

# Workshop Report: Marine Habitat Mapping Technology Workshop for Alaska April 2-4, 2007 Anchorage, Alaska

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## What is benthic habitat mapping?

Many marine species depend on the benthic (seafloor) environment. To address the need for habitat maps that cover

significant areas of the seafloor in an efficient way, the scientific community has developed an approach that combines acoustic (sonar) mapping of a larger area of the seafloor with groundtruth and biological surveys of selected sites by visual observations and sampling. Based on this combination of data, the mapped area is divided, or classified, into different types of habitats. Because this approach is much more efficient than traditional methods, it can be applied over large areas relevant to ecosystems or species populations.

In a strict sense, habitat is defined specifically for a species or biological assemblage that inhabits it. This is the working definition in terrestrial ecological mapping, where habitat distribution is identified primarily by the distribution of the target flora and fauna and characteristics of the habitat are defined in subsequent steps. In benthic marine habitat studies, however, surveying the distribution of different species and biological assemblages is the problem rather than the answer. Instead, seafloor depth, physiography, and substrate characteristics form the framework for classifying the seafloor into regions of distinct benthic habitats. Biological associations with different types of seafloor add to their characterization and help refine the physical criteria by which biologically significant habitats are mapped.

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This can be done in an iterative process as a collaboration between biologists and geologists, depending on how much precision is desired. The power in this approach comes from the ability to extrapolate biological distribution from limited groundtruth and visual surveys to much larger areas, using those biological substrate associations together with classified maps of the seafloor.

## Workshop focus

This workshop was convened to examine the technologies that would be effective for benthic marine habitat mapping in the Alaska region, specifically in the Gulf of Alaska, Bering Sea/Aleutian Islands, and Arctic. Several limitations were imposed in order to focus the workshop. First, the technologies for mapping the water column and the tidal zone are different from those used in mapping subtidal benthic habitat. In order to allow for in-depth discussion of benthic habitat mapping within the time limitations of the workshop, water column survey techniques and tidal zone mapping were not included. Second, the focus of the speaker presentations was on technologies and techniques rather than specific habitat mapping projects, though Alaska examples were used as illustrations. Finally, the speaker presentations were limited to proven technologies that can be applied immediately to address science and management needs in Alaska. However, the poster session was open to a broad array of topics related to benthic habitat mapping, including specific projects, development and testing of new methods, and the concerns and agendas of workshop participants.

The workshop was intended to increase understanding of benthic habitat mapping and to help guide evaluation and selection of technologies for future habitat mapping projects. Presentations and discussions were designed around a synthesis approach, to aid participants who were not experts in the field. The strengths and capabilities of various technologies were addressed, along with their applications to benthic habitat mapping. Logistical issues and cost were included primarily in the discussions by breakout groups.

## Workshop structure

### Participants

Eighty-eight participants attended, with 59 from Alaska, 20 from elsewhere in the United States, seven from Canada, and one each from Australia and Ireland (invited speakers). Participants included fishery and marine resource managers, scientists and hydrographers interested in marine habitat mapping, representatives of nongovernmental organizations, and representatives of companies that conduct marine mapping and imaging surveys.

### Program overview

The first two days of the workshop were designed as a mini short-course on benthic habitat mapping, and to provide a technical overview of current capabilities. Twenty-three invited speakers contributed. The workshop opened with

two presentations that introduced the concept of marine habitat mapping and the need for the workshop. Subsequent presentations on Day 1 addressed the technologies available for remote sensing surveys, primarily methods for acoustic mapping of the seafloor, and their applications to habitat mapping in Alaska. The speakers were hydrographers and marine geologists. These presentations covered lower-resolution methods first, then higher-resolution methods, then use of the data for habitat classification.

Day 2 addressed visual scale methods that could be used for systematic mapping in Alaska waters, including remotely operated vehicles (ROVs), imaging autonomous underwater vehicles (AUVs), human occupied submersibles (HOVs), and towed camera/video sleds. The morning speakers focused on technologies available for in situ scale observations and sampling. These presentations covered towed camera/video sleds, several types of ROVs, the *SeaBED* AUV, and the submersible *Delta*. The speakers were marine biologists. Three mid-day presentations addressed aspects of data analysis and habitat classification using visual-scale data.

Afternoon speakers on Day 2 presented case histories from three major habitat studies outside of Alaska: (1) two decades of habitat research and mapping on Heceta Bank, Oregon; (2) the Irish National Seabed Survey; and (3) Australia's representative marine protected area program. These presentations described contrasting approaches to habitat mapping in large regions, including the different purposes of the studies, the rationale for each approach, types of data required, issues encountered along the way, and the habitat classification maps that resulted.

Sixteen posters submitted by workshop participants were displayed throughout the workshop, including a formal evening poster session. These may be divided into four categories: benthic habitat mapping projects; instruments, vehicles, and techniques for groundtruthing; data processing and classification; and databases and data sources. Abstracts are available in the Program and Abstracts volume, Marine Habitat Mapping Technology Workshop for Alaska ([www.alaskaseagrant.org/conferences](http://www.alaskaseagrant.org/conferences)).

On Day 3, participants broke into three groups for a half-day technical discussion and writing session. The objectives were to summarize the capabilities and operational considerations of habitat mapping technologies, and to make recommendations on how to select appropriate tools and mapping approaches for different marine settings and program needs. At the end of the morning, participants reconvened in a plenary session for reports from each working group. Follow-up contributions were also received from several individuals after the workshop.

## Topic I—Motivation for the workshop

### North Pacific Research Board

Clarence Pautzke (North Pacific Research Board) welcomed participants and described the motivation for the workshop. The research program of the North Pacific Research Board

(NPRB) focuses on the marine ecosystems of the Gulf of Alaska, Bering Sea/Aleutians, and Arctic Ocean, and specifically on information needed to understand and effectively manage these ecosystems. The NPRB Science Plan (2005) outlines habitat research needs, including habitat mapping, fishing effects on habitat, other human-induced impacts on habitat, and ecosystem functions of habitat. NPRB has funded 12 marine habitat studies during its first four years (2002-2006), and plans to continue at a similar level of support. This workshop will provide guidance to NPRB for future habitat research.

### ***Marine habitat mapping: What is it and why do managers need it?***

Jon Kurland (NOAA NMFS, Alaska Region Habitat Conservation Division, Juneau) introduced this topic with the observation that the Alaska region has significant populations of fish and marine mammals, but Alaska resource managers lack basic information about the habitats that sustain these populations. This information is needed in order to predict and understand the effect of human activities in the oceans, and to make informed decisions for managing those activities. Fishery management operates under legal mandates that specifically require habitat information, e.g., Essential Fish Habitat (EFH), Habitat Areas of Particular Concern (HAPC), and closed or regulated state waters. A goal is to develop techniques for habitat-based stock assessment. The ultimate goal, perhaps achievable, would be to understand how much production of a given species can be expected per unit of habitat.

Jon Kurland provided a “working definition” of habitat mapping: “Marine habitat mapping can be defined as the collection and synthesis of physical and biological data necessary to differentiate environmental features that are meaningful to marine organisms—the features that make a particular area suitable or preferable for basic life functions such as feeding, reproduction, and avoiding predators.” This definition was praised by several workshop participants during the subsequent discussion. The speakers also framed habitat mapping in terms of a series of seafloor characteristics that range from fairly stable to highly variable: bathymetry; geological substrate; marine vegetation; attached epifauna; and temperature, currents, and prey.

Doug Woodby (Alaska Department of Fish and Game, Juneau) reviewed a partial list of species that have a strong dependence on benthic habitat, including lingcod, demersal shelf rockfish, and numerous shellfish species. Doug and Jon discussed examples of how habitat maps have been used in Alaska, and how they have affected management decisions. Examples included Aleutian Islands coral gardens and fishing effort in the region; identification of substrate suitable for weathervane scallop beds; the Sitka Pinnacles marine reserve; corals in the eastern Gulf of Alaska; and sea pen habitat off Lena Beach in Juneau. Jon outlined several take-home messages about habitat mapping for marine resource management. Habitat mapping spatially integrates physical

and biological information, to show what features matter for marine life and how those features are distributed. By providing this new information, habitat mapping facilitates informed management decisions. Habitat mapping enables fishery managers to move toward habitat-based stock assessments, i.e., how many fish per unit habitat. It ultimately encourages management based on ecosystem relationships, rather than single-species stock management.

Discussion: A workshop participant asked how management of EFH dealt with short-term variability in habitat. Jon Kurland and Doug Woodby noted that maps must be static, but that councils are encouraged to update them about every five years. Another participant advocated building indications of short-term variability into maps used by councils. Finally, the point was made that seabird habitat should be included in marine habitat mapping and management.

## **Topic II—Remote sensing technologies for seafloor mapping**

### ***Multibeam echo sounding as a tool for fisheries habitat studies***

Larry Mayer (University of New Hampshire, Center for Coastal and Ocean Mapping) set the context for multibeam sonar mapping by describing habitat maps as a series of spatially coregistered layers. The base layer or framework that underpins the habitat maps is seafloor depth and morphology, from multibeam sonar mapping. Multibeam sonar can also provide data on substrate type, i.e., grain size, roughness, and rugosity, and can indicate gear impacts. He illustrated how developments in mapping capabilities have led to new perspectives and new insights about the seafloor.

Resolution, of course, is of critical importance. In multibeam sonar systems, there are direct tradeoffs between operating frequency, signal range, resolution, and the size of the transducer array. Resolution can be improved using recently developed “focused” sonars (focused with respect to water depth).

Backscatter is used to characterize substrates, but backscatter is complex. The acoustic response of the seafloor is controlled by a combination of acoustic impedance of the substrate material, roughness of the seafloor, and volume scattering. Backscatter is also affected by the water column and parameters in the transducer and receiver arrays. Separating these factors is not a simple matter. There are three kinds of backscatter available. Sidescan is simply intensity of the backscattered acoustic energy in a time series, with no angular or location information. Multibeam sonar backscatter gives either a single average value of backscatter intensity per beam, i.e., in a specific location on the seafloor, or a “beam time-series” (Simrad term) or “snippet” (Reson term). This is a time series of backscatter intensity for each beam sampled at the sonar’s sampling rate. The full time series provides much higher resolution than the average intensity value.

Two conflicting goals for multibeam backscatter and sidescan sonar data are (1) to produce a “pretty” sonar mosaic suitable for geologic and habitat interpretation, and (2) quantitative analysis of the data for seafloor characterization. At present, these goals are mutually exclusive. Larry Mayer’s lab is working on this problem, to make a mosaic and separately do angular response analysis. They have created the GEOCODER tool, to automate backscatter parameter corrections and create mosaics. They are now working on inverting the backscatter data for seabed properties of impedance, grain size, and roughness.

Larry Mayer’s lab has also been conducting mapping operations for a possible U.S. submission for an extended continental shelf under Article 76 of the U.N. Law of the Sea. This is a source of new deepwater multibeam data at several sites in the eastern Gulf of Alaska, Bering Sea, and Arctic. The data are available online. He also showed multibeam data collected in Southeast Alaska, on the Ewing cruise EW04-08.

Finally, a new development in multibeam sonar systems is an ability to simultaneously image the seafloor and the water column (fish sonar). Larry Mayer showed a convincing demonstration of this capability using data collected from a Reson 7000 series sonar, surveying a wreck in the Scapa Flow off Scotland.

Discussion: A participant asked whether 100% seafloor coverage is really needed, or whether one can interpolate. Larry Mayer replied that one is hard pressed to get the interpolation right. Over a broad scale, you could make statistical statements with some confidence, but at some level you cannot do this. Sophisticated approaches have been developed to use sparse data to predict the level of uncertainty, and they show that uncertainty grows very quickly away from dense multibeam data. Another participant raised the topic of metadata. Larry replied that this is a big issue, and people encounter problems when they try to reuse old data. In recognition of the importance of metadata, all new data from his lab are fully attributed. A third participant pointed out the tension between International Hydrographic Organization (IHO) standards for hydrographic charting and the needs of habitat mapping.

### ***Multibeam surveys for marine habitat: What can be expected from a multibeam survey?***

Doug Lockhart (Fugro Pelagos Inc.) spoke about the extensive experience of Fugro Pelagos in NOAA hydrographic charting and benthic mapping in Alaska since 1998. Fugro Pelagos has conducted numerous benthic surveys for habitat mapping projects, on behalf of the Alaska Department of Fish and Game, NOAA National Marine Fisheries Service, and other organizations.

The long-term relationship with NOAA has allowed Fugro Pelagos to contribute to multibeam sonar technology developments, now in use by NOAA and the industry in general. One of these was the use of backscatter snippets, which Fugro Pelagos developed in collaboration with Reson (see

discussion of Mayer’s presentation); this effort was specifically motivated by the need for backscatter in benthic habitat mapping. Multibeam backscatter is not as effective as sidescan for target detection. However, compared to sidescan data, the snippet backscatter data have improved signal-to-noise ratios; they are coregistered with the bathymetry data collected simultaneously; and accuracy and efficiency are increased. Multibeam backscatter data acquisition is faster than sidescan because there is no need to tow a sensor.

Data coverage rates increase linearly with depth, from 5 km<sup>2</sup> per day at 10-20 m water depth, to 50 km<sup>2</sup> per day in 100-200 m water depth. The ratio of data processing time to survey time is also highly depth dependent. This ratio is typically 2.5:1 to 5:1, but in deep water it can be 1:1 or less.

Advance planning is crucial, and should include consideration of the resolution, accuracy, data density, and data products that are required. For surveying on a ship that normally conducts hydrographic charting, consider basing survey specifications on the NOS Hydrographic Specifications and Deliverables. Changes or deviations from those specifications can be noted, e.g., backscatter quality or percent coverage required. Cost is always an issue. For any survey, a software tool like Fugro’s Survey Estimator is recommended to optimize survey planning and minimize survey time, because optimal line headings are often counterintuitive.

Success in multibeam sonar survey operations in Alaska waters depends on attention to a number of factors. There will be multiple users for the data, and those users have diverse requirements. For benthic habitat mapping, this includes quality backscatter data. Data quality is established at the moment of acquisition. To achieve high quality data, one needs a consistent level of training and experience among surveyors and processors, and an explicit quality control (QC) program at both acquisition and processing levels, with authority to require re-survey or re-processing. Surveys can be carried out and processed on both tide and ellipsoid data; these are not mutually exclusive. Tide corrections and tidal zoning sometimes add noise that can be avoided through use of an ellipsoid datum.

Fugro Pelagos is currently developing techniques for water column backscatter processing and visualization, for multibeam systems that can simultaneously image the water column and seafloor.

### ***Alaska hydrography for NOAA nautical charting***

CDR Gerd Glang (NOAA Office of Coast Survey, Hydrographic Surveys Division) discussed NOAA’s hydrographic charting program in Alaska, and its relationship to habitat mapping. NOAA’s charting mission is to provide nautical charts and related hydrographic information for safe navigation. The region covered by this mission is the entire U.S. EEZ, a total of 3.4 million square nautical miles. National priority areas, however, are narrowed to 500,000 square nautical miles of Navigationally Significant Areas, and further narrowed to 43,000 square nautical miles of Critical Areas (1994 baseline). Of those, approximately half

are in Alaska waters. Additional Emerging Critical Areas have been added to the list, and this critical list has been further prioritized according to the dates of previous surveys, technologies used in those surveys, and importance of each area for commerce. A large portion of Cook Inlet has been identified for re-survey, as an area of dynamic seafloor. A map of NOAA Hydrographic Survey Priorities for Alaska is available on the NOAA Office of Coast surveys Web site, at <http://chartmaker.ncd.noaa.gov/>.

NOAA runs two survey ships in Alaska: the NOAA Ship *Rainier*, and the NOAA Ship *Fairweather*. NOAA also contracts for additional hydrographic surveys in Alaska. The same survey specifications and deliverables apply to both NOAA surveyors and contractors. Technologies used to acquire hydrographic data in Alaska include Reson and Elac multibeam sonars; airborne LIDAR bathymetry by both Optech and LADS; and Klein 3000 and 5000 sidescan sonar systems. Technologies under evaluation include a Benthos C3D interferometric (phase differencing) sonar, and a vessel-based laser scanner for shoreline delineation.

The hydrographic data are archived at the National Geophysical Data Center (NGDC), and are publicly available online at [http://map.ngdc.noaa.gov/website/mgg/nos\\_hydro/](http://map.ngdc.noaa.gov/website/mgg/nos_hydro/). The highest resolution of survey data is preserved, with metadata. The bathymetry attributed grid, or BAG, indicates levels of data uncertainty. In addition to the final data, intermediate products are also archived, including the raw and processed data, gridded data, backscatter, and snippets. Regarding snippet data, the NOAA Ship *Rainier* has been logging snippets since Reson made this capability available. In recognition of the importance of backscatter data, NOAA is now training surveyors to avoid saturating the backscatter return during hydrographic surveys.

Within NOAA, Integrated Ocean and Coastal Mapping (IOCM) serves as an umbrella for a variety of partnerships both within NOAA Line Offices and with outside partners. IOCM members include CDR Gerd Glang and CDR Doug Baird in Silver Spring, and LCDR Dave Zezula in the Alaska region. NOAA recognizes that seafloor mapping can serve multiple users, and the IOCM works to coordinate partnerships for this purpose. Hydrographic surveys can provide the bathymetric foundation data for habitat mapping; conversely, surveys for habitat mapping can (and do) supplement NOAA hydrography. This approach has been successful to date, and more partnership efforts are planned.

Discussion: A workshop participant asked about NOAA hydrographic charting data. CDR Glang said that the NOAA hydrographers are now training to collect better backscatter data as well as bathymetry, and the backscatter data are being archived, waiting for someone to use them. Doug Lockhart also commented that the newer multibeam sonar systems can handle higher power (to achieve greater range) without saturating and wiping out the backscatter return. Thus the backscatter data quality should be improving, even when it is not a priority of the survey. Another participant asked how survey areas are selected, and whether it is possible to

have an area added to the high-priority list for hydrographic charting. CDR Glang replied that yes, such surveys have been done. To file a survey request, people should either contact the regional Navigation Manager listed at <http://nautical-charts.noaa.gov/Staff/contact.htm#regional> or use the online form at the Coast Survey's Inquiry Web site, <http://ocsdata.ncd.noaa.gov/idrs/inquiry.aspx>.

### ***Bathymetric LIDAR surveys for marine habitat: What can be expected from an airborne bathymetric LIDAR survey?***

Carol Lockhart (Fugro Pelagos Inc.) discussed airborne LIDAR bathymetry (ALB) systems that are used for mapping in shallow nearshore waters. Acronyms abound. LIDAR is light detection and ranging, a concept similar to sonar (sound detection and ranging). Carol Lockhart reviewed the 30-year history of this technology. She noted that there are only a handful of LIDAR systems currently in use: the commercial SHOALS-1000T (Scanning Hydrographic Operation Airborne LIDAR Survey), which Fugro operates commercially; CHARTS (Compact Hydrographic Airborne Total Survey), a variant of the SHOALS system owned by the U.S. government; and the commercial Tenix LADS (Laser Airborne Depth Sounder). Her presentation focused on experience with the SHOALS-1000T.

The LIDAR system is mounted in an ordinary rotary or fixed wing aircraft with a photogrammetric port, and flown over a shoreline or shallow water. A pulsed dual frequency laser transmits two beams, 532 nm (green) and 1,064 (near infrared), and a rotating mirror creates a swath of points. In general terms, the green beam penetrates the water and is used to detect the seafloor, while the infrared beam does not penetrate and is used to detect the sea surface. Raman backscatter is also used to detect the surface. Two-way travel time of each beam in nanoseconds is converted to depth of the seafloor and elevation of the sea surface, relative to the sensor in the airplane. If a post-processed kinematic (PPK) GPS solution is used to position the data, tide corrections are unnecessary. There is an ongoing effort to develop a method of extracting reflectance data from the green laser's waveforms, analogous to the use of multibeam backscatter snippets. Carol Lockhart showed an example of LIDAR reflectance imagery. Standard operations also measure topography of the adjacent land surface and collect digital photos with the LIDAR data, which can be used to create orthorectified image mosaics.

The principal advantages of LIDAR are rapid surveys of shallow underwater areas, up to an order of magnitude faster than multibeam surveys in shallow water, and the ability to survey areas that are unsafe for small-boat operations. The method is most cost-effective for large or regional-scale mapping programs, to achieve efficiency of scale. It is also more cost-effective in regions, or seasons, with favorable operating conditions. Data density may be selected in a range between 2 × 2 m and 5 × 5 m; the choice of data density affects the swath width, coverage rate, and survey cost.

The depth of LIDAR signal penetration is affected largely by water clarity, but also by bottom reflectivity. Generally, the sensor can penetrate two to three times the secchi depth. Operations can also be limited by weather. For example, fog, rain, and low clouds attenuate laser energy. Waves per se are not a problem, but wind can interfere with LIDAR by creating spray and whitewater surface conditions that prevent penetration of the green beam into the water. SeaWiFS and/or Aqua-MODIS satellite imagery is useful for predicting laser penetration.

***What you should and should not expect from towed high-frequency sidescan sonar, compared to other forms of acoustic remote sensing***

Lloyd Huff (University of New Hampshire, Center for Coastal and Ocean Mapping) observed that the complexity of species-habitat relationships is such that multiple parameters are necessary to link different species to their habitats. Benthic habitat is the result of processes that occur on multiple spatial and temporal scales, and there is no single correct scale at which to view fish habitat. Processes that occur at one scale have impacts that are observable at other scales. This is further complicated by patchiness where processes may not be continuous in space or time.

There is a strong desire to find quasi-permanent geophysical features that can serve as surrogates for marine communities. This is an emerging application for acoustic remote sensing systems. Vertical-beam echosounders are good tools for identifying patterns with characteristic lengths of 10s of kilometers. Hull-mounted multibeam sonars are good tools for identifying patterns with characteristic lengths of 10s to 1,000s of meters. Towed sidescan sonars are good tools for identifying patterns with characteristic lengths of 10s of centimeters to 100s of meters.

For sonar mapping systems in general, major considerations are operating range, spatial resolution (cross track and along track), and coverage. Operating range depends on frequency. Resolution depends on frequency, beam width (controlled partly by transducer geometry), and pulse length. In sidescan sonar, the concern for spatial resolution usually dominates. In multibeam sonar, operating range is given priority over resolution.

The different capabilities of multibeam and sidescan sonar now stem less from the type of information collected and more from issues of frequency and geometry. For backscatter data acquisition, operating frequency of the sonar matters a great deal because the wavelengths of sonar frequencies are in the same range as sediment particle diameters. Commercial multibeam and sidescan sonars for seafloor habitat mapping have frequencies that range from 35 kHz to 1,500 kHz. Geometry of the acoustic beam matters because the backscatter response of the seafloor varies with the incidence angle of the acoustic waves. Incidence angles are more uniform with greater height above the seafloor, so hull-mounted multibeam sonar systems produce more uniform incidence angles than sidescan sonars towed close to

the seafloor. Thus with a hull-mounted multibeam sonar, less of the backscatter variation is due to sonar geometry.

Before interpreting backscatter data, several processing steps are typically done. One is an adjustment of backscatter values to what they would have been if the incidence angle had been 45 degrees. This adjustment makes assumptions about the sonar system and the basic acoustic properties of the seabed. Because determining the basic acoustic properties of the seabed is often the objective of the survey, this can lead to circular arguments. Sidescan sonars with bathymetry measurement capabilities provide co-registered backscatter and bathymetry such that the backscatter can be draped on a digital elevation model of the bathymetry, which helps to reveal relationships between features of the seafloor and backscatter.

A major advantage of hull-mounted multibeam backscatter data over towed sidescan sonar is that multibeam backscatter data are more nearly quantitative in comparison to the backscatter data from a sidescan sonar. As a result, the backscatter data from multibeam sonar are more amenable to classification and image processing than backscatter data from sidescan sonar. The qualitative backscatter data from sidescan sonar are well suited for segmentation of the seabed into regions based on common imagery textures, seafloor morphology, and bedforms. However, because backscatter information from sidescan sonar is primarily qualitative, sidescan sonar is not yet optimized for acoustic mapping of benthic habitats.

Conducting habitat mapping with a combination of the different frequencies and different geometries of towed sidescan sonar and hull-mounted multibeam sonar should lead to development of post processing algorithms for estimating seabed properties that are more robust and more accurate than is possible with the present suite of post processing techniques.

Discussion: A workshop participant asked what conditions in Alaska might lead a surveyor to select sidescan sonar over multibeam sonar. Lloyd Huff replied that in areas with large vertical gradients in sound speed, signals from hull-mounted multibeam sonars can suffer from refraction problems, causing streaking in the backscatter data. An example is the summer cold pool in the eastern Bering Sea. In this situation, towing a sonar beneath the cold pool avoids these refraction problems.

Later in the workshop, the point was made that sidescan sonar can be better than multibeam sonar for surveying nearshore. In this environment, sidescan sonar with interferometric (phase difference) bathymetry capability actually provides greater coverage than multibeam sonar. Lloyd Huff stated that for 20 m and shallower, many surveyors are hull mounting sidescan sonar rather than towing them. The increased confidence in the location and motions of the sonar that comes with hull-mounting a sonar results in the acquisition of higher quality bathymetry data than could be achieved if the sonar were towed. Jim Galloway stated that the Canadian Hydrographic Service Pacific has recently

acquired a Benthos C3D sidescan sonar for surveying in depths shallower than 30 m.

**High-resolution multibeam, sidescan, and subbottom surveys of seamounts, submarine canyons, deep-sea fan channels, and gas seeps using the MBARI AUV *D. Allan B.***

Dave Caress (Monterey Bay Aquarium Research Institute) outlined the capabilities of the mapping AUV developed at MBARI, the *D. Allan B.*, and showed results from surveys in several deep-sea environments. The primary advantage of acoustic mapping with an AUV is the ability to conduct efficient, high-resolution seafloor mapping in deep water. The resolution of acoustic mapping depends strongly on higher acoustic frequency and smaller beam footprint, and both of these become problematic with increasing length of signal path through the water. For high resolution mapping in deep water, the solution is to move the high frequency sonar system down into the water, closer to the seafloor. Sonar systems can be mounted on a variety of vehicles: towed sleds, human occupied submersibles, remotely operated vehicles (ROVs), and autonomous underwater vehicles (AUVs). Of these, AUVs are the preferred platform for deep-water surveys over broad areas that cannot be covered efficiently by submersibles or ROVs. AUVs are also very stable platforms and produce high-quality data.

MBARI's mapping AUV, the *D. Allan B.*, is equipped to collect multibeam bathymetric and backscatter data, sidescan sonar data, and subbottom profiles that image the subsurface sediment structure. This is a torpedo-shaped AUV, designed to travel continuously at a typical speed of 1.5 m per s (3 kts). It is rated to 6,000 m depth, and can be operated from vessels of opportunity with appropriate launch and recovery procedures. Mission duration depends on battery power; shortly after the workshop, capacity of the Li-ion battery pack was doubled to 10 kWhr, allowing 17-hour missions. The vehicle has numerous communication systems that enable operators to communicate with it when necessary, as well as backup systems and fail-safe procedures to minimize the chance of losing the vehicle. Navigation is handled by a combination of GPS (at the surface), inertial navigation system (INS), and Doppler velocity log (DVL) which tracks altitude and velocity over the bottom. Ultra-short baseline (USBL) fixes from the ship are also used on deep dives. Navigation accuracy from a known starting point is 0.05% of the distance traveled, if bottom lock is maintained. If not, the INS has been observed to drift by 1 km per hour.

MBARI uses the MB-System software (Caress and Chayes: <http://www.mbari.org/data/mbsystem> or <http://www.ldeo.columbia.edu/MB-System>) for mission planning, data processing, and simple data visualization. This open-source software has been supported by NSF since 1993, and is widely used within the U.S. academic community but is not limited to that community. Dave Caress showed a table of 575 software downloads in the 10-month period between April 2005 and February 2006, divided by IP address into

academic, government agency, and commercial users, as well as U.S. and non-U.S. MB-System currently supports products from numerous sonar systems and 59 data formats, and integrates with the GMT mapping tools package (also NSF-supported).

The *D. Allan B.* became fully operational in 2005. By the date of this workshop, it had conducted surveys in eight locations: cable route surveys for ocean observing systems in Monterey Bay and Barkley Canyon; Monterey Canyon and Lucia Canyon to study sediment transport, canyon evolution, and the nature of seafloor pockmarks; regions with outcrops of methane hydrate in the Santa Monica Basin and Barkley Canyon; Davidson Seamount off the California coast and Axial Seamount on the Juan de Fuca spreading center (an active submarine volcano); and a Navy NFESC site survey. Dave Caress showed products from many of these surveys.

**Small-boat surveys in shallow water**

Rob Hare (Canadian Hydrographic Service, Pacific Region) discussed practical considerations for hydrographic surveying in shallow waters. Small-boat surveys are commonly used for hydrographic charting in the complex coastal waters of British Columbia. Rob Hare briefly reviewed the history and role of soundings, bottom samples, and mapping the low-water line and foreshore type, and then focused on acoustic sensor installations and vessel characteristics that can affect survey operations.

Mapping platforms can range from small launches, used for mapping in depths of 10 m and shallower, to larger vessels that typically operate in water depths greater than 50 m. The small launches can be trailered to survey sites. However, a common problem with small-boat operations in remote areas is their lack of onboard crew accommodations. Some large ships, such as the CCGS *John P. Tully* and the NOAA Ship *Rainier*, can themselves carry launches on board to conduct parallel operations in shallower water. An intermediate-sized vessel is the *Otter Bay*, a 44 ft boat with 1 m draft, 3-4 day endurance, and sleeping accommodations for three people. Ship characteristics to consider are health and safety, working and living space, power budget, noise sources, possible configurations of acoustic sensor installation, and range or endurance. Also required are top-side gear for communications, navigation, ship positioning and orientation, and vessel safety.

Rob Hare reviewed types of acoustic sensor installations for multibeam and sidescan sonars. Types of hull mounts include through-hull mounting in an acoustic window; flush mounting on the outside of the hull; use of fairings, blisters, or pods; retractable systems; and use of a moon pool. Each of these methods has potential problems that must be considered in order to minimize ship's noise, signal attenuation or blockage, vibration, and bubbles washing against the transducers. Debris catchers may be used to protect the transducers. Sensors may also be fixed to the ship on over-the-side or over-the-bow pole mounts. Mounting a sonar on a towed fish improves signal-to-noise, but it is much harder

to accurately track the sonar's location and orientation; thus the emphasis is on systems fixed to the ship.

In conclusion, he showed photographs of ships that had come to grief on shallow rocks, saying of the Canadian Hydrographic Service, "we find the rocks so you don't have to!"

### ***Surficial geology: The third dimension in habitat mapping***

Vaughn Barrie (Geological Survey of Canada-Pacific, and University of Victoria) discussed the technologies for subbottom profiling of shallow sediment structures and sediment sampling, with applications to marine habitat mapping.

Subbottom profiling is normally done as an add-on operation during multibeam or sidescan mapping operations. These systems achieve high-resolution characterization of the uppermost tens to hundreds of meters of sediment. The most common sound source is controlled waveform (sonar), and three typical subbottom profilers are: CHIRP-type swept-frequency systems that operate between 500 Hz and 24 kHz; 3.5 kHz profilers, modern versions of systems that have been standard on oceanographic research ships for decades; and certain lower-frequency echosounders that can achieve subbottom penetration, though at low resolution. Three other types of sound sources are: accelerating water mass sources, such as electrodynamic boomers (e.g., Hunttec DTS, Seistec) and air guns; implosive sources (i.e., water guns); and explosive sources (e.g., sparkers, dynamite). The best resolution is achieved with a well-tuned, towed subbottom boomer.

Subbottom profiling systems may be either towed or mounted on the ship's hull. Those with air gun sources must be towed. Advantages of towed systems are that the sonar is decoupled from the ship's motion; the system can easily be accessed for maintenance; and high levels of sound energy output are possible for better subbottom penetration. Disadvantages are that tow bodies are difficult to navigate; a winch, A-frame, or crane is necessary; the physical size of the tow fish requires careful handling during launch and recovery; and they require high voltage and high current through the tow cable. Air guns can achieve deeper sediment penetration and penetration into bedrock by producing higher energy sound pulses. This is significant for habitat studies because the type of bedrock under the sediment can affect seafloor habitat and biology. However, there is a higher maintenance burden for air guns, the data are subject to bubble pulse interference, and the higher energy output raises concerns for wildlife.

Ship-based methods for collecting sediment samples include piston coring, vibro coring, grab samplers and dredges. These methods were briefly reviewed.

Vaughn Barrie then discussed connections between surficial geology and habitat mapping, and presented examples of studies in British Columbia in which both subbottom profiling and sediment sampling contributed to an understanding of the benthic habitat.

On the continental shelf of British Columbia, surficial geology maps in five locations were compared with groundfish trawl data. The seafloor substrate was found to correlate with the distribution of groundfish species (Sinclair et al., ICES CM 2005/L25).

In the region of the Queen Charlotte Islands, multi-beam sonar maps revealed seafloor scarps at 100-110 m and 140-150 m depth. A combination of C14 dating of sediment samples and geological modeling produced a history of relative sea level change across the region, in which rising sea level combined with uplift in some areas and subsidence in others. The scarps were identified as drowned coastlines. As sea level rose, bottom currents along the base of the scarps cut moats and built moat berms. These features are now a preferred habitat for groundfish.

Pockmarks occur in the deeper regions around the submerged coastlines. These pockmarks were surveyed with multibeam sonar, 3.5 kHz profiling, and sidescan sonar imaging. The 3.5 kHz profiles were used to select sites for piston coring and vibro coring, and revealed that the pockmarks are actively venting gas. A grab sampler was used to sample undisturbed surface sediment and infauna. The pockmarks have carbonate mounds in them, associated with large gastropods and juvenile rockfish. The presence of carbonate mounds explains why fishing gear is lost at these sites.

Another example involves the sponge reefs recently discovered in the Queen Charlotte Basin. These sponge reefs, formed by hexactinellid sponges, were originally identified by a combination of subbottom profiles and seafloor video images. They are associated with very specific local geological and oceanographic conditions, forming in iceberg furrows with favorable current regimes. These sponge reefs are very important habitat for rockfish, especially juveniles. An accurate map of the distribution of the sponge reefs has led to spatially limited, targeted restrictions on trawling and other fishing.

The bottom line: always do subbottom profiling during multibeam mapping operations. The geologic history of the seabed makes a difference to habitats.

Discussion: A workshop participant asked whether hull-mounted or towed profilers were preferred. Vaughn Barrie replied that hull-mounted profilers are not as good as towed profilers, because the beam is not vertical. Doug Lockhart added clarification: the problem with the hull-mounted sonar is not that it cannot detect the return from a non-vertical beam (a 2 × 2 beam pattern has a 45 degree beam). Instead, the problem is interference in the return signal. This results in chopped-up data, and is hard to correct.

A question addressed roll and pitch tolerances. Vaughn Barrie answered that they are not a problem because the vehicles are adequately instrumented to measure roll and pitch. The main problem is navigation. Layback navigation is used to determine the vehicle position relative to the ship, and it is difficult to account for currents in the layback calculation.

Vaughn Barrie and a collaborator in the audience (Gary Greene) mentioned an additional example in which a geologic understanding of the seabed contributed to a better habitat map. In the San Juan Islands, they have mapped locations with dense sand lance populations and determined that these sand lance occupy extensive sand wave fields. Thinner sand deposits were not associated with sand lance concentrations.

### **Systematic seafloor habitat mapping of the British Columbia Coast**

Jim Galloway (Canadian Hydrographic Service, Pacific) reviewed the habitat mapping program of the Canadian Hydrographic Service, Pacific, with specific discussion of data types, seabed classification, and groundtruthing. The current geographic focus of the habitat mapping program is the Strait of Juan de Fuca and Strait of Georgia. Metadata will be publicly available through the DFO GeoBrowser (<http://geoportal-geoportal.gc.ca/en/services.html>).

The basic data for habitat mapping are multibeam or single-beam sonar surveys. From multibeam surveys, the acoustic intensity and surficial scattering, i.e., backscatter data, are used for seafloor classification. From single-beam surveys, the acoustic echo shape and the volume and surface scattering are used. These data are processed using the QTC IMPACT™ and QTC MULTIVIEW™ software tools from Qester Tangent Corporation. This method identifies acoustically distinct areas of the seafloor by processing the acoustic data, stacking adjacent single beam echos to reduce noise, using bathymetry from the survey to correct multibeam backscatter for variation in incident angles, running a principle component analysis to obtain three principle components, and automatically clustering the results into acoustic classes. One could do manual clustering, but that is labor intensive. Classification is done within each data set, or reference to an external library where continuity is required. For constructing a series of classification maps across a region, repeatable results require consistency in acoustic data acquisition.

The Canadian Hydrographic Survey, Pacific chose QTC software because it is commercially available, the company continues to develop and improve the tools, and QTC is in a position to work directly with the Canadian Hydrographic Survey, Pacific on their needs (offices are across the street).

Jim Galloway emphasized that this procedure maps acoustic diversity, not geology. The presumption is that acoustically similar regions will also be geologically and biologically similar, but this must be tested and the geological and biological characteristics must be identified by supervised groundtruthing (checking the seafloor characteristics in selected sites representative of the acoustic diversity). A study of shrimp habitat provides an example of correlation with biota: shrimp density as measured by trawling correlated with acoustic seabed classes. The standard groundtruthing method is a combination of sediment grab samples and seafloor video transects. A modified Folk ternary classification (gravel, sand, mud components) is used to describe

sediments. For example, five acoustically distinct seafloor types in the Georgia Basin acoustic habitat classification chart are labeled organic mud, mud 1, mud 2, sandy-gravelly mud, and gravelly-sandy mud. A difficulty is the difference in scale and resolution of data from acoustic surveys versus video, box cores, piston cores, grab samples, and leadline sediment samples. Physical and visual samples of biota and/or geology do not always accurately reflect the more synoptic view that acoustic surveys and classification provide.

Classification of multibeam data depends on the acoustic intensity and surficial scattering, as there is little to no subbottom penetration. Single-beam surveys have a larger footprint and are usually conducted at lower frequency than multibeam, with potential for subbottom penetration. Classification of single-beam data depends on acoustic echo shape, surface scattering, and some (inconsistent) effect of volume scattering. Multibeam data are better for classification than single-beam data. Jim Galloway compared classification maps of Patricia Bay created from multibeam and from single-beam data sets, using the same groundtruthing information from sediment grabs and seafloor video.

Nearshore environments, with water depth less than 30 m, are important habitats but are relatively difficult and time-consuming to map with acoustic tools. Sidescan sonar has greater range in this environment than multibeam sonar, and bathymetric mapping with sidescan sonar has become a mature technology. The Canadian Hydrographic Service, Pacific has acquired a Benthos C3D bathymetric sidescan for this purpose, and will begin testing it later this year. For habitat classification of the intertidal zone and some nearshore subtidal flora (e.g., seagrass), the ShoreZone program is a successful model (<http://www.coastalandoceans.com/shorezone.html>). Georeferenced airborne video and still imagery are collected along the shore zone at low tide, and the zone from the log line (upper limit of storm-driven waves) to the water line at low tide is classified according to substrate, biota, and coastal exposure. Current ShoreZone coverage extends from northern Washington state to the Alaska Peninsula and Bristol Bay with several significant gaps.

Discussion: A workshop participant (biologist) asked what is an appropriate suite of groundtruthing data, in terms of sediment grain size, porosity, and compaction. Jim Galloway replied that the important point is to match the scales of groundtruthing data and acoustic data. He also recommended including biota that are on the seafloor, e.g., buried crabs. Larry Mayer joined the conversation, asking biologists to tell geologists and surveyors what needs to be mapped. At present, we are asked to map all possible parameters, on the theory that something will turn out to be important. To improve this situation, he asks biologists to determine what parameters are important, and therefore what needs to be groundtruthed. Larry Mayer said that the mean grain size, widely used, does affect the underlying physics of acoustic response of the seafloor but is a poor representation of substrate character; other parameters such as

roughness and impedance are a better representation of substrate character than grain size is. Peter Harris pointed to a paper by J.V. Gardner and others (J. Geophys. Res. 96:5955-5974, 1991) on 6.5 kHz GLORIA sidescan sonar images, in which the authors use multiple groundtruthing techniques to quantitatively evaluate the causes of backscatter variations. The results are relevant to all low-frequency sidescan systems (up to about 15 kHz), i.e., frequencies that penetrate the seabed as well as reflecting off its surface.

### Topic III— Technologies for visual scale surveys

#### *Conducting visual surveys with a small ROV in shallow water: Lessons learned in San Juan Channel (and a few other places)*

Bob Pacunski (Washington Department of Fish and Wildlife, Mill Creek) discussed practical considerations for operating a small ROV in the coastal waters of the San Juan Channel and Hood Canal. The survey goals are to collect habitat and abundance data of the demersal fish, to groundtruth habitat maps created from multibeam sonar surveys, and to develop objective, quantifiable benchmarks for assessing the performance of MPA (marine protected area) networks. These surveys are needed in regions where traditional trawl surveys are impractical (rocky habitats) and the depth is beyond the range of scuba surveys. Drop cameras have been used, but they are inefficient and tend to miss patchy habitats. ROVs are well suited to these needs, and provide nondestructive sampling, virtually unlimited bottom time, and reduced liability as there are no humans under water.

A “small ROV” is defined as low cost (< \$200,000), two-man portable (< 100 kg), and designed for shallow water (< 300 m). Small ROVs range between breadbox size with limited power and qualitative abilities to coffee table size with enough power and payload for quantitative work. They can be leased or purchased. They are less expensive than submersible surveys and more versatile than drop cameras or towed cameras, and they can be deployed from vessels of opportunity. The smallest ROV models, e.g., Seabotix LBV, Fisher Seaotter, Benthos Stingray, and VideoRay SeaSprite, are designed for shallow, protected waters with minimal currents. This presentation focused on ROVs capable of surveying in more demanding conditions.

The San Juan Channel is 12 nm across, with a maximum depth of 147 m and currents over 3 knots. ROV operations are run in conditions up to 2 ft swell, 15 kt wind, and 1.5 kt current. An optimal transect speed is 0.3-1.0 m per s. Examples of ROV models suitable for this environment and purpose are the Phantom HD2+2 and Seaeye Falcon. The Phantom HD2+2 and Seaeye Falcon models have rugged and reliable design, are easy to maintain and upgrade, and can be configured to carry a range of equipment and tools. In addition, experienced users in the marine science community can provide assistance and advice. Limitations include a limited field of view and lack of a 3-D perspective, especially compared to a human observer in a submersible or scuba gear; difficulty

detecting cryptic organisms and determining substrate composition; need for a dedicated power supply of 3-8 W (not boat power); and of course the ROV must be tethered to the ship, which complicates operations.

Vessels of opportunity may be used, if they are appropriately equipped. In addition to the ROV itself, these operations require a gantry, davit, or A-frame; a deck winch; a 3-8 W power supply dedicated to the ROV; adequate working space on deck; and a covered area for ROV electronics and the ROV pilot. The various pieces of equipment necessary to run an ROV operation include a deck computer, an umbilical (tether, cable), tracking and navigation systems, video monitor and recording devices, and a text overlay system. The tether may be deployed freehand in water depths to 30 m or in slack current, although this is an inefficient use of deck space and may interfere with efficiency of the operations. In greater depths, a tether management system, i.e., spool and slip ring, is required. A clump weight (downweight) is recommended to simplify operations and reduce the tether catenary. The ROV and tether have a characteristic level of neutral buoyancy, determined by flotation and hydrodynamics; this is the preferred operating condition. The flotation can be adjusted by re-ballasting the ROV and/or adding flotation to the tether.

For ROV video surveys, the camera setup is crucial. The camera's field of view should be calibrated, and lasers are recommended for scaling objects in the field of view (a wider laser spread is better). Paired lasers are often used. A three-beam laser system provides scaling capability along as well as across the field of view, as illustrated by a three-beam system from Harbor Branch Oceanographic Institution. Image quality is a primary consideration, for both piloting the ROV and for science. If light sources are used, they should be positioned in order to illuminate the field of view while avoiding backscatter toward the camera. A forward-looking video camera is best for the pilot, but provides a narrow field of view. An obliquely mounted camera provides a larger viewing area, and can improve detection and identification of biota. Higher-resolution still cameras and stereo cameras can be useful additions. An altimeter, sonar, and mechanical arm are also useful, but not strictly necessary.

Bob Pacunski reviewed a variety of operational tips regarding safety, communication, planning, dive navigation, hardware trouble-shooting and repair tools, and dealing with unexpected hazards. The latter can include derelict nets, overhangs and power cables, as well as other vessel traffic. ROV operators should issue a broadcast notice to shipping, though not all vessels pay attention to this. Bob Pacunski emphasized the importance of a good skipper. He also urged ROV operators to calibrate, document, and create backups of as many things as possible. This includes a backup recording device if the data are recorded onto digital media. He recommended that operators double-check software drivers and settings, make sure that the software runs on the specific computer that will be used during ROV surveys, and take user manuals on board.

For the San Juan Channel, ROV surveys have been designed using random starting locations. Following pre-planned dive tracks is difficult in strong currents. Instead, the ROV is oriented into the prevailing current and travels a predetermined transect length in that direction. Currents up to 1.5 kts are manageable. Tracking the vehicle is the most problematic part of the operation, and a combination of ship-based USBL tracking, Doppler velocity log (DVL), and Kalman filter is recommended. With adequate tracking, both 2-D and 3-D track lengths can be calculated. Numerous short transects are preferred over one long one. However, this does not mean that the ROV should be retrieved and relaunched for each transect; instead, once the ROV is deployed, leave it down and do a series of transects in the same general area.

### **Use of a shallow-water ROV in the northern Gulf of Alaska**

Mike Byerly (Alaska Department of Fish and Game (ADFG), Homer) described a program for groundfish habitat assessment on the outer coast of the Kenai Peninsula, in Southcentral Alaska. ADFG operates the Phantom HD2+2 *Buttercup*. An 8 ft aluminum van is used as a control van at sea, and can be transported on a trailer. The support vessel is the R/V *Pandalus*, which has a bow thruster and trolling clutch that increases maneuverability and allows 0.5 kt transit speeds. The ship is now equipped with ADCP (acoustic Doppler current profilers), which enables researchers to determine the bottom current before deploying the ROV. They have operated in 2 kt currents, but the system operates optimally in currents less than 1.5 kt. The ROV is tracked relative to the ship using USBL.

To plan this habitat-mapping program, ADFG researchers compiled over 600 existing leadline, single beam and multibeam bathymetry datasets, augmented with other data sources such as substrate type, shorezone mapping, and orthophotos to find areas of probable rocky substrate. Mosaics of gridded bathymetric data sets were based on a wide range of resolutions, and had to be interpreted with the original data density in mind. Using these mosaics, polygons were drawn around probable rocky substrates using heads-up digitizing. The base map used for these ROV surveys was a combination of multibeam and single beam sonar bathymetry.

The ROV surveys were designed to groundtruth substrate types, and to estimate abundances of demersal fishes. They were limited to areas with probable rocky substrate; within these areas the locations and orientations of ROV transects were randomly selected. Transects were 500 m in length, and were run in the uphill direction. Different transect strategies were used for submerged rocky reefs and drowned shorelines. The video data were divided into good and bad quality observations, and analyzed as strip transects. Dynamic segmentation in ArcGIS was used to plot the segments of good video observations on the base map, and to segment them according to habitat classes. The habitat classification included primary and secondary substrate type,

vertical relief, crevice size, and crevice density. From these habitat data and the ROV groundfish observations, indices of habitat use were calculated for individual species. Relatively precise groundfish density estimates were achieved. Current research is directed at experimentally testing the validity of some of the strip transect assumptions: fish movement in response to the ROV, and fish detection.

### **Strategies for visual surveys using the Delta submersible**

Mary Yoklavich (NOAA NMFS, Southwest Fisheries Science Center, Santa Cruz) presented an overview of the *Delta* submersible as a tool for surveying deepwater fishes and benthic habitat. This vehicle has been used for twenty years to conduct fisheries research along the West Coast and Alaska, and to develop new survey techniques for habitat-based stock assessment. Much of the West Coast work has been done by Mary Yoklavich and her collaborators. The advantage of submersible dives lies in the superior ability of human observers in the submersible to detect and identify fishes, particularly in complex habitats, and to link the habitat maps with associated fish and invertebrate species. Thus the primary data set from submersible dives is the audio record of observations by the scientist in the submersible. Video recordings and samples of rock and invertebrates are secondary data sets used to back up the real-time observations and to support additional aspects of the habitat study, including groundtruthing the habitat maps.

The *Delta* submersible has a depth limit of 365 m, and can conduct several dives during a 6-8 hour working day. It carries one pilot and one scientific observer. The *Delta* may be operated from a variety of support ships, most often ships about 33 m (110 feet) in length with accommodations for multi-day dive programs. The submersible is 4.7 m in length, and is deployed over the side with a 10,000 lb crane. Dive transects are tracked by USBL combined with DGPS. Transect speed is 0.4-1.0 kt.

During Mary's surveys, the *Delta* submersible is equipped with three video cameras and a total of 300 W of halogen lights. The camera configuration may be customized, but normally the main observation camera is set up on the starboard side to record the scientific observer's field of view. Paired scaling lasers on this camera assist with size estimates. A second video camera is aimed through a lower port to record fish immediately next to the submersible as well as a higher-angle, closer view of the seafloor. A low-light, wide-angle black and white camera looks forward to monitor avoidance or attraction of fish species to the submersible. The submersible is also equipped with CTD sensors (conductivity, temperature, and depth). Various other sensors and gear may be added: lights, cameras, lasers, tracking devices, sonar, etc.

Mary Yoklavich and her collaborators have established a standard protocol for handling dive data. After a dive, all videos are reviewed to check and transcribe the observer record and to note any fish that were missed. The substrate

is classified from video recordings, by a single observer, using binary codes for primary and secondary substrate types. Additional habitat characteristics such as seafloor relief and distinctive features are also noted, and a separate video analysis for macro-invertebrates may be conducted. The ratio of post-survey data processing to dive time is approximately 3:1. Results of individual dives are presented visually in map form on dive tracklines in GIS, using dynamic segmentation and event locations along the tracklines. Data on survey navigation, fishes, seafloor habitats, invertebrates, and environmental variables are entered into a relational database.

As an illustration, Mary described a recent study of the Cowcod Conservation Areas off southern California. The immediate purpose of this study was to collect baseline data on all groundfishes, and to determine the distribution and use of various benthic habitats. The results will also support the longer-term purpose of evaluating the effectiveness of the MPAs. Because the Cowcod Conservation Areas cover 14,750 km<sup>2</sup>, a selective survey approach was needed. Cowcod distribution is habitat specific, so the submersible surveys were distributed using habitat maps of the full region to identify the locations in which adult cowcod were most likely to be found. This strategy reduced the survey area to 1,330 km<sup>2</sup>, in which 110 *Delta* dives were randomly located. During the dives, fishes were documented in real time using a combination of strip transect and line transect methods. Many species of fishes other than cowcod, along with invertebrates and bottom type, were recorded in 2 m wide strip transects. Cowcod were recorded in a line transect method to increase the sample size, because individuals were rare but were relatively large and could be detected at a distance. Distances to individual cowcod were measured with a diver's hand-held sonar gun. Dive observations yielded 121,108 individual fishes from a minimum of 119 species. Specific habitat associations were determined for the dominant fish species. Cowcod density and biomass estimates were calculated by combining the line transect data, the area covered by those data, and a length-weight relationship previously established for cowcod in this region. Finally, a full fishery-independent stock assessment was achieved by combining the habitat-specific distribution of cowcod, as determined from dive results, with the regional maps of habitat distribution. This assessment has been extensively reviewed and is now used to manage the cowcod fishery.

Mary Yoklavich also addressed the issue of uncertainty in quantitative submersible surveys. Her lab has conducted field tests to measure sources of uncertainty, including the estimate of transect length from USBL tracking and the observer's estimate of fish length using the paired lasers. Observer-specific correction factors may be established to compensate for potential systematic biases. The line transect method assumes that all fishes are detected, that they are randomly distributed with respect to the trackline, and that their distribution is not affected by avoidance or attraction to the submersible. Long experience with the submersible has shown that fish species react to it in characteristic ways, as

they do with other types of undersea vehicles. For the cowcod survey, to determine whether these line transect assumptions were violated either as a result of cowcod movement in response to the submersible or as a result of nonrandom submersible detours around obstacles, video footage from the side-looking cameras was compared with that from the forward-looking, longer range cameras for 24 dives. No bias was observed in the detection of cowcod or their estimated distance from the submersible.

To evaluate the effectiveness of submersible observations in detection and identification of fishes, results from *Delta* dives in the Channel Islands MPAs (Milton Love and Donna Schroeder, University of California Santa Barbara) were compared with observations from a Phantom HD2+2 ROV made in the same region (Konstantin Karpov, California Department of Fish and Game). The results were striking. For four target rockfish species, the mean density estimated from ROV surveys was between 5% and 70% of the density estimated from *Delta* dives, and the discrepancy was greatest for species associated with rocks. The number of species identified at two sites during *Delta* dives was 46 and 47 species, compared to 12 and 14 species detected with the ROV at the same sites. In *Delta* surveys, the species identification rate for rockfishes is 95%. Of the fishes counted during *Delta* dives, 89% were small species and 91% were small individuals. Neither of these groups was counted in the ROV surveys due to limitations of the ROV video resolution. Detection of the small rockfishes is important, as small, fast-growing species are dominant in several areas along the West Coast. While Phantom HD2+2 ROVs are a relatively common choice for work at shelf depths, the capabilities of this vehicle in terms of video imaging, power, and sample collection are limited in comparison to the *Delta*. The deep-diving Canadian ROV *ROPOS* has also been used for fisheries research along the West Coast. *ROPOS* has capabilities more similar to those of the *Delta*, and addition of high definition (HD) digital video cameras would improve its image quality. However, as an ROV it still would not have the 3-D perspective of the *Delta*.

The choice of vehicle best suited to a particular survey depends on the research objectives. Surveys with the *Delta* submersible can provide data on species composition and density, size composition, biomass, reproductive potential, juvenile recruitment, characteristics of associated habitat, and, to a limited extent, changes to the ecosystem. The added information from submersible dives compared to other visual survey techniques is due to the superior ability of the human observer to detect and identify fishes in the environment.

### ***A review of some habitat-based submersible surveys in the Gulf of Alaska and the role of habitat mapping in fisheries management and research in Alaska***

Victoria O'Connell (Coastal Marine Research, Sitka; formerly of ADFG, Sitka) continued the topic of the submersible *Delta* in fisheries research. She prefaced her remarks by voicing

agreement with Mary Yoklavich's comment that human observations by the diver in the submersible take best advantage of the submersible as a research tool and should be the primary source of data from the dives. Her presentation described the use of the submersible *Delta* for habitat mapping and research on the continental shelf and upper slope of the Gulf of Alaska. The *Delta* is used by both federal and state agencies, for research and for formal habitat-based stock assessment.

NOAA's Auke Bay Lab has conducted multibeam mapping and habitat interpretation of multiple sites around the Gulf of Alaska, including Albatross Bank, Portlock Bank, Pamplona Spur, South Yakutat, Cape Ommaney, and Hazy Islands. Sites have been chosen for various reasons, including high levels of fishing activity, distinctive seafloor features, and logistics. *Delta* dives provide biological data for integration with the habitat maps, and are used to groundtruth those maps. The example shown in this presentation was the use of *Delta* in the habitat study at Portlock Bank, on the outer continental shelf northeast of Kodiak. Portlock Bank is located in an area of extensive rockfish fishing; the mapped area includes regions of both high and low levels of commercial fishing activity. Interpretation of new multibeam bathymetry and backscatter data collected for this study identified 22 types of benthic habitat, using the classification scheme of Greene and others. The objective of this study was to examine spatial patterns of fish species distribution with respect to benthic habitat type, using species occurrence and density, and to examine the relationship between fish species distribution and density, benthic habitat, and fishing intensity.

ADFG began using the *Delta* for fisheries research in 1989, and has conducted more than 600 *Delta* dives in rocky habitat on the continental shelf of the eastern Gulf of Alaska. Dive sites have been located at the Yakutat Bay moraine, the eastern bank of the Fairweather Ground, the offshore Edgumbe lava field and pinnacles, Cape Ommaney (with NMFS), Hazy Islands, and near Cape Addington. This long-term effort has focused on developing methods for habitat based stock assessment of rockfish.

Victoria O'Connell described the ADFG stock assessment program for yelloweye rockfish, the main target of the commercial longline fishery for demersal shelf rockfish. Yelloweye rockfish are also the primary bycatch in the halibut longline fishery of the eastern Gulf of Alaska. Conventional stock assessment tools, e.g., trawls, are not useful because of the rocky habitat. Since 1991, for managing yelloweye rockfish the North Pacific Fishery Management Council has relied on methods developed by ADFG for habitat-based stock assessment. Length and biomass are estimated from commercial fishing data, and abundance is determined in submersible dive transects. Line transects are used because of the low number of yelloweye observed in strip transects.

As part of the ongoing effort to develop and improve methods of habitat-based stock assessment, ADFG researchers have evaluated whether geophysical mapping is necessary,

or whether a (less expensive) combination of existing charts and logbook data would be sufficient. In the Cape Ommaney area, new multibeam bathymetric and backscatter data were collected and interpreted to create a map of 14 habitat types. These were consolidated to three simple categories of hard, mixed, and soft substrate. Comparison of the initial assessment of rocky habitat based on NOS charts and logbook data with the habitat interpretation of multibeam sonar data showed major differences in the amount of rocky habitat identified. Victoria O'Connell noted that for stock assessment it is important to accurately assess the area of habitat because there is no variance parameter, and therefore it is difficult to incorporate uncertainty into this parameter. Geophysical surveys provide a basis for mapping the distribution and extent of the different types of rocky habitat, and also provide a basis for stratification of dive transect locations. *Delta* line transects were randomly located in areas identified as prime rocky habitat by both logbook and multibeam data, and in areas of "marginal" rocky habitat identified only by multibeam. Yelloweye rockfish occurred in all rocky habitats within the appropriate depth zone; however, they were found in highest densities in high relief areas of rugged rocks or in areas of boulders with abundant, large void spaces. Densities of yelloweye were also highest in the area that was fished. Nevertheless, significant numbers of yelloweye were also found in the "marginal" habitat. This had a significant effect on biomass estimates, because the areas of "marginal" habitat were extensive. Furthermore, the *Delta* dive observations revealed that yelloweye rockfish densities varied by almost an order of magnitude on different types of adjacent rocky habitat, and that interfaces between habitats were critically important. Thus, refining habitats to more specific categories, even broad ones such as high relief versus low relief rocky habitat, can also result in significant changes in biomass estimates. The combination of geophysical surveys and *Delta* dive observations thus represents a major improvement in capabilities and accuracy of habitat-based stock assessment.

ADFG habitat studies in the eastern Gulf of Alaska, using a combination of multibeam mapping and *Delta* dives, have also revealed that submerged volcanic structures provide prime habitat for a variety of species. Three sites are the Edgumbe Pinnacles near Sitka, the remnant of an eroded volcanic cone in the Fairweather Ground, and a pit crater offshore of Cape Addington. As a result of this research, the Edgumbe Pinnacles Marine Reserve was established as the first no-take groundfish MPA in Alaska.

Discussion: A workshop participant asked what is the basis of uncertainty in dive transect data. Victoria O'Connell replied in terms of the relationship between dive transects and habitat maps. At a broad scale, geophysical data are classified into habitat regions. At a visual scale, dive transects show variation within those individual habitat regions, and this variation can lead to uncertainty. It is addressed by conducting multiple, randomly located transects within the same habitat region.

**Rockfish live on rocks and trawls get stuck on rocks: The development of new methods to monitor populations of West Coast groundfish and their habitats using the SeaBED AUV**

Nick Tolimieri (NOAA NMFS, Northwest Fisheries Science Center, Seattle) described progress of the NWFSC in collaboratively developing an imaging AUV (autonomous underwater vehicle) with Hanumant Singh at the Woods Hole Oceanographic Institution that meets the needs for monitoring groundfish populations on the West Coast. The NWFSC has two needs to address: monitoring groundfish populations for which traditional trawl surveys are inadequate; and monitoring habitat including deep-water corals and sponges in Habitat Areas of Particular Concern (HAPCs) in a nondestructive, non-extractive, and cost effective way. AUVs can be a particularly cost-effective survey method, because they can operate unsupervised while the support ship conducts other operations. Imaging AUVs have potential to accelerate the process of habitat mapping, and may also play a role in monitoring populations of groundfish.

The *SeaBED* AUV is designed to travel at 1.0 m per s or less, typically 0.3–0.5 m per s, maintaining a fixed altitude of above the bottom (in these studies approximately 3 m above the seafloor). The AUV is small, 2.0 m long and 1.5 m high, weighing 250 kg. It can be deployed from vessels of opportunity using a crane or small A-frame. *SeaBED* runs a user programmed survey pattern, using Doppler velocity log (DVL) for bottom tracking combined with position fixes from USBL, LBL, and/or real-time telemetry. Mission duration during NWFSC testing was 8 hours. Its primary data product for NWFSC is a series of still photos, with lighting and color correction, each approximately 3 m<sup>2</sup>. A 3-D photographic image can be created by overlaying the photomosaic onto high-resolution bathymetry. The software also includes a sophisticated graphical user interface (GUI) to assist in analyzing information on the images. In addition to the camera, *SeaBED* can carry a variety of other sensors including multibeam sonar, CTD, and ADCP.

Nick Tolimieri described the results of NWFSC trial missions at Daisy Bank and Coquille Bank off the coast of Oregon, and Santa Lucia Bank off southern California. The AUV effort is directed at monitoring groundfish populations, so the main task was to count groundfish. Counting fish in digital photomosaics has potential pitfalls. If individual fish move, they may be double counted. Paradoxically, a moving fish may also be dropped from the mosaic entirely, if the software interprets the movement as an indication of noise or an artifact. Therefore, instead of counting fish in the photomosaics, NWFSC randomly subsamples individual photos for fish. NWFSC has tested several subsampling schemes, ranging from analysis of all frames in a continuous photomosaic to analysis of random frames along the transect. The data are presented as odds of occurrence in a single photo.

To describe the habitat substrate, they chose the two-letter habitat classification approach that has historically been used on nearby Heceta Bank, recording sediment particle

size for the primary substrate and hard versus soft for the secondary substrate. As in other West Coast habitat studies, depth and substrate are confounding factors, with rocky substrate present in shallower areas and soft sediments covering deeper areas. However, with detailed survey data one can make finer distinctions about fish distributions with respect to habitat. Nick noted several edge effects from their integrated data on substrate and rosethorn rockfish. They saw edge effects in which larger fish and greater biomass were found at the edge of the rocky reefs, and only larger fish were observed outside the rocky area, at the edge of soft sediment regions. This species was more abundant on boulder habitats and less abundant on cobble habitats than expected from random distribution.

While *SeaBED* was designed for seafloor imaging, it was not specifically intended for fisheries applications. Notable limitations of this vehicle include the absence of a human observer, inability to collect physical samples, and inability to change the mission and dive track in real time. The downward-looking camera makes it difficult to identify rockfish that are not distinguishable from the top view. In downward-looking images, NWFSC was able to identify 15% of the fish to species, but many more could be put into species groups (e.g., rockfish group). NWFSC is modifying their AUV to operate with both a forward-looking and downward-looking camera to improve identification of fish. The NWFSC also plans to test an infrared camera and a DIDSON camera on the AUV, to assess fish response to the vehicle. Finally, they are working with Hanumant Singh to develop an automated method for processing images and in particular for counting fish in the still images.

**Underwater video sleds from simple to complex: A series of versatile and cost effective tools for habitat mapping**

Chris Rooper (NOAA NMFS, Alaska Fisheries Science Center, Seattle) presented an overview of video sled capabilities and designs, with examples from Alaska. Video sleds have been in use for decades, and are sometimes overlooked in favor of more complex or novel technologies. However, as the title of the presentation says, they are versatile and cost effective, and can be a good choice for habitat mapping. Video sleds are suitable for substrate mapping, groundtruthing acoustic maps, identifying target fish in acoustic surveys, fish-habitat studies, fish abundance estimation, and estimating stock assessment parameters (e.g.,  $q$ ). Chris Rooper reviewed three basic sled designs: bottom contacting sleds, bottom tending sleds, and suspended or drop cameras. These were illustrated by eight sleds that have been used in Alaska by NOAA and ADFG.

He showed examples of video substrate classification from sled data on sites around Samalga Island and the Islands of Four Mountains. Sidescan images served as base maps, and were classified into distinct substrate types. A towed video survey was used to groundtruth the substrate map. The sled had both forward and downward looking cameras, and

was towed 1-3 m off bottom at 1-1.5 kts. They use DV Logger software for video analysis, available from Craig Rose.

When planning a survey, the first step, very important to do first, is to define the objectives. Second, define the statistical method. Third, what data types are needed to support this method? If qualitative, descriptive data will be sufficient, one might consider a simple approach with simple gear. If quantitative data will be required for statistical analysis, then a more sophisticated survey with high quality video, accurate navigation, and a measure of area swept might be appropriate. Fourth, what are the limitations of the study area? Relevant site characteristics are depth, currents, slope, roughness, and hardness of the substrate. Finally, select or design a sled to meet these needs.

Sled capabilities vary, for example, in the accuracy of sled navigation; image quality and resolution; image range and lighting; quantitative measures of altitude, scale, and area; data rates (digital video can produce > 1GB/min); power source; whether or not the sled and its tether provide a real-time video feed to the ship; and deck gear requirements. Chris Rooper showed a table of these and other variables. Other types of equipment that may be added to video sleds include DIDSON acoustic cameras, fish sonar, CTDs, and current meters. All of these play into another major consideration, cost of the sled, which can vary from \$1,000 to \$100,000.

There are important advantages of video sleds, in comparison to other visual methods. These sleds are relatively small and portable, and do not require a large support vessel. The sleds are generally robust, built to withstand impact with the bottom (to a reasonable degree). Maintenance requirements are modest. The technology is relatively simple, and many custom variations and modifications are possible.

Video sleds do have limitations. They have a relatively small viewing swath, especially in comparison to human-occupied submersibles. Image quality and resolution may limit discrimination of substrates, e.g., sand versus mud. The difficulties involved in tracking a towed vehicle, generally by layback navigation, can compromise position accuracy. It may not be possible to tightly control the vehicle track, due to currents and ship handling constraints. However, all technologies have limitations, and video sleds can be a simple, cost-effective, useful tool for habitat mapping.

Discussion: Doug Woodby asked whether one can put cameras on trawls during trawl surveys. Chris Rooper replied that yes, this can be done, or one can substitute towed video for the trawl survey. Bob McConnaughey commented that he has had trouble putting a camera on trawls. Jennifer Reynolds added that, based on experience with cameras on other types of deep-sea sampling gear, the problem is probably the shock to the camera as the trawl bounces.

## Topic IV—Translating data into habitat classification

### *Video-supervised numerical classification of acoustic data from Glacier Bay, Alaska*

Guy Cochrane (USGS Coastal and Marine Geology, Menlo Park) discussed a method for supervised numerical classification of acoustical data that has been used by USGS researchers and their collaborators in Glacier Bay. Glacier Bay has formed over the past 200 years, as Muir Glacier retreated 60 km up the fjord. This retreat exposed new areas of seafloor to benthic colonization. In addition, because marine environmental conditions change with distance from the face of the glacier, the retreat of the glacier created potential for rapid succession from glacial to estuarine seafloor properties, habitat, and biota in the bay.

Supervised numerical classification is a method of quantitatively classifying acoustical seafloor mapping data into substrate classes chosen by the researcher. (See Jim Galloway's presentation for a discussion of unsupervised numerical classification.) First, sonar mapping data are collected, either multibeam sonar data (including backscatter) or sidescan sonar images. These images show variations in seafloor induration. Visual groundtruth surveys are conducted to identify the substrate classes present in the mapped area. From the sonar data, acoustical signatures are generated for each substrate class, and each pixel in the map is classified based on the closest match of its acoustic signature to those in the defined classes. Two options for matching multibeam backscatter pixels to sonar classification signatures are ArcGIS maximum likelihood classification, which matches to unique sonar signatures, and ERDAS Imagine decision trees. Maximum Likelihood Classification is best when the sonar data are uncalibrated and the range of values is not fixed for each class. Decision Tree Classification is best for calibrated data in which the effects of sonar travel path and seafloor slope have been removed, establishing a consistent and unique range of backscatter values for each substrate class. The substrate classes are further divided into bathymetric or oceanographic zones, depending on the needs of the habitat mapping program. Guy Cochrane and colleagues have found that the data will support no more than three or four substrate classes with either method.

In Glacier Bay, multibeam bathymetric and backscatter mapping was conducted by Thales GeoSolutions (Pacific) using a hull-mounted Reson Seabat 8111, on behalf of the U.S. National Park Service and the U.S. Geological Survey's Biological Resources Division and Coastal and Marine Geology Program. The multibeam survey was followed by two weeks of groundtruthing using the USGS towed video sled. This video sled has forward- and downward-looking cameras, paired scaling lasers, lights, an altimeter and a pressure sensor. Researchers on the ship log real-time, georeferenced

observations at 30 second intervals, including substrate type (primary and secondary), slope, rugosity, small-scale features such as ripples and burrows, general levels of benthic bio-coverage (low, medium, high), and presence of key benthic organisms and demersal fish. The USGS video sled is not optimal for biological surveys, particularly identification at the species level such as of rockfish species. Transect locations are not random; they are chosen to groundtruth the variety of habitats identified in the multibeam maps. Guy Cochrane showed numerous images from groundtruthing transects. The two weeks of video surveys produced 42 hours of georeferenced video along 52 transects.

The goal of the supervised classification of multibeam data is to map areas corresponding to biology-geology correlations that are observed in the video transects. Covariance analysis is useful for identifying these correlations (see report by Etherington and others, 2004, in Proceedings of the Fourth Glacier Bay Science Symposium). In the Glacier Bay study, four geomorphic classes were defined, each with a range of seafloor characteristics, bathymetric and backscatter variance (among pixels within a specified distance), backscatter intensity, and seafloor slope. The four geomorphic classes were assigned shorthand labels of high slope complex rock, low slope complex rock, unsorted glacial sediment, and mud. These geomorphic classes are one of the inputs to habitat classification; the others can be depth, oceanographic conditions, seafloor slope, complexity, small-scale seabed features such as sediment waves, or other factors as needed. The habitat classification map for Glacier Bay is based on the structured classification scheme of Greene and others (Oceanol. Acta 22[6]:663-678, 1999), and contains 48 habitat classes identified as polygons.

The methods used in Glacier Bay have been further developed, and are now being incorporated into standard habitat mapping protocols for the habitat mapping initiatives in California's federal and state waters. Further information on the California program is provided in the paper by Cochrane (this volume).

### ***Video analysis, database management, and statistical analysis***

Brian Tissot (Washington State University Vancouver) studies benthic ecology and habitat along the West Coast. This presentation drew on his extensive experience with analysis of submersible dive videos. He emphasized the importance of defining the objective of the study first, then designing the survey, sampling method, statistical tests, and database to support that objective. Statistical design issues include representation, replication, independence of measurements, and power (ability to detect change). Both the survey and video analysis system must be designed with these issues in mind. Dealing with these issues after the dive program may result in misdirected effort and resources, and data that are not adequate for the purpose at hand. Brian's main point was that detailed advance planning of the dive program and the data collection procedures ensures that the resulting data sets are

suitable for addressing the study objectives.

During a cruise, data collection in support of the study objectives includes taking detailed notes, synchronizing clocks (this links all of the data sets), double checking the navigation data, and backing up absolutely everything. During the dives, researchers are advised to check the video and audio recordings (and use double decks), annotate the audio log, and collect voucher specimens.

Procedures for video analysis in Brian Tissot's lab have been developed both for data quality and to accommodate training new analysts. Formal data logging protocols are very important, as a guide for new analysts and as a check on consistency within the lab. Detailed descriptions of procedures should be written down, shared with colleagues, and modified as needed (with written revision dates). Check that the protocols are being followed. Training is also key for consistency within the lab. For submersible dive video, analysts need training in taxonomic identification, visual survey methodology, habitat classification, understanding navigation, and understanding the equipment, software, and statistical methods used in the analysis. New analysts start by working with others to learn the protocols, then they log a previously analyzed data set. The result is reviewed, and training continues until the result from the new analyst is at least 90% consistent with the existing analysis of the data set. The technician and senior graduate students in the lab are instrumental in training the new graduate students.

Post-cruise analysis of the video recordings will take much longer than the actual dive time, typically in a ratio of 5-10:1. The equipment for productive video analysis include a comfortable work station, quality video player (if using analog recordings), and a production quality monitor. The data should be entered directly into a computer database. Counters or keys programmed to increment a tally simplify the process of counting organisms. Video analysis requires multiple passes, generally by multiple people, to log different types of information from the dives. For example, habitat classification focuses on primary and secondary substrate types. Invertebrate analysis is limited to megafauna at least 5 cm in size. Most invertebrates are grouped as part of habitat patches; only structure forming invertebrates larger than 20 cm are counted individually. For these, their condition (health) and association with fish are also noted.

Database management is essential. The data should be entered into a relational database, not a spreadsheet. Relational databases are much more flexible, easy to modify, less prone to error, and they can be shared among multiple users. Furthermore, they are designed to integrate complex sets of data, and can be queried to join or filter data types. For example, relational databases can accommodate and integrate general cruise metadata, vessel and submersible navigation, CTD data during the dive, fish, invertebrate, and habitat observations. These data can be output to spreadsheets, graphics programs, and statistical packages. Relational databases can also connect directly to ArcGIS, facilitating spatial analysis.

Brian Tissot illustrated possible products with the very extensive database from Heceta Bank, Oregon, which represents research by many collaborators (see Tissot and others, this volume). For invertebrates, analysis of over 100 hours of video recordings combined with taxonomic analysis of voucher specimens has resulted in a database of 65 taxa from six phyla; over 3,000 habitat patches; and more than 500,000 individual invertebrates. Each observation is linked to dive information, location, depth, fish observations, primary and secondary substrate characteristics, oceanographic conditions, etc. These data are well suited to correspondence analysis to identify statistical patterns in the associations of fish, invertebrates, and habitats, and to geospatial analysis. Additional examples drawn from Cordell Bank and the Cowcod MPAs off California show patterns in species and community associations with the physical substrates. These databases enable researchers to integrate observations, form hypotheses, and link the results to management issues.

**Marine benthic habitat classification:  
What is best for Alaska?**

Gary Greene (Moss Landing Marine Laboratories, Center for Habitat Studies) focused on methods and philosophies for classifying marine benthic habitats, with recommendations for habitat mapping in Alaska.

One way of looking at habitat classification is the distinction between classification based on biology and classification based on geological substrate. Classification based on biology has its origins in terrestrial and shallow water marine studies. Where the seafloor itself is in the photic zone, it has encrusting flora and fauna and may be described in terms of biological substrate. Because this is rooted in the effect of the photic zone, it is a top-down (biological cover to substrate surface) approach to classification. In deeper water, below the photic zone, the seafloor is dominated by geological substrate with variable epifauna and infauna. Here the geological substrate controls major habitat characteristics, and provides a unifying framework for classification, in a bottom-up (seafloor up) approach to classification. The disconnect between these two types of classification will not be solved by selecting one over the other, but by combining them in a way that allows a full characterization of a variety of marine benthic habitats.

Habitat characterizations necessarily depend on what is there, and on the technology available to survey it. One critical element of marine benthic habitat characterization is depth, which is related to temperature, photic zone, and seafloor physiography. The seafloor substrate provides structure for refuge, foraging, and reproduction/nesting. Seafloor slope varies in terms of relief, complexity, and rugosity. Currents carry nutrients, distribute sediments, and create disturbance at the seafloor. Seafloor biota are involved in biogeo synergy, and are both inhabitants and part of the habitat. Scale is always an issue; most data are (or should be) interpreted at their highest resolution, and thus data at different scales must be combined for the habitat characterization.

The technologies for surveying habitat may be divided into those that provide in situ observations of small areas, and remote sensing technologies for coverage of larger areas. In situ technologies for use in shallow water (0-30 m) include scuba, human-occupied submersibles, ROVs, camera sleds and drop cameras, and sampling devices. All of these except scuba are used in deep water as well. Remote sensing technologies exclusively for shallow water include LIDAR, hyperspectral surveys, satellite imagery, and airborne digital photography. Others that may be used in both shallow and deep water are multibeam bathymetry and backscatter, sidescan sonar, laser line scan, and subbottom profiling.

Gary Greene briefly reviewed several classification schemes in use around the world. One is unsupervised acoustic classification (e.g., QTC), which produces an acoustic facies map. The European EUNIS system and a U.S. system developed by NOAA and NatureServe are hierarchical habitat classification schemes that accommodate terrestrial to marine ecosystems. In Australia, the deep-water bioregionalization scheme is based on a framework of geomorphology.

Gary Greene and his collaborators have developed a deep-water habitat classification scheme for the U.S. West Coast (modified after Greene and others, *Oceanol. Acta* 226[6]:663-678, 1999). It is in use in the Pacific Northwest, British Columbia, and Alaska. This scheme is structured to accommodate critical information at multiple scales. Remote sensing data are characterized first at the scale of megahabitats (depth-related), covering one to many 10s of km, e.g., S = Shelf, continental and island shelves. Seafloor induration is included, e.g., m = mixed hard and soft substrates (sediment types noted). Next, meso/macrohabitats (scale-related) are characterized at 1 km to 10s of meters, e.g., c = submarine canyon or w = sediment waves. The seafloor morphology is noted, e.g., h = hummocky. Seafloor slope may be included, and is classified in five categories from flat (0-1 degree slope) to overhang (> 90 degree slope). Seafloor complexity is defined as rugosity = surface area/planar area. This is a quantitative, reproducible measure. Seafloor complexity is divided into five categories, from very low (-1 to 0) to very high (3+). The final part of the habitat code is preceded by an asterisk and deals with visual and sampling data at macro/microhabitat scales of cm to meters. This includes both geological attributes, with percent grain sizes when possible, and biological attributes. An example of this part of the attribute code is \*(m)[w]1D, which translates to flat or nearly flat mud (100%) with worm tubes and high complexity. For comparison, \*(s/c)1A translates to sand bottom (>50%) with cobbles (>20%), flat or nearly flat, with very low complexity.

The user can choose the level of detail to include in the attribute code. A simple attribute code based on remote sensing data might be Ss\_u or Shc\_c. A moderately detailed code might be Sh(b)p\_d/v. A highly detailed, complex code that includes both remote sensing and visual data might be Sh(b)p\_d/v\*(b/c/p)[s/c/a]2B.

Gary Greene illustrated the use of these habitat classification codes with examples from the San Juan Islands in

British Columbia, Southeast Alaska, and the Aleutians. The full codes are imported into a GIS environment for spatial analysis, and may be queried to display specific attributes. In one of the habitat maps from the San Juan Channel, which has nine habitat classes, a query for hard substrate identifies “exposed bedrock” and “pinnacle” habitat classes, and displays them on the map. A query for unconsolidated sediment identifies seven other classes. A query for mud identifies one class, and a query for sediment waves identifies two classes. Gary ran through a similar exercise for a site in the Aleutians, querying for bedrock, unconsolidated sediment, and bedforms (e.g., current scour, sediment waves). Thus one does not need to deal with all parts of a complex attribute code in order to make use of it, but once the codes are created all of that information is available to be called up.

In summary, many different classification schemes exist for characterizing marine benthic habitat types. The tools and classification schemes useful in Alaska depend on the objectives and scale of the mapping exercise. Gary Greene encourages adoption of a standard method of mapping marine benthic habitats that is beneficial to users. In any case, habitat interpretation should be done at the highest resolution possible, and archived in a GIS environment.

## Topic V—Case studies

### *Twenty years of fish-habitat studies on Heceta Bank, Oregon*

Brian Tissot (Washington State University Vancouver) presented a twenty-year history of fish-habitat research on Heceta Bank. Heceta Bank is one of the largest deepwater rocky banks on the U.S. West Coast, and has historically hosted a major commercial fishery. The Heceta Bank studies have pioneered applications of direct observation techniques to study fish and invertebrate communities in their habitat. This history tracked the influence of technological developments and changing research priorities.

The initial fish-habitat studies in 1987 were essentially exploratory, and aimed to characterize assemblages of fish species, related them to habitat and depth, and evaluate the importance of the bank as a nursery area. Existing data were limited to bottom trawl sampling from soft-bottom areas, and the NOS chart which showed the basic shape and depth of the bank but provided little information on substrate composition and texture. Sixteen exploratory dives conducted with the *Mermaid II* submersible in 1987 produced a list of fish species and estimates of fish abundance in a broad range of habitat types, along with initial information on the distribution of those habitats. The tools used in these early submersible dives seem relatively primitive from today’s perspective. Navigation was by Loran C, and the support ship tracked the submersible’s position during dives using a surface buoy towed by the submersible. Scale was by reference to a fiberglass rod mounted on the outside of the submersible. Video from a low-resolution camera was recorded to VHS tape, and an externally mounted 35 mm film camera took

higher-resolution still photos. Cluster analysis of the dive data resolved two fish assemblages, one dominated by rock-fish and associated with shallow rock and cobble habitat, and the other dominated by flatfish and associated with deeper mud and cobble habitat. The data also pointed to shallow, rocky areas as important nursery grounds for juvenile rockfishes. Experience with submersible dive data in this early stage contributed to subsequent development of systematic, standardized methods that supported statistical analysis of fish-habitat associations and distribution.

A new series of 42 dives was conducted with the *Delta* submersible in 1988-1990, as part of an Outer Continental Shelf study by the Minerals Management Service on four rocky offshore banks. The purpose of these submersible dives was to establish baseline information on seafloor communities and to examine interannual variation over a three-year period. The dives were conducted as transects from six representative stations selected from the 1987 dive locations, including shallow rocky ridges, mid-depth boulder-cobble-mud areas, and deep mud. Submersible tracking was done with a USBL system combined with Loran C fixes. Voucher specimens of megafaunal invertebrates were collected with *Delta*’s slurp gun. A timed data logger and audio track were added to the video recording. The dive methodology was improved based on experience in 1987, particularly to standardize dive procedures. A major step was development of quantitative approaches to data analysis, including a new system for classifying primary and secondary substrate types in terms of particle size and relief, e.g., mud or boulder. This classification scheme has been widely used in subsequent West Coast habitat research. The dives documented much larger numbers of fish taxa and abundance compared with the 1987 dives, probably due to the greater sampling effort. The analysis of these data, and ability to quantitatively associate fishes with habitat types, led to a new way of thinking about fish-invertebrate-habitat relationships that focused on habitat patches and bottom types rather than sampling stations. This shift was part of an evolution toward ecosystem-based research.

In 1998, a multibeam sonar survey of Heceta Bank was conducted with a Simrad EM300 system (100 kHz). These high-resolution bathymetry and backscatter data revealed the seafloor features on the bank as never before. Existing submersible dive data were integrated with the multibeam map, and fish-habitat associations were applied to areas surrounding the dive tracks, permitting the first estimates of species abundances in habitat patches.

The new map also revealed that characterization of the bank was incomplete in specific ways; some of the habitat types identified in the multibeam map had not been covered by previous submersible dives. A new series of 27 dives was conducted in 2000-2001 with the ROV *ROPOS*, including six new sites. Transects were also conducted at five of the historical sites, using procedures as close as possible to those used with *Delta*. This enabled direct comparison of results from the two vehicles. Technological advances included nav-

igation (GPS instead of Loran C), dynamic positioning of the ship, scale measurements (parallel lasers instead of an object of known size mounted in the field of view), video quality (digital instead of analog VHS), much greater sampling ability of *ROPOS* compared to *Delta*, and increased dive time. The *ROPOS* dives documented comparable numbers of fish taxa and fish abundances as the earlier *Delta* dives. Increased attention to benthic invertebrates in the *ROPOS* dives, especially corals, produced a significant increase in the number of invertebrate taxa identified. New research partners with expertise in taxonomic analysis of invertebrates joined the team, and structure forming invertebrates were analyzed as a component of benthic habitat. More recently, quantitative analysis of the multibeam bathymetry and backscatter parameters has shown a general correlation with bottom type documented in the *ROPOS* dives, to the extent that multibeam data were used to classify the bank into three habitat types: rock outcrop, boulder/cobble, and mud/sand.

In 2002, a series of 18 *Delta* dives was conducted at the six historical stations, at the same time of year and with the same researchers as in 1988-1990. These dives examined long-term change in overall density of fishes and species, and in density on specific bottom types. Statistical analysis showed little change over that time period, with significant differences mainly in species associated with soft sediment.

Developments since 2002 have continued to broaden the scope and application of habitat studies at Heceta Bank. By 2003, efforts to construct regional maps of benthic habitat were underway, and Heceta Bank was included in a generalized seafloor lithology map for Oregon, placing it in a regional context. The use of GIS to synthesize various types of data has improved the ability to use the habitat-based data for stock assessment. In 2005, the Pacific Fishery Management Council produced an EFH Environmental Impact Statement for Heceta Bank, and in 2006 the bank was designated an EFH Conservation Area and was closed to bottom trawling.

In summary, the history of fish-habitat research at Heceta Bank over the past twenty years tracks parallel developments in technology and research objectives. New technologies have opened up possibilities for new research approaches, as well as supporting more effective data collection. Research objectives have evolved from exploration and baseline surveys to multidisciplinary assessment of fish-invertebrate-habitat relationships and long-term changes in benthic ecosystems. These developments have broadened the scales at which fish-habitat associations are understood and applied, and have improved information to decision-makers.

### ***Do large-scale multibeam survey programs improve our knowledge of seafloor habitats? The example of the Irish National Seabed Survey***

Anthony Grehan (National University of Ireland, Galway) presented an overview of the Irish government program for mapping the entire Exclusive Economic Zone of Ireland, over 700,000 km<sup>2</sup>, including the motivations behind the program,

Ireland's approach to dealing with this large area, technologies and techniques used, and benthic habitat map products. This program was included in the workshop as a possible model for broad-scale habitat mapping in Alaska waters. The first stage of the program was the Irish National Seabed Survey (INSS); in 2006 it was succeeded by Integrated Mapping for the Sustainable Development of Ireland's Marine Resource (INFOMAR). The primary source of information for both is a Web site produced by the Geological Survey of Ireland and the Marine Institute, [www.gsiseabed.ie](http://www.gsiseabed.ie).

This program has been motivated by a need for information to support management in the areas of conservation, fisheries, oil and gas, and increased infrastructure in the marine environment. It will establish baseline information for these purposes, and promote marine research. It is based primarily, though not exclusively, on collection of new data sets. The program is viewed as an opportunity to develop national expertise and thus strengthen the government agencies, partners, and commercial sector of the country. It is conducted in the context of several other major European programs for habitat mapping that include areas in Irish waters: Mapping European Seabed Habitats (MESH); Hotspot Ecosystem Research on the Margins of European Seas (HERMES); and Marine Protected Areas as a Tool for Ecosystem Conservation and Fisheries Management (PROTECT).

The initial six-year INSS program represented an investment of approximately \$42 million USD, most of which was devoted to multibeam sonar mapping with Simrad EM120 (12 kHz) and EM1002 (98 kHz) sonar systems. Additional data used for the habitat mapping effort were collected by single-beam echosounder, subbottom profiler, sidescan sonar, groundtruthing by visual surveys and sampling, and water column measurements. Some of these data were drawn from archives, and others were acquired in new surveys. The Geological Survey of Ireland decided to map deep areas first (200-4,000 m) because deep-water areas can be mapped relatively quickly, and this strategy would produce impressive products right away. This would help to maintain support for the program and secure funding beyond the first stage. During the period of deep-water mapping, planning for shallow-water mapping proceeded with extensive stakeholder input, particularly in prioritizing nearshore areas. Shallow-water mapping began in 2006, with the INFOMAR phase of the program.

Seabed classification is an explicit part of the program, as one of the final value-added products. For areas shallower than 200 m, the Geological Survey of Ireland and the Marine Institute are producing classification maps at 1:60,000. INSS has digitized dense single-beam survey lines from 300 paper-based charts, and new shallow-water multibeam data are being collected in the second stage of the program. The seabed is classified into geological substrate types, such as sand, gravel, and bedrock. The primary basis for this classification is acoustic backscatter from single-beam echosounding data, combined with groundtruth information. The backscatter

data are being processed using QTC software from Quester Tangent Corporation.

For areas deeper than 200 m, acoustic backscatter data were collected during the new multibeam sonar mapping program. In water depths to 400 m, the data support preliminary seabed classification. However, the backscatter data from greater water depths are generally not usable. The data are processed with a grid size of 100 square meters, which is not adequate for seabed classification for the intended purposes (fisheries and resource management). In addition, data collection procedures were not optimal, because of gain changes during surveys and inadequate metadata. In recognition of these problems, greater attention will be paid to collecting good backscatter as the mapping program moves into shallow water.

ROV surveys are used to groundtruth the seabed classification maps and to link the seabed classification with biology. The *Bathysaurus* ROV is equipped with a Reson Seabat 8125 multibeam sonar for high-resolution mapping, along with both down-looking and side-looking video cameras.

The combined multibeam and video data sets are subjected to multi-scale analysis of the terrain (slope, aspect, roughness, etc.) and analysis to identify scales at which seabed terrain is related to the distribution of fauna. This analysis in turn provides information for habitat suitability modeling, i.e., determining which terrain or environmental parameters are important habitat characteristics for specific species. Several approaches to habitat suitability modeling were considered, and environmental niche factor analysis was selected. It is used together with Genetic Algorithm for Rule set Production (GARP). A published example of environmental niche factor analysis is the United Nations Environmental Programme (UNEP) 2006 report on *Seamounts, Deep-Sea Corals and Fisheries*. This publication also addresses the problem of managing large areas.

Anthony Grehan presented several examples from the INSS program. He showed multibeam backscatter data from Stanton Bank to illustrate processing techniques used to handle nadir striping and to conduct unsupervised seabed classification. On the Southern Mound Province of Porcupine Bank, multibeam bathymetry and ROV images document coral mounds as high as 130 m, with corals and hexactinellid sponges. The Belgica Mound Province in the Porcupine Seabight contains several hundred coral mini-mounds about 5 m high and 50-100 m in diameter. Their general shape was apparent in the regional multibeam survey, at 25 m grid size. The fine structure was revealed by high-resolution mapping using the ROV as a mapping platform; these multibeam data were gridded at 0.5 m. The Belgica Mound Province is a known hake spawning ground, and is heavily trawled. ROV video showed coral debris covering all mounds; areas between the mounds were composed of sand with sparse fauna.

Finally, Anthony Grehan reviewed lessons from the INSS program to date. For effective habitat mapping, full survey coverage is desirable and a suite of sampling techniques

is required. Sidescan sonar data are very useful, and sub-bottom profiles are worthwhile. Oceanographic information should be added, particularly for habitat suitability models. Factors to be considered in habitat mapping include oceanography, geology, biology, technology, and the management issues that the maps are intended to serve. In Ireland, these management issues are identification of new resources, sustainable development, managing impact of offshore activities, and support for legal mechanisms of marine conservation. The question posed at the beginning of this presentation was whether large-scale multibeam survey programs improve our knowledge of seafloor habitat. The answer is clearly "yes." Deep-water multibeam data support seafloor feature recognition, and provide clues to interesting habitat. Terrain analysis may provide additional useful information for habitat suitability modeling. Shallow water multibeam bathymetry and backscatter may be used for substrate characterization, to provide an excellent foundation for habitat classification. Furthermore, the INSS effort and its successor, INFOMAR, have stimulated major intellectual endeavors to add value to the original dataset, and this has also benefited Ireland. Anthony Grehan concluded by noting that much work remains to better understand the relationships between fish and habitat.

#### ***Application of geoscience information to marine environmental management at the scale of continental margins: Australia's representative marine protected area program***

Peter Harris (Geoscience Australia) described the national program for characterizing seafloor habitat for the Australian EEZ, and discussed its rationale, methods, and products. This Australian program for habitat mapping at the scale of continental margins is relevant to the challenges that Alaska faces. Australia's marine habitat mapping program was established to support creation of a national representative system of marine protected areas. Under the United Nations Convention on Biodiversity, Australia has committed to a goal of setting aside 20% of its EEZ in reserves by 2012. However, MPA selection cannot be made on the basis of species conservation, because the status of most species is not known. In many cases, not even the identity or biodiversity of species is known. An alternative approach is to recognize that biodiversity is tied to habitat diversity, and concentrate on the conservation of habitats. The principle is the same as in terrestrial ecology, in which a small set of environmental variables such as latitude, rainfall, slope, etc. can predict the type of ecosystem with a high degree of confidence, e.g., grassland, tundra, boreal forest; and additional factors can be used to define variability at finer scales.

The marine habitat mapping program in Australia uses a hierarchical scheme to classify bioregions. The broadest classification level is the province or biome, at a scale greater than 100 kilometers (e.g., shelf, slope, abyss). Data layers useful for defining provinces are the geological age of the crust (related to time and conditions for biological evolution), and

demersal fish populations. Key provinces are separated by transition zones that are largely defined by geomorphology and biology. The second level in the hierarchy is the geomorphic unit, at a scale of 10s of kilometers (e.g., canyons, seamounts, reefs). The third level is the biotope, at a one km scale (e.g., low-profile reefs, sand ridges). The fourth scale is that of biological facies, or communities, which exist in patches smaller than 100 meters. The finest scale is micro-communities, including indicator species, at a meter scale achieved by visual surveys. The map scales most useful for management are the first three, as areas smaller than a few hundred meters are not managed separately.

Under the constraints of the timetable for MPA selection, Geoscience Australia has mapped "potential" marine habitats based largely on existing geophysical data. Peter Harris reviewed four reasons to use geophysical data for mapping marine habitats. First, most biological data sets are patchy and are based on data collected for other purposes. In contrast, geophysical data sets aim for continuous coverage, permitting assessment of an entire area without spatial bias. Second, many important ecological factors are physical in nature, such as light, wave energy, and depth. Third, biological sampling in areas impacted by humans shows an altered state of the biota. In contrast, the habitat in human-impacted areas remains basically the same and can be used to predict the long-term potential of a site. Fourth, geological processes integrate temporal variability over a longer term, and geological processes can also cause or reflect disturbance. Thus geology can be more effective than snapshot surveys for revealing disturbance patterns.

Maps of geomorphic units are based on bathymetry and geological information, and are designed to represent the diversity of the seabed at a scale relevant to management applications and ocean policy. To create these maps, Geoscience Australia compiled a database of existing digital bathymetry data and constructed a 250 m bathymetry grid. Approximately 5% of Australia's seabed had been mapped by multibeam sonar; the rest of the data were from single-beam echosounding records and navy chart fair sheets. A geomorphic features map was created by expert interpretation of the bathymetry and geological information, aided by GIS spatial analysis and visualization. Seabed features were classified according to the 20 classes of the International Hydrographic Office (e.g., continental shelf, canyon, pinnacle, apron/fan) with an added class for sandwave/sand bank. Peter Harris provided several examples of geomorphic features with known species associations: seamounts, canyons, and hydrothermal vents and other areas of natural seepage. Peter also remarked that the GLORIA sidescan images from Alaska could be used for geomorphic analysis.

The geomorphic map provided a basis for quantitative assessment of the existing MPAs. The MPAs covered less than 20% of the seabed and thus did not yet meet the national commitment to the United Nations Convention on Biodiversity. Nevertheless, the Australian network of MPAs

was ultimately supposed to be comprehensive and adequately representative. Comparison of existing MPAs with the map of geomorphic features indicated that 17 of 20 types of seabed features were represented. In terms of areal coverage, several types of features were greatly overrepresented, while others were underrepresented or missing. Whether these MPAs were adequately representative is a policy decision.

Ecologists have also documented correlations between other physical variables and benthic biota. These variables can be used as surrogates for biological habitat. Peter Harris showed a table of seventeen surrogates, with references. Many of these are characteristics of the geological substrate, such as percent mud and seabed hardness. Others reflect the seabed energy regime. Depth is a complex surrogate, in that it is related to a host of other habitat parameters: temperature, pressure, light intensity, oxygen content, and food availability. These physical variables operate at more local scales than the geomorphic features.

To account for these variables in Australia's bioregionalization maps, multiple variables are integrated to create a seascape classification map for a specific region. A seascape map might include, for example, tidal currents, bathymetry, slope, and percent sand. The data are subjected to unsupervised classification, using the isoclass algorithm in ER-MAPPER, to define spatial data clusters. The optimal number of classes is selected based on output characteristics. Each spatial point is assigned to a class according to a distance ratio, the average of the mean euclidean distance of each class member to its class mean. For example, seascape input data for the Southwest Planning region included gravel, mud, depth, slope, primary production, and bottom water temperature. These data resulted in a seascape classification map with 10 classes. However, both the seascape map and the geomorphic features map were relevant to habitat classification. Crossing 10 seascape classes with 21 geomorphic classes would produce 210 possible feature types. Further analysis is necessary to create a product that is useful for predicting biodiversity.

The next step is Focal Variety Analysis (ESRI software) to define habitat diversity. This analysis determines the number of unique values in a cell's neighborhood. In analysis of the Southwest Planning Region, the cell size was 1 km and a radius of 20 cells was used. Focal Variety Analysis of the seascape map produces a hotspot map of seascapes, i.e., areas in which the variety of seascapes per unit area is greatest. This analysis also highlights the boundaries between seascapes. Similar analysis creates a hotspot map of geomorphology. These two maps now display the same parameter, diversity, and may be combined to produce a hotspot map of habitat diversity for the region. The areas where habitat diversity is greatest are inferred to be the same areas where biodiversity is greatest. These are potentially good selections for MPAs, to maximize biodiversity in a minimum sized area. They are also potentially the most interesting for further research, and allow scientists to test predicted relationships in small areas.

The national bioregionalization program for Australia demonstrates that geophysical spatial data are useful for characterizing different benthic marine environments at broad spatial scales. Multivariate analysis provides a way to integrate multiple ecologically relevant layers of information. The methods described here could be applied anywhere, including Alaska, and are flexible enough to accommodate whatever types of data are available. Peter Harris ended by noting that further research is needed to better understand relationships between benthic communities and geophysical variables associated with them. (This statement echoed Anthony Grehan's closing remark.)

Discussion: Larry Mayer asked whether applications for claims of Extended Continental Shelf under the United Nations Law of the Sea treaty were a factor in habitat mapping by either Australia or Ireland. Peter Harris replied that this was not a factor in Australia; for claims under the Law of the Sea treaty, Australia needed multichannel seismic data, not seabed characteristics. Anthony Grehan noted that Ireland's claims under the Law of the Sea treaty were filed first, before their mapping program began.

## Discussion

### *Comments after the presentations*

Comment: Alaska concerns are driven by impacts of fishing gear. Under state management, waters are closed to bottom trawling. Under federal management, waters are (generally) open to bottom trawling, and the impact is of concern.

Question from a geophysicist: What is the metric for success in habitat mapping? A biologist replied that the metric is successful prediction and confirmation of critical habitat, as in the Fairweather Grounds study described by Victoria O'Connell. A second biologist commented that the visual images from Fairweather facilitated the political process.

Comment: We should examine the benefits and rationale for simplifying variables. For example, when is it useful and appropriate to take continuous variables and divide them into finite ranges? A geophysicist responded that he likes continuous data, but comparison between datasets requires binning (into finite ranges).

Comment: A geophysicist urged researchers to define the objectives for habitat mapping. WHY map habitat? The answer leads you to WHAT should be mapped. A biologist responded that an example is critical habitat for spectacled eiders. What is drawing them to that habitat?

Comment: Benthic habitat is important for species that are not often considered to be benthic species, for example, spectacled eiders and Pacific walrus. Both of these species feed on clams, and an important question is the present distribution of clam species and their potential distribution if oceanographic conditions change. What technologies or techniques would be productive for answering this question? Can large-scale acoustic or video surveys of the seafloor identify potential clam habitats by mapping key habitat parameters, e.g., depth and sediment type? Can the clams

themselves be detected acoustically within the sediments? Can surveys of present wintering grounds of spectacled eiders, in comparison with other areas, define the characteristics of their critical habitat?

Comment: There is a need for multidisciplinary approach to ecosystem-based management, including chemical, physical, biological, geological, acoustic, and statistical disciplines.

### *Additional issues*

Over the course of the workshop, participants raised additional issues that are outside the scope of this technology-focused workshop but are nevertheless critical to the success of marine habitat mapping. These are summarized below.

#### *Funding*

Does an effective habitat mapping program require inter-agency cooperation or collaboration?

#### *Standards*

Should data standards, or data treatment standards, be developed?

#### *Data archiving and availability*

It is difficult for researchers to determine what data already exist for Alaska environments, where the data reside, and how to gain access to it. A central repository for federally-funded multibeam data (and other sources, when contributed) is the National Geophysical Data Center. What other repositories have Alaska data? A central directory of where to find data, or even just a list of organizations and Web sites, would be helpful. Consider also that individual researchers need a way to cope with the data, in order for it to be useful. These needs will vary by individual and by background.

#### *Mapping oceanographic parameters for habitat studies*

Problems include short time scale of variability, lack of methods for mapping remotely (except for the surface layer) resulting in point data sets, and a different community of researchers who have not been part of habitat mapping efforts.

#### *Temporal variability in the oceans*

In general, the mismatch between dynamic parameters (e.g., physical oceanography) and more static parameters (e.g., substrate) makes it difficult to combine these in a single habitat mapping effort.

In addition, oceanographic observations are dominated by fair-weather data, but those do not comprehensively characterize the habitat and may not characterize it in biologically critical seasons.

#### *Spatial scales*

For sessile fauna or species with site fidelity, mapping habitat at a local scale is fine. However, relevant spatial scales for mobile species are broader. How do you define the relevant scale(s)?

**Table 1. Day rates for remote sensing technologies.**

Technology	Operator	Day rate	Remarks
LIDAR airborne bathymetry	Commercial	\$60,000	All-inclusive for data collection and data processing.
Multibeam sonar, nearshore	Commercial	\$5,500	Includes operators and equipment. Does not include ship or data processing.
	Commercial	\$11,000	Includes operators, equipment, and data processing. Does not include ship.
Support ship	Commercial	\$5,000	
Multibeam sonar, hull-mounted	Commercial	\$38,000	All-inclusive for data collection and data processing.
	Academic	\$30,800 - \$35,700	Includes ship, sonar technicians, and mapping system. Does not include fuel surcharge, watchstanders, or data processing.
Sidescan sonar mapping	Commercial	\$4,000 - \$5,000	Includes operators and equipment. Does not include data processing.
	Commercial	\$10,000	Includes operators, equipment, and data processing.
Subbottom profiling	Commercial	\$5,000	Rate for stand-alone subbottom profiling survey.
	Commercial	\$5,500	Rate for combined sidescan and subbottom profiling survey.
AUV-mounted multibeam sonar	Commercial	\$5,000	Cost to add AUV to another program; no ship needed.
	Commercial	\$15,000	Cost for AUV and small support ship.
	Nonprofit	\$5,000	This at-cost rate includes AUV operators. It does not include data processing.
	Academic 1	\$10,000	Includes AUV operators.
	Academic 2	\$11,400	Includes shipping, AUV operators, travel, and initial data processing.

All rates are for 2008, except where noted. Rates do not include mobilization/demobilization costs. Academic ships do not provide watchstanders or data processing. This table does not include systems operated by federal or state agencies, as those do not have established day rates.

One participant commented that even if migratory species move over large areas, they do have habitat connections. Another commented that oceanography becomes much more critical to habitat mapping as you move into scales at which the oceanography varies.

### *Uncertainty*

There are different levels of uncertainty for different types of data and interpretation, and at different scales. We need to develop strategies for dealing with this.

Managers are faced with uncertainty based on risk. What has turned out to be useful? Alaska is behind the West Coast in answering this.

### *Concerns of the fishing community*

There is a strong tendency for new habitat maps (new information) leading to restrictions on activities in the areas mapped. These areas are not necessarily restricted because they are the most important, but because something is known about them. This pattern leads to mistrust and resistance to acquiring such information. "A little information is dangerous."

Possible solution: If this pattern stems from having too little information, so that any new information has outsized

importance, then a solution would be to collect much more information. If habitat mapping covered a much greater area, critical areas could be identified in a logical rather than serendipitous manner.

Possible solution: Think about "essential harvest habitat." Fishermen think that we are going to shut them out. The council approach is trying to keep harvest areas open. How can this effort be combined with habitat mapping? Involve the fishing community in the effort to create habitat maps.

Possible solution: Include identification of "critical harvest habitat" as well as critical conservation habitat. A successful example is the Canadian scallop fishery on Browns Bank, Nova Scotia. Habitat mapping was a collaboration between government scientists and the commercial fishing industry, and led to increased fishing success as well as decreased seabed impact by the fishery.

### **Day rate tables**

Day rates for habitat mapping technologies discussed in this report are shown in Tables 1 and 2. These tables indicate approximate 2008 charter rates in Alaska. Except where noted, the day rates do not include shipping or mobilization/demobilization costs. Ship costs are listed with vehicle day rates in cases where those costs could be easily identified.

**Table 2. Day rates for visual survey technologies.**

Technology	Operator	Day rate	Remarks
Manned submersible, to 4,500 m	Academic	\$15,400	Includes engineers/pilots. Requires its dedicated support ship.
Dedicated support ship	Academic	\$35,700	
Manned submersible, to 365 m	Commercial	\$6,000	Includes operators/pilots. 2007 rate.
Support ship	Commercial	\$5,400	2007 rate.
Shallow-water ROV, to 200 m	Commercial	\$2,000	Includes operator and equipment. Does not include support ship.
Shallow-water ROV, to 300 m	Commercial	\$15,000	Includes support ship, operator, and equipment.
Deep-diving ROV, to 6,500 m	Academic	\$15,400	Requires a large support ship. Requires 4 port days per cruise.
	Canadian nonprofit	\$25,000	Requires intermediate or large support ship, depending on ROV configuration.
Support ship	Academic	\$30,800 - \$35,700	Includes ship, technicians. Does not include fuel surcharge, watchstanders.
Imaging AUV, to 4,500 m	Academic	\$11,400	Includes vehicle, shipping, AUV operators, travel, initial data processing. Support ship not included.
Camera/video sled, to 200 m	Commercial	\$2,000	A towed ROV. Includes operator and equipment.
Camera/video sled, to 6,000 m	Academic	\$1,800	Includes operator. Requires a standard 0.322" coaxial cable and CTD winch. Carries a CTD, can collect water samples.
Scuba	Academic	\$2,000	Field party of 3, includes local boat charter, modest travel, dive expendables. Does not include dive gear or diver salaries. This estimate is for Southcentral Alaska; more remote sites have higher travel costs and may require additional on-site support facilities or equipment.

All rates are for 2008, except where noted. Rates do not include mobilization/demobilization costs. Academic ships do not provide watchstanders or data processing. This table does not include systems operated by federal or state agencies, as those do not have established day rates.

## Breakout Group I: Selection of appropriate technologies to facilitate multidisciplinary approaches: Integrating biology and geology

### Objectives for habitat mapping

- Fisheries management for stock assessment purposes, e.g., delineate demersal rockfish habit, define habitat requirements for black rockfish and lingcod.
- Characterize habitats for the purpose of impact assessment and monitoring, under management frameworks for species at risk, Essential Fish Habitat (EFH), and Habitat Areas of Particular Concern (HAPC).
- Establish baseline knowledge for assessment of anthropogenic and natural impacts, response to change, and mitigation efforts.
- Maintain biodiversity, and assess potential for marine protected areas.

### Scale

- To most effectively map habitat, apply a combination of techniques at nested scales. Start with broad area, low resolution perspective, then follow up with high resolution coverage of target areas to address specific questions.

- The process will be iterative, refining as knowledge improves.
- Start with questions that are easy, then work up to more difficult ones.
- Objectives drive scale.
- Fractal dimensions need to be considered.

### Technology gaps, conceptual gaps, data gaps

- Understanding of habitat alone is not enough. We don't understand the ecosystem enough to give mappers definitions of what content is needed in the habitat maps.
- Need to incorporate traditional knowledge.
- Long-term data sets needed to be included.
- There is an extreme lack of basic observational data, e.g., currents.
- Need to know not just the means, but also the extremes.
- Integrate local observations and develop large-scale models.
- Consider multiple time scales to understand the environment, e.g., the glaciers modified the geology, which now affects the currents.

- Need to address Alaska-specific issues: sea ice, low light, high currents, high turbidity, weather, temporal bias (e.g., more sampling in summer).
- Automation or improving speed of data processing, particularly for high-resolution video (e.g., MBARI's automated video event detection (AVED) system).

### **Relevant technologies**

- Cabled observatories
- Multibeam echosounders
- Broadband backscatter
- Sidescan sonar
- Subbottom profilers
- Cameras, video
- Laser line scanners
- Remote sensing tools
- CTD, ADCP
- Argo buoys
- AUVs, ROVs, UUVs
- Gliders, crawlers
- Moorings
- Ships

### **What standards are needed for mapping?**

- Time should be part of all data records.
- Horizontal and vertical references.
- Use metadata to establish data quality, so that it can be applied by various users. Sources of metadata standards include the Federal Geographic Data Committee (FGDC) and the International Organization for Standardization (ISO).
- One possible starting point is International Hydrographic Organization (IHO) standards for hydrographic charting.
- Hydrographic surveys should be optimized to collect additional data, e.g., backscatter, including possible additional training for hydrographic crews. (Note: NOAA is working on this.)
- Terminology: Geologists have very specific meanings for terms that might not be used in other fields.
- Need to standardize terminology, define a common glossary and classification. However, terminology must still be flexible enough for individual needs.

## **Breakout Group II: Techniques and tools specific to environments**

### **Objectives of habitat mapping**

1. Identify areas of representative habitats (e.g., for MPA design and subsequent monitoring).

2. Locate and quantify seafloor habitats for habitat-specific stock assessments
3. Locate and quantify seafloor habitats for habitat-specific ecosystem assessments
4. EFH characterization (e.g., Magnuson-Stevens Act mandate to identify, describe, relate to productivity)
5. Identify and describe habitats vulnerable to gear disturbance, e.g., corals (Magnuson-Stevens Act mandate)
6. Identify deep-water coral/sponge and other such communities
7. Identify shallow nearshore (0-40 m) coral/sponge and other such communities
8. Define trawlable and untrawlable habitat for surveys
9. Better define arctic habitat mapping needs, and explore and identify arctic seafloor habitats
10. Identify areas of high biodiversity/hotspots

### **Geological mapping by remote sensing**

#### **Mapping tools by depth:**

*Very nearshore (0-4 m):* Airborne LIDAR, multibeam surveys and interferometric sidescan sonar surveys from small boats/launches. Issues: safety of personnel in small boats, managing sonar transmission and reception.

*Nearshore (0-30 m):* Acoustic surveys from small boats, including multibeam sonar, interferometric sidescan sonar, subbottom profiling, single/split beam echosounders, visual observations for groundtruthing. Issues: safety of personnel in small boats.

*Mid depths (30-200 m):* multibeam sonar, sidescan sonar, subbottom profiling, single/split beam echosounders, visual observations for groundtruthing.

*Deep water (200+ m):* multibeam sonar, sidescan sonar, subbottom profiling, single/split beam echosounders, visual observations for groundtruthing.

#### **Mapping tools, mapping issues for remote sensing**

*LIDAR:* Airborne LIDAR bathymetry uses light (lasers) and is therefore dependent on light penetration through the water. Under favorable conditions, LIDAR can be an efficient method of nearshore bathymetric mapping. LIDAR signal penetration in nearshore Alaska waters is limited to about 20 m because of water clarity. Vegetation coverage (kelp, seagrass) and whitewater conditions can prevent bathymetric mapping. (Workshop presentation by Carol Lockhart.)

*Multibeam sonar:* 12 kHz-500 kHz acoustic operating frequency. Systems at 30 kHz and higher frequencies provide co-registered bathymetry and acoustic backscatter data (similar to sidescan data); lower frequency systems may provide only bathymetry. There is a direct tradeoff between coverage and resolution. Lower resolution, lower frequency systems (12 kHz) are designed for deep water and do not work well at shelf depth. Higher resolution, higher frequency systems are limited by depth of water penetration, but can be used in

deep water if the sonar is mounted on a deep diving vehicle such as an AUV. (Workshop presentations by Larry Mayer, Lloyd Huff, Doug Lockhart, and Dave Caress.)

*Sidescan sonar:* In shallow water, provides broader coverage than multibeam sonar, with lower resolution interferometric bathymetry. Towed systems have less precise navigation than hull-mounted or pole-mounted sonars, and can be problematic in strong currents. (Workshop presentation by Lloyd Huff.)

*Subbottom profiling:* Refers here to acoustic profiling systems that are designed to image the uppermost layers of sediment and rock, including swept-frequency (CHIRP). It aids in identification and interpretation of substrates. Signal penetration is typically a few tens of meters. Subbottom profiling can be conducted simultaneously with multibeam or sidescan mapping, at modest additional cost. (Workshop presentation by Vaughn Barrie.)

*Single/split beam echosounders:* Widely available, and better than nothing, but not a method of choice for habitat mapping. The bathymetry data are rarely dense enough for confident substrate interpretation, and conducting dedicated new surveys for this purpose is inefficient compared to multibeam surveys. Efforts to use single-beam acoustic reflectivity characteristics for automated substrate characterization have been ongoing for several decades; however, methods developed to date are not widely accepted.

### **Biological mapping, and geological groundtruth**

#### **General capabilities**

*Trawling:* Low resolution, broad scale coverage. Biological information from physical samples includes positive species identification, and quantitative measurements of size, weight, age, sex, condition, and food habits. No geological information.

*Grab sampling, cores:* Very high resolution, but sample locations may be poorly known depending on the sampling platform. Provides quantitative data on sediment grain size, pore water chemistry, infauna, and some epifauna. Samples are at a different scale than either trawling or visual observations, complicating interpretation.

*Visual observation methods:* Much higher resolution and lower coverage than trawls. Biological information includes species identification and estimates of size and weight. Some methods can retrieve biological voucher specimens and sediment samples. Visual estimates of substrate grain size at the same observational scale as the biology. Geological mapping at visual scales can be very effective.

#### **Imaging and sampling platforms/tools by depth**

- *Very nearshore (0-4 m):* Scuba, LIDAR, physical sampling.
- *Nearshore (0-30 m):* Scuba, LIDAR, camera sleds, physical sampling (ROV, AUV are possible).
- *Mid depths (30-200 m):* ROV, AUV, human-occupied submersibles, camera sleds, physical sampling.

- *Deep water (200+ m):* ROV, AUV, human-occupied submersibles, camera sleds, physical sampling.

#### **Imaging and sampling platforms/tools and issues**

*LIDAR (airborne):* 0-20 m in Alaska. Coverage is high. Resolution is medium-high. Biological aspects captured are kelp/vegetation. Potential operational difficulties in Alaska with weather (fog), and white water conditions near the shore. Vegetation coverage (kelp, seagrass) can prevent bathymetric mapping. LIDAR signal penetration in nearshore Alaska waters is limited to about 20 m because of water clarity. (Workshop presentation by Carol Lockhart.)

*Scuba:* 0-30 m. Dives can be inexpensive, but high-resolution video technology for scuba is costly at \$10,000-40,000. Cold-water dive training and certification is required. Re-breather technology is used extensively with marine mammal capture work, but requires additional training and is fairly specialized in use. Nitrox gas is viewed as safer than air and allows for extended bottom times, but also requires additional training and equipment and is not widely used in Alaska. Coverage is low, due to time constraints of humans in water, but many sites can be visited over time. Quantitative transects are limited to several tens of meters. Resolution is high, with human observers in the water. Biological aspects sampled: vegetation, invertebrates, fish, sample collection. Divers may conduct manipulative experiments that cannot be done with occupied submersibles due to cost.

*Small ROV:* 0-300 m (e.g., Phantom models, Seaeye Falcon model). Coverage is low to medium (transect width is 2-5 m). Resolution is medium to high, depending on water clarity and video technology. Biological aspects sampled are vegetation, invertebrates, fish. Sample collection capabilities are limited. Very few small ROVs are equipped to work below 300 m, due to vehicle depth rating, tether length, and tether management capability. (Workshop presentations by Bob Pacunski and Mike Byerly.)

*Large ROV:* 100-6,500 m (e.g., ROPOS, Jason/Medea, Global Explorer). Requires a large support ship. Coverage is low to medium (transect width is 2-5 m, transects can be many kilometers in length). Resolution is medium to very high, depending on water clarity and video technology, including use of digital high-definition cameras. Large ROVs carry multiple cameras, monitored in real time, for different fields of view. Biological aspects sampled are invertebrates, fish, infauna, sample collection (biology, water samples, sediment cores and scoops). Large ROVs are the best platforms for voucher sampling in deep water.

*Imaging AUV:* 30-4,500 m (e.g., SeaBED ABE/Sentry). Coverage is low to medium (transect width is 2-5 m, transects are many kilometers in length). Resolution is medium to high. Images are digital still photos, from which photomosaics are constructed (illumination for continuous video requires too much power). Coverage and resolution are the same as ROVs, but transects are run autonomously in a pre-programmed pattern. No sample collection. Issue: currently, the species identification rate (rockfish) is only 15%, due at least in

part to the vertical imaging angle, and must be improved for quantitative research. (Workshop presentation by Nick Tolimieri.)

*Human-Occupied Submersible (HOV):* 30-4,500 m (*Delta* 30-365 m; *Aquarius* 30-400 m; *Pisces IV* and *V* 200-2000 m; *Alvin* 300-4,500 m). Deep-diving HOVs require a large support ship. Coverage is the same as ROVs except that HOVs are generally restricted to 8 hour working days. Resolution is medium to very high, and may include high-definition cameras. The advantage is having a human in the water to annotate video observations and improve identifications. Sampling capabilities vary greatly, and depend on the sophistication of manipulator arms and on vehicle design and payload. (Workshop presentations on *Delta* by Mary Yoklavich and Victoria O'Connell.)

*Camera Sled:* 4-6,000 m (e.g., TACOS, other unnamed sleds). Coverage is low to medium. Resolution can be low or high, depending on the quality of video or camera system, water clarity, and altitude above the seafloor. (Machine-vision cameras with multiple still photos per second can have very high resolution.) Both soft and hard substrates can be imaged. Images can be monitored in real time, but it is not practical to stop and investigate when features of interest are encountered. No sampling capability. (Workshop presentation by Chris Rooper.)

*Trawl/Sampling Gear:* all depths. For cores and grab samples, coverage is low. Resolution is very high, higher than visual observations, but sample locations may not be precise. For trawling and seining, there is a direct trade-off between coverage and resolution. Resolution of trawling is several orders of magnitude lower than visual observations. Trawling is good for broad scale coverage, and is most appropriate for soft sediment environments. Physical samples are collected for epifauna/biological details, including positive species identification, size, weight, age, sex, condition, and food habits. Cores and grab samples also work in soft sediments, can sample epifauna and infauna, and are used for sediment grain size analysis. Issues: impact of sampling operations on habitat and biological communities.

### Technology gaps

1. Visual scale/sampling: Need mid range tools to bridge gaps between low resolution tools (trawls) and high resolution tools (cameras), to give us medium resolution with mid to high coverage, at all depths.
2. Acoustical surveys: Need a reconnaissance acoustic tool for 0-4 m, an alternative to high-resolution multibeam.
3. Acoustical surveys: Need capability to conduct rapid, broad-scale surveys, not necessarily at high resolution. One possibility is to survey at less than 100% coverage. This can be accomplished either by surveying at high speed, allowing along-track gaps in data, or by spacing track lines to allow gaps between the lines, i.e.,

reconnaissance striping. A second possibility is to use new generation sonars, under development, that are designed to greatly increase range at the expense of resolution.

4. Need a quick way to identify soft and hard substrates.

### Overall considerations

1. Considering cost, do we lease or buy the tool (e.g., submersibles, ROVs, ships)?
2. 24 hr operations versus 12 hr or 8 hr operations.
3. Direct observations in situ by humans, versus remote observations with video or other technology.
4. Optical resolution, for both human observer in situ and for video, is limited by water clarity and weather. For video, optical resolution is also dependent on technology.
5. Many technologies with different resolutions (acoustics, multibeam, cameras, CTD, sonars, DIDSON) can be mounted on common platforms.

### Breakout Group III: What can we learn from Ireland, Australia, and California?

#### Objectives of habitat mapping

It is essential to clearly define the program objectives. These drive the structure, scale, and priorities of the program. In all cases, objectives are derived from government and government responsibilities.

**Australia:** The primary objective is to protect biodiversity (not primarily for managing fisheries). United Nations Convention on Biological Diversity led to Australian national legislation for characterization of habitats within the Australian EEZ. This set the scale and purpose of the undertaking. Protection of diversity requires detection and monitoring, which in turn requires establishing a baseline.

**Ireland:** Objectives are to underpin future resource exploitation, mitigate environmental impacts of development (e.g., wind farms, petroleum), fulfill regional and international obligations to protect biodiversity, and fulfill European Union obligation to protect representative habitats. With these objectives in mind, knowledge gaps have been identified.

**United Nations:** Objective of sustainable fisheries calls for ecosystem management, with sustainable/precautionary the principal factor. Also note the biodiversity objective embodied in the Convention on Biological Diversity.

**California:** The primary concern is fisheries collapse. MPAs are viewed as a step in ecosystem management. The United Nations Convention on Biological Diversity also influenced state legislation and program objectives. Shipping is also one of the drivers for better mapping. The habitat mapping program in California state waters is mandated by state legislation, the Marine Life Protection Act. It is in a pilot phase, dealing with optimization questions (not ready to pro-

vide lessons to Alaska).

Alaska: In contrast with the above cases, the principal objective is identification of critical habitats for protection of species-specific fisheries resources (rather than ecosystems). The goal is to create maps of species distribution. Habitat mapping is also connected with surveys for navigation. Legal drivers are the Magnuson-Stevens Act and regional management councils, and the concepts of Essential Fish Habitat and Habitat Areas of Particular Concern (unimpacted/vulnerable areas).

There is the chicken and egg issue—you don't know what you don't know, yet there are legal mandates to find out what you don't know, at least in fisheries management programs.

Progress by academia is independent of other drivers. Projects seek integration to reduce costs, often trying to accomplish multiple purposes in the same area.

### **Habitat mapping at national or regional scales**

- Australia is mapping out to 200 miles (EEZ), using modeling of existing geographic data. Major efforts went into advanced GIS and database management.
- Ireland is mapping out to ~ 500 mi (EEZ and Extended Continental Shelf), with multibeam sonar.
- California is mapping from the shoreline out to 3 miles (state waters), with multibeam sonar, sampling, video, airborne bathymetric LIDAR, aerial photogrammetry.

Which areas should be mapped, and how should the priorities be set?

- To provide the best input for modeling? (with robust models as the outcome)
- Management priorities? (e.g., biodiversity hotspots)
- What role should stakeholder consultation play?
- Are hydrographic surveys for navigation suitable and useful for habitat mapping?
- Modeling and prioritization will aid in being able to go out and acquire funding.

The choices made, and the way they are presented, will affect funding availability.

What level of information is necessary? (map resolution and content)

- Should the level of detail be scaled to distance from shore? or to water depth? or increase the resolution in heavily used areas? (Warning: shallow areas are more costly to map.)
- If coverage of a large area is required, that may force a choice of low resolution.
- Incomplete coverage can be used to guide further efforts.

The type and resolution of information required will drive the choice of technologies.

### **Management/coordination**

- Australia had a governmental group that worked to bring together the multidisciplinary factions for the mapping effort.
- Ireland had a multidisciplinary group to coordinate the mapping activities. This group gathered existing information, met with various stakeholders and groups, determined what interests were still needed and what technologies were available, and then helped to develop the program for the mapping effort.

### **Technology gaps/issues**

- It is too costly and time-consuming to do complete coverage surveys.
- Resolution of surveys from surface ships decreases with increasing water depth. To regain resolution, move the instrument down closer to the seafloor. Examples: deep-towed vehicles, AUVs, ROVs.
- Tools that can fill gaps include high resolution sub-bottom profiling (used in Ireland, California) and magnetometry (Ireland).

### **Summary of lessons learned**

1. California is still IN the learning process . . . not yet ready to provide lessons to others.
2. California's first MPAs were set up before any of the mapping occurred. After the mapping, it is now known that some of these MPAs are not ideal. Same thing happened in Australia.
3. Ireland thinks Alaska should first generate the bathymetry maps, then we can move on to the various ways the maps can be used (geology, biology, industry, etc).
4. Australia thinks we can do more modeling to help minimize the bathymetry mapping effort so it doesn't have to be a full-scale effort, we can focus on assumed bottom types that would be of the highest priority.
5. There are a lot of data out there. You do not want to duplicate efforts unnecessarily. Create a central portal to manage this and provide information on where the data are.
6. There also needs to be more coordination of management—a focal point, a strong steering committee, a centralized funding source, and even include industry into the mix.
7. Meeting with Ireland's overlying management group may be a really good starting point in coming up with a good ways to coordinate the mapping process.
8. Australia also noted that there is a lack of understanding of the relationships between the physical and biological factors. Establishing a better understanding of the interactions is key for future work. Need "process studies."

9. Most of the work in Alaska has been “reactive,” where ideally it should be “proactive” for management purposes.
10. Survey cost and coverage estimates are needed, as input into planning.
11. The first 3 miles would be a very large percentage of the cost to map (because it is shallow).
12. If we don’t have the money to do full bottom mapping, what scale of swath mapping (subsamples) would be beneficial, what level of incomplete coverage could be used? This is what Australia did, and then extrapolated.
13. Habitat mapping is a lot more than just hydrographic mapping; however, hydrographic mapping can be used for habitat mapping.
14. An existing data source is the fisheries echosounding data. Unfortunately, that type of data usually won’t work for management needs.
15. California Fish and Game’s needs were very simple—hard or soft bottom, depth classes. This drove what techniques they needed to use.
16. Geological features seem to be a more useful way of subsampling the bottom for biological questions. Where are the hard spots, where are the soft spots, what organisms do we need information on for management purposes? Having a general idea of where geological features are can help prioritize where and how to look to address the management requirements.
17. We lack detailed bathymetry for Alaska. Detailed mapping of the bathymetry would be a huge help, but it will take 25 years to get all this mapping, and we need it now. Using the data that are already there could help in making some first estimates. We can then go from there to determine priorities to map in relation to the management needs.

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