Using Airborne Hydrographic LiDAR To Support Mapping of California's Waters

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Abstract- **A specialist team comprising academic, industry and government members is underway in a program that will ultimately lead to mapping of all 14,500 km^2 of California's State Waters from MHHW out to the three-nautical-mile boundary. The technical and scientific team is lead by California State Coastal Conservancy[1] through a contract with California State University Monterey Bay (CSUMB), and includes Principle Investigators from the Seafloor Mapping Lab of CSUMB, Fugro Pelagos, Inc; the US Geological Survey's Coastal and Marine Geology Program; and Moss Landing Marine Labs' Center for Habitat Studies.**

The data acquisition program includes a seafloor mapping component that incorporates the latest multibeam echosounding and airborne LiDAR bathymetry technologies and a ground truth component that includes video transects and sampling. This presentation describes the comprehensive and high-resolution seafloor-mapping program, with a focus on integrating the airborne LIDAR component with the multibeam data. The airborne bathymetric LiDAR sensor is capable of providing beach and bluff topography, digital aerial imagery, nearshore bathymetry and nearshore seabed laser reflectance imagery. All LiDAR data will be integrated with deeper water acoustic data and ground truth data to ultimately support a three-tier level of data processing and analyses.

The Tier 1 and Tier 2 products specified as requirements include a minimum of nine GIS Data layers (ESRI compatible) with FGDC compliant metadata files. Two Tier 3 interpretation example products are also being created: 1) an updated 1:100,000 Essential Fish Habitat (EFH) interpretation map, and 2) a 1:24,000 geological quad map.

The first portion of the California coast to be mapped extends from Punta Arena north of the Golden Gate, southward to Punta del Año Nuevo. This area was identified as a high priority during a workshop attended by statewide stakeholders. This ground-breaking program is funded by the California Ocean Protection Council through the California State Coastal Conservancy. The program manager was the Monterey Bay Sanctuary Foundation, working in collaboration with NOAA's National Marine Sanctuary Program.

This presentation includes sections on the various technologies used, examples of results obtained to date, notes on planning the statewide mapping program, and a report on current program status. This major integrated mapping program along 1800km of shoreline is establishing standards that can be applied to new regional coastal and offshore mapping for the management of marine resources.

I. INTRODUCTION

The California State Coastal Conservancy (SCC), Ocean Protection Council (OPC), Department of Fish and Game (DFG), and the NOAA National Marine Sanctuary Program (NMSP) have launched the first phase of a comprehensive state waters mapping program for California. The ultimate goal is the creation of a high-resolution 1:24,000 scale geologic and habitat base map series covering all of California's 14,500 km^2 state waters out to the three-nautical-mile limit. This statewide project requires, involves and leverages expertise from industry, resource management agencies and academia. The first phase of the program is the North Central Coast Mapping Project. This phase has served as the proof-of-concept model demonstrating the viability, efficiency and value of this approach in support of the state's Marine Life Protection Act Initiative (MLPA) goal to create a statewide network of Marine Protected Areas (MPAs). The tiered mapping campaign involves the use of state-of-the-art sonar, LIDAR (both terrestrial and bathymetric) and video seafloor mapping technologies; computer aided classification and visualization; expert geologic and habitat interpretations codified into strip maps spanning California's land/sea boundary; and the creation of an online, publicly accessible data repository for the dissemination of all mapping products.

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[1] This ground-breaking program is funded by the California Ocean Protection Council through the California State Coastal Conservancy. The program manager was the Monterey Bay Sanctuary Foundation, working in collaboration with NOAA's National Marine Sanctuary Program.

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This paper includes some specific discussion of the role and results of the hydrographic (bathymetric) LiDAR component. Funding delays have interrupted completing the first portion of the hydrographic LiDAR surveying, and so the information and examples in this paper are from the initial bathymetry from LiDAR surveying.

II. Survey Area Prioritization

The SCC funded a Statewide Marine Mapping Planning Workshop[2] held at CSU Monterey Bay in December, 2005. The purpose of the workshop was to create a strategic plan for completing the mapping of all seafloor habitats within California State Waters (shoreline out to three nautical miles). The approach was to involve key stakeholders in a gap analysis of existing data coverage, identification and ranking of current mapping information needs, the prioritization of areas for new field data acquisition, and the definition of minimum survey and analysis specification required to support these needs.

The sponsors also requested a separate ranking of mapping priorities within the proposed pilot project area that was subsequently funded as the North Central Coast Mapping Project (NCCMP) (Fig. 1). The two-day workshop attracted 56 invited participants representing 38 institutions including regional, state and federal resource management agencies, universities, research institutions, NGO's and private industry.

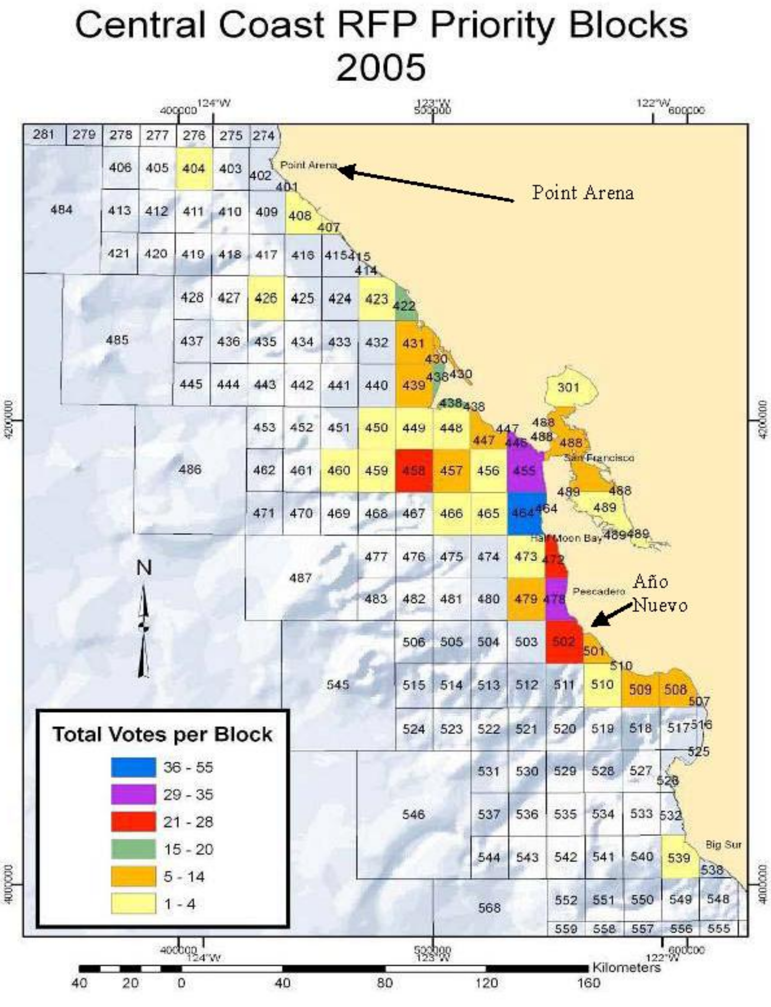

Figure 1. Spatial distribution of number of votes cast per block for the NCCMP priority mapping needs during the 2005 Statewide Marine Mapping Planning Workshop

[2] Go to this Internet link to see the full report on this exemplary meeting: http://seafloor.csumb.edu/StrategicMappingWorkshop.htm

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III. Identification of Data Needs

A surprising degree of overlap was discovered among the participants regarding their need for mapping data products including:

- MPA mapping in support of the MLPA process
- Environmental monitoring and change detection
- Sediment transport dynamics (erosion, deposition and beach nourishment)
- Geologic hazards (faults and landslides capable of producing tsunamis)
- Habitat maps for fisheries management, stock assessment and identification of biological hot spots
- Safe navigation in shallows, bays, harbors and estuaries
- Economical sources of sand
- Data to support wave, current, sediment transport and oil spill prediction models
- Location of shipwrecks with potential for oil leaks
- Location of derelict fishing gear
- Tsunami run-up modelling

Identification and ranking by the participants of areas for future mapping within state waters was conducted through a voting process making use of the existing 10-minute CDFG commercial fishing block designations (Fig. 1). Recommendations for data acquisition and final products were obtained during group and breakout sessions regarding critical elements key to the success of a statewide mapping effort. These elements included: data acquisition, level of interpretation, metadata, and dissemination. There was consensus that the minimum universal seafloor mapping information should cover all "lands" from the shore strand line (MHHW) out to the three-nautical-mile state water limit and include:

- Seabed geomorphology (relief via xyz digital elevation models - DEM)
- Texture (substrate type via backscatter mosaics).
- Ground truthing (via video or physical samples)
- Subsurface structure, sediment thickness and stratigraphy via subbottom profiles & coring
- Meet or exceed International Hydrographic Organization (IHO) Order 1 standards, and be carried out at the maximum resolution obtainable using state-of-the-industry tools.
- Best available geodetic positioning technology (vertical and horizontal)

All present acknowledged the ultimate need for and great value in full geologic and habitat interpretation of collected mapping data. The recommended approach was to consider map product generation as a 3 tiered process, with each tier being constructed from the previous. The first tier consists of the basic survey data (xyz grids [bathymetry] and backscatter [substrate] mosaics). These first tier data sets can be efficiently converted into second tier products in GIS at little additional cost using automated numerical derivatives including autoclassification of substrates and surface models based on parameters (slope, aspect, rugosity, contours, relief, etc.). Second tier products are GIS-ready and are often of high value to management agencies because many of the patterns they are interested in (e.g. rocky versus soft bottom habitats, bed forms, and depth zones) are easily discernable at this intermediate level of data analysis. The third product tier (fully interpreted, classified and attributed geologic and habitat maps), enables consideration of a variety of different types of data of varying scales and so represents considerable "value added" when there are several different data sets to be considered.

Finally, all acknowledged the critical importance of having all data meet FGDC metadata standards. For archiving and dissemination, the recommendation was for a tiered system of accessible databases (ftp with links, http download sites, website images of data that link to data sources, internet GIS map servers).

IV. Phase I Survey Program

The first phase of the anticipated statewide mapping program commenced in November 2006 with support from the OPC, SCC, DFG and NMS. The NCCMP mission is to map the state waters between Ano Nuevo and Point Arena (Fig. 1). The team conducting this work is a uniquely qualified partnership between academia, industry and resource management. Members include the Seafloor Mapping Lab at California State University Monterey Bay, US Geological Survey National Seafloor Mapping and Benthic Habitat Studies Group, Fugro Pelagos Inc. and the Center for Habitat Studies at Moss Landing Marine Labs.

Acquisition of mapping data involves bathymetric LIDAR and multibeam echo sounders (MBES) to obtain bathymetry data, acoustic backscatter and reflectance imagery, as well as acoustic sub-bottom profiling data. An example of the multibeam echosounder data results is shown in Fig. 2, which is of the famous super-large-wave surfing area “Mavericks”. This high-energy surf zone indicates the value bathymetric LiDAR data can add to the program when the zone between MBES surveying at the shoreline are filled safely by this airborne method. The first attempt in this area did not result in full coverage to the specifications due to a period of turbidity from rains that occurred just prior to when the aircraft was in the area. Future airborne LiDAR bathymetry surveying is expected in 2008 or 2009.

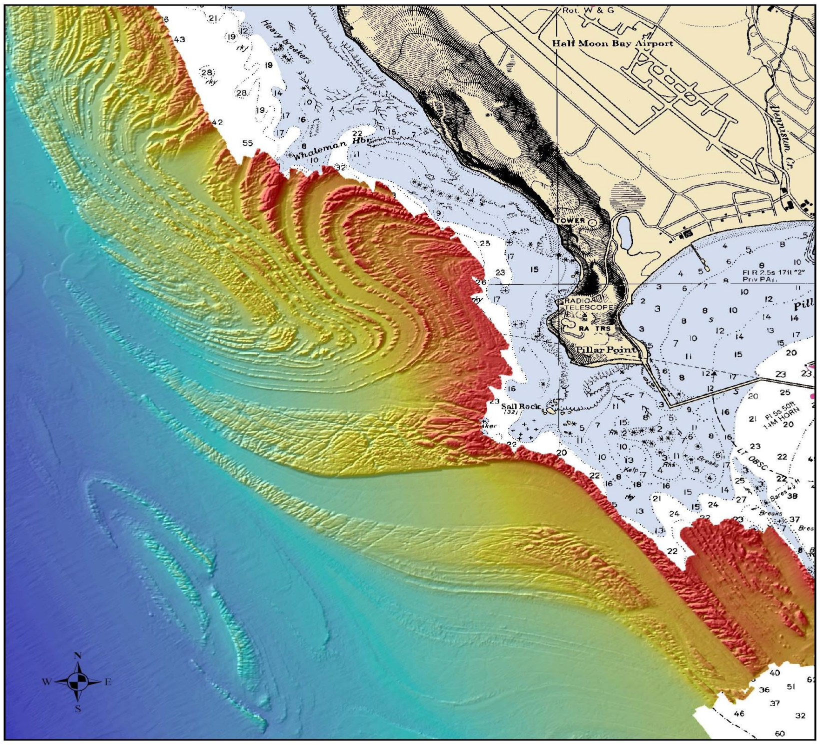

Fig. 2. **Mavericks, Half Moon Bay, California. Preliminary Tier 2 results from NCCMP. High-resolution multibeam sonar map showing spectacularly faulted and deformed seafloor geology, in shaded relief and colored by depth, overlain on the NOAA 18682 nautical chart (depth soundings in feet). This level of detail is needed, but not available for 66% of California state waters. (Source: California OPC North Central Coast Mapping Project).**

The surveys and the information created will comply with the recommended requirements for statewide seafloor mapping as specified in the Workshop Report, including:

- Seabed geomorphology (relief via xyz digital elevation models - DEM)
- Texture (substrate type via acoustic backscatter and reflectance mosaics)
- Ground-truthing (via video or physical samples)
- Surveys designed to meet or exceed IHO Order 1 standards, and to be carried out at the maximum resolution obtainable using state-of-the-industry tools
- Best available geodetic positioning technology (vertical and horizontal)

The Tier 1 and Tier 2 products specified as requirements in the RFP include the following ESRI compatible Data layers with FGDC compliant metadata files:

- Sediment sample point features with grain size attributes
- Video observation point features with geologic and biologic attributes

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- Geologic structure with motion attributes
- Bathymetric ESRI grid and ASCII xyz file
- Bathymetry in shaded relief as georeferenced tiff image (colored by depth and in grey scale)
- Backscatter intensity as georeferenced tiff image
- Bathymetric contour feature layer at 5 meter intervals
- A seafloor texture grid derived from unsupervised clustering of derivatives of the bathymetry and backscatter intensity
- A surficial geologic ESRI grid produced using video-supervised classification of derivatives of the bathymetric and backscatter data

Two Tier 3 interpretation example products are also being created: 1) an updated 1:100,000 Essential Fish Habitat (EFH) interpretation map, and 2) a 1:24,000 quad map set composed of:

- Color coded bathymetry draped over shaded relief bathymetry overlain with bathymetric contours
- Backscatter intensity draped over shaded relief bathymetry
- Color coded seafloor texture draped over shaded relief bathymetry
- Color coded Geologic units draped over shaded relief bathymetry overlain with structure
- Color coded benthic habitat draped over shaded relief bathymetry

For the phase I program, examples of these data deliverables are in process at this writing.

V. Bathymetric LiDAR Technology

ALB technology is analogous to MBES technology in that the system basically measures the time of flight of a signal from its emission from a source to its return to the sensor. But it is not just that the speeds are measured by nanoseconds, because there are two media in which the laser signal travels. this requires double sets of calculations using different velocities, and that leads to the need to adjust for refraction. These most basic aspects of ALB are illustrated in Fig. 3.

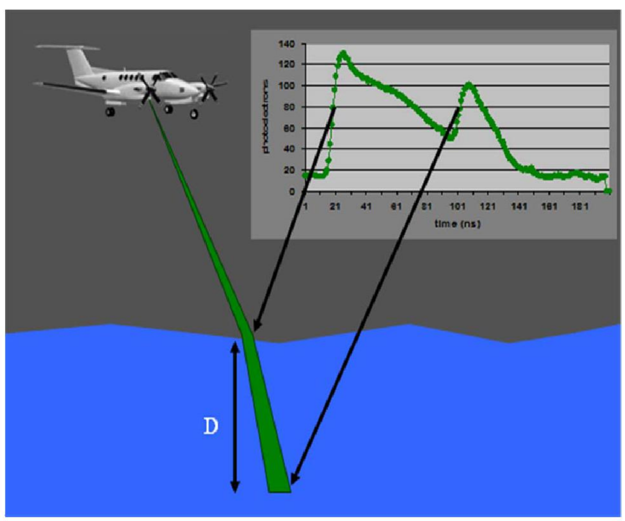

Fig. 3 – Basic concept for ALB depth and water surface measurements.

It is the green (532nm) laser that makes ALB unique with respect to topographic LiDAR, which works using a near-infrared (1064nm) laser. However, the SHOALS-1000T also has the IR laser for detection of the water and land surfaces. Both beams are projected onto a fast rotating mirror, which creates the swath of points. The green beam penetrates the water and also detects the bottom surface when conditions are favorable, as shown in Fig. 4.

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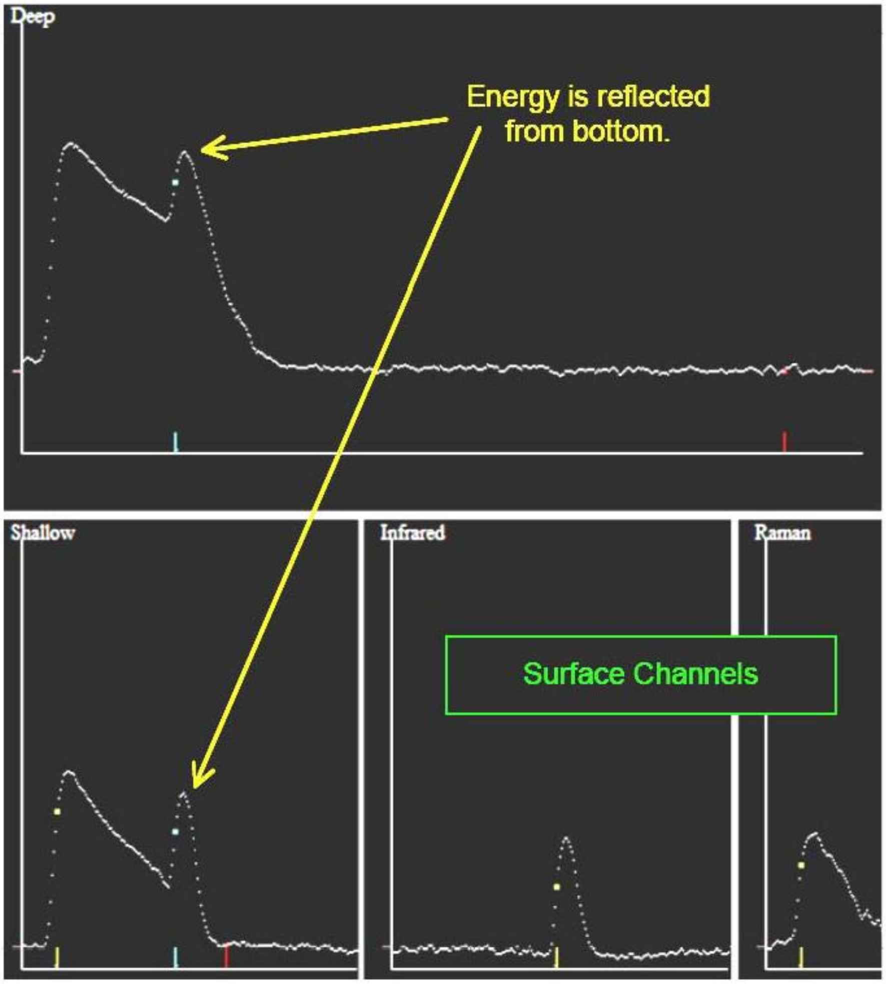

Fig. 4 – Green laser beam waveform captured by the SHOALS-1000T.

These aspects of light properties and system technologies result in the following performance characteristics in the SHOALS-1000T:

Speed over ground:	125-180 knots
Altitude above ground:	300-400 m
Sounding density:	**2x2, 3x3, 4x4, 5x5 m**
Swath width:	60-230 m
Minimum depth:	**0.2m**
Maximum depth:	**50 m**
Depth accuracy:	**IHO Order 1 (0.25m, 1σ)**
Horizontal accuracy:	**IHO Order 1 (2.5 m, 1σ)**
Laser classification:	Class IV laser product (FDA CFR 21)
Eyesafe altitude:	150m
Power requirements:	60 A @ 28VDC

A key technology parameter for the green laser is eye safety. This is not a restriction for the IR laser, but because the green is in the visual range, the power must be limited. This results in a much broader beam footprint, which in turn increases the uncertainty of the horizontal position over topographic LiDARs.

VI. LIDAR BATHYMETRY DATA PRODUCTS

An example of airborne LiDAR bathymetry data merged with multibeam echosounder data from a site at San Elijo, California, is shown in Fig. 5. The block of multibeam data is centered on an outfall pipeline. Note the offset in the pipeline, which was the

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result of adding an extension into deeper waters by attaching it to the end of the original diffuser section. The inshore data set is the bathymetric LiDAR, and the outer edge represents the LiDAR extinction depth for the day of the overflight. The depths on the background navigation chart are in fathoms, and the contour with blue shading on the right and white on the left is the 10-fathom, or 60-foot (18-metre) isobath.

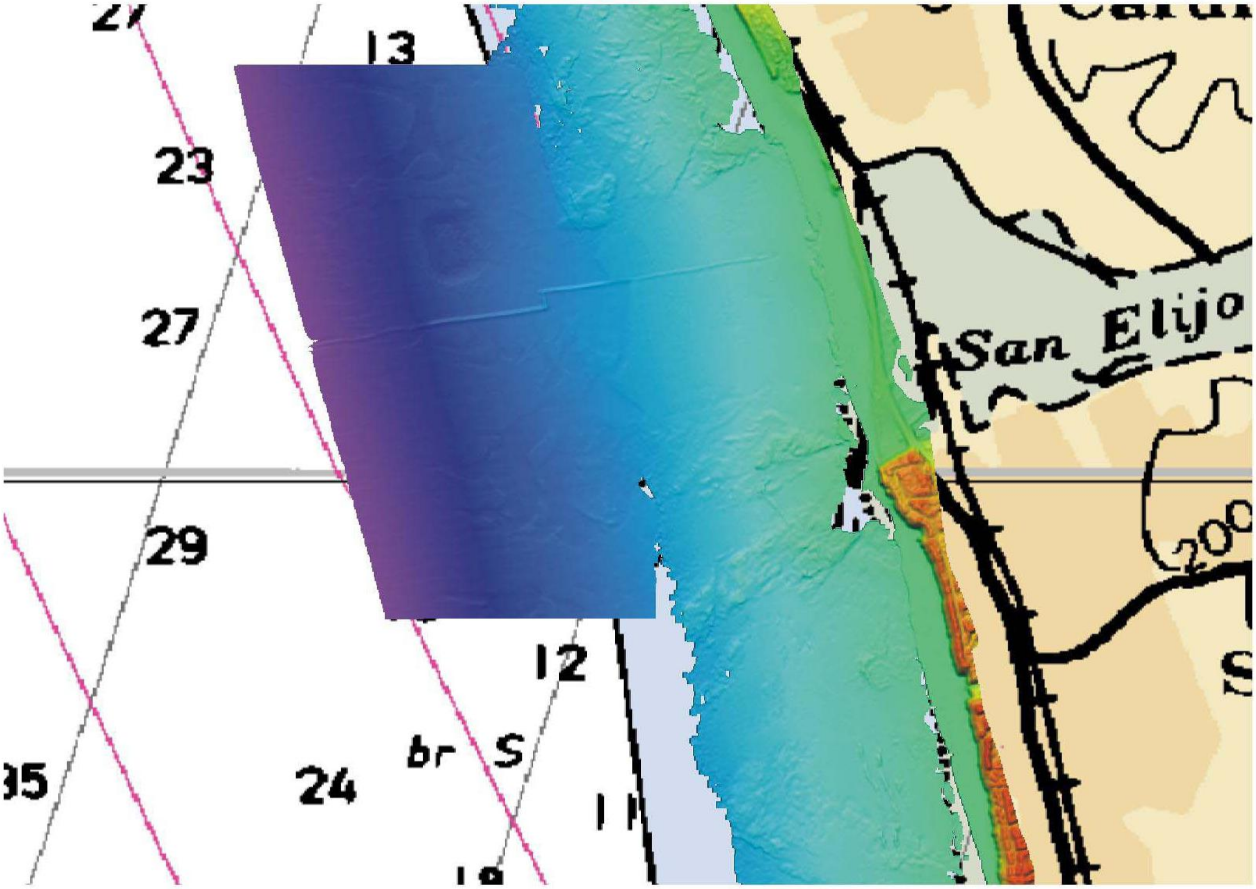

Fig. 5 Merged airborne LiDAR bathymetric and multibeam echosounder data, including onshore topography also from the SHOALS-1000T.

These data together show the full extent of the pipeline exposed above the seafloor. The rectangular pit seen north of the pipeline is a sand mining area to supply a beach replenishment project. Rocky reefs are evident in the LiDAR bathymetry. These reef are seen by the shapes of the data gaps to have breaking surf just before the waves hit the sandy beach line. The beach is evident in the topographic data, which also indicates coastal bluffs in the south. the alignment of the coast highway can also be seen in the topography where it aligns with the road on the navigation chart.

VII. CONCLUSION

Airborne LiDAR bathymetry will play an important role in the major seafloor mapping program starting in California. The LiDAR surveying by the SHOALS-1000T yields onshore topography as well as underwater elevations. Another data product from this system is seafloor reflectance imaging, which can be beneficial to mapping of underwater habitats. More data examples will become available as this ground-breaking program continues.

Acknowledgment

The foresight of the California Ocean Protection Council provided the impetus and funding for this unique program to demonstrate the technology and benefits of a comprehensive program to map all of California's State Waters out to the three-nautical-mile limit. The California Coastal Conservancy provided program management with strong leadership by Sheila Semans.

The co-organizers for the exemplary Statewide Marine Mapping Planning Workshop are Prof R. Kvitek of CSUMB's Seafloor Mapping Lab, G. Cochrane of US Geological Survey CMG, Santa Cruz, and Prof. G. Greene of the Center for Habitat Mapping at Moss Landing Marine Laboratories. These gentlemen continue to play significant and essential roles in advancing the program. Other notable contributors to this work include S. Johnson of USGS CMG, Santa Cruz; C. Wills of the California Geological Survey; the California Department of Fish & Game; National Oceanic and Atmospheric Administration, National Ocean Service, with their National Marine Sanctuaries Program, and the NMS Foundation.