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Final Report

National Sea Grant College System

Project #R/F-181B

Fisheries Habitat Characterization of the California Continental Margin: Identification, Quantification, and Synthesis of Existing Information

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SUMMARY

Sea Grant Project #R/F-181B completed by the CSUMB Seafloor Mapping Lab (SFML) and summarized here, was done in conjunction with the companion Sea Grant Project #R/F-181A, directed by Dr. Gary Greene of Moss Landing Marine Labs (MLML). The goal of these joint collaborative projects, was to use existing industry and newly acquired hydrographic data to create high-resolution marine habitat maps of priority sites identified by participating state, federal, university and NGO partners during the January 2000 California Marine Habitat Task Force meeting. Additional support for the project came from the California Department of Fish and Game to the CSUMB SFML for the acquisition of additional multibeam bathymetry data. The primary project objectives were to:

- 1) Create digital marine benthic habitat maps from pre-existing industry and agency data (analog side-scan sonar mosaics and digital multibeam bathymetry imagery) representing at least 1,500 km² of area
- 2) Create digital marine benthic habitat maps from two or more newly acquired marine geophysical data sets of at least 100 km² collected in high priority areas
- 3) Incorporate all digital habitat maps, side-scan sonar mosaics, and multibeam bathymetry data into a California Marine Habitat GIS database
- 4) Make the California Marine Habitat GIS database publicly accessible via the Internet through standard web browsers on the SFML's Internet Map Server (IMS) (<http://seafloor.csUMB.edu/Seagrant/SeaGrantIMS.HTM>).
- 5) Make the California Marine Habitat GIS database publicly accessible as content that can be added directly to an ArcGIS project via the SFML's Internet Map Server (IMS) as an internet server resource (<http://arcims.csUMB.edu>).
- 6) Make the digital California Marine Habitat GIS content (side-scan sonar mosaics, multibeam data, and interpretive habitat maps) publicly available via CDROM at the cost of reproduction through the MLML Center for Habitat Studies (<http://www.mlml.calstate.edu/groups/geooce/habcent.htm>).
- 7) Catalogue all available industry data at MLML Center for Habitat Studies.
- 8) Create a report and metadata describing data, coverage, data quality, interpretive methods, and results.

We have fulfilled each of these objectives, and final mapping and metadata products can be viewed at <http://seafloor.csUMB.edu/Seagrant/SeaGrantIMS.HTM> and obtained from the MLML Center for Habitat Studies (<http://www.mlml.calstate.edu/groups/geooce/habcent.htm>).

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INTRODUCTION

The 1996 reauthorization of the Magnuson-Stevens Fishery Conservation and Management Act (SFA), establishing a new focus in fisheries management, requires that regional fishery councils and the National Marine Fishery Service (NMFS) identify and designate Essential Fish Habitat (EFH) for each managed species. EFH is defined in the SFA as “waters and substrata necessary to fish for spawning, breeding, feeding or growth to maturity” and constitutes specific habitats within the total available range of a species. The SFA mandates not only the identification of habitats essential to federally managed finfish and shellfish species but also the measures necessary to conserve and enhance these habitats. After an EFH has been identified, fishery managers can use resultant habitat associations of fishes and habitat maps to formulate sustainable management plans. The protection of EFH and associated resources is accomplished through the establishment of Marine Protected Areas (MPAs), such as no-take zones and marine reserves. MPAs are promising management tools because of their potential to enhance populations of overly exploited fish and, thereby, to ultimately benefit fisheries.

Maps that identify and quantify distinct habitat types must be constructed for regions of interest, before the habitat studies necessary to determine what constitutes EFH for a particular species can be effectively conducted. Areas along the California coast in critical need of habitat data were identified at the California Marine Habitat Task Force meeting in January of 2000, hosted by the principal investigators of this project and sponsored by the California Department of Fish and Game (CDFG) and the Special Projects Office of the National Oceanographic and Atmospheric Administration (NOAA)(<http://seafloor.csUMB.edu/taskforce/index.html>). Based on these results, multibeam bathymetric surveys were planned for the creation of habitat maps in those identified areas.

In addition, access to extensive industry side-scan sonar and other marine geologic data holdings has provided an opportunity to create habitat maps within several other nearshore regions of California. A considerable geophysical database was assembled by industry along the California margin between the 1960s and 1980s for hydrocarbon exploration. Many of these data sets are of high quality side-scan sonar mosaics, high-resolution seismic reflection profiles, and sediment data that are useful in marine benthic habitat characterization. These data are particularly valuable because it is much more difficult and expensive to collect such data today.

This project constitutes the initial stages of building a comprehensive GIS of California benthic habitats that can be used to plan and implement effective EFH programs for California. Managers and fishery scientists can now identify data voids and more capably define areas for future studies. Products from this project form the base maps upon which all other parameters, critical to the definition of a marine benthic habitat, can be overlaid and compared.

OBJECTIVES

The objectives of this project were to: 1) create digital marine benthic habitat maps from pre-existing industry and agency data (analog side-scan sonar mosaics and digital multibeam bathymetry imagery) representing at least 1,500 km² of area, 2) create digital marine benthic habitat maps from two or more newly acquired marine geophysical data sets of at least 100 km² collected in high priority areas, 3) incorporate all digital habitat maps, side-scan sonar mosaics, and

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multibeam imagery into a GIS database that can be queried and used for fisheries management and MPA planning, 4) establish a web-based interactive GIS interface allowing public access to the habitat maps and seafloor imagery, 5) Make the California Marine Habitat GIS database publicly accessible as content that can be added directly to an ArcGIS project via the SFML's Internet Map Server (IMS) as an internet server resource, 6) make publicly available CD-ROMs that include side-scan sonar mosaics, multibeam imagery, and interpretive habitat maps for the cost of reproduction, 7) catalogue all available industry data, and 8) create a report and metadata describing data, data quality, interpretive methods, and results. We have fulfilled all objectives.

METHODS

ACQUISITION AND PREPARATION OF PRE-EXISTING DATA RESOURCES

Acquisition of pre-existing sidescan sonar and multibeam bathymetry data was primarily the responsibility of Dr. Gary Greene's Project #R/F-181A. A full description of these data resources can be found in the Project #R/F-181A final report, obtainable from the MLML Center for Habitat Studies (<http://www.mlml.calstate.edu/groups/geooce/habcent.htm>). Here we provide only a brief description of the sources and coverage of the pre-existing data sets used (Table 1).

Analog side-scan mosaics were obtained from Racal Pelagos, Inc. (now Thales Geosolutions [Pacific] Inc.) and Delta Oceanographics, Inc. for the following offshore regions: Bodega Basin, Eel River Basin, Santa Maria River, Point Conception to Point Arguello, Punta Arena Basin, south of Point Conception, and outer Santa Cruz Basin. Additional geospatial data were provided by the U.S. Geological Survey (USGS), Monterey Bay Aquarium Research Institute (MBARI), and several private companies. Industry data sets were far more comprehensive than anticipated and consisted of not only analog side-scan sonar mosaics, but also microfilms of high resolution seismic reflection and bathymetric profiles, rock samples, rock thin sections, core logs, and written reports. Analog side-scan data mosaics were scanned, georeferenced, and saved in digital format.

ACQUISITION AND PREPARATION OF NEW HYDROGRAPHIC DATA

Multibeam bathymetry and sidescan sonar data were collected by the SFML using their Reson 8101 multibeam sonar system. Regions covered included: Bodega Basin, Catalina Island, Farallon Islands, La Jolla, Mackerricher, Point Cabrillo, Point Lobos, Santa Barbara Island, Santa Monica nearshore, and Monterey Peninsula (Table 1). A Trimble 4700 GPS generated differential GPS (DGPS) position data with differential corrections provided by a Trimble ProBeacon receiver. A TSS HDMS heading and motion sensor provided heave, pitch, heading, and roll data. Coastal Oceanographics Hypack® software was used for survey design and execution. All raw data were logged using a Triton-Elics International (TEI) ISIS® data acquisition system. Water column sound velocity profiles were collected using an AML SV+ sound velocity profiler. Bathymetric data were post-processed using CARIS HIPS® hydrographic data cleaning system software. Soundings were corrected for vessel motion using TSS HDMS data while variations in water column sound velocity were corrected using AML SV+ data. Bathymetric data was adjusted to MLLW using NOAA predicted tide models for each coverage region and saved in digital format. Erroneous soundings were removed in CARIS HIPS®. Final survey products included: multibeam bathymetry in shaded relief (geotiff format),

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xyz text files, ESRI ArcView grids, and sidescan sonar mosaics (geotiffs) where appropriate. See <http://seafloor.csUMB.edu> for more information regarding equipment use and survey capabilities.

CREATING HABITAT MAPS FROM SEAFLOOR IMAGERY

Interpretation of the pre-existing and new hydrographic data sets was the responsibility of Dr. Gary Greene's Project # R/F – 181A. The SFML (Project # R/F – 181B) was responsible for converting the manual interpretations into digital GIS layers for attributing. Here we present a summary of the procedure that involved personnel from both laboratories.

Using processed side-scan or multibeam data, layouts were created in ArcView® and exported as .tif files using the extension ArcPress. This process was repeated at different scales until a final scale, most appropriate to the data quality, was chosen as a final basemap for habitat interpretations. If multibeam imagery was used, backscatter data were printed at the same scale. Mylar sheets were affixed over the final printed layouts and tic marks were copied onto the mylar sheets for later georeferencing. For this project, all files are projected in Universal Transverse Mercator (UTM) with a WGS 84 datum and spheroid.

A coding system was established to distinguish habitat types for species of interest and to facilitate ease of use and queries in GIS and other database programs. This code was modified from the deep-water habitat characterization scheme developed by Greene et al. (1999) and is based on interpretations of seafloor geology, morphology, and biology. A copy of this habitat attribute code and a corresponding explanation are included in the Project # R/F – 181A final report.

Seafloor imagery was interpreted and habitat types were outlined (mapped), based on knowledge of the geology and seafloor processes in a particular study area, as the first steps in map production. Mapping was done on a light table by drawing polygons around distinct habitat features on a Mylar overlay of the image. Multibeam and side-scan sonar data provided a general picture of the location of bedrock and unconsolidated sediment. Resolution of the interpretations varied with the quality and scale of the images. However, on most images, we could easily identify such seafloor features as bedrock types (e.g., sedimentary rocks, crystalline rocks, and carbonate mounds), structures (e.g., faults, folds, and landslides), and bedforms of unconsolidated sediment such as sand waves.

The Mylar overlays were scanned using the WideImage® program, with the scan preset on Mylar, georeferenced to 0.5m (when possible), and processed in GIS programs (TNT Mips® and ArcView®). Scanned Mylars were then printed and used to attribute habitats. Individual polygons were color coded on printed copies of the Mylars. This served to check the habitat interpretations and to assist in final editing. Processed files (rasters) were edited in the Spatial Data Editor within TNT Mips®. Unwanted features such as speckles, attribute numbers and text from within the polygons, and tick marks are erased during this process. Dashed lines were connected and missing lines were re-drawn using a drawing tool. The final raster file was then converted to a vector file using the Auto Trace method in TNT Mips®. Several tests were run before the final conversion in order to check the results of the line editing and tracing.

After raster to vector conversion, the vector file was edited to either delete or add nodes and lines and to correct the shape of polygons. During vector editing the original side-scan sonar and multibeam geotiffs were used for reference. Original geotiffs were imported into TNT Mips® using the correct georeferencing, and then projected as layers beneath the vector file in the

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Spatial Data Editor. The edited vector was then warped to create an implied georeference with the output projection set, as appropriate. If necessary, smoothing of the warped vector file was performed with the Vector Filtering tool. If the lines were too angular, the smoothing process was used to better round the curves. Several tests were run before the final smoothing to ensure that no features were omitted during processing.

If more than one interpreted Mylar sheet existed for an area, the warped (and filtered) vector files were merged. Final cleaning was done with the Spatial Data Editor. The original side-scan and bathymetry geotiffs were once again projected as layers beneath the vector file and used as references. Special attention was paid to the overlying areas to make sure that all of the lines met and all polygons closed. Once final cleaning changes were made, the file was exported as a shapefile (.shp). Shapefiles were opened in ArcView® where a legend (explanation) file was added and any additional attribute fields were included in the attribute table. The file was checked for proper georeferencing and for overlapping polygons, and area analysis was performed on each habitat type. The habitat shape file was incorporated into an ArcView® project (.apr) along with the imagery from which it was interpreted, creating a final digital product. Metadata was written and all data burned to CD-ROM.

Scientists who performed the original interpretations were available during all stages and consulted when questions arose. In this way, we were able to provide consistency within and among the various areas and regions.

RESULTS

This work represents the most comprehensive marine benthic habitat characterization of the California continental margin to date. These map products will be useful to marine resource managers, policy makers, and science researchers. Furthermore, the collection of new bathymetric data in shallow shelf areas, where significant data gaps existed and interpretations were needed, contributes to better understanding of habitat types and the role they play in the conservation and management of fisheries.

We mapped 73 habitat types within thirteen regions along the California continental margin. These specific regions are, from south to north: 1) La Jolla, 2) Catalina Island, 3) Santa Barbara Island, 4) Santa Monica Bay, 5) South of Point Conception, 6) Point Conception to Point Arguello, 7) Point Arguello to Santa Maria River, 8) Monterey Peninsula (including Point Lobos), 9) Santa Cruz Basin, 10) Farallon Islands, 11) Bodega Basin, 12) Point Arena Basin (including Mackerricher and Point Cabrillo), and 13) Eel River Basin. The surveyed areas were mostly in shelf depths (less than 200 m). All data sets can be accessed and viewed as interactive GIS files on the SFML's Internet Map Server (IMS) (<http://seafloor.csumb.edu/Seagrant/SeaGrantIMS.HTM>). (See below for description of IMS server and capabilities.) GIS data sets can also be obtained on CDROM from MLML Center for Habitat Studies for the cost of reproduction (<http://www.mlml.calstate.edu/groups/geooce/habcent.htm>).

The habitats we mapped include such features as hard rock exposures, deposits of unconsolidated sediment, canyons and gullies, sediment covered ridges, landslides, mounds, depressions, pinnacles, rills, and human (anthropogenic)-influenced morphologies. Where possible, we distinguished grain size (e.g., sand, mud, and mixed or bimodal distributions) of sediments and mapped dynamic bed forms such as sand waves, channel levees, and fans. All

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mapped characteristics are included in the deep-water marine benthic habitat scheme and GIS attribute code we developed and modified after Greene et al. (1999) for this work and are displayed in the Habitat Key and Explanation (Appendices 1 and 2 included here from Final Report R/F – 181A).

Table 1. Aerial coverage of all habitat maps created for this project including those from new multibeam data acquired by SFML and pre-existing sidescan and multibeam sonar data from other sources.

Survey Area	Area (Km²)
<i>New SFML Multibeam Data</i>	
Mackerricher	9.7
Point Cabrillo	6.4
Bodega Bay	41.2
Farallon Islands	15.4
Monterey Peninsula	30.9
Point Lobos	11.0
Santa Monica -Block 13	20.8
Santa Monica -Block 14	17.8
Santa Monica -Block 15	35.8
Santa Monica -Block 16	24.7
Santa Monica Bay (nearshore)	98.7
Santa Barbara Island	28.8
Catalina Island	1.9
La Jolla	35.9
TOTAL	379
<i>Pre-existing Data (Industry and USGS)</i>	
Eel River Basin	74.9
Punta Arena Basin	117.2
Bodega Basin	167.6
Outer Santa Cruz Basin	167.8
Point Arguello to Santa Maria River	46.8
Point Conception to Point Arguello	18.3
South of Point Conception	37.8
Santa Monica Bay (USGS data)	2163.1
TOTAL	2794

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CSUMB SFML INTERNET MAP SERVER (IMS)

For this project, the SFML obtained and launched a Terabyte GIS map server running ESRI Arc Internet Map Server (ArcIMS) software for public dissemination of the California Marine Habitat GIS content via the Internet. Final products now available on the SFML's IMS include: contour vector themes, geotifs of DEMs in shaded relief, sidescan sonar mosaics and habitat interpretations, as well as links to full FGDC-compliant metadata. ArcIMS provides the foundation for distributing high-end geographic information systems (GIS) and mapping services via the Internet. ArcIMS software enables users to integrate local data sources with Internet data sources for display, query, and analysis in an easy-to-use Web browser. The California Benthic Habitat GIS data layers on the SFML IMS can be accessed, viewed and queried via the Internet in two different ways, one using generic web browser software, and the other as content added directly to an ESRI ArcGIS project running on the user's local PC.

Accessing California Benthic Habitat IMS using a web browser

The California Benthic Habitat GIS content can be access directly using standard Internet browser software (Microsoft Internet Explorer or Netscape Navigator) through the SFML's IMS at: <http://seafloor.csumb.edu/Seagrant/SeaGrantIMS.HTM>

or

<http://arcims.csumb.edu/sfmlweb/>.

This approach provides limited GIS functionality (viewing, overlays, searches, queries, measurements) without the need for GIS software. All content is in Universal Transverse Mercator Grid coordinates, WGS 1984 datum, and depths are referenced to MLLW.

Adding California Benthic Habitat IMS content to a local ArcGIS project

The California Benthic Habitat IMS content can also be added to a user's ArcGIS project on their local PC by selecting: File/add data/internet servers/add internet servers and typing in the URL for the SFML IMS (<http://arcims.csumb.edu>). A list of available IMS projects will appear with names corresponding to the various areas mapped for this and other projects. A wide variety of GIS projects are being served on the CSUMB IMS, and because ArcIMS software does not allow partitioning of the IMS server, the user will see more IMS projects listed than just those for California Benthic Habitat GIS maps. The names of the IMS projects however, generally correspond to the names of areas listed in Table 1.

Technical Description of CSUMB SFML IMS Server

- Make: COMPAQ (HP) Proliant DL 380 Generation 2 (G2) Server
- Speed: Dual 1.4 GHZ Processors
- RAM: 1.2 GB
- Capacity: 200 GB Raid 5 Volume with room for expansion (1 Terabyte)
- Data Transmission Rate: 100 MB/S
- Hard Drive Bays: 5x1" Ultra 3 Hot-plug & 1x1.6" Ultra 3 Hot-plug- for disk or tape
- Server Management: SmartStart, SS Scripting Toolkit, IM, PXE, support for ProLiant Essentials Rapid Development Pack
- Power: 400W Hot plug, with optional redundancy

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- OS: Windows 2000 Server

IMS features

ArcIMS version 4.0 software enables users to integrate local data sources with Internet data sources for display, query, and analysis in an easy-to-use Web browser. More sophisticated functions are possible when IMS map service are accessed through client-side GIS software.

- Ability to combine data from multiple sources
- Secure access to map services
- Wide range of GIS capabilities
- Highly scalable architecture
- Standards-based communication
- Support for a wide range of clients
- Useful metadata services for indexing and sharing geographic information
- Integration with ESRI's ArcGIS Desktop products including the ability to publish ArcMap and ArcPublisher documents on the Internet

Data formats available to use with ArcIMS include:

shapefiles, geodatabases, personal geodatabases, coverages, ArcSDE features, CAD, the most common raster and image data formats (including ESRI Grids, Digest UTM/UPS, ArcSDE Raster, TIFF, GIF, ERDAS (.img, .lan, .gis, .raw), ER Mapper (.ERS), National Image Transfer Format (.NTF), .PNG, MrSID, and TiIFF) TINS, Annotation layers, and VPFs.

APPLICATION

The results from this project are already being widely applied by a variety of state and federal resource management agencies, scientists and conservation groups. Here we list a few examples of how results distributed by the SFML have been and are being applied. Additional examples can be found in the R/F – 181A final report by Dr. Gary Greene.

Multibeam bathymetry products provided by the SFML have already being use by the California Department of Fish and Game (DFG) Marine Region GIS lab. These products now form the basis for all remotely operated vehicle (ROV) invertebrate and fish stock assessment surveys conducted by DFG in the state. The DFG ROV team has now designed their survey system such that they are able to navigate their ROV over our habitat maps in real-time, thus maximizing the accuracy of species/habitat codification and stock assessment based on habitat distribution. The GIS layers are also being applied by DFG in the design, management and use of marine reserves at Bodega Bay, Pt Lobos, Catalina Island, Pt. Cabrillo, Mackerricher State Park, and Santa Barbara Island. PISCO (<http://www.piscoweb.org/>) is using our results to plan and calibrate their subtidal biotic surveys in conjunction with DFG's ROV team around Monterey Peninsula. Results delivered to the Santa Monica Bay Restoration Project, Santa Monica, Ca., are being used to identify suitable habitat and develop plans for kelp forest restoration. In Monterey Bay, a consortium of user groups including the Monterey Bay National Marine Sanctuary were guided by a CSUMB undergraduate student using these data in her senior research thesis to establish cruise ship anchoring sites that have eliminated damage to sensitive benthic habitats. All cruise ships that have visited Monterey following the designation of two acceptable anchoring sites have complied with the restrictions and anchored within 10m of the prescribed sites, thus preserving the highly sensitive Delmonte "shalebeds" (Fig. 1).

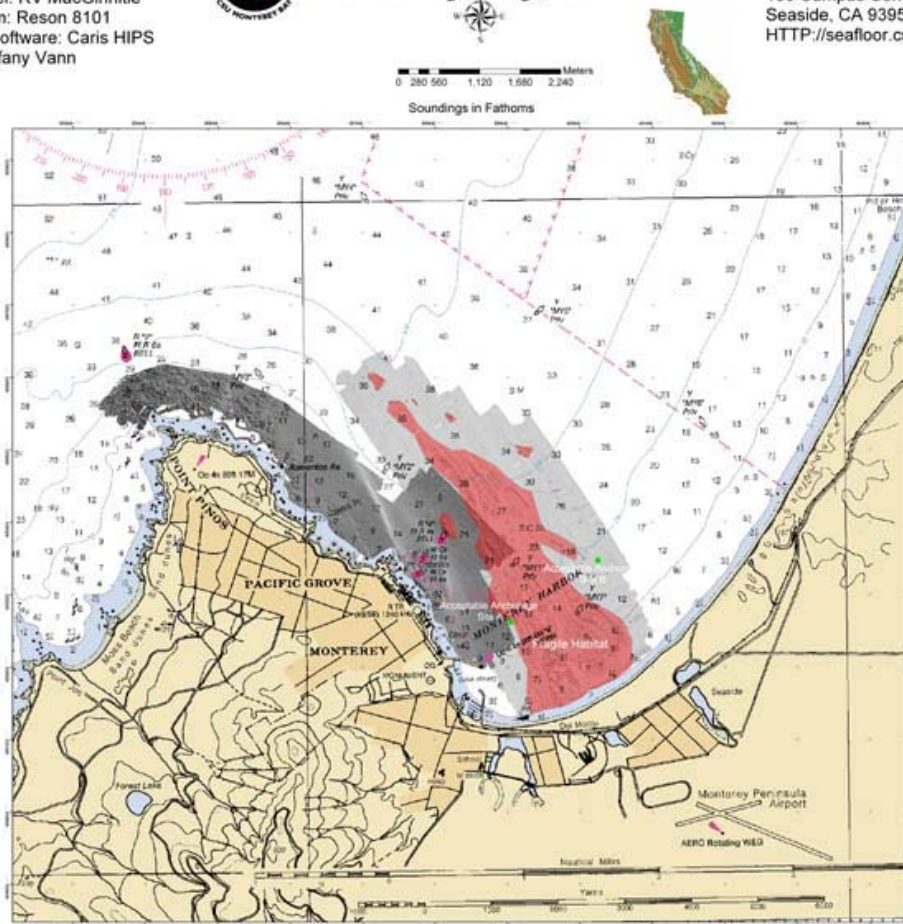
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Multibeam bathymetry in shaded relief
Coordinates: UTM zone 10 WGS 1984
Resolution: 1-3m
Survey Vessel: RV MacGinitie
Sonar System: Reson 8101
Processing Software: Caris HIPS
Layout by Tiffany Vann



Del Monte Shale Beds Monterey Bay, California

Surveyors: Seafloor Mapping Lab
CSU Monterey Bay
Earth Systems Science & Policy
100 Campus Center
Seaside, CA 93955
[HTTP://seafloor.csumb.edu](http://seafloor.csumb.edu)



May 7, 2002
Princess Cruise Lines
Star Princess



September 18, 2002
Royal Caribbean
Grandeur of the Sea

Beginning in 2002, Monterey Bay has become a destination spot for domestic cruises. Three cruise ships will have entered Monterey Bay waters by the year's end, and it is rumored that more ships will arrive in 2003 and 2004. Cruise ships have the potential to add significant revenue to our local tourism-supported community. However, cruise ship anchors have the potential to damage fragile marine habitats, including the Shale Beds of Monterey Bay. As these vessels drop anchor in Monterey Harbor, the shear weight and size of their anchors may negatively impact the delicate rocky ledges and outcrops. The cracks and crevices of the rocky ledges are inhabited by a rich diversity of marine organisms, including commercially important Rockfish species. In addition, benthic organisms utilize the Shale Beds for shelter, such as sea stars, sea anemones, sponges, and nudibranchs. In 2001 the Sea Floor Mapping Lab conducted a survey for the Monterey Shale Beds using the research vessel MacGinitie. Identification of sensitive habitats was accomplished by the utilization of acoustic remote sensing. Specifically, multibeam bathymetry and sidescan sonar were used in a GIS analysis.

In an effort to save this delicate marine ecosystem, the Sea Floor Mapping Lab of California State University Monterey Bay in cooperation with the Monterey Bay National Marine Sanctuary, the Monterey Harbor Master's office, and the San Francisco Bar Pilots identified two acceptable anchorage sites for these massive ships. To date, all cruise lines have complied with the proposed anchorage sites.

Figure 1. Application of benthic habitat mapping results in the protection of the Delmonte Shale Beds, Monterey Bay from cruise ship anchoring. Senior Research Thesis work by CSUMB undergraduate, Tiffany Vann.

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EDUCATION

Our work has incorporated a strong educational component for both undergraduate and graduate students (Appendix 3). CSUMB SFML personnel included 11 undergraduate and 2 graduate students working under the mentorship of three professionals. The MLML Center for Habitat Studies team included five graduate students and a California Sea Grant Fellow. Students were trained in multibeam bathymetry data acquisition and processing, GIS methodologies and benthic habitat interpretations. Some of these students used data produced during this project for Master of Science thesis research at MLML and Capstone Senior Undergraduate Research Theses at CSUMB (Fig. 1).

PUBLICATIONS AND PRESENTATIONS

Major publications of results from this project have not yet been completed because we only recently completed the maps and other final products. Many presentations however have been given based on the methodologies and results of this project. Although other scientists and researchers have used these map products in their own presentations (esp. Gary Greene, Chris Lowe, Mary Yoklavich, and Milton Love), only talks and publications authored by SFML are listed below.

PUBLICATIONS

Veisze, P., N. Wright, and R. Kvitek. (in press) California Department of Fish and Game Marine Region GIS Developments - 2002.Proceedings: 2002 California and the World Ocean Conference

ORAL PRESENTATIONS:

Kvitek, R. G. Marine Habitat Mapping with Multibeam and Sidescan Sonar. Sanctuary Currents: Annual Monterey Bay National Marine Sanctuary Research Symposium. March 2002.

Kvitek, R. G. and Iampietro, P. J. Marine habitat mapping. Italian Antarctic Research Program, Tera Nova Bay, Antarctica. January 2002

Iampietro, P. J. and R. G. Kvitek. Quantitative Seafloor Habitat Classification Using GIS Terrain Analysis: Effects of Data Density, Resolution, and Scale. GeoHab 2002 – Moss Landing Marine Lab. May 2002

Kvitek, R. G. Application of Acoustic Remote Sensing and Multimedia GIS for Mapping Marine Habitats in Santa Monica Bay. Presentation to Santa Monica Bay Restoration Project Technical Advisory Committee. June 2001.

Kvitek, R. G. Applications of Multimedia GIS, Acoustic Remote Sensing and 3D Visualization for Marine Habitat Mapping and Ecosystem-Based Management. Keynote speaker: California Coastal Commission All Staff Training Conference. Asilomar Conference Center, Pacific Grove, CA. June 2001.

Kvitek, R. G. Applications of Multimedia GIS, Acoustic Remote Sensing and 3D Visualization for Marine Habitat Mapping and Ecosystem-Based Management. Invited speaker: Virtual Oceans Symposium, Annual Meeting Southern California Academy of Science. CSULA, Los Angeles May 2001.

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- Kvitek, R. G., K. Thomas, T. Vann, and J. Mansour. Public display of seafloor mapping results and technology. Invited presenter: Oceans Fair 2002 – Monterey Bay National Marine Sanctuary’s 10th Anniversary Celebration. Monterey, CA.
- Kvitek, R. G. Application of seafloor mapping to MPA development. Invited speaker: Pacific Coast Marine Protected Areas – Science and Coordination Workshop. Santa Cruz, CA. 2001
- Kvitek, R. G. Acoustic remote sensing and habitat mapping for ecosystem-based management and design of marine protected areas. Invited speaker: Building Linkages for Marine Protected Areas in North America II: A workshop of the North American Marine Protected Areas Network. Seaside, CA.2001.
- Kvitek, R. G., G. Greene, N. Wright and D. VenTresca. Pushing the waters back: What we could see if we drained the bay: Using sound to map our marine habitats. Invited speaker: Monterey Bay Crescent Ocean Research Consortium (MBCORC) Executive Session at Fleet Numerical Open House. Monterey, CA. 2001
- Kvitek, R. G. Acoustic remote sensing and habitat mapping for ecosystem-based management Triton-Elics International Users Conference. Monterey, CA 2001
- Kvitek, R. G. Acoustic Remote Sensing and Multimedia GIS: Applications for Ecosystem Management & Design of Marine Protected Areas California Cooperative Oceanic Fisheries Investigations (CalCOFI) Annual Conference. UCLA Lake Arrowhead, CA. 2000
- Kvitek, R. G. Acoustic Remote Sensing and Multimedia GIS: Applications for Ecosystem Management. Invited speaker: Annual GIS Day 2000 – Central Coast Joint Data Committee, Moss Landing, CA. 2000

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APPENDIX 1. BENTHIC HABITAT CLASSIFICATION SCHEME

(From R/F 181A Final Report)

Deep-Water Marine Benthic Habitat Classification Scheme

Key to Habitat Classification Code for Mapping and use with GIS programs

(modified after Greene et al., 1999)

Interpreted from remote sensing imagery for mapping purposes

Megahabitat - Use capital letters (based on depth and general physiographic boundaries; depth ranges approximate and specific to study area).

A = Aprons, continental rise, deep fans and bajadas (3000-5000 m)

B = Basin floors, Borderland types (floors at 1000-2500 m)

F = Flanks, continental slope, basin/island-atoll flanks (200-3000 m)

I = Inland seas, fiords (0-200 m)

P = Plains, abyssal (>5000 m)

R = Ridges, banks and seamounts (crests at 200-2500 m)

S = Shelf, continental and island shelves (0-200 m)

Seafloor Induration - Use lower-case letters (based on substrate hardness).

h = hard substrate, rock outcrop, relic beach rock or sediment pavement

m = mixed (hard & soft substrate)

s = soft substrate, sediment covered

Sediment types (for above indurations) - Use parentheses.

(b) = boulder

(c) = cobble

(g) = gravel

(h) = halimeda sediment, carbonate

(m) = mud, silt, clay

(p) = pebble

(s) = sand

Meso/Macrohabitat - Use lower-case letters (scale related).

a = atoll

b = beach, relic

c = canyon

d = deformed, tilted and folded bedrock

e = exposure, bedrock

f = flats

g = gully, channel

i = ice-formed feature or deposit, moraine, drop-stone depression

k = karst, solution pit, sink

l = landslide

m = mound, depression

n = enclosed waters, lagoon

o = overbank deposit (levee)

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p = pinnacle
r = rill
s = scarp, cliff, fault or slump
t = terrace
w = sediment waves
y = delta, fan
z# = zooxanthellae hosting structure, carbonate reef
 1 = barrier reef
 2 = fringing reef
 3 = head, bommie
 4 = patch reef

Modifier - Use lower-case subscript letters or underscore for GIS programs (textural and lithologic relationship).

a = anthropogenic (artificial reef/breakwall/shipwreck)
b = bimodal (conglomeratic, mixed [includes gravel, cobbles and pebbles])
c = consolidated sediment (includes claystone, mudstone, siltstone, sandstone, breccia, or conglomerate)
d = differentially eroded
f = fracture, joints-faulted
g = granite
h = hummocky, irregular relief
i = interface, lithologic contact
k = kelp
l = limestone or carbonate
m = massive
o = outwash
p = pavement
r = ripples
s = scour (current or ice, direction noted)
u = unconsolidated sediment
v = volcanic rock

Seafloor Slope - Use category numbers. Calculated for survey area from x-y-z multibeam data.

1 Flat (0-1°)
2 Sloping (1-30°)
3 Steeply Sloping (30-60°)
4 Vertical (60-90°)
5 Overhang (> 90°)

Seafloor Complexity - Use category letters (in caps). Calculated for survey area from x-y-z multibeam slope data using neighborhood statistics and reported in standard deviation units.

A Very Low Complexity (-1 to 0)
B Low Complexity (0 to 1)
C Moderate Complexity (1 to 2)
D High Complexity (2 to 3)
E Very High Complexity (3+)

Geologic Unit - When possible, the associated geologic unit is identified for each habitat type and follows the habitat designation in parentheses.

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Examples:

Shp_d1D(Q/R) - Continental shelf megahabitat; flat, highly complex hard seafloor with pinnacles differentially eroded.

Geologic unit = Quaternary/Recent.

Fhd_d2C (Tmm) - Continental slope megahabitat; sloping hard seafloor of deformed (tilted, faulted, folded), differentially eroded bedrock exposure forming overhangs and caves.

Geologic unit = Tertiary Miocene Monterey Formation.

Determined from video, still photos, or direct observation.

Macro/Microhabitat - Preceded by an asterix. Use parentheses for geologic attributes, brackets for biologic attributes. Based on observed small-scale seafloor features.

Geologic attributes (note percent grain sizes when possible)

(b) = boulder

(c) = cobble

(d) = deformed, faulted, or folded

(e) = exposure, bedrock (sedimentary, igneous, or metamorphic)

(f) = fans

(g) = gravel

(h) = halimeda sediment, carbonate slates or mounds

(i) = interface

(j) = joints, cracks, and crevices

(m) = mud, silt, or clay

(p) = pebble

(q) = coquina (shell hash)

(r) = rubble

(s) = sand

(t) = terrace-like seafloor including sedimentary pavements

(w) = wall, scarp, or cliff

Biologic attributes

[a] = algae

[b] = bryozoans

[c] = corals

[d] = detritus, drift algae

[g] = gorgonians

[n] = anemones

[o] = other sessile organisms

[s] = sponges

[t] = tracks, trails, or trace fossils

[u] = unusual organisms, or chemosynthetic communities

[w] = worm tubes

Seafloor Slope - Use category numbers. Estimated from video, still photos, or direct

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observation.

- 1 Flat (0-1°)
- 2 Sloping (1-30°)
- 3 Steeply Sloping (30-60°)
- 4 Vertical (60 - 90°)
- 5 Overhang (90°+)

Seafloor Complexity - Use category numbers. Estimated from video, still photos, or direct observation. Numbers represent seafloor rugosity values calculated as the ratio of surface area to linear area along a measured transect or patch.

- A Very Low Complexity (1 to 1.25)
- B Low Complexity (1.25 to 1.50)
- C Moderate Complexity (1.50 to 1.75)
- D High Complexity (1.75 to 2.00)
- E Very High Complexity (2+)

Examples: *(m)[w]1C - Flat or nearly flat mud (100%) bottom with worm tubes; moderate complexity.

*(s/c)1A - Sand bottom (>50%) with cobbles.
Flat or nearly flat with very low complexity.

*(h)[c]1E - Coral reef on flat bottom with halimeda sediment. Very high complexity.

Shp_d1D(Q/R)*(m)[w]1C - *Large-scale habitat type*: Continental shelf megahabitat; flat, highly complex hard seafloor with pinnacles differentially eroded. Geologic unit = Quaternary/Recent. *Small-scale habitat type*: Flat or nearly flat mud (100%) bottom with worm tubes; moderate complexity.

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APPENDIX 2. EXPLANATION OF HABITAT CLASSIFICATION CODE

(From R/F 181A Final Report)

Deep-Water Marine Benthic Habitat Classification Scheme

Explanation for Habitat Classification Code

(modified after Greene et al., 1999)

Habitat Classification Code

A habitat classification code, based on the deep-water habitat characterization scheme developed by Greene et al. (1999), was created to easily distinguish marine benthic habitats and to facilitate ease of use and queries within GIS (e.g., ArcView®, TNT Mips®, and ArcGIS®) and database (e.g., Microsoft Access® or Excel®) programs. The code is derived from several categories and can be subdivided based on the spatial scale of the data. The following categories apply directly to habitat interpretations determined from remote sensing imagery collected at the scale of 10s of kilometers to 1 meter: Megahabitat, Seafloor Induration, Meso/Macrohabitat, Modifier, Seafloor Slope, Seafloor Complexity, and Geologic Unit. Additional categories of Macro/Microhabitat, Seafloor Slope, and Seafloor Complexity apply to areas at the scale of 10 meters to centimeters and are determined from video, still photos, or direct observations. These two components can be used in conjunction to define a habitat across spatial scales or separately for comparisons between large and small-scale habitat types. Categories are explained in detail below. Not all categories may be required or possible given the study objectives, data availability, or data quality and in these cases categories may be omitted.

Explanation of Attribute Categories and their Use

Determined from Remote Sensing Imagery (for creation of large-scale habitat maps)

1) Megahabitat - This category is based on depth and general physiographic boundaries and is used to distinguish regions and features on a scale of 10s of kilometers to kilometers. Depth ranges listed for category attributes in the key are given as generalized examples. This category is listed first in the code and denoted with a capital letter.

2) Seafloor Induration - Seafloor induration refers to substrate hardness and is depicted by the second letter (a lower-case letter) in the code. Designations of hard, mixed, and soft substrate can be further subdivided into distinct sediment types, and are then listed immediately afterwards in parentheses either in alphabetical order or in order of relative abundance.

3) Meso/Macrohabitat - This distinction is related to the scale of the habitat and consists of seafloor features ranging from 1 kilometer to 1 meter. Meso/Macrohabitats are noted as the third letter (a lower-case letter) in the code. If necessary, several Meso/Macrohabitats can be included either alphabetically or in order of relative abundance and separated by a backslash.

4) Modifier - The fourth letter in the code, a modifier, is noted with a lower-case subscript letter or separated by an underline in some GIS programs (e.g., ArcView®). Modifiers describe the texture or lithology of the seafloor. If necessary, several modifiers can be included alphabetically or in order of relative abundance and separated by a backslash.

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5) Seafloor Slope - The fifth category, listed by a number following the modifier subscript, denotes slope. Slope is calculated for a survey area from x-y-z multibeam data and category values can be modified based on characteristics of the study region.

6) Seafloor Complexity - Complexity is denoted by the sixth letter and listed in caps. Complexity is calculated from slope data using neighborhood statistics and reported in standard deviation units. As with slope, category values can be modified based on characteristics of the study region.

7) Geologic Unit - When possible, the geologic unit is determined and listed subsequent to the habitat classification code, in parentheses.

Determined from video, still photos, or direct observation (for designation of small-scale habitat types)

8) Macro/Microhabitat -Macro/Microhabitats are noted by the eighth letter in the code (or first letter, if used separately) and preceded by an asterisk. This category is subdivided between geologic (surrounded by parentheses) and biologic (surrounded by brackets) attributes. Dynamic segmentation can be used to plot macroscale habitat patches on Mega/Mesoscale habitat interpretations (Nasby 2000).

9) Seafloor Slope - The ninth category (or second category, if used separately), listed by a number denotes slope. Unlike the previous slope designation (#5), the clarity of this estimate can be made at smaller scales and groundtruthed or compared with category #5. Category values can be modified based on characteristics of the study region.

10) Seafloor Complexity - The designations in this category, unlike those in category #6, are based on seafloor rugosity values calculated as the ratio of surface area to linear area along a measured transect or patch. Category letters are listed in caps and category values can be modified based on characteristics of the study region.

Literature Cited:

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Nasby, N.M. 2000. Integration of submersible transect data and high-resolution sonar imagery for a habitat-based groundfish assessment of Heceta Bank, Oregon. M.S. Thesis, College of Oceanic and Atmospheric Science, Oregon State University. pp. 49.

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APPENDIX 3. PROJECT PERSONNEL

Project Personnel (all graduate students are listed in blue, undergrads in red, and other researchers in black) are listed along with their primary responsibilities during this project.

PROJECT # R/F – 181A

Center for Habitat Studies – Moss Landing Marine Laboratories

Dr. H. Gary Greene	Project Director, Chief Habitat Interpreter
Joseph J. Bizzarro	Project Manager, Chief GIS Analyst
Mercedes Erdey	GIS Technician
Holly Lopez	GIS Technician
Tracy Vallier	Habitat Interpretations
Ray McClain	GIS Analyst, Computer Technician
Janet Tilden	Habitat Interpretations
Isabelle Herbert	Administrative Support
Steven Watt	GIS Support
Lee Murai	GIS Support

PROJECT # R/F – 181B

Seafloor Mapping Lab – California State University, Monterey Bay

Dr. Rikk Kvitek	Project Director
Pat Iampietro	Project Manager, Chief Hydrographer
Carrie Bretz	Project Manager, GIS/IMS and Metadata Manager
Eric Sandoval	Habitat Interpretations, GIS Analyst
Kate Thomas	Hydrographic Surveyor, Multibeam and GIS Analyst
Tania Leisten	Multibeam and Sidescan Sonar Technician
Tiffany Vann	GIS/Habitat Mapping Technician
Edwin Dean	GIS/Hydrographic Data Technician
Billy Jakl	GIS/Hydrographic Data Technician
Jason Mansour	GIS/Hydrographic Data Technician
Erica Summers	GIS/Hydrographic Data Technician
Henna Ruiz	GIS/Hydrographic Data Technician
Josh Sampey	GIS/Hydrographic Data Technician
Paul Chua	GIS/Hydrographic Data Technician
Jerry Brantner	GIS/Hydrographic Data Technician
Jennifer Schellinger	Web site and IMS design