Mosaics of Benthic Habitats using Laser Line Scan Technology

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Amend, M.R., Yoklavich, M.M., Rzhanov, Y., Grimes, C.B., and Wakefield, W.W., 2007, Mosaics of benthic habitats using laser line scan technology, in *Todd, B.J., and Greene, H.G., eds., Mapping the Seafloor for Habitat Characterization: Geological Association of Canada, Special Paper 47, p. 61-69.*

Abstract

*Laser Line Scan (LLS) systems can serve as a bridge between fine-resolution, low-coverage video survey tools (*e.g.*, Remotely Operated Vehicle (ROV), manned submersible, towed sled) and coarse-resolution, high-coverage acoustic technologies (*e.g.*, multibeam and sidescan sonar). In an evaluation of LLS for fishery habitat assessments, a survey was conducted by NOAA Fisheries in the fall of 2001, off the central coast of California using a Northrop-Grumman SM2000 LLS. A video survey was conducted also, using an ROV across parts of the study area, to ground-truth the LLS data and to compare observations made from a forward-looking video camera with those from LLS reflectance imagery. The LLS was successful in generating high resolution (1-2 cm across-track) imagery of rock outcrops, sand waves and ripples, drift kelp, patches of large anemones, groups of fishes off, and on, the seafloor, starfish, sea pens, and salp chains. As expected, the LLS system provided imagery of higher areal coverage but with lower taxonomic identification than the ROV video.*

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*Developing the capability to process and mosaic imagery and produce seafloor maps is a significant step in advancing the efficient application of LLS technology. To assess the mapping capabilities of the system, a series of georeferenced mosaic images of LLS data were generated at 2-cm pixel resolution across the survey area. The data acquisition hardware downsampled or did not log all sensor data, which made an accurate expression of the LLS configuration (*i.e., *instrument settings) difficult to achieve. As a result, a large amount of detail and object recognition observed in the original LLS imagery was lost upon geometric translation. However, combined with information obtained from reviewing the original imagery, the mosaic representation did demonstrate spatial configuration and context of organisms and geologic features at varying spatial scales. The mosaicing process exposed limitations with data acquisition and georeferencing that must be addressed before this technology can advance as a habitat-assessment tool. Future improvements to the LLS system and data processing will contribute to our understanding of fish–habitat relationships and coastal physical processes that influence dynamic benthic habitats.*

Résumé

Les systèmes d'analyseur laser à balayage linéaire (ALBL) peuvent servir de pont entre les instruments de levé vidéo à haute résolution et à couverture basse (p. ex. engin télécommandé, submersible habité, traîneau) et les technologies acoustiques à résolution grossière et à couverture élevée (p. ex. multifaisceaux et sonar à balayage latéral). Dans une étude par ALBL visant à évaluer des habitats de pêche, un levé a été réalisé par la NOAA Fisheries à l'automne 2001, au large de la côte centrale de la Californie à l'aide d'un appareil Northrop-Grumman SM2000 LLS. Un levé vidéo a aussi été réalisé dans certaines parties de la zone d'étude, à l'aide d'un engin télécommandé, afin de vérifier sur place les données de l'ALBL et de comparer les observations faites à partir d'une caméra vidéo à visée vers l'avant à celles de l'imagerie par réflectance de l'ALBL. L'ALBL a réussit à produire des images de haute résolution (1-2 cm transversal) des affleurements rocheux, des vagues de sables et des rides, du varech échoué, des amas de grandes anémones, de groupe de poissons sur le fond marin ou au-dessus, d'étoiles de mer, de plumes de mer, et de chaînes de salpes. Comme prévu, le système d'ALBL a permis d'obtenir des images qui couvrent une plus grande superficie, mais qui permettent une plus faible identification taxinomique que la vidéo par engin télécommandé.

Le développement de la capacité à traiter et à produire des images en mosaïque, ainsi qu'à produire des cartes du fond marin, est une étape importante dans la progression de la mise en application efficace de la technologie de l'ALBL. Afin d'évaluer les capacités cartographiques du système, une série d'images en mosaïque géoréférencées provenant de données d'ALBL ont été générées à une résolution de 2 pixels par cm dans la zone d'étude. Le matériel d'acquisition de données a sous-échantillonné ou n'a pas enregistré toutes les données de détection, ce qui a empêché de configurer l'ALBL avec précision (c.-à-d. les paramètres de l'instrument). En conséquence, l'identification d'objets observés dans les images de l'ALBL et de nombreux détails ont été perdus dans la traduction géométrique. Cependant, la représentation mosaïque combinée à l'information obtenue en révisant l'image originale a permis de montrer la configuration spatiale des organismes et le contexte dans lequel ils évoluent, ainsi que les caractéristiques géologiques à différentes échelles spatiales. Le processus de production de mosaïques a montré quelles sont les limites de l'acquisition et de la géoréférence des données qui doivent être abordées avant que cette technologie puisse progresser en tant qu'outil d'évaluation d'habitats. De futures améliorations au système d'ALBL et au traitement des données vont contribuer à la compréhension des relations poissons-habitat et des processus physiques du littoral qui influencent les habitats benthiques dynamiques.

INTRODUCTION

Methods to survey northeast Pacific groundfish habitat in deep water (30-350 m) have been through several stages of development in the past decade. Direct observations using an occupied submersible have guided our interpretations of habitat associations for fishes and invertebrates. Studies by Pearcy *et al.* (1989), Stein *et al.* (1992), and O'Connell and Carlile (1993) were some of the first to quantify groundfish densities in complex habitats that are not easily sampled using traditional fishing methods (*e.g.*, trawl nets, hook and line). Fish assemblages were not only quantified by abundance and size, but their local associations with surficial geology, relief and invertebrates were characterized as well. Remotely Operated Vehicle (ROV) technology, introduced on the US east coast by Auster *et al.* (1991), and later used by Adams *et al.* (1995), and Norcross and Mueter (1999), represented an alternative to manned submersibles for *in situ* surveys. Video cameras and directed lighting were used to help capture fine-scale observations for processing and quantification. ROVs, having extended bottom time, made surveys less expensive and potentially more efficient than a submersible. While both forms of data acquisition provided detailed observations useful at fine spatial scales (1-2 m), the context of the observations with their broader surroundings was not directly available.

Throughout the development of technologies for direct observation, there was an increase in the use of seafloor maps to plan deep-water video surveys and to incorporate geologic interpretation into our understanding of fish habitat. The sonar survey, a common method to collect information on marine geology, began to be used as a tool to map fish habitat on a broad spatial scale (Able *et al.*, 1987; Yoklavich, 1997). The interaction of the seafloor with an acoustic source can be analyzed for textural characteristics (backscatter) and relief (depth). Typical sonar surveys cover a broad swath (*e.g.*, tens of metres to kilometres in the open ocean) and are an efficient and valuable method to gather backscatter imagery of large (*e.g.*, faults and emergent rock) and small (*e.g.*, sand waves and boulder fields) geologic features. Studies using sidescan sonar (Yoklavich *et al.*, 1995, 1997, 2000) demonstrated the use of this information in a habitat context. More recently, multibeam sonar systems have increasingly been used in place of sidescan sonars (Dartnell, 2000; Nasby-Lucas *et al.*, 2002; Cutter *et al.*, 2003). By incorporating a suite of precise positioning and motion sensors as part of the sonar system, accurately measured seafloor characteristics (*i.e.*, co-registered backscatter and depth) can be turned into spatial models that represent aspects of potential habitat.

The use of Geographic Information Systems (GIS) to manage and analyze seafloor data also has grown dramatically in the past decade (Wright, 1996; Bobbitt *et al.*, 1997; Wright and Goodchild, 1997; Hatcher and Maher, 1999). Digital backscatter mosaics and backscatter/bathymetry grids derived from sonar data are now easily integrated with spatially referenced databases created from video observations using submersibles and ROVs using GIS tools. In joining these observations with sonar, GIS expands our capability to interpret habitats from the macro (1-10 m) to meso scale (10 m to several km; Yoklavich *et al.*, 2002). The analysis of such data in GIS also has resulted in the use of habitat classification schemes (Greene *et al.*, 1999), predictive models of groundfish habitat (Fox *et al.*, 1999; Dartnell, 2000; Whitmire *et al.*, this volume), and estimates of historical fish abundance (Nasby-Lucas *et al.*, 2002). Nevertheless, merging the disparate spatial scales of video and acoustic survey methods is a challenge (Anderson *et al.*, 2005). The goal is to efficiently collect data at spatial scales that are appropriate both for accurate identification and broad-scale mapping of the organisms and their habitats.

Laser Line Scan (LLS) is an imaging technology that can potentially meet the broad and fine scale needs for mapping fish habitat (for review of LLS systems, see Jaffe *et al.*, 2001). Developed primarily for military applications, LLS can also provide detailed information useful for ecological purposes, including identification of coral species using multispectral fluorescence imagery (Mazel *et al.*, 2003), examination of shellfish behaviour (Tracey *et al.*, 1998), environmental assessments (Gabbianelli *et al.*, 1997), mapping a deep-sea chemosynthetic community (MacDonald *et al.*, 2003), and surveying fish and megafaunal invertebrate abundance and associated habitat (Carey *et al.*, 2003; Yoklavich *et al.*, 2003). Briefly, laser light of a particular wavelength rapidly scans a small spot (mm to cm resolution) across a fixed-angle swath (typically 70°) and the reflected light is sensed and formed into an image. The extent to which the laser light reaches the seafloor is a function of laser wavelength and water clarity. The recorded intensity of the reflected light is then a function of both water clarity and the target object's own absorptive and reflective response to the laser wavelength. Reflectance imagery is formed by an accumulation of scanline data, which requires forward motion of the sensor platform (*e.g.*, tow body or submersible). The results are detailed, photo-like depictions of objects within the sensor's field of view. Currently, there are only a limited number of LLS systems available, and therefore development and application of this technology has not proceeded as rapidly as other methods (*i.e.*, video, acoustic).

The goal of this paper is to expand on earlier work by Yoklavich *et al.* (2003), where LLS was evaluated as a tool for assessing deep-water seafloor habitats in the Monterey Bay National Marine Sanctuary. The previous work was based on reviewing LLS imagery stored on videotape media as a continuous real-time "waterfall", whereas this paper reports on the utility of digital file-based LLS imagery data in the production of spatial LLS mosaic images.

METHODS

During a survey, off the central California coast, LLS data were collected in the fall of 2001 using a Northrop-Grumman SM2000 monochrome LLS system, integrated with a MacArtney Underwater Technology FOCUS™ remote operated towed vehicle, owned and operated by Science Applications International Corporation (SAIC). Details on the study site, methods, and the results of a comparison between LLS and ROV-video survey methods are given in Yoklavich *et al.* (2003). Laser Line Scan was successful at imaging some benthic organisms and geologic features at high resolutions (~1 cm). However, the system was not as effective as video at discerning taxonomic distinctions (*e.g.*, species identification) critical to many population assessments. During the survey, LLS data were collected on two media types: 1) digital videotapes of greyscale scan-line imagery that was sequentially generated and displayed as a continuously downward-scrolling waterfall, and 2) digital data files of captured imagery and embedded navigation information at two-second intervals, the focus of the current study.

Data from the LLS survey (Yoklavich *et al.*, 2003) were processed into georeferenced mosaics to evaluate identification and areal distribution of seafloor objects (*i.e.*, organisms and habitat). For each survey trackline, a proprietary data file format contained the output data from the LLS. Each data file consisted of an incremental sequence of video frame-grab images (640 pixel columns x 480 rows, called "frames" hereafter) and navigation data, both captured and stored every two seconds. Methods were developed to read these LLS image data files, remove the redundancy of the frames by finding similar image rows, extract the embedded navigation data, warp the imagery using the spatial information, and assemble all trackline imagery into a georeferenced mosaic.

In the LLS image data files, frames duplicated each other by some number of rows due to the combined effect of a variable scanning rate and the fixed-interval acquisition of video frames. A slower scan speed, for example, would result in a high amount of overlap. Frame overlap was determined using frequency analysis between the rows of adjacent frames to find concordant matches of pixels. A new series of trackline image files composed of continuous and unique laser scans were then created with a width of 640 pixel columns and up to 350,000 pixel rows per survey trackline.

During the survey, data from the ultra-short baseline navigation system was acquired, processed, and logged using WinFrog™ (Thales Geosolutions, Inc.), and then combined as serial output with SM2000 control settings to produce calculations of swath width. In the LLS acquisition system, a subset of the navigation data was then inserted as a text string every two seconds into the LLS image data file adjacent to the most recent scan (image pixel row) in the frame for that time. This data string was composed of date, time, latitude, longitude, heading, swath width, altitude, depth, and speed. To exploit this information, the data string was extracted along with the corresponding trackline image pixel row at which it was embedded.

There were significant limitations in the embedded navigation data that appeared to be the result of a malfunctioning LLS acquisition system. Most critically, time content was consistently truncated at the ten-second digit and position coordinate precision was in tenths of arc-seconds, or approximately 2 m. Accepting these limitations, the geographic coordinates were converted to a Universal Transverse Mercator (UTM) coordinate system to more easily evaluate image resolution in metric units. Position data were then smoothed with an 11-point cosine filter. A new navigation data file was created containing values of eastings, northings, heading (course-made-good), swath width, altitude, and the corresponding row number in the trackline image file.

To translate LLS trackline image pixels into a spatial mosaic, three components of the new navigation data were used. At the first and last row of each frame unit (defined by the acquisition time interval, containing unique rows in each unit) in a trackline image file, the row-specific position, heading and swath width were used to calculate along- and across-track UTM coordinate control points with respect to a central trackline axis. Pixels in each segment were then linearly displaced between these points. The process was repeated for each trackline image file. In instances of pixel overlap (*e.g.*, inter-trackline swath overlap) pixel values were averaged. All data were processed to the finest possible resolution before objects (*e.g.*, individual fish) became difficult to distinguish due to blank areas from inter-scan spacing. The resulting bitmap images were converted to georeferenced GeoTIFF image files for mosaic representation in GIS.

GIS was used to integrate and further analyze information obtained from the LLS survey data. Habitat polygons were created in GIS by digitizing the mosaic images. Also, observations taken from the video waterfall playback (Yoklavich *et al.*, 2003) were brought into GIS by using a time-based linear referencing data model (Wong *et al.*, 1996; Nasby-Lucas *et al.*, 2002; Brennan, 2003). A polyline was first created from the navigation position fixes for each trackline. Each polyline was then indexed by time, using fix points as index vertices with time values linearly interpolated along the line segment between vertices. The observational information was then linked to the trackline polyline by the time of observation as recorded on the videocassettes. The observational data were displayed and spatial pattern in the survey area was examined. Finally, the observational data and the altitude sensor measurements at the navigation fix vertices were spatially joined via nearest neighbour analysis to evaluate the observational performance of the system relative to altitude.

RESULTS

A complete mosaic of the entire survey area (total planar area estimated to cover 38 ha) at 2 cm pixel resolution was constructed by a tiled assembly of individual georeferenced LLS mosaic images (Figure 1). Tiling allowed for both efficient storage and display of this large volume of image data (4 GB). The tiled mosaic was composed of 158, 8-bit greyscale GeoTIFF tiles of 5000 x 5000 pixels each. Continued experimentation with georeferenced image resolution to finer levels (<2 cm pixels) resulted in inter-scan spacing artifacts for all the acquired data. Average swath width throughout the mosaic was 7.8 m (*SE* = 0.04, *N* = 10,573), and depended on altitude or height of sensor over bottom, a function both of bathymetry and operator control. Narrow swath widths were encountered over pinnacle tops while the widest widths were over the two canyon heads in the survey area. Altitude ranged from 0.6 to 30.5 m (mean = 5.7 m, *SE* = 0.03). The LLS system was towed at depths from 16 to 96 m (mean = 53.1 m, *SE* = 0.1). Survey speed averaged 2.7 kt (*SE* = 0.01).

Closer inspection of the complete mosaic requires direct viewing of the digital data (see examples, Figure 2). The unique frame units of each trackline were transformed into trapezoids scaled by the navigation control points (Figure 2a). Schools of groundfish were imaged in context to neighbouring rock habitat. Sand waves, clearly imaged in one trackline, were not detectable in the adjacent tracklines, which was mostly a result of an increase in scanner altitude and the subsequent effects of light absorption and scattering following passage over pinnacles (*e.g.*, see the narrow swath in the upper left region of Figure 2a). Image distortions from abrupt changes in altitude (and consequential changes in the swath width) often occurred in association with rock outcrops. Sand waves and low relief rock were less distorted.

Scanner motor speed had a distinct effect on along-track resolution (Figure 2b). A slow scan speed resulted in wide inter-scan spacing that made positive identification of various features difficult. A higher speed allowed for an increased level of detail that made identification more likely.

The translation of the original trackline imagery to a sensor-derived geometry resulted in the loss of detailed information (Figure 3). An illustrative example is found in the loss of a starfish (inset of Figure 3b), of approximately 10-20 cm in diameter, present in the original image (inset of Figure 3a). Small groundfish associated with the rock feature (Figure 3a) became clusters of pixels with few or no identifying characteristics due to the displacement of pixels to the translated geometry of each frame unit. The mosaic retained the identity of broad features, such as a single rock outcrop, but fine-scale objects were degraded to the point of obscurity.

Polygons of habitat types were created from the mosaic (Figure 4a). Due to differences in seafloor reflectance throughout the survey area, vector polygons could be created only for the most distinct habitat features in the imaged tracklines: rock and sand waves. Mud and sand ripples, known to exist in much of the survey area (Yoklavich *et al.*, 2003, figs. 3 and 4), appeared uniformly grey and distinct boundaries could not be identified.

Time-based observations of specific organisms (starfish, flatfish, and sea pens) from the waterfall video playback described in Yoklavich *et al.* (2003) were expressed spatially (Figure 4b). These particular organisms were selected based on the level of confidence in identifying them. Patterns of spatial distribution alongside habitat (Figure 4a) were apparent. Starfish were found within the vicinity of sand waves. Flatfishes were more evenly distributed across habitat types. Sea pens were clustered near rock features. Regardless of identification quality, the mean altitude (4.8 m, *SE* = 0.03, *N* = 2024) of all observations in the waterfall video (all organisms, habitat, unidentifiable objects) was significantly lower than

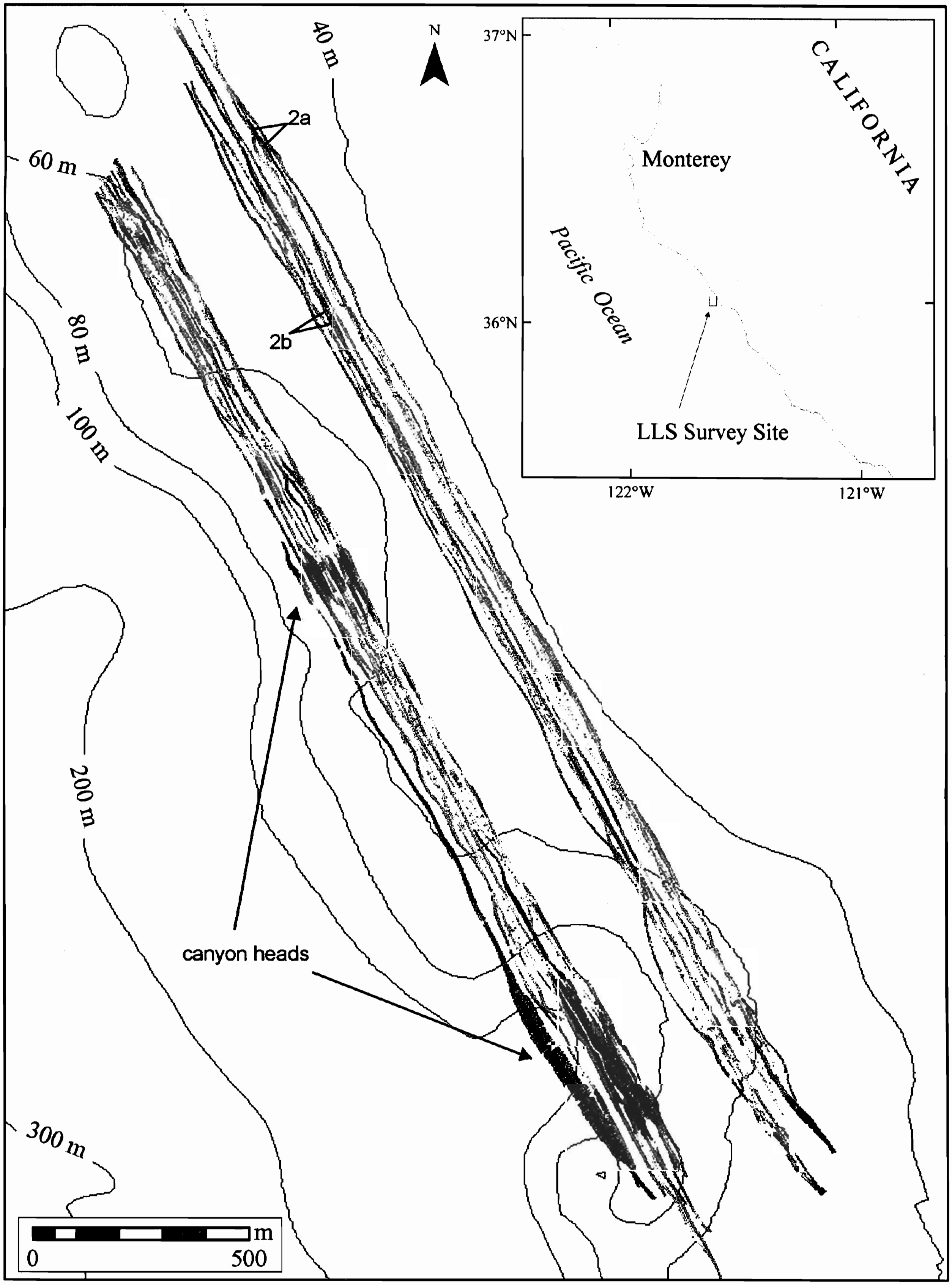

Figure 1. *High-resolution (2 cm pixels) Laser Line Scan (LLS) mosaic map constructed from 158 mosaic images covering 21 tracklines surveyed off the Big Sur coast of central California (see Yoklavich* et al., *2003, for study details). Arrows indicate two submarine canyon heads encountered during the survey. Two close-up areas shown in Figures 2a and b, are indicated.*

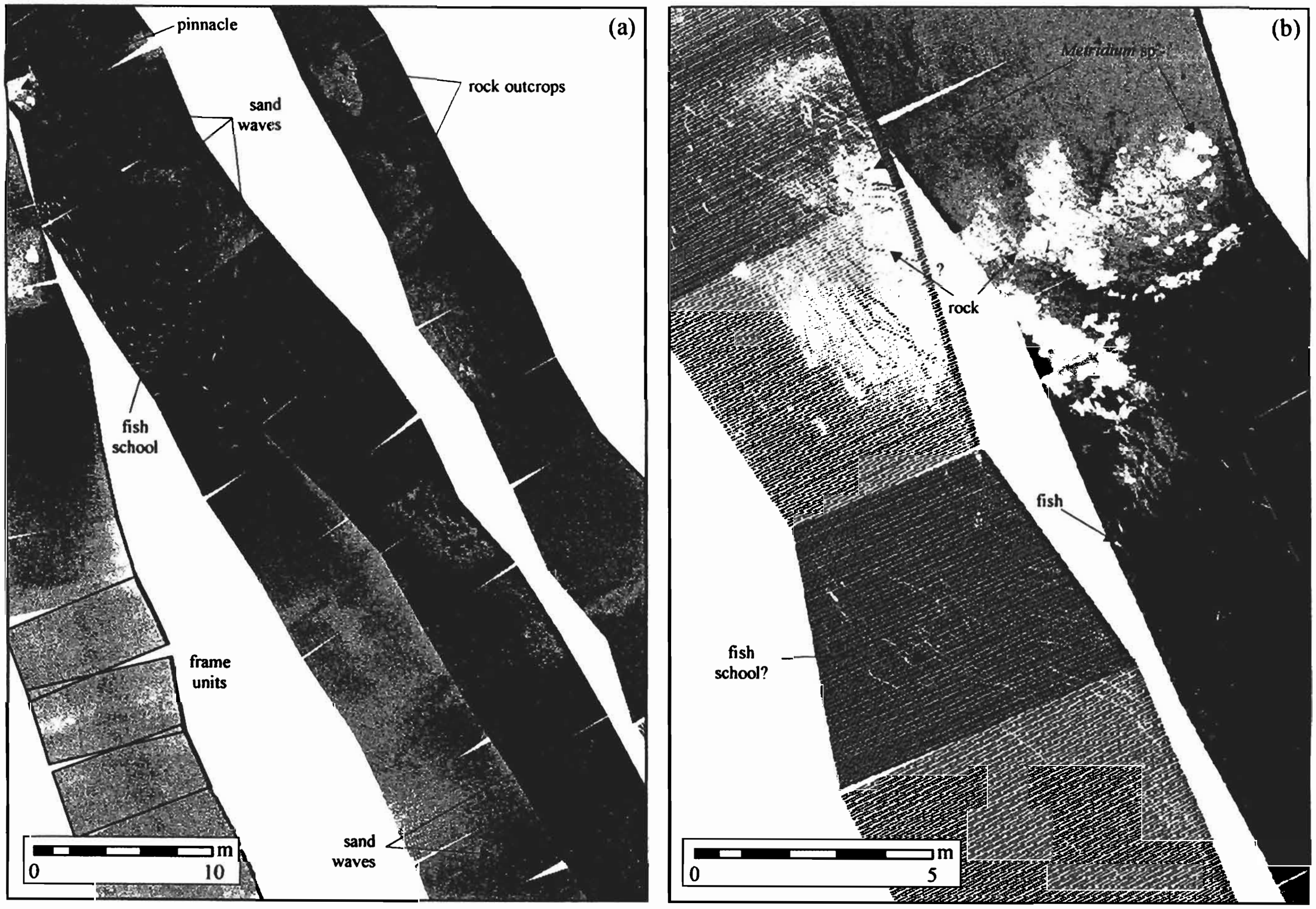

Figure 2. *a) Closer inspection of the LLS mosaic (see Figure 1 for broad-scale perspective). Individual frame units are outlined in the lower left portion. In this example, a fish school and distinct habitats are clearly imaged (see arrows) alongside less certain features (arrows indicated with ?); b) Illustrative example of scan motor speed effects on along-track resolution. The trackline to the left has a slower scan speed than that on the right. Organisms and habitat are broken and difficult to discern in the slower speed trackline.*

the mean altitude (5.7 m) during the survey (two-sample t-test for unequal variances, $p < 0.001$).

DISCUSSION

A complete series of georeferenced mosaic images was successfully created using navigation information to geometrically translate imagery data from the LLS system. The goal was not, however, simply to create a map of LLS data. Degradation of the quality of image upon translation of the original LLS data exemplifies several issues that need to be addressed for LLS systems to be considered as a functional fish-habitat survey method.

In Yoklavich *et al.* (2003), playback of the continuous waterfall video was reviewed for each trackline of the survey. Organisms were identified to the lowest taxa possible and enumerated, and habitats were described. The waterfall display clearly depicted organisms and habitats to a high level of detail (Yoklavich *et al.*, 2003, figs. 3 to 6). In that study, the size of features was estimated *relative to* swath width values that were nearby in time. The approach in translating the frame-grab data into a spatial mosaic provided a more dynamic depiction of the spatial scale of the imagery as it varied with time, accurate to the geometry provided by the navigation system. However, this advancement to a more accurate geometry was accompanied by a significant loss in resolution and the ability to identify small targets (*e.g.*, a starfish). In other words, one might measure, but not effectively identify, objects in the mosaic. The highest level of target identification was contained in the playback of the waterfall video.

In applying geometric transformations to the LLS imagery, there are limiting elements of the LLS acquisition system design that ultimately dictate the fine-scale spatial expression of the reflectance data. For each scan, the spatial aspect across-track was estimated through the swath width value calculated from altitude data, at two-second intervals, and an assumed flat seafloor across the swath. In the along-track dimension (the cumulative build up of scan pixel rows), the rotation rate of the mirror prism (scan motor speed) seemed to affect spatial aspect as well. The scan motor speed changed autonomously during the survey, adjusting to towbody speed through a communications link with the navigation acquisition computer. The number of scans per second unfortunately was not logged anywhere in the acquisition system, nor could it be back-calculated due to the limitations of the embedded navigation data.

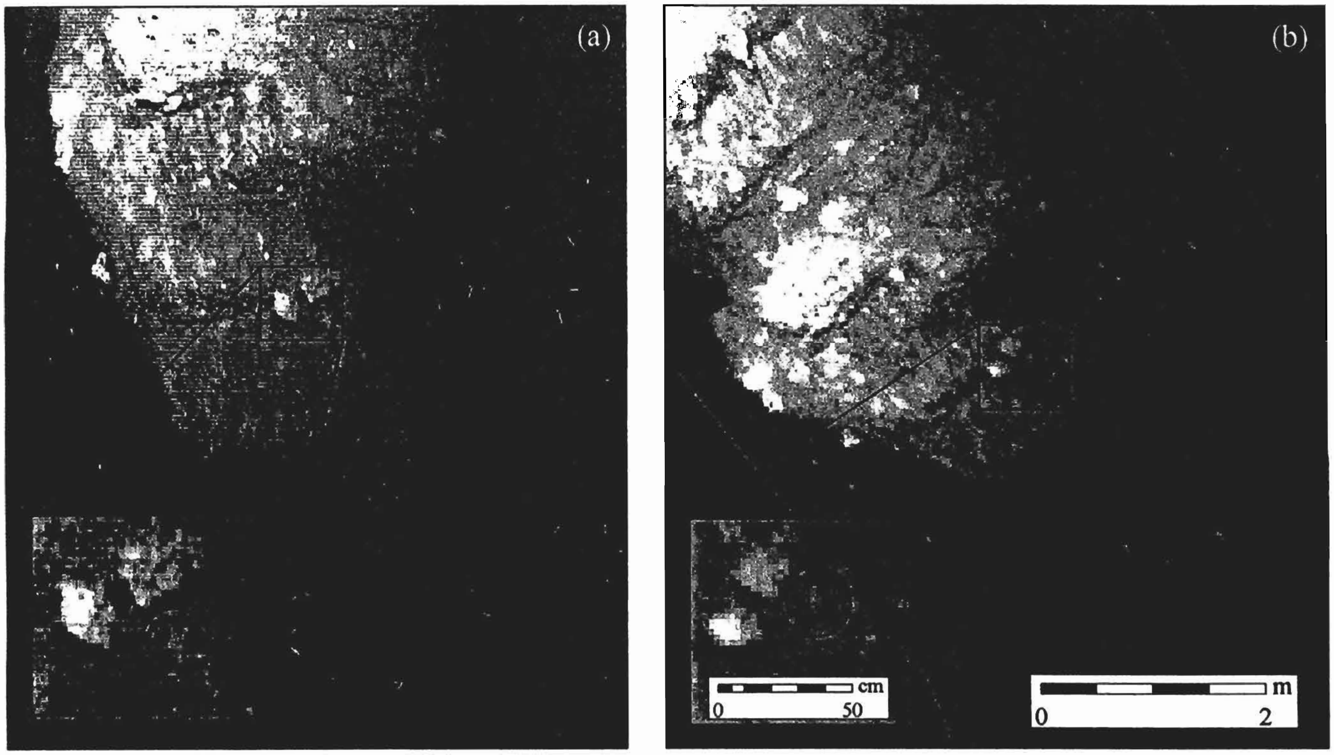

Figure 3. *Example of LLS reflectance data over a rock structure, a) before, and b) after conversion to a georeferenced high-resolution mosaic. Note the loss of the highlighted starfish (within the circle symbol) after the geometric translation, and degradation in detail of fish aggregating around rock.*

While the intent of the variable scan rate in the system design was to provide consistent along-track coverage, it was not apparent that the system was working correctly. A fast scan speed relative to tow speed would increase the number of scans (and hence pixel rows) along-track relative to across-track. This dense coverage provided additional data with which to identify objects. One side effect was that recognizable objects appeared spatially stretched in the mosaic images, as expected from the quality of source navigation data. A slow scan speed relative to tow speed, on the other hand, caused spatial under-sampling. Although the manner in which the LLS data were acquired constrained the spatial representation of the scanned objects, the identity of objects was retained in the waterfall video display as observed in Yoklavich *et al.* (2003) because of the high pixel density provided by the LLS system and prior knowledge of the anticipated targets.

While environmental conditions such as water clarity have a large effect on the quality of LLS imaging (Rhoads *et al.*, 1997), experience here shows that LLS is limited also by operator-controlled survey altitude. Poorly imaged habitats and their associated organisms may have been a result of instances where the FOCUS vehicle was at a high altitude for safety reasons, not solely a function of water clarity. The presence of pinnacles and two canyon heads (*i.e.*, potential collision targets) likely played a role to some extent, but maintaining the high altitude near these features resulted in low-quality reflectance data around them. Admittedly, the expense and rarity of LLS systems dictates an inherently cautious survey design. Because LLS image quality is mostly environmentally driven and yet can be altered by operator-controlled altitude, adaptations to collect the highest quality data carry a high risk.

Ideally, a fish-habitat survey instrument would have the ability to consistently image the area covered by the angular swath and discriminate between fine-scale contrasting features. This is especially desired for the complex habitats of certain groups of Pacific groundfishes (*e.g.*, rockfishes), which are often composed of gradients and edges such as a matrix of cobbles and boulders interfaced with sand and isolated rock outcrops. As an example of this type of application, Mazel *et al.* (2003) used a multispectral Fluorescence Imaging LLS (FILLS) to survey a coral reef. Different groups of organisms responded uniquely to various laser wavelengths. The response could then be later analyzed using image classification. The authors also had access to digital signal information from the scanner, which added to the dimensionality of source data. This ability to further improve upon laser imaging through sophisticated design and analyses enhances the effectiveness of LLS in seafloor characterization.

Mosaics of LLS data have been constructed previously for deep-water locations. An archeological site (USS Monitor wreckage) was imaged using a LLS system (Jaffe *et al.*, 2001, fig. 8); the mosaic was warped manually to approximate the known dimensions of the object. In another study, hydrocarbon seeps were surveyed using LLS (MacDonald *et al.*, 2003); spatial coordinates were used to georeference the start and ends of each trackline image, making the geometric translation essentially rotational.

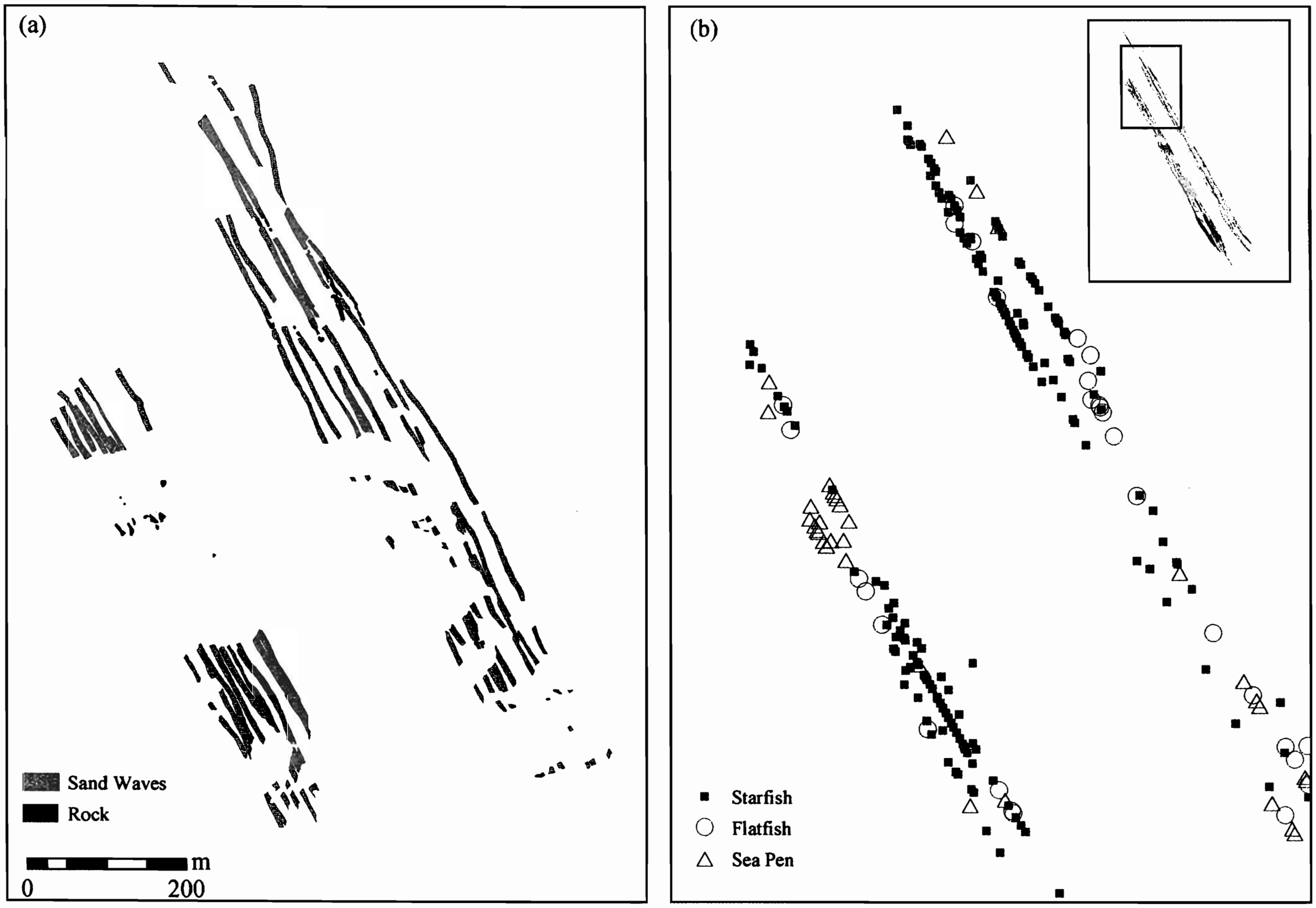

Figure 4. *a) Digitized habitat (sand waves and rock), and b) time-based video waterfall observations of select organisms (starfish, flatfish, and sea pens) from Yoklavich* et al. *(2003) in the identical region in the northern part of the survey area (see inset map). Only polygons of distinct habitat types were created from the mosaic. Observations were linked to navigation data using a linear referencing model.*

Both of these cases used submersibles, which are relatively stable and manoeuvrable platforms, to acquire the LLS data. These studies did not incorporate additional orientation data (*e.g.*, heading and swath width) to digitally construct a LLS mosaic. If LLS is to be used as functional seafloor mapping method, it is essential that position and orientation parameters be applied to the acquired reflectance data.

Additional variables that can be measured aboard the LLS sensor platform may have a profound effect on the quality and usefulness of reflectance data for fish-habitat mapping. It is likely that logging highly accurate information on the orientation and position of the scanner for each scan line, as well as changes in scanner settings (such as scan motor speed, field-of-view), will improve the mapped product. Acoustic survey tools are mature in this respect, whereby several existing software packages record not only raw signals but also any integrated information from associated sensors and any changes to the instrument settings. An acoustic survey essentially can be re-run on playback to generate a geometrically correct mosaic.

As in Yoklavich *et al.* (2003), these results highlight several limitations of the LLS system that require a response from industry. This mosaic certainly could have been improved if higher resolution source data was collected in the original survey, *i.e.*, the values of the raw reflectance signal (non-video) should be acquired at a higher level of precision (*i.e.*, 4096 pixels vs. 640 pixels, 12-bit vs. 8-bit video). Scan motor speed should remain constant and as rapid as possible for a maximum along-track resolution. While a fixed rate may not be ideal for the waterfall presentation due to motion distortion, a high scan rate would improve the utility of pixel information in a spatial mosaic. Identity of organisms and description of habitats would likely be retained during geometric translation because of the increase in reflectance data per unit area and per unit time. The incorporation of attitude data sensors (*e.g.*, heave, pitch, roll, gyrocompass, doppler velocity log) would be essential in translating such high-density data. These suggestions presently are being addressed through newly developed advanced LLS acquisition procedures (Reed, 2001). Field-testing of an improved LLS system is anxiously anticipated by the benthic fish-habitat community.

ACKNOWLEDGMENTS

The authors would like to thank all of those who made this study possible, including support from NOAA's National Undersea Research Program and Office of Ocean Exploration. We also would like to thank the University of New Hampshire's Center for Coastal and Ocean Mapping/Joint Hydrographic Center for collaborating on the development of processing the SM2000 data. Thanks go to T. Laidig and E.J. Dick for helping interpret the video waterfall observation data. The authors thank two anonymous reviewers for reading an earlier version of this manuscript.

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Mapping the Seafloor for Habitat Characterization

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Australian Government
Geoscience Australia

Fugro Pelagos, Inc.

Geological Association of Canada Special Paper 47

2007

Library and Archives Canada Cataloguing in Publication

Mapping the Seafloor for Habitat Characterization / edited by B.J. Todd and H.G. Greene

(Geological Association of Canada special paper; 47)
Includes bibliographical references and index. Includes some text in French.
ISBN 978-1-897095-33-1

1. Benthos–Habitat. 2. Ecological mapping. 3. Marine animals–Habitat. 4. Marine plants–Habitat. 5. Ocean bottom–.I. Todd, Brian Jeremy II. Greene, H.G. III. Geological Association of Canada.

GC83.M34 2008 577.7'7 C2008-901670-X

Publisher
Geological Association of Canada
c/o Department of Earth Sciences
Memorial University of Newfoundland
St. John's, Newfoundland & Labrador, Canada A1B 3X5
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Layout, typesetting and production: Joanne Rooney, St. John's, NL
Cover design and cartography: Dave Leonard, St. John's, NL
Cover photographs and images: H. Gary Greene / Brian J. Todd
Endpaper photographs and images: H. Gary Greene / Cleo K. Brylinskey
Printed by: TRI-CO Group Inc.

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PRINTED IN CANADA