HYPERSPECTRAL SEAFLOOR MAPPING AND DIRECT BATHYMETRY CALCULATION USING HYMAP DATA FROM THE NINGALOO REEF AND ROTTNEST ISLAND AREAS IN WESTERN AUSTRALIA

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ABSTRACT

Hyperspectral sensing allows us to view the earth not only in a few, but hundreds of different spectral channels over a wide wavelength range and to map the surface composition based on the spectral signatures observed. Applications range from mineral mapping to environmental monitoring, but aquatic spectral mapping has advanced steadily over the last few years as processing time and algorithms become faster and more efficient.

The HyMap airborne spectrometer is an airborne remote sensing instrument collecting data in 126 spectral channels from the visible (VIS) to the shortwave infrared (SWIR) wavelength regions (0.45 to 2.5 um). In the past it has been seen by various scientists as not adequate to provide sufficient spectral information for aquatic applications. With a multitude of applications over the last few years however, it was demonstrated that the high signal to noise ratio allows for good spectral discrimination in the visible wavelength region and the added SWIR spectral modules allow for improved sun-glint removal techniques to be applied. Furthermore any floating substances can be better discriminated from suspended matter by having SWIR channels available.

HyMap data was collected for two aquatic R&D projects in Western Australia: one over the Ningaloo Reef, near Yardie Creek, in N-WA and the other over Rottnest Island near Perth. Bathymetry calculations to 20m and seafloor mapping results are being presented, introducing new processing techniques - developed initially by DLR (Germany) - to Australian waters. These products allow seamless mosaicking of multiple flight lines and demonstrate a high level of accuracy compared to conventional mapping methods. Furthermore they provide 100 % coverage and results on a pixel by pixel base compared to interpolated results derived from line profiling methods.

HYPERSPECTRAL SENSING FOR AQUATIC APPLICATIONS

Hyperspectral (HS) remote sensing (RS) is up ‘til now mostly the domain of airborne instruments. The Australian built HyMap sensor (i) with its 126 spectral channels covering the VIS-SWIR (0.45 to 2.5 um) spectral regions was initially designed for the mineral exploration market, but has since conquered many other areas, water remote sensing being one of them. It allows airborne RS data to be collected with a spatial resolution of down to 3m pixel size and collects the spectral information in one optical path.

Various scientists and users of HS data have raised concerns in the past that the HyMap was not adequate in providing sufficient spectral information for aquatic applications. However with a variety of different projects over the last few years however, it was demonstrated that the high signal to noise ratio allows for good spectral discrimination in the visible wavelength region and the added SWIR spectral modules allow for improved sun-glint removal techniques to be applied. By having the SWIR spectral region available, we also can extend the applications area to the bordering land component of the survey area and provide seamless analysis for the catchment and drainage areas affecting the water body being investigated.

Aquatic HS applications such as the mapping of seafloor substrate, submerged vegetation, bathymetry and water constituents are the dominating examples in the marine and limnological environments. However general environmental monitoring and pollution mapping are also important aspects in the aquatic areas of interest. With the ongoing concerns about the quality and availability of drinking water and the status of marine life and habitats, HS mapping offers a unique opportunity to provide 'state of the art' baseline mapping and best practise for regular monitoring of environmentally high sensitive areas.

DEDICATED SPECTRAL WATER PROCESSING

Compared to the 'land' applications for HS data – the water environment poses an added challenge for the processing when using the Modular Inversion and Processing System MIP initially developed at DLR.

PROCESSING SYSTEM MIP

The generation of thematic products for aquatic systems from calibrated HyMap radiances is performed using the Modular Inversion and Processing System MIP (ii,iii). MIP is designed for the physically based recovery of hydro-biological parameters from multi- and hyperspectral remote sensing data and used for the environmental mapping of aquatic shallow and deep waters of inland waters, coastal zones and wetlands. The architecture of the program binds a set of general and transferable computational schemes in a chain, connecting bio-physical parameters with the measured sensor radiances.

The physical background of the hyperspectral and full transferable system incorporates the Finite Element Method for forward calculations of the radiative transfer in a multilayer atmosphere-ocean system (iv). It is used for the atmospheric-, sunglitter-, water surface- and Q-factor -correction of the underwater light field as explained in (iii). The different program modules support transferable algorithms. The adjustment of algorithms to sensor specifications and recording conditions is supported automatically in MIP. The inversion itself is based on a spectral matching technique.

With data from the hyperspectral sensor HyMap, all essential information needed for the data processing can be extracted from the hyperspectral signal itself. Additional ground truth measurements are not needed due to the high calibration accuracy and signal sensitivity of the sensor on one side and the completely physically based structure of MIP on the other side. However, the final quantitative values of the data product bathymetry can be improved by adjusting the scaling factors by use of few ground control points.

Program modules of MIP used here provide the retrieval of aerosols, pixel by pixel sun glitter correction, atmosphere and water surface corrections, retrieval of water constituents in optically deep waters, water column correction and the classification of substrates such as coral reef, seagrass vegetation and bottom sediments (v,vi). The processing system has been tested and validated in many surveys over German inland waters and Australian coastal zones, that were performed by airborne and satellite sensors.

ATMOSPHERIC CORRECTION

Aerosol concentrations are retrieved using a coupled inversion procedure of atmospheric properties and water constituents according to Miksa et al. (vii). Two sun glint correction approaches (method of HyVista and MIP internal method for correction, that is coupled with the atmospheric correction procedure) were tested and successfully applied (see next section). Both algorithms correct the sun glint radiance individually for each pixel using a standardized processing procedure. The resulting sun glint free radiances at sensor altitude L are converted into subsurface reflectances R–. A bi-directional correction for the underwater light field is applied by use of the so called Q- database (iii).

SUN GLINT CORRECTION

The HyMap sensor has a number of spectral channels in the SWIR – a spectral region in which the solar irradiance is completely absorbed by the water and one can safely assume that no water leaving radiance is present. The only signal contributions would come from atmospheric scattering or reflected from floating surface materials. Utilising such knowledge we can devise a sun glint correction algorithm using the signal from the SWIR channels and perform a sun glint removal. HyVista Corp. has devised a simple, but efficient processing tool to remove the sun glint very effective in its 1st order. An example demonstrating the technique is provided in Figure 1 (viii) – the area in the pictures if offshore and located in the Timor sea, NW Australia (ix) Four HyMap lines are mosaicked in 3 'true colour' channels and show in Figure 1a the uncorrected and 1b the sun glint corrected composite. The sun glint signal in this example is very strong, if possible one would avoid to conduct a survey under such conditions, but operational parameters allow occasionally no other choice. The water depth over the coral reef structure is up to 25 m in that particular location. The corrected HyMap data is shown in Figure 1b and allows now the classification and mapping of the underwater structures with conventional or advanced HS processing methods.

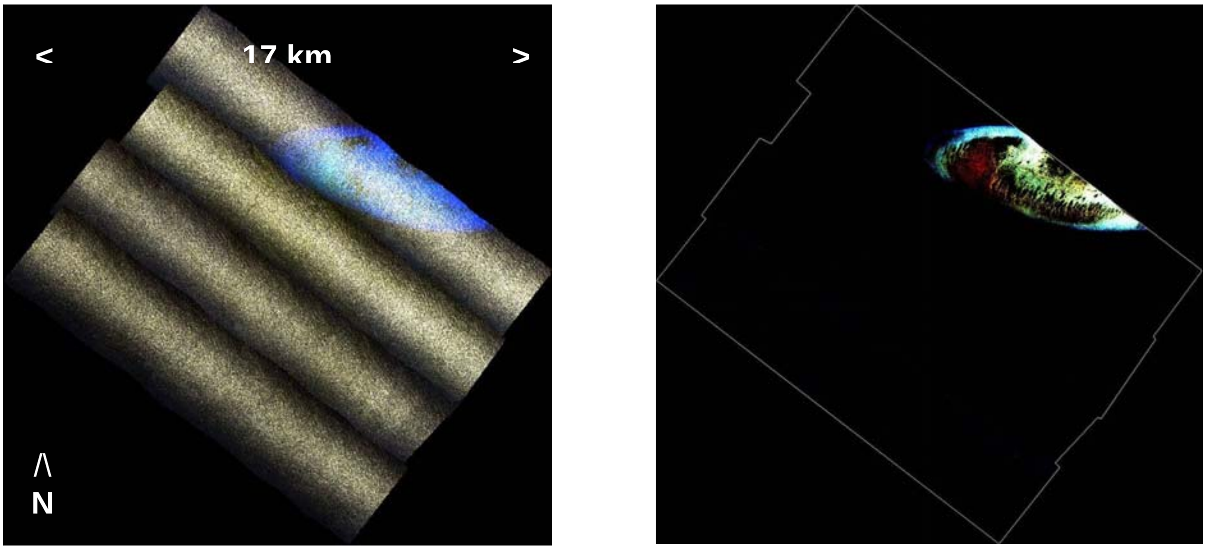

Figure 1a left hand: HyMap 'true' colour composite over submerged coral reef in open water. Figure 1b right hand: HyMap 'true' colour composite – 'sun glint corrected '.

BATHYMETRY AND SEAFLOOR MAPPING

The transformation of subsurface reflectance to the bottom albedo is done here based on the equations published by Albert et al. (xi). The unknown input value of depth is calculated iteratively in combination with the spectral unmixing of the respective bottom reflectance. The unmixing procedure produces the seafloor coverage of three main bottom components and the residual error between the model bottom reflectance and the calculated reflectance. The final depth, bottom reflectance and bottom coverage is achieved at the minimum value of the residual error. The final step of the thematic processing classifies the bottom reflectance due to the spectral signature of different bottom types and species using a Fuzzy Logic method and assignment of individual probability functions for each defined sea floor component.

Having 'input' spectra into the algorithm of the 'to be expected' or 'actually present' seafloor cover components will improve the end results as demonstrated by Pinnel (xii) for macrophyte species in inland waters.

APPLICATION EXMAPLE: ROTTNEST ISLAND, WA

LOCATION DESCRIPTION – AREA BACKGROUND

Rottnest Island is a marine reserve which lies 20km offshore of Perth. It has a subtropical climate and due to the south flowing warm Leeuwin Current many tropical as well as temperate marine species are found here. Many marine organisms are considered as isolated, at their southernmost extent (xiii). The marine reserve is mostly in shallow (less than 20m depth) and is made up by the following main categories of habitats: sand, seagrass mixed seagrass and reef, reef, intertidal platform and reef wash. The largest area is made up by the reef habitat (~45%), followed by sand (20%) and seagrass (21%) (xiv). The island also has important but not extensive cover of coral communities. Bathymetry of the waters surrounding Rottnest Island is quite varied, owing to the presence of many submerged limestone formations, favourite spots for divers and snorkellers. Waters along the west coast of WA are generally nutrient poor and low in turbidity which makes them ideal for optical remote sensing methods. The ability of the environmental management agencies to sustainably manage marine parks is closely linked to the availability of basic data sets such as high resolution marine habitat maps and bathymetry.

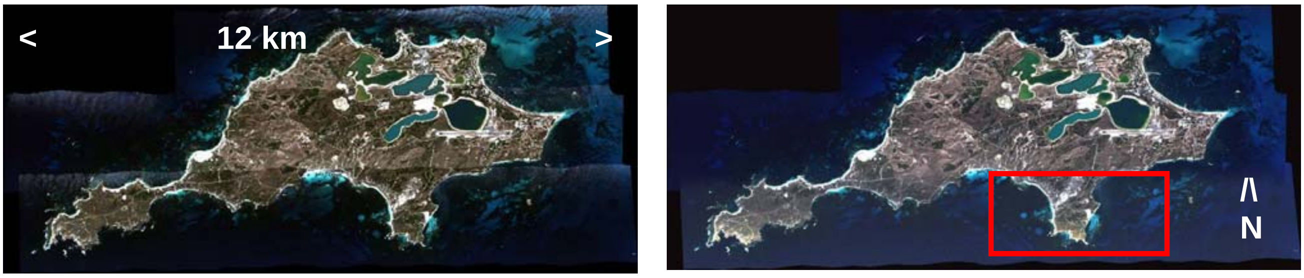

Figure 2: HyMap 'true' colour composites – left hand: uncorrected. Right hand: corrected for sun glint over water and BRDF effects over land. Red box indicates area of figure 5.

HYMAP DATA

A HyMap survey was flown in 2004 as part of a joint R&D effort over Rottnest Island and 4 data lines collected with a spatial resolution of 3.5 m pixel size. Three of these four HyMap lines can be

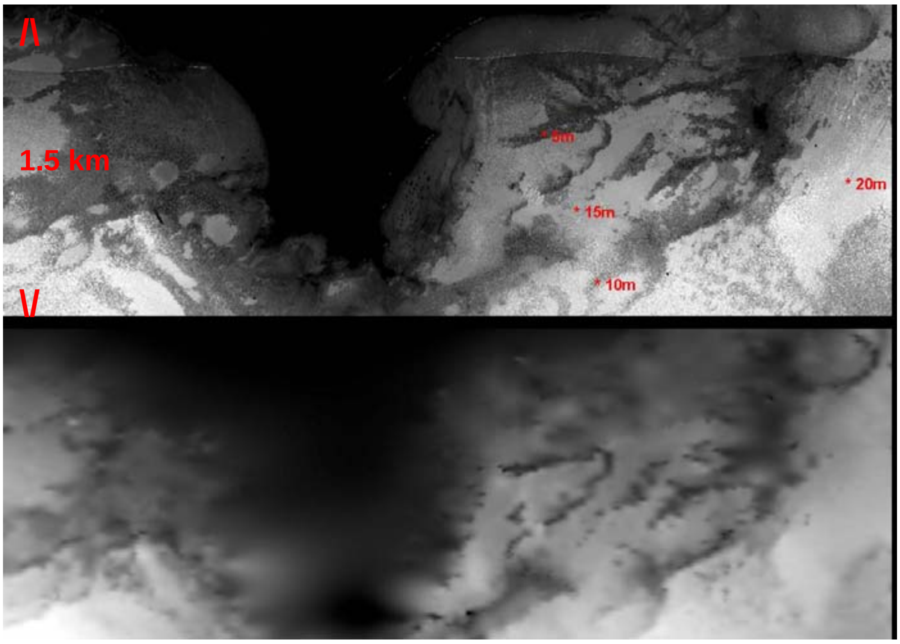

Figure 3: HyMap derived bathymetry subset (top) and comparison to gridded echo sounding derived map (bottom).

seen in Figure 2 both uncorrected and corrected and mosaicked seamlessly. As part of the HyVista standard processing water and land surfaces can be separated and processed independently. Bathymetry was calculated for all three lines and a comparison with echo sounding showed quite good results (see detail in figure 3). The average retrieved RMS is 20% and lower in waters 0 to 15m depth. Depth retrieved from deeper areas (>15m) has a fairly constant but larger error.. For other data sets (e.g. the Ningaloo data), even deeper areas up to 20m are generating stable, consistent results. However, the final quantitative values of the bathymetric data product had to be improved by simple adjusting the scaling by use of few ground control points. Further results and a detailed analysis of the Rottnest Island data will be published in an upcoming PhD thesis by Harvey (xv).

APPLICATION EXMAPLE: NINGALOO REEF, WA

The Ningaloo Reef is over 300km long and is the longest fringing reef in Australia. It is located some 1200km north of Perth and spans two bioregions: Ningaloo Bioregion and the Pilbara Bioregion (xvi) Most of the area is now protected within the recently declared marine park. Many varied substrate types and oceanographic conditions support diverse and unique habitats and high species richness. Barrier enclosing the lagoon shelters the waters and allowed for development of extremely varied coral colonies. This lagoon is mostly shallow (< 20m) and varies in width between 200m to less than 7km.

The climate of the area is arid with less than 300mm of rain, mostly in summer during cyclone season. Biota of Ningaloo area are high in species richness and many of the species are endemic. Some 200 species of coral, 600 species of molluscs and 500 species of fish occur in the area. The area is also very important for turtles, dugongs, whale sharks, and manta rays.

Because of its high biodiversity and relatively easy access to the reef, this region has recently seen an expansion in tourism as well as recreational fishing. These pressures are combined with a number of oil and gas production facilities in the region and have added urgency for the management agencies to devise plans to protect and conserve the environment (xvii). While broad marine habitat maps exist; there is an urgent need for high-resolution bathymetry and improved mapping of shallow water habitats. Hyperspectral remote sensing offers unique opportunity to provide these basic data sets and to help manage this fragile environment.

A HyMap survey was flown in 2005 as part of a HyVista sponsored R&D effort over the Ningaloo reef area near Yardie Creek (visible in the central area in Figure 4) and 3 data lines collected with a spatial resolution of 3.2 m pixel size. A colour composite of the survey lines can be seen in Figure 4 both uncorrected (left) and corrected and mosaicked seamlessly (right).

Figure 5 shows some of the processing results derived with the MIP software. On the left hand image a three channel colour composite of the resulting bottom reflectance is displayed. It is normalized and the influence of both water depth and water body properties are corrected for. One can think of it as if we would look at the seafloor and all the water above is removed, looking directly at it. The right hand image shows a group classification result of the seafloor bottom coverage. The colour composite displays sediments in red, vegetation components in green and remaining benthic substrates in blue colours, with mixtures coloured according to the chart in Figure 5. This product is already a very powerful demonstration of what we can achieve with hyperspectral sensing over coral reef areas, since even such a simple classification in high detail and accuracy can not be obtained easily with other methods.

Even more impressive is the determination of detailed bathymetry over the whole survey area calculated independently for each flight line and mosaicked seamlessly over the entire survey area. Note the spatial resolution of the HyMap data is here 3.2 m pixel size. The bathymetry values range from 0.1 up to 25m. Depth differences of 10cm can clearly be identified in the shallow water regions at the reef. Obvious errors are sparsely distributed and visible in the region of breaking waves and white caps. Hence doing such a survey in calm sea state conditions is desirable.

Figure 4: HyMap raw data (left) with atmospheric and sunglint effects. In the corrected image mosaic (right) no remaining artefacts are visible even at the boundary between two adjoining flight tracks.

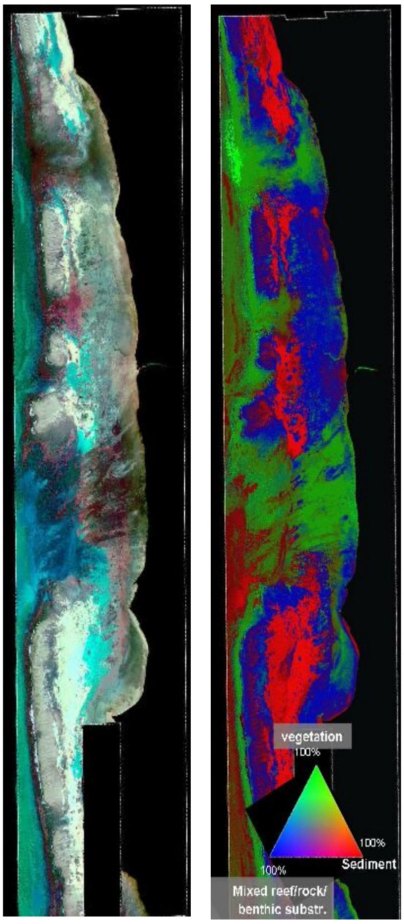

Figure 5: HyMap derived bottom reflectance corrected for depth and water body properties (left). General classification of the three main seafloor coverage groups (right).

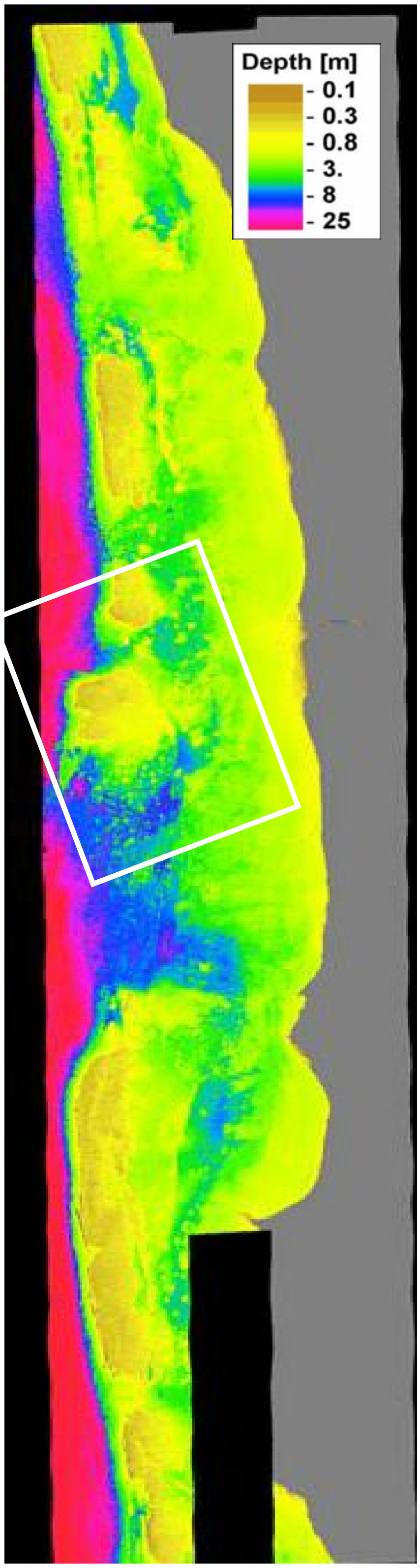

Figure 6 HyMap derived bathymetry

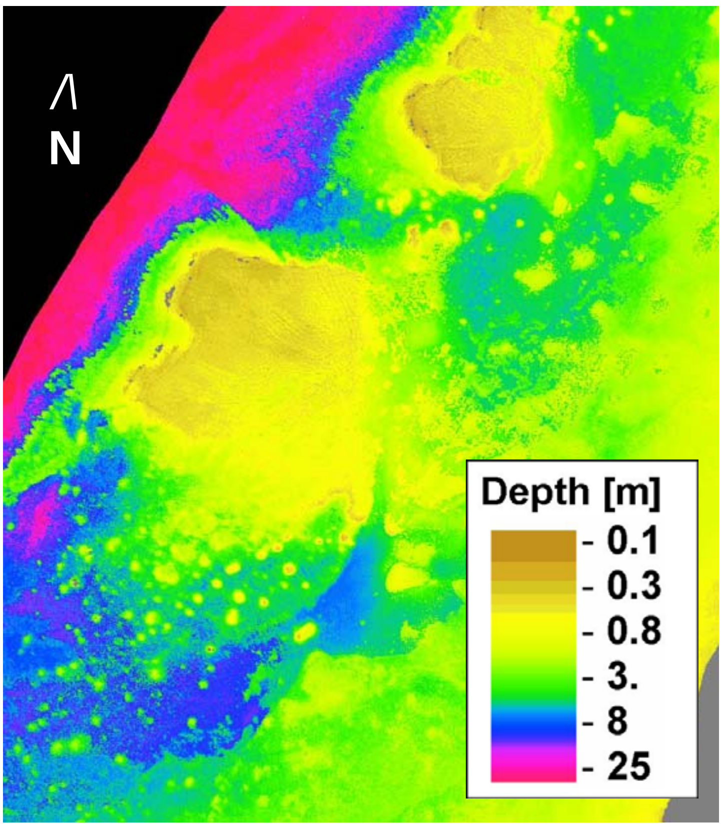

Figure 7: Subset of Fig. 6, demonstrating the spatial resolution of 3.2m pixel size and show the seamless mapping.

An enlarged and north orientated section of the right hand display of Figure 6 can be seen in Figure 7, emphasising again the high spatial resolution by showing the fast drop off at the outer reef area and distribution of large coral ‘bombies’ in shallower sections of the Ningaloo reef.

CONCLUSIONS

HyMap works well for coral reef applications, even if no additional field data are available. Bathymetry was determined successfully with a relative error of 20% up to a depth of 15 in comparison with echo sounding data (where the error bar was unknown). Further data products such as the seafloor coverage of the main components give reasonable results, but could not be compared with ground truth measurements up to now. The same does apply for the final fuzzy logic classification: Knowledge about the specific spectral characteristics of different vegetation species, coral reef habitats and sediments can be directly transformed to an extensive classification result of the whole reef area using this procedure.

The MP data processing is stable, applicable for extensive mappings and worldwide transferable. Comparable results with exactly the same standardized processing procedure were retrieved for several inland waters such as Lake Starnberg or Lake Constance in Germany. The validation here confirms the good results for bathymetry (RMS of 0.15m in Lake Constance), main bottom classes (accuracy of 73%) and vegetation species (Pinnel, 2007).

Based on our HyMap results, the Australian Institute for Marine Science commissioned a large scale HyMap survey in April 2006 covering the whole Ningaloo Marine Park with 65 flight lines at 3.5 m spatial resolution covering about 3500 sqkm in total (xviii), the largest such survey ever undertaken. This data will provide basic data sets such as bathymetry and high resolution habitat information in a collaborative research project “Reef use, biodiversity and socio-economics for integrated management strategy evaluation of Ningaloo”

ACKNOWLEDGEMENTS

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