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Browse LNG Development

ECOLOGY, EXTENT AND TEMPORAL VARIABILITY OF NEARSHORE SEAGRASS, JAMES PRICE POINT COASTAL AREA

Assessment and analysis of 2008 to 2009 surveys

Woodside Energy Ltd

- Rev 3
- 15 October 2012

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Executive Summary

Woodside Energy Ltd (Woodside), as operator of the proposed Browse Liquefied Natural Gas (BLNG) Development, plans to commercialise the Browse Joint Venture’s three gas and condensate fields, Brecknock, Calliance and Torosa, located 425 km north of Broome off the Kimberley coast. Subject to government approvals, Woodside plans to extract gas and liquids from these fields using offshore facilities, which will then be brought to an onshore LNG plant for processing at the Western Australian Government’s planned Browse LNG Precinct, near James Price Point, about 60 kilometres north of Broome. The Department of State Development, as the Precinct proponent, is progressing a Strategic Assessment of the area.

A detailed understanding of the existing marine environment will facilitate an accurate evaluation of potential impacts that may emanate from a proposed development in the coastal environment. Seagrass communities have been identified as a benthic primary producer habitat (BPPH) type within the James Price Point coastal area. Previous studies have shown that the distribution and abundance of tropical seagrass communities can vary temporally. Seasonally abundant, patchy, and sparse seagrass beds have previously been identified in the James Price Point coastal area during a dry season field survey in June 2008 (Fry *et al*., 2008). In order to assess the current distribution and investigate the temporal variability of seagrass in this area, a second field survey was conducted during the wet season by SKM using a towed video approach in November 2009. The aim of the 2009 survey was to determine whether the distribution, extent and degree of temporal variation in seagrass communities within the James Price Point coastal area exhibited a similar seasonal pattern to that observed in earlier surveys during the dry season by Fry *et al* (2008).

To achieve this overall aim, specific objectives included:

- re-examining field sites that were assessed in 2008
- modelling and mapping the distribution of seagrass across the study area from both 2008 and 2009 surveys
- comparing the predicted distribution and confirmed extent of seagrass to determine any variability in observed distributions between 2008 and 2009.

Areas where seagrass had been previously observed from 2008 were re-assessed. However, due to difficulty in repeating exact transect locations previously sampled in 2008, replicate transects were sampled within selected areas (or ‘patches’) that were noted as having seagrass present in 2008. Areas where no seagrass had been observed in 2008, but had similar environmental conditions to the areas where seagrass had been observed, were also sampled in 2009. Laser Airborne Depth Survey (LADS) bathymetry data collected in 2009 were used to define areas with similar environmental conditions and topographic features of interest.

The towed video data collected in June 2008 (Fry *et al*., 2008) and November 2009 (this study) were then classified according to substrate type, habitat class and seagrass cover, and a visual comparisons of data (patch analysis) was undertaken to make an assessment of the degree of temporal and spatial variation between years (seasons). Predictive modelling of the seagrass distribution was also conducted using video data, LADS bathymetry and derived topographic features.

Results from this study identified that seagrass communities within the James Price Point coastal area exhibited high spatial variability, were patchily distributed and generally sparse in cover between the two sampling years. Due to the low prevalence of seagrass observed over the area (3.4% in 2008 and 4.8% in 2009) modelling could not define a consistent relationship between the observed distribution and the environmental conditions. Therefore, attempts to map the predicted distribution of seagrass across the entire study area for both years were constrained. Minimum modelling requirements typically demand greater than 5% prevalence within a dataset to accurately define and map distributions. Seagrass distribution within the James Price Point coastal area is sparse in cover but widespread geographically over an area with little topographic complexity or defining environmental characteristics. This exacerbated the difficulties of defining the distribution of species that are highly variable in space and time, such as the dominant *Halophila* species observed in this study.

Towed video surveys were conducted in two different years (2008 and 2009) as well as in two different seasons (June and November). While there was a clear indication of temporal variability between the two data sets, changes in distribution were inconsistent across the study area, with some patches of seagrass increasing (size and percent cover) and others decreasing. Therefore, it was difficult to conclude whether there was a seasonal increase in seagrass distribution when the June 2008 data were compared with the November 2009 data. Observed temporal variation may not only be a result of seasonal trends, but inter-annual changes and general natural variation.

Temporal differences are likely to play a substantial role in the observed differences and further sampling within seasons may assist in confirming likely distribution patterns. Sampling precision between surveys may also contribute to the differences in distribution observed, with it being difficult to sample the exact location twice due to differences in currents and tides during sampling. However, both surveys confirmed that on the whole seagrass cover is low within the study area.

Contents

List of Figures

List of Tables

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1. Introduction

1.1. Project Overview

Woodside Energy Ltd (Woodside), as operator of the proposed Browse Liquefied Natural Gas (BLNG) Development, plans to commercialise the Browse Joint Venture’s three gas and condensate fields, Brecknock, Calliance and Torosa, located 425 km north of Broome off the Kimberley coast. Subject to government approvals, Woodside plans to extract gas and liquids from these fields using offshore facilities, which will then be brought to an onshore LNG plant for processing at the Western Australian Government’s planned Browse LNG Precinct, near James Price Point, about 60 kilometres north of Broome. The Department of State Development, as the Precinct proponent, is progressing a Strategic Assessment of the area.

A detailed understanding of the existing marine environment will facilitate an accurate evaluation of potential impacts likely to emanate from a proposed development in the coastal environment. The marine benthic communities within the Kimberley region are largely unstudied and the need for increased and on-going research to develop an understanding of the distribution, extent and ecology of significant sensitive habitats has been identified (Wood and Mills, 2008).

Seagrass communities have been identified as a benthic primary producer habitat (BPPH) type within the region considered to be at risk from potential impacts associated with the proposed development. The *Kimberley Science and Conservation Strategy* recognises seagrass communities as a key ecological attribute of the nearshore environment, but report their distribution as patchy and seasonally abundant (Masini *et al.*, 2009) (see Section 2.2). Repeat surveys undertaken by the Western Australian Department of Environment and Conservation (DEC) at the same locations identified that areas that had seagrass in November 2007 did not have seagrass present in April 2008, but that they had re-established by June 2008 (Masini *et al.*, 2009).

Seagrass distribution in the region has principally been determined from extensive sampling undertaken by Fry *et al.* (2008) during June 2008. To investigate how the distribution of seagrass communities in the James Price Point coastal area varies in space and time, further sampling was proposed during the summer months of 2009/2010 when the distribution and abundance of seagrass was expected to be greater. The additional information gathered was intended to inform an assessment to determine whether the seasonal variability of seagrass reported by Masini *et al.* (2009) is a regular phenomenon in this area and consolidate the understanding of seagrass distribution in the area. These data on the extent and seasonality of seagrass are necessary for any future assessments to determine any potential impact to, or loss of, BPPH in accordance with the level of detail stipulated within the Environmental Protection Authority’s (EPA) Environmental Assessment Guidelines No. 3, ‘Protection of Benthic Primary Producer Habitats in Western Australia’s Marine Environment’ (EPA, 2009).

1.2. Objectives and Scope

The primary objective of this study was to conduct a towed video survey in November 2009 and use these data, in conjunction with that previously collected in June 2008 (Fry *et al*., 2008), to determine whether the distribution, extent and degree of temporal variation of seagrass communities within the James Price Point coastal area (Figure 1) exhibited a similar seasonal pattern to that observed in earlier surveys.

To achieve this objective, the scope of works included:

- undertake a towed video survey in November 2009 to re-sample areas found to contain seagrass during June 2008 (Fry *et al*., 2008)
- evaluate how variable the observed seagrass distribution in November 2009 was from the observed distribution in June 2008
- model and map the distribution of seagrass for the entire study area using towed video data collected from November 2009 and compare this to the distribution predicted from June 2008 data using the same modelling method
- discuss the results of the mapping and any temporal variation in the spatial distribution of seagrass with reference to the ecology and biology of the species found.

It is understood that seasonal variation may occur throughout the year that will influence the growth, resulting cover and distribution of seagrass within the study area and that the predicted distributions from each survey period may exhibit this potential variability. Whilst the intention of the study is to determine this potential variation, data from each survey is considered to be a single representation only of the expected conditions within that seasonal period in which the data was collected. Alternate states may exist and the potential influence this may have on the reported outcomes are discussed in Section 5.

1.3. Study Area

The study area was defined by the spatial extent for which high resolution LADS (Laser Airborne Depth Survey) bathymetry data exists within the vicinity of James Price Point. The data covers an area of approximately 500 km^2 (Figure 1) and were collected across the region from north of Coulomb Point to Cape Boileau in the south to approximately the 25 m depth contour (approximately 12.5 km offshore) in May 2009 by Fugro LADS Corporation (FLC).

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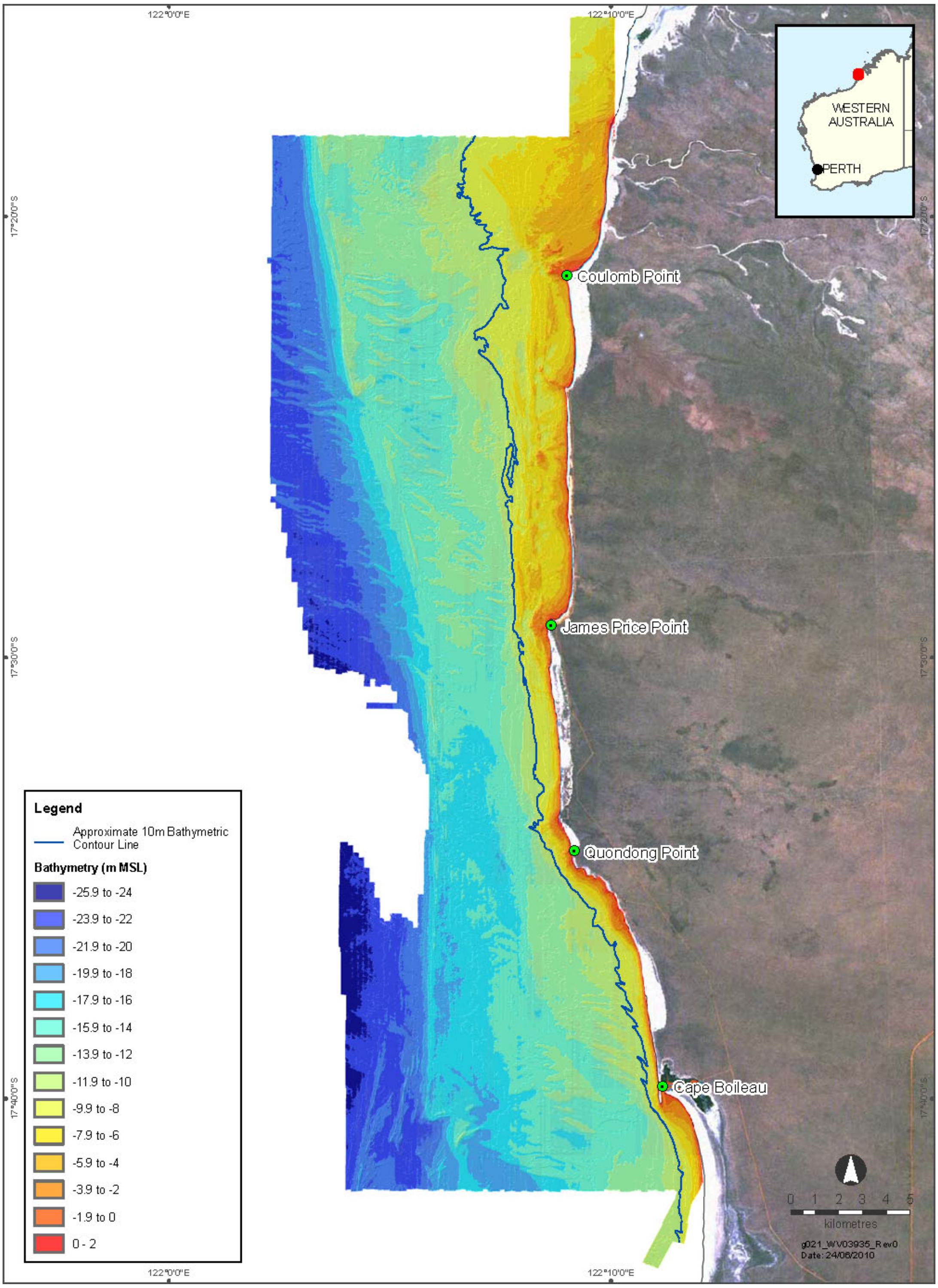


- **Figure 1 Location of the study area at James Price Point based on the extent of the bathymetric data collected by Fugro LADS Corporation in May 2009**

2. Biology and Ecology of Seagrasses

Section 2.1 below is intended to provide a broad summary of the basic requirements for seagrass growth and reproduction. Section 2.2 summarises available information on the seagrasses found specifically within the study region, specifically *Halophila* species. The spatial and temporal variation in *Halophila*, their basic requirements as well as their sensitivity and resilience to environmental stressors are reviewed.

2.1. Basic Requirements

The spatial and temporal distribution of seagrass can be highly variable and is dependent on a combination of physical and biological controls. Physical controls such as temperature, salinity, water and sediment movement, depth, light availability, nutrients and substrate type regulate the physiological activity of seagrass. Biological controls include epiphytic growth, predation, competition and reproductive strategies (Short *et al*., 2001).

Temporal variability can occur as a result of seasonal cycles and inter-annual change due to sporadic environmental events such as cyclones and natural variation. Seasonal trends in seagrass distribution, density and community composition have been documented in temperate and tropical waters in Australia and are largely driven by changes in growth and reproduction as controlled by temperature and light (Duarte *et al*., 2006; Lehnert *et al*., 2003; Short *et al*., 2001; Kenyon *et al*., 1997; Lanyon and Marsh, 1995).

Experiments have shown there is a rapid decline in seagrass photosynthesis and productivity when temperature exceeds the optimum temperature range (Hillman *et al*., 1989; Campbell *et al*., 2006) and fluctuations in seasonal seawater temperatures in tropical habitats can range from 19.8 to 41°C (McKenzie and Campbell, 2004; McKenzie, 1994). Growth of seagrasses in high (saturating) light environments increases with temperature, whereas growth of seagrasses in low (near the light compensation point) light environments decreases as temperature increases suggesting the response of seagrasses (growth) to light and temperature is complex (Bulthuis, 1987). Dawes *et al* (1989) examined the response of *Halophila decipiens* to changes in temperature. The results indicated that 30°C was the optimum temperature for photosynthesis but plants can likely survive in water ranging from 20°C to 40°C. Further studies suggest that the optimal growth temperature for tropical/subtropical species is between 23°C and 32°C (Lee *et al*., 2007), whereas the optimal temperature range in which seagrass becomes reproductive is 20 to 26ºC (McMillan, 1982). McMillian (1982) suggested that temperature was the critical factor governing the reproductive physiology of tropical seagrass.

2.1.1. Depth and Light Availability

The overall distribution and extent of seagrass is frequently cited as being largely controlled by depth, and thus light availability (Dennison *et al*., 1993; Cabello-Pasini *et al*., 2003). Seagrass communities are generally found in coastal waters at depths of 2 to 10 m, although they have been recorded at 60 m in some Australian waters (Waycott *et al*., 2004). The average minimum light requirement for seagrass is between 10 to 20% of sub-surface light, yet different species are known to have varying light requirements due to unique physiological and morphological adaptations (Dennison *et al*., 1993). Shallow water distribution of seagrass may conversely be inhibited by exposure to high light conditions (Larkum *et al*., 2006). The optimal depth range is largely defined by the availability of light.

2.1.2. Reproduction

Seagrass can reproduce sexually via seeds or asexually via propagules and spreading rhizomes. Some species of *Halophila* are known to have separate male and female plants. *Halophila ovalis* reach peak abundance (defined by percent cover and/or standing crop) during the Northern Australian wet season in November to March or late spring and summer and then die off in the dry season (Waycott *et al*., 2004; Lanyon and Marsh, 1995). Tropical seagrasses have been induced to flower under continuous light, suggesting that day length plays a minor role in reproductive periodicity (McMillam, 1982). Growth is more commonly via asexual reproduction of rhizomes that extend laterally, although some reproduction occurs through sexual recruitment (Rasheed, 2004). Fruits of *H. ovalis* are known to develop on rhizome nodes of the female plants during summer to autumn (February to April) in southern Western Australia (Kuo and Kirkman, 1992). *H. ovalis* and *H. uninervis* appear to be the most successful at re-colonisation of plots, isolated from asexual colonisation, through production of sexual propagules (Rasheed, 2004). *H. ovalis* appears to display characteristics of high reproductive output and little investment in competition or maintenance (Rasheed, 2004). A strategy of strong local clonal growth and limited dispersal of sexual propagules may offer advantages to plants, such as seagrass, that grow in restricted and spatially infrequent habitats that are subject to temporally unpredictable mortality of the adult population.

Both seed germination and flowering in some seagrass species is influenced by a variety of environmental factors such as light (De Cock, 1981a; McMillan, 1980a), temperature (De Cock, 1981b; McMillan, 1979), nutrients (Duarte and Sand-Jensen, 1996; McMillan, 1980b) and salinity (McMillan, 1976). Flowering often occurs only within a narrow range of one or more of these factors for some seagrass species (McMillan, 1980b). However, seeds of *H. uninervis* may be viable in the sediments for several years (McMillan, 1991). *H. decipiens* may be capable of long distance dispersal, implied by its global distribution with very little genetic divergence and often behaves as an annual, growing, flowering, setting seed and dying in a short period of time

(Waycott *et al.*, 2004). Tropical seagrass meadows are subject to temporally unpredictable devastation through tropical storms or cyclones (*e.g.* Preen *et al*., 1995; Birch and Birch, 1984; Poiner *et al.*, 1989; Poiner and Peterkin, 1995). Long-lived locally dispersed seeds offer seagrass a means to re-colonise areas following such infrequent meadow scale losses of adult plants, and it is suggested that recruitment from seed is important for sustaining seagrass communities in such areas (Masini *et al*., 2009).

2.2. Regional Context

Western Australia has a high diversity of seagrass and 12 of the 25 species found in Western Australia have been reported to occur within north Western Australia's tropical waters. Of these, 11 have been recorded from around the coastal margin of the Dampier Peninsula (Kenneally *et al*., 1996) and at intertidal sites in the Kimberley by Walker (1992; 1995; 1996; 1997). As the majority of studies have been based on collections specimens from the intertidal zone (Walker, 1992; 1995; 1996; 1997; Walker and Prince, 1987), the overall distribution and ecological role of subtidal seagrass communities in tropical, north Western Australia has been poorly documented.

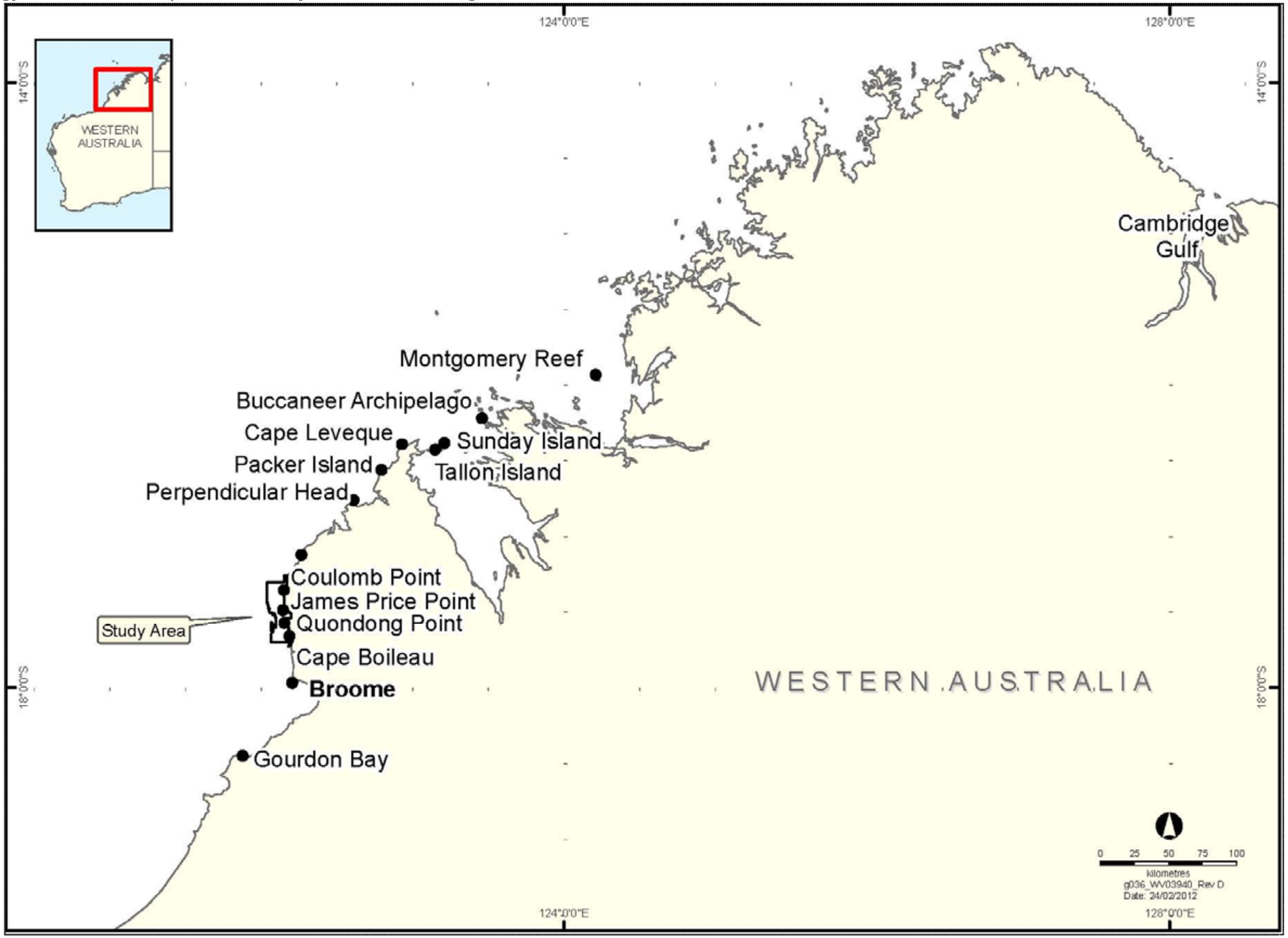
Very limited information existed on the subtidal seagrass communities in the region, until the recent surveys by Fry *et al.* (2008), a study undertaken by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) Centre for Marine and Atmospheric Research (CMAR) division and the Australian Institute of Marine Science (AIMS), contracted through the Western Australian Marine Science Institute (WAMSI) in collaboration with the DEC. The surveys used a combination of towed video and dredge tows to undertake a rapid assessment of the marine benthic communities within the Kimberley region in June 2008 at four locations, namely Gourdon Bay, Quondong to Coulomb Point, Perpendicular Head and Packer Island (Fry *et al.*, 2008). Based on the results of this work, seagrass appears to be well represented regionally and not specific to the James Price Point coastal area.

2.2.1. Spatial and Temporal Variation

Although widespread in occurrence, seagrass habitats within the region have generally been found to be sparse and patchy, occurring in shallow water (less than 20 m) near offshore reefs, shoals and the mainland in both subtidal and intertidal sheltered environments, such as flats and large bays (Fry *et al.*, 2008). Communities are generally sparse, occurring in low abundance on shallow sandy sediments (Jones, 2004; Semeniuk *et al*., 1982).

Seasonally abundant, subtidal seagrass communities have been found to be patchily distributed across large areas along the Dampier Peninsula, (Kenneally *et al*., 1996) and Fry *et al*. (2008) recorded sparse patches of *Halophila* spp. in the shallows at Perpendicular Head and Packer Island (Figure 2). Further south at Gourdon Bay, mean seagrass coverage was 4% and was never observed

with densities classified as greater than sparse (Fry *et al*., 2008). Extensive seagrass meadows were documented from the southern Kimberley region particularly around Sunday and Tallon islands (Cape Leveque to Montgomery Reef) (Figure 2) from which eight species were identified (Walker, 1995; Wells *et al*., 1995). Areas of seagrass in the central and northern Kimberley region, Buccaneer Archipelago in the south to Cambridge Gulf in the north (Figure 2), were found to be not as extensive or diverse as those from the Southern Kimberley (Walker, 1997; 1996).



- **Figure 2 Regional map displaying the locations where seagrass has been documented to occur**

The seagrass genera known to occur within the region include *Cymodocea*, *Enhalus*, *Halodule*, *Halophila Syringodium*, *Thalassia* and *Thalassodendron*. Commonly occuring species are: *Thalassia hemprichii*, often covering 30 to 50% of the substratum when present; followed by *Enhalus acoroides; Halophila ovalis; Halodule uninervis; Thalassodendron ciliatum;* and *Halophila decipiens* (Huisman and Borowitzka, 2003; Walker, 1997; 1996; 1995; 1992; Kenneally *et al.*, 1996). *Thalassia hemprichii* was associated with coral rubble at all levels of the shore. *Enhalus acoroides* was typically found in deep fine sediment, usually in shallow water, and often in front of mangroves (Walker, 1997; 1996; 1995; 1992). The species *H. ovalis* often formed extensive beds with a large depth range and greater tolerance to exposed conditions compared with other species of this genus (Edgar, 1997). In mixed seagrass communities, where the substrate was fully exposed at low tide, *H. uninervis* was the dominant species and appears to be a rapid coloniser that plays an important role in maintaining seagrass habitat in areas of high disturbance (Waycott *et al.*, 2004; Kenneally *et al.*, 1996). Other species, such as *T. ciliatum*, were located in areas with strong currents, growing directly on reef or coarse shell grit (Kenneally *et al.*, 1996). *H. decipiens* was the only species identified in four tow samples from the Dampier Peninsula and Gourdon Bay (Irvine and Keesing, 2009). *H. decipiens* was the most common seagrass found in deeper waters and was also common in reef and sandy habitats (Irvine and Keesing, 2009).

Halophila species appear to be the most common within the region, with Fry *et al*. (2008) finding this genus represented at all four locations assessed: Gourdon Bay; Quondong to Coulomb Point; Perpendicular Head; and Packer Island, with a mean coverage of between 1 to 6 %.

While there are limited studies of the temporal variability of seagrass communities in the north-west of Western Australia, elsewhere in Australia the distribution and abundance of tropical seagrass (total seagrass and individual species) has been found to peak during summer/early autumn (November to March) with abundance declining in the dry season (August to September) (Mellors *et al.*, 1993; Moriarty *et al.*, 1990). Recovery of seagrass has been indicated by an increase in abundance of new growth in with onset of the wet season (September to November) (Lanyon and Marsh, 1995). Rainfall, day length and temperature have been found to correlate with seasonal seagrass abundance (Mellors *et al.*, 1993). These seasonal trends have been documented in other geographical regions for *Halodule wrightii* (Brazil: Creed, 1999), *H. uninervis* (Indonesia: de Iongh *et al*., 1995) and *H. ovalis* (Oman: Jupp *et al*., 1996). Similar studies in Western Australia found both short and long term changes in the seagrass communities of Exmouth Gulf (Lehnert *et al*., 2003 in Loneragan *et al*., 2003). Long term increases in species richness and extent were attributed to succession processes following a cyclone disturbance, whilst short term changes were part of the seasonal cycle of seagrass communities. There was a dramatic increase in biomass within a year between October and November suggesting a seasonal cycle in above ground biomass and likely influenced by the fast growing species that were present in the Gulf, such as *Halophila spinulosa*, *H. ovalis* and *H. uninervis*.

SINCLAIR KNIGHT MERZ SKM

2.3. James Price Point - *Halophila* spp.

The most common species found in the James Price Point area to date are *Halophila* spp. (Fry *et al*., 2008). Species known to exist within the north west of Western Australia include *H. ovalis*, *H. decipiens*, *H. minor*, *H. ovata* and *H. spinulosa* (DEWHA, 2009), although it is important to recognise that the taxonomy of several of these species is confused (Waycott *et al.*, 2004). These species have similar morphologies (excluding *H. spinulosa* which has fern-like leaves), making it difficult to identify sightings to species level. *Halophila* spp. are common in tropical waters and typically utilise the space between other seagrass species or biota types forming mixed beds, although they can form exclusive beds (Huisman, 2000). They have the greatest depth limit, and consequently the lowest minimum light requirement among seagrass species and have been recorded at depths of up to 60 m where they receive approximately 5% of surface irradiance (Butler and Jernakoff, 1999). The morphological characteristics of *Halophila* spp. such as the broad leaves, likely contribute to their low minimum light requirement. *Halophila* spp. are positioned lower in the canopy, and thus likely to be shade adapted. *H. decipiens* is the most common seagrass in deeper waters as it is very tolerant to low light conditions (Waycott *et al*., 2004). Although, *H. decipiens* is generally regarded as a species of deeper water, found at depth of 35 m on the Western Australian coast, it can also be found in rock pools at the mid-tide level (Walker and Prince, 1987). *H. decipiens* often grow in large mono-specific meadows or sometimes with *H. ovalis* (Waycott *et al*, 2004).

2.3.1. Spatial and Temporal Variation

The James Price Point coastal area has been shown to support extensive, seasonally abundant, subtidal seagrass communities consisting principally of *Halophila* spp. in waters approximately 10 m deep (Fry *et al*., 2008). Although some dense areas have been observed, seagrass was usually sparse, patchily distributed and generally interspersed with other habitats on sand areas between reef patches. Seagrass was largely restricted to the flat sand areas to the south of Coulomb Point within the 5 to 10 m depth contours. Some small patches were also recorded further south between James Price Point and Quondong Point. The mean coverage was less than 6%.

Previous studies (Unpublished data DEC and AIMS, 2007; 2008) found areas of dense *Halophila* spp. with high biomass in November 2007 followed by a decline in April 2008 and further increase in June and December 2008 with prolific seed production observed suggesting these communities were seasonally abundant (Masini *et al.*, 2009).

2.3.2. Sensitivity and Resilience

Seagrass species vary widely in their tolerance to light deprivation and this variation often relates to their morphology or ability to tolerate such stresses through photo-adaptation of physiological processes allowing more efficient use of low light. *Halophila* spp. are known to survive in deep

water environments under reduced light conditions. Survival in these environments can partially be attributed to their petiolate leaves (Kuo and den Hartog, 2006) as it is likely that such leaves, with elliptic or ovate blades, are more efficient at harvesting light than linear or lanceolate leaves. Yet in the case of severe light deprivation when prolonged light attenuation occurs (e.g. as experienced during dredging operations), *H. ovalis* displays lower tolerance, with plant death occurring after 38 days of dark conditions (Longstaff and Dennison, 1999).

Two primary factors appear to affect the survival of seagrass in environments that experience transient light deprivation events: the duration of time that plants are light deprived; and the light history prior to light deprivation (in terms of frequency and duration of light deprivation events) (Longstaff *et al*., 1999). Although existing information suggests that *Halophila* spp. are often quick to re-colonise areas following a disturbance due to their fast growth rate (Nakaoka and Aioi, 1999), studies have shown that they are vulnerable to severe light deprivation. *H. ovalis* is less structurally complex, with low storage capacity for carbohydrates which can be used for growth during periods of low light (Bite, 2007). Above ground biomass has been shown to decline rapidly during severe light deprivation (2% of surface irradiance, Longstaff *et al*., 1999). The fact that *H. ovalis* biomass declines rapidly during light deprivation predisposes this species to become vulnerable to transient light deprivation events (Longstaff *et al*., 1999). If a light deprivation event, caused by factors such as land run-off or dredging, persisted for 30 days or longer, then *Halophila* spp. would probably die off and recovery would only be likely to occur through growth of seeds and/or settling vegetative propagules. Because biomass declines rapidly and recovers slowly, *H. ovalis* die-off may also occur after a sequence of shorter light deprivation events in which there is limited time for the recovery between light reduction events (Longstaff *et al*., 1999).

Whilst being sensitive to prolonged light reduction, in preferred conditions *Halophila ovalis* is the fastest growing tropical seagrass species and prefers slightly more exposed conditions than other *Halophila* species (Vermaat *et al*., 1995) making it a common pioneer species that can rapidly colonise areas and survive well in unstable depositional environments following a disturbance (Huisman, 2000; Birch and Birch, 1984). Rasheed (2004) found *H. ovalis* initially colonised gaps via asexual colonisation but was displaced by other species within ten months. Furthermore, a study by Nakaoka and Aioi (1999) found that it took two months for a patch within a seagrass bed that was removed of *H. ovalis* to reach the same state of colonisation prior to disturbance. Poiner *et al*. (1989) reported that following a cyclone there was a decrease in the above-ground biomass of less than 10 ha in a seagrass bed, but within six months there was no difference between pre- and post-cyclone biomass estimates. These observations indicate that tropical seagrass beds can recover from minor disturbances provided there is sufficient structure for re-establishment.

The dominance of *Halophila* in the areas off James Price Point, suggest the shallow water habitats where it is present may be subject to periodic (and regular) disturbances which affect the distribution and abundance of seagrass. Disturbances from cyclones and storms are largely

confined to the wet season months (summer) and so may impact upon seagrass during the period of the year when they typically exhibit an increase in abundance (and productivity). Therefore it is useful to assess whether the regularly observed pattern of increased distribution and abundance of seagrass during the summer months can be affected by disturbance.

3. Methods

3.1. Towed Video Data Collection

A subtidal towed video survey was conducted within the study area (Figure 1) by SKM from November 23rd to 29th 2009. The 2009 sampling plan was developed using information from previous video footage (Fry *et al.*, 2008), and the topographic features as determined from the LADS data. Locations to be sampled in 2009 included areas previously observed to have seagrass (i.e. transects from June 2008), areas not previously sampled, but which had similar environmental conditions (i.e. bathymetry and topographic features) to areas previously observed to have seagrass, and areas not previously sampled, but which were predicted to have a range of other biota types (SKM, 2010).

The timing of the field survey was selected to exploit favourable weather conditions during a neap tide period. However, the tides and winds often make it difficult to navigate the vessel along a pre-determined, straight line transect at a constant slow speed. Due to the difficulty of repeating previously sampled transects that contained seagrass in the 2008 survey, an attempt to quantify the change in seagrass distribution and percent cover between sampling times at the same location was made by sampling replicate transects within selected seagrass areas (‘patches’) identified from the 2008 survey results.

The survey was timed to coincide with the wet season and was intended to provide a comparison to the seagrass distribution and cover observed during the dry season by Fry *et al* (2008). There are limitations in this approach, in that variation may occur within the wet (November to April) and dry seasons (May to October) that will influence growth, resulting cover and distribution estimates. Whilst changes are expected to be less during the dry season, each survey conducted is considered to be a single representation only of the expected seasonal conditions.

A small, lightweight, high-resolution video camera was towed along the seafloor from a vessel. The camera was towed at a speed of between 1 and 2 km/hr approximately 1 m above the substratum. This obtained a transect width of approximately 1 m. The towed video camera was controlled remotely from the vessel and real-time footage was displayed on a monitor onboard, in relation to navigation software showing the vessel position. The video footage was geo-referenced with latitude and longitude coordinates using a Furuno GP-37 differential global positioning system (DGPS). This achieved a positioning accuracy of approximately 5 m for 95% of the time. The video and audio tracks were encoded with the GPS position (one GPS encoding per second) and recorded to a portable hard drive recorder. In total, 161 video transects were completed, representing 150 individual transect sites with replicate tows at nine of those sites. Transects were generally between 300 and 500 m long. Figure 3 shows the location of all video transects conducted during both the June 2008 and November 2009 surveys.

3.1.1. Classification of Video Footage

Towed video footage collected in 2008 and 2009 was classified using the same method to ensure consistency between observers and to allow for comparison between surveys. However, it must be noted that the 2008 survey was less focused on surveying seagrass and the quality of the towed video footage (speed and distance above the substrate) sometimes made it difficult to identify the presence of seagrass. A custom visual basic interface was used to assign a habitat classification to the corresponding geo-referenced video data in a spreadsheet during video play back (Appendix A). A classification was assigned to each unique GPS coordinate that corresponded to a second of video footage. The scheme caters for detailed taxonomic data of biota to be collected in the same format and nested within the higher groups, for example, fine scale classification at lower taxonomic levels, such as family or species can be nested within higher groups. Seagrass was classified when it was observed with a cover greater than 1%, across 5 m of video footage (5 m x 1 m area).

The percent cover was further classified (qualitatively) into density categories: 1-5%; 5-25%; 25-50%; 50-75%; and 75-100% (Table 1). The percent cover was measured as an average over a distance of 5 m. Using the classified data, a table detailing the presence (1), absence (0) and cover of seagrass at each GPS coordinate (site) was developed for all 2008 and 2009 data. All data were stored in a Microsoft Access database for error and quality control checking before use.

SINCLAIR KNIGHT MERZ
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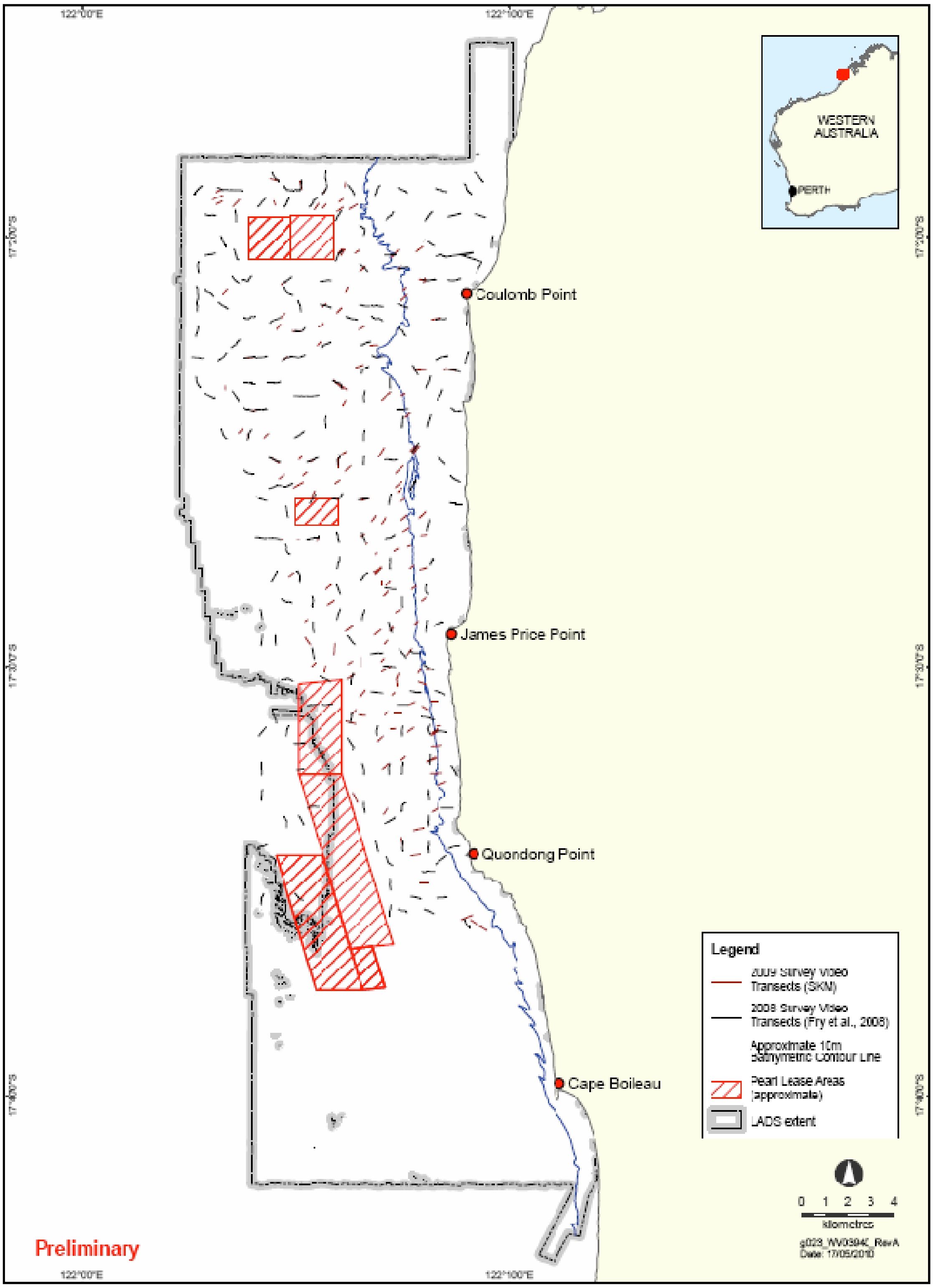


- **Figure 3 Location of the towed video transects surveyed in 2008 (Fry *et al.*, 2008) and in 2009 (SKM, this study)**

- **Table 1 Density categories used to qualitatively classify the percent cover of seagrass**

Category	Description
Not classified	< 1%
Very sparse	Percent cover 1-5%
Sparse	Percent cover 5-25%
Medium	Percent cover 25-50%
Dense	Percent cover 50-75%
Very dense	Percent cover >75%

3.2. Mapping Seagrass Distribution and Percent Cover

Prior to sampling, it had been proposed that the distribution of seagrass as observed in 2008 and 2009 would be modelled to define the relationship between the observed distribution and the environmental characteristics and mapped with a view to compare the full coverage 'predicted' distribution of seagrass between the two surveys. In order to be able to develop robust models for predicting distributions, the habitat class must have been observed with sufficient prevalence (i.e. observed number of classifications/total number of classifications must be at least 5%). Models developed for habitat classes that were observed with lower prevalence will not be robust as there would be insufficient presence data to train the models. In essence, the model would be trained to predict where that biota class would not be found and where it would have extremely poor ability to predict presences.

During both the 2008 and 2009 surveys, seagrass was observed with lower prevalence than 5% (3.4% in 2008 and 4.8% in 2009). However, an attempt to model the distribution of seagrass was made using the approach described in SKM (2010). Unfortunately, due to the very low prevalence across the study area, and the highly variable temporal distribution observed between the 2008 and 2009 surveys, the models were unable to define robust relationships between the environmental characteristics and the observed distributions. The seagrass models were unable to explain much of the variation in the observed distribution and the final models were dependent on which dataset was used to train the models, such that the relationships between the 2008 observed distribution of seagrass and the set of environmental characteristics differed from the relationships defined using the 2009 observed distribution data and the set of environmental characteristics. Such outcomes are clear indicators of unstable models and also suggest that there is a poor association between seagrass distribution and the set of environmental characteristics used as predictor variables.

While not conducive to modelling seagrass distribution, this result did highlight the highly variable nature of seagrass distribution in the James Price Point coastal area, whereas models for other

habitat types present in the region were relatively consistent across the two sampling periods (SKM, 2010; SKM, unpublished data).

The conclusion drawn was that there could be no confidence in the maps of seagrass distribution that could be developed from the model predictions. If predictions of probable seagrass distribution were made, the model could predict the distribution of absences very accurately, but would predict the presence of seagrass very poorly. This issue, coupled with the highly variable distribution of seagrass through time prevented the use of modelling to reliably predict and map seagrass distribution across the study area. No modelling results are therefore presented in this report.

The remaining approach was to compare the general trends in seagrass distribution and cover between 2008 and 2009, with specific comparisons made between those transects sampled in both 2008 and 2009 as described in Section 3.3.

3.3. Patch Analysis

To evaluate temporal variability of seagrass distribution and percent cover on a finer spatial scale, a selection of video transects that were observed to have seagrass in 2008 were repeated in 2009. The repeated transects in 2009 were designed to collect video footage along the same vessel course of the 2008 transects to determine if the seagrass patch had changed between survey times. A total of 20 towed video transects sampled in 2008 were repeated in 2009. Due to the difficulty of repeating previously sampled transects, two or three replicate tows were conducted for nine of those transects to allow some determination of whether sampling bias (i.e. the inability to navigate exactly along a pre-determined path) would influence a visual comparison of seagrass distribution in those areas. A detailed assessment of the presence, cover and apparent health of seagrass patches along each of the transects surveyed in 2008 and 2009 was made during video classification.

Given the fundamental differences in the objectives, sampling design, data collection methods and equipment used between the 2008 and 2009 surveys, no quantitative comparison of patch size or percent seagrass composition could be made, and direct comparisons of individual locations must be made with caution as there may be some variation in the spatial accuracy (geo-referencing) of the different towed video data. The objective of the 2009 survey was primarily to identify and sample seagrass distribution, whilst the 2008 survey aimed to provide a broad and even coverage of the area to produce a basic benthic substratum and biota community map (Fry *et al*., 2008).

4. Results

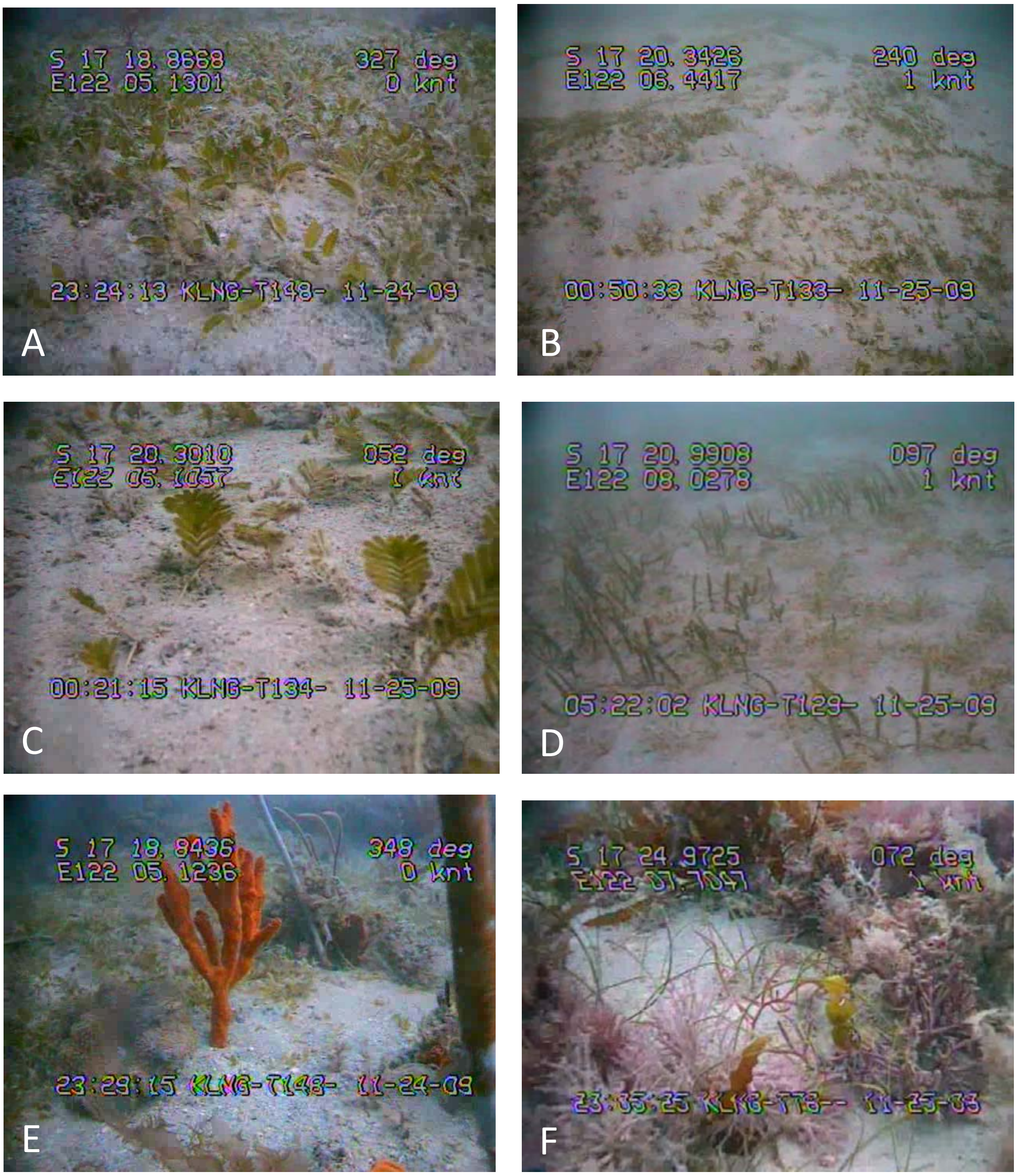
4.1. Seagrass Distribution and Cover

The general trends in seagrass distribution, percent cover and health that were observed while classifying the towed video footage were compared for the 2008 and 2009 surveys. It was difficult to consistently identify seagrass from the towed video footage due to the small size of some species, the smothering by epiphytes and microphytobenthos (MPB), and the shading from larger biota. However, *Halophila* was the dominant genus recorded and was the easiest to identify from the video footage. It was not possible to determine the species present, although *Halophila decipens*, *H. ovalis*, *H. ovate*, *H. minor* and *H. spinulosa* are common in tropical north-west waters and were assumed to be present in the study area (see Section 2.3). Other seagrasses possibly observed at some sites were *Halodule univervis*, *Cymodocea* spp. and *Syringodium* spp. These species were less commonly observed and in much sparser densities compared with *Halophila* spp.

Visual comparison of the 2008 and 2009 data suggests that there was a greater distribution and extent of seagrass in 2009 compared to 2008. This was particularly so for areas to the north of James Price Point.

In 2008, seagrass was more commonly observed growing on soft sediment in mixed communities between patches of hard substrate. These mixed communities consisted of seagrass with macroalgae and sessile invertebrates. Homogenous meadows of *Halophila* spp. were also observed in various densities and patch sizes (Figure 4). Seagrass was observed throughout the study area (Figure 5), but more commonly in the north and with a patch just south of James Price Point. Seagrass was surveyed at a depth range of 4.2-18.6 m, with percent cover ranging from 1-75%. The majority of seagrass was less than 5% or 5-25% in cover (Table 2) and Fry *et al*. (2008) reported a mean percent coverage of less than 6%. Overall, seagrass appeared to be sparse and patchy with no preference among depths or north-south distribution.

In 2009, seagrass was again observed throughout the study but more frequently north of James Price Point (Figure 6). As seen in 2008, seagrass was generally sparse, patchily distributed and often found in mixed habitats between areas of hard substrate. The depth range in which seagrass was observed in 2009 was 6.4-19.8 m. There were a few examples where a higher percent cover was observed in 2009 compared to 2008, but this was not the general pattern. Only five transects in 2009 contained seagrass with cover greater than 75%, while the majority of transects contained seagrass of less than 25% cover. Relatively more of the seagrass patches observed in the 2009 survey exhibited the lowest category of 1-5% cover.



- **Figure 4 Classified seagrass including, (A) dense *Halophila* sp. meadow, (B) sparse *Halophila* sp. meadow, (C) *Halophila spinulosa,* (D) *Halodule* sp., (E) *Halophila* sp with sessile invertebrates, and (F) a mixed community of macroalgae containing *Syringodium* sp.**

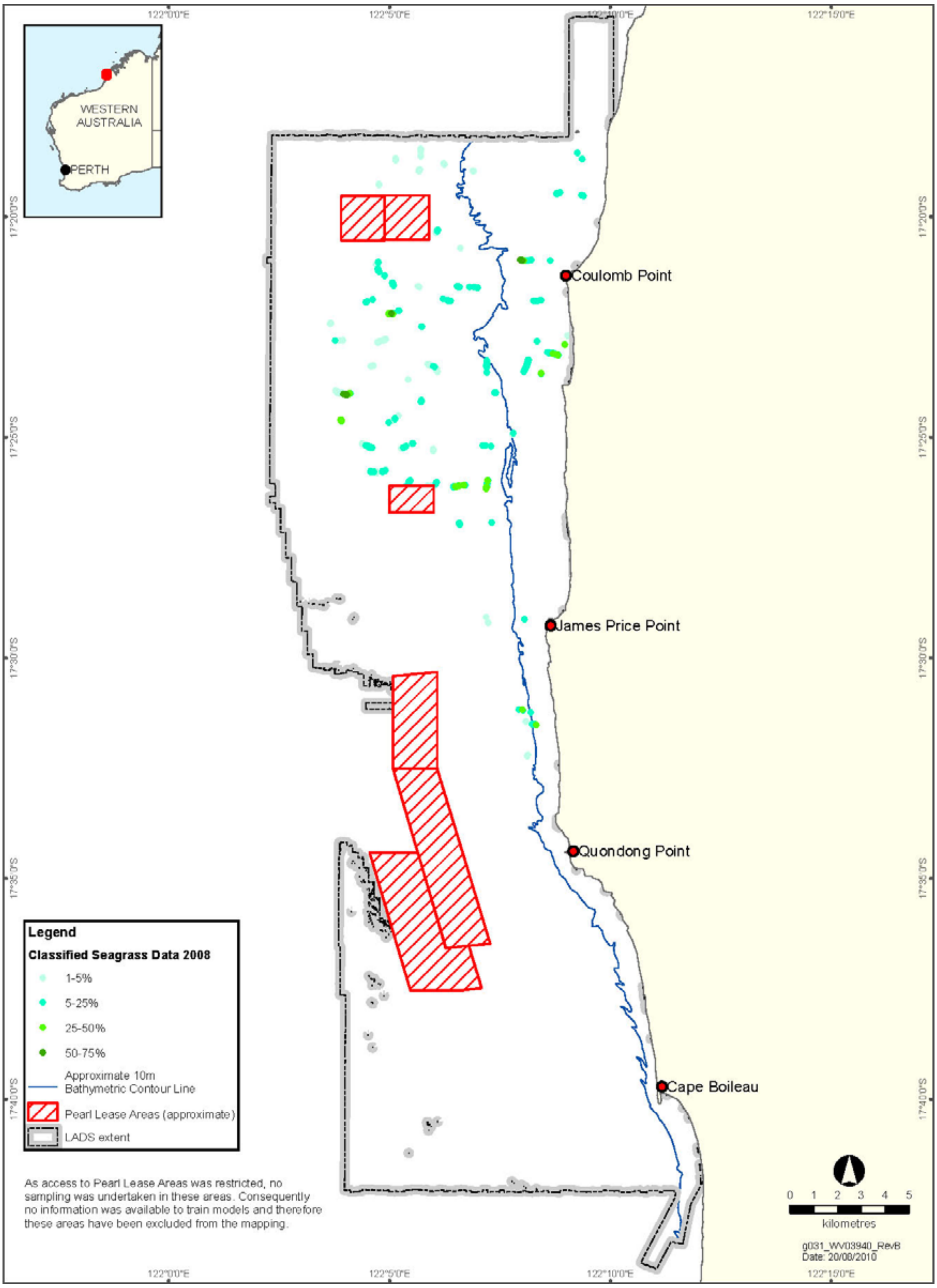
- **Table 2 The number and percent of GPS points classified for each seagrass density category for 2008 and 2009**

Category	2008 Count	2008 Percent	2009 Count	2009 Percent
Absent	29894	93.8	17313	85.1
1-5%	879	2.8	2092	10.3
5-25%	845	2.6	476	2.3
25-50%	148	0.5	291	1.4
50-75%	90	0.3	125	0.6
75-100%	0	0.0	43	0.2
Total	31856	100	20340	100

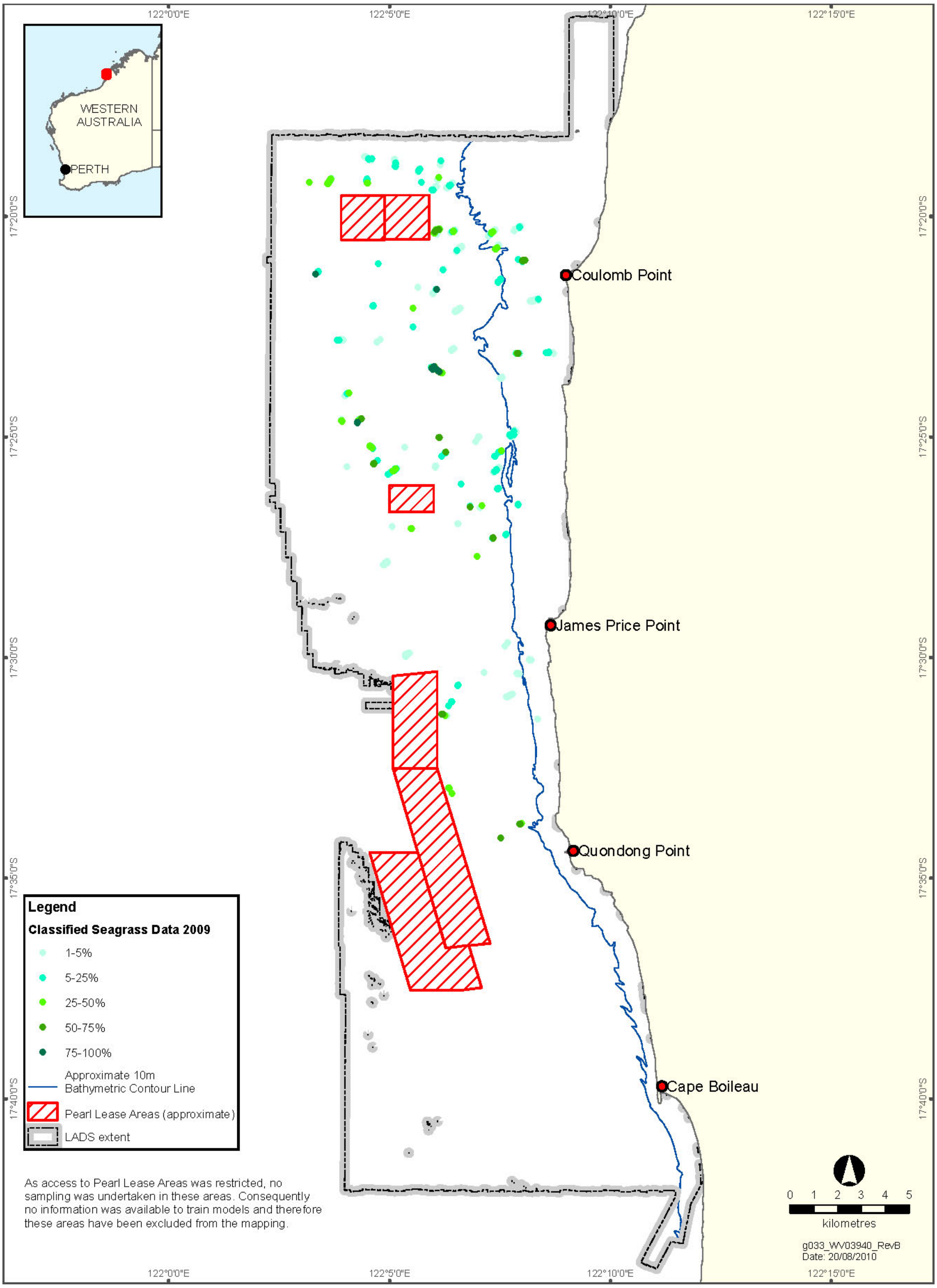
4.2. Patch Analysis of Temporal Differences between 2008 and 2009

Comparison of the seagrass patches observed along repeated transects between 2008 and 2009 indicated that the distribution and percent cover was highly variable in space and time. There was no consistent trend between years, with some repeated transects having similar distribution and percent cover between 2008 and 2009, while some had more (occurrence and cover) in 2008 and others more in 2009. Some transects were completely different, with seagrass no longer present in 2009, or not previously observed in 2008. Four locations where there were repeated transects were compared in detail and their location in the study area can be seen in Figure 7. The remaining repeated transects are shown in Appendix B. It should be noted that due to the spatial accuracy with which towed video surveys can be geo-referenced (i.e. 2008 survey conducted by Fry *et al* did not use differential GPS), some differences in spatial location of seagrass may be due to sampling error that cannot be resolved.

Figure 8 compares the seagrass distribution at one of the deeper sites that had seagrass and identifies that while the overall patch size was relatively consistent between 2008 and 2009 (approximately 100 m in a north-south direction), percent cover varied considerably between surveys. The cover at the north of the patch was higher in 2008 (5-25%) compared to 2009 (1-5%), while the southern part of the patch showed the reverse, with cover 25-50% in 2009 compared to 1-5% in 2008. The seagrass in 2009 appeared to have a greater amount of epiphytic growth compared to 2008 which may explain why the 2009 seagrass appeared to have reduced health and colour. It may be that the seagrass present at this site in 2009 was deteriorating with further deterioration/mortality possible in the future.



- **Figure 5 Distribution of classified seagrass percent cover from 2008 towed video data**



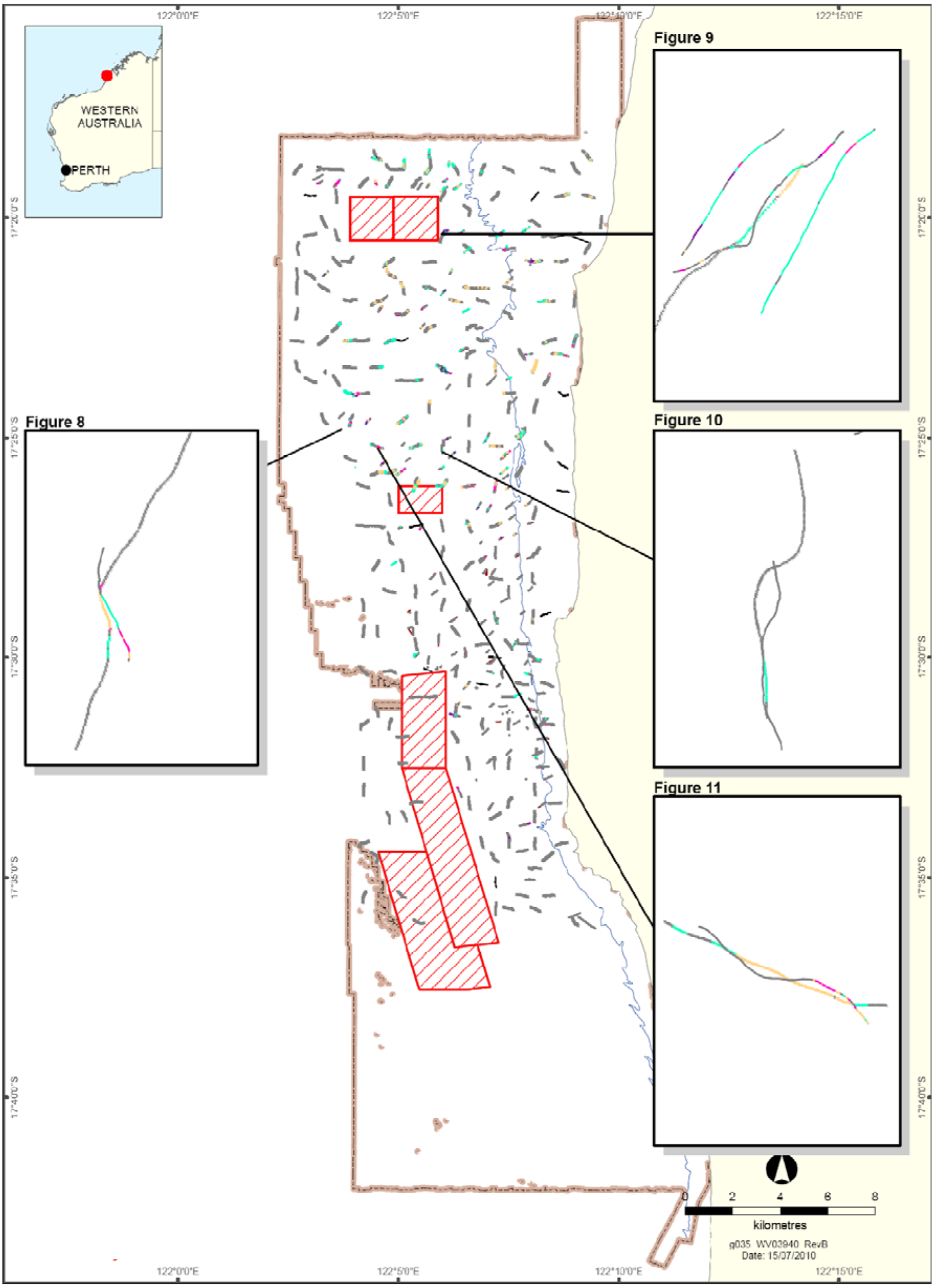
- **Figure 6 Distribution of classified seagrass percent cover from 2009 towed video data**

Figure 9 shows the repeated transects in the north of the study area and demonstrates the variable nature of seagrass in both space and time. While a continuous patch of seagrass of approximately 130 m long with 1-5% cover (up to 25-50%) was observed along the 2008 transect, the replicated transect in 2009 was nearly completely barren of seagrass. However, 50 m on either side of the 2009 transect, there were patches of seagrass with cover of 1-5% and 50-75% observed with a similar patch size to that seen in 2008. It is possible that positioning issues may influence comparisons and also that seagrass patches were not necessarily present between years, and that new areas are appearing at different locations. This is consistent with the biology of the species of the dominant genus, *Halophila*, and the likely role of seed germination as a recruitment strategy. The variation may also be in part due to the variability in the substrate/sediment thickness which results from the shifting sediment around this area. This result highlights how the sampling regime and design can influence the observed pattern of distribution for habitat classes with such variable distributions. It also highlights the potentially erroneous approach of assuming that areas between sampled locations will be the same habitat type, even over small distances.

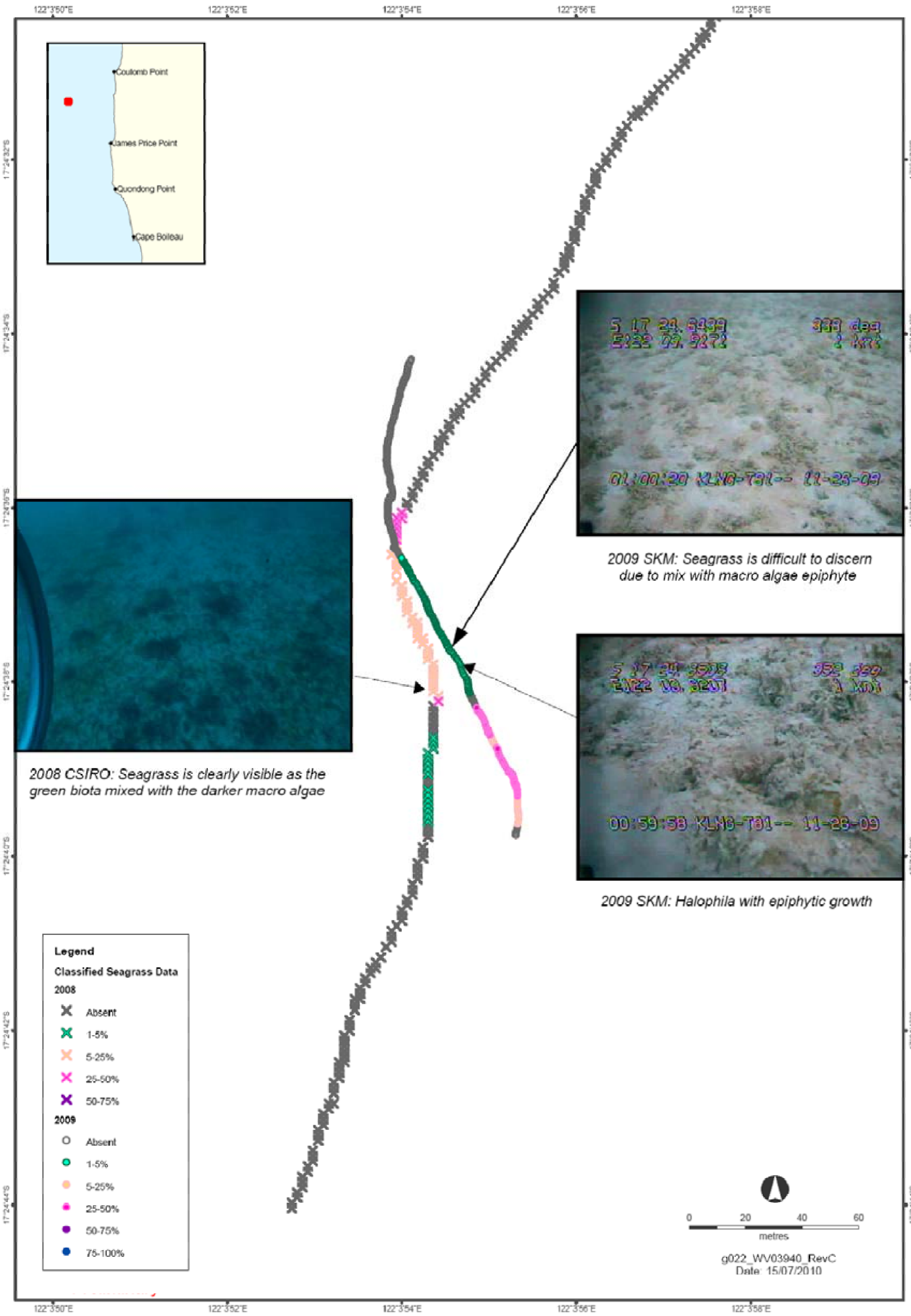
Another example where seagrass was observed in 2008, but not in 2009 is shown in Figure 8. In 2008, a 100 m long patch of 1-5% cover was recorded, but in 2009, no seagrass was recorded, only bare substrate.

The final comparison between repeated transects (Figure 11) shows an example where part of a seagrass patch observed in 2008 has disappeared, but another part of it has increased in cover from 5-25% to 25-50%. In 2009, the seagrass patch size was approximately 50 m long compared with 400 m in 2008 and the condition of the seagrass and macroalgae in 2009 appeared to be less healthy than in 2008. It was difficult to identify and accurately classify the percent cover of the seagrass from the video 2008 footage because it was coexisting in a mixed community of large macroalgae. However, it was clear that the seagrass patch size in 2008 at this site was larger compared to 2009.

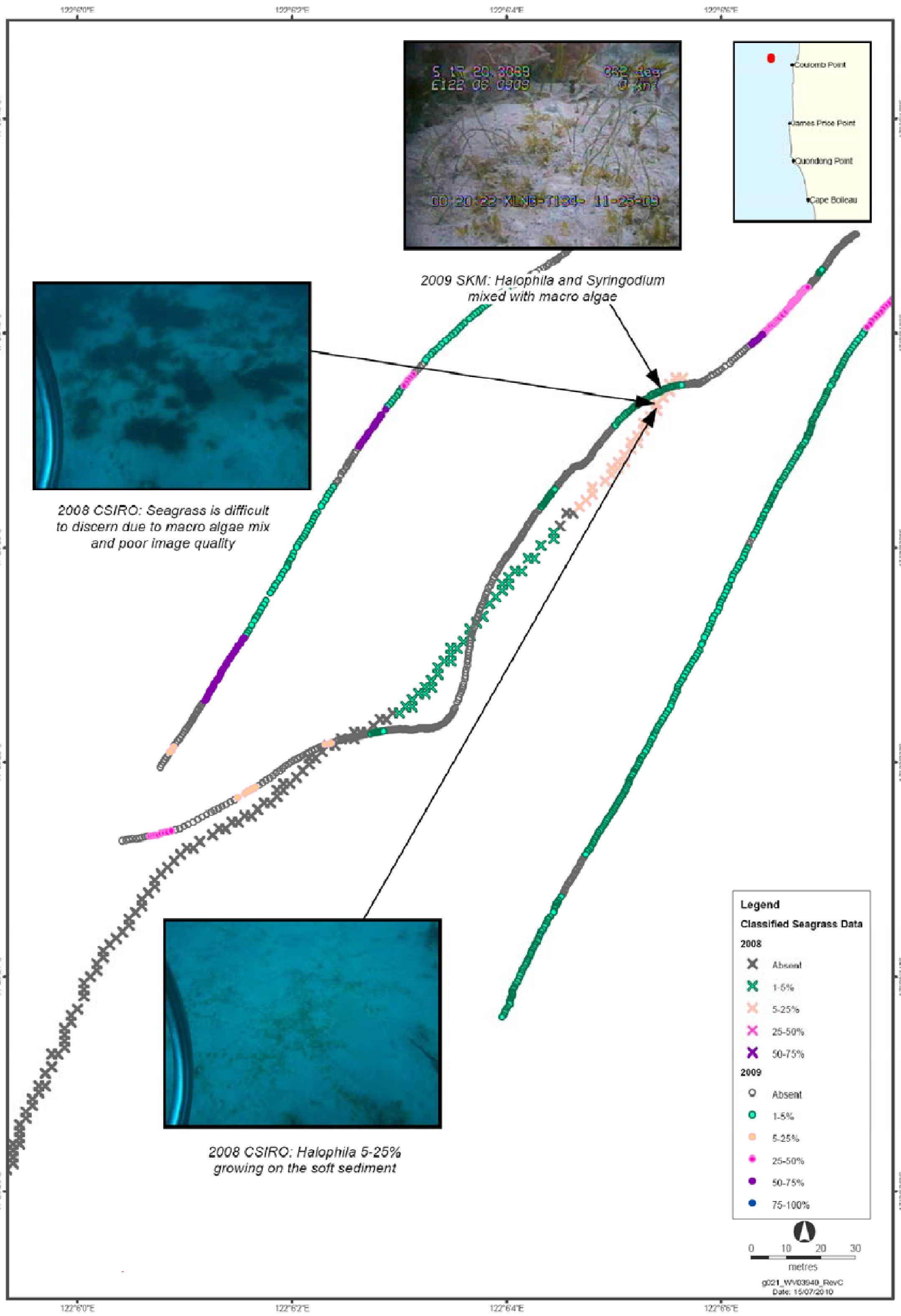
Similar patterns as described here were observed when comparing the other replicated transects from 2008 and 2009 that are shown in Appendix B.



■ **Figure 7 Location of the repeated transects included in patch analysis**



■ **Figure 8 Patch size and percent cover between 2008 and 2009**



- **Figure 9 Patch size and percent cover between 2008 and 2009**

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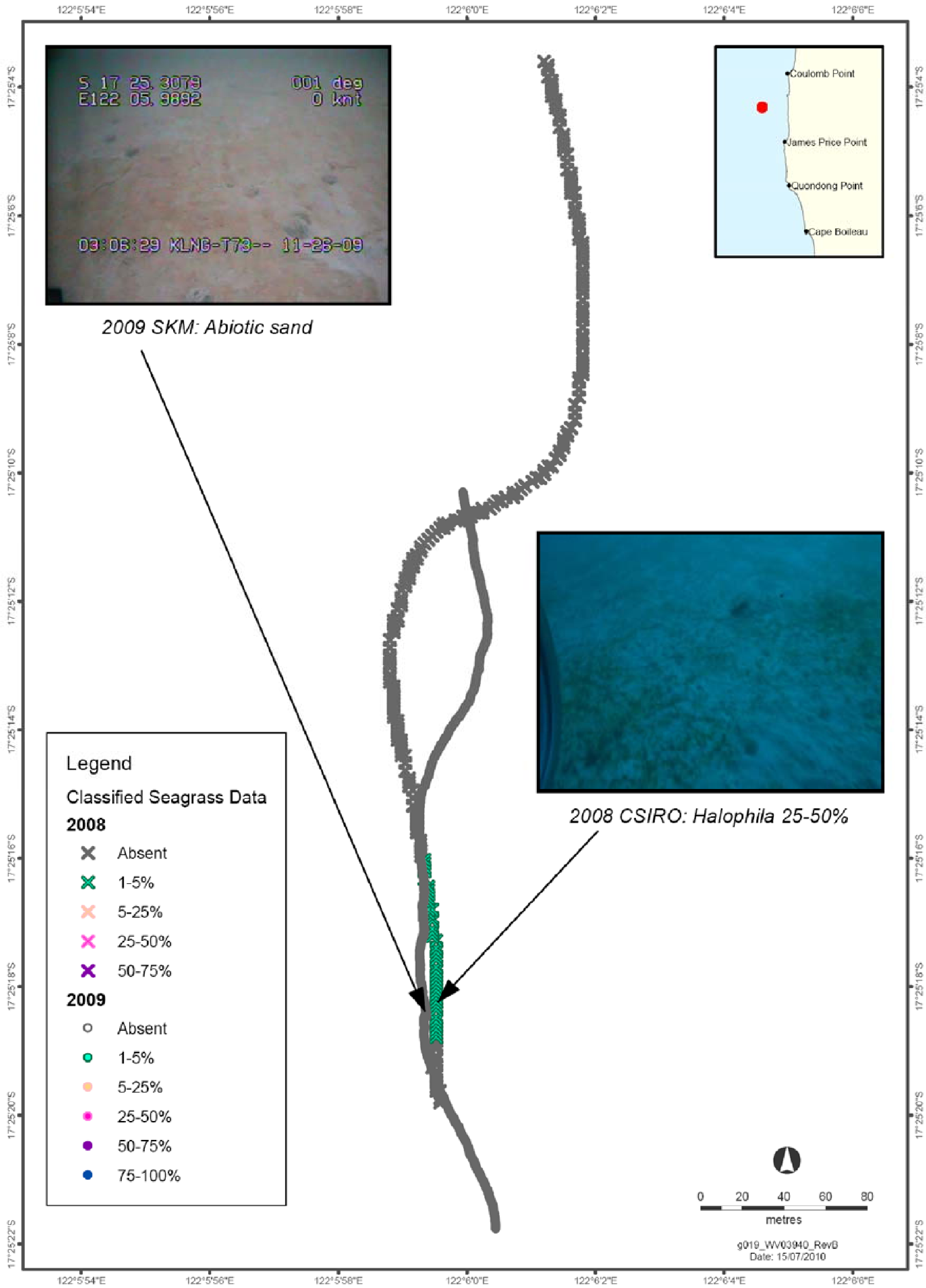
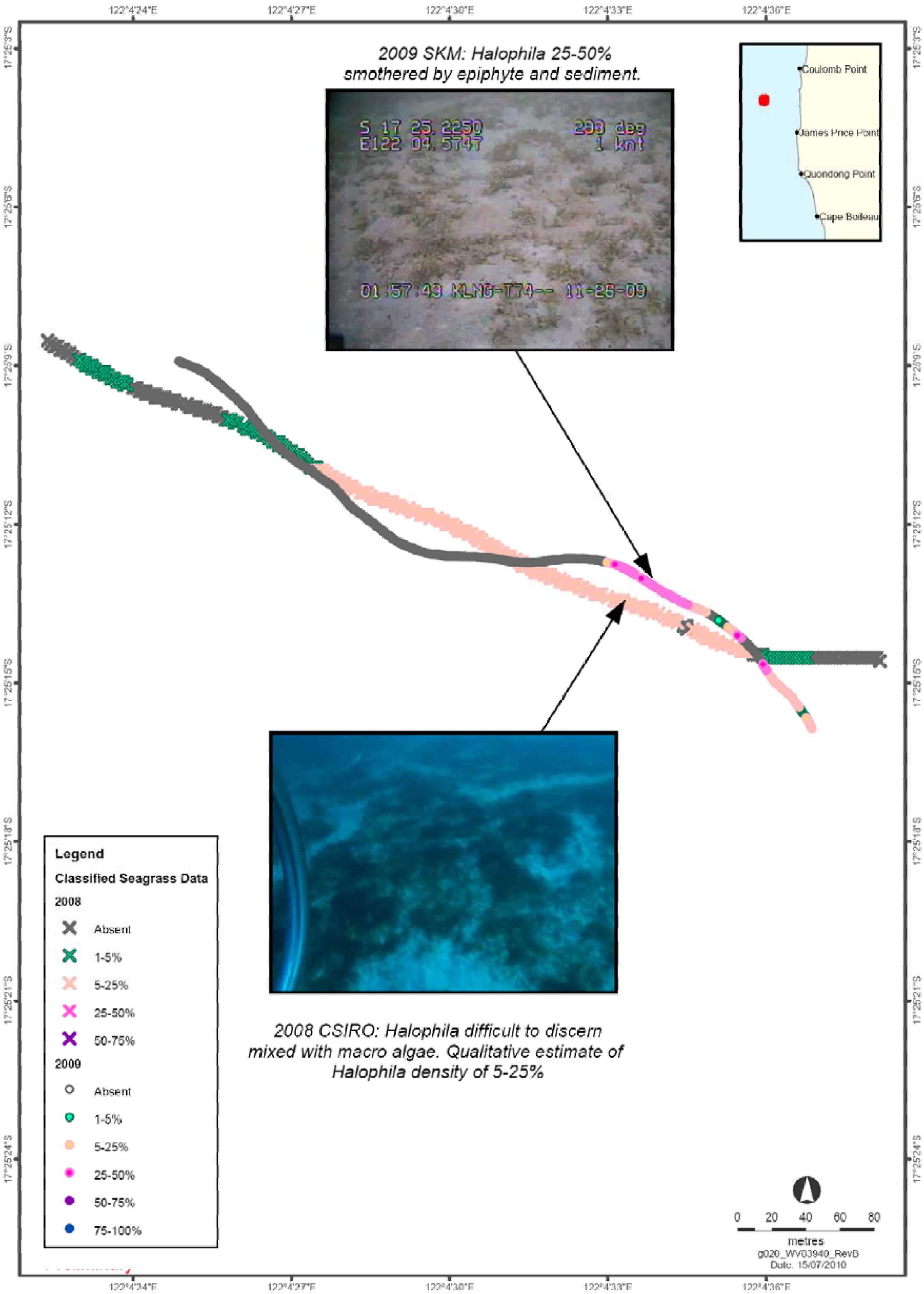


▪ **Figure 10 Patch size and percent cover between 2008 and 2009**



■ **Figure 11 Patch size and percent cover between 2008 and 2009**

5. Discussion

Comparing the observed distribution of seagrass in June 2008 with that observed in November 2009 has demonstrated that seagrass distribution within the James Price Point coastal area is highly variable in both space and time. Not only did seagrass vary in its spatial/temporal distribution over large areas (km), it also varied substantially across smaller areas (20-100 m). There was no consistent trend in how seagrass distribution varied between the two times with examples of patch size increasing with a reduction in percent cover, and examples where patch size decreased, but an increase in percent cover was observed. Some of the observations made in 2009 suggest that in some areas the health of seagrass was poor by comparison with observations made during 2008. This could be due to increased coverage of epiphytes (as observed), or it may be an indication that the seagrass has recently experienced prolonged periods of lower light availability due to increased turbidity (e.g. re-suspended sediment) that occurs in the area. Observations determined directly from video for each of the survey years are discussed below, followed by a comparison of patch differences between years and a discussion of what may explain the temporal variability and low cover of seagrass observed.

5.1. Observed Seagrass Distribution and Percent Cover in 2008 and 2009

The seagrass genera observed from video data collected during this study (*Halodule*, *Halophila* and *Syringodium*) have previously been reported from the region (Huisman and Borowitzka, 2003; Walker, 1997; 1996; 1995; 1992; Kenneally *et al.*, 1996). *Halophila* spp. were most commonly observed and appear to be the most common genera within the region. *Halophila decipiens* was the most common seagrass found in deeper waters and was also common in reef and sandy habitats (Irvine and Keesing, 2009). Fry *et al*. (2008) found *Halophila* spp. present from Quondong to Coulomb Point with coverage of between 1 and 6%.

Seagrass distribution was observed and classified to be patchy and sparse across the study area in both survey periods. This implies there is a high level of spatial variability of seagrass within the study area throughout the year. Seagrass is restricted to the soft sediments in the study area, but some of these areas may be unstable and so large amounts of sediment may be regularly mobilised and redistributed by storms and also by spring tides, creating and removing potential seagrass habitat with the shifting sediments. Thus, the potential habitat for seagrass at any given time may be quite broad given the large areas of sand obscured reef, particularly to the north of the study area and in the open areas of sediment within the central section. Genera such as *Halophila* are known to have a wide depth distribution from the mid-tidal level up to 60 m deep (Walker and Prince, 1987; Butler and Jernakoff, 1999). *Halophila* spp. were observed between approximately 6 and 20 m during the various field surveys undertaken in the area (Masini *et al.*, 2009), but the actual depth range occupied by these species in the area may be greater than the range observed.

Percent cover was generally less than 25% in both surveys and patches were usually interspersed among areas of hard substrate. Other studies within the region found generally sparse areas of seagrass, occurring in low abundance on shallow sandy sediments (Jones, 2004; Semeniuk *et al*., 1982). There were a few areas in both 2008 and 2009 surveys where extensive (500 m long), homogeneous *Halophila* spp. meadows were observed but these were rare. Seagrass was most often observed in very low densities (<5% cover), in mixed communities with algae and filter feeders. *Halophila* spp. typically utilise the space between other seagrass species or biota types forming mixed beds, although they can form exclusive beds (Huisman, 2000).

5.2. Temporal Differences Between 2008 and 2009 Surveys

The towed video survey conducted in November 2009 by SKM provided data representative of the early wet (summer) season, for a temporal comparison with that collected in June 2008 (Fry *et al*., 2008). A combination of visual comparisons between classified data and patch analysis were used to assess the degree of temporal variation between the 2008 and 2009 surveys.

In this study towed video surveys were conducted in two different years (2008 and 2009) as well as in two different seasons (June and November). Thus, observed variation may not only be a result of seasonal trends, but inter-annual changes and general natural variation. Non-periodic weather events operating within the study area could contribute to temporal variability. For example, storms, cyclones and general differences in water temperature, irradiance levels and nutrient availability can all contribute to changes in the distribution and percent cover of seagrass from year to year (Short *et al*., 2001). In December 2008, ex tropical cyclone Billy passed close to the James Price Point coastline before moving out to sea and re-intensifying (http://www.bom.gov.au/cyclone/history/wa/2009.shtml). The passage of this storm so close to the study area is likely to have had some effect on shallow water habitats along the coastline.

Studies at other sites in Western Australia found short and long term changes in the seagrass communities of Exmouth Gulf (Lehnert *et al*., 2003 in Loneragan *et al*., 2003). Long term increases in species richness and extent were attributed to succession processes following a cyclone disturbance, whilst short term changes were part of the seasonal cycle of seagrass communities. Loneragan *et al*. (2003) found a dramatic increase in biomass within a year between October and November suggesting a seasonal cycle in above ground biomass and likely influenced by the fast growing species that were present in the Gulf, such as *Halophila spinulosa*, *H*. ovalis and *H. uninervis*.

The distribution of seagrass varied between 2008 and 2009 but was not always consistent across the study area. Some patches declined while new areas appeared. In addition, some individual patches of seagrass appeared to be stable, while new beds were appearing suggesting a complex interaction between temporal variability and general spatial variability of seagrass within the study

area. New, medium density areas were sampled in the north of the study area in 2009 that were not present in 2008. In contrast, some repeated transects had seagrass in 2008 but bare substrate in 2009. Growth in *Halophila* spp. is more commonly via asexual reproduction of rhizomes that extend laterally (Rasheed, 2004), suggesting that areas of seagrass will expand and contract in size between seasons. However, some reproduction also occurs through sexual recruitment via seed production. Fruits of *H. ovalis* are known to develop on rhizome nodes of the female plants during summer to autumn (February to April) in southern Western Australia (Kuo and Kirkman, 1992). *Halophila ovalis* and *H. uninervis* appear to be the most successful at re-colonisation of bare plots, isolated from asexual colonisation, through production of sexual propagules (Rasheed, 2004). Thus new areas previously bare in 2008 could have been colonised between the surveys.

Temporal variability in the distribution and abundance of seagrass has been documented elsewhere in tropical Australia (Duarte *et al*., 2006; Lehnert *et al*., 2003; Short *et al*., 2001; Kenyon *et al*., 1997; Lanyon and Marsh, 1995). Generally, species were found to peak during summer (November to March) through an increase in abundance of new growth in spring (September to November) (Lanyon and Marsh, 1995). Further sampling in the present study area towards the end of summer (February and March) may therefore reveal a much greater area of seagrass as new growth associated with the onset of summer may only just be appearing in November.

Previous surveys (Fry *et al.*, 2008; Masini *et al*., 2009) were undertaken at the beginning of summer and found areas of dense *Halophila* spp. with high biomass in November 2007 followed by a repeat survey in April 2008 during which no sea grass was recorded (unpublished data 2007; 2008). These observations fit the seasonal abundance model, although the absence of seagrass as early as April suggests that factors other than light and temperature may have been responsible (e.g. storms/cyclones). The areas devoid of seagrass in April 2008 were found to have seagrass present in June 2008, with a further increase in December 2008. The appearance of new areas of seagrass in June 2008 on areas that were devoid of seagrass in April suggests that seasonal trends may not always be obvious, and may be masked by the influence of other factors. The prolific seed production observed in December 2008 suggests that recruitment from seed may be an important process in these communities (Masini *et al*., 2009). The capacity of *Halophila* spp. to rapidly colonise areas denuded of sea grass has been documented, for example a study by Nakaoka and Aioi (1999) found that it took two months for a patch within a seagrass bed that was removed of *H. ovalis* to reach the same state of colonisation prior to disturbance. Growth of this species is typically fast and temporal change can occur rapidly over a period of months.

Due to the highly variable nature of dominant *Halophila spp*. and the very low prevalence of seagrass across the study area (3.4% in 2008 and 4.8% in 2009), the predictive modelling approach described in SKM (2010) was unable to define and model the environmental conditions in which seagrass would be found from the classified video data. Therefore, it was not possible to reliably model and map the predicted distribution of seagrass from the survey data from both years.

Minimum modelling requirements typically demand greater than 5% prevalence within a dataset to accurately define and map distributions (Fielding & Bell, 1997). If a distribution is sparse in cover but widespread geographically over an area with little topographic complexity, the difficulties in modelling are exacerbated. Such is the case for seagrass within the James Price Point coastal area.

Individual patch analysis allowed comparisons of seagrass at the same locations and over the same areas between 2008 and 2009. Video footage suggests that some patches of seagrass appeared dense and healthy in 2008 but were smothered in epiphytic growth in 2009. Biological factors such as epiphytic growth, predation and competition can also influence the spatial and temporal variability of seagrass (Short *et al*., 2001). These pressures may have contributed to a reduced patch size along some transects from 2008 to 2009. Sampling precision may also have been a factor on patch size, as the 2008 survey did not use differential GPS. This may have resulted in a shift in positioning of up to 10 metres in the location of video transects.

6. Conclusions

Results from this study suggest that seagrass communities within the James Price Point coast area were highly spatially variable, patchily distributed and generally sparse in cover. Overall, it was not possible to draw a conclusion that a significant seasonal increase in seagrass distribution occurred, when comparing between a dry season (winter) survey (June 2008) and a wet season (summer) survey (November 2009), as has been previously reported for similar communities elsewhere in the tropics. However, a clear indication of temporal variability between surveys was present. Trends in variability were inconsistent across the study area as some patches of seagrass were larger in 2009, while others were smaller.

Similarly, the percent cover within seagrass patches was also observed to be variable between surveys. A greater proportion of the patches of seagrass observed in 2009 were classified as comprising 1-5% cover relative to the 2008 survey results. There was a slight increase in the number of points classified within the denser categories of cover (>50%). The patches of seagrass were also spatially variable and patches observed in the June 2008 data were often absent in the November 2009 data, while new patches were also present in the 2009 data.

Seagrass distribution was sparse in cover but widespread geographically over an area with little topographic complexity or defining environmental characteristics. Therefore, it was not possible to reliably model and map the predicted distribution of seagrasses across the study area from both years. Unfortunately, this objective was not achieved. Difficulties in defining seagrass distribution were exacerbated by the dominance of *Halophila* species that are by nature highly variable in space and time.

Temporal differences are likely to play a substantial role in the observed differences and further sampling within seasons may assist in confirming likely distribution patterns, particularly in low coverage conditions dominated by ephemeral species. Sampling precision between surveys may also contribute to the differences in distribution observed, with it being difficult to sample the exact location twice due to differences in currents and tides during sampling, as well as potential geo-referencing issues. However, both surveys indicate that on the whole seagrass cover is low within the study area.

An array of factors such as temperature, salinity, water and sediment movement, depth, light availability, nutrients and substrate type are also likely to be important in limiting distribution and cover of seagrass, along with interactions such as epiphytic growth, predation and competition. In light of these multiple factors, isolating particular patterns in spatial variation of cover and understanding why temporal differences may or may not occur is likely to be difficult to definitively determine without repeated seasonal sampling within and across years. While there was some evidence of similar patches being present from one survey to the next, persistence of

dense seagrass meadows was not observed. It is expected use of DGPS and repeated sampling would improve understanding of the possible changes in seagrass boundaries (e.g. of meadows) through time, although again the overall sparse, widespread coverage of seagrass observed in both studies suggest this may be difficult.

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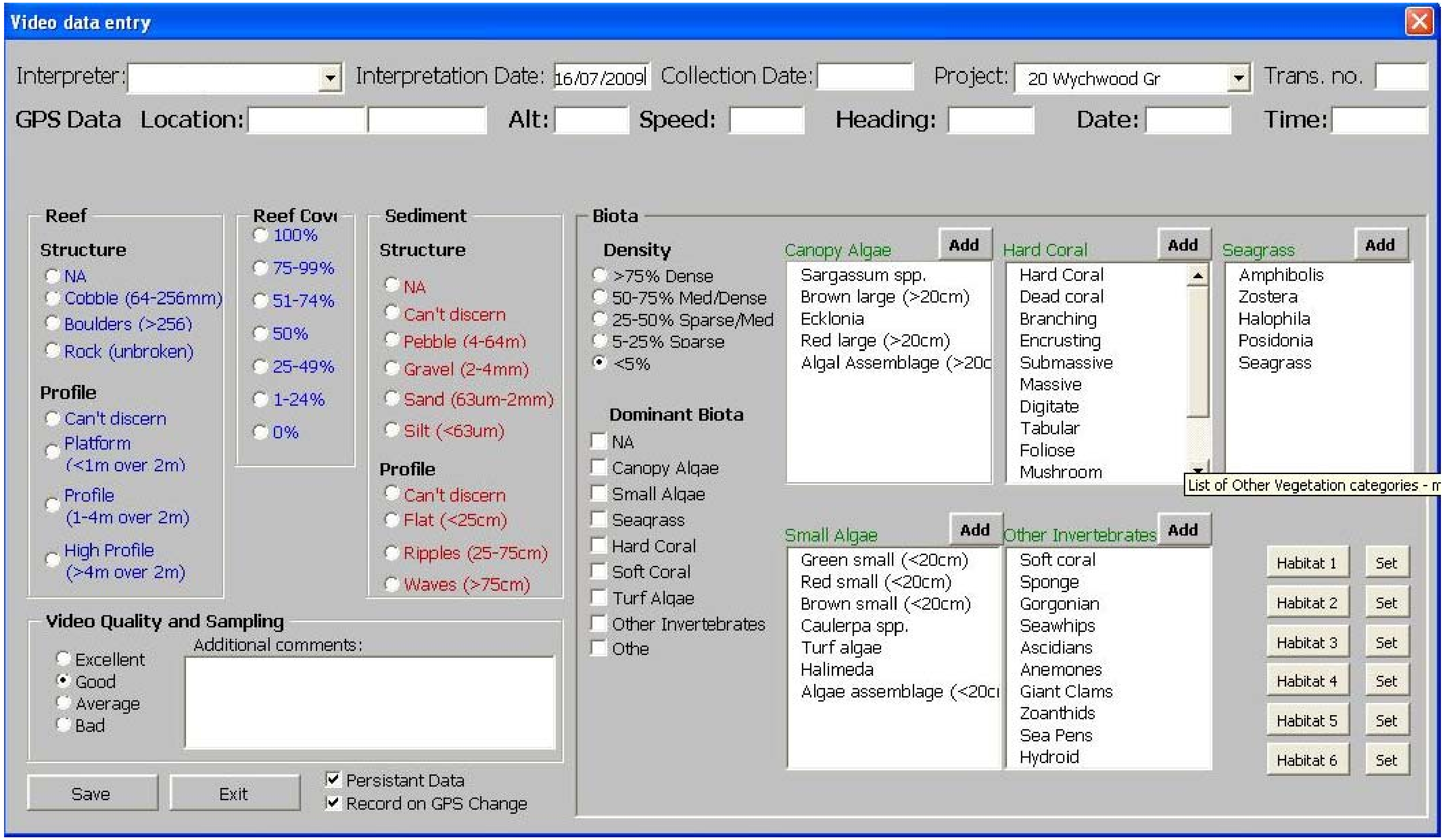
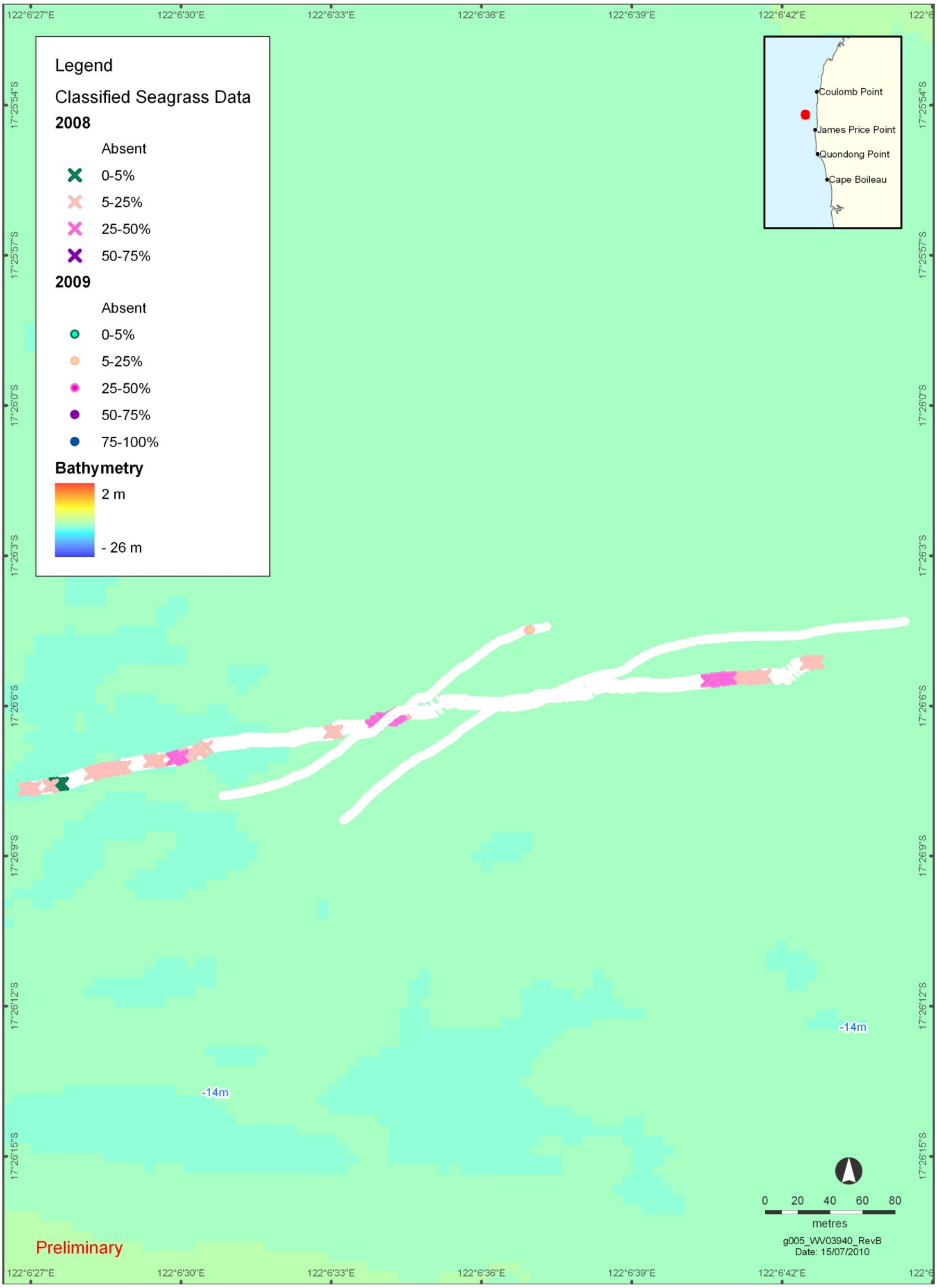
Appendix A Custom Visual Basic Software Interface



Appendix B Patch Comparisons Along Transects Between 2008 and 2009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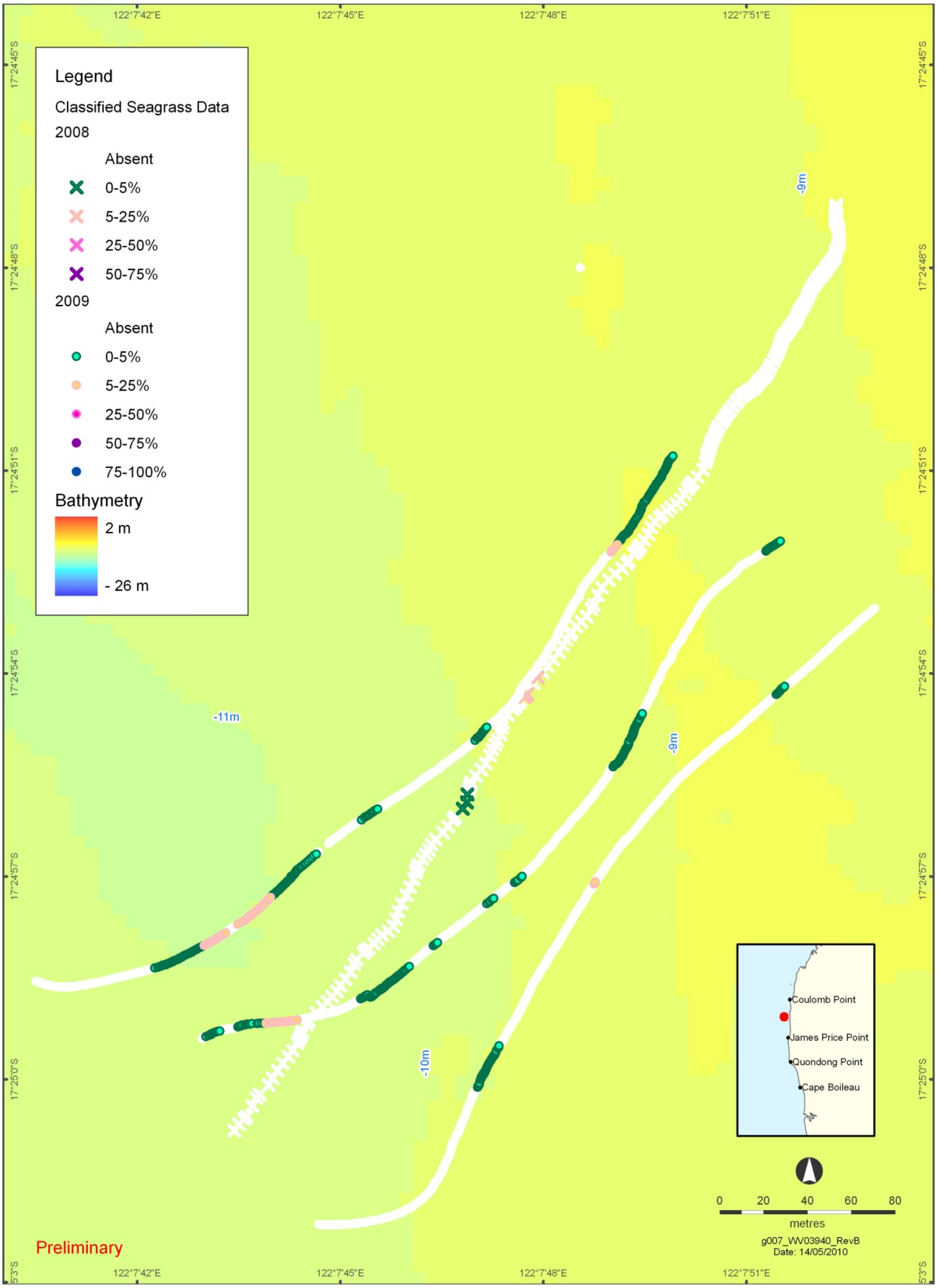
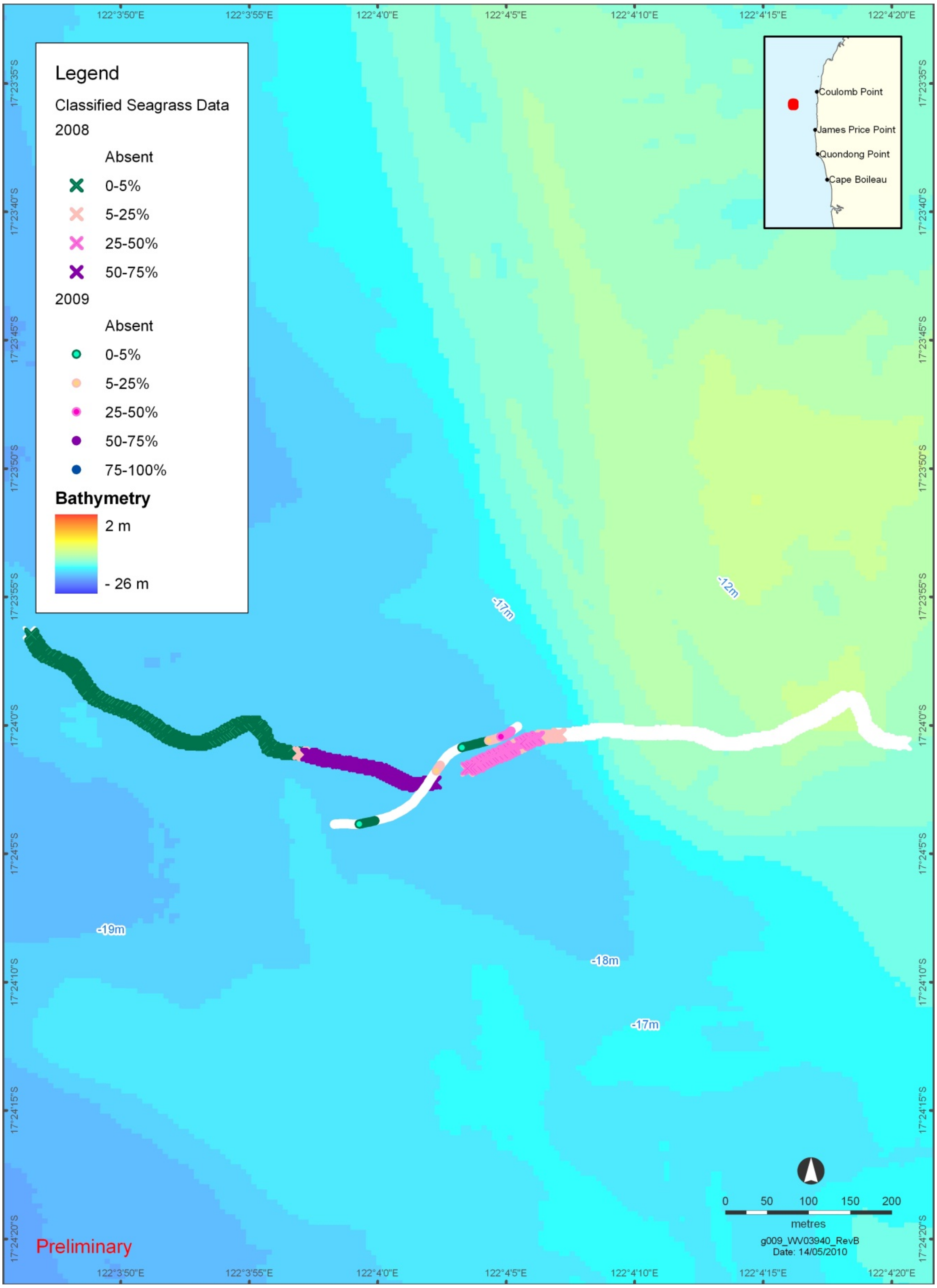
Classified Seagrass Data
2008
Absent
0-5%
5-25%
25-50%
50-75%
2009
Absent
0-5%
5-25%
25-50%
50-75%
75-100%
Bathymetry
2 m
- 26 m
Coulomb Point
James Price Point
Quondong Point
Cape Boileau
122°6'27"E
122°6'30"E
122°6'33"E
122°6'36"E
122°6'39"E
122°6'42"E
17°25'54"S
17°25'57"S
17°26'0"S
17°26'3"S
17°26'6"S
17°26'9"S
17°26'12"S
17°26'15"S
-14m
-14m
0 20 40 60 80
metres
g005_WV03940_RevB
Date: 15/07/2010
Preliminary



122°7'42"E
122°7'45"E
122°7'48"E
122°7'51"E
17°24'45"S
17°24'48"S
17°24'51"S
17°24'54"S
17°24'57"S
17°25'0"S
Legend
Classified Seagrass Data
2008
Absent
0-5%
5-25%
25-50%
50-75%
2009
Absent
0-5%
5-25%
25-50%
50-75%
75-100%
Bathymetry
2 m
- 26 m
-9m
-11m
-10m
Coulomb Point
James Price Point
Quondong Point
Cape Boileau
0 20 40 60 80
metres
g007_WV03940_RevB
Date: 14/05/2010
Preliminary



Legend
Classified Seagrass Data
2008
Absent
0-5%
5-25%
25-50%
50-75%
2009
Absent
0-5%
5-25%
25-50%
50-75%
75-100%
Bathymetry
2 m
- 26 m
Coulomb Point
James Price Point
Quondong Point
Cape Boileau
-17m
-12m
-19m
-18m
-17m
0
50
100
150
200
metres
g009_WV03940_RevB
Date: 14/05/2010
Preliminary
122°3'50"E
122°3'55"E
122°4'0"E
122°4'5"E
122°4'10"E
122°4'15"E
122°4'20"E
17°23'35"S
17°23'40"S
17°23'45"S
17°23'50"S
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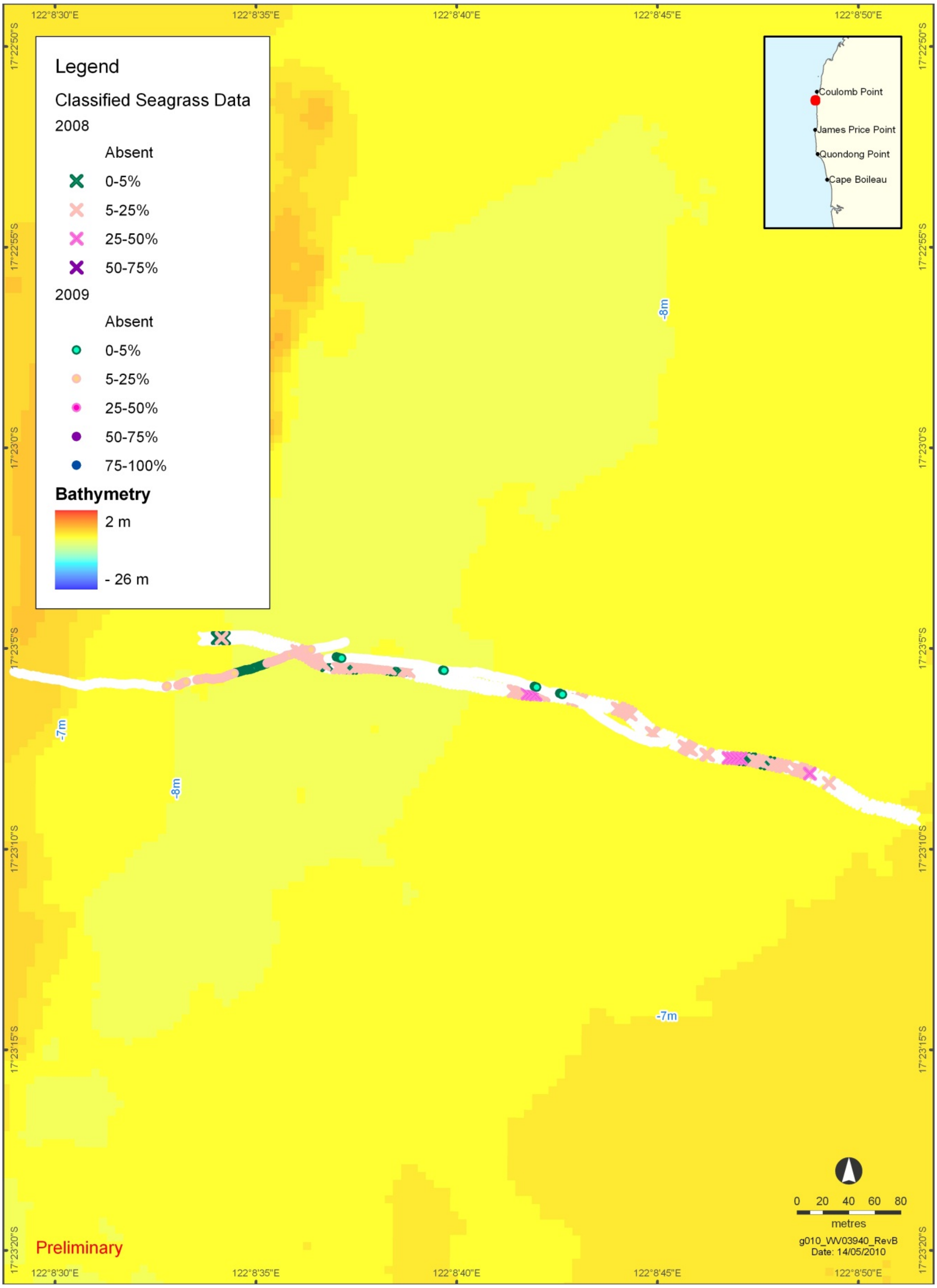
17°24'20"S



Legend
Classified Seagrass Data
2008
Absent
0-5%
5-25%
25-50%
50-75%
2009
Absent
0-5%
5-25%
25-50%
50-75%
75-100%
Bathymetry
2 m
- 26 m
Coulomb Point
James Price Point
Quondong Point
Cape Boileau
-8m
-7m
-8m
-7m
0 20 40 60 80
metres
g010_WV03940_RevB
Date: 14/05/2010
Preliminary
122°8'30"E
122°8'35"E
122°8'40"E
122°8'45"E
122°8'50"E
17°22'50"S
17°22'55"S
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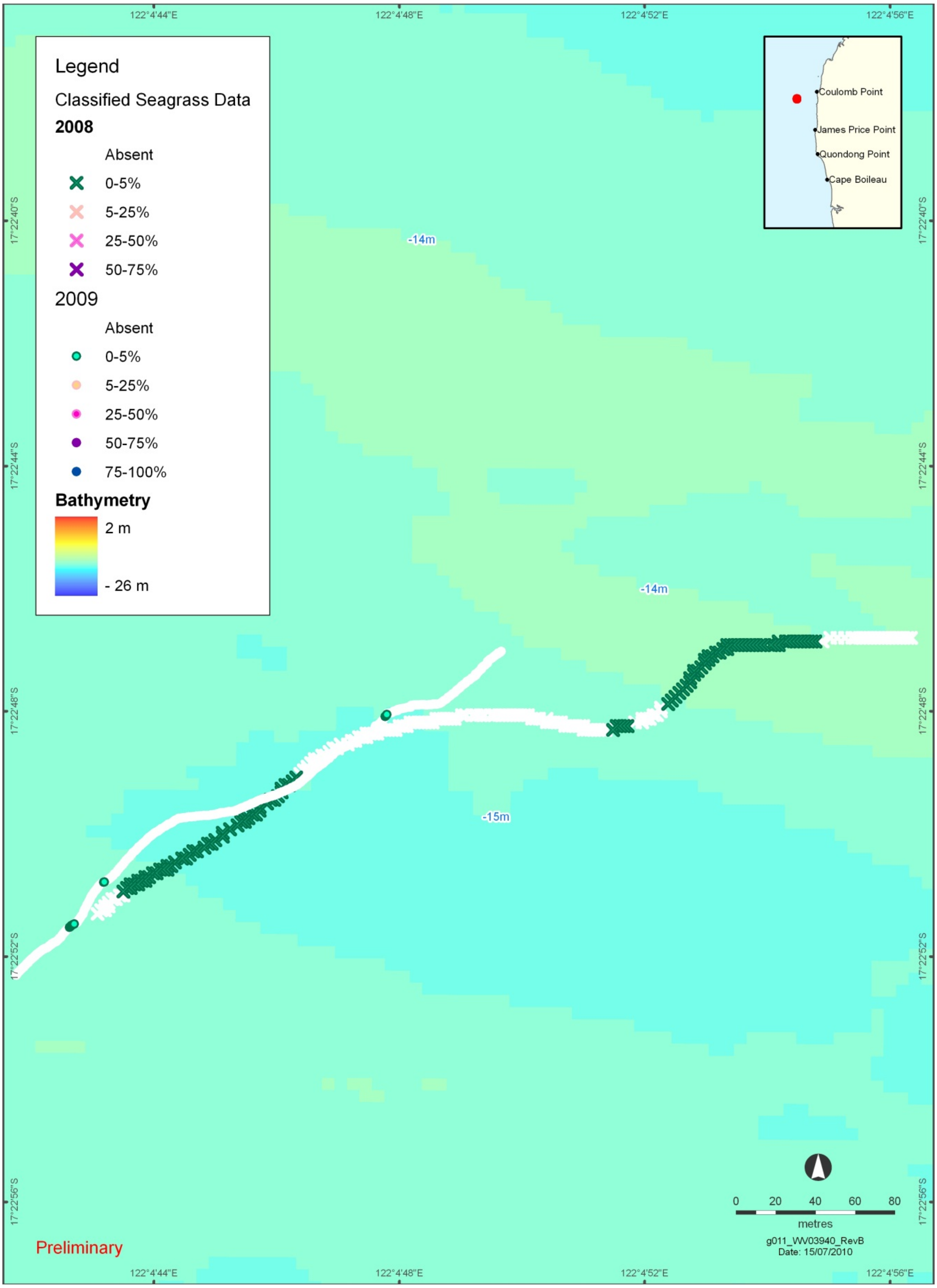
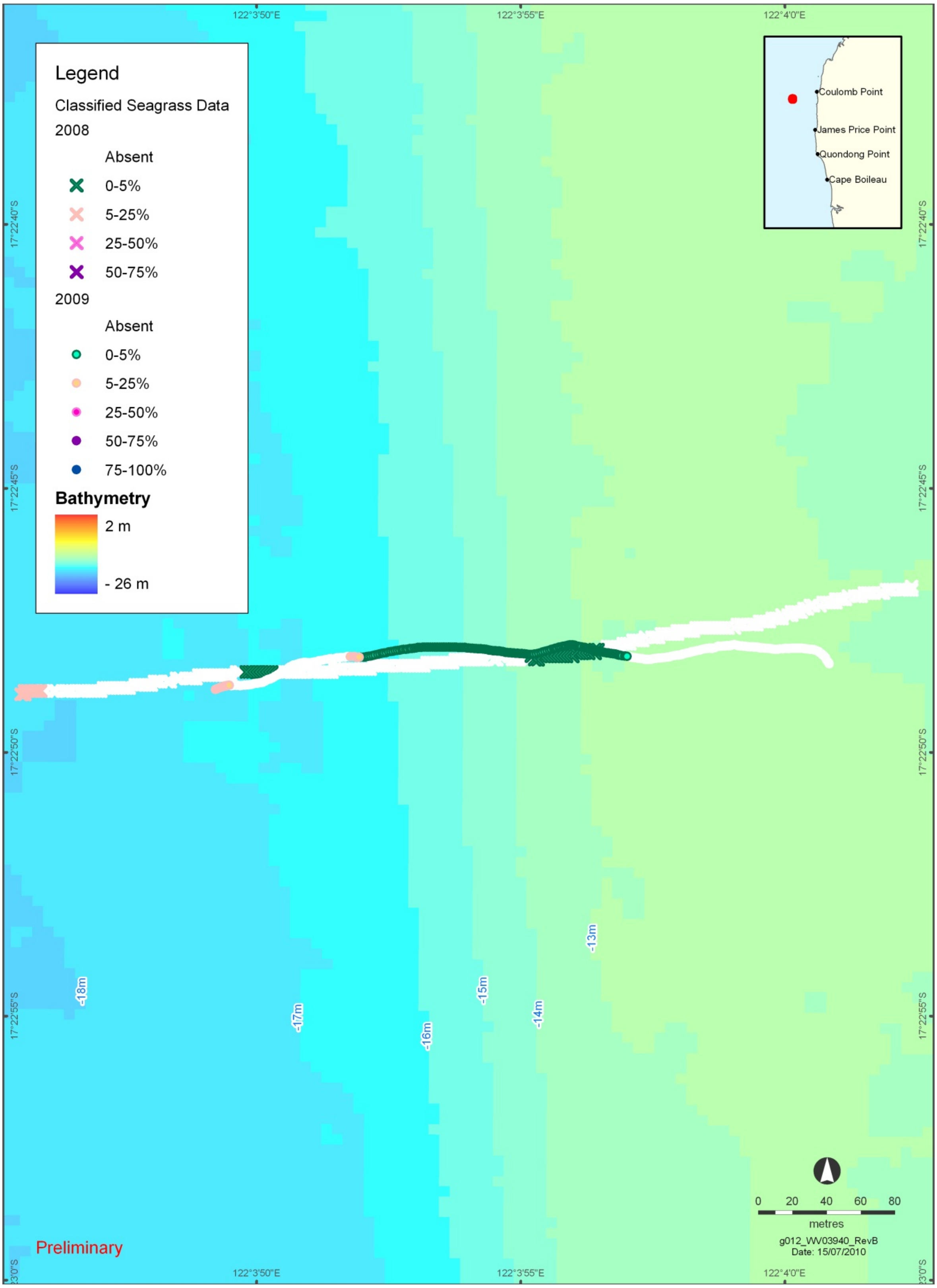
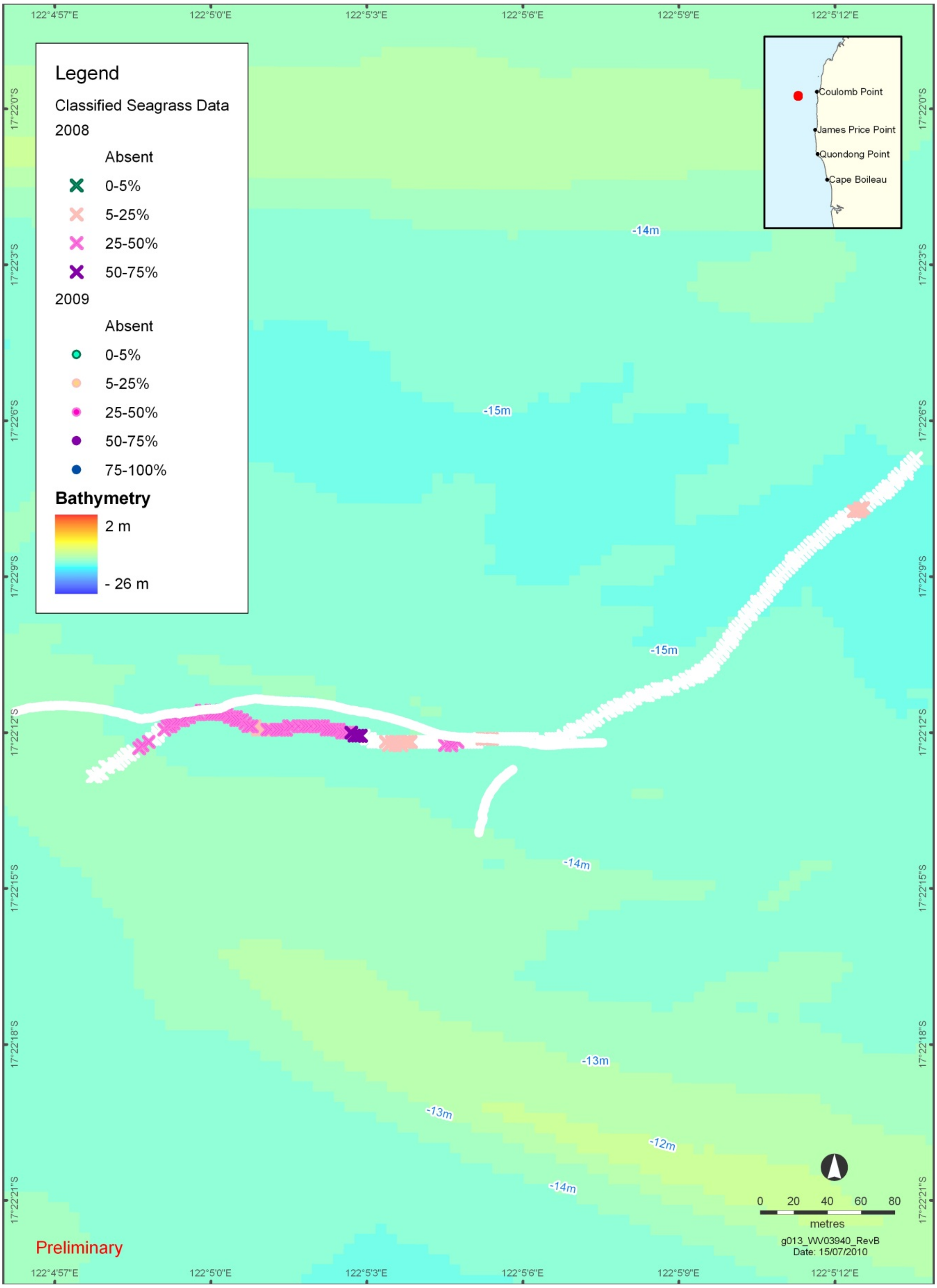
17°23'15"S
17°23'20"S



122°4'44"E
122°4'48"E
122°4'52"E
122°4'56"E
17°22'40"S
17°22'44"S
17°22'48"S
17°22'52"S
17°22'56"S
Legend
Classified Seagrass Data
2008
Absent
0-5%
5-25%
25-50%
50-75%
2009
Absent
0-5%
5-25%
25-50%
50-75%
75-100%
Bathymetry
2 m
- 26 m
Coulomb Point
James Price Point
Quondong Point
Cape Boileau
-14m
-14m
-15m
0 20 40 60 80
metres
g011_WV03940_RevB
Date: 15/07/2010
Preliminary


122°3'50"E
122°3'55"E
122°4'0"E
Legend
Classified Seagrass Data
2008
Absent
0-5%
5-25%
25-50%
50-75%
2009
Absent
0-5%
5-25%
25-50%
50-75%
75-100%
Bathymetry
2 m
- 26 m
Coulomb Point
James Price Point
Quondong Point
Cape Boileau
17°22'40"S
17°22'45"S
17°22'50"S
17°22'55"S
-18m
-17m
-16m
-15m
-14m
-13m
0 20 40 60 80
metres
g012_WV03940_RevB
Date: 15/07/2010
Preliminary



Legend
Classified Seagrass Data
2008
Absent
0-5%
5-25%
25-50%
50-75%
2009
Absent
0-5%
5-25%
25-50%
50-75%
75-100%
Bathymetry
2 m
- 26 m
Coulomb Point
James Price Point
Quondong Point
Cape Boileau
-14m
-15m
-13m
-12m
0 20 40 60 80
metres
g013_WV03940_RevB
Date: 15/07/2010
Preliminary