ArcGIS 8.x Benthic Terrain Modeler: Analysis in American Samoa

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Abstract

Remotely sensed multibeam data can produce high quality maps of the marine and coastal benthic environment. However, to date there has not been a widely adopted methodology for translating multibeam data into a useful product for characterizing and predicting benthic biotic community assemblages. Our goal was to develop a systematic and robust methodology by which multibeam data can be transformed into a classified product that is useful for coastal and marine resource managers, scientists and educators in American Samoa. This methodology analyzes bathymetry to derive slope, aspect, rugosity, and bathymetric position index. The NOAA Coastal Services Center has developed a new ArcGIS 8.x compatible tool, tentatively named the Benthic Terrain Modeler (BTM), based on this methodology. This extension's wizard interface educates and guides the user through a series of analysis steps, resulting in a classified terrain that may be suitable for tying to benthic species distributions for the preparation of benthic habitat maps. This methodology has been used to produce the first benthic habitat maps and 3-D visualizations of Vatia Bay, American Samoa.

Introduction

The coral reef ecosystems of the American Samoa islands have faced multiple natural and anthropogenic effects in recent decades (e.g., see the Fagatele Bay National

Marine Sanctuary web site at fagatelebay.noaa.gov). The American Samoa GIS (ASGIS) user group is a grassroots and local government initiative to advance the use of spatial technology especially with regards to land use, public utilities, cultural and ecological resources of the islands (e.g., Wright, 2002a; doc.asg.as). To effectively plan and manage needs related to coral reefs requires an accurate assessment of the abiotic and biotic environment. The Benthic Terrain Modeler (BTM) was created in response to these needs for assessing the coral ecosystems, specifically in American Samoa, beginning with the Fagatele Bay National Marine Sanctuary.

American Samoa is a chain of five volcanic islands and two atolls located at approximately 178° W and 14° S in the South Pacific, west of Fiji and north of New Zealand (Figure 1).

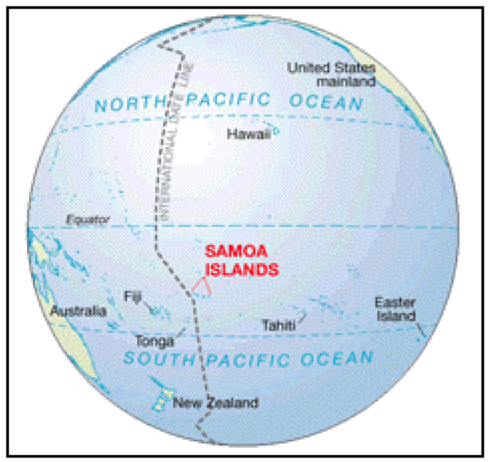

Figure 1. American Samoa is approximately 2,200 miles SW of Honolulu, Hawaii.

Continued concern over the ecosystem health of the coral reefs in American Samoa, including the Fagatele Bay National Marine Sanctuary, prompted several multibeam missions to map and study the region (Figure 2) (Wright et al. 2002). To effectively plan and manage needs related to coral reefs in these locations requires an accurate assessment of the abiotic and biotic environment, including accurate base maps (Wright et al. 2002).

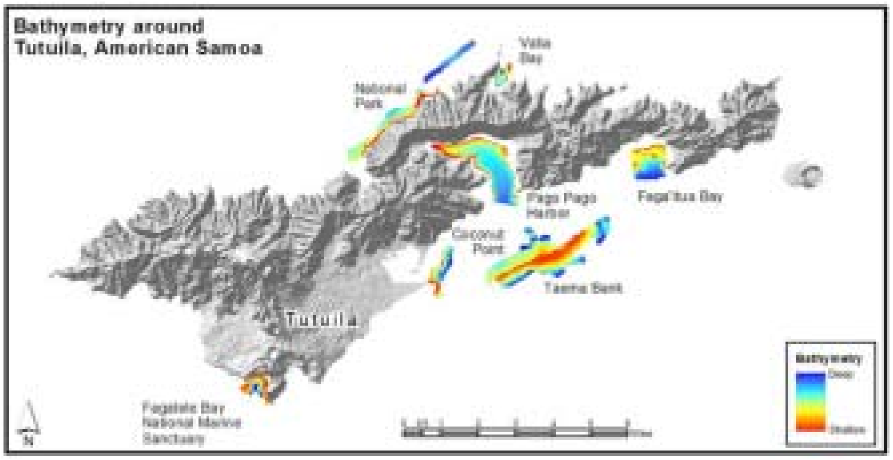

Figure 2. Bathymetry for the seven study sites located around Tutuila, American Samoa.

To generate these base maps two shallow water multibeam surveys were conducted in 2001 and 2002 using a Kongsberg-Simrad EM-3000 system (Wright, 2002b; Wright et al. 2002). A total of seven sites were surveyed including: Fagatele Bay National Marine Sanctuary, Cocunut Point, Taema Bank, Fagaitua Bay, Pago-Pago Harbor, Faga'itua Bay, National Park and Vatia Bay (Figure 2.). Once the data was collected and post-processed several techniques were used in combination to create benthic terrain maps.

Benthic terrain maps move beyond a simple representation of bathymetry, providing classifications that use intuitive landscape descriptors such as 'reef crest' or 'reef flat'. However these terms are often used without any quantitatively described features. Without a quantitative description features classified by one investigator can often be very different than those described by another investigator (Coops 1998). The BTM was created to fill this need for repeatable, quantitatively described benthic terrain maps. Many of the techniques of the BTM are drawn from a similar process developed by Iampeitro and Kvitek (2002).

The BTM is an ArcGIS 8.x compatible tool that creates a user defined classification system of benthic terrain. The classified product transforms digital elevation data, which is generally gathered with a multibeam echo sounder, into a classified product for use in research or natural resource management.. However the principles behind the tool are general enough to be used on any digital elevation data. The inclusion of a flexible and customizable terrain dictionary allows investigators and managers to create benthic terrain maps in a variety of benthic environments, not just coral reef dominated ones.

User Requirements and Availability

The minimum software requirements require the user to have a licensed copy of the ArcGIS 8.x platform as well as the Spatial Analyst extension. Input rasters need to be in the ESRI GRID format.

There are no minimum hardware requirements other than those suggested by ESRI for the ArcGIS 8.x platform with the Spatial Analyst extension. However it is worth noting that the analysis, especially the Bathymetric Position Index grids, can be time consuming for large datasets, even on fast (>2.0 GHz) processors. The user must also maintain some free space on their hard disk as this program can use several hundred megabytes up to a gigabyte or more of hard disk swap space during the analysis. In general, as the number of rows and columns in the grid increase so does the processing time and hard disk requirements.

Several processing optimization steps have been included to reduce processing time and increase productivity. These include a built in grid re-sampler and the option to save and re-use certain intermediate step grids for re-iterative analyses.

The tool itself is in the various stages of software development. Upon completion, it will be freely distributed and available for download from the Fagatele Bay National Marine Sanctuary GIS Data Archive located at http://dusk.geo.orst.edu/djl/samoa/ .

User Interface

The BTM is a Graphical User Interface (GUI) driven analysis package that uses the familiar 'wizard' interface (Figure 3) to guide the user. The GUI is designed to guide the user through a step wise process with the end result being a classified benthic

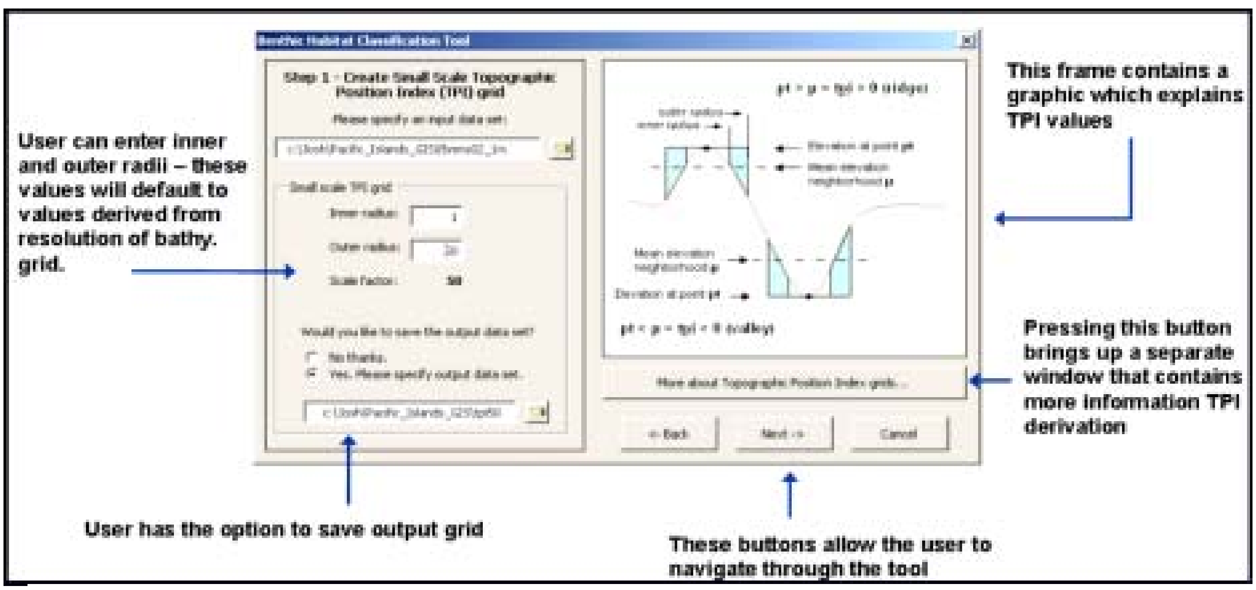

Figure 3. This is a sample screen shot from the BTM for the benthic position index process.

terrain grid. The advantage of this approach is that it is difficult for the user to skip a critical step, thus lower the learning curve and speeding up the process of generating a classified benthic terrain product. The user interface also includes a series of optional information buttons (Figure 3) at each step of the process that are designed to educate the user about the analysis methods that are employed in this tool.

A potential disadvantage of this system was limiting the more advanced spatial analyst. To avoid this situation the BTM allows the option to create a customized terrain classification dictionary as well as the option to save the grids that are produced at several intermediate steps before the final grid is produced.

Terrain Classification Dictionary

The terrain classification dictionary is an XML (eXtensible Markup Language) formatted text document that stores a customized benthic terrain classification scheme. This document contains the set of parameters that differentiate one benthic terrain type from another.

Since the terrain classification dictionary is stored in the XML format the user may either chose to create/modify a classification dictionary using the GUI in the BTM tool or they may edit the XML document directly with a text editing program like Microsoft Notepad. The XML format is simple to learn. Users that have experience with HTML (Hyper-Text Markup Language) or CSS (Cascading Style Sheets) will have little difficulty working with this format.

Another advantage of the customizable terrain classification dictionary is that the same classification parameters can be shared between different users thus ensuring a level of consistency in benthic terrain terminology being used between different users and user groups.

A default classification scheme is included with the BTM. The default classification was used in preparing detailed benthic terrain maps for six locations in American Samoa (Figure 2). The default is intended to be a template, and will not necessarily yield accurate results across a variety of spatial scales.
Therefore, the user of the BTM is encouraged to find a classification scheme that fits their needs and customize it to be appropriate for the scale of processes and phenomena under investigation.

Bathymetric Position Index

The Bathymetric Position Index (BPI) is the marine equivalent of the Topographic Position Index described in detail by Weiss, 2001. The index is a characterization of bathymetric features in their local/regional context. Examples of index descriptors commonly used include 'reef crest', 'lagoon', 'reef flat' etc. The BPI is an

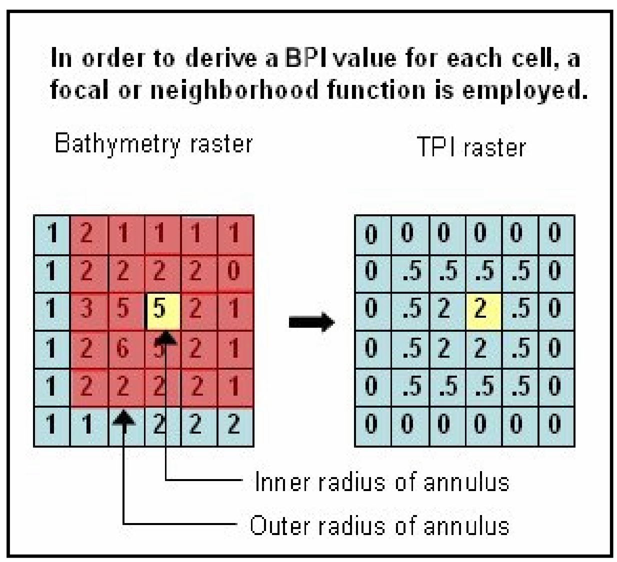

Figure 4. The Bathymetric Position Index is an annulus focal function that compares a single cells height to its neighborhood of cells.

attempt to quantitatively describe the terrain of the benthic environment based on a Digital Elevation Model (DEM or equivalent X, Y, Z co-ordinate data set).

The BPI analysis used in the BTM is a roving local annulus calculation (Figure 4). The annulus is defined by the user and starts in the cell adjacent to the center cell ad extend outward, or the analysis can create a 'dough-nut' shape around the focal cell by giving the analysis annulus an inner radius value greater than one cell value. The height of each cell in the DEM is compared to the heights of neighboring cells within a user defined annular area.

This tool calculates a fine scale and a coarse scale BPI grid. These two grids are then merged into a single BPI composite grid that takes into account coarse features and fine features to capture the cross-scalar spatial heterogeneity of terrain features within the DEM.

Rugosity

Rugosity is a measure of terrain complexity. The BTM measure of rugosity is based on the *Surface Areas and Elevation Grids* ArcView extension available from Jenness Enterprises (Jenness, 2002).

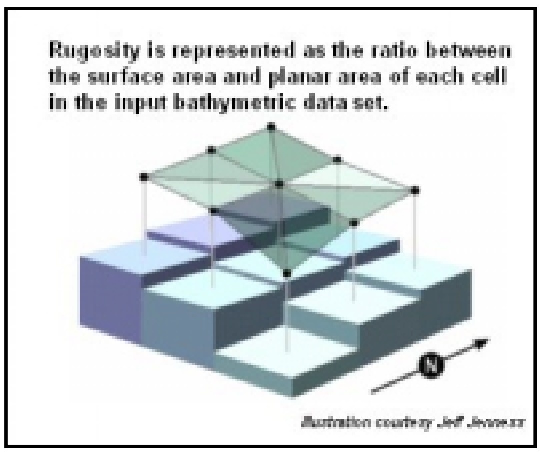

Figure 5. The rugosity calculation estimates the surface area of a cell by approximation with eight triangles in relation to the eight neighboring cells.

The calculation process starts with a cluster of nine grid cells. The center grid cell is the unit whose value will be calculated based on its relation to its eight neighboring cells (Figure 5). A simple triangle is created by linking the center points of two grid cells to the central grid cell's centroid then the resulting triangle's area is calculated. A triangular area is created for each of the cells surrounding the center cell. Next the triangle is truncated so that only the portion of the triangle that covers the center cell is used, and the portion of the triangle that covers cells adjacent to the central cell are discarded. Then the areas of all eight truncated triangles are calculated and summed for comparison to the planimetric area of the center cell. This simple ratio of truncated-triangle area versus planimetric area has a minimum value of one while typical values range from one to three although larger values are possible in very steep terrains.

Case Study Site: Vatia Bay, American Samoa

Figure 6. Vatia is a small inlet on the north side of Tutuila.

Vatia Bay is located on the north side of Tutuila Island(Figure 6), the largest of the five islands that comprise this southwestern most U.S. territory. High-resolution (2m) acoustic multibeam bathymetry was collected for Vatia Bay in November of 2002 (Wright 2002b). Multibeam was the preferred data collection method because, compared to feasible alternatives, it can yield large quantities of dense data and cover large swaths of the sea floor in a short period of time. The data was post-processed and cleaned for navigational and acoustic ping errors and corrected for tidal variations based on NOAA tide data.

The processed-grids were brought into the ArcGIS 8.x program and analyzed using the same methodology as the BTM (Figure 7). First, BPI grids at fine and coarse scales were generated and standardized. Next, the BPI grids were combined along with slope and depth to generate a benthic terrain map (Figure 8). This benthic terrain map can be augmented with rugosity to create an enhanced benthic terrain map. A rugosity map that has not be combined with benthic terrain data is shown in Figure 9. These, or similar, classified maps are intended for use by the members of the ASGIS, which includes the Fagatele Bay National Marine Sanctuary, in natural resource planning efforts (Wright 2002a). These benthic terrain models will be 'ground-truthed' and assessed for accuracy in upcoming (2005) submersible dives in American Samoa.

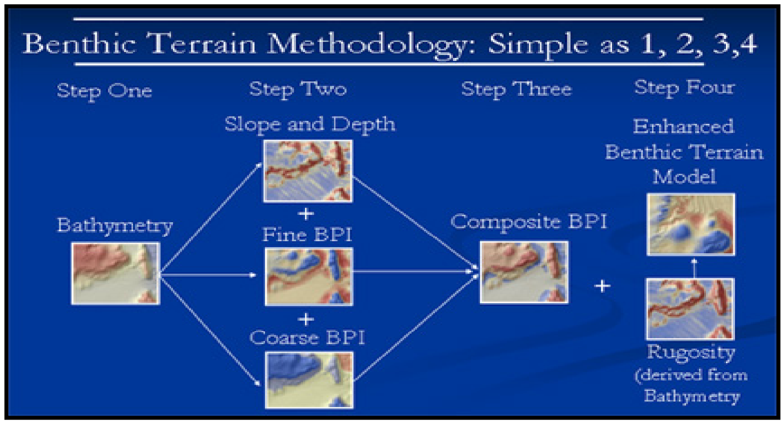

Figure 7. The four step methodology for the BTM. A standardization procedure has been left out since it is merely a numerical preparation for the Composite BPI in step three.

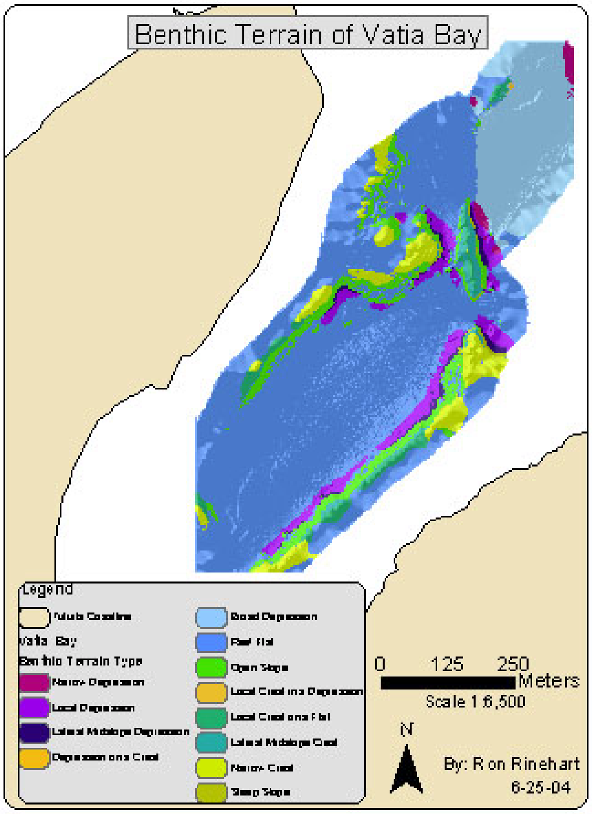

Figure 8. Classified benthic terrain derived from composite BPI, depth and slope.

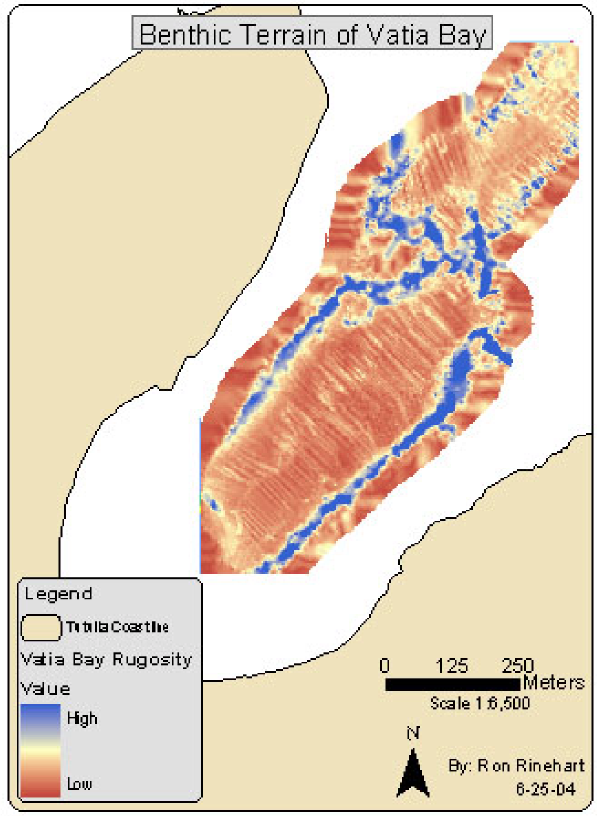

Figure 9. Rugosity derived from 2m bathymetry for Vatia Bay.

Conclusion

The ArcGIS 8.x platform with the Spatial Analyst extension offers a powerful analysis environment. The BTM, although a standalone executable, provides an additional extension of this platform. As the direct output of the analysis is in the ESRI GRID format, the investigator can perform additional analysis or cartographic procedures that are not offered directly through the BTM tool, yet are available through the ArcGIS 8.x suite of programs.

Planned improvements for a future release version of the BTM include the additional parameters of slope-aspect, and simple light attenuation with depth at user specified electromagnetic radiation frequencies, as well as the analysis of multibeam backscatter data. These improvements have potential for increasing the accuracy with which benthic terrains can be classified based on information gathered with multibeam sonar systems.

Acknowledgments

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