

FINAL REPORT
EARLY IMPLEMENTATION OF NEARSHORE ECOSYSTEM DATABASE
PROJECT

TASK 2: Habitat Metadata Catalog (marine habitat substrate data for the California continental shelf not currently held by CDF&G)

TASK 3: Review of Procedures, Protocols, Technologies and Providers for Nearshore Marine Habitat Mapping

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and

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1. EXECUTIVE SUMMARY AND RECOMMENDATIONS

1.1. BACKGROUND

The California Department of Fish and Game Nearshore Ecosystem Database Project is designed to address the policy of the State to assess, conserve, restore, and manage California's ocean resources and the ecosystem as stated in Executive Order No. W-162-97. The purpose of this project is to enable the Department to expand its Geographic Information System (GIS) database to include and make available to CERES, data from the marine subtidal and nearshore ecosystems. The primary components of the project are: GIS mapping of essential marine habitats, nearshore reef fish stock assessment, and marine reserve research. The Early Implementation Phase of this project has focused on accelerating the acquisition of baseline bathymetry and substrate data as outlined in the GIS Mapping of Essential Marine Habitats portion of the project. This effort has included four tasks:

- Task 1) Data Needs: Identification of departmental needs for bathymetry and substrate data.
- Task 2) Data Catalog: Assessment and collection of metadata for currently available data on marine bathymetry and seafloor substrates.
- Task 3) Procedures, Protocols and New Technologies: A review of current and emerging methods and providers for mapping marine habitats.
- Task 4) Data Processing: Process and incorporate existing bathymetric and substrate data into Department GIS coverage themes.

1.2. PURPOSE AND SCOPE

The focus of this report is on those portions of Tasks 2 and 3 subcontracted to Moss Landing Marine Laboratories and California State University Monterey Bay through San Jose State University Foundation (Contract # FG 7335 MR). For Task 2, the work was divided, with the Department taking on the collection and assessment of metadata for bathymetry, and this contract covering the metadata for existing substrate information. For Task 3 our assignment was to survey and evaluate currently available techniques for mapping marine habitats, and to assess their adequacy for meeting stated Department data needs. Here our goal has been to provide the Department with the information needed to make decisions on: 1) how habitats of interest should be mapped given the needs of the Department, 2) the selection of providers of marine habitat mapping services and equipment, and 3) the relative costs in time and money associated with acquiring the types of habitat data needed.

The Department requested that we limit our scope to the California continental shelf, giving primary attention to the nearshore 0-30 m depth zone. It is this shallow coastal zone that is often the most heavily utilized and impacted by human activities, yet it is also the zone for which we have the least amount of bathymetric and substrate data. This data scarcity is due in large part to the challenging and often dangerous logistics associated with conducting hydrographic

surveys in shallow, open coast environments. High use and data scarcities have made the 0-30 m depth zone a high priority for habitat mapping over the next decade.

1.3. FINAL PRODUCTS

Our final products for this project include the written final report and two Microsoft Access databases, one containing information on habitat mapping technologies and providers (Mapping Tools Database), and the other the CERES compliant metadata catalogue for existing seafloor substrate data sets. In the report we review and summarize the reasons for, approaches to and requirements of habitat mapping as they apply to nearshore marine resource management. Also in the report, we review and summarize in tabular form the data contained in the two databases. The Habitat Mapping Tools Database contains information on the Tools, Tool Manufacturers, Survey Equipment Providers, and Survey Service Providers (including private companies, universities and government agencies). The Seafloor Substrate Metadata Catalog contains information on 85 data sets obtained after contacting 86 potential sources.

1.4. SUMMARY

A habitat is the place where a particular species lives or biotic community is normally found. Habitat mapping is often undertaken by resource agencies to serve a variety of purposes including:

- ◆ Assessment of habitat change due to natural or human impacts (e.g. climate change, oil spills, trawl disturbance)
- ◆ Monitoring and protecting important habitats (e.g. marine reserves, spawning areas, harvest closure areas)
- ◆ Design and location of marine reserves or aquaculture projects
- ◆ Species distributions and stock assessment

While most subtidal species and resources can only be sampled directly using observational or other large scale (>1:10,000) survey techniques, it would be impractical to apply this level of effort to the entire coast of California. A major goal of habitat mapping, therefore, is to develop the ability to predict the distribution and abundance of species and resources from those physical and biotic parameters that can be remotely sampled.

Habitat parameters important to the distribution and abundance of benthic and nearshore species include but are not limited to: water depth, substrate type, rugosity, slope/aspect, voids (abundance, type and size), sediment type and depth, exposure, vegetation, chemistry, temperature, presence of other species.

Because the response of different species often varies with the spatial extent of these parameters, habitat scale is another factor important in defining where different species and biotic communities are likely to be found. For this reason, a benthic habitat classification system useful for defining species/habitat associations based on the parameters listed above must also be hierarchically organized according to relevant spatial scales.

Given these considerations, a regional habitat mapping program should include the following elements:

- ◆ Clear statement of purpose for the mapping project (e.g. well defined goals and objectives).
- ◆ Selections of scales for map extents and data resolution appropriate to the stated purpose.
- ◆ A universally accepted and broadly applicable hierarchical habitat classification system based on spatially nested physical and biophysical characteristics that control where species live.
- ◆ A means for acquiring data at appropriate resolutions and spatial scales for each of the relevant habitat characteristics.
- ◆ A means for combining, analyzing and displaying geospatial data sets collected in diverse formats, and at different scales and resolutions such that the habitat classification system can be applied.

1.5. GENERAL FINDINGS

There are now keen interests, new legislative mandates, and compelling needs driving many state and federal management agencies in the direction of nearshore habitat mapping. Most agencies, however, lack the expertise, equipment, and financial ability to collect, process, analyze, and use the types of habitat data required by these new mandates. Those that do or did, such as the US Geological Survey, have been faced with the loss of experienced personnel through downsizing, and the fiscal inability to keep up with the rapidly changing and very expensive technologies required. While there are numerous private companies that do have these capabilities, much of their mapping work has been done for private interests (e.g. telecommunications companies) that are either not permitted or willing to share their data with public agencies due to a highly competitive market place. Military data, though potentially abundant regionally, is primarily in hard copy form, poorly georeferenced, and difficult to locate and access without help and interest from within the military.

As a result of these factors, several agencies including the Department of Fish and Game are exploring the avenues open to them for acquiring and utilizing marine habitat data. To date, however, there has been little coordination to leverage these efforts among the interested agencies. Further confounding matters is the lack of a generally accepted habitat classification system appropriate for nearshore marine environments. This lack of coordination means that efforts will be duplicated, and that data sharing will be hampered by lack of uniformity in data collection, classification and processing protocols. Given that marine biotic habitat mapping is still in its infancy, however, there remains an opportunity to coordinate and leverage resources in the development of these habitat maps, technologies and protocols.

The established methods and acoustic mapping technologies in current use are capable of creating highly detailed maps of 3D seafloor morphology and substrate type at sub-meter resolutions over broad areas of habitat. Much of the biotically important detail in habitats,

however, can occur at the level of decimeters and centimeters. As a result, direct sampling and video imagery are often necessary to augment the detail provided via acoustic remote sensing. While the combination of these methods is capable of yielding highly detailed results, the expense involved can be impractical due to the relatively slow data acquisition rates compared to that required for remote sensing in terrestrial habitats. Obtaining a high resolution, groundtruthed image of a square kilometer of seafloor can take more than a day to acquire at great expense, compared to just minutes needed to obtain relatively inexpensive aerial photographic coverage of terrestrial habitat. Given the extensive coastline of California and the fact that it is often impossible to conduct conventional boat-based acoustic surveys in the 0-10m depth range due to geohazards, new more efficient mapping technologies need to be developed. Emerging laser and digital video mapping techniques such as LIDAR, Laser linescan and CASI, may enable aircraft to routinely sample the bathymetry and substrate in intertidal and shallow subtidal habitats that are inaccessible or too costly for conventional acoustic survey methods.

Regardless of which type of high resolution, broad coverage seafloor mapping techniques are selected, the cost of the equipment and expertise required to effectively operate and maintain it will generally be outside the budget of most resource management agencies. As a result, most agencies will find it cost effective to contract out for the actual acquisition of seafloor survey data, while developing the more generically useful GIS capabilities in-house that are required for the synthesis, analysis, display and application of these data.

1.6. RECOMMENDATIONS

Based on these findings we make the following recommendations to the Department regarding the development of habitat maps for the California nearshore environment.

1. Identify, collect, evaluate and convert all existing seafloor substrate and bathymetry data to digital GIS format for habitat classification. Special emphasis should be given to the 1986 Geology Maps of the California Continental Margin compiled by the USGS and California Department of Conservation Mines and Geology.
2. Convene a strategic planning workshop involving all parties having a vested interest in mapping California continental shelf habitats to:
 - Identify opportunities for leveraging resources, combining missions and sharing data
 - Define and adopt a universally applicable habitat classification scheme
 - Develop criteria and standards for prioritizing sites to be mapped
 - Develop criteria and standards for selecting mapping methods, scale and resolution
 - Develop a prioritized list of sites to be mapped
 - Draft a mission statement and strategic plan for funding
3. Create an initial set of “baseline” habitat maps for the continental shelf by applying the adopted classification scheme to existing seafloor habitat data in GIS format. The 1986 Geology Maps of the California Margin offer an ideal starting point.

4. Ground truth these baseline maps for accuracy and value.
5. Pursue in-house and multi-agency funding and support to carry out a strategic plan for mapping the habitats of the California continental shelf over the next decade
6. Develop partnerships with universities and other resource agencies as cost effective means for acquiring new data and developing new methods for data analysis and display.
7. Evaluate new technologies for more efficient and higher resolution habitat mapping in shallow nearshore environments. Testing these new techniques at sites where conventionally acquired data is already available or acquired simultaneously would be a logical first step in the assessment process.
8. Build up expertise and infrastructure for GIS analysis within the DFG marine group to make use of newly acquired and reprocessed geospatial habitat data.
9. Use GIS to combine geophysical habitat data (depth, slope, aspect & substrate) with new and existing species distribution and fishery data to test and refine the habitat classification scheme.
10. Explore links with NOAA and the military to reprocess existing data as well as collect new habitat data needed to complete the strategic plan.

2. CONSIDERATIONS FOR EFFECTIVE HABITAT MAPPING

2.1. RATIONALE FOR HABITAT MAPPING

A habitat is the place where a particular species lives or biotic community is normally found, and is often characterized by the dominant life form (e.g. kelp forest habitat) or physical characteristics (e.g. rocky subtidal habitat). Because habitats are repetitive physical or biophysical units found within ecosystems the same habitat may be found within different biogeographical provinces. Habitat mapping is typically undertaken by resource agencies to serve a variety of purposes including:

- ◆ Assessment of habitat change due to natural or human impacts (e.g. climate change, oil spills, trawl disturbance)
- ◆ Monitoring and protecting important habitats (e.g. marine reserves, spawning areas, harvest closure areas)
- ◆ Design and location of marine reserves or aquaculture projects
- ◆ Species distributions and stock assessment

While most subtidal species and resources can only be sampled directly using observational or other large scale (>1:10,000) survey techniques, it is often unreasonable to apply this level of effort to the entire coast of California. A major goal of habitat mapping, therefore, is to develop the ability to predict the distribution and abundance of species and resources from those physical and biotic parameters that define where species live and which can be remotely sampled.

The geographic limits to the distribution of many marine species result from barriers to migration, reproduction or survival. These biogeographic barriers result in ranges within which a species or community assemblage are likely to occur within the same habitat types. The habitat types can be defined in terms of those variables that control where a species lives within its range. Habitat parameters important to the distribution and abundance of benthic and nearshore species include:

- | | |
|-------------------------------|----------------------|
| ◆ Water depth | ◆ Exposure |
| ◆ Substrate type | ◆ Vegetation |
| ◆ Rugosity | ◆ Water Chemistry |
| ◆ Slope/Aspect | ◆ Water Temperature |
| ◆ Void Abundance, Type & Size | ◆ Biotic Interaction |
| ◆ Sediment Type & Depth | |

Because the response of different species often varies with the spatial extent of these parameters, habitat scale is another factor important in defining where different species and biotic communities are likely to be found. For this reason, a benthic habitat classification system useful for defining species/habitat associations based on the parameters listed above, must also

be hierarchically organized according to relevant spatial scales (see Habitat Classification Systems below).

Given these considerations, a successful, regional habitat mapping program needs to include the following elements:

- ◆ Clear statement of purpose for the mapping project (e.g. well defined goals and objectives).
- ◆ Selections of scales for map extents and data resolution appropriate to the stated purpose.
- ◆ A universally accepted and broadly applicable hierarchical habitat classification system based on spatially nested physical and biophysical characteristics that control where species live.
- ◆ A means for acquiring data at appropriate resolutions and spatial scales for each of the relevant habitat characteristics.
- ◆ A means for combining, analyzing and displaying these various geospatial data sets collected in diverse formats, and at different scales and resolutions such that the habitat classification system may be applied.

Each of these elements is discussed in the following sections. In Section 2.2 we give a brief overview of the purposes for and general approach to benthic habitat mapping. We then cover some of the issues pertaining to scale and georeferencing habitat data in Section 2.3. Requirements and recommendations for a suitable benthic habitat classification system are discussed in Section 3. We then review and provide examples from a wide range of habitat data acquisition methods in Section 4, covering the advantages and limitations of standard methods as well as those of emerging new technologies. Information on specifications, manufacturers, and service providers using these data acquisition tools have been compiled into an extensive database, and summarized in tables presented in Section 5.

In our discussion of the types of final product options available for habitat mapping projects in Section 6, we give only a brief overview of the various approaches available for data fusion, analysis and display of habitat data. Recent advances in Geographic Information Systems (GIS) have now brought spatial data analysis and display capabilities to virtually every desk top computer. While we use GIS extensively in our own habitat mapping work, and will make use of several of our GIS products as examples in this report, we will leave the review and assessment of GIS systems and applications to other authors. This decision is consistent with DFG's request that we focus our efforts on reviewing the specific technologies for the acquisition and classification of seafloor substrate and depth data.

2.2. GENERAL APPROACH TO HABITAT MAPPING

In recent years, many marine benthic habitats have been described using biological and geophysical data. Consequently, remote sensing and large-scale mapping of the seafloor are gaining popularity for assessing habitats as well as potential impact of human disturbances (such as bottom trawling) on benthic organisms. Because many benthic habitats are defined by their

geology (along with depth, chemistry, associated biotic communities and other attributes), geophysical techniques are critical in determining habitat type. However, with the increased use of multidisciplinary techniques (i.e., *in situ* observations as well as geophysical sensors) and nomenclature (geological, geophysical and biological) to define benthic habitats, a standard habitat characterization scheme is needed to more accurately and efficiently interpret and compare habitats and associated assemblages across biogeographic regions and among scientific disciplines (Greene et al. *in press*).

Geophysical techniques that help identify and define large-scale marine benthic features are valuable in appraising essential habitats of marine benthic fish assemblages. Interpretations and verification of sidescan sonar, swath bathymetry, backscatter imagery, and seismic reflection profiles with direct observation and sampling of rock and biogenic fauna are critical in characterizing these habitats. As a result, the adopted classification scheme must be compatible with data collected with all types of sensor systems used to characterize habitats (e.g. acoustic, Electro-optical, optical and direct sampling).

Modern marine geophysical techniques are now being used to investigate and characterize benthic habitats (Able et al., 1987, 1995; Auster et al., 1995; Greene et al., 1993, 1994, 1995; O'Connell and Wakefield, 1995; O'Connell et al., 1997; Twichell and Able, 1993; Yoklavich, 1997; Yoklavich et al., 1992, 1995, 1997; Wakefield et al., 1996; Valentine and Lough, 1991; Valentine and Schmuck, 1995). The most commonly applied remote sensing methods for benthic habitats involve acoustical techniques that use sound sources of different frequencies to produce images of surface and subsurface features of the seafloor. Reflected sound waves are recorded as seafloor images in plane, aerial and cross-section views. Additionally, increased availability and use of underwater video systems on remotely operated vehicles (ROVs), submersibles, and camera sleds have made fine-grained remote sensing surveys of habitats and associated biological assemblages more commonplace, thereby expanding our understanding of the processes that help define these communities and the spatial scale at which these processes operate (Greene et al. *in press*). Once perfected, emerging new technologies such as LIDAR, CASI and Laser Line Scanners may greatly increase the speed and efficiency of collecting high-resolution habitat data (see Chapter 4 below).

Although habitat characterization pertaining to fish and fisheries is in its infancy, several pioneering studies have been done along the continental margin of North America. Fisheries habitat has been studied in the Gulf of Maine, over the Georges and Stellwagen Banks (Lough et al., 1989, 1992, 1993; Valentine and Lough, 1991; Valentine and Schmuck, 1995), middle Atlantic Bight (Auster et al., 1991), and other areas along the east coast of the US (Able et al., 1987, 1995; Twichell and Able, 1993). Along the west coast of North America recent investigations of benthic habitats of rockfishes have been reported of central California (Greene et al., 1994, 1995; Yoklavich et al., 1992, 1995, 1997), British Columbia (Matthew and Richards, 1991) and in southeast Alaska (O'Connell and Carlile, 1993; O'Connell et al. 1997).

2.3. DISPLAYING & GEOREFERENCING HABITAT DATA

There are four key considerations related to the display and georeferencing of habitat data:

- ◆ The scales at which the data are to be displayed and applied
- ◆ The selection of base maps to which the data are to be georeferenced
- ◆ The methods and objects used to depict the data (raster imagery, points, lines and areas).
- ◆ The coordinate system, datum and projection the data are to be used or displayed in.

Map scales and data resolution

With the advent of geographic information systems (GIS) it is now possible to merge, layer and display virtually all geocoded habitat data at any desired scale. Unfortunately, data collected at one scale may lose its meaning when displayed at a scale that is inappropriate for either the resolution (spatial density) or extent of the data set. Thus, while data collected at a particular resolution within a given area may be adequate for one purpose, it may not be suitable for other habitat mapping needs. For example, polygon features representing habitat classes measuring $< 100 \text{ m}^2$ within a small coastal marine reserve can be accurately displayed at large map scales ($>1:10,000$). These same features will shrink to lines, points or disappear entirely on smaller scale maps ($< 1:50,000$) such as those used for displaying the regional distribution of fisheries or habitats (Table 2.1). Although GIS can circumvent this issue of display scale to some extent by providing the user with the ability to zoom in and out, the utility of hardcopy products are severely effected by the scale of display.

Table 2.1 Standard mapping scales and resulting display resolutions (adapted from Booth et al. 1996 and Greene et al. in press).

Scale	1 mm = (m)	1 mm ² = (ha or m ²)	Planning Class	Features that can be displayed at this map scale
1:10 ⁶	1,000	100 ha	Hemisphere	Megahabitats, Biogeographic regions, species & fisheries range boundaries
1:500,000	500	25 ha	Regional	Megahabitats, Biogeographic zones, gross shoreline features, resource management jurisdictions
1:250,000	250	6.25 ha	Sub-regional	Megahabitats, Geologic mapping, river mouths, bays, estuaries, habitat features, fishing grounds
1:50,000 to 100,000	50-100	0.25 to 1.00 ha	Local	Mesohabitats, Marine reserve boundaries, small islands and inlets, habitat classes
1:24,000	24	576 m ²	Local, site	Mesohabitats, Fine grain habitat mapping, off-shore rocks, kelp beds, substrate type
1:10,000	10	100 m ²	Site	Mesohabitats, High resolution habitat mapping, seabed texture

1:1,000 to 5,000	1 - 5	1 - 25 m ²	Site	Macro- and Microhabitats, Biotic community and site level mapping
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There is also the relationship between map scale and data resolution. While it is possible to collect high-resolution data over vast areas, the cost of doing so, and the size of the resulting data sets may be impractical if the primary purpose is to provide a regional overview of gross habitat types. Consequently, the selection of map scale depends on two factors: 1) the scale of the base map to be used (see below) and 2) the purpose of the study.

Table 2.2 General categories of methods for sampling coastal subtidal habitats and the scales at which they can be used (after Robinson et al. 1996).

Sampling scale	Method	Examples
1:30,000	Satellite sensors	SPOT, Landsat, AVHRR
1:5,000 to 1:20,000	Airborne sensors	Aerial Video Imagery (AVI) and Aerial Photography (AP)
		Larsen Airborne Laser Bathymetry (LIDAR) which uses infrared and blue/green laser pulses to measure seafloor depth; possibly other information contained in backscatter characteristics such as fish schools and bottom type
		Compact Airborne Spectral Imager (CASI): a multispectral sensor that digitally records data along the flight path.
1:10 to 1:10,000	Laser line scanner	Towed or airborne sensor capable of near video quality swath imaging of seafloor
1:1000 to 1:10,000	Hydroacoustic sensors and post-processors	Low frequency echosounders for water depth and with post-processing of return backscatter for substrate characteristics.
		Sidescan sonar can visualize seafloor morphology and seabed texture
1:10 to 1:1000	In situ visual or camera sampling	Free swimming or towed SCUBA Remotely Operated Vehicles (ROV) Drop or towed cameras
1:10 to 1:100	Removal sampling methods	In situ sampling by divers or ROV's Remote stationary sampling methods: grab or core samples

Sampling scales

The highest level of a hierarchical classification system that can be applied to an ecosystem will depend on those variables that can be sampled at the smallest scale. This consideration is especially relevant to the California shallow nearshore coastal zone, which is long but very narrow. The high length to width aspect ratio of this zone requires larger sampling scales to provide adequate habitat resolution than is customary in offshore or terrestrial habitat mapping. Otherwise, along shore habitat features will be reduced to lines rather than areas. Booth et al. (1996) point out, however, that there are several large scale variables (e.g. wave height, current velocity, exposure, coastal morphology) that can be derived from smaller scale features such as coastlines on maps drawn at the 1:40,000 to 1:200,000 scale.

Because the way in which a variable is sampled will affect the scale at which it can be meaningfully displayed or classified, it is important to match how habitats are sampled with the overall scale of the project. Robinson et al. (1996) reviewed the sampling methodology presently available for sampling subtidal environments (Table 2.2).

Map scale and extent

California coastal habitats within the 0 - 30 m depth range exist within a narrow zone often extending no more than a kilometer from shore. As a result, many of the coastal features such as reefs and islands are lost at smaller mapping scales (<1:100,000) and must be mapped and displayed at larger scale.

MEGA-HABITAT MAPPING SCALES (< 1:100,000)

The published California Continental Margin maps (Greene and Kennedy 1986) drawn at the 1:250,000 scale, show the major geophysical seafloor features for the California continental shelf. While the sediments and substrate types depicted on these maps are relevant to the classification of marine habitats, the scale at which they are depicted limits their utility within the shallow subtidal. At this scale, habitat elements within the 0-30 m depth range are reduced to line features at best. These maps are nevertheless an excellent reference data set for megahabitat or regional scale habitat mapping, and correspond to the 1:250,000 mapping scale recommended as a standard for mapping coastal resources at the "Provincial" (regional) scale in Booth et al.'s 1996 technical report to Fisheries and Oceans Canada. Larger map scales (>1:50,000), however, are required for mapping and displaying most of the habitat features within the 0-30m depth zone.

MESO-HABITAT MAPPING SCALES (1:100,000 TO 10,000)

Even at the larger mapping scale of 1:50,000, important coastal habitat features such as kelp forests, offshore rocks and reefs become reduced to one dimensional line features rather than polygons. More appropriate for nearshore habitat mapping of coastal features is the 1:24,000 scale common to the USGS topographic 7.5 minute quadrangle maps. This scale and set of map boundaries have already been used to provide the base maps for:

- ◆ U.S. Fish and Wildlife National Wetlands Inventory

- ◆ USGS digital ortho quads (DOQ)
- ◆ California coastline maps used by DFG, the California State Lands Commission, the TEALE data center, and the California Coastal Commission

At this scale, features down to 24 m in linear dimension can be easily depicted. Given the wide application of the 7.5 minute quad scale and footprint, we recommend its extension to nearshore coastal habitat mapping at the local scale.

MACRO- AND MICRO- HABITAT MAPPING SCALES

Much of the physical detail important to many species occurs at the meter and sub-meter scale (e.g. substrate texture, grain size, void spacing and size). As a result, data collection and mapping capable of depicting this detail is critical to habitat classification at the Macro- and Micro-habitat scales (Figs. 2.1 and 2.2).



Figure 2.1. Biological microhabitats of hydrocorals and sea anemones with lingcod (*Ophiodon elongatus*) and young of the year rockfish (*Sebastodes* spp.) on top of rock pinnacle mesohabitat (photo courtesy of Greene et al. in press).

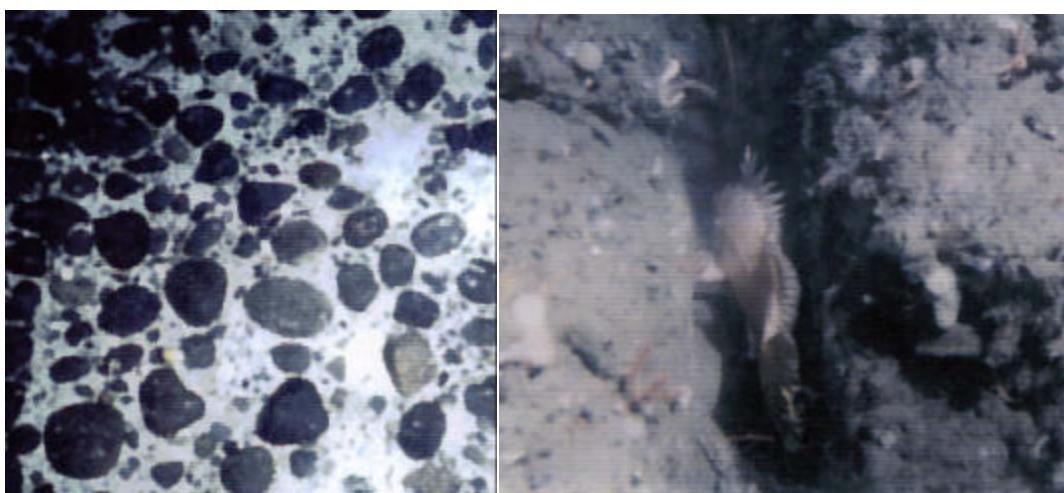


Figure 2.2. Examples of Micro- and Macro-habitats. (Left) Pebble microhabitat in offshore Edgecumbe lava field, southeast Alaska (Greene et al. in press). (Right) Crevice in the Pliocene Purisima Formation that has been differentially eroded along the walls of Soquel Canyon, Monterey Bay, California (photos courtesy of Greene et al. in press).

Coordinate systems, datums and projections

As with scale, GIS can be used to display and merge virtually any geocoded habitat data regardless of the geodetic parameters under which they are collected or archived. For example, vector data collected in latitude and longitude NAD83 can be easily combined with raster imagery registered as UTM WGS 1984 data. However, the importance of selecting and knowing the geodetic parameters of the data sets cannot be over emphasized. First, while most true GIS systems (e.g. ArcInfo, TNT mips) are able to process and merge data having different geodetic parameters, this data fusion is only successful when these parameters are correctly defined for the program. If, for example, lat long data collected in California using the North American Datum 1927 (NAD27) is merged with lat long North American Datum 1983 (NAD83) data without specifying the correct datum for each data set, the registration of the two data sets will be off by nearly 100 m in the east/west direction.

Secondly, not all “GIS” type programs are capable of accurately merging data having different geodetic parameters. ArcView, the most popular GIS viewer program, cannot be used to reproject geospatial data. Once an ArcView project file has been created for a specific set of geodetic parameters, only those data sets stored in the same coordinate system, datum and projection as the project file can be accurately added as a theme. Here again, while it may be possible to import data sets having different geodetic parameters into ArcView as themes, they will not be correctly georegistered. ArcView, however, is a rapidly evolving program, and may eventually have the ability to reproject and co-register data from different projections, datums and coordinate systems. Until this capability is added, data will have to be initially collected or reprocessed using a true GIS program to be compatible with existing ArcView data sets. This consideration is especially important when sharing data between organizations using different geodetic parameters for their geospatial products and data.

3. HABITAT CLASSIFICATION SYSTEMS

Habitat mapping is being increasingly relied upon by resource management agencies as a tool for predicting the real or potential distribution of species or communities that are difficult to survey directly. To facilitate effective data sharing between organizations seeking to leverage their resources, a single, universal benthic habitat classification system is needed to insure that results from different studies can be efficiently and effectively combined.

While a variety of habitat classification systems have been proposed and applied to the benthos, most have been derived from intertidal or terrestrial classification models (e.g. Dethier 1992), and their use has generally been restricted to the intertidal or very shallow subtidal (Booth et al. 1996). As importantly, most other systems have not been explicitly tailored to make use of the types of data available from modern geophysical remote sensing techniques used to map

subtidal features.

Booth et al. (1996) have identified the following principles that should be included in a subtidal habitat classification system:

- ◆ Subtidal habitats must be identifiable, repeatable environmental units, divided into types or classes.
- ◆ Classes must represent the full range of subtidal habitats located within the region to be mapped.
- ◆ The classification system must be of use to resource managers. Classes must have biological meaning so factors that determine the biotic community structure (or those that control suitability of the habitat for a particular biotic resource) should be incorporated into the classification scheme, preferably at as high a level as possible.
- ◆ The classification system must be hierarchical with application at various scales depending on the intended use and data sources. The top levels must be based on characteristics that can be mapped at a small scale using remote sensing methods and will define the boundaries within which other levels are subdivisions.
- ◆ All types of sampling techniques should result in the same habitat classes or community definitions. The level to which a habitat can be classified will, however, be determined by the resolution of the sampling technique.
- ◆ The classification system should recognize time scales over which variables change. Habitat variables that change over shorter time scales should be incorporated at a lower level than variables that vary over longer time scales. For example, rock substrate changes over a longer time frame than sediment type, which changes less rapidly than kelp canopies or eel grass beds.
- ◆ The system must attempt to incorporate established classifications wherever possible to aid in the incorporation of existing data sets and compatibility with other studies.
- ◆ The system must be able to respond to foreseeable changes in information requirements and advances in processing and presentation technology.
- ◆ The system must be sensitive to existing sampling programs and be able to respond to foreseeable advances in data collection methods.

Here we present two example classification schemes developed for the subtidal environment. The system proposed by Booth et al. (1996) for the shallow subtidal habitats of British Columbia, Canada incorporates those classes found to be in current usage (Table 3.1). The more broadly applicable and detailed subtidal habitat classification system being developed and applied by Greene et al. (in press) also satisfies virtually all of principles listed by Booth et al. (1996). We present this latter scheme here as an example and possible starting point for the development of a universal benthic habitat classification protocol, and one ideally suited for nearshore marine habitat classification in California.

Table 3.1. Proposed physical habitat variables with examples of habitat classes for creating a coastal subtidal benthic habitat classification system (Booth et al. 1996).

Variable	Examples of habitat classes currently in use
Geographic location	Ecozone, Ecoprovince, Ecoregion and Ecodistrict
Depth	0-2m, 2-5 m, 5-10 m, 10-20 m
Wave exposure	Very exposed, exposed, semi-exposed, semi-protected, protected
Tidal currents	High (>100 cm/s), medium (50-100 cm/s), low (<50 cm/s)
Substrate	Rock, rock+sediment, sediment, anthropogenic
Sediment	Gravel, sand, mud
Minimum salinity	Marine (>30 ‰), estuarine (15-30 ‰), dilute (<15 ‰)
Maximum temperature	High (> 15° C), medium (9-15° C), low (<9°C)
Suspended sediment	High, low, none
Bottom slope	Cliff (>20°), ramp (5-20°), platform (<5°)
Bottom complexity	Present, absent
Estuary	Size: major, minor Circulation: well mixed, partially mixed, salt wedge Type: inlet, bay, sound, arm
Vegetation	Kelp canopy, eelgrass, other macrophyte coverage, non-vegetated

3.1. HABITAT CLASSIFICATION SYSTEM PROPOSED BY GREENE ET AL.

Based on the results from previous studies and using geology, geophysics, and biological observations, Greene et al. (in press) have developed a classification scheme now being applied primarily to benthic habitats of rockfish assemblages along the West Coast of North America. This scheme has been modified after Cowardin et al. (1979) and Dethier (1992), and is now being proposed for further development as a model for characterizing benthic habitats elsewhere. The system is specifically designed to make use of data acquired with modern geophysical remote sensing technology. The authors emphasize, however, that the interpretation and classification of any remotely acquired geophysical and geological data needs to be groundtruthed using *in situ* seafloor observations.

Classification of Habitat Scales

Megahabitats refer to large physiographic features, having sizes from kilometers to tens of kilometers, and larger. *Megahabitats* lie within major physiographic provinces, e.g., continental shelf, slope, and abyssal plane (Shepard, 1973). A given physiographic province itself can be a *megahabitat*; however, more often these provinces are comprised of more than one *megahabitat*. Other examples of *megahabitats* include submarine canyons, seamounts, lava fields, plateaus, and large banks, reefs, terraces, and expanses of sediment-covered seafloor.

Mesohabitats are those features having a size from tens of meters to a kilometer, include small seamounts, canyons, banks, reefs, glacial moraines, lava fields, mass wasting (landslide) fields, gravel, pebble and cobble fields, caves, overhangs and bedrock outcrops. More than one *mesohabitat*, and similar *mesohabitats* (in terms of complexity, roughness, and relief), may occur within a *megahabitat*. Distribution,

abundance, and diversity of demersal fishes vary among *mesohabitats* (Able et al 1987; Stein et al. 1992; O'Connell and Carlile 1993; Yoklavich et al. unpublished manuscript). Similar *megahabitats* that include different *mesohabitats* likely will comprise different assemblages of fishes and, following from this, similar *mesohabitats* from different geographic regions likely comprise similar fish assemblages (Fig. 2.1).

Macrohabitats range in size from one to ten meters, and include seafloor materials and features such as boulders, blocks, reefs, carbonate buildups, sediment waves, bars crevices, cracks, caves, scarps, sink holes and bedrock outcrops (Auster et al 1995; O'Connell and Carlile 1993). *Mesohabitats* can comprise several *macrohabitats*. Biogenic structures such as kelp beds, corals (solitary and reef-building) or algal mats, also represent *macrohabitats* (Fig. 2.2).

Microhabitats include seafloor materials and features that are centimeters in size and smaller, such as sand, silt, gravel, pebbles, small cracks, crevices, and fractures (Auster et al 1991). *Macrohabitats* can be divided into microhabitats. Individual biogenic structures such as solitary gorgonian corals (e.g., *Primnoa*), sea anemones (e.g., *Metridium*), and basket sponges (e.g., genus or family) form *macro-* and *microhabitats* (Fig. 2.2).

CLASSIFICATION STRUCTURE AND TERMINOLOGY

System (based on salinity and proximity to bottom):

- e.g.,
 - Marine Benthic
 - Estuarine Benthic

Subsystem (mega-and mesohabitats based on physiography and depth):

- e.g.,
 - Continental Shelf
 - Intertidal (salt spray to extreme low water)
 - Shallow Subtidal (0-30 m)
 - Outer (30-200 m [location of shelf break])
 - Continental Slope
 - Upper (200 m [location of shelf break]- 500 m)
 - Intermediate (500-1,000 m)
 - Lower (1,000+ m)
 - Continental Rise
 - Abyssal Plains
 - Trenches
 - Submarine Canyons
 - Head (10 - 100 m)
 - Upper (100 - 300 m)
 - Middle (300 - 500 m)
 - Lower (500 - 1,000+ m)
 - Seamounts
 - Top

Flank

Base

Class (meso- or macrohabitats based on seafloor morphology):

e.g., -Bars

-Sediment waves

-Banks

-moraines

-Caves, crevices (ragged features)

-Sinks

-Debris field, slump, block glide, rockfalls

-Grooves, channels (smooth features)

-Ledges

-Vertical wall

-Pinnacles

-Mounds, buildups, crusts (>3 m in size)

-Slabs

-Reefs (carbonate features)

 biogenic

 nonbiogenic

-Scarps, scars

-Terraces

-Vents

-Artificial Structures (wrecks, breakwaters, piers)

-lava fields

 compression ridges

 lava tubes

 craters

 lava flows

SubClass (macro- or microhabitats based on substratum textures)

e.g., -Organic debris (coquina; shell hash; drift algae)

-Mud (clay to silt; <0.06 mm)

-Sand (0.06-2 mm)

-Gravel (2-4 mm)

-Pebble (2-64 mm)

-Cobble (64-256 mm)

-Boulder (0.25-3.0 m)

-Bedrock

 Igneous (granitic; volcanic)

 Metamorphic

 Sedimentary

Subclass (macro- and microhabitats based on slope)

- e.g., -Flat (0-5°)
 -Sloping (5-30°)
 -Steeply sloping (30-45°)
 -Vertical (45-90°)
 -Overhang (> 90°)

Modifiers**-for bottom morphology**

- regular (continuous homogeneous bottom with little relief)
- irregular (continuous non-uniform bottom with local relief 1-10 m)
- hummocky (uniform bottom w/ mounds/depressions 0-3 m)
- structure (fractured, faulted, folded)
- outcrop (amount of exposure)
 - bedding
 - massive
 - friable

-for bottom deposition

- consolidation (unconsolidated, semi-consolidated, well consolidated)
- erodability (uniform, differential)
- sediment cover
 - dusting (<1 cm)
 - thin (1-5 cm)
 - thick (>5 cm)

-for bottom texture

- voids (percentage volume occupied by clasts or rock)
- sorting (i.e., well sorted; poorly sorted)
- packing (i.e., well packed; poorly packed)
- density (particle concentration)
 - occasional (random occurrence of feature, e.g., boulder)
 - scattered (feature covers 10-50% of area)
 - contiguous (features are close to touching)
 - pavement (features are touching everywhere)

-lithification

- jointing
- clast (rock) roundness
- clast shape
 - blocky
 - lensoidal
 - boitroidal (e.g., pillow lava)
 - needle-like
 - angular

-for physical processes

-currents

- winnowing
- scouring or lag deposits
- sediment trail

-wave activity

- upwelling
- seismic (earthquakes, shaking and fault rupture)

-for chemical processes

- vent chemistry (sulfur, methane, freshwater, CO₂)
- cementation
- weathering or oxidation (fresh to highly weathered)

-for biological processes

- bioturbation (tracks, trails, burrows, excavation, mounds)

-cover of encrusting organisms

- continuous (>70%)
- patchy (20-70% cover)
- little to no cover (<20%)

-communities (examples of conspicuous species)

- sea anemones
- crinoids
- vase sponges
- coralline algae
- kelp understory
- sea grasses
- kelp forest

-for anthropogenic processes an open-ended list of human disturbances)

- artificial reefs
- dredge spoil piles
- trawl tracks
- dredge tracks

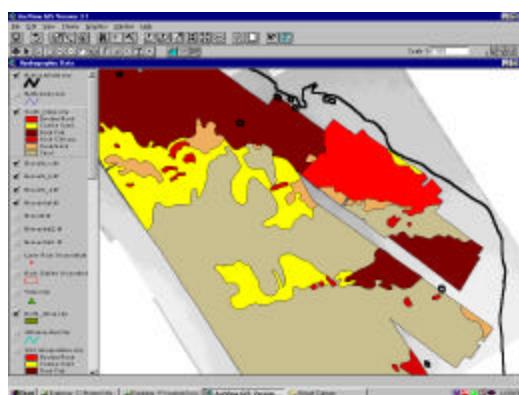
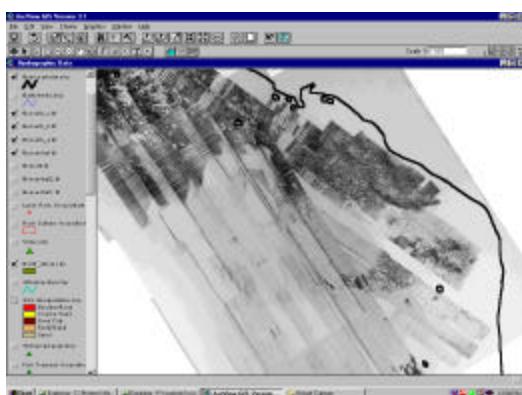


Figure 3.1. ArcView interface views of a sidescan sonar mosaic (left) and resulting interpretation (right) of a portion of the Big Creek Ecological Research Reserve. Interpretation of the sidescan data was based on the application of the Greene et al. system that characterizes this site as: a flat marine megahabitat on continental shelf in shallow water depths (0-30 m). Mesohabitats include sand waves, sand stringers and cobble patches interspersed with rock outcrops and reefs; isolated boulders and pinnacles are examples of macrohabitats.

4. DATA ACQUISITION METHODS

In Section 3, we described those physical and biophysical parameters important in determining the distribution and abundance of many benthic and nearshore species, and around which a habitat classification system must be organized. It follows therefore, that for a classification scheme to be applied, data from the region of interest must be acquired for these parameters at the appropriate scale and resolution. Here we present a review of the methods currently in use for acquiring habitat data as well as new technologies that hold great promise for increasing both survey coverage and data resolution in shallow marine environments. We focus primarily on methods appropriate for collecting data at various scales and resolutions on water depth, substrate type, rugosity, slope and aspect.

There are two main reasons for reviewing the capabilities, advantages, limitations and costs of these systems. First, although the most cost-effective means for obtaining habitat data is to make use of existing data sets, we have found that there is a great scarcity of suitable data available for the shallow nearshore marine environment along most of the California coast (Section 7). This situation will necessitate the acquisition of new data for most fine grain habitat mapping applications. Our hope is that this review will enable those responsible for planning, conducting or contracting for habitat mapping studies to make a more informed decision on the types of methods to be employed. The other reason for this review is to help those needing to evaluate the suitability of previously collected data for habitat mapping based on the performance characteristics of the acquisition methods used.

4.1. DEPTH AND SUBSTRATE DATA TYPES

Bathymetry data

As stated above, our primary focus here is to review the technologies available for mapping water depth and seafloor substrate. Depth or bathymetry data is usually recorded as x,y,z point data, and can be used to generate depth contours (line and area vector data) as well as digital elevation models (DEM) (Fig. 4.1).

Depending on the horizontal spacing of the depth data, DEM of sufficient resolution can be developed for determining the values for other parameters important in classifying habitat types such as exposure, rugosity, slope and aspect (Fig. 4.1). Bathymetry data can be collected using a wide variety of sensors including: lead lines, singlebeam and multibeam acoustic depth sounders, as well as airborne laser sensors (LIDAR). Each of these systems has its inherent advantages and limitations that will be discussed in the following sections. The range of sampling scales for these instruments is presented in Table 2.2.

The utility of bathymetric data depends on the resolution at which it is collected. Until recently most bathymetry data was collected as discrete point data along survey vessel track lines with singlebeam acoustic depth sounders.

The introduction of swathmapping and multibeam bathymetry systems has dramatically improved our ability to acquire continuous high-resolution depth data (See section 4.3 below). Bathymetric data with horizontal postings of less than 1m are now routinely collected over wide areas using multibeam techniques (Fig. 4.2). Comparable data resolutions are also now possible with some of the new LIDAR laser topographic mapping systems, although water clarity generally limits their application is to the very nearshore environment (< 20m) (see section 4.3 below).

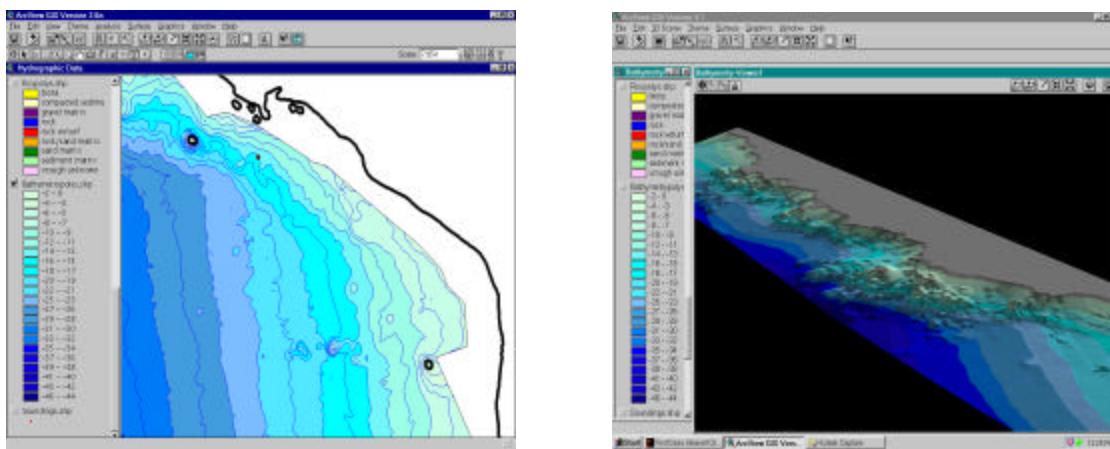


Figure 4.1 GIS products displayed in ArcView created for Big Creek Marine Ecological Reserve from x,y,z bathymetry data. Left) Two dimensional depth contour polygons can be used to stratify the site by water depth. Shoreline vectors (black lines) including offshore rocks can be used to define the “zero” depths when constructing the gridded bathymetry prior to contouring. Right) DEM of the same location shown in shaded relief and draped with depth polygons is used to illustrate slope, aspect, depth, and sea floor morphology simultaneously (Kvitek et al. unpublished data).

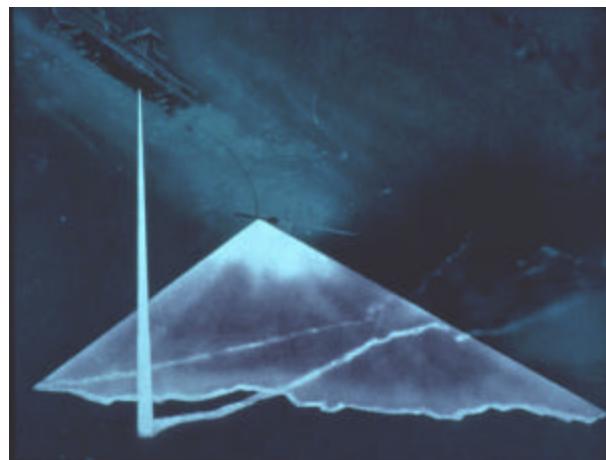
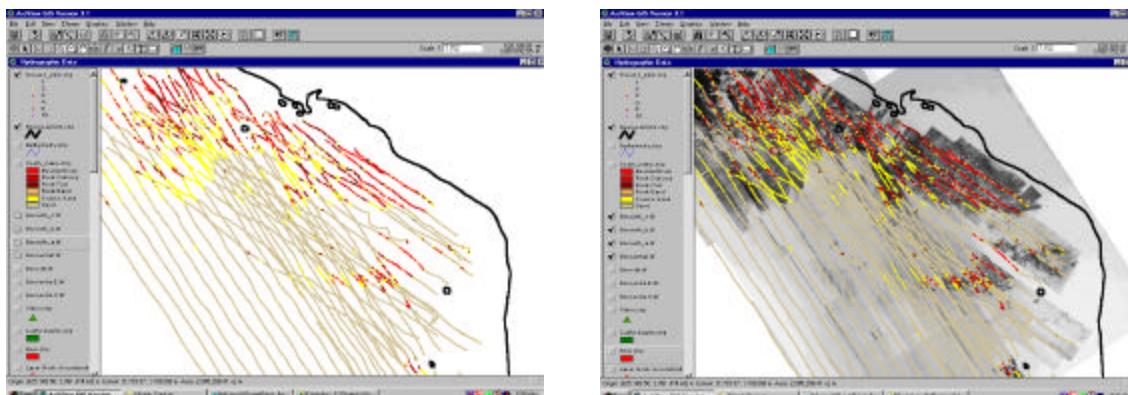


Figure 4.2. Illustration showing difference in coverage between singlebeam versus sidescan sonar and multibeam acoustic depth sounders (courtesy S. Blasco, Geologic Survey of Canada).

Seafloor substrate point data

Information on substrate type and texture can be collected as either point (x,y,z) data or as broad coverage raster imagery analogous to aerial photographs. Point data on substrate composition can come from georeferenced grab or core samples or even underwater photographs and video. Spatial resolution from this type of sampling, however, tends to be very limited due to the effort and cost required to increase data density while maintaining the spatial extents of the survey area. Point data on substrate type can also be acquired through co-processing or post-processing depth sounder data. For example, RoxAnn and Quester Tangent products make use of the multiple returns from echo sounders to classify seafloor substrates according to roughness and hardness parameters. This technology is similar to that applied in



acoustic fishfinders, making use of the character and intensity as well as the timing of the return signal. With these add-on devices, it is possible to acquire information on the character of the substrate at each bathymetric sounding position. Similar approaches are now being developed for application to multibeam data. However, rigorous groundtruthing to verify that the resulting classifications are accurate is essential, because the results from this “automated” approach to seafloor substrate classification can vary widely between sites and with environmental conditions.

Figure 4.3 Left) RoxAnn substrate classification data collected in conjunction with bathymetry data at the Big Creek Ecological Research. Red = rock, Yellow = cobble, Tan = sand. Right) Same RoxAnn classifications varified against sidescan sonar imagery. (Kvitek et al. unpublished data).

Seafloor substrate raster data – acoustical methods

Seafloor substrate information can also be collected as continuous coverage raster imagery from reflected acoustic or optical backscatter intensity values. Because reflected intensities vary with substrate hardness, texture, slope and aspect, sidescan sonar has been used widely for over 30 years to create detailed mosaic images of seafloor habitats at resolutions as fine as 20 cm (Fig.

4.3). In recent years, this same approach has been applied to the backscatter values of multibeam bathymetry data (Fig. 4.4).

While multibeam backscatter images generally lack the resolutions and detail found in conventional sidescan images, they can be corrected for distortion resulting from unintended sensor motion (e.g. roll, pitch, and heave due to waves). This type of correction has not yet been developed for sidescan sonar systems. As a result, shallow water sidescan sonar operations are generally restricted to days with relatively calm sea states, a rarity in many open coast areas. Multibeam systems equipped with motion sensors can be used under a much wider range of sea conditions. One other advantage multibeam systems have over sidescan sonar is continuous coverage directly below the sensor. Sidescan sonar systems have two side-facing transducers that do not ensonify the seafloor directly beneath the towfish.

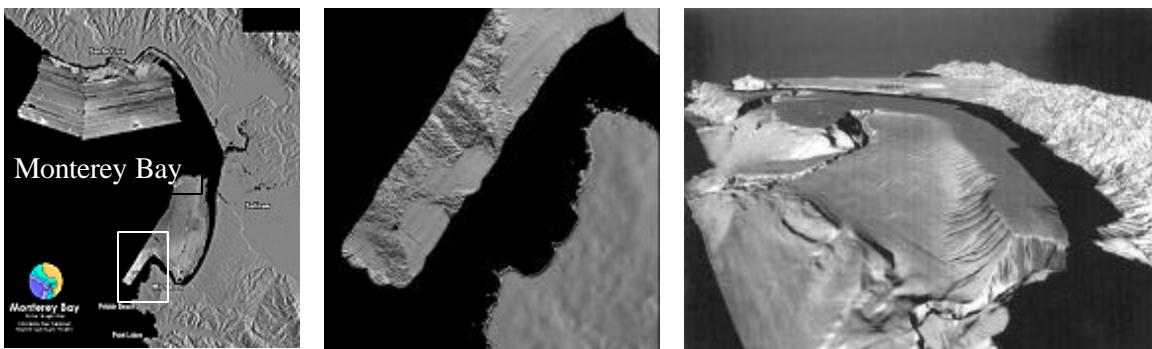


Figure 4.4 USGS high resolution bathymetry coverage in Monterey Bay, Ca. (a). Panel (b) shows multibeam bathymetry imagery from the inset. Panel (c) shows 3D digital terrain model fusion of offshore multibeam and terrestrial DEM data. Note the black “data gap” zone (0-100m water depth) between the terrestrial and USGS data coverage restricted to the offshore habitats.

Seafloor substrate raster data – electro-optical methods

Optical techniques are also being developed for seafloor substrate mapping, including laser linescanner and multispectral imaging. Few of these instruments are in service at this time, in part due to their high cost and the still experimental nature of the technology. For this reason there is a scarcity of examples for comparison in terms of cost, quality, resolution, scale, etc. Nevertheless, these instruments show great promise; laser linescanners for their potential to dramatically increase image resolution over broad survey areas; and airborne multispectral systems for their ability to rapidly map habitat and vegetation types at meter resolution over vast areas in depths too shallow for survey vessel operations. As with all optical sensors, however, both of these technologies are limited in their depth range by water clarity. Below, we discuss the performance characteristics and costs associated with each of these new optical methods in greater detail.

Limitations to acoustic substrate acquisition techniques

Despite the high-resolution seafloor imagery obtainable using acoustic backscatter systems, their application can be limited by several factors including resolution, survey speed, swath width, and water depth.

The relatively slow survey speeds (4-10 knots) required for acoustic surveys can make mapping large areas at high resolution a long and costly enterprise. This situation is especially true in shallow water habitats due to the limitations imposed on swath width by water depth. For sidescan and multibeam systems, the closer the sensor is to the seafloor, the narrow the swath coverage. For most sidescan systems, swath width is limited to no more than 80% of the transducer altitude above the seafloor. Although multibeam systems can have very wide beam angles, data from the outer beams are usually of questionable value, especially in high relief areas where much of the seafloor at the edges of the swath is block from “view” due to acoustic shadowing by the relief. Survey track line spacing for shallow water surveys must therefore be closer than for deeper water work, where wider swath ranges can be successfully used. Even where wider swaths can be used, however, there is a trade off with resolution, which is directly and inversely proportional to swath width. (A sidescan sonar resolution of 20 cm at the 50 m range, drops to 40 cm at the 100 m range.)

Data acquisition in the very nearshore (0-10 m)

Although acoustic methods are not theoretically limited to a given depth range, several practical considerations generally preclude survey boat operations in the very nearshore (0-10 m). Wave height, submerged rocks, kelp canopy and irregular coastlines all make boat based survey operations difficult to impossible within this depth zone along the open coast. While a new technique has been developed for conducting acoustic surveys in kelp forests (see below), the other factors still argue for more efficient, safe and reliable means of mapping California’s extensive intertidal to shallow subtidal habitat. Airborne techniques including lasers and multispectral sensors, while limited to shallow water applications by their optical nature, may be the ideal tools for rapidly collecting elevation, depth, substrate and time series data along this vast and essentially unmapped zone.

4.2. CONSIDERATIONS IN SELECTING DATA ACQUISITION METHODS

A variety of remote and direct methods are available for acquiring depth and substrate data including: acoustic, electro-optical, physical and observational. Selection of which methods to use will be based on geographic extent of the project (scale) and the resolution required (data density), which in turn, are based on the purpose and goals of the project. Identifying the correct scale and resolution for a project in advance is important for two reasons. First, survey costs scale directly with each of these parameters, and there is generally a direct trade-off between scale and resolution if cost is to be held constant. As the aerial extent of a survey increases, resolution must decrease or survey time and costs will increase proportionally. Identifying the scale and resolution required for a given project is also an important consideration for selecting appropriate survey methods. If, for example, the goal is to simply map the aerial extent and depth of sandy versus rocky areas at mega- or meso-scales (1-10km) in moderate water depths (20-80m), then relatively low cost, low resolution techniques such as widely spaced acoustic survey lines would be adequate. Much higher resolution techniques would

be required if the goal was to characterize the complexity of rocky reef habitats by quantifying the relative cover of specific substrate types (e.g. boulder fields, pinnacles, cobble beds, rocky outcrops, algal cover and sand channels), as well as sub-meter relief and the abundance of cracks and ledges because each of these meso- and macro-habitats supports a different species assemblage.

Once the scale, data resolution and budget for the project have been determined given the overall goal, it is then possible to move on to the selection of appropriate methods and tools.

In the following section we present a description of specific technologies commonly used or showing promise in the acquisition of depth and substrate data for nearshore benthic habitats. Wherever possible, we also present sample imagery and products as well as relationships between resolution, scale and cost.

4.3. ACOUSTICAL METHODS

Single-beam Bathymetry

The utility of bathymetric data is highly dependent on the resolution at which it is collected. Until recently most bathymetry data was collected as discrete point data along survey vessel track lines with singlebeam acoustic depth sounders. These sounders work on the principle that the distance between a vertically positioned transducer and the seabed can be calculated by halving the return time of an acoustic pulse emitted by the transducer. All that is required is an accurate value for the speed of sound through the intervening water column. The speed value can be back calculated by adjusting the sounder to display the correct depth while maintaining a known distance between the transducer and an acoustically reflective object (e.g. seafloor measured with a lead line, or calibration plate suspended at a known depth).

The horizontal resolution, or posting, of singlebeam acoustic data is defined by the sampling interval along the track lines and the spacing between track lines. Because it is generally impossible or too costly to space survey lines as close together as the interval between soundings along the track lines, most older bathymetry data sets tends to have much higher resolution along track than across track. This situation necessarily leads to considerable interpolation between track lines when constructing contours or gridded DEM. As a result, the DEM are generally either too coarse (postings at > 50m) or inaccurate for fine grain mapping at macro- or micro-habitat scales.

One advantage of single beam depth sounders however, is the ability to interface them with acoustic substrate classifiers. These co-processors correlate the intensity values from the single beam echo returns with seafloor substrate hardness and roughness.

Acoustic Substrate Classifiers

The most accurate method of bottom classification is that of *in situ* testing. Direct observations by SCUBA divers, drop or ROV video, or submersible provide substrate classifications with very high confidence levels, as do grab samples or cores; the latter two methods are especially useful for classifying sediments. However, application of these high-resolution, high-confidence methods of substrate classification in large area mapping projects can be quite costly in terms of

money and effort. While *class* resolution of core and grab samples can be extremely high, the samples must be very closely spaced in order to give appreciable *spatial* (x,y) resolution. Similar obstacles exist for application of direct visual observation or video imagery to large areas; because of the limitations imposed by visibility underwater, cameras and/or observers must be placed in close proximity to the seabed that is to be classified, and achieving good bottom coverage becomes logically difficult. In essence, drop camera samples are analogous to cores and grabs in that they are *point* samples, while ROV and submersible observations and video surveys may provide *swath* or *area* information within the visibility and physical range limits of their traveled course. Logistical constraints (in terms of cost, equipment required, support, etc.) can be quite high for ROV and especially submersible work. Towed camera systems may offer a considerably lower cost alternative to ROV or submersible observations while giving greater aerial coverage than drop cameras, but are also difficult to deploy in complex bathymetric settings, owing to the fact that they must be “flown” quite near the bottom due to visibility limitations. Over relatively flat bottom, or with very good visibility, however, these systems may be quite useful. All of these factors make direct observation of bottom type a much more appropriate tool for *groundtruthing* classifications derived from a remote sensing method with higher efficiency in covering large areas and lower cost per unit effort. Indeed, groundtruthing using the above methods is crucial when employing remote sensing techniques. In addition to providing greater coverage efficiency, bottom classifiers can help automate the classification process to some degree, especially relative to the human interpretation that must be applied to sidescan sonar or video imagery in order to map large areas. The primary means of remotely sensing and classifying substrate in the marine environment are acoustic methods.

The following text discussing acoustic substrate classifiers is drawn primarily from “Bottom Sediment Classification In Route Survey” (Mike Brissette, Ocean Mapping Group, Department of Geodesy and Geomatics Engineering, University of New Brunswick, http://www.omg.unb.ca/~mbriss/BSC_paper/BSC_paper.html#Bottom Sediment Classification). Additional text has been added, but the bulk of this section is quoted directly from that report.

This section will discuss two such sonars, namely Marine Micro System's 'RoxAnn', and Quester Tangent's 'QTC View'. Each discussion will look at the theory of operation behind each sonar as well as performance size requirements and costs.

RoxAnn

Theory of Operation

RoxAnn is manufactured by Marine Micro Systems of Aberdeen Scotland. RoxAnn uses the first and second echo returns in order to perform bottom sediment classification. The first echo is reflected directly from the sea bed and the second is reflected twice off of the seabed and once off of the sea surface (Fig. 4.4). This method was first used by experienced fishers using regular echo sounders [Chivers et al, 1990]. The fishers observed that the length of the first echo was a good measure of hardness in calm weather.

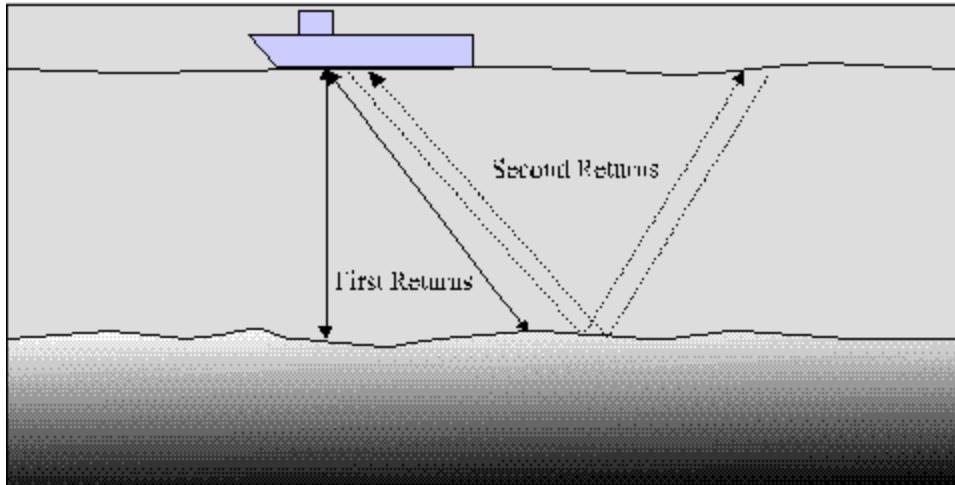


Figure 4.4. Diagrammatic representation of first and second returns (from Chivers et al, 1990).

The second echo, which mimicked the first echo, was much less affected by rough weather. RoxAnn uses two values, E1 and E2, in order to estimate two key parameters of the sea floor, namely roughness and hardness. The first echo contains contributions from both sub-bottom reverberation and oblique surface backscatter from the seabed. It has been shown that oblique backscattering strength is dependent on the angle of incidence for different seabed materials. At 30 degrees there is almost a 10 dB difference in scattering level between mud, sand, gravel and rock [Chivers et al, 1990]. The first part of the first echo contains ambiguous sub-bottom reverberations and is therefore removed (Fig. 4.5). Most or all of the remaining portion of the first echo is then integrated to provide E1, the measure of roughness. The exact parameters within which E1 is integrated are difficult to estimate and is therefore based on empirical observations in a number of different oceans [Chivers et al, 1990]. The entire second echo is integrated, which is the relative measure of hardness and is designated E2 [Schlagintweit, 1993]. A processor is used to interpret E1 and E2 such that bottom characteristics may be determined [Rougeau, 1989]. Looking at E1, on a perfectly flat sea floor, non incident rays would be expected to reflect away from the transducer. As the sea floor is not perfectly flat, the returning energy from non incident rays coincides and interferes with the incident rays and indicates the roughness of the sea floor [Chivers et al, 1993]. The specular reflection of the sea floor is a direct measurement of acoustic impedance relative to the sea water above it. Hardness can be estimated using E2 because the acoustic impedance is a product of the density and speed of longitudinal sound in the sea bed [Chivers et al, 1990].

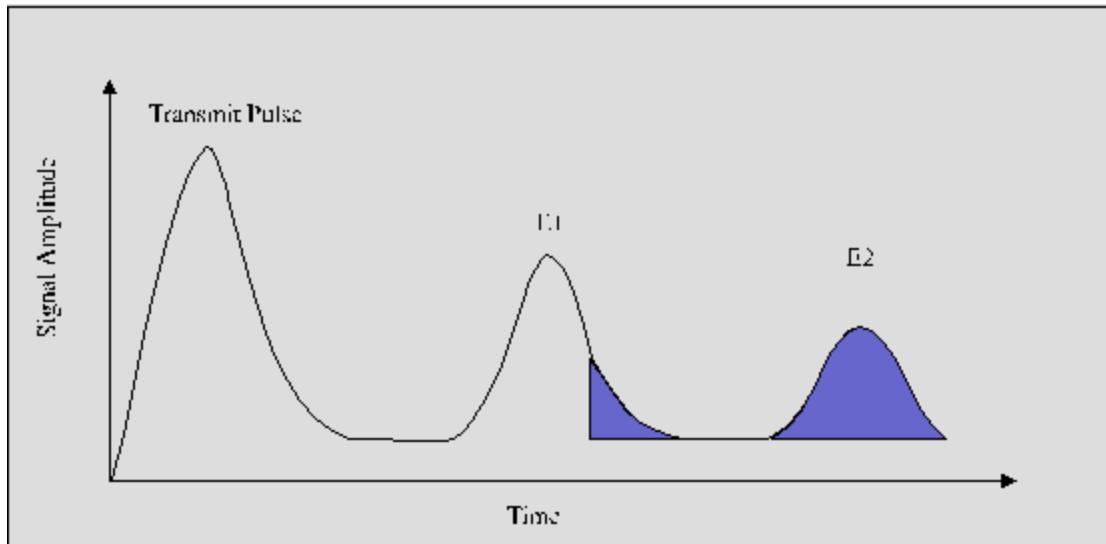


Figure 4.5. First and Second Return Waveforms (from Schlagintweit, 1993)

Test Results

Schlagintweit [1993] conducted a field evaluation of RoxAnn in Saanich Inlet off of Vancouver Island using two frequencies, 40 kHz and 208 kHz. RoxAnn was deployed over a ground-truthed area that had been previously inspected by divers. A supervised classification method was used and a "modest" correlation was found at both frequencies. Classification differences between the two frequencies were due to the different sea bed penetration depths of these frequencies on various sea floor types. That is, the frequency dependent penetration factor into the sea floor depended on the local sea floor itself. Schlagintweit felt that the frequency should be chosen according to the application. Schlagintweit believed that an unsupervised classification method would be the best alternative, i.e., let the system select the natural groupings and then look at ground truthing. Both the Chivers et al [1990] and Rougeau [1989] articles support this method of an initial calibration. In separate tests, Kvitek et al [in press] found quite good agreement between classes created from sidescan sonar interpretation and those created using unsupervised classification of RoxAnn E1 & E2 values at the Big Creek Ecological Reserve in Big Sur, CA (Fig. 4.3). Using sidescan imagery and video groundtruthing, Kvitek et al found that RoxAnn successfully classified sand, rock, and coarse sand/gravel between 6-30m depth in a 2-3 sq. km area in this study.

RoxAnn Equipment

The RoxAnn system is very compact. The entire unit consists of a head amplifier (not shown) which is connected across an existing echosounder transducer in parallel with the existing echo sounder transmitter, and tuned to the transmitter frequency. The parallel receiver accepts the echo train from the head amplifier [Schlagintweit, 1993]. The installation requires no extra hull fittings, simply room for the processing equipment. The required processing equipment includes an IBM compatible computer and an EGA monitor [Rougeau, 1989]. Software which is specifically written to handle RoxAnn data must then be installed on the computer for processing analysis. The RoxAnn Seabed Classification System retails for about \$15,000 US and the

additional RoxAnn software costs about \$10,000 US. Other programs such as Hypack, which retails for US\$ 11,000, are also compatible with the RoxAnn hardware [Clarke, 1997]. These prices do not include taxes, installation expenses or services of a technician for calibration and sea trials.

QTC VIEW

Theory of Operation

QTC View is manufactured and distributed by Quester Tangent Corporation of Sidney, BC [Quester Tangent Corporation, 1997]. Like RoxAnn, Quester Tangent's QTC View uses the existing echo sounder transducer; however, QTC View does not examine two different waveforms. Instead, analysis is performed on the first return only. Quester Tangent's other classification system ISAH-S (Integrated System for Automated Hydrography) is also available, and uses the same approach as QTC View in wave form analysis. However, ISAH-S offers multiple channels for multi-transducer platforms, integration with positioning and motion sensors, and helmsman displays. QTC View is more of a standalone system accepting GPS input for georeferencing of echo sounder data. QTC View operates in the following manner. First, both the transmitted echo sounder signal and return signals are captured and digitized by QTC View. Second, the sea bed echo is located (bottom pick), and an averaged echo from several consecutive returns is computed [Prager 1995]. Next, the effects of the water column and beam spreading are removed such that the remaining wave form represents the seabed and the immediate subsurface [Collins et al, 1996]. Quester Tangent's echo shape analysis works on the principle that different sea beds result in unique wave forms. Through principal component analysis, complex echo shapes are reduced into common characteristics. Each wave form is processed by a series of algorithms which subdivides it into 166 shape parameters [Collins et al, 1996]. A covariance matrix of dimension 166 x 166 is produced and the eigen vectors and eigen values are calculated. In general, three of the 166 eigenvectors account for more than 95 per cent of the covariance found in all the wave forms. The 166 (full-feature) elements of the original eigen vector are reduced to three elements ("Q values"). These reduced feature elements will cluster around locations in reduced feature space corresponding to a sea bed type [Prager, 1995]. Test Results QTC View was designed to operate in both the supervised and unsupervised classification modes. If no ground-truthing has taken place in an area of interest, QTC View will still cluster-like areas such that some type of calibration or ground truthing may be performed after the survey. In a test conducted by the Esquimalt Defense Research Detachment, QTC View was found to have produced very good results. QTC View was used over the same area where the RoxAnn tests were conducted off of Vancouver Island in the unsupervised classification mode. QTC View was able to discriminate between eight different seabed types. After a calibration, QTC view was found to agree with each ground truthed area and showed good transition from seabed type to seabed type [Prager, 1995].

QTC View Equipment

QTC View is comprised of a head amplifier and PC with a DX2/66 processor. The head amplifier is connected in parallel across the existing transducer and to the PC via a RS232 cable. The PC also accepts the GPS data in NMEA-0183 standard GGA or GGL format for

georeferencing of data [Collins et al, 1996]. The PC displays three windows: one for the reduced vector space, one for the track plot and classification and the third for seabed profile and classification. Figure 4.6 illustrates the QTC View screen output.

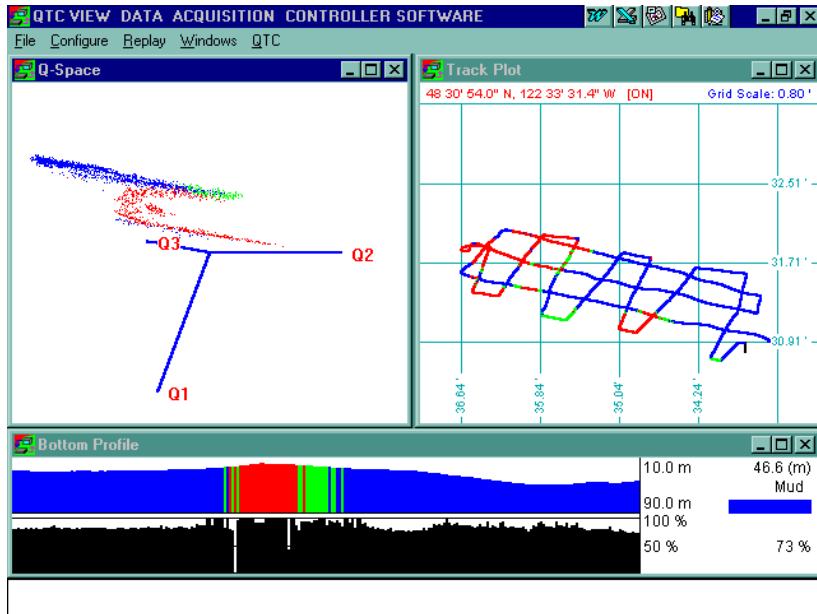


Figure 4.6. QTC View Screen Display (from Quester Tangent, 1997)

QTC is presently working with Reson, Inc. on adaptation of QTC View for use with multibeam depth sounders. This development will greatly increase survey efficiency by supplying substrate class data over most or all of the multibeam swath, but it is unknown when this product will be available. At present, however, QTC View will work with the Reson 8101 multibeam head, although it uses only the nadir beam data. QTC View retails for approximately US \$15,000 [pers com J. Tamplin] [Lacroix, 1997] whereas ISAH-S retails for approximately \$35,000 [Collins, 1997]. Unlike RoxAnn, the QTC View purchase price includes the software, and like RoxAnn the user must supply the computer. Hypack is not yet capable of acquiring raw QTC View data, but Coastal Oceanographics has provided support for recording the reduced dataset (3 "Q" values) processed in realtime by QTC view. The above prices do not include taxes or installation.

Summary

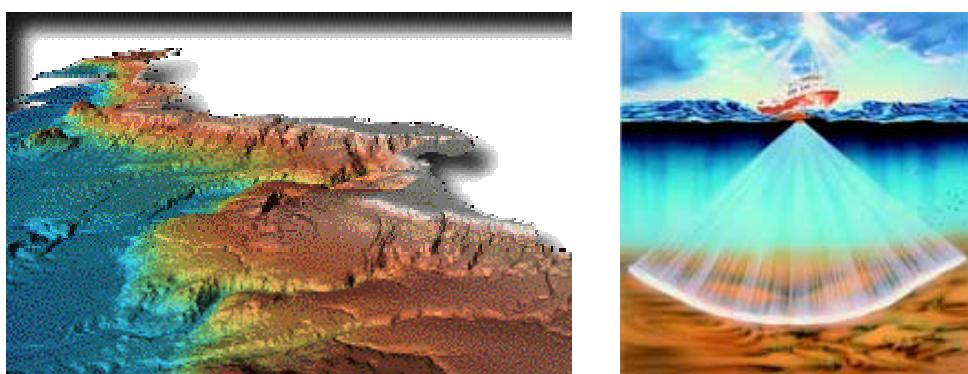
Both products discussed above have been shown to be useful tools for acoustic bottom substrate classification. The levels of success achieved in past studies using these tools is a function of the inherent qualities of the tools themselves, the operator and processor/analyzer expertise of those involved, the methods used, and the specific conditions of the areas studied. For this reason, true between-product comparisons are difficult. By far the most important fact to remember when using either of these tools (or any remote sensing method, for that matter) is that classifications created using these methods *must* be groundtruthed using one of the direct

observation methods discussed above. Only with independent verification can confidence be placed in remotely sensed data.

Multi-Beam Bathymetry

During the last 10-15 years, use of multibeam bathymetry in hydrographic mapping has become increasingly common and accepted. Initially fraught with considerable accuracy and precision issues, multibeam sonar technology has improved vastly and rigorous testing has established its reliability. The ability to acquire *denser* sounding data while surveying *fewer* tracklines (with greater spacing between lines), and simultaneously acquiring backscatter imagery using the same sensor, has made multibeam a popular tool. Using this technology, however, requires attention to a number of considerations that are less crucial when using single-beam technology.

Multibeam depth sounders, as their name implies, acquire bathymetric soundings across a swath of seabed using a collection of acoustic beams (Fig. 4.7 right), as opposed to a single beam, which ensonifies only the area directly below the transducer. The number of beams and arc



coverage of the transducer varies among makes and models, and determines the swath width across which a multibeam sounder acquires depth measurements in a given depth of water (Fig. 4.7 and 4.8). It is important to note that effective swath width is often somewhat less than potential swath width, as data from the outer most beams is often unusable due to large deviations induced by ship roll and interference from bottom features such as pinnacles. The potential swath width shown in Figure 4.8 may only be realized under calm conditions over a relatively flat bottom. Swath width is depth dependent, requiring closer line spacing in shallower water if full coverage is to be maintained. The mechanics and physics of how the beams are formed varies as well among makes and models, and may be a consideration of importance if extremely high resolution, precision, and accuracy are required.

Figure 4.7. (Left) Multibeam generated DEM of central California coast from shore to abyssal depths. Monterey Bay is at center right. (NOAA National Data Centers NDGC, <http://web.ngdc.noaa.gov/mgg/bathymetry/multibeam.html>). (Right) Conceptual drawing of multibeam ensonification of seafloor (Kongsberg Simrad AS, <http://www.kongsberg-simrad.com>)

In order for the multibeam system to calculate accurate x, y, and z positions for soundings from all off-nadir (non-vertical) beams (every beam other than the center beam), precise measurement of ship and transducer attitude is required. This includes measurement of pitch, roll, heading, and (preferably) vertical heave. Thus, a motion sensor must be interfaced to the

unit, so that its output may be used to adjust and correct the multibeam data in either real time or post-processing.

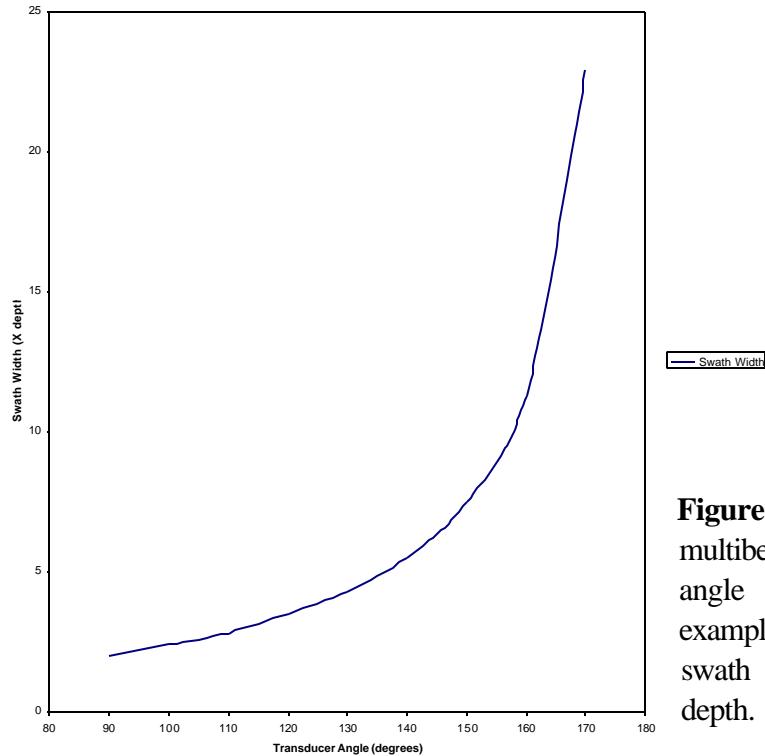


Figure 4.8. Relationship between multibeam bathymetry transducer beam angle and swath coverage. For example: with a 90 degree beam angle swath width will be twice the water depth.

In addition, because of longer travel times for off-nadir beams, variations in the speed of sound in water (SOS) can induce relatively large errors in these beams; especially if temperature stratification exists in the water column. For this reason, sound velocity profiling should be conducted on site during a survey, and the SOS data used to adjust depth soundings. Controlling for variations in SOS is of increasing importance as depth increases. Multibeam surveying also requires more rigorous system calibration to account for systemic variations in, and improve the accuracy of, heading, roll, and pitch sensor values, as well as any adjustment to navigation time tags that will reduce timing errors between navigation and sonar data. This calibration, known as a “Patch Test”, is typically conducted by running a series of survey lines over the same area with relative orientations that allow assessment of the variables listed above.

Multibeam bathymetric surveying generates orders of magnitude more data than single-beam surveying, resulting in greater storage requirements, longer processing times, and the need in some cases for greater processing power. Gigabytes of data may be generated daily, (as opposed to megabytes in single-beam surveys), especially if backscatter imagery is being recorded as well. The removal of bad sounding data during the editing process is, accordingly, a much larger task in multibeam than in single beam surveys, although some processing packages allow some degree of automation of this process.

The considerations and requirements listed above make multibeam surveying a much more complex and expensive undertaking relative to single beam, but the benefits in cost per unit

effort and resolution can well outweigh the hardships, especially if extensive surveying is planned. Survey speeds of up to 30 knots are now possible with some systems. Minimal costs for setting up a multibeam system range from \$75,000-\$150,000 US for equipment alone, not including vessel, installation, and maintenance costs. Higher precision equipment with greater capabilities and more features can cost substantially more.

Sidescan Sonar

Sidescan sonar is the only technology capable of producing continuous coverage imagery of the seafloor surface at all depths. (Blondel and Murton [1997] give an excellent and comprehensive review of sidescan sonar theory, technology, imagery and application in their recent book, *Handbook of Seafloor Sonar Imagery*.) These systems transmit two acoustic beams, one to each side of the survey track line. Most sidescan systems use transducers mounted on a towfish pulled behind the survey boat (Fig. 4.2 & 4.9), but some are hull mounted. Because towfish can be deployed well below the water's surface, they can be used in deeper habitats than hull mounted systems.

Sidescan sonar beams interact with the seafloor and most of their energy is reflected away from the transducer, but a small portion is scattered back to the sonar where it is amplified and recorded. The intensity of the backscatter signal is affected by the following factors in decreasing order of importance:

- Sonar frequency (higher frequencies give higher resolution but attenuate more quickly with range than lower frequencies)
- The geometric relationship between the transducer and the target object (substrate slope)
- Physical characteristics of the surface (micro-scale roughness)
- Nature of the surface (composition, density)

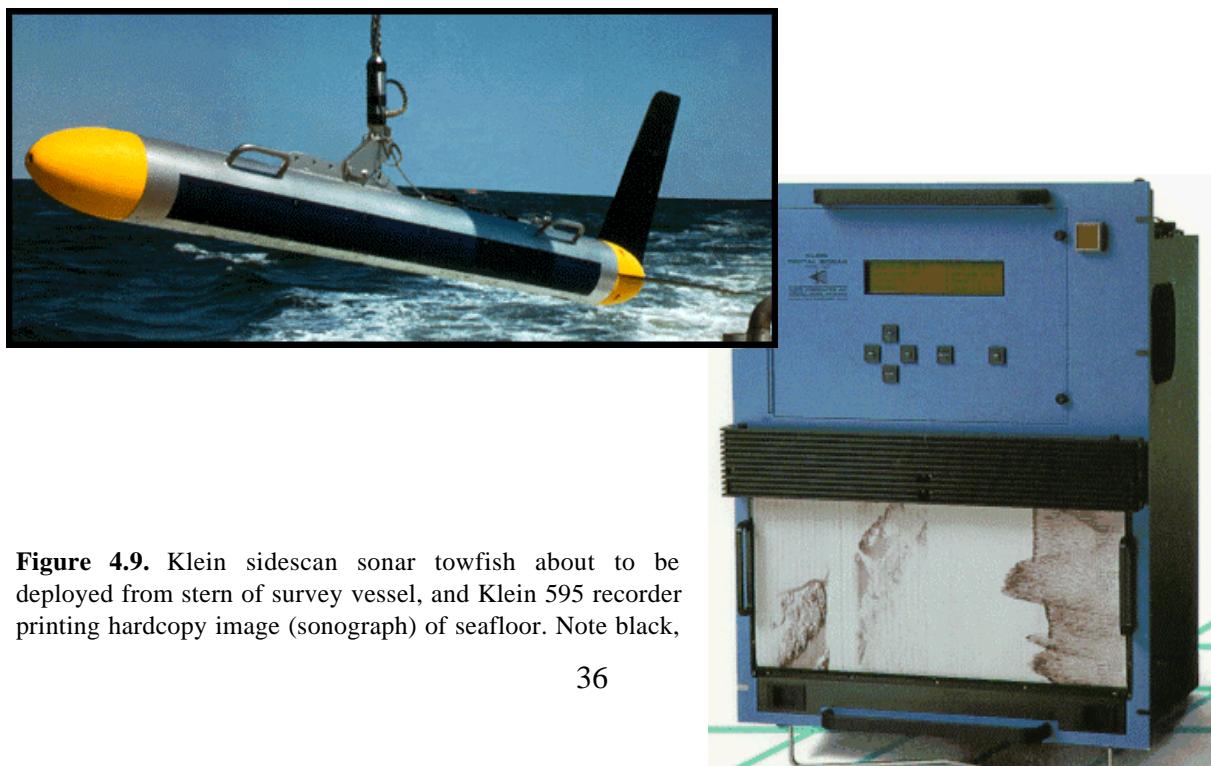


Figure 4.9. Klein sidescan sonar towfish about to be deployed from stern of survey vessel, and Klein 595 recorder printing hardcopy image (sonograph) of seafloor. Note black,

port transducer running down the left side of the towfish (Klein Associates).

For each sonar pulse or ping, the received signal is recorded over a relatively long-time window, such that the backscatter returned from a broad swath of seafloor is stored sequentially. This cross-track scanning is used to create individual profiles of backscatter intensity that can be plotted along track to create a continuous image of the seafloor along the swath (Fig. 4.9).

Swath width is selectable but maximum usable range varies with frequency. High frequencies such as 500kHz to 1MHz give excellent resolutions but the acoustic energy only travels a short distance (< 100 m). Lower frequencies such as 50kHz or 100kHz give lower resolution but the distance that the energy travels is greatly improved (>300 m). Typical systems used for nearshore mapping have frequency ranges from 100 to 500 kHz with resolution as fine as 20 cm. Resolution also varies with swath width. Thus, while a 500 kHz system set at range of 75m will cover a 150m swath at 20 cm resolution, a 100 kHz system set at a range of 250m will cover a 500m swath but at a resolution closer to 1m. There is also a direct relationship between maximum allowable survey vessel speed and range. The shorter the range, the slower the speed and the more survey lines required to cover a given area. (Typical sidescan sonar survey speeds are around 4-5 knots, but with newer systems have been increase to 10 knots.) Thus, the trade-offs between swathwidth, resolution, survey speed, and financial resources must be considered when planning a survey. The choices will depend on: 1) the size of the area to be surveyed, 2) what resolution of substrate definition is required, and 3) how much time and money is available for the survey. Interactive survey time estimate calculation tables such as the Hydrographic Survey Time Estimate Worksheet shown below can be easily constructed in a spreadsheet program such as Microsoft Excel. These tables can be used to construct what-if scenarios to explore the relative time requirements and costs for different survey parameters.

Another variable important to survey time is the amount of overlap desired between adjacent track lines. Most sidescan sonar systems cannot “see” the seafloor directly beneath the towfish. (Klein’s new multibeam sidescan system is an exception.) As a result, if complete coverage of the seafloor is required, it will be necessary to have up to 100% overlap of the sidescan swaths, such that the port side of swath along one track line is completely covered by the starboard side of the swath from the adjacent track line. In this manner, the outer range of one swath can be used to “fill-in” the missing inner-range of the adjacent swath during post-processing.

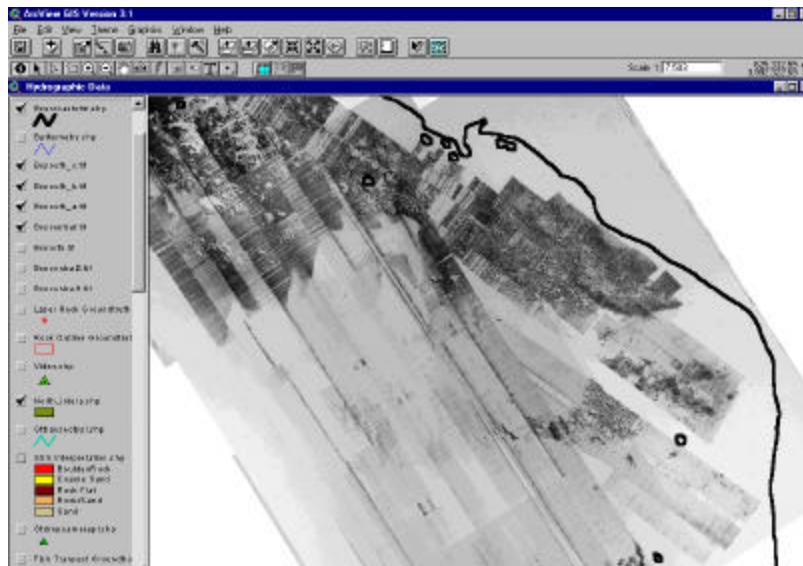
HYDROGRAPHIC SURVEY TIME ESTIMATE WORKSHEET	
Client: CDF&G	Project description:
Project Name: Big Creek Reserve Kelp Forest Survey	Map & classify kelp forest/rockfish habitat
Preparation date: 18 April, 1996	Bathymetry, sidescan sonar, RoxAnn
Prepared by: Rikk Kvitek (831) 582-3529	

Survey area specifications	Plan A	Plan B	Plan C	Plan D
Survey area width (m)	1,000 m	10,000 m	100,000 m	100,000 m
Survey line length (m)	1,000 m	10,000 m	100,000 m	100,000 m
Line spacing (m)	50 m	50 m	50 m	500 m
Survey speed (knots)	4 knots	4 knots	4 knots	10 knots
Survey estimates				
Number of lines	20	200	2000	200
Minutes per line (+1 for turn)	9 min	84 min	834 min	334 min
Total survey time (hours)	3 hr	281 hr	27811 hr	1114 hr

An additional advantage of designing overlap into the survey is to provide different views of the seafloor. This approach is especially important in areas of high relief, where features such as rock pinnacles may block the acoustic beam from striking and reflecting off that part of the seafloor hidden from towfish view. This interruption of the acoustic beam will create shadows or blind spots in the record, which can be filled with information from adjacent tracklines if there is sufficient overlap. Running track lines at different angles over the survey area can also be used to give a more complete picture of what the habitat looks like. For example, the acoustic appearance of canyons, pinnacles and exposed rock strata can vary greatly with approach angle.

Once the survey is completed, the swath images or sonographs can then be combined into a composite image or mosaic of the entire area surveyed (Fig. 4.10). Traditionally, these sonographs were created as hardcopy originals by the sidescan recorder, but are now more often recorded in digital form. As a result, all post-processing, including image enhancement, mosaicking and GIS product creation can be done electronically. Interfacing the sidescan with a differential GPS navigation system can produce georeferencing and imaging accuracy at submeter resolutions. To obtain this accuracy, however, requires that the off-set or “layback” between the sidescan sonar transducer and the GPS antenna is accurately determined and recorded throughout the survey.

Figure 4.10. Sidescan sonar mosaic of Big Creek Ecological Reserve, Big Sur, California produced with an EG&G 260 100 kHz towfish sidescan



sonar system (authors' unpublished data).

The sonographs and mosaics are used to create what is known as a sidescan interpretation. This process involves tracing polygons around regions of similar substrate as identified on the sonograph (Fig. 4.11). While it is relatively easy to differentiate between rock and sediment on the sonograph, caution must be exercised in the interpretation of the substrate based solely on the sidescan imagery if finer division of the substrate type is required (e.g. cobble, gravel, coarse sand, fine sand, silt, clay, etc.). As a result, it is often necessary to augment the sidescan data with some form of direct sampling (scuba, video, ROV, bottom grabs, etc.) in order to groundtruth the interpretation.

Groundtruthing is especially critical when image analysis software first developed and refined for use with satellite imagery is used to automate the classification and interpretation of the sidescan imagery. Classification involves identifying different features or classes in an image based on their reflectance characteristics. There are two principal methods for performing a classification of an image. “Unsupervised classification” is a method for grouping pixels in an image into classes or “clusters”, based on their statistical properties, without the user supplying any prior information on the classes. Once the unsupervised classification has been performed, the clusters that the classifier has identified can be examined and labeled according to what class they represent in the real-world as determined via groundtruthing.

“Supervised classification” involves the user first “training” the system in recognizing different classes by selecting representative samples of each class or habitat type from the image: these samples are known as training sets and should be groundtruthed prior to performing the supervised classification. The system then assigns each pixel in the image to one of these pre-determined classes. Some groundtruthing is essential for accurate classification results regardless of the method used. While highly effective in processing aerial imagery of terrestrial habitats, development of classification techniques is still in its infancy for application to acoustically derived images of marine habitats. These classification routines are available in stand-alone image processing software packages such as ERDAS and DIMPLE, as well as accessories or modules for some GIS software packages including those offered by ESRI and MicroImages.

Once processed and correctly georeferenced, the sidescan imagery and interpretations can also be draped over DEM's to give a 3D representation of the seafloor (Fig. 4.12).

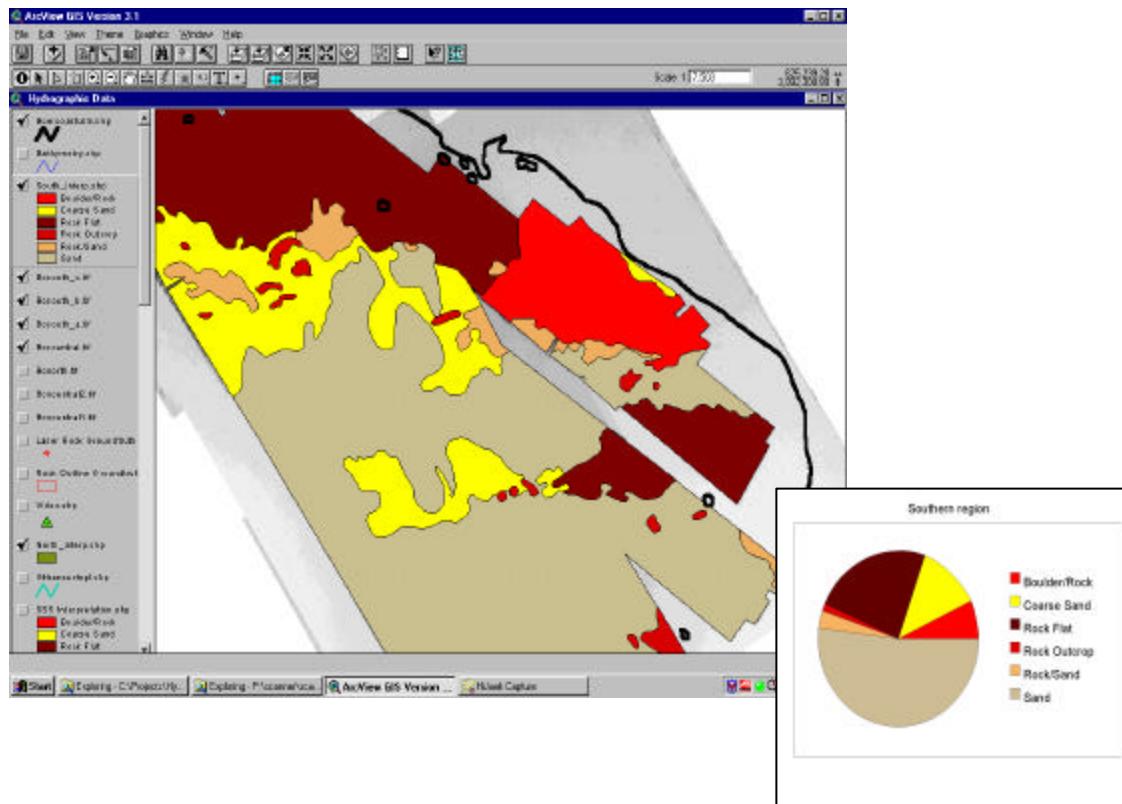


Figure 4.11. Sidescan sonar interpretation created from mosaic shown in Figure 4.10 of the Big Creek Ecological Reserve, (authors' unpublished data).

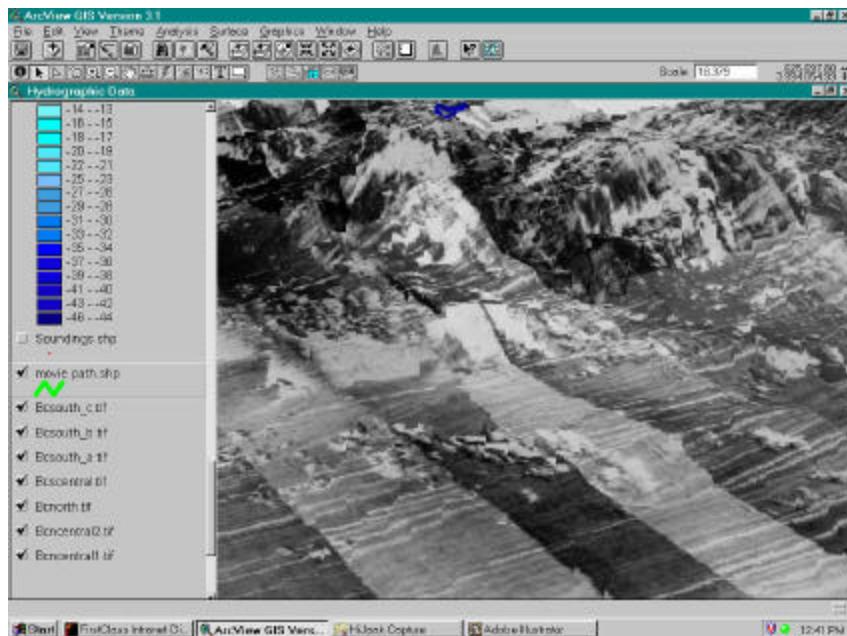


Figure 4.12. Sidescan sonar mosaic draped over DEM of Big Creek Ecological Reserve, (authors' unpublished data).

SPECIAL CHALLENGES TO SIDESCAN SONAR SURVEYS IN SHALLOW WATER

Challenges specific to shallow water nearshore marine habitats make sidescan sonar surveys in these areas more difficult, and costly than for deep water offshore surveys. Close to shore, waves are often higher and small vessels must be used where larger ones will serve in deeper waters. These factors combined with the shorter cable lengths required for shallow water surveys mean that under a given set of conditions, there will be more wave induced vessel motion transferred to the towfish during a shallow water versus a deep water survey. Any towfish motion other than along track movement (e.g. pitch, yaw and heave) will create distortion in the sonograph. While motion sensors are available for single beam and multibeam bathymetry systems, they have not yet been developed to remove motion induced distortion from sidescan sonar data. For this reason, shallow water sidescan sonar surveys conducted when seas are $> 2\text{m}$ produce results of little value.

Geohazards

Geohazards are also more of a consideration in shallow waters because towfish altitude above the seafloor is often limited by water depth. Towfish altitude should be kept between 10% and 40% of the range if full coverage of the selected swath width is desired. Less than 10% will result in loss of signal from the outside part of the range, and greater than 40% will produce a large gap in coverage directly below the fish. In water depths of $> 40\text{m}$ a towfish could be kept up to 40m off the bottom while still maintaining a range of 100m on a side. This margin of safety is not available, however, in water depths of 10 to 30 m, where the towfish must be kept at least 10m off the bottom but cannot be raised more than the water depth. Thus, a 20m pinnacle in 30m of water presents a very serious hazard to sidescan operations. For this reason, it is always advisable to conduct a bathymetric survey prior to the sidescan work in areas of uncertain seafloor morphology.

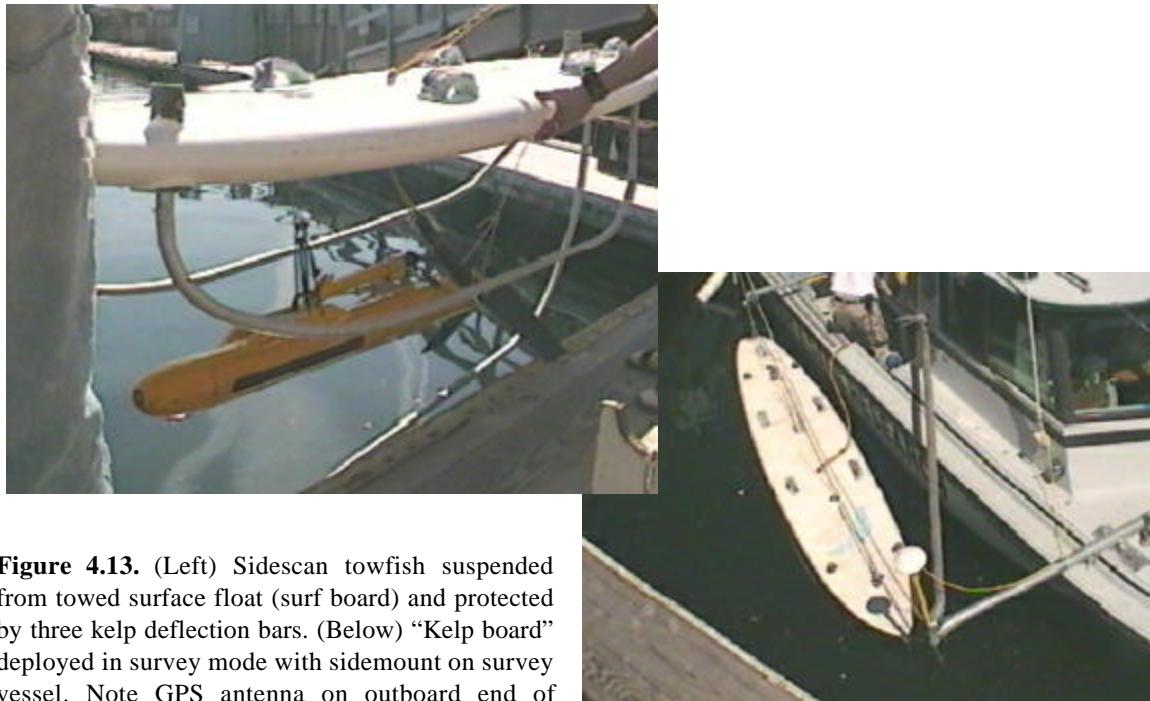


Figure 4.13. (Left) Sidescan towfish suspended from towed surface float (surf board) and protected by three kelp deflection bars. (Below) “Kelp board” deployed in survey mode with sidemount on survey vessel. Note GPS antenna on outboard end of sidemount arm.

Kelp

Kelp canopy presents another hazard for shallow water sidescan work. Although a survey vessel may be able to motor through a sparse kelp canopy, even the smallest amount of kelp that snags on the towfish will result in distortion of the sidescan record due to erratic motion of the towfish. The seafloor mapping group at California State University Monterey Bay has developed a system for shielding their towfish from kelp as it is towed through canopy cover, and are now routinely surveying in areas previously off limits to sidescan (Fig. 4.13).

In summary, the advantages of sidescan sonar for habitat mapping are that these systems can produce continuous coverage georeferenced digital imagery of the seafloor substrate at resolutions on the order of decimeters. This technology is analogous to the use of aerial photography for mapping habitats in terrestrial systems. The constraints imposed by the aquatic medium, however, make sidescan sonar a costly endeavor. Vessels are slower than aircraft, sidescan systems are more expensive than cameras, sound energy attenuates more rapidly in water than light does in air, and airplanes need not fly through tree canopies to get their imagery. Costs for complete sidescan sonar systems including dGPS navigation interface and digital data acquisition and processing start at over \$150,000.

4.4. ELECTRO-OPTICAL MAPPING TECHNIQUES

In recent years, several new technologies have emerged that may be applied to coastal marine habitat mapping; these tools rely upon the electro-optical, rather than the acoustic, spectra to make measurements and create imagery. Three main types of electro-optical tools show great potential for use in habitat mapping: CASI, LIDAR, and laser line scan (LLS). Two of these tools (CASI and LIDAR) are aircraft-deployed, offering great improvements in vessel speed

and survey efficiency (but with lower resolutions in some cases), while the third (LLS) is typically deployed in a towed body similar to sidescan sonar systems. Each tool has specific capabilities, limitations, and considerations, which will be addressed in detail below.

Compact Airborne Spectrographic Imager (CASI)

The Compact Airborne Spectrographic Imager (CASI) system, developed by ITRES Research Ltd., is an imaging system with a two-dimensional CCD array and reflection grating to provide spectral dispersion of the incoming optical signal. The CASI instrument is described in detail in the account of its use in the BOREAS project (Earth Observations Laboratory, <http://www.eol.lists.ca/projects/boreas/>) and consists of five modules: Sensor head, Instrument Control Unit, Keyboard, PowerSupply Module and Monitor (Fig. 4.14). The following text is directly paraphrased from that document.



Figure 4.14 CASI-2 system manufactured by Itres Research, Ltd.

Total instrument weight is 55 kg. Power requirements are 110 volts at 2.4 amps and with a suitable inverter the CASI can be operated from the 28 volts DC power found on many aircraft. Designed to be compact enough to be flown on light aircraft, the CASI has been flown on quite small aircraft such as the Piper Aztec and Cessna Citation. With no moving parts to the optics, the CASI is a "push broom" imaging spectrograph with a reflection grating and a two-dimensional CCD (charge coupled device) solid-state array detector.

The CCD sensor is a P86520 series frame transfer device (EEV Inc. Chelmsford, UK). The array is thermoelectrically cooled to 2 C to reduce dark current. The imaging area of the array is 578 x 288 pixels with each element measuring 15.5 by 22 um. The instrument operates by looking down and imaging a line perpendicular to the aircraft line of flight. A two-dimensional image is created as the forward motion of the aircraft allows the imaging of successive lines under the aircraft (Anger et al. 1990). The reflection grating provides spectral dispersion of the incoming optical signal. CASI has a nominal spectral range of 391 nm to 904 nm with a spatial resolution of 512 pixels across the 35-degree field of view (FOV). Ground resolution depends on the aircraft altitude and ranges from one to ten meters. The spectral resolution is nominally 2.5 nm FWHM (full width, half-maximum), with 288 spectral channels centered at 1.8 nm intervals. This bandwidth increases with wavelength. The CCD sensor is read and digitized to 12 bits by a programmable electronics system, which is controlled by an internal single-board computer. Data are recorded on a built-in digital tape recorder (Exabyte) which uses 8 mm cassettes, or to other removable or hard disk media. This low cost, standardized, data storage medium greatly facilitates post processing of the data. Each tape can store up to one gigabytes

of data or depending on the frame-rate up to one hour of imagery. A representative value for the frame rate under typical conditions is 20 frames (lines) /sec for eight spectral channels in imaging mode. Due to the high data rate of the CASI sensor, three user selectable operating modes have been developed. Each mode maximizes the information content while keeping the data rate at a manageable level.

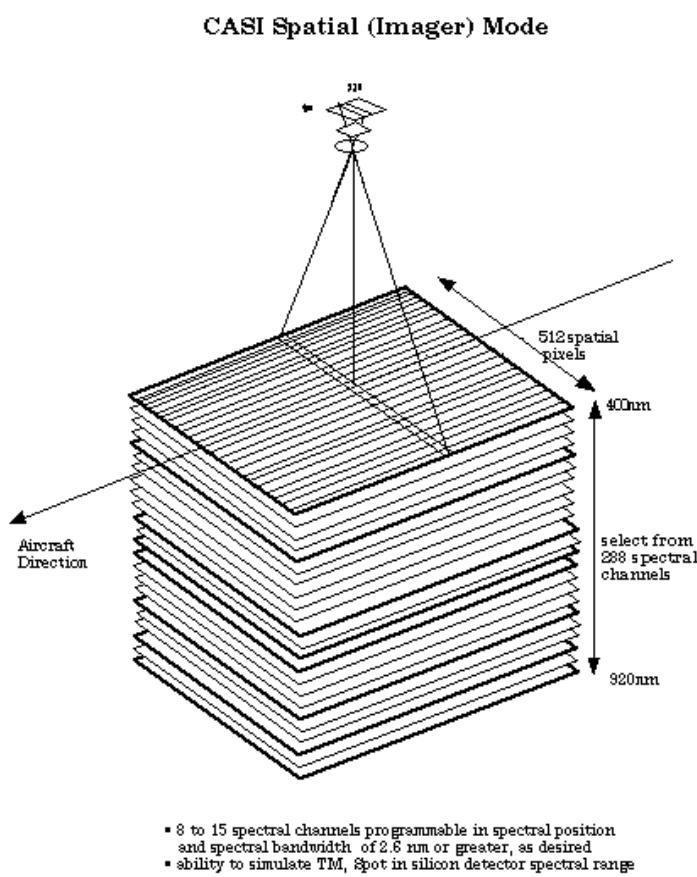


Figure 4.15 Diagram of CASI in Imaging Mode (IM), showing spatial and pixel coverage (Earth Observations Laboratory, <http://www.eol.ists.ca/projects/boreas/>)

The three operating modes are Imaging mode (IM), multispectral mode (MS), and Full-frame mode (FFM). In IM, full spatial resolution of 512 spatial pixels across the 35 degree swath is achieved (Fig. 4.15).

Channel wavelengths and bandwidths are user specified (up to 15 bands). In imaging mode, the image width is 512 pixels, and the image length is determined by the length of time that the imager is allowed to operate. Each picture element records radiance values in up to 15 bands between 391 and 904 nm, the spectral location of the bands being

selectable by the operator. The pixel size is approximately 1 m by 2 m, when the aircraft is flown at 2000 m above the target surface. Slowing the aircraft substantially may be able to reduce pixel size to as little as 60 cm, but to accomplish this one must reduce the number of bands to about 10 or use band averaging to 16 nm wide bands. Imaging mode is also sometimes called spatial mode.

In multispectrometer mode (MSM, Figure 4.16), full spectral resolution of 288 channels for up to 39 look directions across the 35 degree swath are possible. Look direction spacing and location are user specified to sample the array. This sampling produces an image rake or comb.

A single channel, full spatial scene recovery channel can be selected. In multi-spectrometer mode, the image width is up to 39 pixels, the image length is determined by the length of time that the imager is allowed to operate, and each picture element records the radiance values at up to 288 wavelength intervals in the region from 391 nm to 904 nm. The pixel width is the same as that in imaging mode, however adjacent pixels on the image represent ground points separated by approximately 20 m. The pixel length is approximately 6 to 8 m, and depends on the speed of the aircraft, and on the integration time selected. When the imager is operated in

multispectrometer mode, it produces a second image, called the "track recovery row", which consists of only one spectral interval, but is at the spatial resolution of the imager when operated in spatial mode. This track recovery image is usually used solely for locating the multispectrometer image, although it could be included as part of the data stream. This mode is also sometimes called spectral mode.

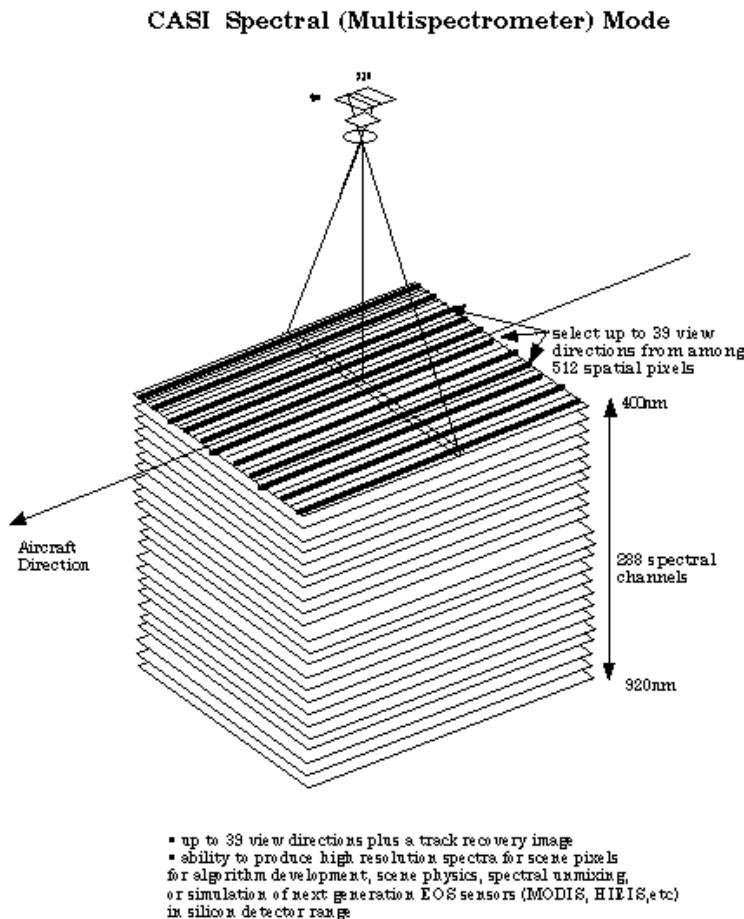


Figure 4.16. Diagram of CASI in Multispectrometer Mode (MSM), showing spatial and pixel coverage (Earth Observations Laboratory, <http://www.eol.ists.ca/projects/boreas>).

In full-frame mode (FFM, sometimes called calibration mode), CASI outputs all the 288 spectral channels for all 512 spatial pixels (i.e. the whole array). This mode requires long data readout times, in the order of one second or more. In airborne operation the first two modes are typically used in successive flights of the same target area. The full-frame mode is used for calibration and ground measurements. CASI has been used successfully in terrestrial, freshwater, and marine settings, to map vegetation, substrate, phytoplankton abundance, thermal and pollution plumes, and other features. By imaging reflectance in different spectral bands, vegetation can be distinguished taxonomically, to species in some cases. In the marine environment, CASI has been used to map benthic algae and substrate type in one of the largest

airborne mapping projects to date, to map benthic habitats in shallow coastal waters in Port Phillip Bay, Australia (Anstee et al., 1997, Figs. 4.17 and 4.18).

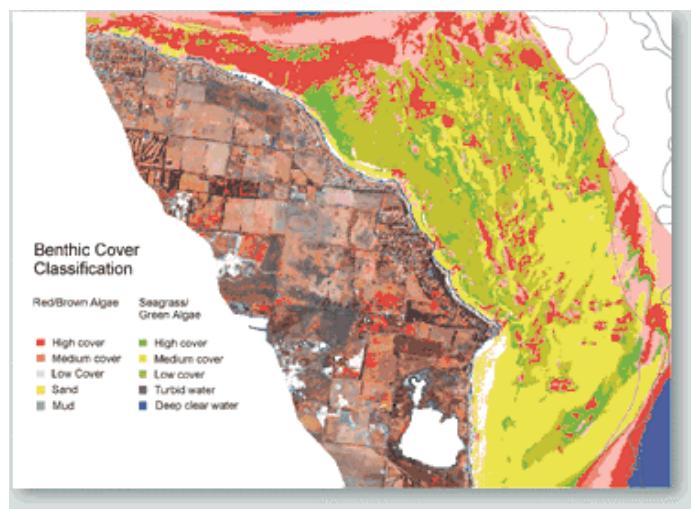


Figure 4.17 Benthic cover classification using CASI (Anstee et al., 1997, <http://www.clw.csiro.au/research/environment/remote/australia.html>).

This large embayment adjacent to Melbourne has an area of about 1,950 km². It is relatively shallow with over half the area being less than 10 m deep. Urban population and industrial development on its shores has been increasing, creating growing pressures on the bay's ecology and water quality.

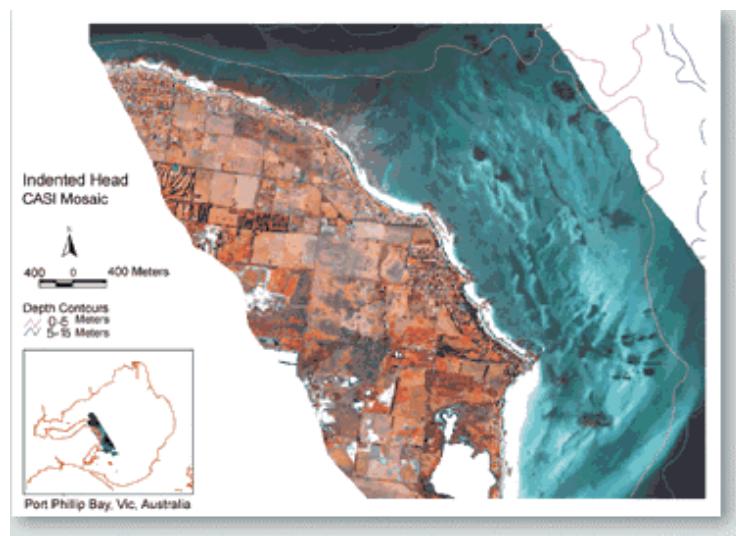


Figure 4.18 Color image mosaic created using CASI (Anstee et al., 1997, <http://www.clw.csiro.au/research/environment/remote/australia.html>).

The CASI was used to map the whole of the bay to a depth of 15 m (the major portion of the bay), to derive maps of benthic type and cover to 1:25,000 map accuracy, and to help develop

objective ecological categories to provide a base for monitoring. Starting with 6 GB of raw CASI data (72 flightlines) at 5 m pixel resolution, laboratory and field methods were developed for mapping spectrally distinguishable benthic materials and optical water quality in the bay. The major breakthroughs of this work, conducted by CSIRO, included the ability to treat the data as physical reflectance, to use large mosaics on a consistent physical basis as ‘single’ images, and (through physical modeling) to abolish the need for coincident in-water data collection.

An important consideration when using CASI, as with other electro-optical methods, is water clarity. Turbid or otherwise poor-visibility conditions reduce the depth capabilities and resolving power of CASI. A rule of thumb is that CASI is generally effective only within approximately the secchi depth, typically 5-15 m in coastal California waters < 30m deep. Positional accuracy of CASI data is dependent upon type of GPS positioning used (i.e. differential or RTK GPS) and accuracy of aircraft attitude sensor used (as with all airborne data collection methods, aircraft pitch, roll and yaw must be accounted for). Accuracies of $\pm 2\text{m}$ are common with dGPS. CASI may be deployed simultaneously with LIDAR, achieving greater survey efficiency by simultaneously collecting two types of complementary data (see below).

LIDAR

Light Detection And Ranging (LIDAR) technology has been used to map topography and bathymetry, and to detect objects (mines, fish schools, etc.) in the water column in marine and

freshwater bodies of water. As with CASI, LIDAR is deployed from an aircraft, either fixed-wing or helicopter. Systems for hydrographic mapping typically use a blue-green laser (532 nm) to optimize penetration depth. One such system, the SHOALS (Scanning Hydrographic Operational Airborne LIDAR Survey system) (Fig. 4.19), operated by USACE, is capable of mapping both coastal topography and nearshore bathymetry simultaneously, by the addition of a dual-frequency IR laser.

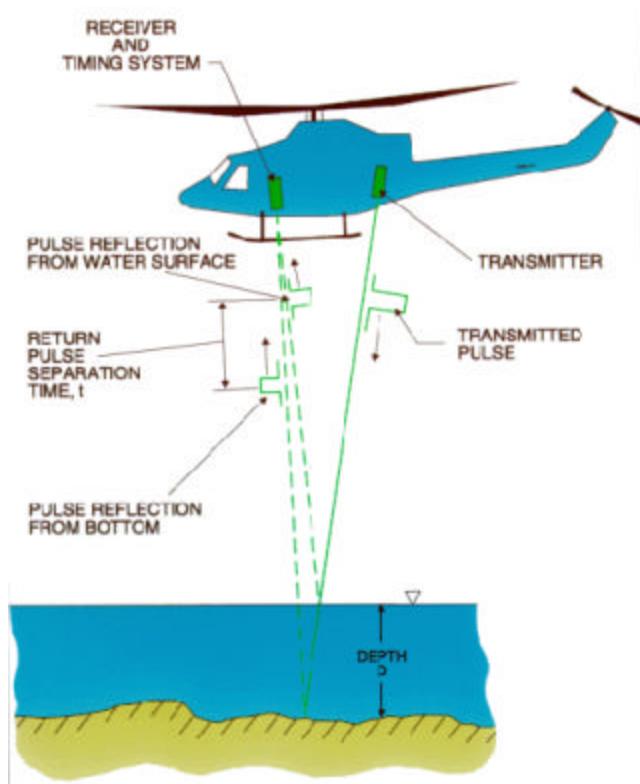


Figure 4.19 SHOALS LIDAR system (<http://shoals.sam.usace.army.mil/>).

One half of the altitude-dependent swath-width must be over water for this to function; at normal altitude (200m), this allows a 50 m portion of the terrestrial coastline to be mapped.

Other LIDAR systems optimized for terrestrial mapping might then be used if terrestrial elevation data beyond this 50 m swath are desired. Under normal operating conditions (an altitude of 200 meters and a speed of 60 or 120 knots) the system can survey up to 8-32 square kilometers in one hour, collecting depth soundings on a 4 meter horizontal grid. Using dGPS, SHOALS references each depth measurement to a horizontal position accurate to 3 meters and a vertical position accurate to 15 centimeters. RTK GPS can increase the horizontal accuracy to the sub-meter level. Water clarity affects the depth capabilities of LIDAR; under ideal conditions, up to 60 m penetration is possible. In a project in Redondo Beach, CA, 20-25 m penetration was achieved.

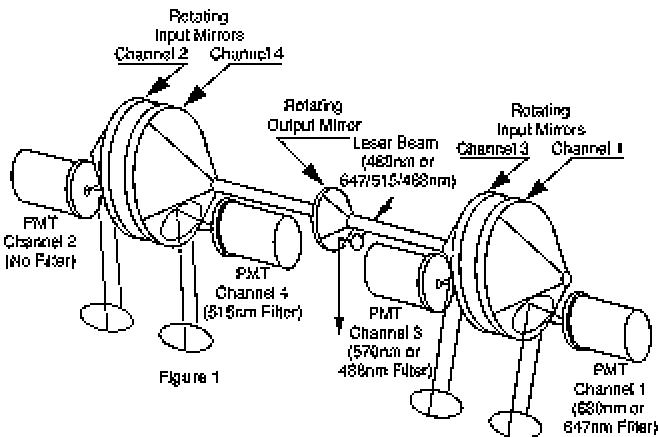
Georeferenced video is recorded simultaneously with the SHOALS LIDAR depth & elevation data. This imagery may be used to help interpret data inconsistencies and to construct mosaics of aerial imagery. As mentioned above, LIDAR may be co-deployed with CASI. Use of the SHOALS system costs \$8,000-\$10,000 US per square mile (approximately \$3100-\$3900 per square km), depending on whether dGPS or RTK GPS is used. For this price, both raw and processed x, y, z data are provided on a CD-ROM, as well as raw video imagery if desired (CASI is not included and must be arranged separately).

Laser Line Scanner (LLS)

Unlike the previous two tools, laser line scan (LLS) systems are deployed either in towed bodies similar to a sidescan sonar fish, or on submersibles. This tool, originally developed by the military for mine hunting applications, uses laser light to create high-resolution seafloor imagery (Fig. 4.18). LLS systems were used recently in the search for the TWA 800 and Swissair 111 air disaster remains. A solid state blue-green laser is continuously scanned across a 70° field of view illuminating only a pencil diameter spot at any one time. This spot is tracked by a highly sensitive narrow beam sensor, thereby vastly reducing the effects of backscatter from waterborne particles. The data from the receiver are digitized in real time and stored in an image buffer for display, line by line, on a conventional video monitor, and stored on computer disk for further processing. Data volumes generated are dependent upon resolution, but are substantial (GBs). Potential resolution is much better than that provided by sidescan sonar, as fine as 1 mm. LLS thus provides a resolution midway between that provided by video and still imagery, but at a much higher coverage rate and with much better penetrating capabilities (up to four or five times that of video, Table 4.1). As with video, water clarity limits viewing altitude, and thus swath width and resolution possible (Tables 4.2, 4.3). Survey speeds of 1 to 6 knots are possible, in water from 3 to 1500 m deep. At present, systems manufactured by Northrop-Grumman (formerly Westinghouse) and Raytheon Corporation are available, although high purchase price and related costs may make contracting survey companies offering LLS services (such as SAIC) a more viable option. Additionally a single multi-spectral LLS system exists, owned and operated by the U.S. Navy. At present, it can be deployed only on a submersible. This system and its uses are described in Strand et al., 199X, (<http://www.ncsc.navy.mil/css/papers/oceanopeoid.htm>). The fundamental difference between this sensor and more conventional laser line scan systems, such as the CSS/Raytheon EOID

Sensor or the Raytheon LS-4096, is the fact that this sensor has four separate receivers (Fig. 4.20).

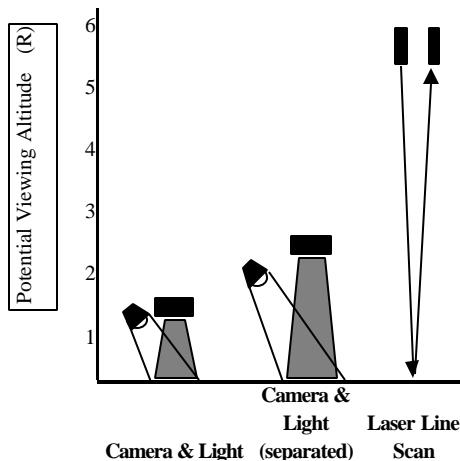
Figure 4.20. Multi-spectral LLS system owned by U.S. Navy and used in the CoBOP Program (Strand et al., 199X).



Each receiver consists of a rotating optical assembly, a controllable aperture assembly, a photomultiplier tube (PMT), a preamplifier and signal conditioning electronics, and an analog-to-digital converter (ADC). Each of the receivers' rotating optical assemblies can be fitted with optical interference filters and other optical elements, such as polarization analyzers, which allow various aspects of the reflected light field to be evaluated. In a conventional laser line scan system, the receiver is used to measure the magnitude of the reflected light field and the receiver is therefore fitted with no filter or with a filter whose center wavelength matches the wavelength of the outgoing laser light. The use of an optical filter in this case helps reduce the undesirable energy due to ambient sunlight or auxiliary luminaries that may be mounted on the deployment platform. During the CoBOP Program (Strand et al., 199X, <http://www.ncsc.navy.mil/css/papers/oceanopeoid.htm>) the multi-receiver laser line scan system was used to investigate biological fluorescence by using a short wavelength laser and fitting the receivers with optical filters whose center wavelengths correspond to known fluorescence wavelengths. An Argon Ion laser whose output was tuned to 488nm was used as the stimulating light source and three of the receivers were fitted with interference filters. A 680nm (20nm FWHM) filter was installed in channel #1, a 570nm (40nm FWHM) filter was installed in channel #3, a 515 nm (20nm FWHM) filter was installed in channel #4, and channel #2 was left open without any filter. When the system is used to create color images the Argon Ion laser is replaced with an Argon/Krypton mixed gas laser which provides simultaneous outputs at 647nm (red), 515nm (green), and 488nm (blue). Matching filters, with 6nm FWHM bandwidths, are then added to three of the four receivers and the data required to produce RGB color images can be collected. The images presented in Strand et al. (199X) demonstrate that the quantity and quality of target related information produced by a laser line scan system can be increased dramatically by evaluating other linear and non-linear, or elastic and inelastic, characteristics of the light field.

Table 4.1. Comparison of potential range (or viewing altitude, expressed in terms of R, the range of video camera & light systems), resolution, and search rate for camera and laser line scan systems. Source: SAIC.

	Camera & Light (separated)		
	Camera & Light	Light	Laser Line Scan
Range	R	2R	5R
Resolution	Excellent	Excellent	Good
Search Rate	Poor	Poor	Excellent



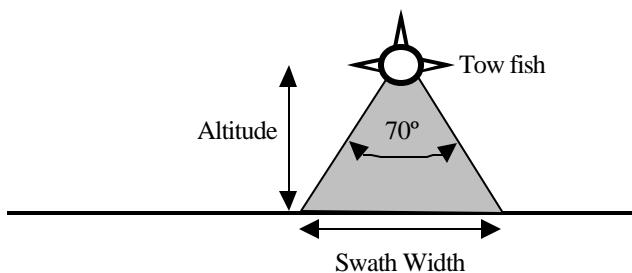
Colorful RGB images, for example, can be produced by illuminating the object with a multi-colored laser and simultaneously monitoring the magnitude of the reflected light at three coordinated wavelengths (Figs. 4.21-4.24). The color images produced in this manner have been shown to be very realistic and could be produced at a range that was 8-10 times greater than the range at which a three chip color CCD television camera was able to produce useful color information. These images also demonstrate conclusively that inelastic, or trans-spectral, phenomena such as fluorescence can also be used to great benefit. Fluorescence maps can be produced that describe, on a point-by-point basis, the fluorescent characteristics of large and small individuals within a relatively large, panoramic field of view. While the importance and application of these fluorescence maps is just beginning to be explored, the intimate connection of fluorescence with key biological processes makes the potential utility of FILLS imagery appear to be particularly tantalizing. Possible applications of these new image forms include wide area evaluation and assessment of specie diversity and distribution, the study of inter-relationships between species and individuals, evaluation and mapping of the health and biological vigor of coral reef communities, and the possible localization and identification of pollutants and other negative stress factors.

Table 4.2. Comparison of resolution, positional accuracy, coverage rate, and sea bottom impacts for sidescan sonar, camera, and laser line scan systems. Source: SAIC.

	Sidescan Sonar	Video/ROV	Laser Line Scan
Resolution	Low	High	High
Positional Accuracy	< 5 m	< 5 m	< 5 m
Rate of Coverage	Very High	Low	High
Sea Bottom Impact	None	Low-Medium	None

Table 43. Effect of water clarity on potential imaging altitude, swath width, coverage rate, and resolution for laser line scan systems. Source: SAIC.

Water Clarity	Typical Imaging Altitude	Swath Width	Area Coverage Rate (@ 3 kts)	Sampling Resolution (@ 2048 Samples)
Very Clear (Hawaii)	45m	65m	346,000 m ² /hr	3 cm
Clear (Eolian Islands)	22 m	30 m	161,000 m ² /hr	1.5 cm
Moderate (WA State, MA Bay)	9 m	13 m	69,000 m ² /hr	0.6 cm
Poor (Boston Harbor)	3 m	4 m	23,000 m ² /hr	0.2 cm



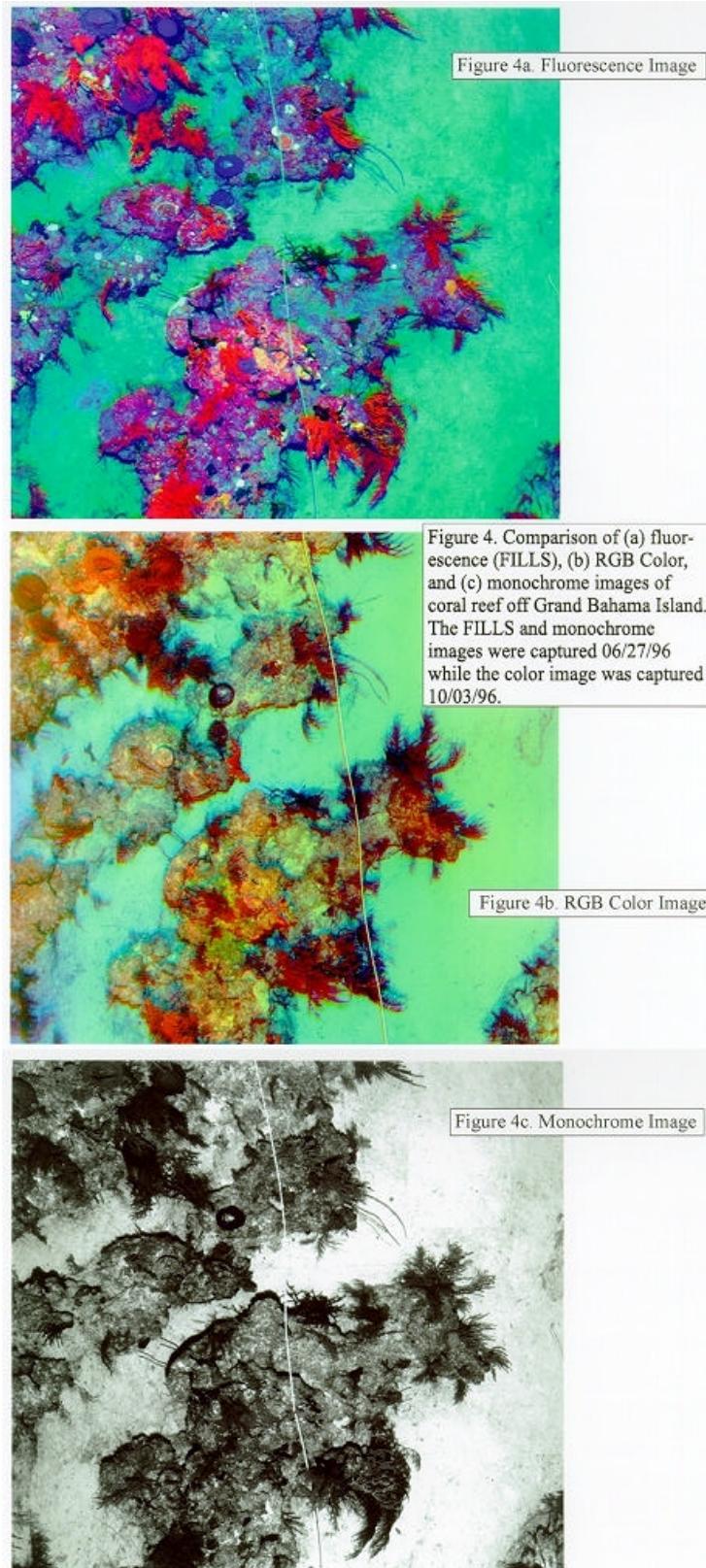


Figure 4.21. Comparison of LLS Fluorescence, RGB Color and Monochrome Images. (Source Strand, et al. 199x).

Figure 3a. Monochrome Image

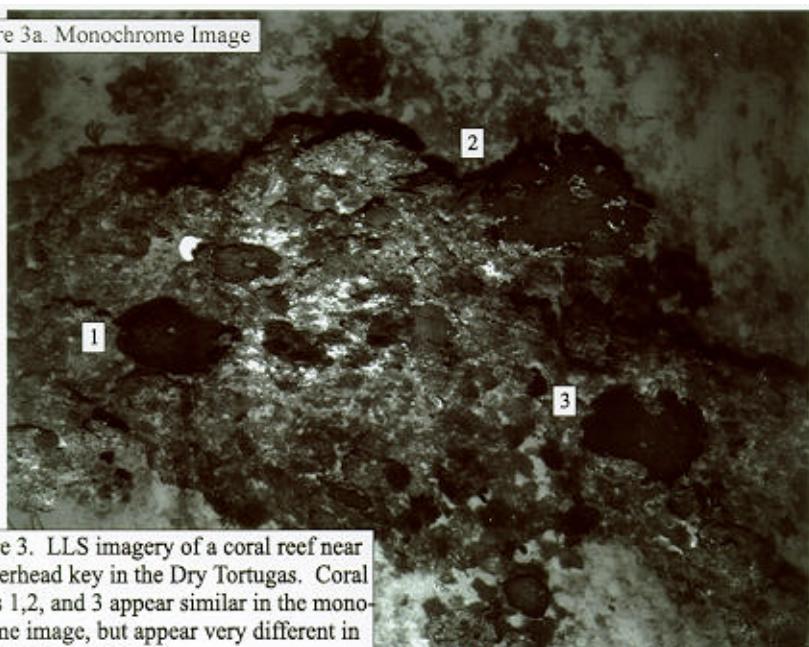


Figure 3. LLS imagery of a coral reef near Loggerhead key in the Dry Tortugas. Coral heads 1,2, and 3 appear similar in the monochrome image, but appear very different in the pseudocolor image.

Figure 3b. Pseudocolor Fluorescence Image

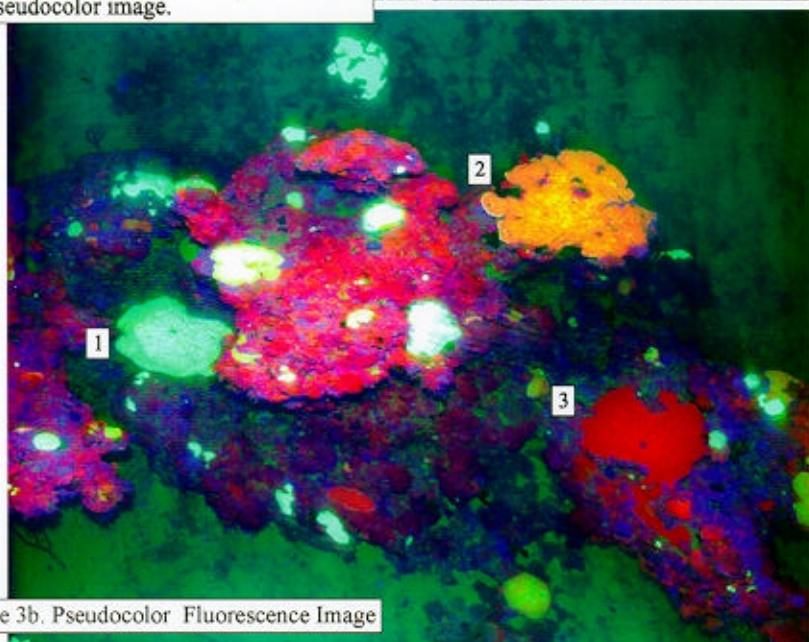


Figure 4.22. Comparison of LLS Monochrome and Pseudocolor Fluorescence Images. (Source Strand, et al. 199x).

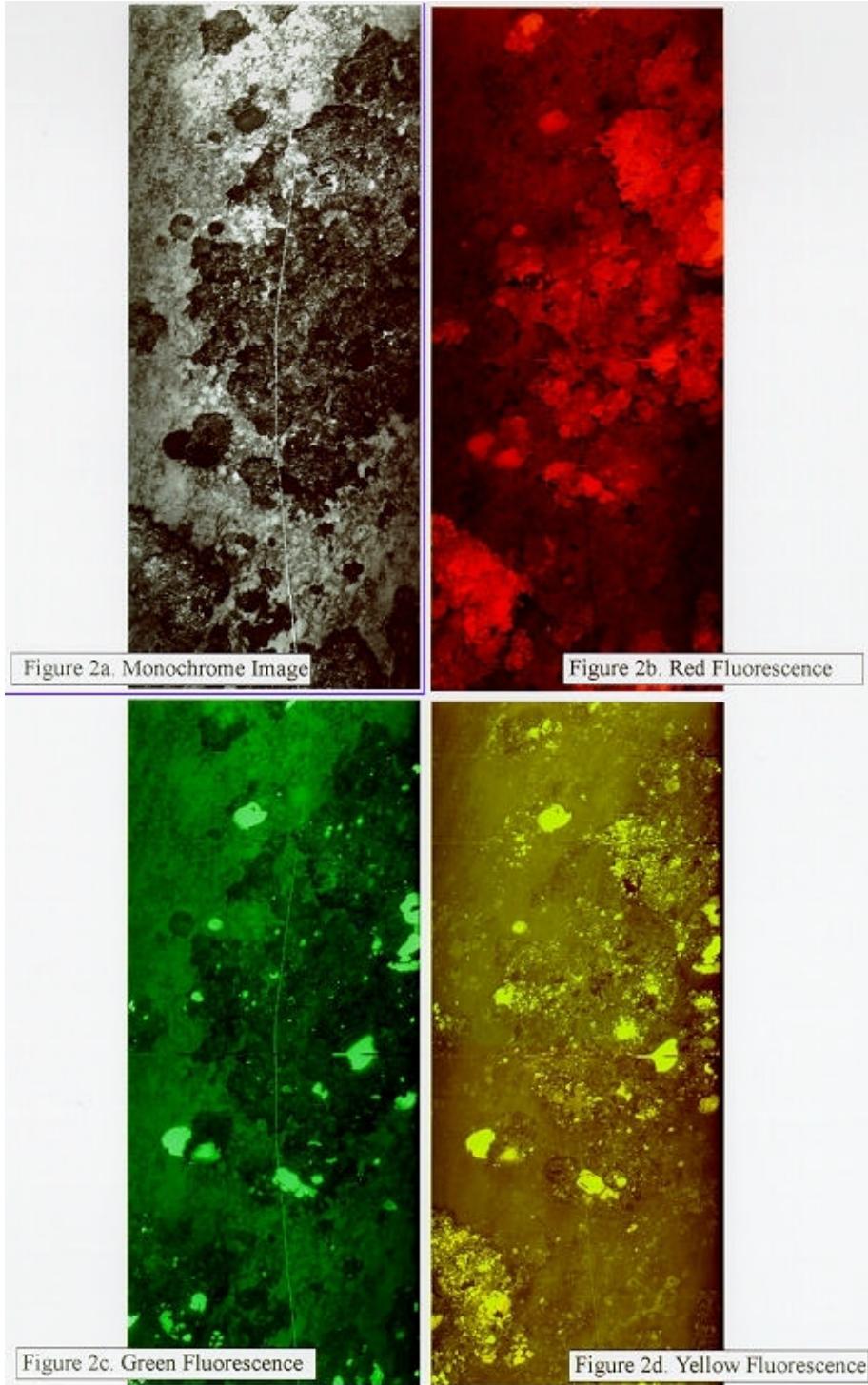


Figure 4.23. Comparison of Monochrome LLS Image, Red Fluorescence, Green Fluorescence, Yellow Fluorescence. (Source Strand, et al. 199x).

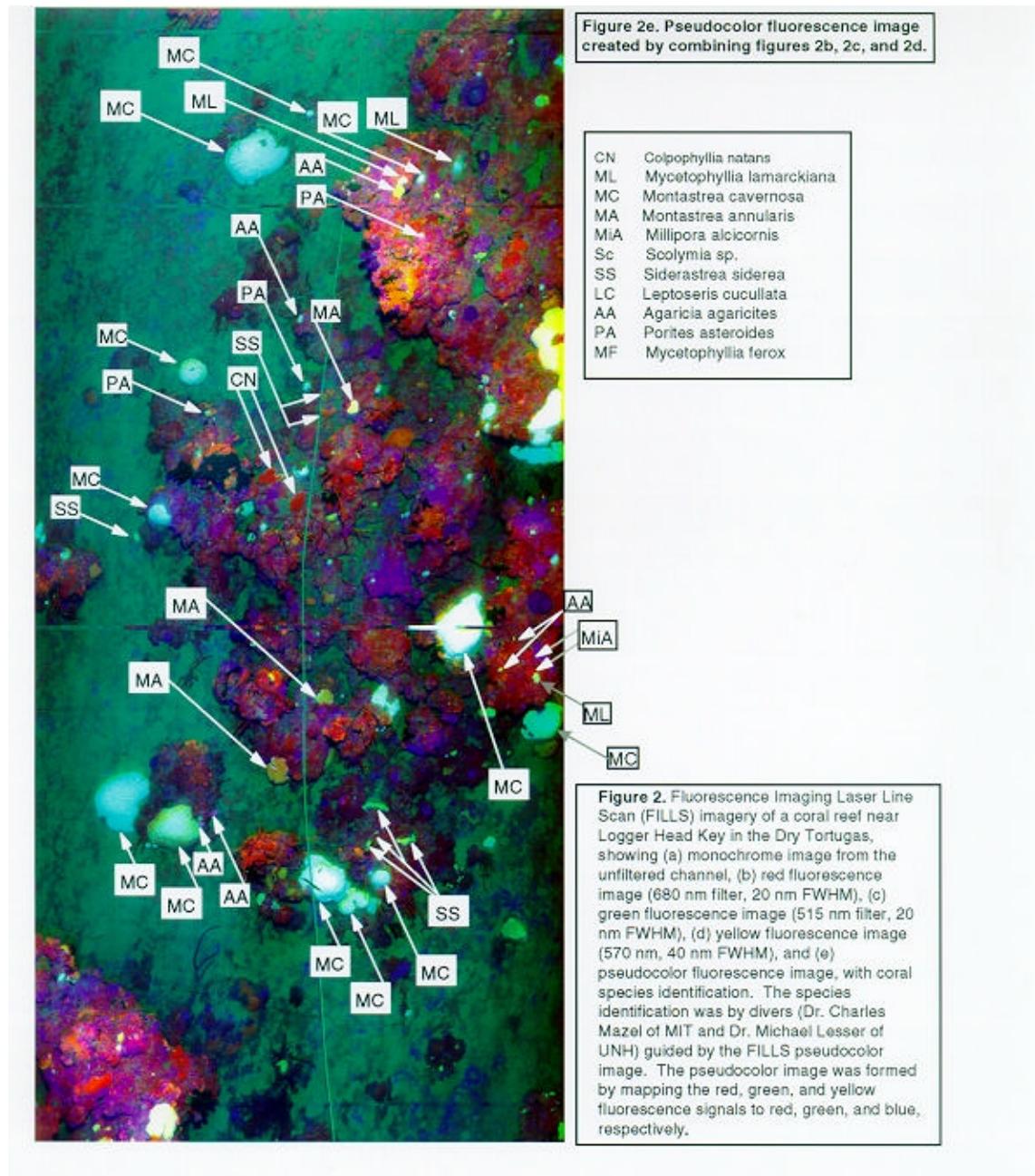


Figure 4.24. Pseudocolor LLS Image created by combining Red Fluorescence, Green Fluorescence, Yellow Fluorescence (Source Strand, et al. 199x).

4.5. DIRECT 1:1 SAMPLING METHODS

Groundtruthing

Despite the remarkably fine resolution now achievable using acoustic and electromagnetic remote sensing techniques, direct or 1:1 sampling (scuba observation, cores, video, etc.) is still critical to the success of any subtidal mapping program for at least three reasons. First, while remote sensing technologies are capable of submeter resolution, much of the habitat detail important to the biotic communities can occur on the scale of centimeters. Grain size, small cracks, pits and mounds that may be below the resolving capabilities of remote sensing systems can be sampled using direct techniques. Secondly, some types of biotically important features, such as void spaces between rocks, can be difficult or impossible to accurately quantify in terms of size and distribution using acoustic techniques. Finally, if accurate habitat maps are to be produced from remotely sensed data, the results need to be groundtruthed using direct methods. For example, a white area on a sidescan sonograph is the result of no or very low reflected signal. Without directly sampling the area, the operator may not be able to determine whether the light patch is a region of very soft sediment which reflected little of the signal, or a shadow cast behind an object projecting up into the water column. Although this is an extreme case, the issue remains that sonographs are merely spatial patterns of acoustic reflectance which often have to be “spot-checked” with direct techniques if the true nature of the substrate is to be identified (e.g. grain size, rock type, biotic cover, etc.).

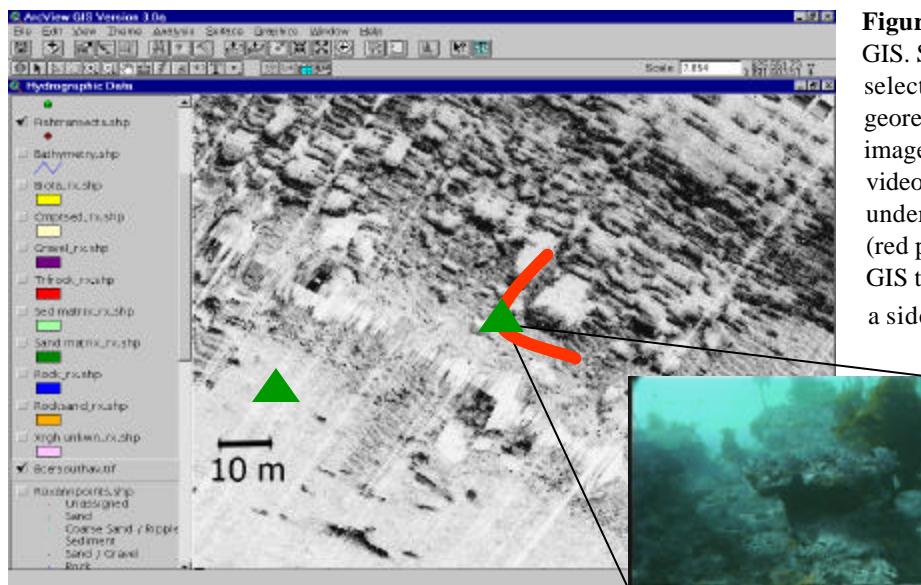


Figure 4.25. Multimedia GIS. Symbols can be selected to display georeferenced digital still images (green triangle) or video movie clips from an underwater video transect (red path) embedded in a GIS theme displayed over a sidescan sonograph.

Underwater positioning and georeferencing

A variety of methods are available for groundtruthing and 1:1 sampling of the seafloor including: direct observations by scuba divers, diver operated still and video cameras, sediment cores and grabs, drop cameras deployed from a vessel, submersibles, and remotely operated vehicles (ROV) guided by a pilot from a deployment vessel. Common to all of these methods, however,

is the need for accurate georeferencing of where the samples are collected. Again, there are a variety of methods for determining the x, y, z location of where a sample is taken. The simplest methods for geolocating sampling locations involve determining the surface position of the deployment vessel using GPS and assuming the location of the sample is directly below the boat or float. This approach is most successful for cores, grabs, and drop-cameras used in areas of low current and wind, such that the cable or tether remains nearly vertical.

Under circumstances where there may be significant horizontal displacement of the sampling device away from the deployment vessel, such as with divers and ROV's, some type of underwater tracking will be required if meter level resolution is required. Acoustic tracking systems, such as DiveTracker from Desert Star and Track Point II® from ORE International, can be used for underwater tracking and navigation in real-world coordinates when interfaced with dGPS. Using these systems, divers, submersibles and ROVs equipped with video cameras can be precisely guided along pre-determined transect lines. These georeferenced video images can be incorporated directly into GIS products as snap shots or "move clips" to illustrate what the habitat actually looks like (Fig. 4.25) (Bretz, Kvitek and Iampietro 1998). Also, when equipped with paired reference lasers set a known distance apart, video transects and quadrats can be used to quantify the size, distribution and abundance of many habitat features as well as species. Vertical images of the seafloor, if precisely georeferenced, can even be mosaicked to produce continuous, highly detailed views of larger areas (Fig. 4.26). Furthermore, with the advent of digital video imagery, these mosaic images can be greatly enhanced to reveal much detail normally obscure in conventional analogue imagery (Howland et al. 1999).

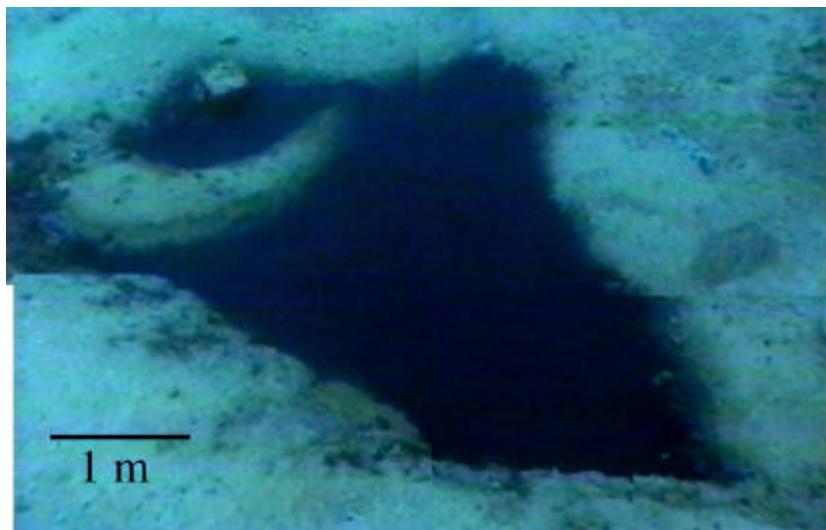


Figure 4.26. Example of georeferenced seafloor video mosaic. Image is of hypoxic brine pool found at 10m water depth in Resolute Bay, Canada. Picture was created from four digital video stills images (Kvitek et al. 1998).

5. DATA ACQUISITION TOOLS AND PROVIDERS DATABASE

5.1. PURPOSE

Part of Task 3, as defined in the California Department of Fish and Game (DFG) Nearshore Ecosystem Database Project (NEDP) was to collect information on remote sensing technologies applicable to nearshore habitat mapping. This information was to include:

- ◆ The types of tools in use and available, as well as emerging new technologies
- ◆ A comparison of the performance specifications for these systems
- ◆ A manufacturers reference list
- ◆ A summary of service providers capable of using these tools to meet DFG mapping needs
- ◆ The relative cost of using these tools to acquire nearshore (0-30 m) habitat data over different ranges of scale and resolution

Here we define “tool” as any piece of hardware or software that is used for acquisition, processing, or display of bathymetric or backscatter data. Our goal was to create a database containing this information in a format useful to DFG personnel charged with planning, acquiring, or using benthic habitat mapping data from nearshore, shallow water environments. Our objective was to collect, organize, and present all relevant information in a useable database. The following categories were used to organize the information: Tools, Tool Manufacturers, Survey Service Providers, Survey Equipment Providers, University Contact List, University Capabilities, and Government and Non-Profit Agencies. Our general approach was to first identify the types of tools most commonly used for acquiring seafloor depth and substrate data as well as new technologies that show promise for shallow water mapping. Once the list was developed, the next objective was to contact as many reliable sources possible to gather information about the relative performance and costs of using these tools, as well as service providers available on the West coast. This information was then compiled into the table presented below as well as a Microsoft Access database as requested by DFG.

A list of common tools was obtained from published reports, personal contacts, trade journals conversations, information packets and survey service provider websites.

5.2. METHODS

Prior to beginning our search for information, a database was developed in Microsoft Access for archiving the information and to allow for queries and relational searches. Data tables were created for each type of entry (tools specification, provider services and costs, etc.), and where appropriate tables have been linked to another table via an intermediate relational table. A unique ID number has been assigned to each entry, and these ID numbers have been placed in a relationship table to allow for crossover queries. Forms have already been developed to aid in, and display the results from the most common types of queries likely to be performed by DFG. Although there is more information in the database than reflected on the current forms, these

forms can be easily adjusted to fit specific needs. New relationships and forms can also be created as needed.

While the database was being setup, a preliminary search for information was done using the web, industry and scientific journals (i.e. *Sea Technology*, *Geology*, etc.), and personal contacts. This search was used to create lists of those manufactures, service providers, universities, survey equipment providers, and agencies capable of meeting DFG mapping needs. Our focus was on technologies suitable for the acquisition and processing of seafloor depth and substrate data along the California continental shelf, with special attention given to the shallow nearshore (0-30 m depth).

Manufacturers were first asked to fax information packets to aid in our initial evaluation of tools. Tools specifications and prices were recorded. Manufacturers were then re-contacted to obtain references for relevant tools and any information unavailable in the information packets. Tools were then tabulated and placed in categories such as: multibeam, side scan sonar, processing and acquisition, seabed classification systems and electro-optical systems. Common questions asked were based on model, type, sub-type, cost, swath width (if applicable), resolution (if applicable), max survey speed (if applicable), frequency, max depth, is it hardware or software (yes/no), references, requirements, comments, and user comments.

A Survey Equipment Provider list was obtained from advertisements in *Sea Technology*, web searches and manufacturer references. Information was either faxed or obtained from a company's web site. Rates for commonly used tools were requested and company information (contact, phone number, address, and website address) and comments were recorded.

Lists of Survey Service Providers and universities were created from searches on the web. Representatives for Service Providers and geology or biology departments at universities were contacted via phone to ascertain capabilities. Similar to Tool Manufactures, Service Providers were first asked to fax information packets for evaluation. Requested information included: address, website, phone number, contact name, comments, references, capabilities, tools used for acquiring bathymetric and substrate data, and resolution range. The same information was requested from all state universities (UC and CSU campuses). Here our approach was to first contact the geology department chairs or department secretaries and request a list of faculty members with experience in seafloor mapping. Biology departments were contacted when a university did not have a geology department. We then contacted and interviewed the faculty member to obtain the required information.

Government and Non-profit agencies were identified through references and personal contacts. Projects, contact information, tools used, and comments were recorded. Projects were given an ID number for relational queries. Service providers and universities were also asked to submit cost estimates for typical surveys conducted at three different spatial scales and two levels of substrate backscatter resolution. Spatial scales for scenarios A, B, and C were 1 mile², 10 mile², and 100 mile² respectively. The two different pixel resolutions specified for the substrate backscatter imagery data at each of these scales were 20-50 cm and 1-2 m. All six scenarios had a specified x, y bathymetry posting of 2 m, and vertical resolution of 1 m. All

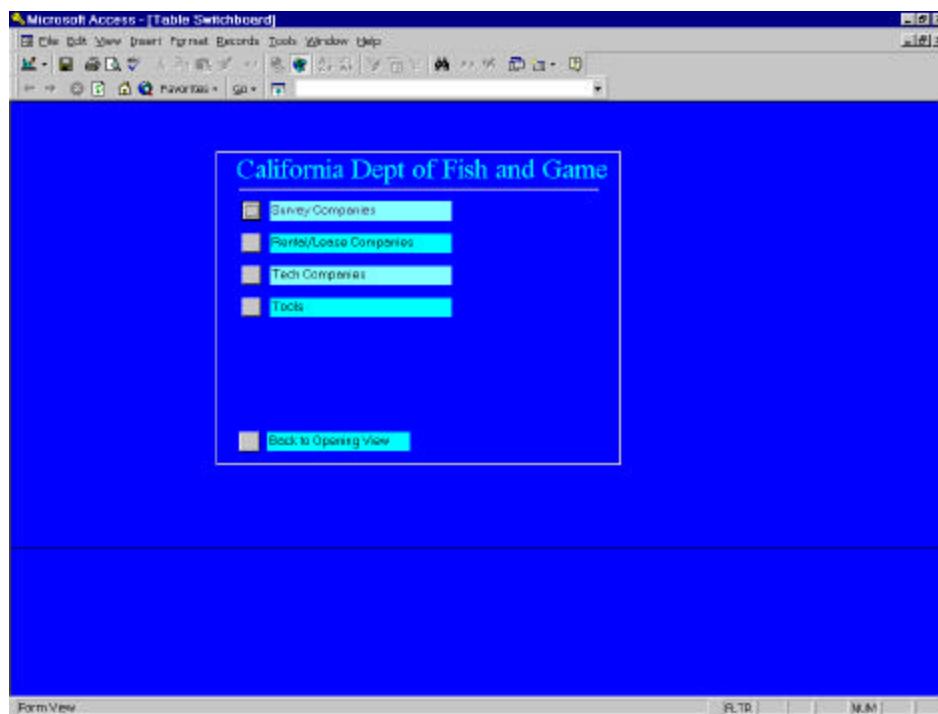
scenarios were based upon the assumption that the service providers had multibeam capabilities.

5.3. RESULTS

The Seafloor Habitat Mapping Tools database was created with an Opening Switchboard and Main Switchboard (Fig. 5.1) to help the user navigate to various tables and forms. A few standard queries have been developed along with display forms. The two forms for consultants and universities capabilities are similar in format (Fig. 5.2). Various questions were asked and the capabilities of each were evaluated as a yes/no answer. For instance, if a company did not have the capability of delivering the data in a GIS vector polygon format, a box next to that category was not checked.

We have used the database to create a series of tables summarizing the information collected to date. Tool manufacturers for multibeam, sidescan sonar, process and acquisition equipment and seabed classification systems are listed in Table 5.1. A total of 16 companies were contacted and listed.

The Tools section consists of the model, type, sub type, cost, swath width (if applicable), resolution (if applicable), max survey speed (if applicable), frequency, max depth, is hardware or software (yes/no), reference, requirements, comments, and user comments. Most pertinent information was included, but a relational query has been set so that each tool is linked to its manufacturer and website, allowing more detailed information to be accessed. The database contains data for multibeam (Table 5.2), side scan sonar (Table 5.3), processing and acquisition (Table 5.4), and seabed classification systems (Table 5.5). There are 16 multibeam tools, 25 side scan sonar tools, 22 processing and acquisition tools, and 2 seabed classification systems



listed.

Figure 5.1. Main switchboard for Tools Database.

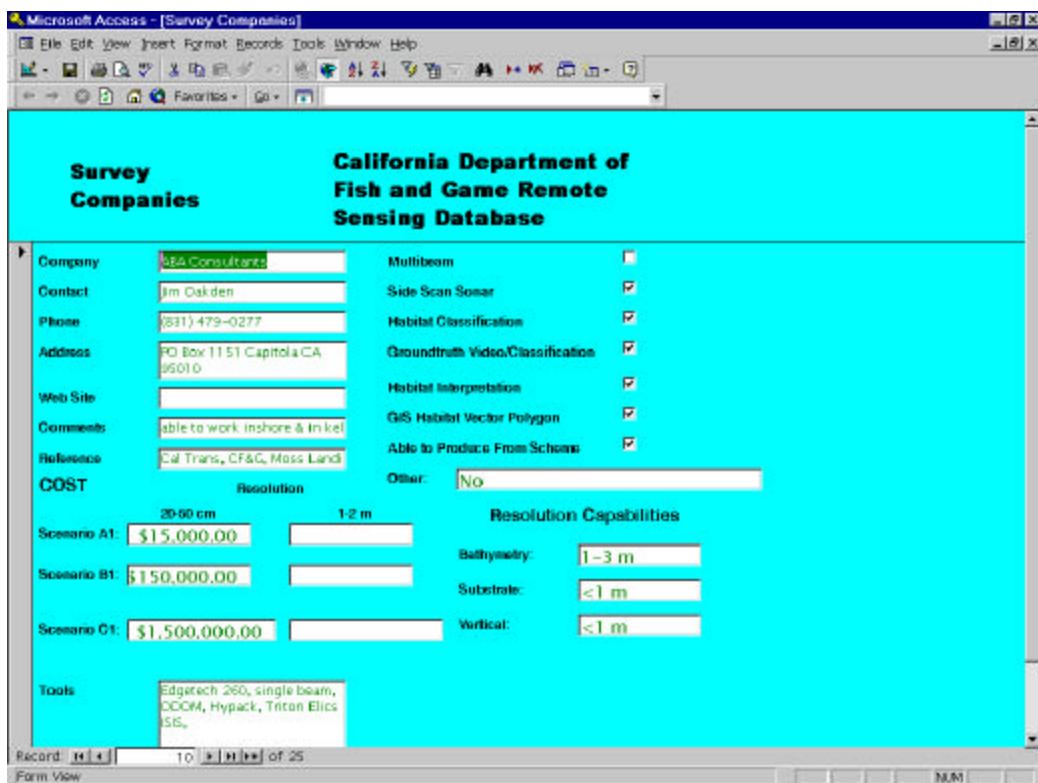


Figure 5.2. Service providers: Survey Companies database template.

A search for Electro-optical methods was also done. Manufacturer information, descriptions, resolution, system requirements, users, data output, and cost were recorded (Table 5.6). Only four main types of Electro-optical methods were listed. Because most of these technologies are very recent, few companies offer them as survey options. While satellite imagery is used widely by various companies and separate industries it may be of limited value in of mapping subtidal habitats, with the exception of kelp canopy cover.

Information from survey equipment providers on the specifications and costs of frequently used tools is presented in Table 5.7. Survey equipment providers were defined as companies that rent, sell or lease the necessary equip for seafloor mapping. Each company deals with separate equipment and some provide experienced support for setup and (sometimes) acquisition. Since each company deals with a large number of items, a complete list of items was not entered into the database. Only common items were listed in the database. Comments and references for

the company were also included. The database is set with tool ID numbers so that a query can be made to determine rental sources for a particular tool. Six companies have been listed.

Survey Service providers were placed in three categories: Universities, private consultants, and government or non-profit agencies. Geology departments were contacted at all universities within the University of California and California State University systems (Table 5.8). In almost all cases, only one faculty member at each university was involved with marine surveying or had surveying experience. Most work and experience was related to sub-bottom profiling or was done in deep water and done at a very small scale. Very few universities actually owned survey equipment. Most research is done using UNOLS vessels, vessels of opportunity or contracted out to private consultants. Most researchers within the university system had little or no experience with habitat classification based upon substrate identification. Information is pending from UCSD, UCSB, UCLA, and CSU Northridge.

Information about universities that had survey experience was placed in another table (Table 5.9). Capabilities and cost estimates for three standard scenarios at two backscatter resolutions are also shown. A total of 34 universities were contacted; 4 had no response after repeated attempts were made to gain information, 8 have limited capabilities, 5 have full survey capabilities, and 17 have no experience or capabilities.

Government agency and non-profit information is presented in Table 5.10. This information includes agency name, contact, phone number, address, projects, description of projects, and tools used. Seven agencies were contacted.

The contact information and capabilities of private consulting companies is provided in Table 5.11. Cost estimates are listed separately for each company and based upon the same three scenarios used to evaluate university rates Table 5.12. Several companies did not respond with cost estimates and a few companies had no response at all after repeated attempts were made to gain information. Although private service providers have done an extensive amount of seafloor mapping, most referrals for habitat mapping mentioned USGS, MBARI, and Moss Landing Marine Laboratories. Very few organizations or companies seem to have experience in creating habitat maps. Most of the work they reported was related to geologic research (seismic), oil speculation, dredging, telecommunication assessment or sea-lane hazard assessment, although the equipment and techniques used are also applicable to habitat mapping. Six private consulting firms (Racal Pelagos, Fugro, David Evans and Associates, S.A.I.C., C&C Technologies and ABA Consultants) have done extensive biological and near-shore work.

Only four firms replied with cost estimates. C&C Technologies and Fugro West submitted single, itemized quotes, which were extrapolated into separate quotes for the six scenarios. David Evans & Associates submitted two verbal quotes during initial conversations and ABA Consultants submitted two quotes, which were also extrapolated into separate quotes for the six scenarios. Although requests were made, most companies never replied with cost estimates. It appears that only the larger companies have the experience or capabilities necessary for

CDF&G needs. Many of the overseas and smaller companies did not reply to messages or could not be reached.

Many pieces of hardware appear to be have capabilities beyond the scope of CDF & G needs. Since deep-water tow equipment will not be used for CDF & G projects, equipment specifications were included, but cost estimates were not requested. Some equipment that is in use or has been used in past research projects is no longer produced or supported.

5.4. CONCLUSIONS

A truly comprehensive list of all survey tools, service providers, equipment providers and manufacturers would be very large and is beyond the scope of this work. We have, however, compiled information from a broad cross-section that we consider to be representative of what is generally available. This information is now archived in the Survey Tools Database created to allow queries for easy access and retrieval, as well as updating of the records.

Careful judgement must be applied when considering the cost estimates obtained from service providers and universities. All contacts stated their reluctance to give any “quote” regarding services when the scenario was so general. As a result, these figures provide general estimates to be used for relative comparison and selection of methods. Accurate quotes for actual survey costs at a given location and time will require more detailed, site specific information. Another consideration when using the database information is that rates for equipment rentals and pricing for equipment purchase can change relatively quickly. During the course of the project, tools (Klein 500 series & ISIS 100) were phased out and discontinued (although technical support will still be provided).

Although many of the hardware tools are easily compared in terms of performance and specifications, software for data acquisition and processing also need to be carefully considered when evaluating the needs and limitations of a survey project. Access to technical support is often critical to the success of mapping projects. Based on conversations with many of the users, some manufacturers appear to supply better customer support than their regional representatives do. Some survey companies have developed proprietary software for hardware and have yet to market these tools.

Table 5.1. Tool Manufacturers. Contains the company, address, phone number, contact person and type of tools manufactured. Tool abbreviations: prs= processing, acq=acquisition, sss=side scan sonar, mb=multibeam, ecs=echosounder.

<i>Company</i>	<i>Address</i>	<i>Phone</i>	<i>Contact</i>	<i>Tools</i>
Caris	264 Rockwood Ave, Fredericton, NB Canada E3B2M2	(506) 458-8533	Derrick R. Peyton	prs
Coda Technologies	9800 Richmond Ave Ste 480 Houston TX 77042	(713) 780-3223	Stacie Talbott	prs
Polaris Imaging Inc	70 Dean knauss Dr. Narragansett, R.I. 02882	(401) 789-2475	John Thayer	prs
Triton Erics Technology	125 Westridge Dr. Watsonville, CA. 95076	(831) 722-7373	Francois Wolf	prs, acq
Meridian Sciences	10015 Old Columbia Rd. Ste A-200 Columbia MD 21046	(410) 381-2270	Jeff Burns	prs
Klein Associates, Inc	11 Klein Dr Salem, NH 03079	(603) 893-6131	Garry Kozak	sss
Edgetech	455 Fortune Blvd Milford MA 01757	(508) 478-9500	Darren Moss	sss
Datasonics	7709 Prospect Place, La Jolla, CA 92037	(619) 259-1011	Brock Rosental	sss
McQuest Marine Sciences Limited	489 Enfield Rd. Burlington, Ontario CAN L7T 2X5	(905) 639-0931	Darren Keyes	ecs
GeoAcoustics	GeoPulseSystemsInc 25 DelanoAve Suite200 RevereMA	(781) 286 2944	George O'Keefe	ecs
Odom Hydrographic Systems,	8178 GSRI Ave. Bldg B Baton Rouge, Louisiana 70820	(504) 769-3051	Brian Apsy (Pres)	sss,mb
Tritech International Limited	WesthillBusinessPark,Westhill,Aberdeen, AB326JL,UK	+44 (0)1224 744111	No reply from company	ecs
Reson	300 Lopez Rd, Goleta, CA 9317	(805) 964-6260	Jeff Garlik	mb,ecs
Seabeam	141 Washington St, East Wapole, MA	(508) 660-6000	Hugh Murphy	mb,
Atlas	Sebaldsbrucker HeerstraBe 235 28305 Bremen Germany	+04 21 457-4902	Contact Odom Hydrographics	mb
Simrad	7250 Langtry St Houston TX 77040-6625	(713) 934-8885	Chris Hancock	mb

Table 5.2 Multibeam Tools. Contains a list of systems and corresponding specifications for each model. NA= Not applicable for proposed work. NR= No response from company. NM= No longer in production/distributed.

System	<i>EM 1002</i>	<i>EM 952</i>	<i>EM 3000</i>	<i>EM 1000</i>	<i>EM 950</i>	<i>SEABAT 8101</i>	<i>SEABAT 8124</i>
Specification update	1998	1998	1996	1993	1993	1997	1995
Frequency (kHz)	95	95	300	95	95	240	200
Transducer	160° r=45cm	160° r=45cm	Single or dual	160° r=45cm	160° r=45cm	Single 150°	171° r=8.8cm
Source Level (dB rel Pa/m)	226	226	215	226	225	217	210
Power (kW)	4.5	4.5	0.6	4.5	4.5	1.2	0.5
Pulse length (ms)	0.2/0.7/2	0.2	0.15	0.2/0.7/2	0.2	0.07	0.07
Xmt beamwidth (deg) athwartships*fore-aft	60-200*3.3	60-200*3.3	130*1.5	150/120/60*3.3	150*3.3	170*1.5/3	140*1.5/2.4/10
Transmit steps	1	1	1	1	1	1	1
Beamforming	digital	digital	digital	digital	digital	digital	analog
number of beams	111	111	127	120/96/48 in 2 pings	120 in 2 pings	101	40
Beam spacing (deg)	0.5-1.5	0.5-1.5	0.9	2.5(1.25)	2.5(1.25)	1.5	3
Max ping rate (1/s)	10	10	30	4	4	30	30
Minimum range (m)	2	2	0.3	3	3	0.25	1
Cost (\$US)	NM	NM	\$183,000.00	NA	NA	\$200,00.00	\$95,000.00

Survey Speed (knots)	NM	NM	20	10	NR	30	16

Table 5.2 Multibeam Tools (continued)

System	<i>SEABAT 9001</i>	<i>ELAC BCC- MK2*</i>	<i>ELAC BCC- MK2**</i>	<i>ELAC BCC- SEE28***</i>	<i>Fansweep 15</i>	<i>Fansweep 20</i>	<i>Fansweep 20</i>
Specification update	1993	1997	1997	1993	1998	1996	1996
Frequency (kHz)	455	50	180	180	200	100	200
Transducer	171° r=8.8cm	dual (53*29cm)	dual (25.5*18cm)	dual (25.5*18cm)	single (35*35 cm)	dual (48*48cm)	dual (35*35cm)
Source Level (dB rel Pa/m)	210	234	217	217	227	227	227
Power (kW)	0.5	2*3.5	2*0.6	2*0.6	2*0.7	2*0.7	2*0.7
Pulse length (ms)	0.07	0.15/0.3/1/3/10	0.15/0.3/1/3	0.3/1/3	0.02	0.06	0.02
Xmt beamwidth (deg) athwartships*fore-aft	100*1.5/2.4/10	150*3	150*3	120*5.2	160*1.2	180*1.2	180*1.2
Transmit steps	1	3(42 beams each)	3(42 beams each)	7(8 beams each)	1	1	1
Beamforming	analog	digital	digital	digital	digital	digital	digital
number of beams	60	126 in 3 pingsx	126 in 3 pings	56 in 7 pings	20-600	20-1440	20-1440
Beam spacing (deg)	1.5	1.25	3.75(1.25)	2.2	?	?	?
Max ping rate (1/s)	15	10	12/25	5	12	12	12
Minimum range (m)	1	5	1	1.8	0.5	0.5	0.5
Cost	\$134,000.00	NR	NR	NR	\$105,894	\$156,723	\$140,385
Survey Speed (knots)	16	NR	NR	NR	16	16	16

* Seabeam 1050

** Seabeam 1180

*** Seabeam 1185

Table 5.2 Multibeam Tools (continued)

System	<i>ISIS 2000</i>	<i>ISIS 100</i>	<i>ECHOSCAN</i>
Specification update	1998	1996	1996
Frequency (kHz)	117,234,58.5, 468	117, 234	200
Transducer	dual (49*19.5cm)	dual (30*13cm)	900 (48.3x26.7cm)
Source Level (dB rel Pa/m)	219	219	225
Power (kW)	1	1	0.1
Pulse length (ms)	0.08	0.08-0.2	0.02
Xmt beamwidth (deg) athwartships*fore-aft	50*1.7	50*1.0	100*2.5
Transmit steps	1	1	1
Beamforming	phase measurements analog	phase measurements analog	none
number of beams	up to 15 pairs	up to 6 pairs	30
Beam spacing (deg)	single beam	single beam	3
Max ping rate (1/s)	2.5	2.5	15
Minimum range (m)	1.0	1.5	2
Cost	\$120,696.00	NR	\$137,600.00
Survey Speed (knots)	16	16	17

Source C. de Mousier 1999

Table 5.3 Side Scan Sonar Tools. List of sidescan sonar equipment and specifications.

Model	<i>Widescan 60</i>	<i>AMS - 36/120S1</i>	<i>Sys09 (SSI Int'l.)</i>	<i>Hydrosweep</i>	<i>Simrad EM - 12</i>	<i>Simrad EM - 100</i>	<i>Simrad EM - 1000</i>
Operator(s)	Commercial applications, SOC	Acoustic Marine Systems, Inc.	Commercial applications	UW, LDEO, Germany, India, others...	SIMRAD A/S, RVS, IFREMER	SIMRAD A/S, Canadian Hydrographic Service ...	SIMRAD A/S, Canadian Hydrographic Service ...
Type	Shallow-tow	Deep-tow	Shallow-tow	Hull-mounted	Hull-mounted	Hull-mounted	Hull-mounted
Depth range	<300 m	<6,000 m	60 - 10,000 m	10 - 10,000 m	10 - 11,000 m	10-700 m	3-1,000 m
Total swath width	37.5 x 400 m	< or = 1,000 m	< 20 km	2 x water depth (less if depth > 7 km)	150° (7.3 x water depth) 90° - 120° for EM-12S	150° (7.3 x water depth)	150° (7.3 x water depth)
Typical navigation error	< 100 m satellite + near-shore reckoning	100 - 1000 m satellite	100 - 1000 m satellite	100 - 1,000 m (satellite positioning)	100 - 1,000 m (satellite positioning)	100 - 1,000 m (satellite positioning)	100 - 1,000 m (satellite positioning)
Frequency (wavelength)	100 kHz/325 kHz	33.3 / 36 kHz	9/10 kHz	15.5 kHz (9.7 cm)	13 kHz (11.5 cm)	95 kHz (1.6 cm)	95 kHz (1.6 cm)
Footprint size (along-x across-track)	~ 0.2 m	< 1 m	0.2 x 0.2 m to 10 x 10 m	134 x 134 m	170 x 170 m	170 x 170 m	170 x 170 m
Output data	Imagery	Imagery	Imagery Bathymetry	Bathymetry + backscattering amplitude	Bathymetry + backscattering amplitude	Bathymetry + backscattering amplitude	Bathymetry + backscattering amplitude
Typical size of daily data	<< 1 Gbyte	< or = 1 Gbyte	> 1 Gbyte	~ 1 Gbyte	Not available	Not available	Not available
Ancillary data	Altitude	Altitude, roll, pitch, yaw	N/A	Heading + roll, pitch	Heading + roll, pitch, yaw	Heading + roll, pitch, yaw	Heading + roll, pitch, yaw
Cost (\$US)	NR	NR	NA	NR	NR	NR	NR

Comments	NR	NR	NA	NR	NR	NR	NR
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Table 5.3 Side Scan Sonar Tools (continued)

Model	<i>GLORIA</i> <i>Mk II</i>	<i>GLORIA - B</i>	<i>TOBI</i>	<i>SeaMARC II/HMR-1</i>	<i>SAR 190 kHz</i>	<i>DSL-120</i>	<i>Jason 200 kHz</i>	<i>EG&G 990S</i>	<i>EG&G Deep-Tow</i>
Operator(s)	SOC, USGS, ...	SOC	SOC	Univ. of Hawaii	IFREMER	WHOI	WHOI	Commercial applications, GPI Kiel	Government & commercial surveys
Type	Shallow-tow	Shallow-tow	Deep-tow	Shallow-tow	Deep-tow	Deep-tow	Deep-tow	Deep-tow	Deep-tow
Depth range	200-11,000m	200-11,000m	< 10,500m	100-11,000m	< 6,200m	< 6,100m	< 6,000m	Pending	< 600 m
Total swath width	up to 60 km (typically 45)	45 km (imagery) 4.5 x depth (bathymetry)	6 km	up to 10 km (typically 10 km)	up to 1.5 km	0.1 to 1 km (typically 1 km)	0.3 km	2 x 400 m	< 1 km
Typical navigation error	100-1000m satellite	100-1000m satellite	50-500m long-baseline	100-1000m satellite	5-10m long-baseline	5-10m long-baseline	0.1-10 m short-or long-baseline	< 100 m satellite + near-shore reckoning	< 100 m satellite + near-shore reckoning
Frequency (wavelength)	6.3 - 6.7 kHz 23.8 - 22.4 cm	6.25 - 6.75 kHz 24 - 22.2 cm	30 - 32 kHz 5 - 4.7 cm	11 - 12 kHz 14.9 cm	13.6 - 0.9-0.8 cm	170-190 kHz 1.25 cm	120 kHz 0.75 cm	Pending	59 kHz
Footprint size (along-x across-track)	175 x45 to 657 x 45 m	125 x 45 m to 1000 x 45 m	8 x 3.5 m to 43 x 2.1 m	120 x 10 m to x 2 m	197	0.7 x 0.8 m to 3 x 0.4 m	3.3 x 0.33 m to 13.7 x 0.15 m	0.5 x 0.29 m to 2.4 x 0.15 m	N/A
Output data	Imagery	Imagery Bathymetry	Imagery	Imagery Bathymetry	Imagery	Imagery Bathymetry	Imagery Bathymetry	Imagery	Imagery
Typical size of daily data	< 1 Gbyte	~ 5.3 Mbyte	528 Mbyte	< 1 Gbyte	< 1 Gbyte	> 1 Gbyte	~ 100 Mbyte	Paper record	NA
Ancillary data	Heading	Heading + Roll, Pitch, yaw	Heading, depth, speed + Roll, Pitch, yaw	Heading + Roll, Pitch, yaw	Heading, depth, speed	Heading, depth + Roll, Pitch, yaw	Heading, depth + Roll, Pitch, yaw	Pressure, heading, speed, temperature	Speed, depth, temperature
Cost (\$US)	NA	NA	NR	NA	NR	NR	NR	NA	NA

Comments	Older system. No longer used	Older system. No longer used	Used only for deep water	NA	Used only for deep water	Used only for deep water	Used only for deep water	Used only for deep water	Used only for deep water
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Table 5.3 Side Scan Sonar Tools (continued)

Model	<i>EG&G model 272T</i>	[TAMU]2	<i>Klein 590/595</i>	<i>Klein 520</i>	<i>Simrad MS-992</i>	<i>OKEAN</i>	<i>MAK-1</i>
Operator(s)	Government & commercial surveys	Texas A&M Univ.	Klein Assoc. Massachusetts, U. Kiel, ...	U. Kiel, Klein Assoc., etc.	Commercial, military...	CIS States	CIS States
Type	Shallow-tow	Shallow-tow	Shallow-tow	Shallow-tow	Deep-tow	Shallow-tow	Deep-tow
Depth range	< 1,000m	< 500 m	< 1,000m	< 300 m	< 1,000m	NR	NR
Total swath width	N/A	100 m -30 km	< 600 m (100 kHz) < 400 m (500 kHz)	25 m - 600m	10 m - 800 km	2 x 8,000 m	2 x 1,000 m or 2 x 250 m
Typical navigation error	< 100 m satellite + near-shore reckoning	100-1000 m Satellite	SBL net				
Frequency (wavelength)	105 kHz	11/12 kHz 72 kHz	100 kHz 500 kHz	500 kHz	120 kHz 330 kHz	9.5 kHz	30 kHz or 100 kHz
Footprint size (along-x across-track)	N/A	Not Available	N/A	N/A	N/A	100 x 5 m	35 x 0.5 m
Output data	Imagery	Imagery Bathymetry	Imagery	Imagery	Imagery	Imagery	Imagery
Typical size of daily data	< 1 Gbyte	< 1 Gbyte	< 1 Gbyte	< 1 Gbyte	unknown	< or = 350 Mbyte	< or = 1 Gbyte
Ancillary data	N/A	Depth + Roll, Pitch, yaw	N/A	N/A	N/A	N/A	N/A
Cost	\$15,500.00	NR	\$74,770	NM	NA	NR	NR
Comments	100/500kHz Max speed 12.7 knots	NR	1-8 kots survey speed	No longer manufactured	Used only for deep water	NR	Used only for deep water

Source C. de Mousier 1999

Table 5.4 Processing Tools. Contains model, type, cost, description, reference, requirements

Model	Sub-Type	Cost	Description	Tool Ref	Tool Req
<i>Caris-SIPS</i>	Image processing	\$11,285.00	Sonar image processing	David Evans & Associates	training @ \$2500/person or \$6000 for field training
<i>Caris-HIPS</i>	Image processing	\$13,570.00	Hydrographic data processing	David Evans & Associates	training @ \$2500/person or \$6000 for field training
<i>Caris-GIS</i>	Image processing	\$2,300.00	GIS system for hydrographic data	Seafloor Systems	training @ \$2500/person or \$6000 for field training
<i>Caris-Object Manager</i>	Image processing Interactive w/editing features	No response	Create, edit, maintain and output hydro data	Seafloor Systems	training @ \$2500/person or \$6000 for field training
<i>CODA-GeoKit</i>	data interpretation	No response	Online interpretation and reporting of seabed features	No response	DA-100 or DA-200
<i>CODA-TrackPlot</i>	planning & real-time coverage	\$3,192.00	Real-time track and survey coverage information	C & C Technologies	DA-100 or DA-200
<i>CODA-TrackPlotplus</i>	interactive w/ editing features	No response	Real-time track and survey coverage information	No response	DA-100 or DA-200
<i>CODA-Bathy</i>	acquire, display, & record data	Still in development	Acquire, display and record swathe & seismic bathymetry data	DiGimap	DA-100 or DA-200
<i>CODA-Mosaic</i>	Image processing	\$12,792.00	Post Processing	Milford Haven Port Authority	DA-100 or DA-200

Table 5.4 Processing Tools (continued)

Model	Sub-Type	Cost	Description	Tool Ref	Tool Req
<i>CODA-DA100</i>	acquisition and processing	\$35,102.00	TVG, slant range cor, 2 channelwaterfall	C & C Technologies	GPS & sensor input
<i>CODA-DA200</i>	multiple acquisition, display, and interpretation	\$47,992.00	Acquisition sidescan sonar and sub-bottom profiler.	Milford Haven Port Authority	Towfish
<i>Polaris-EOSCAN</i>	Acquisition and processing	\$23,000.00	Data acquisition	U of Rhode Island	Exabyte download capabilities
<i>Triton Erics ISIS</i>	Acquisition and processing	\$67,500.00	data acquisition, display, and mosaic	Fugro West	Data recorder, Towfish, positioning system
<i>Polaris-EOMAP</i>	Image processing	\$9,000.00	Digital Mosaic software	U of Rhode Island	400mhz pentium computer
<i>Polaris-EOSCAN LTE</i>	Acquisition and processing	\$18,000.00	Simplified version of EOSCAN	U of Rhode Island	Used with analog sss systems
<i>Edgetech-260</i>	Data aquistion & Thermal printer	\$36,900.00	Control, printer and acquisition for towvehicle	Moss Landing Laboratories	Data recorder, Towfish, positioning system
<i>Edgetech-Model 560D</i>	Sidescan sonar processor	\$12,500.00	data acquisition, display and control	Seafloor Systems	Towfish, positioning system
<i>Edgetech-DF-1000</i>	Digital Control Interface	\$7,500.00	data acquistion, display and control	Seafloor Systems	Towfish, positioning

Table 5.4 Processing Tools (continued)

Model	Sub-Type	Cost	Description	Tool Ref	Tool Req
<i>Edgetech-MIDAS</i>	Data acquisition for DF-1000 fish	No response	data fusion	Racal pelagos	Towfish
<i>Datasonics-SIS-1500 Chirp Side Scan System</i>	Sidescan acquisition/processing	\$55,800.00	dsp of backscatter,mosaic upgrade available	Ocean Innovations	Towvehicle
<i>Datasonics-SIS-1000 Seafloor Imaging System</i>	Sidescan/sub-bottom acquisition/process	\$91,600.00	dsp w/Chirpscan3 software	Ocean Innovations	Towvehicle

Table 5.5 Seabed Classification Tools

Company	<i>Marine MicroSystems</i>	<i>Quester Tangent Inc</i>
Address	Offshore House, Clymore Dr, Bridge of Don, Aberdeen AB 23 8GD Scotland UK	99-9865 West Saanich Rd, Sidney BC Canada V8L5Y8
Phone	1-800-460-5789	250-656-6677
Contact	John Tamplin (503) 356-8717	Chris Elliot
Model	Roxann	QTC View
Reference	Rikk Kvitek Cal State University Monterey Bay	Robert McConaughey NMFS Alaska Fisheries Science Center
Cost	\$18,400.00	\$15,000.00
Description	software and processor	software and processor
Tool Requirements	486 DX 33, 200Mb Hard Disk, 4 Mb Ram, 4 RS232 ports, 0.5 Mb SVGA video card, 1 parallel port, for 15-210kHz, min depth of 0.5m max 1500m	486 DX2-66, 8 Mb RAM, Windows 3.1 or 95, one dedicated serial port, Rs 232 port, GPS NMEA 0183 standard, for freq of 22- 250kHz
Comments	Difficult to contact, Main office located in UK.	On-site assistance \$697/day, phone \$75/hr
Classifying values	E1 and E2	Q1, Q2, and Q3

Table 5.6 Electro-Optical Tools. Contains manufacturer, address, phone number and contact. Also, contains description of equipment, resolution, requirements, user, type of data output, and cost.

Tool	<i>LIDAR</i>	<i>Laser Line Scan</i>	<i>CASI</i>	<i>Satellite</i>
Manufacturer	NOAA, NASA	Raytheon	ITRES Research Limited	NOAA, Weather Service, Military
Address	2234 South Hobson Ave. Charleston SC 29405	141 Spring St Lexington MA 02421	Ste 155 East Atrium 37 Ave N.E. Calgary, Alberta Canada T1Y	NOAA NESDIS OSDPD E/SP, RM 1069, FB4 5200 Auth Road Suitland, MD 20746-4304
Phone	(843) 740-1200	(781) 862-6600	(403) 250-9944	(301) 457.5120
Contact	William Krabill	B.W. Coles	Jeff Lilycrop	Gary Davis
Description	airborne imaging system	Scaning laser to produce GB images	airborne imaging system	TM, multispectral images at various resolution
Resolution	10-15 cm	<1 m	1-10 m ² 288 spectral bands, 15m depth	1-30m
Requirements	aircraft	Processing software	Aircraft, 20 GB storage capacity	Access to data and proper GIS analytical software
User	NOAA, NASA, USGS	Scientific Application International Corporation	Tres research Limited	Various, govt, agriculture, environmental monitoring firms
Data Output	>1G	>5G	>5G dependant on survey area	variable
Cost	\$8,000.00-\$10,000.00 per square mile	Rental or purchase of data only. No response from SAIC on cost estimates.	\$8,000.00-\$10,000.00 per square mile	Purchase of data only. Price variable. Depends on coverage and resolution

Table 5.7 Survey Equipment Providers. Lists companies, contacts phone numbers and comments. Includes price of Side Scan Sonar, Single Beam Bathymetric and Processing equipment based upon daily (d), weekly (w), and monthly (m) rates.

<i>Company</i>	<i>Contact</i>	<i>Phone</i>	<i>SSS Rates</i>	<i>Bathy Rates</i>	<i>Processing Rates</i>	<i>Comments</i>
Rentmar	Chris Sabo	410-990-0566	No response	No response	No response	Low prices but questionable support/service. Sell and rent of equipment
Ashtead	Chris Flynn	281-398-9533	\$550(d) \$3465(w) \$13,200 (m)	\$95(d) \$599(w) \$2,280(m)	N/A	no min rental duration, rental period is "door to door", equip must be insured by renter. Reson 8101 \$900(d), \$5670(w) \$21,600(m)
						support \$500/day + exp, can provide all levels of tech assistance, reduced rate for 2-3 wk term, on call 24 hr
McQuest	Darren Keyes	905-639-0931	\$470(d), \$2491(w) \$8695(m)	\$75(d), \$397(w), \$1387(m)	\$120(d), \$636(w), \$2220(m)	Minimum rental 3-4 days, Support \$450/day + exp
GSE Rentals	Alan Cameron	+441224-771247	\$280(d), \$1960(w), \$7680(m)	\$120(d), \$840(w), \$3120(m)	N/A	On call 24hr, Do not pay for shipping time. All levels of support: installation to survey. SeaBat \$1080(d), \$7560(w), \$28800(m)
ORE	Carl Shue	281-879-727	No response	No response	No response	No response
Sonar Equipment	Les Ford	+441493-443363	\$1520(d), \$10,640(w))\$45,600(m)	\$288(d), \$2016(w), \$8,640(m)	N/A	Difficult to contact
						Freight is an extra %15

Table 5.8 University Contact List. Contains the university, contact, phone, survey capabilities and comments.

<i>University</i>	<i>Contact</i>	<i>Phone</i>	<i>Survey Capabilities</i>		<i>Comments</i>
			Full	Limited	
CSU Bakersfield	Rob Negrini	(661) 664-3027			no experience
CSU Chico	Vic Fischer	(530) 898-5266	X		no equip, limited GIS capability, hasn't done work before
CSU Fresno	Stephen Lewis	(209) 278-6956	X		no rapid response, leases or rents equip
CSU Fullerton	John Foster	(714) 278-7096			no experience
CSU Hayward	Calvin lee	(510) 885-3088	X		seismic, sss interp exp, use of MLML facilities
CSU Humboldt	Jeff Borgeld	(707) 826-3328	X		expertise, but no equip or GIS capability.
CSU Long Beach	Robert (Dan) Francis	(562)985-4929	X		seismic survey, analog only, no GIS
CSU Los Angeles	Ivan Colburn	(323) 343-2413			no experience
CSU Monterey Bay	Rikk Kvitek	(831) 582-3529	X		rapid response ability
Moss Landing Marine Laboratories	Gary Greene	(831) 633-7264	X		rapid response ability
CSU Northridge	Peter Fischer	(818) 677-3574			No response
CSU Pomona	John Klasik	(909) 869-3454			no experience
CSU Sacramento	Diane Carlson	(916) 278-6382			no experience
CSU San Bernardino	Sally McGill	(909) 880-5347			no experience
CSU San Diego	Clive Dorman	(619) 594-5707			no experience
CSU San Fancisco	Karen Grove	(415) 338-2061			no experience
CSU San Jose	Don Reed	(408) 924-5036	X		limited inshore exp, no equip, non-rapid response, limited GIS capability
CSU Sonoma	Tom Anderson	(707) 664-2176			no experience

Table 5.8 University Contact List (continued)

<i>University</i>	<i>Contact</i>	<i>Phone</i>	<i>Survey Capabilities</i>		<i>Comments</i>
			Full	Limited	
CSU Stanislaus	Mario Giaramita	(209) 3090	667-		no experience
CSU San Luis Obispo	Mark Moline	(805) 2948	756-		no experience
CSU Channel Islands	J. Handel Evans	(805) 8400	383-		no experience
CSU Dominguez Hills	David Sigurdson	(310) 3316	243-		no experience
CSU San Marcos	Dick Bray	(760) 4175	750-		no experience
UC Berkeley	William Dietrich	(510) 2633	642-		No response
UC Riverside	Carole Carpenter	(909) 3435	787-		no experience
UC San Diego	Christian de Mousier	(619) 6322	534-	X	min depth 10-20m, extensive experience, suited for deeper water only, rapid response capability
UC San Francisco	na	na			no experience, no dept; medical institution
UC Santa Barbara	Bruce Luyendyk	(805) 2827	893-		No response
UC Santa Cruz	J. Casey Moore	(831) 2574	459-	X	experience, no equip, no exp inshore
SCMI	Rick Piper	(310) 3172	519-	X	equip & vessels but no experienced personnel. Teaching
UC Davis	Jim McClain	(530) 7093	752-	X	limited inshore exp, no equip, non-rapid response
UC Irvine	Ellen Druffel	(949) 2116	824-		no experience
UC Los Angeles	Frank Kyte	(310) 2015	825-		No response
Summary	34 Universities contacted				
	4 non responses				
	8 Limited Capabilities				
	5 Full Survey Capabilities				
	17 Have No Experience or Capabilities				

Table 5.9 List of universities and with full survey capabilities. Lists capabilities for each university with cost estimates for three scenarios at two resolutions. Capability Symbols: MB= Multibeam, SSS= Side Scan Sonar, SBB= Single Beam Bathymetry, HC= Habitat Classification, GVC= Groundtruth Video/Classification, HI= Habitat Interpretation, GIS=GIS Habitat Vector Polygons, APS= Able to Produce Product from Scheme, R/L= Rent or Lease. Scenario A= 1 mile², 2 m posting, 1 m vertical resolution, Scenario B= 10 mile², 2 m posting, 1 m vertical resolution, Scenario C= 100 mile², 2 m posting, 1 m vertical resolution. Subscript 1=Backscatter resolution 20-50cm, Subscript 2=Backscatter resolution 1-2 m. NR= No response from contact.

University	Capabilities	Scenario	Scenario	Scenario	Scenario	Scenario	Scenario
		<i>A₁</i>	<i>A₂</i>	<i>B₁</i>	<i>B₂</i>	<i>C₁</i>	<i>C₂</i>
CSU San Jose	MB, SSS, SBB, HI, GIS, APS, R/L	NR	NR	NR	NR	NR	NR
CSU Monterey Bay	MB (pending), SSS, SBB, HC, GVC, HI, GIS, APS	\$10,000.00	\$6,000.00	\$100,000.00	\$60,000.00	\$1,000,000.00	\$600,000.00
CSU Fresno	MB, SSS, SBB, HI, GIS, APS, R/L	NR	NR	NR	NR	NR	NR
Moss Landing Marine Laboratories	MB, SSS, SBB, HC, GVC, HI, GIS, APS	\$10,000.00	\$6,000.00	\$100,000.00	\$60,000.00	\$1,000,000.00	\$600,000.00

Table 5.10 Agencies Involved in Habitat Mapping. Contains the agency, contact, phone number, address, related projects, description of work, and tools used.

Agency	<i>Coastal Service Center</i>	<i>USGS</i>	<i>Army Corp Of Engineers</i>	<i>Naval PostGraduate School</i>	<i>NFMS</i>	<i>MBARI</i>	<i>Mineral Management Services</i>
Contact	William Krabill	James Gardner	Lee Estip	James Lynch	Robert McConaughey	Gerry Hatcher	Daniel Leedy
Phone	301-713-2770	(650) 329-5469	(213) 452-3675	(831) 656-3268	(206) 526-4000	(831) 775-1700	(805) 389-7818
Address	1315 East West Highway Silver Spring, Maryland 20910-3285	U.S. Geological Survey 345 Middlefield Road Menlo Park, California 94025-3591	Waterways Experiment Station, 3909 Falls Ferry Road Vicksburg, Mississippi USA	1 University Circle Monterey, CA 93943	7600 Sand Point Way NE, Seattle WA 98115	7700 Sandholdt Road P.O. Box 628 Moss Landing, CA 95039-0628	Environmental Assessment 770 Paseo Camarillo 2 nd Floor Camarillo CA 93010
Projects	Assesment of Coastal Erosion	Various	SHOALS	Error Sources and Their Mitigation for PPS Shipborne Systems	Fish Habitat Management	Hawaii Mapping Project	Geological and Petroleum management
Description	Evaluation of beach/dune morphology, catastrophic coastal change, and erosion	Coastal Mapping Project	Coastal Mapping Project using fixed wing aircraft	Testing Precise Positioning Service Novel uses of shipboard high accuracy positioning	Habitat mapping Rockfish fishery management	Deep Water geologic evaluation. Deep water habitat assesment	Inner Channel Islands surveys
Tools	LIDAR	Multibeam, Side Scan Sonar	LIDAR CASI BATHYMETRY	Multibeam Side Scan Sonar Single Beam Bathymetry	Single Beam Bathymetry, QTC View Seabed Classification System	Single Beam Bathymetry, QTC View Seabed Classification System	Single Beam Bathymetry, QTC View Seabed Classification System

Table 5.11. Survey Service Providers. Contains company, contact, phone address web site, comments, references, capabilities, tools used, and bathymetry, substrate, and vertical resolution capabilities. Capability Symbols: MB= Multibeam, SSS= Side Scan Sonar, SBB= Single Beam Bathymetry, HC= Habitat Classification, GVC= Groundtruth Video/Classification, HI= Habitat Interpretation, GIS=GIS Habitat Vector Polygons, APS= Able to Produce Product from Scheme, R/L= Company Rents or Leases equipment. Does not own equipment.

Company	<i>Meridian</i>	<i>Fugro Group</i>	<i>Seabed Explorations</i>	<i>Canadian Seabed Research</i>	<i>Scientific Marine Services Inc</i>	<i>Racal Pelagos</i>
Contact	Tim Janitess	Robin Villa (VP)	Martin Morrison (President)	Patrick Campell	NA	Jerry Wilson
Phone	800-784-6336	(401) 562-8931	(902) 422-3688	(902) 827-4200	(760) 737-3505	(713) 784-4482
Address	1343 Ashton Rd Hanover, Maryland 21076	845 Industry Dr Hartford MA 01856	1675 Bedford Row 2nd Fl Halifax, Nova Scotia Canada B3J1t1	3737 Snowhomish Wy BC L2J3t4 Canada	101 State Place Ste N Escondido CA 92029	3624 Westchase Dr Houston TX 77042
Web site	www.mersci.com	www.fugro.ltd	www.seainc.ca	none	www.scimar.com	www.racal-survey.com
Comments		Extensive experience		LIDAR capabilities	No service available	Extensive experience
Reference	No response	AT&T, MCI	Dept of Fisheries and Oceans	Swiss Air Canadian Air Transportation	US ACE	US ACE NOAA
Capabilities	SSS, SBB, GIS	MB,SSS, SBB, GIS,GVC, HC, HI, APS	MB,SSS, SBB, GIS	SSS, SBB, GIS,GVC, HC, HI, APS	Engineering co. Subcontract's survey work	MB,SSS, SBB, GIS,GVC, HC, HI,
Tools	AMS 60 SSS Triton ISIS Ashtech GPS Remora ROV	Klein Reson ArcView	Klein Caris Simrad ArcView Variable	Klein Triton ISIS ArcView	NA	Reson Klein EG&G ArcView <2 m
Bathymetry	No response	<2 m	Variable	Variable	NA	<2 m
Substrate	No response	<1 m	<1 m	<1 m	NA	<1 m
Vertical	No response	<1 m	<1 m	<1 m	NA	<1 m

Table 5.11 Survey Service Providers (continued)

Company	<i>David Evans and Associates</i>	<i>C & C Technologies</i>	<i>Smedvig Technologies</i>	<i>W.L. Williamson & Associates Ltd</i>	<i>ABA Consultants</i>	<i>Office of Coast Survey</i>
Contact	Jon Dasler	Art Kleiner	NA	Nick Lesnikowski	Jim Oakden	William Krabill
Phone	(503) 223-6663	(318) 261-0660	(713) 339-2626	(206) 285-8273	(831) 479-0277	(301) 7 13-2770
Address	2828 S.W. Corbett Ave Portland, Oregon 972011	730 East Kaliste Saloon Road, Lafayette LA 70508	2925 Briarpark Dr Ste 1000 Houston, TX 77042	4200 23rd Ave W. Seattle WA 98199	PO Box 1151 Capitola CA 95010	1315 East West Highway Silver Spring, Maryland 20910-3285
Web site	www.deainc.com	www.cctechnol.com	www.smedtech.com	www.wassoc.com	none	www.noaa.gov
Comments	Large survey company. Extensive experience and resources	Expereince on West Coast	Oil surveys only. Won't do work.	Large trans-oceanic cable routing. Won't do small surveys	able to work inshore & in kelp beds	Evaluation of beach/dune morphology, catastrophic coastal change, and erosion
Reference	Idaho Power	NOAA MBARI USGS	NA	NA	Cal Trans, CF&G, Moss Landing Harbor District,	No response
Capabilities	MB,SSS, HC, GVC,HI, SBB, APS, GIS	MB,SSS, GIS	NA	SSS	MB,SSS, HC, GVC,HI, SBB, APS, GIS	MB,SSS, SBB, GIS
Tools	Reson Edgetech Caris ArcView	Simrad Coda Edgetech Triton ISIS	Sub bottom profilers	Reson AMS 150	Edgetech 260, Edgetech 272, Hypack, Triton Elics ISIS, Roxann	No response
Bathymetry	1 m	<1 m	NA	NA	1-3 m	No response
Substrate	<1 m	1 m	NA	NA	<1 m	No response
Vertical	Variable	1-3 m	NA	NA	<1 m	No response

Table 5.11 Survey Service Providers (continued)

Company	<i>EMC, Inc</i>	<i>Kenneth Balk & Associates</i>	<i>Science Applications International Corp</i>	<i>Seavisual Consulting Inc.</i>	<i>Hawaii Mapping Research Group</i>	<i>Western Subsea Technology Ltd.</i>
Contact	Mark Mattox	Ray Armstrong	Rod Evans	Terry Sulivan	Bruce Applegate	Mike Muirhead
Phone	(601) 453-0325	(314) 576-2021	(401) 847-4783	(503) 663-2894	(808) 956-9720	(250) 380-2830
Address	209 Main St Greenwood Miss 38930	1066 Executive Parkway PO Box 419038 St Louis Missouri 63141-9038	211 Third St Newport, RI 02840	29245 South East Stone Road Gresham, OR 97080	University of Hawaii HIG 205 2525 Correa Road HI, 96822	Pacific Marine Technology Center #1-203 Harbour Rd Victoria BC V9A3S2
Web site	www.emcsurvey.com	www.kba.net	www.saic.com	none	www.soest.hawaii.edu	www.islandnet.com/subsea
Comments	Extremely limited experience and capabilities	Limited shallow work. Large company, extensive experience and resources	LLS and LIDAR capabilities	Very limited capabilities	Specialized for deep water surveys	No response
Reference	None given	US ACOE	US ACOE NOAA MB,SSS, SBB, GIS,GVC, HC, HI, APS	Oregon Dept of Fish and Game MB,SSS, SBB, GIS	None given	No response
Capabilities	MB,SSB	MB,SSS, SBB, GIS			MB,SSS, SBB, GIS	SBB, GIS,GVC, HC, HI,
Tools	Hypack Reson	Roxann Reson Innerspace Hypack ArclInfo	Roxann Reson Innerspace Hypack ArclInfo	Reson	Proprietary research equipment	No response
Bathymetry	Variable	<2 m	<1	1-2 m	No response	No response
Substrate	Unknown	<1 m	<1	Unknown	No response	No response
Vertical	1-3 m	<1 m	<1	2 m	No response	No response

Table 5.11. Survey Service Providers (continued).

Company	<i>Geoprobe</i>	<i>ABS Marine Consultants</i>	<i>McKim & Creed</i>	<i>Atlantic Marine</i>	<i>Clydeside Surveys Limited</i>	<i>Coastal Geoscience Research</i>
Contact	Paul Kronfield	Kit Kuittinen	Tim Cawood	No response	No response	No response
Phone	(713) 974-3205	(707) 987-9567	(901) 251-8282	+44 (0)1273-248800	+44-1475-520394	(250) 380-6866
Address	No response	No response	243 North Front St. Wilmington, NC 28401	Maritime House Basin Road North Hove, East Sussex BN41WR UK	'Rowan' The Lane, Skelmorlie, Ayrshire, PA175AP, UK	2601 Scott St.Victoria B.C. V8R 4J1
Web site	www.geoprobe.com	www.absmarineconsultants.com	www.mckimcreed.com	www.atlanmar.demon.co.uk	www.clydesidesurveys.ltd.uk	www.tdw.doaktown.nb.ca/coastal
Comments	No response	ROV & submersible services	Most likely would subcontract work to SAIC or David Evans & Assoc.	No response	No response	No response
Reference	US ACOE Shell Oil	No response	Stromn Thurman Lake	No response	No response	No response
Capabilities	SSS, GIS	SSS, SBB,GVC	MB,SSS, SBB, GIS	MB,SSS, SBB, GIS	MB,SSS, SBB, GIS	MB,SSS, SBB, GIS
Tools	Edgetech	No response	Eckotrac Reson NA	No response	No response	No response
Bathymetry	No response	No response	NA	No response	No response	No response
Substrate	No response	No response	NA	No response	No response	No response
Vertical	No response	No response	NA	No response	No response	No response

Table 5.12 Survey Service Providers Quotes. Scenario A= 1 mile², 2 m posting, 1 m vertical resolution, Scenario B= 10 mile², 2 m posting, 1 m vertical resolution, Scenario C= 100 mile², 2 m posting, 1 m vertical resolution. Subscript 1=Backscatter resolution 20-50cm, Subscript 2=Backscatter resolution 1-2 m. Of the 24 private consulting firms contacted only four replied with cost estimates. All requests were made via phone and fax.

Company	<i>C & C Technologies</i>	<i>ABA Consultants</i>	<i>David Evans & Associates</i>	<i>Fugro West</i>
Reference	NOAA MBARI USGS	CF&G, Moss Landing Harbor District,	Idaho Power	AT&T, MCI
Scenario A1	\$87,600.00	\$10,000.00	\$25,000.00	\$18,480.00
Scenario B1	\$384,600.00	\$100,000.00	\$250,000.00	\$108,300.00
Scenario C1	\$3,414,000.00	\$1,000,000.00	\$2,500,000.00	\$1,006,500.00
Scenario A2	\$87,600.00	\$6,000.00	\$20,000.00	\$18,480.00
Scenario B2	\$384,600.00	\$60,000.00	\$200,000.00	\$108,300.00
Scenario C2	\$3,414,000.00	\$600,000.00	\$2,000,000.00	\$1,006,500.00

6. FINAL PRODUCT OPTIONS

A successful habitat mapping project should be planned from the top down. In addition to having identified the purpose, scope and scales of a project, the format and content of the final products should also be considered well in advance of field work and budgeting. Habitat data can be received and presented as: 1) raw or intermediate data, 2) hardcopy maps and 3) digital maps and GIS themes, 4) multimedia GIS and 3D rendering. Here we provide only a brief description of each of these options because they are not specific to marine habitat mapping, but are broadly considered by all those working with geospatial technology.

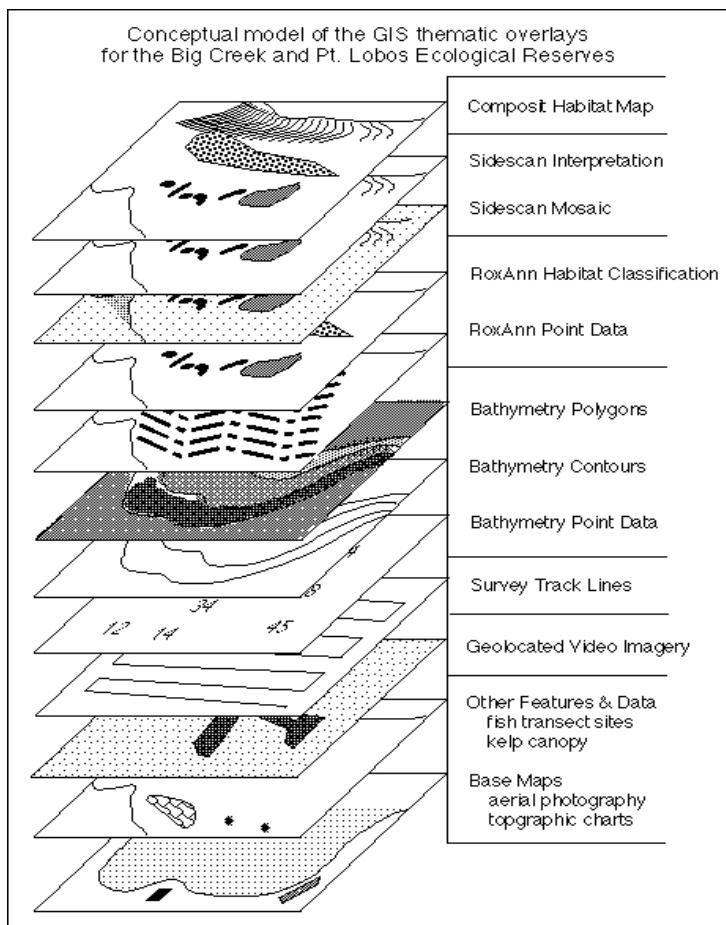


Figure 6.1. Conceptual model of how GIS can be used to combine data of diverse sources, formats and content for marine habitat analysis and classification.

Raw or intermediate data sets include x, y, z point data, gridded bathymetry, and raster backscatter imagery of substrates. Often, the first generation of data recorded from the sensor is stored in a proprietary format. This raw data is not only unreadable by other programs, but it usually requires some degree of filtering to remove spurious points and errors. Once filtered and checked for accurate georeferencing, the data is usually stored in a more generic format for additional processing and export to GIS. While raw and intermediate data are the most flexible, they also require advanced skills, training and technology for analysis, interpretation, display, and merging. Unless the end user has the capabilities

required to process data in these forms, they may be best served by requesting more finished products in addition to copies of the earlier data. These finished products might include depth contours, substrate interpretation in GIS themes compatible with those already held by the end user. Care must often be taken in specifying the correct datum, projection and coordinate system when GIS themes are to be combined. If the end user is not equipped to make use of GIS ready files, hardcopy maps may be the final product of choice.

While traditional and familiar, hardcopy paper maps are the least flexible, have the greatest limits to display resolution, scale, data density and layering, merging and updating, and dissemination. Combining kelp forest canopy coverage or interpretations from high-resolution (< 1m) sidescan sonar surveys with bathymetric contours for the entire width of the continental shelf would be pointless.

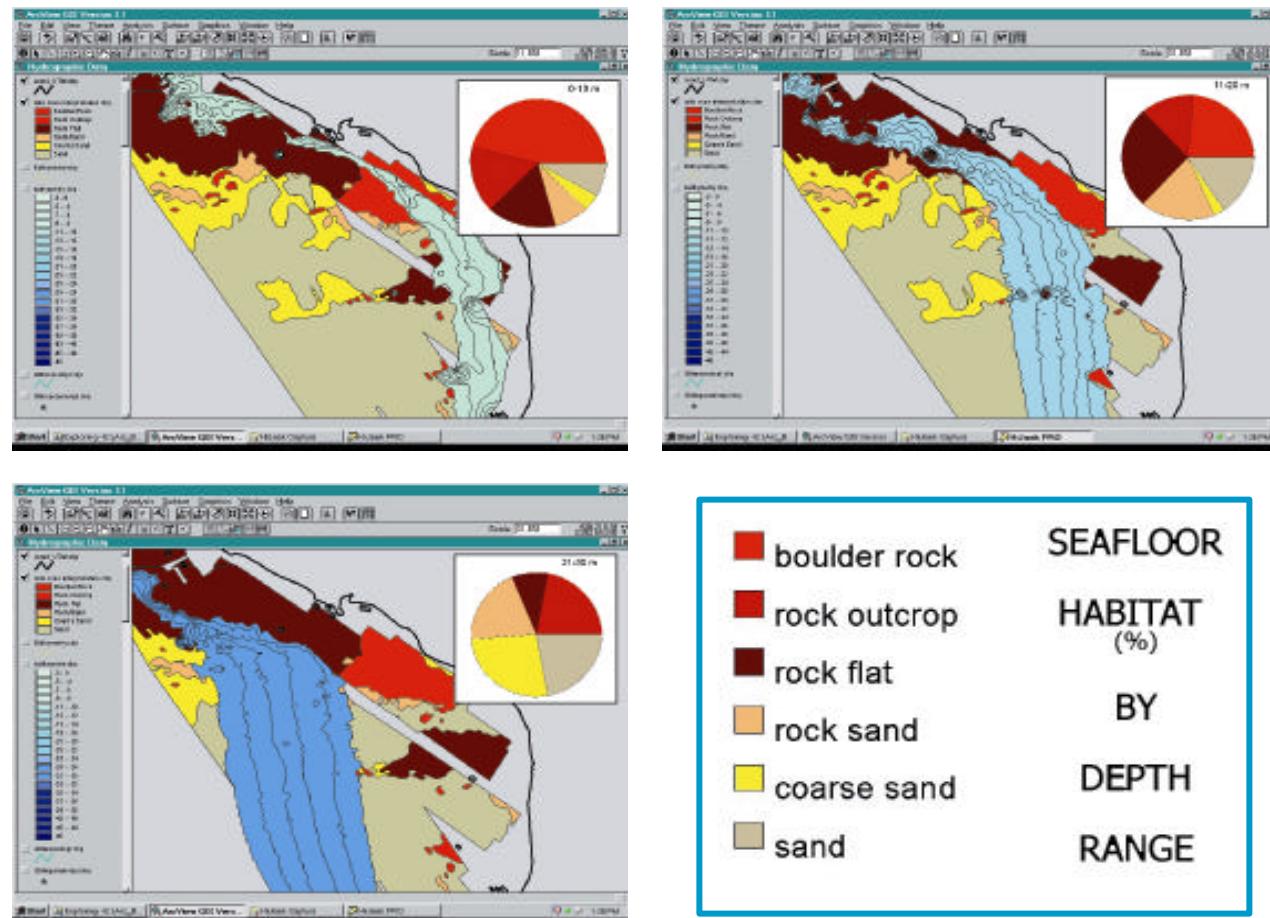


Figure 6.2. Habitat at Big Creek Marine Reserve sorted by depth and substrate type using GIS (authors' unpublished data).

Geographic Information Systems (GIS) are the most flexible and powerful means available for combining database, text, raster, vector, and CAD data, while maintaining the ability to layer, compare, and quarry data sets (Fig. 6.1). GIS also contributes to the ease of storing metadata, assessing and sorting by QA/QC, and displaying or exporting data in any coordinate system or datum. As a result, sidescan sonar images can be layered and displayed along with the substrate interpretation, and bathymetry contours, as well as species distribution or catch data as a means of assessing species/habitat associations. Indeed, the ability of GIS to use virtually any type of geocoded data to sort

and classify habitat by depth, substrate, slope and aspect makes it the single most powerful tool for habitat analysis available (Fig. 6.2). Simulated 3D fly-throughs of subtidal habitats can be created in some GIS programs by drawing a path in the plan-view of the area (Fig 6.3 left) to be followed by the 3D display view when the “flight” is initiated (Fig. 6.3 right). The 3D view is created by draping a plan view image of the area (e.g. sonograph, interpretation, aerial photograph, etc.) over a digital elevation model created from the bathymetric data.

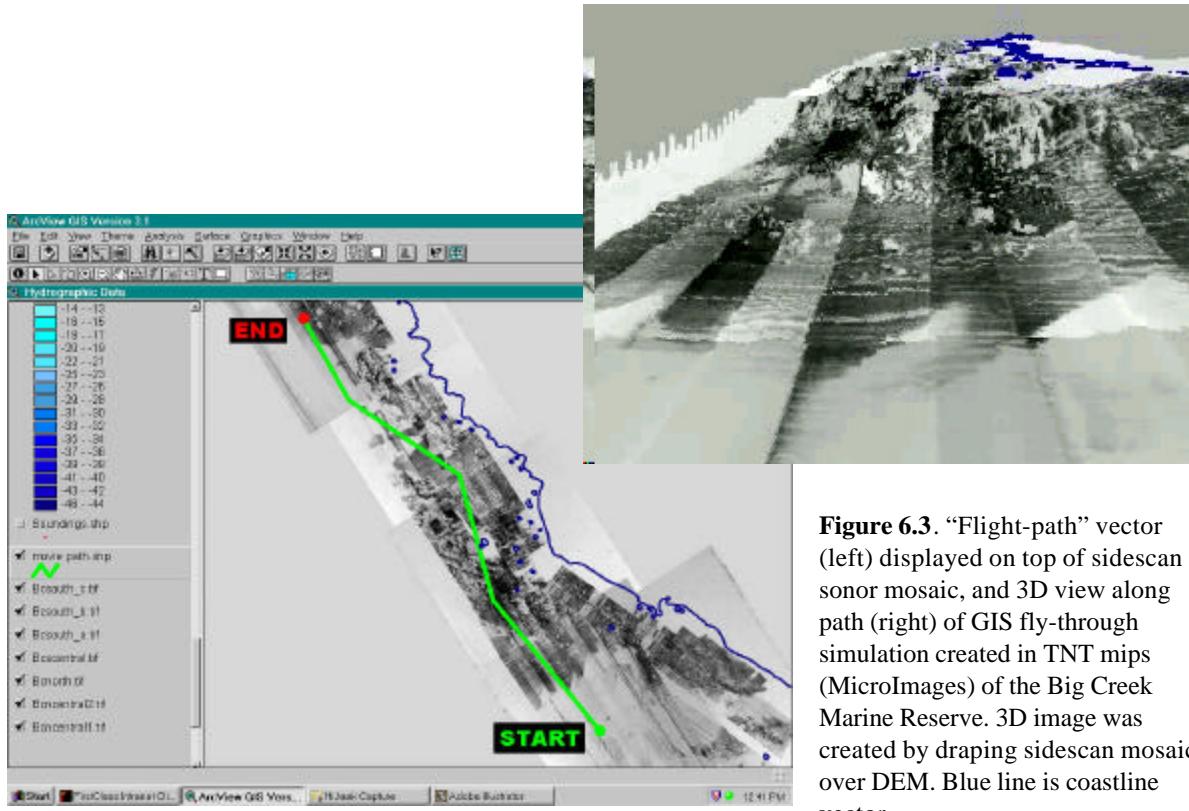


Figure 6.3. “Flight-path” vector (left) displayed on top of sidescan sonar mosaic, and 3D view along path (right) of GIS fly-through simulation created in TNT mips (MicroImages) of the Big Creek Marine Reserve. 3D image was created by draping sidescan mosaic over DEM. Blue line is coastline vector.

7. EXISTING SEAFLOOR SUBSTRATE DATA CATALOG (NEDP-TASK 2)

7.1. INTRODUCTION

The purpose of this portion of the project was to contribute to the completion of Task 2: Data Catalog, for the California Department of Fish and Game (DFG) Nearshore Ecosystem Database Project (NEDP). The Department's objective for this task was to conduct an assessment of currently available data not presently held by DFG on marine bathymetry and substrates, and to assess the adequacy of those data to meet their needs for defining and mapping nearshore habitats. The results from the assessments were to be entered as metadata into the CERES database Metadata Management System as part of the DFG Marine Region GIS Catalogue. Key issues were to include:

- From whom and where can the data be obtain?
- How old are the data?
- What is the resolution of the data?
- What is the accuracy of the data?
- How large are the data sets (what are the storage requirements)?
- How much do the data cost?
- What additional data are needed?

Data sets on depth and substrate were selected by the DFG because they are two of the most important physical habitat variables effecting the distribution and abundance of benthic and nearshore species (see sections 2 and 3). Because DFG took on the task of identifying and catalogue existing depth data (bathymetry) for California waters, we were instructed to restrict our search to identifying data sets relating to seafloor substrate, and to concentrate our efforts primarily on data within the 0-30m depth zone).

Our goal has been to create a Spatial Metadata Database for Seafloor Habitat Data containing all existing seafloor substrate data relevant to habitat mapping on the California continental shelf. Once combined with the CDF&G bathymetry data catalogue, this database will enable the Department to identify gaps in the existing data needed for mapping California's nearshore benthic habitats.

Our general approach was to contact all institutions, agencies and private companies likely to have data holdings related to seafloor substrate and request the relevant metadata. The majority of these types of data sets have been acquired using acoustic techniques (sidescan sonar, multibeam bathymetry with backscatter, or some type of acoustic ground discrimination sonar such as RoxAnn). Although newer electromagnetic technologies show great promise for increased data resolutions and efficiencies (see section 4), very few habitat mapping results have been obtain from these techniques along the California coast to date. For this reason, we focused our efforts on collecting metadata primarily on acoustic remote sensing survey results. DFG requested that we archive and append these metadata to the DFG Marine Regions GIS Catalogue within the CERES Metadata Management System using their existing Microsoft Access template for CERES Spatial Metadata entry (Fig. 7.1). The CERES database conforms to the Federal Geographic Data Committee Standard.

7.2. METHODS

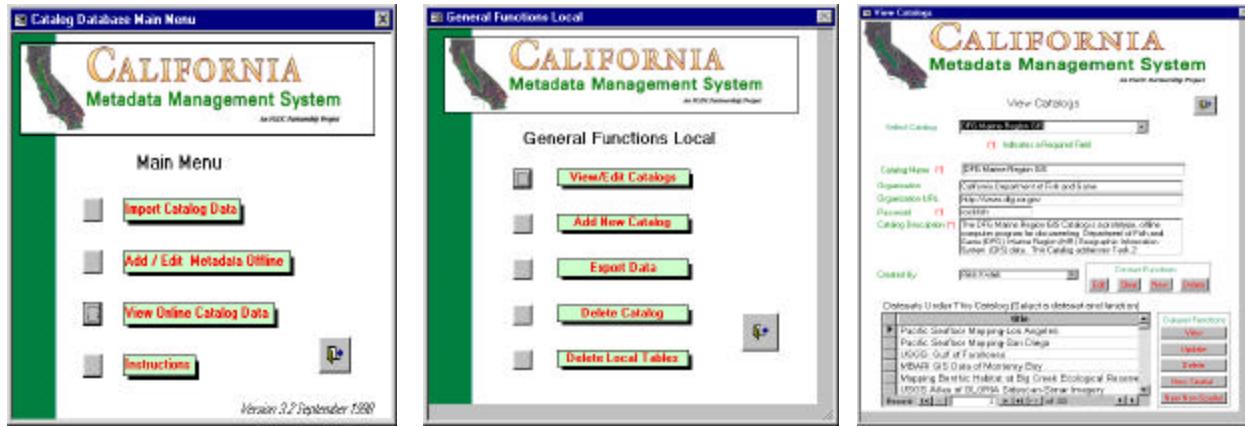
A variety of methods were used to locate appropriate data sets. The data search began using the Internet. Two different search engines (HotBot and AltaVista) were used on the following keywords: seafloor mapping, habitat mapping, sidescan sonar, bathymetry, and marine survey and habitat classification. The results of these searches were thoroughly checked and all leads followed for at least the first 200 matches.

The next step was to contact agencies and groups involved with hydrographic surveying activities along the California coast. This list included the United States Geological Survey(USGS), California Dept. of Mines and Geology(CDMG), Monterey Bay Aquarium Research Institute(MBARI), Army Corp Of Engineers, Mineral Management Services, Office of Naval Research(ONR), National Marine Fisheries-NOAA, National Geophysical Data Center(NGDC), Scientific Applications International Corporation(SAIC), Racal, Seafloor Surveys Inc., California State University Geology Chairs, UC Santa Barbara, UC Santa Cruz and UC San Diego. All of these agencies were contacted by phone and/or e-mail, and questioned as to their knowledge of existing data sets. If the contacts had data and were willing to share it then a metadata questionnaire was sent out to get the specific information we were looking for (see questionnaire below). Upon return these data were entered into the DFG Marine Region GIS Metadata Catalogue using the CERES Spatial Metadata Record template with Microsoft Access software (Fig. 7.1).

Questionnaire for Seafloor Substrate Metadata

- Data set name
- Data type
- Source
- Collector
- Date of Collection
- Date of Publication/completion
- Equipment used including age and/or version:
- Vessel-
- Hardware-
- Software-
- Collection method-
- What are the data resolution and accuracy?
- Is Product in raw data form, partially processed or is it a finished product, i.e. does it exist only as pretty pictures?
- If it is a finished product are the raw and/or intermediate files available for processing and interpretation?
- If data are unprocessed, is there a planned date for further processing?
- What QA/QC measures were followed during collection & processing of data?
- How was final product groundtruthed?
- Data file format and size-
- Spatial Extents and scale-
- Depth range-
- Contact-

- Availability/Access limits
- Cost
- AdditionalComment



a) Metadata database Main Menu. b) Path to catalogue records. c) Data record entry fields.

Figure 7.1 CERES Metadata Entry Template. The hierarchical sequence for entering metadata for each record into the DFG Marine Region GIS Spatial Metadata Database catalogue within CERES using the Microsoft Access template. While conforming to FGDC Standards, the predefined record fields in the Spatial Metadata Database were not always suitable for hydrographic data, thereby constraining the utility of the database for marine habitat mapping.

7.3. RESULTS

A total of 85 data sets have been catalogue to date after contacting 86 sources. Most of the catalogued data sets came from a relatively small number of sources (Table 7.1), and results from many of the contacted sources are still pending and will be added once received (Table 7.2). The majority of the institutions and individuals contacted did not have access to relevant data that could be contributed (Table 7.3). The metadata provided by these contacts are summarized in Table 7.4, and a complete listing of all information catalogued is accessible via the Ceres Spatial Metadata Records Database on the accompanying CD. Below we present an overview description of the major data resources on seafloor substrate available to DFG.

California Dept. of Conservation- Division of Mines and Geology/Moss Landing Marine Labs

In 1986 Gary Greene of the USGS and Michael Kennedy of the CDMG compiled all existing data available at that time for the state of California into a series of 1: 250,000 scale hardcopy maps entitled Geology of the California Continental Margin. Although the relatively coarse scale of this data set limits its usefulness for classifying habitats in the nearshore environment, these maps do provide a useful baseline to determine how much progress has been made in the intervening years in the field of habitat classification. The metadata for these geology maps are included in the database. An initial search of

Gary Green's holdings has been conducted to identify all potentially useful data, but it's possible that more relevant data exists there that were not found during this search.

US Geological Survey

The Pacific Mapping Group at Menlo Park headed by James Gardner responded with metadata information on four different surveys they ran using multibeam with backscatter. The four sites are the Santa Monica Bay area, the Eel River Delta, the mouth of San Francisco Bay, and an area off of San Diego. Through other contacts at USGS we also obtained metadata on a side scan survey done in the Gulf of the Farallones, and the GLORIA side scan project which has mapped the deep water areas of the entire coast. We are awaiting metadata on surveys done in the Monterey Bay, Big Sur, Ano Nuevo, Channel Islands and Santa Barbara areas by the USGS. Results from these later surveys have not yet been released for general distribution, but will undoubtedly be of value for coastal habitat mapping.

National Geodetic Data Center

The NGDC stores digital multibeam bathymetry data and analog sidescan sonar data collected by NOAA, UC San Diego, University of Rhode Island, Woods Hole, Lamont-Doherty Earth Observatory, University of New Hampshire and the University of Hawaii. Unfortunately the multibeam data does not contain backscatter information and the side scan data set is stored on 35mm micro film with no easy way of transferring to digital format. Furthermore, the side scan data has questionable positioning and there is no indication that data for California exists. Thus the usefulness of the NGDC data included in the database will be limited.

Monterey Bay Aquarium Research Institute

MBARI sent us a CD with bathymetric data and shaded relief imagery of seafloor morphology of the Monterey Canyon and surrounding areas. They have indicated that there will be more data forthcoming, but we have yet to receive it. An overview with examples of their data resources is also available on their web site. Although MBARI has undertaken an ambitious program of high resolution (1-2 m) multibeam and backscatter mapping along the California coast, the majority of their survey work and data have been restricted to depths below the continental shelf break (130 m water depth).

California State University Monterey Bay

California State University Monterey Bay has produced three data sets aimed specifically at habitat mapping which include sidescan with habitat interpretation, bathymetric contours and RoxAnn data. These data were collected at the Punta Gorda Ecological Refuge, the Big Creek Ecological Refuge and the Point Lobos Reserve as part of work done for DFG.

Ecoscan Resource Data

Over two decades worth of DFG aerial photographic transparencies covering California's central coast kelp forests are currently being archived by Bob VanWagenen of Ecoscan Resource Data. These 35 and 70 mm slides owned by DFG, have not been catalogued or converted to digital format. They could provide valuable information on the distribution and historic changes in kelp forest habitats once digitized, georeferenced and brought into GIS for analysis. Combining these time series photos with

substrate maps could provide new insights into how the seasonal distribution of kelp forests varies with physical habitat type.

Proprietary Data

It has become apparent that there are proprietary data that exist for the coast of California. Four of the survey companies, Williamson & Assoc., David Evans & Assoc., Fugro West and Racal/Pelagos, responded that while significant portions of the coast have been surveyed, the data are proprietary and thus must be tracked down from the client side to determine the coverage, type, value and availability of these data sets. Although we have not received responses from all the survey companies contacted, it is likely that their answers will also be tangled in issues of propriety. Those consulting companies we have contacted are not able to reveal their client list, but we have reason to believe that the largest customer groups are the communications (offshore cable routes) and petroleum industries. At this time we have not made any positive contacts with these industries, but continued effort in this direction may be warranted.

Office of Naval Research

We believe that the Office of Naval Research facility at the Stennis Space Center in Mississippi has vast holdings of seafloor mapping data that could be potentially useful. The person who has been responsible for these archives for many years has recently retired, and the replacement personnel have not been available since we tracked down this facility. An incomplete entry has been made in the database for this location so that this potential source can be pursued in the future. Information from other sources we have contacted suggest that while the Navy may have vast holdings of excellent high resolution side scan sonar data, the majority of these records are hardcopy sonographs with questionable positioning data. Thus, while the images may be very good, a great deal of processing and difficult georeferencing will be required to turn them into usable digital habitat data suitable for GIS applications. Nevertheless, an excellent peace time use of military personnel and resources might be to "mine" and process these archives for habitat mapping products.

Limitations of the CERES Spatial Metadata Record Template

The ability to accurately characterize and represent the results from seafloor mapping surveys was limited by the data entry fields currently available within the CERES Spatial Metadata Record template. As a result, a separate table called 'dataset_2' was created within the database. We linked the dataset_2 table to the original table containing the data entered into the CERES template. The fields in dataset_2 are: ApproxArea, GeoRegion, oid, Min Depth(m), Max Depth(m), Min Resolution, Max Resolution, Data Type and Hardware. None of these fields are visible in the front end of the database but they can be queried and used in reports. We believe that these fields contain some of the most vital information in terms of evaluating potential habitat data. Because these fields are not visible in the CERES template the relevant information from these fields has been recorded in the "Supplemental" field of the database. Also, because the CERES database limits entry of the survey area extents to the northern, southern, western and easternmost points of the data set, the area covered by the actual data may be exaggerated. For example, a long and narrow survey (e.g. 5 km x 0.5 km) running from NW to SE, which is typical for many nearshore coastal surveys, will be calculated to have a 5 km x 5 km

footprint. This error will result in an estimated survey area 10 times larger (25 km^2) than the area actually covered (2.5 km^2).

Primary sources & pending data

Most of the organizations contacted referred us to either the US Geological Survey, Gary Greene at Moss Landing Marine Labs or MBARI as the primary sources for seafloor data along the California continental shelf. We also encountered a fair amount of data that was judged by the contacts to be simply too old or having unreliable positioning information to be useful. These data sets were therefore not included in the database.

Throughout the course of this project we have made positive contacts that have yet to yield results in terms of metadata. Several scientists at USGS confirmed they had relevant data for which we are still waiting. The one survey company that didn't automatically decline to participate for reasons of client proprietary ownership was SAIC. While not being specific, this company did claim to have relevant data, but we have yet to receive the metadata they agreed to send. There are also at least two data sets collected by other CSU schools for which we are still awaiting the metadata. It is also likely that there are very recent datasets which will not be available for some time. We believe this is true for USGS at the very least.

7.4. CONCLUSIONS

A surprisingly small amount of habitat data has been collected for the nearshore California continental shelf since the 1986 Marine Geology of California maps were produced by Greene and Kennedy. Much of the data that we did find is questionable in its usefulness. High resolution, accurately georeferenced substrate data suitable for habitat mapping within the 0-30 m depth zone is extremely rare. Data scarcity within this zone is probably due to several factors:

- 1) shallow water and high relief make these waters inaccessible to the larger survey vessels typically used for seafloor mapping
- 2) sensor motion due to the high wave height to water depth ratio in these areas on most days of the year along the open coast results in highly distorted data from towed or hull mounted sensors aboard the smaller survey vessels required for nearshore work
- 3) sensor entanglement in kelp canopy has previously made nearshore acoustic surveys in many rocky areas virtually impossible
- 4) surf conditions often preclude safe survey operations within this depth zone
- 5) irregular shorelines and high bottom relief often prevent the use of more efficient long, straight survey track lines resulting in much higher survey times and costs

7.5. RECOMMENDATIONS

Greene and Kennedy developed the most comprehensive representation of seafloor substrate data in their 1986 1:250,000 scale maps of the entire California continental shelf. These maps were based on all the acoustic, observational and direct sampling information available at the time. Indeed, our search results show that little non-proprietary work appears to have been done in shallow waters since. These

maps were first developed at 1:50,000 scales, and then combined to yield a set of seven maps covering the shelf at a scale of 1:250,000. Developed as geology maps, these paper products represent the ideal starting point for classifying and mapping benthic habitats along the California coast. Our recommendations for producing habitat maps at sufficient resolution for managing the California nearshore environment are to:

- 1) convert the 1986 geology maps to GIS products
- 2) follow up on the Office of Naval Research archives and proprietary data sets identified in this report to see if any of these can be made available and are of use to this effort
- 3) augment the resulting GIS products with any of the newer, higher resolution substrate data identified in the metadata database that meet the standards for inclusion
- 4) use GIS to merge the resulting composite substrate coverages with the most accurate bathymetric data being compiled by DFG as part of the NEDP
- 5) apply a habitat classification system for converting the geologic descriptors to habitat types using GIS
- 6) verify the resulting habitat maps with modern remote sensing methods according to DFG site selection priorities
- 7) begin acquiring higher resolution habitat data (<1:50,000) based on DFG priorities for filling data gaps

The USGS is the most active group currently involved in mapping the California coast and they have indicated intentions of continued small-scale projects that may turn out to be useful for habitat mapping on the shelf. However, most of their past as well as planned survey work will be confined to depths beyond the 50m contour. As a result, following the completion of updating the small scale 1:250,000 geology maps produced by Greene and Kennedy in 1986, there is a clear need for a dedicated project to take on the task of mapping California's nearshore (0-30 m) environment at a much larger scale (<1:20,000). Finding ways to complete such a vast mapping effort will undoubtedly require the use of newer and more cost effective technologies for mapping large shallow subtidal areas at high resolution.

Table 7.1. Existing Seafloor Data Metadata Contacts. Organizations contacted that have existing seafloor data for which metadata has been received and catalogued in the CERES Spatial Metadata Database for Seafloor Habitat Data according to the Federal Geographic Data Committee (FGDC) Standard (<http://fgdc.er.usgs.gov/>). Data types catalogued include: multibeam bathymetry with backscatter data (mb/b), singlebeam bathymetry (b), sidescan sonar (sss), geologic interpretation of merged data sets (geologic interp.), Roxanne seafloor classification (rox), and photographic transparencies (35mm & 70mm slides). Each data record is referenced in the metadata catalogue with a unique three digit identifier number (Oid).

Organizations with Data	Contact Person	Contact Information	Data	Oids
			Type	

California Dept. of Conservation- Division of Mines and Geology/Moss Landing Marine Labs	Michael Kennedy Gary Greene	(213)620-3560 (831) 633-7264	geologic interp.	560, 563, 602, 604, 606, 608, 610, 612, 614, 616, 618, 620, 622, 624, 626, 628, 630, 632, 634, 636, 638, 640, 641, 643, 645, 647, 649, 651, 653, 655, 657, 659, 661, 663, 665, 669, 671, 672
Ecoscan Resource Data (ECI) for California Department of Fish and Game	Bob VanWagenen (ECI)	Vanwagenen@aol.com	35mm & 70mm slides	613
CSU Long Beach	Robert Francis	(562)985-4929	Sss	685

Table 7.1. Existing Seafloor Data Metadata Contacts. (Continued.)

CSU Monterey Bay	Rikk Kvitek	(831)582-3529	sss, rox	555, 557
US Army Corp of Engineers	Art Shak	(213)452-3675	LIDAR	681
Office of Naval Research	Bruce Layborn	(228)688-4075		680
Monterey Bay Research Institute	Gerry Hatcher and Norm Maher	gerry@mbari.org nmaher@mbari.org	bathy	444
ABA Consultants	James Oakden	(831)633-7252	Sss,rox	674, 676
National Geodetic Data Center	Robin Warnken	(303)497-6338	bathy	558
US Navy- CSC/SPAWAR	Marissa Caballero	(619)-553-5334		679
US Geological Survey	Pat S. Chavez Jr.	(520)556-7221	sss	443
US Geological Survey	James Gardner	(650)329-5469	mb/b	441, 442, 447, 448
US Geological Survey	Christine Gutmacher	(650)329-5309	sss	446, 565, 567, 569, 571, 573, 575, 577, 579, 581, 583, 585, 587, 589, 591, 593, 595, 597, 599
US Geological Survey	Roberto Anyma	(650)329-5212	Mb/b	683
US Geological Survey	Guy Cochrane	(650)329-5076	Sss	682
US Geological Survey	Steve Eittreim	(650)329-5272	Sss,mb, rox	678,684

US Geological Survey	http://walrus.wr.usgs.gov/docs/infoba/nk/bear/programs/html/years2idshtml/years.html	bathy	451, 453, 455, 457, 459, 461, 463, 465, 467, 471, 473, 475, 477, 479, 481, 483, 485, 487, 489, 491, 493, 495, 497, 499, 501, 503, 505, 507, 509, 511, 513, 515, 517, 519, 521, 523, 525, 527, 529, 544, 546, 548, 550, 552, 554
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Table 7.2 Pending Seafloor Data Metadata Contacts. Sources with existing seafloor data holdings for which the metadata have not yet been received by the authors as of this writing.

Organizations with Data	Contact person	Contact Information
ABS Marine Consultants	Kit Kuittinen	(707) 987-9567
Atlantic Marine		+44 1273-248800
C & C Technologies	Mike Dupuis	(318) 261-0660
Canadian Seabed Research	Rob Myers	(902) 827-4200
Clydeside Surveys Limited		+44-1475-520394
Coastal Geoscience Research		(250) 380-6866
CSU Hayward	Calvin Lee	(510) 885-3088
CSU Long Beach	Dan Francis	(562) 985-4929
CSU Northridge	Peter Fischer	(818) 677-3574
EMC, Inc		(601) 453-0325
Geoprobe	Paul Kronfield	(713) 974-3205
Hawaii Mapping Research Group	Bruce Applegate	(808) 956-9720
Kenneth Balk & Associates		(314) 576-2021
McKim & Creed	Tim Cawood	(901)343-1048
Meridian	Jonathan Snow	(410)562-8931
Mineral Management Services	James Lima	(805)389-7847
NOAA	Coastal Services Center	csc@csc.noaa.gov
Office of Coast Survey		(301) 713-2770
SAIC	Steve Miller	(401)847-4210
Science Applications International Corp	Rod Evans	(401) 847-4783
Scientific Marine Services Inc		(760) 737-3505
Seabed Explorations	Martin Morrison	(902)422-3688
Seavisual Consulting Inc.	Terry Sullivan	(503) 663-2894
Smedvig Technologies		(713) 339-2626
UC Berkely	William Dietrich	(510)642-2633
UC Santa Barbara	Milton Love	(805)893-2935
Scripps Institute of Oceanography	Michael Buckingham	(619)534-7977
US Geological Survey	Roberto Anima	(650)329-5212
US Geological Survey	Guy Cochrane	(650)329-5076
US Geological Survey	Steve Eittreim	(650)329-5272
Office of Naval Research	Bruce Layborn	(228)688-4075
Army Corp of Engineers	Art Shak	(213)452-3675
Western Subsea Technology Ltd.	Mike Muirhead	(250) 380-2830

Table 7.3 Contacted sources without seafloor habitat data. Potential sources contacted who did not have access to additional seafloor habitat data holdings for coastal California.

Organizations without Data	Contacts	Contact Information
Army Corp of Engineers	Frank Rezac	(415)977-8272
Army Corp of Engineers	Wayne Stroup	800-522-6937x2404
Army Corp of Engineers	Jack Kilgore	(601)634-3397
Ca Dept. Conservation- Mines & Geology	Dave Wagner	(916)445-1825
California Coastal Commision	J. Van Coutts	(408)427-4863
California State Lands Commision	Eric Coffman	(916)574-1879
California State Lands Commision	Arthur Mitsche	(805)966-7107
Caulfield Engineering	Dave Caulfield	(250)548-3244
Channel Islands National Marine Sanctuary	Ben Waltzenberger	(805)966-7107x461
CSU Bakersfield	Rob Negrini	(805) 664-2185
CSU Channel Islands	J Handel Evans	(805)383-8400
CSU Chico	Vic Fisher	(916) 898-5262
CSU Dominguez Hills	David Sigurdson	(310)243-3316
CSU Fresno	Stephen Lewis	(209) 278-6956
CSU Fullerton	John Foster	(714) 278-7096
CSU Humbolt	Jeff Borgeld	(707)826-3328
CSU Los Angeles	Ivan Colburn	(323) 343-2413
CSU Monterey Bay	John Stamm	(831) 582-3743
CSU Pomona	John Klasik	(909) 869-3454
CSU Sacramento	Diane Carlson	(916) 278-6382
CSU San Bernadino	Sally McGill	(909) 880-5347
CSU San Diego	Clive Dorman	(619) 594-5707
CSU San Francisco	Karen Grove	(415) 338-2061
CSU San Jose	Don Reed	(408)924-5036
CSU San Luis Obispo	Mark Moline	(805)756-2948
CSU San Marcos	Dick Bray	(760)750-4175
CSU Sonoma	Thomas Anderson	(707) 664-2176
CSU Stanislaus	Mario Giaramita	(209) 667-3090
David Evans & Associates	Jon Dasler	(503)223-6663
Fleet Numerical Meteorologic and Oceanographic Center	Carl Thormeyer	(831)656-4584
Fleet Numerical Meteorologic and Oceanographic Center	Mike Clancy	(831)656-4414
Fugro West	Sean Johnson	(805)658-0455
Gulf of Farallones National Marine Sanctuary	Dan Hallard	(415)561-6622
Menlo Scientific Acoustics	Neil Shaw	(310)455-2221
Monterey Bay Aquarium Research Inst.	David Clague	(831)775-1781
National Geodetic Data Center	Bill Virden	(303)497-7278

National Marine Fisheries Service	Bob Hoffman	(562)980-4043
National Marine Fisheries Service	Rich Cosgrove	(619)546-7057

Table 7.3 Contacted sources without seafloor habitat data. (Continued.)

National Marine Fisheries Service	Frank Schwing	(831)648-9034
Naval Postgraduate School	Bill Garwood	(831)656-2673
Newfoundland Ocean Ind. Assoc.		noia@nfld.com
NOAA	Ken Long	ken.long@noaa.gov
NOAA	Richard Wright	(619)594-5466
Office of Naval Research	Ellen Livingston	(703)696-4203
Racal Pelagos	Jerry Wilson	(713) 784-4482
Scripps Institute of Oceanography	Christian Demoustier	(619)534-6322
Seafloor Surveys Inc.	Frizbie Campbell	(206)441-9305
Southern California Coastal Water Research Project	Larry Cooper	(714)894-2222
Southern California Marine Institute	Rick Piper	(310)519-3172
UC Davis	Jim McClain	(530)752-7093
UC Irvine	Ellen Druffel	(949)824-2166
UC Merced	Joe Castro	(209)241-7120
UC Riverside	Carole Carpenter	(909)787-3435
UC Santa Barbara	Phil Sharfstein	pjs@magic.geol.ucsb.edu
UC Santa Cruz	Gary Griggs	(831)459-5006
UC Santa Cruz	Casey Moore	(831)459-2574
UCLA	Frank Kyte	(310)825-2015
University of Texas	John A. Goff	goff@utig.ig.utexas.edu
US Environmental Protection Agency	Bob Hall	(415)744-1936
US Fish and Wildlife Service	Jennifer Greiner	(703)358-2201
US Fish and Wildlife Service	Tony McKenzie	(916)979-2710
US Geological Survey	Peter Dartnell	(650)329-5460
US Geological Survey	Randy Hanson	(619)637-6839
US Geological Survey	Michael Carr	
Williamson & Associates		(206)285-8273

Table 7.4 Seafloor Substrate Metadata Search Summary. Summary of each record entered into the CERES DFG Marine Region GIS Metadata Catalogue as part of this project, and identified by its unique oid record number. *The ArcView script for calculating the entries for the Approximate Area covered by each data set is being completed, and these results will be added to the final table.* The extents of the data set are given as decimal degrees longitude and latitude. The Description of Data provided here is from the Supplement field in the database.

oid	Source	Data Type	Approx. Area	GeoRegion	Extents (N,S,E,W)	Description of Data
441	US Geological Survey	multibeam backscatter	Pending	Santa Monica Bay	37.55 37.15 -114.2 -115.23	Collector-- Dr. James V. Gardner Dataset name CS-1-96 & A-2-98 individual subareas vary in spatial resolution from 4m (bathy)/2 m (backscatter) to 16 m/8 m. Overview at 16 m/8 m. Bathymetry accuracy is function of water depth, but is at least as good as 0.04% water depth. Backscatter is calibrated albedo, referenced to 1 m from transducers. QA/QC by Patch test was conducted prior to survey; CTDs and XBT collected throughout survey to assure proper water velocity corrections; TSS/POS/MV motion sensor; dual DGPS with SkyFix reference for navigation. All data tide-corrected. Coordinate system, Datum, Projection-latitude/longitude; WGS84; Mercator. Depth range- 20 to 800 m Vessel- Coastal Surveyor & Ocean Alert
442	US Geological Survey	multibeam backscatter	Pending	San Diego	36.42 36.3 -113.5 -114.1	Collector-- Dr. James V. Gardner Dataset name A-2-98 Vessel- Ocean Alert Hardware- Kongsberg Simrad EM-300 Software- Swathed (OMG.UNB) Collection method- digital, spatial resolution from 4m (bathy)/2 m (backscatter) to 16 m/8 m. Bathymetry accuracy is function of water depth, but is at least as good as 0.04% water depth. Backscatter is calibrated albedo, referenced to 1 m from transducers.QA/QC Patch test was conducted prior to survey; CTDs and XBT collected throughout survey to assure proper water velocity corrections; TSS/POS/MV motion sensor; dual DGPS with SkyFix reference for navigation. All data tide-corrected Coordinate system, Datum, Projection-latitude/longitude; WGS84; Mercator. Depth range- 20 to 800 m

443	US Geological Survey	sidescan	Pending	Gulf of Farallones	37.8 37.1 -122.48 -123.6	Digital sidescan-sonar images collected by a high-resolution (one- to two-meter pixels) system were used as input for barrel detection analysis. The data were collected by the SeaMarc 1A sidescan sonar imaging system and cover an area approximately 50 km by 75 km.
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444	Monterey Bay	bathymetry	Pending	Monterey Bay	45	CD-ROM	Contains files under the headings of:	Features, Grids, Images,
	Aquarium				33	ASCII	and	Miscellaneous.These files are:
	Research				-117.249	Features-		
	Institute				-124.599	100mcont.shp - gridded contours		
						-10m_cont.shp - gridded contours		
						-200mcont.shp - gridded contours		
						-dnc_appr.shp - coastline w/1:50,000 scale and +/- 100m accuracy		
						-dnc_harb.shp - harbor coastline w/1:10,000 scale and +/- 50m accuracy		
						-faults.shp		
						landmask.shp - 1:50,000 and +/- 100m in Bay		
						moorings.shp		
						Grids	bathy20 - 20m grid	
						bathy200 - 200m grid		
						bathy20f - filtered 20m grid		
						hshd_dem - shaded DEM w/ 1:100,000 scale		
						hshd20 - shaded 20m grid		
						hshd200 - shaded 200m grid		
						hshd20f - shaded and filtered 20m grid		
						mont_dem - lattice DEM		
						Images		
						c18685.tif - NOAA Chart w/ 1:210,668 scale and +/- 15m accuracy		
						dem_sea.tif - Merged bathy and topo, +/- 100m accuracy		
						geology.tif - 1: 250,000 scale and +/- 300m accuracy		
						gryshade.tif - Bathy 20f w/ accuracy of +/- 100m		
						mb50sat.tif - Merged bathy and LandSat w/ accuracy +/- 500m		
						mb50slar.tif - Merged bathy and SLAR w/ accuracy of +/- 500m		
						landsat.tif - accuracy of +/- 50m		
						topo_map.tif - accuracy of +/- 250m		
					109	sidescan.tif - San Gregario fault zone		
						sseast.tif - Monterey Canyon w/ 7m/pixel resolution		

445	National Oceanic and Atmospheric Administration	sidescan	24.6km ²	Big Creek	36.13 36 -121.57 -121.68	Side scan sonar in depths from 30-200m
446	US Geological Survey	sidescan	Pending	California	42 32.53 -117.2 -126	GLORIA
447	Ocean Mapping Group, Univ. of New Brunswick	multibeam backscatter	Pending	Eel River Delta	41.083 40.65 -124.1 -124.57	<p>Collector-Dr. Larry A. Mayer Dataset name PH-1-96 spatial resolution from 4m (bathy)/2 m (backscatter) to 16 m/8 m. Bathymetry accuracy is function of water depth, but is at least as good as 0.04% water depth. Backscatter is calibrated albedo, referenced to 1 m from transducers.QA/QC Patch test was conducted prior to survey; CTDs and XBT collected throughout survey to assure proper water velocity corrections; TSS/POS/MV motion sensor; dual DGPS with SkyFix reference for navigation. All data tide-corrected. Groundtruthing by Box, gravity, and piston coring. Depth range- 20 to 600 m.</p> <p>Vessel- Pacific Hunter</p> <p>Hardware- Kongsberg Simrad EM-1000</p> <p>Software- Swathed (OMG.UNB)</p> <p>Collection method- digital Coordinate system, Datum, Projection- latitude/longitude; WGS84; Mercator</p>

448	US Geological Survey	multibeam backscatter	Pending	SF Bay	37.9 37.8 -122.39 -122.49	Collector-Dr. James V. Gardner Surveyor Hardware- Kongsberg Simrad EM-1000 Software- Swathed (OMG.UNB)	Dataset name	CS-1-97	Vessel-Coastal
						Collection method- digital, spatial resolution from 4m (bathy)/2 m (backscatter) to 16 m/8 m. Bathymetry accuracy is function of water depth, but is at least as good as 0.04% water depth. Backscatter is calibrated albedo, referenced to 1 m from transducers, QA/QC Patch test was conducted prior to survey; CTDs and XBT collected throughout survey to assure proper water velocity corrections; TSS/POS/MV motion sensor; dual DGPS with SkyFix reference for navigation. All data tide-corrected. Coordinate system, Datum, Projection-latitude/longitude; WGS84; Mercator. Depth range- 4 to 120 m			
451	US Geological Survey	bathymetry	Pending	Humbolt Bay	40.7711 40.7528 -124.2172 -124.2456	Survey conducted in 1984	Chief Scientist(John Dingler)		
453	US Geological Survey	bathymetry	Pending	Monterey Bay	37.0981 36.8041 -121.8943 -122.3805	Survey conducted in 1995,Chief Scientist Stevenson, Steve MONTEREY BAY MARINE SANCTUARY	(Roberto Anima, Andy Eittreim)		
455	US Geological Survey	bathymetry	Pending	Monterey Bay	37.1115 36.9184 -121.8671 -122.3648	Survey conducted in 1995,Chief Scientist Stevenson, Steve Eittreim) MONTEREY BAY NATIONAL MARINE SANCTUARY PROJECT	(Roberto Anima, Andy Eittreim)		
457	US Geological Survey	bathymetry	Pending	North Coast	42.7348 37.7072 -122.9749 -125.9102	Survey conducted in 1977	Chief Scientist(John Dingler)Bathymetry instrumentation 12 KHZ DIGITIZED BATHY 3.5 KHZ,Additional forms of bathymetric data Yes,General rate of bathymetry in file (unspecified)		
459	US Geological Survey	bathymetry	Pending	North Coast	37.8097 36.6068 -121.7967 -123.5573	Survey conducted in 1978	Chief Scientist(Gary Greene),Bathymetry instrumentation BATHYMETRY 12 KHZ BATHYMETRY 3.5KHZ		

461	US Geological Survey	bathymetry Pending	North Coast	39.5261 34.2581 -119.1586 -124.6121	Survey conducted in 1979 Chief Scientist(Gary Greene)
463	US Geological Survey	bathymetry Pending	SF Area	37.8477 37.1844 -122.2016 -123.5431	Survey conducted in 1979 Chief Scientist(Steve Eittreim), Bathymetry instrumentation (unspecified) Additional forms of bathymetric data (unspecified) General rate of bathymetry in file 1.1 minutes
465	US Geological Survey	bathymetry Pending	SF Area	39.5697 34.8838 -121.889 -126.2568	Survey conducted in 1984 Chief Scientist(BILL NORMARK),Bathymetry instrumentation(unspecified) Additional forms of bathymetric data (unspecified) General rate of bathymetry in file 2.4 minutes
467	US Geological Survey	bathymetry Pending	SF Area	38.4646 37.1539 -122.3008 -123.4518	Survey conducted in 1979 Chief Scientist(DAVE CACCHIONE, DAVE DRAKE) Bathymetry instrumentation (unspecified)
471	US Geological Survey	bathymetry Pending	Monterey Bay	36.7032 36.6074 -121.8121 -121.8863	Survey conducted in 1980 Chief Scientist(John Dingler),Bathymetry instrumentation (unspecified) Additional forms of bathymetric data (unspecified) General rate of bathymetry in file 1.0 minutes
473	US Geological Survey	bathymetry Pending	North Coast	44.8911 40.7209 -124.1286 -125.3529	Survey conducted in 1981 Chief Scientist(Sam Clarke, Mike Field, Parke Snavely) Bathymetry instrumentation 12KHZ NARROW 1SEC,3.5KHZ WIDE
475	US Geological Survey	bathymetry Pending	Monterey Bay	36.8365 36.4971 -121.7884 -121.9948	Survey conducted in 1981 Chief Scientist(John Dingler)

477	US Geological Survey	bathymetry Pending	San Mateo Coast	37.8191 34.0857 -119.2096 -122.6471	Survey conducted in 1981 Chief Scientist(Dave McCulloch) Bathymetry instrumentation 12KHZ NARROW 1 SEC, 3.5KHZ WIDE Additional forms of bathymetric data RECORDER ROLLS General rate of bathymetry in file (unspecified)
479	US Geological Survey	bathymetry Pending	SF Area	37.8336 37.1029 -122.1862 -123.0338	Survey conducted in 1981 Chief Scientist(Dave McCulloch) Bathymetry instrumentation 12KHZ NARROW 1 SEC, 3.5 KHZ WIDE Additional forms of bathymetric data RECORDER ROLLS General rate of bathymetry in file (unspecified)
481	US Geological Survey	bathymetry Pending	North Coast	41.7398 37.5118 -122.1882 -124.6569	Bathymetry instrumentation (unspecified) Additional forms of bathymetric data (unspecified) General rate of bathymetry in file 1.0 minutes General collection rate of bathymetry (unspecified) Assumed sound velocity 1463.0 m/sec
483	US Geological Survey	bathymetry Pending	SF Area	37.8351 37.4433 -122.1978 -123.6276	Survey conducted in 1982 Chief Scientist(TERRY KELLEY), Bathymetry instrumentation (unspecified) Additional forms of bathymetric data (unspecified) General rate of bathymetry in file 0.9 minutes
485	US Geological Survey	bathymetry Pending	SF Area	37.8387 34.0152 -122.1948 -123.49	Survey conducted in 1982 Chief Scientist(Don Tompkins),Bathymetry instrumentation (unspecified) Additional forms of bathymetric data (unspecified) General rate of bathymetry in file 0.8 minutes
487	US Geological Survey	bathymetry Pending	SF Area	37.8352 36.5244 -122.2276 -123.0654	Survey conducted in 1982 Chief Scientist(Dave McCulloch), Bathymetry instrumentation (unspecified),Additional forms of bathymetric data (unspecified),General rate of bathymetry in file 0.8 minutes

489	US Geological Survey	bathymetry Pending	North Coast	41.7567 41.7306 -124.1871 -124.211	Survey conducted in 1983 Chief Scientist(John Dingler)
491	US Geological Survey	bathymetry Pending	Big Sur	38.9693 33.6742 -118.21 -127.868	Survey conducted in 1984 Chief Scientist(JIM GARDNER, DAVE MCCULLOCH) Bathymetry instrumentation 3.5 KHZ Additional forms of bathymetric data (unspecified)
493	US Geological Survey	bathymetry Pending	North Coast	43.0418 38.2203 -123.5092 -129.3419	Survey conducted in 1984 Chief Scientist(DAVE CACCHIONE, DAVE DRAKE) Bathymetry instrumentation 3.5 KHZ
495	US Geological Survey	bathymetry Pending	North Coast	44.6513 37.8644 -122.7374 -124.8141	Survey conducted in 1985 Chief Scientist(MIKE FIELD, DAVE CACCHIONE) Bathymetry instrumentation (unspecified)
497	US Geological Survey	bathymetry Pending	SF Area	37.8345 37.471 -122.1912 -123.0471	Survey conducted in 1985 Chief Scientist(BOB HALL, MIKE TORRESAN) Bathymetry instrumentation (unspecified)
499	US Geological Survey	bathymetry Pending	SF Area	37.8666 37.1673 -122.1917 -123.5588	Survey conducted in 1985 Chief Scientist(BILL NORMARK, JAN MORTON) Bathymetry instrumentation (unspecified)
501	US Geological Survey	bathymetry Pending	North Coast	46.6212 37.7603 -122.3597 -126.6053	Survey conducted in 1986 Chief Scientist(DAVE DRAKE, DAVE CACCHIONE)
503	US Geological Survey	bathymetry Pending	N Coast Offshore	42.9149 40.7465 -124.1863 -127.8136	Survey conducted in 1986 Chief Scientist(DAVE CLAGUE, PETER RONA) Bathymetry instrumentation (unspecified)

505	US Geological Survey	bathymetry Pending	N Coast Offshore	41.0738 37.5881 -122.2269 -127.7148	Survey conducted in 1986 Bathymetry instrumentation Bathy 12 kHz Bathy 3.5 kHz	Chief Scientist(JAN MORTON)
507	US Geological Survey	bathymetry Pending	Pt. Reyes	38.0029 37.5071 -122.1934 -123.3872	Survey conducted in 1989 Chief Scientist(John Chin, Herman Karl, Bill Schwab)	
509	US Geological Survey	bathymetry Pending	SF Area	37.8345 37.1091 -122.1932 -123.6317	Survey conducted in 1990	Chief Scientist(HERMAN KARL, DAVE DRAKE)
511	US Geological Survey	bathymetry Pending	SF Area	38.0707 37.1622 -122.2008 -123.5319	Survey conducted in 1990	Chief Scientist(HERMAN KARL, DAVE DRAKE)
513	US Geological Survey	bathymetry Pending	North Coast	41.7676 37.763 -122.3808 -125.8284	Survey conducted in 1994	Chief Scientist(Ann Meltzer, Sam Clarke)
515	US Geological Survey	bathymetry Pending	SF Area	37.8242 37.0537 -122.1929 -123.3102	Survey conducted in 1994	Chief Scientist(Herman Karl)
517	US Geological Survey	bathymetry Pending	Big Sur	37.7153 32.4051 -117.3873 -123.6525	Survey conducted in 1972 Bathymetry instrumentation (unspecified)	Chief Scientist(Gary Greene, Eli Silver)
519	US Geological Survey	bathymetry Pending	South Coast	34.8004 32.49 -117.1478 -121.3818	Survey conducted in 1978 Bathymetry instrumentation 12 KHZ BATHY 3.5 KHZ BATHMETRY	Chief Scientist(GARY GREENE)

521	US Geological Survey	bathymetry Pending	Los Angeles	33.9168 33.5298 -117.9149 -119.0659	Survey conducted in 1978 DRAKE) Bathymetry instrumentation -12 KHZ BATHYMETRY 3.5 KHZ BATHYMETRY	Chief Scientist(DAVE CACCHIONE, DAVE
523	US Geological Survey	bathymetry Pending	S Coast Offshore	36.4325 32.1815 -117.6097 -124.621	Survey conducted in 1978	Chief Scientist(BILL NORMARK)
525	US Geological Survey	bathymetry Pending	Pt. Conception	36.3606 34.1341 -119.2357 -122.0314	Survey conducted in 1978 Bathymetry instrumentation (unspecified)	Chief Scientist(DAVE MCCULLOCH)
527	US Geological Survey	bathymetry Pending	South Coast	34.4063 33.2003 -118.3828 -120.5252	Survey conducted in 1981 Bathymetry instrumentation (unspecified)	Chief Scientist(BRIAN EDWARDS)
529	US Geological Survey	bathymetry Pending	South Coast	34.864 30.7953 -117.1378 -125.3672	Survey conducted in 1984 Bathymetry instrumentation 3.5 KHZ BATHY	Chief Scientist(MIKE FIELD, BRIAN EDWARDS)
544	US Geological Survey	bathymetry Pending	South Coast	34.6017 34.0822 -124.0107 -124.4843	Survey conducted in 1987 Bathymetry instrumentation 10 kHz bathy 12 kHz bathy 3.5	Chief Scientist(MIKE FIELD, JIM GARDNER)
546	US Geological Survey	bathymetry Pending	South Coast	36.2842 34.0178 -123.0124 -124.7272	Survey conducted in 1989	Chief Scientist(MIKE FIELD, JIM GARDNER)
548	US Geological Survey	bathymetry Pending	South Coast	36.6499 31.188 -117.3812 -122.0151	Survey conducted in 1990	Chief Scientist(BOB BOHANNON, STEVE EITTREIM)

550	US Geological Survey	bathymetry	Pending	Big Sur Offshore	37.832 33.728 -122.0106 -125.0181	Survey conducted in 1990) Chief Scientist(JIM GARDNER, DOUG MASSON
552	US Geological Survey	bathymetry	Pending	Palos Verdes	37.5024 33.517 -118.2169 -122.6505	Survey conducted in 1992 Chief Scientist(HERMAN KARL, MONTY HAMPTON)
554	US Geological Survey	bathymetry	Pending	South Coast	37.5101 33.277 -112.8973 -123.9548	Survey conducted in 1998 Chief Scientist(Bill Normark)
555	California State University Monterey Bay	sidescan, Roxann	Pending	Punta Gorda	40.2744 40.2386 -124.3527 -124.389	Projection -Albers Conical Equal Area Datum- NAD27, Navigation equipment used - Trimble 4000RL GPS receiver with PRO BEACON differential corrections applied for +/- 2m accuracy. Survey equipment - Innerspace analog bathymetric recorder and 208 kHz transducer. EG&G Model 260TH side-scan sonar recorder with model 272TD towfish. Marine Micro Systems RoxAnn bottom classification hardware. Hypack for Windows hydrographic survey software used to coordinate all systems and record bathymetric, RoxAnn and navigation data. The analog side-scan data was hand mosaiced, digitally scanned and incorporated into the GIS database. Survey vessel - DF&G Melanops The bathymetry is available as:raw data in ASCII format, in grids, and as contour files. Grid spacing - 20m. The final product consists of depth contour lines and polygons.

557	California State University Monterey Bay	sidescan, roxann	Pending	Big Creek	36.0924 36.0578 -121.5931 -121.6292	Projection -Lat/Long, Navigation equipment used - Trimble 4000RL GPS receiver with PRO BEACON differential corrections applied for +/- 2m accuracy. Survey equipment - Innerspace analog bathymetric recorder and 208 kHz transducer. EG&G Model 260TH side-scan sonar recorder with model 272TD towfish. Marine Micro Systems RoxAnn bottom classification hardware. Hypack for Windows hydrographic survey software used to coordinate all systems and record bathymetric, RoxAnn and navigation data. The analog side-scan data was hand mosaiced, digitally scanned and incorporated into the GIS database. Survey vessel - DF&G Melanops The bathymetry is available as: raw data in ASCII format, in grids, and as contour files. Grid spacing - 12m. The final product consists of depth contour lines and polygons
558	National Geodetic Data Center - NOAA	bathymetry	Pending	California	42 32 -117 -126	The National Ocean Service (NOS) Survey Data provides the most extensive digital bathymetric data available for the coastal waters of the continental United States, Alaska, Hawaii and Puerto Rico/Virgin Islands. Because the database contains depth values obtained during surveys, more detailed bathymetric information is available than can normally be found on published nautical charts. The dense inshore and shallow-water data are well suited for computer generation of grids to be used in hydrodynamic models of estuaries and other coastal systems. Both inshore data and the less dense offshore and deep-water data are valuable input to: bathymetric basemaps, Geographic Information Systems (GIS), geophysical exploration, coastal engineering studies, and other research purposes. This two disc CD-ROM set includes Header- and Data- Records (see below) stored in a compacted binary format. Also included on the CD-ROMs is custom menu-driven, GEODAS (GEophysical DAta System) software developed by NGDC specifically for managing geophysical and hydrographic data.
560	USGS, California Dept. of Conservation-Mines and Geology	subbottom	Pending	California	42 32 -117 -126	The series of maps representing the California Coastal Margin are broken up into 7 distinct geographic regions. These regions are classified as: Inner Southern, Mid-Southern, Outer-Southern, South-Central, Central, North-Central and Northen. All data is in hardcopy format

563	USGS, California Dept. of Conservation- Mines and Geology	subbottom	Pending	North Coast	42 40 -124 -126	This series of maps represents Area 7, the northernmost section of the California coast. There are 4 maps representing the geology, selected faults and earthquake epicenters, gravity and magnetic anomaly, and well, trackline and data source classifications
565	US Geological Survey	sidescan	Pending	Far North	42 40 -127 -129	Quad 22 is one of the northern most quads and at that latitude is the farthest west. GLORIA data for California. There is close to full coverage within the given extents
567	US Geological Survey	sidescan	Pending	Far North	42 40 -125 -127	Quad 21 is one of the northern most quads and is longitudinally centered between the other datasets at this latitude. GLORIA data for California. There is full coverage within the given extents
569	US Geological Survey	sidescan	Pending	Far North	42 40 -124.55 -125	Quad 20 is one of the northern most quads and at that latitude is the nearest to shore. GLORIA data for California. There is close to full coverage within the given extents however this is a very SMALL QUAD relative to the others.
571	US Geological Survey	sidescan	Pending	Mendicino	40 38 -127 -129	Quad 19 is one of the northern quads and at that latitude is the farthest west. GLORIA data for California. There is approximately 75% data coverage extending from the north-east corner within the given extents
573	US Geological Survey	sidescan	Pending	Mendicino	40 38 -125 -127	Quad 18 is one of the northern quads and at that latitude it is centered between the other datasets. GLORIA data for California. There is full coverage within the given extents
575	US Geological Survey	sidescan	Pending	Mendicino	40 38 -123 -125	Quad 17 is one of the northern quads and at that latitude it is nearest to shore. GLORIA data for California. There is approximately 50% coverage extending from the western boundary within the given extents
577	US Geological Survey	sidescan	Pending	Central Coast	38 36 -127 -129	Quad 16 is located in the central part of the state off of San Francisco. It is the western most quad at this latitude. There is less than 50% coverage extending from the north_east corner within the given extents

579	US Geological Survey	sidescan	Pending	Central Coast	38 36 -125 -127	Quad 15 is located in the central part of the state off of San Francisco. It is next to the western most quad at this latitude. There is close to full coverage within the given extents
581	US Geological Survey	sidescan	Pending	Central Coast	38 36 -123 -125	Quad 14 is located in the central part of the state off of San Francisco. It is next to the nearest shore quad at this latitude. There is close to full coverage within the given extents
583	US Geological Survey	sidescan	Pending	Central Coast	38 36 -121 -123	Quad 13 is located in the central part of the state off of San Francisco. It is the nearest shore quad at this latitude. There is less than 50% coverage extending from the south-west corner within the given extents
585	US Geological Survey	sidescan	Pending	Southern Cal	36 34 -125 -127	Quad 12 is located in the south central part of the state off of Pt. Conception. It is the western most quad at this latitude. There is less than 50% coverage extending from the north-east corner within the given extents
587	US Geological Survey	sidescan	Pending	Southern Cal	36 34 -123 -125	Quad 11 is located in the south central part of the state off of Pt. Conception. It is next to the western most quad at this latitude. There is close to full coverage within the given extents
589	US Geological Survey	sidescan	Pending	Southern Cal	36 34 -121 -123	Quad 10 is located in the south central part of the state off of Pt. Conception. It is next to the nearest shore quad at this latitude. There is close to full coverage within the given extents
591	US Geological Survey	sidescan	Pending	Southern Cal	36 34 -119 -121	Quad 9 is located in the south central part of the state off of Pt. Conception. It is the nearest shore quad at this latitude. There is less than 25% coverage extending from the south-west corner within the given extents
593	US Geological Survey	sidescan	Pending	Far South	34 32 -123 -125	Quad 8 is located in the far southern section of the state. It is the farthest west quad at this latitude. There is approximately 50% coverage extending from the north-east corner within the given extents

595	US Geological Survey	sidescan	Pending	Far South	34 32 -121 -123	Quad 7 is located in the far southern section of the state. It is next to the farthest west quad at this latitude. There is full coverage within the given extents
597	US Geological Survey	sidescan	Pending	Far South	34 32 -119 -121	Quad 6 is located in the far southern section of the state. It is next to the nearest shore quad at this latitude. There is approximately 80% coverage within the given extents
599	US Geological Survey	sidescan	Pending	Far South	34 32 -117 -119	Quad 5 is located in the far southern section of the state. It is the nearest shore quad at this latitude. There is approximately 50% coverage from the west boundary within the given extents
602	USGS, California Dept. of Conservation-Mines and Geology	subbottom, bathymetry	Pending	Mendicino Coast	40 38.01 -122.85 -124.86	This series of maps represents Area 6, the Mendicino coast section of the California coast. There are 4 maps representing the geology, selected faults and earthquake epicenters, gravity and magnetic anomaly, and well, trackline and data source classifications
604	USGS, California Dept. of Conservation-Mines and Geology	subbottom, bathymetry	Pending	Central Coast	38.01 36.01 -121.53 -123.53	This series of maps represents Area 5, the central coast section of the California coast. There are 4 maps representing the geology, selected faults and earthquake epicenters, gravity and magnetic anomaly, and well, trackline and data source classifications
606	USGS, California Dept. of Conservation-Mines and Geology	subbottom, bathymetry	Pending	Big Sur Coast	36.01 33.99 -119.93 -121.94	This series of maps represents Area 4, the Big Sur coast section of the California coast. There are 4 maps representing the geology, selected faults and earthquake epicenters, gravity and magnetic anomaly, and well, trackline and data source classifications

608	USGS, California Dept. of Conservation- Mines and Geology	subbottom, Pending bathymetry	Channel Islands	33.99 32 -120 -121.94	This series of maps represents Area 3, the offshore, Channel Islands section of the California coast. There are 4 maps representing the geology, selected faults and earthquake epicenters, gravity and magnetic anomaly, and well, trackline and data source classifications	
610	USGS, California Dept. of Conservation- Mines and Geology	subbottom, Pending bathymetry	Los Angeles	34.5 32 118 120	This series of maps represents Area 2, the Los Angeles area of the California coast. There are 4 maps representing the geology, selected faults and earthquake epicenters, gravity and magnetic anomaly, and well, trackline and data source classifications.	
612	USGS, California Dept. of Conservation- Mines and Geology	subbottom, Pending bathymetry	San Diego	33.99 32 -115.91 -118	This series of maps represents Area 1, the southeastern most section of the California coast. There are 4 maps representing the geology, selected faults and earthquake epicenters, gravity and magnetic anomaly, and well, trackline and data source classifications	
613	California Dept. of Fish and Game	35mm slides	Pending	Central Coast	36.75 36.2 -121.8 -122	CA DFG: 1967 (at least a few), 70 (at least a few), 73, 74, 75, 76, 77, 78, 79, and 89; These 35 mm slides cover at least the area of the MTY peninsula and multiple flights were made in numerous years (the extent of the 89 survey was the entire CA coast). VanWagenen: 1980, 81, 82, 83, 84 (might be DFG's), 87, 88, 91, 92, 94, 97; Again, these 35 mm slides covered at least the MTY peninsula (and probably more). The 94 and 97 surveys are in 70 mm slide format. Monterey Bay Aquarium: 1985 - 1991, taken approx. monthly from Marina to Big Sur (excellent dataset!)
614	USGS- H. Gary Greene	unknown	Pending	Monterey Bay	37 36.5 -122 -123	A geologic interpretation. This map is on vellum. This map was used in the construction of the 'Geology of California Continental Margin' series produced by USGS and the California Dept. of Mines and Geology. The time period for this study is approximate.
616	USGS- H. Gary	unknown	Pending	Monterey Bay	37	A geologic interpretation. This map is on vellum. This map was used in the

	Greene				36.5 -122 -123	construction of the 'Geology of California Continental Margin' series produced by USGS and the California Dept. of Mines and Geology. The time period for this study is approximate.
618	USGS- H. Gary Greene	unknown	Pending	Upper Sur Slope	36.5 36 -121.92 -122.42	Preliminary geology and geomorphology. This map was used in the construction of the 'Geology of California Continental Margin' series produced by USGS and the California Dept. of Mines and Geology. The time period for this study is approximate.
620	USGS- H. Gary Greene	unknown	Pending	Lower Sur Slope	36.5 36 -122.42 -122.66	Preliminary geology and geomorphology. This map was used in the construction of the 'Geology of California Continental Margin' series produced by USGS and the California Dept. of Mines and Geology. The time period for this study is approximate.
622	USGS- H. Gary Greene	unknown	Pending	Monterey Bay	36.5 36 -122.75 -123	Preliminary geology and geomorphology. This map was used in the construction of the 'Geology of California Continental Margin' series produced by USGS and the California Dept. of Mines and Geology. The time period for this study is approximate.
624	USGS- H. Gary Greene	unknown	Pending	Monterey Bay	36.42 36.08 -122.75 -123	Preliminary geology. This map was used in the construction of the 'Geology of California Continental Margin' series produced by USGS and the California Dept. of Mines and Geology. The time period for this study is approximate.
626	USGS- H. Gary Greene	unknown	Pending	Central Coast	37 36.5 -121.83 -123	Preliminary geology and geomorphology. This map was used in the construction of the 'Geology of California Continental Margin' series produced by USGS and the California Dept. of Mines and Geology. The time period for this study is approximate.
628	USGS- H. Gary Greene	unknown	Pending	Central Coast	37 36.5 -121.83 -123	Geology and geomorphology. This map was used in the construction of the 'Geology of California Continental Margin' series produced by USGS and the California Dept. of Mines and Geology. The time period for this study is approximate.
630	USGS- H. Gary Greene	unknown	Pending	Monterey Bay	36.5 36 -122.75 -123	A geologic interpretation. This copy is on vellum. This map was used in the construction of the 'Geology of California Continental Margin' series produced by USGS and the California Dept. of Mines and Geology. The time period for this study is approximate.

632	USGS- H. Gary Green	unknown	Pending	Monterey Bay	36.5 36 -122.75 -123	A geologic interpretation. This copy is on vellum. This map was used in the construction of the 'Geology of California Continental Margin' series produced by USGS and the California Dept. of Mines and Geology. The time period for this study is approximate.
634	USGS- H. Gary Greene	unknown	Pending	Big Sur	36.5 36 -122 -122.33	A geologic interpretation. This map was used in the construction of the 'Geology of California Continental Margin' series produced by USGS and the California Dept. of Mines and Geology. The time period for this study is approximate.
636	USGS- H. Gary Greene	unknown	Pending	Southern California	33.66 33.5 -117.66 -117.83	A geologic interpretation. This map is on vellum. This map was used in the construction of the 'Geology of California Continental Margin' series produced by USGS and the California Dept. of Mines and Geology. The time period for this study is approximate.
638	USGS- H. Gary Greene	unknown	Pending	Southern California	33.66 33.5 -118 -118.33	A geologic interpretation. This map is on vellum. This map was used in the construction of the 'Geology of California Continental Margin' series produced by USGS and the California Dept. of Mines and Geology. The time period for this study is approximate.
640	USGS- H. Gary Greene	unknown	Pending	Southern California	33.66 33.5 -118 -118.33	Geologic structures. This map was used in the construction of the 'Geology of California Continental Margin' series produced by USGS and the California Dept. of Mines and Geology. The time period for this study is approximate.
641	USGS- H. Gary Greene	Magnetic Intensity	Pending	Ventura/Oxnard	34.33 33.92 -119 -119.5	Contour intervals of 25 gammas. This map is available as a negative. This map was used in the construction of the 'Geology of California Continental Margin' series produced by USGS and the California Dept. of Mines and Geology. The time period for this
643	USGS- H. Gary Greene	unknown	Pending	Ventura/Oxnard	34.33 33.92 -119 -119.5	Earthquake epicenters. This map is available as a negative. This map was used in the construction of the 'Geology of California Continental Margin' series produced by USGS and the California Dept. of Mines and Geology. The time period for this study is approximate.
647	USGS- H. Gary Greene	bottom grabs	Pending	Ventura/Oxnard	33.6 33 -119.5 -120	Sample sites. This map is available as a negative. Sample types are: dart cores, gravity cores, Van Veen, box cores and chain dredges. This map was used in the construction of the 'Geology of California Continental Margin' series produced by USGS and the California

649	USGS- H. Gary Greene	unknown	Pending	Santa Rosa Ridge	34 33.5 -119.5 -120.5	Survey tracklines. This map was used in the construction of the 'Geology of California Continental Margin' series produced by USGS and the California Dept. of Mines and Geology. The time period for this study is approximate.
651	USGS- H. Gary Greene	unknown	Pending	Mugu/Santa Monica	34 33.5 -118.33 -119.17	Geologic Interpretation. This map was used in the construction of the 'Geology of California Continental Margin' series produced by USGS and the California Dept. of Mines and Geology. The time period for this study is approximate.
653	USGS- H. Gary Greene	unknown	Pending	Tanner-Cortes Bank	32.83 32.25 -118.83 -119.5	Preliminary geology. This map is available as a negative. This map was used in the construction of the 'Geology of California Continental Margin' series produced by USGS and the California Dept. of Mines and Geology. The time period for this study is approximate.
655	USGS- H. Gary Greene	Seismic Reflection	Pending	San Pedro	33.58 33.42 -117.83 -118.17	High resolution seismic reflection. This map was used in the construction of the 'Geology of California Continental Margin' series produced by USGS and the California Dept. of Mines and Geology. The time period for this study is approximate.
657	USGS- H. Gary Greene	unknown	Pending	San Pedro	33.58 33.42 -117.83 -118.17	Geologic Interpretation. This map was used in the construction of the 'Geology of California Continental Margin' series produced by USGS and the California Dept. of Mines and Geology. The time period for this study is approximate.
659	USGS- H. Gary Greene	Seismic Reflection	Pending	Santa Cruz	37.2 36.8 -122.2 -123	High resolution seismic reflection. The geolocation of this map is approximated. This map is available as a negative. This map was used in the construction of the 'Geology of California Continental Margin' series produced by USGS and the California Dept. of Mines and Geology. The time pe
661	USGS- H. Gary Greene	unknown	Pending	Mugu/Santa Monica	34.17 33.5 -118.42 -119.08	Geologic Interpretation. This map was used in the construction of the 'Geology of California Continental Margin' series produced by USGS and the California Dept. of Mines and Geology. The time period for this study is approximate.
663	USGS- H. Gary Greene	multibeam	Pending	Monterey Bay	36.5 36 -122.42	Slumps from Seabeam data. This map was used in the construction of the 'Geology of California Continental Margin' series produced by USGS and the California Dept. of Mines and Geology. The time period for this study is

					-122.66	approximate.
665	USGS- H. Gary Greene	unknown	Pending	Monterey Bay	37.25 36.25 -121.25 -122.5	Geologic interpretation. This map was used in the construction of the 'Geology of California Continental Margin' series produced by USGS and the California Dept. of Mines and Geology.
669	USGS- H. Gary Greene	bottom grabs	Pending	San Pedro	33 32.5 -117.25 -117.5	Sample sites. This map is available as a negative. Sample types are: dart cores, gravity cores, Van Veen, box cores and chain dredges. This map was used in the construction of the 'Geology of California Continental Margin' series produced by USGS and the California
671	USGS- H. Gary Greene	unknown	Pending	San Pedro	33.1 32.75 -117.25 -117.75	Survey tracklines. This map is available as a negative. This map was used in the construction of the 'Geology of California Continental Margin' series produced by USGS and the California Dept. of Mines and Geology. The time period for this study is approximate.
672	USGS- H. Gary Greene	unknown	Pending	Santa Barbara	34.5 34 -120 -120.5	Seismotectonics. This map contains information on faults and folds. This map was used in the construction of the 'Geology of California Continental Margin' series produced by USGS and the California Dept. of Mines and Geology.
674	ABA Consultants	sidescan, roxann	Pending	Big Sur	36.164 36.1585 -121.674 -121.681	Navigation equipment used - Trimble 4000RL GPS receiver with PRO BEACON differential corrections applied for +/- 2m accuracy used for the 1997 and 1998 surveys. For the earlier surveys a 4000RL GPS receiver was used as a base station transmitter in con
676	ABA Consultants	sidescan, roxann	Pending	Marin Coast	37.881 37.854 -122.582 -122.646	Navigation equipment used - Trimble 4000RL GPS receiver used in conjunction with a 2nd 4000RL transmitting base station position information for +/- 2m accuracy. Survey equipment - Innerspace analog bathymetric recorder and 208 kHz transd
678	USGS- Steve Eittreim	sidescan,m ultibeam, roxann	Pending	Ft. Ord	36.775 36.6 -121.83 -122	Navigation equipment used - Trimble 4000RL GPS receiver used in conjunction with a 2nd 4000RL transmitting base station position information for +/- 2m accuracy. Survey equipment -Simrad EM-1000 multibeam system, Innerspace analog bathyme
679	U. S. Navy	unknown	Pending	San Diego Bay	32.74 32.61	The geolocation of this dataset is taken from a subset of 5,000 points and is therefore an approximation to the coverage of the entire dataset. The data

					-117.1 -117.24	can be downloaded directly from the website location following these instructions:
680	Office of Naval Research	unknown	Pending	California	42 32 -117 -126	So far we have been unable to contact the ONR at Stennis Space Center but we do have contact information. The spatial extents are estimated and the time period is unknown.
681	U.S. Army Corp of Engineers	LIDAR	Pending	Santa Monica	34 33.5 -118.33 -119.17	The metadata for this dataset has not yet been received. The spatial extents are estimated as is the time period.
682	U.S. Geologic Society	sidescan	Pending	Channel Islands	34.2 33.8 -119.7 -120.3	Metadata for the Channel Islands surveys has not yet been received. The spatial extents and time period are estimates.
683	U.S. Geologic Society	sidescan	Pending	Monterey Bay	37.17 36.83 -121.83 -123	Metadata for this project has not yet been received. The spatial extents are estimated.
684	U.S. Geologic Society	multibeam backscatter	Pending	Big Sur	36.25 36 -122 -122.5	The metadata for this survey has not yet been received. The spatial extents and time period are estimates.
685	CSU Long Beach	sidescan	Pending	Los Angeles Harbor	33.4 33.39 -117.69 -117.75	The metadata for this project has not yet been received. The spatial extents and time period are estimates.

8. BIBLIOGRAPHY

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