A NEW SYSTEM FOR HIGH RESOLUTION MAPPING OF SEAGRASS.

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There is a long history in NSW of mapping estuarine habitats, with the initial inventory of estuarine macrophytes being completed in 1985, the Comprehensive Coastal Assessment completed in 2007 and the Seabed Mapping project in 2009. Over this time, there have been advances in technology that have enabled increases in mapping accuracy, detail and processing time, but there are still issues relating to the imagery available for the mapping. Specifically, there has been reliance on imagery that is often several years old and was captured for other purposes (typically for terrestrial applications). As such, the imagery is not always suitable for mapping estuarine macrophytes, in particular seagrass, due to factors such as sun glare, wind tide and poor water clarity. While it is possible to have imagery flown to target seagrass, the costs are generally prohibitive.

To address these issues, we developed a new helicopter-based image capture system which utilizes a high resolution digital camera and integrated GPS/Inertial Navigation Unit (GPS/INU). The system captures spatially referenced colour digital imagery that can be readily ortho-rectified and mosaiced to provide imagery that has high spatial resolution and positional accuracy. The imagery can be analysed using state of the art image classification/segmentation techniques to map seagrass in high detail. The high positional accuracy makes it possible map and monitor changes over time including variations of in bed species composition and total coverage as well as investigating physical impacts including moorings and boat propeller damage. The system provides a cost effective platform that can be deployed when the conditions are ideal and then validated soon afterwards, thereby maximising our ability to map and monitor seagrass beds accurately within NSW estuaries.

Background

Estuarine habitats, including seagrasses, mangroves and saltmarshes (i.e. macrophytes) have been extensively mapped in NSW. The first complete assessment of seagrasses in NSW was completed in 1985 by the then NSW Department of Agriculture, which included NSW Fisheries. The inventory depicted the extent of estuarine macrophytes in 134 estuaries (West *et al.* 1985). In 2003 a more detailed mapping of the estuarine macrophytes was initiated as part of the Comprehensive Coastal Assessment (CCA) resulting in many of the estuaries being re-mapped. The CCA project enabled a redefinition of mapping standards for the mapping of estuarine macrophytes and resulted in some of the most detailed maps of seagrasses, mangroves and saltmarshes with in NSW (Williams *et al*. 2007). The remaining estuaries that were not mapped as part of the CCA were updated in the Seabed Mapping Project (SMP) in 2009 (Creese *et al.* 2009), which continued the use of the mapping methods defined in the CCA. Combining these two most recent projects has created the most current complete coverage of seagrasses in NSW.

The technology involved in the mapping of these habitats has changed significantly over time. The original estuarine inventory was mapped using the Camera Lucida technique (CL). This process involved the manual transfer of habitat information from aerial photographs onto sheets with coastlines traced from 1:25000 topographic maps. This resulted in seagrass boundaries being transferred using a 1 mm thick pen giving an approximate positional accuracy of 25m and a minimum mapping unit of 0.5 ha (Meehan *et al.* 2005). Area calculations for these polygons were calculated using 1 mm graph paper (West et al 1985). Meehan *et al.* (2005) found that there may be significant over estimates in area of seagrass associated with mapping done using this method.

The mapping methodology defined for the CCA and SMP is based on modern computer based Geographic Information System (GIS) techniques. These techniques include the use of geo-rectified film based imagery similar to that used in the CL method. The imagery is scanned and ortho-rectified to align with geographic coordinates. The habitat features are directly digitised using onscreen mapping techniques (Williams *et al.* 2007). This method not only provides greater spatial accuracy (including better area estimates) it also gives the user significantly more control over the imagery, enabling image contrast and brightness to be adjusted, thereby enhancing the visual interpretation of the features. The positional accuracy achieved using this technique is generally 10 m or better. Habitats for the CCA were digitised at a scale of 1:1500 with a minimum mapping unit of 0.0016 ha (16 m^2).

While the shift in technology from the CL technique to the GIS based system has resulted in much greater mapping detail and accuracy, both methods are based on the analysis of the same type of film based imagery. This imagery, primarily provided by NSW Land and Property Management Authority (LPMA), is more often than not captured for terrestrial applications and as such is not always suitable for mapping seagrass. In general terms, imagery that is to be used for mapping seagrass needs to take into account several important factors including; tide, sun angle, wind conditions and water quality (Finkbeiner et al. 2001, Mount 2006). The quality of aquatic imagery is often adversely affected by one or several of these factors, making the mapping of seagrass very difficult (and almost certainly inaccurate) or impossible. In addition, the imagery is often several years old and the habitats mapped from this imagery can be quite different from those present when the field validation occurs. It is possible to have imagery flown on demand to target seagrass however the costs are generally prohibitive (Table 1). There are alternative imagery options such as satellite imagery that has been used with some success to map seagrass in NSW (Dekkar *et al.* 2003 and Anstee *et al.* 2009). This imagery has the benefit of increased spectral resolution but, with the exception of Landsat data which can be obtained for free, is also quite expensive, has limited spatial resolution in comparison to aerial imagery (Table 1), is often not available for the target locations and can be affected by cloud cover and other environmental factors.

Table 1. Estimated cost of imagery per square kilometre for mapping seagrass in Wallis Lake. Prices based on quoted image acquisition for 2010.

Image type	**Area**	**Resolution (pixel size)**	**Approx cost per km^2**
Aerial photos (ADS40)	variable	0.5 m`	$38
Satellite imagery (Quickbird)	16.5kma	0.6 m*/2.4 m`	$45
Satellite imagery (WorldView 2)	16.5km^	0.5 m*/1.8 m`	$40
Satellite imagery (Landsat)	185km^	15 m*/30 m`	$0

^ - Swath width, * - Panchromatic band, ` - Multispectral imagery

In 2007, LMPA shifted from the standard film-based aerial photography system to a digital imaging system. This system comprises a Leica ADS40 Aerial Digital Sensor and captures multispectral digital imagery suitable for photogrammatic and remote sensing applications (Sandau *et al.* 2000). The imagery created using this system is of very high quality both spatially and spectrally and is exceptionally well suited for the discrimination of terrestrial based features including mangroves and saltmarsh. As with other airborne based platforms, this system is also susceptible to the impacts of environmental factors including sun glint, wind surface disturbance, tide and water quality. Unlike standard film-based imagery, the ADS40 imagery is captured in a continuous strip along the flight line, meaning the best overlapping images cannot be selected to overcome the effects of minor sun glint. The continuous scanning process utilised by the ADS40 sensor captures any sun glint in the entire strip, making the mapping of seagrass difficult.

Industry and Investment NSW (I&I NSW) has been provided with ADS40 imagery for 87 NSW estuaries. A review of this imagery indicates that seagrass can be mapped in 46 estuaries; the remaining 38 estuaries are impacted by poor water quality, sun glint, cloud or have incomplete coverage (Table 2). Most images, however, were suitable for mapping mangrove and saltmarsh habitats.

Table 2. Usefulness of current ADS40 imagery for mapping seagrass in NSW.

Image Quality	**Number of estuaries**	**Percent**
Good	46	53
Poor water quality	8	9
Sun glint	24	28
Cloud	1	1
Incomplete coverage	8	9
Total	87	100

Industry and Investment NSW has a commitment to continue mapping seagrass in NSW, but based on the ADS40 imagery currently available, only about 50% of the estuaries could be mapped adequately with these images. Furthermore, it is hoped that seagrasses and other macrophytes can be mapped repeatedly over time to test for changes in distribution, yet we cannot be sure that good ADS40 imagery will be captured for the same estuaries on multiple occasions. In addition, the ADS40 imagery for large estuaries is often a composite of imagery captured at different times (sometimes different years), which is far from ideal for mapping as it confounds spatial and temporal change. It was therefore decided that a system was needed to supplement the current ADS40 imagery. Such a system needed to be cost effective and flexible enough to be able to be deployed when the environmental conditions are optimal. It also needed to be of comparable resolution to ADS40 imagery, ideally with the possibility of capturing even higher resolution imagery.

In 2008 a Small Format Aerial Photography System (SFAPS) was developed to capture imagery for sampling marine organisms growing on subtidal and intertidal rocky reefs as part of the state-wide marine natural resource monitoring program. A review of remote sensing options was commissioned and it was concluded that sampling using high resolution digital images taken from a helicopter would be the best methodology. Because a helicopter can hover, it enables images of open coast intertidal areas to be captured when there are no breaking waves obscuring the species on the rock platform. The system developed comprised of a digital SLR camera connected to a Global Positioning System (GPS) and mounted in a helipod attached to one of the skids of a small helicopter (Figure 1). The pod-mounted system provides the ability to capture high resolution imagery that is geo-located, meaning that it is potential useful for mapping habitats. This paper describes the setup of the helicopter SFAPS and explains the application of the SFAPS to capturing imagery suitable for mapping seagrass. We investigate the usefulness of the basic system as it stands and an enhanced system which incorporates a devise to facilitate the rectification of imagery.

Figure 1. Helicopter with helipod (containing SFAPS system)

Description of Imaging System

The basic SFAPS system is comprised of a Nikon D3 digital still camera (12 megapixel resolution), nominally with a 35mm lens, mounted in a helipod attached to one of the skids of a Robinson R44 helicopter. The camera is linked to a laptop and GPS which the operator controls in the helicopter cabin (Figure 2). Camera Control Pro software, provided by Nikon, enables full control of the camera and also enables the laptop to serve as a storage system for the images captured. Custom navigation software has been developed to aid in navigation and for traversing along predefined flight lines. The scale and resolution of the images are determined by the altitude of the aircraft and/or the lens size. For example, from an altitude of ~ 300 m with a 35 mm lens, seagrass habitats can be captured over an area of ~ 205 x 310 m with a resolution of 7.2 cm (Table 3). Typically the helicopter will travel at a speed of around 40 kts and an image will be captured every 1.5 seconds, meaning that a series of images can be obtained with approximately 60% overlap in a 310 m wide strip (depending on the altitude and lens). All imagery is captured when the environmental conditions are most suitable; a wind speed of < 15 kts (ideally < 10 kts), no cloud cover and during the morning or afternoon when the sun angle is optimal to minimise sun glint.

Rectification of the images captured using the basic SFAPS system requires many well spread out high quality ground control points. Reliable ground control points which are typically easy to find on land are rare or non-existent in most aquatic environments, meaning that marker buoys need to be deployed and accurately geo-located. This process is outlined in the case study below and we later discuss an improved SFAPS system which incorporates a devise to facilitate the rectification of imagery.

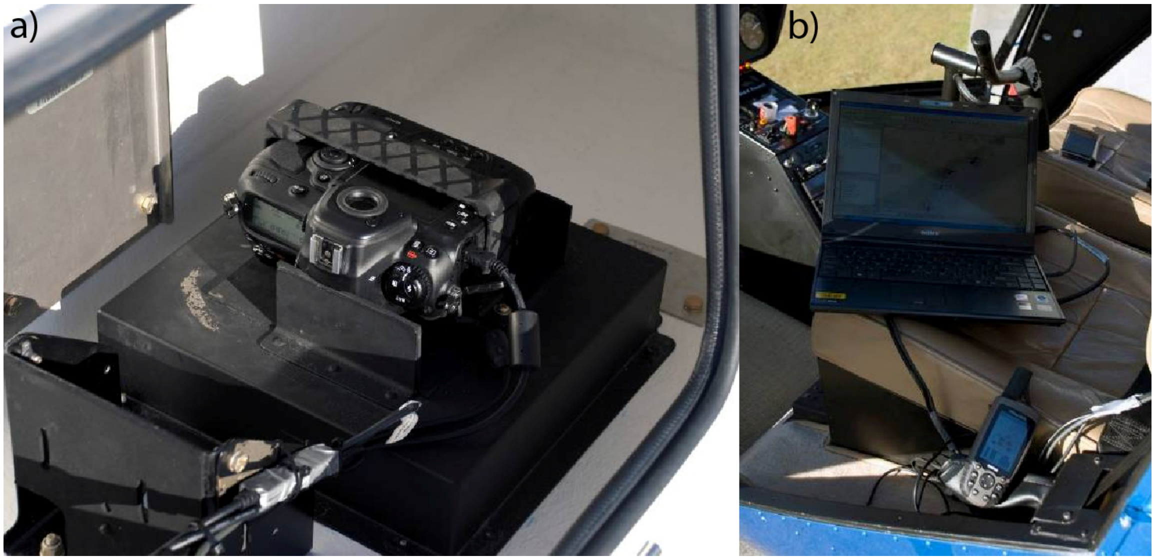

Figure 2. (a) Nikon D3 mounted vertically in helipod and attached to (b) laptop computer and GPS in the cabin

Table 3. Approximate areas (m) and resolution (cm) of images captured by the SFAPS system at different altitudes and with different lenses

Altitude	24 mm lens	35 mm lens	50 mm lens
150 m	150 x 225 m 5.3 cm	105 x 155 m 3.6 cm	70 x 105 m 2.5 cm
300 m	300 x 450 m 10.6 cm	205 x 310 7.2 cm	145 x 215 5.1 cm
500 m	750 x 500 m 17.6 cm	345 x 515 m 12.1 cm	240 x 360 m 8.5 cm
1000 m	1500 x 1000 m 35 cm	1025 x 685 m 25 cm	720 x 480 m 17cm

Case study – mapping seagrasses in Lake Munmorah

To determine the applicability of the SFAPS for capturing imagery suitable for mapping seagrass, we established a trial area in Lake Munmorah. This location was selected as it is a part of an already established seagrass monitoring program and it has relatively easy access for locally based field teams. An area of approximately 300 ha was selected on the eastern side of Lake Munmorah (Figure 3). This area is predominantly shallow with depths less than 5 m and extensive areas of seagrass, mostly *Zostera capricorni,* in depths of less than 2 m.

All imagery was captured using a 35 mm lens at an altitude of 1000 m. This configuration provided a swath width of 1000 m at sea level. Two flight lines were created to maximise the area covered by the imagery (Figure 3). Based on these flight lines, approximately 50% of each image would be over the water, thus 50% of each image would have little or no ground control points (GCPs). A system of floating GCP markers was created using highly visible, buoyant fluorescent pink plastic sheeting. This sheeting was cut into rectangles 1 m x 1.5 m which were attached to floats on the surface and anchored to the bottom using small concrete blocks. The markers were regularly placed around the study area on the outer edge of the seagrass (Figure 3) and their locations were recorded using a differential GPS with 1 m accuracy. Land-based GCPs were collected from ortho-rectified imagery provided by LMPA which also had a spatial accuracy of approximately 1 m.

To minimise the effects of sun glint and wind, the flight was conducted before 11am, on a day in which wind speed was less than 10 kts and when there was minimal to no cloud cover. Water clarity was also a priority, so it was important that there had been no significant rain for a week prior image capture. Lake Munmorah has limited tidal range, so tidal stage was not an important consideration.

All captured images were reviewed, adjusted for exposure and colour balance and saved as 16bit Tiff format images. The image rectification process was carried out using ERDAS Leica Photogrammetric System (LPS) software.

Figure 2. The area of Lake Munmorah covered in the case study (orange boundary). The green lines indicate the flight lines and the red points the floating ground control markers. Image courtesy of LPMA.

Results

A total of 12 images were captured at an altitude of 1000 m. All images were reviewed and minor adjustments to exposure and colour balance were made. Most images were free from any sun glint or wind surface effects. The images were then imported into the LPS software. The camera profile in the software was setup as a non-calibrated digital camera with a 35 mm lens. Ground control was established using the ortho-rectified imagery and the float marker locations. A total of 22 control points were selected for all images, including the locations of the float markers. Elevation data for the ortho-rectification process was based on a 25 m digital elevation model provided by LMPA. Once all GCPs were entered tie points for all images were automatically generated. The tie points were checked for accuracy and the aerial triangulation process was performed. The residuals for the tie points and GCPs were then evaluated and the images were ortho-rectified with a resolution of 25 cm.

The results of the aerial triangulation process indicated that the spatial error for all images was excellent (RMS = 0.5 m). The images were then overlaid to determine mismatch or displacement error between the images. All images were found to be within 3 pixels (~0.75 m) of each other in overlapping regions, indicating that there was good concordance of positional accuracy across the imagery. Cut lines were then determined and the images were mosaiced together. Figure 4 shows the final mosaiced imagery overlaid on the ortho-rectified base layer. A higher resolution section of the imagery (Figure 5) shows the detail that can be captured using this system.

Figure 4. Ortho-rectified and mosaiced images captured using the SFAPS (February 2010). The SFAPS imagery is overlaid on an older, lower resolution ortho image of the same area.

Figure 5. A higher resolution image showing the detail captured using this SFAPS. Considerable detail can be discerned in the seagrass beds. The pink floating GCP markers are also visible in the lower half of the image.

Discussion and future directions

The SFAPS has been proven to be an efficient and accurate tool for capturing digital imagery for monitoring intertidal and subtidal habitats. The SFAPS system can therefore capture imagery for mapping seagrasses and other aquatic habitats when no other imagery is available, and the resulting imagery can be far more detailed than any that is currently available from other systems. The case study indicates that it is possible to use this basic system as it stands to capture imagery that has high spatial resolution and accuracy that is suitable for mapping aquatic habitats.

A major limiting factor of the basic SFAPS, however, is the need for GCPs in the aquatic sections of the imagery. Whilst it may be possible to deploy a field team to distribute floating GCP markers in selected study areas or small estuaries, this is not a feasible approach for larger estuaries, large numbers of estuaries or when mapping remote locations. To make this system a viable approach for capturing imagery for habitat mapping it will be important to overcome this issue.

Various SFAPS have been developed to capture imagery for the purpose of mapping. Several of these use have been developed with technologies that enable the capture and rectification of the imagery with minimal or no GCPs. Inertial Measurement Units (IMU) provides the ability to capture the attitude (pitch, roll and heading) of the camera platform at the time the images are captured. The inclusion of a GPS and Inertial Measurement Unit (GPS/IMU) enables the capture of the camera platform attitude and accurate GPS location. This extra attitude data enables the rectification of the imagery with few to no ground control points (Nagai *et al.* 2009, ERDAS 2010) making the rectification of the data considerably easier.

There are several pre-existing systems designed for capturing/producing rectified digital aerial imagery, including Applanix's POS, Leicas's ADS40 and AeroDiDOS. All of these are relatively expensive and/or would not easily integrate with the basic SFAPS system in the helipod. The ideal system needs to be compatible with the existing SFAPS hardware, must be compact, light weight and relatively inexpensive. Several customised small format aerial photography systems have been developed to capture digital imagery. Many of these have been developed for the capture of high resolution data in remote areas and many have been built using off the shelf GPS and separate IMU components (e.g. Nagai 2009). These systems however, are often complex and require the development of customised interfaces and software to coordinate and manage the system. Based on this, we have selected an Oxford Technical Solutions RT3102 GPS inertial navigation unit. This unit is fully self contained and includes 2 survey grade GPS units accurate to 0.5 m and a six axis IMU to provide accurate position, pitch, roll and yaw (i.e. heading). The GPS/IMU is portable and can be mounted in the helipod with the camera and a 12 volt power supply. The unit can be connected to the camera to provide accurate GPS location and to the laptop to provide real-time measurements of pitch roll and heading of the platform as the images are being captured. A custom made remote trigger will be used to trigger the camera and signal the GPS/IMU when the images are being captured. All images and platform attitude data will be saved on the laptop which operates the camera. The ERDAS LPS software can directly import the imagery and attitude data and initial trials indicate that this imagery can be processed with minimal GCPs to obtain high quality imagery similar to that of the standard SFAPS. The system however is still under development with full deployment expected by the end of 2010.

Conclusions

The helicopter based SFAPS has proven to be a highly versatile system. It can not only provide high quality imagery for sampling abundances and distributions of species in coastal marine habitats, but it can also capture imagery that can be readily rectified and incorporated into GIS based systems for mapping habitats. The system also provides the ability to capture imagery in remote and difficult to access locations that may have otherwise been inaccessible using standard fixed wing aircraft.

The system is highly flexible and through the use of different lenses or by varying the altitude, the foot print of the imagery and hence its resolution can be customised to suit the features of interest.

Deployment of the system is relatively easy with minimal lead time required to get the system in the air. This makes it possible to capture the imagery when the conditions are ideal thereby minimising the impacts of sun glint, wind, tide and poor water quality.

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