Classification of nearshore materials on the Bay of Fundy coast using LiDAR intensity data

C. Beasy[1], C. Hopkinson[2] & T. Webster[2]

[1] Applied Geomatics Research Group (AGRG), NSCC Campus, Middleton, N.S.
E-mail: c.beasy@ns.sympatico.ca
[2] AGRG, Middleton, N.S.

ABSTRACT

LiDAR data have, traditionally, consisted of x, y, and z points used to build high-resolution DEMs. Recently, however, the intensity of the reflected laser pulses has been incorporated into the data provided by LiDAR surveyors. The exploitation of this information for mapping and analysis has received little attention and the research that has been conducted has dealt with landcover classification for inland targets. As part of a broader research project, this study examines the application of LiDAR intensity data and height metrics to classify the nearshore materials at an ocean beach on the Fundy coast of Nova Scotia using the Nova Scotia Department of Natural Resources shoreline classification scheme. Supervised and unsupervised classifications are performed in order to separate a shoreline at Young's Cove into bedrock, cobble and sand. Additionally, bedrock covered with barnacles and seaweed at the site is included in the classification. Analysis is performed to investigate possible connections between cover-type and orthometric height, proximity to the ocean and geomorphological change. This last analysis is possible because the LiDAR data available consists of a survey from July of 2000 with last returns and a recent survey from April of 2004, which has first and last returns with intensity values on alternating returns.[1]

Keywords: LiDAR, intensity, nearshore materials, classification.

1 BACKGROUND

Nova Scotia's Department of Natural Resources (DNR) has designated ninety-four beaches in the Province as Shoreline Protected Areas. This study is part of a larger project entitled "LiDAR Applications in Support of Management Decisions for Shoreline Protected Areas: A Nova Scotian Case Study." The purpose of this project was to investigate what useful knowledge could be derived from LiDAR data with the ultimate aim of supporting management decision-making. In addition, this knowledge can be used to help determine what future data acquisition surveys are carried out and how. As the project developed, it took on the added objective of testing LiDAR as a cost-effective method to acquire large amounts of useful data, given the budget restraints on DNR. One area of investigation identified by a preliminary literature review was Classification Using Intensity.

Pulse return intensity is available with most LiDAR surveys now. The newer systems have the capability to measure and record the strength of a hit's energy. While this data increases the amount of storage space required, it has the potential to provide valuable information regarding the surface being surveyed. While most terrestrial LiDAR systems make use of near-infrared lasers, the fact that they are active sensors means that the reflectance properties that characterize substances, surfaces and features in the context of spectral imaging do not apply. This is because light strikes the object from one direction, not many, as is the case with reflected sunlight. There exists a multitude of variables that can affect a hit's intensity value and the data is usually noisy. Song et al. (2002) assert that this is mainly due to the angle of reflection or the angle at which the laser pulse strikes the target. The data can be corrected for this (if the scan angle for each pulse is recorded) but there has been relatively little research to date. Intensity is a very imprecise tool at this point in LiDAR's development. For this reason, it appears that the best way to use intensity is as a complement to other, more exact data and/or as an approximation. The idea here is to find a

[1] *Paper No. 11, Proceedings of the 26th Canadian Symposium on Remote Sensing, Wolfville, Nova Scotia, June 14-16, 2005*

trend in a local area's intensity values. For example, the intensity value of one specific point will not have a precise and absolute correspondence to any material; however, that point, along with the others surrounding it, can indicate a general region of difference from other groups of hits. The key is the relative intensity values of reflectors within the dataset.

The original intent was to use the classes used by DNR: bedrock; cobble; and sand. Unfortunately, there is very little sand along the Fundy coast for which AGRG has LiDAR data and none present at the selected study site, although a small stretch of sand beach at another location was found. A third class, bedrock covered with barnacles and seaweed was added because it characterizes a very large proportion of the Fundy shoreline at low tide and because it is so apparent in the intensity grids.

2 QUESTION

Can LiDAR intensity data be used to classify nearshore materials?

3 STUDY AREAS

The AGRG possesses LiDAR intensity data for none of Nova Scotia's Shoreline Protected Areas; therefore, it was necessary to select another location. Young's Cove was chosen to be the study area for this analysis because ground-truthing and RTK GPS for it would serve for another component of the larger project. Young's Cove is located approximately seven kilometres southwest of Hampton, down the Fundy coast. See Figure 1 for location.

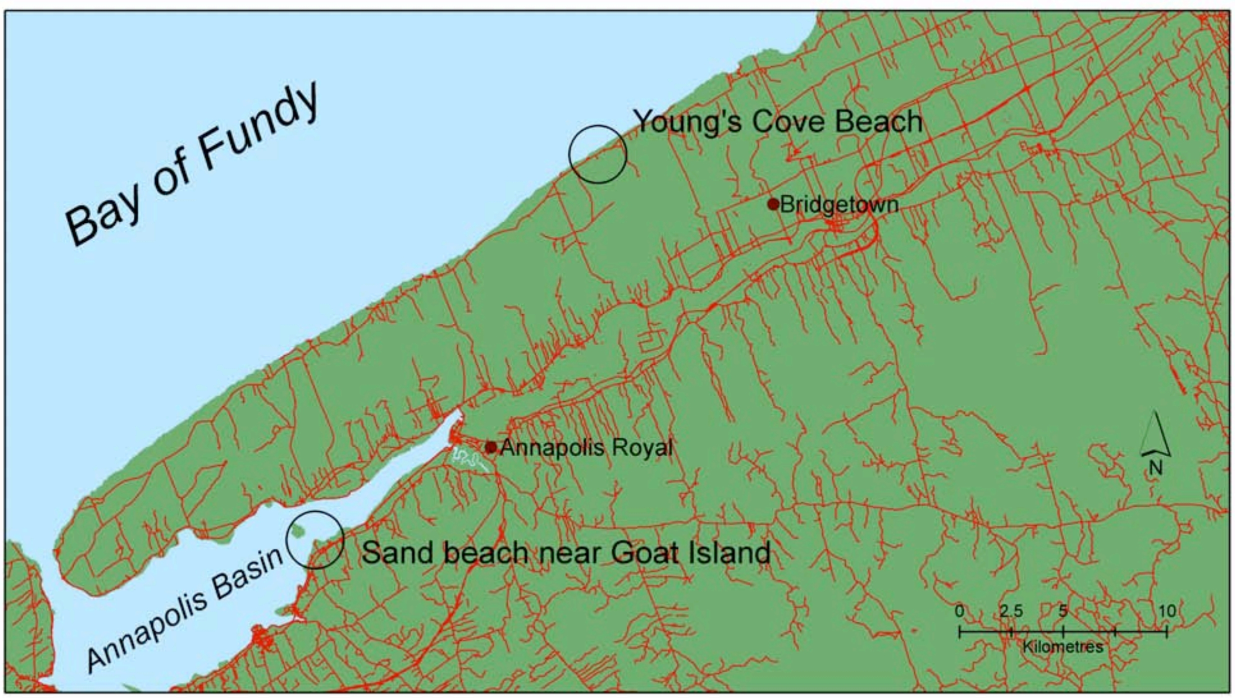

Figure 1. Location of the study areas

4 DATA

LiDAR: Terra Remote Sensing, flown April, 2004 with Mark II. First and last returns with intensity on alternating first and last returns and >18 cm footprint.

1:10,000 colour air photo of Young's Cove:
from DNR, taken July 12, 2002. Scanned at 0.25 m resolution and ortho-rectified

1:10,000 colour air photo of sand beach near Goat Island:
from DNR, taken August 30, 1992. Scanned at 0.3 m resolution and ortho-rectified

5 METHODOLOGY

The methodology for this analysis consists of the creation and comparison of various inputs to the classification. Three interpolated surfaces of two-metre resolution were produced from the intensity values associated with the hits from the 2004 Terra survey at the Young's Cove site. Return intensity was recorded on alternating first and last returns for each pulse. In almost all instances, the first and last returns were one and the same, due to the fact that there was no vegetation (apart from seaweed) and little terrain that would cause multiple returns. The interpolators employed were kriging, IDW and a linear lattice created from a TIN.

Kriging and IDW were selected for two reasons: precedent in a previous study and aptness according to the literature. Song et al (2002) used both IDW and kriging with good results, although they do not explain why they chose those two interpolation methods. The Vertical Mapper User Guide – Vertical Mapper is the grid extension for MapInfo GIS software – suggests that IDW and kriging are appropriate for point data that is distributed in lines as is LiDAR and for data that is not particularly accurate (Northwood Technologies Inc. and Marconi Mobile Limited, 2001, pgs. 20 – 23). Given that intensity values are relative and subject to numerous factors that can have important impacts, the absolute accuracy of each one is questionable. David F. Maune states that the tendency of kriging is to emphasize local trends rather than individual values (Maune, 2001, pgs. 14, 15). This is suitable because the goal is to derive generalized areas of nearshore materials from point values with some degree of variation within a range. IDW interpolates values based on the values of neighbouring points; the closer the point, the greater its influence. The linear lattice method was chosen on the recommendations of Tim Webster and Russell Brennan of the AGRG, who have had success with it in their research using intensity.

After the interpolated rasters were made, each was filtered using the median values within a moving 3 x 3 cell box in order to remove some of the noise and produce smoother surfaces. Song et al (2002) found that median filtering reduced the deviation within their classes without significant change to the average values, thereby, improving class separability.

The intensity data is 9-bit, ranging from zero to a maximum possible value of 511. It was converted to 16-bit in PCI. Two new 8-bit channels were created in Focus to represent luminance and texture for the classification.

Classifications with all six grids were performed with intensity alone and, additionally, with luminance and texture. Orthometric height and proximity to the water were also tried; the results were more detrimental than beneficial. The luminance channel is an 8-bit single-band panchromatic image made by averaging the DN values of the red, green and blue bands from the colour air photo that had been ortho-rectified previously. A simple visual examination of the luminance segment reveals one reason why it was chosen: the three classes are very discernible. The texture, or roughness, channel presents the difference between the maximum and minimum orthometric heights within a 3 x 3 cell window around each cell in the 1994 Terra DEM. It is similar to slope. This channel was also 8-bit. In addition to luminance, Charaniya et al. (2004) used texture – they called it "height variation" – to aid with classification using intensity. They found it effective for identifying trees and, sometimes, buildings. Texture was selected as an input for this analysis due to the variation in terrain smoothness between the bedrock and cobble areas. Because there was some overlap of intensity values between the bedrock covered with barnacles and seaweed and the cobble areas, it was expected that texture would improve separability between these classes. There is some question as to whether or not a focal standard deviation would better represent texture.

Figure 2. Air photo of the Young's Cove study area (~ 1600 m end to end)

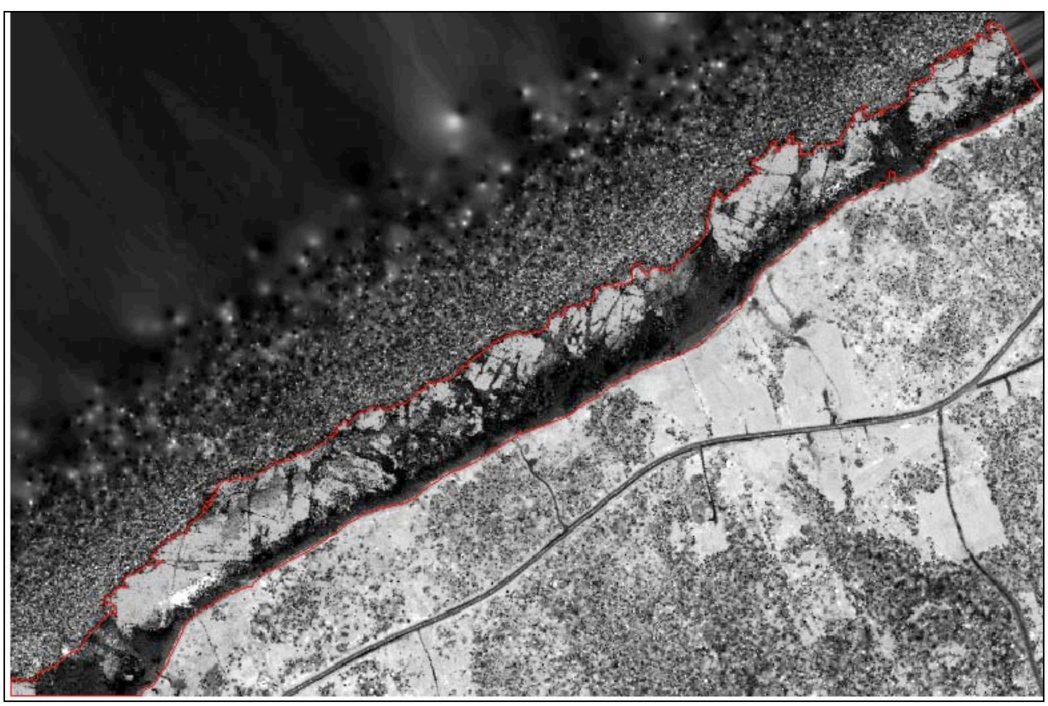

Figure 3. IDW intensity grid (all-hits) and the Young's Cove study area (~ 1600 m end to end)

5.1 The Training Sites

Table 1. Intensity grid values over cobble

	MEAN	STANDARD DEVIATION
LINEAR	9011.42	1397.1
LINEAR FILTERED	9013.63	1379.44
IDW	8962.74	1313.86
IDW FILTERED	9013.19	908.38
KRIGING	8552.99	1282.45
KRIGING FILTERED	8553.1	1270.76

Table 2. Intensity grid values over bedrock (bare)

	MEAN	STANDARD DEVIATION
LINEAR	4276.6	2031.7
LINEAR FILTERED	4277.68	2004.07
IDW	4270.41	1646.35
IDW FILTERED	4401.3	936.388
KRIGING	3955.3	1395.76
KRIGING FILTERED	3952.58	1376.69

Table 3. Intensity grid values over bedrock (B&S)

	MEAN	STANDARD DEVIATION
LINEAR	18,287.5	4264.5
LINEAR FILTERED	18,301.3	4233.3
IDW	18,327.9	4113.37
IDW FILTERED	18,743.3	3279.87
KRIGING	17,850.9	3969.12
KRIGING FILTERED	17,858.2	3948.68

Table 4. Luminance and texture grid values over cobble

	MEAN	STANDARD DEVIATION
LUMINANCE	175.036	9.9
TEXTURE	21.6987	4.44949

Table 5. Luminance and texture grid values over bedrock (bare)

	MEAN	STANDARD DEVIATION
LUMINANCE	152.016	13.6471
TEXTURE	25.887	9.94875

Table 6. Luminance and texture grid values over bedrock (B&S)

	MEAN	STANDARD DEVIATION
LUMINANCE	138.469	20.9771
TEXTURE	23.8089	9.00792

A band at the seaward edge of the luminance raster five to twenty-five metres wide contains invalid data due to the fact that the source air photo was taken at a higher tide than the LiDAR survey. Thus, there is water covering a strip of the beach in the photo where the other rasters have real data.

5.2 Signature Separability of the Classes at the Training Sites

The divergence of the signatures is given in Bhattacharrya (or Jeffries-Mastusuta) Distance, with values ranging from zero to two where two indicates complete divergence. On their website at http://www.pcigeomatics.com/cgi-bin/pcihlp/CLWORKS|Signature+Separability, PCI suggests the following ranges for separability values:

0.0 to 1.0 (very poor separability)
1.0 to 1.9 (poor separability)
1.9 to 2.0 (good separability)

Table 7. Separability of Individual and Combined Surfaces

	AVERAGE	MINIMUM	MAXIMUM
LINEAR	1.850717	1.231241	2.0
LINEAR FILTERED	1.854616	1.250433	2.0
KRIGING	1.899606	1.541319	2.0
KRIGING FILTERED	1.902425	1.557745	2.0
IDW	1.882462	1.428872	2.0
IDW FILTERED	1.970571	1.814118	2.0
LUMINANCE	1.605563	0.222788	2.0
TEXTURE	1.459005	0.016842	2.0
LINEAR & LUMINANCE	1.898303	1.512663	2.0
FILTERED LINEAR & LUMINANCE	1.901039	1.525826	2.0
KRIGING & LUMINANCE	1.931892	1.691756	2.0
FILTERED KRIGING & LUMINANCE	1.933724	1.695797	2.0
IDW & LUMINANCE	1.920297	1.641095	2.0
FILTERED IDW & LUMINANCE	1.979138	1.851087	2.0
LINEAR & TEXTURE	1.872695	1.381737	2.0
FILTERED LINEAR & TEXTURE	1.876105	1.397105	2.0
KRIGING & TEXTURE	1.915665	1.615340	2.0
FILTERED KRIGING & TEXTURE	1.918087	1.622115	2.0
IDW & TEXTURE	1.900794	1.549548	2.0
FILTERED IDW & TEXTURE	1.976169	1.841120	2.0
LINEAR, LUMINANCE & TEXTURE	1.915074	1.627804	2.0
FILTERED LINEAR, LUMINANCE & TEXTURE	1.917395	1.637917	2.0
KRIGING, LUMINANCE & TEXTURE	1.943957	1.731739	2.0
FILTERED KRIGING, LUMINANCE & TEXTURE	1.945482	1.735134	2.0
IDW, LUMINANCE & TEXTURE	1.934169	1.721973	2.0
FILTERED IDW, LUMINANCE & TEXTURE	1.982836	1.868809	2.0

A look at the six interpolated surfaces alone reveals that a fairly high level of separability is possible with nothing more than the intensity. This is a result of the three classes being represented by quite distinct ranges of values. In fact, none of the surfaces exhibits overlap of classes within one standard deviation of their means. The luminance and texture rasters, in contrast, present much more class overlap. This is particularly true of the latter, though, not surprising.

The separability of the three classes in all of the intensity surfaces was improved to some degree by the median filter. In the cases of the linear and kriging surfaces, the improvements were marginal; however, the IDW class separability was enhanced markedly. The standard deviations decreased drastically while the mean values increased somewhat. This is unimportant as the goal here is relative rather than absolute value. Kriging tends to produce surfaces that are smooth and, therefore, the grid interpolated with that method showed less improvement when filtered than the other two types. By nature, IDW generated speckled surfaces caused by the dimpling effect discussed in the Geomorphology and Change section. The use of a median filter on an IDW surface by Song et al (2002) is supported by these results.

The linear, IDW and kriging intensity rasters were combined with the luminance grid, the texture grid and then both. There were incremental gains in separability for the three classes in all cases. It is debatable, though, whether or not the benefits justify the costs. For the purpose of categorizing a shoreline into these three classes, it might not be worth it. It is unfortunate that there are no areas of sand at Young's Cove; additional classes - such as sand and grass - could require more than simply intensity.

Ultimately, all interpolated grids were improved by adding the luminance and texture, both separately and together. Filtered IDW shows the highest separability values although no grid reaches 1.9 for all separability values.

6 RESULTS AND DISCUSSION

As with Song et al. (2002), the IDW interpolated surfaces provided the best results in terms of value ranges for each class and this resulted in superior separability. It is possible that kriging is capable of producing better results than IDW; however, it is a much more complicated interpolator and can consume long periods of preparation and processing time. For this reason, unless the user has in-depth knowledge of kriging, IDW is the best option of the three tested here. Median filtering improved all surfaces by reducing the range of values within each class.

As can be appreciated in Figures 4 – 9, the classification executed with the Maximum Likelihood algorithm is more generalized than the others and includes many areas at the landward edge of the beach as bedrock covered with barnacles and seaweed. The latter is found only where the sea covers the beach every high tide. Minimum Distance, on the other hand, does not do this and appears to classify doubtful areas as "Cobble," which is probably correct in the sense that loose stones can be found everywhere on the beach. Maximum Likelihood with Null Class assigned the Null Class to all ambiguous areas. One can conclude that the choice of classifier depends on how the result will be used. This report will work with the Minimum Distance classification because it does not confuse finer cobble and organic debris with bedrock covered with barnacles and seaweed.

6.1 Classification Results – Maximum Likelihood

Average accuracy = 99.36

Overall accuracy = 99.62

Kappa Coefficient = 0.99460

Standard Deviation = 0.00032

Area assigned to each class:

Cobble – 33,402.06 sq m
Bedrock covered with barnacles and seaweed - 126,006.13 sq m
Bare bedrock – 37,733.5 sq m
Total - 197,141.69 sq m

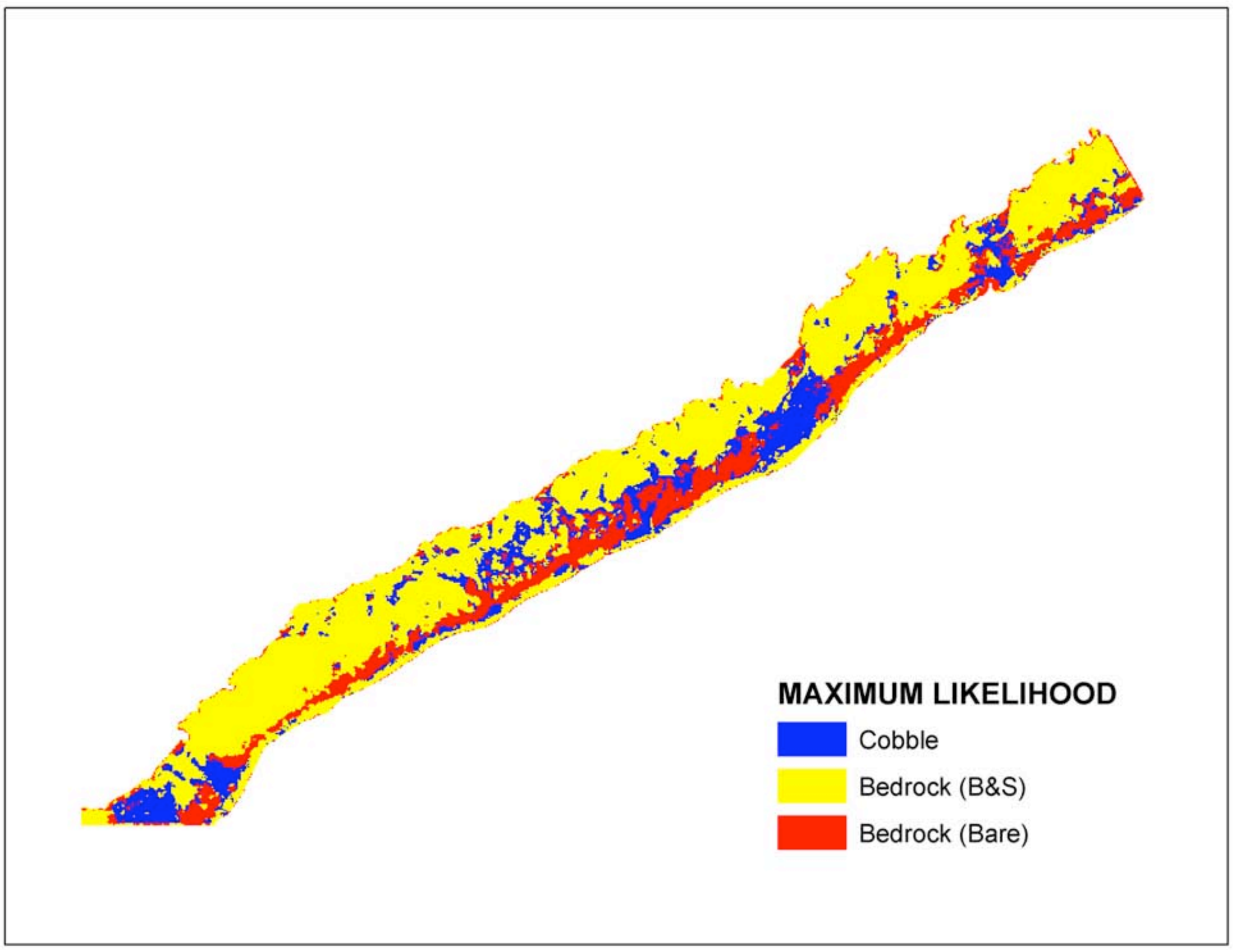

Figure 4. Results of Maximum Likelihood Classification (~1600 metres from end to end)

6.2 Classification Results – Maximum Likelihood with Null Class

Average accuracy = 97.57

Overall accuracy = 97.92

Kappa Coefficient = 0.97039

Standard Deviation = 0.00074

Area assigned to each class:

Cobble – 24,658.06 sq m
Bedrock covered with barnacles and seaweed – 81,132.13 sq m
Bare bedrock – 19,760.5 sq m
Null class – 71,591 sq m
Total - 197,141.69 sq m

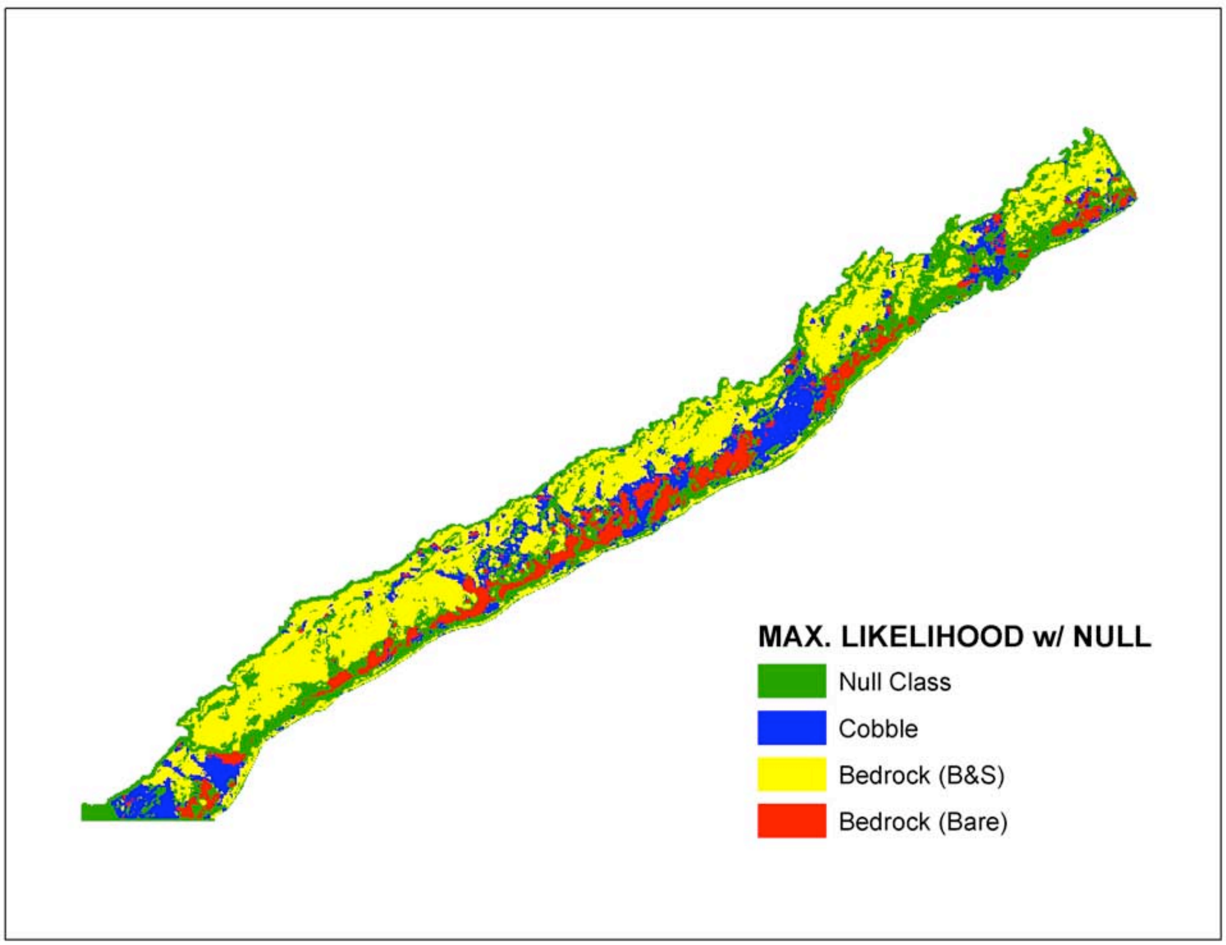

Figure 5. Results of Maximum Likelihood with Null Class Classification (~1600 metres from end to end)

6.3 Classification Results – Minimum Distance*

Average accuracy = 96.21

Overall accuracy = 95.01

Kappa Coefficient = 0.92890

Standard Deviation = 0.00113

Area assigned to each class:

Cobble – 88,474.56 sq m
Bedrock covered with barnacles and seaweed – 79,861.63 sq m
Bare bedrock – 24,674.5 sq m
Total - 193,010.69 sq m

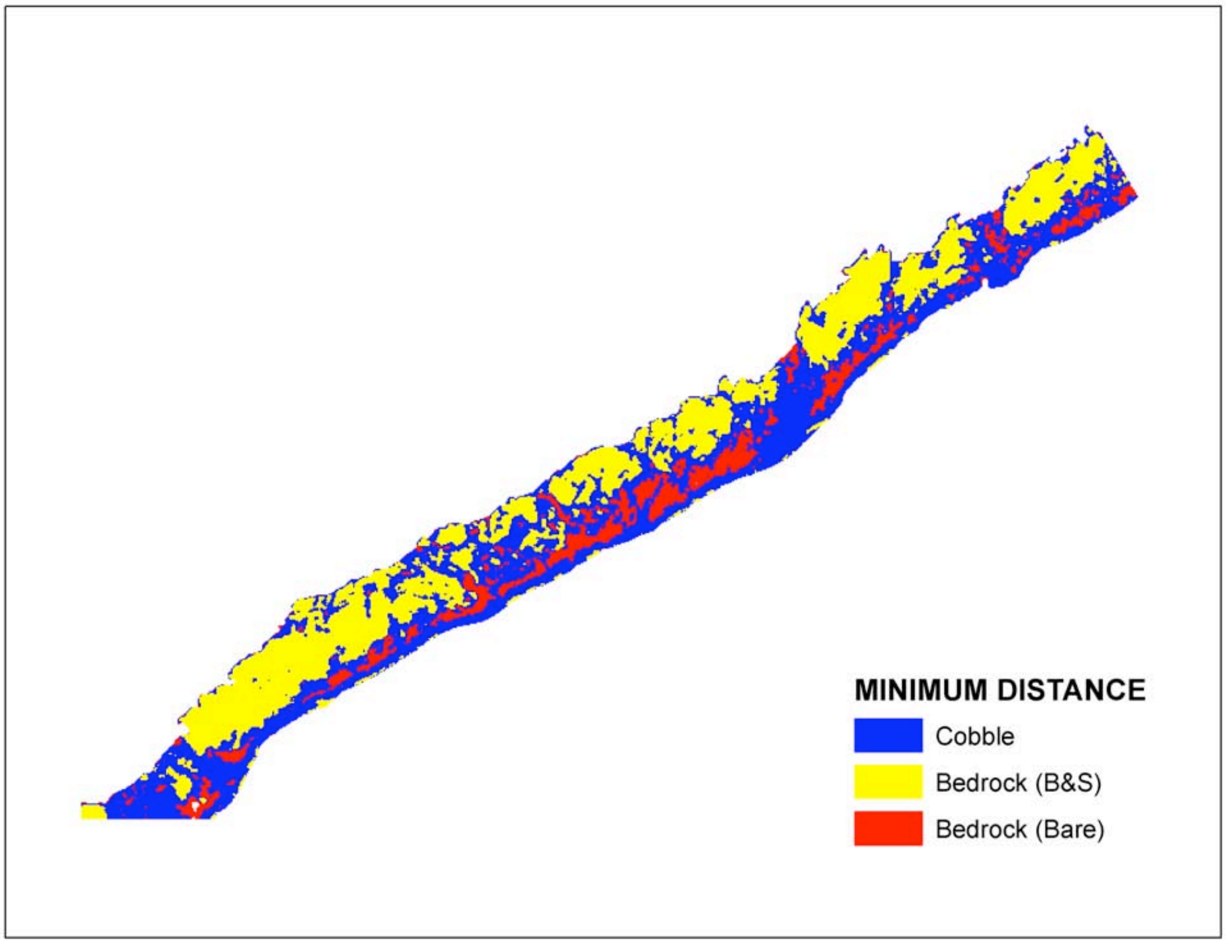

Figure 6. Results of Minimum Distance Classification (~1600 metres from end to end)

* This classifier produced results some 4000 square metres smaller than the Maximum Likelihood algorithms. The differences occur along the edges of the study area.

6.4 Comparison with GPS Ground-truthing

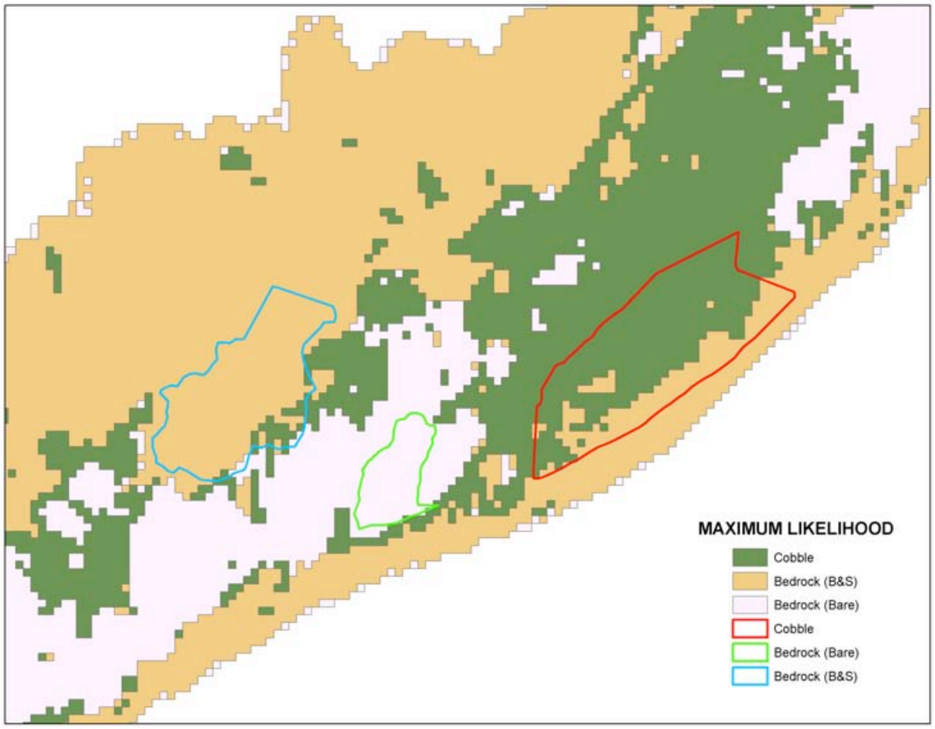

Figure 7. Maximum Likelihood Classification vs. GPS (image ~ 250 metres across)

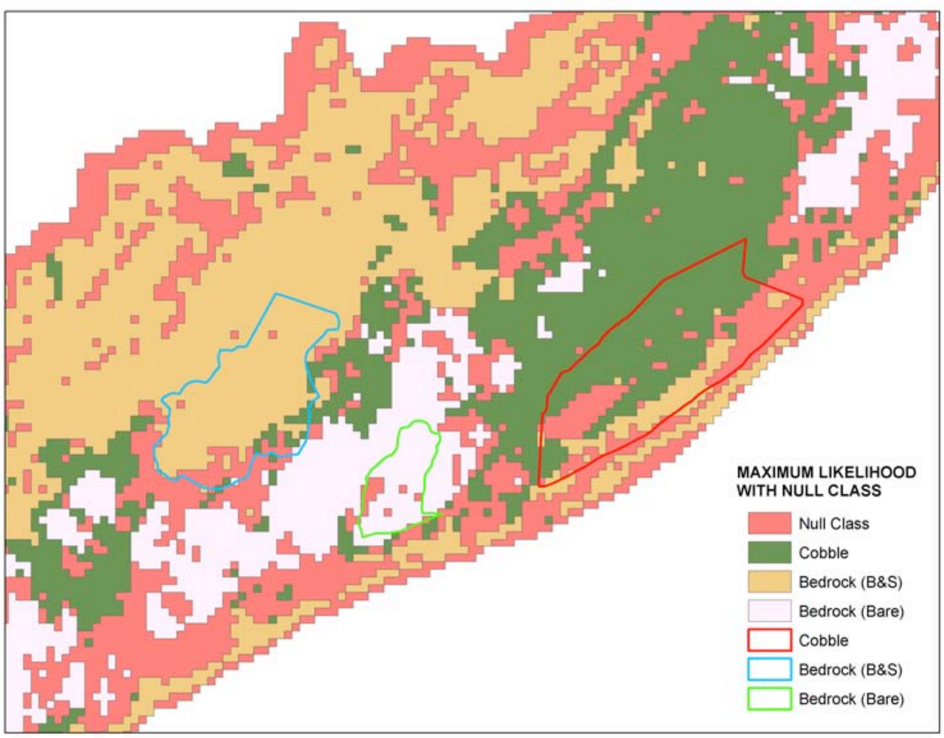

Figure 8. Maximum Likelihood with Null Class Classification vs. GPS (image ~ 250 metres across)

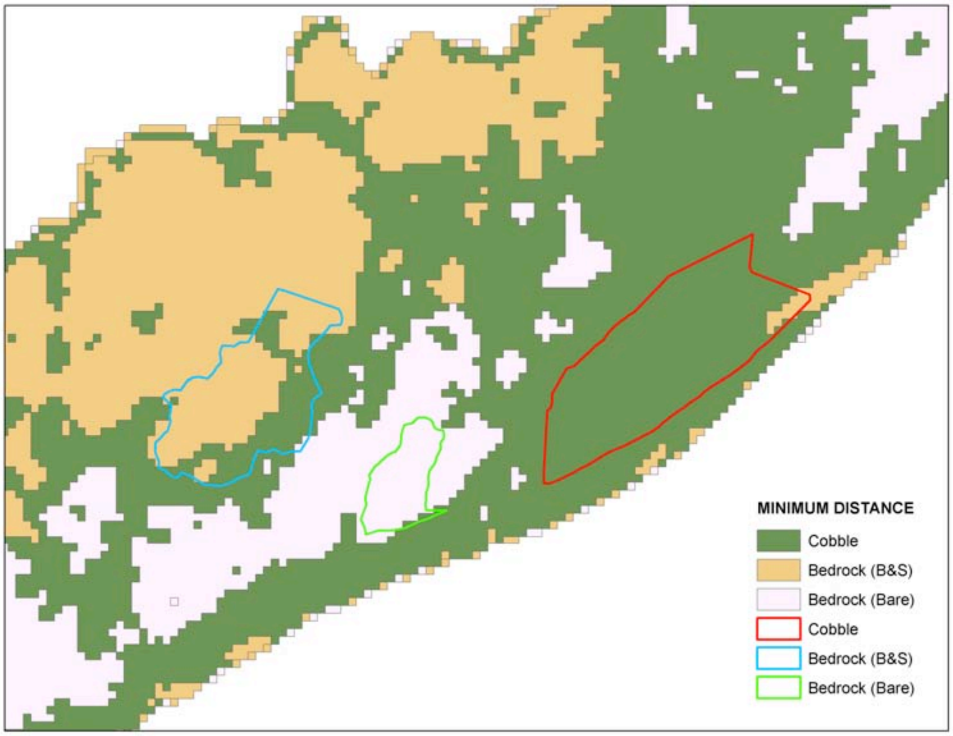

Figure 9. Minimum Distance Classification vs. GPS (image ~ 250 metres across)

Unfortunately, the site visit to acquire the GPS data was not contemporaneous with the LiDAR and occurred during a different season, also: winter and spring, respectively. Material on the cobble portion of the beach is dynamic and such material might also move on and off and from one point to another over areas of bedrock. As a result, the areas surveyed as cobble in January, 2005 could have been smaller or larger in the spring of 2004 than when the LiDAR data was acquired. In addition, it should be borne in mind that the GPS surveys of cobble, bare bedrock and bedrock covered with barnacles and seaweed regions were meant to represent areas entirely of one type and not to include the entire extent of a particular material.

Interestingly, there is no difference between a Minimum Distance classification performed with the intensity grid alone and one with the luminance and texture grids included despite the lower separability figures. This might not be the case for all types of beaches and all examples of each type of beach. Further research will be required to determine this.

In any case, it does demonstrate that the marginal gains in separability provided by the inclusion of these segments are, perhaps, not worth the time, cost and effort to incorporate them. Moreover, acceptable classifications appear possible with minimal input. In fact, simple density-slicing of a filtered intensity grid in ArcMap based on value ranges produced results very similar to the PCI classification, albeit with more speckling. Depending on the accuracy required or desired, this might be a suitable option; it would certainly be easier and do away with the need for specialized classification software. The data can be queried and densities set accordingly if there is no overlap.

The organic debris near the beach edge that has been classified as bedrock covered with barnacles and seaweed can be reclassified by creating a raster for distance from the edge of the beach. All cells from the bedrock with barnacles and seaweed class that lie within a certain distance of the edge can then be reclassified.

6.5 A Brief Look at a Sand Beach

Very few areas of sand beach exist within the geographical extent of the Terra LiDAR survey with intensity and only one was located: on the south shore of the Annapolis Basin at the mouth of the Annapolis River and near Goat Island. This small stretch of sand extends little more than 150 metres in length and is composed of two low dunes, one behind the other and running more or less east-west. Most of the shoreline of the Annapolis Basin is composed of mud from sediment deposited by the river. It is quite distinct from the Fundy coast of the Young's Cove area and, because the data was acquired at different times, comparison of the intensity values between the sites can only serve as an indicator. Both the Young's Cove and the sand beach data are from the same survey but were acquired on different days (Goat Island on Day 4 of the survey, Young's Cove on Day 6).

Nevertheless, relative difference is the key to working with LiDAR intensity for this kind of classification. The range of intensity values of the LiDAR hits on the sand at the Goat Island area hints that classification might be possible even on beaches with sand, cobble and bedrock (bare and covered with barnacles and seaweed). A sample of values of interpolated intensity surfaces (IDW with identical parameters and 2 metre cell size) shows the following:

SAND (Goat Island):	180 - 210
MUD (Goat Island):	130 - 170
COBBLE (Young's Cove):	85 - 120
BARE BEDROCK (Young's Cove):	180 - 195
BARNACLES & SEAWEED (Young's Cove):	40 - 80

The ranges of mud and sand are distinct; given the results at Young's Cove, the classes should be separable. The use of additional segments ought to improve separability as it did at Young's Cove; while the textures of the sand and mud surfaces will be very similar, the luminance values will differ. When querying luminance values, the sand averages about 160 whereas the mud averages approximately 100. There is no overlap.

At shorelines where contiguous areas of all five material types exist, if the above relative intensity ranges hold true, then bare bedrock and sand are the only classes with strong overlap. Luminance and texture values are quite distinct between them, though, and separability should be sufficient to allow classification. There is only a small degree of luminance range coincidence among the classes in the imagery.

Texture, or the range in orthometric height of a group of grid cells, may well add a further degree of differentiation between classes as was the case at Young's Cove where it improved separability marginally. Steeply-sloping cobble berms and sand dunes can produce texture values very similar to rough terrain such as the igneous bedrock at Young's Cove. In these cases, it may be necessary to normalize texture for slope. Conversely, as at Young's Cove, if the overall grade of a beach is maintained from one class to another, any effect on texture attributable to slope should be equalized.

It must be remembered, in any case, that much depends on material colour, wetness and type, among other factors. For example, not all sand is of the same colour and brightness. Although LiDAR reflectance of materials is a question that needs to be studied further, the potential for its use to classify nearshore materials is encouraging. Ultimately, no two classes have similar value ranges in intensity, luminance and texture.

Forested areas should be identifiable, including differentiation between coniferous and deciduous. Single trees and shrubs will be more difficult.

7 CONCLUSIONS

Relative LiDAR intensity values of regions within an intensity grid do create separability.

Meaningful classification of nearshore materials is possible using only LiDAR intensity values, at least, on beaches similar to the Young's Cove study area, where the classes fall into distinct value ranges.

While separability can be enhanced by including luminance and texture in the classification, the final results do not necessarily change.

On beaches where the classes fall into distinct value ranges, classifications that resemble those done in PCI Focus can be executed using only a simple density-slicing technique. This could eliminate the need for such software and reduce the time required to classify shorelines.

While a beach with all classes together was not tested, the indication is that sand might well be a separable class.

ACKNOWLEDGEMENTS

Russell Brennan, Laura Chasmer, David Colville, David Cowan, Art Lynds, Bob Maher Andy Sharpe and NSERC

REFERENCES

[1] CHARANIYA, A.P., MANDUCHI, R. AND LODHA, S.K. (2004). Supervised Parametric Classification of Aerial LiDAR Data. Retrieved October 2004 from http://www.cse.ucsc.edu/~manduchi/papers/Amin3D.pdf

[2] MAUNE, D.F. (2001). Digital Elevation Model Technologies and Applications: The DEM Users Manual. American Society for Photogrammetry and Remote Sensing Bethesda, Maryland pp 539.

[3] NORTHWOOD TECHNOLOGIES INC. AND MARCONI MOBILE LIMITED (2001). Vertical Mapper User Manual. Courtesy of COGS.

[4] PCI GEOMATICS. Signature Separability. Retrieved April 2005 from http://www.pcigeomatics.com/cgi-bin/pcihlp/CLWORKS|Signature+Separability.

[5] SONG, J.-H., HAN, S.-H., YU, K. AND KIM, Y.-I., 2002. Assessing the Possibility of Land-Cover Classification Using LIDAR Intensity Data. ISPRS Commission III, Symposium 2002. Retrieved November 2004 from http://www.isprs.org/commission3/proceedings/papers/paper128.pdf

[6] WEBSTER, T., CHRISTIAN, M., SANGSTER, C. AND KINGSTON D. (2004). High Resolution Elevation and Image Data Within the Bay of Fundy Coastal Zone, Nova Scotia, Canada. Pages: 197 – 218. In Bartlett, D.J. and J.L. Smith (Ed.): GIS for Coastal Zone Management. Coast GIS '01 Conference (2001: Halifax, N.S., Canada). CRC Press, Boca Raton, FL. pp 328.