

## **Southern GBR Coastal Habitat Archive and Monitoring Program (S-GBR CHAMP)**

**Progress Report December 2016**

Norman Duke and Jock Mackenzie



# **Southern GBR Coastal Habitat Archive and Monitoring Program (S-GBR CHAMP)**

**Progress Report December 2016**

Norman C. Duke<sup>1</sup> & Jock Mackenzie<sup>1</sup>

<sup>1</sup>Centre for Tropical Water and Aquatic Ecosystem Research, James Cook University



Supported by the Australian Government's  
National Environmental Science Programme  
Project 2.3.4: Working with Traditional Owners and local citizens to better manage GBR estuarine wetlands

© James Cook University, 2016



Creative Commons Attribution

*Southern GBR Coastal Habitat Archive and Monitoring Program (S-GBR CHAMP): Progress Report December 2016* is licensed by James Cook University for use under a Creative Commons Attribution 4.0 Australia licence. For licence conditions see: <https://creativecommons.org/licenses/by/4.0/>

This report should be cited as:

Duke, N.C. and Mackenzie, J. (2016) *Southern GBR Coastal Habitat Archive and Monitoring Program (S-GBR CHAMP): Progress Report December 2016*. Report to the National Environmental Science Programme. Reef and Rainforest Research Centre Limited, Cairns (68 pp.).

Published by the Reef and Rainforest Research Centre on behalf of the Australian Government's National Environmental Science Programme (NESP) Tropical Water Quality (TWQ) Hub.

The Tropical Water Quality Hub is part of the Australian Government's National Environmental Science Programme and is administered by the Reef and Rainforest Research Centre Limited (RRRC). The NESP TWQ Hub addresses water quality and coastal management in the World Heritage listed Great Barrier Reef, its catchments and other tropical waters, through the generation and transfer of world-class research and shared knowledge.

This publication is copyright. The Copyright Act 1968 permits fair dealing for study, research, information or educational purposes subject to inclusion of a sufficient acknowledgement of the source.

The views and opinions expressed in this publication are those of the authors and do not necessarily reflect those of the Australian Government.

While reasonable effort has been made to ensure that the contents of this publication are factually correct, the Commonwealth does not accept responsibility for the accuracy or completeness of the contents, and shall not be liable for any loss or damage that may be occasioned directly or indirectly through the use of, or reliance on, the contents of this publication.

Cover photographs: Norman Duke

This report is available for download from the NESP Tropical Water Quality Hub website:  
<http://www.nesptropical.edu.au>

# CONTENTS

|                                                                                   |     |
|-----------------------------------------------------------------------------------|-----|
| Contents.....                                                                     | i   |
| List of Tables.....                                                               | iii |
| List of Figures.....                                                              | iii |
| Acronyms .....                                                                    | v   |
| Abbreviations .....                                                               | v   |
| Acknowledgements .....                                                            | vi  |
| Executive Summary .....                                                           | vii |
| 1.0 Introduction .....                                                            | 1   |
| 2.0 Methodology.....                                                              | 3   |
| 2.1 Project operations, logistics and management .....                            | 3   |
| 2.2 Mapping of Tidal Wetland Resources.....                                       | 6   |
| 2.3 Boat-based Shoreline Surveys.....                                             | 7   |
| 3.0 Results .....                                                                 | 9   |
| 3.1 Post-flood evaluation of the Burnett River estuary.....                       | 9   |
| 3.2 Preliminary assessment of tidal wetlands in the Elliott River estuary.....    | 9   |
| 3.2.1 Introduction.....                                                           | 10  |
| 3.2.2 Methods .....                                                               | 12  |
| 3.2.3 Results .....                                                               | 15  |
| 3.2.4 Discussion .....                                                            | 20  |
| 3.2.5 Photo gallery of key issues affecting the Elliott River tidal wetlands..... | 29  |
| 3.3 Ongoing survey work, training & capacity building of the Rangers .....        | 35  |
| 3.3.1 Survey future scheduling .....                                              | 35  |
| 3.3.2 Rangers identify shoreline tree damage and poisoning during surveys.....    | 36  |
| 3.4 Defining values and threats to saltmarsh habitat in the Southern GBR .....    | 38  |
| 3.4.1 Where is the Saltmarsh? .....                                               | 40  |
| 3.4.2 What's in the Saltmarsh?.....                                               | 40  |
| 3.4.3 How valuable is Southern GBR Saltmarsh?.....                                | 41  |
| 3.4.4 What makes a Saltmarsh a good water filter?.....                            | 42  |
| 3.4.5 Indicators of Saltmarsh Water Quality Improvement Value .....               | 43  |
| 3.4.6 What makes a Saltmarsh good fish habitat?.....                              | 43  |
| 3.4.7 What makes a Saltmarsh a good carbon store? .....                           | 43  |
| 3.4.8 What makes a Saltmarsh good habitat? .....                                  | 44  |
| 3.4.9 Prioritizing Investment in Southern GBR Saltmarsh.....                      | 45  |
| 3.5 Presentations by Duke and Mackenzie at the 2016 MMM4 Conference.....          | 47  |

|                                                                                                                                                                                              |    |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----|
| 3.5.1 Presentation by Dr Duke.....                                                                                                                                                           | 47 |
| 3.5.2 Presentation by Jock Mackenzie .....                                                                                                                                                   | 48 |
| 3.6 Presentation by Duke at a citizen science forum in Brisbane .....                                                                                                                        | 49 |
| 3.7 Presentations by Duke and Mackenzie at citizen science forum in Cairns.....                                                                                                              | 50 |
| 3.8 Presentations by Duke at the Territory Natural Resource Management (TNRM) 2016 Conference and workshop in Darwin .....                                                                   | 52 |
| 3.9 Publications related to the Southern GBR CHAMP NESP project .....                                                                                                                        | 54 |
| 3.10 Grants awarded re this Southern GBR CHAMP NESP project.....                                                                                                                             | 56 |
| 3.10.1 Wallace Creek Reserve Project.....                                                                                                                                                    | 56 |
| 3.10.2 Enhancing traditional owner capacity to protect mangroves against climate change through cross-cultural exchange .....                                                                | 58 |
| 3.11 Pending Expressions of Interest regarding this Southern GBR CHAMP NESP project .....                                                                                                    | 59 |
| 3.11.1 Protecting vital fish habitat with the rehabilitation of estuarine living shorelines (mangroves, saltmarsh and shellfish) along the southern GBR coast: Burnett River .....           | 59 |
| 3.11.2 Protecting vital fish habitat with the rehabilitation of estuarine living shorelines (mangroves, saltmarsh and shellfish) along the southern GBR coast: Kolan River.....              | 61 |
| 3.11.3 Vehicle and grazing track impacts on sub-tropical saltmarsh – investigating their effects on fisheries values using an innovative remote sensing saltmarsh track detection tool ..... | 63 |
| 4.0 References.....                                                                                                                                                                          | 67 |

## LIST OF TABLES

|                  |                                                                                                                         |    |
|------------------|-------------------------------------------------------------------------------------------------------------------------|----|
| <b>Table 1:</b>  | Research End Users and Stakeholders for the Southern GBR CHAMP .....                                                    | 3  |
| <b>Table 2:</b>  | Project Milestone Schedule 2016-2018 .....                                                                              | 4  |
| <b>Table 3:</b>  | Planned Diary Dates for the Southern GBR CHAMP Project 2016-2018 .....                                                  | 5  |
| <b>Table 4:</b>  | Timeline of tidal wetland surveys and mapping in the Elliott River .....                                                | 9  |
| <b>Table 5:</b>  | Saltmarsh and Mangrove flora present within the Elliott River .....                                                     | 13 |
| <b>Table 6:</b>  | Mangrove and Saltmarsh Area in the Elliott River 1970 to 2016 .....                                                     | 16 |
| <b>Table 7:</b>  | Detailed Assessment of Tidal Wetland Vegetation Change in the Elliott River 1970 and 2010.....                          | 20 |
| <b>Table 8:</b>  | Summary of Management Issues Threatening Elliott River Tidal Wetlands. ..                                               | 26 |
| <b>Table 9:</b>  | Landuse types adjacent to the Elliott River estuary within 500 m of HAT (Source: QLUMP 2009).....                       | 33 |
| <b>Table 10:</b> | Summary of illegal damage to riparian and marine plants along the waters' edge at 23 Mariners Way, North Bundaberg..... | 37 |
| <b>Table 11:</b> | Saltmarsh plant species of the Southern GBR.....                                                                        | 41 |

## LIST OF FIGURES

|                   |                                                                                                                                                                                                                                                   |    |
|-------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----|
| <b>Figure 1:</b>  | TropWATER scientists with Gidarjil DC Rangers providing advice and guidance for habitat rehabilitation at Wallace Creek Reserve Area. ....                                                                                                        | ix |
| <b>Figure 2:</b>  | Google Earth satellite imagery of the Southern GBR CHAMP study area (yellow line) compared to the smaller PCPA CHAMP study area (red line). The major estuaries in this region are listed as the case study locations throughout the region. .... | 1  |
| <b>Figure 3:</b>  | Map of the Southern GBR shoreline showing the location of the 8 estuarine systems used as case studies in this project. ....                                                                                                                      | 6  |
| <b>Figure 4:</b>  | Tidal wetland vegetation units: mangrove, saltmarsh and other coastal vegetation.....                                                                                                                                                             | 10 |
| <b>Figure 5:</b>  | Location of the Elliott River estuary.....                                                                                                                                                                                                        | 13 |
| <b>Figure 6:</b>  | Elliott River Tidal Wetland Change 1970 to 2016.....                                                                                                                                                                                              | 17 |
| <b>Figure 7:</b>  | Elliott River Change in Mangrove Extent 2010 to 2013 .....                                                                                                                                                                                        | 18 |
| <b>Figure 8:</b>  | Elliott River Change in Mangrove Extent 2013 to 2016 .....                                                                                                                                                                                        | 19 |
| <b>Figure 9:</b>  | Elliott Heads Mean Annual Rainfall 1966 to 2015 (Bureau of Meteorology (BoM) 2016).....                                                                                                                                                           | 21 |
| <b>Figure 10:</b> | Mean Monthly Elliot River Water Level at Dr Mays Crossing. Data from Queensland Government Water Monitoring Portal (DNRM 2016).....                                                                                                               | 22 |
| <b>Figure 11:</b> | 1994 Aerial image of Upper Yellow-waterholes Creek showing outline of 2010 mangrove extent (red). Note the presence of saltpan within the red outline. ...                                                                                        | 22 |
| <b>Figure 12:</b> | Monthly sea level residual relative to tide guage position (AHD) at Bundaberg Port, Burnett River (Bureau of Meteorology (BoM) 2016).....                                                                                                         | 23 |
| <b>Figure 13:</b> | Map of the Woongarra groundwater system adjacent to the Elliott River estuary (AGWF, 2007) .....                                                                                                                                                  | 24 |
| <b>Figure 14:</b> | Areas of recent (2016) Aegiceras dieback (Images: Nearmap 22/06/16) .....                                                                                                                                                                         | 25 |

|                   |                                                                                                                                                                                                                                                                                                                                                                                                           |    |
|-------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----|
| <b>Figure 15:</b> | Tidal Wetland Drivers of Change in the Elliott River estuary 2008. (Mackenzie and Duke, 2011).....                                                                                                                                                                                                                                                                                                        | 27 |
| <b>Figure 16:</b> | Map of Elliott River tidal wetland area showing areas impacted by direct disturbance.....                                                                                                                                                                                                                                                                                                                 | 28 |
| <b>Figure 17:</b> | Area of vehicle damage at the southern lower estuary. Yellow circles represent access points. (Image: Nearmap 22/06/16) .....                                                                                                                                                                                                                                                                             | 29 |
| <b>Figure 18:</b> | Oblique aerial image taken September 2008 showing the same level of impact in the same area.....                                                                                                                                                                                                                                                                                                          | 29 |
| <b>Figure 19:</b> | Vehicle damage at Yellow-Waterholes Creek. Note the car body on the saltpan and altered hydrology from vehicle impacts (Image: Nearmap 22/06/16).....                                                                                                                                                                                                                                                     | 30 |
| <b>Figure 20:</b> | Uncontrolled access in the upper estuary at Palm Springs Drv, resulting in severe erosion and sediment runoff (Image: Nearmap 22/06/16).....                                                                                                                                                                                                                                                              | 31 |
| <b>Figure 21:</b> | Uncontrolled access to Yellow-Waterholes Creek resulting in damage to marine plants and shoreline erosion (Image: Nearmap 22/06/16).....                                                                                                                                                                                                                                                                  | 31 |
| <b>Figure 22:</b> | The effect of cattle grazing on tidal wetland sea level rise resilience. (Image: Nearmap 22/06/16).....                                                                                                                                                                                                                                                                                                   | 32 |
| <b>Figure 23:</b> | Possible damage to buffer zone vegetation at Elliott Heads (Image: Nearmap 22/06/16). .....                                                                                                                                                                                                                                                                                                               | 32 |
| <b>Figure 24:</b> | Map of Elliott River estuary showing adjacent landuse within 500 m of HAT..                                                                                                                                                                                                                                                                                                                               | 34 |
| <b>Figure 25:</b> | Schedule of river systems being surveyed prior to, and during, the Southern GBR CHAMP project. Where surveys in the eight (8) study estuaries are repeated, this gives opportunities for measuring change like flood recovery. Note that systems surveyed to date are those in southern parts of the Southern GBR shoreline. The emphasis will shift to the north in the next year of field surveys. .... | 35 |
| <b>Figure 26:</b> | Affected shoreline around Mariners Way, North Bundaberg, showing dead and dying trees, as observed by the Gidarjil Rangers during survey work on the Burnett River.....                                                                                                                                                                                                                                   | 36 |
| <b>Figure 27:</b> | Tidal wetlands within the NESP study region. Tidal wetland layer derived from the Queensland State Government Queensland Wetlands Mapping Program. ....                                                                                                                                                                                                                                                   | 39 |
| <b>Figure 28:</b> | Title slide .....                                                                                                                                                                                                                                                                                                                                                                                         | 48 |
| <b>Figure 29:</b> | Title slide of the presentation about Moreton Bay MangroveWatch and the role of citizen scientists in shoreline monitoring and management. ....                                                                                                                                                                                                                                                           | 49 |
| <b>Figure 30:</b> | Title slide of the presentation about Moreton Bay MangroveWatch and the role of citizen scientists in shoreline monitoring and management. ....                                                                                                                                                                                                                                                           | 50 |
| <b>Figure 31:</b> | Title slide of the presentation about mangroves and the role of citizen scientists in shoreline monitoring and management. ....                                                                                                                                                                                                                                                                           | 51 |
| <b>Figure 32:</b> | Media release for the ReefBlitz activities of MangroveWatch made of the 28 <sup>th</sup> October 2016.....                                                                                                                                                                                                                                                                                                | 52 |
| <b>Figure 33:</b> | Title slide of the presentation about the role of Indigenous Rangers in shoreline monitoring and management. ....                                                                                                                                                                                                                                                                                         | 53 |
| <b>Figure 34:</b> | Map of Wallace Creek Project site at the mouth of the Burnett River, BMR. ..                                                                                                                                                                                                                                                                                                                              | 57 |
| <b>Figure 35:</b> | Proposed Burnett River Fish Habitat Rehabilitation plan.....                                                                                                                                                                                                                                                                                                                                              | 60 |
| <b>Figure 36:</b> | Kolan River Fish Habitat Rehabilitation Plan.....                                                                                                                                                                                                                                                                                                                                                         | 62 |
| <b>Figure 37:</b> | Study sites proposed for the Burnett region rehabilitation trials.....                                                                                                                                                                                                                                                                                                                                    | 64 |

## ACRONYMS

|                  |                                                                  |
|------------------|------------------------------------------------------------------|
| <b>BMRG</b>      | Burnett Mary Regional Group                                      |
| <b>BoM</b>       | Bureau of Meteorology                                            |
| <b>CHAMP</b>     | Coastal Habitat Archive and Monitoring Program                   |
| <b>CVA</b>       | Conservation Volunteers Australia                                |
| <b>FBA</b>       | Fitzroy Basin Association                                        |
| <b>FHA</b>       | Fish Habitat Area                                                |
| <b>GBR</b>       | Great Barrier Reef                                               |
| <b>GDC</b>       | Gidarjil Development Corporation                                 |
| <b>GHHP</b>      | Gladstone Healthy Harbour Partnership                            |
| <b>HAT</b>       | Highest Astronomical Tide                                        |
| <b>JCU</b>       | James Cook University                                            |
| <b>MMP</b>       | Mangrove Management Plan                                         |
| <b>NDVI</b>      | Normalized Difference Vegetation Index                           |
| <b>NESP</b>      | National Environmental Science Programme                         |
| <b>NRM</b>       | Natural Resource Management                                      |
| <b>PCCC</b>      | Port Curtis Coral Coast                                          |
| <b>QDAF</b>      | Queensland Department of Agriculture and Fisheries               |
| <b>QNPSR</b>     | Queensland National Parks, Sport and Racing                      |
| <b>QWMP</b>      | Queensland Wetlands Mapping Program                              |
| <b>DNRM</b>      | Department of Natural Resources and Mines                        |
| <b>QPWS</b>      | Queensland Parks and Wildlife Service                            |
| <b>QWMCP</b>     | Queensland Wetland Mapping and Classification Project            |
| <b>SGAP</b>      | Society for Growing Australian Plants                            |
| <b>SGBR</b>      | Southern Great Barrier Reef                                      |
| <b>S-VAM</b>     | Shoreline Video Assessment Method                                |
| <b>TNRM</b>      | Territory Natural Resource Management                            |
| <b>TropWATER</b> | The Centre for Tropical Water & Aquatic Ecosystem Research, JCU  |
| <b>TUMRA</b>     | Traditional Use of Marine Resources Area                         |
| <b>TWQ</b>       | Tropical Water Quality                                           |
| <b>UNESCO</b>    | United Nations Educational, Scientific and Cultural Organisation |

## ABBREVIATIONS

|           |            |
|-----------|------------|
| <b>cm</b> | centimetre |
| <b>ha</b> | hectare    |
| <b>m</b>  | metre      |

## **ACKNOWLEDGEMENTS**

We thank the Ranger team members with the Gidarjil Development Corporation project staff in Gladstone and Bundaberg for their contributions and support during this project.



## **EXECUTIVE SUMMARY**

- 1) This 2016 December Milestone Report documents the status and key current findings from the program of works from 1 June to 1 December 2016 directed by Dr Norm Duke with Jock Mackenzie from James Cook University (JCU) TopWATER Centre, plus key project partners: Prof John Kovacs of Nipissing University in Canada, Peter Brockhurst and Ric Fennessy with the Rangers of the Gidarjil Development Corporation, Kirsten Worsel (replacing Sue Sargent) with Burnett Mary Regional Group, and Rebecca French and Shannon van Nunen with Fitzroy Basin Association.
- 2) Progress during this period was not only achieved in meeting immediate milestone objectives, but also in gaining two additional grants using surveys and skills of the Rangers gained with this National Environmental Science Programme (NESP) Tropical Water Quality (TWQ) Hub project; notably where: a) the Rangers were successful in winning a grant to look after part of the Burnett River estuarine shoreline; and b) the JCU team were successful in gaining a Department of Foreign Affairs and Trade (DFAT) United Nations Educational, Scientific and Cultural Organisation (UNESCO) grant for exchanges involving the rangers with counterparts in Brazil. Three additional rehabilitation project grants and tenders are pending.
- 3) A post-flood assessment of the Burnett River estuary was completed. Results were presented and discussed at the 4<sup>th</sup> Mangrove and Macrobenthos Meeting (MMM4) conference in Florida USA (see below).
- 4) Preliminary baseline evaluation and mapping of mangroves and saltmarsh tidal wetlands was done for the Elliott River estuary.
- 5) Rangers report on an area of shoreline damage and poisoning to mangroves and riparian vegetation along the Burnett River shoreline.
- 6) Assessment protocols formulated for values and threats to saltmarsh habitats in the southern GBR region.
- 7) Additional Shoreline Video Assessments are planned in early January by the Gidarjil Rangers starting with Baffle Creek, prior to further surveys in northern estuaries.
- 8) During the week of 19-22 July 2016 at the MMM4 conference in Florida USA (the premier international mangrove ecology meeting), presentations were made by Dr Duke and Jock Mackenzie, including observations and findings from this NESP Southern CHAMP project.
- 9) During the week of 25-29 July 2016 at the MMM4 workshop in Florida Keys, USA (the premier international mangrove ecology meeting) future publications were devised using observations from this NESP project.
- 10) Public presentation by Dr Duke on Tuesday 11 Oct in Brisbane, talking at a citizen science venue hosted by the Brisbane City Council.

- 11) Public presentations by Dr Duke and Jock Mackenzie on Saturday 29 October in Cairns, talking at a citizen science venue called Reef Blitz 'Magnificent Mangroves' hosted by the Great Barrier Reef Citizen Science Alliance and the Great Barrier Reef Foundation.
- 12) Public presentation by Dr Duke on Wednesday 23 November in Darwin, talking at the Territory Natural Resource Management (TNRM) 2016 Conference. The talk focused on the NESP project's assessment methodologies, Ranger involvement - and used to evaluate extensive severe dieback of mangroves in the Gulf region.
- 13) Public presentation by Dr Duke on Thursday 24 November in Darwin, at a TNRM workshop on coastal condition and change. This talk specifically focused on this NESP project's engagement, partnership and experiences gained with Gidarjil indigenous rangers in the monitoring and assessment of shoreline habitats in the southern GBR region.
- 14) Research publications of relevance by Dr Duke and Jock Mackenzie during this period include: 'The Shoreline Video Assessment Method (S-VAM): using dynamic hyperlapse image acquisition to evaluate shoreline mangrove forest structure, values, degradation and threats' in the journal *Marine Pollution Bulletin*; 'Oil spill impacts on mangroves: recommendations for operational procedures and planning based on a global review' in the journal *Marine Pollution Bulletin*; 'The state of legislation and policy protecting Australia's mangrove and salt marsh and their ecosystem services' in the journal *Marine Policy*; and the Australian mangrove plant identification guide called 'Mangrove Click! Australia: expert ID for Australia's mangrove plants' on the Apple iTunes Store. The latter is a useful and handy smart device tool for Rangers to have available when they identify mangrove plants.
- 15) Two additional grants awarded that enhance and build upon the objectives of the Southern GBR CHAMP NESP project, include: a) Wallace Creek Reserve restoration project on the Burnett River – a grant awarded to the Gidarjil Development Corporation as a community science project funded by the Gladstone Ports Corporation (Figure 1); and b) An Australian Government DFAT additional project with UNESCO is a boost for building indigenous ranger capacity in shoreline monitoring and management.
- 16) Tenders submitted and pending for major rehabilitation works with Queensland DAF identified from surveys by the GBR CHAMP NESP project team, include: a) rehabilitation of the Burnett River shoreline near the port and downstream sections of the estuary; (b) rehabilitation of the Kolan River shoreline near the sugar mill and nearby sections of the estuary; and c) research into best practice and effective methods for shoreline mitigation works in the Burnett region.



**Figure 1:** TropWATER scientists with Gidarjil DC Rangers providing advice and guidance for habitat rehabilitation at Wallace Creek Reserve Area.

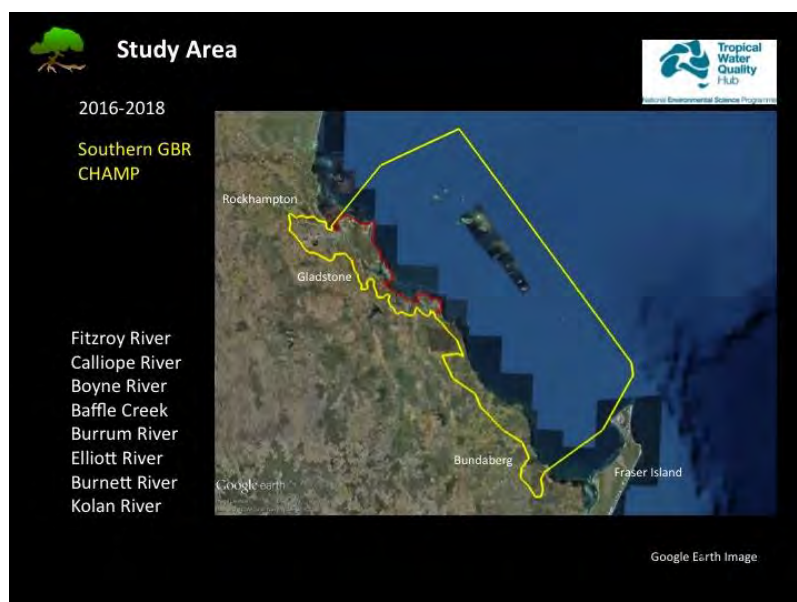


## 1.0 INTRODUCTION

Mangrove tidal wetland shorelines are being surveyed and monitored as part of this Coastal Habitat Archive and Monitoring Program (CHAMP) for the southern GBR region. The project is led by scientists from James Cook University's TropWATER Centre. The project forms part of the National Environmental Science Programme (NESP) with the Tropical Water Quality Hub (TWQ) Hub.

Traditional Owner rangers and local citizens of the Port Curtis Coral Coast (PCCC) Traditional Use of Marine Resources Area (TUMRA) are being engaged in the development of a Mangrove Management Plan (MMP) that provides a strategic basis for estuarine repair activity and maximizes water quality outcomes in the southern GBR region. Development of this MMP is building capacity amongst staff and rangers of the Gidarjil Development Corporation (GDC), as well as within the local community for gathering ecological monitoring and assessment data that is scientifically-rigorous and applied. These management and rehabilitation strategies will help protect sea country resources through our partnership between community, scientists and local Natural Resource Management (NRM) agencies. The MMP is enabling rangers and citizen scientists to conduct scientifically valid surveys of estuarine monitoring, management and rehabilitation within the PCCC TUMRA area.

This second milestone report, plus appendices, further shows the progress made for this project towards its two years of assessment and monitoring of mangrove tidal wetlands of the southern GBR region (see Figure 2). Over the last six months of 2016, the plan has been to continue to generate baseline data, to inform communities of the region about the project, to work with local NRM managers, and to especially raise capacity and confidence amongst the Gidarjil Rangers to initiate and conduct shoreline surveys and monitoring.



**Figure 2:** Google Earth satellite imagery of the Southern GBR CHAMP study area (yellow line) compared to the smaller PCCA CHAMP study area (red line). The major estuaries in this region are listed as the case study locations throughout the region.

The information presented in this report has been gathered mostly with the on-going project logistics, planning, personnel and training. These tasks are fundamental to meeting the

objectives of this program. These tasks are essential to the projects' success in fully preparing the Rangers with the necessary skill levels and facilities for meeting the tasks required; and as specified further below.

Current data presented have been generated as a result of observations made starting with the training sessions, and now extending to specific surveys. We have also been building on the prior *ad hoc* opportunities conducted for earlier projects. While some data maybe considered opportunistic, it has been fundamental in the establishment of baseline records as well as being extremely useful as training and familiarisation for all participants.

Briefly, the program proposed is to complete the three (3) components for the Southern GBR area, as:

1. High resolution maps of tidal wetlands, plus historical assessment plus change detection;
2. Shoreline condition monitoring using boat-based video image data acquisition by Gidarjil DC rangers and community volunteers; and,
3. Compilation of any other information pertinent to the health, viability and rehabilitation of tidal wetlands of the region, supporting their role in improving water quality along the southern GBR coastline.

Over the project life, each component will be addressed in detail by personnel from JCU TropWATER Centre who are primarily responsible for the delivery of the program with the TWQH. The program is led by TropWATER specialists in tidal wetland research, who will help characterise shoreline environmental values for the Southern GBR area. This is being achieved through the implementation of the Shoreline Video Assessment Method (S-VAM) along with an integrated monitoring and archiving program, bringing together partners in field research, remote sensing, IT and teaching skills.

This project is an important opportunity to achieve world best practice for compilation and dissemination of data and expert advice gathered from field surveys and stakeholder meetings with key contributors from industry, government, universities and with indigenous rangers and community volunteers. The planned outcomes will be a comprehensive baseline assessment of ecological condition and health for the region (building on prior surveys like Duke et al. 2003; 2005; 2010; Mackenzie & Duke 2011). The information collected in this project is intended for future use; being a tangible, permanent resource for regional managers, industry stakeholders and community members wishing to maximise conservation benefits while maintaining environmentally appropriate coastal development works.

The project integrates scientific, industrial, management and Indigenous cultural knowledge to better inform environmental managers of tidal wetlands for improved mitigation actions in the Southern GBR region. Our partnership approach is expected to enhance local capacity for implementation of ongoing shoreline assessment as well as maintaining sustainable environmental monitoring outcomes.

## 2.0 METHODOLOGY

### 2.1 Project operations, logistics and management

The JCU Centre for Tropical Water and Aquatic Ecosystem Research (TropWATER) is ideally placed to draw upon a wide range of expertise available and necessary for the delivery of the Southern GBR CHAMP project. The works include monitoring the condition, survival and recovery of shorelines, specifically regards tidal wetlands.

While TropWATER Centre at JCU is the lead agent for this project, we are collaborating in partnership with the following organisations using individual sub-contract arrangements for each, as appropriate:

- a. Gidarjil Development Corporation indigenous Rangers along with community volunteers in the Southern GBR region, are assisting in the field surveys of monitoring and assessment of coastal tidal wetland habitats (Component 2);
- b. Collaboration with Prof John Kovacs of Nipissing University, Canada, for specialised remote sensing assessments and mapping of tidal wetland habitats in the region (Components 1 primarily, plus taking other opportunities for ground truth and data validation);
- c. Partnerships with two (2) NRM regional groups, the Burnett Mary Regional Group, and the Fitzroy Basin Association, for development and implementation of the planned Mangrove Management Plan (all components).

While the program is an integrated package, it is being achieved under the three broad Project Components. To a large extent, the project outcomes will be influenced and enhanced during the collaborations generated with potential end users and stakeholders in tidal wetlands and shorelines of the Southern GBR region. Our core end users for this project are listed in Table 1.

**Table 1:** Research End Users and Stakeholders for the Southern GBR CHAMP

| <b>Research End Users<br/>(section/programme/organisation)</b>                                                                                                             | <b>Name/s</b>                      | <b>Email (optional)</b>                                                                                                                                                                                                                |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| DoEE – Wetland Policy and Projects Branch                                                                                                                                  | Jenny Tomkins,<br>A/Director       | <a href="mailto:jenny.tomkins@environment.gov.au">jenny.tomkins@environment.gov.au</a>                                                                                                                                                 |
| <b>Key Stakeholders<br/>(organisation/programme)</b>                                                                                                                       |                                    |                                                                                                                                                                                                                                        |
| Queensland Marine Parks, Marine Resource Management (QNPSR) Fish Habitat Area (FHA) development and management – specifically the declaration of a new Calliope River FHA. | Nicola Udy                         | <a href="mailto:nicola.udy@npsr.gov.au">nicola.udy@npsr.gov.au</a>                                                                                                                                                                     |
| Queensland Fisheries Service (QDAF) fish habitat protection policy                                                                                                         | Melissa Dixon                      | <a href="mailto:melissa.dixon@daf.qld.gov.au">melissa.dixon@daf.qld.gov.au</a>                                                                                                                                                         |
| QPWS                                                                                                                                                                       | Rachell Jupp                       |                                                                                                                                                                                                                                        |
| Gidarjil Development Corporation Ltd                                                                                                                                       | Kerry Blackman<br>Peter Brockhurst | <a href="mailto:kerry.blackman@gmail.com">kerry.blackman@gmail.com</a><br><a href="mailto:tumra@gidarjil.com.au">tumra@gidarjil.com.au</a><br><a href="mailto:go.projectmanager@gidarjil.com.au">go.projectmanager@gidarjil.com.au</a> |

|                                                              |                                                                                                                  |                                                                                                                                                                                                                                                  |
|--------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                              | Annette Rutherford                                                                                               |                                                                                                                                                                                                                                                  |
| Great Barrier Reef Marine Park Authority, Coastal Ecosystems | Donna Audas                                                                                                      | <a href="mailto:donna.audas@gbrmpa.gov.au">donna.audas@gbrmpa.gov.au</a>                                                                                                                                                                         |
| Gladstone Healthy Harbour Partnership (GHHP)                 | Ian Poiner,<br>John Kirkwood                                                                                     | <a href="mailto:ian.poiner@me.com">ian.poiner@me.com</a><br><a href="mailto:john.kirkwood@ghhp.org.au">john.kirkwood@ghhp.org.au</a>                                                                                                             |
| Fitzroy Basin Natural Resource Management Group              | Rebecca French<br>Shannon Van Nunen, Coastal and Marine Manager                                                  | <a href="mailto:Rebecca.French@fba.org.au">Rebecca.French@fba.org.au</a><br><a href="mailto:Shannon.vanNunen@fba.org.au">Shannon.vanNunen@fba.org.au</a>                                                                                         |
| Burnett Mary Regional Group                                  | Sheila Charlesworth<br>CEO,<br>Kirsten Wortel,<br>Jacinta Jowett<br>(replacing Penny Hall, ex CEO & Sue Sargent) | <a href="mailto:Sheila.Charlesworth@bmrq.org.au">Sheila.Charlesworth@bmrq.org.au</a><br><a href="mailto:Kirsten.Wortel@bmrq.org.au">Kirsten.Wortel@bmrq.org.au</a><br><a href="mailto:Jacinta.Jowett@bmrq.org.au">Jacinta.Jowett@bmrq.org.au</a> |
| Gladstone Ports Corporation, Marine Environment Office       | Megan Ellis                                                                                                      | <a href="mailto:EllisM@gpcl.com.au">EllisM@gpcl.com.au</a>                                                                                                                                                                                       |
| Estuarine Research and Monitoring Program                    | Chris Crossland                                                                                                  | <a href="mailto:chris.crossland44@gmail.com">chris.crossland44@gmail.com</a>                                                                                                                                                                     |
| Wildlife Queensland Coastal Citizen Science                  | Simon Baltais<br>Debra Henry                                                                                     | <a href="mailto:baltais@bigpond.net.au">baltais@bigpond.net.au</a><br><a href="mailto:DebraHenry@wildlife.org.au">DebraHenry@wildlife.org.au</a>                                                                                                 |
| Society for Growing Australian Plants (SGAP)                 | Ruth Crosson,<br>John Holzapfel                                                                                  | <a href="mailto:sgap-gladstone@hotmail.com">sgap-gladstone@hotmail.com</a><br><a href="mailto:johnholzapfel@bigpond.com">johnholzapfel@bigpond.com</a>                                                                                           |
| Conservation Volunteers Australia (CVA)                      | Jodi Jones                                                                                                       |                                                                                                                                                                                                                                                  |

Milestone activity scheduling for the Southern GBR CHAMP project are shown in Table 2.

**Table 2:** Project Milestone Schedule 2016-2018

| Milestone Activities                                                                                           | Jun 2016 | Dec 2016 | Jun 2017 | Dec 2017 | Feb 2018 |
|----------------------------------------------------------------------------------------------------------------|----------|----------|----------|----------|----------|
| <b>Consultation with Stakeholders</b>                                                                          | X        | X        | X        | X        | X        |
| <b>Stakeholder Workshops</b><br>Bundaberg & Gladstone                                                          | X        |          |          | X        |          |
| <b>Training Workshop - Field Team</b><br>Bundaberg & Gladstone                                                 | X        | X        | X        | X        |          |
| <b>Field Surveys</b> by Gidarjil Rangers<br><b>Southern estuaries:</b> Baffle, Burrum, Elliott, Burnett, Kolan | X        | X        |          |          |          |
| <b>Field Surveys</b> by Gidarjil Rangers<br><b>Northern estuaries:</b> Boyne, Calliope, Fitzroy                |          |          | X        | X        |          |
| <b>Condition Data Assessment</b><br>JCU assessment of Field Survey data about estuarine tidal wetlands         |          | X        | X        | X        |          |
| <b>Restoration Protocols</b><br>& Potential Target Sites                                                       |          |          |          | X        |          |
| <b>Towards a</b>                                                                                               | X        | X        | X        | X        | X        |

|                                                                                                      |   |   |   |   |   |
|------------------------------------------------------------------------------------------------------|---|---|---|---|---|
| <b>Mangrove Management Plan</b> (MMP) for southern GBR, with Traditional Owners                      |   |   |   |   |   |
| <b>Photos</b> to eAtlas/RRRC                                                                         | X |   | X | X |   |
| <b>Data management plan</b> to eAtlas                                                                |   | X | X | X |   |
| <b>Datasets for publication</b> in eAtlas, publication standards                                     |   |   |   | X |   |
| <b>Milestone REPORTING by JCU</b><br>GDC Ranger engagement and Data Acquisitions and JCU Assessments | X | X | X | X | X |

The proposed scheduling of project activities are shown in Table 3.

**Table 3:** Planned Diary Dates for the Southern GBR CHAMP Project 2016-2018

|                                   |                                                                                                                                                                                                                                                                                       |
|-----------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>2016</b>                       |                                                                                                                                                                                                                                                                                       |
| 12 Feb                            | NESP TWQ Project Leaders Meeting #1 – ND to attend in Townsville.                                                                                                                                                                                                                     |
| 18-22 Apr                         | Stakeholder Meeting (one day), BMRG & Southern Training Workshop (2-3 days), Bundaberg, GDC                                                                                                                                                                                           |
| Apr-May                           | Field data collection by Rangers for Baffle, Burrum, Elliott, Burnett, Kolan - GDC lead (~2 days S-VAM & 2 days walkabout each estuary). Dates for surveys are dependent on tides and weather conditions. An earlier start to surveys is encouraged for Ranger teams already trained. |
| Apr-June                          | Wetland mapping by JCU of Baffle, Burrum, Elliott, Burnett, Kolan, in collaboration with BMRG and JK. Map cover and quality depends on availability of aerial/satellite imagery from BMRG and other sources.                                                                          |
| <b>1 June</b>                     | <b>Milestone #1 of 5 – First Report, JCU with GDC, BMRG, FBA advice</b>                                                                                                                                                                                                               |
| June-July                         | Assessment of field data by JCU for Baffle, Burrum, Elliott, Burnett, Kolan.                                                                                                                                                                                                          |
| 8-12 Aug                          | Northern Ranger Training & Ranger Feedback (2-3 days), Consultation, JCU Field Surveys in Southern Estuaries (4 days)                                                                                                                                                                 |
| <b>1 Dec</b>                      | <b>Milestone #2 of 5 – Southern Surveys Report, JCU with GDC, BMRG, FBA advice</b>                                                                                                                                                                                                    |
| <b>2017</b>                       |                                                                                                                                                                                                                                                                                       |
| NB: dates for some activities TBA |                                                                                                                                                                                                                                                                                       |
| Apr-May                           | Field data collection by Rangers for Boyne, Calliope, Fitzroy - GDC lead (~3 days S-VAM & 3 days walkabout each estuary. Survey dates dependent on tides and weather conditions.                                                                                                      |
| Apr-June                          | Wetland mapping by JCU of Boyne, Calliope, Fitzroy, in collaboration with FBA and JK. Map cover and quality depends on availability of aerial/satellite imagery from FBA and other sources.                                                                                           |
| <b>1 June</b>                     | <b>Milestone #3 of 5 – Northern Surveys &amp; Southern Assessments Report, JCU with GDC, BMRG, FBA advice</b>                                                                                                                                                                         |
| June-July                         | Assessment of field data by JCU for Boyne, Calliope, Fitzroy.                                                                                                                                                                                                                         |
| 7-11 Aug                          | Ranger Feedback Workshop (one day), Consultation & JCU Field Surveys in Northern Estuaries (4 days), plus Stakeholder Meeting (one day), FBA                                                                                                                                          |
| <b>1 Dec</b>                      | <b>Milestone #4 of 5 – Northern Assessments &amp; Management Plan Report, JCU with GDC, BMRG, FBA advice</b>                                                                                                                                                                          |
| <b>2018</b>                       |                                                                                                                                                                                                                                                                                       |
| 31 Jan                            | Finalise Mangrove Management Plan, eAtlas requirements and final reporting components with all participants                                                                                                                                                                           |
| <b>1 Feb</b>                      | <b>Milestone #5 of 5 – FINAL REPORT, JCU with GDC, BMRG, FBA advice</b>                                                                                                                                                                                                               |

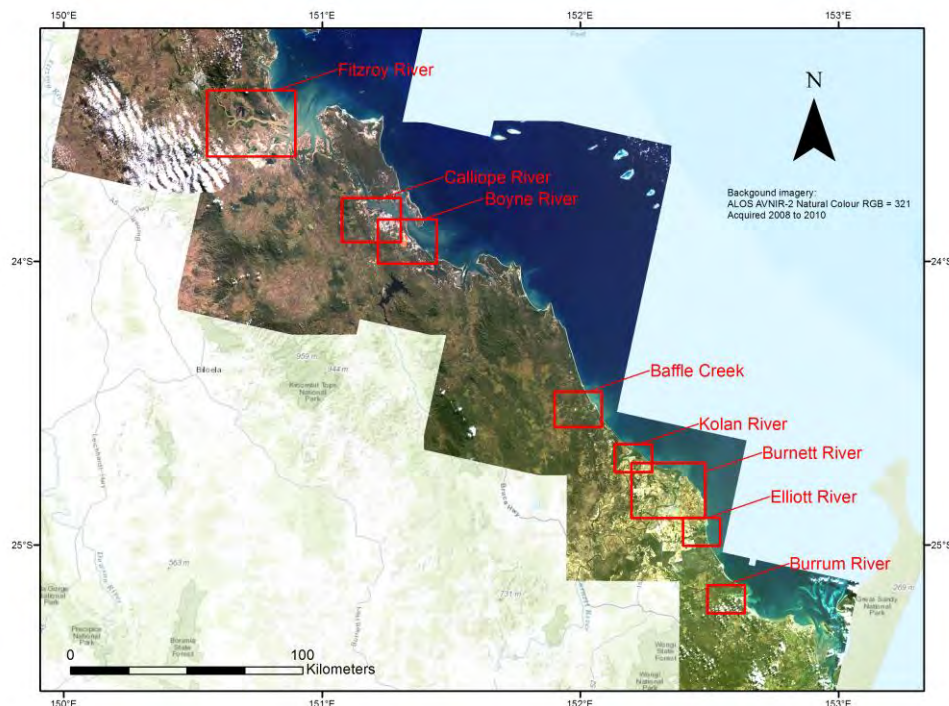
## 2.2 Mapping of Tidal Wetland Resources

|                      |                                                                                                                                                                                       |
|----------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Criteria:</b>     | Mapping of tidal wetland vegetation types along with historical change detection to identify areas of net loss and gain in key habitat components (mangroves, saltmarsh and saltpans) |
| <b>Project Lead:</b> | Dr Norm Duke, TropWATER, JCU                                                                                                                                                          |
| <b>Partners:</b>     | Prof. John Kovacs, Nipissing University, Canada                                                                                                                                       |

### Specific Tasks

The team will acquire suitably fine-scaled, multispectral Image data for mapping mangroves, tidal saltmarsh and tidal saltpan flats, as the key vegetation types of tidal wetlands in each of the case study estuaries.

To display areas of mangrove and saltmarsh which had been previously identified, a series of maps were produced for the major estuaries which extend along the Southern Great Barrier Reef (GBR) study area (Figure 3).



**Figure 3:** Map of the Southern GBR shoreline showing the location of the 8 estuarine systems used as case studies in this project.

Specifically, polygons were extracted from the Queensland Wetland Mapping and Classification Project (QWMCP) that represents saltmarsh and mangrove ecosystems. The QWMCP was last updated in 2009. Within this dataset, each ecosystem is identified by a specific three number code that describes both the physical and vegetative conditions. The codes used for the mangrove polygon extraction are shown in Table 4. In total eight (8) maps were produced for the following major estuaries along the SGBR coast (ordered from North to South):

- Fitzroy River
- Calliope River
- Boyne River
- Baffle Creek
- Kolan River
- Burnett River
- Elliott River
- Burrum River

For each map, the extracted mangrove and saltmarsh regional ecosystem polygons were overlaid on a background base map derived of mosaiced ALOS AVNIR-2 satellite imagery. Specifically, the base map employed the spectral band 3 of the AVNIR-2 imagery which represents the red region (630-685 nm) of the electromagnetic spectrum.

The polygons extracted from the QWMCP will be used as a general guide for assisting in the classification of these ecosystems using updated high resolution satellite imagery. Higher spatial resolution imagery, possibly *GeoEye-1*, *RapidEye* or *SPOT-7*, will be acquired for either 2014 or 2015. Once collected, these data will first be radiometrically corrected to surface reflectance using *PCI Geomatica's ATCOR* module. If necessary these images may also be geometrically corrected using *PCI Geomatica's Orthoengine*. Since several swaths of imagery are likely to be needed to cover the study area, the many surface reflectance images may also be mosaiced. The Normalized Difference Vegetation Index (NDVI) will then be produced from each surface reflectance mosaic. NDVI is calculated using the following formula:  $NDVI = \frac{(NIR - Red)}{(NIR + Red)}$ . The NDVI images can then be used to monitor changes in the health of the vegetation by comparing them with future NDVI images collected of the same locations. Finally, using ancillary data (e.g., QWMCP, Gidarjil field surveys), a per pixel classification procedure will be applied to the newly acquired imagery in order to map the most recent areas of mangrove and saltmarsh land cover.

## 2.3 Boat-based Shoreline Surveys

|                      |                                                                                                                            |
|----------------------|----------------------------------------------------------------------------------------------------------------------------|
| <b>Criteria:</b>     | Shoreline condition monitoring using boat-based video image data acquisition by Gidarjil rangers and community volunteers. |
| <b>Project Lead:</b> | Dr Norm Duke, TropWATER, JCU<br>Jock Mackenzie, TropWATER, JCU                                                             |
| <b>Partners:</b>     | Gidarjil Development Corporation<br>MangroveWatch Ltd                                                                      |

### Specific Tasks

The methods used in these surveys are geo-referenced videography called the Shoreline Video Assessment Method (Mackenzie & Duke 2016). All imagery is collected by either indigenous rangers or by community volunteers – supervised by TropWATER science specialists. All participants are trained by the TropWATER project team. In the study area, many indigenous rangers have been trained, and they are operationally ready to conduct the surveys identified for the study area – namely the eight estuarine case study areas. These data collection surveys are well advanced. Processing of image data collected by community members will be done by the TropWATER project team at the Mangrove Hub at JCU. Data

taken from imagery and from survey diaries are used to further visualise and describe coastline condition, to make ecological assessments of shoreline composition, the status and health of those shorelines. These data and information will contribute directly to the Southern GBR Mangrove Management Plan.

The specific methodology that will be employed is:

1. Collect source video and still imagery taken laterally from small boats around 50 m distance to shoreward margins. Filming will be undertaken such that it covers continuous shorelines of specific sections of estuarine areas and embayments. The intent of the project team is to cover all seaward margins in the study area, but limitations of funding dictate that only approximately 200 km of shoreline will be filmed and assessed. Ideally, the extent of shorelines filmed will include continuous coverage of most mainland and island shorelines (as mangrove seaward margins mostly, but not restricted to them) in the study area. Attention will be made of specific sections of the coastline as the eight (8) estuarine river systems.
2. Training has been given to the Gidarjil Rangers by the TropWATER project team to ultimately develop their skill base for the effective, independent gathering of imagery and other data for description of shoreline profiles relevant to this project.
3. The project team plans to make annual temporal assessments. There is sufficient funding support in the budget proposed to make at least 2 surveys during the 2 full years of the project, working with the Gidarjil Rangers until the project end in 2018. If there is spare time, or other funding available, the intention is to fill gaps and/or expand the existing number of local estuarine systems. A number of strategies will be employed: 1) additional funds will be sought with appropriate grant applications to further employ Gidarjil Rangers; and 2) community volunteers will be enlisted, trained and equipped. In this way, additional locations may be assessed.
4. The choice of days for boat surveys will be determined by the suitability of weather conditions, the time of day, coupled with periods of relatively low to mid tide.
5. Initial, sometimes prior, survey data will be used as baseline condition. Subsequent records will provide measures of differences. Specific observations will describe occurrences of habitat type, condition and change; noting: vegetative condition like species type; biomass; dieback condition; presence of plant mutations; notable erosion; root/bank exposure; sediment deposition; presence of seedlings; and seasonal changes along with species present in each habitat assemblage.
6. These findings will provide backup, support and validation for the mapping component.

## 3.0 RESULTS

### 3.1 Post-flood evaluation of the Burnett River estuary

The post-flood assessment of the Burnett River estuary was completed and the preliminary results presented at the international conference, MMM4 in Florida, USA on 22 July 2016. Refer to Appendix 2 for a copy of the power point presentation.

### 3.2 Preliminary assessment of tidal wetlands in the Elliott River estuary

We provide a preliminary analysis of historical tidal wetland change in the Elliott River estuary and review the factors driving long term changes in tidal wetland ecosystem structure and function that are likely to impact GBR water quality. Through this process we identify ongoing and emerging threats and management issues that can be addressed through direct on-ground investment to improve GBR water quality. This current assessment is designed to inform future on-ground assessment to then prioritize those activities to maximize water quality outcomes.

This current study is part of an ongoing focus on tidal wetland health in the Elliott River and continues on from previous assessments (Table 4).

**Table 4:** Timeline of tidal wetland surveys and mapping in the Elliott River

|                  |                                                                                                                                                                                                           |
|------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>1978</b>      | Biological resources survey (estuarine inventory). Round Hill Head to Tin Can Bay (Dowling 1978)                                                                                                          |
| <b>1993</b>      | Fisheries Resource Assessment of the Elliott River System (Lupton 1993)                                                                                                                                   |
| <b>1997</b>      | Queensland Coastal Wetland Resources: Round Hill Head to Tin Can Inlet. Qld. Dept. of Primary Industries (Bruinsma and Danaher 2000)                                                                      |
| <b>2002</b>      | Declaration of Elliott River fish habitat area (Mckinnon et al 2002)                                                                                                                                      |
| <b>2007-2008</b> | State of the Mangroves Burnett Mary Region (Mackenzie and Duke 2011)                                                                                                                                      |
| <b>2008</b>      | Aerial Estuarine Survey: Daintree to Moreton Bay (Duke and Mackenzie, unpub data 2008)                                                                                                                    |
| <b>2009</b>      | MangroveWatch BMR (Duke et al 2010) – surveys by Elliott Heads Progress Association                                                                                                                       |
| <b>2010</b>      | MangroveWatch BMR (Duke et al 2010) – surveys by Elliott Heads Progress Association                                                                                                                       |
| <b>2011</b>      | MangroveWatch BMR (unpub data 2010) – surveys by Elliott Heads Progress Association                                                                                                                       |
| <b>2013</b>      | Burnett Mary Post-flood Tidal Wetland Assessment – TropWATER, JCU in partnership with Elliott Heads Progress Association and Gidarjil Development Corporation (Mackenzie, Heid and Duke, unpub data 2013) |
| <b>2016</b>      | Southern GBR Coastal Habitat Archive and Monitoring Program (this project)                                                                                                                                |

*\*The Elliott River is part of the ongoing state-wide Queensland Wetland Mapping Program, providing tidal wetland mapping at 1:100,000 scale*

### 3.2.1 Introduction

Tidal wetlands, comprising mangroves, saltmarsh and coastal vegetation assemblages (Figure 4), are vital ecosystems for maintaining estuarine ecological values and play an important role in protecting adjacent near-shore habitats such as seagrass and coral reef. Although often overlooked, tidal wetlands are an important ecological player in the management of water quality in the Great Barrier Reef.



**Figure 4:** Tidal wetland vegetation units: mangrove, saltmarsh and other coastal vegetation

The importance of tidal wetlands to the Great Barrier Reef relates to their capacity to trap, process and store anthropogenically derived nutrients and sediments delivered to the coastal zone via overland flow, riverine flow and within receiving tidal waters. It is estimated that tidal wetlands, specifically mangroves, can trap up to 80% of sediment delivered during tidal inundation (Furukawa et al., 1997) totalling 50 to 60 tonnes of sediment per hectare, per year (Lovelock and Ellison, 2007). Similarly, tidal wetlands have been demonstrated to trap around one quarter of land-derived nutrients (Valiela and Cole, 2002) and between 22% and 61% of dissolved nitrogen and phosphorous in tidal waters (Adame et al., 2010), totalling 140 to 170 kg Nitrogen ha<sup>-1</sup> yr<sup>-1</sup> (Lovelock and Ellison, 2007). The capacity of tidal wetlands to trap and process nutrients and sediment is dependent on spatial context, habitat structural complexity, vegetation structure and productivity and is highly variable globally (Adame and Lovelock, 2011). As for many ecosystem services, different tidal wetland habitat types are likely to serve different roles in the overall ecosystem service provision of water quality maintenance (Ewel et al., 1998). For example, fringing mangroves trap around 52% of sediment during tidal cycles owing to their proximity to the water's edge and the initial interception of tidal flows. Whereas, highly dense and productive fields of the C4 saltmarsh grass *Sporobolus virginicus* located in the upper tidal zone is more likely to trap and retain sediment and nutrients derived from overland flows. Changes in the spatial and structural habitat complexity of tidal wetlands is therefore likely to alter the function of tidal wetlands in relation to sediment and nutrient retention. This applies for most tidal wetland ecosystem services.

Tidal wetlands are naturally dynamic and structurally variable systems, subject to a high degree of physical and physio-chemical variation over time in relation to tidal cycles and short and long-term weather and climate variables. For instance, within relatively pristine estuaries, the proportion of mangrove and saltmarsh is generally reflective of long-term rainfall conditions (Duke et al *in prep* 2016). The proportion of mangrove therefore increases with long-term increases in rainfall and reduce during periods of low rainfall (drought) (Eslami-Andargoli et al., 2010). Flood events can cause shoreline erosion along estuary margins resulting in habitat loss that exposes more complex higher elevation tidal wetland habitat to direct estuary flows. These losses are offset by sediment depositional gain and new mangrove colonisation elsewhere and increased productivity at higher elevations through sediment and nutrient deposition. The apparent maintenance of tidal wetland structural complexity and ecosystem function over time in natural settings despite natural disturbance, suggests that tidal wetlands are generally highly resilient ecosystems.

Anthropogenic influences within and around estuaries can alter the spatial dynamics and structural complexity of tidal wetlands and therefore reduce ecosystem service provision capacity and resilience to natural disturbance. Altered hydrology, pollutants, elevated nutrient loads and altered sediment loads can all modify tidal wetland processes leading to large spatial changes in habitat structure, loss of structural complexity and ultimately a likely reduction in ecosystem service provision. In the context of sea level rise and climate change the presence of these anthropogenic drivers is likely to have even more severe consequences.

One of the most well documented changes in tidal wetland structure linked to indirect anthropogenic disturbance has been the phenomena of mangrove expansion into saltmarsh habitat in tidal wetlands along the east coast of Australia. The drivers of mangrove upland migration have been attributed to various factors such as rainfall, altered hydrology, elevated nutrient loads, tidal wetland surface elevation change and sea level rise and is possibly a combination of many of these factors. What is clear is that this change is taking place across a large area and resulting in a significant reduction in saltmarsh habitat at both estuary and regional scales.

The loss of saltmarsh habitat is cause for concern. Saltmarsh habitat provides important tidal wetland habitat diversity and complexity for estuary fauna including fisheries resources, internationally significant migratory shorebirds and EPBC listed fauna like the Endangered Water Mouse (*Xeromys myoides*). Saltmarsh habitat is also critical for maintaining estuarine water quality and productivity. Dense stands of saltmarsh vegetation, specifically *Juncus kraussii* and *Sporobolus virginicus*, are effective sediment and nutrient traps. Dense algal mat across saltpan surfaces bind sediment deposited during tidal inundation and process nutrients within the water column, as well as providing significant carbon contributions to tidal waters. Historically, large areas of saltmarsh within the South-East Queensland Bioregion and in southern Australia have been lost due to conversion to alternate land-use., saltmarsh remains highly threatened by sea level rise and ‘coastal squeeze’, where upland migration of saltmarsh in response to sea level rise is prevented by adjacent infrastructure and land use. In 2013, sub-tropical and temperate saltmarsh was listed as an endangered ecological community under the Environment Biodiversity and Protection Act (1999), as recognition of both its high value and threatened status. The distribution of sub-tropical saltmarsh extends north to Port Curtis in Queensland and includes the Elliott River estuary.

The loss of saltmarsh habitat resulting from mangrove upland migration and the probable additional loss of saltmarsh habitat due to sea level rise is further compounded by the presence of direct anthropogenic disturbance within many GBR estuaries in the form of vehicle damage, cattle grazing and feral pigs. These direct impacts also reduce the ecosystem service capacity of saltmarsh habitat, specifically sediment and nutrient reduction. Direct damage to saltmarsh plants reduces vegetation cover leading to reduced sediment and nutrient trapping capacity. Damage to the saltmarsh sediment surface structure increases sediment export and erosion, with sediment compaction resulting in limited vegetation recovery potential in the long term. Of greatest concern is damage to algal mat communities that is likely to have far reaching consequences for tidal wetland and estuary function. All these factors are likely to not only reduce the capacity of tidal wetlands to improve estuarine water quality but also to result in these tidal wetlands becoming a contributor to poor water quality in the Great Barrier Reef.

It is therefore essential to understand the drivers of habitat change within the tidal wetlands of the GBR and identify key management issues that threaten tidal wetland ecosystem service provision and ecosystem resilience.

### **3.2.2 Methods**

**Study Location:** Elliott River

**Central Burnett-Mary Region**

**Location:** 24°55'39; 152°29'1

The Elliott River is an intermittently flowing river system, with a moderately sized estuary located 16km to the south-east of Bundaberg (Figure 5). The river and estuary are groundwater dependent systems, with groundwater flows driving hydrological conditions, process and ecological function. Surrounding the estuary are palustrine and lacustrine wetland habitats, and the upper-estuary features extensive groundwater dependent tidal wetland habitat. Tidal wetlands in the estuary have high habitat complexity, saltmarsh species diversity (Table 5) and ecological integrity. These ecosystems are threatened by excessive groundwater extraction, altered terrestrial hydrological connectivity and eutrophication.

*(Excerpt from Mackenzie & Duke, 2011)*



Figure 5: Location of the Elliott River estuary

Table 5: Saltmarsh and Mangrove flora present within the Elliott River

| Species Name                       | Common Name          | Present      |
|------------------------------------|----------------------|--------------|
| <b>Saltmarsh</b>                   |                      | <b>22/31</b> |
| <i>Atriplex semibaccata</i>        | Creeping Saltbush    | Yes          |
| <i>Bacopa monnieri</i>             | Water hyssop         | No           |
| <i>Baumea juncea</i>               | Bare Twig Rush       | Yes          |
| <i>Carpobrotus glaucescens</i>     | Pigface              | Yes          |
| <i>Cynanchum carnosum</i>          | mangrove vine        | Yes          |
| <i>Dysphania littoralis</i>        | red crumbweed        | Yes          |
| <i>Einadia hastata</i>             | Red-berried Saltbush | No           |
| <i>Enchylaena tomentose</i>        | Ruby saltbush        | Yes          |
| <i>Fimbristylis ferruginea</i>     | Common Fringe Rush   | Yes          |
| <i>Fimbristylis polytrichoides</i> | Rust Sedge           | Yes          |
| <i>Juncus kraussii</i>             | Sea Rush             | Yes          |
| <i>Limonium australe</i>           | Yellow Sea-Lavender  | No           |
| <i>Limonium solanderi</i>          | Sea Lavender         | Yes          |
| <i>Paspalum vaginatum</i>          | Saltwater couch      | Yes          |
| <i>Phragmites australis</i>        | Common Reed          | No           |
| <i>Portulaca oleracea</i>          | Pigweed              | Yes          |

|                                  |                                     |              |
|----------------------------------|-------------------------------------|--------------|
| <i>Portulaca pilosa</i>          | Hairy pigweed                       | No           |
| <i>Ruppia maritima</i>           | Ditch grass                         | No           |
| <i>Salsola australis</i>         | Roly poly                           | Yes          |
| <i>Sarcocornia quinqueflora</i>  | beaded samphire                     | Yes          |
| <i>Schoenoplectus subulatus</i>  | Club rush                           | No           |
| <i>Sesuvium portulacastrum</i>   | sea purslane                        | Yes          |
| <i>Sporobolus virginicus</i>     | Salt couch                          | Yes          |
| <i>Suaeda arbusculoides</i>      | jelly-bean plant                    | Yes          |
| <i>Suaeda australis</i>          | seablite                            | Yes          |
| <i>Tecticornia halocnemoides</i> | Small segmented blackseed Glasswort | Yes          |
| <i>Tecticornia indica</i>        | Brown-headed Samphire               | Yes          |
| <i>Tecticornia pergranulata</i>  | Blackseed Samphire                  | Yes          |
| <i>Tetragonia tetragonoides</i>  | New Zealand Spinach                 |              |
| <i>Triglochin striata</i>        | Streaked Arrowgrass                 | No           |
| <i>Zoysia macrantha</i>          | Prickly couch                       | Yes          |
| <b>Mangrove</b>                  |                                     | <b>10/11</b> |
| <i>Acrostichum speciosum</i>     | Mangrove fern                       | Yes          |
| <i>Aegialitis annulata</i>       | Club Mangrove                       | Yes          |
| <i>Aegiceras corniculatum</i>    | River Mangrove                      | Yes          |
| <i>Avicennia marina</i>          | Grey Mangrove                       | Yes          |
| <i>Bruguiera gymnorhiza</i>      | Orange Mangrove                     | Yes          |
| <i>Ceriops australis</i>         | Yellow mangrove                     | Yes          |
| <i>Excoecaria agallocha</i>      | Milky Mangrove                      | Yes          |
| <i>Lumnitzera racemosa</i>       | White-flowered Black Mangrove       | Yes          |
| <i>Osbornia octodonta</i>        | Myrtle Mangrove                     | Yes          |
| <i>Rhizophora stylosa</i>        | Red Mangrove                        | Yes          |
| <i>Xylocarpus granatum</i>       | Cannonball Mangrove                 | No           |

### Tidal Wetland Mapping

Mangrove, saltmarsh and other tidal wetland vegetation outlines for the Elliott River were manually digitized in ArcGIS 10.0 using visual interpretation of a combination of aerial and satellite imagery.

First, a baseline map of tidal wetland vegetation cover was generated using a 2010 50cm Digital Ortho-rectified aerial mosaic (supplied by BMRG). To generate the baseline map, the tidal wetland area was defined around the Elliott River estuary using a Highest Astronomical Tide (HAT) polyline from the Queensland Government Erosion Prone Area Series. Existing tidal wetland layers available from the Queensland Wetland Mapping Program (QWMP, 2013), the Queensland Coastal Wetland Resource Assessment (Bruinsma and Danaher, 2000) and the State of the Mangrove Report (Mackenzie and Duke, 2011) were used to assist initial vegetation unit classification and define estuary water-bodies. False-colour enhancement of the 2010 image was also used to assist distinguishing trees from saltmarsh and unvegetated tidal areas. Polylines were drawn around mangrove (trees), saltmarsh/saltpan and other non-

mangrove tree vegetation present below HAT at 1:5,000 scale. This initial classification was checked against NDVI values generated from 2010 Landsat 5 imagery (30 m resolution). Areas classified as 'mangrove' with low ( $< 0.3$ ) NDVI values representing low canopy cover were reclassified as 'saltmarsh/saltpan' as these were likely to be only sparse mangrove cover or represent dense samphire cover, sometimes confused for shrubby low stature mangroves.

After the production of the baseline map, more detailed, high-resolution (60 cm) orth-rectified aerial imagery became available from Nearmap. The 2010 baseline vegetation units from 2010 were cross-checked against the 2013 Nearmap images imported into ArcGIS to remove obvious vegetation misclassification. Reclassification was undertaken at the higher-resolution 1:2,500 scale. These amended polylines were then reassessed in the 2010 image to define 2010 tidal wetland vegetation units. Individual vegetation layers were also generated for 2013.

Historical aerial imagery from 1970 was geo-referenced using the 2010 image to create an image mosaic. The 2010 baseline polylines were overlaid on the 1970 images and redefined based on the absence or presence of different vegetation units.

A 2016 mangrove layer was created using available 2016 Neamap aerial imagery in ArcGIS based on observed differences between the derived 2013 mangrove layer and the 2016 image. Further detailed classification of the 2016 imagery is currently in progress.

### **Management Issue Identification**

Management issues were identified based on visual inspection of current Nearmap high resolution aerial imagery and comparison with past tidal wetland surveys. The area of impact was then digitized in ArcGIS. Land-use adjacent to the Elliott River was derived from the Queensland Land Use Mapping Program dataset (QLUMP, 2009) from within a 500m buffer of the HAT polyline

### **3.2.3 Results**

Within the Elliott River estuary there has been a net increase in mangrove area of 68.2 ha (23%) between 2013 and 1970, with the total mangrove area remaining the same between 2013 and 2016 (Table 6). There has been a net loss of saltmarsh/saltpan area of 48 ha (29%) over the same period. This represents a loss of ~1 ha of saltmarsh per year within the Elliott River estuary.

Describing changes in tidal wetland cover using the proportion of mangrove to saltmarsh is a useful index (herein referred to as the Wetland Cover Index (WCI)) to compare net changes in tidal wetland vegetation over time (Duke *in prep* 2016). The WCI also allows some comparative interpretation of different mapping methods, as was used to derive 1997 and 2005 data. The results presented in (Table 6) show that there was a significant increase in WCI between 1970 and 1997, after which it has remained stable at 0.74, with a small increase between 2010 and 2013.

Detailed comparison between 1970 and 2010 tidal wetland vegetation shows that much of the change in mangrove and saltmarsh area during that period can be attributed to mangrove expansion. Whilst there was some expansion of mangroves at the shoreline margin into the estuary (herein referred to as depositional gain), these gains were mostly offset by mangrove

loss due to erosion along shoreline margins. Only 3 ha of mangrove were lost due to direct human removal. Saltmarsh upland expansion resulted in a loss of 8.65 ha of other (non-mangrove) tidal wetland trees.

Overall, shoreline erosion resulted in a loss of 22.8 ha of tidal land, of which 14.1 ha was offset by subsequent shoreline expansion (Table 7; Figs. 6 to 8). The total shoreline loss to gain ratio within the Elliott River is 1.6. This is compared to the loss to gain ratio for shoreline mangroves at 0.82.

**Table 6:** Mangrove and Saltmarsh Area in the Elliott River 1970 to 2016

|                            | <b>1970</b> | <b>1997<sup>1</sup></b> | <b>2005<sup>2</sup></b> | <b>2010</b> | <b>2013</b> | <b>2016</b> |
|----------------------------|-------------|-------------------------|-------------------------|-------------|-------------|-------------|
| <b>Mangrove Area (ha)</b>  | 295.8       | 304.2                   | 357                     | 354.9       | 363.8       | 364         |
| <b>Saltmarsh Area (ha)</b> | 165.2       | 105.1                   | 127                     | 126.1       | 117.2       | n/a         |
| <b>Wetland Cover Index</b> | 0.64        | 0.74                    | 0.74                    | 0.74        | 0.76        | n/a         |

<sup>1</sup> Bruinsma and Danaher (2000); <sup>2</sup> Mackenzie and Duke (2011)

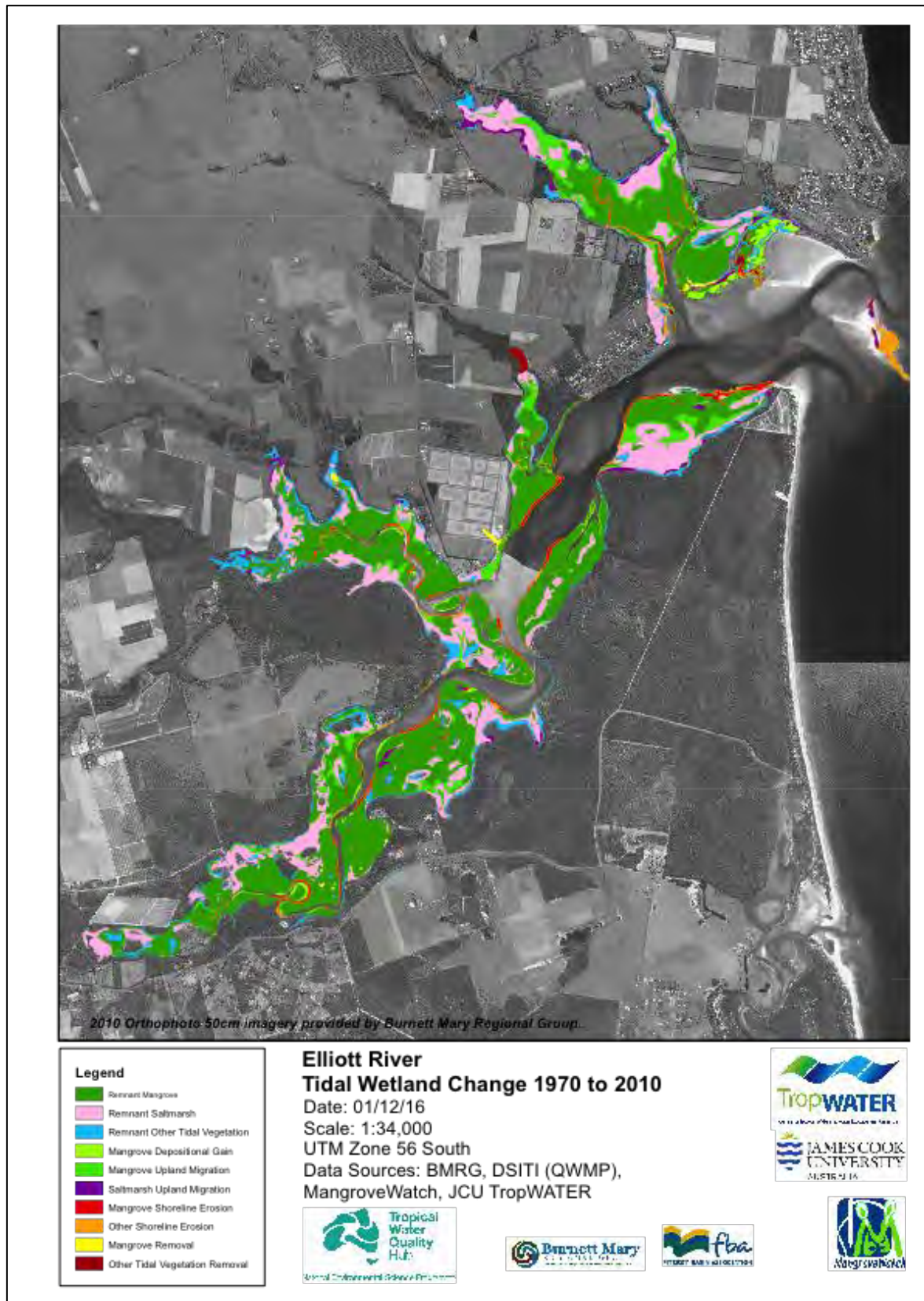
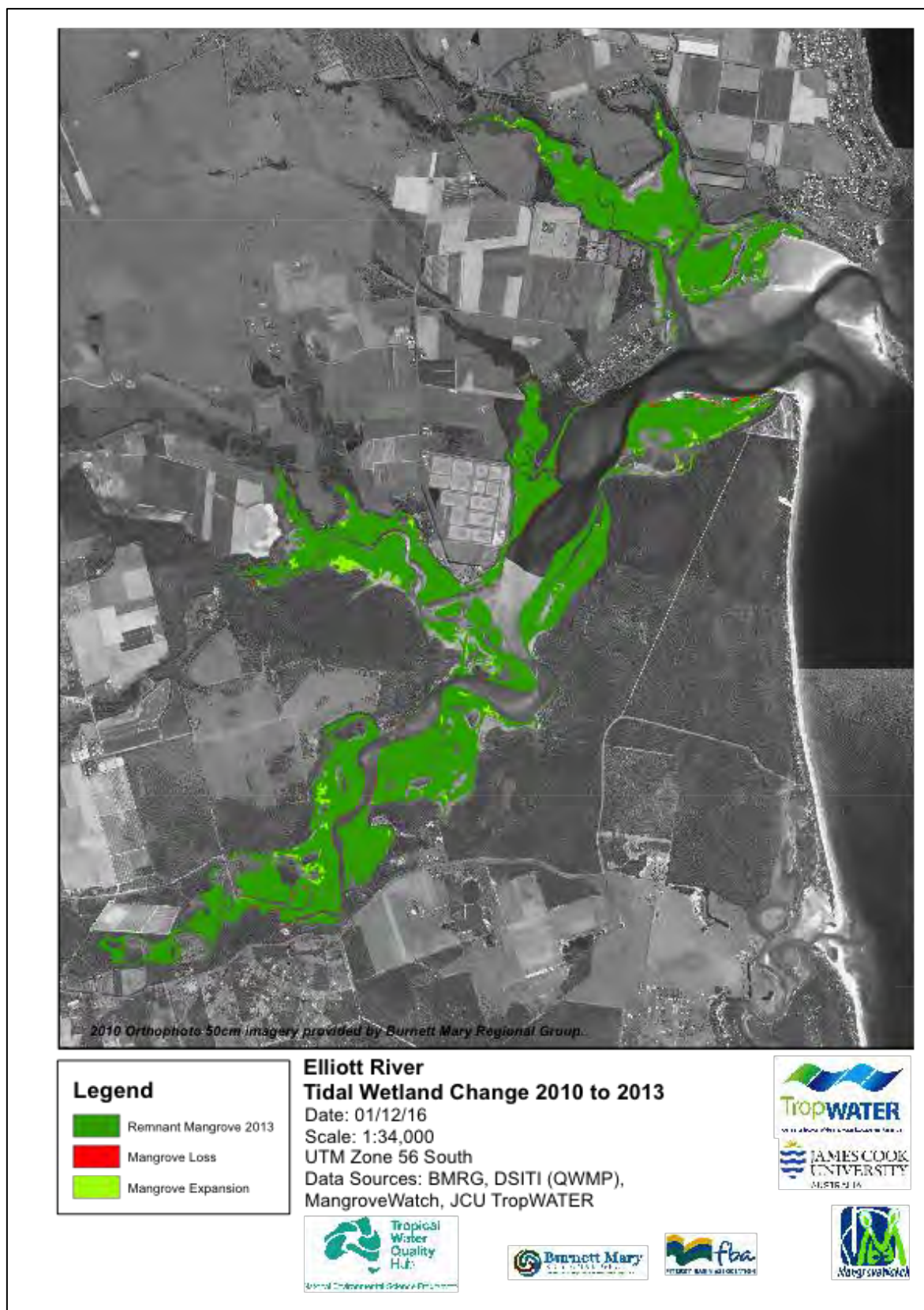
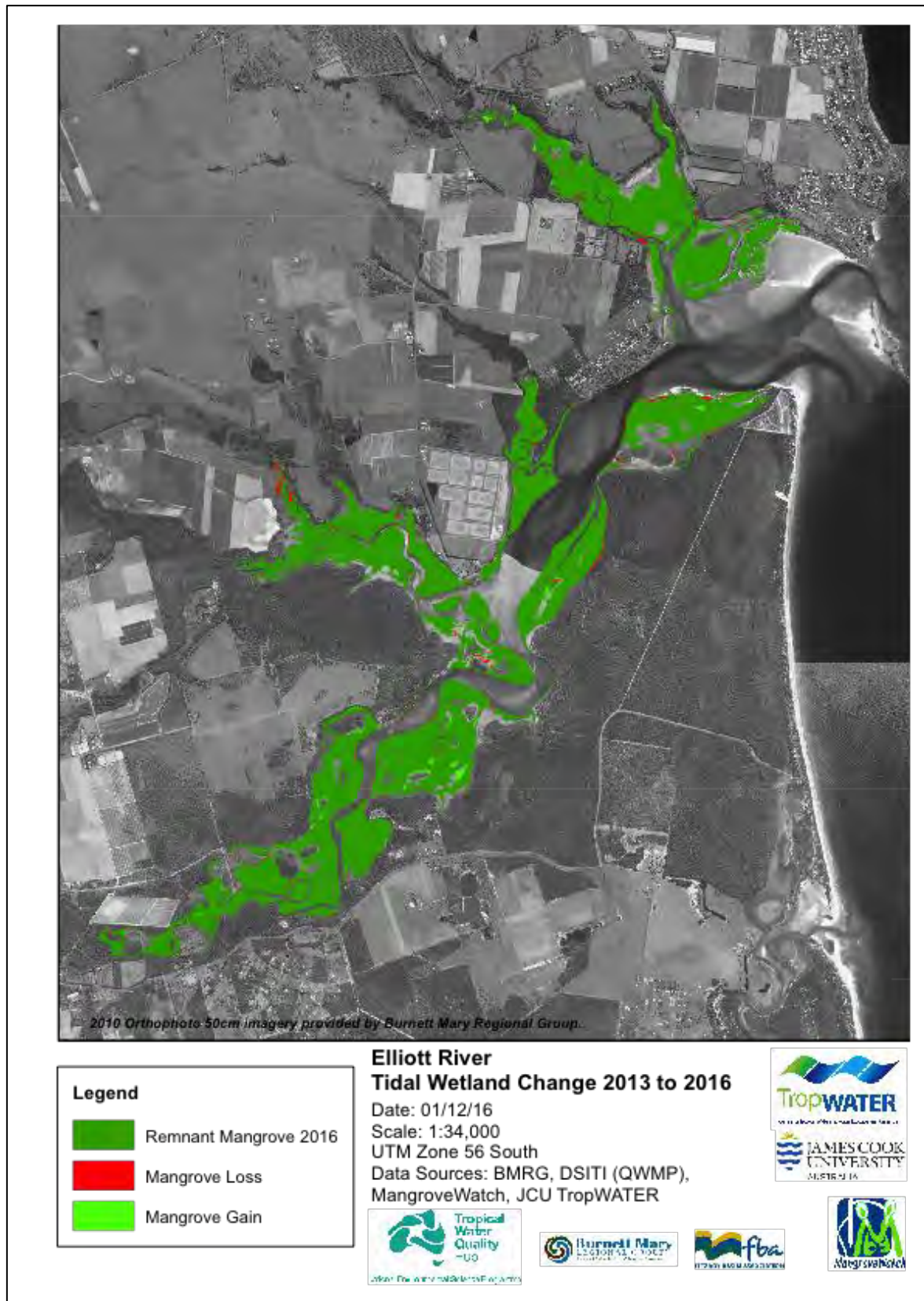


Figure 6: Elliott River Tidal Wetland Change 1970 to 2016



**Figure 7: Elliott River Change in Mangrove Extent 2010 to 2013**



**Figure 8:** Elliott River Change in Mangrove Extent 2013 to 2016

**Table 7:** Detailed Assessment of Tidal Wetland Vegetation Change in the Elliott River 1970 and 2010

| <b>Tidal Wetland Classification</b>                  | <b>1970</b> | <b>2010</b> | <b>Area Change (ha)</b> | <b>% Change</b> |
|------------------------------------------------------|-------------|-------------|-------------------------|-----------------|
| Mangrove Area (ha)                                   | 295.8       | 354.9       | 59.1                    | 20              |
| Saltmarsh Area (ha)                                  | 165.2       | 126.1       | -39                     | -24             |
| Other Tidal Vegetation (ha)                          | 54          | 45.9        | -8.1                    | -15             |
| Total Tidal Land (ha)                                | 522.7       | 514.1       | -8.7                    | -1.7            |
| <i>Wetland Cover Index</i>                           | 0.64        | 0.74        | 0.1                     | 10              |
| <i>Proportion of tidal land that is mangrove (%)</i> | 57          | 69          |                         | 12              |

| <b>Detailed Tidal Wetland Area Change 1970 to 2010 (ha)</b> |      |
|-------------------------------------------------------------|------|
| Mangrove Expansion into Saltmarsh                           | 47.7 |
| Mangrove Depositional Gain                                  | 13.4 |
| Mangrove Shoreline Erosion                                  | 10.9 |
| Saltmarsh Expansion                                         | 8.7  |
| Other Shoreline Erosion                                     | 11.9 |
| Other Shoreline Deposition (gain)                           | 0.8  |

### 3.2.4 Discussion

Detailed mapping of tidal wetland vegetation changes over time provides important insight into large estuary-scale processes and localised changes that can assist in determining appropriate tidal wetland management outcomes. The method of tidal wetland assessment used in this study relied heavily on manual visual interpretation. However the results are comparable with the previous assessments of Bruinsma and Danaher (2000) and Mackenzie and Duke (2011), suggesting relative accuracy. Based on visual assessment of imagery, it was apparent that the existing state wide 1:100,000 tidal wetland extent data provided by the Queensland Wetlands Mapping Program is not suitable for local management applications.

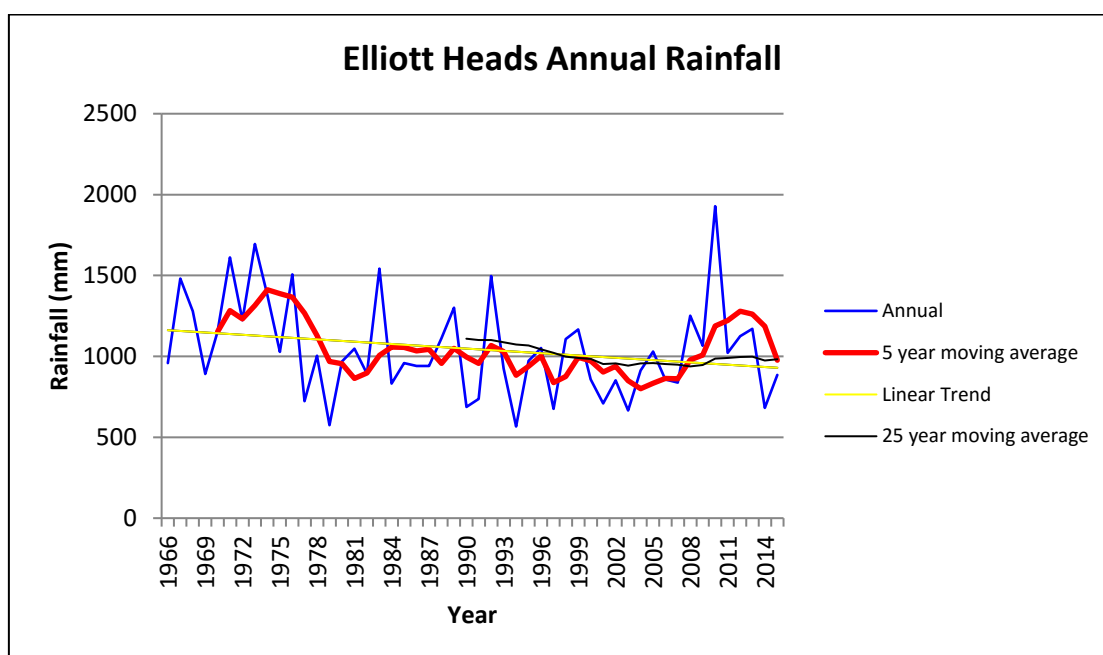
It is apparent in Figures 6 to 8, that the main tidal wetland vegetation shift with the Elliott River estuary is ongoing upland expansion of mangroves into 'saltmarsh/saltpan' habitat. Between 1970 and 2010, 47.7 ha (29%) of saltmarsh habitat changed to mangrove habitat. This is consistent with similar studies in Moreton Bay (Accad et al., 2016) and New South Wales (Saintilan and Williams, 1999; Saintilan and Wilton, 2001) and Victoria (Rogers et al., 2005). This study represents the northernmost quantified account of this phenomena in Australia. Loss of saltpan as a result of mangrove expansion has been observed as far north as Hinchinbrook Island (Saintilan and Williams, 1999). The results presented though are much lower than for Moreton Bay (47% between 1955 and 2012) (Accad et al. 2016) and is at the lower end of figures for New South Wales reported in Saintilan and Williams (1999). However, a similar figure (20.1%) was derived for smaller estuaries in Moreton Bay between 1972 and 2004 (Eslami-Andargoli et al., 2009).

The drivers of upland mangrove migration are noted to be variable and the phenomena is likely a complex interplay of natural and anthropogenic factors (Harty, 2009). Causes of upland

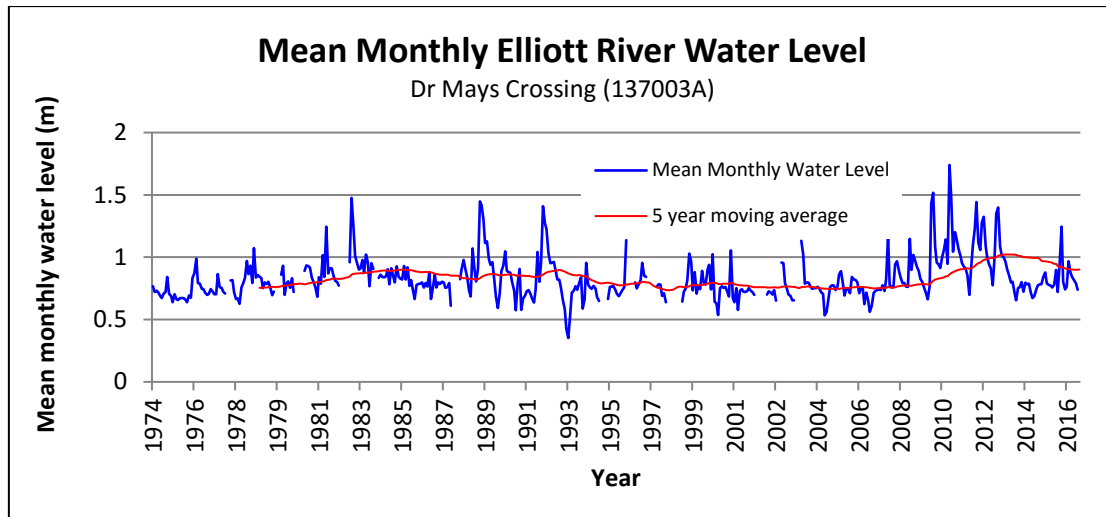
mangrove expansion have been attributed to rainfall, local subsidence, surface elevation change, altered hydrology, specifically increased freshwater flows, elevated nutrient supply and sea level rise.

A review of locally available data for the Elliott River estuary was used to rule out some of these causes.

Rainfall has been proposed as a driver of mangrove expansion following the rationale that increased freshwater availability reduces salinity extremes at landward mangrove margins allowing mangrove seedlings to establish and grow at higher elevations along the tidal profile. Examination of long-term rainfall (Figure 9) and river height data (used as a proxy for catchment rainfall) (**Error! Reference source not found.**) show that the period between 1970 and 2010 represented a largely dry period for the Elliott River estuary. In Moreton Bay, Eslami-Andargoli et al. (2009) used rainfall as a variable to describe mangrove expansion between two time periods (1972 to 1990 and 1990 to 2004) and described a significant effect of mean rainfall within the two time periods and rate of mangrove expansion. There is a possibility that with further assessment between multiple time periods, this same association may be present within the Elliott River. However, rainfall does not adequately explain why during the relatively dry period between 1996 and 2010 (Figure 9), mangroves did not retreat extensively at landward margins as would be expected during prolonged drought, returning mangroves to approximate 1970 extent. If higher rainfall was the primary driver of mangrove expansion in the Elliott River, it stands to reason that lower rainfall would result in similar mangrove retreat. Visual inspection of 1994 aerial imagery indicates that mangrove expansion continued rapidly through to 2010. Whilst the overall rate of change may have differed relative to rainfall, the overall trend of mangrove expansion continued irrespective of rainfall, suggesting another factor may be a more influential driver of mangrove expansion and enable mangroves to both persist during low rainfall periods and also expand.



**Figure 9:** Elliott Heads Mean Annual Rainfall 1966 to 2015 (Bureau of Meteorology (BoM) 2016)



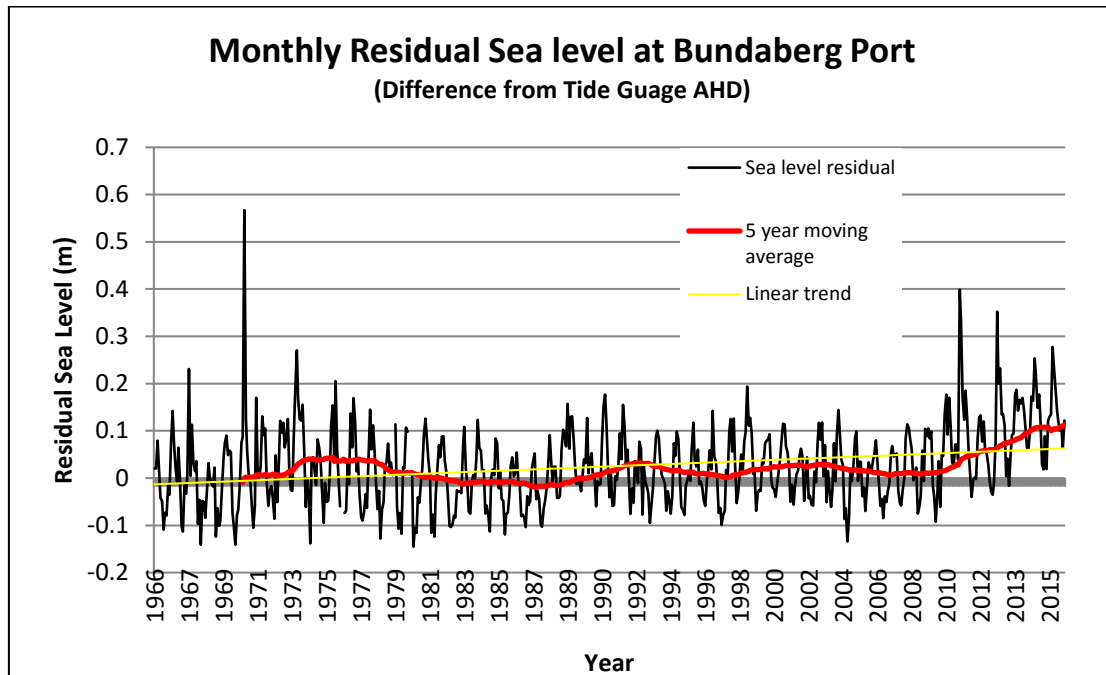
**Figure 10:** Mean Monthly Elliot River Water Level at Dr Mays Crossing. Data from Queensland Government Water Monitoring Portal (DNRM 2016)

Nutrient enrichment was initially proposed as a potential driver of mangrove expansion due to the high incidence of saltmarsh loss in estuaries within agricultural landscapes (McLoughlin, 2000). Fertilisation trials by Saintilan (2010) showed that nutrient enrichment did not enhance seedling survivorship at mangrove landward margins. However, it may be a factor that promotes mangrove survivorship following expansion. The 2008 State of the Estuarine Environment Report (Burnett Mary Regional Group et al., 2008) described the Elliott River as having 'Excellent' water quality with nutrient levels within recommended guidelines, despite a highly modified catchment dominated by agriculture.



**Figure 11:** 1994 Aerial image of Upper Yellow-waterholes Creek showing outline of 2010 mangrove extent (red). Note the presence of saltpan within the red outline.

Sea level rise is a logical factor likely to result in upland mangrove expansion (Figure 11). As sea level rises, mangroves will move landward. However, inspection of local sea level variability in the nearby Burnett River (Figure 12) shows little change in overall sea level trend between 1970 and 2010. This would suggest that sea level is not a primary driver of mangrove expansion in the Elliott River estuary. Of concern, is the notable rapid sea level increase of approximately 10mm in the years after 2010. This is likely to play a role in current tidal wetland vegetation dynamics.

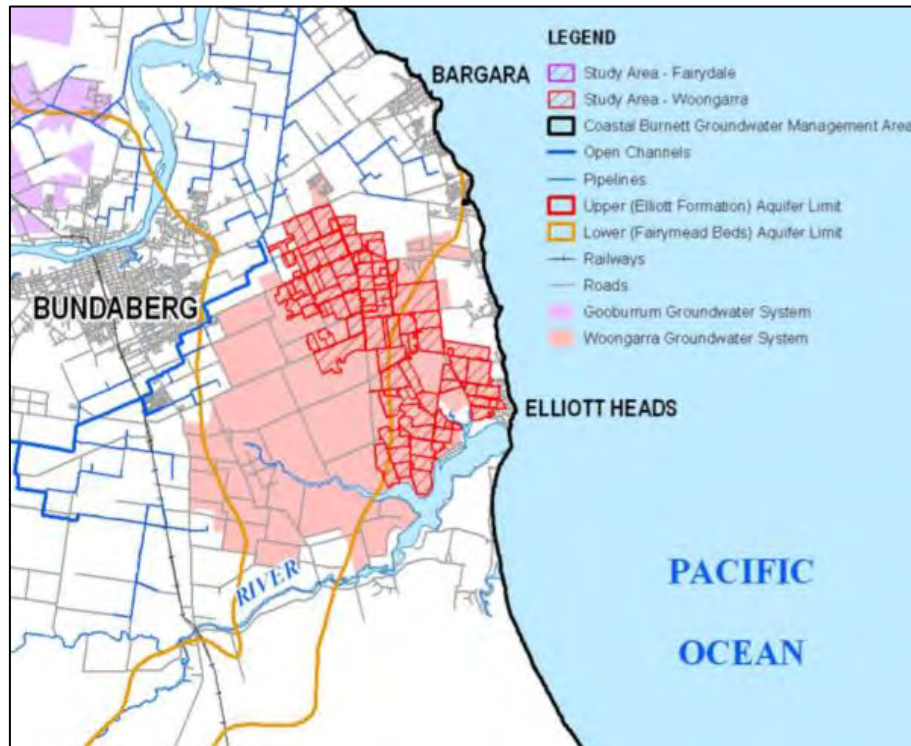


**Figure 12:** Monthly sea level residual relative to tide gauge position (AHD) at Bundaberg Port, Burnett River (Bureau of Meteorology (BoM) 2016).

Rogers et al. (2005) demonstrated that for southern estuaries, eustatic sea level rise and associated sub-surface sediment process and auto-compaction of tidal wetland sediments was strongly related to mangrove expansion. Changes in tidal wetland surface elevation can occur independent of sea level change and has been associated with periods of *El-nino* and associated drought (Lovelock et al., 2011; Rogers and Saintilan, 2008). Additionally, groundwater level can have a significant effect on tidal wetland surface elevation (Rogers and Saintilan, 2008; Whelan et al., 2005). We suggest that within the Elliott River system, autocompaction and surface elevation loss irrespective of sea level, may be the primary driver of the observed mangrove expansion.

The Elliott River has previously been identified as a groundwater dependent system, with low salinity in the upper estuary maintained irrespective of rainfall and river flow (DSITIA, 2013). The presence of extensive *Bruguiera gymnorhiza* forest and dense *Acrostichum speciosum* in the upper estuary (Mackenzie and Duke, 2011) support this view. Intensive agricultural development surrounding the Elliott River estuary in the 1960's dramatically increased demand for groundwater (DSITIA, 2013). Uncontrolled groundwater extraction resulted in excessive draw-down of the aquifer leading to sea water intrusion. It was not until the late 1990s that groundwater was effectively managed in the region. The primary area of groundwater extraction is on agricultural properties in the Woongarra Groundwater system located in the

North-East lower estuary (Figure 13). Tidal wetlands within the Woongarra Groundwater system matches the greatest increases in mangrove extent within the Elliott River, specifically Yellow Waterholes Creek and the Northern anabranch of the river at Elliott Heads. The extraction of groundwater is a potential driver of tidal wetland subsidence (Rogers and Saintilan, 2008) allowing mangroves to expand upland along channel heads. Corresponding drought conditions during the assessment period would have also contributed to loss of tidal surface elevation.



**Figure 13:** Map of the Woongarra groundwater system adjacent to the Elliott River estuary (AGWF, 2007)

The importance of managing groundwater extraction for maintaining Elliott River tidal wetland function is further demonstrated by recent dieback of *Aegiceras corniculatum* within the estuary. *Aegiceras* is identified as a freshwater dependent species in the Elliott River and is used as an indicator species to monitor impacts of water extraction on downstream environmental assets within the Burnett Basin Water Resource Management Plan (DSITIA, 2013). *Aegiceras* dieback coincides with recent dry conditions (Figure 14) but may indicate the need for increased water allocation to environmental flows in the Elliott River estuary.



**Figure 14:** Areas of recent (2016) *Aegiceras* dieback (Images: Nearmap 22/06/16)

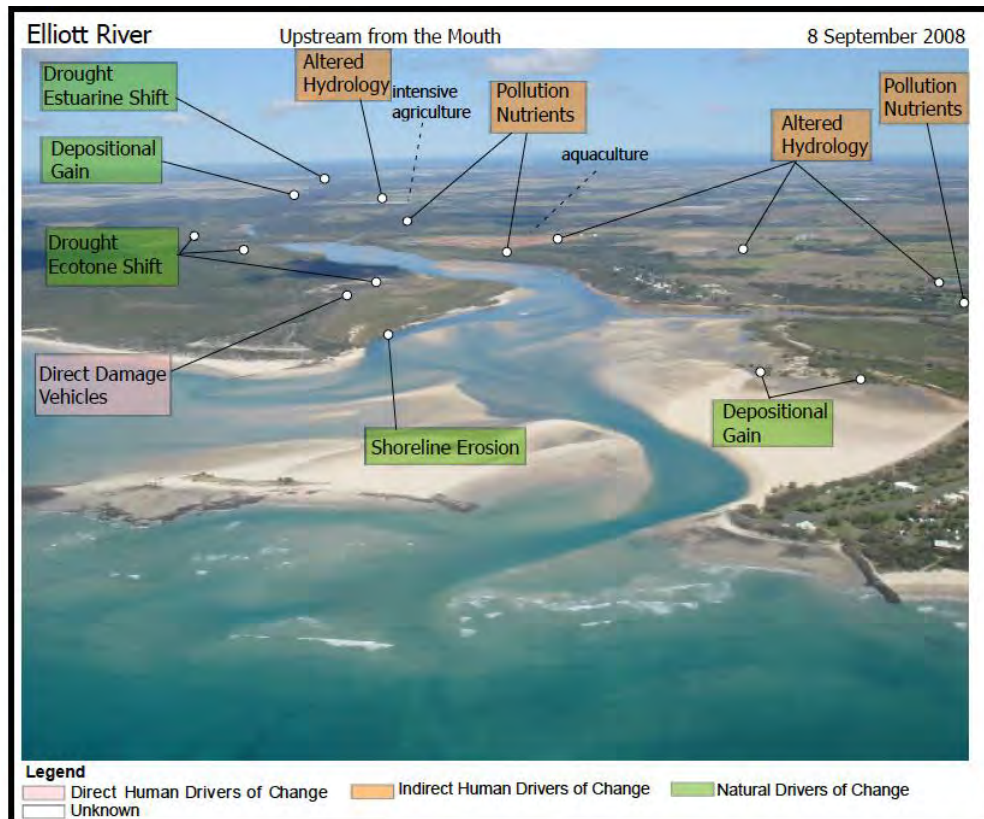
### **Management Issues threatening tidal wetland habitat and decreasing estuary water quality in the Elliott River**

#### ***Summary Observations*** (Table 8; Figures 15-16)

The overall assessment of the Elliott River tidal wetlands can be summarised according to measures of impact on the various types of damage – as indicative of the key drivers of change. In Table 8, the question of accumulative impacts is also addressed where levels of impact have been totalled at the bottom. These views provide greater insight into both the types of damage and their causes, as well as giving a basis for prioritization and deployment of on-going mitigation efforts. The rangers can use this information in collaboration with local environmental managers to be more effective custodians of estuarine habitats and their capacity to improve water quality in southern GBR waters.

**Table 8:** Summary of Management Issues Threatening Elliott River Tidal Wetlands.

| Damage Type                 | Area Impacted<br>(Ha) | % Tidal Wetland Area |
|-----------------------------|-----------------------|----------------------|
| <b>Altered Hydrology</b>    | <b>0.4</b>            | <b>0.1</b>           |
| 1 Minor                     | 0.2                   | 0.0                  |
| 2 Moderate                  | 0.2                   | 0.0                  |
| <b>Buffer Zone Clearing</b> | <b>5.2</b>            | <b>1.1</b>           |
| 1 Minor                     | 5.2                   | 1.1                  |
| <b>Grazing</b>              | <b>16.2</b>           | <b>3.4</b>           |
| 1 Minor                     | 2.3                   | 0.5                  |
| 2 Moderate                  | 13.2                  | 2.7                  |
| 3 Major                     | 0.7                   | 0.1                  |
| <b>Trampling</b>            | <b>1.5</b>            | <b>0.3</b>           |
| 1 Minor                     | 1.5                   | 0.3                  |
| <b>Vehicle</b>              | <b>41.3</b>           | <b>8.6</b>           |
| 1 Minor                     | 12.2                  | 2.5                  |
| 2 Moderate                  | 9.2                   | 1.9                  |
| 3 Major                     | 19.9                  | 4.1                  |
| <b>Grand Total</b>          | <b>64.6</b>           |                      |
| <b>Total Tidal Wetland</b>  | <b>59.4</b>           | <b>12.4</b>          |
| <b>Major Impact</b>         | <b>14.5</b>           | <b>3.0</b>           |
| <b>Moderate Impact</b>      | <b>20.9</b>           | <b>4.3</b>           |
| <b>Minor Impact</b>         | <b>22.6</b>           | <b>4.7</b>           |



**Figure 15:** Tidal Wetland Drivers of Change in the Elliott River estuary 2008. (Mackenzie and Duke, 2011).

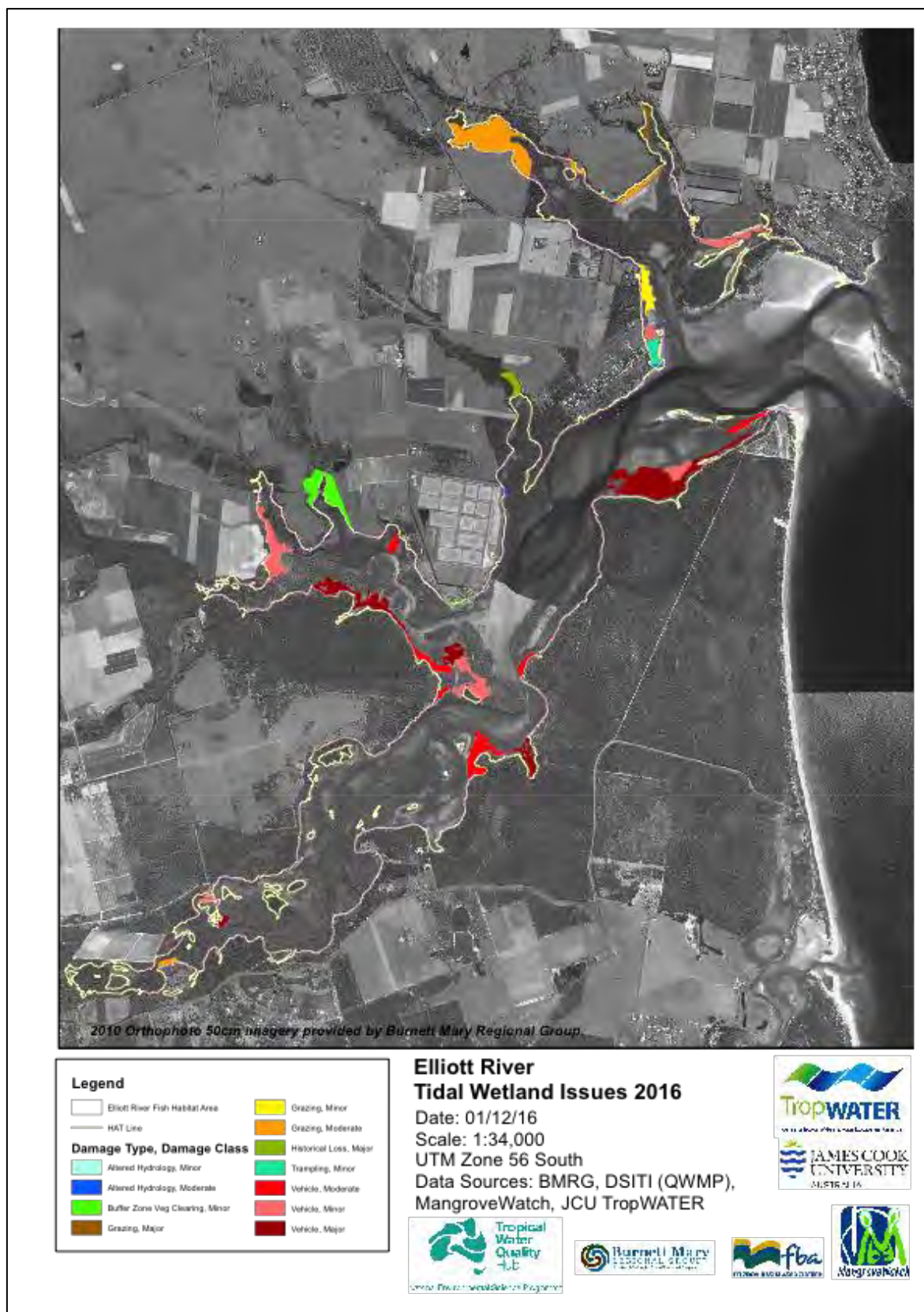


Figure 16: Map of Elliott River tidal wetland area showing areas impacted by direct disturbance.

### 3.2.5 Photo gallery of key issues affecting the Elliott River tidal wetlands

#### ISSUE 1. Vehicle access, roads and tracks



**Figure 17:** Area of vehicle damage at the southern lower estuary. Yellow circles represent access points. (Image: Nearmap 22/06/16)



**Figure 18:** Oblique aerial image taken September 2008 showing the same level of impact in the same area.



**Figure 19:** Vehicle damage at Yellow-Waterholes Creek. Note the car body on the saltpan and altered hydrology from vehicle impacts (Image: Nearmap 22/06/16).



**Figure 20:** Uncontrolled access in the upper estuary at Palm Springs Drv, resulting in severe erosion and sediment runoff (Image: Nearmap 22/06/16).



**Figure 21:** Uncontrolled access to Yellow-Waterholes Creek resulting in damage to marine plants and shoreline erosion (Image: Nearmap 22/06/16).

## ISSUE 2. Cattle Grazing



**Figure 22:** The effect of cattle grazing on tidal wetland sea level rise resilience. (Image: Nearmap 22/06/16)

## ISSUE 3. Damage to Buffer Zone Vegetation



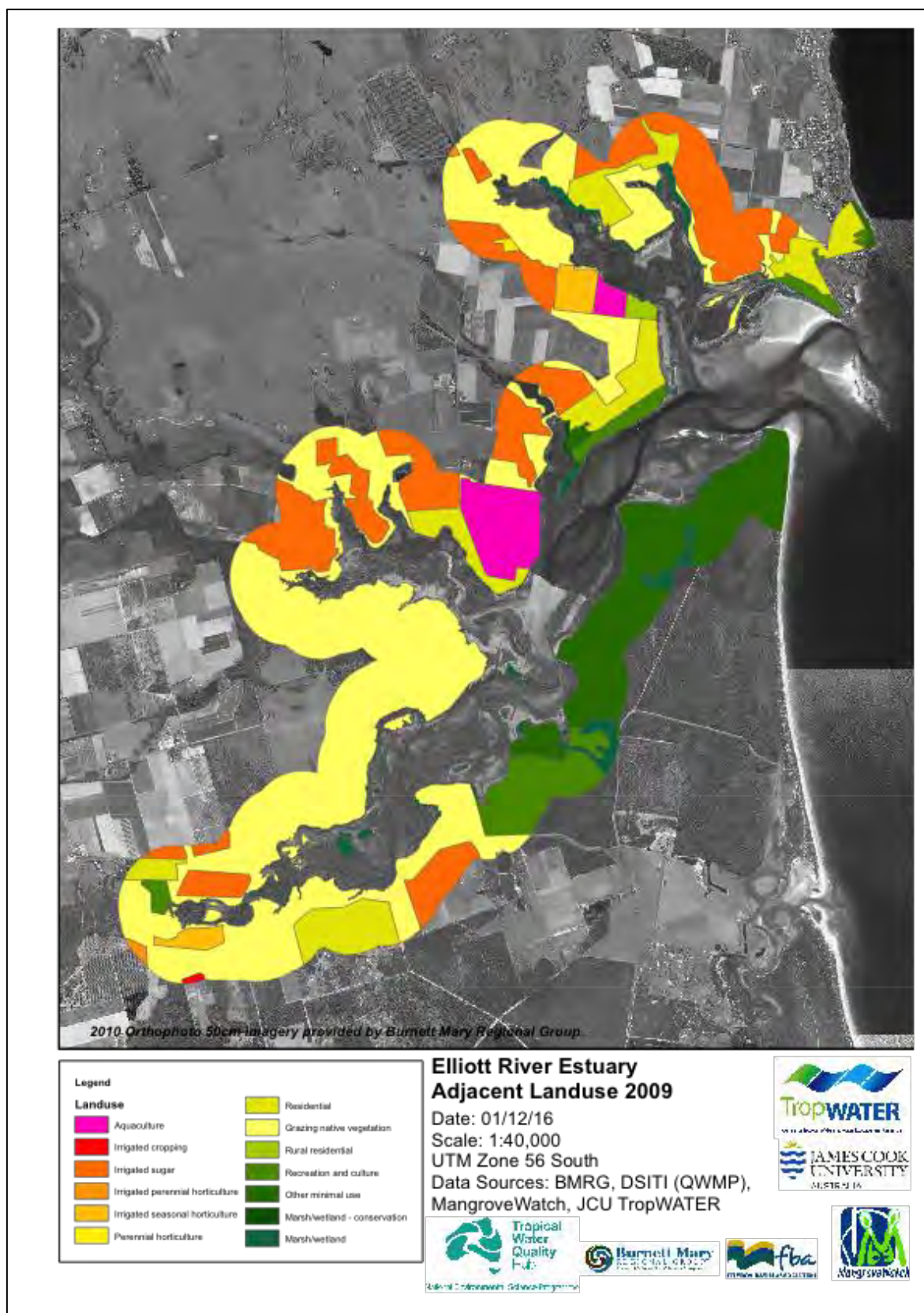
**Figure 23:** Possible damage to buffer zone vegetation at Elliott Heads (Image: Nearmap 22/06/16).

**ISSUE 4. Adjacent Landuse - Coastal Squeeze and Sea Level Rise Resilience**

See Table 9 and Figure 24.

**Table 9:** Landuse types adjacent to the Elliott River estuary within 500 m of HAT (Source: QLUMP 2009)

| <b>Tertiary Landuse Classification</b> | <b>Total Area</b> | <b>% Tidal Wetland<br/>500 m Buffer<br/>Zone</b> |
|----------------------------------------|-------------------|--------------------------------------------------|
| Aquaculture                            | 58.0              | 3.7                                              |
| Irrigated cropping                     | 1.1               | 0.1                                              |
| Irrigated sugar                        | 292.6             | 18.8                                             |
| Irrigated perennial horticulture       | 2.6               | 0.2                                              |
| Irrigated seasonal horticulture        | 23.4              | 1.5                                              |
| Perennial horticulture                 | 1.7               | 0.1                                              |
| Residential                            | 148.2             | 9.5                                              |
| Grazing native vegetation              | 692.4             | 44.5                                             |
| Rural residential                      | 4.8               | 0.3                                              |
| Recreation and culture                 | 82.3              | 5.3                                              |
| Other minimal use                      | 187.9             | 12.1                                             |
| Marsh/wetland                          | 40.8              | 2.6                                              |
| Marsh/wetland - conservation           | 1.5               | 0.1                                              |
| <b>Grand Total</b>                     | <b>1556.9</b>     |                                                  |



**Figure 24:** Map of Elliott River estuary showing adjacent landuse within 500 m of HAT.

### 3.3 Ongoing survey work, training & capacity building of the Rangers

#### 3.3.1 Survey future scheduling

An important part of the training involved the practical application of the Shoreline Video Assessment Method (S-VAM) culminating in its immediate practical application in boat-based shoreline surveys of the Burnett River. This is additional to the 8 designated case study estuarine sites (Figure 25).

Additional Shoreline Video Assessments are planned in coming days by the Gidarjil Rangers focusing on Baffle Creek.

| GIDARJIL Shoreline Video Assessment Surveys |            |                         |           |           |           |                     |
|---------------------------------------------|------------|-------------------------|-----------|-----------|-----------|---------------------|
| S-GBR CHAMP project study sites             |            |                         |           |           |           |                     |
| COMPLETED                                   |            |                         |           |           |           | TO DO               |
| #                                           | NRM region | PCCC System             | 2012-2013 | 2013-2014 | 2014-2015 | 2015-2016 2016-2017 |
| 1                                           | FBA        | Fitzroy River           |           |           |           | 5                   |
| 2                                           | FBA        | Balclava Island         |           |           | 3         | 3                   |
| 3                                           | FBA        | Port Alma               |           |           | 3         | 3                   |
| 4                                           | FBA        | Maria Inlet             |           |           |           |                     |
| 5                                           | FBA        | Barker Ck               |           |           |           |                     |
| 6                                           | FBA        | Mosquito Ck             |           |           |           |                     |
| 7                                           | FBA        | Deception Ck            |           |           |           |                     |
| 8                                           | FBA        | Badger Ck               |           |           |           |                     |
| 9                                           | FBA        | Monte Christo Ck        |           |           |           |                     |
| 10                                          | FBA        | Middle Ck               |           |           |           |                     |
| 11                                          | FBA        | The Narrows Ck          |           |           |           |                     |
| 12                                          | FBA        | Black Swan              |           |           |           |                     |
| 13                                          | FBA        | Graham Ck               |           |           |           | 4                   |
| 14                                          | FBA        | Targinie Ck             |           |           | 4         |                     |
| 15                                          | FBA        | Endfield Ck             |           |           |           | 4                   |
| 16                                          | FBA        | Port Curtis             |           |           | 3         | 3                   |
| 17                                          | FBA        | Calliope (Upper +Lower) |           |           | 4         | 5                   |
| 18                                          | FBA        | Auckland Ck             |           |           |           | 4                   |
| 19                                          | FBA        | W Facing Island         |           |           |           | 3                   |
| 20                                          | FBA        | South Trees             |           | 2         |           | 4                   |
| 21                                          | FBA        | Boyne R                 |           | 2         | 4         | 5 5                 |
| 22                                          | BMRG       | Wild Cattle Ck          |           |           |           |                     |
| 23                                          | BMRG       | Pancake Ck              |           |           |           |                     |
| 24                                          | BMRG       | Rodds Bay               |           |           | 3         | 3                   |
| 25                                          | BMRG       | Eurimbula               |           |           |           |                     |
| 26                                          | BMRG       | Round Hill Ck           |           |           |           |                     |
| 27                                          | BMRG       | Deepwater               |           |           |           |                     |
| 28                                          | BMRG       | Baffle                  |           |           |           | 5                   |
| 29                                          | BMRG       | Littabella              |           |           |           |                     |
| 30                                          | BMRG       | Kolan                   | 1         |           |           | 5 5                 |
| 31                                          | BMRG       | Burnett                 | 1         |           |           | 5 5                 |
| 32                                          | BMRG       | Elliott                 | 1         |           |           | 5 5                 |
| 33                                          | BMRG       | Coonarr                 |           |           |           |                     |
| 34                                          | BMRG       | Theodilite              |           |           |           |                     |
| 35                                          | BMRG       | Burrum                  | 1         |           |           | 5 5                 |
| 36                                          | BMRG       | Gregory                 |           |           |           | 5                   |
| 37                                          | BMRG       | Isis                    |           |           |           | 5                   |
| 38                                          | BMRG       | Cherwell                |           |           |           |                     |
| Survey #'s                                  |            |                         | 4         | 2         | 7         | 7 17                |

Legend - survey teams

|   |                     |
|---|---------------------|
| 1 | JCU BMRG            |
| 2 | JCU C-4-C           |
| 3 | JCU CHAMP           |
| 4 | GDC PCPA CHAMP ERMP |
| 5 | GDC SGBR CHAMP NESP |

| Legend - survey teams |                     |
|-----------------------|---------------------|
| 1                     | JCU BMRG            |
| 2                     | JCU C-4-C           |
| 3                     | JCU CHAMP           |
| 4                     | GOC PCPA CHAMP ERMP |
| 5                     | GOC SGBR CHAMP NESP |

**Figure 25:** Schedule of river systems being surveyed prior to, and during, the Southern GBR CHAMP project. Where surveys in the eight (8) study estuaries are repeated, this gives opportunities for measuring change like flood recovery. Note that systems surveyed to date are those in southern parts of the Southern GBR shoreline. The emphasis will shift to the north in the next year of field surveys.

As noted, on Thursday 10 June 2016, Arthur Dahl a ranger supervisor with Gidarjil DC led an independent survey where the rangers re-filmed shorelines of the Boyne River estuary.

Field notes show that the Rangers involved were: Arthur Dahl, Noah Saumalu Johnson, Jayme Cook and William Waia (an EQIP work experience student).

The vessel used was a hire boat from the BIEEC, inflatable about 4m long. About 26 km of the Boyne River was surveyed, covering both sides of the river up to the bridge. The mangroves were all looking stressed to some degree, and many have died. They do not seem to like having debris (even branches and wigs) caught up in them.

There was a small green turtle (about 40 cm carapace length) at the mouth of the Boyne River at high tide, and another larger green turtle (about 100 cm carapace length) was seen about 10 km upstream, moving with the incoming tide.

### ***3.3.2 Rangers identify shoreline tree damage and poisoning during surveys***

During video monitoring, the Gidarjil Rangers working on the S-GBR CHAMP project, observed damage to shoreline vegetation along the town reach. As a result of their observations, the damage became recognised as notable foreshore vandalism. A number of riparian and marine plants had been damaged and poisoned from 21 to 25 Mariner's Way, North Bundaberg (Figure 26). The site was notably marked by deposits of cracker dust amongst the mangroves at the river's edge, to an approximate width of 4-5 m.



**Figure 26:** Affected shoreline around Mariners Way, North Bundaberg, showing dead and dying trees, as observed by the Gidarjil Rangers during survey work on the Burnett River.

Bundaberg Regional Council (BRC) also received a report from one of its slasher operators in the area to say he had observed ring-barking of some riparian vegetation and marine plants along the particular stretch of the riverside reserve of Mariner's Way.

Further investigation revealed that additional gravel material had been deposited later to extend down closer to the low tide mark. It was also noted that a number of both mangrove and riparian plants trees had recent axe marks near the base and have likely been poisoned before being removed. The largest tree damaged was a Blue Gum with twin trunks, the largest of which had a diameter of 76 cm. This tree was considered to have been at least 100 years old.

The Gidarjil Rangers expressed interest in pursuing rehabilitation of the mangrove verge if needed, in collaboration with Bundaberg Regional Council and other management agencies.

Council's Natural Areas Officer Carl Moller provided a brief report of the vandalism of trees at the esplanade at Mariner's Way, North Bundaberg (Table 9). A site visit was undertaken by Nick Maclean and Carl Moller on 5th May 2016. The report specifically described damaged plants (species, size/age and number damaged), specific locations, and so on. The aim was to circulate this information to appropriate authorities.

**Table 10:** Summary of illegal damage to riparian and marine plants along the waters' edge at 23 Mariners Way, North Bundaberg.

| Botanical name                   | Common name                    | Number affected | Damage                              |
|----------------------------------|--------------------------------|-----------------|-------------------------------------|
| <i>Eucalyptus tereticornis</i>   | Blue gum                       | 8               | Bark with cuts and some leaves dead |
| <i>Aphananthe philippensis</i>   | Native elm                     | 3               | Bark with cuts and some leaves dead |
| <i>Cupaniopsis anacardiodes</i>  | Tuckeroo                       | 11              | Bark with cuts and some leaves dead |
| <i>Cupaniopsis anacardiodes</i>  | Tuckeroo                       | 6               | Completely cut down                 |
| <i>Streblus brunonianus</i>      | Whalebone tree                 | 1               | Bark with cuts and most leaves dead |
| <i>Streblus brunonianus</i>      | Whalebone tree                 | 3               | Completely cut down                 |
| <i>Casuarina glauca</i>          | Swamp she-oak                  | 4               | Bark with cuts and some leaves dead |
| <i>Melaleuca linariifolia</i>    | Narrow leaved paperbark        | 11              | Bark with cuts and most leaves dead |
| <i>Melaleuca linariifolia</i>    | Narrow leaved paperbark        | 5               | Completely cut down                 |
| <i>Corymbia torelliana</i>       | Cadaghji                       | 3               | Bark with cuts and some leaves dead |
| <i>Dysoxylum gaudichaudianum</i> | Ivory Mahogany                 | 1               | Bark with cuts and some leaves dead |
| <i>Araucaria heterophylla</i>    | Norfolk Island Pine            | 1               | Bark with cuts and some leaves dead |
| <i>Avicennia marina</i>          | Grey mangrove (<10cm diameter) | 42              | Completely cut down                 |
| <i>Avicennia marina</i>          | Grey mangrove (>10cm diameter) | 30              | Bark with cuts and most leaves dead |
| <b>Total</b>                     |                                | <b>129</b>      |                                     |

The report describes tree damage along the esplanade, below high tide mark. Most of the damaged trees had cuts in the bark and their leaves were brown, indicating some kind of systemic herbicide had been applied some time earlier (most likely Tordon). Smaller trees, particularly mangroves had been cut off towards the base and their trunks and branches were strewn around. An attempt had also been made to burn some branches and foliage.

On a subsequent site visit, Nick Maclean with Council employee Steve Manderson, noted that road base (gravel) had been deposited below high water mark also, and more dead trees had been cut further, grass had been mown, and extra cuts placed on some of the trees. Some smaller trees had also re-sprouted and new growth was estimated to be less than 4 weeks old. They concluded that most of the tree damage had occurred no earlier than 2 months previous.

The application of systemic herbicide has clearly been very effective and most of the treated plants were dying or dead. It was considered prudent to source earlier relevant imagery and observations of the site.

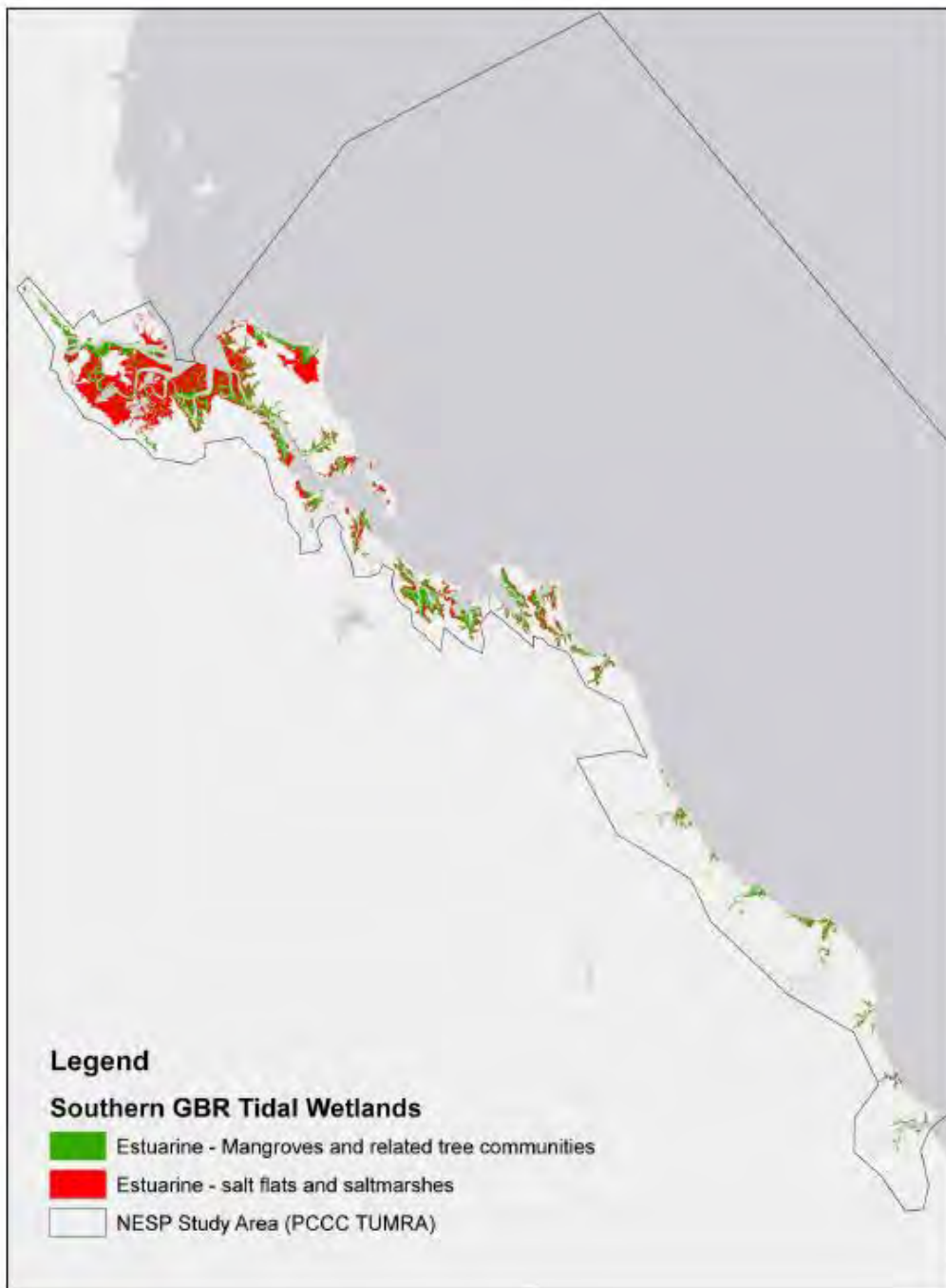
Subsequently, a number of officials were informed including: Environmental Health Officer, Ron Paauwe from an illegal dumping and poison use perspective; QLD Boating and Fisheries Patrol Officers, Geoff Fergusson and Paul Nichols from a Marine Plant clearing and illegal boat ramp perspective; DNRM Veg Officer, Trent Juster from a category R clearing perspective; and, EHP Regulatory Officer (Coastal) Brock Newbry from an interfering with tidal lands perspective. This includes: Ric Fennessy from Gidarjil Development Corp; and, Jock Mackenzie from JCU TropWATER and MangroveWatch, for their information.

Mike Johnson of Landcare informed both the News Mail and local news outlets about the illegal clearing and damage. Geoff Ferguson and Paul Nicholls have taken photos, and so has Darryl Hampson. Because of all this public attention, the perpetrator may never be caught in the act.

A round table meeting of managers and other stakeholders is considered warranted so that all ideas can be discussed regards how the area might be re-habilitated, as well as perhaps gathering further evidence.

### **3.4 Defining values and threats to saltmarsh habitat in the Southern GBR**

Saltmarsh is a marine plant ecosystem that occupies the upper tidal zone above mean sea level but below the highest astronomical tide (HAT) mark, and receives regular but infrequent tidal flooding. Saltmarsh areas in the Southern GBR (Figure 27) generally occur where <30% of tides inundate the tidal zone (Mackenzie, 2005). The landward extent is largely determined by the penetration of spring high tides but is now often determined by man-made structures (e.g. sea walls, roads etc.). Saltmarsh includes rarely-inundated tidal areas supra-tidal areas and areas with saline groundwater tidal connectivity. The saltmarsh ecosystem consists of salt tolerant (halophyte) plant communities, algal mat and claypan/ saltpan complexes with less than 50% tree cover.



**Figure 27:** Tidal wetlands within the NESP study region. Tidal wetland layer derived from the Queensland State Government Queensland Wetlands Mapping Program.

These complex ecosystems occupy protected coastlines such as embayments, and along banks of tidal creeks and rivers, or within dune swales. Saltmarsh plants are salt tolerant herbs, small shrubs and grasses (halophytes) that are usually restrained in stature (<0.5 m tall) and highly adapted to harsh growing conditions such as high salinity, full light exposure and moisture extremes.

Mangroves and saltmarsh share the tidal zone. Saltmarsh plants thrive where mangroves are absent due to increased salinity and variable soil moisture further up the tidal zone. The proportion of mangroves and saltmarsh habitat within the tidal zone is largely a function of

rainfall, with higher rainfall leading to more mangroves. Local factors such as groundwater upwelling, terrestrial and urban runoff can allow mangroves to establish higher up the tidal profile in some areas.

Saltmarsh edges are fuzzy, with gradual change from mangrove to saltmarsh or saltmarsh to adjacent coastal habitats like *Casuarina* and *Melaleuca* spp. Ecotone zones are still considered saltmarsh if > 50% of the groundcover is saltmarsh.

### **3.4.1 Where is the Saltmarsh?**

There are ~37,388 ha of mangrove habitat and ~43,003 ha of saltmarsh habitat within the NESP study region. Current data for the saltmarsh mapping comes from the Queensland State Government Queensland Wetlands Mapping Program (QWMP). This mapping was done Statewide at a scale of 1:100,000. As such, some local inaccuracies do exist and small saltmarsh patches can be overlooked.

The greatest extent of saltmarsh occurs in the north of the study region.

#### **Accurate Mapping - How you can help.**

You can help map saltmarsh more accurately in the Southern GBR. If you have access to a GPS or a tracking app on your phone (like Runkeeper). Take a walk around a saltmarsh patch one day. Send the track to us at [mangrovewatch@gmail.com](mailto:mangrovewatch@gmail.com) or put the track on Google Earth and send us the .kmz.

### **3.4.2 What's in the Saltmarsh?**

There are 88 recorded and potentially 111 plant species that may occur within tidal wetlands of the Southern GBR region. Of these 28 are plants that are mostly restricted to the saltmarsh zone (or listed as commonly occurring in saltmarsh) and 25 are plants not restricted to saltmarsh areas and commonly found in both saltmarsh and adjacent saline-influenced habitats and saltmarsh buffer zones (Table 11).

These records are based on herbarium records and sightings recorded on the Atlas of Living Australia database. This is an incomplete list and should be considered a work in progress. Having a species inventory is the first step in ensuring conservation of a habitat. Species records of tidal wetland plants in the Southern GBR are particularly important as some of these plants are at or near their distributional limits. As the climate warms the distribution of these plants is likely to change. Additionally, as climate change exerts increasing pressure of coastal habitats there is an increasing risk of weed invasion. Weeds in tidal wetland buffer zones will also prevent tidal wetlands from adjusting to rising sea levels, hampering tidal wetland upland migration.

**Table 11:** Saltmarsh plant species of the Southern GBR.

| Species Name                       | Common Name                         |
|------------------------------------|-------------------------------------|
| <i>Atriplex semibaccata</i>        | Creeping saltbush                   |
| <i>Bacopa monnieri</i>             | Water hyssop                        |
| <i>Baumea juncea</i>               | Bare-twigg rush                     |
| <i>Carpobrotus glaucescens</i>     | Pigface                             |
| <i>Cynanchum carnosum</i>          | Mangrove vine                       |
| <i>Dysphania littoralis</i>        | Red crumbweed                       |
| <i>Enchylaena tomentosa</i>        | Ruby saltbush                       |
| <i>Fimbristylis ferruginea</i>     | Common fringe rush                  |
| <i>Fimbristylis polytrichoides</i> | Rusty sedge                         |
| <i>Juncus kraussii</i>             | Sea rush                            |
| <i>Limonium australe</i>           | Yellow sea-lavender                 |
| <i>Limonium solanderi</i>          | Sea Lavender                        |
| <i>Paspalum vaginatum</i>          | Saltwater couch                     |
| <i>Phragmites australis</i>        | Common reed                         |
| <i>Portulaca oleracea</i>          | Pigweed                             |
| <i>Portulaca pilosa</i>            | Hairy pigweed                       |
| <i>Ruppia maritima</i>             | Ditch grass                         |
| <i>Sarcocornia quinqueflora</i>    | Beaded samphire                     |
| <i>Schoenoplectus subulatus</i>    | Club rush                           |
| <i>Sesuvium portulacastrum</i>     | Sea purslane                        |
| <i>Sporobolus virginicus</i>       | Salt couch                          |
| <i>Suaeda arbusculoides</i>        | Jelly-bean plant                    |
| <i>Suaeda australis</i>            | Seablite                            |
| <i>Tecticornia halocnemoides</i>   | Small-segmented blackseed glasswort |
| <i>Tecticornia indica</i>          | Brown-headed samphire               |
| <i>Tecticornia pergranulata</i>    | Blackseed samphire                  |
| <i>Triglochin striata</i>          | Streaked arrowgrass                 |
| <i>Zoysia macrantha</i>            | Prickly couch                       |

#### **Accurate Species Records- How you can help.**

You can help create an accurate list of tidal wetland plants in the Southern GBR. Next time you're out in the saltmarsh, take a photo of the plants you see (using your phone is fine). Send the photo to us at [mangrovetwatch@gmail.com](mailto:mangrovetwatch@gmail.com) or record your sighting at the Atlas of Living Australia (<http://www.ala.org.au/get-involved/>). If you're really keen to help – use the species checklist form at the end of this document to record your tidal wetland species observations. In the coming months we hope to generate a visual guide to Southern GBR Tidal Wetland Plants – but we need to know what's there first!

#### **3.4.3 How valuable is Southern GBR Saltmarsh?**

Saltmarsh and mangroves perform many ecosystem services that support and protect coastal communities and coastal economies like yours in the Southern GBR. Here are some of the common ecosystem services that saltmarshes and tidal wetlands do for you:

Water Quality Improvement – Tidal wetlands can trap 50-80% of sediment in tidal waters and runoff. Sediment is harmful to nearby reef and seagrass habitat, making the water dirty and preventing light from getting to these habitats. Bound to the sediment is often potentially harmful nutrients and chemicals that can also damage reef and seagrass. Saltmarsh clean water in 2 ways; 1 – from land-based runoff like urban stormwater and 2. Cleaning tidal water during a flooding tide.

### **3.4.4 What makes a Saltmarsh a good water filter?**

#### **1. Sediment & Nutrient trapping and retention capacity**

The denser the vegetation, the higher the capacity to trap sediment so dense sedge swamps and dense saline grassland are very good at trapping sediment. Vegetation slows water flow allowing sediment to drop out of the water column and remain on the saltmarsh as the tide drops. As the sediment layer builds up over time, plant roots and algae bind the sediment making it permanently part of the saltmarsh.

Sediment surface process in saltmarsh are assisted by the presence of fauna such as crabs and snails.

Nutrients and chemicals are often bound to sediment so sediment trapping also traps nutrients and chemicals.

Proximity to freshwater sources such as groundwater also plays a role. Rapid changes in salinity when salty tidal water meets freshwater sources like groundwater causes sediment particles to 'floc' out of the tidal water where it can remain on the saltmarsh.

Algal mat, epiphytic algae on saltmarsh plants and cyanobacteria in saltmarsh sediments can also trap sediment and nutrients. Often wet muddy surfaces in the tidal zone are covered with a thin layer of microorganism goo that can trap sediment and bind nutrients.

#### **2. Nutrient Conversion & Processing Capacity**

Nutrients bound to sediment that enter saltmarsh are processed by algae and cyanobacteria. Extensive algal mat can be a good indicator of saltmarsh water filtration capacity.

Crabs and snails also process nutrients on the saltmarsh by eating detritus and particulate matter. This material is often buried in burrows where it becomes available to saltmarsh plants. Nutrient export occurs when birds and fish eat these organisms.

Saltmarsh plant growth uses nutrients delivered to the saltmarsh allowing vegetation expansion and more sediment trapping.

#### **3. Location – freshwater flow and tidal inundation frequency**

Saltmarsh areas receiving direct freshwater runoff or with frequent tidal inundation (high tidal connectivity and lower elevation profile) have the greatest capacity to filter water.

### **3.4.5 Indicators of Saltmarsh Water Quality Improvement Value**

#### **Vegetation Structure**

1. Vegetation Extent
2. Vegetation Density
3. Healthy Algal Mat

#### **Saltmarsh Condition**

4. Saltmarsh plant and algal mat productivity
5. Faunal abundance and diversity

#### **Proximity and Connectivity**

6. Tidal inundation frequency
7. Direct freshwater flow
8. Proximity to point sources
9. Proximity to freshwater sources (groundwater, wetlands)

**Fish Habitat** – >75% of seafood species rely on saltmarsh as habitat including commonly caught Bream, Prawns, Mud Crab, Mullet and Flathead. If you love fish and fishing – you love saltmarsh!

### **3.4.6 What makes a Saltmarsh good fish habitat?**

1. Proximity to other tidal habitats like mangroves, seagrass and reefs
2. Accessibility (Connectivity) – having tidal channels that fish can use to swim up onto the saltmarsh at high tide or being in close proximity to deep channels and the shoreline.
3. Food Sources – fish feed on epifauna (crabs and snails) that live amongst saltmarsh plants and these feed on Algal Mat. So, a good cover of algal mat and saltmarsh plants is good fish habitat.

**Carbon Storage** – Mangroves and saltmarsh store 5 times more Carbon than any other ecosystem and they trap Carbon Dioxide (CO<sub>2</sub>) from the air 50 times faster. That's some super carbon storage! The carbon stored in tidal wetlands is often called Blue Carbon and is increasingly recognized as being an important part of the fight against climate change.

### **3.4.7 What makes a Saltmarsh a good carbon store?**

The carbon trapped and stored in saltmarsh is facilitated by vegetation turnover, tidal export of plant material and burial by crabs and snails.

Some saltmarsh is better at trapping carbon because of higher rates of leaf turnover and trapping capacity of the vegetation. Here is the order of importance of vegetation types for carbon storage in Southern GBR Saltmarsh:

***Mangroves > Juncus (Sedges) & Brackish Wetland Areas > Sporobolus (saline grassland) > Samphire > Algal mat.***

The more vegetation cover the more carbon trapping.

Different sediment types have different carbon storage capacity. Here is the order of importance of saltmarsh sediment types for carbon storage in the Southern GBR:

***Anoxic (mostly always wet) Wetland Peat > Occasionally dry peat (upper tidal zone) > Marine clay > Sand***

**Habitat for Endangered Species (and other cool critters)** - Have you come across the Water Mouse (*Xeromys myoides*)? This cute critter lives in the tidal wetland of the Southern GBR and depends on saltmarsh for food and shelter. Unfortunately the Water Mouse is also one of Australia's rarest native rodents. In addition to the Water Mouse, internationally protected migratory shorebirds use saltmarsh as feeding grounds and occasionally as roosting sites. Saltmarsh is recognized as general wader bird habitat, with some areas forming part of the regional Ramsar sites.

### **3.4.8 What makes a Saltmarsh good habitat?**

Both the Water Mouse and Wader Birds use saltmarsh for the same thing – food! Abundant crabs and snails make good habitat and these crabs and snails rely on a mosaic of habitat including salt grass, samphire and algal mat. For the water mouse specifically, being close to protective tree cover is also important, so proximity to *Melaleuca* wetlands and Dense Mangrove areas with old trees with hollows present makes good water mouse habitat. Wader birds on the other hand generally like large open spaces so they can see predators when feeding. The more open the saltmarsh, the better wader bird habitat.

So the features that makes saltmarsh good habitat are:

- Habitat diversity
- Proximity to other tree dominated habitats
- Openness
- Crab and snail abundance – healthy vegetation and healthy algal mat

The best indicator of good saltmarsh habitat is the presence of animals using the habitat. Keep an eye out for Water Mouse burrows and migratory shorebirds!

**Aesthetic and Recreation Value** – although in the past saltmarshes have been regarded as smelly wastelands only to be used for building on, they are increasingly recognized as an important 'green space'. The open expanse of saltmarsh makes them a great location for a casual stroll. The red and green hues of saltmarsh samphire can create a very visually appealing mosaic that has captured the imagination of local artists and photographers. I encourage everyone to watch a summer sunrise over saltmarsh to catch the huge array of spider webs glistening on a dewy morning. The presence of migratory birds also makes saltmarsh attractive locations for twitchers and birders.

**What makes a saltmarsh good Greenspace?** – Accessibility is the most important aspect of saltmarsh as Greenspace. The presence of samphire mosaics and the presence of wader birds are also important. But beauty is in the eye of the beholder, so there really is no prescriptive list!

**Protecting adjacent habitat from the sea and sea level rise** – Some areas of saltmarsh in the Southern GBR are adjacent to endangered Regional Ecosystems. Saltmarsh helps protect these habitats from the impacts of storm surge and in the future may help to reduce the impacts of sea level rise.

**What makes a saltmarsh a good Coastal Buffer?** - In short, healthy habitat. If the saltmarsh is free from human-related stressors, like runoff or damage from vehicles, it is more likely to provide a more effective buffer against storm surge and sea level rise. Areas with more extensive salt-grass and sedge swamps are also likely to be more effective at 'keeping-pace' with sea level rise as these areas are more effective at trapping sediment.

These are just some of the known and recognized general values of saltmarsh habitat. There may be others that are locally specific.

### **3.4.9 Prioritizing Investment in Southern GBR Saltmarsh**

#### **Valuing Southern GBR Saltmarsh?**

The aim of this project is to prioritize saltmarsh areas for restoration investment to improve Southern GBR water quality. Areas that have high value but are at the greatest risk of loss and destruction have the highest priority for restoration. The first step of this project is to identify the very high value (all saltmarsh is valuable) areas in the Southern GBR. To start this process, we need to map saltmarsh values using available mapping layers related to saltmarsh conservation values and also include local community-based values.

Mapping layers that will be used to map saltmarsh value include:

- Queensland Wetlands Mapping Program layers
- Queensland Regional Ecosystem Mapping
- GBRMPA zoning maps
- WildNet (recording sighting of EPBC listed species such as water mouse and wader birds)
- Queensland Wader Study Group migratory bird habitat layers
- Regional Seagrass and Reef mapping layers
- Estuary Water Quality Data
- Fish Habitat Areas
- Local government storm-water drain locations, sediment and nutrient point-source mapping and hydrological maps
- Local government recreation areas and recreation reserves
- Groundwater dependent ecosystem mapping
- QLUMP Landuse data
- Topographical mapping
- Available high-resolution multiband satellite imagery
- Landsat Data (NDVI & other vegetation cover indices)

Have we missed anything?

**Accurate Value Mapping - How you can help.**

What information do you think will help to value saltmarsh and prioritize investment to improve GBR water quality?

We need your help to determine the most valuable saltmarsh habitat Southern GBR. Fill in the value form included in this document to help us identify areas that you think are valuable and why. That way we can make sure that future investment is directed to the right place so that saltmarsh in the Southern GBR can keep providing all those excellent ecosystem services.

Or, fill in the online survey that will be sent out over the next few weeks.

Threats to Southern GBR Saltmarsh that reduce water quality improvement capacity

Loss of vegetation extent, diversity, and algal may cover

Direct factors that cause physical damage to saltmarsh can reduce water quality improvement value. These include:

- Vehicle Damage
- Cattle Damage
- Human trampling
- Mowing
- Burning
- Poisoning

Vegetation cover can also be reduced by:

- Sediment deposition during flooding
- Erosion due to high water flow during flooding and poor drainage management
- Sediment dumping
- Chemical drift from weed spraying - Shoreline erosion

**Saltmarsh Condition**

Saltmarsh plant and algal-mat productivity can be reduced by indirect factors that reduce plant health. Prolonged exposure to these factors leads to loss of vegetation cover and density. These factors include:

- Herbicides & chemical pollution (oil spills)
- Altered hydrology causing reduced freshwater flow or tidal exchange
- Drought

These factors also can affect faunal abundance.

**Connectivity**

Loss of tidal exchange or freshwater connectivity caused by ***altered hydrology***.

### **Identifying Southern GBR Threats and Current Issues**

We need to know where southern GBR saltmarsh are threatened by the above drivers or any other factors that you may have observed.

Fill in the threats form included in this document to help us identify areas that you think are valuable and why. That way we can make sure that future investment is directed to the right place so that saltmarsh in the Southern GBR can keep providing all those excellent ecosystem services.

Or, fill in the online survey that will be sent out over the next few weeks.

You can also identify issues using Google Earth. Place locations on a Google Earth map, identify the driver, create a .kml file and send to use at mangrovetwatch@gmail.com

## **3.5 Presentations by Duke and Mackenzie at the 2016 MMM4 Conference**

The presentations made by Dr Duke and Jock Mackenzie helped raise awareness of this NESP TWQH project amongst an international audience of world mangrove specialists attending the 4<sup>th</sup> Mangrove and Macrobenthos Meeting (MMM4) conference in Florida USA.

Abstracts for the oral presentations made on 22<sup>nd</sup> July 2016 at the MMM4 Conference in St Augustine Florida, USA.

### **3.5.1 Presentation by Dr Duke**

**Managing oil spill impacts on mangroves: should we be concerned?** (Figure 28)

#### **Abstract**

Mangroves are widely acknowledged as highly vulnerable to oil spills, but this is measured mostly in terms of severity of impacts on vegetation rather than their longer term recovery and the consequences for associated trophic processes. Little is known about key linkages and functional relationships between the plants and animals making up mangrove habitat. This includes not knowing how long it takes for oil-damaged mangrove habitat to recover. While recovery of forest structure appears to occur within three decades, full habitat recovery may take much longer. From the limited data available, it seems that prevention would be the better option, rather than restoring oil-damaged habitat. But, when mangrove habitat is oiled then an effective strategy is needed.

When petroleum oil deposits on sensitive plant surfaces, it also affects soils and dependant animal life, causing a range of lethal and sublethal impacts that extend widely throughout associated coastal and estuarine ecosystems. Such disruptions also affect ecosystem services, like fisheries production and shoreline protection. And, all such impacts may persist for decades, as well as occurring at any time and at any place. So, for as long as oil is extracted and transported, there will be an ever-present risk to the health and survival of mangrove habitats worldwide. Therefore, it is essential where possible to be prepared.

Preparedness includes evaluation of risks and vulnerability, developed from baseline shoreline surveys, records of earlier impacts and recovery, and using effective longer-term monitoring. For instance, impact severity on mangroves might easily be quantified by the area of tree death along with other pragmatic descriptors, like the estimated volume of oil lost, the types of oil, the area of oiled habitat, and the area of likely sublethal impacts. The situation would also be much improved by an agreed global assessment strategy using standard criteria for the longer term, better management and monitoring of mangrove habitat affected by large oil spills. Only in applying such a strategy will it be possible to adequately understand, evaluate and assist longer term recovery of oil-impacted mangrove ecosystems.



Figure 28: Title slide

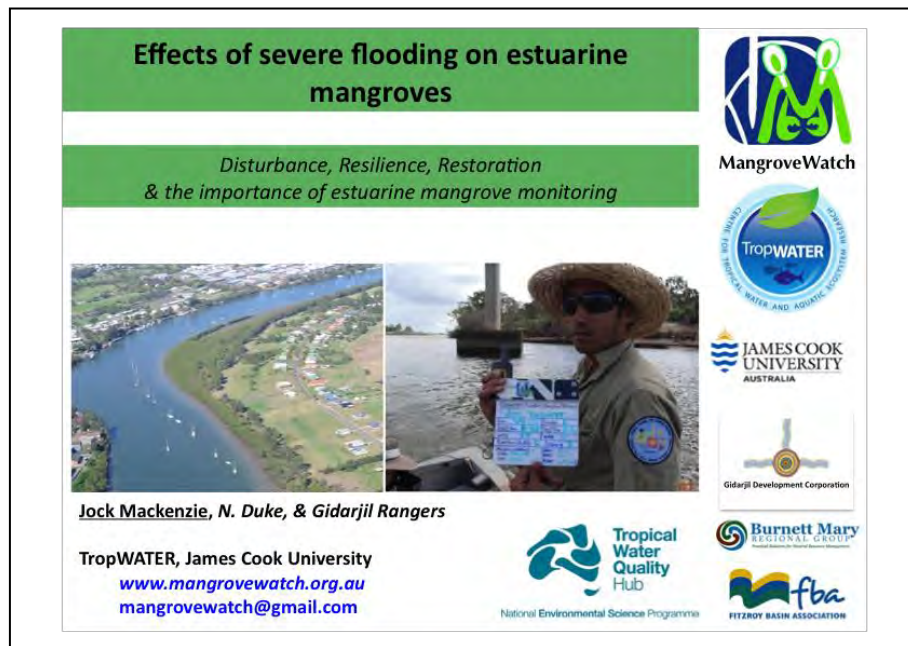
### 3.5.2 Presentation by Jock Mackenzie

**Effects of severe flooding on estuarine mangroves – disturbance, resilience and restoration** (Figure 29)

#### **Abstract**

“I love a sunburnt country, a land of sweeping plains, of ragged mountain ranges of droughts and flooding rains, I love her far horizons, I love her jewel-sea, her beauty and her terror, the wide brown land for me” (excerpt from Dorethea Mackellar’s ‘My Country’). Australia is a country typified by diverse and iconic landscapes, severe climate and severe weather events, which are at times terrifying in their power and destruction. Mangroves are highly adapted to extreme environments as demonstrated by their survival at the interface between land and sea, exposing them to short and long-term climate extremes such as cyclones, floods and droughts. But anthropogenic driven degradation of estuarine mangroves may threaten the capacity of mangroves to withstand extreme climate events. Direct damage leading to mangrove loss and fragmentation and indirect effects such as altered hydrology and eutrophication reduce the capacity of mangroves to withstand climate extremes and limits their resilience capacity. It is expected that extreme weather events will increase in both severity and frequency in coming years. It is therefore imperative that we understand how

anthropogenic degradation of mangroves influences their resistance and resilience to extreme weather events in order to inform better mangrove management. Recently, a series of severe flood events impacted the east coast of Australia, causing extreme flooding in major coastal rivers and estuaries. These flood events caused widespread loss of shoreline mangroves, with an estimated loss of 30% of estuarine mangroves in some coastal estuaries. Some of the estuaries impacted form part of the monitoring network of MangroveWatch, a citizen-science based program designed to monitor long-term changes in the condition of shoreline mangroves using geo-tagged video. The MangroveWatch monitoring data enabled assessment of mangrove condition before and after flooding. Here we examine the effect of flooding on estuarine mangroves in three different coastal settings with differing levels of human impacts to assess the effects of estuarine and catchment modification on mangrove resilience to severe flood events. Our results show that shoreline mangrove forest fragmentation, eutrophication and estuarine shoreline modification result in greater risk of estuarine mangrove loss during severe flood events with recovery dependent on pre-existing forest structure, forest continuity, condition, level of anthropogenic disturbance and adjacent land use. This information is used to develop a strategic approach to mangrove rehabilitation investment in the target estuaries and inform future estuarine mangrove management.



**Figure 29:** Title slide of the presentation about Moreton Bay MangroveWatch and the role of citizen scientists in shoreline monitoring and management.

### 3.6 Presentation by Duke at a citizen science forum in Brisbane

The presentations made by Dr Duke and Jock Mackenzie helped raise awareness of this NESP TWQ Hub project amongst a local audience of citizen scientists of the west Brisbane area.

**Title: Moreton Bay MangroveWatch 2016** (Figure 30)

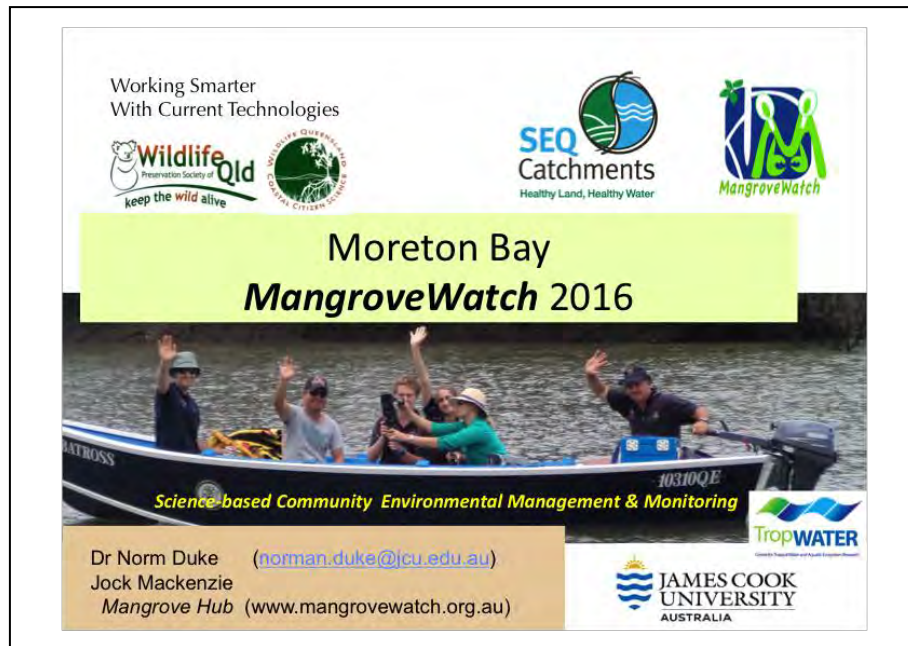


Figure 30: Title slide of the presentation about Moreton Bay MangroveWatch and the role of citizen scientists in shoreline monitoring and management.

### Abstract

It is all about protecting our Magnificent Mangroves. Citizen scientists have an important and crucial role to play in protecting mangroves and our estuarine shorelines generally. While scientists cannot be everywhere, is a distinct advantage in having trained, local community observers collecting information from the environment. With MangroveWatch we monitor shoreline condition and health, and we describe the factors affecting the condition, and even get in and do something about it. But, basic to all MangroveWatch activities is the Shoreline Video Assessment Method (S-VAM). With this easy method anyone can get involved and make valuable contributions to shoreline management and repair. Some of the achievements of citizen scientists have been in the news recently with a citizen explorer discovering of a new species of mangrove tree for Australia; and other citizens raises the emerging critical issue of massive mangrove dieback along the remote Gulf coastline. This talk build on such achievements as well as a summary of the more systematic surveys done by MangroveWatch teams around the country, as well as in the Brisbane area.

### 3.7 Presentations by Duke and Mackenzie at citizen science forum in Cairns

The presentations made by Dr Duke and Jock Mackenzie (Figure 31) helped raise awareness of this NESP TWQ Hub project amongst a local Cairns audience of local citizens, as well as local citizen scientists.



**Figure 31:** Title slide of the presentation about mangroves and the role of citizen scientists in shoreline monitoring and management.

We invited the residents of Cairns to learn more about mangroves as unique and vital ecosystems on their doorstep! People could join in on three mangrove topic educational events over the weekend. People could discover how much carbon our local mangroves are sequestering, attend a mangrove themed art show in the evening, and then jump aboard and cruise up Trinity Inlet.

The three events (Figure 32) organised include:

***EVENT 1: ‘Mangrove Discovery: Boardwalk tour & survey’***

Saturday 29th November 12 – 4pm Jack Barnes Memorial Boardwalk, Airport Avenue  
Field venue was the council mangrove boardwalk to learn about the spectacular local mangroves of Cairns with the MangroveWatch team. There were also opportunities to learn about mangrove forests and to help scientists collect crucial data on carbon sequestration by local mangroves.

***EVENT 2 ‘Mangrove Science & Art Show: The Beauty Within’***

Saturday 29th November 7 - 9.30pm, Stratford Library  
This event was held amongst the beautiful local art describing and showing the passion people have for mangrove places – both as an indigenous cultural experience as well as other community artists! The mangrove specialists were there also to discuss the benefits of mangroves and the threats they face. Questions were discussed, like what can be done to help.

***EVENT 3 ‘Mangrove Health Check: Trinity Inlet Boat Cruise’***

Sunday 30th November 8am – 1.30pm, Trinity Inlet  
This event involved an educational cruise, with participants learning about mangroves first hand, and about how citizen scientists can help in the assessment process. Our hosts for this event were the Djunbunji Land & Sea Rangers along with the scientists from the MangroveWatch Hub.

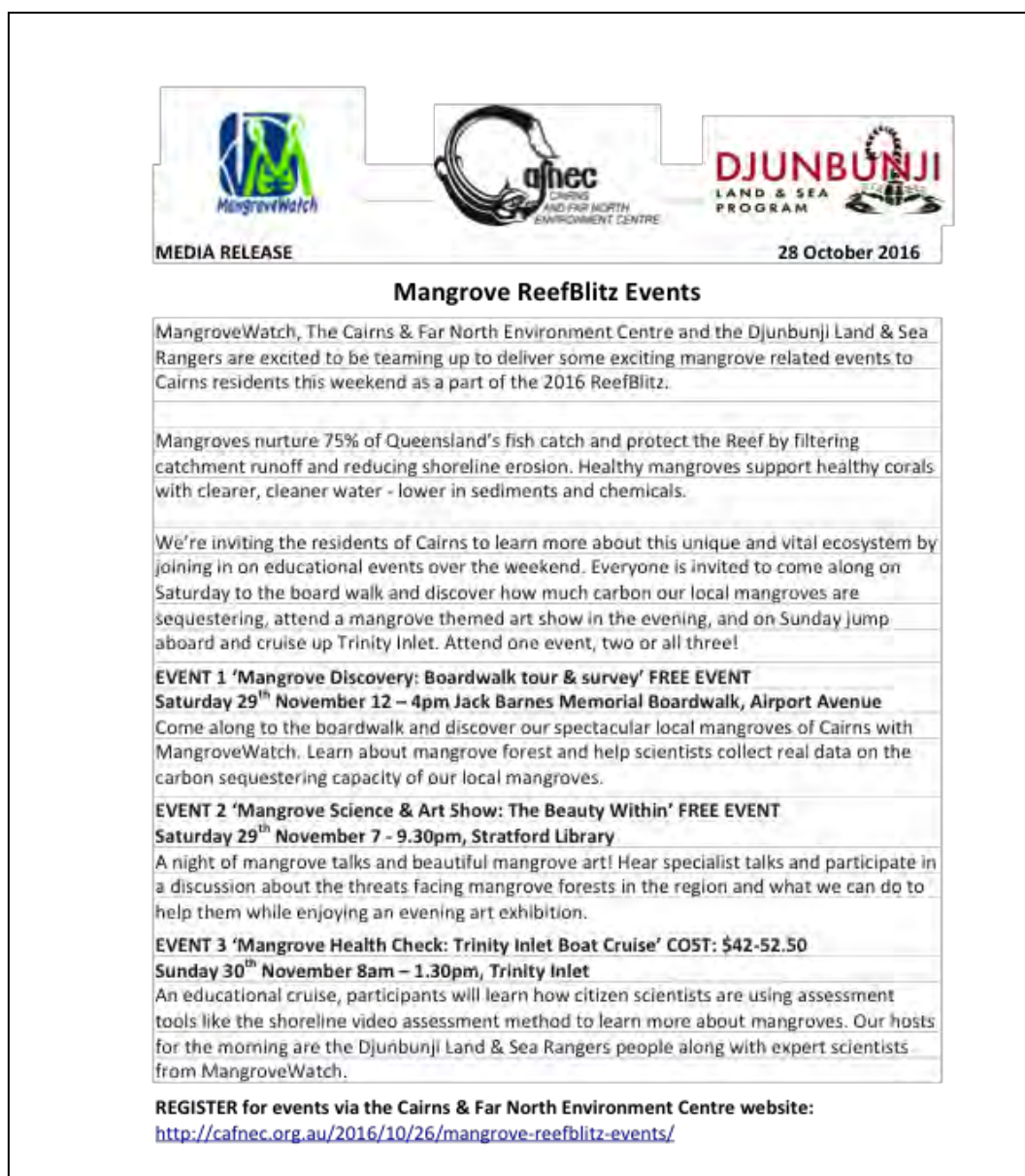


Figure 32: Media release for the ReefBlitz activities of MangroveWatch made of the 28<sup>th</sup> October 2016.

### 3.8 Presentations by Duke at the Territory Natural Resource Management (TNRM) 2016 Conference and workshop in Darwin

The presentations made by Dr Duke (Figure 33) helped raise awareness of this NESP TWQH project amongst a Northern Territory audience of natural resource use specialists attending the 2016 TNRM conference in Darwin.



**Figure 33:** Title slide of the presentation about the role of Indigenous Rangers in shoreline monitoring and management.

### Abstract

There are good reasons for protecting Australia's northern coastal and estuarine tidal wetlands. They provide essential ecosystem services of lucrative resources like fisheries productivity, protection of Australia's northern shorelines, buffering erosion, and bolstering coastal water quality. But, these benefits and the habitats themselves are threatened by human development as well as from occasional climate events like the recent extensive dieback in the Gulf. A national strategy is needed for prioritising at-risk and damaged shorelines to help in their protection and rehabilitation, as needed.

Scientists at TropWATER Centre James Cook University are working on a number of innovative projects with Traditional Owner rangers and local citizens to meet these national objectives. These partnerships are delivered in a program called MangroveWatch which raises capacity for shoreline assessment amongst individual groups. Key recent projects with indigenous partners include: the Southern GBR estuaries with Gidarjil Development Corporation, Eastern Princess Charlotte Bay shorelines with Balkanu, Noosa and Maroochy region with Bunya Bunya Corporation, Torres Strait islands with Torres Strait Regional Authority, and most recently in the south-eastern Gulf region with the Carpentaria Land Council Aboriginal Corporation.

In each project, close partnerships are producing beneficial outcomes that deliver detailed assessments of shoreline health, condition, vulnerability, dominant issues, and prioritisation of shoreline sites for rehabilitation. Indigenous Rangers make key contributions as they monitor, assess, manage and rehabilitate estuarine wetlands within their individual cultural landscapes. At the same time, scientists and regional managers obtain first hand observations, data and imagery for better understanding changes taking place in each region. It's a win-win outcome!

### 3.9 Publications related to the Southern GBR CHAMP NESP project

Publications of relevance to this project during this semester.



***'The Shoreline Video Assessment Method (S-VAM): using dynamic hyperlapse image acquisition to evaluate shoreline mangrove forest structure, values, degradation and threats' in Marine Pollution Bulletin.***

Mangrove and tidal wetland habitats worldwide are threatened by climate change. Considered mitigation is required to increase the resilience

Climate change presents a significant threat to shoreline mangroves. Improving mangrove forest resilience to climate change requires both the identification of anthropogenic drivers of degradation and the development of targeted rehabilitation and protection strategies. Using the Shoreline video assessment method (S-VAM), in Kien Giang, Vietnam, we found that mangroves occupy 78% of

the shoreline, a much greater extent than previously recognized. Kien Giang shoreline mangroves were shown to support local livelihoods, with 87% of near-shore fish traps associated with mangrove forest presence, and were found to be in poor condition and threatened by erosion, herbivory and overharvesting. Current mangrove rehabilitation strategies were demonstrated to be ineffective and opportunities for enhanced rehabilitation programs identified to address this issue. This Kien Giang data demonstrates the value of S-VAM in assessing narrow fringing shoreline mangrove forests; a habitat previously overlooked in mangrove assessment approaches. It further demonstrates the suitability of S-VAM to accurately quantify shoreline mangrove forest attributes and as an effective and informative mangrove conservation and management tool.



***'Oil spill impacts on mangroves: recommendations for operational procedures and planning based on a global review' in the journal Marine Pollution Bulletin.***

Mangrove tidal wetland habitats are recognized as highly vulnerable to large and chronic oil spills. This review of current literature and public databases covers the last 6 decades, summarising global data on oil spill incidents affecting, or likely to have affected, mangrove habitat. Over this period, there have been at least 238 notable oil spills along mangrove shorelines worldwide. In total, at least 5.5 million tonnes of oil has been released into mangrove-lined, coastal waters, oiling possibly up to around 1.94 million ha of mangrove habitat, and killing at least 126,000 ha of mangrove vegetation since 1958.

However, there were assessment limitations with incomplete and unavailable data, as well as unequal coverage across world regions. To redress the gaps described here in reporting on oil spill impacts on mangroves and their

recovery worldwide, a number of recommendations and suggestions are made for refreshing and updating standard operational procedures for responders, managers and researchers alike.



### ***'The state of legislation and policy protecting Australia's mangrove and salt marsh and their ecosystem services' in the journal Marine Policy.***

Saline coastal wetlands, such as mangrove and coastal salt marsh, provide many ecosystem services. In Australia, large areas have been lost since European colonization, particularly as a result of drainage, infilling and flood-mitigation works, often starting in the mid-19<sup>th</sup> century and aimed primarily towards converting land to agricultural, urban or industrial uses. These threats remain ongoing, perhaps even exacerbated by rapid population growth, and will be made worse by climate change and associated sea-level rise. There has been little effort directed towards quantifying the ecosystem services provided by mangrove

and salt marsh in Australia. Establishing changes in these services is confounded by the absence of a nationally consistent approach to mapping wetlands and defining the boundaries of different types of coastal wetland. Moreover, climate change and its projected effect on mangrove and salt marsh distribution and ecosystem services is poorly if at all acknowledged in existing legislation and policy. There has also been a tendency to move away from proactive approaches to planning for sea-level rise and ecosystem adaptation, such as the use of sea-level rise planning benchmarks. In a federation such as Australia, national, state/territory and local governments have different and sometimes overlapping policies, legislation and planning instruments and this leads to legislative and management complexity. Within the existing planning and policy framework we identify a range of approaches that could be used to protect coastal ecosystems and the ecosystem services they provide. Actions that build upon the momentum to mitigate climate change by sequestering carbon – 'blue carbon' – could achieve multiple desirable objectives, including climate-change mitigation and adaptation, floodplain rehabilitation and habitat protection. Intensifying climate change means that there is little time to be complacent; indeed, there is an urgent need for proper valuation of ecosystem services and explicit recognition of ecosystem services within policy and legislation.



### ***'Mangrove Click! Australia: expert ID for Australia's mangrove plants' on the Apple iTunes Store.***

This smart device app helps you to identify the Australian mangrove plants. It is a useful and handy tool for Rangers to have available when they identify mangrove plants in the field and in the office.

'Mangrove Click! Australia' or 'Mangrove AU' is an e-book app, and a living expert guide to all 47 Mangrove plants in Australia, plus 6 common Associate plants. AND, this app has KEYS to help identify your mangrove plant specimen! The app facilitates the collection of botanical knowledge of mangrove plants wherever you are in Australia or its offshore territories. Try the location Key to get a short list

of mangrove species of the Natural Resource Management area where you are using the app. If it's right or wrong send a message to let us know.

### **3.10 Grants awarded re this Southern GBR CHAMP NESP project**

Grants were awarded for two proposals based on project data gathered with the GBR CHAMP NESP project, including: a) rehabilitation works of the Wallace Creek tidal tributary near the Bundaberg Port area; and b) for capacity building amongst Gidarjil Rangers and with counterparts in Brazil.

#### **3.10.1 Wallace Creek Reserve Project**

Gidarjil Caring for Country (CFC) program will work in partnership with Gladstone Ports Corporation, Mangrove Watch and Burnett Mary Regional Group to rehabilitate Wallace Creek at Burnett Heads from current threats and impacts to ecosystems such as, acid sulfate soils that are developing; dumped waste including asbestos; suspected illegal fishing; and, recreational vehicle access that is impacting the salt marsh.

Gidarjil Caring for Country program partnered with Tangaroa Blue in August 2016 for a marine debris clean-up project at Wallace Creek. Gidarjil CFC and Tangaroa Blue also have trained the Green Army, Gidarjil SQW NRM and Gidarjil School Based Sea Rangers in Marine Debris to build our local community's capacity to undertake such environmental projects.

Wallace Creek Reserve Project Goals are: To manage, monitor and rehabilitate the Wallace Creek Reserve in Burnett Heads/Bundaberg Port; minimise threats to Wallace Creek and to ensure sustainability and survival of native flora and fauna species and traditional knowledge through managing pollution, inappropriate access & suspected illegal fishing; Provide education and training to raise awareness of the local community to sustainably manage and take an active interest in Wallace Creek mangrove and saltmarsh ecosystems; and, continue to work with JCU's Dr Norm Duke and Jock Mackenzie with the MangroveWatch program to these threatened mangrove ecosystems.



**Figure 34:** Map of Wallace Creek Project site at the mouth of the Burnett River, BMR.

Since before European settlement, just over 200 years ago, Aboriginal people of the Bundaberg region have long-held cultural and traditional responsibilities to protect and manage their land and sea country. Many natural resource products were gathered and were used in a sustainable way for more than 40,000 years. The Port of Bundaberg and Burnett Heads has always been an important place of cultural practice and their significant cultural heritage sites abound such as shell middens, a fish trap, stone artefacts and a burial site found in area.

The project will contribute to the implementation of Local NRM strategies and plans in a coherent and effective way, through working closely with Gladstone Ports Corporation, Bundaberg Regional Council and Burnett Mary Regional Group programs to build the capacity of our Indigenous community to contribute to managing land and sea country. Careful management of these areas is necessary to ensure their ongoing protection and contribution to the region's natural ecosystems. The Wallace Creek Reserve Project would include but not limited to: Pollution/marine debris management. Marine debris comes from both land and sea-based sources and can travel immense distances. It can pose a navigation hazard, has the potential to transport chemical contaminants and transport invasive species. It can also, entangle wildlife or be ingested. Marine Debris not only causes death or injury to wildlife it negatively affects tourism and poses a threat to human health. This issue is particularly relevant with nearby Sea Turtle Rookery's including the Mon Repos; and, Managing the access into Wallace Creek to protect the saltmarsh. Illegal access to Wallace Creek has become a major impact and threat to the saltmarsh and suspected illegal fishing in the creek.

The Gidarjil Caring for Country Program plans to rehabilitate the Wallace Creek Reserve and protect it from current threats and impacts to its ecosystem.

Project Manager: Ric Fennessy

Gidarjil Caring for Country Program, Caring for Country office

### **3.10.2 Enhancing traditional owner capacity to protect mangroves against climate change through cross-cultural exchange**

#### **Australian National Commission for UNESCO 16-17 Grants**

**Applicant: TropWATER, JCU**

Mangroves are a valuable natural resource in many UNESCO managed regions. Due to the



combined impacts of human stressors, climate change and natural process, mangroves are disappearing faster than any other forest type. Enhancing and empowering indigenous traditional owner management of mangrove resources in areas like the Great Barrier Reef World Heritage Area (GBRWhA), Great Sandy Biosphere Reserve (GSBR) and the Atlantic Forest South-East Reserves will generate better outcomes for mangrove conservation.

This project will establish a research collaboration between James Cook University and Universidade Estadual Paulista and their existing Indigenous representative partner organisations; Gidarjil Development Corporation (<http://www.gidarjil.com.au>) (Australia) and AMOAMCA - Associação de Monitores Ambientais de Cananéia. This research and traditional owner partnership aims to strengthen the capacity of traditional owners to effectively engage in mangrove ecosystem monitoring and research to inform traditional owner mangrove management in UNESCO managed areas.

The Port Curtis and Coral Coast Traditional Use Management Area (PCCC TUMRA) ([http://www.gbrmpa.gov.au/\\_\\_data/assets/pdf\\_file/0017/13814/PCCC-TUMRA-Map-Schedule-1-FINAL.pdf](http://www.gbrmpa.gov.au/__data/assets/pdf_file/0017/13814/PCCC-TUMRA-Map-Schedule-1-FINAL.pdf)) which includes part of the Great Barrier Reef World Heritage Area (GBRWhA) and Great Sandy Biosphere Reserve (GSBR). The Cananeia-Iguape Coastal System, part of the World Heritage Site Atlantic Forest South-East Reserves (<http://whc.unesco.org/en/list/893>), São Paulo state, Brazil.

This project will establish a research collaboration between James Cook University and Universidade Estadual Paulista and their existing indigenous representative partner organisations; Gidarjil Development Corporation (<http://www.gidarjil.com.au>) (Australia) and AMOAMCA - Associação de Monitores Ambientais de Cananéia (<https://www.facebook.com/monitores.amoamca/>) (Brazil). These organisations currently undertake mangrove monitoring in UNESCO World Heritage Areas and Biosphere Reserves in Australia and Brazil. This partnership will facilitate cross-cultural knowledge exchange between two culturally distinct indigenous groups actively engaged in traditional owner mangrove management and facing similar climate change and human impact management challenges.

This project has 5 key objectives:

1. Strengthen capacity of two traditional owner groups to undertake effective mangrove management by enhancing the role of indigenous rangers as empowered citizen-scientists.

2. Promote cross-cultural collaboration and knowledge sharing between two culturally distinct indigenous groups in similar latitudinal and climatic zones to improve mangrove resilience to climate change through traditional owner management in three UNESCO managed areas.
3. Create an international partnership between scientists and traditional owners to enhance mangrove knowledge exchange and improve communication of traditional owner values, observations and knowledge to inform mangrove management.
4. Promote international scientific cooperation on developing innovative mangrove monitoring and assessment methods that promote indigenous and citizen-scientist engagement and address the critical challenge of managing mangroves under threat from climate change.
5. Establish a MangroveWatch partnership between Brazil and Australia to improve knowledge of climate change impacts on mangrove ecosystems, management challenges and effective management solutions in geographically and culturally distinct, but climatically, latitudinal and geomorphologically comparative UNESCO managed areas.

This project will assist UNESCO deliver on strategic objectives for natural sciences outlined in the Medium-Term Strategy for 2014-2021 (37 C/4).

The project will achieve the stated objectives via the establishment of the first Brazilian MangroveWatch Hub. The formation of this hub will involve two exchange trips between researchers from Brazil and Australia. On each occasion, researchers will be accompanied by a representative from respective partner indigenous organisations.

Project Managers: Dr Norm Duke & Jock Mackenzie  
TropWATER Centre, JCU

### **3.11 Pending Expressions of Interest regarding this Southern GBR CHAMP NESP project**

Expressions of Interest have been submitted and are pending. These propose substantive rehabilitation works with DAF Fisheries Queensland identified during surveys by the GBR CHAMP NESP project team, include: a) rehabilitation of the Burnett River shoreline near the port and downstream sections of the estuary; b) rehabilitation of the Kolan River shoreline near the sugar mill and nearby sections of the estuary; and c) research into best practice and effective methods for shoreline mitigation works in the Burnett region.

The proponents for each proposal are:

TropWATER Centre, JCU; and the Gidarjil Development Corporation.

#### ***3.11.1 Protecting vital fish habitat with the rehabilitation of estuarine living shorelines (mangroves, saltmarsh and shellfish) along the southern GBR coast: Burnett River***

With this two year project, we proposed to use innovative techniques for restoration and rehabilitation of living natural shoreline habitats along sections of the Burnett River estuary. These works are based on observations made during survey works with the Gidarjil Rangers. On-ground works will be used to stabilize a section of badly flood eroded and retreating

shoreline that threatens adjacent endangered sub-tropical saltmarsh, mangroves and riparian communities.

On-ground works will involve placement of rock, sand, coir logs and 'oyster balls' to modify shoreline slope and create an environment that encourages long-term saltmarsh, mangrove and oyster reef establishment. These living structured-shorelines will supplement constructed river bank verges to help prevent further shoreline retreat and improve fish habitat value. This technique has previously been used in the southern USA to protect saltmarsh wetlands with the creation of additional fish habitat there.

The current project proposed for central Queensland will be the first to combine the re-establishment of three key biologically structured living shoreline habitats, including saltmarsh, mangrove and oyster reef. These 'living shorelines' were present historically in the region, and they are expected to enhance and protect fish habitat within this Queensland estuary.

As the rehabilitation project involves construction of infrastructure within tidal areas, with potential minor disturbances to existing marine plants (present along the eroded shoreline face), and collection of mangrove and saltmarsh plant material for planting, plus local shellfish, appropriate permits will be sought through Queensland DAFF under the Fisheries Act 1994.

### Selected Rehabilitation Site

The proposed works will be undertaken along a 618 m section of the Burnett River shoreline on land controlled by the Gladstone Ports Corporation Ltd. We estimate this mitigation action will create and protect 7.4 ha of tidal wetland fish habitat and have indirect benefit to the remnant 49 ha of fish habitat on the site (Figure 35).



Figure 35: Proposed Burnett River Fish Habitat Rehabilitation plan.

### **Summary of site suitability, benefits and risks**

1. A map of the site is shown in Plate 3 for comparison with the Shoreline Video Assessment for the whole system in 2015:
2. This tidal wetland area in the Burnett River estuary represents the largest continuous extent of high-intertidal sub-tropical saltmarsh having direct fish habitat connectivity to the river
3. The location is the last section of unmodified 'natural' shoreline sections in the lower Burnett River and has significant value for fish habitat connectivity along the estuary.
4. The lower Burnett estuary is still utilized by commercial beam-trawl operators, as well as being a popular area for recreational line fishing. Enhancement of fish habitat in this area will have direct benefit to commercial and recreational fisheries in the Burnett River estuary
5. The location within the lower estuary is suitable for a number of local mangrove and shellfish species. There is possibility enhance mangrove and shellfish biodiversity within the lower Burnett River.
6. The site location has high visibility from the estuary, with limited public access. There is some risk that future flood events may result in loss of living shoreline assets once established. It is likely that construction of living shoreline infrastructure will minimize these risks and any future erosion at the site will be no greater than what would have occurred without intervention.

### **Site post-works evaluations and assessment will be undertaken by Gidarjil Rangers, advised by JCU scientists.**

Engaging Traditional Owners in this site rehabilitation will ensure direct stewardship of this site, with ongoing monitoring and evaluation highly likely through continuing existing partnerships between Gidarjil, MangroveWatch, JCU and GPCL.

### ***3.11.2 Protecting vital fish habitat with the rehabilitation of estuarine living shorelines (mangroves, saltmarsh and shellfish) along the southern GBR coast: Kolan River***

This is a two year project proposal to use innovative techniques for restoration and rehabilitation of living natural shoreline habitats along sections of the Kolan River estuary. On-ground works will be used to stabilize a section of badly flood eroded and retreating shoreline that threatens adjacent agricultural land, tidal land and riparian communities.

On-ground works will involve placement of rock, sand, coir logs and 'oyster balls' to modify shoreline slope and create an environment that encourages long-term saltmarsh, mangrove and oyster reef establishment. These living structured-shorelines will supplement constructed river bank verges with planted riparian vegetation to help prevent further shoreline retreat and improve fish habitat value. This technique has previously been used in the southern USA to protect saltmarsh wetlands with the creation of additional fish habitat there (Figure 36).

The current project proposed for central Queensland will be the first to combine the re-establishment of three key biologically structured living shoreline habitats, including saltmarsh, mangrove and oyster reef. These 'living shorelines' were present historically in the region, and they are expected to enhance and protect fish habitat within this Queensland estuary.

As the rehabilitation project involves construction of infrastructure within tidal areas, with potential minor disturbances to existing marine plants (present along the eroded shoreline

face), and collection of mangrove and saltmarsh plant material for planting, plus local shellfish, appropriate permits will be sought through Queensland DAFF under the Fisheries Act 1994.

### Proposed Site

The proposed works will be undertaken along 3 shoreline sections totalling 1.93 km (555 m, 529 m & 847 m) of the mid Kolan River estuary on land controlled by Bundaberg Sugar Corporation Ltd (Figure 36). The three sites are located adjacent to farmed cane land, near Yandaran Creek (Lots 38-40/ RP37081 & Lot 3 / RP107724). Recent flood events resulted in severe shoreline erosion which threatens productive farmland. On Lot 3, flooding resulted in scouring of agricultural land and recreation of a historical tidal channel, creating an estimated 11.3 ha of naturally reclaimed tidal habitat. The proposed living shoreline works will stabilize shoreline considered to be at high risk of erosion, protecting both agricultural assets and facilitate natural habitat regeneration on recreated tidal land. These works will also create new fish habitat and increase connectivity between existing tidal wetland habitat patches.

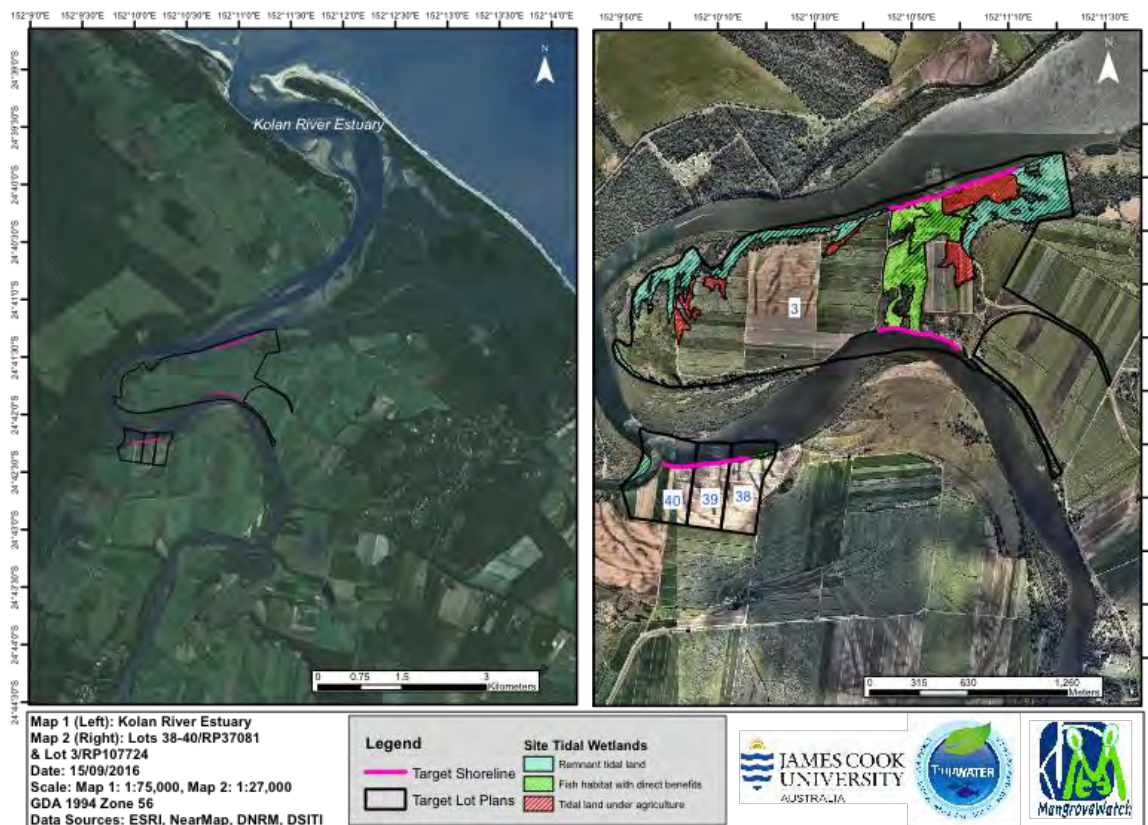


Figure 36: Kolan River Fish Habitat Rehabilitation Plan.

### Summary of site suitability, benefits and risks

A map of the site is shown in Figure 36 for comparison with prior Shoreline Video Assessment imagery:

1. The Kolan River is a degraded estuary due to poor water quality, modified flow and limited agricultural buffer zones. But, the estuary has high conservation value as demonstrated by the presence of the Mouth of the Kolan Conservation Park and the Kolan River FHA. The Kolan River estuary supports fisheries values including an important commercial prawn fishery; recreational finfish area; Indigenous fishing;

breem; estuary cod; flathead; garfish; grey mackerel; mangrove jack; sea mullet; school mackerel; whiting; banana prawns (NPRSR, 2012).

2. Recent flooding has severely damaged fish habitat in the upper Kolan estuary.
3. The sites are located in the mid-estuary and present an opportunity to improve fish habitat connectivity.
4. The creation of oyster reef environments elsewhere have been demonstrated to improve adjacent water quality and facilitate seagrass colonization. There is historical evidence of seagrass in the Kolan River estuary.
5. The selected shoreline is adjacent to agricultural assets, as such fish habitat rehabilitation works will serve to provide multiple benefits, including shoreline protection, water quality improvement and create a wildlife corridor, reducing habitat fragmentation. The additional economic benefits of shoreline stabilization provides further incentive for the maintenance of living shoreline assets by the landholder into the future.
6. On Lot 3, 14.5 ha of agricultural land is present below HAT, with historical conversion of fish habitat. The creation of new fish habitat and protection of naturally reclaimed fish habitat will serve to help offset these historical losses.
7. Our project partner, and landholder, Bundaberg Sugar, currently manages large sections of estuary shoreline in the region. Many of these areas are experiencing erosion. The successful implementation of living shorelines to promote fish habitat and agricultural asset protection in the Kolan River, will encourage future private investment in fish habitat creation elsewhere. These works will supercede current hard infrastructure, with minimal habitat benefits being used by landholders in the region to prevent shoreline erosion.
8. These works present an opportunity to enhance indigenous stewardship of the Kolan River estuary and will provide opportunities to improve skills of Gidarjil Indigenous Corporation employees and school-based trainees.

There is some risk that future flood events may result in the loss of living shoreline assets. However, there is unlikely to be additional risk to adjacent landholders or estuarine habitat as a result. It is likely that even in the worst case scenario of a large-scale flood event resulting in loss of assets, the presence of living shoreline infrastructure will minimise shoreline erosion and protect adjacent tidal lands and agricultural assets.

**Site post-works evaluations and assessment will be undertaken by Gidarjil Rangers, advised by JCU scientists with advice from Oceanwatch Australia, TNC and other project advisors.**

Engaging Traditional Owners in this site rehabilitation will ensure direct stewardship of this site, with ongoing monitoring and evaluation highly likely through continuing existing partnerships between Gidarjil, MangroveWatch, JCU and Bundaberg Sugar.

### ***3.11.3 Vehicle and grazing track impacts on sub-tropical saltmarsh – investigating their effects on fisheries values using an innovative remote sensing saltmarsh track detection tool***

Vehicle and grazing tracks impacts pose a significant threat to endangered subtropical saltmarsh fish habitat. Vehicle and cattle damage (Figure 37) causes direct damage to marine

plants, alters tidal wetland hydrology and sediment structure, reduce saltmarsh fauna and ecosystem service delivery, including reduced sediment and nutrient retention capacity and carbon storage. These impacts are expected to result in the loss of fish habitat function and value. From previous studies in Moreton Bay by the research team, it has been shown that whilst fish still utilize damaged saltmarsh, fish diversity is reduced. Similarly, marine snail and crab populations are reduced, corresponding to reduced vegetation cover, and altered sediment structure. There is also a likely reduction in saltmarsh insect populations. In the Burnett-Mary region, all major estuaries have some level of vehicle damage to saltmarsh and 42% of estuaries along the Great Barrier Reef coastline are impacted (Mackenzie & Duke, State of the Mangroves report for BMR, 2011).



**Figure 37:** Study sites proposed for the Burnett region rehabilitation trials.

In the Burnett-Mary region there have been few attempts to reduce these impacts due to complex socio-economic constraints involved in vehicle and grazing restrictions. Generally, most attempts to restrict access involves fencing or bollards and installation of signage. Once installed, there is little to no follow-up monitoring undertaken to determine successful recovery of fisheries values. In Moreton Bay, and elsewhere, it has been demonstrated that rapid improvements in saltmarsh vegetation cover can occur, but not always, and there is limited information on whether this alone can improve fish habitat values. It is not clearly understood what factors limit natural recovery and what factors may indicate the need for active rehabilitation. With the declaration of subtropical saltmarsh as a federally-listed ecological community under the EPBC Act in 2013, which recognizes its vulnerability to sea level rise and other impacts, there is an increasing need to reduce vehicle impacts on this important fish habitat.

This project has three primary objectives that align with FHRMP (2016) objectives:

1. To effectively communicate the direct effects of direct damage to saltmarsh habitat on fisheries resource values through comparative assessment of fish utilization and fisheries relevant saltmarsh faunal communities in damaged and undamaged saltmarsh areas. (FHRMP Stream 2 – 2. Impacts on fish habitats & Stream 1 – Fish habitat utilisation)
2. To examine factors that limit natural saltmarsh recovery and experimentally evaluate rehabilitation techniques to promote rapid habitat recovery and improve fisheries resource values (FHRMP Stream 4 Rehabilitation of fish habitats)
3. To develop a saltmarsh track detection tool (STDT) using innovative remote sensing techniques to quantify the extent, impact and recovery of vehicle impacts in saltmarsh areas (FHRMP Stream 5 – Habitat data for response management)

This project will enhance findings from past and current research into track impacts into saltmarsh, including Green (2015), Mackenzie (2013, 2014 & 2016), Trave (2015), Kellaway (2005) and Laegdsgaard (2005). These studies provide important contributions of applicable data collection methods and current understanding of saltmarsh track impacts and rehabilitation options. The proposed study presents an opportunity to compile and synthesize these findings and to test current knowledge in a variety of different estuarine and impacted settings to further inform appropriate management responses. And, this study will focus specifically on fisheries resource values. The overall outcome of the study will be an increased understanding of the impacts of track damage on saltmarsh biodiversity and function, with the development of appropriate indicators to assess saltmarsh condition.

The study will assess saltmarsh habitat in 5 estuarine systems in the Burnett region (Figure 37), namely; Theodolite Ck, Coonarr Ck, Elliott River, Walkers Ck (Burnett Heads) and Kolan River (Miara). Vehicle and grazing impacts are an ongoing issue in the Bundaberg Regional Council Region. And, every major estuary system has some level of track impact to saltmarsh habitat (Mackenzie & Duke 2011).

We have framed our investigations in three objectives regards key questions, as follows:

**Question 1: What are the indicators of saltmarsh condition relevant to vehicle/grazing impacts and fisheries resource values and how can they be assessed?** Objective: To

develop a set of tools to quantify the extent, impact and recovery of vehicle and grazing impacts in saltmarsh areas (FHRMP Stream 5 – Habitat data for response management).

**Question 2: Does track damage reduce saltmarsh fisheries resource value at site specific, estuary and regional scales?** Objective: To quantify effects of vehicle and grazing damage on fisheries resource values, diversity and abundance of fish, gastropods, crustaceans, insects and vegetation and algae cover.

**Question 3: Does active rehabilitation enhance saltmarsh vegetation and faunal recovery following exclusion of access to vehicles and grazing?** Objective: To examine factors that limit natural saltmarsh vegetation recovery and experimentally evaluate rehabilitation techniques to promote rapid saltmarsh recovery and improve fisheries resource values (FHRMP Stream 4 Rehabilitation of fish habitats).

All data collection will be undertaken in partnership with traditional owners and Gidarjil Development Corporation Indigenous Rangers and school-based trainees.

### **Specific Outcomes Proposed**

1. A detailed understanding of track impacts on saltmarsh fisheries resources to assist in improving public awareness.
2. Indicators of saltmarsh habitat condition specific to fisheries resource values.
3. Suitable rehabilitation techniques to enhance saltmarsh recovery from track impacts.
4. A saltmarsh track detection tool (STDT) to assist with prioritizing investment in saltmarsh habitat repair, identify new impacts to inform compliance, and enable assessment of saltmarsh management success.
5. A saltmarsh condition assessment manual.
6. Improved capacity for local management and environmental stewardship of saltmarsh habitat in the Burnett-Mary Region.

## 4.0 REFERENCES

- Accad, A., Li, J., Dowling, R., Guymer, G., Queensland, H., 2016. Mangrove and associated communities of Moreton Bay, Queensland, Australia: change in extent 1955-1997-2012.
- Adame, M.a.F., Virdis, B., Lovelock, C.E., 2010. Effect of geomorphological setting and rainfall on nutrient exchange in mangroves during tidal inundation. *MF Marine and Freshwater Research* 61, 1197-1206.
- Adame, M.F., Lovelock, C.E., 2011. Carbon and nutrient exchange of mangrove forests with the coastal ocean. *Hydrobiologia* 663, 23-50.
- Bruinsma, C., Danaher, K., 2000. Queensland Coastal Wetland Resources: Riund Hill Head to Tin Can Inlet. Department of Primary Industries, Brisbane.
- Burnett Mary Regional Group, Moss, A., Scheltinga, D., Tilden, J., 2008. State of the Estuarine Environment Report for the Burnett Mary NRM Region 2008. Burnett Mary Regional Group, Bundaberg, Qld. p. 239.
- DSITIA, 2013. Review of Water Resource (Burnett Basin) Plan 2000 and Resource Operations Plan: Environmental Assessment Report. Department of Science, Information Technology, Innovation and the Arts, Brisbane.
- Duke, N.C. 2016. Oil spill impacts on mangroves: recommendations for operational procedures and planning based on a global review. *Marine Pollution Bulletin* 109(2): 700-715.
- Duke, N.C. 2016. Mangrove Click! Australia: expert ID for Australia's mangrove plants. Currumbin, MangroveWatch Publication. ISBN: 978-0-9923659-2-9. <https://itunes.apple.com/us/app/mangrove-au/id1157235522?mt=8>
- Duke et al 2016. Ecotone shift in mangrove tidal wetlands. in prep
- Eslami-Andargoli, L., Dale, P., Sipe, N., Chaseling, J., 2009. Mangrove expansion and rainfall patterns in Moreton Bay, Southeast Queensland, Australia. *YECSS Estuarine, Coastal and Shelf Science* 85, 292-298.
- Eslami-Andargoli, L., Dale, P., Sipe, N., Chaseling, J., 2010. Local and landscape effects on spatial patterns of mangrove forest during wetter and drier periods: Moreton Bay, Southeast Queensland, Australia. *Estuarine Coastal and Shelf Science* 89, 53-61.
- Ewel, K., TWILLEY, R., Ong, J., 1998. Different kinds of mangrove forests provide different goods and services. *Global Ecology & Biogeography Letters* 7, 83-94.
- Furukawa, K., Wolanski, E., Mueller, H., 1997. Currents and sediment transport in mangrove forests. *Estuarine, Coastal and Shelf Science* 44, 301-310.
- Harty, C., 2009. Mangrove planning and management in New Zealand and South East Australia—A reflection on approaches. *Ocean & Coastal Management* 52, 278-286.
- Lovelock, C.E., Bennion, V., Grinham, A., Cahoon, D.R., 2011. The Role of Surface and Subsurface Processes in Keeping Pace with Sea Level Rise in Intertidal Wetlands of Moreton Bay, Queensland, Australia. *Ecosystems* 14, 745-757.
- Lovelock, C.E., Ellison, J., 2007. Vulnerability of mangroves and tidal wetlands of the Great Barrier Reef to climate change.
- Mackenzie, J.R., Duke, N.C., 2011. State of the Mangroves 2008: Condition Assessment of the Tidal Wetlands of the Burnett Mary Region. School of Biological Sciences, University of Queensland., Brisbane.
- Mackenzie, J.R., N.C. Duke. 2011. State of the Mangroves Report 2008: Condition assessment of the tidal wetlands of the Burnett Mary Region. Final Report to the Burnett Mary Regional Group. University of Queensland, Centre for Marine Studies, Brisbane. 430 pages plus appendices.
- Mackenzie, J.R., N.C. Duke and A.L. Wood. 2016. The Shoreline Video Assessment Method (S-VAM): using dynamic hyperlapse image acquisition to evaluate shoreline mangrove forest structure, values, degradation and threats. *Marine Pollution Bulletin* 109(2): 751-763.

- McLoughlin, L.C., 2000. Estuarine wetlands distribution along the Parramatta River, Sydney, 1788–1940: implications for planning and conservation. *Cunninghamia* 6, 579-610.
- Rogers, K., Saintilan, N., 2008. Relationships between surface elevation and groundwater in mangrove forests of southeast Australia. *Journal of Coastal Research* 24, 63-69.
- Rogers, K., Saintilan, N., Heijnis, H., 2005. Mangrove encroachment of salt marsh in Western Port Bay, Victoria: the role of sedimentation, subsidence, and sea level rise. *Estuaries* 28, 551-559.
- Rogers, K., Wilton, K., Saintilan, N., 2006. Vegetation change and surface elevation dynamics in estuarine wetlands of southeast Australia. *Estuarine, Coastal and Shelf Science* 66, 559-569.
- Rogers, K., P. Boon, S. Branigan, N.C. Duke, C.D. Field, J. Fitzsimons, H. Kirkman, J. Mackenzie and N. Saintilan. 2016. The state of legislation and policy protecting Australia's mangrove and salt marsh and their ecosystem services. *Marine Policy* 72: 139–155.
- Saintilan, N., 2010. The influence of nutrient enrichment upon mangrove seedling establishment and growth in the Hawkesbury River Estuary, New South Wales, Australia. *Wetlands Australia Journal* 21.
- Saintilan, N., Williams, R.J., 1999. Mangrove transgression into saltmarsh environments in south-east Australia. *Global Ecology and Biogeography* 8, 117-124.
- Saintilan, N., Wilton, K., 2001. Changes in the distribution of mangroves and saltmarshes in Jervis Bay, Australia. *Wetlands Ecology and Management* 9, 409-420.
- Valiela, I., Cole, M.L., 2002. Comparative evidence that salt marshes and mangroves may protect seagrass meadows from land-derived nitrogen loads. *Ecosystems* 5, 92-102.
- Whelan, K.R., Smith, T.J., Cahoon, D.R., Lynch, J.C., Anderson, G.H., 2005. Groundwater control of mangrove surface elevation: Shrink and swell varies with soil depth. *Estuaries* 28, 833-843.

