Land Use/Land Cover of two bioluminescent bays in Puerto Rico

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Abstract

The Land Use/Land Cover maps have the capacity to illustrate the interaction between humans and the surroundings and are also available to see different conditions in the same or similar environments. Puerto Mosquito Bay in Vieques and La Parguera Bioluminescence Bay in Lajas, Puerto Rico (two bioluminescence bays) are used to produce Land Use/Land Cover maps, which show environmental and geological characteristics. The major objective of this research was to produce and compares Land Use/Land Cover specific maps for the land around two bioluminescence bays. To produce Land Use/Land cover maps the Remote Sensing Technology was applied, this is the practice of deriving information regarding the earth's land and water surfaces using images. The images used to produce the maps were taken from space using a sensor called IKONOS at 1 meter of spatial resolution. All supervised classifications, Maximum Likelihood, Mahalanobis Distance, Minimum Distance, and Parallelepiped, were tested to determine the best result based on the spectral response for each image. The best supervised classification obtained in La Parguera Bioluminescence Bay was minimum distance classifier and for Puerto Mosquito the best method was Maximum Likelihood. By using the images from IKONOS it is possible to calculate the Normalized Difference Vegetation Index (NDVI). Using Environment for Visualizing Images (ENVI), the classification was exported to GIS and incorporated the shapefile with the catchment information. In a qualitative comparison, La Parguera Bioluminescence Bay has more interaction with anthropogenic activities than Puerto Mosquito. La Parguera Bioluminescence Bay has less density of vegetation than Puerto Mosquito. The ability to recognize, enumerate, and update these land use and land cover areas are valuable tools for future research and assure adequate management of the bioluminescent bays environment. . For future research, is suggested used older images and make supervised classification to determine changes in time and vegetation.

Key Words: Bioluminescence Bays, Remote Sensing, Supervised Classification, Land Use/Land Cover Maps, Index of Vegetation.

Introduction

Land around Puerto Mosquito Bay in Vieques and La Parguera Bioluminescence Bay in Lajas, Puerto Rico (two bioluminescence bays) are used to produce Land Use/ Land Cover maps, which show environmental and geological characteristics. Land use can be defined as the use of land by humans, usually with emphasis on the functional role of land in economic activities. Land cover designates only the vegetation, either natural or man made, on the earth surface all specific time of observation. In a much broader sense, land cover designates the visible evidence of land use, to include vegetation and non- vegetation features (Campbell, 2002). Examples of these include: urban structures, forest, agriculture, water resources, vegetations index and others. Also land use information is an important element in forming policies regarding, economic, demographic and environmental issues. The Land Use/Land Cover maps have the capacity to illustrate the interaction between human and the surroundings and also are available to see different condition in the same or similar environments.

In Puerto Rico, general maps of Land Uses/Land Cover were produced in 1999 for La Parguera and Vieques Island (Figure 1 and 2), but do not exist for land around Puerto Mosquito Bay and La Parguera Bioluminescence Bay. The main objective of this research was to produce and compare Land Use/Land Cover specific maps for the land around and two bioluminescence bays. To produce Land Use/Land Cover maps the Remote Sensing Technology was applied. Remote Sensing is the practice of deriving information about the earth's land and water surfaces using images acquired from an overhead perspective, using electromagnetic radiation in one or more regions of the electromagnetic spectrum, reflected or emitted from the earth's surface (Campbell, 2002). The images used to produce the maps were taken from the space using a sensor called IKONOS at 1 meter of spatial resolution.

The study areas are: Puerto Mosquito Bay and La Parguera Bioluminescence Bay (Figure 3). The Bioluminescence is the emission of light by microscopic organisms called *Pyrodinium bahamense.* The main conditions aiding the accumulation of these organisms are: shallow basin with low tidal and narrow mouth and surrounded by mangroves. Puerto Mosquito and La Parguera bays are denominated most incredible bioluminescent bays of Puerto Rico, but La Parguera Bay has shown a decrease in its bioluminescence by approximately 80% during recent years compared with Puerto Mosquito (Walker, 1997).

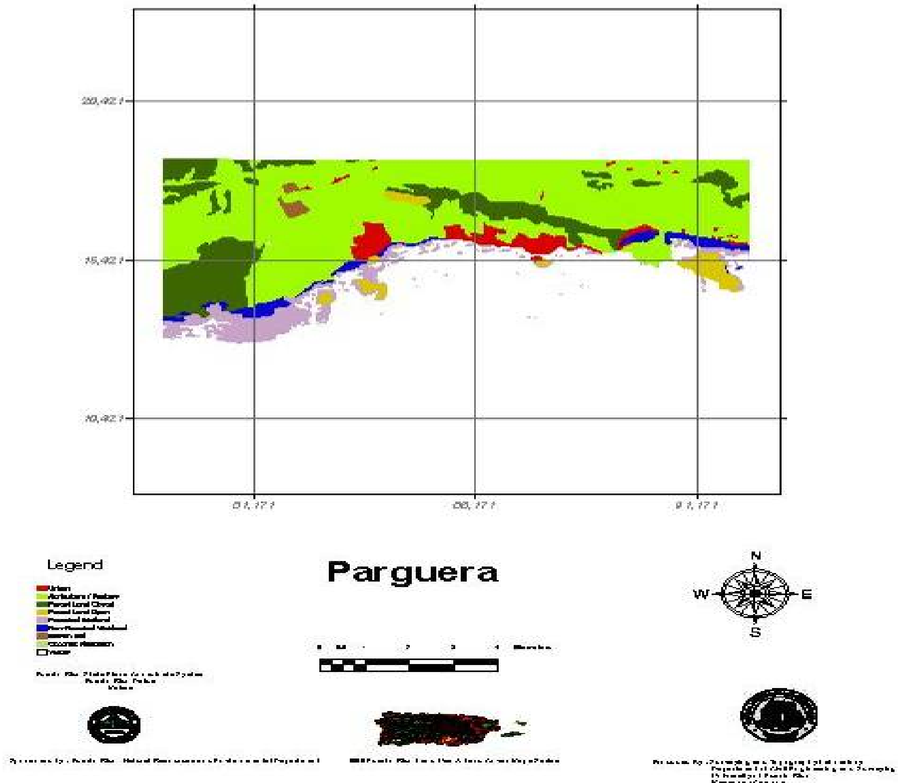

Figure 1. Land Use/ Land Cover Maps of La Parguera Bioluminescence Bay, 1999.

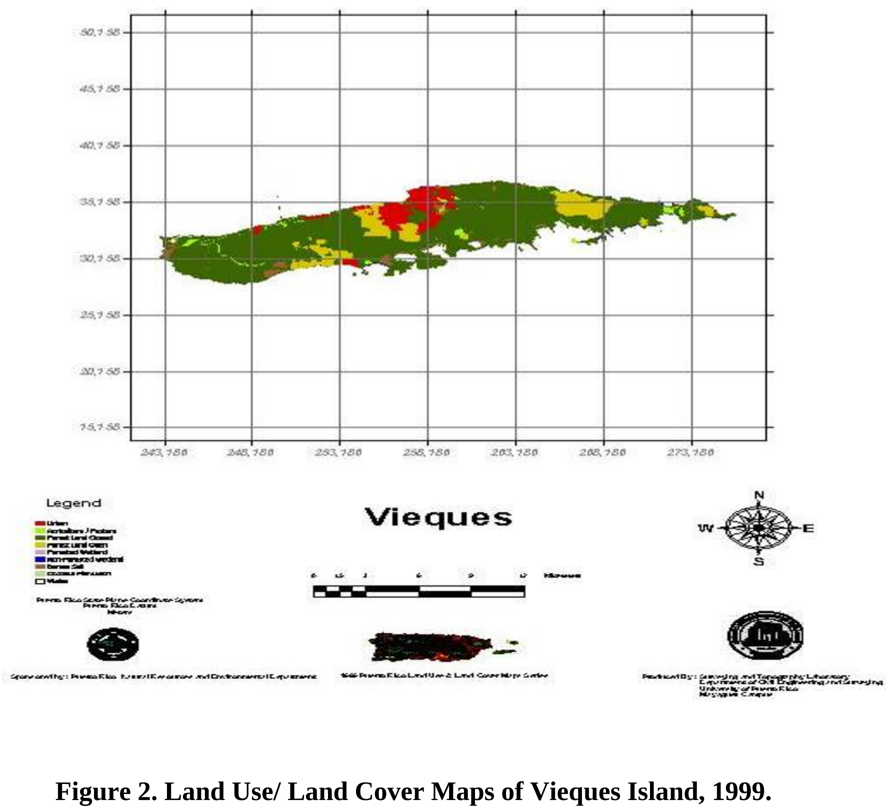

Figure 2. Land Use/ Land Cover Maps of Vieques Island, 1999.

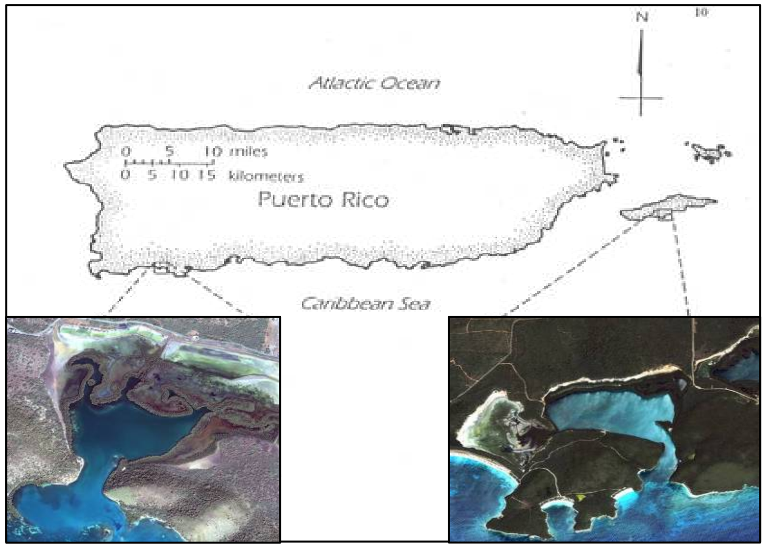

Figure 3. Study Area (La Parguera Bioluminescence Bay and Vieques Island)
(Adapted Walker, 1997 and GERS Lab.)

Puerto Mosquito is located in the south coast of Vieques Island between 18° 6’ N and 62° 26’ W. It has a depth of 3.9 meters in the inner zone and 1.8 meters at the mouth. It has 76.4 hectares of Mangroves surrounded the bay. Vieques has two bioluminescent bays: Puerto Ferro and Tapón Bay. But, Puerto Mosquito is the bigger with 65 km^2 with a narrow entrance and surrounded by mangroves that dominate *Rhizophora mangle* and *Avicennia germinans* (Connelly, 1993). The geology in Puerto Mosquito Bay is (QTu) sedimentary deposits undivided Marine limestone, calcarenite, sandstone, shale, marl, chalk, sand, clay and alluvial landslide beach, dune, swamp, marsh and reef deposit (Figure 4).

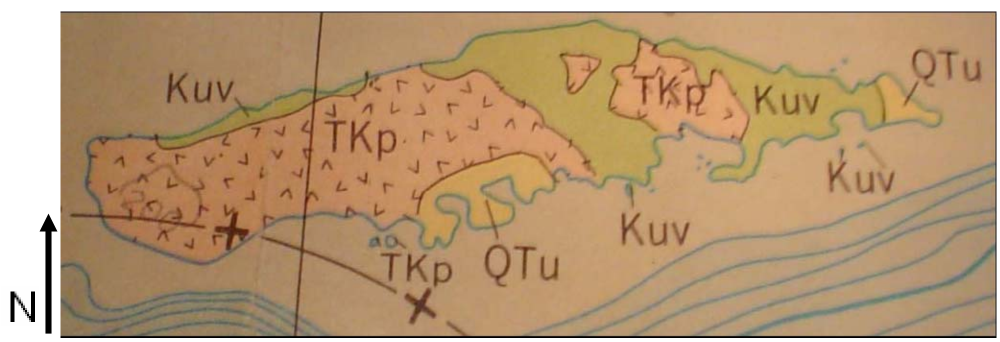

Figure 4. Geologic map of Vieques Island (1:20,000)

La Parguera Bay is located at southwest of Puerto Rico between 17° 58’ N and 67° 2’W and has an approximated depth of 4.5 meters in the inner zone and approximately 2.3 meters in the mouth of the bay (Seixas, 1988). The geomorphology of the area is the result of deformation of Limestone in early Cretaceous (Glynn, 1973). The bottom sediments are composed by fine mud, marine plants and mangrove leaves. (Margalef, 1961). Also the bay have high rate of evaporation because the arid conditions in the southwest of Puerto Rico.

The geology of La Parguera area is composed by extensive growth of mangroves (*Rhizophora mangle)*, underlaying by fine sand and silt trapped by mangrove roots. Basaltic andesite-porphyritic basalt and andesite, beach deposit, sand, minor gravel, consist of rounded fragments of shell debris, volcanic rocks, chert and locally quartz. Alluvium Deposit and La Parguera limestone (Figure 5). (Walkmann, 1984).

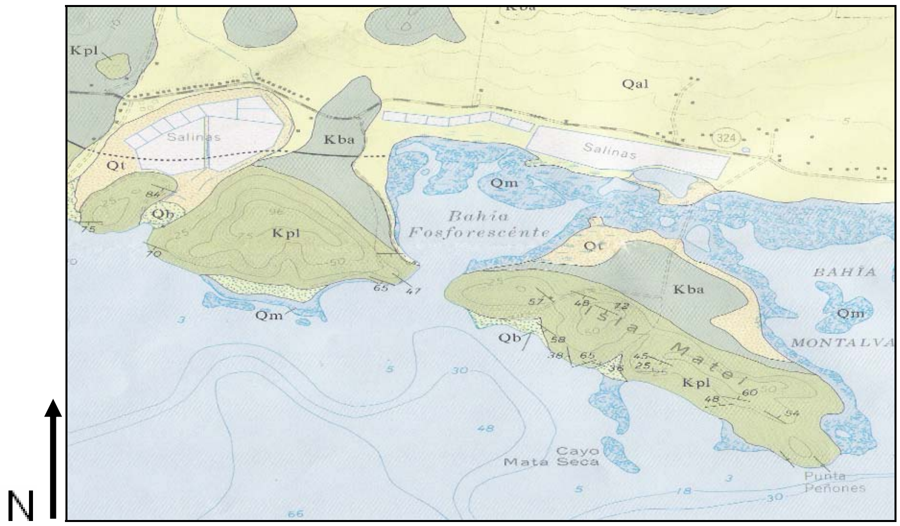

Figure 5. Geologic Map of La Parguera Bioluminescence Bay (Volckmann, 1984) (1:20,000)

Methodology

Remote Sensing data and existing digital data bases were incorporated into a Geographic Information System (GIS). The software used was Environment for Visualizing Images (ENVI). The images used for this research were from IKONOS sensor. IKONOS was launched in September 1999 operated by Space Imaging in Colorado. In panchromatic mode, IKONOS provides spatial resolution at 1 meter, in the spectral range 0.45- 0.90 μm. In multispectral mode, it provides imagery at 4 m spatial in four spectral bands. The images of La Parguera Bioluminescence Bay were taken during 2006 and Puerto Mosquito Bay was taken during 2000, both at 1 meter of spatial resolution (Figure 6 and 7).

The images was submitted to a preprocessing like a correction for atmosphere (Dark Subtract), geometric transformation, vegetation index, subsetting (portions of larger images selected to show only the region of interest). For a successful classification an atmospheric correction method (dark substract) that is defined as atmospheric scattering corrections to the image data was required. The digital number to subtract from each band can be either the band minimum, an average based upon a user defined region of interest, or a specific value (Campbell, 2002). The images was displayed using all available bands; red, green, blue (RGB) and infrared band. To perform a supervised classification requires the selection of different Regions of Interest (ROI's). Region of Interest is the process of using samples of known identity to classify pixels of unknown identity.

Figure 6. La Parguera Bioluminescence Bay at 1 meter of spatial resolution, during 2006.

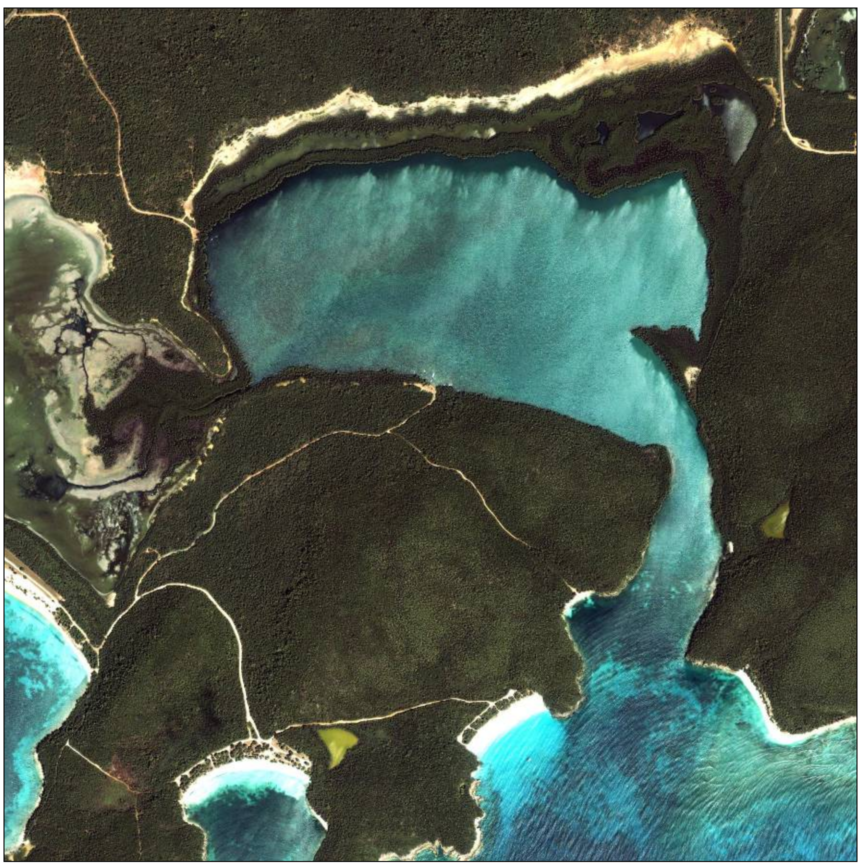

Figure 7. Puerto Mosquito Bay at 1 meter of spatial resolution, during 2000.

The classification system used to select the ROI's is compatible with other maps that have been used in the past because it is important to compare changes. The Land Use and Land Cover classification system used in this research was defined by United States Geological Survey (USGS), which started in 1970 a program to develop maps using aerial photography and interpretation of remotely sensed images (Campbell, 2002. The system used by USGS features the Level I which is adapted to use with large scale, coarse resolution. Level II are more detailed and can be interpreted in large scale, fine resolution images (Table 1). The produced ROI's were classified in Level I: Urban or built-up land, Forest land, water, wetland, Barren land.

USGS LAND-USE AND LAND COVER CLASSIFICATION

Level I		Level II	
1	Urban or built-up land	11	Residential
		12	Commercial and services
		13	Industrial
		14	Transportation, communications, and utilities
		15	Industrial and commercial complexes
		16	Mixed urban or built-up land
		17	Other urban or built-up land
2	Agricultural land	21	Croplands and pasture
		22	Orchards, groves, vineyards, nurseries, and ornamental horticultural areas
		23	Confined feeding operations
		24	Other agricultural land
3	Rangeland	31	Herbaceous rangeland
		32	Shrub and brush rangeland
		33	Mixed rangeland
4	Forest land	41	Deciduous forest land
		42	Evergreen forest land
		43	Mixed forest land

USGS LAND-USE AND LAND COVER CLASSIFICATION

5	Water	51	Streams and canals
		52	Lakes
		53	Reservoirs
		54	Bays and estuaries
6	Wetland	61	Forested wetland
		62	Nonforested wetland
7	Barren land	71	Dry salt flats
		72	Beaches
		73	Sandy areas other than beaches
		74	Bare exposed rock
		75	Strip mines, quarries, and gravel pits
		76	Transitional areas
		77	Mixed barren land
8	Tundra	81	Shrub and brush tundra
		82	Herbaceous tundra
		83	Bare ground tundra
		84	Wet tundra
		85	Mixed tundra
9	Perennial snow or ice	91	Perennial snowfields
		92	Glaciers

Note. From Anderson et al. (1976, p. 8).

Table 1.USGS Land Cover Use and Land Cover Classification (Campbell, 2002)

ENVI allows selection of any combination of polygons, points, or vectors as a region of interest. Multiple regions of interest can be defined and drawn in any of the Image, Scroll, or Zoom windows. The ROI's used for La Parguera Bioluminescence Bay classification were; Urban or built-up land (22,762 points), Forest land (46,397 points), Water (3,445,009 points), Wetland 44,439 (points), Barren land (22,048 points). The ROI's used for Puerto Mosquito bay classification were; Forest land (789,274 points), Water (853,408 points), Wetland (7,491 points), Barren land (20,104 points) (Figure 8).

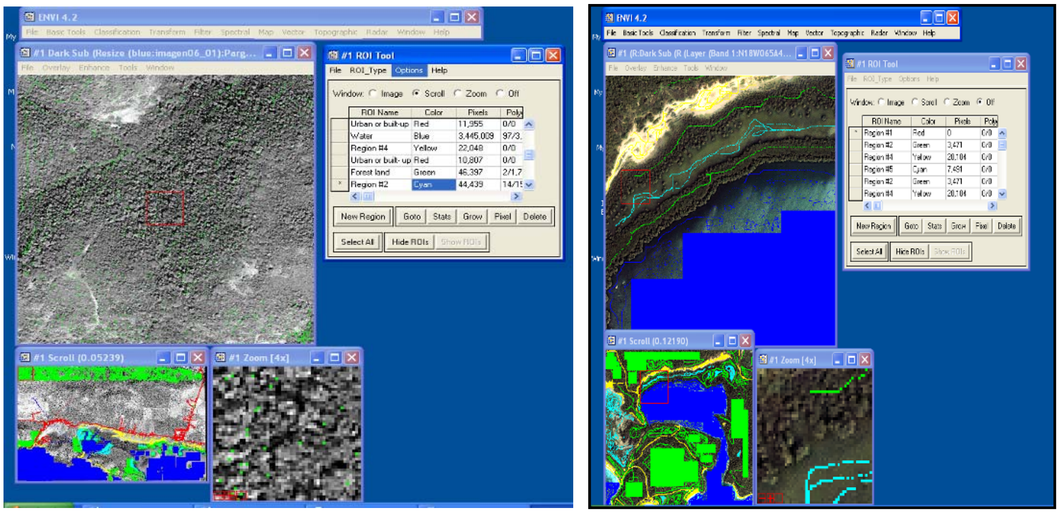

Figure 8. Selection ROI's for land around La Parguera Bioluminescence Bay and Puerto Mosquito Bay.

Various supervised classification methods were evaluated to determine which one is the best product for the selected bays. ENVI has the following classification methods: Parallelepiped, Minimum Distance, Mahalanobis Distance and Maximum Likelihood. Parallelepiped classification ranges of values within training data to define regions within a multidimensional data space. The minimum distance classification uses the mean vectors of each ROI's and calculates the Euclidean distance from each unknown pixel to the mean vector for each class. All pixels are classified to the closest ROI's class unless the user specifies standard deviation or distance thresholds, in which case some pixels may be unclassified if they do not meet the selected criteria. The Mahalanobis Distance classification is a direction sensitive distance classifier that uses statistics for each class. Maximum likelihood classification assumes that the statistics for each class in each band are normally distributed and calculates the probability that a given pixel belongs to a specific class (Campbell, 2002).

An interactive class tool to obtain statistics for classes and to change class colors and names were used to produce a report showing the number of pixels and percentage of pixels in each class. The report is processed and displayed in the Classification Distribution window. The report is automatically updated as pixels are added or removed from classes during editing

The validation accuracy of supervised classified was evaluated using post classification option, Confusion Matrix method, using ground truth image and ROI's. This is calculated by the comparison of the location and class of each ground truth point with the corresponding location and class in the classified image. This error matrix is a square array of rows and columns where the columns represent the reference data and the rows the classification generated by the remote sensed data and each cell has the sampling sited per class. Classified images were evaluated using the general, user, and producer accuracy computed from the derived confusion matrices (Green et.al.2000). The general accuracy is calculated by the sum of the number of pixels classified correctly divided by the sum of all the pixels in the entire ground truth classes. Ground truth ROI's defines the true class of the pixels (Figure 9).

The user's accuracy is map based accuracy where the number of pixels correctly classified as a class is divided by the total number of pixels classified in that class. It is the probability that a pixel classified on the image is correctly classified when compared in the field. Error of commission occur when a pixel in a class is included when should be excluded. The producer accuracy is a reference based accuracy based in the probability that the classifier has labeled an image pixel into a specific class given that the ground truth is that class. It is the probability that any pixel in that category has been correctly classified. Correctly classified pixels are divided by the total number of ground reference pixels in that class. Error of omission will be to exclude a pixel that should be included in the class. The producer's and user's accuracy show the classification accuracy of individual classes. The kappa coefficient is another method for accuracy assessment and is included in the results. The Kappa coefficient is a measure of the proportional improvement by the 36 classifier over a purely random assignment of classes. It is calculated by multiplying the total number of pixels in all the ground truth classes by the sum of the confusion matrix diagonals, subtracting the sum of the ground truth pixels in a class times the sum of the classified pixels in that class summed over all classes, and dividing by the total number of pixels squared minus the sum of the ground truth pixels in that class times the sum of the classified pixels in that class summed over all classes (ENVI 4.2 Tutorials).

Class Confusion Matrix

File

Confusion Matrix: C:\Documents and Settings\yadira soto\Desktop\TOPICO #2 (2007)\Par

Overall Accuracy = (3490287/3524615) 99.0260%
Kappa Coefficient = 0.8091

	Ground Truth (Pixels)				
Class	Urban or buil	Water	Region #4	Urban or buil	Forest land
Minimun Dista	0	0	0	0	0
Urban or buil	4876	1	3082	3106	5
Water	68	3428650	6	87	41
Barren land	2821	174	13385	2941	1439
Urban or buil	1726	60	2929	1246	14
Forest land	188	2476	362	728	42130
Urban or buil	0	0	0	0	0
Total	9679	3431361	19764	8108	43629

	Ground Truth (Pixels)	
Class	Region #2	Total
Minimun Dista	0	0
Urban or buil	0	11070
Water	6082	3434934
Barren land	5686	26446
Urban or buil	0	5975
Forest land	306	46190
Urban or buil	0	0
Total	12074	3524615

Figure 9. Confusion matrix method, using ROI's

Using the images from IKONOS we can calculate the Normalized Difference Vegetation Index (NDVI). NDVI serves as assistant in image classification and mapping device to separate vegetated from non-vegetated areas to distinguish between different types and densities of vegetation and also monitoring seasonal variations (Campbell, 2002). The algorithm used is NDVI= Infrared (IR)-Red(R)/ Infrared (IR)+ Red(R). NDVI transforms multispectral data into a single image band representing vegetation distribution. The bands used to calculate the NDVI are automatically entered into the Red and Near IR. When the Vegetation Index is applied the ENVI provides a color ramp to cover the vegetation. The NDVI results represent amounts of green vegetation present in the pixel, higher NDVI values indicate more green vegetation (Figure 10).

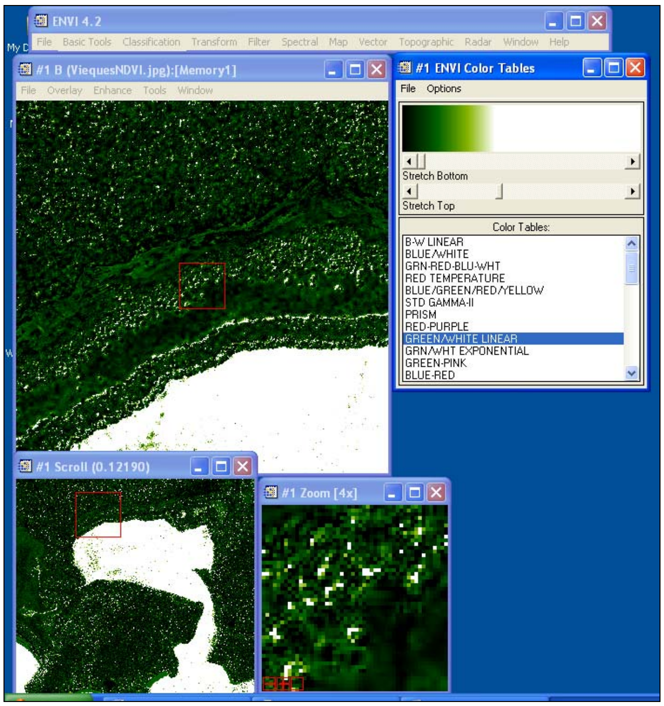

Figure 10. NDVI results of land around Puerto Mosquito Bay and the method to assign the color ramp.

Using the best result of supervised classification, the results were added to the Geographic Information System (GIS) to produce Land Cover/Land Use Maps for each bioluminescent bay. The source of hydrology information was taken from USGS publication files. Using ENVI the classification was exported to GIS and incorporated the shapefile with the catchment information, then created a new shapefile using only the area of the classified image and added the information required to produce the map (Figure11).

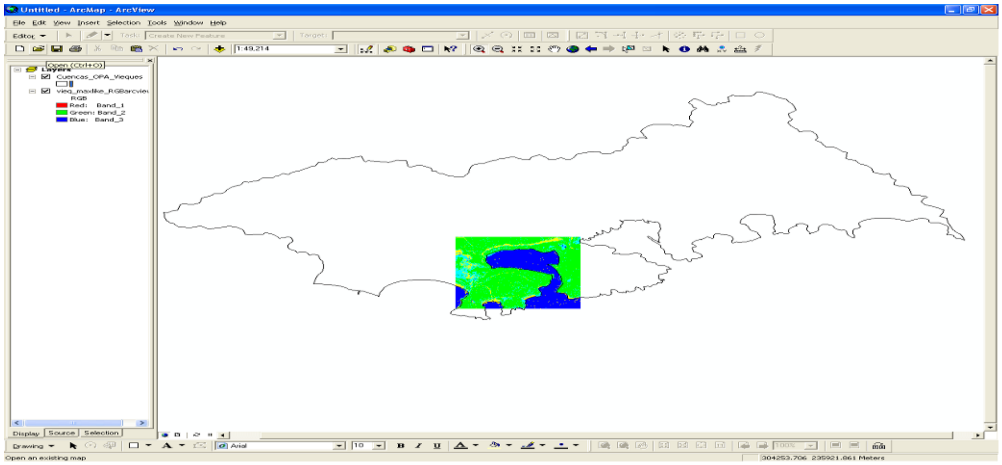

Figure 11. Puerto Mosquito Bay, USGS Catchment shapefile.

Results

All supervised classifications, Maximum Likelihood, Mahalanobis Distance, Minimum Distance, and Parallelepiped, were tested to determine the best result based on the spectral response for each image. La Parguera Bioluminescence Bay surroundings have five regions of interest: Urban or Built land, Water, Forest land, Barren land and Wetland each one have a different spectral response or wave length (Table 2). The best supervised classification obtained was Minimum distance classifier; each of these pixels is assigned to the class with the neighboring centroid, as measured using the distance measures. The other supervised classifications proofed to be inadequate, because the method confuses the spectral response of each class. The Parallelepiped classification cannot be used because the result was too deficient.

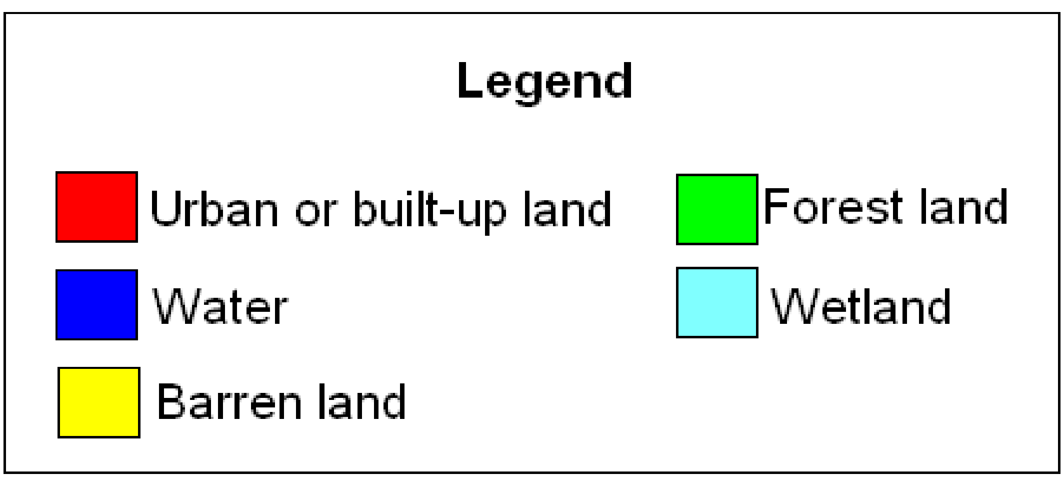

Table 2. Classes using for supervised classification.

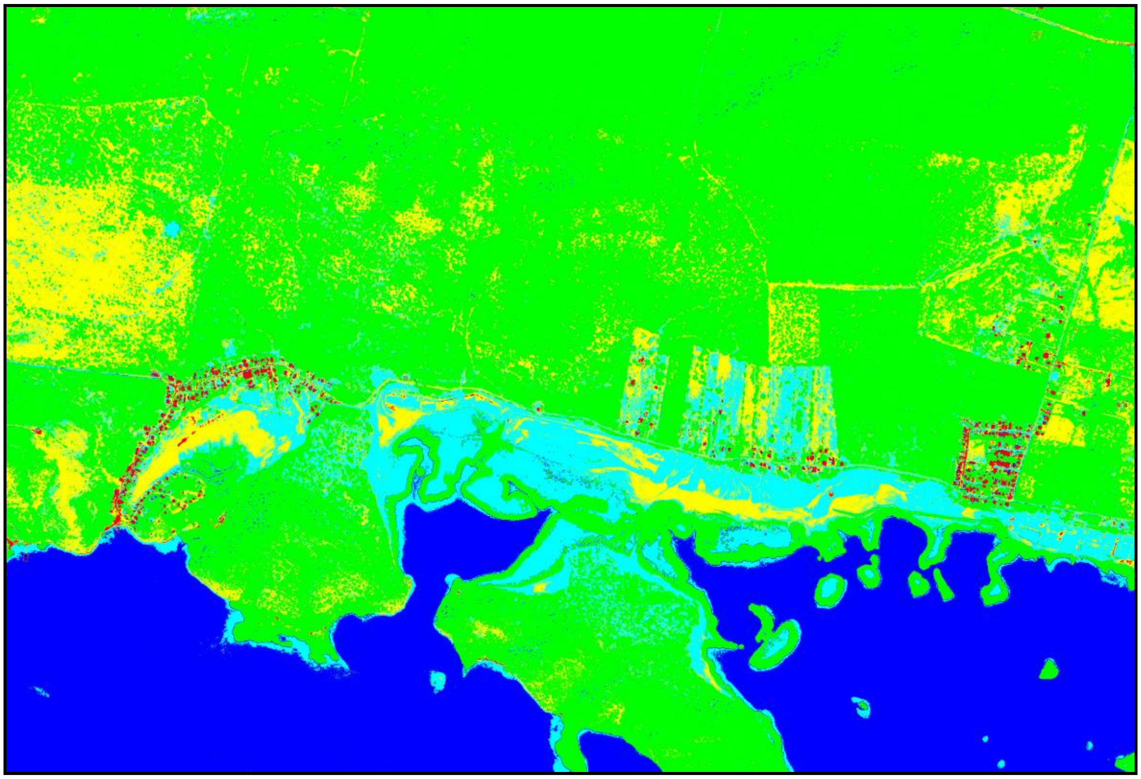

Figure 12. Maximum likehood classification around La Parguera Bioluminescence bay, classes are illustrating using the color in table 2.

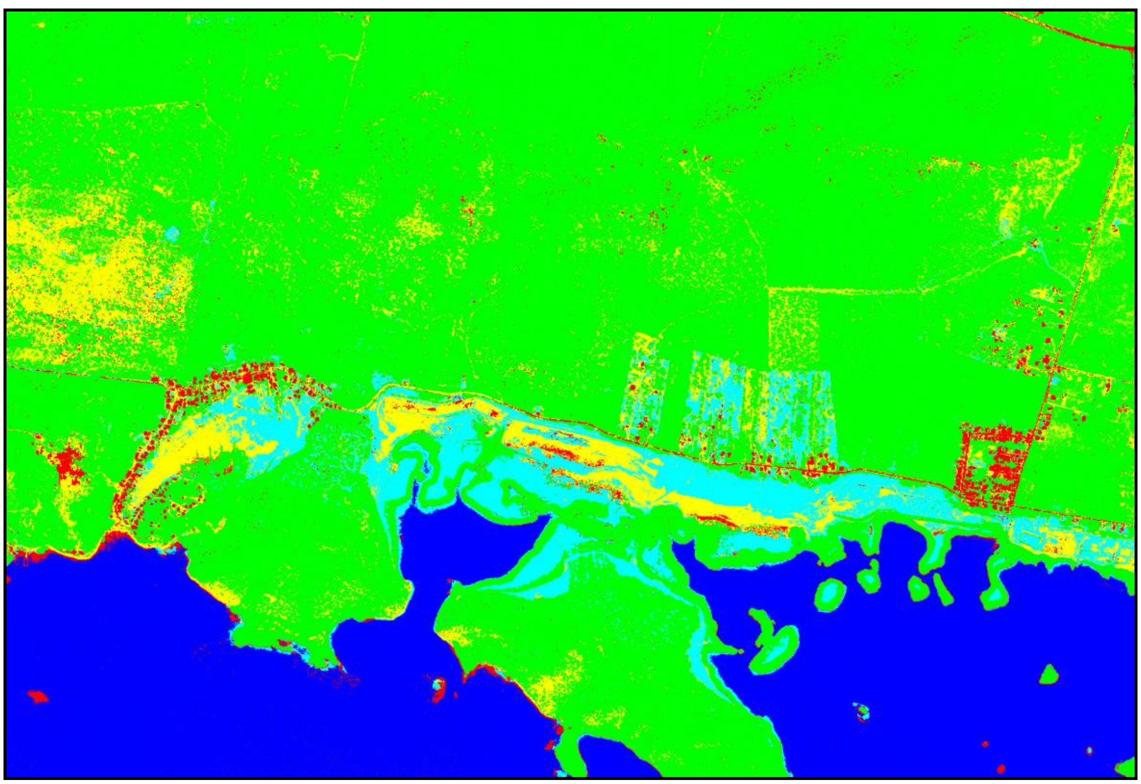

Figure 13. Mahalanobis Distance classification around La Parguera Bioluminescence bay, classes are illustrating using the color in table 2.

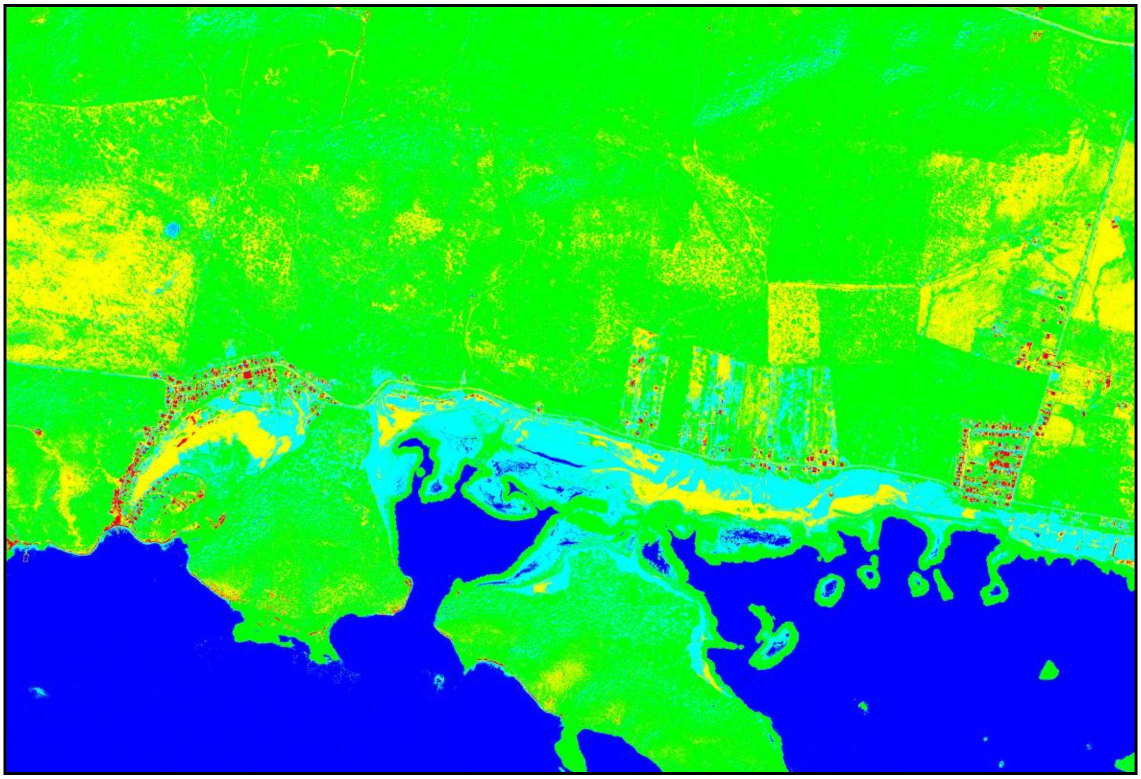

Figure 14. Minimum Distance classification around La Parguera Bioluminescence bay, classes are illustrating using the color in table 2.

The Puerto Mosquito Bay surroundings have five regions of interest: Water, Forest land, Barren land and Wetland, each one have a different spectral response or wave length. The best supervised classification obtained was Maximum Likelihood, this method assumes that the statistics for each class in each band are normally distributed and calculates the probability that a given pixel belongs to a specific class. The other supervised classifications proofed to be inadequate, because it confuses the class spectral response.

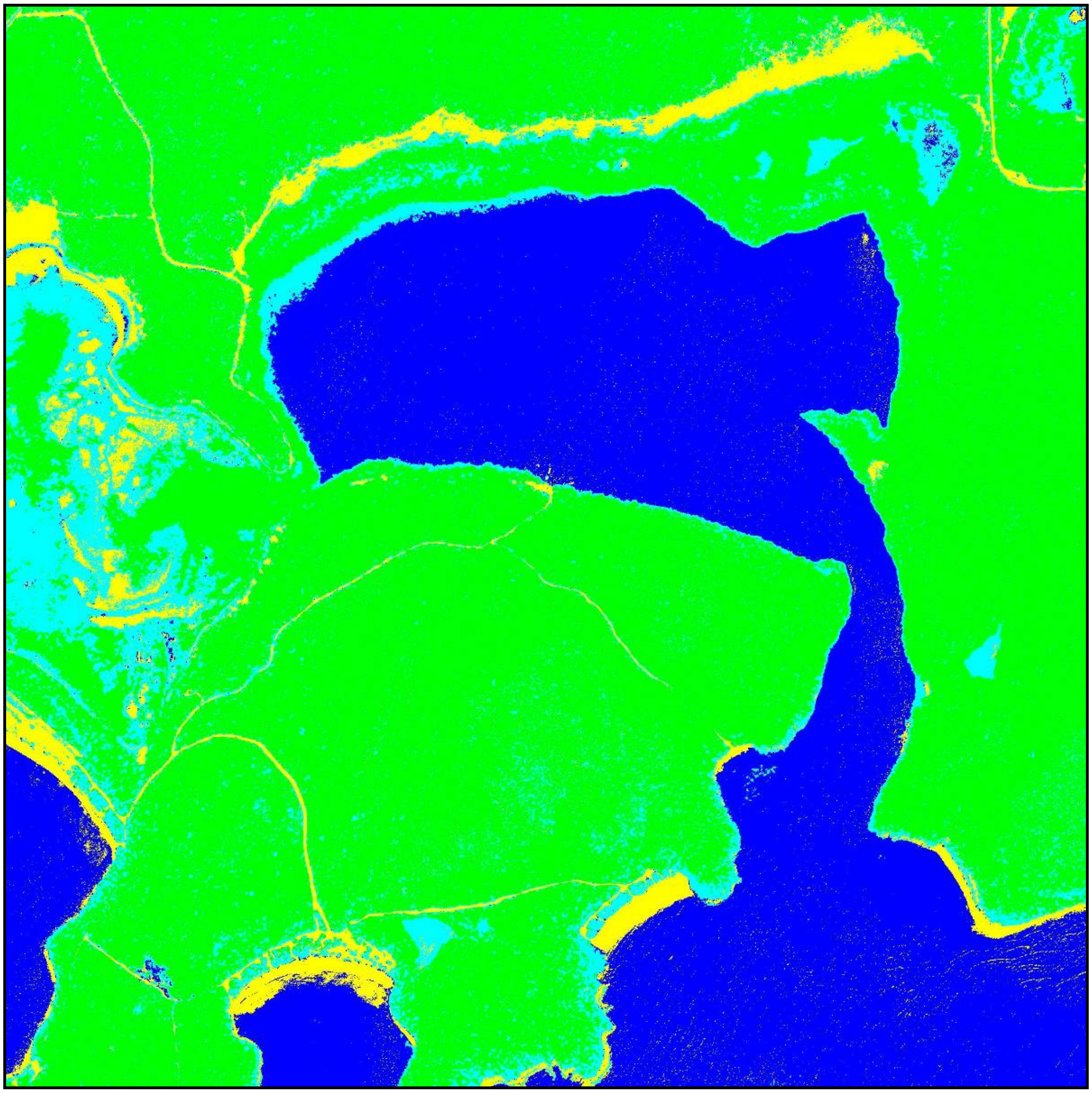

Figure 15. Maximum likehood classification around Puerto Mosquito bay, classes are illustrating using the color in table 2.

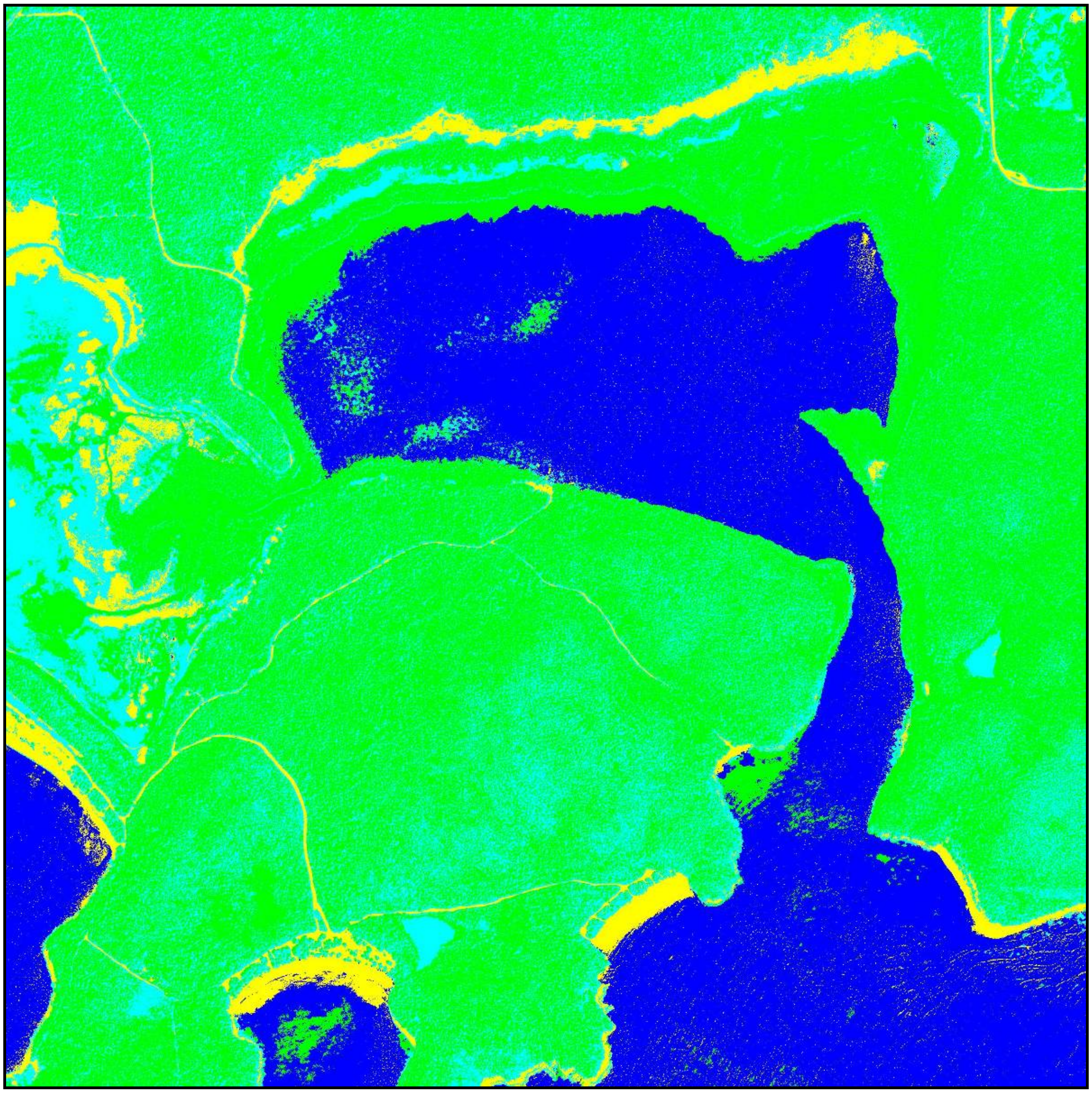

Figure 16. Mahalanobis Distance classification around Puerto Mosquito bay, classes are illustrating using the color in table 2.

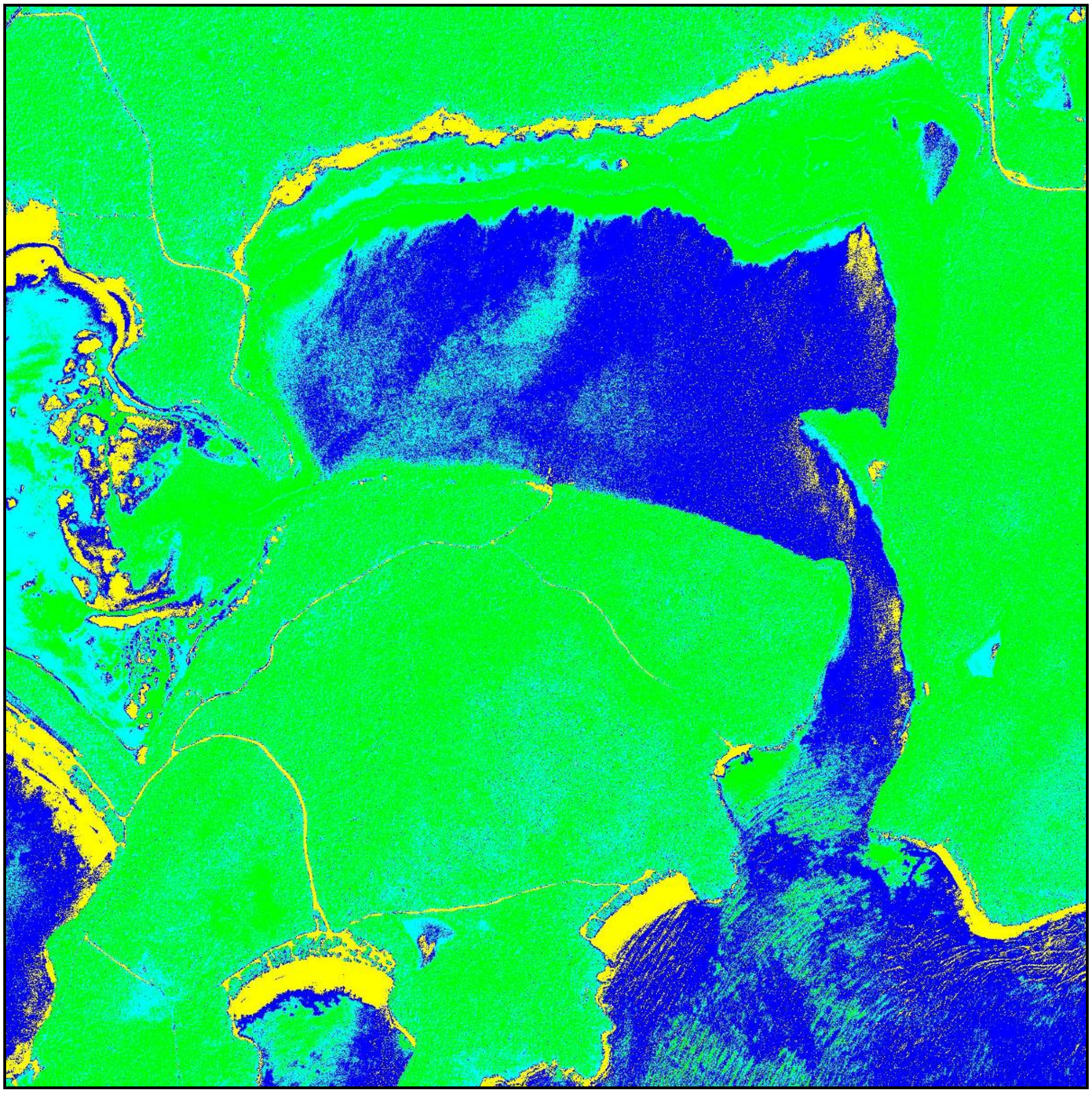

Figure 17. Minimum Distance classification around Puerto Mosquito bay, classes are illustrating using the color in table 2.

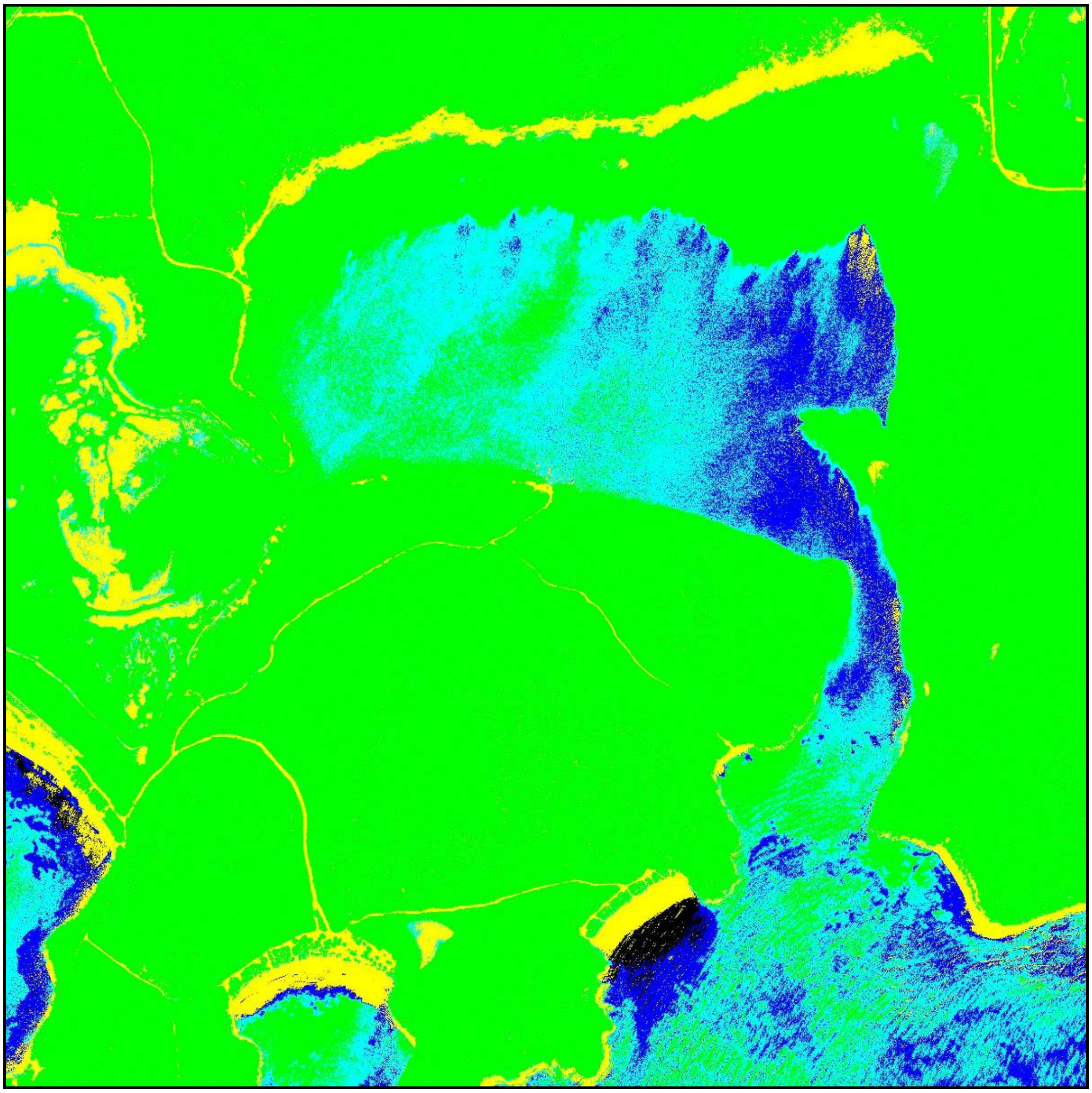

Figure 18. Parallelepiped classification around Puerto Mosquito Bay, classes are illustrating using the color in table 2.

Using a routine in ENVI it is possible to determine the distribution of classes for each environment to produce a report showing the number of pixels and percentage of pixels in each class. The report is processed and displayed in the Classification Distribution window. The report is automatically updated as pixels are added or removed from classes during editing. The classifications produced in La Parguera Bioluminescence Bay were: Urban or built-up land (1%), Forest land (55%), Water (23 %), Wetland (9%), Barren land (12%) (Figure 18). The distribution of classes of Puerto Mosquito Bay: Urban or built-up land (0%), Forest land (57%), Water (27 %), Wetland (11%) and Barren land (5%) (Figure 18 and 19).

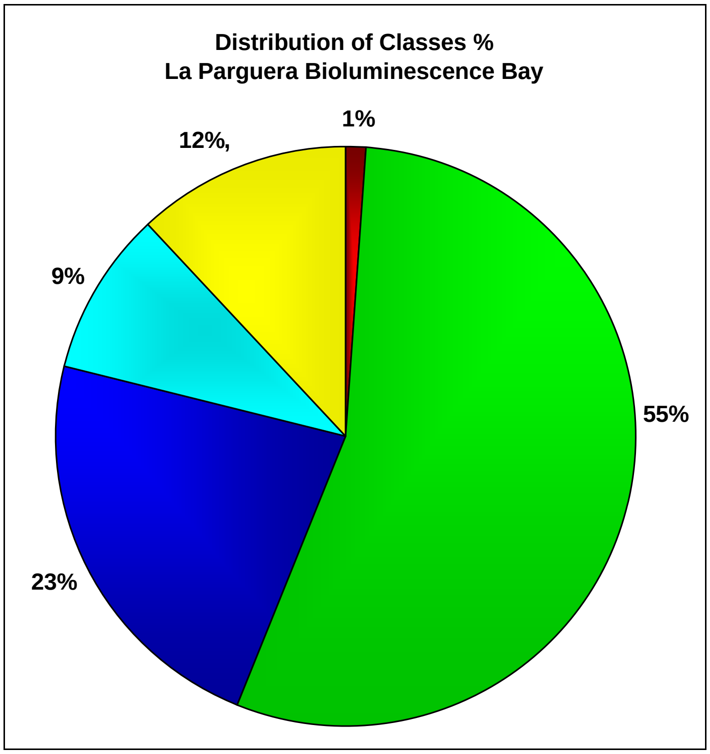

Figure 19. Distributions of Classes around Parguera Bioluminescence Bay, classes are illustrating using the color in table 2.

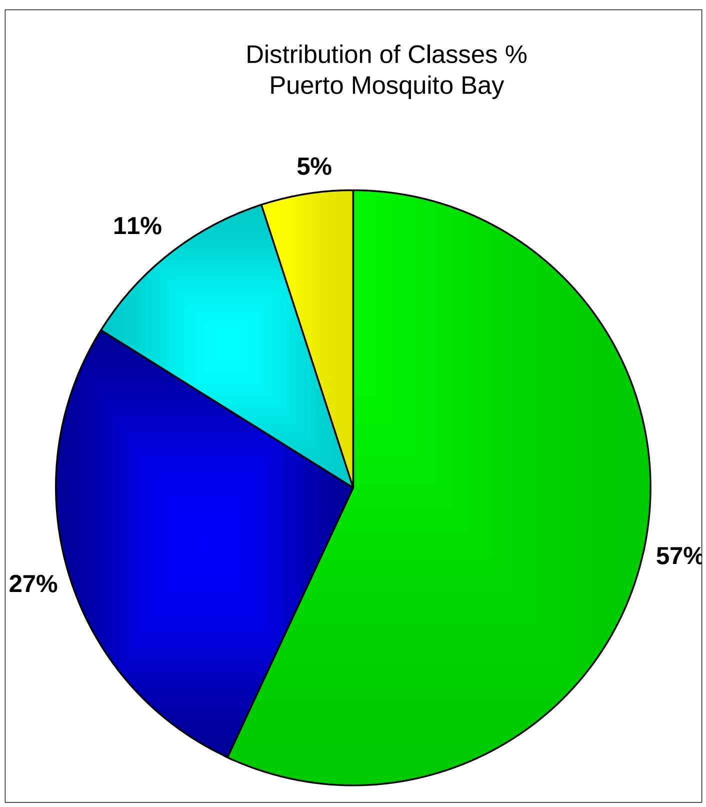

Figure 20. Distributions of Classes around Puerto Mosquito Bay, classes are illustrating using the color in table 2.

The validation process result of confusion matrix for La Parguera Bioluminescence Bay, using Ground Truth ROI, was 99% and the kappa coefficient was 0.80. Puerto Mosquito Bay was 90% and the kappa Coefficient was 0.5%(Figure 21).

Figure 21. Confusion Matrix using ground truth ROI's

The confusion matrix, using Ground Truth Image, was 100% and the kappa coefficient was 1 for both bays (Figure 22).

Figure 22. Confusion Matrix using ground image

The index of vegetation (NDVI) helped as an assistant in image classification tool to separate vegetated from non-vegetated areas to distinguish between different densities of vegetation. The NDVI results represent amounts of green vegetation present in the pixel-higher values, darker green color represent more density of vegetation (figure 23 and 24).

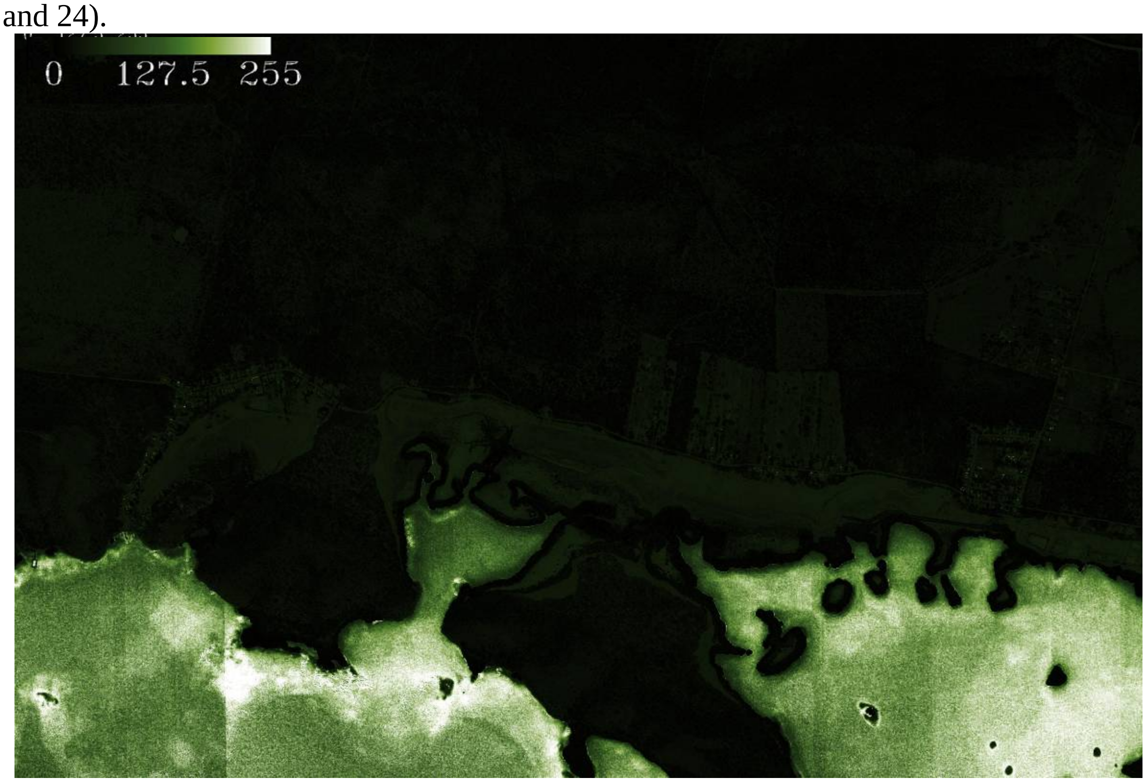

Figure 23. Index of vegetation in the surroundings of La Parguera Bioluminescence bay.

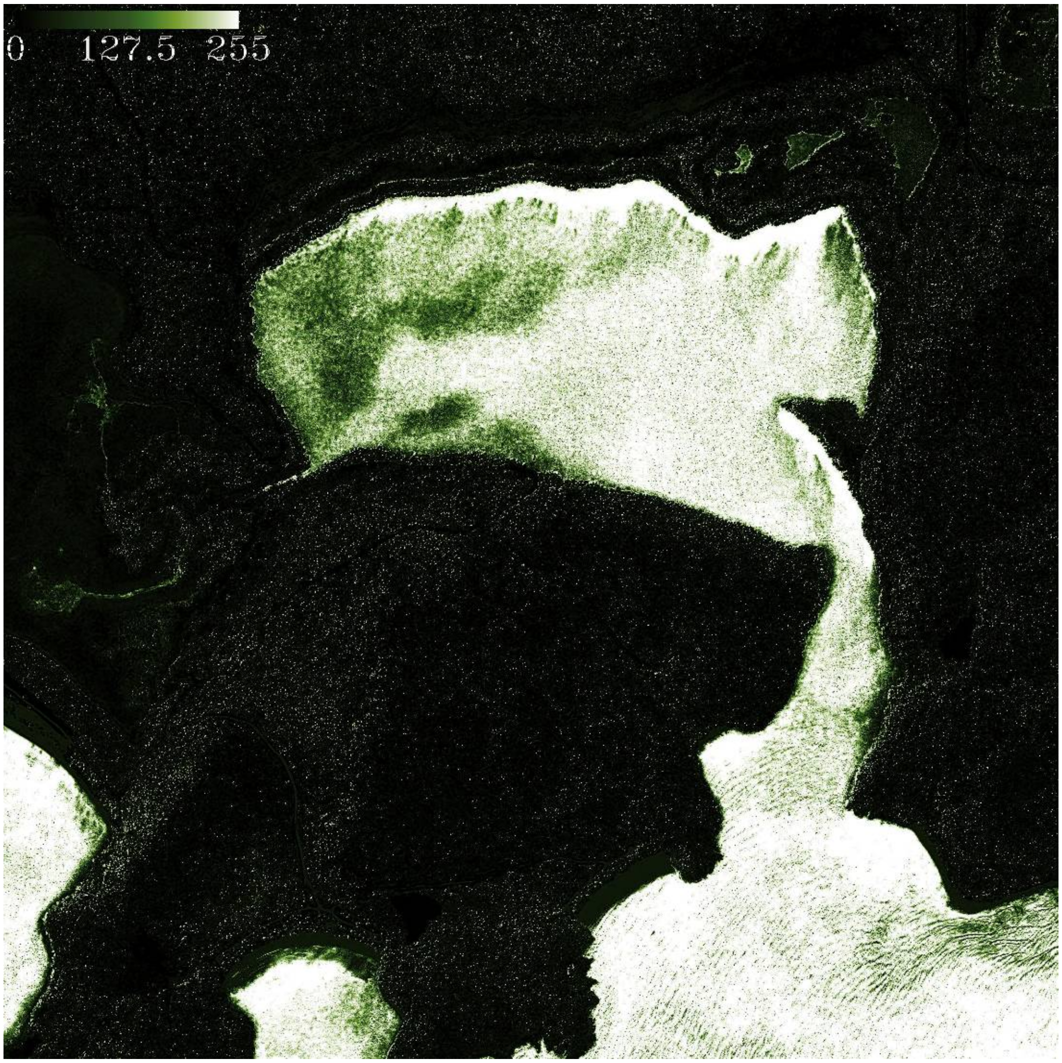

Figure 24. Index of vegetation in the surroundings of Puerto Mosquito bay.

The final result was the production of a Land Cover/ Land Use map, using the selected classification in ENVI and incorporating GIS, using the catchments layer (shapefiles) taken from United States Geological Survey (USGS) publication files (Figure25 and 26).

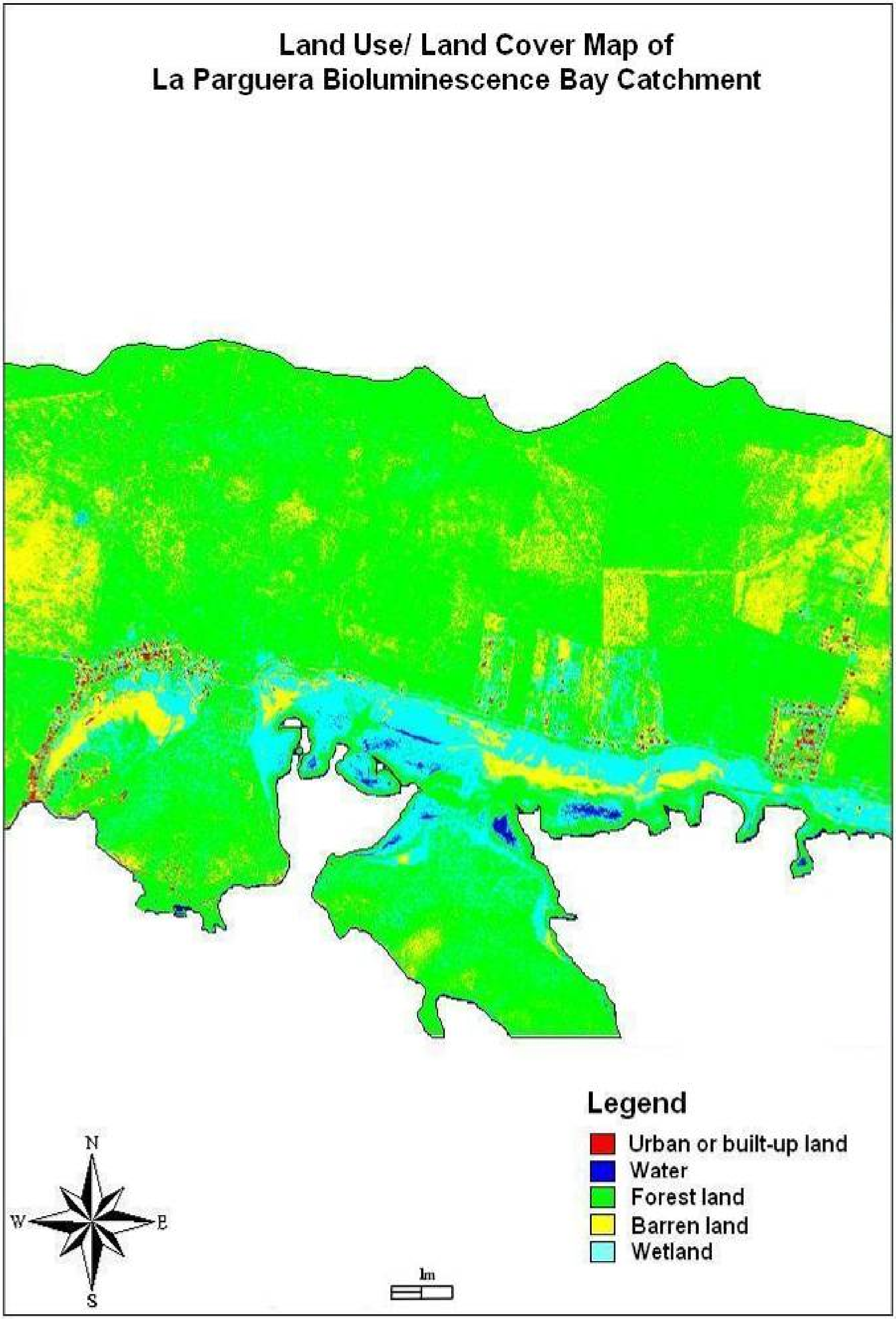

Figure 25. Land Use/ Land Cover for La Parguera Bioluminescence Bay.

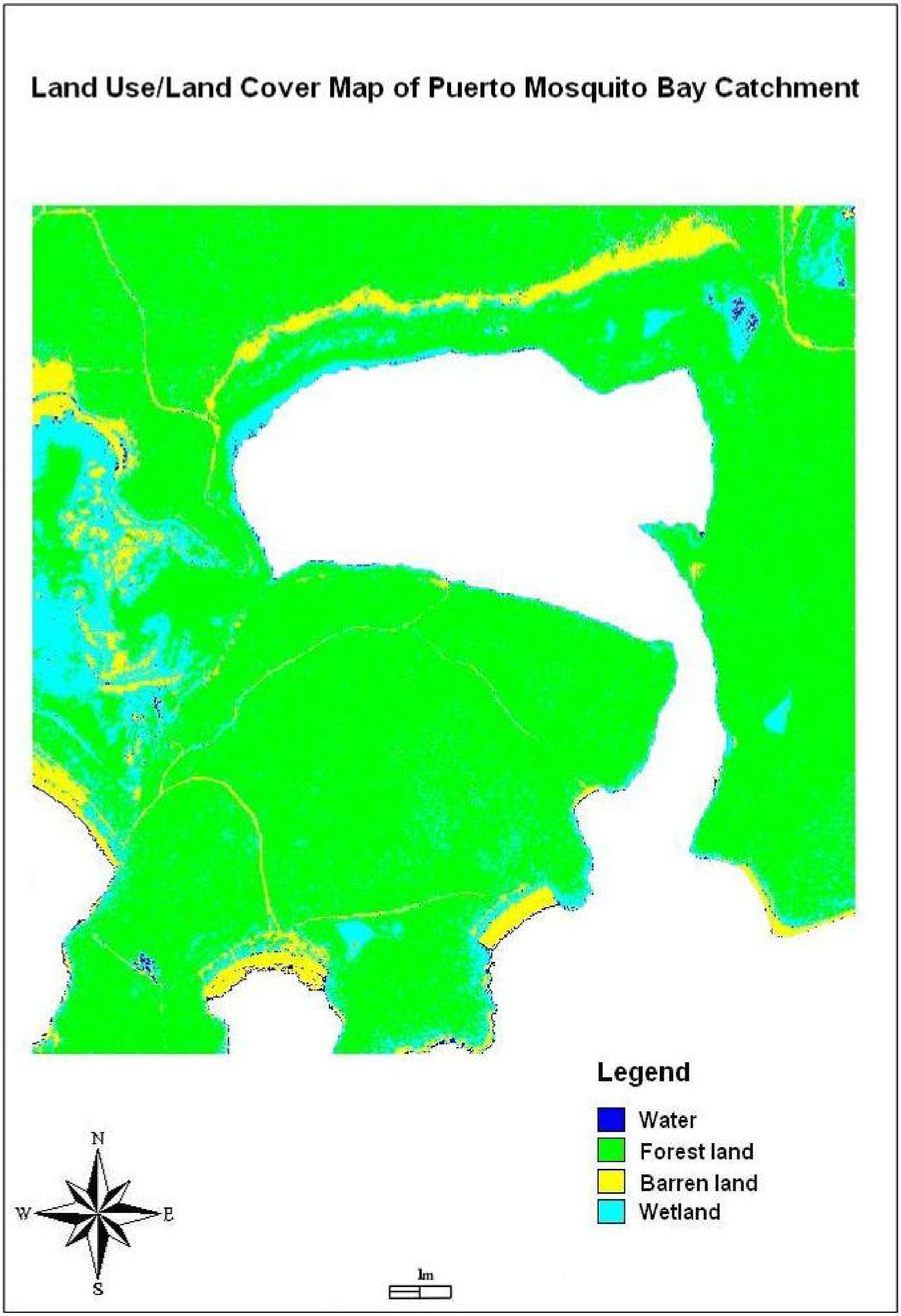

Figure 26. Land Use/ Land Cover for land around Puerto Mosquito Bay.

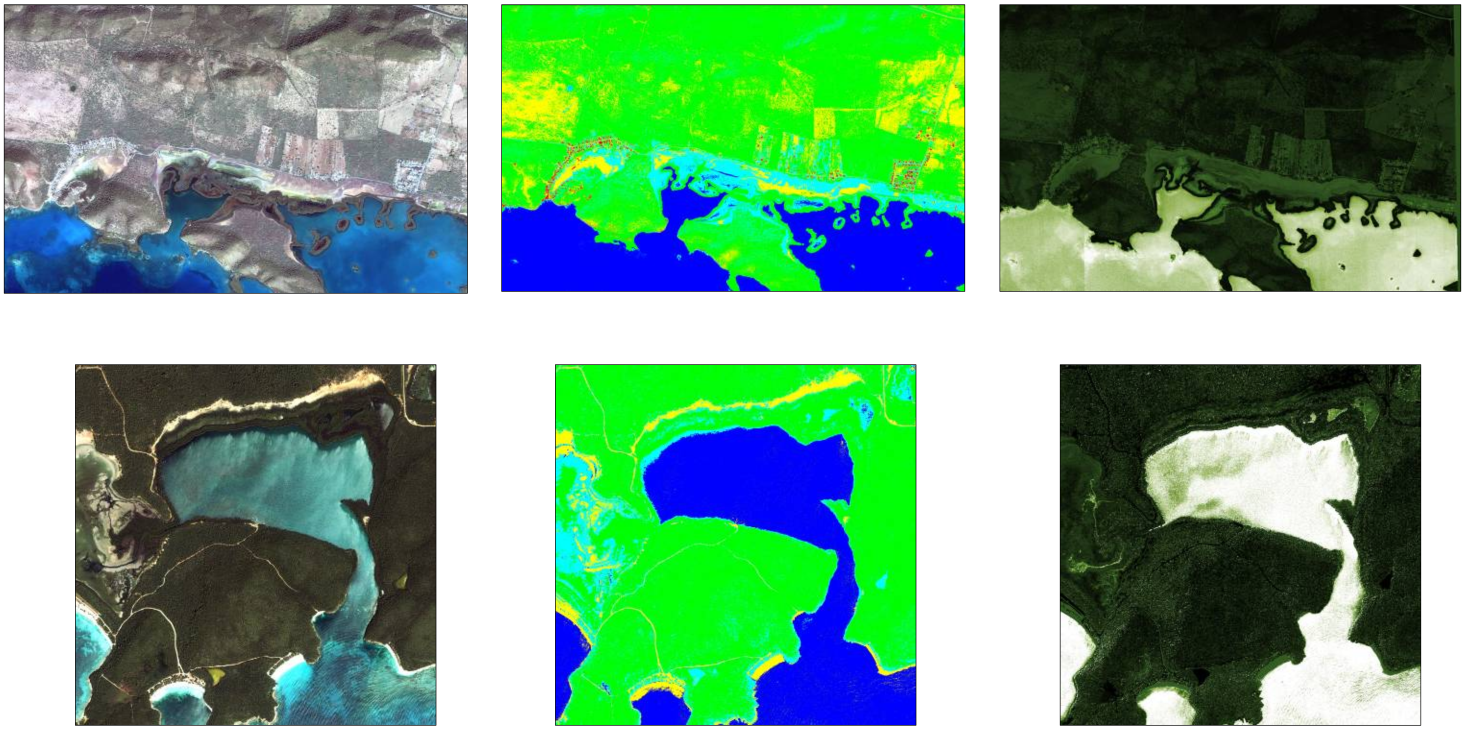

Figure 27. Image taken from IKONOS, supervised classification and Index of vegetation.

Discussion/ Interpretation

The advantage of the supervised classification is that the analyst has control of the selected categories depending of the purpose of the research or the geographic region; also, the analyst can detect serious errors in classification. All supervised classifications, Maximum Likelihood, Mahalanobis Distance, Minimum Distance, and Parallelepiped, were tested to determine the best result based on the spectral response for each image. In La Parguera Bioluminescence Bay the minimum distance classification was the best result; each of these pixels is assigned to the class with the neighboring centroid. For Puerto Mosquito Bay the best result was Maximum Likelihood; this method assumed that the information for each class in each band are normally distributed and calculates the probability that a given pixel belongs to a specific class (Campbell, 2002). The best classification depends on the spectral response of each class and the classification method. The other supervised classifications proofed to be inadequate, because the method confuses the spectral response of each class. For example: Barren land and Urban or built-up those have similar spectral response for that reason in places where it is suppose to be barren land the color is red. The distribution of classes a great tool see different condition in the same or similar environments. For La Parguera Bioluminescence Bay the percentage distribution in water, barren land, forest and wetland were similar in the two bays, except for urban or built up. This statement is considerating a qualitative comparison between to similar environment. In La Parguera Bioluminescence Bay has more interaction with anthropogenic activities than Puerto

Mosquito Bay. For that reason was concluded that La Parguera bay has more exposure to anthropogenic activities or urban which affects the bioluminescent bays, also contribute to reduce the bioluminescent. Human activities have a substantial impact on the hydrology characteristic of the bay, also the sediment impute to the bay has been variable due to human activities. The index of vegetation for La Parguera Bioluminescence Bay and Puerto Mosquito Bay shows the differentiation of vegetation in the surrounding of the bay. The produced NDVI can distinguish between densities of vegetation; the colors vary; light green (low vegetation) to dark green (high vegetation). It is visible to recognize that La Parguera Bioluminescence Bay has less density of vegetation than Puerto Mosquito Bay. The produced Land Use/Land Cover maps of La Parguera Bioluminescence Bay and Puerto Mosquito Bay show the interaction between humans and the impact on the catchments of the bay. Typically emphasis on the conservation of the main conditions that help the accumulation of *Pyrodinium bahamense* that produce the bioluminescent. Alterations to these bays and or some areas of their can affect the equilibrium for a high bioluminescence. Is important to recognize the geological characteristic take an important role for the distribution and impute of sediments and metals that have an effect into the bay.

Conclusion

Remote sensing technology has been a helpful way to monitor activities and conditions at the Earth's surface. This research presents the use of remote sensing and geographic information systems for monitoring land use and land cover of La Parguera Bioluminescence Bay and Puerto Mosquito Bay catchment using the hydrology information taken from the United States Geological Survey. The capacity to recognize, enumerates, and updates these land use and land cover areas are important tools for future research. The information provided in this report is a valuable tool in the development of priorities for the management of La Parguera Bioluminescence Bay and Puerto Mosquito. Land Use map reflects the character of society interaction between men with its physical environment. The fact becomes obvious when it is possible to see different economic and social systems occupying similar environments. The fact that the presence of the urban or anthropogenic activities affects the bioluminescent bays, also contribute to reduce the bioluminescent. Human activities have a substantial impact on the hydrology characteristic of the bay. Houses surrounded the bay, the intensity of artificial light, dredging; the poor land planification in the near areas can also affect the environment. The destruction of vegetation and the transit of boats can also affect the bay. Any other activity that may alter the land surrounding the bays, such as discharge of any type of effluents into the bays, must be prohibited. Any minimum change in morphology of the shoreline, marine currents and increase levels of contamination can extinguish the bioluminescent produced by dinoflagellates. For future research, is suggested used older images and make supervised classification to determine changes in time and vegetation.

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Acknowledgments

I want to thank Dr. Fernando Gilbes Santaella for unconditional support and help in working on this research. Thanks William Hernández to provide the USGS information and support me.