Developing a GIS of the Bioluminescent Bays on Vieques, Puerto Rico

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ABSTRACT

The Puerto Rico Department of Natural Resources (DRNA) and the US Fish & Wildlife Service oversee the largest wildlife reserve in the Caribbean. Included within the reserve is Mosquito Bay, which is considered to be one of the densest and brightest bioluminescent bays (biobays) in the world. The end of US Navy exercises on Vieques is stimulating new land development projects near the wildlife reserve area. These projects, if not managed properly, can cause irreversible damage to the biobay system. There is now a greater need to better understand and protect the Vieques Biobays. As a community service project, the National Imagery and Mapping Agency (*) developed a Biobay GIS for the reserve managers and local conservation groups. An Arc Published Map File provides potential applications of land management, ecologic monitoring, terrain analysis, and urban planning.

(*) On November 24th 2003, NIMA became the National Geospatial-Intelligence Agency, NGA.

INTRODUCTION

Bioluminescence is a phenomenon that occurs naturally throughout the world in various concentrations and degrees of intensity. In vary rare instances, unique ecological ingredients combine to allow for large concentrations of microscopic underwater organisms called dinoflagellates. Within the small Puerto Rican municipality of the Island of Vieques lies Mosquito Bay (a.k.a. Puerto Mosquito), which is managed by the DRNA. Puerto Mosquito contains a bioluminescent species of a dinoflagellate named Pyrodinium bahamense (see Figure 1) that exists in concentrations that are as high as 720,000 per gallon of water. These organisms exhibit a defense mechanism that, when agitated, releases a flash of light. The unusually large numbers of these organisms create a level bioluminescence that makes Mosquito Bay a unique place that must be preserved.

Figure 1: Pyrodinium bahamense (courtesy of www.golden-heron.com)

In May of 2003, the Department of Defense transferred the land adjacent to Puerto Mosquito, known as Camp Garcia and which served for years as a US Navy training area, to the Department of the Interior's US Fish and Wildlife Service (USFWS). Of note, included on the land transfer was another biobay,

Puerto Ferro, just east of Mosquito Bay. Puerto Ferro doesn't exhibit the intensity of its neighbor, and little is known of it due to its off-limits status as part of the military reservation.

This author recognized the value that a Geographic Information System (GIS) could do to manage and conserve the Vieques Biobays, noting that neither DRNA, nor the local USFWS managers had the resources to design and maintain such a system. After getting the required permissions, this GIS was created as a gift to Puerto Rico so that Mosquito Bay might still glow in its present wonder for future generations.

This paper discuss the four phases for the creation process of the Vieques Bioluminescent Bay GIS:

Phase I – Data Collection
Phase II – Field Survey
Phase III – Geospatial Analysis
Phase IV – Product Generation and Distribution

PHASE I – DATA COLLECTION

This author recognized that numerous disparate data sets of geospatial information already existed over the study area. A comprehensive search and gathering process was needed in order to determine the best available source and to subsequently identify the data and information shortfalls prior to moving on to the next phases of the study. The following paragraphs identify the primary sources and types of geospatial information found.

National Imagery and Mapping Agency (NIMA): Two data sources were researched and obtained from NIMA: a March 2000 Ikonos Multi-spectral commercial imagery collection; and a 30-meter post-spacing (Level 2) reflective surface digital elevation model collected in 2000 during the Shuttle Radar Topography Mission (SRTM).

US Navy: Through the US Navy, Atlantic Division in Norfolk Virginia, it was learned that the Navy had previously contracted the creation of GIS data sets over Camp Garcia. These data sets were now residing with the new land managers – USFWS. Of the entire GIS data sets, this author got permission to use and distribute the following GIS layers: Roads, Fish & Wildlife Area Land Cover, Sea Floor, Soils and Geology.

United States Geological Survey (USGS): Obtained USGS 1994 Digital Ortho-photo Quads (DOQs) over Vieques. Although not intended for distribution with the GIS, this spatially accurate imagery product would be needed to geo-position other data layers. The local USGS office in Guaynabo, Puerto Rico provided a shapefile of Streams on Vieques.

National Oceanic and Atmospheric Administration (NOAA): Obtained a copy of the NOAA published CD entitled "Benthic Habitats of Puerto Rico and the U.S. Virgin Islands." This CD contains public domain information on Benthic Types, Zones and Habitats over the study area in shapefile format

Department of Earth & Environmental Sciences, Wesleyan University, Middletown, CT: Provided a dense hydrographic sounding survey from early 2003 of Mosquito Bay. The University set no restrictions on the use or distribution of the data

Reservas Naturales y Refugios de Vida Silvestre, San Juan, PR: This DRNA division served to be the primary customer for this effort. DRNA provided hard copy maps of "Vegetacion" (vegetation) and "Uso De Terreno" (land use) from their 1999 Vieques Land Management Plan. DRNA also provided logistical support for the field survey as well as extensive technical guidance from their resident biologists on the reserve. The hardcopy maps were scanned, geo-corrected and then digitized into shapefiles. Additional GIS files generated by the author with the assistance of DRNA are: Reserve Limits and DRNA Points of Interest.

PHASE II – FIELD SURVEY

It was determined that a field survey using a hand-held Global Positioning System (GPS) was required around the study area in order to obtain ground truth to assist in performing a supervised classification of the multi-spectral imagery. It was presumed that changes in vegetation have occurred naturally during the three years since the Ikonos imagery was collected. One goal of the field study was to obtain multiple GPS-derived coordinates centering over large “old growth” red and black mangrove forests, wetlands, salt flats and erosion areas. Of note is the fact that these readings were to be obtained only around the vicinity of Mosquito and Ferro bays. DRNA provided a 4-wheel buggy and ATV with driver as well as a resident biologist to assist in locating the required vegetation areas for GPS measurements. Track points were collected throughout the survey and specific measurements were recorded as waypoints. Just prior to the May 2003 survey, an unusual tropical storm produced 18 inches of rainfall in a 24-hour period, making all of the wetlands completely inaccessible.

After reviewing the Wesleyan U. depth soundings, it was determined that additional measurements should be collected around the mouth of Mosquito Bay as well as a sampling of depth information from within Ferro Bay. DRNA provided a boat, pilot and two resident biologists to assist in recording the depth readings. Using the hand-held GPS and a measured weighted line, depth readings were written down and waypoints collected for each sample measurement (see Figure 2). Later, the depth would be added to the attribute table for each waypoint collected, resulting in an X, Y and Z point file.

Lastly, during the Field Survey, the resident biologists provided location information for protected habitats such as turtle nesting areas, bird sanctuaries and restoration areas.

Figure 2: Field Survey Of Mosquito Bay

PHASE III – GEOSPATIAL ANALYSIS

Imagery Processing: For imagery processing I used Erdas Imagine v8.6. The Ikonos imagery was imported as a layer stack. The images were actually three separate scenes that collectively covered the entire island of Vieques. All three images were collected on the same pass, with the center scene covering all the Ferro and Mosquito Bay areas. As an early Ikonos collection, the image carried the GeoTiff format, in lieu of the preferred NITF standard. This raises the problem of spatial accuracy issues with regard to the imagery, which requires the source and any files generated from that source to be

further geo-corrected. This correction, using USGS DOQ source as a control, was performed only after all multi-spectral image processing and classifications were complete.

To distinguish the shoreline of Vieques, the Infrared (IR) layer was first processed for all three scenes to obtain a land/water layer. Next, the layers were rescaled to Unsigned 1-bit in order to reduce the file size. Finally the files were geo-corrected to the DOQs, reprojected to UTM and merged into a mosaic file.

Next, a supervised classification was generated for all scenes in order to separate the following land cover classes: Urban / Cloud Shadow, Evergreen Forest, Forest and Scrub, Scrub and Brush, Brush and Grass, Sand / Cloud Cover. Ground truth from the field study provided information on appropriate areas to use as sample polygons during the supervised classification process. This classification scheme was generated for the entire island. A separate supervised classification was performed on only the center scene in order to catalogue the following land cover classes within the biobays: Wetlands, Erosion / Salt Flats, Red Mangroves, Black Mangroves. Although these features exist throughout Vieques, they are only available in the GIS over the study area. Then, both land cover classes were recoded into a single center scene file. All files were then geo-corrected to the USGS DOQs, reprojected to UTM, and then stitched into a single mosaic file of Satellite Derived Land Cover (see Figure 3). The accuracy of the forest, scrub, brush and grass classifications has not been thoroughly verified for currency. Also, all land cover classes outside of the immediate study area have not been verified for accuracy.

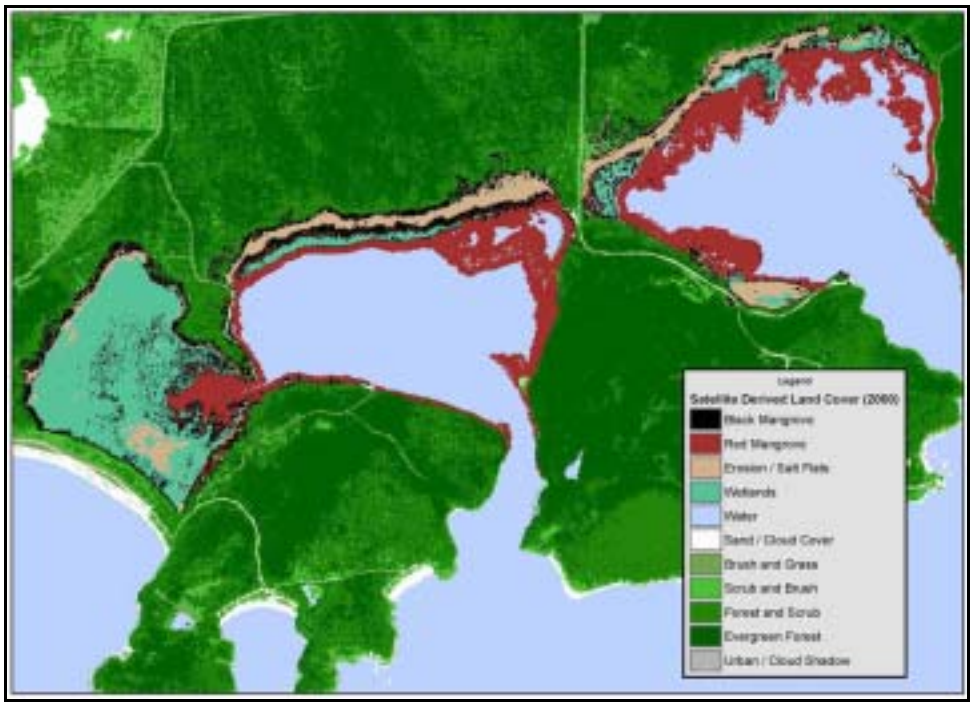

Figure 3: Vieques Land cover Generated From Ikonos MS

Terrain Analysis: The SRTM2 data provides for the subsequent generation of contour information, watershed and line of sight analysis, which will now be discussed. However, it must be clearly noted that the SRTM2 data is a *reflective* surface model generated from radar not a *ground* surface elevation model. The radar does not and cannot completely penetrate tree canopy. Also, over urban areas, the SRTM data is reflective of the top of buildings. The SRTM2 data used for this project is unfinished; bodies of water have been flattened, but spikes and wells have not yet been corrected. Users should use caution because of the unfinished nature of this data set.

The SRTM2 data over the entire island of Vieques was first imported into Erdas Imagine, reprojected to UTM and then subsetted into a new Terrain Elevation Model. This file would serve as a tinted elevation layer for use in the GIS.

Next, the file was then exported out of Erdas and into an ArcInfo grid file. Using ArcInfo Workstation, a low pass filter command was run on the file for five iterations in order to smooth out the grid. Then, using the lattice contour command in ArcInfo Workstation, coverages were generated for 5, 10, 20 and 50 meter contour intervals. The coverages were then exported into shapefile format.

Using the digital elevation model along with the USGS river/stream and contour files, a polygon was drawn to delineate the watershed of Mosquito and Ferro bays. Though somewhat approximate, this Watershed shapefile, (see Figure 4) provides a basis for understanding areas where land clearing and erosion could lead to excessive sediment runoff into the area of interest.

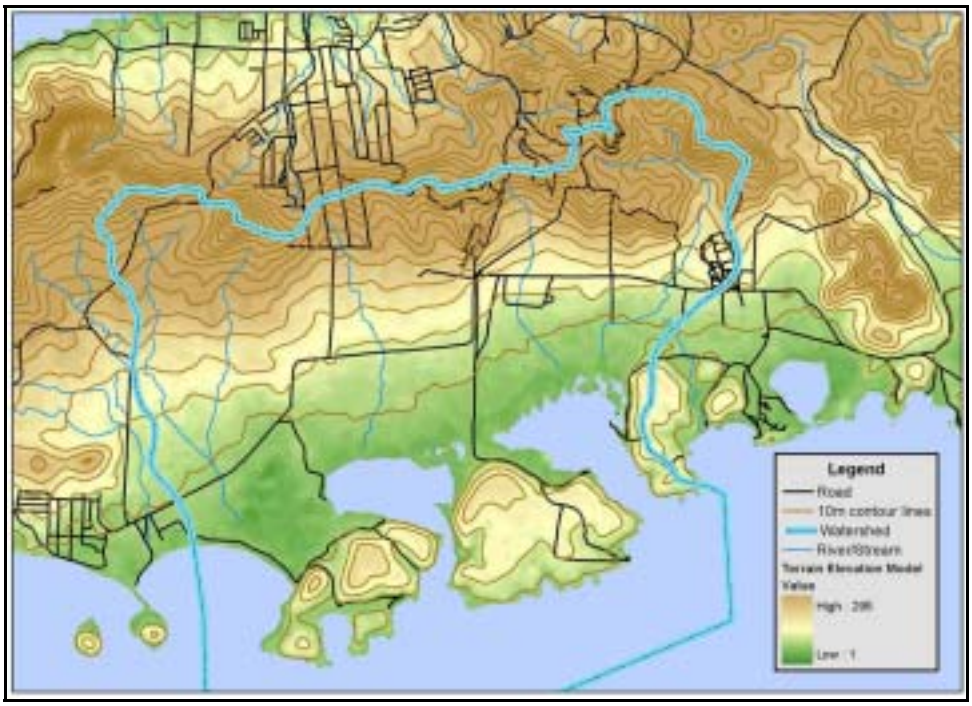

Figure 4: Watershed of Mosquito and Ferro Bays

Imagine yourself sitting in a boat at night within the biobay and try to visualize what land features you can see from the bay. In an ideal world, one would want to remove all forms of artificial lighting from this viewshed in order to maximize the bioluminescence phenomenon. Light pollution, in the form of street lights, sports complexes, commercial areas and residential homes would all lead to distract and to even degrade from the unique experience of the Vieques biobays. The ArcGIS Spatial Analyst extension has a Surface Analysis function called Viewshed that provides for line of sight analysis. This author wanted to create a line of sight layer that provides information on terrain that can be seen from any point within either Ferro or Mosquito bays. To make this, the SRTM grid was converted into a point matrix and all elevation posts that fell outside of Ferro and Mosquito Bays were removed. This resulted in a zero elevation point matrix over the water bodies of both bays; a fleet of boats placed 30 meters apart, if you will. Next, using ArcGIS, the point matrix was applied to the SRTM elevation model to generate a temporary grid file. The grid was further cleaned up and recoded in Erdas and saved as a Line Of Sight layer (see Figure 5). This viewshed layer provides information to urban planners and reserve managers on how to avoid and/or remove light pollution as seen from within the biobay viewing area.

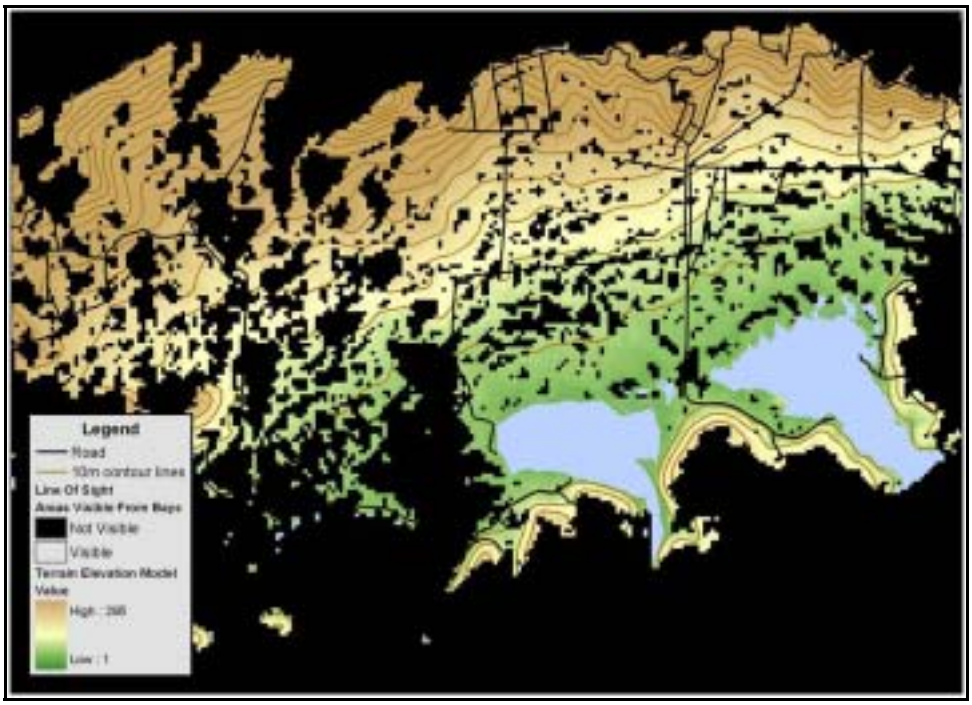

Figure 5: Viewshed Layer

Bathymetric Analysis: A digital bottom depth model needed to be created over the biobays. To accomplish this task, three data types were used: SRTM2 for the land, NOAA 50-meter spaced depths over the ocean and the previously mentioned readings within Ferro and Mosquito Bays. The three files were cleaned up and merged into a single point file (see Figure 6).

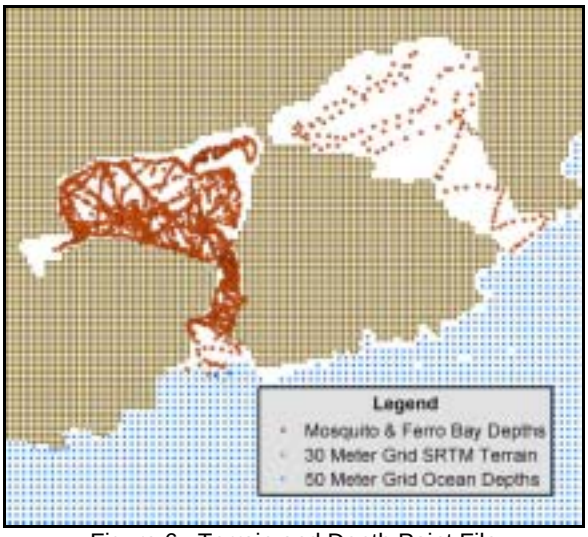

Figure 6: Terrain and Depth Point File

With the data preparation complete, the appropriate elevation and depth models could now be built. ArcGIS has a function within the Spatial Analyst extension called Interpolate to Rastor that provides this capability. Using the point matrix as an input to the Interpolation function, and using the Inverse Distance Weighted option, a temporary 20-meter grid was created over the study area. A review of the grid quickly indicated that there were insufficient depth readings over Ferro, which resulted in a poor depth model of the bay. The Mosquito model looked better so the point matrix was subsetted to exclude the Ferro bay

area. By excluding the Ferro bay points, a denser 5-meter post matrix was possible and the new Mosquito Bay Depth Model was generated.

This 5-meter matrix was symbolized for the depth values only and reviewed for anomolies. Although some of the point tracks appeared to be inconsistent and are seen as “spikes or wells”, the overall grid looked acceptable (see Figure 7). Further analysis of the Mosquito Bay depth model revealed a shallow sandbar section within the neck of the bay where the maximum depth is only one meter deep along the channel. Noting that tidal water exchange is somewhat dependent on depth, reserve managers should periodically monitor this section of the bay to see if there is a loss or gain in sedimentation.

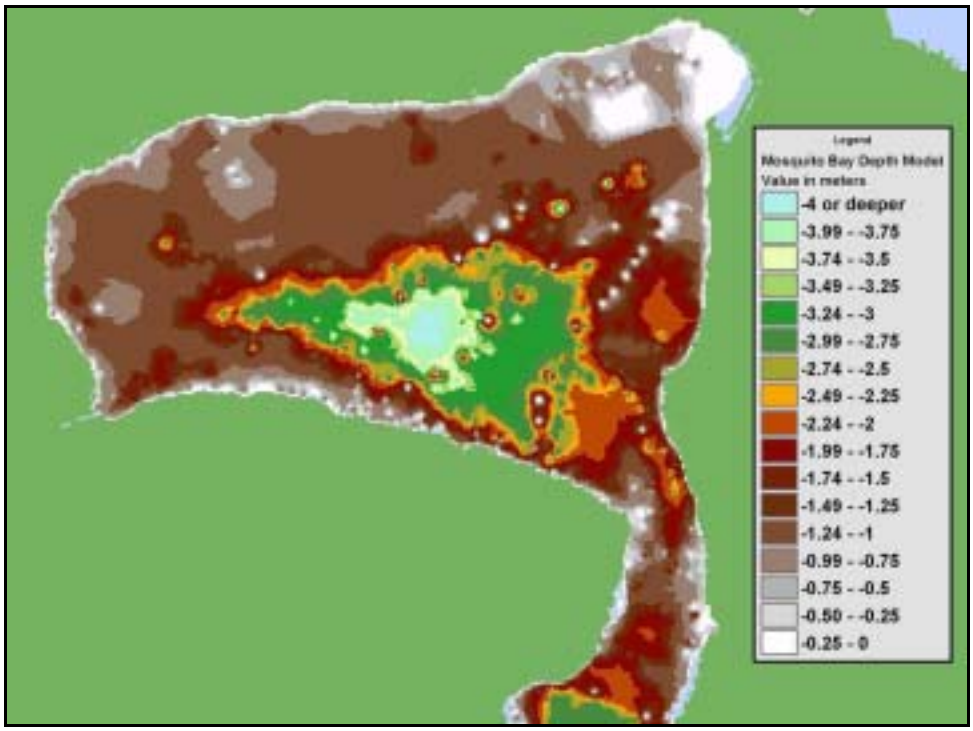

Figure 7: Mosquito Bay Bottom Depth Grid

Volumetric Analysis: Given that an adequate bottom model existed for Mosquito Bay, some approximate volumetric figures could now be generated. To do this, a fictional dam was generated by raising the heights of the ocean posts at the mouth of the Mosquito Bay. The ArcGIS Spatial Analyst point to grid interpolation was re-run and the temporary grid file was then imported into Erdas Imagine. Using the VirtualGIS Module of Imagine, a Water Layer was generated at zero elevation/sea level to fill the scene within the bay. The following table lists the approximate volume and surface area of Puerto Mosquito as generated in Erdas:

Volume of Water			
Gallons	Liters	Cubic Feet	Cubic Meters
17,785,800	1,202,950,000	42,481,700	1,202,950
Surface Area			
Square Miles	Acres	Hectares	
0.33	212	86	

PHASE IV – PRODUCT GENERATION AND DISTRIBUTION

Given that the local reserve managers had no existing GIS capabilities, a product generation and distribution problem existed. The solution was ArcGIS Publisher and ArcReader.

Product Generation: Through the freely distributable ArcReader application a Published Map File allows the user to identify, find and/or measure individual layer types, interactively display different layers, zoom in and out to rescale, pan/roam around the geographic extent and to print custom produced map graphics. The Bioluminescent Bay GIS Published Map Files contains all of the following finished GIS layers:

1. Trails
2. Roads
3. DRNA Reserve Limits
4. 50m contour lines
5. 20m contour lines
6. 10m contour lines
7. 5m contour lines
8. Watershed
9. River/Streams
10. DRNA Points of Interest
11. DRNA Area Land Cover
12. Fish & Wildlife Area Land Cover
13. DRNA Land Use
14. Line Of Sight
15. Soils
16. Geology
17. Sea Floor Cover
18. NOAA Benthic Zones
19. NOAA Benthic Habitats
20. NOAA Benthic Types
21. Mosquito Bay Depth Model
22. Satellite Derived Land Cover (2000)
23. Ocean Area
24. Terrain Elevation Model
25. Island Area

Map printing issues were solved by generating an 8 x 10.5” size Published Map File so that printing can be accomplished from any standard letter size printer (see Figure 8). The map composition is projected to UTM Zone 20 and contains both a 1,000 meter UTM grid as well as 1 minute Geographic tics. A reference overview map of Vieques displays the current area of interest and updates as the user changes scale or location. An interactive scale bar showing distances in miles, nautical miles and kilometers adjusts according to changes in scale, and an interactive legend updates as various layers are activated. Included is a 17 x 26” published map file as well as two 19 x 32” map files of Eastern and Western Vieques with place names. Readme files in both Spanish and English provide detailed instructions on how to load the ArcReader software CD as well as information on each map data layer. The Readme also contain a complete listing of acknowledgements and information on the following additional files included on the CD: freeware to convert Garmin GPS points to shapefiles and a Erdas generated 3 dimensional map Fly-through movie over Vieques.

Product Distribution: After finishing the project, the customers were contacted and given training by this author on how to use ArcReader to exploit the Published Map Files found in the Bioluminescent Bay GIS CD. They were provided with multiple copies of the finished CD and the ArcReader installation disk as well as hardcopy map plots of the larger map sheets included in the GIS. In addition to DNRA and USFWS, the product was also given to the following local conservation groups: The Biobay Conservation Group (www.biobay.org) and The Vieques Conservation & Historical Trust (www.vcht.org). To further assist in making this product available to anyone as a learning tool, the GIS was loaded in the Historical Trust’s computer lab, which is accessible and free to the general public.

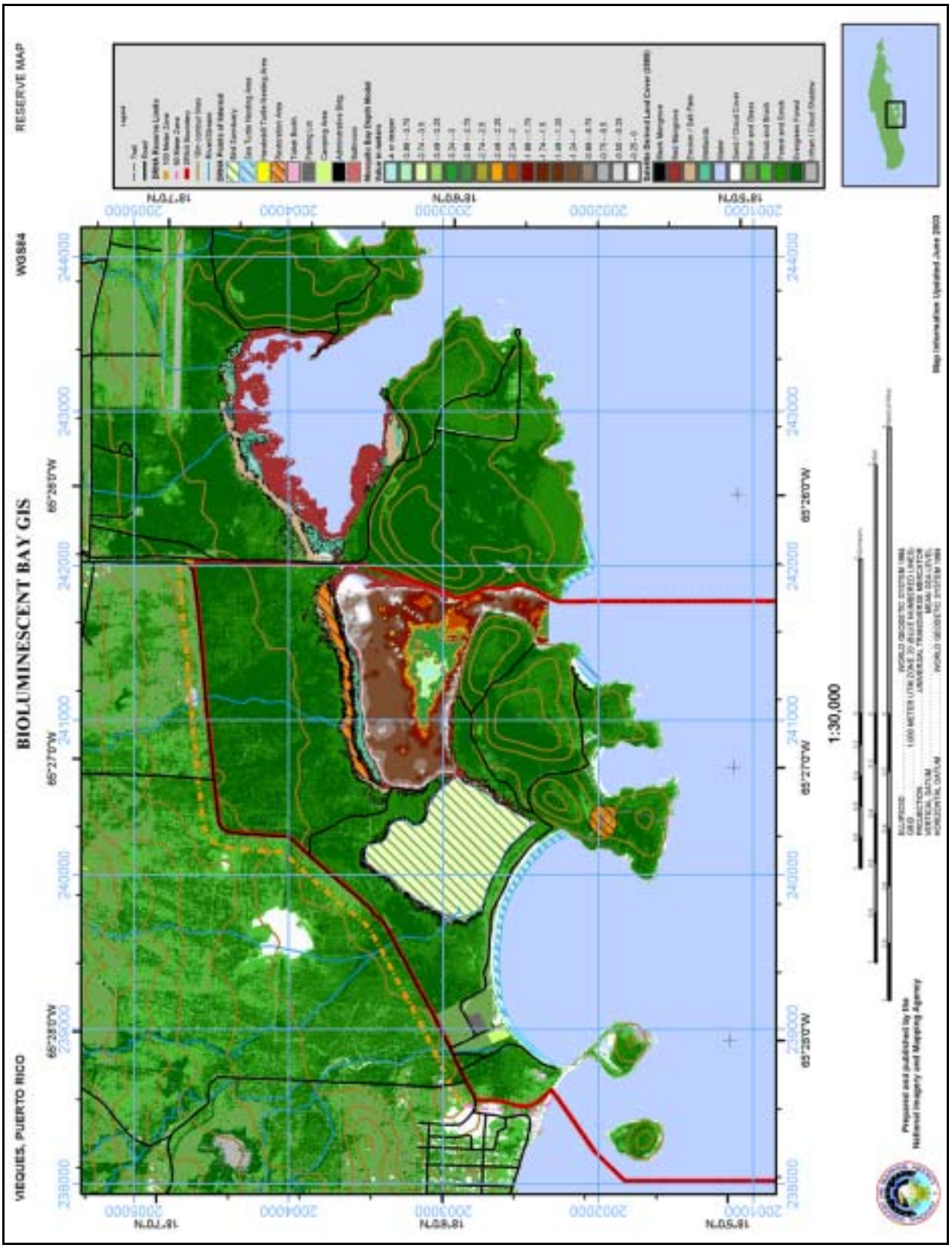

Figure 8: Published Map File (a sampling of the 25 interactive layers available)

CONCLUSION

The exact recipe of ecological ingredients that give rise to such large numbers of the bioluminescent variety of dinoflagellates in Vieques is unknown. Understanding factors such as terrain, watershed, land cover and benthic habitats as well as their proximity to existing or proposed urban developments can assist greatly in preserving the Vieques Biobays.

The Puerto Rico Department of Natural Resources is in the process of updating their Land Management Plan for Vieques and this project is being incorporated into that plan. By providing the reserve managers with improved visualization and analysis tools, critical information can be provided to the appropriate decision makers to assist in preserving the Vieques Biobays.

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