A Rapid Method to Characterize Seabed Habitats and Associated Macro-organisms

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Abstract

*This study presents a method for rapidly collecting, processing, and interrogating real-time abiotic and biotic seabed data to determine seabed habitat classifications. This is done from data collected over a large area of an acoustically derived seabed map, along multidirectional transects, using a towed small camera-sled. The seabed, within the newly designated Point Harris Marine Reserve on the northern coast of San Miguel Island, California, was acoustically imaged using sidescan sonar, then ground-truthed using a towed small camera-sled. Seabed characterizations were made from video observations, and were logged to a laptop computer (PC) in real time. To ground-truth the acoustic mosaic, and to characterize abiotic and biotic aspects of the seabed, a three-tiered characterization scheme was employed that described the substratum type, physical structure (*i.e., *bedform or vertical relief), and the occurrence of benthic macrofauna and flora. A crucial advantage of the method described here, is that preliminary seabed character-*

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izations can be interrogated and mapped over the sidescan mosaic and other seabed information within hours of data collection. This ability to rapidly process seabed data is invaluable to scientists and managers, particularly in modifying concurrent or planning subsequent surveys.

Résumé

Cette étude présente une méthode qui permet de recueillir, de traiter et d'interroger rapidement des données abiotiques et biotiques du fond marin en temps réel afin de définir des classifications d'habitats du fond marin. Cette méthode s'applique à des données recueillies sur une large superficie d'une carte du fond marin obtenue à partir de données acoustiques, le long de transects multidirectionnels, en utilisant une petite caméra remorquée sur une plate-forme. Le fond marin, dans la réserve marine de Point Harris qui vient d'être désignée sur la côte nord de l'île de San Miguel, en Californie, a été représenté par imagerie acoustique à l'aide d'un sonar à balayage latéral, et ensuite des vérifications sur place ont été faites à l'aide d'une petite caméra remorquée sur une plate-forme. Les caractéristiques du fond marin ont été tirées d'observations vidéo et ont été enregistrées dans un ordinateur portable (PC) en temps réel. Afin de vérifier sur place la mosaïque acoustique et de caractériser les aspects abiotiques et biotiques du fond marin, une méthode de caractérisation en trois points a été utilisée pour décrire le type de substrat, la structure physique (c.-à-d. les formes de relief sous-marines ou le relief vertical), et la présence de macrofaune et de flore benthiques. La méthode décrite dans cet article offre l'avantage indéniable de permettre d'interroger et de cartographier les caractéristiques préliminaires du fond marin en les superposant à la mosaïque par balayage latéral et à d'autres renseignements sur le fond marin quelques heures après la collecte des données. Cette capacité de traiter rapidement les données du fond marin est inestimable pour les scientifiques et les gestionnaires, puisqu'elle permet notamment de modifier les levés en cours ou de planifier les levés subséquents.

INTRODUCTION

Management of benthic marine resources is becoming a prime scientific focus throughout the world (*e.g.*, Canada's *Oceans Act 1996*; New Zealand's *Fisheries Act 1996*; US's *Magnuson-Stevens Fishery Conservation and Management Act 1996*; Australia's *Environment Protection and Biodiversity Conservation Act 1999*). Successful management strategies for the protection and sustainability of marine resources, such as the designation and management of Marine Protected Areas (MPAs; *e.g.*, Dayton *et al.*, 2000; Airamé *et al.*, 2003; Yoklavich *et al.*, 2002), protection and management of essential habitats (*e.g.*, Magnuson-Stevens Act 1996; Benaka, 1999; Dayton *et al.*, 2000), and impact assessment relative to future change (Underwood, 1994), requires knowledge of the distribution of habitats and the organisms that inhabit them at all scales of occurrences. Given that benthic organisms may be strongly associated with specific habitat variables (*e.g.*, O'Connell and Carlile, 1993; Syms, 1995; Yoklavich *et al.*, 2000), a predictable relationship between organism and habitat may also present the possibility of using habitat as a proxy to predict species distribution and abundance over large regions, but hinges on the capability to accurately map habitats over these same regions of interest (see Anderson *et al.*, 2005).

Mapping seabed characteristics in deep continental shelf environments relies primarily on remote acoustic methods. Acoustic systems, such as sidescan and multibeam sonars, have been developed to rapidly collect acoustic data from wide swaths of the seabed (Miller *et al.*, 1997; Blondel and Murton, 1997). Due to a trade-off between the ability to image large areas of seabed and resolve fine-scale seabed features (metres down to centimetres resolution), the spatial resolution of data collected over large areas generally ranges from 1-10s m horizontally, and reliably resolve hard, mixed (*i.e.*, areas containing hard and soft substrata) and soft substrata (Mitchell and Hughes Clarke, 1994).

The interpretation of acoustic data into a seabed classification scheme is complex and requires ground-truthing (Gardner *et al.*, 1991; Cochrane and Lafferty, 2002). Samples employed to ground-truth seabed maps (*e.g.*, grab samples, video observations) have traditionally been collected opportunistically from a limited number of locations or habitats covered by the acoustic survey. While any ground-truthing samples are valuable data for the interpretation and validation of acoustic images, high densities of ground-truthing samples across the acoustic image will reduce uncertainties in the accuracy of the final seabed map.

Many aspects of the seabed may be important in characterizing benthic habitats (Greene *et al.*, 1999). Visual observations on the physical nature of the seabed (*e.g.*, substratum composition, shapes, and relief) not only ground-truths acoustic data, but the ability to characterize abiotic and biotic variables also may provide valuable 'predictive' insight into the spatial structuring of the seabed, and the distribution and relationships between these variables (Legendre *et al.*, 1989). Towed camera-sled surveys provide the opportunity to collect fine scale *in situ* observations over large areas of seabed, with the advantage of simultaneously collecting information on organisms and habitat variables. In addition, a towed-camera system is easily applied to transect-sampling over large linear distances of the seabed, and unlike isolated point-sampling, can provide information on the location of abiotic and biotic transition zones (Legendre *et al.*, 1989; Fortin *et al.*, 1989). While these larger scale patterns are central to most regional management issues, these combinations of data have been rarely available.

In addition to potential differences in sampling strategies, there is also a sizeable disparity in the time that acoustic and ground-truthing data can be processed. Acoustic data can now be collected, processed, and mosaiced at sea within hours of collection. In contrast, seabed samples that are essential to the interpretation and

ground-truthing of the acoustic sonograph, generally require longer times for post-processing (English *et al.*, 1997). For example, point samples of sediment or infauna are usually processed onshore after the marine survey. Also, visual observations are usually made and transcribed from videotape, which requires considerable post-processing times. These time lags limit the rate at which data can be examined, and so there is a clear need to develop the ability to rapidly record and process ground-truthing observations to allow both the acoustic and ground-truth data to be visualized and examined together at sea. These data can then be fed back into the planning, data gathering and sample design processes within the duration of a cruise for onsite decisions to be made.

In this study, a rapid method for collecting and processing ground-truth data that characterized abiotic and biotic habitats in real-time and over large areas of seabed is evaluated. Further, these data can be studied and plotted as preliminary seabed maps while at sea. Within the Point Harris Marine Reserve, where the seabed was acoustically surveyed, multidirectional camera-lines were run. The seabed was ground-truthed at 30 second intervals along each transect using a three-tiered characterization scheme that described both the physical setting (substratum type, and bedform or relief), and the presence of benthic macrofauna and flora. Data were then processed using a series of formalized data checking and formatting steps, and then both uploaded to a database for interrogation and plotted in ArcGIS over the sidescan mosaic for exploratory interpretation – all within hours of data collection.

METHODS

Site and Survey Design

A nine-day field survey (9-18 July, 2003) was undertaken to map the seabed within the Point Harris Marine Reserve (latitude range 34.40367°-33.72434°N: longitude range 120.54922°-119.20618° W) located on the northern side of San Miguel Island. San Miguel Island is the western-most and most exposed of the five Channel Islands in the Channel Islands National Marine Sanctuary (CINMS; Figure 1a). The Point Harris Marine Reserve is exposed to high winds, prevailing from the northwest, and subsequent high seas because of its location and aspect. To produce a seabed habitat map for the reserve, the objectives were to trial a ground-truth method that would operate in open-ocean conditions and provide rapid feedback to researchers and managers. To achieve this, both the sidescan and the video camera were deployed from the *'McArthur II'* a large (224 ft) NOAA research vessel. Using this vessel, continuous 24-hr operations were run to acoustically survey the seabed using sidescan sonar (14 daytime hours), and then ground-truth these acoustic data, and characterize the seabed using a towed camera-sled (10 nighttime hours).

Acoustic Survey

A Klein 3000 sidescan sonar system (130 kHz and 445 kHz) was deployed from the stern of the vessel and towed at a speed, over ground, of 3-4 kt, and at an altitude of 25 m above the seabed to survey the reserve. Sidescan track lines (each ~16 km in length) were run parallel to shore (SE–NW) beginning at the 50 m contour and extending out to a depth of 100 m. Acoustic data were acquired at 130 kHz across a 300 m swath, with ~30% overlap, giving a parallel-track resolution of 0.4 m and a cross-track resolution of 0.2 m. Layback from the ship's GPS antenna to the A-frame block at the stern was 25 m. Additional layback from the block to the sidescan fish was estimated using the water depth minus the fish altitude and an assumed wire angle of 45°.

Seabed Characterizations

To ground-truth the sonographs and characterize the seabed, camera observations of the seabed were obtained using a small (136 cm long, 44 cm wide, and 52 cm high) towed camera-sled (Figure 2). Camera lines were run in multiple directions: 6 lines separated by 500 m, were run parallel to shore (SE–NW) across the 10 km width of the reserve. An additional 6 lines were run at a 40° angle from the shoreline and were approximately 1 to 4 km in length. During seabed observation, the camera-sled was towed 1-2 m above the seabed at a speed, over ground, of 0.6 to 1.7 kt. A CTD mounted on the sled recorded depth and altitude while a person operating an electro-hydraulic winch topside controlled the sled's height above the seabed. As with the sidescan, the layback from the ship's GPS antenna to the A-frame block at the stern was 25 m. Additional layback from the block to the towed camera was estimated using the seabed depth minus the sled altitude, subtracted from the tow-wire length. Camera-sled layback was, on average, approximately 4 m (ranging up to 6 m) when the seabed was in view and ship's direction was maintained into the swell and wind. In contrast, layback was considerably greater (commonly about 9-12 m) when the ship's heading was lost and the tow direction was counter to the wind and swell. However, transecting logistically required an into-the-wind heading, consequently the ship would immediately increase speed to regain its heading. Counter-current headings were therefore brief, *i.e.*, a few minutes.

Seabed observations were made from a forward-facing video camera; the system displayed the image onboard ship and the data were recorded to videotape. Paired lasers, set 20 cm apart, were projected onto the seabed and provided a visual reference to size objects and organisms. Seabed habitats and the biota were categorized in real-time at frequent intervals (>5 seconds, maximum of 30 seconds) along each camera-transect. For each data entry point, a 10 second moving window (*i.e.*, 5 seconds prior to and 5 seconds following a GPS fix) was used to evaluate and characterize the seabed, using a three-tiered description of substratum composition, bedform-relief, and biota presence (Table 1). Substrata composition (*i.e.*, rocks, boulders (>25.5 cm), cobbles (6.5-25.5 cm), sand, and mud) was categorized by primary (>50% cover) and secondary (>20% cover) percent-cover, following the protocol of Stein *et al.* (1992) and Yoklavich *et al.* (2000). For example, where the seabed was comprised of >50% rock and >20% boulders, substratum composition was classified as 'rock-boulder' (RB); an area comprised of >70% mud was classified as 'mud-mud' (MM). Bedform-relief was defined as either soft-sediment 'bedform' such as sediment ripples, sediment waves, or bioturbated sediments; or by the vertical 'relief' of consolidated sediments. This was accomplished using a simple qualitative visual reference, aided by the depth and altitude of the sled, where classes ranged from flat (0 m), low (<1 m), moderate (1-3 m), to high relief (>3 m), or rock walls (high-relief with >80° incline). Benthic composition was described by recording the presence of benthic macro-organisms and flora. Organisms were identi-

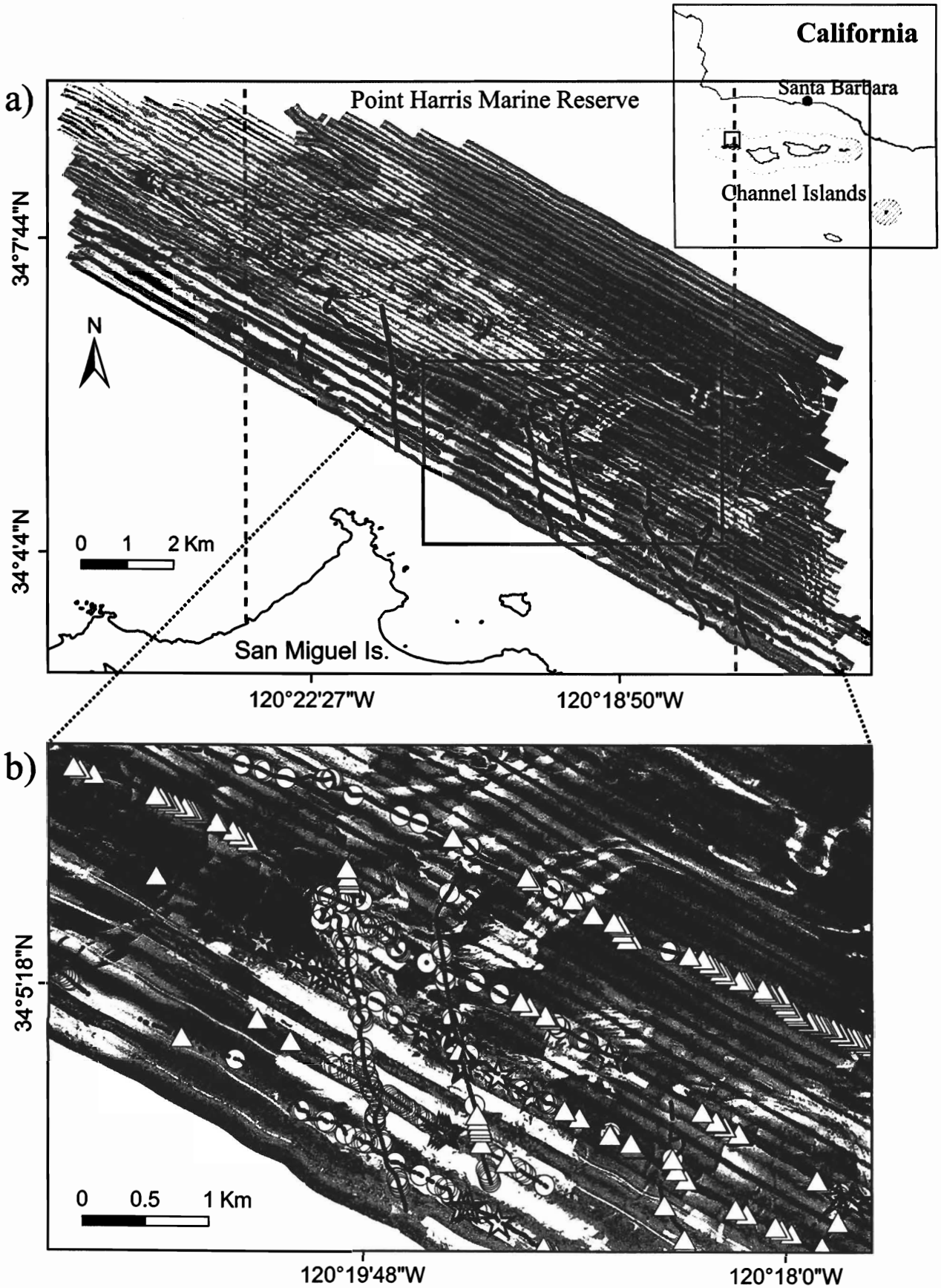

Figure 1. *Caption on opposite page.*

Table 1. Seabed characterization scheme: substratum, bedform-relief, and biota types and definitions used to characterize the seabed

	Type	Definition
Substratum	rock	Exposed bedrock
	boulders	Boulders (>25.5 cm loose material)
	cobbles	Cobbles (>6.5 cm and < 25.5 cm)
	sand	Sand (lighter colour, grains visible to naked eye)
	mud	Mud (darker colour than sand, grains not visible)
	coquina	Shell-hash, finely (~2 mm) broken shell material
Bedform	waves	Wave-like bedform in sediment
	rippled	Ripple-like bedform in sediment
	bioturbated*	Bioturbation (burrows, mounds, or tracks) >50% of surface-area
Relief	flat relief	0 m substratum relief
	low relief	<1 m substratum relief
	moderate relief	1-3 m substratum relief
	high relief	>3 m substratum relief
	rock wall	High relief with >80° incline
Biota	feather stars	Crinoidea
	anenomes*	Actiniaria
	sponges*	Porifera
	stars*	Asteroidea
	brittle stars*	Ophiurida
	basket stars*	Euryalina
	white sea urchins	*Lytechinus anamesus*
	other sea urchins*	*Strongylocentrotus* sp.
	sea cucumbers	Holothuroidea
	sea fans	Gorgonacea,
	sea whips*	Gorgonacea
	sea pens	Pennatulacea
	octopus*	Octopoda
	crabs*	Decapoda
	sea hare	*Aplysia californica*
	hydroids	Hydrozoa
	rockfishes*	juvenile and adult *Sebastes* sp. (rockfishes >5 cm)
	yoy rockfishes	young-of-year *Sebastes* sp. (rockfishes <5 cm)
	combfishes	*Zaniolepis* sp.
	flatfishes*	all flatfish species (*e.g.*, soles, sanddabs, halibut, turbots)
	other fishes*	any other fish species (*e.g.*, cusk-eels, ratfish, hagfish, cod, sharks)
	macroalgae	attached macroalgae
	drift algae	macroalgae not attached to the substratum
	invertebrates	invertebrate cover, such as encrusting sponges, bryozoans etc.
Additional variables	fishing gear	any form of fishing gear (*e.g.*, lines, netting)
	interface	boundary between two substrata (*e.g.*, bedrock vs. soft-sediment)
	barren	substratum was visible, and no invertebrates were present
	unknown	substratum was visible, but invertebrates were indiscernible
	undefined	could not see the seabed

* indicates 'types' where finer levels of classifications are recommended and have since been incorporated into more recent surveys

Figure 1 (opposite). *A preliminary seabed map of the Point Harris Marine Reserve, on the northern side of San Miguel Island, California. a) Sidescan mosaic of the seabed within the reserve, processed during the cruise. Dashed lines depict the boundaries of the reserve, black lines depict ground-truthing camera lines, the box depicts the area of seabed seen in Figure 1b. Insert (right hand image) depicts the central California coastline and the location of the study area (dark box), the hashed region around the islands depicts the boundaries of the CINMS. b) An enlarged section of the reserve illustrating a subset of seabed variables processed and plotted over the sidescan mosaic while at sea. (Circles = rockfishes, triangles = sea whips, and stars = brittlestars.) Features depicted in the sonograph are represented by light areas = hard substrata, and dark areas = soft substrata. Diagonal lines across the sonograph = nadir trackline noise from the sidescan tow-fish.*

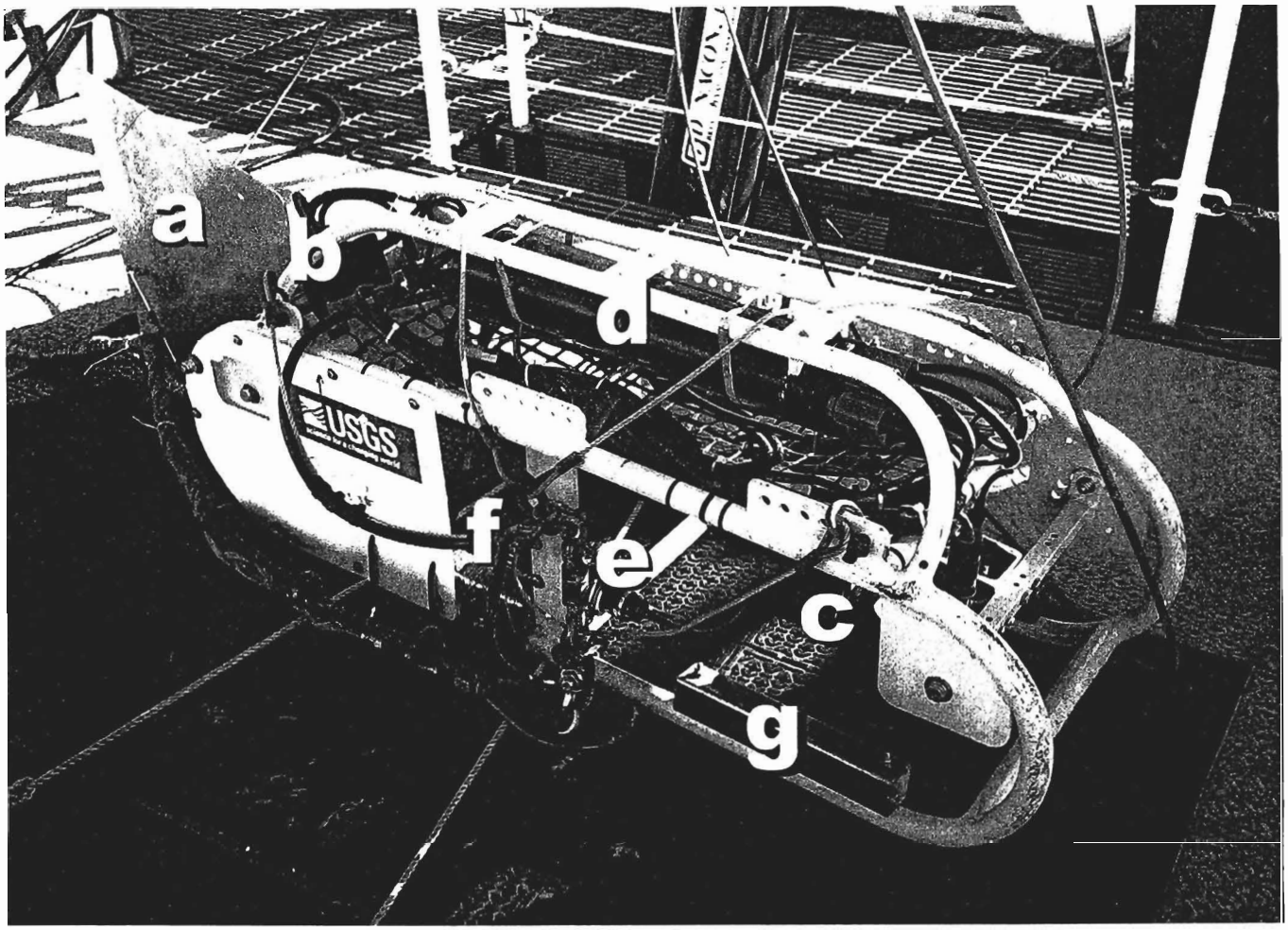

Figure 2. *Small USGS camera-sled system employed to collect seabed observation in the Point Harris Marine Reserve, California. a) stabilizer fin, b) forward-looking camera, c) downward-looking camera and both flood lights, d) Subsea electronics housing, e) altimeter, f) four point bridle assembly attached to a swivel, g) one of four 18 lb. weights (each 12" long, 2" wide, 2" high) positioned at the corners of the sled.*

fied to species level, where possible (*e.g.*, the sea hare *Aplysia californica*), groups (*e.g.*, starfish, brittlestars and basketstars), class (*e.g.*, featherstars and anemones), or broad ecological categories (*e.g.*, rockfishes and flatfishes). For each data entry, observations were entered in 'GNav Real-time GIS Tracker' software© (Hatcher, 2002) using an X-Keys® programmable keypad (Registered trademarks of P.I. Engineering, Inc.). Seabed data entry took between 3 and 12 seconds, and required a two-person team (*i.e.*, observer and data-enterer), using a rotation of four people to provide rest. Ships navigation (UTC date, time, latitude, longitude, speed over ground, heading) was captured for each data-entry location, and also was logged continuously (1-2 second fixes) to provide navigational tracks.

Data Processing

Sidescan imagery was processed using Isis Sonar and Delph Map into a 1-m resolution sidescan mosaic, and exported in decimal degree coordinates as a georeferenced TIFF image. Seabed characterization data was processed in the Statistic Analysis System (SAS Institute Inc., 2001) using a macro-program that parsed the variable-length text file, checked and cleaned syntax and format-errors, and exported the file as a database (*i.e.*, Dbase) file. Data checking of seabed characterizations at sea, using the automated procedure, did not physically check sidescan data against video. All data were processed at sea (Figure 3) following the completion of nighttime operations. This automated procedure enabled seabed characterizations to be rapidly processed (<1 hr) making them available for statistical analysis in SAS, database interrogation, visualization as both GIS layers (ArcGIS™; see Figure 1b) and GNav data layers (along with the sidescan mosaic) to aid subsequent navigation of the camera-sled. The ability to view in GNav the location of the camera-sled relative to data layers, including those collected during the cruise (*e.g.*, habitat type, and relief inferred from sonar shadows), provided a reliable and extremely valuable means of anticipating bottom features that required pre-emptive winch actions if collision was to be avoided. As a result of this rapid feedback of data into GNav, the towed camera-sled safely traversed numerous high terrain features, including abrupt (up to 30 m) changes in vertical relief without major incidents.

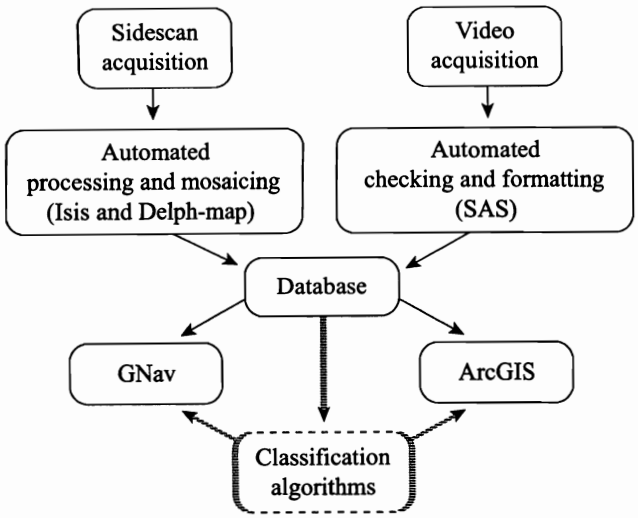

Figure 3. *Schematic outline of data acquisition and processing steps. Acoustic data and real-time video observations were independently processed and checked using software programs (*e.g.*, Isis and Delph Map, and SAS) and exported into a common data repository. Following automatic checking, data displays were fed back into GNav and ArcGIS systems. Future developments (dashed lines) could include additional habitat classifications using clustering, ordination, or discriminant function techniques that can in turn feedback into the data displays.*

RESULTS

Acoustic Survey

Fifty-three hours, over 5 days, was spent in sidescan acquisition that imaged approximately 140 km^2 of seabed within the reserve. Rocks within the reserve are of the Miocene Monterey Formation, which consists of marine siliceous shale and mudstone with layers of hard porcellaneous shale and chert that outcrop as raised resistant ridges on the seafloor. These rocks are deformed by broad open folds, trending approximately east–west, and have dips of generally less than about 25°. Unconsolidated sand overlies these rocks in small patches on the order of tens of metres across, and a larger, finer-grained deposit covers the northeast study area in water depths greater than 90 m. Resistant bedrock layers that have been undercut to form boulder outcrops and overhangs about 0.5-2 m high and 3-5 m wide and up to several hundred metres long. Between these ridges are flat, low-relief areas underlain by rock, often mantled by thin deposits of unconsolidated sand and gravel.

Seabed Characterizations

Thirty hours, over 3 nights (~10 hours per night), were spent observing the seabed during data acquisition in which 68.21 linear km of the seabed (~2.2 km per hour) were surveyed. A total of 4575 seabed characterizations were recorded in real-time from alongshore and offshore transects. Seabed characterizations were collected at least every 30 seconds (2128 data points), and more regularly in areas of high transition – 5-15 second intervals (n=1271), and 15-25 second intervals (n=1055). In some instances, distances greater than 30 seconds (n=405) also occurred but were due to breaks in the transect due to logistical problems or when the seabed was not visible due to high camera-sled altitudes.

The three-tiered seabed characterizations provided unique information on seabed type and form, and their associated macrobiotic assemblages. Primary and secondary habitat classifications provided valuable information on the types and combinations of habitats present within the reserve. Homogeneous soft sediments were the most common habitat recorded (63% of all locations) within the reserve. Hard reefs were also common (26.5% of all locations), while mixed substrata (areas comprised of hard and soft sediments) were less common (11% of all locations). Mud (41% of all locations), sand (28%) and rock (28%) were the most common primary substratum types (*i.e.*, >50% of each location) recorded within the reserve, while boulders (2.9%) and cobbles (0.4%) were rare. The inclusion of secondary substratum type provided information on fine-scale (~10 m) strata heterogeneity. For example, muds (MM 25% of all locations) and fine sands (muddy sand, MS 19%, sandy mud, SM 16.5%) were common, but coarse sands were rare (SS 7%). Similarly, homogeneous rocky areas were common (RR 19%), but outcrops of rocks and boulders were infrequent (RB 5.4%, BR 0.2%), and boulder fields (BB 0.8%) were rare.

The physical structure and relief of the seabed also provide information on the spatial structuring of the seabed. For example, 92% of all soft-sediment locations were physically structured, and occurred as bioturbated sediments (51%), sediment waves (30%) or ripples (11%). Mixed substrata were characterized by low- (52%) to moderate-relief outcrops, (23%) abutting sediment or sand wave dominated sediments, (12%) abutting outcrop. Hard substrata were characterized by a range of moderate- (41%), high- (36%), and low- (16%) relief outcrops, while vertical walls or flat reefs were rare (4% and 1%, respectively). The ability to visualize the occurrence of biota types relative to the combination of sidescan mosaic and the visually recorded substratum types and bedform-relief characteristics provided valuable information on the spatial patterns and potential requirements of these biota. For example, sea-whips were found in soft-sediment habitats, had higher occurrences offshore, but had a strongly negative association with mobile sediments such as sediment waves or sediment ripple habitats.

Trained observers were used to characterize the seabed. Pre-cruise training, clear guidelines, and observer overlap (*i.e.*, each observer was the prior observers data-enterer) were used to ensure that the characterizations were consistent between observers. Post-cruise data checks (n=471 data points - ~10% of the dataset) and intersecting transects (n=16 intersects) were undertaken to determine the reliability and consistency of these data. Different observers consistently and correctly identified substratum types (97%), with the noticeable exception of sand and mud combinations. In contrast with other substrata, muddy sand (MS) and sandy mud (SM) categories were difficult to distinguish and there was considerable variability between observers (57% error). Consequently, all mud–sand and sand–mud classifications were combined and simply termed fine sands. Bedform-relief classifications, although potentially more subjective, were consistent both through time and between observers due to pre-cruise training (<9% error). One exception to this was the difficulty in characterizing sediment waves versus ripples within a short section of a transect. However,

this difficulty occurred within what appeared to be 'ripple to wave transition zones' which occurred over scales of metres to hundreds of metres. Here, the inclusion of an additional bedform category, such as 'subtle waves', to characterize these transitional habitats has been adopted.

In this initial study, biota categories were taxonomically simple (*e.g.*, starfish, sea whip, crab, macroalgae), and only a few inconsistent identifications were made (<3% error for all biota types). However, coarse taxonomic categorization of common taxa, such as starfish, were of little use in assessing distribution and habitat patterns of these taxa, as members occurred in almost all areas and habitats. In contrast, a finer differentiation by genus (*e.g.*, *Pycnopodia*, *Luidia*, and *Mediaster*) could provide more valuable habitat classification and discriminatory ability, but as taxonomic resolution increases, so will the need for trained observers with specialized taxonomic skills and, in some situations, either a reduction in the number of other variables that could be recorded in real time or an increase in the temporal sampling interval. However, all seabed observations were recorded to videotape and are therefore available for further scrutiny and finer post-processing study.

DISCUSSION

In this study, a combination of tools (camera-sled and equipment, X-Keys, GNav, ArcGIS) and methods (multidirectional transecting, real-time data entry, and rapid data processing) enabled the acquisition of ground-truthing data in combination with acoustic data to rapidly analyse and visualize seabed data, including the construction of a multilayered seabed map. While the tools and methods used in this survey are widely available and have been employed in the past, it is their combined application within a rapid assessment framework that can provide both scientists and managers with an extremely valuable tool.

Post-processing is expensive in time and requires dedicated personnel. Many agencies house unprocessed videotape, often as a consequence of unforeseen project constraints that restrict further processing. The data often remain unanalyzed. The logistical cost of seabed surveys and the contractual commitments of funding agencies are also driving the need to rapidly process seabed data. Many funding agencies now require end-of-cruise reports with summary findings upon cruise completion (*e.g.*, National Undersea Research Program funding). Therefore, the ability to generate preliminary maps displaying seabed characterizations over the sidescan mosaic enables a visual product to be generated and assists the researchers in describing their findings to fulfill the agency reporting requirements and deadlines. Having preliminary maps also enables researchers to be selective, relative to logistic constraints, in the post-processing priorities. For example, examination and data checking of complex habitats might be prioritized. The ability to view onboard results also enables sampling programs to be modified at sea, enabling data to be collected during the cruise to resolve uncertainties in the acoustic image, or alternatively, to verify unanticipated findings. This is a major advantage as follow-up cruises are extremely costly, and in most studies, limited budgets prohibit this luxury. Consequently, unresolved or high uncertainty regions found during post-processing may also be unresolved in the final seabed maps.

There is a widely recognized need for ground-truthing of sidescan data. However, samples employed to ground-truth seabed maps have traditionally been collected opportunistically, and often from a limited number of locations or habitats covered by the acoustic survey. Continuous-recording methods such as video transects have become more popular, and have the potential to provide fine-scale observations across the large regional areas covered by the acoustic methods. In this survey, 4575 ground-truthing data points were recorded over 68.31 linear km – giving, on average, one data point every 15 m. Importantly, this method still allows for complex levels of habitat and biotic variable classification. While finer-scale spatial frequency in data collection can also be collected, it will come at a cost of reducing the number or types of variables recorded and will ultimately depend on the questions and goals of the survey. In this study, a three-tiered classification approach with substratum type, physical structure (*i.e.*, bedform or relief), and 25 biota types was used. This level of complexity could still be easily collected, processed and uploaded to a database and subsequently interrogated and plotted with other habitat layers.

The ability to plot the occurrence of biota types relative to habitat types, seabed features, and/or the physical structure of the seabed can discern many important relationships, and may also identify potential processes driving these patterns. The ability to rapidly analyze these data also means that concurrent fine-scale studies (*e.g.*, submersibles, trawls, dredges, grabs, and baited-remote-underwater-video surveys) can utilize these data to identify habitat types within which more detailed quantitative information might be gathered. Future applications using rapid, automated processing methods could go further by also running automated sets of queries or analyses to identify community classifications using ordination or clustering techniques. As with concurrent survey designs, the rapid interrogation of seabed data, such as preliminary maps, can be valuable in planning future research projects. A clear example of this is a recent survey run off the coast of Monterey, California. Using the method described here, hotspots of newly-settled and juvenile rockfishes were identified. Based on the findings of this seabed survey, NOAA fisheries researchers were rapidly able to target these hotspots and stratify their planned field sampling by the habitat types identified (S. Sogard, personal communications, 2004).

While there is an obvious need to collect, collate, and analyse seabed and mapping data rapidly, these outcomes should not be seen as final products. Additional post-processing and quality-assurance should still be undertaken to maximize outputs. While it could be argued that once the preliminary integrated maps have been created, scientists and managers may have less incentive to undertake the necessary post-processing steps (*e.g.*, data checking and validation) required for final map production. However, it is important to recognize that no more time or effort is required to validate these data than is currently required for the traditional 'entirely post-processing' methods. The rapid availability of these preliminary maps might stimulate the need and desire for validation as demand increases for their application, and as managers and funding agencies see real short-term returns.

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REFERENCES

Airamé, S., Dugan, J.E., Lafferty, K.D., Leslie, H., McArdle, D.A., and Warner, R.R., 2003, Applying ecological criteria to marine reserve design: A case study from the California Channel Islands: Ecological Applications, v. 13, p. S170-S184.

Anderson, T.J., Yoklavich, M.M., and Eittreim, S.L., 2005, Linking fine-scale groundfish distributions with large-scale seabed maps: Issues and challenges of combining biological and geological data, *in* Barnes, P.W., and Thomas, J.P., eds., Benthic Habitats and the Effects of Fishing: American Fisheries Society, Symposium 41, Bethesda, Maryland, p. 667-678.

Australia "Environment Protection and Biodiversity Conservation Act, 1999", Commonwealth Consolidated Acts: Commonwealth of Australia, (http://www.austlii.edu.au/au/legis/cth/consol_act/epabca1999588/)

Benaka, L., 1999, Fish Habitat: Essential Fish Habitat and Rehabilitation: American Fisheries Society, Symposium 22, Bethesda, Maryland, 400 p.

Blondel, P., and Murton, B.J., 1997, Handbook of Seabed Sonar Imagery: Wiley, West Sussex, UK, 314 p.

Canada "Oceans Act 1996", Annual Statutes of Canada, Chapter 31 (Bill C-26), parts 2 and 3: Canadian Department of Justice, (http://www.canlii.org/ca/sta/o-2.4/whole.html)

Cochrane, G.R., and Lafferty, K.D., 2002, Use of acoustic classification of sidescan sonar data for mapping benthic habitat in the Northern Channel Islands, California: Continental Shelf Research, v. 22, p. 683-690.

Dayton, P.K., Sala, E., Tegner, M.J., and Thrush, S., 2000, Marine reserves: Parks, baselines, and fishery management: Bulletin of Marine Science, v. 66, p. 617-634.

English, S., Wilkinson, C., and Baker, V., 1997, Survey manual for tropical marine resources: 2nd Edition, Australian Institute of Marine Sciences, Australia, p. 390.

Fortin, M.-J., Drapeau, P., and Legendre, P., 1989, Spatial autocorrelation and sampling design in plant ecology: Vegetatio, v. 83, p. 209-222.

Gardner, J.V., Field, M.E., Lee, H., Edwards, B., Masson, D.G., Kenyon, N., and Kidd, R.B., 1991, Ground-truthing 6.5-khz Side Scan Sonographs: What are we really imaging?: Journal of Geophysical Research, v. 96, p. 5955-5974.

Greene, G.H., Yoklavich, M.M., Starr, R.M., O'Connell, V.M., Wakefield, W.W., Sullivan, D.E., McRea, J.E., and Cailliet, G.M., 1999, A classification scheme for deep seabed habitats: Oceanologica Acta, v. 22, p. 663-678.

Hatcher, J., 2002, GNav Real-time GIS Tracker' companion CD, *in* Wright, D.J., ed., Undersea with GIS, ESRI Press, Redlands, California, (Book and CD edition), p. 253.

Legendre, P., Trousellier, M., Jarry, V., and Fortin, M.J., 1989, Design for simultaneous sampling of ecological variables: from concepts to numerical solutions: Oikos, v. 55, p. 30-42.

Miller, J.E., Hughes Clarke, J. and Patterson, J., 1997, How effectively have you covered your bottom?: Hydrographic Journal, v. 83, p. 3-10.

Mitchell, N.C., and Hughes Clarke, J.E., 1994, Classification of seabed geology using multibeam sonar data from the Scotian Shelf: Marine Geology, v. 121, p. 143-160.

New Zealand "Fisheries Act 1996", No 88, Part 2, section 9, Statutes of New Zealand. (http://www.legislation.govt.nz/libraries/contents/om_isapi.dll?clientID=500079101&infobase=pal_statutes.nfo&jump=a1996-088&softpage=DOC)

O'Connell, V.M., and Carlile, D.W., 1993, Habitat-specific density of adult yelloweye rockfish *Sebastes ruberrimus* in the eastern Gulf of Alaska: Fishery Bulletin U.S., v. 91, p. 304-309.

SAS Institute Inc., 2004, SAS Software and OnlineDoc® 9.1.3., Cary, NC: SAS Institute Inc., USA.

Stein, D.L., Tissot, B.N., Hixon, M.A., and Barss, W., 1992, Fish-habitat associations on a deep reef at the edge of the Oregon continental shelf: Fishery Bulletin U.S., v. 90, p. 540-551.

Syms, C., 1995, Multi-scale analysis of habitat association in a guild of blennioid fishes: Marine Ecology Progress Series, v. 125, p. 31-43.

Underwood, A.J., 1994, On beyond BACI: sampling designs that might reliably detect environmental disturbances: Ecological Applications, v. 4, p. 3-15.

United States "Magnuson-Stevens Fishery Conservation and Management Act, amended 1996", Public Law 94-265, April 13, 1976, 90 Stat. 331 (16 U.S.C. 1801 et seq.) as amended through October 11, 1996: (http://uscode.house.gov/uscode-cgi/fastweb.exe?getdoc+uscview+t13t16+7117+15++%28Magnuson-)

Yoklavich, M.M., Caillet, G.M., Lea, R.N., Greene, H.G., Starr, R.M., de Marignac, J., and Field, J., 2002, Deepwater habitat and fish resources associated with the Big Creek Marine Ecological Reserve: CalCOFI, v. 43, p. 120-140.

Yoklavich, M.M., Greene, H.G., Caillet, G.M., Sullivan, D.E., Lea, R.N., and Love, M.S., 2000, Habitat associations of deep-water rockfishes in a submarine canyon: an example of a natural refuge: Fishery Bulletin U.S., v. 98, p. 625-641.

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