# An Integrated Field and Remote Sensing Approach for Mapping Seagrass Cover, Moreton Bay, Australia

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*Creating accurate maps of seagrass cover is a challenging procedure in coastal waters with variable water clarity and depths. This paper presents an approach for mapping seagrass cover from data sources commonly collected by natural resource management agencies responsible for coastal environments. The aim of the study was to develop an approach for mapping classes of seagrass cover from field and/or image data for an area with variable water clarity and depths. The study was carried out in Moreton Bay in eastern Australia. A Landsat 5 Thematic Mapper satellite image was acquired for the same area in August 2004. The image data were used to map seagrass cover in the exposed inter-tidal and clear shallow water areas to depths of 3 m. Field survey data were collected, in July – August 2004, to map deep (> 3 m) and turbid sub-tidal areas, using: real time video, snorkeller observations and transect surveys . The resulting maps were combined into a single layer of polygons, with the same seagrass cover classes used as existing mapping programs and with each polygon assigned to one of five cover classes (0 %, 1-25 %, 25-50 %, 50-75 %, 75-100 %). As independent field data were not available for accuracy assessment, a reliability assessment indicated that > 75 percent of the Bay was mapped with high categorical reliability. Most previously published seagrass mapping projects covered areas < 400 km$^2$, were based on single data sets, and lacked assessment of accuracy or reliability. Our approach and methods address this gap and present guidelines for a generally applicable method to integrate image and field data sets over large areas (> 1000 km$^2$) commonly used for monitoring and management..*

**Keywords:** Seagrass cover, Landsat Thematic Mapper, benthic surveys, integrated field-image mapping, Australia.

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# INTRODUCTION

Seagrass meadows in Moreton Bay, Queensland, perform critical ecological functions. They support local fisheries by providing nursery and juvenile habitat, stabilise sediment and provide a direct food source for dugongs and green turtles. These environments are under increasing direct and indirect stress associated with coastal developments and use of marine and coastal resources (Waycott *et al.*, 2004). The seagrass beds in Moreton Bay are significantly affected by the quality of water being delivered to the western Bay by several large river systems that drain the rapidly developing south-east Queensland region (Dennison and Abal, 1999). Understanding the extent and condition of these seagrass beds and how they change over time is essential for their management and sustained use (Dennison and Abal, 1999; Short and Coles, 2004; Waycott *et al.*, 2004). Regularly updated and accurate information on the percentage cover, species composition and biomass of seagrasses is an essential component of the knowledge required to monitor, understand and manage this resource. In this paper a method for combining complimentary sources of spatial information to map seagrass cover across the range of water clarities found in coastal embayments around the world is presented. Seagrass cover is referred to as the horizontally projected foliage cover of the seagrass canopy, which is recognised as a key information requirement for seagrass monitoring (McKenzie *et al.*, 2001). Over the years, a number of approaches have been applied to produce maps of the seagrass beds of Moreton Bay for a range of scientific and management purposes. With the exception of Hyland *et al.* (1989), none of these past works covers the entire Bay, nor do they provide an approach able to be replicated, or data that can be validated and shared by management agencies using commonly available hardware and software. Each past approach is summarised in Table 1.

An approach was developed in direct response to: (1) the need for an up-to date map of seagrass cover for Moreton Bay by its management agencies; and (2) limitations of past published works on seagrass mapping, in terms of limited areal coverage, limited applicability to variable depths and water clarities, and absence of accuracy or reliability assessment. This paper outlines the spatial information required for management of seagrass in Moreton Bay first, and then describes and applies an approach to integrate field and image data from different management agencies, to produce a uniform map of seagrass cover.

With the exception of Hyland *et al.* (1989) and Dennison *et al.* (1999), previous approaches for mapping benthic cover in Moreton Bay, including seagrass, have focused on limited areas. All approaches created polygons by interpolating and/or extrapolating field survey data. Only Zharikov *et al.* (2005) used a spatially extensive approach by manually digitising boundaries of seagrass cover classes, however this was limited to a small section in the eastern part of the Bay. None of the published papers provides data collection and mapping methods which could be applied to the range of water depths and clarities found across the whole Bay, on a repeated basis, and which could be validated against reference data.

It is now possible to obtain moderate to high spatial resolution satellite and airborne image data on a regular basis, and to collect georeferenced benthic cover information in a semi-automated manner. Hence, the combination of these data collection techniques with image-based mapping and spatial analysis approaches should allow mapping of seagrass cover in optically shallow and exposed inter-tidal areas from image data, and in optically deep and/or turbid intertidal areas from field survey. Although this combination of techniques has been proposed for a range of benthic cover applications, there is limited description and assessment of such programs in peer-reviewed literature, making it difficult to assess and implement for management agencies.

Mapping of seagrass properties from remote sensing and/or field data has been conducted in other tropical, sub-tropical and temperate environments. The papers listed in Table 2 represent peer-reviewed literature, and there may be other publications in the non-peer reviewed literature dealing with this subject. The scientific quality of non-reviewed literature,

| Author, Date | Mapped seagrass property and data format (point, raster or vector type) | Extent of Moreton Bay covered by the map | Mapping method(s) used |
|---|---|---|---|
| Welsby, 1905 | Presence (vector) | Inter-tidal zone | Described and drawn on map using unknown approach |
| Young and Kirkman, 1975 | Species - Five categories where each is a combination of different seagrass species. (vector) | Inter-tidal zone | Visual assessment of seagrass meadows in littoral areas from a boat survey, with extent being estimated by aerial surveys |
| Hyland *et al.*, 1989 | Cover and Species: Four categories (patchy, sparse, light, dense). (vector) Species assigned to the polygons. | Inter-tidal and sub-tidal down to 10 m. Excluding the central bay. | Transect surveys and spot check points. Transects (0.5 - 2 km in length) were located perpendicular to the shoreline and spaced at 2 km intervals. Sampling along transect at 50 - 500 m interval. Areas were delineated based on field data and bathymetry. |
| Dennison and Abal, 1999 | Cover and Species: 10 categories (0,1-10, 10-20,20-30,...,90-100%) (vector) and species (point). | Inter-tidal and sub-tidal up to 10 m. Excluding the central bay | Recorded benthic/substrate type and seagrass species in Moreton Bay along 20 m dive/snorkel transects at 1575 sample sites. Boundaries were interpolated and guided by the 2m depth contour and the coastline. |
| Stevens and Connolly, 2005 | Cover Type: Nine categories of which one is "Seagrass dominated" (point) | 53 sites in deeper central bay | A towed underwater video surveyed 500 m of substrate at each site, with sites spaced 5 km apart. Each site was assigned a cover type. |
| Zharikov *et al.*, 2005 | Cover: Eight intertidal categories of which three were seagrass ">80%", "50-80%" and "5-49%" (Vector) | Inter-tidal Western / Southern coastal perimeter, Excludes the Eastern Banks and west of Moreton Island | The map was based on visual interpretation of colour aerial photography resampled to 2.5 m pixel resolution. Using these photographs, boundaries of benthic cover habitats in the inter-tidal zone were manually digitised |

**Table 1.** *Published seagrass mapping studies for Moreton Bay from 1905-2005*

| Area | Method | Presence/ Absence | Cover | Species | Biomass | Reference |
|---|---|---|---|---|---|---|
| < 360 $km^2$ | Acoustic | | | Y | | Komatsu *et al.*, 2003; Pasqualini *et al.*, 2000 |
| | | Y | | | | Riegl *et al.*, 2005; Jordan *et al.*, 2005 |
| | Aerial photo with field data | Y | | | | Cuevas-Jimenez and Ardisson, 2002; Kendrick *et al.*, 2002; Benton and Newman, 1976 |
| | | | | Y | | Holmes *et al.*, 2007; Murdoch *et al.* 2007 |
| | | | y | | | Lathrop *et al.*, 2006; Orth *et al.* 2006 |
| | Image | | y | | | Habeeb *et al.*, 2007; Dierssen *et al.*, 2003; Call *et al.*, 2003; Mishra *et al.*, 2006; Maeder *et al.*, 2002; Ackleson and Klemas, 1987; Chauvaud *et al.*, 1998; Andrefouet *et al.*, 2002; Bouvet *et al.*, 2003; Chauvaud *et al.*, 2001; Lennon and Luck, 1990 |
| | | | | | y | Armstrong, 1993 |
| | | Y | | | | Gullstrom *et al.*, 2006; Vanderstraete *et al.*, 2006; Purkis and Riegl, 2005 |
| | | | | Y | | Pasqualini *et al.*, 2005 |
| | | | y | Y | | Dekker *et al.*, 2006 |
| | | | y | Y | y | Mumby *et al.*, 2002; Phinn *et al.* 2007 |
| | Image/acoustic | Y | | Y | | Fornes *et al.*, 2006 |
| 360- 1250 $km^2$ | no peer-reviewed publications able to be located | | | | | |
| 1250 $km^2$ | Image | | y | | y | Schweizer *et al.*, 2005 |
| 1500 $km^2$ | Image and field | | y | | | This study |
| >1000 $km^2$ | Aerial photo with field data | | y | Y | | Meehan *et al.*, 2005 |
| 18310 $km^2$ | Aerial photo with field data | | y | Y | | Moore *et al.*, 2000 |

**Table 2.** *Published papers on mapping seagrass characteristics (presence, percent cover, species composition and biomass) using field or remote sensing approaches.*

such as government reports, cannot be assured and they are difficult to locate, and are not reliable for building operational mapping and monitoring programs. Considering the scope of the mapping activities presented in Table 2, and reviews of seagrass mapping (McKenzie *et al.*, 2001; Dekker *et al.*, 2006), it was evident that most previous seagrass mapping from remote sensing data has been conducted over small areas (< 360 $km^2$); and has not integrated field survey based maps and image based maps.

As seagrass distribution in coastal environments occurs over a range of water depths and clarities (Larkum *et al.*, 2006), if they are to be inventoried and then monitored over time there is a need for accurate and reliable mapping techniques to work over this range of conditions. The papers presented in Table 2 map seagrass over relatively small areas, with limited variations in water depth and clarity, and retain one data type and technique to complete the mapping. Most seagrass mapping and monitoring programs for local, state and national scale mapping requirements need mapping approaches that are able to be implemented over large areas, on a repeated basis, using readily available personnel, data, hardware and software. In addition, they may have to perform accuracy and reliability assessments using limited or sub-optimal data sets. An assessment of the published papers in Table 2 indicates that most approaches do not meet the criteria for mapping and monitoring programs. To address the need for a revised map of Moreton Bay's seagrass cover, this research builds an approach to address the limitations of previously applied methods listed in Table 2. The approach used is a collaborative, multi-agency data collection and mapping effort to produce a Bay-wide map of seagrass cover. In 2004 a collaborative mapping program was initiated by the Ecosystem Health Monitoring Program of the Queensland Environmental Protection Agency (EPA) and the Centre for Remote Sensing and Spatial Information Science at the University of Queensland with support from the Cooperative Research Centre for Coastal Zone, Estuary and Waterways Management. The EPA and the University of Queensland coordinated field surveys, image processing and data collation with Moreton Bay Marine Park, the Port of Brisbane Corporation and Seagrass-Watch staff. This paper presents the field and satellite image data collection and processing techniques, followed by the mapping and reliability assessment procedures used to create and validate a single map of seagrass cover for Moreton Bay, Australia.

## DATA AND METHODOLOGY

### Study Site

Moreton Bay (27°15′ S, 153°15′ E, 1 582 $km^2$) is a partially enclosed, relatively shallow embayment, bounded to the east by several large sand islands and receiving input from five large rivers on the western side (Figure 1). Maximum water depth within the Bay is approximately 30 m in shipping channels, with most of the Bay being less than 12 m deep. The area has a semi-diurnal tidal range of about 1.7 m (Dennison *et al., 2004).*

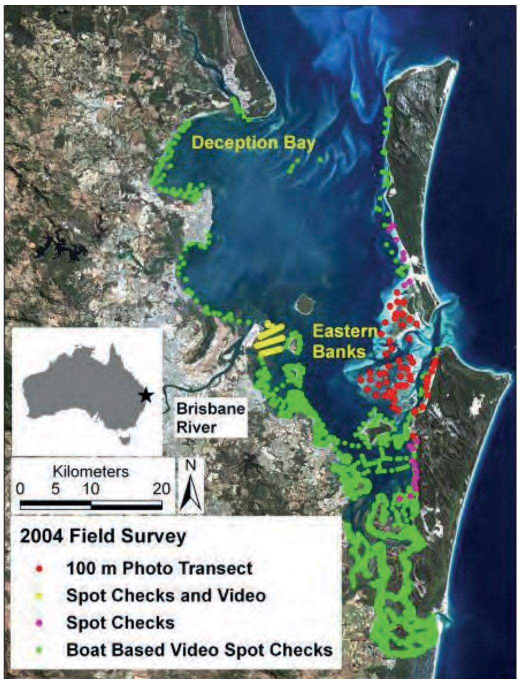


**Figure 1.** *Landsat 5 Thematic Mapper subset acquired on the 8th August 2004 of Moreton Bay, South East Queensland, Australia with the field study sites used for calibration and validation for seagrass cover maps.*

As a result of wind generated re-suspension of sediment, riverine inflows and tidal in-flows, spatial and temporal variations of water clarity throughout the Bay are highly dynamic, changing on time-scales of hours to days (Dennison and Abal, 1999). This optically complex environment contains approximately 190 km$^2$ of inter-and sub-tidal seagrass beds (Dennison and Abal, 1999). The seagrass species found in the Bay include, *Halophila ovalis, H. decipiens, H. spinulosa, Halodule uninervis, Zostera muelleri (previously Zostera capricorni) (Waycott et al., 2004), Cymodocea serrulata and Syringodium isoetifolium.* Canopy heights of these seagrasses reach a maximum of ~0.5 m in the shallows of the western and southern areas of the Bay, with an average of 0.07 m across the entire Bay. The most extensive seagrass beds occur in the clear, tidally flushed areas of the Eastern Banks (Dennison and Abal, 1999; Dennison *et al.*, 2004). In terms of water clarity, Secchi depth varies from 0.1 m in the turbid waters of the western Bay, to 15 m in the clearer waters of the eastern Bay. The winter months of June to August produce the clearest waters, due to lower rainfall riverine input and less frequent strong winds (EHMP, 2006).

## Mapping Overview

The mapping approach developed and applied for this project integrated field and image data sets to produce a map showing the extent and

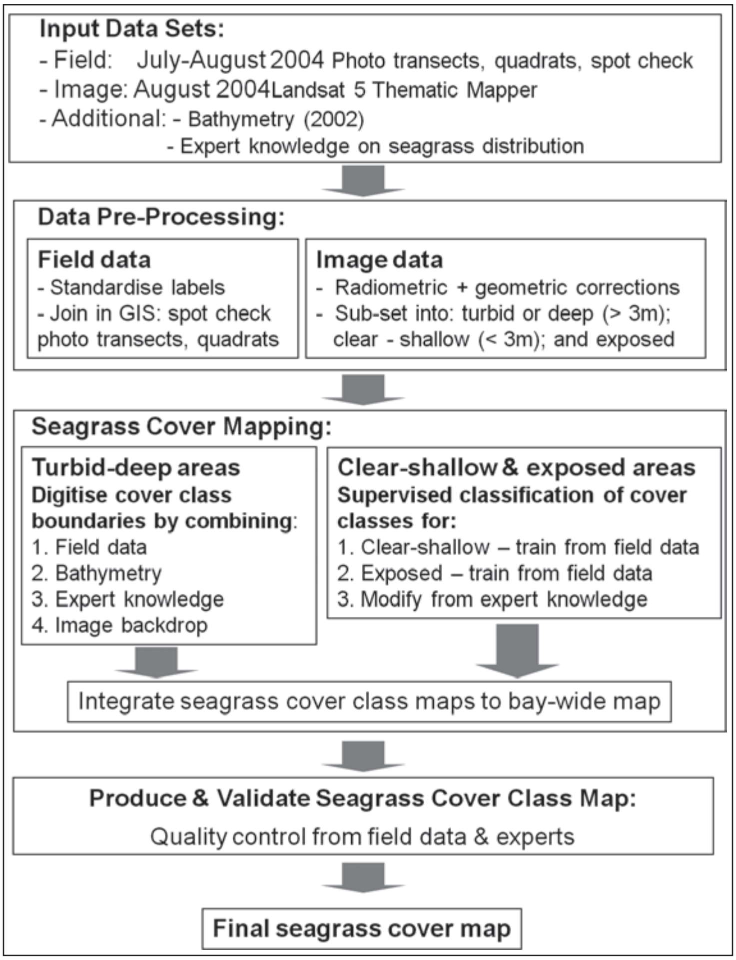


**Figure 2.** *The approach used to integrate field and image data to map seagrass cover through a combination of manual digitising of seagrass cover level boundaries and supervised classification of the Landsat 5 TM image. Both the digitising and classification were guided by a variety of input data sets, including field survey, bathymetry, satellite imagery and expert knowledge.*

percentage cover of inter-tidal and sub-tidal seagrass in Moreton Bay (Figure 2). The only area not covered by field or image data was in the northern central part of the Bay, where it is considered too deep and turbid for seagrass beds (Hyland *et al.,* 1989). The area mapped is significantly larger than any of the previous seagrass maps of Moreton Bay. Image based mapping, using a Landsat 5 TM (Thematic Mapper) image and a selection of field survey data, was applied to the exposed inter-tidal areas and the clear shallow areas of the Eastern Banks, Fisherman's Island, northern Deception Bay and parts of the southern Bay. Mapping based on manual interpolation of point sampled field survey of seagrass cover was applied to the turbid and deep water areas (Figure 2). This process was guided by bathymetric data and the Landsat 5 TM image. The resulting maps from the image based and field data based mapping procedures were combined into a single final map of polygons representing five seagrass cover classes.

## Input Data - Field

Field data were gathered through spot checks, quadrats and photo transect surveys between July and September 2004. Survey sites were selected using a March 23, 2001 Landsat 7 Enhanced Thematic Mapper image of Moreton Bay, previous survey sites, seagrass cover maps (Hyland *et al.,* 1989) and bathymetric data. Survey sites were chosen to represent locations which: (1) had a history of continual seagrass cover; (2) had a potential for seagrass cover (suitable depth and water clarity); and (3) were evenly distributed across the Bay. Site coordinates were recorded in the field with a 12 channel handheld GPS receiver.

**Spot Check Surveys**. Spot check surveys using a drop video camera or snorkelers were conducted in turbid or deep ( > 3 m) waters, where the seabed was not visible from the surface. The spot checks marked the outside or deeper edge of the seagrass meadow at a particular location and then obtained data on seagrass from one or more points inside the meadow on a transect perpendicular to the shoreline. This provided information on the seagrass composition and location of the meadow's edge and the composition of the meadow itself.

The drop video camera was lowered over the side of a survey vessel to relay images to a monitor on board. Real time interpretations of benthic species and percent cover data were entered directly into a purpose-built program in Labview® (National Instruments) via a touch screen laptop computer. With a GPS unit connected to the computer, the program simultaneously georeferenced the benthic habitat information for a survey point, allowing the data to be downloaded directly into a geographic information system (GIS) database. On survey vessels not equipped with this equipment; an observer would snorkel over the benthos for a distance of approximately 10 m and record species composition, cover and location. The seagrass cover class levels used were: *none, sparse, medium, medium-dense* and *dense*. The combined video and snorkel data were stored in a Microsoft Excel spreadsheet and imported into a GIS environment (ESRI ArcView 3.3) and checked for any spatial and attribute errors.

**Quadrat Surveys.** Quadrat surveys were conducted at 50 Seagrass-Watch sites across the Bay (www.seagrasswatch.org/moreton_bay.html) using the Seagrass-Watch monitoring protocols (McKenzie *et al.*, 2001). At each site, within a 50 m x 50 m area, three transects were placed parallel to each other and 25 m apart. Along each transect eleven 0.5 m x 0.5 m quadrats were surveyed for species composition, substrate type and percentage cover. The Seagrass-Watch data were used to verify the mapping results.

**100m Photo Transects.** Detailed information was gathered in the clear shallow waters of the Eastern Banks region of Moreton Bay using a repeatable and fine scale technique for surveying benthic cover (Roelfsema *et al.*, 2004). A 100 m transect tape was deployed at each site on the benthos down to a maximum depth of 3.0 m. A snorkeller followed the transect tape and took a photograph of the benthos every 2.0 m. Using a plumb-line fixed to the camera, photographs were taken at 0.5 m directly above the bottom using a Sony Cybershot digital camera in a marine-pack housing with a 16 mm wide-angle lens. The transects were placed to ensure they traversed gradients or edge features to ensure that a change would be detected in species or percent cover. The location of the snorkeller along the transect was logged every five seconds by a handheld Garmin 72 GPS, floating in a dry-bag as close as possible to the snorkeller. Each photograph was analysed by overlaying 24 random points. At each point, the cover type (e.g. seagrass species, algae species, sand, mud) was determined and later stored in a Microsoft Access database; this was then used to automatically calculate seagrass percentage cover as described in previous work (Joyce *et al.*, 2002; Roelfsema *et al.*, 2004). Photograph attributes were then linked to the coordinates of each photograph and imported into the GIS.

## Input Data - Satellite Image Collection and Correction

A cloud free Landsat 5 Thematic Mapper scene was acquired at 9:40 am, 15 minutes after low tide at Brisbane Bar, on the 8th August 2004, and pre-processed for use in the mapping process. Radiometric corrections involved transformation of pixel digital number values to remote sensing reflectance values using the method outlined in Brando and Dekker (2003). These corrections reduced atmospheric and air-water interface attenuation effects, both of which significantly reduce the signal from benthic features. The corrected image maximised the radiance signal leaving the water, which contains information about water depth, water column constituents and the reflectance properties of substrate cover types (Brando and Dekker, 2003). Geometric corrections were based on the image provider's approaches and no further georeferencing was conducted as more detailed ground control was not available. The image provider (Geoimage Pty Ltd, Brisbane) delivered a *map oriented* product based on geometric corrections to a 1:50 000 topographic base map for the area. A subset of the 2004 image containing only submerged features and the exposed inter-tidal areas was created by masking out land areas above the high tide limit. The land mask was created based on the extent of water bodies defined from a spring high tide NIR (near-infrared) band image of Moreton Bay acquired in March 2001 (Phinn *et al.*, 2005). The NIR band of the 2004 image subset was then used to further divide this subset into submerged and exposed areas.

## Field and Image Data Pre-Processing

**Joining the field data sets.** As each of the management agencies involved in the field survey used slightly different seagrass cover survey protocols, a procedure was applied to standardise the seagrass cover classes recorded and analysed. The three seagrass cover class labelling schemes were: (1) n*one, sparse, medium, medium-dense* and *dense*, (2) *none, sparse, moderate* and *dense* and (3) *percentage cover* (number between 0 and 100). The normalised seagrass cover class labels selected were: 0 %, 1-25 %, 25-50 %, 50-75 % and 75-100 % seagrass cover. These labels complied with the categories used by the local agencies (Queensland Environmental Protection Agency) in their field surveys (Dennison and Abal 1999). An algae class was added, due to extensive algal cover on the northern Eastern Banks. After translating the existing class levels to the revised seagrass cover class labels, the data sets were joined so that they could be used as one for mapping or calibrating the satellite imagery.

Sub-division for image or field based mapping. To use the field and image data sources most effectively, the survey sites were divided into areas which could be mapped using an image based approach (for clear shallow waters and exposed areas), and manual interpolation of field data where only field data was available (turbid and/or deeper waters). The image subset containing inter-tidal and sub-tidal areas was subdivided into exposed inter-tidal, clear shallow and deep turbid areas. From the land masked image, the exposed inter-tidal areas were derived, by filtering out the areas covered by water using the NIR band characteristics which do not penetrate the water. The mask to separate shallow clear waters was developed by digitising a boundary around areas on the corrected image where the bottom was visible, with some guidance being provided by bathymetric contours. This approach was used as opposed to an image based threshold due to large variation in water clarity throughout the Bay. The remaining areas were considered *deep-turbid* as benthic features could not be seen in the image due to water depth or turbidity.

## Seagrass Cover Mapping

**Turbid and deep areas – mapping based on field data interpretation.** For the *deep-turbid* areas the georeferenced seagrass cover point data obtained from spot check surveys was displayed in a GIS environment on top of the corrected true-colour Landsat 5 TM image from 8 August 2004, and a bathymetry data set. Polygons for specific seagrass cover levels were produced by manually digitising boundaries around these points, visually interpolating and extrapolating boundaries. Polygon boundaries were also determined from the spot-check data points in relation to bathymetric contour lines positioned on the Landsat 5 TM satellite imagery. The benthos were not surveyed in areas > 10m due to the depth limits of the field approaches used and the very sparse cover levels previously observed at these depths (Waycott *et al*., 2004).

**Exposed and shallow clear areas – mapping based on image classification.** Previous field-survey and modelling work by the authors has shown that airborne and satellite image based mapping can only accurately map variations in benthic cover properties within waters shallower than 3.0m on the Eastern Banks of Moreton Bay (Phinn *et al.*, 2005; Roelfsema *et al*., 2006). Past approaches were used as a basis for this project and represent a combination of supervised and un-supervised image classification techniques (Jensen, 1996). For the exposed and shallow clear water areas, the georeferenced spot check, quadrat and transect data were used to determine training sites for five levels of seagrass cover classes (0 %, 1-25 %, 25-50 %, 50-75 % and 75-100 %) in the supervised image classification process. Reflectance signatures for each of the five different seagrass cover classes were extracted from the Landsat 5 Thematic Mapper scene of Moreton Bay for the calibration field sites, which served as training sites for the image classification process. Characteristic *spectral reflectance signatures* were defined for each of the target levels of seagrass cover to be mapped, in clear-shallow areas or inter-tidal areas. The image subsets of exposed and shallow-clear waters were then subjected to a minimum distance to means classification algorithm to group pixels with similar spectral reflectance signatures. The minimum distance to means algorithm was used for classification based on the authors' past experience in mapping seagrass cover classes from multi-spectral images, as most of the classes were

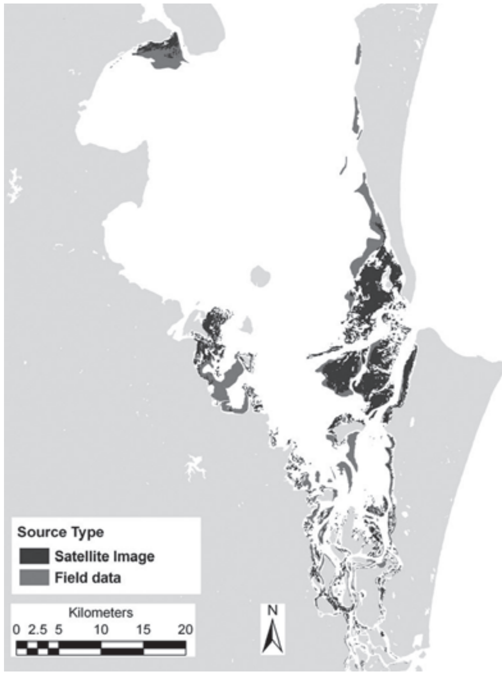


**Figure 3.** *Areas of Moreton Bay included in the seagrass map and the data sources used to derive the maps.*

uni-modal and did not exhibit a large range if variation in reflectance in the visible bands was used (Phinn *et al.*, in Press). This process enabled each pixel to be assigned to one seagrass cover class.

Once a seagrass cover map had been produced for each *deep-turbid, shallow-clear and exposed area,* a pseudo-accuracy, or reliability assessment was performed to quantify the level of agreement between the seagrass cover classes mapped from the image classification and the field survey data used to train the image classification process. A true reference set would have used independently selected sites where seagrass cover had been measured and not used to train the image classification process. Overall, adjusted and individual class accuracies were calculated for the image based seagrass cover map (Congalton and Green, 1999).

**Production and validation of Bay-wide seagrass cover class map.** The seagrass cover class polygons resulting from the field and image classification approaches were combined using ESRI's ArcView 3.3 to create a single map layer covering Moreton Bay. The union command was used to join polygon data sets. Where there was an overlap between field and image data polygons a choice was made to keep or delete each polygon based on the accuracy of the field or image data at that area. To reduce the amount of polygons with dimensions of one Landsat 5 TM pixel, the dissolve option was applied.

Three levels of reliability, similar to those proposed by Pasqualini *et al*. (1997): *high, medium* or *low*, were assigned to represent the positional and attribute reliability of each individual seagrass cover polygon. Table 3 explains the sources of reference information used to estimate the level of reliability for each polygon. The reliability levels were based on subjective assessments of the quality of spatial information used to derive the location and seagrass cover level for each polygon. Although this was neither an ideal or quantitative approach compared to the process commonly used for assessing map accuracy, it did enable a measure of reliability to be provided for users to decide which areas of the map to trust, or to decide where more work was required in future. As a large number of previous studies had no accuracy assessment, and monitoring agencies are often not able to access validation data, this method enables a minimum assessment to be made of the map's accuracy. This is an improvement, when compared to the 20 peer-reviewed papers out of 35 in Table 2 which have no or limited accuracy assessment for seagrass/coastal mapping.

| ***Estimated Reliability Level*** | **Source information for determining positional and attribute (seagrass cover) information for each polygon** |
|---|---|
| ***High*** | Corrected Landsat 5 TM image<br>Bathymetric data<br>Large number of field sample points in polygon<br>Expert knowledge available for the area |
| ***Medium*** | Bathymetric data<br>Large number of field sample points in polygon<br>Expert knowledge available for the area |
| ***Low*** | Bathymetric data<br>Expert knowledge available for the area |

**Table 3.** *Listing of the information from each seagrass cover polygon used to assign a level of reliability for the positional and attribute (seagrass cover class level) information. Reliability was estimated from data sources used to derive the boundary and cover level of the polygon.*

## RESULTS

### Field data

Seagrass species and cover data were collected from 4 927 sites throughout Moreton Bay using video or snorkeller based spot check surveys. The 2 856 photographs, produced from the 56 transect surveys, were analysed to estimate seagrass species composition and cover. Analysis of the spot check and photo-transect data resulted in a point based data set for seagrass cover and species composition. Positional accuracy (x, y) for each field site varied between 5 m and 10 m, depending on the availability and distribution of GPS satellites on the day of surveys. Attribute naming conventions for species composition and cover estimates were made as consistent as possible and checked by experts. However, small variations occurred based on the experience level of the photo analyst or field survey person.

### Seagrass cover map

This method provides a new map showing seagrass distribution and abundance, in terms of seagrass cover, throughout Moreton Bay (Figure 4). In comparison to previous studies, such as Hyland *et al.* (1989) the image maps and field data in this study show the same seagrass species, mixtures and relative distributions. The Eastern Banks seagrass beds covered the largest

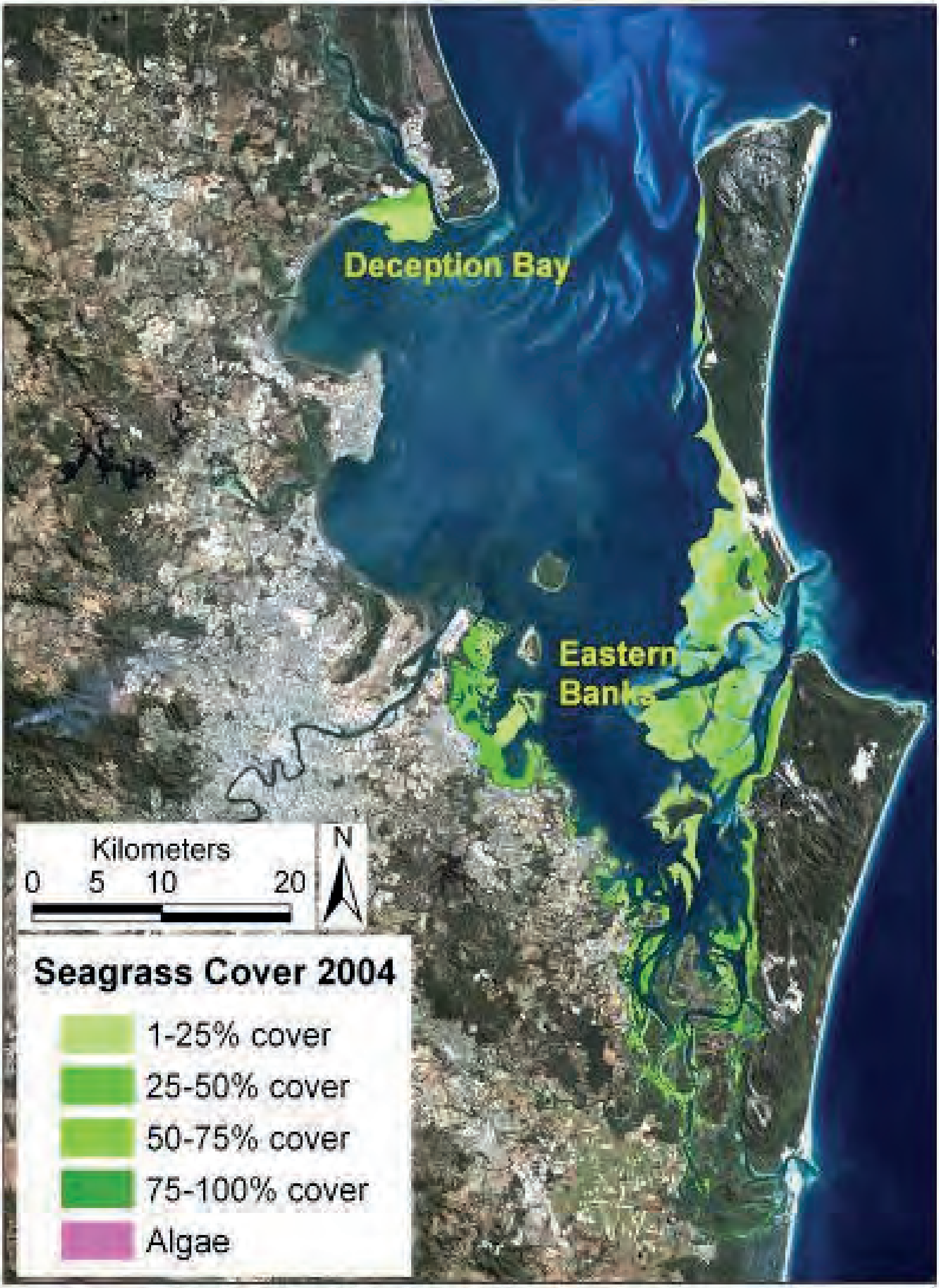


**Figure 4.** *Seagrass cover for areas shallower than 10 m in depth, from Moreton Bay, Australia, produced from a combination of field and image data collected in July-September 2004.*

area (approximately 100 km$^2$) followed by the beds present in the northern Deception Bay and Waterloo Bay regions. Although the southern Bay is dominated by widely dispersed, small patches of seagrass, it still covers a significant area (47 km$^2$ ). No seagrass was detected from surveys in the shallow waters at the northern entrance to the Bay, and on the western side of the Bay between Deception Bay and the Brisbane River mouth.

Table 4 shows that 12 percent of the Moreton Bay study area (1 582 km2) was covered by seagrass, most of which was found on the shallow banks (< 5 m). Low seagrass cover levels (1-25 percent) were present in 56 percent of the seagrass areas mapped. These were mainly found on the western and deeper sides of the Eastern Banks region. Areas of high seagrass cover (75-100 percent) were mainly mapped on the Eastern Banks, which is shallow and dominated by constant tidal flushing of clear oceanic waters. Field data showed that large areas of seagrass on the Eastern Banks were covered with epiphytic algae (*Hydroclathrus clathratus*), so a class was included to take this into account. Of the total area mapped as seagrass, 61 percent were derived from the image based mapping and 39 percent by field based mapping.

| | **Area (km$^2$)** | **Percentage of Moreton Bay area** | **Percentage of seagrass area** |
|---|---|---|---|
| Area of Moreton Bay below spring high tide level | 1582 | 100 | |
| Area shallower than 5 m | 853 | 54 | |
| Total area covered by seagrass | 189 | 12 | 100 |
| Seagrass cover 1-25% | 106 | | 56 |
| Seagrass cover 25-50% | 41 | | 22 |
| Seagrass cover 50-75% | 38 | | 20 |
| Seagrass cover 75-100% | 3 | | 2 |
| Algae cover on Eastern Banks | 2 | | 1 |
| Seagrass area based on image data | 115 | | 61 |
| Seagrass area based on field data | 74 | | 39 |

**Table 4.** *Area of seagrass cover classes in Moreton Bay, Australia. Numbers are based on inter- and sub-tidal areas within the Landsat scene.*

| **Reliability level for positional and attribute information** | **Seagrass cover polygon areas: positional reliability (km$^2$)[%]** | **Seagrass cover polygon areas: cover reliability ( km$^2$) [%]** |
|---|---|---|
| **High** | 139 [74] | 156 [83] |
| **Medium** | 29 [15] | 19 [10] |
| **Low** | 20 [11] | 13 [7] |
| **Total** | 188 | 188 |

**Table 5.** *Total surface areas covered by seagrass cover polygons assigned to each of the three levels of positional and attribute reliability.*

## Seagrass Cover Map – Reliability Levels

The subjective assessment of reliability labelled the majority of areas mapped as seagrass with high positional and attribute reliability levels (Table 5). This was partly a function of the larger areas being mapped from the image data.

# DISCUSSION

## Mapping Approach

The approach described in this paper can be repeated to create maps of seagrass cover in coastal environments with variable water clarities and depths. Common and commercially available image data and field data collected by multiple agencies using different field survey techniques forms the basis of the approach. The key to integrating these data sets and producing a single map product and monitoring program was coordination by a central person, to organise data collection, collation, checking and analysis, and to motivate all parties to contribute and share in a product which was significantly more than what they could produce individually. As the majority of coastal embayments and nearshore areas around the world are optically complex, with mixtures of turbid and clear waters, many do not have operational mapping methods, and the approach described here provides a way of using complimentary data collection approaches to build the necessary spatial information database (Green *et al.*, 2000; Dekker *et al.*, 2001; McKenzie *et al.*, 2001; Roelfsema *et al.*, 2001; Andréfouët *et al.*, 2004; Mumby *et al.*, 2004; Phinn *et al.*, 2005; Dekker *et al.*, 2006). Georeferenced field survey data acquired through direct or indirect means using a video or digital still camera, can be used to map benthic features in the areas too deep or turbid for satellite or airborne remote sensing, while the shallow clear areas are mapped by aircraft and satellite imaging systems. Data collected from acoustic surveys could also be used in this context (Jordan *et al.*, 2005; Riegl *et al.*, 2005), however, their suitability and cost effectiveness in shallow environments is limited due to limited swath width.

The approach presented here provides a means to combine information from separate sources while maximising areal coverage and mapping accuracy. Visual field surveys conducted by spot checks from divers, snorkellers or drop cameras, resulted in relatively accurate field data, in terms of spatial location (e.g. handheld Garmin 76 providing an average positional error +/-5-10 m) and mapped seagrass cover class. For this project, an area of approximately 853 km2, covering the inter- and sub-tidal areas shallower than 5 m in Moreton Bay, was mapped using remote sensing and field data. The field data only covers 0.126 km2, less than 0.1 percent of the total area of Moreton Bay, but does so with near 100 percent accuracy. For those areas where satellite image data were used, it provided 100 percent coverage, but with lower mapping accuracies. This difference in accuracy levels and areal coverage is due to the fundamental difference in how the two data sets were collected. Field data were collected from a direct observation at a known point by a single person. Image data were collected remotely and are averaged over a sampling area (image pixel). Areal coverage versus accuracy is the fundamental trade-off that managers and scientists will always face when deciding how to map a coastal-marine environment for monitoring or management purposes: should a smaller area be covered at a higher accuracy, or should a larger area be covered at lower accuracy (Roelfsema *et al.*, 2006)?

The approach applied in this research provides an operational means to map and monitor the full spatial coverage of seagrass beds in Moreton Bay. This addresses a limitation of past seagrass mapping approaches within the Bay. For example, the approach by Zharikov et. al. (2005) focused on several habitat categories and did not map seagrass percent cover classes. Likewise, Stevens and Connolly (2005) did not focus on seagrass and only covered deep water regions (> 5.0 m) using video image analysis. Both of these approaches did collect field and image data in the same time period. Even though our work was restricted to depths < 5.0 m, the field survey methods can be used down to the maximum depths in Moreton Bay if required.

One drawback of the proposed approach is the potential inconsistency in the accuracy and precision of seagrass cover levels determined from the benthic photo analysis in comparison to the spot checks in the field. Percentage cover values determined from the photo analysis may have a higher accuracy and precision level than those estimated from spot check surveys in the field. In an ideal situation all assessments should be standardised and have a similar accuracy and precision. This could be accomplished by collecting all field data as digital photographs or video, and analysing them using standard sampling and cover estimate techniques (e.g. Kohler and Gill, 2006).

Future work will cross-calibrate each seagrass cover field survey approach on the same sites and establish compensation factors for use in visual estimates, as these approaches are typically applied in other resource surveys to reduce bias between human observers. Accurate assessment of error levels from each survey and mapping approach will be another challenge to address, as another drawback of the approach used is that the different sources of data have different amounts of error in relation to their positional and cover level values. As these are combined in the final map product, future error assessments may have to be done on individual data sources prior to and after their integration in the map.

## Seagrass Cover Map

The seagrass cover map produced in this research presents a similar pattern in terms of overall distribution and cover levels to recent and historic maps of seagrass in Moreton Bay (Young and Kirkman, 1975; Hyland *et al.*, 1989; Dennison and Abal, 1999; EHMP, 2005; EHMP, 2006). The most extensive and highest cover seagrass beds were found in shallow areas of the Eastern Banks, Northern Deception Bay and Waterloo Bay, with no seagrass beds found in the shallow and turbid western areas between the Brisbane River mouth and southern Deception Bay. The deeper areas of the bay were not included in this study as there is generally insufficient light to support seagrass in these areas (Longstaff, 2002). If it does occur, the cover is very sparse (less than 5 percent) and ephemeral.

## Recommendations for Future Mapping

This paper presents the results of a multi-institutional field and satellite image based approach to mapping seagrass properties where field and image data were used in complimentary areas. The approach is repeatable for the study area, as the different organisations involved have all the resources in place to do it again. Similar mapping programs for seagrass environments have used remote sensing with success, but often do not show any seagrass information for exposed inter-tidal areas or the areas where the water was too turbid or deep for passive remote sensing to operate (Dekker *et al.*, 2005). Active remote sensing could be used in turbid and deep areas to map seagrass. This would only work for limited areas in Moreton Bay due to minimum depth limitations of side-scan sonar mapping systems and the relatively low canopy height of seagrass which makes seagrass species harder to distinguish from each other (Jordan *et al.*, 2005; Riegl *et al.*, 2005).

The strength of the approach presented here is the combination of mapping techniques that are complimentary in terms of variable water depth and clarity conditions for which they are suitable. As a consistent validation dataset was not collected across the survey area, a detailed accuracy assessment could not be conducted. Instead the reliability of the approach was evaluated qualitatively. Future work should collect and use another independent data set for validation purposes.

The seagrass cover mapping approach presented in this paper is the first in the region which combined satellite image data with several forms of field data to map seagrass cover over a range of water clarities. To extend and apply this approach in future, several steps need to be followed:

- Active involvement of government and non-government organisations which have an obligation to monitor seagrass;
- Awareness by these organisations that they all want the same type of data;
- Willingness of these organisations to gather and share data;

- Presence of a coordinating body which assures that the data gathered will be comparable and of suitable quality;
- Available resources, knowledge and skill to gather and process field data; and
- Available hardware, software, knowledge and skill to create satellite image based maps and integrate field based maps

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