ESTUARINE MONITORING: PRELIMINARY ASSESSMENT OF REMOTE SENSING OPTIONS FOR MAPPING MACROPHYTES

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Presented at the 18th NSW Coastal Management Conference, 3-6 November 2009, Ballina NSW.

Resolving the choice of optimal satellite monitoring platform based on monitoring objectives and cost

Abstract

Remote sensing provides a spatially comprehensive, cost-effect means for monitoring coastal and estuarine areas. To resolve the type of sensor to be used for routine monitoring, the type of monitoring needs to be clearly defined. While it might be financially attractive to employ Landsat for broad scale monitoring, its 30 m resolution is so coarse as to preclude fine scale patterns and texture displayed by small patches of aquatic macrophytes. It is these small patches that can be diagnostic of catchment-scale activities such as excessive erosion, sedimentation or pollution, or local issues such as off-road vehicle use. Management intervention may not be timely for such effects if adequate spatial and .temporal data are not available. The criteria that bear on the monitoring of these circumstances include purchase cost, image resolution, frequency of overpass, and processing cost.

This paper discusses choosing optimal imagery based using Wallis Lake, NSW as an example .

Introduction

A combination of anthropogenic pressure on the NSW coast along with climate change and rising sea level may significantly alter estuarine ecology. There is consequently an increasing need to obtain regular, accurate and up-to-date information on the extent of estuarine resources.

One estuarine resource of special importance is the complex of large plants known as macrophytes. These plants include seagrass, mangrove and saltmarsh and provide fish habitat, contribute to food chains, enhance water clarity and reduce erosion. An atlas of the cover of these plants for NSW was generated three decades ago (West *et al.* 1985) but that project was a labour-intensive exercise with limited flexibility in terms of reproduction or interrogation. A second atlas is preparation (West *et al.* in prep.), and the comparison of these data sets will provide a valuable first approximation of trends of cover of these plants for the whole of the NSW coast. Even though the second atlas is more technically sophisticated than the first, being generated within a geographic information system (GIS), the difference in methodologies should not affect the ability to identify potential problem areas and prioritise additional monitoring. For example, where minimal change in extent of cover of one or more macrophytes is seen, this implies only a modest need for future monitoring, whereas at sites showing large changes further investigations would be needed to resolve any artefacts arising from the methodological differences as opposed to any real changes associated with natural or human induced disturbance. The forecast rise in sealevel may be particularly relevant in this context as it is expected to significantly alter the distribution of estuarine macrophytes, modifying coastal ecologies as well as economies.

The increasing sophistication and progressive reduction in operational costs of GIS over the past two decades have overcome difficulties that arise in the production of regular and accurate maps, and sequences of these maps can be used to establish and extend trend analyses. In other cases, archival data can be used to reveal long term dynamics of the cover of estuarine macrophytes, or, where the interval between data sets is small, establish seasonal fluctuations.

A new generation of mapping and monitoring protocol(s) needs to be developed to apply to regular monitoring of estuarine macrophytes for the whole of NSW coastline. This new approach might rely on aerial photography, a technology that continues to improve in resolution via use of high resolution digital cameras. Geo-referenced photos derived from such cameras enhance the means by which area calculations of estuarine macrophytes are determined. Alternatively, new protocols might build on images from different types of satellites as a means by which to obtain data of variable resolution and cost. Previously, satellite data did not offer the necessary spatial resolution to meet management needs, but recent technological improvements, resulting in sensors with higher spatial resolution, have enabled these objectives to be achieved. Historical airphoto and/or satellite data, if properly archived and accessible allow, re-processing whenever new or improved processing techniques are developed.

Objectives

This presentation provides an overview of past techniques by which to remotely sense the extent of estuarine macrophytes. It aims to evaluate the cost-effectiveness of several current remote sensing methods to support coastal management objectives. Wallis Lake in northern NSW is used as a demonstration site. Several specific questions are proposed and evaluated:

- Can moderate spatial resolution Landsat data be used for trend detection?
- Can high spatial resolution QuickBird data be used for trend detection?
- What imagery is the optimal data to use? Is extremely fine spatial resolution worth the additional cost

Previous Approaches

Baseline data on the extent of cover for seagrass, mangrove and saltmarsh was obtained for the whole of the NSW coast in the early 1980s (West *et al.* 1985). Maps were produced from aerial photographs using the *camera lucida* technique, an analogue exercise that took at least 10 person-years to complete. The management objective was to identify the extent of these important macrophytes such that appropriate conservation controls could be implemented. While the methodology employed was a standard approach for its time, it had systemic operational errors that reduced its accuracy. These errors have been reviewed (Williams *et al.* 2003, Meehan *et al.* 2005), some of which relate to factors such as the varying age (two to five years before field checks were conducted) and scale of aerial photos that were available (from 1: 25,000 to 1: 16,000), and width of the drawing implement used to create polygons that were traced to an adjacent map sheet of scale 1: 25,000.

A second atlas of the cover of estuarine macrophytes of NSW is currently being compiled (West *et al.* in prep.). A major portion of the mapping for this new atlas was initiated via the NSW Comprehensive Coastal Assessment which concentrated on estuaries of the north and south coast (Williams *et al.* 2007). More recently, emphasis has shifted to the central coast such that trends of cover for the whole of the state can be developed. The second atlas is digitally based, with aerial photographs being geo-referenced and magnified for on-screen digitising. Even though there are inherent differences in production of the earlier and current types of map, a prioritisation scheme can be generated to differentiate estuaries in which little change has occurred from others in which change is large, or is at least suggestive to a degree of change where reanalysis might be appropriate. In some preliminary comparisons an increase in seagrass has been seen and this result is welcomed as implying that appropriate conservation techniques are in place. However, in other cases some covenants will need to be applied to any trend analysis. Firstly, for saltmarsh, the area determined in the more recent digital analysis is in many cases larger than the analogue output. This difference does not appear to be an actual increase but reflects an enhancement in method that more accurately identifies the presence of small patches of saltmarsh, particularly patches hidden under tree canopy (Kelleway *et al.* 2007). But, in relation to mangrove, because this type of plant is readily determined in the analysis of analogue as well as digital airphotos, it would appear that there has been an actual increase in area over time at some locations. Such increases have been reported previously for southeast Australia due to one or a number of causes, some of which might relate to catchment management procedures (Saintilan and Williams 1999, 2000).

Current satellite remote sensing Options and Wallis Lake studies

Beginning with the launch of Landsat1 in 1972, there has been an ever increasing array of platforms and sensors utilised to remotely sense the natural environment. Successive satellite platforms have offered progressively greater spatial resolution and archival data sources are available for retrospective analyses. Pointable sensors are available in some space platforms that can be adjusted to obtain repeated coverage of specific sites. There is now such an array of techniques that many methods can be tailored to suit monitoring needs.

A study assessing change in the subtidal habitat in Wallis Lake over a 14 year period using historical Landsat satellite multispectral imagery from 1988 - 2002 (Anstee *et al.* 2003, Dekker *et al.* 2005) proved that retrospective change analysis is possible. A key recommendation from Dekker *et al.* (2005) was to implement higher resolution imagery to see if classification accuracy could be improved. Currently, Landsat ETM+ and SPOT 4 images are not used in NSW for the purpose of mapping benthic habitats as their spatial scale is considered too coarse for accurate trend assessment. As platforms such as QuickBird and IKONOS carry sensors with increased spatial resolution (Appendix 3), there is a need to determine if the use of these sensors would improve classification accuracy. Nevertheless, other mapping projects have found the highest spatial resolution imagery available (QuickBird) may not be the best for the identification of some features (Alexandridis *et al.* 2008, Mumby and Edwards 1999). Coles *et al.* (1995) suggest that temporal and spatial scale should be specified on the basis of monitoring objectives.

The current study was conducted to build on the earlier results from Wallis Lake (Dekker *et al.* 2005) and to expand the remote sensing methodology to make use of the much higher spatial resolution offered by the QuickBird (2.6 m pixels) satellite imaging system. A second aim was to determine whether spatial resolution influences the classification. The potential use of archival remote sensing data for detection of Wallis Lake benthic cover was also investigated, and compared with recent higher spatial resolution data from the QuickBird sensor. Techniques such as atmospheric correction, field spectroradiometry and classification were to be consistently applied to the imagery, following a repeatable, objective pathway.

Fine-scale changes in small patches of aquatic macrophytes may be diagnostic of catchment-scale disturbances such as excessive erosion, sedimentation or pollution, or local issues such as bait gathering or off-road vehicle use. The breaking up of a patch of seagrass (fractionalisation), mangrove or saltmarsh is one of the first indications of environmental stress, and timely measurement of such small scale change across the many estuaries of NSW from shore-based monitoring is difficult if not impossible. Recognition of these small scale disturbances requires high resolution data, but the 30m resolution of Landsat ETM+ images is too coarse to detect such fine-scale changes on an appropriate time-scale and may result in a delay in management intervention.

Spatial resolution significantly impacts classification accuracy; specifically in terms of the location of small beds of vegetation that can not be resolved unless a high resolution imaging device is used. Coastal managers must determine whether these differences are significant to the question being asked and whether the trade-off of low cost for coarse spatial resolution imagery (with the potential of increasing the frequency of acquisition) is worth the loss in detailed change detection. Remote sensing, using the right platform, offers a cost efficient way by which to conduct this monitoring. Field studies have indicated that for seagrass (West and Williams 2008) and saltmarsh (Kelleway *et al.* 2007) the median size category of patches is between $10m^2$ and $100m^2$ and early detection of change must be able to focus at this size.

Method

To assist in the better understanding of the application of fine-scale sensors to the monitoring of estuarine macrophytes and to determine the relevant costs of such an exercise, a project was undertaken at Wallis Lake, NSW in 2008 and 2009. For a more detailed description of the methodology used in that project see Anstee *et al.* (2009).

Wallis Lake is an immature barrier estuary (Roy *et al.* 2001) located on the central coast of NSW. Extensive areas of seagrass, mangrove and saltmarsh have been mapped from aerial photographs. The area of the latter was estimated at 3,079 ha by West *et al.* (1985) and 3,320 ha by Williams *et al.* (2007). Cover of seagrass for a representative portion of the lake was determined by satellite imagery for 1988 (400ha) and 2002 (488ha) (Dekker *et al.* 2005).

The number of taxa and proximity of some of the estuarine macrophytes to each other in Wallis Lake creates a complex vegetated substrata. Thus, the lake poses a challenging target for developing a method for change detection by satellite remote sensing that could be applied to other estuarine systems.

Field data collection

A field campaign was conducted at representative sites around the Lake in May and September 2008. Field spectra and survey points (using a differential-global positioning system) of target materials were recorded. GPS depth transects and polygons (around specific features such as seagrass boundaries) were recorded over a variety of substrata to obtain a representative *in situ* dataset (Figure 1). These substrata included saltmarsh, mangrove, seagrass and bare sand. Only the results for the subtidal sites are reported here. The seagrasses identified were *Posidonia australis, Zostera capricorni, Halophila ovalis* and *Ruppia megacarpa*. Georeferenced observations were recorded on species found covering a minimum of a QuickBird pixel (2.6m x 2.6m). The *H. ovalis* occurred in insufficient densities to warrant its inclusion.

Image acquisition and –processing

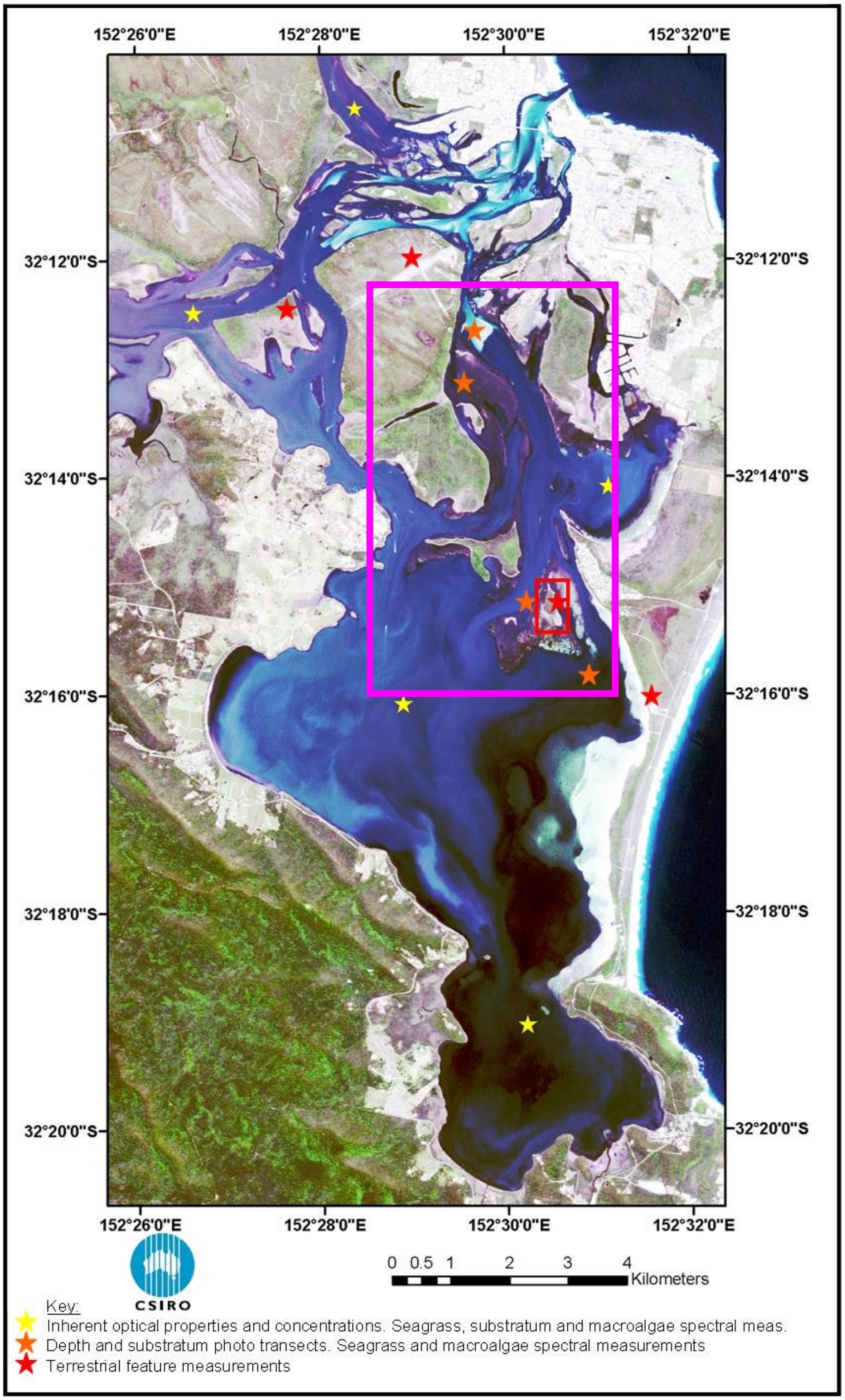
Landsat (30m pixels) and QuickBird (2.6m pixels) satellite imagery of Wallis Lake was acquired. These images spanned a period of five years between 2002 and 2008 (**Error! Reference source not found.**).

Table 1 Specifications of the satellite images selected for multitemporal and multisensor analysis in Wallis Lake's subtidal environment.

Sensor	**Date**	**Pixel resolution**	**Source**	**Comments**
Landsat ETM+	12/09/2002	30m	CSIRO image archive	Sensor striping
QuickBird	24/01/2003	2.6m	CSIRO image archive	Partial coverage
QuickBird	16/09/2008	2.6m	Specifically tasked for the project	Good quality
Landsat TM5	20/09/2008	30m	USGS image archive	Good quality

As atmospheric effects contribute significantly to the signal received by the satellite, particularly for low-reflecting targets such as water (Hadjimitsis 2009), these effects should be removed before any temporal comparisons are attempted. A standard empirical line correction (ELC) technique was used to correct the satellite data. The ELC implements a linear regression between spectral data in the scene to match selected field reflectance spectra for each (Moran *et al.* 2001). Spectral measurements of terrestrial and aquatic targets, collected during the field campaign (Figure 1), were selected for this purpose. An air/water interface correction (Brando and Dekker 2003), was applied to the atmospherically corrected data to retrieve subsurface irradiance reflectance.

Figure 1 Location of field observation sites at Wallis Lake, NSW. The pink box defines the subset used in this study.



To ensure that each pixel represents the same area in each image, it was necessary to co-register each image to a base image. The September 2008 QuickBird image was chosen for this purpose because it was the most recent high resolution image in the temporal dataset.

An area of 29.68 km^2 at the entrance of the lake (pink box in Figure 1) was chosen to be a representative area for testing multi-temporal analyses and calculating seagrass coverage. This region was covered by the three major seagrass classes *Posidonia*, *Zostera* and *Ruppia*, and the *Posidonia* beds have been extremely stable over extended periods of time (West *et al.* 1985, Laegdsgaard 2001,). This area is relatively close to the entrance, facilitating tidally-induced flushing by clear ocean water, and reducing the susceptibility to high turbidity levels by river discharge that would mask the substrata. This region also incorporated Pipers Creek and Bay, identified by the Water Quality Improvement Plan (WQIP) as the most degraded part of Wallis Lake (Great Lakes Council 2009).

Benthic Substrata Classification

After removal of atmospheric effects and applying an air/water interface correction, the subtidal regions for the target area underwent a standard spectral angle mapping (SAM) supervised classification. SAM is an automated method that permits rapid mapping of spectral similarity of image spectra to field spectra (Yuhas *et al.* 1992, Kruse *et al.* 1993, Maritorena *et al.* 1994, Dekker *et al.* 2001). Endmember spectra were extracted directly from each image as Region of Interest (ROI) average spectra, based on geo-located field observations where relatively uniform coverage of each vegetation class could be found.

Classification accuracy was assessed with standard post-classification statistical analysis tools using a validation dataset of georeferenced *in situ* observations. Changes in the vegetation classes over the medium term were determined using a standard post-classification change-detection technique.

Results

Classification results

The extent (ha) of each of the five general benthic aquatic classes is reported in Table 2. The locations of the vegetation classes are represented in Figure 2 - 5.

Table 2 Extent (reported in ha) of five aquatic substratum classes, captured on four separate dates with Landsat and QuickBird sensors, respectively.

Category	Landsat 7ETM+ (Sept. 02)	Landsat 5TM (Sept. 08)	QuickBird (Jan. 03)	QuickBird (Sept. 08)
Zostera	2.87	2.94	3.24	4.19
Posidonia	3.67	3.70	2.35	1.86
sand	1.53	3.25	1.37	2.14
Ruppia	3.17	0.68	0.61	0.84
deep water	5.90	5.19	9.48	8.27

Analysis of the classification accuracy indicated good agreement between the ground observations and the classified Landsat and QuickBird images. Thus the two September 2008 images classified more accurately (Table 3) than the 2002 or 2003 images. True validation is not possible for archival images due to the lack of concurrent field observations. QuickBird also achieved a higher accuracy due to its finer spatial scale, 2.6m compared to the 30m resolution of Landsat.

Ruppia and sand appear to be consistently misclassified in all the images except the QuickBird 2008 (Table 3). The *Ruppia* misclassification in the Landsat ETM+ 2002 image could be attributed to noise such as sensor striping or glint. The extent and temporal trend for the Landsat image pair was distorted as a result of the misclassification (Figure 6d).

Table 3 Percentage accurately classified pixels in each class, calculated for the SAM classification of benthic substratum types at Wallis Lake, mapped from the Landsat 7ETM+, Landsat 5MSS and QuickBird images.

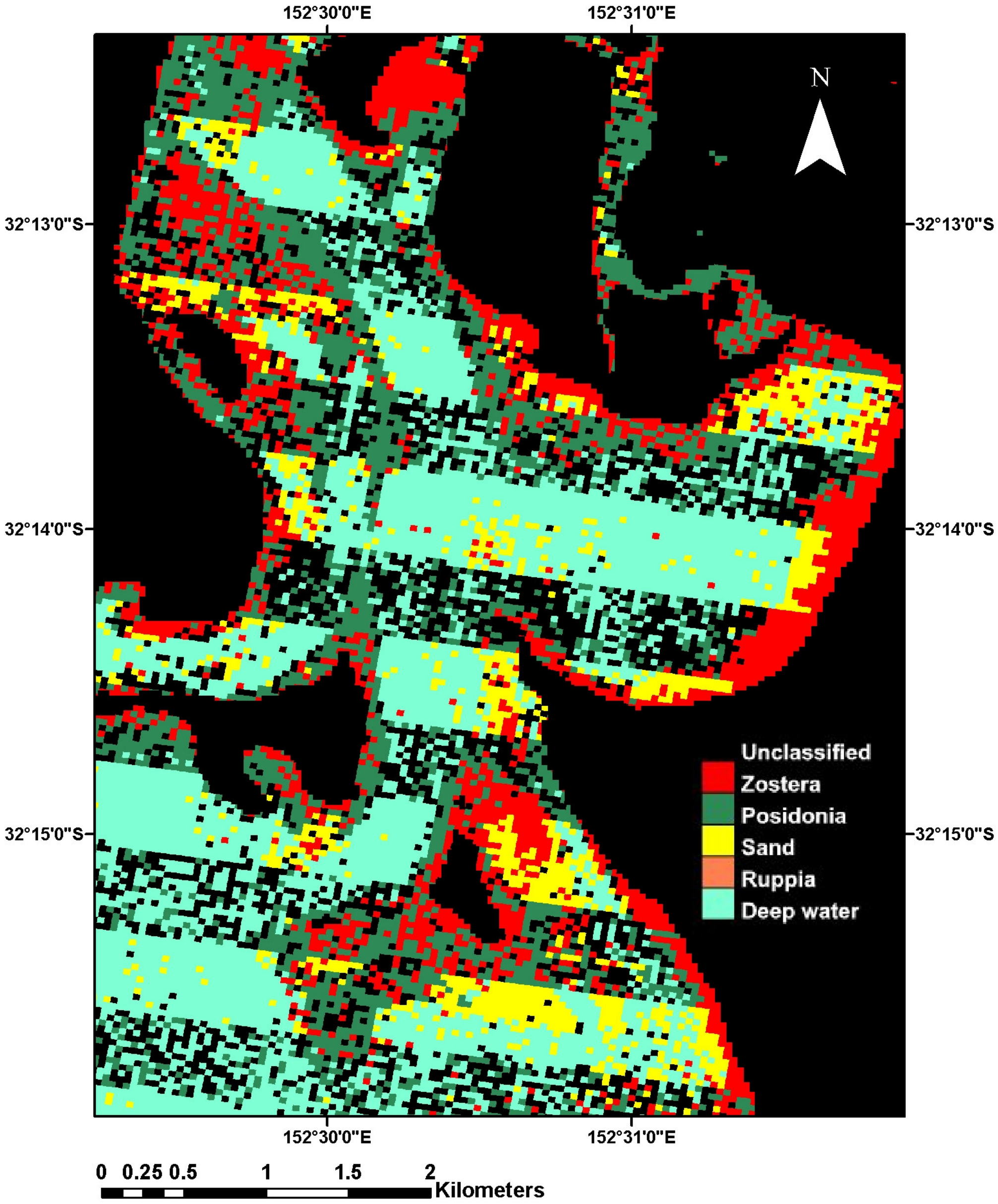
	Landsat 7ETM+ Sept. 02	**Landsat TM5 Sept. 08**	**QuickBird Jan. 03**	**QuickBird Sept. 08**
Overall Accuracy (%)	44.9%	42.5%	45.3%	71.1%
Kappa Coefficient	0.1709	0.1348	0.2401	0.5471
Zostera	50	44	63	92
Posidonia	55	43	43	62
sand	1	10	12	87
Ruppia	60	45	40	90
deep water	0	100	100	100

Change Detection

Each pair of classified Landsat and QuickBird images was compared using ENVI post-classification tools. Changes for each classification pair are presented in Figure 6. Although classification accuracy was assessed on each of the image classifications, true validation could only be estimated in the Landsat TM5 2008 and QuickBird 2008 images and therefore it is only for these images that the classification error is reported. Confusion matrices relevant to each pair are shown in Appendices 1 and 2.

Comparison of the cover of *Zostera* between the two platforms suggests there has been no loss over the study interval (Figure 6a). Two important features emerge,. Firstly, the QuickBird data indicate there is more *Zostera* present than is indicated by Landsat, and secondly, the former implies an increase in cover by 100 hectares over time. There may, however, be a seasonal trend in cover as the pair of QuickBird images were acquired in summer (January 2003) and late winter (September 2008), and Moore & Short (2006) describe the occurrence of seasonal growth optimum for *Zostera* in response to temperature variations causing a fluctuation of biomass. If such were to have been the case at the time these images were acquired then one might expect the late winter data would show cover at its minimal. Confusion matrices for *Zostera* show an increase of 0.06km^2 for the Landsat pair and an increase of 0.95km^2 for the QuickBird pair.

Figure 2 A Spectral Angle Mapper Classification of the Landsat ETM+ 12 September 2002 image. The diagonal striping is due to sensor calibration errors.



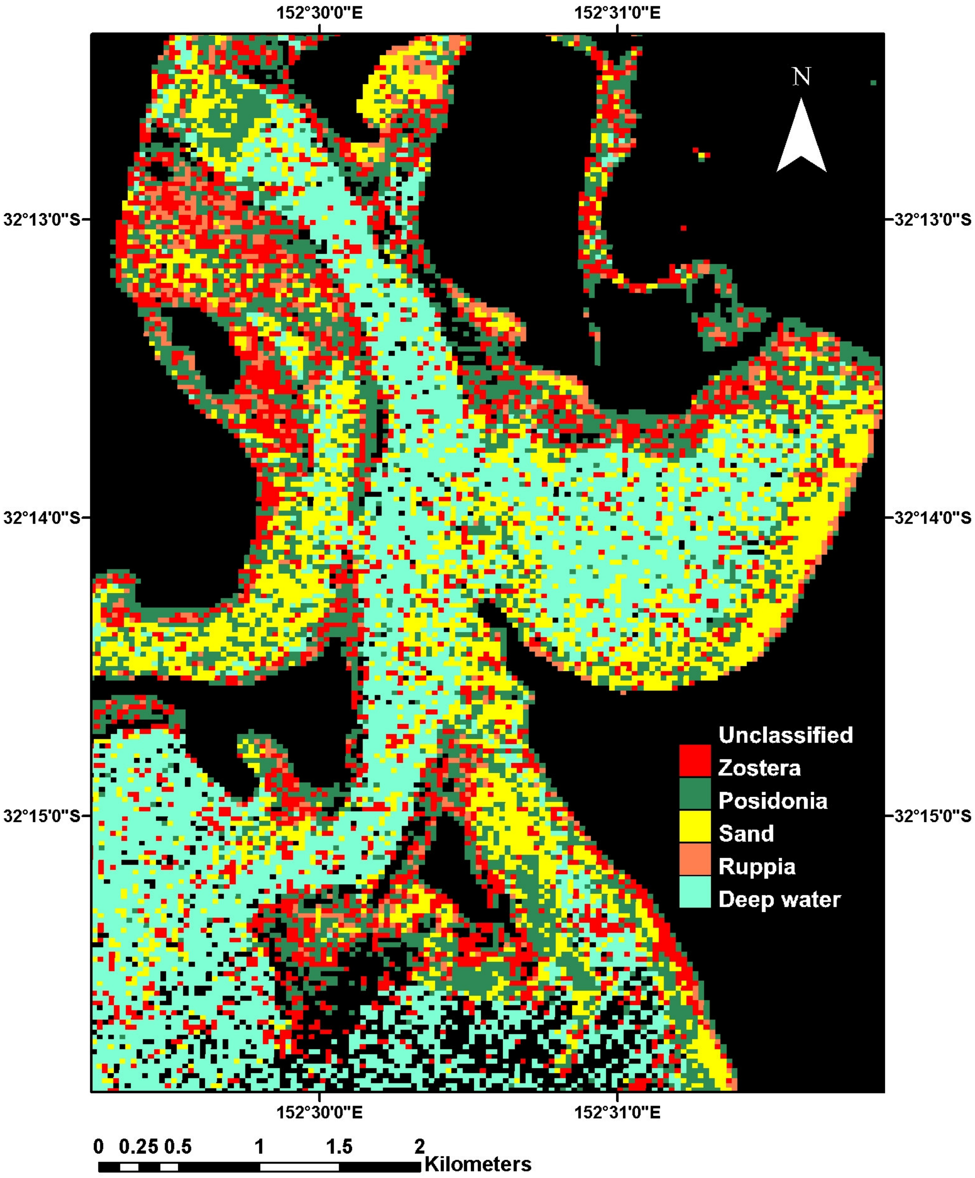


Figure 3 A Spectral Angle Mapper Classification of the Landsat TM 20 September 2008 image.

Figure 4 A Spectral Angle Mapper Classification of the Quickbird 24 January 2003 image.

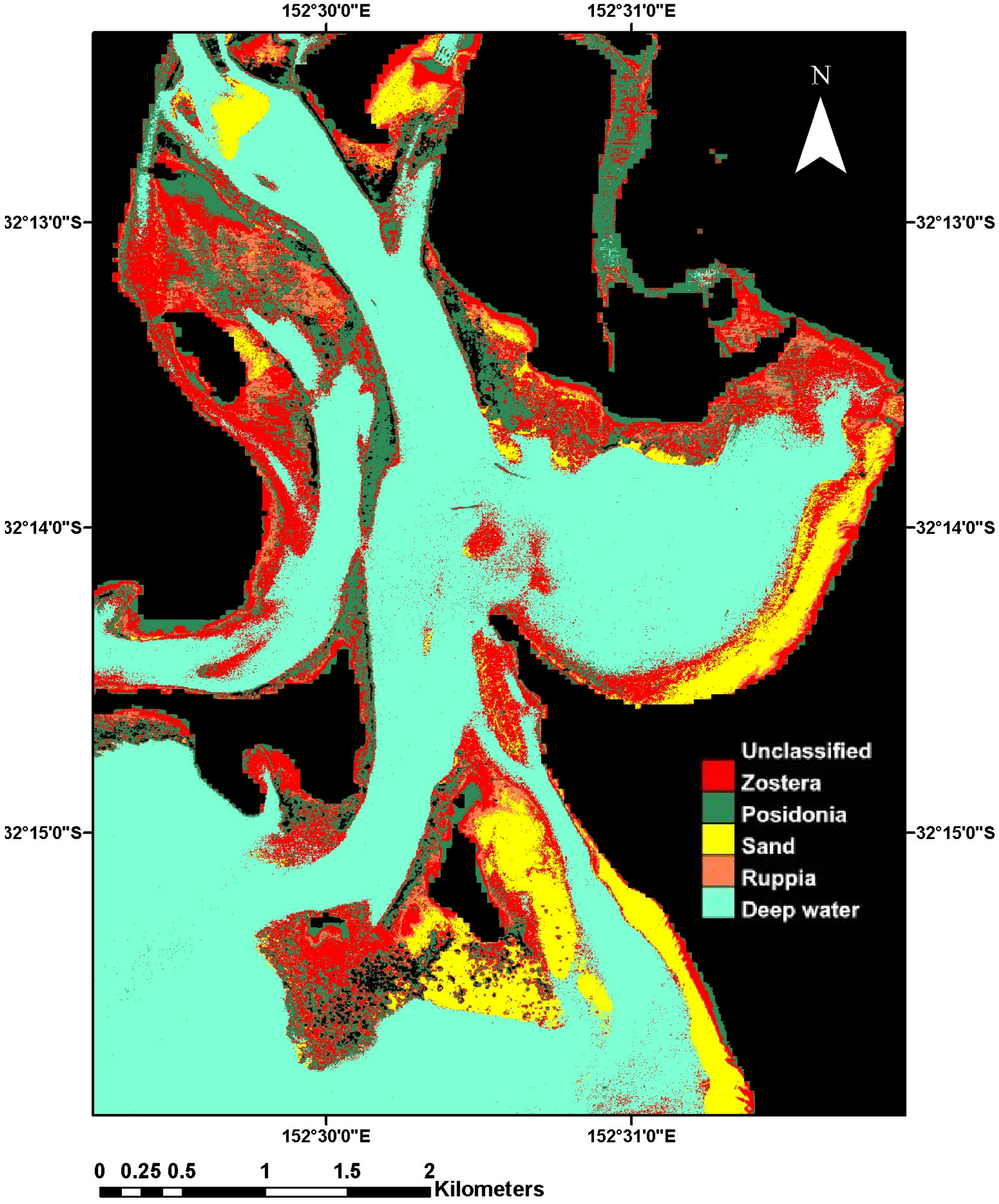


Figure 5 A Spectral Angle Mapper Classification of the QuickBird 12 September 2008 image.

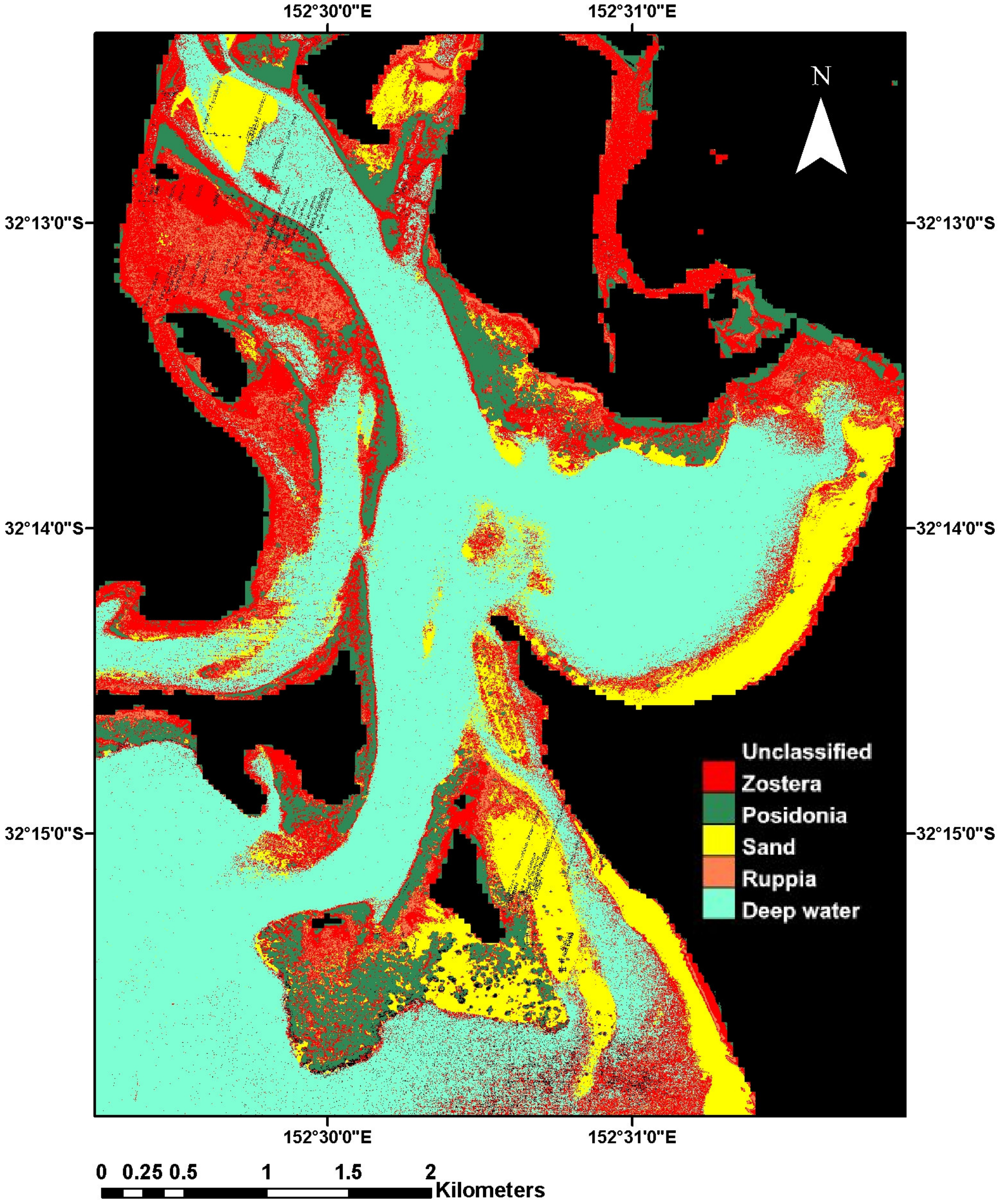
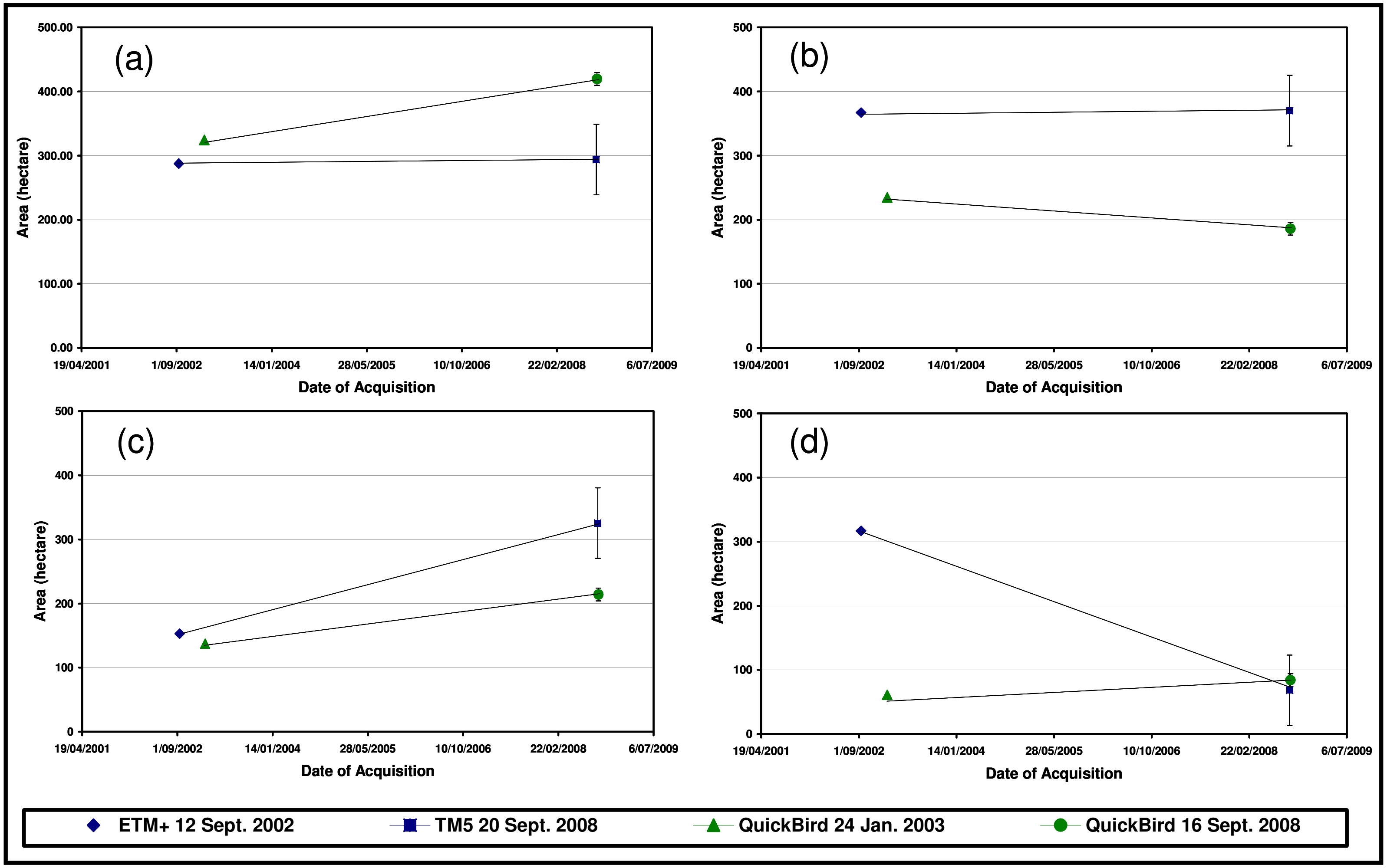


Figure 6 Trend in benthic cover of (a) *Zostera*, (b) *Posidonia*, (c) Sand and (d) *Ruppia* over a five year period detected from classified Landsat and Quickbird multispectral images. The 2008 image classifications have been validated using *in situ* field observations collected in September 2008. Lack of historical validation data allows only reporting of the 2008 classification accuracy.



A reverse response was seen in the paired images for *Posidonia*, in which a much smaller amount of this seagrass was derived from the pair of QuickBird images compared to the Landsat images (Figure 6b). Furthermore, the amount of *Posidonia* appears to fall by some tens of hectares. In the QuickBird pair, a large proportion of the *Posidonia* appears to change to a *Zostera* class (Appendix 2). This suggests either spectral confusion between *Zostera* and *Posidonia*, or genuine transition from *Posidonia* to *Zostera*, and requires additional investigations to validate. Confusion matrices for *Posidonia* show an increase of 1.72km^2 for the Landsat pair and a decrease of 0.49km^2 for the QuickBird pair. As *Posidonia* is a long-lived seagrass (4-30 years) with a long leaf lifespan (Gobert *et al.* 2006), it is thought that this difference could be derived mainly by the sensor resolution differences and the subpixel mixing of substrate spectra (mixel effect). In the Landsat pair, a large proportion of the *Posidonia* cover appears to change to a sand class (Appendix 2). As implied in the next paragraph, the low classification accuracy of the sand class (Table 3) suggests spectral confusion between sand and *Posidonia*, especially in areas where *Posidonia* density may be low causing mixel effects.

The cover of *sand*, like that of *Posidonia* appears to be over-estimated by the Landsat images, but for both pairs of images there is an increase in area over time (Figure 6c). Bright sand covered by a shallow water layer and submerged seagrass may appear spectrally similar enough to the classification algorithm to be potentially mis-classified as a vegetated substratum under some conditions, especially where there is a sparse seagrass cover present. This may explain the low classification accuracy of the sand-class in both the Landsat images and the 2003 QuickBird Image (Table 3). Due to the low classification accuracy of the sand class, significant changes in this class over time must be considered with some caution.

Ruppia (Figure 6d) is the only macrophyte for which one pair of images (Landsat) shows a decrease in cover, while the other pair suggests an increase, albeit small. Confusion matrices for *Ruppia* show a decrease of 0.71km^2 for the Landsat pair and an increase of 0.23km^2 for the QuickBird pair (Figure 6). *Ruppia* has been found to occur in a range of turbidities and salinities and is also commonly found in areas of high freshwater input (Coles *et al.*, 2003), therefore it is possible that this increase of *Ruppia* could be due to variable turbidity and salinity regimes within the lake. *Ruppia* might be more sensitive to these types of changes than the other two types of seagrass.

Discussion

While Landsat ETM+ has been applied widely for use on a range of terrestrial targets, there has been limited application to aquatic targets (Dekker *et al*. 2006). A notable exception has been estuarine habitat monitoring of seagrass change (for example, Dekker *et al*. 2003, 2005, Phinn *et al*. 2008).

The two previous estuarine macrophyte surveys of NSW (West *et al*. 1985, West *et al*. in prep) were estimated (Williams *et al*. 2003) to each take in the order of 10 person years to complete. To this cost must be added the purchase of aerial photos from which the data were extracted plus other operational requirements. A more cost-effective spatially comprehensive, standardised and objective approach must be considered to deliver monitoring results within management relevant timelines and budgets. Remote sensing, using the right platform, offers a cost efficient, alternative way by which to conduct this monitoring. Remote sensing interpretation requires comprehensive *in situ* observations for validation and classification seeding. These *in situ* observations should be spatially compatible with the remote sensing format. The Wallis Lake field campaigns were designed to integrate in-field taxonomic identification with the *in situ* measurements, enabling a robust estimation of the classification accuracy.

For macrophytes with small, fragmented patches, the finer scaled QuickBird images provided higher accuracy than the medium scaled Landsat images. For example, spectral confusion of the sand and *Posidonia* classes in the Landsat pair demonstrates the limitations of a 30m spectral resolution. As limited data (Kelleway *et al*. 2007, West and Williams 2008) suggest the median size category of macrophyte patches for NSW estuaries is between 10m^2 and 100m^2, the minimum effect size for effective monitoring may be patches of 10m in diameter.

Coastal mangers must consider the monitoring objectives when deciding on the type of remote sensing required and determine whether the trade-off of reduced costs for coarser spatial resolution imagery is worth the loss in detailed change detection. The reduction or break-up of patches of aquatic macrophytes may be diagnostic of catchment-scale disturbances, and timely recognition of small scale disturbances enables appropriate management intervention. Coarse scale monitoring can be implemented to resolve longer term disturbances on estuarine and coastal resources where the effect size is large (such as, sea-level rises and coastal erosion). Appendix 3 lists a range of remote sensing platform options, ranging in spatial, temporal and spectral resolution.

Future Options

Satellite data are priced comparatively cheaply per unit area relative to the cost for aerial acquisition, and in addition, the price of archival data is often discounted. Thus, satellite data can often provide a useful input to coastal zone mapping. The new generation of high spatial resolution, mid-spectral resolution sensors such as QuickBird, IKONOS and WorldView-2 are commercially available, or due to be launched in the near future. Pan sharpening may help resolve some of these deficiencies of the lower resolution imagery.

For data captured with advanced airborne sensors (e.g., hyperspectral data using HyMap, CASI and AISA) acquisition costs are becoming increasingly competitive with the costs of aerial photography/digital camera (ADAR) or multispectral video data (DMSI).

Spaceborne hyperspectral satellites will be launched from mid 2011 onwards and will allow more feature extraction from the satellite imagery as they are able to detect and identify more water column and macrophytes optical properties.

Inclusion of pattern recognition techniques may enhance the effectiveness of mapping estuarine macrophytes from existing multispectral satellite images, especially from high spatial resolution data (Lu & Weng 2007, Brando *et al.* 2009).

KEY POINTS

- To assist with coastal management, trend assessment of estuarine macrophyte extent is required.
- Trend assessments require forethought to maximise cost-benefit efficiency in terms of:
    - Targets (subtidal, intertidal and/or supratidal resources)
    - Effect size - fine or coarse scale

    - Frequency of data acquisition (archival or tasked; short, medium or long term).
- Standardised *in situ* observations for image classification, validation and integration with remote sensing formats are needed.
- Temporal and spatial scale should be specified on the basis of monitoring objectives.
    - Fine scaled monitoring is required for the recognition of small scale disturbances where time appropriate management intervention is required, such as loss of patches of seagrass.
    - Coarse scaled monitoring can be implemented where the effect size is large, such as coastal erosion due to sea-level changes.
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Recommendations

- A rotational scheme of data acquisition on estuarine macrophyte cover for the NSW coast should be initiated.
- Moderate resolution data such as Landsat should be used to map large scale areas of 1,000's to 10,000's km^2. Where necessary, fine scale resolution data such as QuickBird can map typically 1,000's to a few hundred km^2.
- *In situ* field observations should be augmented on an opportunistic basis.
- All future fieldwork should include the systematic gathering of georeferenced *in situ* point data (GPS) at the highest spatial detail possible and polygon data (mapping units of a systematic composition, monospecies or characteristic species complexes).
- Local expert knowledge should be employed to improve the effectiveness of a spectral library field data collection campaign.
- Future projects should assess the relevance of hyperspectral satellite data which will significantly enhance the number of environmental variables to be mapped.

Acknowledgements

Funding for this study was in part provided by the then NSW Department of Primary Industry under the NSW Monitoring Evaluation and Reporting Project. The NLWRA Audit funded the acquisition of the September 2008 QuickBird images.

The following CSIRO staff contributed to this project: Paul Daniel and Young Je Park assisted with fieldwork; Rebecca Edwards compiled the substrata spectral library; Vittorio Brando provided significant advice on the image processing; and Lesley Clementson performed the water quality analyses.

Christopher Gallen of Industry and Innovation NSW made numerous logistic arrangements and contributed to fieldwork including identification of species.

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Appendix 1 Change detection statistics report for Landsat images. The report list the initial state (Landsat 7 ETM+, September 2002) in the columns and the final state (Landsat5 MSS, September 2008) in the rows. For each initial state class, the table indicates how these pixels were classified in the final state image and the units are in km^2.

		Initial state (September 2002)						
		Zostera	***Posidonia***	**Sand**	***Ruppia***	**Deep water**	**Row total**	**Class total**
Final state (September 2008)	**unclassified**	0.18	0.08	0.27	0.58	0.45	1.55	13.91
	Zostera	0.67 (23%)	0.26 (17%)	0.48 (15%)	0.59 (10%)	0.89 (24%)	2.89	2.94
	Posidonia	0.96 (34%)	0.45 (30%)	0.54 (17%)	0.49 (8%)	1.15 (31%)	3.59	3.7
	sand	0.67 (23%)	0.48 (31%)	0.62 (20%)	1.05 (18%)	0.43 (12%)	3.25	3.25
	Ruppia	0.34 (12%)	0.05 (3%)	0.08 (3%)	0.02 (0.3%)	0.19 (5%)	0.67	0.68
	deep water	0.07 (2%)	0.21 (14%)	1.18 (37%)	3.17 (54%)	0.55 (15%)	5.18	5.19
	Class totals	2.87	1.53	3.17	5.9	3.67		
	Class changes	2.21	1.05	3.09	2.72	2.52		
	Image_difference	0.06	1.72	-2.48	-0.71	0.03		

Appendix 2 Change detection statistics report for the Quickbird images. The report list the initial state (January 2003) in the columns and the final state (September 2008) in the rows. For each initial state class, the table indicates how these pixels were classified in the final state image.

		Initial state (January 2003)						
		Zostera	***Posidonia***	**Sand**	***Ruppia***	**Deep water**	**Row total**	**Class total**
Final state (September 2008)	**unclassified**	0.01	0.02	0	0	0.1	0.14	12.38
	Zostera	1.68 (52%)	1.12 (48%)	0.13 (0.1%)	0.3 (49%)	0.92 (10%)	4.15	4.19
	Posidonia	0.47 (15%)	0.95 (45%)	0.01 (10%)	0.08 (13%)	0.01 (0.1%)	1.52	1.86
	sand	0.46 (14%)	0.02 (1%)	1.2 (87%)	0.12 (19%)	0.34 (4%)	2.14	2.14
	Ruppia	0.44 (14%)	0.18 (8%)	0.02 (2%)	0.12 (19%)	0.07 (1%)	0.84	0.84
	deep water	0.17 (5%)	0.05 (2%)	0.01 (0.4%)	0 (0%)	8.04 (85%)	8.27	8.27
	Class totals	3.24	2.35	1.37	0.61	9.48		
	Class changes	1.56	1.4	0.18	0.5	1.44		
	Image_difference	0.95	-0.49	0.77	0.23	-1.21		

Appendix 3 Pricing for data collection for macrophyte mapping.

Sensor	Vehicle	Spectral Resolution	Spectral Range	Spatial Resolution	Cost \$AUD
Hyperion	Satellite	Hyper	224 bands	30m	Free from August 2009
CASI/AISA	Aircraft	Hyper	Up to 256 bands VIS-NIR	<1m to >5m (dependent on aircraft altitude)	\$17,000-\$34,000
HYMAP	Aircraft	Hyper	126 bands VIS-SWIR	<1m to >5m (dependent on aircraft altitude)	For areas around 200km^2 : 3m \$195/ km^2 ; 5m \$180/ km^2; 10m \$170/ km^2 For areas around 500km^2: 3m \$120/ km^2 ; 5m \$100/ km^2; 10m \$80/ km^2 For areas around 1000km^2: 3m \$80/ km^2 ; 5m \$60/ km^2; 10m \$45/ km^2
GeoEye-1 (minimum order; 49km^2 archive or 100km^2 tasked)	Satellite	Medium	1 PAN 4 VNIR	0.5m PAN 1.65m MS	\$16 km^2 (archive; 0.5m pan or 1.65m MS) \$32 km^2 (tasked; 0.5m pan or 1.65m MS)
IKONOS (minimum order 100km^2)	Satellite	Medium	1 PAN 4 VNIR	0.82m PAN 3.28m MS	\$13 km2 (archive 4m MS) \$23 km^2 (tasked 4m MS) \$25 km^2 (tasked PAN-sharpened MS) \$32 km^2 (tasked 1m pan + 4m MS)
QuickBird (minimum order 25km^2)	Satellite	Medium	1 PAN 4 VNIR	0.6m PAN 2.6m MS	\$20 km^2 (archive 2.6m MS) \$28 km^2 (tasked 2.6m MS) \$22-35 km^2 (PAN-sharpened MS)
ALOS AVNIR	Satellite	Medium	1 PAN 4 VNIR	10m MS	\$440 per scene
Landsat ETM+ Landsat TM5	Satellite	Medium	8 bands (4 VNIR, 2 SWIR + 1 TIR)	25m MS 15m PAN	Free from USGS
Spot 5	Satellite	Medium	1 Pan 3 VNIR 1 SWIR	2.5/5m. 10m VNIR 20m SWIR	\$3,300 standard tasked 10m colour (1/8 scene) Up to \$6,300 orthorectified tasked 2.5m colour (7’30x7’30 map frame) [Costs subject to change due to new receiving station in Australia]
Analogue camera	Aircraft	Low	Black and white (1930s to 1970s)	2m	\$1,000: (\$50 per first run photo and \$35 for subsequent photos)
Analogue camera	Aircraft	Low	Colour (1970s to 1990s)	2m	\$1,000: (\$50 per first run photo and \$35 for subsequent photos) Archival data from Geoscience Australia

Appendix 3 (continued)

Sensor	Vehicle	Spectral Resolution	Spectral Range	Spatial Resolution	Cost $AUD
Digital camera	Aircraft	Low	Colour (2000s to present)	variable	Various photomapping services operating in Australia with various prices but archival data available, for example: QLD Environment and Resource Management 300 DPI covering a 1:100,000 map sheet $135.30
Digital Multi-Spectral Imager DMSI	Aircraft (light single or large twin)	Medium Spectral band width 10-25nm	4VNIR	0.5-2m	For areas around 5,000ha: 0.5m $7/ha; 1.0m $3/ha For areas around 100,000ha: 0.5m $1.25/ha; 1.0m $0.50/ha Based on the assumption that site is in reasonable proximity to a suitable airport. Additional cost may include ferrying, overnight accommodation or standby rates for inclement weather.

Note: Bulk purchase discounts are available from most resellers; discounts of up to 50% have been offered previously for bulk archival imagery. DSMI prices include processing through to georeferenced digital mosaics.

CSIRO has made every effort to ensure the accuracy and currency of the costs of data acquisition from data providers as at the date of this report. The costs of data acquisition are subject to change without notice. Before relying on the data acquisition costs provided, users should independently verify the currency of the costs with the data provider. CSIRO and the data provider exclude all liability to any person arising directly or indirectly from any variations in data acquisition costs from those documented in this report.

Updated DMSI, GeoEye-1, ALOS AVNIR, IKONOS & QuickBird prices, based on 1AU = 0.8US (exchange rate as of 16 June 09).
PAN = panchromatic, MS= multispectral