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 $^{0}/_{00}$), estuarine (15-30 $^{0}/_{00}$), dilute (<15 $^{0}/_{00}$)
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

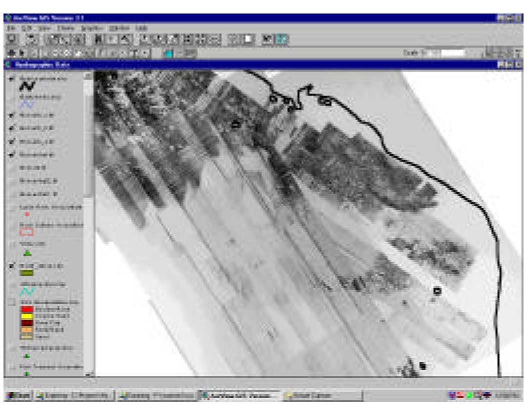
-for bottom morphology
- -regular (continuous homogeneous bottom with little relief)
- -irregular (continuous non-uniform bottom with local relief 1-10 m)
- -hummocky (uniform bottom w/ mounds/depressions 0-3 m)
- -structure (fractured, faulted, folded)
- -outcrop (amount of exposure)
    - -bedding
    - -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, CO_2)
-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



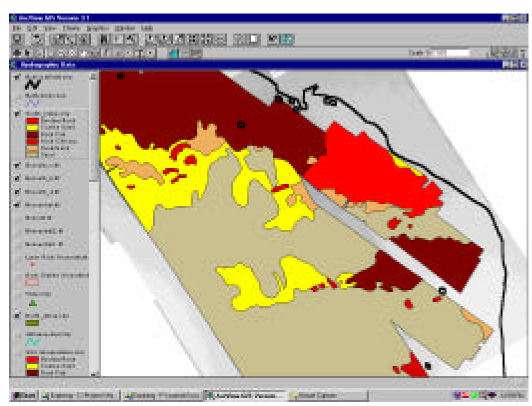


Figure 3.1. ArcView interface views of a sidescan sonar mosaic (left) and resulting interpretation (right) of a portion of the Big Creek Ecological Research Reserve. Interpretation of the sidescan data was based on the application of the Greene et al. system that characterizes this site as: a flat marine 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.