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

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 (ROV's), 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 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, Biogeograhic regions, species & fisheries range boundaries
1:500,000	500	25 ha	Regional	Megahabitats, Biogeograhic 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

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).

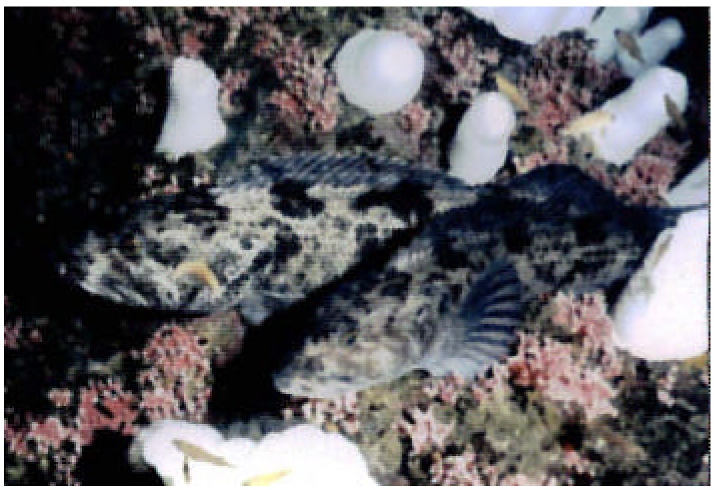

Figure 2.1. Biological microhabitats of hydrocorals and sea anemones with lingcod (*Ophiodon* elongatus) and young of the year rockfish (*Sebastes* spp.) on top of rock pinnacle mesohabitat (photo courtesy of Greene et al. in press).

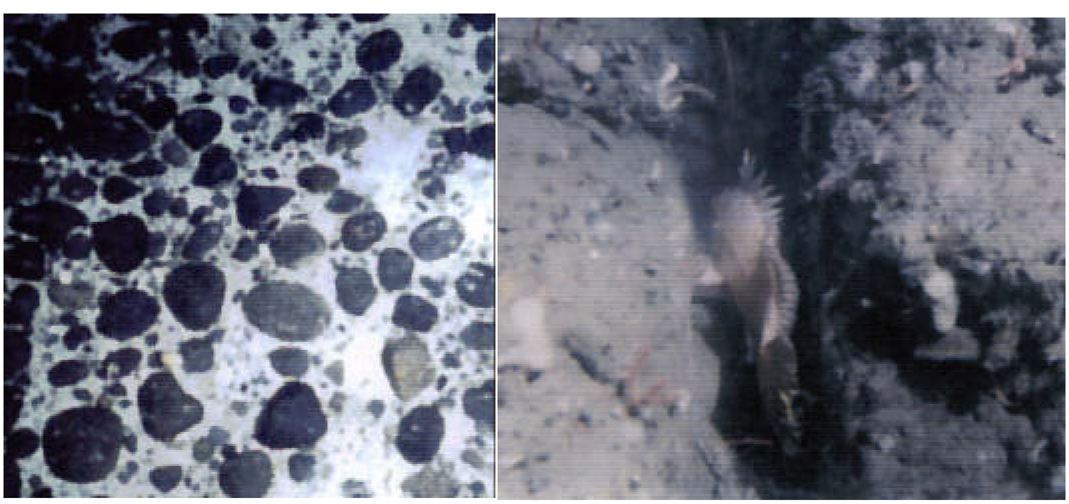

Figure 2.2. Examples of Micro- and Macro-habitats. (Left) Pebble microhabitat in offshore Edgecumbe lava field, southeast Alaska (Greene et al. in press). (Right) Crevice in the Pliocene Purisima Formation that has been differentially eroded along the walls of Soquel Canyon, Monterey Bay, California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