Ocean Imaging Processing Sections for Thales report for SANDAG
Habitat Mapping

2 Data Acquisition
2.2 Digital Multispectral Camera
Ocean Imaging (OI) owns and operates a 4-channel aerial imaging sensor – the DMSC – manufactured by SpecTerra, LTD in Australia. The unit incorporates 4 synchronized, progressive scan 1024x1024 CCD cameras with spectral range capability from 350-990nm. Data is captured in 12-bit format. The unit is integrated with a DGPS for synchronous frame location logging. The channel wavelengths are customized by the use of narrow-band (10-20nm) interference filters. Spectral sensitivity is also customizable through software controlled shutter speed.

The DMSC is a portable system suitable for mounting on a variety of aircraft. It acquires successive image frames at a rate automatically computed from the DGPS-derived ground speed and user-specified frame-to-frame overlap margin.

2.2.1 Equipment and Procedures
For this project OI configured the DMSC with 10nm bandwidth filters corresponding to 450, 550, 600 and 643 center wavelengths. These were chosen based on previous submerged substrate mapping experience to allow good water penetration while providing sufficient spectral differences for separation of anticipated substrate types both in the intertidal and subtidal regions.

The DMSC was flown aboard a Partenavia twin engine aircraft, specially equipped for aerial imaging. The pilot utilized a separate video camera system to precisely follow the coastline. In areas where the coast angle changed too rapidly to allow horizontal change of aircraft direction (i.e. without banking which would introduce excessive spatial distortion in the image data), the plane looped back and resumed data acquisition in the new direction.

Successful image acquisition for submerged substrate mapping requires that a combination of factors coincides: Cloudless weather, good water clarity, minimal waves and surge, and low tides occurring either during morning or afternoon hours when sun angles are below approximately 30º to prevent surface glint contamination. The tide vs. sun angle requirements themselves limited data acquisition possibilities to approximately 5-6 days per month during the August-October, 2002 interval.

Data were acquired over the entire area on the afternoon of 10/4/02 during moderately low tide. The coastline from North Pacific Beach to Dana Pt. was re-flown on 10/6/02, timed to coincide with the day’s peak low tide (-1.2”) in order to provide better imagery of the intertidal zone where some wave and whitewater interference was experienced on 10/4. The duplicate data will be combined to eliminate whitewater interference from the final product. The 10/6 flight was also completed to produce final, post-flight processed data with 90cm resolution vs. 120cm resolution on 10/4 to provide greater detail deemed
necessary for better substrate classification at some of the north county reef and intertidal areas.

2.2.2 Calibration and Quality Control

In order to minimize surface sunglint contamination, image acquisition was done only after 2pm on both days to limit the sun angle to <27°. On both days the image radiometric range was initially adjusted for all bands using real-time histogram matching while test-flying over a representative nearshore area. The shutter speed of the 600 and 643nm channels was increased slightly (5-10ms) to adjust for the decrease in radiometric brightness at the CCD for the longer wavelengths. Data quality was monitored during data acquisition through real-time visual inspection and histogram tracking. Data quality was also checked immediately after the overflight by pre-processing random image frames, as well as frames containing specific substrate types. As is noted above, a re-flight of some of the areas at greater spatial resolution and at lower tide was deemed appropriate to increase substrate classification accuracy and whitewater interference in some intertidal areas.

2.2.3 Data Quality

On both acquisition days, weather and water conditions were excellent, with sunny skies, very low winds, waves listed in the 1-2” range and excellent water visibility over most of the coastline. Somewhat lower visibility was experienced from San Mateo Pt. northward. Very localized streams of higher turbidity were also noted at a few spots along northern Pt. Loma. The first week in October, 2002 luckily offered relatively rare conditions combining calm seas, peak low tides and excellent water visibility.

The DMSC system performed well providing good 12-bit data. The single factor most compromising data quality was increased turbidity nearshore along sections near the U.S./Mexico border, the southern part of Pt. Loma and north of San Mateo Pt.

3 Data Processing

3.2 Digital Multispectral Camera

Upon completion of each flight, image data were downloaded from the DMSV onto in-house hard drives and back-up copies were burned on CDs. Pre-processing included a two-step procedure to eliminate slight band-to-band misalignment. This was done using customized software to first compute an overall shift of bands 1, 3 and 4 relative to band 2, and shifting the three bands by that amount in the x-y direction. Each 4-band image frame was then run through a Fast Fourier Transform (FFT)-based pattern recognition routine which tiles the image into 80 pixel sections and computes a secondary, regional pixel shift on each band. The pre-processed data were then imported into tnt-Mips image processing software for further manipulation.

3.2.1 Image Georeferencing
Each DMSC image frame contains in its metadata the DGPS-logged location of the frame center. This allows rapid automosaicking of a multi-image set. However, the accuracy deemed necessary for this project necessitated further, manual geopositioning correction of each acquired frame.

The obtained image frames were manually georeferenced to a quality-controlled base layer. Initially, 1m USGS DOQQs were used, but SANDAG made available to Thales and OI 0.6m color orthophotos acquired in 2001. OI used the higher resolution orthophotos as the final base layer. The photos provided both on-land and underwater feature signatures that could be used as tie-points. The accuracy of the base layer was tested by field testing the orthophoto locations against OI field-derived DGPS locations and control position obtained during a Thales survey at various locations. The base layer was found to be in agreement with the field positions within 4m RMS.

3.2.2 Mosaic creation and radiometric balancing

Following georeferencing of the individual image frames, they were combined into a multi-banded image mosaic. For ease of processing, the entire coastal region was mosaicked into 12 sections. To reduce any frame edge effects (increased haze/aerosol attenuation near image edges, vignetting effects, etc.) only the innermost portions (approximately 35%) of each frame were retained for the final mosaic. The mosaic algorithm was run using the piecewise affine model (which “locks in place” the utilized georeference pixels and distributes any georectification error progressively between them. This approach was found to retain the greatest spatial accuracy. Feathering was used to lessen the effects of image-to-image seams and help with image-to-image radiometric balancing.

4 Generation of Data Products
4.2 Habitat Classification

Several substrate classification approaches were explored and results judged through field verification conducted by OI, with additional field data supplied by Thales and Mr. Dennis Lees. The final, most successful approach utilized unsupervised classifications done separately on 12 sections of the coast, and manual assignment of substrate type to each of the 100 cluster classes. 10 bands formed the input into the classifier, including the 4 original bands and several computed band combinations/enhancements as is described below. Because kelp and some surf grass tended to be indistinguishable in some areas for the unsupervised procedure, a supervised maximum likelihood classification for kelp-only (using only the original 4 channels) was performed in those regions and merged with the unsupervised results. Several iterations/corrections were performed on each data section, guided by previously collected field data and additional field verifications conducted by Mr. Dennis Lees. Final, section by section corrections were performed before generation of the final products to correct small, localized errors revealed by field data comparisons.
Following is a detailed outline of the initial processing/classification:

**Image Mosaics**

The above image mosaic files were classified. The SDP2_01_030_046 and SDP2_01_014_30 image mosaics were reprojected to State Plane, CA VI, NAD83 prior to enhancement processing and classification. Image mosaic file names are indicated in the processed image files by the site name and the last three digits of the above mosaic file names.

**Pre-processing Steps**

Enhanced image layers were derived from the four wavebands of the original 12 DMSC image mosaics and utilized during the image classification process. These layers included the natural logarithm values from each of the four wavebands (calculated after dark-object subtraction radiometric normalization — described below); depth-invariant index layers derived from pairs of the natural logarithm-normalized image layers, and band ratio images. Areas outside of the inter-tidal zone were masked from the images prior to any other pre-processing. Urban features and any vegetation sand/cliffs above the high tide mark were masked by manually digitizing polygons and excluding these areas from further processing.

**Dark Object Subtraction Radiometric Normalization and Natural Logarithm Calculation**

Image statistics from each layer of the 12 mosaics were reviewed. The image mosaic with the lowest radiometric values in three of the four wavebands (1, 2, and 3) was determined to be the La Jolla Cove (_011) mosaic. Dark object values from this mosaic were derived by finding the radiometric values at which histogram frequency reached near-zero when reviewing image DN values from high to low. The lowest values in the image were not chosen, as they may be associated with noise. As indicated above, values at the lower tail of the histogram were utilized for the dark object subtraction.
(DOS) radiometric normalization. The La Jolla Cove (011) image mosaic layers were reviewed to identify which pixel values were below the derived dark object values. In general, pixels below the derived dark object threshold values corresponded to a few dark pixels in the kelp area in the southwest portion of the mosaic.

The dark object values utilized in the dark-object subtraction were 340, 320, 185, and 135 for bands 1-4, respectively. These values were subtracted from each mosaic on a per-waveband basis.

The natural logarithm of the radiometrically normalized image layers was calculated and new four-layer image mosaics were created.

**Depth-Invariant Index**

Depth-invariant index image layers were created using the water column correction procedure described on the UNESCO remote sensing website: [www.unesco.org/csi/pub/source/rs10.htm](http://www.unesco.org/csi/pub/source/rs10.htm). To calculate the ratio of attenuation coefficients, image pixels were sampled from the four layers of the natural logarithm enhanced, La Jolla image mosaic. These pixels were sampled from a polygon around the line illustrated in the below graphics. The trend in the below graphics illustrates the effect of depth on radiometric values within the sand corridor.
Six depth-invariant index image layers were created using two-band combinations from the four layers of the natural logarithm enhanced mosaics. The procedure is described on the above mentioned website. The ratio of attenuation coefficients for each two-band combination were:

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<td>0.476765</td>
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**Waveband Ratio Images**

Waveband ratio images were created and utilized in the classification. These ratios were band 4/band 2 and band 4/band 1.

**Scaling Enhanced Image Layers**

The Natural Logarithm enhanced mosaic layers, the depth invariant image layers, and the ratio images were scaled to extend their narrow value ranges (originally set as float) to ranges which could be set as 16-bit. This was performed by adding 10 to each layer and multiplying by 1000. Scaled values generally ranged from 10,000 – 20,000 DNs.

**Image Classification**

Image classification tests were initially performed with 10-layer image mosaics. Final image classifications utilized 9-layer image mosaics. The 10-layer and 9-layer image mosaics included the following image enhancement products:

<table>
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<tr>
<th>10-Layer</th>
<th>9 Layer</th>
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<tr>
<td>Image Layer</td>
<td>Enhancement Product</td>
</tr>
<tr>
<td>1</td>
<td>B1 \ln</td>
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<td>2</td>
<td>B2 \ln</td>
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</table>
Bx ln indicates the natural logarithm enhancement of the DOS radiometrically normalized image layers; \(_x\_y \text{ DII}\) indicates the depth invariant index created using \(Bx\ ln\) and \(By\ ln\); and \(x/y\ Ratio\) is the ratio between \(Bx\ ln\) and \(By\ ln\) image layers. The 3_4 DII was found to be very noisy. The 1_2 DII and 1_3 DII were found to confuse the classification of surf grass extent.

**Unsupervised Image Classification**

Image frames comprising the 12 image mosaics were not acquired on the same day, or with the same camera settings. Therefore, DN values were sufficiently different between mosaics that supervised classification could not be applied to all mosaics using a single training set. It was decided that unsupervised classifications would be performed independently for each of the 12 mosaics.

One hundred unsupervised cluster classes were created for each of the 12 9-layer image mosaics. Each class was labeled and notes were made regarding potential class confusion and editing that should be performed. These notes are listed per spectral cluster class and per mosaic in the Excel file named `Unsup_100class_classnames.xls`. Potential classes to be labeled were: sand, unvegetated rock, vegetated rock, surf grass, kelp, and cobble.

**Ocean Imaging Personnel**

The following OI personnel were involved in this project:

**Dr. Jan Svejkovsky**, OI President: general management of the project, involved in image data acquisition, oversaw data processing and product generation, also performed field verification surveys.

**Dr. Larry Deyscher**: acted as project liaison between OI and other project partners, involved in field verification surveys, oversaw final product QC.

**Pete Coulter**: performed most classification processing

**Jamie Kum**: performed final classification and QC adjustments and final product file generation.
Jeff Conger: performed data acquisition, field verification and georeferencing/mosaicking

Aubrey Parra and Mark Hess: performed georeferencing/mosaicking.