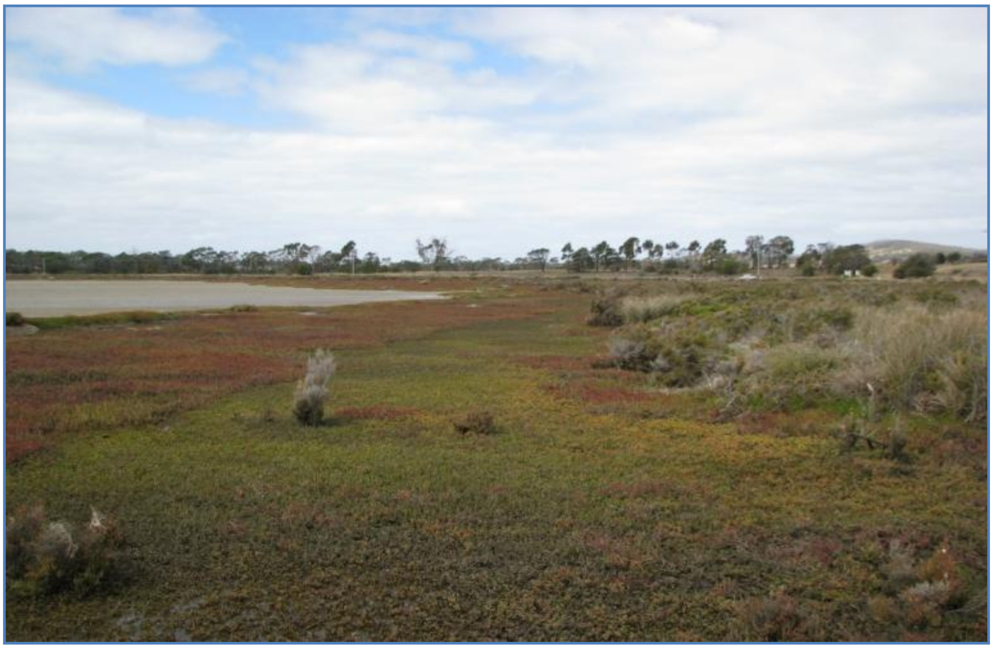
The Future of the Derwent Estuary Saltmarshes and Tidal Freshwater Wetlands in Response to Sea Level Rise



Initiated by

Derwent Estuary Program

Funded by

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Dr Jason Whitehead from the Derwent Estuary Program initiated the project and provided guidance throughout the course of the project. NRM South provided the funding for the project. Jill Pearson from NRM South provided support in the initial planning stages of the project and organised funding from the NRM side. Megan Carroll from the Research Office Commercialisation Unit of the University of Tasmania facilitated the contractual arrangements. Professor Jamie Kirkpatrick, School of Geography and Environmental Studies, University of Tasmania, provided thoughts and comments during the course of the project. Dr Kathleen McInnes (CSIRO) provided the storm tide data.

PROJECT OUTPUTS

The project generated six vector layers:

1. SM_Current_Extent_2005_MGA55: current extent of tidal wetlands in the Derwent Estuary.
2. SM_Future_Extent_2100_MGA55: modelled future extent of tidal wetlands (wetland refugia) in the Derwent Estuary.
3. Derwent_TideRange_0SLR_MGA: the approximate present day mean high tide mark as extrapolated from tidal range provided by the National Tidal Centre.
4. Derwent_1in100ST_0SLR_MGA: 1 in 100 year storm tide without sea level rise.
5. Derwent_1in100ST_82cmSLR_MGA: 1 in 100 year storm tide plus 82 cm sea level rise.
6. Derwent_1in100ST_110cmSLR_MGA: 1 in 100 year storm tide plus 110 cm sea level rise.

The project involved running inundation modelling for the entire estuary, and produced grid files in ESRI ArcGIS format for each of the scenarios modelled.

DISCLAIMER

It must be noted that this project is only a preliminary assessment of the future extent of tidal wetlands in the Derwent Estuary. The areas depicted as future saltmarsh and freshwater tidal wetland refugia are only indicative of where favourable conditions (i.e. tidal inundation) might prevail in the future to allow the establishment of marsh plants over other vegetation communities. The modelled future extent does not take into account factors such as sedimentation, wind-wave modelling, vegetation associations, historical change analysis or anthropogenic threats. Also, no ground truthing has been done as a part of the project. Hence, while the outputs from this project may provide an important first step in assessing the future conservation needs of Derwent Estuary tidal wetlands in the face of accelerated sea level rise, further work might be in order to substantiate these findings and improve our understanding of these highly dynamic coastal environments in time of change.

The University of Tasmania uses reasonable means to verify the validity and accuracy of the data contained herein at the date of this report, however to the extent allowed by law, it does not warrant or represent that the data will be correct, current, fit/suitable for a particular purpose or not-misleading. Specifically, the data should not be relied upon (that is, professional advice should be sought) if that data is to be used for purposes outside the scope of this project, such as for assessing inundation potential.

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Cover photo: Saltmarsh vegetation zonation in the Lauderdale area of Derwent Estuary. Photo by Vishnu N. Prahalad, 2009.

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1. Introduction

The primary objective of this project is to predict the future extent and migration pathways of tidal wetlands in the Derwent Estuary in the event of predicted future sea level rise. To enable this assessment, the current extent of all tidally influenced wetlands and saltmarshes and their immediately adjacent freshwater wetlands have been mapped (though not ground truthed) and then the entire estuary analysed with inundation modelling using the best available sea level rise projections for the year 2100. Section 2 of this report provides information about the methods used. Results are documented in Section 3. The fourth and final Section briefly discusses the results in the context of the future conservation and management of Derwent Estuary wetlands.

This work was initiated and guided by the Derwent Estuary Program, funded by NRM South, and undertaken by the School of Geography and Environmental Studies, University of Tasmania.

2. Methods

Broadly, the project involved three main stages: mapping current extent; inundation modelling; and analysis of future extent. It must be noted that this project is a preliminary assessment of the future extent of saltmarshes and freshwater wetlands, and does not include any consideration of the rates of sedimentation (vertical accretion), wind-wave climate (fetch modelling) and historical shoreline changes among others. All geoprocessing was done in ESRI ArcMAP™ Version 9.3, with data referenced to MGA94 Zone 55 (GDA94) and AHD vertical map datum.

2.1. Study Area

The Derwent Estuary covers an area of nearly 200 km^2 extending from New Norfolk to a line between Tinderbox and Iron Pot (Derwent Estuary Program, 2009). Salinity varies greatly along the estuary and this is reflected in the wetland vegetation type. The lower portions of the estuary (from the Tamar Bridge to the line between Tinderbox and Iron Pot) are generally characterised by the presence of coastal saltmarshes dominated by *Tecticornia arbuscula* shrubland, a community non-existent in the middle and upper sections of the estuary (Bridgewater to Tamar Bridge) (pers. obs.; Glasby, 1975; Prahalad, 2009). The middle sections are constituted by less saline (brackish) marshes dominated mainly by *Juncus kraussii* and *Leptocarpus brownii* (pers. obs.; Glasby, 1975). The upper section of the estuary (New Norfolk to Bridgewater) is mostly comprised of unusual tidally influenced freshwater wetlands interspersed with saline grasslands (MacDonald, 1995). Within this broad subdivision, henceforth referred to as 'wetland regions' or simply 'regions', smaller areas of wetlands are affected by local factors such as freshwater inflows from rivers and streams, for example, the Jordan River and Browns Rivulet. These factors, along with the relative position of the wetland within the salinity gradient of the estuary, largely determine the extent and vegetation composition of each of the Derwent Estuary tidal wetlands. Hence, this report subdivides the estuary in to three wetland regions and twelve major local wetland areas in order to facilitate clear and directed discussion of extent, values, threats and future conservation needs of each area and region of tidal wetland within the estuary (Figure 1; Figure 2; Figure 3).

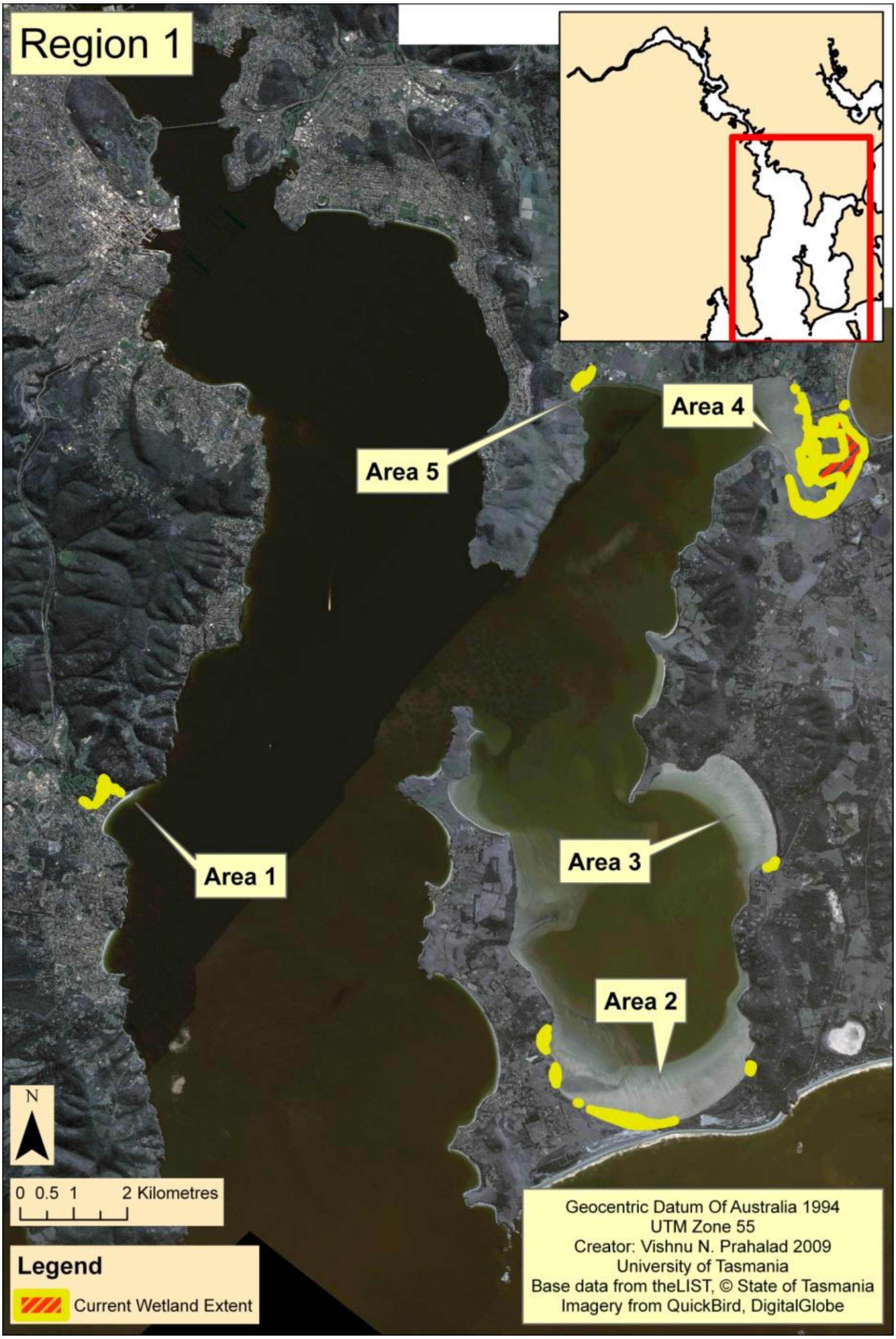

Figure 1. Region 1 (Areas 1-5) Lower Derwent Estuary

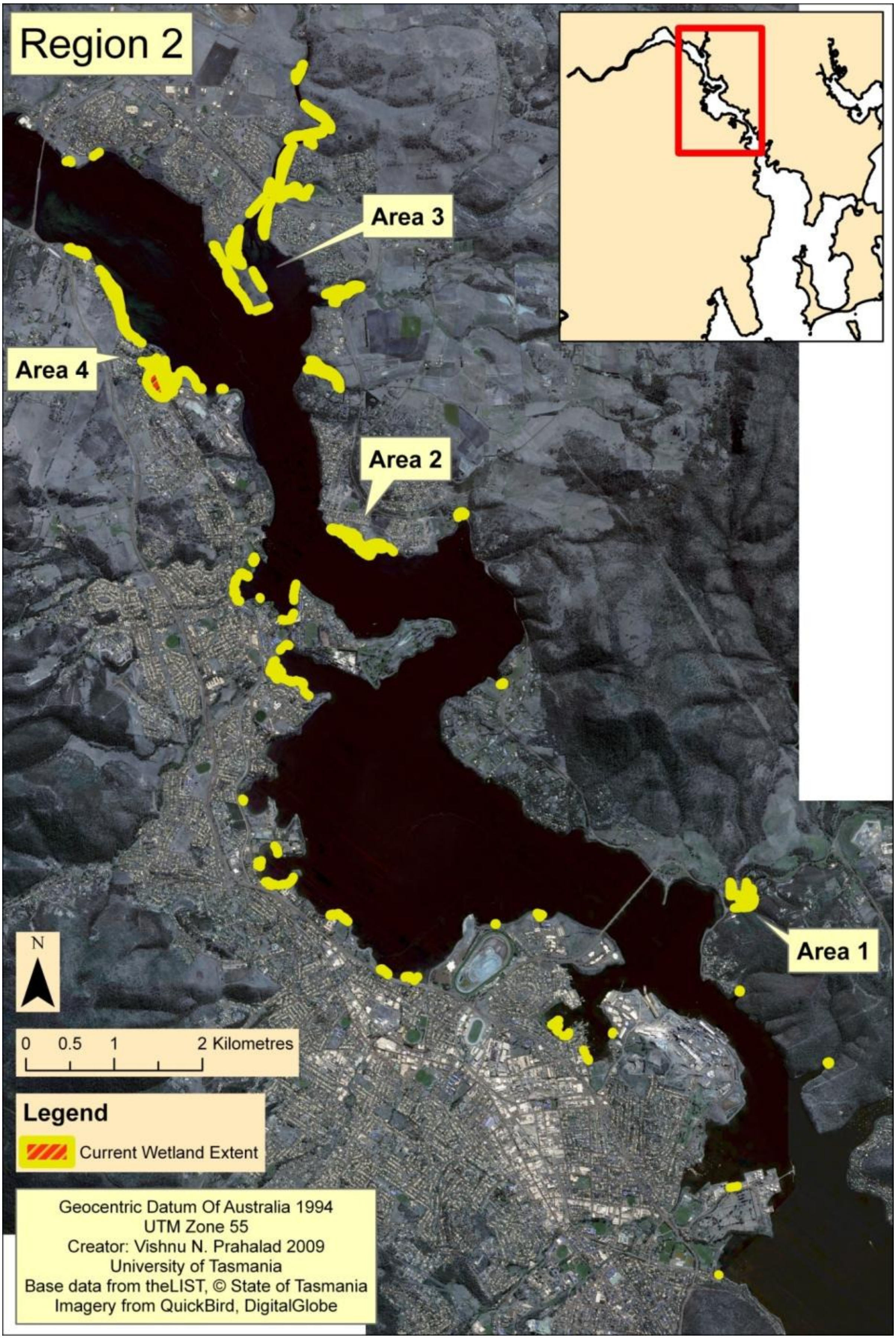

Figure 2. Region 2 (Areas 1-4) Middle Derwent Estuary

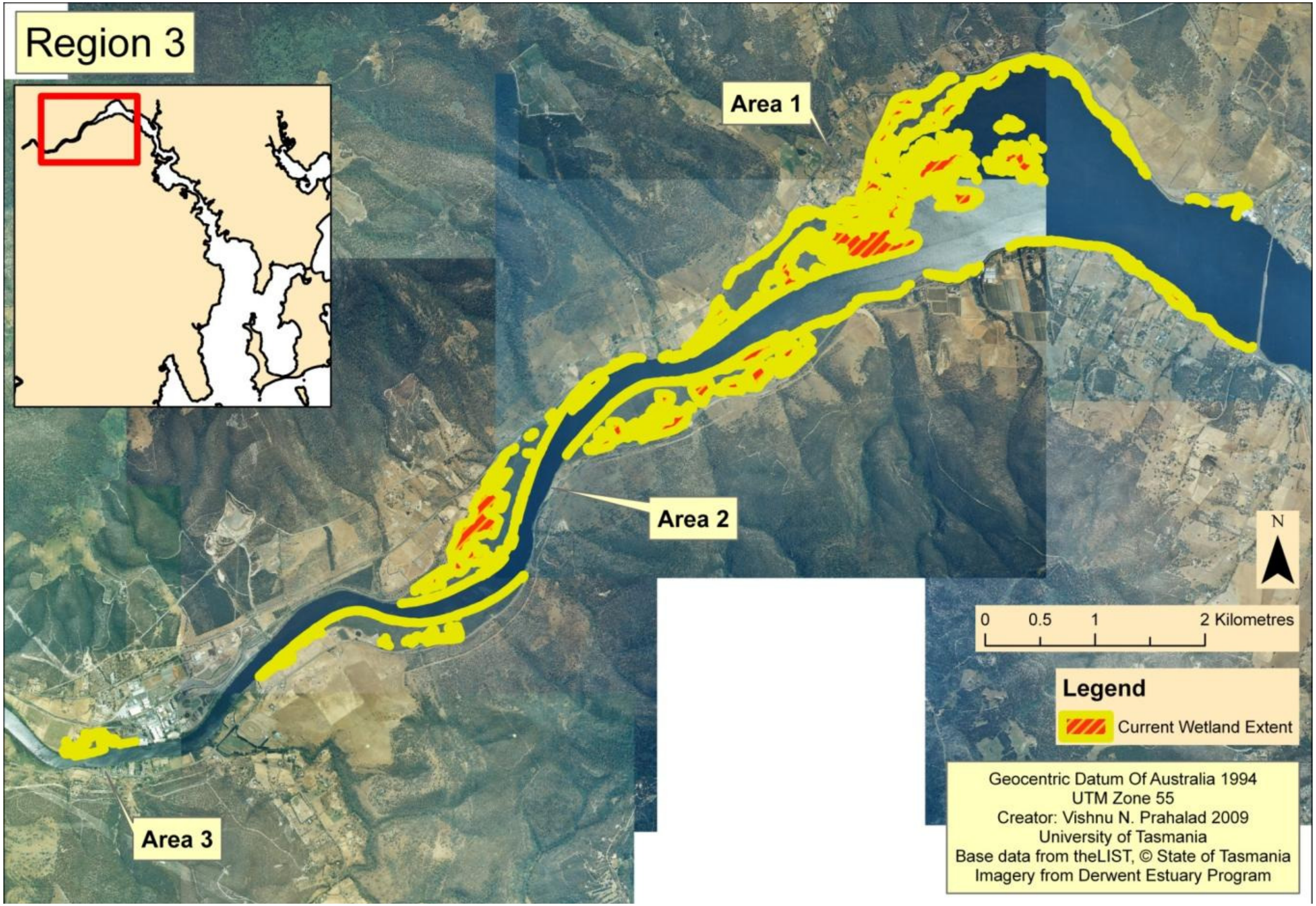

Figure 3. Region 3 (Areas 1-3) Upper Derwent Estuary

Definitions:

Any mapping project requires the clear definition of the objects being mapped keeping in mind the project purposes. The chief objective of this report is to predict the future extent of Derwent Estuary wetlands in view of predicted sea level rise. Hence, estuarine wetlands mapped as a part of this project are essentially areas of 'tidal saltmarshes' and 'tidal freshwater wetlands'. These are mainly represented by the three TASVEG communities ASS (Succulent Saline Herbland); ARS (Saline Sedgeland/Rushland); and ASF (Freshwater Aquatic Sedgeland and Rushland) (Harris and Kitchener, 2005). Some communities occur at supratidal elevations (sometimes excluded by human infrastructure such as roads and levees) and in depressions. Though non-tidal, most of these depressional wetlands are mapped as a part of the project, as they form a functional wetland component of the Derwent Estuary ecosystem. Two other TASVEG wetland communities, AHL (Lacustrine Herbland) and AHS (Saline Aquatic Herbland), are present within the estuary in limited extent.

2.2. Mapping Current Extent

The Derwent Estuary wetlands have been mapped primarily from QuickBird satellite imagery compiled for the Greater Hobart Area in 2005 (provided by DigitalGlobe). Images covered Region 1 and Region 2 comprehensively, but only covered the lower sections of Region 3. Orthorectified Aerial Photographs (dated 2001), provided by the Derwent Estuary Program, were used in the areas within Region 3 which were not covered by the QuickBird imagery. The mapped polygons were then verified with satellite imagery available online from Google Earth. Some oblique aerial photographs, obtained from Dr Richard Mount (co-author), were also used in some areas to verify the extent of the wetland polygons.

All polygons are assigned with a 'confidence level' (1-4) that is an indication of the accuracy of the polygon boundaries at depicting the actual extent of the wetland on the ground. Confidence levels 1-3 covers Region 1 and 2 while level 4 covers Region 3. A confidence level 1 indicates a higher accuracy, level 2 indicates moderate accuracy, and level 3 indicates lower accuracy (this latter level primarily indicates polygons where transgression might be currently occurring). Regions 1 and 2 were mapped with very high detail at a scale of 1:1,000. A separate confidence level was required for Region 4 as the polygons were digitised employing a different methodology. First, the wetland polygons digitised by NorthBarker Ecosystem Services Ltd were extracted (at 1 ha resolution or to 0.25 ha where a threatened vegetation community was suspected), and verified with the available QuickBird imagery and oblique aerial photographs. Most of the major polygons were realigned to the vegetation extents visible in the imagery (at a finer scale, around 1:1,000), but the others were left unchanged where imagery was lacking.

2.3. Inundation Modelling

Inundation modelling was done using the Climate Futures LiDAR Digital Elevation Model (DEM) Dataset that was compiled for the Climate Futures of Tasmania project by Antarctic Climate and Ecosystems Cooperative Research Centre (ACECRC) and the State Emergency Service. The dataset has a vertical and horizontal accuracy of +/- 25 cm. The DEM is in Australian Height Datum (Tasmania), which is intended to represent mean sea level (based on mean sea level for 1972 at the tide gauges at Hobart and Burnie; ICSM, n.d.). However, it must be noted that the mean sea level is about 6 cm higher than zero AHD.

The results from inundation modelling (relative to zero AHD) represent the probability of area being inundated under a specific given scenario, where the probabilities are derived from known errors in the input datasets. Four vector layers were generated from the inundation modelling at 50% probability:

1. Derwent_TideRange_0SLR_MGA.shp: Approximate present day mean high tide mark as extrapolated from tidal range provided by the National Tidal Centre. The mean high water mark (MHWM) and the mean low water mark (MLWM) are predictions derived from a four-constituent model (M2, S2, O1 and K1) produced by the National Tidal Centre. This uses mean sea level as its datum.
2. Derwent_1in100ST_0SLR_MGA.shp: 1 in 100 year storm tide without sea level rise. Projected level for a 1 in 100 year storm tide event at present day.
3. Derwent_1in100ST_82cmSLR_MGA.shp: 1 in 100 year storm tide plus 82 cm sea level rise. Sea level rise of 82 cm is consistent with the upper limit of the IPCC A1F1 projection for year 2100 (AR4) (IPCC, 2007).
4. Derwent_1in100ST_110cmSLR_MGA.shp: 1 in 100 year storm tide plus 110 cm sea level rise. Sea level rise of 110 cm is consistent with possible high end projection for year 2100 by Vellinga (2008).

Storm tide data was provided By Dr Kathleen McInnes (CSIRO) and the modelling carried out Dr Michael Lacey (co-author). The storm tide data uses observed mean sea level from the Hobart Ports tide gauge. The modelled storm tide heights for a 1 in 100 year storm tide plus 110 cm sea level rise was 2.28 m (relative to AHD). This falls within the range identified by Hunter (2008), which is 2.1 m and 2.3 m (relative to AHD). The modelled storm tide heights for a 1 in 100 year storm tide plus 82 cm sea level rise was 2.0 m (relative to AHD). The modelled storm tide heights for a 1 in 100 year storm tide without sea level rise was 1.18 m (relative to AHD).

2.4. Analysis of Future Extent

Tidal influence is a primary driver of the development, extent and function of tidal wetlands, especially saltmarshes (e.g. Chapman, 1974; Huiskes, 1990). They are generally known to occur between the area below the mean high tide mark and the storm tide mark, with salt spray extending this range further inland in some cases. This hypothesis was supported by the current landward extent of the saltmarshes within the Derwent Estuary, which, in most cases, aligned well with the greatest landward intrusion of the modelled storm tide (i.e. the 1 in 100 year storm tide with current sea level). Hence, the future landward extent of the saltmarsh can be reasonably expected to fit with the landward intrusion boundary of the future modelled storm tide plus the projected sea level rise. A future tidal wetland extent layer has been digitised with this hypothesis, and a scenario of 110 cm sea level rise in the year 2100. It is possible that saltmarshes may not be able to establish where 'concrete human footprints' exists in the form of houses, roads and other constructed environments. Hence, the future tidal wetland extent layer does not include areas of these concrete human footprints.

Also, while digitising the future tidal wetland extent layer, information about the land tenure and the glycophytic (i.e. non-saltmarsh) vegetation type that are likely to be affected have been recorded. The land tenure layer was obtained from Information Land Services by the Derwent Estuary Program. The vegetation layers were obtained from Derwent Estuary Program, and compiled by NorthBarker Ecosystem Services Ltd using 2001 aerial photographs and some ground truthing. This information is expected to assist stakeholders in developing management strategies. For example, an area of private agricultural land can be a suitable area for saltmarsh migration provided no artificial impediments are placed against the migration.

It must be noted that the future tidal wetland extent layer is only an indication of the areas important for wetland refuge rather than a prediction of the exact future extent. The latter is hard to predict without information about sedimentation rates, among others.

3. Results

3.1. Mapping Current Extent

Derwent Estuary has an estimated amount of 3,429,894 m^2 of total saltmarsh and tidal freshwater wetland area spread across the three regions. Region 1 has 1,069,771 m^2 of wetland area, with a significant percentage (78%) present in the Lauderdale area. Region 2 has a smaller wetland extent compared to the other regions, with an area of 424,448 m^2. Region 3 has the largest extent of wetlands covering an area of 1,935,675 m^2 accounting for 58% of the total saltmarsh and tidal freshwater wetland area within the estuary. More than 80% of the tidal wetland area within the estuary lies within public land, albeit under various administrative and hence, management arrangements. Table 1 provides a summary of each major wetland area spread across three regions. Appendix 1 has maps with the extent of wetlands within each regions and area.

The saltmarshes in the estuary are generally found within enclosed bays and the mouths of creeks and streams flowing into the estuary, with the extent largely depending on the tidal range and the topography of the adjacent landform. The northern section of Ralphs Bay (near Lauderdale), being highly sheltered and having large areas of low lying landform provides habitat for the largest extent of saltmarshes within the estuary. Several bays in and around the Hobart City have been developed and have constructed shorelines devoid of saltmarshes. In some parts, saltmarshes exist as a thin fringe along the shore.

Table 1. Details of the current extent, dominant vegetation types, saltmarsh response (see next section for details) and land tenure for each wetland area. Confidence levels for the extent and vegetation type are also provided; refer to the Section 2.2. for details regarding mapping and confidence levels. TASVEG Communities: ASS (Succulent Saline Herbland); ARS (Saline Sedgeland/Rushland); and ASF (Freshwater Aquatic Sedgeland and Rushland).

Region	Area	Current Extent (m^2)	Confi-dence Level	Dominant TASVEG Community	Saltmarsh Response (see Section 3.2 for details)	Land Tenure
1	Browns Rivulet (Kingston)	21,383	1	ARS	2, 4	Private
	Southern Section (Ralphs Bay)	174,272	1	ASS	1, 4	Private
	Mortimer Bay (Ralphs Bay)	5,190	2	ARS	2	Public
	Lauderdale (Ralphs Bay)	868,926	2	ASS, ARS	1, 4	Private
	Droughty Point Road (Ralphs Bay)	29,997	1	ASS	2	Private
2	Risdon Cove	20,987	1	ARS	2, 4	Aboriginal
	Old Beach	48,022	1	ARS, ASS	4	Public/ Private
	Jordan River, Green Point and surrounds	185,544	2	ARS, ASF	1, 2	Private
	Goulds Lagoon and surrounds	131,731	2	ARS, ASF	1	Public/ Private
3	Murphy's Flat (Upper Derwent – Lower)	1,240,688	3	ARS, ASF	1, 4	Public/ Private
	Upper Derwent – Middle	666,116	3	ARS, ASF	4	Public/ Private
	New Norfolk (Upper Derwent – Upper)	28,871	3	ARS, ASF	4	Private

3.2. Inundation Modelling

Inundation modelling results indicate that a high proportion of the wetlands within the estuary will be affected due to the projected sea level rise scenarios. However, most wetlands have low lying upland areas that they can potentially migrate in to provided that no anthropogenic impediments exist. Of the four types of saltmarsh response to sea level rise and inundation (Prahalad, 2009), the Derwent Estuary wetlands were found to fit mainly into type 1 (coastal squeeze or submergence), type 2 (creeks and confined patches) and type 4 (uplands). An assessment of the inundation impacts and migration pathways for each area are detailed in Section 3.3.

3.3. Analysis of Future Extent

Maps depicting the current extent and the modelled future extent of tidal wetlands are provided in Appendix 1.

3.3.1. Region 1 – Area 1 – Browns Rivulet (Kingston)

The Browns River saltmarshes can potentially move into upland areas provided there are no impediments to their landward transgression. Except for two areas on either side of the mouth of the rivulet, most other projected future extent area lies within private land (a golf course).

3.3.2. Region 1 – Area 2 – Southern Section (Ralphs Bay)

The saltmarshes in the Southern Section of Ralphs Bay can potentially expand and move upland. However, the South Arm Highway separates the current tidal saltmarsh area and the area identified for future extent. Two smaller patches of saltmarshes to the western side of this area are predicted to be squeezed between the rising sea level and the adjoining steep upland.

3.3.3. Region 1 – Area 3 – Mortimer Bay (Ralphs Bay)

The current limited extent of the Mortimer Bay saltmarsh may potentially expand considerably and occupy low lying areas currently dominated by glycophytes. This area is an interesting example of a tide dominated bay with a beach and dune system responding to sea level rise (Sharples, pers. comm.). As sea level rises, saltmarshes can potentially form behind the dune system as back-barrier marshes. The entire extent of land identified as a future saltmarsh refuge falls within public land.

3.3.4. Region 1 – Area 4 – Lauderdale (Ralphs Bay)

The Lauderdale saltmarsh has a diverse vegetation community complex (Prahalad, 2009) and has the largest extent of saltmarshes within the Derwent Estuary. While most saltmarshes that occur on the seaward side of the South Arm Highway are predicted to be squeezed, the saltmarsh area behind the highway can potentially expand and transgress into nearby uplands, most of which is private property.

3.3.5. Region 1 – Area 5 – Droughty Point Road (Ralphs Bay)

The saltmarsh near the Droughty Point Road in the northern section of Ralphs Bay can potentially expand and occupy nearby upland, and also move up the creek. Almost the entire extent of land identified as future saltmarsh refuge falls within private agricultural land.

3.3.6. Region 2 – Area 1 – Risdon Cove

While some of the saltmarsh in Risdon Cove area may be squeezed, others can potentially migrate to nearby upland owned by the Aboriginal community.

3.3.7. Region 2 – Area 2 – Old Beach

The Old Beach saltmarsh can potentially transgress upland, while housing developments might limit the extent to which they are able to move inland. Most of the area identified as future saltmarsh refuge fall within private land (vacant residential areas).

3.3.8. Region 2 – Area 3 – Jordan River, Green Point and surrounds

The Jordan River and Green Point area are surrounded by large areas of brackish and freshwater marshes. Most of the brackish marshes are predicted to be squeezed, while the freshwater marshes may become more saline due to seawater intrusion. Most of the current wetland extent lies within public land, while two marshes (one on the southern end and one on the northern end of the area) are on private land. These two marshes can provide an indicator for both marsh transgression and vegetation changes into the future.

3.3.9. Region 2 – Area 4 – Goulds Lagoon and surrounds

Goulds Lagoon is an impounded (by Main Road) freshwater lagoon that is currently reserved as a Wildlife Sanctuary. The lagoon may become brackish with seawater intrusion in the future. However, the road infrastructure currently in place might prevent this from happening. The other nearby areas of marshland further up the estuary from Goulds Lagoon may be squeezed due to the road infrastructure (Main Road) directly behind the marsh.

3.3.10. Region 3 – Area 1 – Murphy's Flat (Upper Derwent – Lower)

The Murphy's Flat wetlands forms a complex of freshwater and saline wetlands interspersed with other vegetation types such as the Dry Scrub and Leptospermum Scrub. The seaward patches of these wetlands are likely to be submerged due to sea level rise, while the marshes on the landward side and on higher land might survive albeit with a possible changed vegetation composition. Sea water inundation might also facilitate the marsh vegetation to colonise and eventually dominate other vegetation types within the area.

3.3.11. Region 3 – Area 2 – Upper Derwent – Middle

The next area of wetlands further up the estuary from Murphy's Flat have a similar community structure to the others in the Region. However, the modelling results indicate that the current extent of wetlands will increase at the expense of other vegetation communities. While a large area identified as the future wetland migration pathway lies within public land, some areas are within private land with little human infrastructure, providing an opportunity for investment in future wetland conservation.

3.3.12. Region 3 – Area 3 – New Norfolk (Upper Derwent – Upper)

The New Norfolk area is the furthest upriver extent of both the estuary and estuarine wetlands. Currently, only the lower section of this area has been identified to support wetlands. With an increase in sea levels in the future, more wetland habitats might be formed in this area. Several of these potential future wetland areas lie within public land, while one patch (on the uppermost section) lies within private agricultural land.

4. Discussion

Sea level rise poses a major threat to tidal wetlands, and recent research has indicated that these threats are already apparent in saltmarshes in Lauderdale and the nearby Pitt Water (Prahalad, 2009). Hence, as a management response to sea level rise, researchers have suggested that the intertidal profiles should be allowed to migrate landwards and upstream (e.g. Pethick, 1993). The landward migration of tidal wetlands is often planned and implemented as a conservation strategy to offset the impacts due to sea level rise, primarily in the form of erosion and vegetation change (Boorman, 1999; Adam, 2002). Planning for such landward migration will require knowledge of the current extent of tidal wetlands and an understanding of how sea level rise will affect the estuary in terms of inundation and sea water incursion. This understanding can be effectively supported with inundation modelling, such as that used in this project.

Armed with both the information about current wetland extent and areas that are modelled to be affected by sea water intrusion, it is possible to conduct a preliminary investigation of the areas that might be able to support tidal wetlands in the future. This information can then be useful to inform land-use planning in the identified 'refuge areas' to provide the space for tidal wetlands to survive and continue to provide extensive ecosystem services within the estuary. These services include, inter alia: protecting the hinterland against coastal surges; providing a source of organic materials required for estuarine and marine food webs (supporting coastal fisheries); filtering out contaminants (e.g. nitrates) in freshwater runoff from land before it reaches the sea; conserving biodiversity (e.g. critical habitat for migratory birds); and providing many educational and recreational opportunities (Boorman, 1999; Deegan *et al*., 2000; Teal and Howes, 2000; Doody, 2008).

The objective of this project was to conduct a preliminary assessment of the tidal wetlands in the Derwent Estuary to better understand the impact of sea level rise on these habitats and identify areas to which they can migrate. The findings from this project indicate there is definite potential for tidal wetlands, especially saltmarshes, to migrate upland, provided the land use is compatible with saltmarsh colonisation. However, most areas identified as future wetland refugia lie within private land and require management actions aimed at either acquiring important areas for reservation, or engaging in conservation covenants with landowners to promote wetland conservation. Some refuge areas lie within public land, which can be designated for future wetland conservation.

It is recommended that each 'wetland region' and 'wetland area' identified within the estuary is analysed separately for selecting wetland refugia. Suitable refuge areas need to be selected keeping in mind 'migration pathways' or 'migration corridors' rather than only looking at the future modelled extent. This approach can be further explained by looking at a case study. Figure 4 shows a patch of saltmarsh (red polygon) associated with a creek mouth in the south end of Region 1, near Bridgewater. Here, the future modelled extent (orange polygon) is only a small patch which is sandwiched between two roads. However, a closer examination reveals that there are areas further up the intermittent creek where tidal wetlands can develop (indicated by arrows) provided natural tidal movement is facilitated by providing extra large culverts under the roads. This approach is practical and has proven benefits as seen in the case of Orielton Lagoon (Prahalad, 2009).

Pethick (1993) has suggested that the upper estuaries will provide refugia for saltmarsh species in the event of accelerated sea level rise. Hence, areas need to allocated for saltmarsh refugia in the upper estuary, and also within rivers, streams (Jordan River and Browns Rivulet) and smaller creeks.

Figure 4. A case for creating a 'migration pathway', see text for explanation.

Future Work:

This study did not include any measure of sedimentation (vertical accretion) in modelling the future extent. Since sedimentation may offset some of the impacts from sea-level rise, a measure of sediment budget in the estuary might provide more information in determining the future extent of tidal wetlands. Historical spatial analysis of change in the area, the direction of change and the type of change using historic aerial photos, satellite image time series and ground survey will inform us considerably about the dynamics of the tidal wetlands in the area and their resilience.

Vegetation plays a central role in saltmarshes by structuring the environment and providing habitat for the fauna (Adam, 1990). Hence, a systematic survey and mapping of the saltmarsh and freshwater wetland vegetation within the estuary will not only inform us of the diversity of the wetland types (habitats) within the estuary, but also provide an important baseline data (inventory) against which future changes can be compared and managed. Furthermore, selection of refuge areas should be such that each representative vegetation type is given adequate space to survive the accelerated sea level rise. It may be that such a survey would provide a basis for listing some saltmarsh communities as threatened vegetation communities under Tasmanian legislation. Monitoring mechanisms should be set in place, which can use the baseline data to study the condition of the wetlands and their response to sea level rise.

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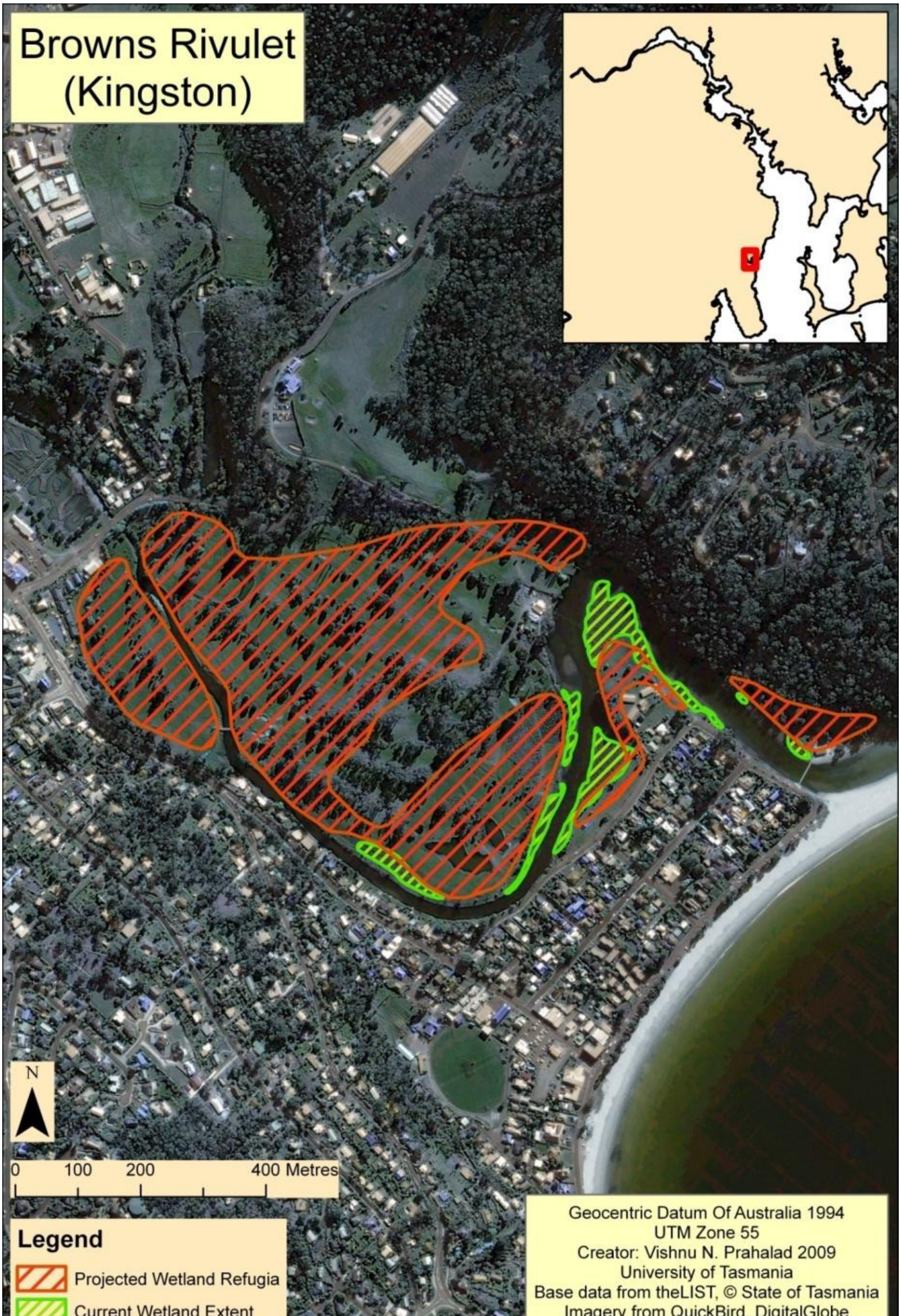
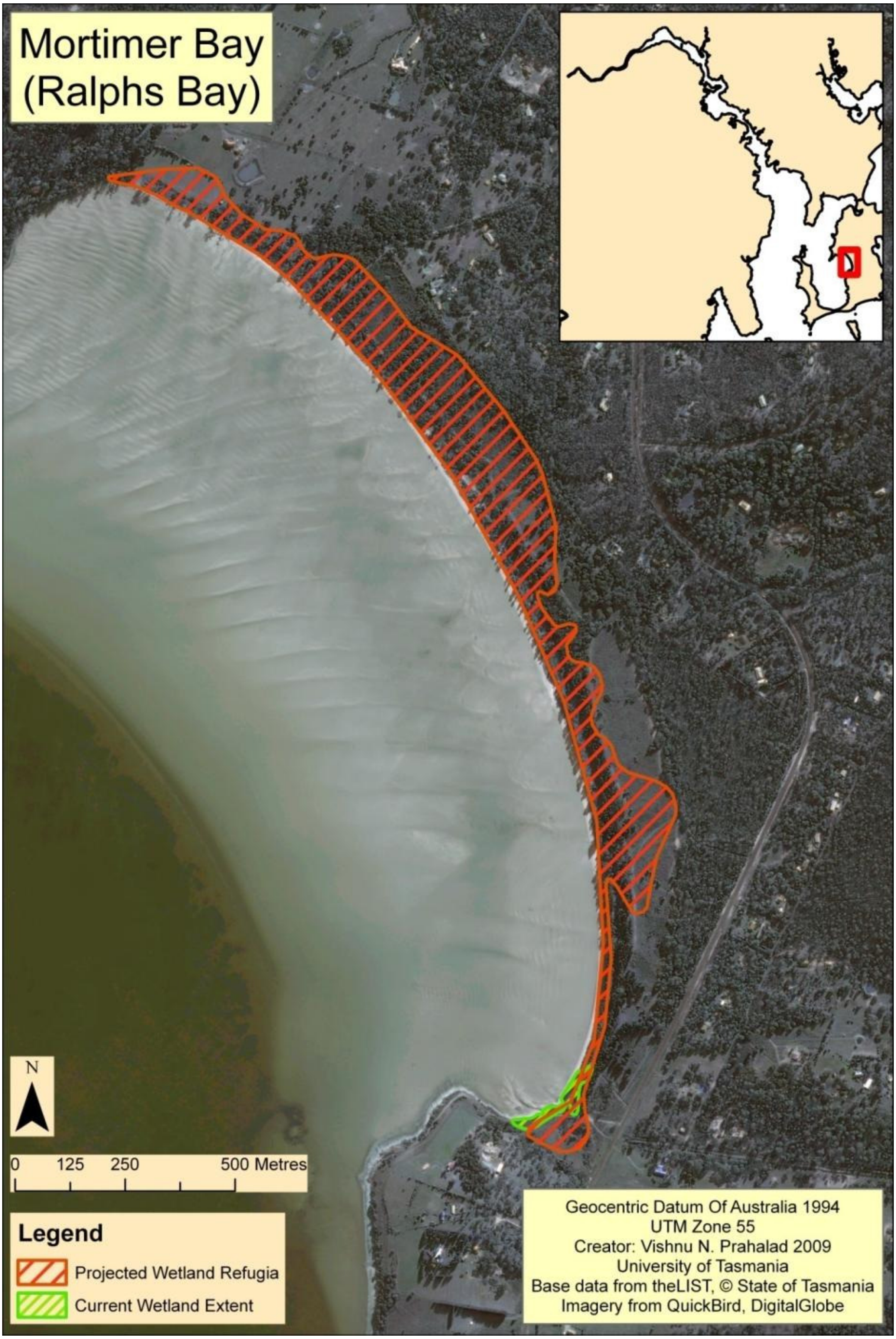
Appendix 1: Maps Depicting the Current and Future Tidal Wetland Extent for Each Area


Browns Rivulet
(Kingston)
N
0
100
200
400 Metres
Legend
Projected Wetland Refugia
Current Wetland Extent
Geocentric Datum Of Australia 1994
UTM Zone 55
Creator: Vishnu N. Prahalad 2009
University of Tasmania
Base data from theLIST, © State of Tasmania
Imagery from QuickBird, DigitalGlobe


Southern Section
(Ralphs Bay)
N
0 250 500 1,000 Metres
Legend
Projected Wetland Refugia
Current Wetland Extent
Geocentric Datum Of Australia 1994
UTM Zone 55
Creator: Vishnu N. Prahalad 2009
University of Tasmania
Base data from theLIST, © State of Tasmania
Imagery from QuickBird, DigitalGlobe


Mortimer Bay
(Ralphs Bay)
N
0 125 250 500 Metres
Legend
Projected Wetland Refugia
Current Wetland Extent
Geocentric Datum Of Australia 1994
UTM Zone 55
Creator: Vishnu N. Prahalad 2009
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Lauderdale
(Ralphs Bay)
N
0
162.5
325
650 Metres
Legend
Projected Wetland Refugia
Current Wetland Extent
Geocentric Datum Of Australia 1994
UTM Zone 55
Creator: Vishnu N. Prahalad 2009
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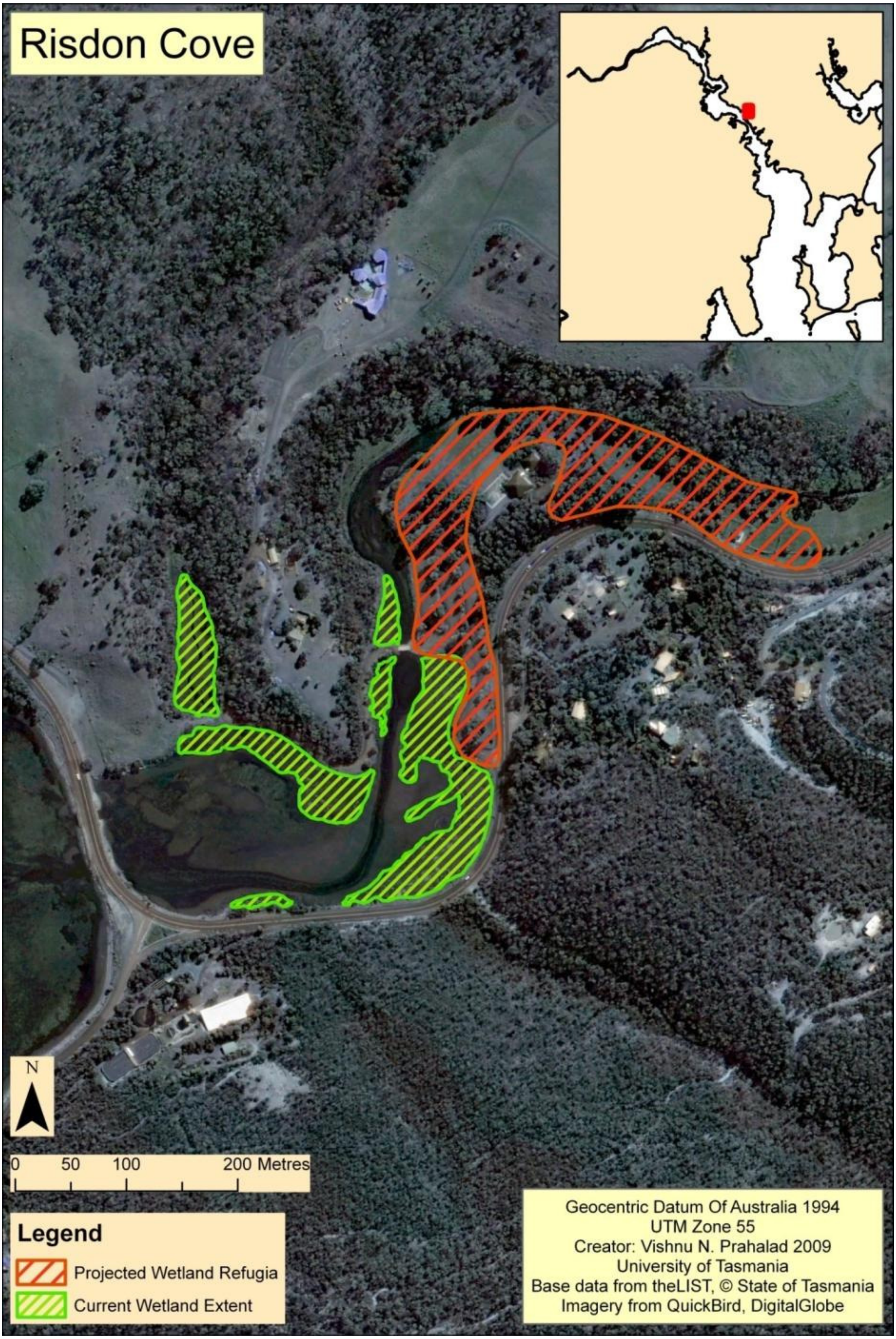
Droughty Point Road
(Ralphs Bay)
N
0
55
110
220 Metres
Legend
Projected Wetland Refugia
Current Wetland Extent
Geocentric Datum Of Australia 1994
UTM Zone 55
Creator: Vishnu N. Prahalad 2009
University of Tasmania
Base data from theLIST, © State of Tasmania
Imagery from QuickBird, DigitalGlobe


Risdon Cove
N
0 50 100 200 Metres
Legend
Projected Wetland Refugia
Current Wetland Extent
Geocentric Datum Of Australia 1994
UTM Zone 55
Creator: Vishnu N. Prahalad 2009
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Old Beach
N
0 50 100 200 Metres
Legend
Projected Wetland Refugia
Current Wetland Extent
Geocentric Datum Of Australia 1994
UTM Zone 55
Creator: Vishnu N. Prahalad 2009
University of Tasmania
Base data from theLIST, © State of Tasmania
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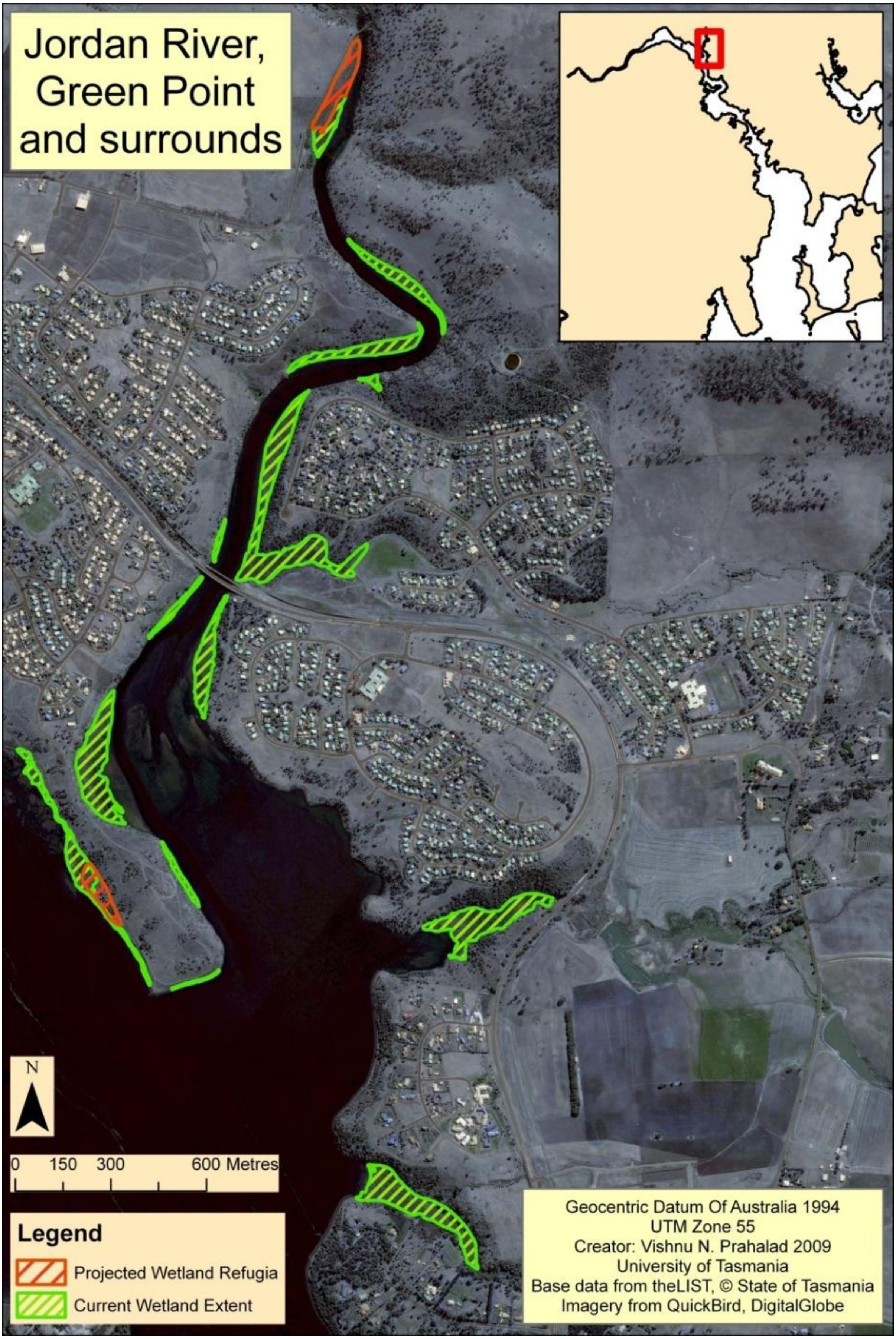
Jordan River, Green Point and surrounds
N
0 150 300 600 Metres
Legend
Projected Wetland Refugia
Current Wetland Extent
Geocentric Datum Of Australia 1994
UTM Zone 55
Creator: Vishnu N. Prahalad 2009
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Base data from theLIST, © State of Tasmania
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Goulds Lagoon and surrounds
N
0 100 200 400 Metres
Legend
Projected Wetland Refugia
Current Wetland Extent
Geocentric Datum Of Australia 1994
UTM Zone 55
Creator: Vishnu N. Prahalad 2009
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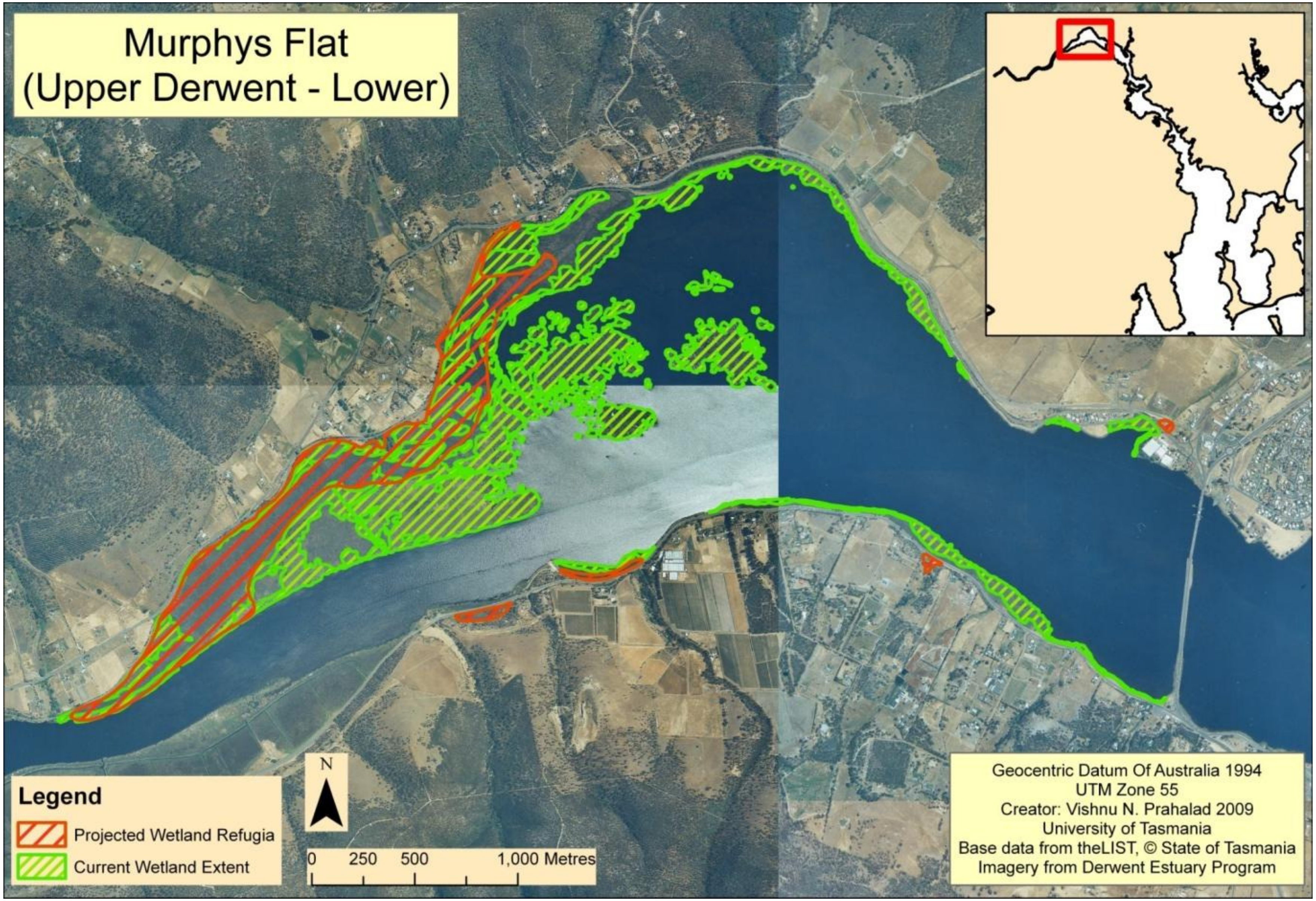
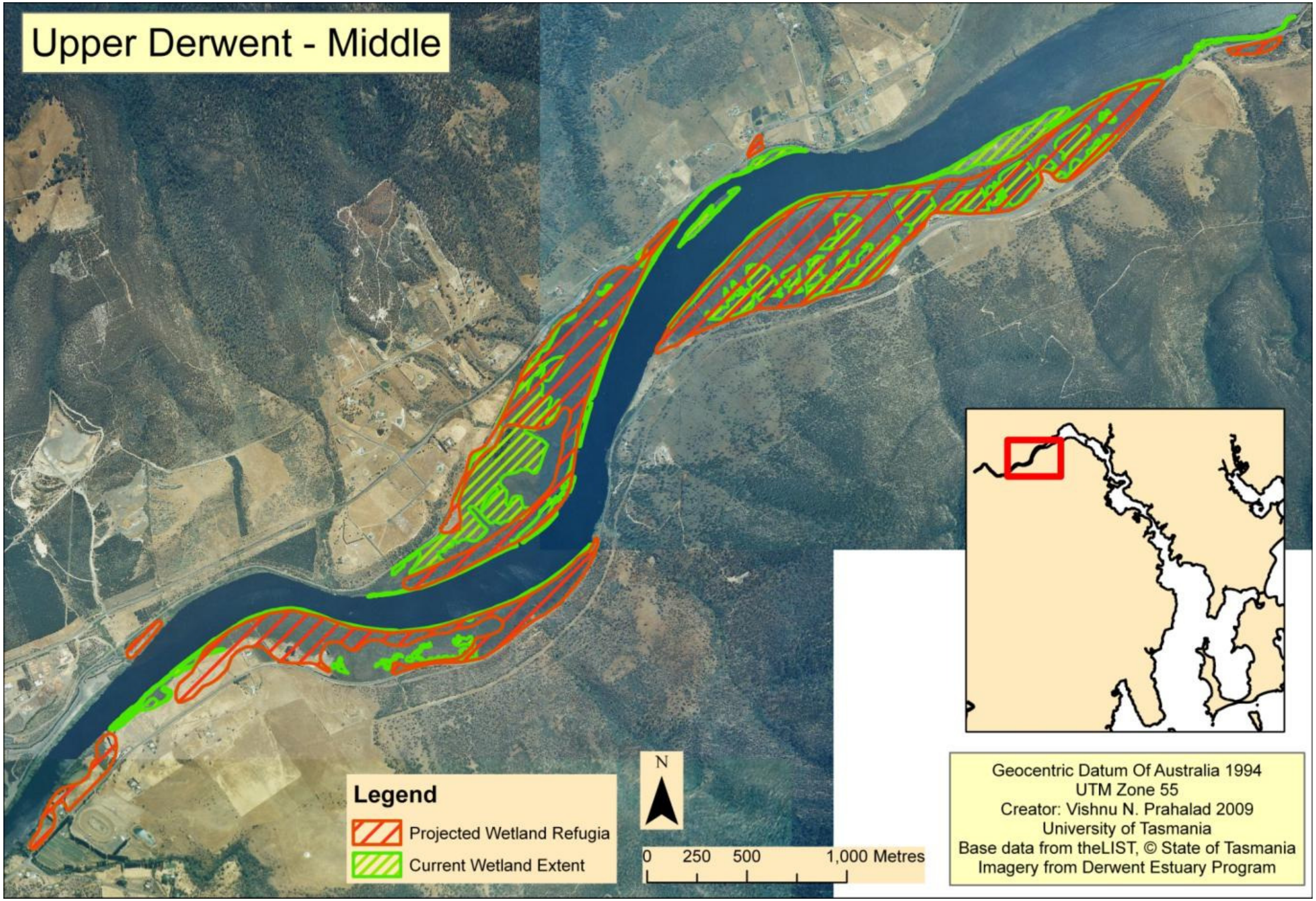
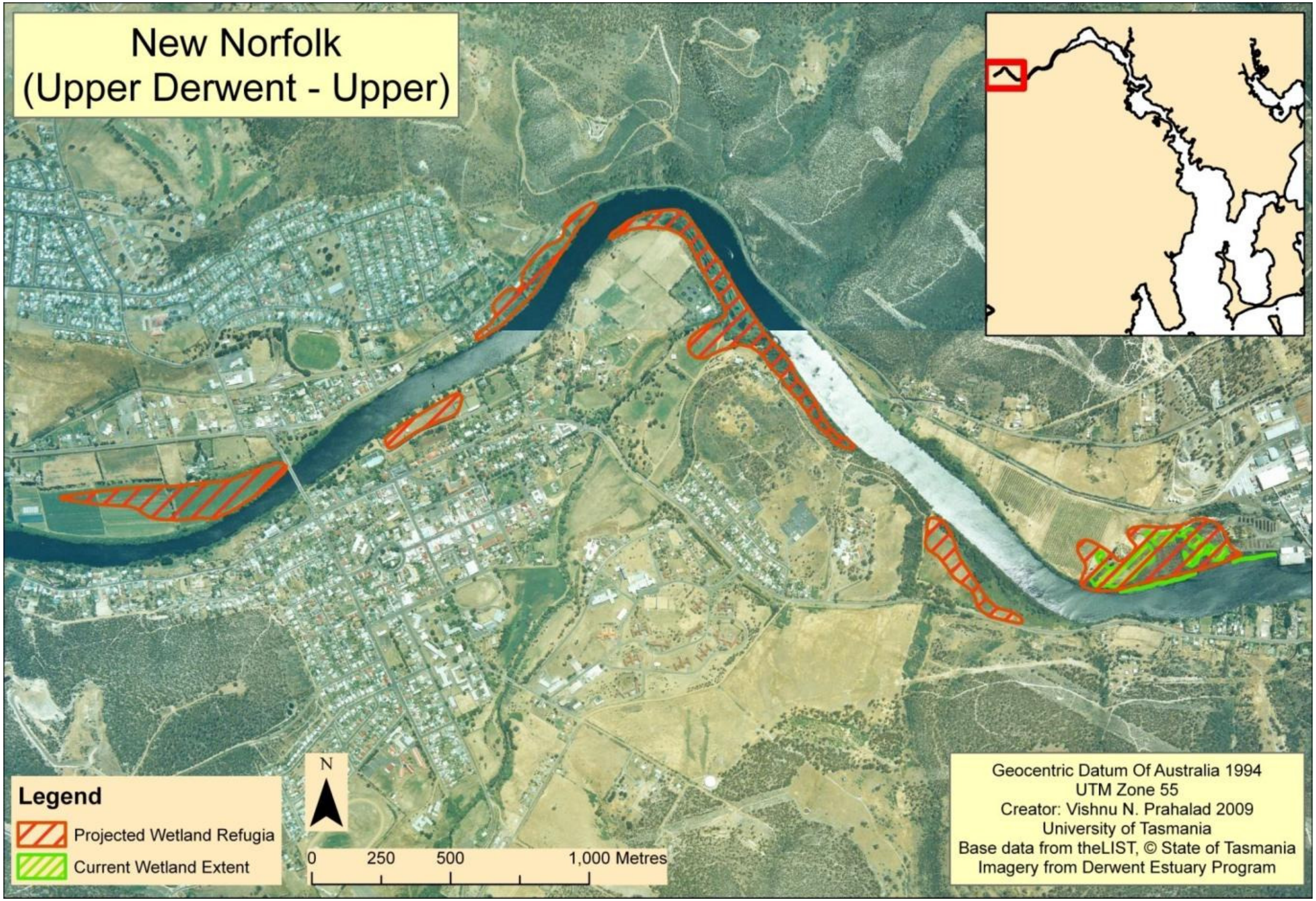

Murphys Flat
(Upper Derwent - Lower)
Legend
Projected Wetland Refugia
Current Wetland Extent
N
0 250 500 1,000 Metres
Geocentric Datum Of Australia 1994
UTM Zone 55
Creator: Vishnu N. Prahalad 2009
University of Tasmania
Base data from theLIST, © State of Tasmania
Imagery from Derwent Estuary Program


Upper Derwent - Middle
Legend
Projected Wetland Refugia
Current Wetland Extent
N
0 250 500 1,000 Metres
Geocentric Datum Of Australia 1994
UTM Zone 55
Creator: Vishnu N. Prahalad 2009
University of Tasmania
Base data from theLIST, © State of Tasmania
Imagery from Derwent Estuary Program


New Norfolk
(Upper Derwent - Upper)
Legend
Projected Wetland Refugia
Current Wetland Extent
N
0
250
500
1,000 Metres
Geocentric Datum Of Australia 1994
UTM Zone 55
Creator: Vishnu N. Prahalad 2009
University of Tasmania
Base data from theLIST, © State of Tasmania
Imagery from Derwent Estuary Program