, making it less expensive for regional scales and detecting features which cannot be easily delineated on the ground, such as the lower extent of shallow eelgrass beds or mudflats.
- Aerial surveys can be planned for times of lowest low tides to maximize the area of the intertidal zone which is visible.
- Survey technique is repeatable, which allows comparable data collections at different times.
- Passive form of data collection, meaning collection of the data does not disturb the area of interest.

4.3 Limitations for aerial imagery for mapping coastal features

Using aerial imagery for classifying and mapping coastal features does have limitations which include:

- Imagery scale is not suitable for detailed observations at species level or for small physical features. Study design needs to ensure that mapping objectives (i.e., scale and detail of attributes to be mapped) are suitable for using remote imagery as basis for inventory.
- Only the surface layers of visible features are mappable from the imagery, making overlapping attributes (i.e., mixed sediments or combinations of attached biota) hard to characterize in a single layer on the map. Sparsely distributed features (i.e., scattered clumps of several types of small algae) are also hard to delineate or to separate from the signature of the underlying substrate. Features which were most successfully mapped from the imagery were those which were observed on the ground as having ~50% cover or more.
- Vertical aerial imagery does not 'see' detail on vertical (3D) surfaces (i.e., seawalls, pilings and other steeper features) and inventory of those would need to be mapped using alternate methods.
- Shadows and shading in imagery obscure understory features. In the backshore, shadows cast by tall structures and trees were observed during the pilot study. Overhanging riparian vegetation (usually tree and/or shrub canopies) hid the upper intertidal zone in a few sites. Pilings under docks were also obscured in imagery. Classification of the features present in shaded areas would require ground truth checking or alternate data source.
- Only shallow subtidal features are identifiable in remote sensing, meaning the upper extents of emergent eelgrass or other shallow subtidal vegetation may be visible in imagery, while the lower extent in deeper water is not. General extent of eelgrass in shallow water could be identified from aerial imagery, and if more detailed metrics to assess stand health are required, site-specific on-the-ground measurement of shoot density and/or leaf area index, for example, could be collected and then added to the database of attributes associated with the mapped eelgrass feature.

- For updating subtidal habitat inventory, surveys at depths greater than ~0.5 m will need to be conducted using alternative methodologies, such as towed video, drop camera or diver surveys.
- Aerial imagery is collected at a snapshot in time and will not represent seasonal variation. Spectral signatures for fresh-grown spring vegetation differs greatly from later in the summer when vegetation dies back or changes colour.

4.4 HEIR Ecological Ratings

The original HEIR ecological ratings exist as line files throughout the five harbour areas except for the shoreline of Strait of Juan de Fuca, between Esquimalt and Victoria Harbour (Figure 1). As the rating system has already been developed, the original files can be integrated into an updated Harbour Atlas and shoreline units will be updated where applicable. This assumes that the original HEIR dataset has been reviewed and deemed to be appropriate to include in the Harbour Atlas by the CRD.

5 User Needs Workshop

A workshop was sponsored by CRD to gather a group of representatives from agencies and groups who are interested in using the proposed updated harbour atlas data. Workshop participants included representatives from local municipalities, Fisheries and Oceans Canada, Songhees First Nation, Coast Guard, Department of National Defense, Transport Canada, community stewardship groups, environmental consultants, and others.

The workshop agenda included a review of the summer's pilot project with an overview of results from the pilot sites surveyed; a summary of the preliminary recommendations for the methodologies to use to survey the whole Harbours areas; and facilitated breakout group discussions to gather user suggestions on their data/ mapping needs for the updated inventory.

A First Nations representative emphasized the importance of engaging local indigenous bands during the planning and implementation of the updated inventory, in particular for including cultural sites and traditional resource uses.

Three questions were posed to the five breakout groups, which ran concurrently and had wide-ranging discussions about what should be included in the planned Harbour Atlas updates. Comments were summarized on flip charts by each groups' facilitator and were reported back to the whole group after each breakout. Discussions included backshore, intertidal zone and nearshore subtidal zone areas. Wrap up 'take home messages' were then outlined at the end of the workshop by *raconteur* Brian Emmett; however, specific items raised in discussions were not tallied.

The first questions posed to workshop participants was: *What inventory information is useful to you (biological, physical, natural, anthropogenic)?* Responses to this question included:

- Specific resources (i.e., eelgrass, kelp, shellfish, forage fish spawning sites, bird use, other species at risk, First Nation traditional use; municipal infrastructure and property boundaries). Include historical habitat use areas (e.g. native oysters).
- Natural shore types and physical features (e.g., soft sediments, nearshore bathymetry, shoreline location, LIDAR detailed elevations).
- Shoreline process which could be used to inform land-use planning (e.g., areas of erosion, accretion, inundation; sensitive sites; change over time; historical land uses).
- Anthropogenic structures including shore modifications/structures (i.e., storm drains; seawalls; marina berths; administrative boundaries/land use designations; aquaculture sites; shoreline access points; other cultural heritage sites; educational/recreational sites).
- Indicators of human/ecosystem health (i.e., contaminants in water column/ tissues/ sediments).

The second breakout group session discussed the question: W*hat interpretive data would be useful to derive from the inventory data (e.g. ecological ratings, shoreline restoration priorities, spill response sensitivity etc.)?* Responses to this question included:

- Updated ecological ratings including criteria for scoring critical/sensitive/vulnerable habitats/ecological function/naturalness.
- Identifying habitats with restoration or habitat compensation potential (e.g., forage fish spawning/habitat connectivity).
- Spill response/emergency response planning.
- Assessing habitat vulnerability/adaptation opportunities for sea level rise.
- Identifying barriers to connectivity between habitats (i.e., alongshore or across-shore movements).
- Priority areas for First Nations coastal protection or restoration.
- Contribute to drafting best management practices for stewardship or development planning.
- Community/public education of coastal habitats in the harbours.
- Green Shores assessment and ratings.
- Maintenance of existing infrastructure/ identify priorities for replacements.
- Identify areas of recreational use.

The final question for the breakout groups discussed was: *How would you use this information, and how would you prefer it to be presented and made accessible?* Responses to this question included:

- Participants agreed that new spatial data must be easy to use, with downloadable spatial data files (WMS for example) as well as map-making functions as PDF
- Make data available at multiple scales, from area overview to site-specific
- Download access to shoreline photos or videos was suggested, including orthophotos through time
- Download files to include metadata, with glossary
- Map-making function needs to be query-able and include legend and measuring tools

- Include data from historic inventories, if available. Include sliding time scale on presented data.
- Compatible with other data atlases (i.e., fish atlas, older land use maps, previous ecological ratings, LIDAR data).
- Collaboration and resource sharing were mentioned as being key to ensuring that new inventory can be combined with spatial data from other sources.

6 Recommendations

The recommendations outlined below are based on the results of the pilot study and outcome of the user needs workshop.

We recommend a four-step process for the inventory of the Harbours project area, including:

1. Geodatabase structure and design
2. Orthophotography-based supervised classification.
3. Complete review by human mapper
4. Ground truthing surveys to add further details to the classification of features as needed

6.1.1 Geodatabase Structure and Design

In collaboration with CRD and a CRD GIS specialist, a geodatabase and map structure will be designed for the updated harbour atlas[16]. We recommend the inclusion or consideration of the following:

- Classification of the features shown in Table 13. This list will be refined through consultation with the CRD.
- Features may be depicted as polygons, lines or points as appropriate (a minimum mapping unit will be defined).
- Capacity to add finer-scale, site-specific observations and details into the data associated with the mapped features.
- Allow for additional features and details to be added into the dataset during mapping and/or field verification steps.
- Include an attribute that indicates if a physical shoreline attribute is natural or anthropogenic, or a combination of the two.
- Accept georeferenced photos collected during ground surveys.
- The ability to track the QAQC process (verification by human classifier and ground truthing).
- Original HEIR ratings (line files) will be included in the Harbour Atlas with ability to update ratings during classification[17].
- Ability to:
    - Download spatial files and photos
    - Query spatial data
    - View a meaningful legend
- Allow for additional layers identified as important during the workshop that will require further scoping and are beyond the scope of this pilot study including:
    - First Nations traditional use/culturally important areas
    - Forage fish spawning sites
    - Species at risk

[16] It is assumed that the CRD would be responsible for data design, storage and display.
[17] This assumes that the original HEIR data has been reviewed and updated if appropriate by the CRD and has been determined to be of value in the updated Harbour Atlas.

- Municipal Infrastructure and shoreline types
- Data from existing atlases
- Higher high-water shoreline and chart datum lower low water line in spatial files.
- Shoreline processes (areas of erosion, accretion, inundation, sensitive sites, change over time, historical uses)

Detailed mapping protocols that fit with the geodatabase design will be documented for polygons, lines and point features.

Table 13. Features identified as appropriate for mapping using orthophoto imagery.

Intertidal and Nearshore Subtidal Biological Features	**Intertidal Physical Features**	**Backshore Features**
Saltmarsh	Bedrock	Deciduous and/or coniferous trees and shrubs
Intertidal turf algae (rockweed, red and or green algae)	Coarse sediments	Grass
Subtidal turf algae (green, red and/or brown algae)	Mixed fine and coarse sediments	Bare ground/parking lots/paths
Intertidal and shallow subtidal eelgrass	Fine sediments	Rip rap
Bladed kelp	Rip rap	
	Sea walls	

6.1.2 Orthophotography based supervised classification

- Collect low level 4 band photo and orthophoto covering the general area of the project (~100 km^2) at 10 cm pixel resolution.
- Imagery deliverables to include ortho-rectified and referenced individual unenhanced 4 band Red-Green-Blue (RGB), Near Infrared (NIR) images[18] as well as the orthorectified mosaic enhanced 3 band images.
- Use supervised classification to delineate and classify feature polygons. This would include a sampling campaign that would include the collection of ground-truthing datasets, ideally in coordination with the timing of imagery acquisition.

Optional

- Use existing 2019 imagery.
- Collect higher resolution 2.5 cm pixel ortho imagery.
- Use 8 band 0.5 m hyperspectral imagery.

[18] NIR image is most useful for analysis if it has not been enhanced nor mosaiced.

6.1.3 Review of classification

- An individual experienced in classification of the intertidal zone and backshore zone using aerial imagery will verify all features delineated by the supervised classification. If features have been incorrectly classified, they will be modified.
- Physical features beneath biological features can be interpreted when possible. Other features which are not easily classified by the supervised classification of imagery can be added (i.e., seawalls).
- Additional attribute data will be entered in the geodatabase including comments and percent cover categories if applicable.
- Species groups (i.e. red algae, green algae, rockweed) if clearly visible will documented during the classification review.
- Feature boundaries will be modified if required.
- During the classification review, the original HEIR classifications and ecological ratings will be reviewed and revised when appropriate if it is determined by the CRD that the original classification is relevant and valued for an updated Harbour Atlas[19]. This assumes that the original HEIR dataset has been reviewed by the CRD and a protocol for updating the dataset has been developed in collaboration with the CRD.

6.1.4 Ground surveys

- Conduct ground truthing for substrate, species and species groups (if applicable) and any other specific sites with features of interest (e.g. sea walls, areas with overhanging trees).
- Features and attributes in the classification will be modified as needed.
- Plan 2020 field survey days for image acquisition and ground truth (including special inventory seawalls, pilings and other sites of interest) for available mid-day, summer low tide dates in summer. Predicted tides less than 30 cm: June 5 - 9, June 21 - 24, and/or July 3 - 7 and July 19 - 22, 2020.
- Collect georeferenced ground photo image during summer lower low tides to be included in the spatial data.

[19] The old shoreline units will not necessarily line up with the newly delineated features.

7 References

Archipelago Marine Research Ltd. And Westland Resource Group. 2002. HEIR Needs Assessment Workshop, Summary Report. Unpublished Contract report to CRD Victoria, BC. 18p.

BC ShoreZone (link access December 2019) https://catalogue.data.gov.bc.ca/dataset?q=shorezone&type=Geographic&sort=score+desc%2C+record_publish_date+desc

Harbours Ecological Inventory and Rating (HEIR) Program 1997. Unpublished contract report prepared by Archipelago Marine Research Ltd. and Westland Resource Group for CRD Victoria, BC. 36p.

8 Appendices

Appendix A – Ground survey features and site descriptions

a. Esquimalt Lagoon Ground Survey Classification

Esquimalt Lagoon
Site visit on July 3, 2019

The Esquimalt Lagoon site shoreline is much modified by human activity, included the road bridge and footings at the east end of the unit and the paved street and parking area covering the whole backshore.

Features surveyed/observed on the ground survey included:

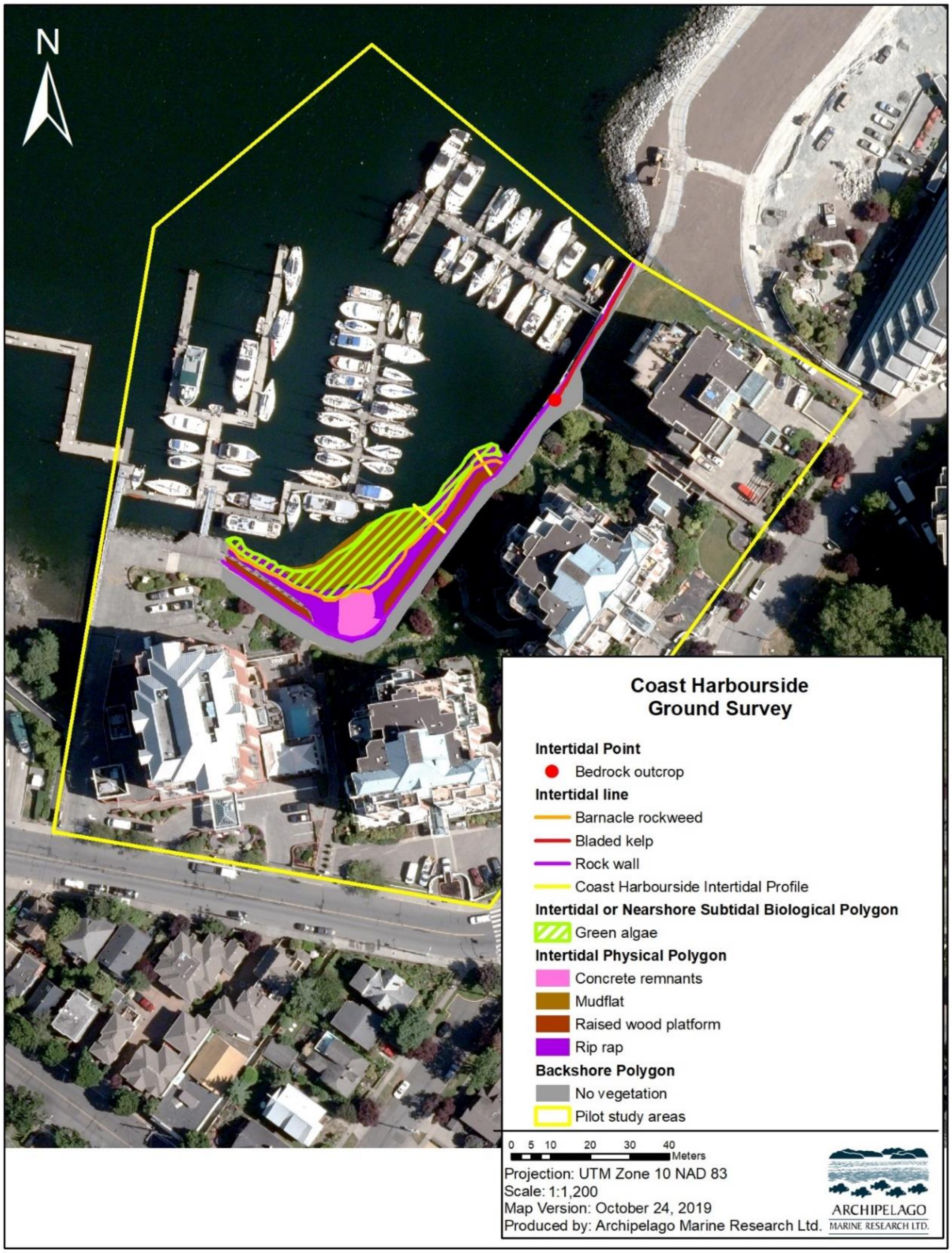
- bedrock outcrop and concrete monument and old anchor at the west end of the site
- pebble beach face
- fringing salt-tolerant native herbs in the driftwood line (Gumweed, Yarrow, Sea Rocket and Beach burweed)
- thick swash line of washed in eelgrass and other organics
- riprap fill surrounds the bridge footings and the information sign kiosk at east end of the site
- shallow nearshore subtidal sand bars
- two small offshore islets (one is gravelly and covered in a thicket of Nootka rose and other shrubs and herbs; the other smaller islet is bare bedrock).

Numbers of visitors use the site, including for dog walking, bird viewing and picnicking. More than 5 Great Blue Heron and a small group of Black Oystercatchers were observed resting on the offshore grassy islet. Many Canada geese were present and were being chased around the lagoon by an aggressive Trumpeter Swan.

Features noted at site during ground survey, by type and by feature name.

Zone	Feature Name	Description
Intertidal Physical Polygon	Bedrock	Small bedrock outcrop, patches of splashzone plants on top, lichens; shell hash/ pebble beach pocket at toe
	Pebble beach face	-- swash line of eelgrass on upper beach
Intertidal Biological Polygon	Salt Marsh	
Backshore Polygon	Invasive plants	Note cultural material along eroding upper edge of beach face at lower boundary of the polygon, above the scattered salt marsh plants at logline
	No vegetation	
Intertidal Line	Shoreline	

b. Coast Harbourside Ground Survey Classification



Coast Harbourside

Site visit on July 4, 2019

Despite this unit being substantially modified, the site includes a variety of habitats and is spatially complex. Backshore completely modified by residential buildings, landscaping and paving.

Lush and diverse biota present in the lower intertidal zone (bladed kelps, mudflat with infaunal clams and worms; bull kelp bed nearby) likely due to the proximity of the site to Harbour entrance and the input to the harbour from the cold, nutrient-rich waters of Juan de Fuca Strait.

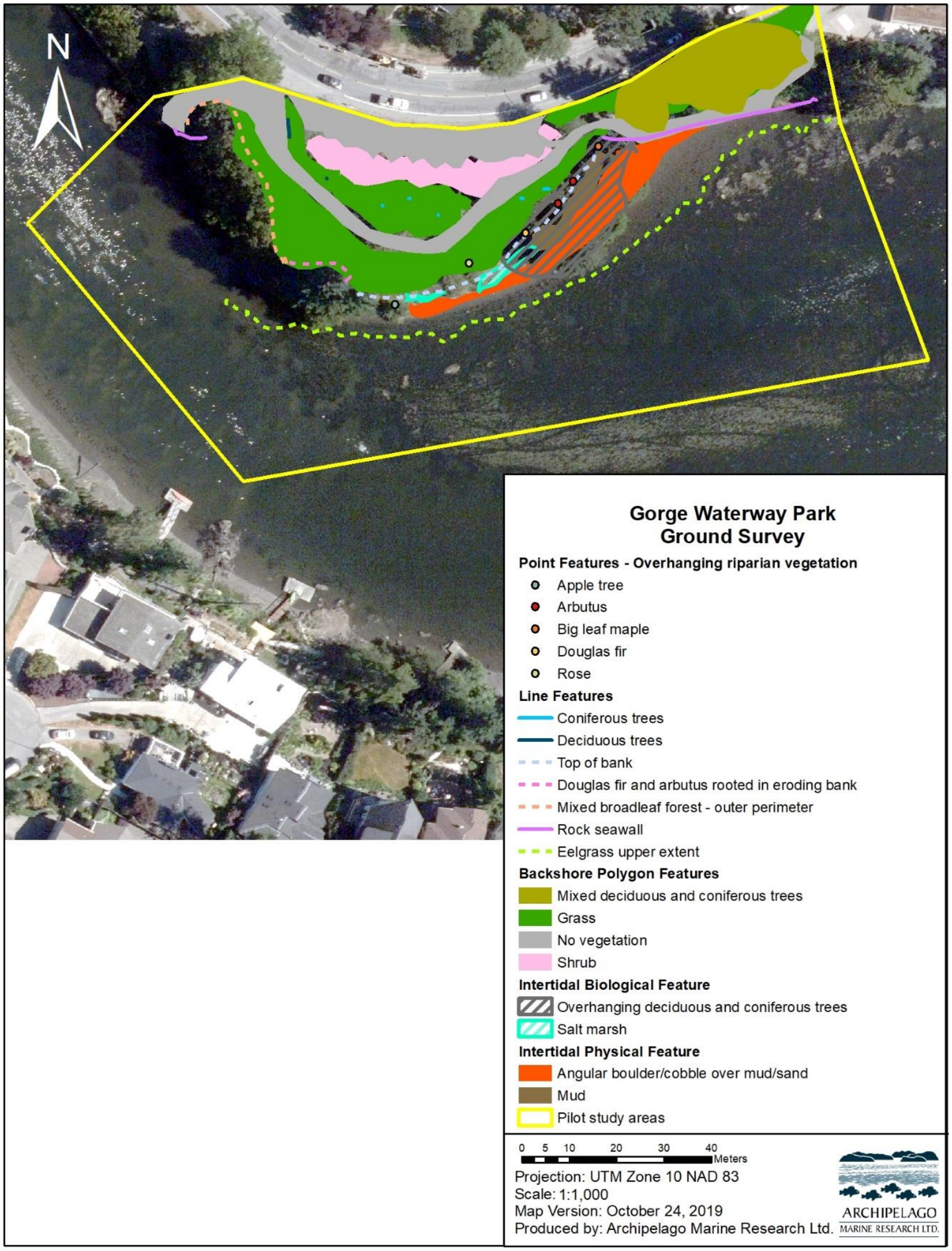
Features observed/surveyed on the ground included:

- Vertical concrete seawall, in part of upper intertidal zone
- Floating docks, wharves and pilings in the nearby marina
- Riprap sections, lower intertidal zone, in part of the site, mostly at the north end of the unit
- Piled walkway over upper intertidal riprap, in part of the site
- Mud/boulder flats below at lower intertidal zone, in the corner, in part of the site
- Sparse gumweed, sea asparagus on upper riprap
- Clams squirting from lower intertidal zone flats
- Thick bladed benthic kelps at foot of seawall at north end of unit
- Bull kelp offshore, north end of unit
- Unusual-looking concreted fill area in upper intertidal near the corner of the unit

Features noted at site, by type and by feature name.

Zone	Feature Name	Description
Intertidal Physical Polygon	Mudflat	Bases of former pilings, eroded flat in the mud
	Riprap	
	Concrete remnants	
	Raised wood platform	
	Dock	In the marinas
Intertidal Biological Polygon	Green algae	
Backshore Polygon	Bare ground	Raised walkway on piles
	No vegetation	Paved sidewalk path
Intertidal Line	Border of Barnacle and Rockweed	On riprap
	Top of concrete seawall	
	Bladed kelps along seawall	
Intertidal points	Bedrock outcrop	
Intertidal profiles	Riprap bank x2	
	Vertical seawall	

c. **Gorge Waterway Park Ground Survey Classification**



Gorge Park

Site visit on July 5, 2019

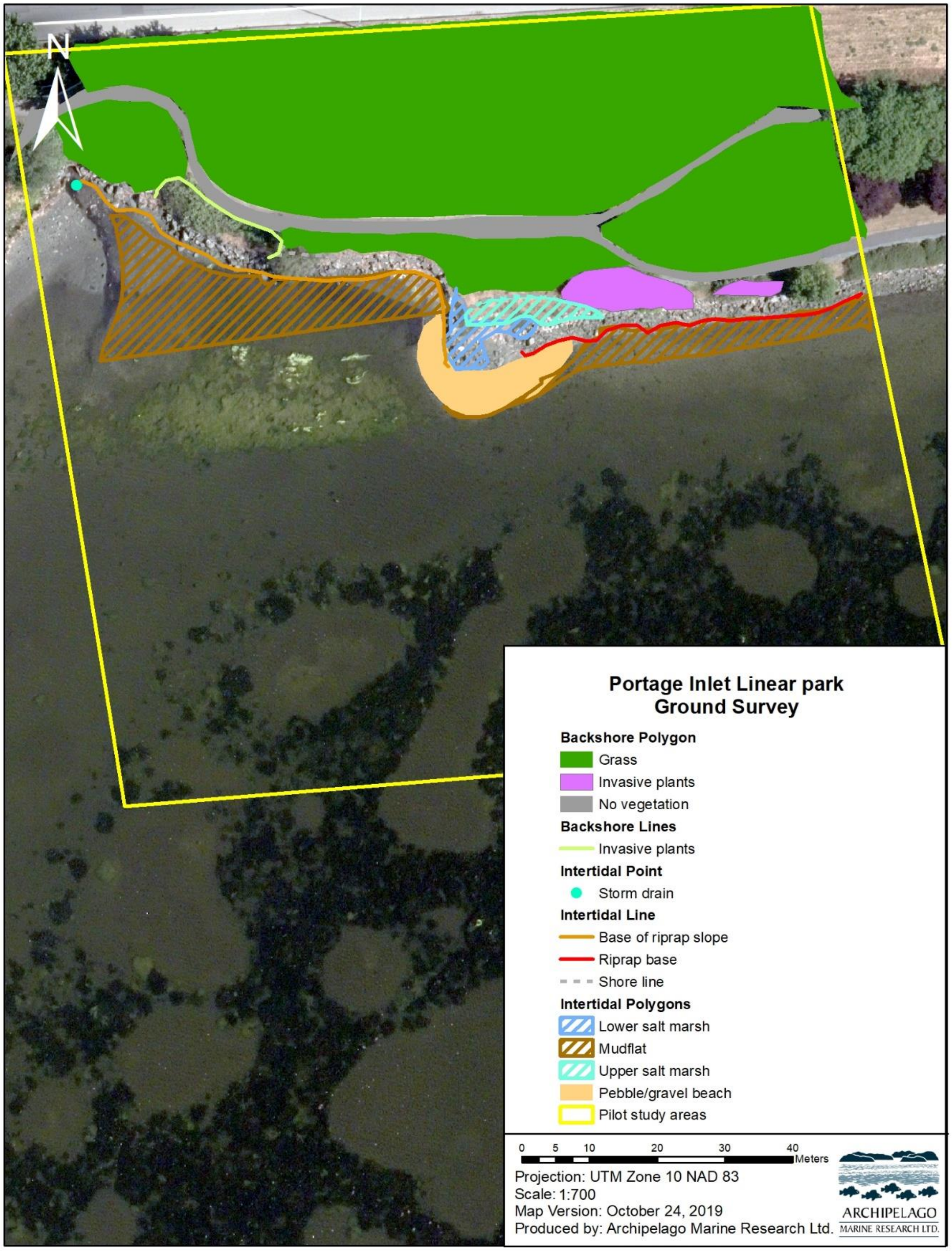
The Gorge Park unit has a low, steep cutbank along the length of the upper most 'splashzone', with sections of dense riparian vegetation overhang, including mature Douglas fir, Broad Leaf Maple and Arbutus; as well as small patches of salt marsh and escaped garden plants. Vertical stone seawall occurs at each end of the section. Evidence of former concrete steps, apple tree and rose bush along top of cutbank indicate sites of former houses and disturbed soils in backshore.

The lower slope is mostly a narrow beach face. Angular cobble and debris present as veneer over finer material on beach. Abundant introduced snail (spiral shell *Batillaria*) are present. Native oyster and other clams and oysters observed. Abundant rooted eelgrass in nearshore subtidal, and drift eelgrass on swash line.

Features observed/surveyed at site, by type and by feature name.

Zone	Feature Name	Description
Intertidal Physical Polygon	Angular boulder/cobble over mud/sand	
	Mud	
Intertidal Biological Polygon	Salt Marsh X2	
	Overhanging deciduous and coniferous trees	
Backshore polygon	Grass X3	
	Shrub X2	
	No vegetation X2	
Backshore line	Coniferous forest	Edge of clumps of trees in park
	Deciduous forest	Edge of clumps of trees in park
	Deciduous forest	
Intertidal Line	Rock sea wall X2	
	Eelgrass upper edge	
	Douglas fir and Arbutus in eroding bank	
	Mixed broadleaf forest- outer perimeter	
	Top of Bank	
Point Features	Apple tree	Points mark location of vegetation rooted at top of bank and overhanging in riparian
	Douglas fir	
	Arbutus X2	
	Rose bush	
	Big leaf Maple	

d. Portage Inlet Linear Park Ground Survey Classification



Portage Inlet
July 19, 2019

Unit length at upper Portage Inlet shoreline is completely modified along the linear park area between the TransCanada Highway and the riprap bank at the higher high-water line. Backshore is landscaped parkland with thicket of blackberry and shrubs along the riparian.

Small areas of upper splashzone vegetation and salt marsh are present. Below the riprap bank, a linear muddy pebble beach is present, covered in abundant introduced snail, *Batillaria.* A few clumps of old peat were noted, emerging from base of riprap at the upper edge of the mudflat.

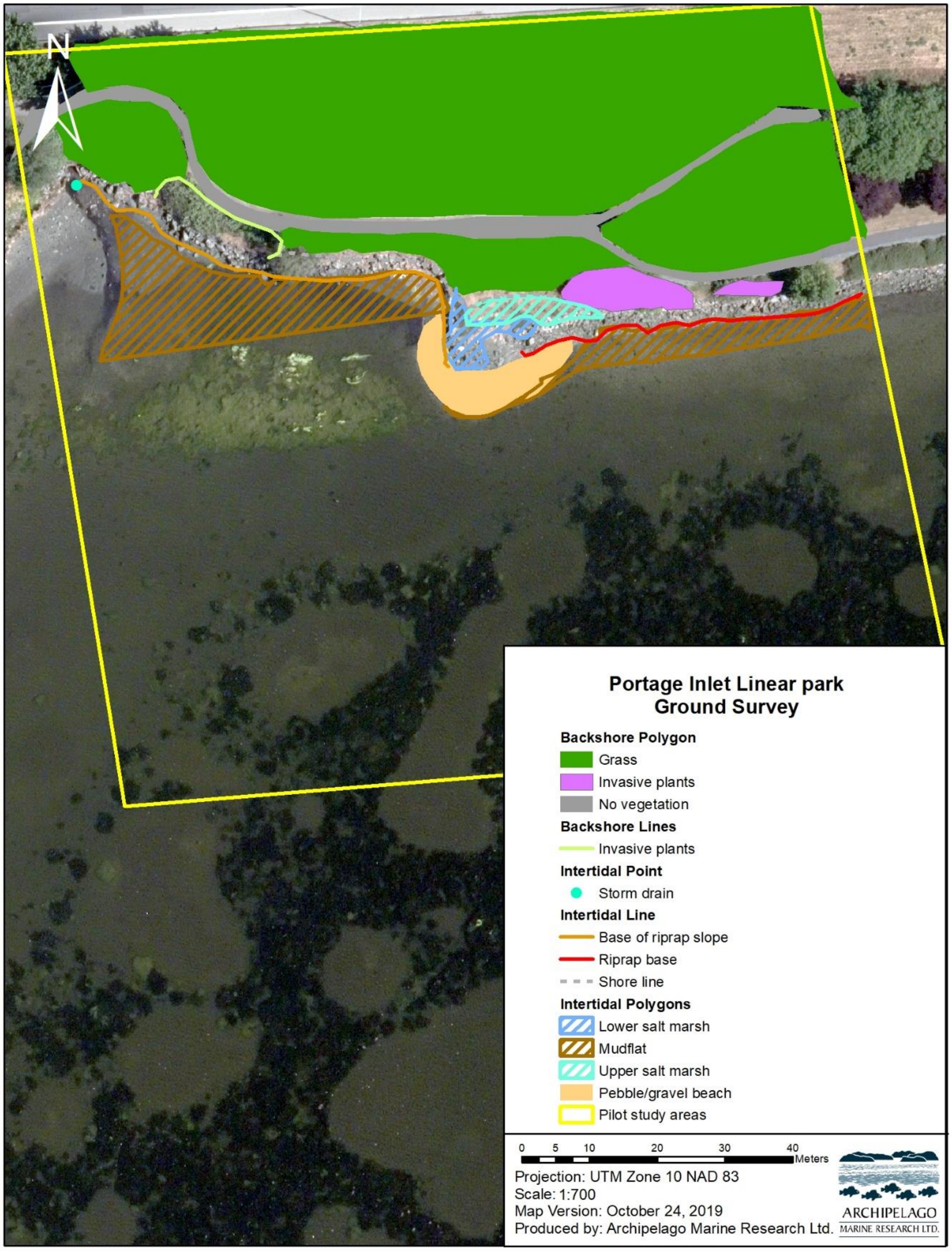
Nearshore water is shallow, < .5m water depth with dense bed of eelgrass extending across the Inlet. Thick swash line of dried eelgrass observed on the higher high-water swash across the riprap bank.

West end of unit includes a storm drain and a few clumps of sedges on upper delta fan of finer sediment pebble/sand/mud formed below the culvert.

Features observed/surveyed at site, by type and by feature name.

Zone	Feature Name	Description
Intertidal Physical Polygon	Pebble/gravel beach	Angular boulder/cobble
Intertidal Biological Polygon	Mudflat X2	
	Upper salt marsh	
	Lower salt marsh	
Backshore Polygon	No vegetation	
	Invasive plants X3	
	Grass X4	
Backshore Line	Invasive plants	Marine limit/shoreline, along top of riprap and surveyed in two sections
Intertidal Line	Waterline	
	Base of riprap X2	
Intertidal Point	Storm drain	

e. Rose Bay Ground Survey Classification



Rose Bay

Site visit on August 28, 2019

Pocket beach and mudflat at the south shore of entrance to Victoria Harbour. Backshore is much modified by buildings and roads however mature stands of trees and shrubs are present, including in the dense riparian vegetation along the north half of the unit which overhangs parts of the intertidal zone at the high-water line.

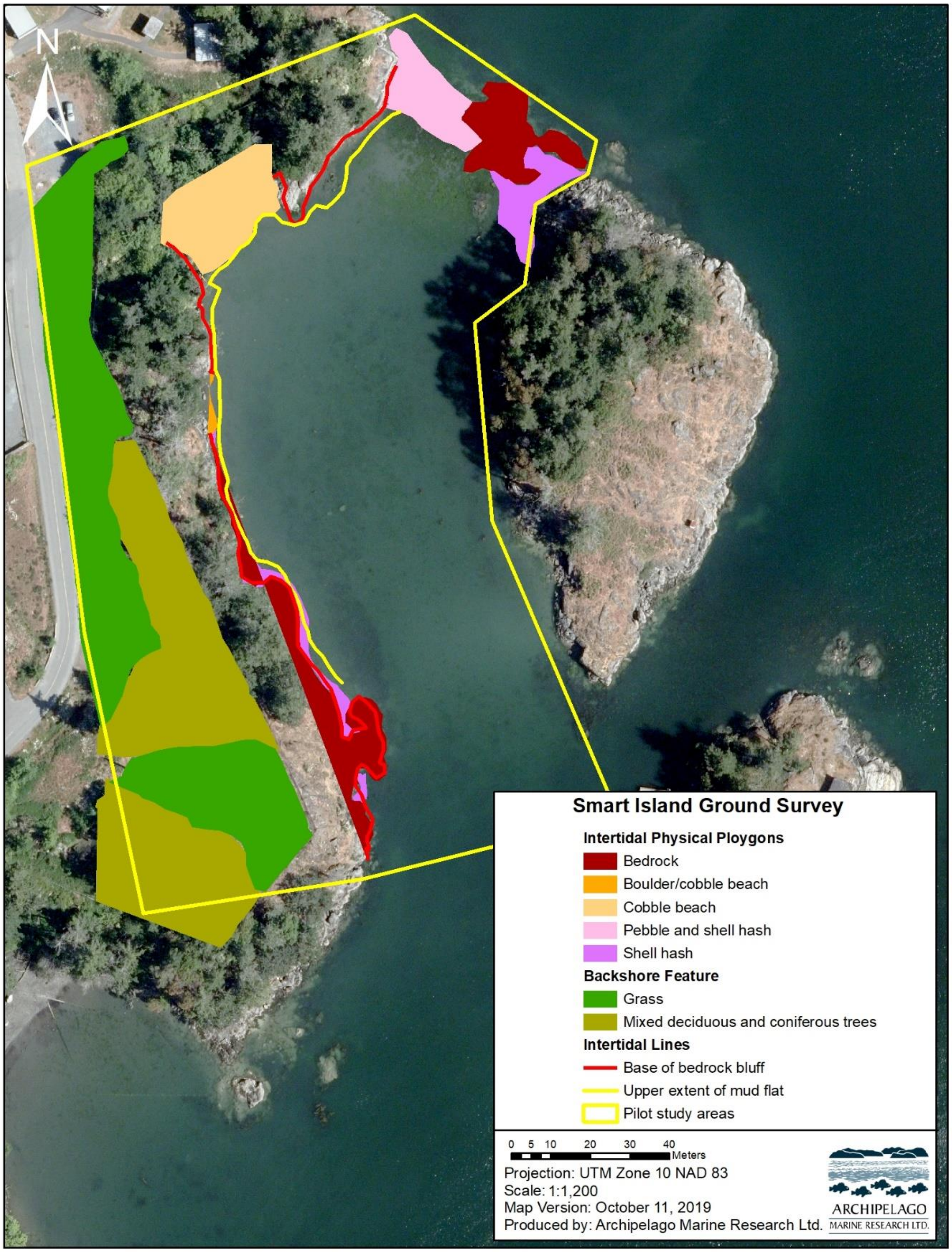
Natural bedrock ramp dominates the upper half of the intertidal zone at the south end of the unit, beach face of cobble/pebble/debris extends along the north half of the unit. Soft mud fills the lower intertidal zone of the bay and is notable for abundance of infaunal shows of clam squirts and tubeworms. A set of old concrete wharf footings crosses the mudflats.

Rubble on beach includes areas of bricks. Brick pylon structure and concrete steps are present at north end of the beach. Veneer of coal fragments are at the finer sands on the beach face at the north end of the beach. Numerous raccoon tracks and dug pits were seen. Riprap encircles the filled area of the RV park.

Features observed/surveyed:

Zone	**Feature Name**	**Description**
Intertidal Physical Polygon	Footings of pilings	On mudflat, concrete and rubble piles
	Bedrock outcroppings	Upper and mid intertidal, above mudflat
	Cobble boulder brick beach face	Small pocket beach at south; main biggest beach
	Sand, mud, pebble beach face with a coal veneer	
Intertidal Line	Upper edge of mudflat	Substrate on mudflat is soft to mucky mud with abundant shell hash; pebble veneer at upper edge near bedrock (esp. at SW end); cultural debris, including bottles/metal fragments
	Concrete seawall	At uppermost beach
Intertidal point	Brick pylons X2	Upper coal beach, north end
Backshore	Mixed deciduous/conifer/shrub	
	Grassy knoll	
Transect	1 on bedrock point	Old concrete square footings and steps nearby to south

f. Smart Island Ground Survey Classification



Smart Island

Site visit on August 29 and 30, 2019

Smart Island site includes natural bedrock ramp and cliffs, pebble/cobble beaches and mudflats. Backshore is mature mixed conifer/deciduous dry forest, with open areas of grasses and weeds along roadside.

Intertidal zone includes low turf of attached algae and small invertebrates, and the broad shallow nearshore subtidal extends across the bay to Smart Island on the east. The site is partially open to the south, towards the harbour mouth, and several clumps of drift bull kelp and bladed benthic kelps were present on the flats.

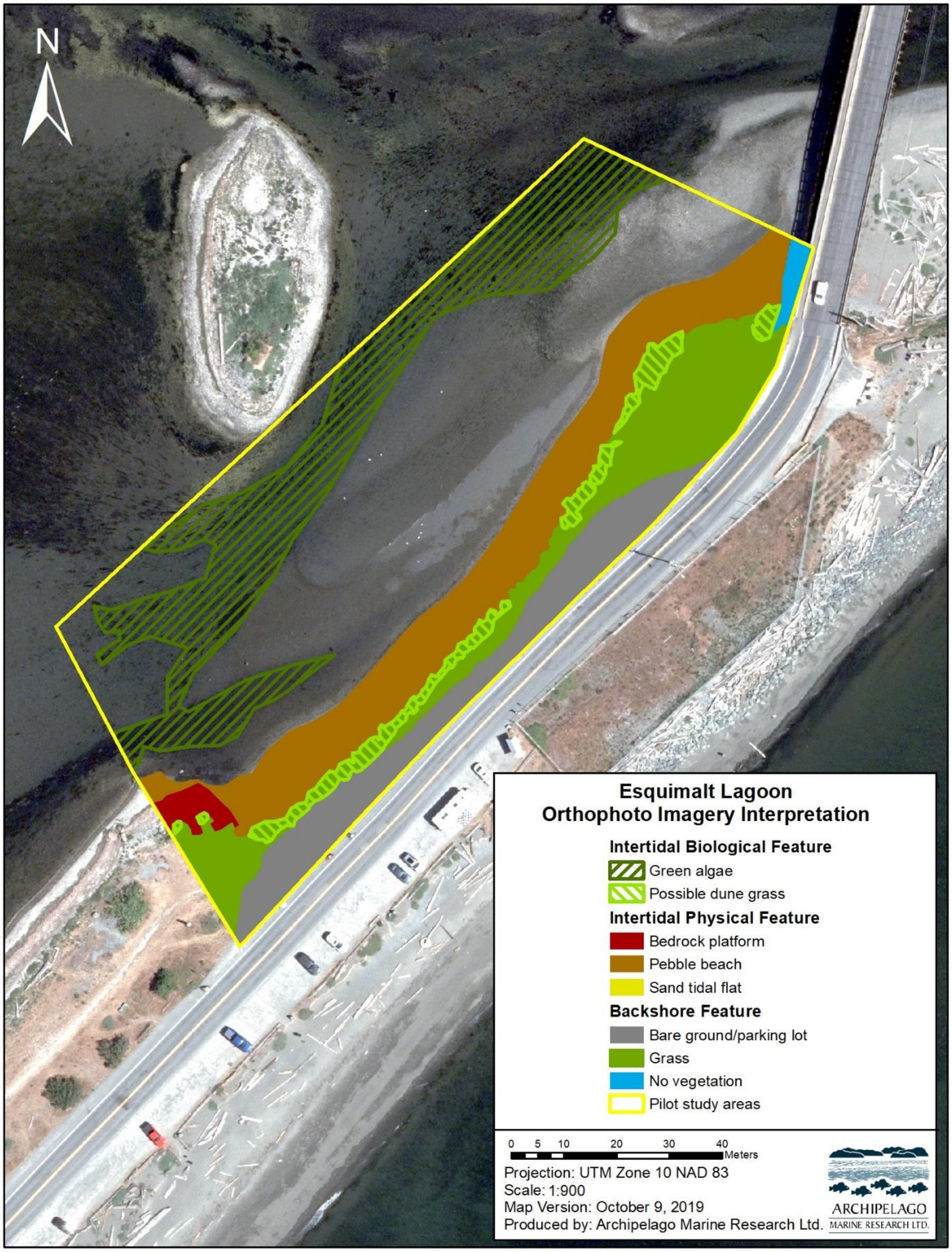
Abundant infaunal clams were observed squirting on the lower flats, around the washover tombolo area at the north end of the unit.

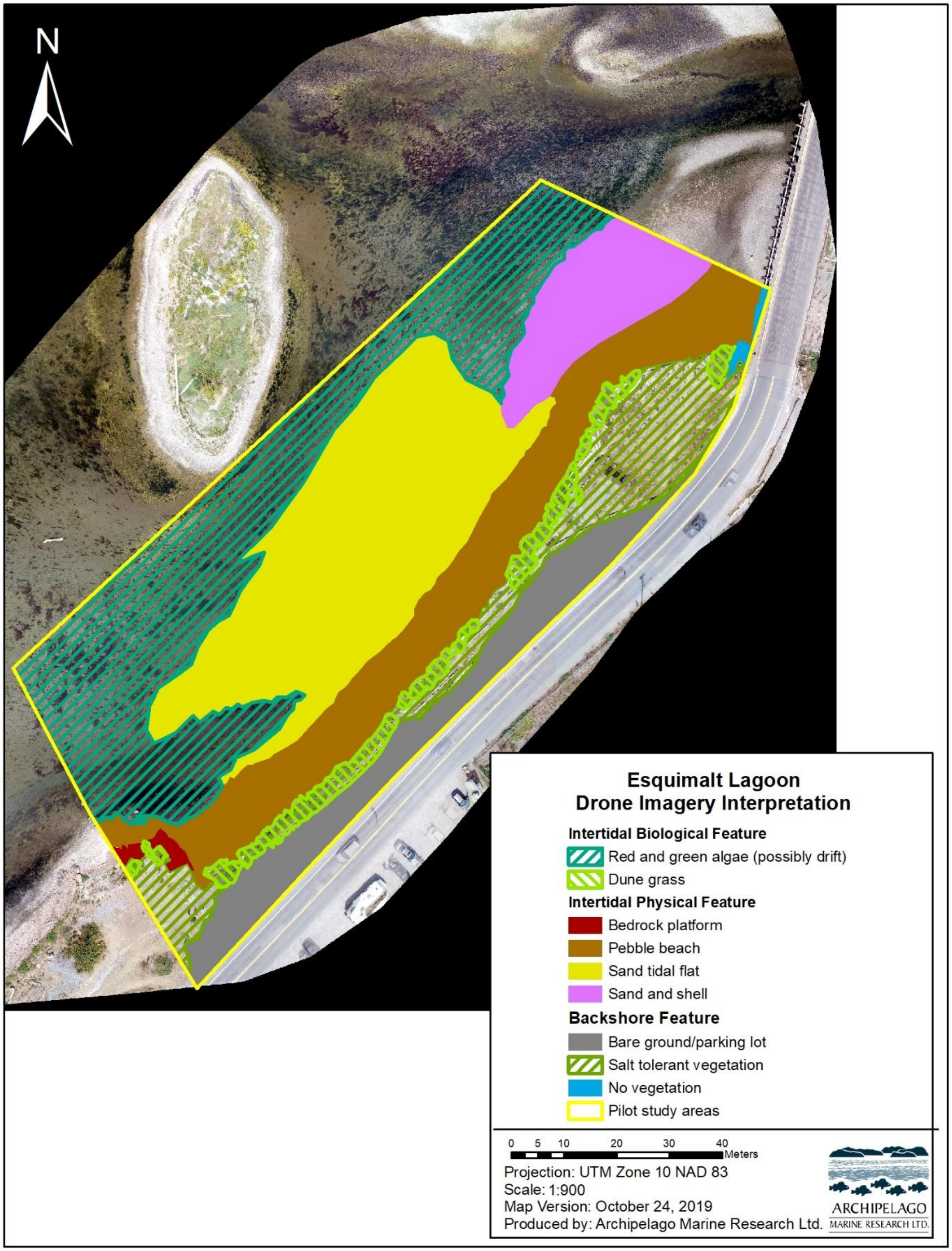
Features observed/surveyed:

Zone	Feature Name	Description
Backshore	Grassy knoll	Mixed dry grasses and weeds
	Bedrock outcrops	
	Mixed deciduous and conifer X2	
	Grassy hummock	Along the side of the road, mixed dry grasses and weeds
Intertidal Line	Lower edge Bedrock, upper edge mudflat	
Intertidal physical polygon	Mudflat	Abundant clams squirting, many horse clam siphons observed
	Tombolo flats with bedrock outcrops	Clam shell washover beach around bedrock outcrops
	Beach face X2	Veneer of pebble/cobble over sand
Intertidal profile	On bedrock ramp	

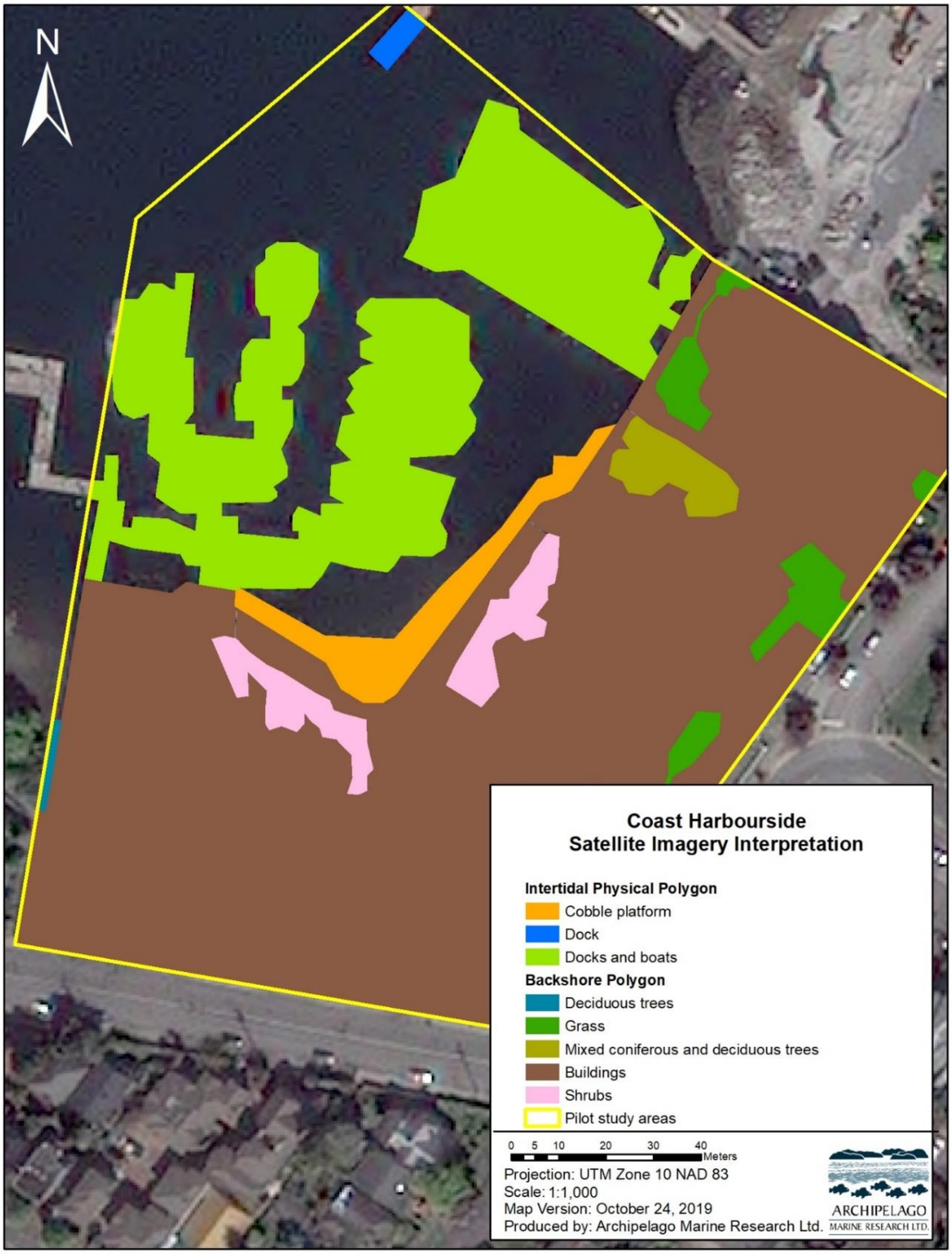
Appendix B – Image interpretation for three image types (satellite, orthophoto, and drone) at all six CRD pilot study sites

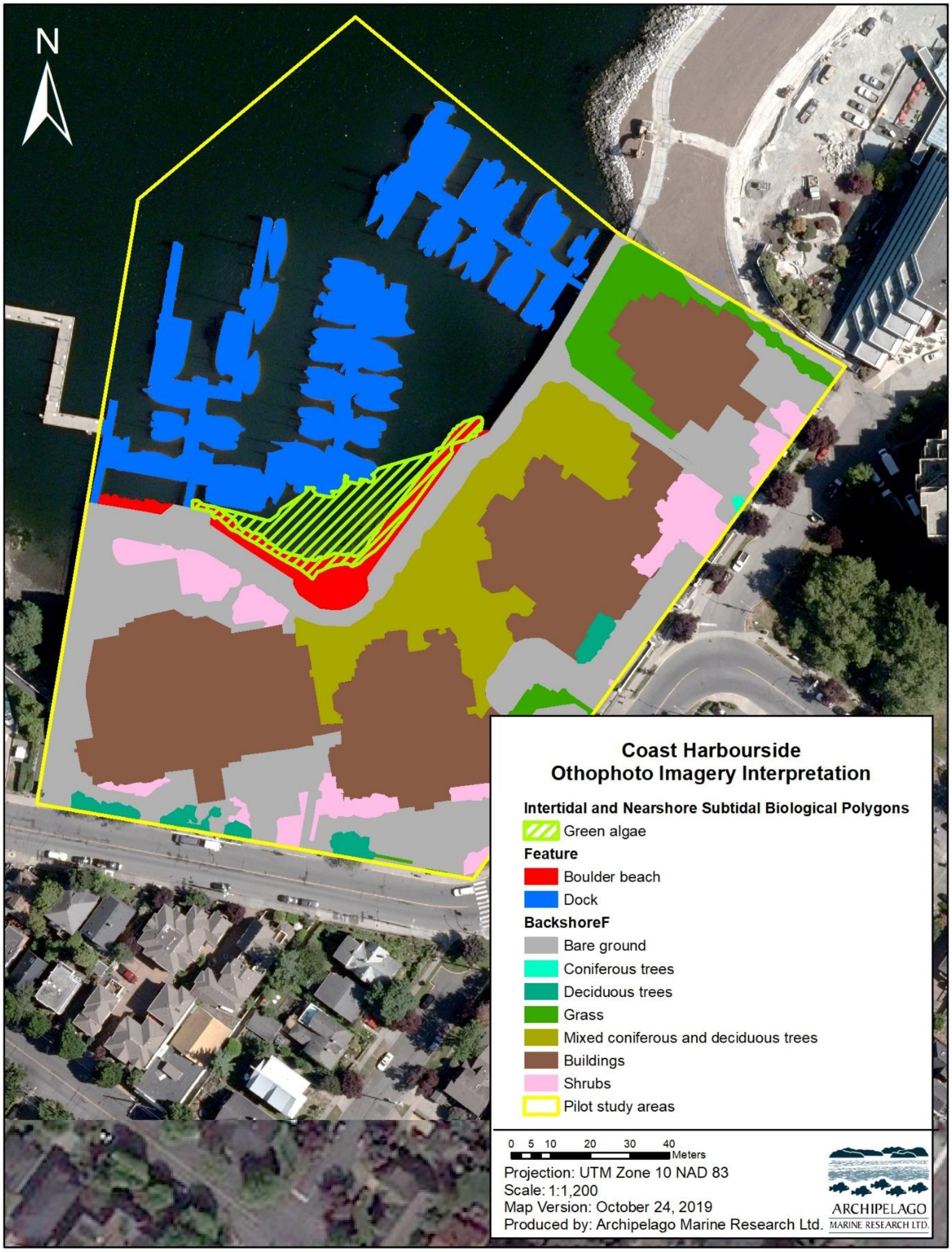
a. **Esquimalt Lagoon Image Interpretation (satellite, orthophoto, and drone respectively)**

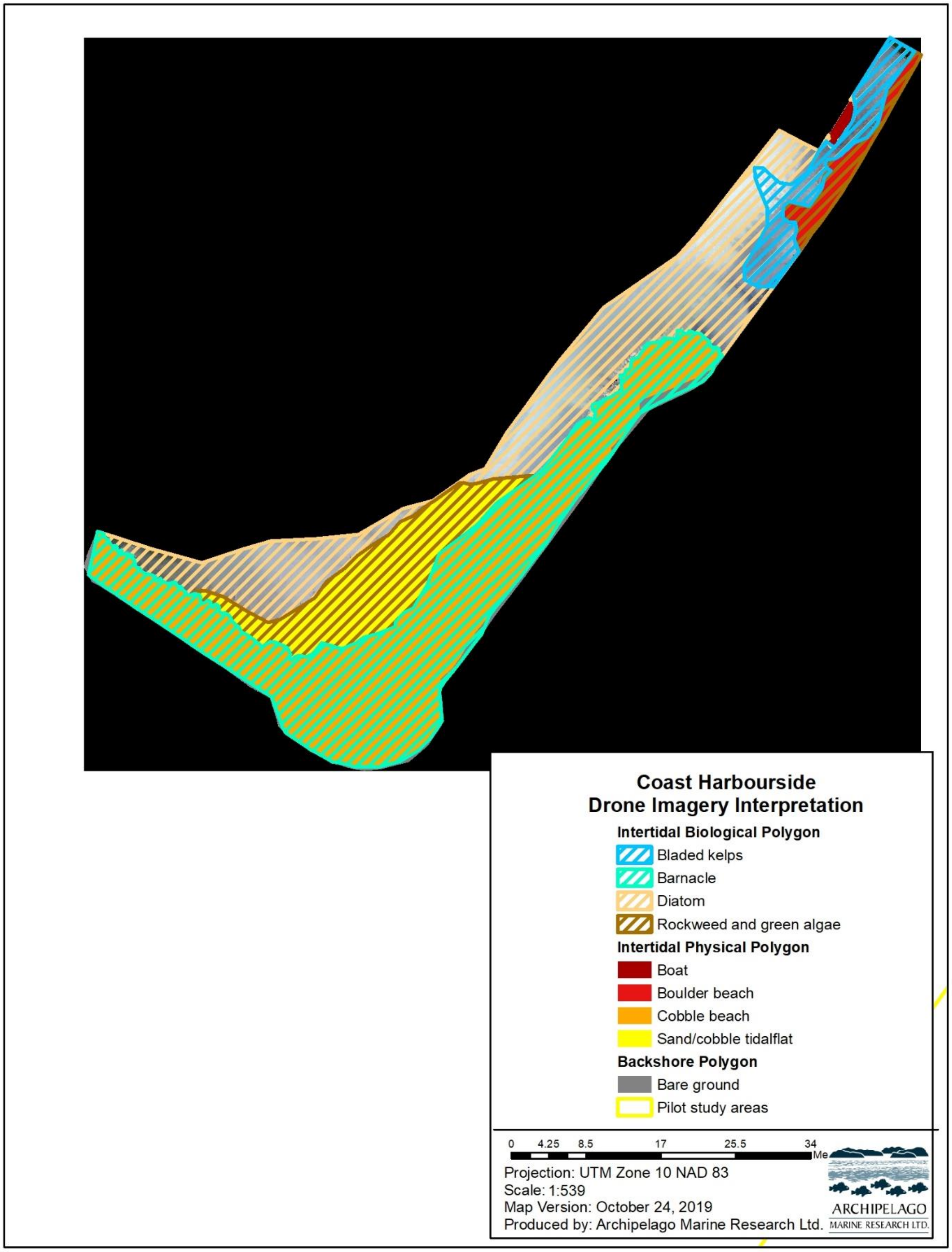

N
Esquimalt Lagoon
Orthophoto Imagery Interpretation
Intertidal Biological Feature
Green algae
Possible dune grass
Intertidal Physical Feature
Bedrock platform
Pebble beach
Sand tidal flat
Backshore Feature
Bare ground/parking lot
Grass
No vegetation
Pilot study areas
0 5 10 20 30 40
Meters
Projection: UTM Zone 10 NAD 83
Scale: 1:900
Map Version: October 9, 2019
Produced by: Archipelago Marine Research Ltd.
ARCHIPELAGO
MARINE RESEARCH LTD.


N
Esquimalt Lagoon
Drone Imagery Interpretation
Intertidal Biological Feature
Red and green algae (possibly drift)
Dune grass
Intertidal Physical Feature
Bedrock platform
Pebble beach
Sand tidal flat
Sand and shell
Backshore Feature
Bare ground/parking lot
Salt tolerant vegetation
No vegetation
Pilot study areas
0 5 10 20 30 40 Meters
Projection: UTM Zone 10 NAD 83
Scale: 1:900
Map Version: October 24, 2019
Produced by: Archipelago Marine Research Ltd.
ARCHIPELAGO MARINE RESEARCH LTD.

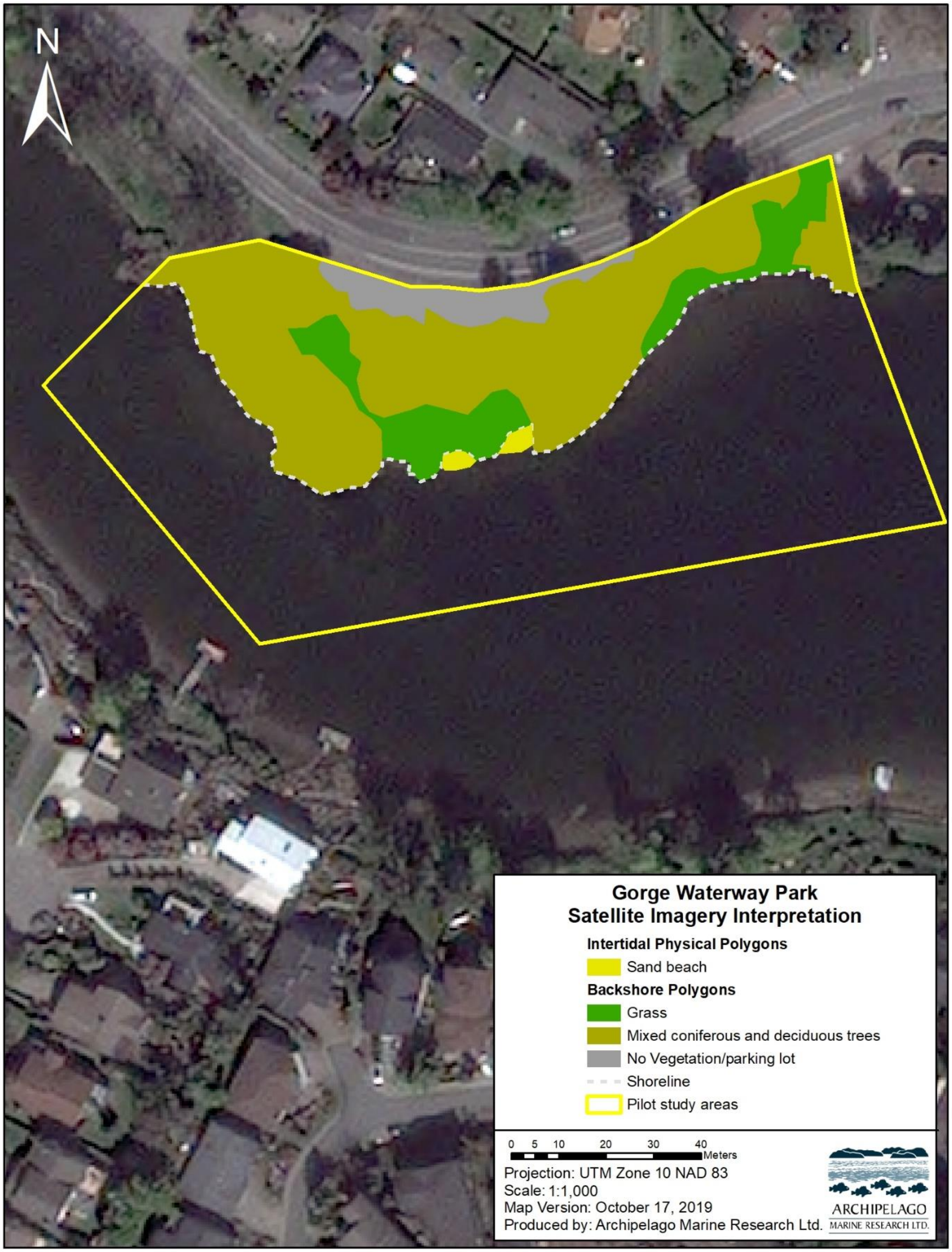
b. Coast Harbourside Image Interpretation (satellite, orthophoto, and drone respectively)

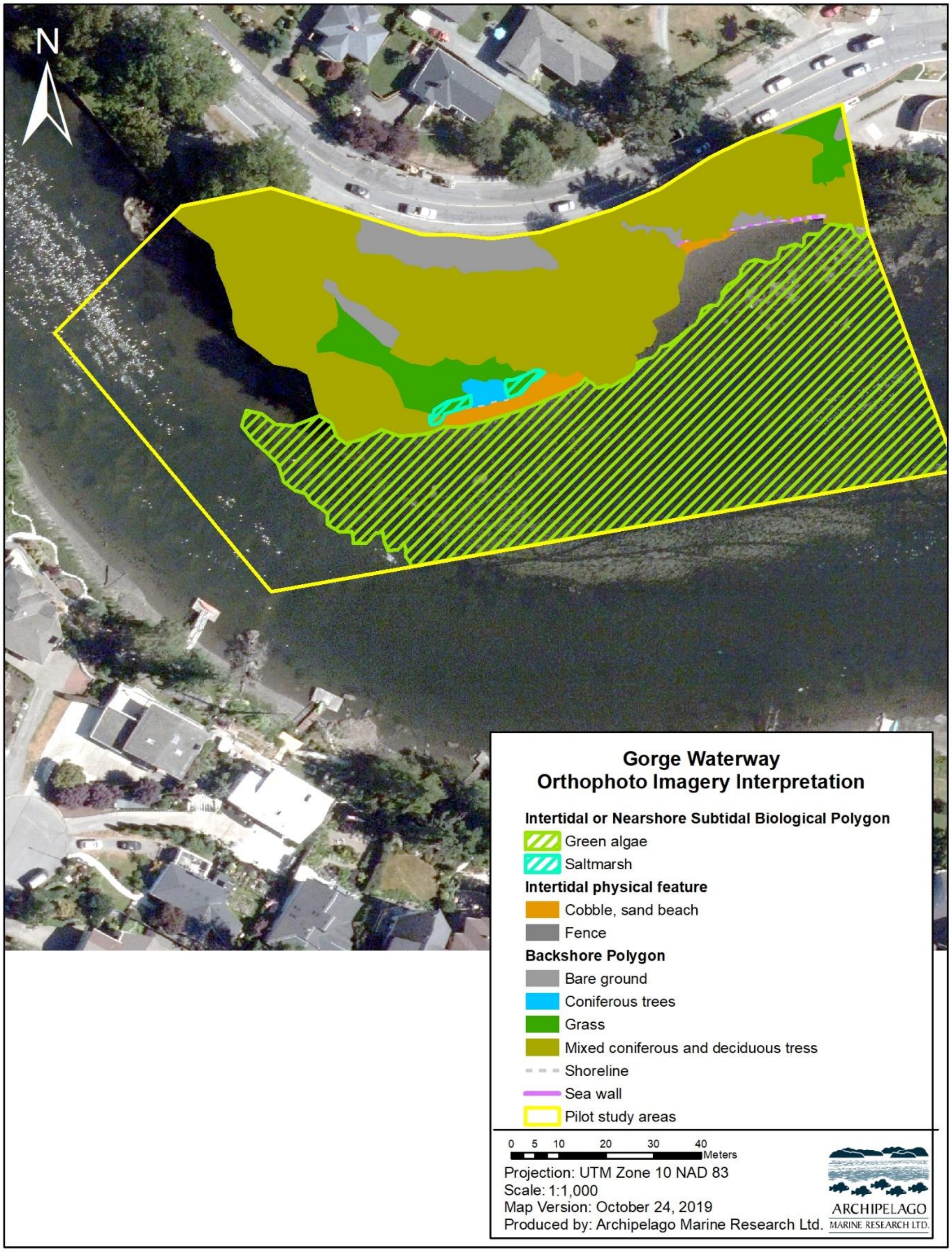


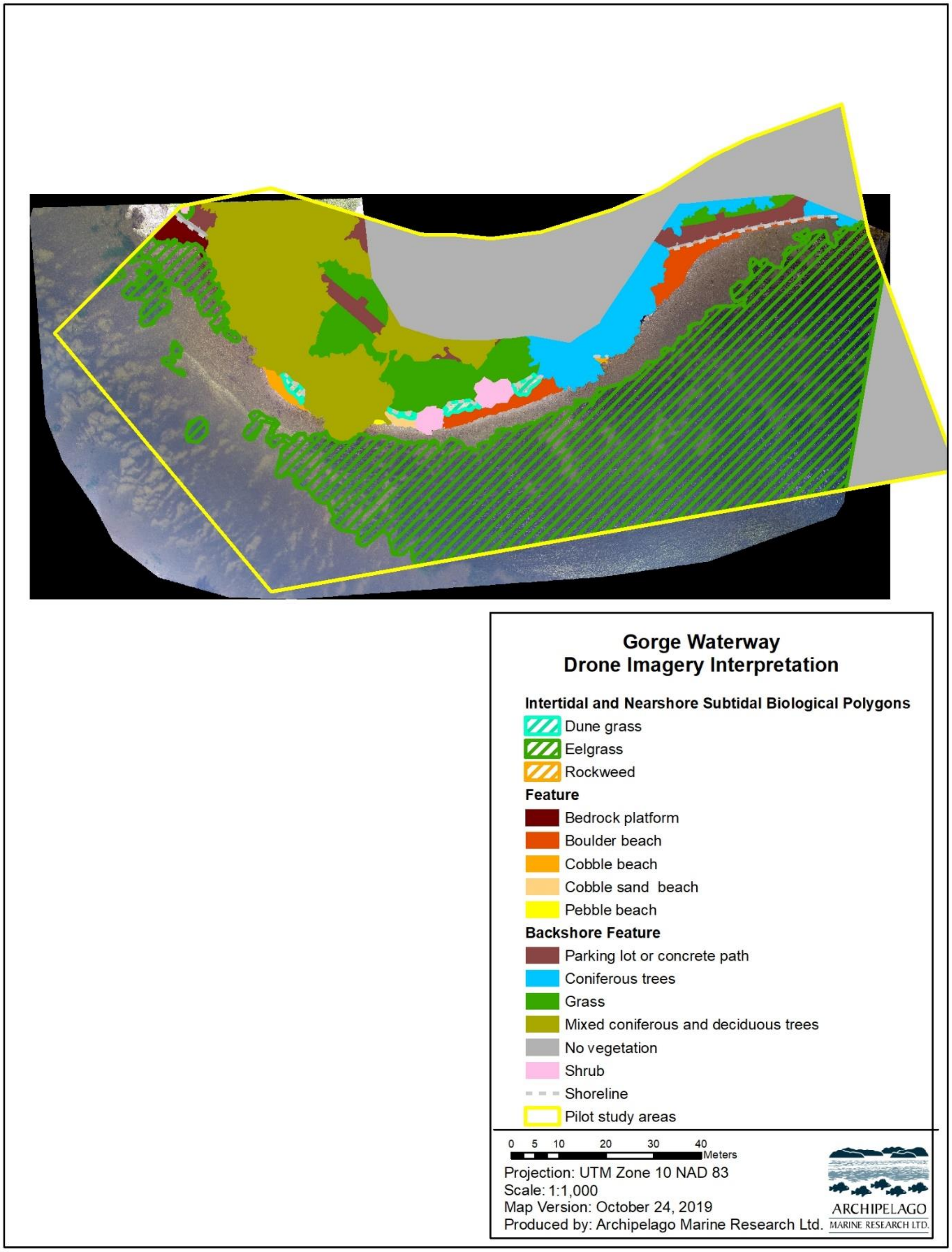

N
Coast Harbourside
Othophoto Imagery Interpretation
Intertidal and Nearshore Subtidal Biological Polygons
Green algae
Feature
Boulder beach
Dock
BackshoreF
Bare ground
Coniferous trees
Deciduous trees
Grass
Mixed coniferous and deciduous trees
Buildings
Shrubs
Pilot study areas
0 5 10 20 30 40 Meters
Projection: UTM Zone 10 NAD 83
Scale: 1:1,200
Map Version: October 24, 2019
Produced by: Archipelago Marine Research Ltd.
ARCHIPELAGO MARINE RESEARCH LTD.


Coast Harbourside
Drone Imagery Interpretation
Intertidal Biological Polygon
Bladed kelps
Barnacle
Diatom
Rockweed and green algae
Intertidal Physical Polygon
Boat
Boulder beach
Cobble beach
Sand/cobble tidalflat
Backshore Polygon
Bare ground
Pilot study areas
0 4.25 8.5 17 25.5 34
Projection: UTM Zone 10 NAD 83
Scale: 1:539
Map Version: October 24, 2019
Produced by: Archipelago Marine Research Ltd.
ARCHIPELAGO
MARINE RESEARCH LTD.

c. **Gorge Waterway Image Interpretation (satellite, orthophoto, and drone respectively)**

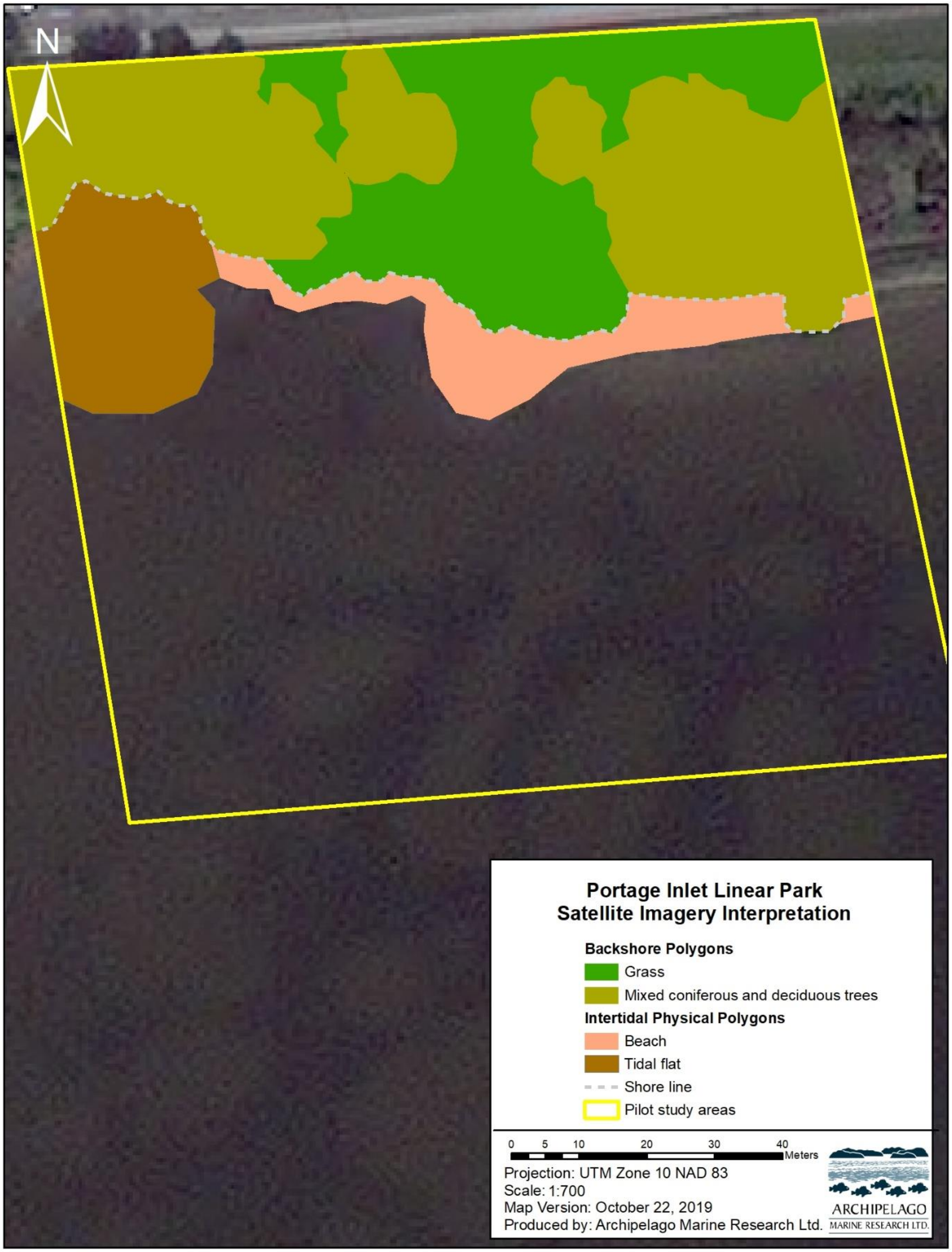


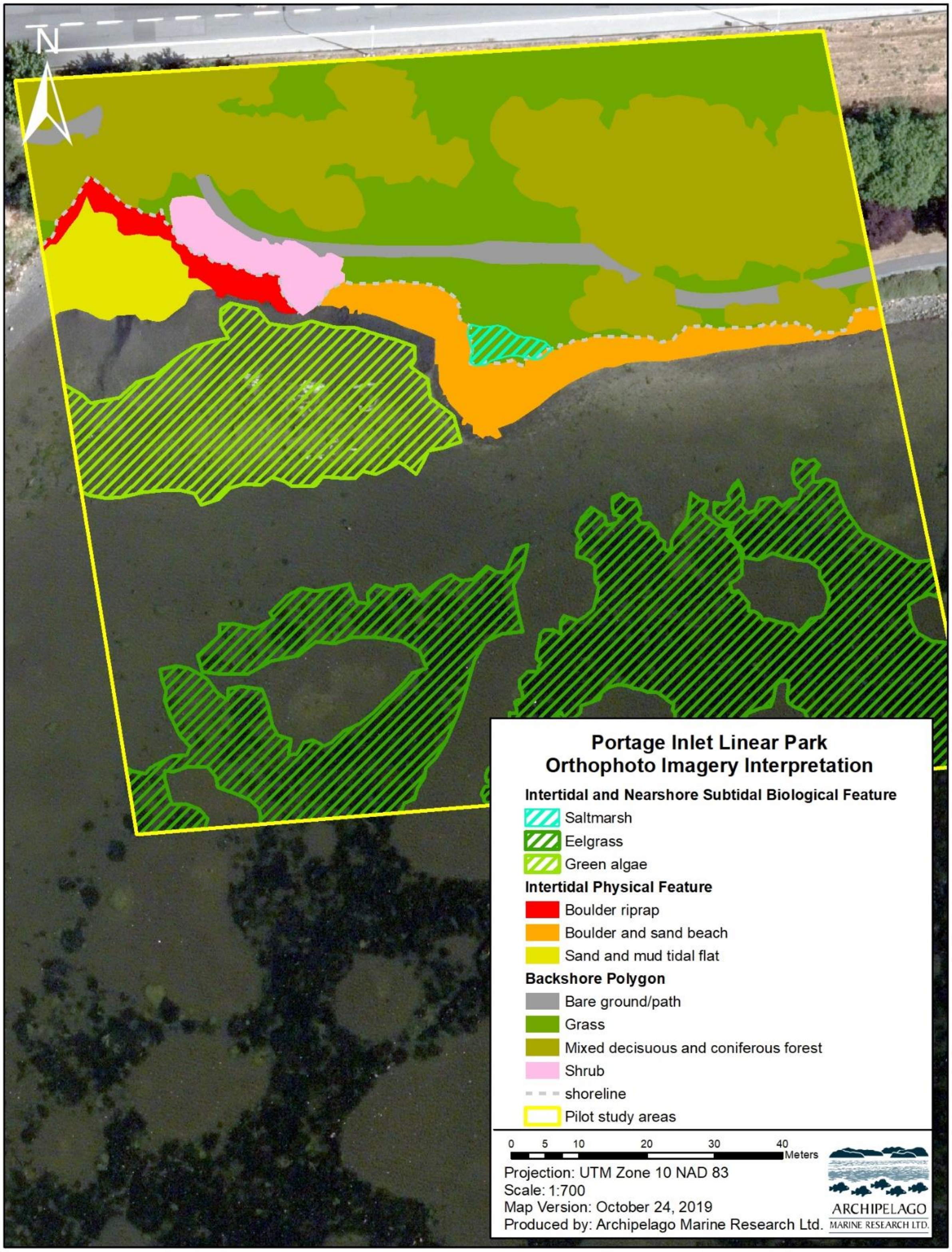

N
Gorge Waterway
Orthophoto Imagery Interpretation
Intertidal or Nearshore Subtidal Biological Polygon
Green algae
Saltmarsh
Intertidal physical feature
Cobble, sand beach
Fence
Backshore Polygon
Bare ground
Coniferous trees
Grass
Mixed coniferous and deciduous tress
Shoreline
Sea wall
Pilot study areas
0 5 10 20 30 40
Meters
Projection: UTM Zone 10 NAD 83
Scale: 1:1,000
Map Version: October 24, 2019
Produced by: Archipelago Marine Research Ltd.
ARCHIPELAGO
MARINE RESEARCH LTD.

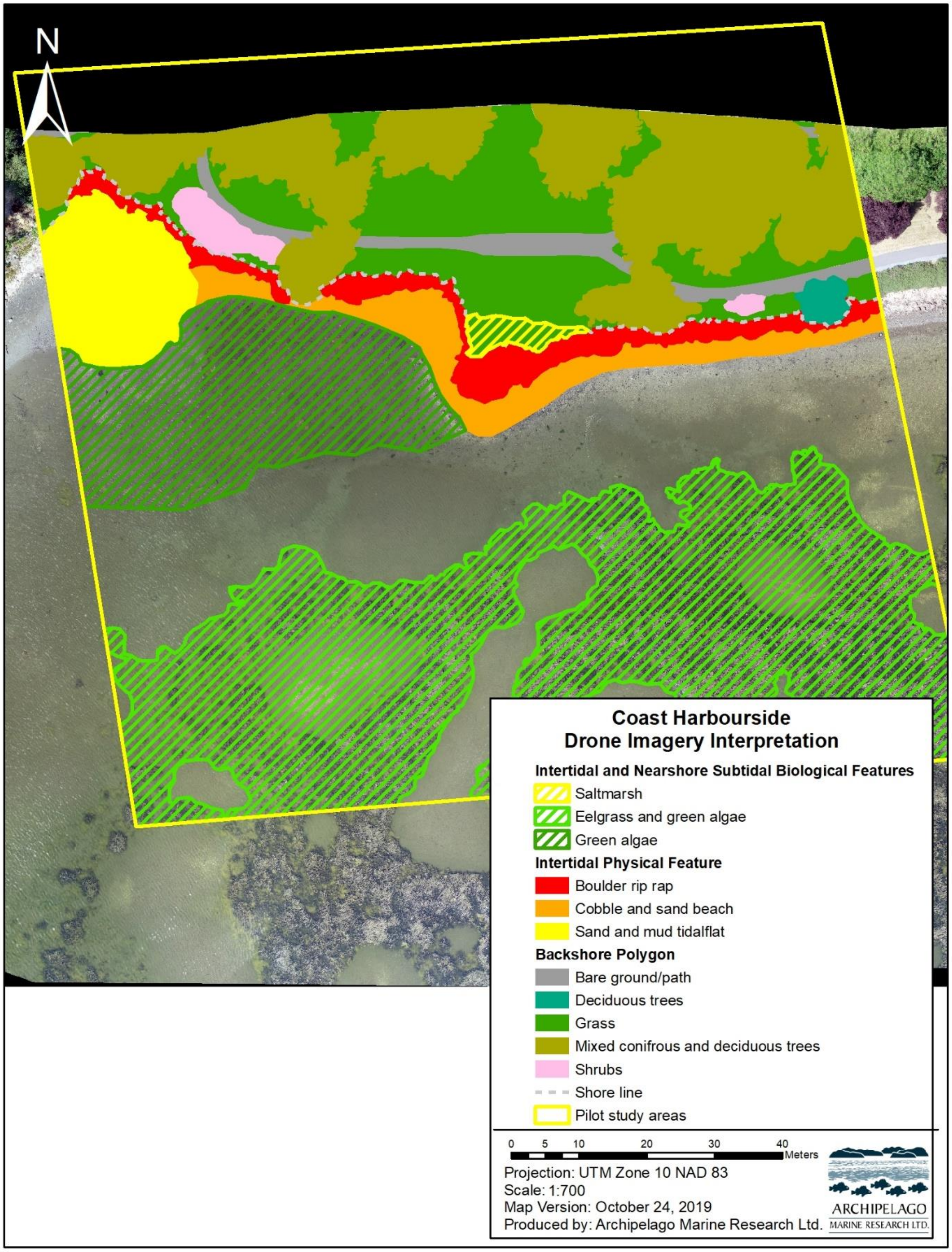


Gorge Waterway
Drone Imagery Interpretation
Intertidal and Nearshore Subtidal Biological Polygons
Dune grass
Eelgrass
Rockweed
Feature
Bedrock platform
Boulder beach
Cobble beach
Cobble sand beach
Pebble beach
Backshore Feature
Parking lot or concrete path
Coniferous trees
Grass
Mixed coniferous and deciduous trees
No vegetation
Shrub
Shoreline
Pilot study areas
0 5 10 20 30 40
Meters
Projection: UTM Zone 10 NAD 83
Scale: 1:1,000
Map Version: October 24, 2019
Produced by: Archipelago Marine Research Ltd.
ARCHIPELAGO
MARINE RESEARCH LTD.

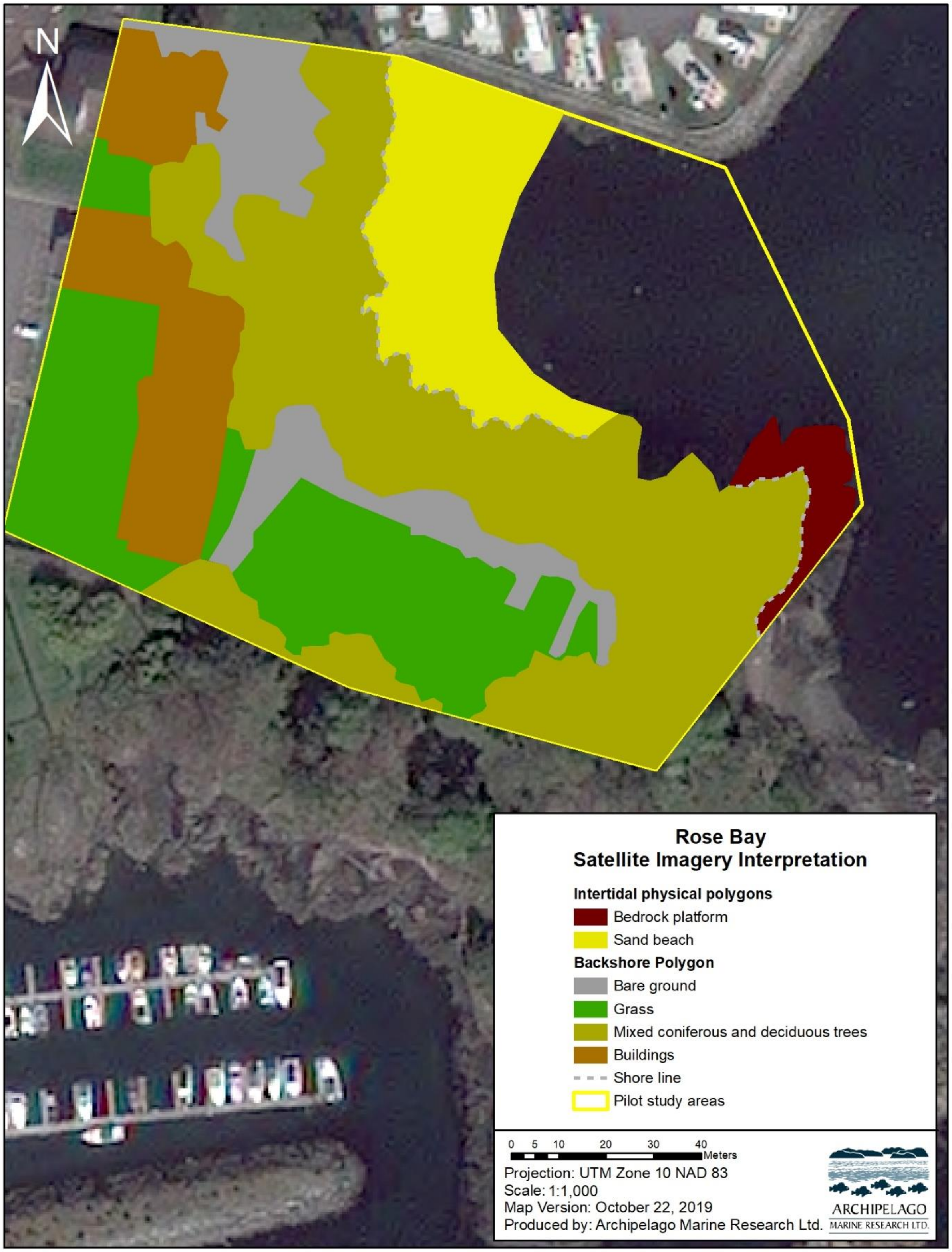
d. Portage Inlet Linear Park Image Interpretation (satellite, orthophoto, and drone respectively)

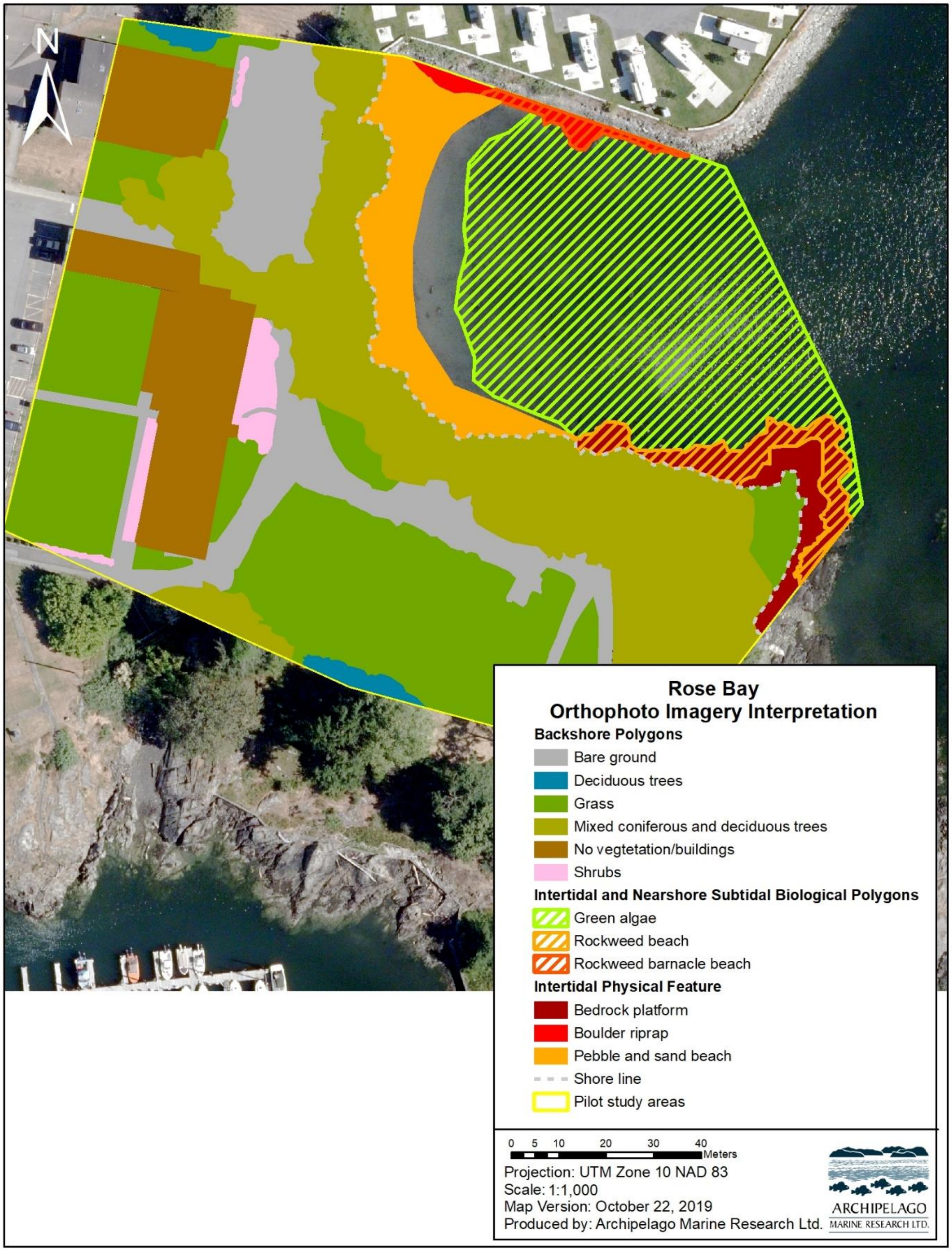


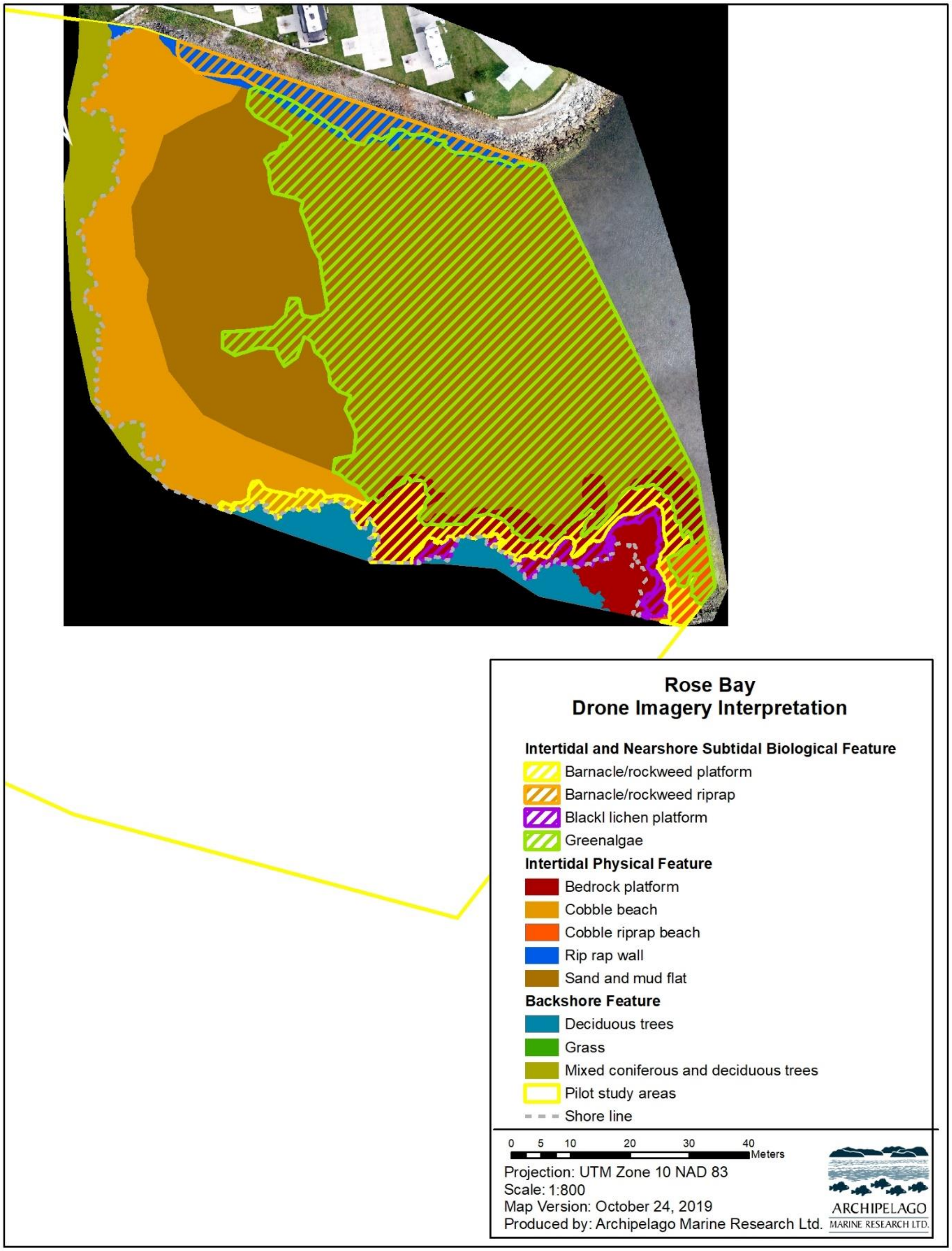

N
Portage Inlet Linear Park
Orthophoto Imagery Interpretation
Intertidal and Nearshore Subtidal Biological Feature
Saltmarsh
Eelgrass
Green algae
Intertidal Physical Feature
Boulder riprap
Boulder and sand beach
Sand and mud tidal flat
Backshore Polygon
Bare ground/path
Grass
Mixed decisuous and coniferous forest
Shrub
shoreline
Pilot study areas
0 5 10 20 30 40 Meters
Projection: UTM Zone 10 NAD 83
Scale: 1:700
Map Version: October 24, 2019
Produced by: Archipelago Marine Research Ltd.
ARCHIPELAGO MARINE RESEARCH LTD.


N
Coast Harbourside
Drone Imagery Interpretation
Intertidal and Nearshore Subtidal Biological Features
Saltmarsh
Eelgrass and green algae
Green algae
Intertidal Physical Feature
Boulder rip rap
Cobble and sand beach
Sand and mud tidalflat
Backshore Polygon
Bare ground/path
Deciduous trees
Grass
Mixed conifrous and deciduous trees
Shrubs
Shore line
Pilot study areas
0 5 10 20 30 40 Meters
Projection: UTM Zone 10 NAD 83
Scale: 1:700
Map Version: October 24, 2019
Produced by: Archipelago Marine Research Ltd.
ARCHIPELAGO
MARINE RESEARCH LTD.

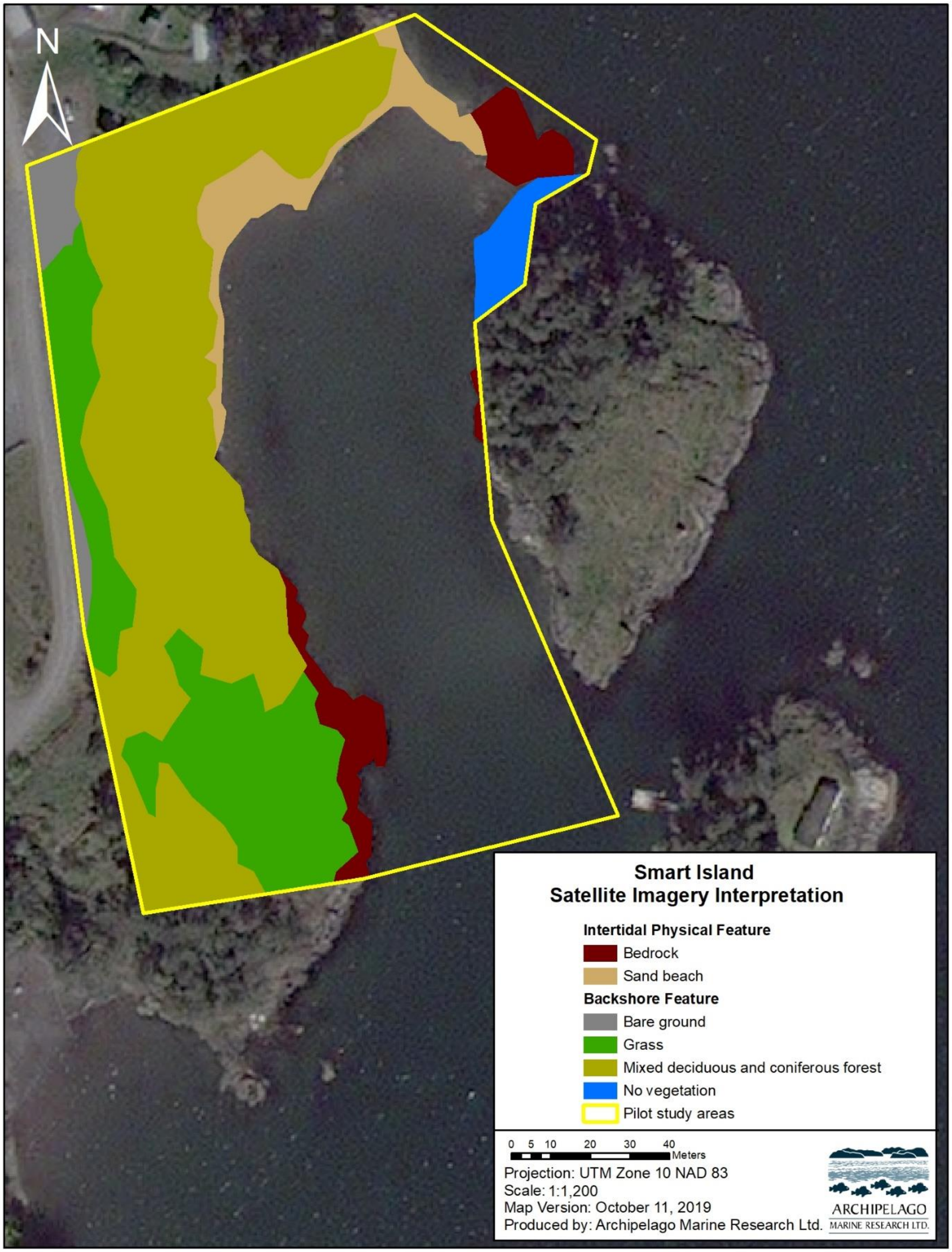
e. Rose Bay Image Interpretation (satellite, orthophoto, and drone respectively

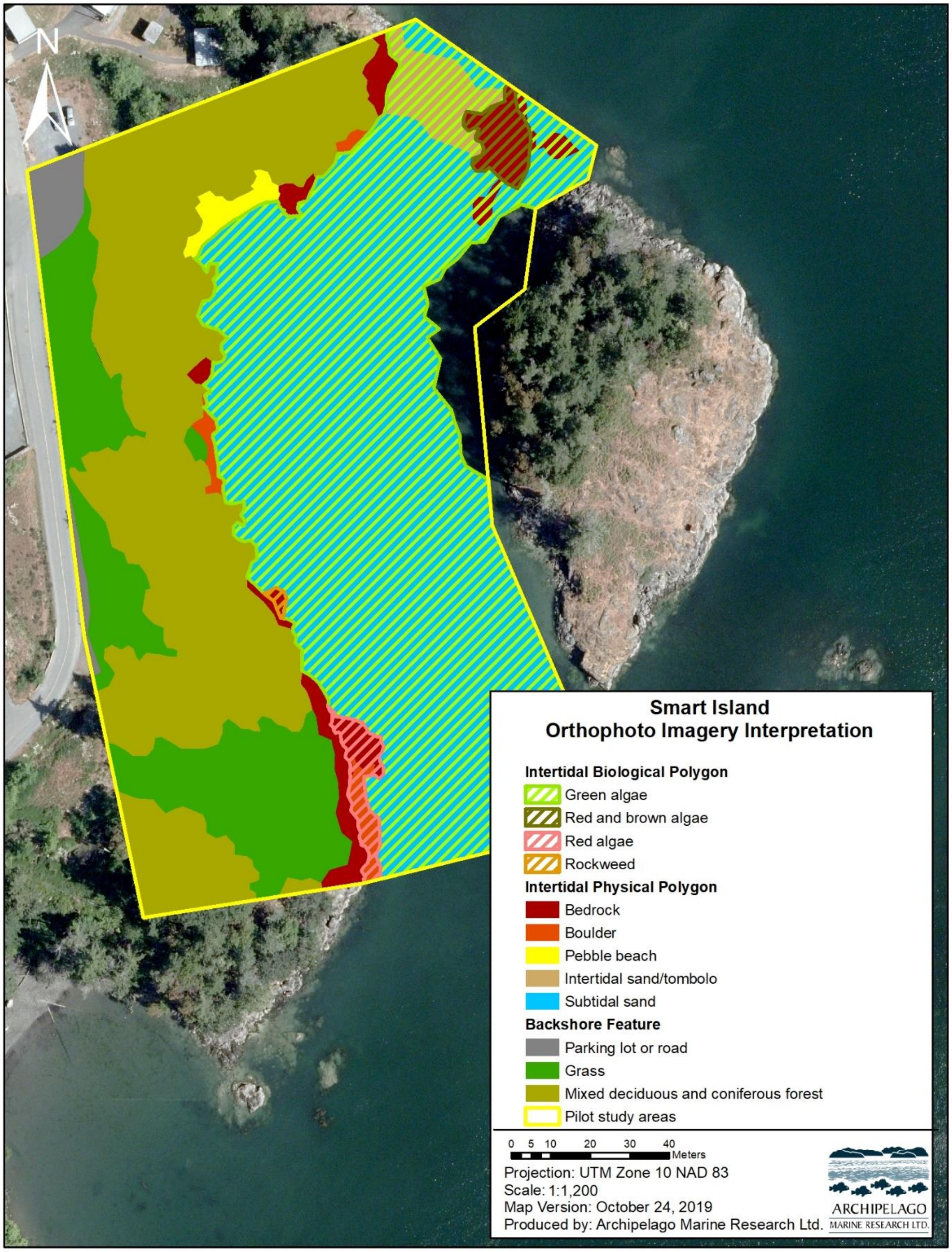


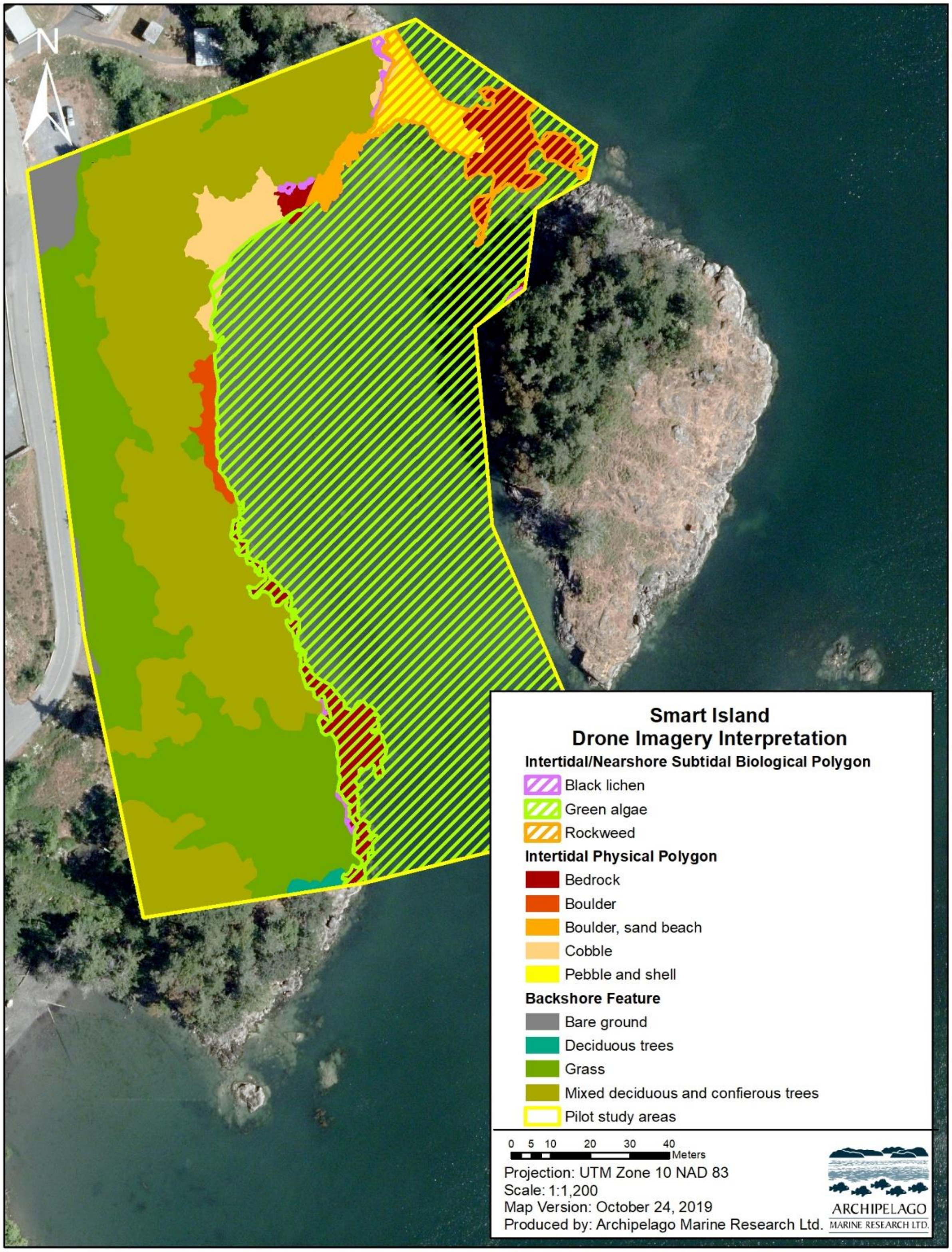

N
Rose Bay
Orthophoto Imagery Interpretation
Backshore Polygons
Bare ground
Deciduous trees
Grass
Mixed coniferous and deciduous trees
No vegtetation/buildings
Shrubs
Intertidal and Nearshore Subtidal Biological Polygons
Green algae
Rockweed beach
Rockweed barnacle beach
Intertidal Physical Feature
Bedrock platform
Boulder riprap
Pebble and sand beach
Shore line
Pilot study areas
0 5 10 20 30 40
Meters
Projection: UTM Zone 10 NAD 83
Scale: 1:1,000
Map Version: October 22, 2019
Produced by: Archipelago Marine Research Ltd.
ARCHIPELAGO
MARINE RESEARCH LTD.


Rose Bay
Drone Imagery Interpretation
Intertidal and Nearshore Subtidal Biological Feature
Barnacle/rockweed platform
Barnacle/rockweed riprap
Blackl lichen platform
Greenalgae
Intertidal Physical Feature
Bedrock platform
Cobble beach
Cobble riprap beach
Rip rap wall
Sand and mud flat
Backshore Feature
Deciduous trees
Grass
Mixed coniferous and deciduous trees
Pilot study areas
Shore line
0 5 10 20 30 40
Meters
Projection: UTM Zone 10 NAD 83
Scale: 1:800
Map Version: October 24, 2019
Produced by: Archipelago Marine Research Ltd.
ARCHIPELAGO
MARINE RESEARCH LTD.

f. Smart Island Image Interpretation (satellite, orthophoto, and drone respectively)




N
Smart Island
Orthophoto Imagery Interpretation
Intertidal Biological Polygon
Green algae
Red and brown algae
Red algae
Rockweed
Intertidal Physical Polygon
Bedrock
Boulder
Pebble beach
Intertidal sand/tombolo
Subtidal sand
Backshore Feature
Parking lot or road
Grass
Mixed deciduous and coniferous forest
Pilot study areas
0 5 10 20 30 40
Meters
Projection: UTM Zone 10 NAD 83
Scale: 1:1,200
Map Version: October 24, 2019
Produced by: Archipelago Marine Research Ltd.
ARCHIPELAGO
MARINE RESEARCH LTD.


N
Smart Island
Drone Imagery Interpretation
Intertidal/Nearshore Subtidal Biological Polygon
Black lichen
Green algae
Rockweed
Intertidal Physical Polygon
Bedrock
Boulder
Boulder, sand beach
Cobble
Pebble and shell
Backshore Feature
Bare ground
Deciduous trees
Grass
Mixed deciduous and confierous trees
Pilot study areas
0 5 10 20 30 40
Meters
Projection: UTM Zone 10 NAD 83
Scale: 1:1,200
Map Version: October 24, 2019
Produced by: Archipelago Marine Research Ltd.
ARCHIPELAGO
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Appendix C – Comparing mapped features for ground observations to three image types, for all six pilot study sites

Match Score	Definition
1	Perfect match -- Feature identified and area of extent the same as identified on the ground.
2	Match – Feature classification match but mapped extent differs due to variable tide heights or imagery covers subtidal or backshore areas not surveyed during ground survey.
3	Partial Match - Matched feature but mismatched elevation/ zone.
4	Partial Match - Mismatched feature but correct zone/elevation
5	No match - Detected during ground survey but not classified in imagery (omission)
6	No match - Mapped from imagery and not observed from ground survey (error)
Colour gradient	Feature delineated correctly in one location of the site, but same feature incorrectly mapped in another location of the site.
n/a	Feature present but not delineated on the ground; or feature present but not mapped separately in imagery.
	Imagery not available or submerged physical feature

a. Esquimalt Lagoon, comparing mapped features from ground survey to three image types.

Feature Type	Feature	Area mapped (m^2)			
		Ground Survey	Satellite	Orthophoto	Drone
Physical -- Intertidal	Bedrock	84		85	45
	Pebble beach	1297	1525	1441	2269
	Tidal flat	n/a		2835	2415
	Sand and shell	n/a			667
Biological -- Intertidal or Nearshore Subtidal	Saltmarsh	1180	1147	1227	1290
	Green algae (subtidal)	n/a		1916	2757
	Green algae(intertidal)	n/a	51		
Backshore	Invasive plants	73			
	Parking lot	879	911	809	854
	Rip rap	n/a		60	31

b. Coast Harbourside, comparing mapped features from ground survey to three image types.

Feature Type	Feature	Area mapped (m^2)			
		Ground Survey	Satellite	Orthophoto	Drone
Physical -- Intertidal	Mudflat (mud with boulder and sand)	325			212
	Rip rap	578	622	600	638
	Concrete remnants	103	n/a	n/a	n/a
	Raised wood platform	61			
	Dock or dock and boats	n/a	5061	3606	n/a
	Rock wall/sea wall	n/a			
	Boulder beach	n/a			47
Biological -- Intertidal or Nearshore Subtidal	Green algae	431		820	212
	Bladed kelp	n/a			101
	Barnacle/rockweed	n/a			650
Backshore	Bare ground/concrete walkway	550		5084	
	Buildings	n/a	13753	6105	
	Mixed coniferous and deciduous trees	n/a	305	1971	
	Grass	n/a	711	782	
	Deciduous trees	n/a	37	272	
	Shrubs	n/a	616	1223	
	Coniferous trees	n/a		11	

c. Gorge Waterway Park, comparing mapped features from ground survey to three image types.

Feature Type	Feature	Area mapped (m^2)			
		Ground Survey	Satellite	Orthophoto	Drone
Physical -- Intertidal	Boulder/cobble over mud/sand	320	51	129	189
	Mud	85			
	Rock sea wall	n/a		n/a	19
	Bedrock	n/a			46
Biological -- Intertidal or Nearshore Subtidal	Saltmarsh	32		42	39
	Eelgrass	n/a		4824	4288
Backshore	Parking lots and paths	1037	374	406	192
	Grass	1708	804	423	491
	Mixed coniferous and deciduous fores	520	3274	3480	1248
	Shrub	308		44	73

d. Portage Inlet Linear Park, comparing mapped features from ground survey to three image types.

Feature Type	Feature	Area mapped (m^2)			
		Ground Survey	Satellite	Orthophoto	Drone
Physical -- Intertidal	Pebble/gravel beach	156	n/a	n/a	n/a
	mudflat	687	734	263	405
	Rip rap	n/a	577	573	360
Biological -- Intertidal or Nearshore Subtidal	Salt marsh	116		46	60
	Subtidal green algae	n/a		1087	2101
	Subtidal eelgrass	n/a		2969	3765
Backshore	No vegetation/pathway	377		223	207
	Invasive plants/shrubs	113		171	103
	Grass	n/a	1656	1540	1082
	Mixed confierous and deciduous trees	n/a	2562	2382	1616
	Storm drain (point)	n/a			

e. Rose Bay, comparing mapped features from ground survey to three image types.

Feature Type	Feature	Area mapped (m^2)			
		Ground Survey	Satellite	Orthophoto	Drone
Physical -- Intertidal	Concrete footing	4			
	Bedrock	526	427	614	700
	Cobble, boulder, brick beach	776	2122	971	1092
	Sand, mud, pebble with coal veneer	234	n/a	n/a	2
	Mudflat	n/a			4461
	Rock concrete wall	n/a			
	Boulder rip rap	n/a		150	266
	Cobble/rip rap beach	n/a			95
	Brick structure	n/a			
Biological -- Intertidal or Nearshore Subtidal	Green algae	n/a		4080	3362
	Rockweed and or rockweed/barnacle	n/a		1348	554
	Black lichen	n/a			114
Backshore	Mixed confierous and deciduous trees	2614	6395	4652	329
	Bare ground/road/parking lot	n/a	1703	2245	
	Grass	n/a	3673	4162	86
	Buildings	n/a	1969	1734	
	Deciduous trees	n/a		147	230
	Shrubs			330	

f. Smart Island, comparing mapped features from ground survey to three image types.

Feature Type	Feature	Area mapped (m2)			
		Ground Survey	Satellite	Orthophoto	Drone
Physical -- Intertidal	Shell hash	450			
	Boulder/cobble beach	18		71	153
	Cobble Beach	598	834	173	375
	Boulder/sand	n/a	n/a	26	85
	Pebble and shell hash/tombolo	363	n/a	472	329
	Bedrock Islet	413	371	357	455
	Bedrock (with low cover of boulder)	580	502	472	470
Biological -- Intertidal or Nearshore Subtidal	Green algae (subtidal)	n/a		11581	11527
	Black lichen	n/a			46
	Mixed intertidal algae. Red/green/brown/rockweed	n/a		512	1338
Backshore	Mixed deciduous and coniferous forest	2833	6987	6738	5928
	Grass	3020	2989	2931	3869
	Bare ground/parking lot	n/a	287	283	257
	Bare ground/roadside	n/a	107	87	47
	Deciduous trees	n/a			50

Appendix D – Examples of features mapped during the ground survey.

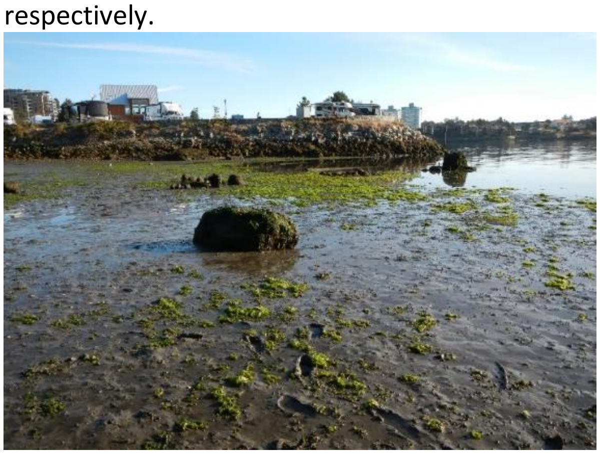
Table 14. Examples of biophysical features mapped during the ground survey including comments on classification accuracy using the three imagery types.

Bedrock ramp, Smart Island

-- Natural shoreline, with sparse cover of acorn barnacle, rockweed, and foliose green algae and invertebrates.
--High, moderate and low accuracy score for UAV, orthophoto and drone imagery interpretation respectively.

Shell hash beach, Smart Island

-- Natural shoreline.
-- Sediment beaches or flats which are primarily composed of shell hash.
--Shell hash was not classified from any of the imagery types (omission).



Fine sediments (includes mud or sand flats) Rose Bay
-- Often in the lower intertidal zone.
-- Sediment may be obscured by biota.
-- May occur downslope of both natural or modified upper intertidal zone features.
--Moderate accuracy from interpretation of UAV imagery. Low accuracy from interpretation of orthophoto and satellite imagery, partly because of higher tides in imagery.

Green algae (intertidal), Smart Island
-- Usually observed at < 100% cover.
-- On immobile substrate (bedrock outcrop in this example).
-- High classification accuracy score when rolled up into ‘rockweed, green or red algae (intertidal)’ category using UAV and orthophoto imagery. Not classified using satellite imagery.

Salt marsh, Gorge Park
-- Salt-tolerant herbs/grasses/sedges in the upper intertidal zone and logline.
-- only small areas of salt marsh were observed at any of the pilot study sites.
-- high classification accuracy using UAV and orthophoto imagery. Not mapped using satellite imagery.

Subtidal eelgrass, Gorge Park
-- Often mixed with green or brown algae
-- May be sparse cover.
-- Only eelgrass in the shallow subtidal areas are visible in aerial imagery or on the ground.
-- High and moderate classification accuracy using UAV and orthophoto imagery respectively.

Barnacle/Rockweed, Rose Bay
- Usually co-occurring frosting of barnacle with variable cover of rockweed.
- Rose Bay example included scattered tufts of filamentous red algae and several common invertebrates.
-- High classification accuracy score when rolled up into 'rockweed, green or red algae (intertidal)' category using UAV and orthophoto imagery. Not classified using satellite imagery.

Subtidal Bladed kelp, Coast Harbourside
-- Nearshore subtidal understory kelps.
-- Not observed at any other pilot study site.
-- High classification accuracy using drone imagery (only assessed at one site). Accuracy assessment not completed for other imagery types.

Appendix E – Vertex report for supervised classification results

19N-02439

Supervised Image Classification – CRD Pilot Harbours Ecological Inventory for Mapping Purposes

Prepared for:
Archipelago Marine Research Ltd.

Prepared by:
Vertex Resource Group Ltd.

Date:
January 27, 2020

Supervised Image Classification – CRD Pilot Harbours Ecological Inventory for Mapping Purposes

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____ Jan 27, 2020 ________________________________

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Date

Table of Contents

List of Tables

List of Appendices

1.0 Project Overview

1.1 Concept

The objective of this project was to conduct supervised image classifications over six study areas selected by Archipelago Marine Research Ltd ("Archipelago") to evaluate the potential of using remotely-sensed data in detecting and mapping features in the backshore, and intertidal and subtidal areas.

1.2 Study Areas

Six study areas were chosen for the project, including Victoria Coast Harbourside, Esquimalt Lagoon, Gorge Park, Portage Inlet, Rose Bay, and Smart Island.

1.3 Data

Remotely-sensed optical image data were collected by McElhanney (Table 1). Both the spaceborne and airborne imagery contained data in the visible (red, green, blue wavelengths) and near-infrared parts of the electromagnetic spectrum while the UAV data did not have Infrared data. The visible and near-infrared (VNIR) portions of the spectrum (400-1,000 nm) are well-suited for identifying vegetation vigor or greenness.

In addition to the imagery, we were also supplied by Archipelago with site photos and GIS geodatabases that documented and attributed sampling locations for each of the six study sites.

Table 1. Image data types collected by McElhanney.

Imagery Type	Resolution	# of Bands	Spectral Bands
Pléiades Multispectral, High-spatial resolution Satellite	200 cm	4	- Red - Green - Blue - Near Infrared
Aerial Orthophoto	10 cm	4	- Red - Green - Blue - Near Infrared
Unmanned Aerial Vehicle (UAV) (aka Drone)	4 cm	3	- Red - Green - Blue

2.0 Methods

2.1 Supervised Image Classification

We began our analysis with a review and evaluation of the imagery and spatial data to assess classification methods best suited to use with the available data. Our review concluded that, because the data were acquired on several different dates and at different times of the day, each image would require an independent set of training sites with which to perform a supervised classification. We also determined that the imagery could not support detailed vegetation extraction such as kelp, algae, or eel grass, but was better suited to broad classes including trees, grass/herb, or intertidal vegetation.

We created a set of potential land cover classes that could be reasonably extracted from the data (Table 2). Classes where we had two divisions within a class were done so that we could "roll-up" the sub-classes into one parent class, should separability not be achievable. The number of classes varied by site due to several factors:

- sensor limits what is separable (primarily UAV);
- extent of the image (UAV) may not encompass areas of all classes;
- acquisition date/timing may mean that some intertidal classes were not present in all imagery.

For any given image, not all classes will necessarily be present or detectable.

Table 2. Land cover classes chosen for the supervised image classification.

	Unclassified
	Water
	Shadow
	Rock/Rubble
	Fine Sediments
	Mixed Fine/Coarse Sediments
	Mud: mixed sediments with direct water influence
	Man-Made 1: Concrete, asphalt, roofing materials
	Man-made 2: Metal, canvas, plastics, and other synthetic materials
	Tree - trees greater than ~2m in height
	Shrub - woody stemmed vegetation less than ~2m in height
	Grass/Herb - stressed
	Grass/herb - healthy
	Submerged/Emergent Vegetation - direct water influence 1
	Submerged/Emergent Vegetation - direct water influence 2
	Intertidal Vegetation - no direct water influence 1
	Intertidal Vegetation - no direct water influence 2

Eighteen sets of training data were collected for the study sites and were used to create land cover classification maps. No accuracy assessments were performed on the results due to the quality and limited number of ground-truth data points. First, all supplied data, were provided as point data and associated descriptions but without any spectral characteristics. There was some spatial uncertainty translating the point data to area-based measurements and then correlating those positions to three different images, each with varying degrees of positional accuracy. A high degree of positional accuracy is required for both the *in situ* measurements and the remotely-sensed imagery to ensure that the two datasets correlate well.

Some point data locations appeared to be in areas that were smaller than the physical dimensions of the satellite imagery – this means that the pixels would also be impure (mixed) and would be influenced by the reflected light from various materials.

Furthermore, in most cases, the sensors used lack the spectral resolution to differentiate the materials that were sampled; a large number of training sites are also required to accurately train a classifier. So, in order to assess the accuracy of image classifications confidently, the collection of ground-truth datasets must be in larger numbers and be done in coordination with the timing of the image acquisitions.

Note that class "grass/herb" was split in two because the spectral response was significantly different between them in the Red and IR wavelengths. This difference is the basis for many vegetation indices and helps distinguish vegetation from other non-vegetation materials.

3.0 Results

The collection of sample locations to use as input for training the image classifier posed significant challenges due to the inherent differences between the types of imagery. These differences required new training sites to be collected for each image and at each site, resulting in 18 sets of training data. Because the training data are different for each image introduces potential inconsistency between classifications. The impacts of these differences are summarized below:

- Images acquired at different times of day/year present challenges when collecting training sites due to shadow changes, solar illumination differences, growth cycle changes, and responses to weather (a rain event between collection dates can cause changes in vegetation);
- Some ground-truth data were taken at lower tide than was evident in the imagery, negating the applicability of those sites;
- Issues with geometric distortion due to feature height, sensor look angle, and solar illumination response related to the different sensors impacts collection;
- Changes in spatial resolution of the images affect what features can be seen and ultimately affect how many classes can be detected;
- The field data collected were not directly translatable into training sites for several reasons: tide height changes, minimum number of samples required for the classifier (at a minimum it should be the number of bands in the image plus 1 [b+1]), sample dimension and homogeneity, geometric accuracy of the sample site and imagery.

Additional limitations of the classification results include:

- Spectral resolution of the images is the dominant limiting factor in the classification results at higher spatial resolution (UAV); with the spaceborne data (Pléiades), the expected number of classes was not feasible;
- Sun glint on the water due to sun angle and wind-related effects impacted classification results negatively;
- Mosaicking of the UAV data introduced image distortion that impacted the ability to classify imagery. Although this was not widespread, it was still present.

Classification results are presented in Appendix A: Deliverables.

4.0 Conclusions and Recommendations

The results of the supervised image classification presented here demonstrated that remotely-sensed data can be used effectively to complement and enhance visual classifications. Of all three image types we classified, we determined that aerial orthophotos are the best option for a future classification of the CRD shoreline based on several factors, including:

- Spatial resolution
- Field-of-view
- Spectral resolution
- Temporal resolution
- Logistical
- Tides
- Cost
- Acquisition window

The spatial resolution of the spaceborne imagery was not fine enough for a detailed classification of the study sites. Even the 8-band WorldView imagery would likely not have been that much better since its spatial resolution was similar to the Pléiades imagery.

On the other hand, UAV data had the highest spatial resolution of all image types used here, but not enough spectral resolution to be able to discriminate different vegetation classes due to the lack of near-infrared data. Nevertheless, UAV data can be used to help focus on high-value areas previously classified from airborne imagery.

Furthermore, this kind of analysis could benefit from the use of hyperspectral imagery for a more accurate characterization of the different land cover types. For this, a ground-truth campaign using a spectroradiometer would be essential.

5.0 Limitations

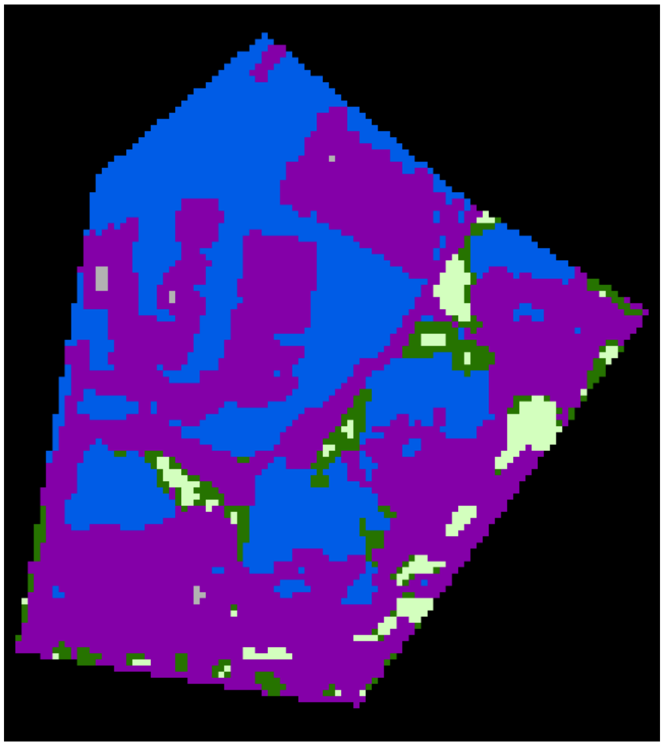
This report has been prepared for the sole benefit of Archipelago. This document may not be used by any other person or entity without the express written consent of Vertex and Archipelago. Any use of this report by a third party, or any reliance on decisions made based on it, or damages suffered as a result of the use of this report are the sole responsibility of the user.

The information and conclusions contained in this report are based upon work undertaken by trained professional and technical staff in accordance with generally accepted scientific practices current at the time the work was performed. The conclusions and recommendations presented represent the best judgement of Vertex based on the data collected during the assessment. Due to the nature of the assessment and the data available, Vertex cannot warrant against undiscovered environmental liabilities. Conclusions and recommendations presented in this report should not be considered legal advice.

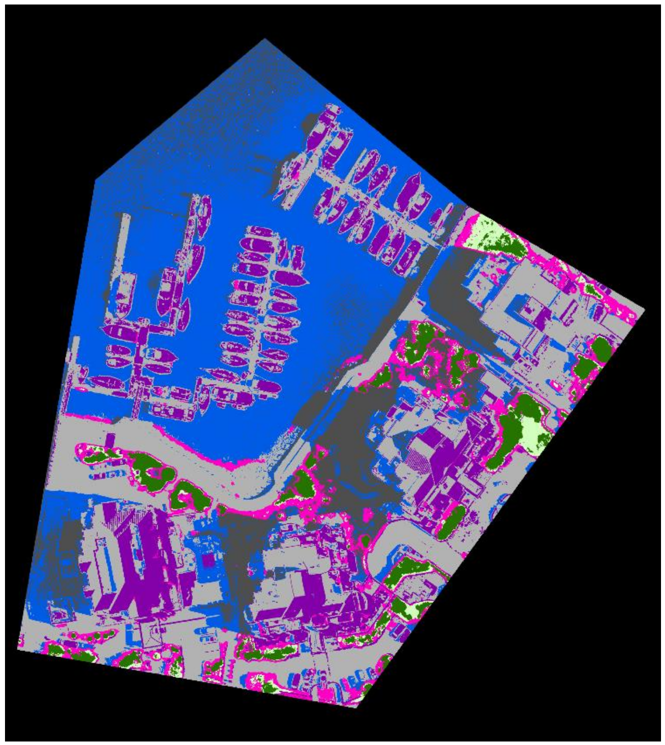
Appendix A: Deliverables

- Classification results (also delivered digitally on Oct 28, 2019)

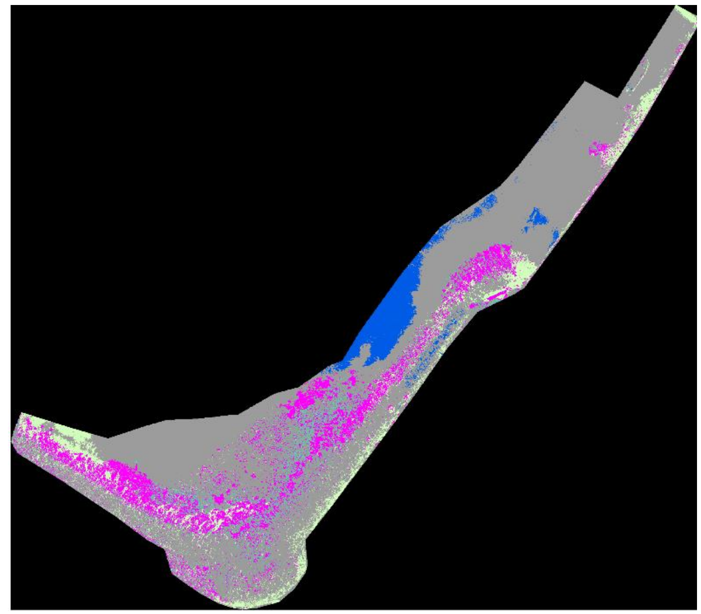
Coast Harbourside



Pléiades

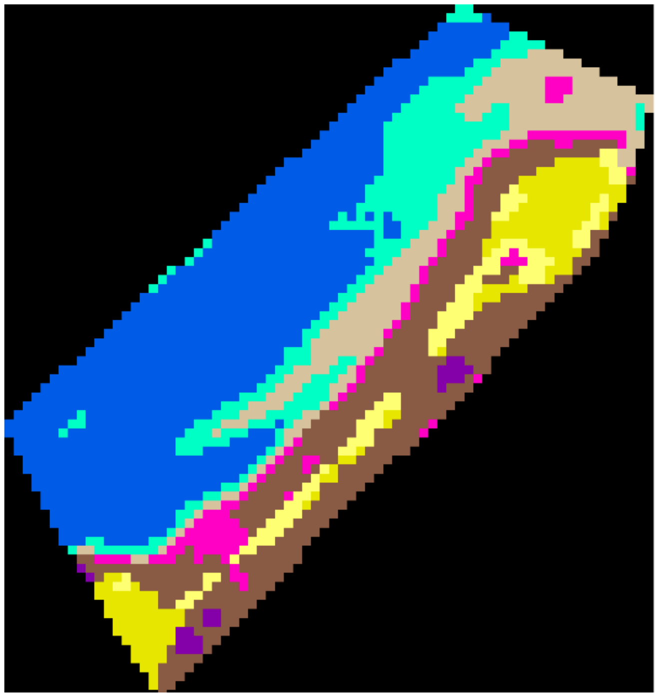


Orthophoto

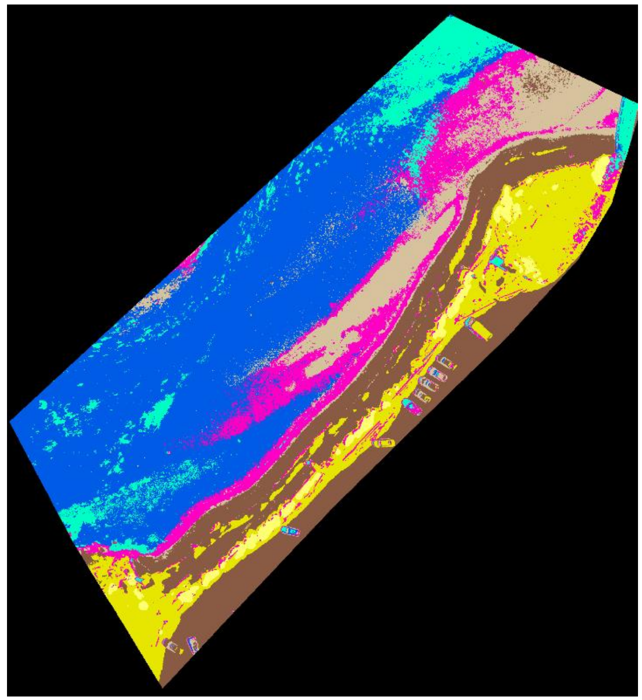


UAV

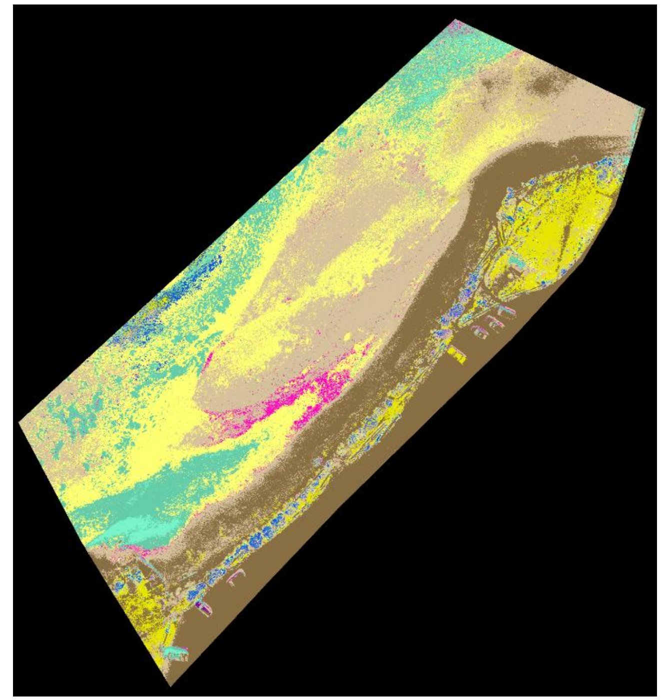
Esquimalt Lagoon



Pléiades

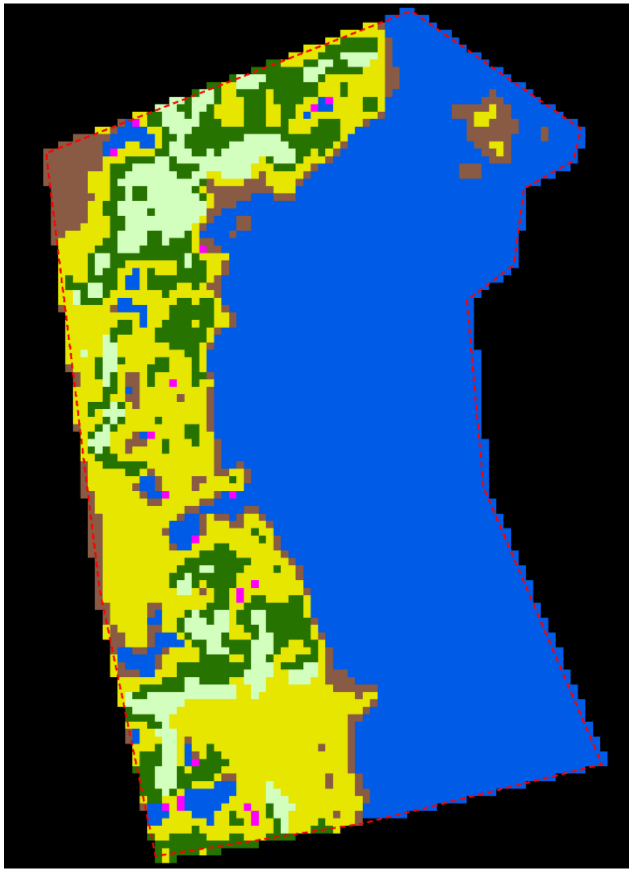


Orthophoto

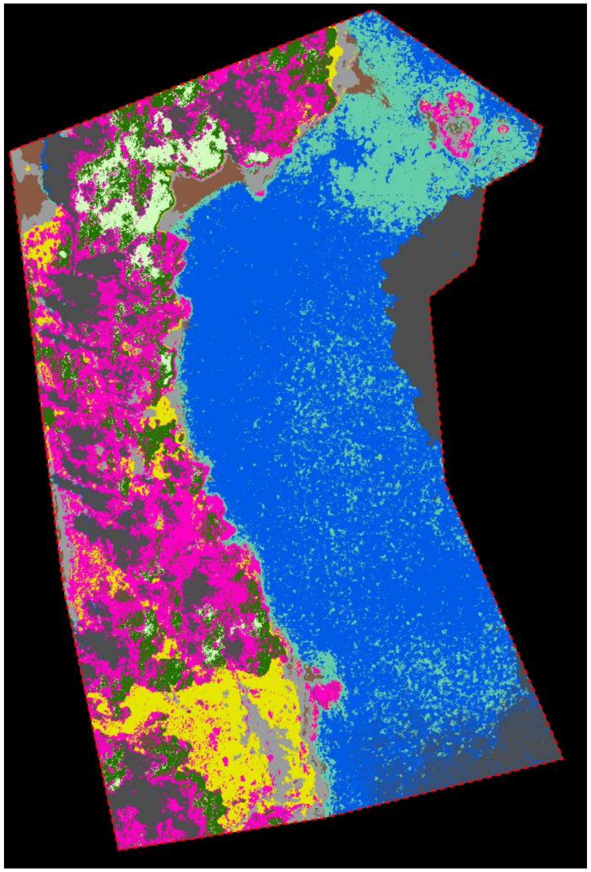


UAV

Smart Island



Pléiades



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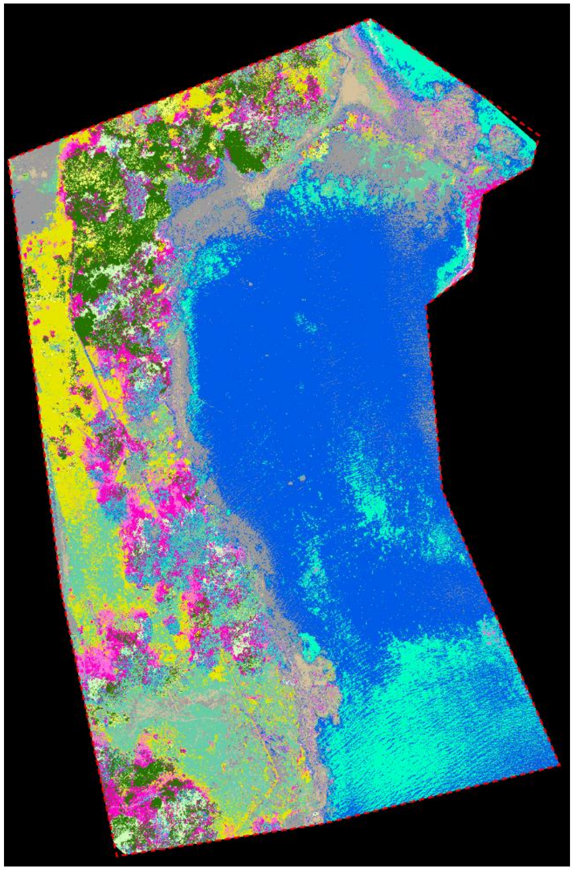
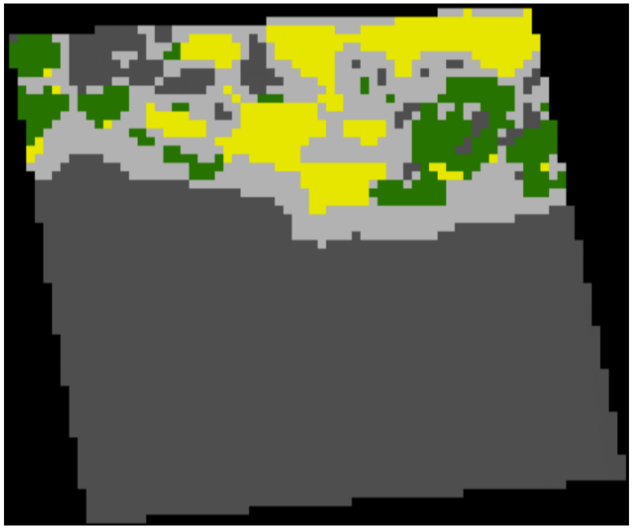
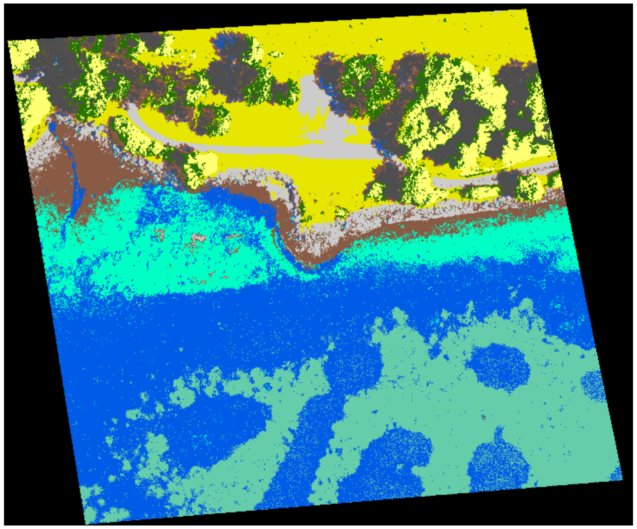


UAV

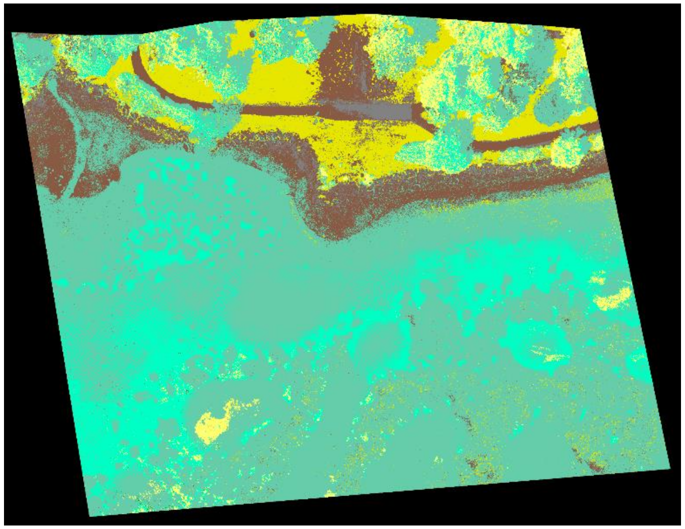
Portage Inlet



Pléiades

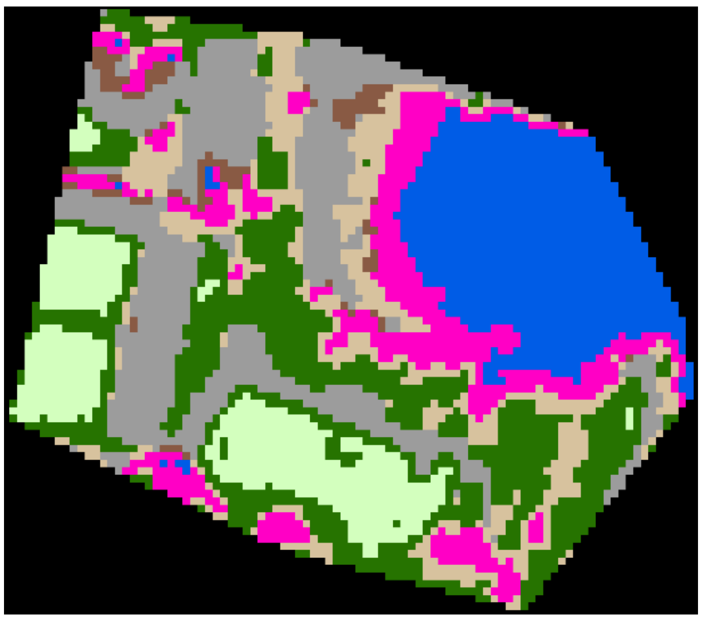


Orthophoto

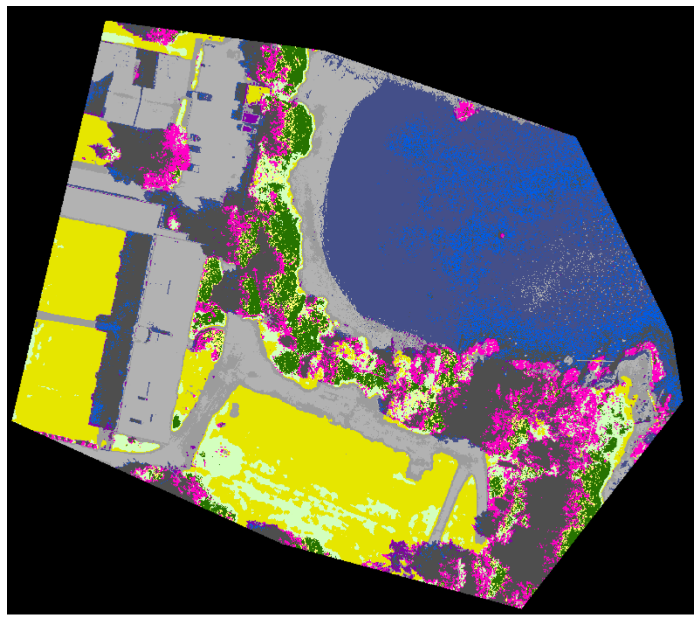


UAV

Rose Bay



Pléiades



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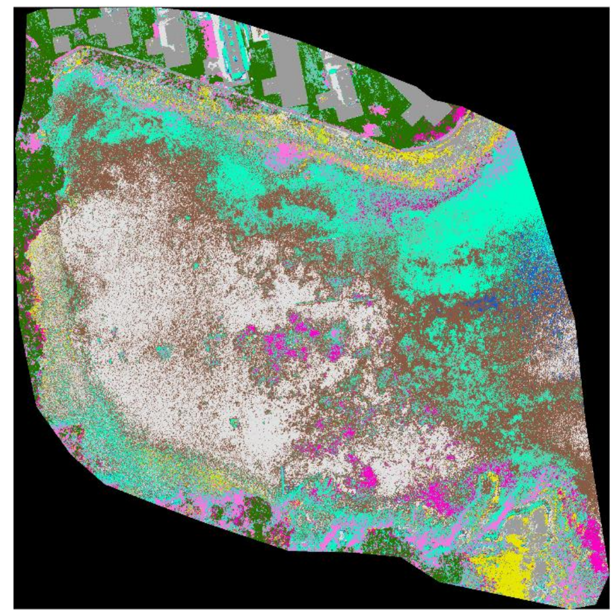
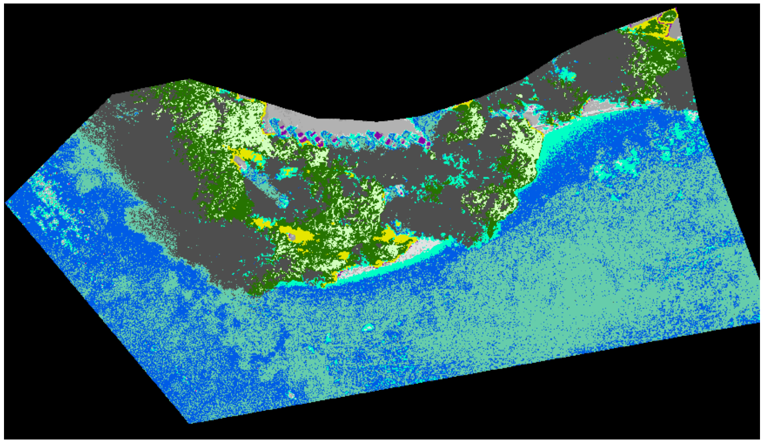


UAV

Gorge Park

Pléiades



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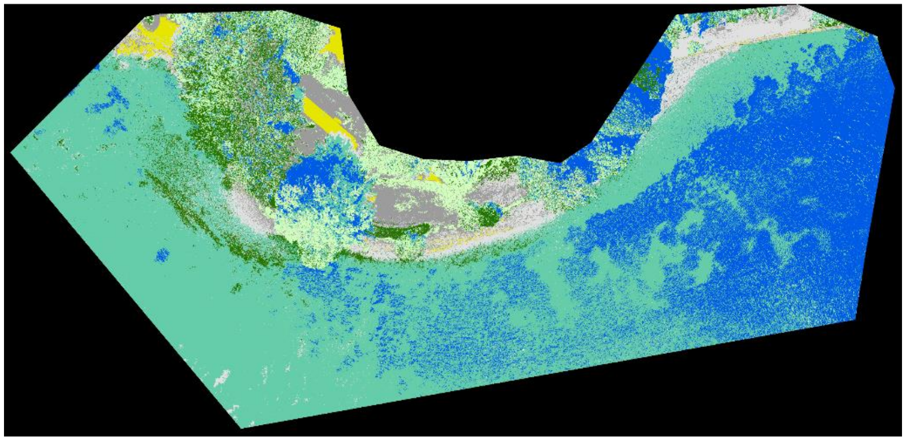

UAV