

Southern Great Barrier Reef Coastal Habitat Archive and Monitoring Program: Mangrove Management Plan Volume 2

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Volume 2

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ACRONYMS

AMSN	Australian Mangrove and Saltmarsh Network
BMRG	Burnett Mary Regional Group
CBPM	Community-based Participatory Mapping
CFC	Caring for Country
CFI	Carbon Farming Initiative
CHAMP	Coastal Habitat Archive and Monitoring Program
CLCAC	Carpentaria Land Council Aboriginal Corporation
CS	Condition Scores
DAF	Department of Agriculture and Fisheries
DES	Department of Environment and Science
DoEE	Department of the Environment and Energy
ERMP	Environmental Research and Monitoring Program
FBA	Fitzroy Basin Association
GBR	Great Barrier Reef
GBRWA	Great Barrier Reef World Heritage Area
GBRMP	Great Barrier Reef Marine Park
GDC	Gidarjil Development Corporation
GHHP	Gladstone Healthy Harbour Partnership
GPC	Gladstone Ports Corporation
GSBR	Great Sandy Biosphere Reserve
ISP	Independent Science Panel
IT	Information Technology
JCU	James Cook University
LMAC	Local Marine Advisory Committee
MMP	Mangrove Management Plan
MSS	Multi-Spectral Scanner
NDVI	Normalized Difference Vegetation Index
NESP	National Environmental Science Program
NRM	Natural Resource Management
NU	Nipissing University
PCCC	Port Curtis Coral Coast
PCPA	Port Curtis and Port Alma
PSR	Pressure-State-Response
QAL	Queensland Alumina Limited
QCIF	Queensland Cyber Infrastructure Foundation
QWMPC	Queensland Wetland Mapping and Classification Project
RRRC	Reef and Rainforest Research Centre Limited
SEQ	South East Queensland
SGAP	Society for Growing Australian Plants
SQW	Skilling Queenslanders for Work
S-VAM	Shoreline Video Assessment Method
SVU	Structural Vegetation Unit
TNC	The Nature Conservancy
TropWATER	The Centre for Tropical Water and Aquatic Ecosystem Research
TUMRA	Traditional Use of Marine Resources Agreement

TWQ..... Tropical Water Quality
UNESCO..... United Nations Educational Scientific and Cultural Organisation
WCI..... Wetland Cover Index
WPSQ..... Wildlife Preservation Society Queensland
WQRS..... Water Quality Regulation Score

ABBREVIATIONS

ha..... hectares
km..... kilometres
km² kilometres square
m..... metres
mm..... millimetres
m/y..... metres per year

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

We further acknowledge the contributions by a number of community volunteers who assisted ranger surveys during the project.

The partnerships formed have lasting contributions towards the longer term benefits in improving the management of natural tidal wetlands and estuaries of the southern Great Barrier Reef region.

EXECUTIVE SUMMARY

- 1) Traditional Owner rangers and local citizens of the Port Curtis Coral Coast (PCCC) Traditional Use of Marine Resources Agreement (TUMRA) area were engaged in developing a Mangrove Management Plan (MMP) to provide a strategic basis for ongoing estuarine monitoring and repair activity for the maximization of water quality outcomes in southern Great Barrier Reef (GBR) waters. Development of this MMP has built essential capacity amongst the Gidarjil Development Corporation (GDC) rangers and the local community to conduct scientifically-rigorous, ecological monitoring and assessment of key local estuarine resources. The management and rehabilitation strategies are needed for the protection of sea country assets using the partnerships forged between community, scientists and local Natural Resource Management (NRM) agencies. The MMP has enabled rangers and citizen scientists to undertake scientifically valid surveys for estuarine habitat monitoring, management and rehabilitation within the PCCC TUMRA area.
- 2) The project was led by Dr Norm Duke with Jock Mackenzie from James Cook University (JCU) Centre for Tropical Water and Aquatic Ecosystem Research (TropWATER), plus project partners: Prof John Kovacs of Nipissing University (NU) in Canada, Ric Fennessy with Rangers of the GDC, Kirsten Wortel and Sue Sargent with Burnett Mary Regional Group (BMRG), and, Rebecca French, Holly Lambert and Shannon van Nunen with Fitzroy Basin Association (FBA).
- 3) The primary undertaking of this program was to build the capacity of Gidarjil Rangers for monitoring, managing and rehabilitating estuarine wetland sea country within the PCCC TUMRA, southern GBR. The PCCC is the 5th largest TUMRA of its kind. Estuarine wetlands are an integral component of this sea country, comprising sites of immense cultural heritage significance, including middens, fish traps, and traditional fishery resources. Estuarine wetlands also provide essential ecosystem services that protect the GBR, including water quality improvement. But, shoreline habitats within estuaries of the southern GBR have been badly damaged by repeated, recent extreme flood events. Existing anthropogenic stressors reduce the recovery potential of these impacted estuarine wetlands, reducing ecosystem resilience to future damaging events. Estuarine wetland repair is a priority for improving GBR water quality. However, there are no existing national strategies for prioritizing sites of estuarine wetland rehabilitation, to minimize anthropogenic stressors that maximize water quality improvement and other ecosystem services. A whole-of-system assessment is necessary, incorporating socio-cultural, ecological, and economic considerations, to inform cost-effective, successful investment in shoreline habitat rehabilitation.
- 4) Local stakeholders and end users were specifically sought out and engaged in a series of two dedicated workshops in early 2016 and 2017. The workshops were hosted by the BMRG and the FBA respectively. Both workshops were highly successful with broad and representative gatherings of end users attending. All participants actively contributed to the listing of issues raised and the general exchange of ideas. Attendees included members of all local governments (Rockhampton, Gladstone, Livingstone, Bundaberg), a number of State agency officers (Department of Agriculture and Fisheries (DAF), Herbarium, Department of Environment and Science (DES)), industry representatives like Gladstone

Ports Corporation (GPC) and Bundaberg Sugar, members of the general public, as well as the local NRM groups (FBA and BMRG) and the Gidarjil rangers (Fig. 1).

- 5) Training sessions for rangers were undertaken in conjunction with each of the two stakeholder workshop meetings. Additional training sessions were included as needed, in an on-going effort to accommodate the scheduled field program, changes in ranger staff, and the development of new projects. Training followed the standard estuarine field survey methods used by the MangroveWatch community partnership organisation (www.mangrovetwatch.org.au), using mostly the Shoreline Video Assessment Method (S-VAM). Training involved discussions, equipment demonstrations, practice sessions and field surveys in small boats. Dedicated field equipment of cameras, gps and other items were purchased beforehand, specifically for the training program and the field surveys.
- 6) In collaboration with project partner, Prof Kovacs, evaluation and mapping of mangroves and saltmarsh tidal wetlands was done for all eight estuarine systems with on-going development of methods to be used in the overall data management plan. These plans included the evaluation of values and threats to saltmarsh habitats in the southern GBR region.
- 7) Field surveys of specific estuarine river systems were undertaken by Gidarjil rangers initially with JCU researchers until the rangers achieved confidence in conducting this task independently. The estuarine systems surveyed for this project included: Calliope River, South Trees Inlet, Boyne River, Baffle Creek, Kolan River, Burnett River, Elliott River and Burrum River. One amendment to the selection of rivers had been made to ensure all estuarine systems were within the appropriate PCCC sector of the TUMRA. Assessments were done for each of the eight estuarine systems making observations and capturing imagery of the condition, management issues and the notable drivers of change.
- 8) Regional impacts related to climate change and sea level rise were apparent in all eight estuarine systems surveyed. Specific indicators included: unusually high proportions of shoreline and bank erosion, saltmarsh-saltpan scouring, upland migration, and terrestrial retreat. These factors were exacerbated further by recent severe weather events with intense periods of either drought, cyclonic winds, torrential rains or severe flooding. These influences were notably combined with local environmental issues associated with a range of direct human activities. The resulting overall condition differed for each estuary.
- 9) Calliope River estuary, a modified system of ~794 ha of tidal wetlands, was successfully surveyed by 12 Gidarjil rangers and three community members on three occasions in 2015, 2017 and 2018, filming 51 km of shorelines. Overall condition was scored at 74 with ~53% directly human related impacts. The main local management issues identified were driven by development expansion, shoreline habitat modification, and the loss of tidal wetland areas.
- 10) South Trees Inlet estuary, a modified system of ~1,802 ha of tidal wetlands, was successfully surveyed by eight Gidarjil rangers and three community members on two occasions in 2014 and 2018, filming 32 km of shorelines. Overall condition was scored at 73 with ~50% directly human related impacts. The main local management issues

identified were driven by development expansion, altered hydrology, and the loss of tidal wetland areas.

- 11) Boyne River estuary, a modified system of ~105 ha of tidal wetlands, was successfully surveyed by 10 Gidarjil rangers and five community members on four occasions in 2014, 2015, 2016 and 2018 filming 21.5 km of shorelines. Overall condition was scored at 73.5 with ~48% directly human related impacts. The main local management issues identified were driven by development expansion, agricultural intensification, and the flood damage of tidal wetland areas.
- 12) Baffle Creek estuary, a near pristine system of ~1,209 ha of tidal wetlands, was successfully surveyed by 12 Gidarjil rangers and two community members on two occasions in 2017 and 2018 filming 89.7 km of shorelines. Overall condition was scored at 79 with ~59% directly human related impacts. The main local management issues identified were driven by cattle grazing, vehicle damage of tidal wetland areas, and extreme weather events.
- 13) Kolan River estuary, a modified system of ~969 ha of tidal wetlands, was successfully surveyed by 16 Gidarjil rangers and three community members on three occasions in 2013, 2016 and 2018 filming 51.6 km of shorelines. Overall condition was scored at 84 with ~69% directly human related impacts. The main local management issues identified were driven by altered hydrology, agricultural intensification, bank erosion damage of tidal wetland areas, and extreme weather events.
- 14) Burnett River estuary, an extensively modified system of ~540 ha of tidal wetlands, was successfully surveyed by 13 Gidarjil rangers and two community members on three occasions in 2013, 2016 and 2018 filming 52 km of shorelines. Overall condition was scored at 89 with ~69% directly human related impacts. The main local management issues identified were driven by development expansion, agricultural intensification, altered hydrology, extreme weather events, and the loss of tidal wetland areas.
- 15) Elliott River estuary, a largely unmodified system of ~589 ha of tidal wetlands, was successfully surveyed by eight Gidarjil rangers and two community members on three occasions in 2013, 2016 and 2017 filming 19.4 km of shorelines. Overall condition was scored as 79 with ~48% directly human related impacts. The main local management issues identified were driven by development expansion, ground water extraction, and the vehicle damage of tidal wetland areas.
- 16) Burrum River estuary, a largely unmodified system of ~644 ha of tidal wetlands, was successfully surveyed by 12 Gidarjil rangers and three community members on three occasions in 2013, 2016 and 2018 filming 58.4 km of shorelines. Overall condition was scored as 65 with ~60% directly human related impacts. The main local management issues identified were driven by development expansion, agricultural intensification, altered hydrology, and the loss of tidal wetland areas.
- 17) Key project recommendations include: continue supporting Gidarjil rangers (Fig. 1) in the monitoring of estuarine shorelines in their region; support on-going shoreline video

assessment analyses along with the development of a regional report card on southern Great Barrier Reef estuarine waters.



Figure 1: Gidarjil Rangers on MangroveWatch surveys in Kolan River estuary during May 2016.

1.0 ASSESSMENT AND MAPPING OF EIGHT SOUTHERN GREAT BARRIER REEF ESTUARIES

The project integrates scientific, industrial, management and Indigenous cultural knowledge (Fig. 2) to better inform environmental managers of tidal wetlands for improved rehabilitation actions in the southern GBR region. Our partnership approach has enhanced the local capacity for the conduct of ongoing shoreline monitoring and assessment surveys as well as the implementation of sustainable rehabilitation works.



Figure 2: Gidarjil Rangers on MangroveWatch S-VAM surveys in Baffle Creek during May 2017.

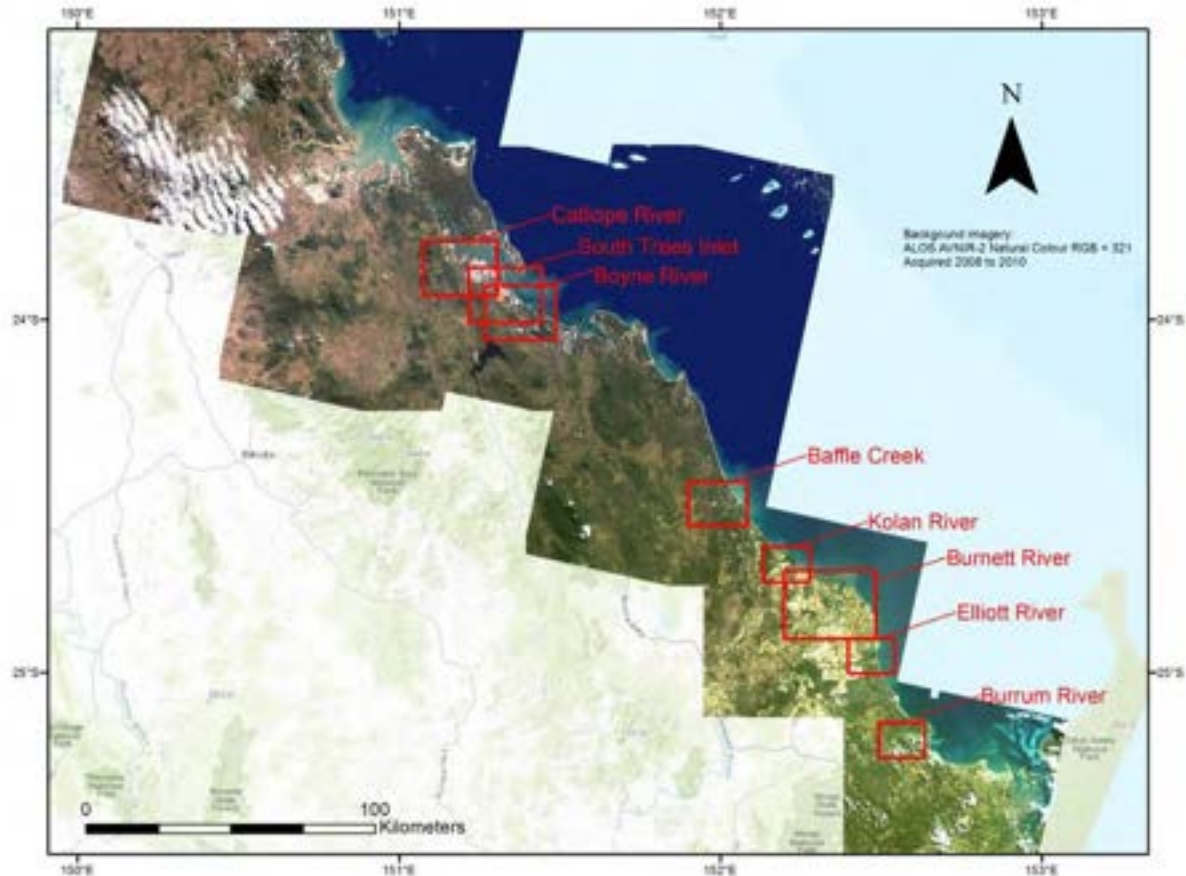


Figure 3: Map of the southern GBR shoreline showing the location of the 8 estuarine case study systems used in this project.

This report provides a compilation of 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.

Survey works include monitoring the condition, survival and recovery of shorelines, specifically regards tidal wetlands of the eight selected estuarine systems (Fig. 3), including: Calliope River; South Trees Inlet; Boyne River; Baffle Creek; Kolan River; Burnett River; Elliott River and Burrum River.

TropWATER Centre at JCU was the lead agent for the project, collaborating with the following organisations:

- a. Gidarjil Development Corporation indigenous Rangers along with community volunteers in the southern GBR region, assisted with field surveys of monitoring and assessment of coastal tidal wetland habitats (Component 2);
- b. Prof John Kovacs and students at 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); and
- c. Two NRM regional groups, the Burnett Mary Regional Group, and the Fitzroy Basin Association, for advice, support and implementation of proposed tasks for the Mangrove Management Plan (all components).

Mapping. Mapping of tidal wetland vegetation types along with historical change detection to identify areas of net loss and gain in key habitat components including mangroves, saltmarsh and saltpans. The team acquired suitably fine-scaled, multispectral Image data for mapping each estuary. A series of maps were produced for each estuary in order to evaluate the role of each in influencing the water quality of the southern Great Barrier Reef (GBR) study area (Fig. 3).



Figure 4: Gidarjil Rangers independently surveying shorelines and gathering imagery of the habitat condition of estuaries in the Southern GBR region; Baffle Creek during May 2017.

Shoreline monitoring surveys. Shoreline condition monitoring using boat-based video image data acquisition by Gidarjil Rangers (Figs. 4 and 5). The surveys of the eight estuarine systems used geo-referenced videography according the Shoreline Video Assessment Method (Mackenzie et al., 2016). All imagery data were collected by local Indigenous rangers – trained and supervised by the TropWATER science specialists. Processing of data collected was undertaken at the Mangrove Hub at JCU. Data taken were used to describe coastline condition, to make ecological assessments of shoreline composition, the status and health of each estuarine system. These data assessments and information form the first southern GBR Mangrove Management Plan.



Figure 5: Field training and surveys followed the Stakeholder Workshop, with practical sessions using the JCU boat 'Guyala' in the Burnett River estuary.

2.0 CALLIOPE RIVER ESTUARY

Fitzroy Basin region

Mouth location:	-23.824308; 151.218041
Condition:	Modified, river & tide dominated
Area of tidal wetlands (QWMP 2018)	
Mangroves:	567 ha
Tidal saltmarsh and salt pans:	226 ha
Total tidal wetland:	794 ha
Wetland Cover Index:	71.4%
Mean Annual Rainfall:	801 mm
Catchment Area:	1,834 km ²



Figure 6: The mouth of the Calliope River viewed looking upstream in 2008.



Figure 7: Achievements regards successful field surveys undertaken in the Calliope River estuary in collaboration with Gidarjil Rangers up to late 2018. Tracks (yellow lines) are shown on satellite images for 2015, 2017 and 2018.

Summary Description

The Calliope River flows into Port Curtis just north of the port and industrial city of Gladstone (Fig. 6). It drains a relatively large catchment area of around 1,854 km². The river has the distinction of having few major impediments to fish migrations upstream (NPRSR 2014). Downstream, the river supports extensive areas of estuarine tidal wetlands dominated by largely shrubby mangrove forests backed by vast saltpans with patchy saltmarsh plants and wide salt couch grasslands. Nearshore there are extensive seagrass beds with active populations of sea turtles and dugongs. These valuable wetland areas are recognised in the Directory of Important Wetlands of Australia (DIWA). The wetlands are significant to the maintenance of regional genetic diversity for a range of marine and estuarine species. The mid and upper reaches of the Calliope estuary were listed as Fish Habitat Area (B) in 2014 in recognition of the important fish habitat values of this estuary for maintaining fisheries in the Port Curtis and southern GBR region. The estuary was surveyed in 2015, 2016 and 2018 by Gidarjil Rangers (see Fig. 7).

Estuary Features

Physical setting. The largely unregulated flows of the river cover approximately 100 km from the Calliope Ranges to Port Curtis. Four major tributaries drain into the reefal lagoon waters of the Great Barrier Reef World Heritage Area (GBRWHA). Immediately to the south the busy port and industrial city of Gladstone has a population around 61,000 people. Gladstone's population has opportunities for employment increasing in line with industrial development expansion.



Figure 8: Preliminary estuarine zones of the Calliope River.

Estuarine zones (Fig. 8). The lower reaches are dominated by Queensland's largest multicommodity port and one of the top five coal export ports in the world, handling in excess of 500 million tonnes of coal per annum. The major industrial city of Gladstone lies on the southern bank of the lower reaches and on the northern bank adjoining the anabranch is the

Gladstone State Development Area. The nearby region supports several major industries, including Queensland's largest coal fired power station, a major chemical plant producing bulk sodium cyanide and ammonium nitrate (Orica) and a shale oil plant (QER). Major industrial developments are under construction on the land and water near the lower reaches of the Calliope River with one project planning the construction of infrastructure within the river mouth itself. The remainder of the Calliope catchment upstream is dominated by grazing land.

Changes to natural habitats. Changes to natural habitats are driven by a combination of human and natural drivers of change. A large proportion of Gladstone's industrial land is reclaimed from the natural tidal wetland and marine environment, in particular, salt flats, mangroves and shallow marine environments (Duke et al., 2003). Since 1941 more than 16.5% of mangrove and 26% of coastal salt flat has been cleared for development within the Gladstone region, equating to more than 1,600 hectares of tidal wetlands. Industrial development and expansion from 2006 to 2013 has destroyed in excess of 680ha of fish habitat during construction activities and for reclamation. This level of fish habitat destruction could be a significant contributor to declining catch rates in Gladstone's inshore recreational fishery as recorded over the last two decades (Platten 2004). The river's mouth and the adjacent Auckland Creek wetlands have been directly impacted upon by reclamation for industrial development, however the remainder of the Calliope River remains in a relatively undisturbed state (McKinnon et al. 2004). Tidal wetlands are dominated by two distinct vegetation types including mangroves and saltmarsh-pans. Rainfall influences will have altered the relative area of these habitats (Duke et al. 2019) along with the changes caused by direct human impacts.

Tidal wetland vegetation

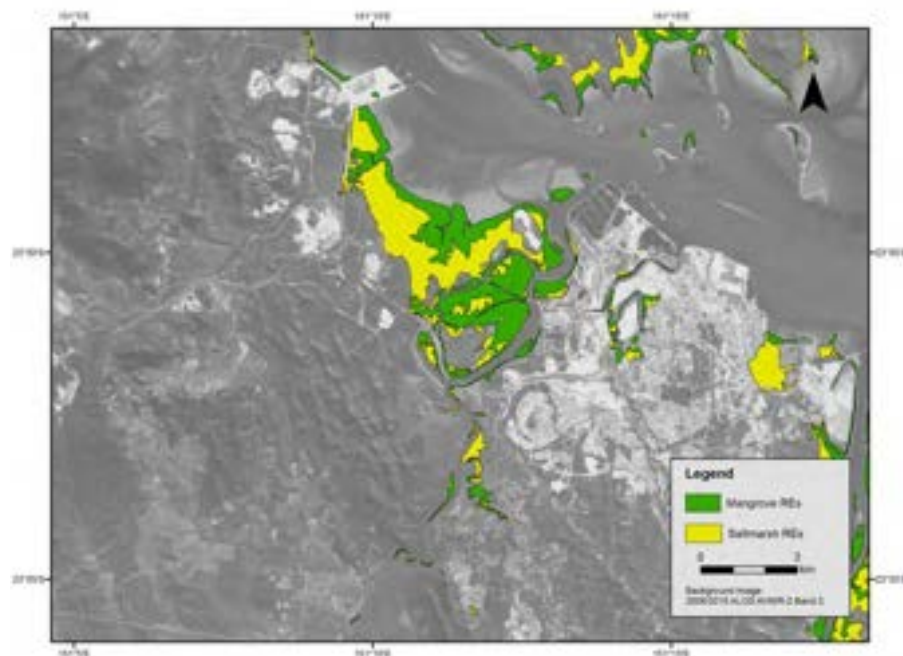


Figure 9: Tidal wetlands of the Calliope River showing mangrove and saltmarsh-pan areas.

Table 1: Tidal wetland plants recorded for the estuary of Calliope River estuary.

Mangrove Species	Saltmarsh Species
<i>Acanthus ilicifolius</i>	<i>Atriplex semibaccata</i>
<i>Acrostichum speciosum</i>	<i>Baumea juncea</i>
<i>Aegialitis annulata</i>	<i>Dysphania littoralis</i>
<i>Aegiceras corniculatum</i>	<i>Enchylaena tomentosa</i>
<i>Avicennia marina</i>	<i>Fimbristylis ferruginea</i>
<i>Bruguiera exaristata</i>	<i>Fimbristylis polytrichoides</i>
<i>Bruguiera gymnorhiza</i>	<i>Limonium australe</i>
<i>Ceriops australis</i>	<i>Limonium solanderi</i>
<i>Excoecaria agallocha</i>	<i>Salsola australis</i>
<i>Lumnitzera racemosa</i>	<i>Sarcocornia quinqueflora</i>
<i>Osbornia octodonta</i>	<i>Sesuvium portulacastrum</i>
<i>Pemphis acidula</i>	<i>Sporobolus virginicus</i>
<i>Rhizophora stylosa</i>	<i>Suaeda australis</i>
<i>Scyphiphora hydrophylacea</i>	<i>Suaeda arbusculoides</i>
<i>Xylocarpus granatum</i>	<i>Tecticornia halocnemoides</i>
<i>Xylocarpus mollucensis</i>	<i>Tecticornia indica</i>
	<i>Tecticornia pergranulata</i>

Mangrove habitat (Fig. 9). Calliope estuary has up to 16 mangrove species present (Table 1), including a relatively large number at, or close to, their southern-most distributional limits. The port area of Port Curtis in particular, marks the most southern occurrence of Holly Mangrove (*Acanthus ilicifolius* to Endfield Creek - 23.76 deg S) and Rib fruited orange mangrove (*Bruguiera exaristata* to the vicinity - 23.82 deg S). Three others drop out just a little further south of South Trees Inlet (Duke 2006). These observations update prior records for the Calliope River estuary of twelve species listed in earlier reports (Saenger 1996; McKinnon et al. 1995). Mangrove species are able to tolerate a wide range of environmental factors such as salinity, levels of inundation, soil types and wave action (Danaher 1995; Duke et al., 1998; Duke et al., 2003). These conditions influence the density and diversity of mangrove communities in tidal wetlands around the river mouth. Mangrove forests close to the mouth of the river are dominated by *Rhizophora stylosa*, *Ceriops australis* and *Avicennia marina*. *Rhizophora stylosa* is the most common due to its high tolerance of regular inundation and protective shoreline mantel of tangled exposed roots. Along river banks upstream, the shoreline edges are densely fringed by *Aegiceras corniculatum* backed by other species. The least represented are *Acanthus ilicifolius*, *Bruguiera exaristata*, *Lumnitzera racemosa*, *Pemphis acidula*, *Scyphiphora hydrophylacea* and *Xylocarpus granatum*.

Saltmarsh-saltpan habitat (Fig. 9). The Calliope estuary has at least 13 saltmarsh species (Table 1). Saltmarsh-pan areas often occur mostly behind mangrove shoreline fringes and within upper zones of tidal wetlands. There are a mix of intertidal wetlands dominated by saltpans. *Sporobolus virginicus* (salt couch) is represented throughout the estuarine section of

the river, with its distribution and abundance dependent upon the riverbank profile and the size of salt flats towards upper intertidal margins. At a number of locations, *Sporobolus* is the dominant vegetation, with succulent species, including *Sesuvium portulacastrum* and *Sarcocornia quinqueflora* occurring in small numbers within the salt couch or on bare substrate. Areas bare of macrophytes are however covered in a dense layer of microphytobenthos (microscopic algae). This layer is highly productive during and after each wet season. So, despite their lesser duration of inundation, tidal saltmarshes and saltpan habitats have significant habitat values for many species of estuarine fish, including those of economic importance such as bream, whiting and mullet (Thomas & Connolly 2001). A direct link has been reported between intertidal saltmarsh inundation and crab larvae recruitment to coastal waters, which also contributed significantly to the diet of even offshore fish species also utilising saltmarsh-pan vegetation. As with mangrove vegetation, any loss of area is likely to impact on fish species, as with the large areas of saltmarsh-pan (greater than 180ha) reclaimed for port infrastructure development.

Biomass of tidal wetlands of the Calliope River estuary

Tree heights were recorded in satellite imagery and verified in field surveys. The overall height of mangrove vegetation across the broad tidal wetland areas of the Calliope River were relatively low, around 3-5 m or less. This is consistent with areas of relatively low rainfall. Slightly taller stands were notably observed surrounding lower elevation shorelines just above mean sea level, as depicted in maps and imagery (Fig. 10).

The zone immediately above the tidal wetland zone (i.e., 1m > HAT) refers to the supra tidal zone. The vegetation in this zone is considered vulnerable to a number of human and natural factors, including: vehicle access, reclamation damage, severe storms, flooding, feral pigs, exotic weeds, and sea level rise. The supra tidal vegetation was noticeable in downstream areas, but it was virtually non-existent upstream.

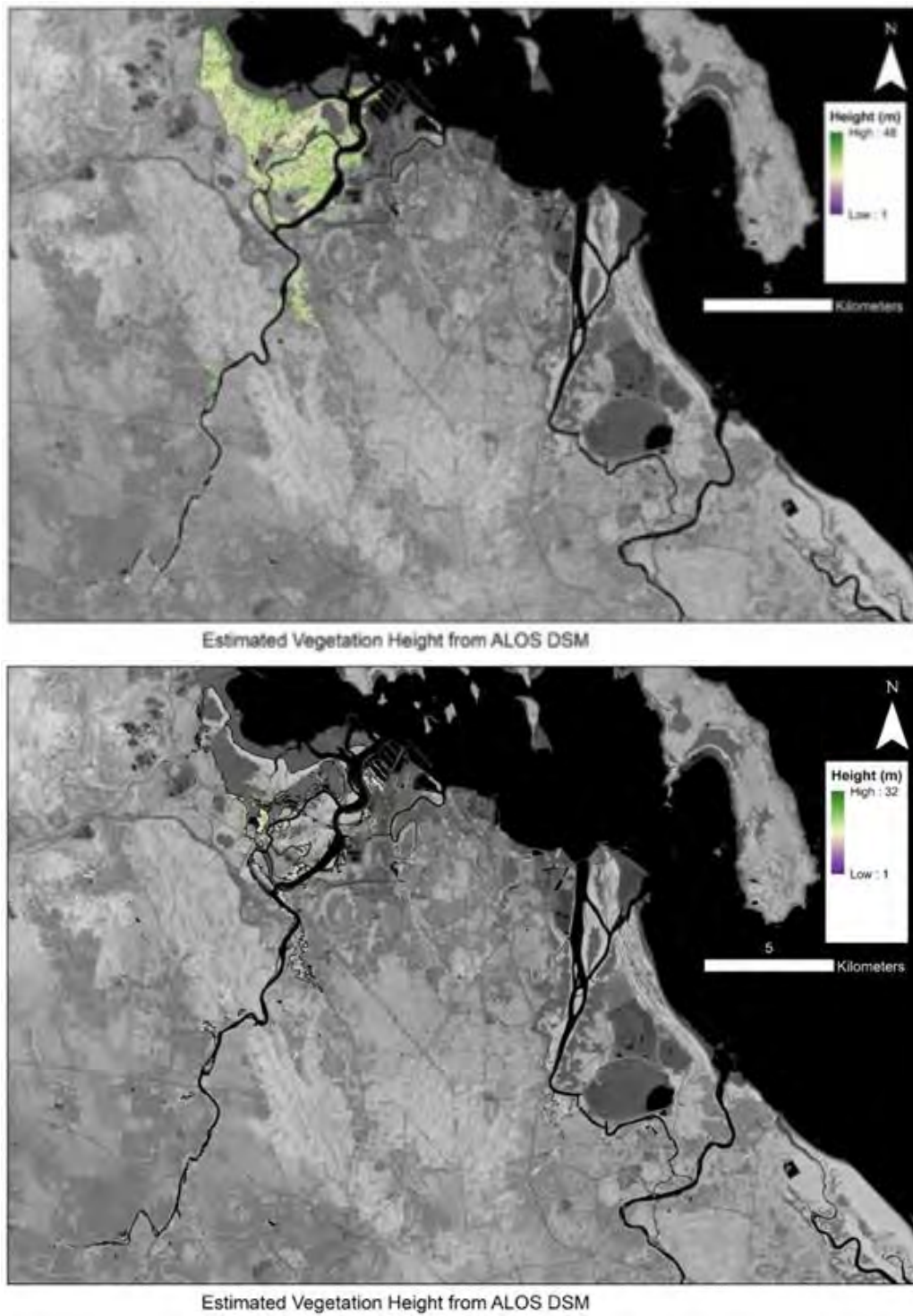


Figure 10: Satellite images of the Calliope River estuarine areas showing height of vegetation for A) tidal wetlands (MSL-HAT) and B) the supra tidal zone (HAT +1m) for 2010 using ALOS DSM.

Changes taking place in tidal wetlands of the Calliope River estuary

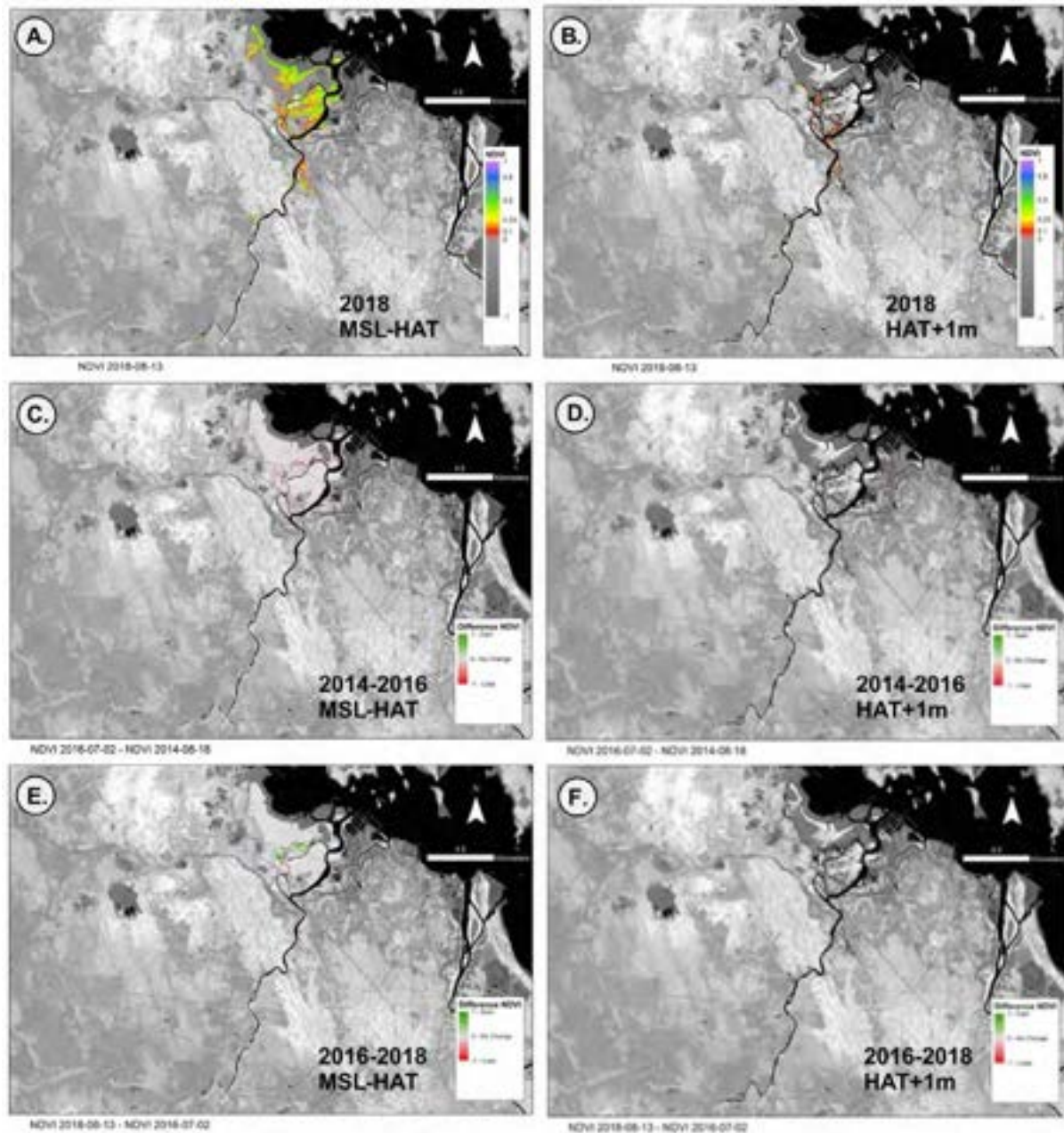


Figure 11: Satellite images of the Calliope River estuarine areas showing NDVI measures of vegetation condition for tidal wetlands (MSL-HAT) and supra tidal zone (HAT +1m) for 2018 (A & B), and two change detection periods 2014-2016 (C & D) and 2016-2018 (E & F).

A first evaluation of the condition of vegetation cover was made using vegetation indices (like NDVI) from satellite imagery (Fig. 11). The indices for specific dates represent measures of sub-lethal status at the time (A & B in 2018 – for tidal wetlands and supra tidal areas, respectively). Colours towards the red end of the scale showed vegetation in relatively poor condition while that at the green-blue end is indicated they were healthier. In the 2018 views, tidal wetlands and supra tidal vegetation were in poorer condition upstream than for stands towards the mouth.

When change detection was done comparing scenes from two different time periods (C-F), the scales from red to green indicated relative losses or gains. Comparison of two concurrent time periods show notably different responses where losses suffered in one time period might show gains with recovery in the subsequent time period. The time periods shown in the figure included 2014-2016 (C & D) and 2016-2018 (E & F). By comparing C & E, it was seen that tidal wetlands downstream were damaged and lost in the first period while in the second period these same areas showed detectable gains. These differences represented a severe disturbance event in the first period with flooding and cyclonic conditions causing damage to vegetation cover. And subsequently, these damaged areas showed notable recovery was taking place one-two years afterwards. The effects on supra tidal areas were poorly recognisable.

Management issues registered at community workshops

Key issues flagged at 2016 and 2017 community workshops included altered hydrology, likely oil spill pollution, damaged mangrove stands, and high value wetlands at Byellee (see Fig. 12).



Figure 12: Digitised outcomes of the workshop community-based participatory mapping of Calliope River tidal wetland management issues.

Environmental management issues in the Calliope estuary

- Mangrove Removal/ Trimming
- Altered Hydrology – Waterway Barriers
- Altered Hydrology – Restricted Flows
- Vehicle access damage
- Chemical Inputs – pollutants and excess nutrients

The Calliope River, although lacking a constructed flow barrier, does have a number of highly significant modifications and extensive development pressures. These chiefly relate to its occurrence adjacent to the active industrial city of Gladstone, the highly productive port

installations, and the massive associated industrial areas. For starters, the downstream areas and particularly the intertidal wetland areas have been heavily modified and largely removed in landfill associated with port expansion. These changes have their own inherent impacts underpinned by the prevailing loss of primary functionality and connectivity amongst estuarine and marine species. Also present now is the constant threat of large pollution effects from oil spills or other industrial-scale environmental contamination events. These are being carefully managed, but the risk remains requiring those doing the managing to be extra vigilant and ever watchful.

Despite these circumstances, the estuarine areas of the Calliope flow into extensive areas of mangrove-lined channels, seagrass meadows, intertidal mud banks, extensive saltmarsh-saltpan flats and salt couch grasslands. Land use along the majority of the Calliope River estuary upstream is generally considered low impact agriculture and grazing, with the industrial pressures towards the mouth considered the greater risk for potential negative impacts. But, these views need to be re-evaluated. There are considerable, highly detrimental factors acting also on these upstream areas, including: widespread land clearing, intensive agriculture, large-scale application of agricultural chemicals, the lack of riparian vegetation buffers to protect vulnerable river banks, plus the perverse pressures from feral pest animals, invasive weeds and uncontrolled fires. All these factors contribute to the on-going deterioration of upstream estuarine condition and functionality. Unfortunately, the river and estuary have become a large drain to be hardened and tolerated at best – being the previously established best-practice land management strategy used. The ecological environment and its functional requirements are only now being appropriately understood and appreciated. Already, it is clear there are huge economic benefits and advantages in applying the correct environmental management regime. This is especially true as this estuary, like all others, face greater detrimental damage from increasingly more extreme weather events (flooding, cyclones, etc.) combined with the ever-expanding footprint of human development.

Recommended management actions:

- maintain environmental freshwater flows to the estuary
- Restore natural hydrological conditions to tidal wetlands
- Reduce runoff of sediments and agricultural chemicals into the river
- Increase awareness regarding the importance of estuaries and tidal wetlands
- Maintain regular monitoring of the health and condition of riparian buffers and tidal wetland vegetation along entire estuary and upstream shorelines

Drivers of change up to 2018

Calliope River estuary – chief drivers, condition & threats – a summary			
Drivers of Change	Severity*	Scale*	Score**
Direct Human Drivers			
Direct Damage - Cutting/ Removal	5	3	15
Direct Damage - Vehicle Damage	2	2	4
Indirect Human Drivers			
Altered Hydrology - Restricted Flow	3	3	9
Altered Hydrology - Waterway Barriers	4.5	2	9
Pollutants – Herbicides, Nutrients	2	1	2
Natural Drivers			
Fringe Collapse	2.5	2	5
Bank Erosion	3	3	9
Saltpan Scouring	2	1	2
Ecotone Shift (Drought)	2	2	4
Ecotone Shift (+ve)	1	1	1
Depositional Gain	1	2	2
Light Gaps	2	1	2
Bat Roosting	4	1	4
Flood Damage	3	2	6
Human Impact Score:			39
Overall Condition Score:			74
* ranking of 5 condition levels – minimal to high impact			
**overall measure is the multiple of severity and scale scores			
Future threats to tidal wetland condition:-			
1. Proximity to major urban, industrial and port area			
2. Shoreline habitat modification			
3. Future extreme climatic & weather events – rising sea levels			

Descriptions of management issues and drivers of change

Direct Human Drivers

Direct Damage - Cutting/ Removal (Fig. 13)

The accumulation of multiple small constructions has amounted to the massive and progressive deterioration of the entire estuarine system affecting not only it's overall health but also, it's resilience and capacity to recover and repair itself after being damaged by large-scale catastrophic events, like severe flooding or cyclonic winds. Direct losses were observed along

most of the Calliope River estuary ranging from things like cutting of riparian vegetation, installation of boat ramps, construction of bridges, and verge hardening with rock walls, constructed shorelines and landfill replacement of tidal wetlands. This factor was the one most highly rated as detrimental to the condition of the Calliope River estuary.

Furthermore, construction of shoreline infrastructures has never been made to minimise or mitigate the negative consequences on ambient living environmental elements, like marine intertidal plants and animals. These beneficial and foundation ecological contributors have been ignored at best, and negatively targeted at worst. For example, it was not long ago that mangrove seedling recruits were actively killed and removed after finding themselves established on constructed rockwalls in harbour areas.



Figure 13: Cutting a new track through to the river bank in a particularly vulnerable area. Is this permitted?

Direct Damage - Vehicle Access (Fig. 14)

People access tracks were observed in many places along the estuary. Some were official and well-constructed, but there were many others consisting of little more than a cleared track through mangroves to the waters' edge. Further to these instances, there were many places also where vehicle access onto saltpan-saltmarsh areas had resulted in track runnels, damage to saltmarsh vegetation and unnatural ponding across expansive areas also littered with abandoned rusting vehicles. The damage to soil and vegetation integrity is widespread and extensive.



Figure 14: Vehicle access to the river bank is taken for granted without account of the damage to shoreline sediments and buffering vegetation.

Indirect Human Drivers

Altered Hydrology - Restricted Flow (Fig. 15)

Also notable during the field surveys was the number of constructions affecting the natural flows of tides and river runoff. These have sometimes quite noticeable consequences with either sometimes dramatic effects like severe erosion, or sites of massive sediment deposits. These might arise after a particularly extreme flow event or storm, but they also occur during relatively benign weather conditions after some significant change has been made to the natural runoff. Some examples observed along the estuary include ponded pastures, fish farm ponds, road and bridge verges, drain paths, and encroachment and land fill across tidal flats, and construction of bund walls and roads without adequate drainage.



Figure 15: Landfill with bund wall blocks a natural drainage tributary altering the hydrology of the estuary.

Altered Hydrology - Waterway Barriers (Figs. 16 - 17)

Structures like bund walls, breakwaters and constructed drains were all observed along the estuary. These were particularly common along the lower estuarine reaches. The observation was also made that native wildlife (birds, fish, marine vegetation, mangroves) were greatly reduced in diversity and numbers in areas surrounded by hardened structural walls. The overwhelming conclusion during these surveys was that there must be a better way to do this,

to construct safe and practical environments where wildlife are included. The anticipated benefits would also make this idea economical as well as meeting the practical needs of port and river operations.



Figure 16: Reclamation areas appear as sterile places with low biological diversity compared to the adjacent mangrove systems.

Pollutants - plus Excess Nutrients (Fig. 18)

There was a small number of field observations listing the presence of possible pollutant sources at places along the estuary. One was the presence of a pump draining water from the coal terminal reclamation area near the mouth. This was reported as an unlikely source of pollution but it should be validated by an independent assessor. Another record of concern included observations of scum and froth across river waters associated with the outflow pipes carrying warmed cooling waters from the local power plant. The agent responsible needs to be minimised and controlled better to reduce and prevent this occurrence. There were no indications of habitat damage or biotic impacts associated with these events.

The presence of green algae covering exposed mud flats fronting mangroves is considered an indicator of excess nutrients in surrounding waters. These occurrences were mainly associated with outflow drains in the lower estuary.



Figure 17: Drains along the landfill reclaimed areas are a feature downstream.

Natural Drivers

Climate and Weather Impacts

Fringe Collapse

This driver refers to the loss of shoreline mangroves towards the mouth and downstream waters edges. This is usually caused by strong winds and storm events. For the most part, this estuary is relatively protected, but there were a few instances of shoreline fringe damage associated with storm events including the 1998 hail storm that hit the area on the western side of the estuary in the mid-stream to down-stream area (Houston 1999).



Figure 18: Species specific death of *Avicennia* trees is indicative of herbicides in runoff waters.

Bank Erosion (Fig. 19)

Bank erosion refers to the collapse of river banks. The frequency of its occurrence largely determines whether this is natural or not. For instance, where there is a corresponding amount of depositional gain (=expanding bank) as a direct counter process, used to quantify the net result of overall erosion or deposition of banks throughout the system. In this case, the erosion appears to be greatly exceeding deposition. Bank erosion is accelerated in areas lacking riparian vegetation, the presence of fires damaging vegetation, vehicles damaging vegetation, and changes to hydrologies, including rising sea levels.



Figure 19: Bank erosion is seemingly unabated where vegetation present is unable to stop the loss of land and tidal wetland areas. Note also the industrial litter along the edge.

Saltpan Scouring (Fig. 20)

Saltpan scouring was observed in many lower estuarine areas. It involves the sheet erosion of surface sediments across saltmarsh removing saltmarsh plants and establishment of broad drainage channels. This process is accelerated by vehicle damage, drought conditions and rising sea levels.



Figure 20: Scouring of saltmarsh-saltpan areas.

Ecotone Shift (drought for -ve; and wetter for +ve)

Ecotone shift can proceed in one of two direction – as expansion of mangroves, or expansion of saltmarsh-saltpan depending on longer term rainfall trends (Duke et al., 2019). Where rainfall levels decline, the mangroves dieback from the ecotone and the pan area increases. It is possible for the alternate processes to co-exist in the same estuarine location since the expansion or contraction also depends on other localised factors like nutrients and moisture availability. The Calliope catchment is suffering from the longer term decline in rainfall levels so mangrove areas are understandably contracting. This is seen as dieback at the ecotone boundaries. In the proximity of nutrient sources, like fish farms, there can also be mangrove expansion driven by excess nutrients and moisture in point source runoff.

Depositional Gain (Fig. 21)

Depositional gain as noted is often seen as the counter process to bank erosion along estuarine shorelines. It can also occur when sediments accumulate in estuarine systems for other reasons like catchment vegetation clearing, tilled agriculture in the catchment, installation of weirs and dams blocking the normal tidal and river flow hydrologies. It is useful to consider all the likely influences before making conclusions about the dominant cause. The depositional gain indicator is the occurrence of young seedlings in front of established frontal mangrove trees. The age of the young stand is indicative also of when new sediment levels on the mud bank exceed mean sea level making the site available for natural mangrove colonisation. As such, depositional gain is driven by sediment supply.



Figure 21: Depositional gain with young seedlings taking advantage of the recently accreted mud bank.

Light Gaps

Light gaps were observed at several locations along the shoreline. These special forest gaps are formed naturally by lightning strikes which kill small circular patches of mangrove trees (Duke 2001). These patches are common and there is a distinct and ordered recovery process as they are colonised by seedlings that progressively grow and fill the gap, returning the canopy to its uniform condition. This is considered an essential contributor to natural forest turnover and replacement of mangrove forests. The moderate frequency of these gaps is indicative of a healthy mangrove forest. Should the rate of gap creation be increased, then this is likely to cause the collapse of this essential recovery process and the functioning of the mangrove forest. The frequency of gaps observed in the Calliope River estuary appear normal.

Bat Roosting

Bats, or flying foxes, or fruit bats, were not observed during these surveys. However, at least one site was known to occur in the estuary. This colony of several thousand individuals had been abandoned. It was of interest that the site on a dense mangrove island adjacent to the WICET facilities in the lower estuary showed no signs of the bats having caused damage to the canopy foliage.

Flood Damage (Fig. 22)

Flood damage was notable in upstream locations where the width of mangrove stands were very narrow and the banks usually much steeper. These features would have likely contributed to the greater damage with faster concentrated water flows – in these narrower deeper estuarine reaches. The indicators recorded were dead trees lying angled downstream and often covered in silt and occasionally either undermined or with roots buried under sediments.



Figure 22: Flood damaged mangrove verge in the Calliope upstream estuary.

Potential future threats to tidal wetland condition

- **Increased Population Density**
 - Increased mangrove trimming and mangrove removal for view increased shoreline access
- **Agricultural Intensification in the Gregory and Isis catchments**
 - Increased risk of herbicide contamination
 - Increased sediment delivery to the estuary
 - Increased water extraction and reduced flows
- **Future extreme climatic events – drought**
 - Increased effect of drought resulting from reduced tidal wetland ecosystem resistance and resilience as a consequence of waterway barrier construction.

3.0 SOUTH TREES INLET

Fitzroy Basin region

Mouth location:	-23.860699; 151.304014
Condition:	Modified, largely tide dominated
Area of tidal wetlands (QWMP 2018)	
Mangroves:	1,058 ha
Tidal saltmarsh and salt pans:	745 ha
Total tidal wetland:	1,802 ha
Wetland Cover Index:	58.7%
Mean Annual Rainfall:	879 mm
Catchment Area:	92 km ²



Figure 23: The mouth of South Trees Inlet viewed looking upstream in 2008.



Figure 24: Achievements regards successful field surveys undertaken in the South Trees Inlet estuary in collaboration with Gidarrjil Rangers up to late 2018. Tracks (yellow lines) are shown on satellite images for 2014 and 2018.

Summary Description

South Trees Inlet is a tidal inlet facing Auckland Channel, the main waterway entrance to Port Curtis and Gladstone Harbour (Fig. 23). Shoreline areas around the mouth are characterised by expansive tidal wetlands dominated by facilities of the Queensland Alumina Limited (QAL) refinery and Boyne aluminium smelter. The South Trees Industrial Estate is located also next to Wapentake Creek which flows into the western side of the inlet just south of South Trees Island. Upstream the estuary connects indirectly also with the Boyne River estuary. The estuary was surveyed in 2014 and 2018 by the Gidarjil Rangers (see Fig. 24).

Estuary Features

Physical setting. The expansive tidal wetlands around the mouth and upstream are dominated by the South Trees Industrial Estate. This includes a refinery and light industrial facilities around Parsons Point on the northern bank, plus other industrial operations like a sewage treatment plant. The southern side of the mouth is connected by a causeway bridge to the Boyne aluminium smelter with its South Trees wharf, storage and settlement pond facilities on South Trees Island. The tidal wetlands have significant importance to local marine and estuarine species. Fishery habitats are protected in significant parts of South Trees Inlet between the northern edge of the bridge over the inlet on Boyne Island Road and the inlet's junction with the Boyne River. This protection is legislated under the Fisheries Regulations 1995 and the Fisheries (East Coast Trawl) Management Plan 1999.

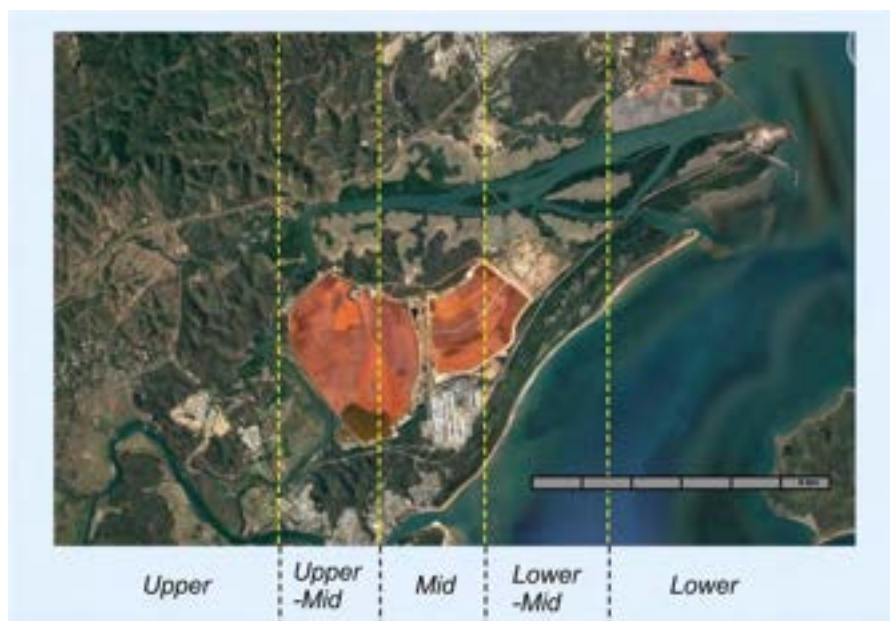


Figure 25: Estuary zones of the South Trees Inlet.

Estuarine zones (Fig. 25). As noted, the lower reaches are dominated by industrial and development facilities associated with the South Trees Industrial Estate including one of the world's largest alumina refineries, Queensland Alumina Limited (QAL). Further upstream, particularly on northern banks and to the west, there are significantly fewer development pressures on remnant natural vegetative habitats.

Changes to natural habitats. Changes to natural habitats are driven by a combination of human and natural drivers of change. The dominant feature of this coastal area are the large, bright red settlement ponds used by QAL. The development of these areas required the reclamation of large natural areas. There are also other questions regards ground water movement, altered hydrology and the potential for contamination caused by all industrial works. Rainfall influences will have altered the relative area of these habitats (Duke et al. 2019) along with the changes caused by direct human impacts.

Tidal wetland vegetation

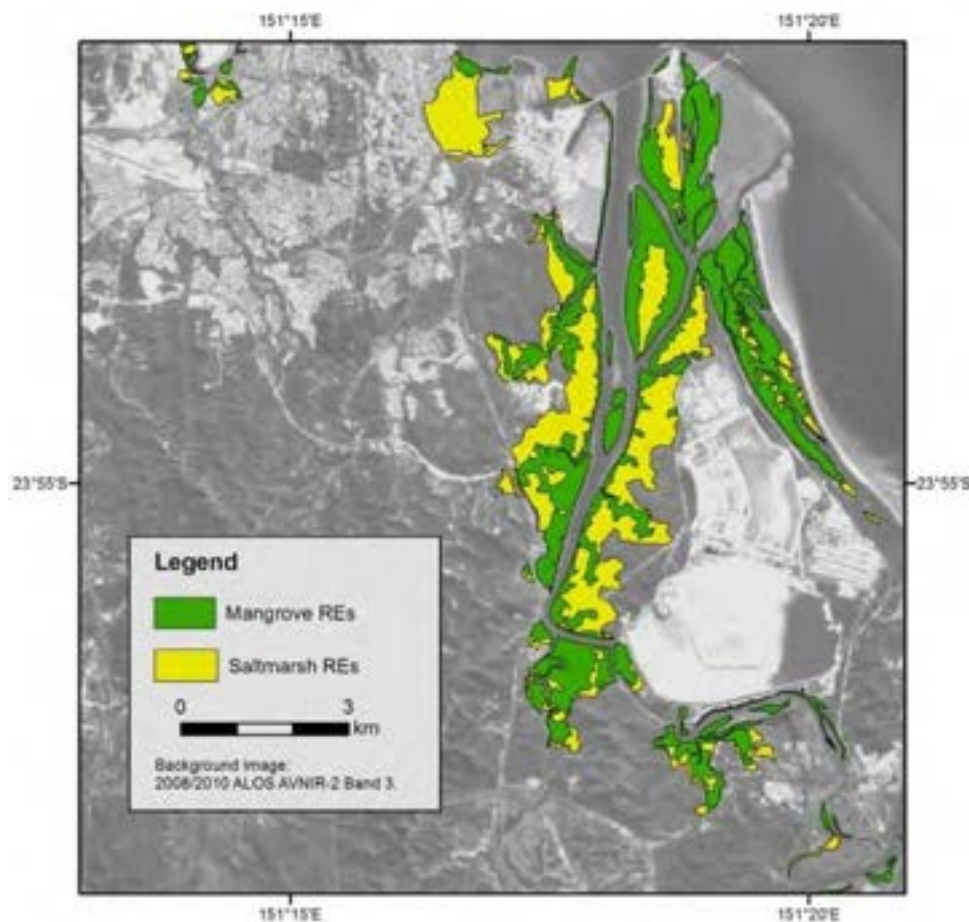


Figure 26: South Trees Inlet showing mangrove and saltmarsh areas.

Mangrove habitat (Fig. 26). South Trees Inlet has 14 mangrove species (Table 2); including a number with their southern-most distributions just to the south. In particular, the inlet marks the most southern occurrence of Cedar Mangrove (*Xylocarpus moluccensis*) (Duke 2006). Two other species drop out a few kilometres further south, including *Pemphis acidula* and *Scyphiphora hydrophylacea* with southern limits at Bustard Head around 24.02 degS (Duke 2006). These observations update prior records for the Port Curtis area that recorded twelve species (Saenger 1996; McKinnon et al. 1995). Mangrove species are able to tolerate a wide range of environmental factors such as salinity, levels of inundation, soil types and wave action (Danaher 1995; Duke et al., 1998; Duke et al., 2003). These conditions influence the density and diversity of mangrove communities in tidal wetlands of South Trees Inlet. Mangrove forests

close to the mouth of the inlet are dominated by *Rhizophora stylosa*, *Ceriops australis* and *Avicennia marina*. *Rhizophora stylosa* is the most common due to its high tolerance of regular inundation and protective shoreline mantle of tangled exposed roots. Along river banks upstream, the shoreline edges are densely fringed by *Aegiceras corniculatum* backed by other species. The least represented are *Lumnitzera racemosa*, *Pemphis acidula*, *Scyphiphora hydrophyllacea* and *Xylocarpus granatum*.

Table 2: Tidal wetland plants recorded for the estuary of South Trees estuary.

Mangrove Species	Saltmarsh Species
<i>Acrostichum speciosum</i>	<i>Atriplex semibaccata</i>
<i>Aegialitis annulata</i>	<i>Baumea juncea</i>
<i>Aegiceras corniculatum</i>	<i>Fimbristylis ferruginea</i>
<i>Avicennia marina</i>	<i>Fimbristylis polytrichoides</i>
<i>Bruguiera gymnorhiza</i>	<i>Salsola australis</i>
<i>Ceriops australis</i>	<i>Sarcocornia quinqueflora</i>
<i>Excoecaria agallocha</i>	<i>Sesuvium portulacastrum</i>
<i>Lumnitzera racemosa</i>	<i>Sporobolus virginicus</i>
<i>Osbornia octodonta</i>	<i>Suaeda australis</i>
<i>Pemphis acidula</i>	<i>Suaeda arbusculoides</i>
<i>Rhizophora stylosa</i>	<i>Tecticornia halocnemoides</i>
<i>Scyphiphora hydrophyllacea</i>	<i>Tecticornia indica</i>
<i>Xylocarpus granatum</i>	<i>Tecticornia pergranulata</i>
<i>Xylocarpus mollucensis</i>	

Saltmarsh-pan habitat (Fig. 26). The South Trees estuary has around 13 saltmarsh species (Table 2). Saltmarsh-pan areas (Fig. 27) often occur mostly behind mangrove shoreline fringes and within upper zones of tidal wetlands.



Figure 27: Much saltmarsh vegetation typically sits low on the ground.

Biomass of tidal wetlands of the South Trees Inlet estuary

Tree heights were recorded in satellite imagery and verified in field surveys. The overall height of mangrove vegetation across the broad tidal wetland areas of the Calliope River are relatively low, around 3-5 m or less. This is consistent with areas of relatively low rainfall. Slightly taller stands were notably observed surrounding lower elevation shorelines just above mean sea level and towards the estuary mouth, as depicted in maps and imagery (Fig. 28).

The zone immediately above the tidal wetland zone (i.e., $1\text{m} > \text{HAT}$) refers to the supra tidal zone. The vegetation in this zone is considered vulnerable to a number of human and natural factors, including vehicle access, reclamation damage, severe storms, flooding, feral pigs, exotic weeds, and sea level rise. Upstream areas were either low in stature or non-existent. Downstream and along shoreline areas there were a mixture of low-level patches.

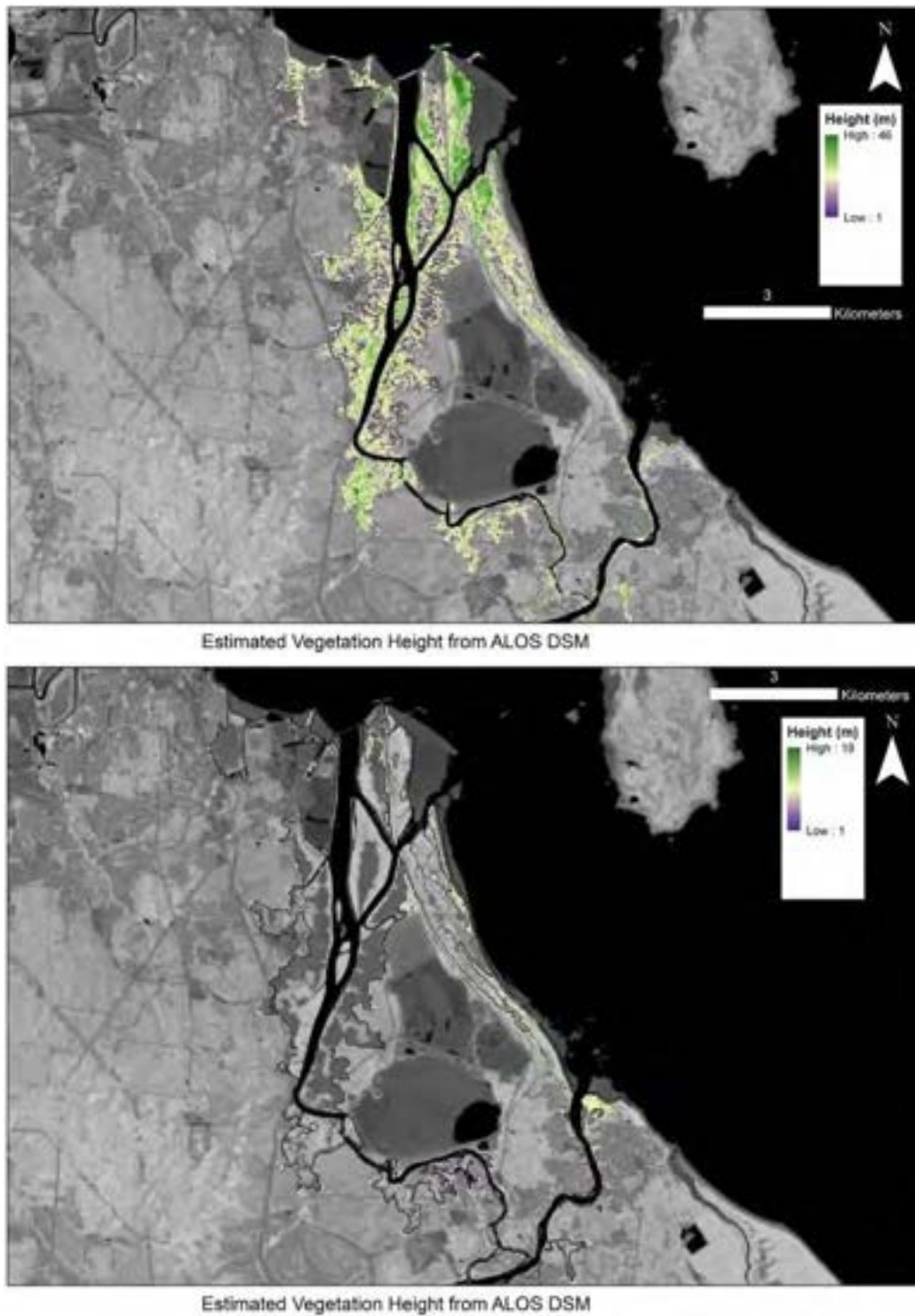


Figure 28: Satellite images of South Trees Inlet estuarine areas showing height of vegetation for A) tidal wetlands (MSL-HAT) and B) the supra tidal zone (HAT +1m) for 2010 using ALOS DSM.

Changes taking place in tidal wetlands of South Trees Inlet estuary

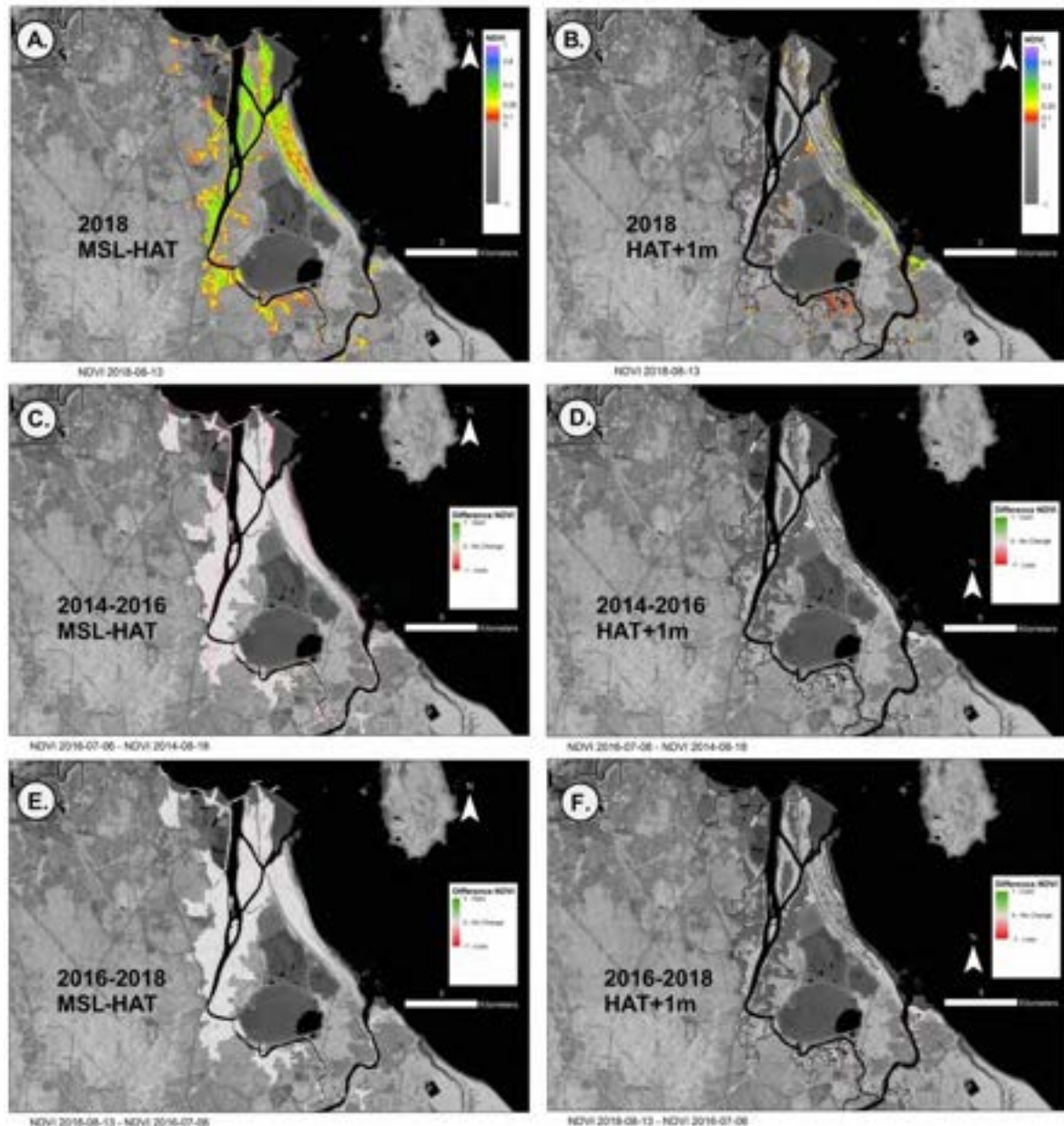


Figure 29: Satellite images of the South Trees Inlet estuarine areas showing NDVI measures of vegetation condition for tidal wetlands (MSL-HAT) and supra tidal zone (HAT +1m) for 2018 (A & B), and two change detection periods 2014-2016 (C & D) and 2016-2018 (E & F).

A first evaluation of changes to vegetation cover was made using vegetation indices (like NDVI) from satellite imagery (Fig. 29). The indices for specific dates represent measures of sub-lethal condition at the time (A & B for 2018 – for tidal wetlands, and supra tidal areas respectively). Colours towards the red end of the scale show vegetation in relatively poor condition while that at the green-blue end is notably healthier. In the 2018 views, tidal wetlands and supra tidal vegetation were in poorer condition at high intertidal margins virtually throughout. When change detection is done comparing scenes from two different time periods (C-F), the scales from red to green indicate relative losses or gains. Comparison of two time periods show notably different responses where losses suffered in one time period might show gains with recovery in a subsequent time period. The time periods shown in the figure include 2014-2016

(C & D) and 2016-2018 (E & F). By comparing C & E, it can be seen that tidal wetlands generally and at their low intertidal edges were damaged and lost in the first period while in the second period these same areas showed no detectable change. These differences represent severe disturbance event in the first period possibly associated with drought effects on vegetation cover. And, these damaged areas showed no recovery had taken place one-two years afterwards. By contrast, the supra tidal vegetation showed noticeable losses in the second period while there were few detectable changes in the first period.

Management issues registered at community workshops

Key issues flagged at 2016 and 2017 community workshops included altered hydrology, weed infestations and vehicle access damage (see Fig. 30).

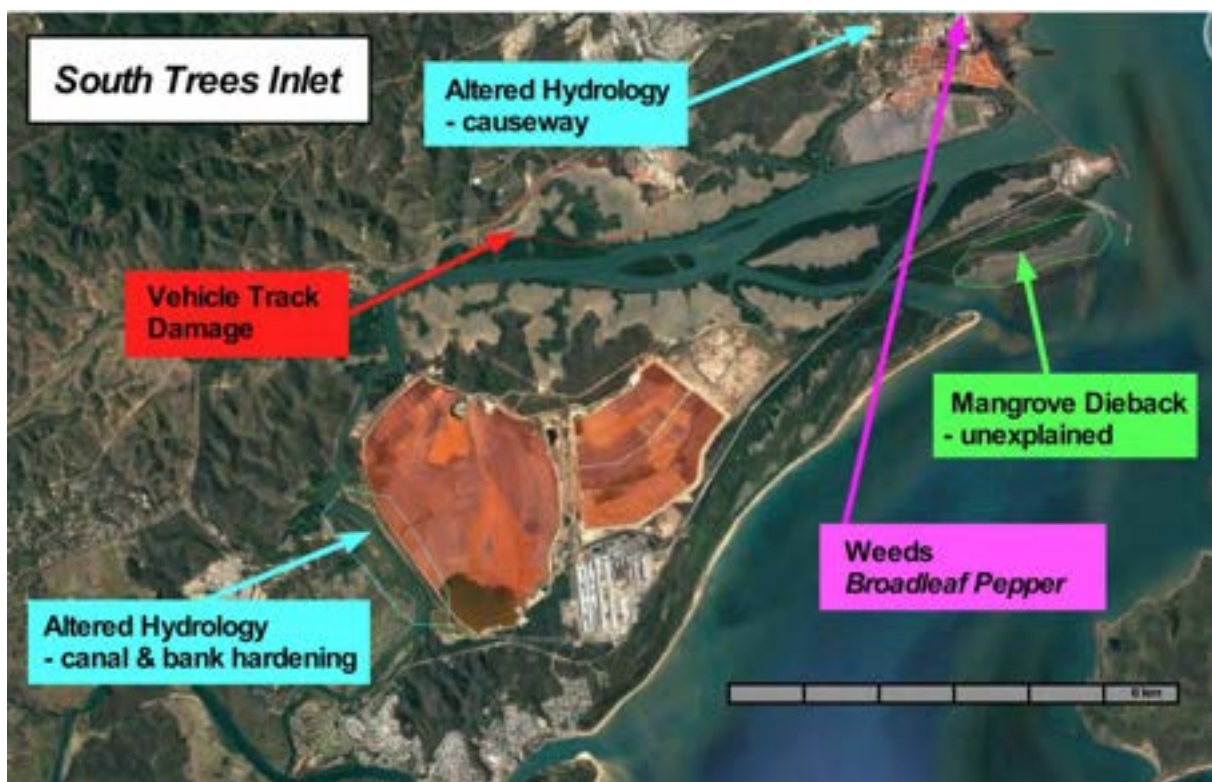


Figure 30: Digitised outcomes of the workshop community-based participatory mapping of South Trees Inlet tidal wetland management issues.

Environmental management issues in the South Trees estuary

- Mangrove Removal/ Trimming
- Altered Hydrology – Waterway Barriers
- Altered Hydrology – Restricted Flows
- Chemical Inputs – pollutants and excess nutrients
- Vehicle access damage

South Trees Inlet is situated amongst areas of significant development largely in the form of industrial facilities, altered land use, constructed shorelines affecting natural flows, along with pressures from agricultural use. The inlet mostly consists of broad downstream tidal wetlands with extensive mangrove forests and areas of saltmarsh-salt pans. These relatively large areas of mangroves are generally low in stature but they are typically dense, uniform and mostly in good condition. But, there are some factors causing impacts likely to be affecting their functioning and well-being. Some of these issues need to be watched and monitored closely.

The most dominant impacts affecting this estuarine system concern the extent of areas of altered flow hydrology. This, in particular, concerns those areas near to the construction, rockwalls and channelling associated with the broad spoil ponds and the port and industrial facilities. The spoil ponds are also loaded with discarded mine waste. These factors identify notable environmental risks with their potential for on-going consequences that need to be constantly monitored and evaluated.

During this project, there were a number of specific issues identified including: dust damage affecting some mangrove areas, and the large area of mangrove dieback on the south-eastern side of South Trees Island bordering the southern channel into the estuary.

Recommended Management Actions:

- maintain environmental freshwater flows to the estuary
- minimise dust levels reaching mangroves and other native vegetation
- Increase public awareness regarding the importance of tidal wetlands.
- maintain regular monitoring of the health and condition of riparian and tidal wetland vegetation surrounding the estuary
- maintain regular monitoring of the areas damaged by severe storms

Drivers of change up to 2018

South Trees Inlet estuary – chief drivers, condition & threats – a summary			
Drivers of Change	Severity*	Scale*	Score**
Direct Human Drivers			
Direct Damage - Cutting/ Removal	5	3	15
Direct Damage - Vehicle Damage	2	1	2
Indirect Human Drivers			
Altered Hydrology - Restricted Flow	3.5	3	10.5
Altered Hydrology - Waterway Barriers	3	2	6
Pollutants – Herbicides, Nutrients	3	1	3
Natural Drivers			
Storm Damage	4	1	4
Shore Erosion	2.5	2	5
Root Burial	4	1	4
Fringe Collapse	2.5	1	2.5
Saltpan Scouring	2	2	4
Ecotone Shift (Drought)	4	1	4
Ecotone Shift (+ve)	1	2	2
Terrestrial Retreat	3	1	3
Light Gaps	4	1	4
Flood Damage	4	1	4
Human Impact Score:			36.5
Overall Condition Score:			73
* ranking of 5 condition levels – minimal to high impact			
**overall measure is the multiple of severity and scale scores			
Future threats to tidal wetland condition:-			
1. Proximity to major urban, industrial and port area - encroachment			
2. Pollution from air-born dust on foliage			
3. Altered hydrology of major channels affecting natural flows			

Descriptions of management issues and drivers of change

Direct Human Drivers

Direct Damage - Cutting/ Removal (Fig. 31)

Extensive construction works have affected the hydrology of this estuarine system. This situation has amplified the risks to the overall health of this largely estuarine system. This affects its resilience and capacity to recover and repair itself after being damaged by large-

scale catastrophic events, like severe flooding, cyclonic winds or sea level rise. Direct losses were observed mostly towards the mouth of the estuary, But, this also includes issues like cutting of riparian vegetation, installation of boat ramps, construction of bridges, and verge hardening with rock walls, constructed shorelines and landfill replacement of tidal wetlands. This driver was the one most highly rated as detrimental to the condition of the South Trees Inlet estuary.



Figure 31: Landfill sites fronted by remnant mangroves dominate the lower downstream estuarine areas.

Direct Damage - Vehicle Damage (Fig. 32)

Human access tracks were observed in many places along the estuary. Some tracks were official and well-constructed, but others were not. In addition, there were a number of places where vehicle access onto saltpan-saltmarsh areas had resulted in track runnelling, damage to saltmarsh vegetation and unnatural ponding across expansive areas also littered with abandoned rusting vehicles. The damage to soil and vegetation integrity is locally severe.



Figure 32: Vehicle access onto delicate and vulnerable shoreline verges seems quite normal.

Indirect Human Drivers

Altered Hydrology - Restricted Flow (Fig. 33)

It was noted during field surveys that there were extensive constructed facilities affecting the natural flows of tidal flooding and ebbing. Some examples observed along the estuary include road and bridge verges, drain paths, and encroachment and land fill across tidal flats, and construction of bund walls and roads without adequate drainage.



Figure 33: Damaged tidal wetland habitats are common adjacent to constructed structures needed for industry operations.

Altered Hydrology - Waterway Barriers (Fig. 34 - 35)

Structures like bund walls, breakwaters and constructed drains were all observed along the estuary. The observation was also made that native wildlife (birds, fish, marine vegetation, mangroves) were greatly reduced in diversity and numbers in areas surrounded by hardened structural walls.



Figure 34: Constructed walls mark the perimeter of landfill areas with added drains from which flows unknown waste waters.



Figure 35: Channel modification has been undertaken on a massive scale in the channel connecting the inlet with Boyne estuaries.

Pollutants – nutrients & dust (Fig. 36)

There were a number of survey observations listing the presence of possible pollutant sources at places along the estuary. One was the presence of red dust covering foliage of mangrove trees near the mouth adjacent to the bridge at the mouth. Another observation was of the presence of green algae on exposed mud flats fronting mangroves. This was considered an indicator of excess nutrients in surrounding waters. These occurrences were possibly associated with outflow drains in the lower estuary.



Figure 36: Trees bearing pollutant-related, albino propagules are commonly seen during the fruiting season.

Natural Drivers

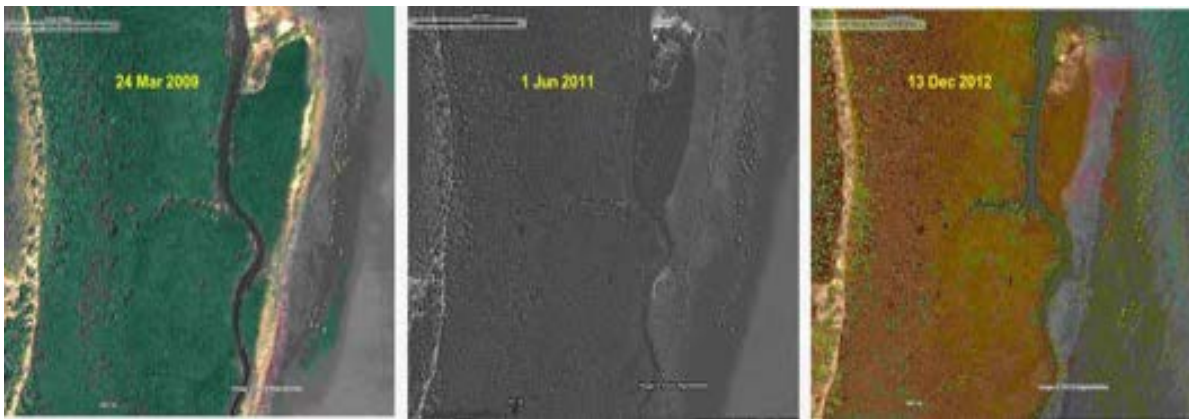


Figure 37: Occurrence of large mangrove dieback patch on South Trees Island.

Storm Damage & Shore Erosion (Figs. 37 - 38)

A large patch of mangrove dieback was noted along the eastern side of South Trees Island at the south-eastern mouth of the estuary. The imagery available confirms this occurred around 2010. The cause is not known but it appears to be the result of storm damage contributing to shoreline erosion. A field investigation is needed to resolve this question.



Figure 38: Bank erosion and slumping is not too common in the estuary.

Root burial

There are a few observations that identify mangrove dieback associated with sediment burial of roots. Sites were mostly associated with relatively exposed shoreline locations, including in the vicinity of the large area of mangrove dieback on South Trees Island.

Fringe collapse

There was a small number of locations showing signs of fringe collapse. This appears to be caused by strong winds and storm events.

Saltpan scouring

Saltpan scouring was observed in a number of lower estuarine areas. The process is characterised by sheet erosion of surface sediments across salt pans removing saltmarsh

plants and establishment of broad drainage runnels. This process is accelerated by vehicle damage, drought conditions and rising sea levels.

Ecotone Shift (drought for -ve; and wetter for +ve)

Ecotone shift can proceed in one of two direction – as expansion of mangroves, or expansion of saltmarsh-saltpan depending on longer term rainfall trends (Duke et al., 2019). Where rainfall levels decline, the mangroves dieback from the ecotone and the pan area increases. It is possible for the alternate processes to co-exist in the same estuarine location since the expansion or contraction also depends on other localised factors like nutrients and moisture availability. The South Trees Inlet area is suffering from the longer term decline in rainfall levels so mangrove areas are understandably contracting. This is seen as dieback at the ecotone boundaries. In the proximity of nutrient sources, like sewage treatment works, there can also be mangrove expansion driven by excess nutrients and moisture from point source runoff.

Terrestrial retreat & upland migration

Loss of low-lying, terrestrial edge trees were noted in a few places. These were also associated with the upland establishment of young mangrove plants , often also accompanied by the erosion of terrestrial verges around the highest tide levels. The indicators of terrestrial retreat were the presence of an eroding upland margin.

Light gaps

Light gaps were observed at several locations along the shoreline. These unusual forest gaps are formed naturally by lightning strikes killing trees in small circular patches (Duke 2001). These patches were common and there is a distinct and ordered recovery process as the gaps are colonised by seedlings that progressively grow and fill the gap, returning the canopy to its uniform condition. This is considered an essential contributor to natural forest turnover and replacement of mangrove forests. The moderate frequency of these gaps is indicative of a healthy mangrove forest. Should the rate of gap creation be increased however, then this is likely to cause the collapse of this essential recovery process and the functioning of these mangrove forests. The frequency of gaps observed in the South Trees Inlet estuary appear normal.

Flood damage (Fig. 39)

Flood damage was notable in upstream locations along the main channel connecting this system with the Boyne River estuary. The indicators observed were dead trees lying angled downstream and often covered in silt and occasionally either undermined or with roots buried under sediments.



Figure 39: Stand damage attributed to flood damage.

4.0 BOYNE RIVER ESTUARY

Fitzroy Basin region

Mouth location: -23.936567; 151.355977
Condition: Modified, river & tide dominated

Area of tidal wetlands (QWMP 2018)

Mangroves:	51 ha
Tidal saltmarsh and salt pans:	54 ha
Total tidal wetland:	105 ha
Wetland Cover Index:	48.6%
Mean Annual Rainfall:	879 mm
Catchment Area:	2,409 km ²



Figure 40: The mouth of the Boyne River viewed looking upstream.



Figure 41: Achievements regards successful field surveys undertaken in the Boyne River estuary in collaboration with Gidarjil Rangers up to late 2018. Tracks (yellow lines) are shown on satellite images for 2014, 2015, 2016 and 2018.

Summary Description

The Boyne River catchment (Fig. 40) drains a broad area of around 2,409 km² from the Great Dividing Range through the Boyne valley where it is held in the large dammed area of Lake Awonga. Flows downstream from the artificial lake discharge into Port Curtis between the towns of Boyne Inlet and Tannum Sands. A bridge across the lower estuary joins the two largely urban populated areas. The Queensland Department of Environment and Heritage Protection had at one time considered the Boyne River to be the southern habitat extent of saltwater crocodiles. The riverine estuary is narrowly fringed with tidal wetlands with few broad expanses. The estuary was surveyed in 2014, 2015, 2016 and 2018 by the Gidarjil Rangers (see Fig. 41).

Estuary Features

Physical setting. Flows and connectivity of the Boyne River are primarily disrupted by Awonga Dam which is the major water source for the Gladstone and Port Curtis region. Large numbers of barramundi are stocked in the Dam and may be introduced into the Boyne Estuary when the dam overtops. In 2011, the river was the site of large-scale mortality of many of the introduced barramundi and other fish. Further downstream, estuarine connectivity is severely limited also by Mann's Weir as an artificial partial barrier to fish movement between freshwater and saltwater habitats downstream of the dam. The weir is semi-permanent and connectivity occurs only when the structure is washed over by high flows, a critical mechanism for the movement and recruitment of many catadromous fish species in this estuary. This particular water resource development has severely impacted estuarine habitats of the Boyne River with its significant reduction in estuary length restricting brackish conditions downstream of the weir.

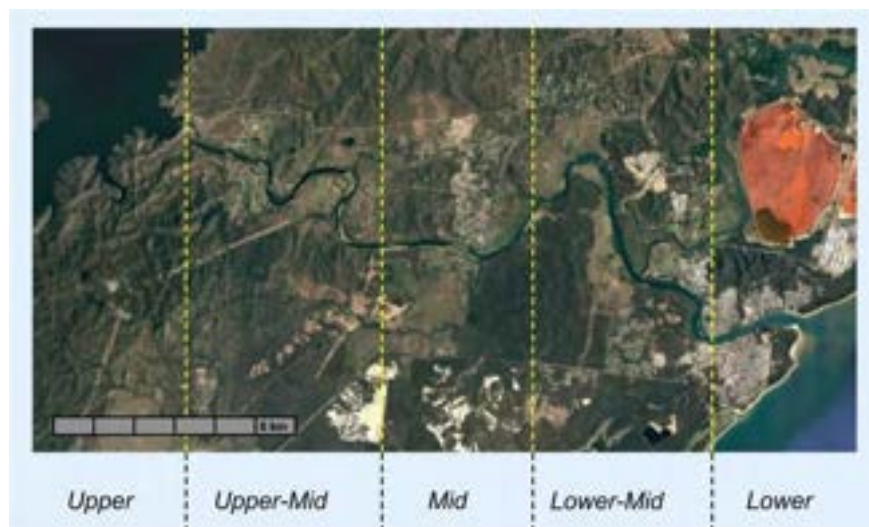


Figure 42: Estuary zones of the Boyne River.

Estuarine zones (Fig. 42). The lower reach of the Boyne River flows from the dam through predominately agricultural land that has pockets of remnant vegetation. Before entering the south-eastern part of Port Curtis, the Boyne River flows through the residential communities of Boyne Island and Tannum Sands. Flows and connectivity between the Boyne estuary and South Trees Inlet via their estuarine junction appear relatively minor.

Changes to natural habitats. Changes to natural habitats are driven by a combination of human and natural drivers of change. The dominant features of this coastal area are Awonga Dam and Mann's Weir. The development of these water resource features have significantly altered the estuarine areas downstream. There are also other questions regards ground urban expansion and altered hydrology plus the impacts of severe flooding. Rainfall influences will have altered the relative area of tidal wetland habitats (Duke et al. 2019) along with the changes caused by direct human impacts.

Tidal wetland vegetation

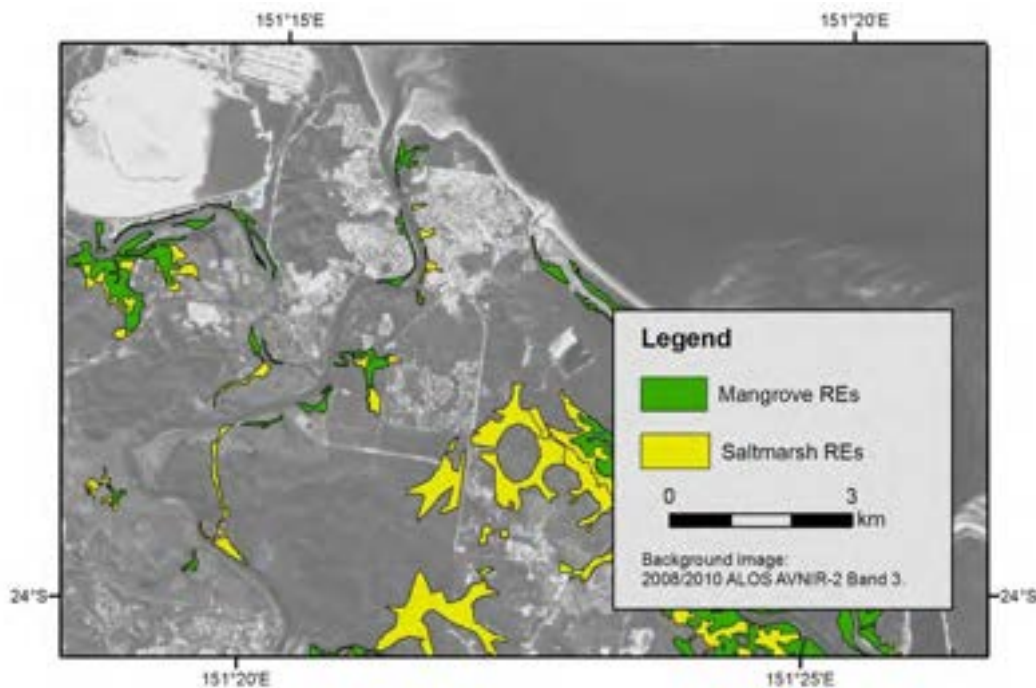


Figure 43: Boyne River estuary showing mangrove and saltmarsh areas.

Mangrove habitat (Fig. 43). The Boyne estuary has 13 mangrove species (Table 3); including two with their southern-most distributions just to the south (Duke 2006). These two include *Pemphis acidula* and *Scyphiphora hydrophylacea* with their southern limits at Bustard Head around 24.02 degS (Duke 2006). These observations update prior records for the Port Curtis area that recorded twelve species (Saenger 1996; McKinnon et al. 1995). The local mangrove species are able to tolerate a wide range of environmental factors such as salinity, levels of inundation, soil types and wave action (Danaher 1995; Duke et al., 1998; Duke et al., 2003). These conditions influence the density and diversity of mangrove communities in tidal wetlands of South Trees Inlet. Mangrove forests close to the mouth of the inlet are dominated by *Rhizophora stylosa*, *Ceriops australis* and *Avicennia marina*. *Rhizophora stylosa* is the most common due to its high tolerance of regular inundation and protective shoreline mantle of tangled exposed roots. Along river banks upstream, the shoreline edges are densely fringed by *Aegiceras corniculatum* backed by other species. The least represented are *Lumnitzera racemosa*, *Pemphis acidula*, *Scyphiphora hydrophylacea* and *Xylocarpus granatum*.

Table 3: Tidal wetland plants recorded for the estuary of Boyne River estuary.

Mangrove Species	Saltmarsh Species
<i>Acrostichum speciosum</i>	<i>Atriplex semibaccata</i>
<i>Aegialitis annulata</i>	<i>Baumea juncea</i>
<i>Aegiceras corniculatum</i>	<i>Fimbristylis ferruginea</i>
<i>Avicennia marina</i>	<i>Fimbristylis polytrichoides</i>
<i>Bruguiera gymnorhiza</i>	<i>Salsola australis</i>
<i>Ceriops australis</i>	<i>Sarcocornia quinqueflora</i>
<i>Excoecaria agallocha</i>	<i>Sesuvium portulacastrum</i>
<i>Lumnitzera racemosa</i>	<i>Sporobolus virginicus</i>
<i>Osbornia octodonta</i>	<i>Suaeda australis</i>
<i>Pemphis acidula</i>	<i>Suaeda arbusculoides</i>
<i>Rhizophora stylosa</i>	<i>Tecticornia halocnemoides</i>
<i>Scyphiphora hydrophylacea</i>	<i>Tecticornia indica</i>
<i>Xylocarpus granatum</i>	<i>Tecticornia pergranulata</i>

Saltmarsh-pan habitat (Fig. 43). The Boyne estuary has around 13 saltmarsh species (Table 3). Saltmarsh-pan areas often occur mostly behind mangrove shoreline fringes and within upper zones of tidal wetlands.

Biomass of tidal wetlands of the Boyne River estuary

Tree heights were recorded in satellite imagery and verified in field surveys. The overall height of mangrove vegetation across the broad tidal wetland areas of the Boyne River are relatively low and variable, around 3-5 m. This is consistent with relatively low rainfall and possibly some patches of severe damage. This patchiness was depicted in maps and imagery (Fig. 44).

The zone immediately above the tidal wetland zone (i.e., 1m > HAT) refers to the supra tidal zone. The vegetation in this zone is considered vulnerable to a number of human and natural factors, including vehicle access, reclamation damage, severe storms, flooding, feral pigs, exotic weeds, and sea level rise. The supra tidal vegetation appears more or less non-existent except for some stands at the mouth.

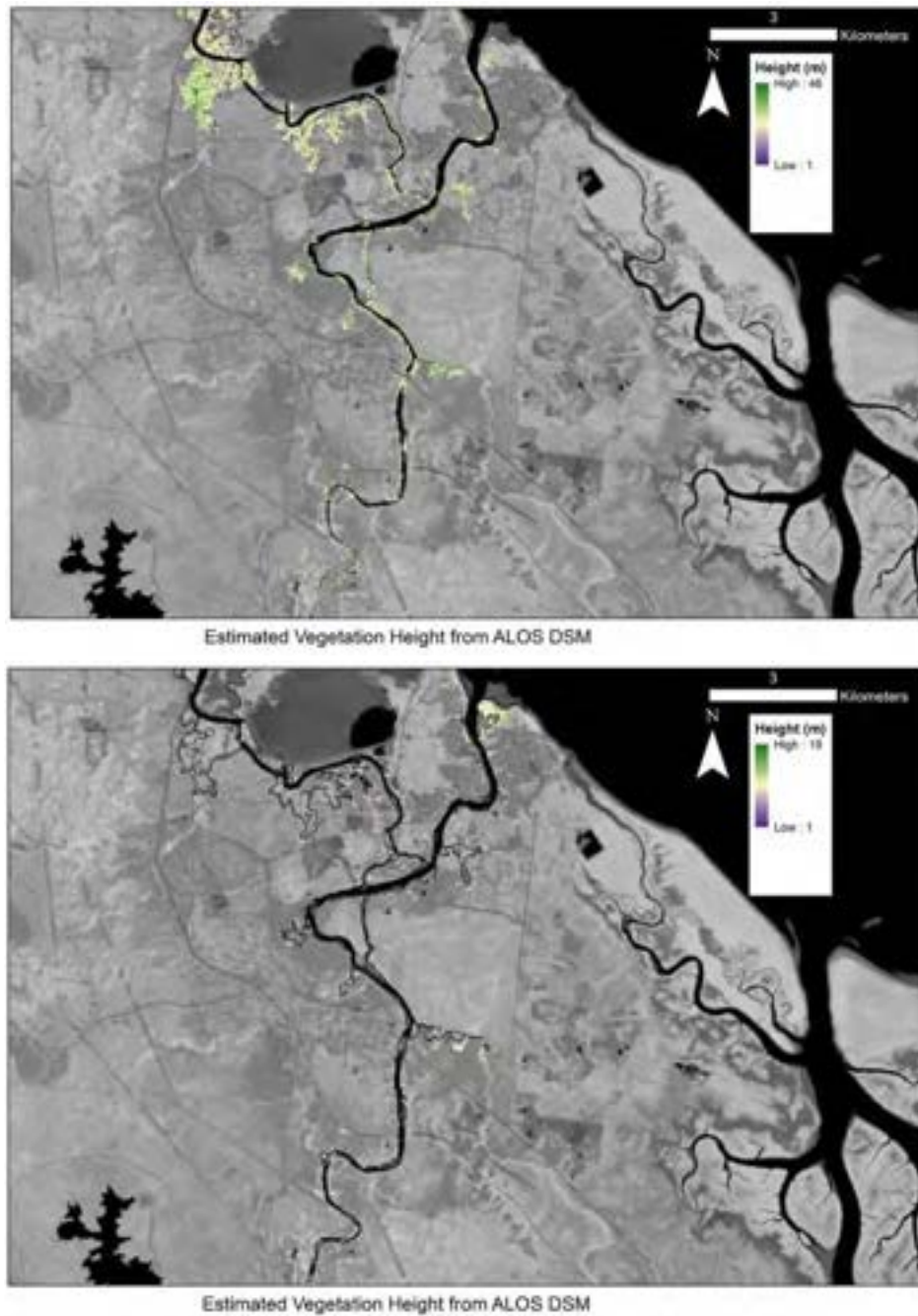


Figure 44: Satellite images of the Boyne River estuarine areas showing height of vegetation for A) tidal wetlands (MSL-HAT) and B) the supra tidal zone (HAT +1m) for 2010 using ALOS DSM.

Changes taking place in tidal wetlands of the Boyne River estuary

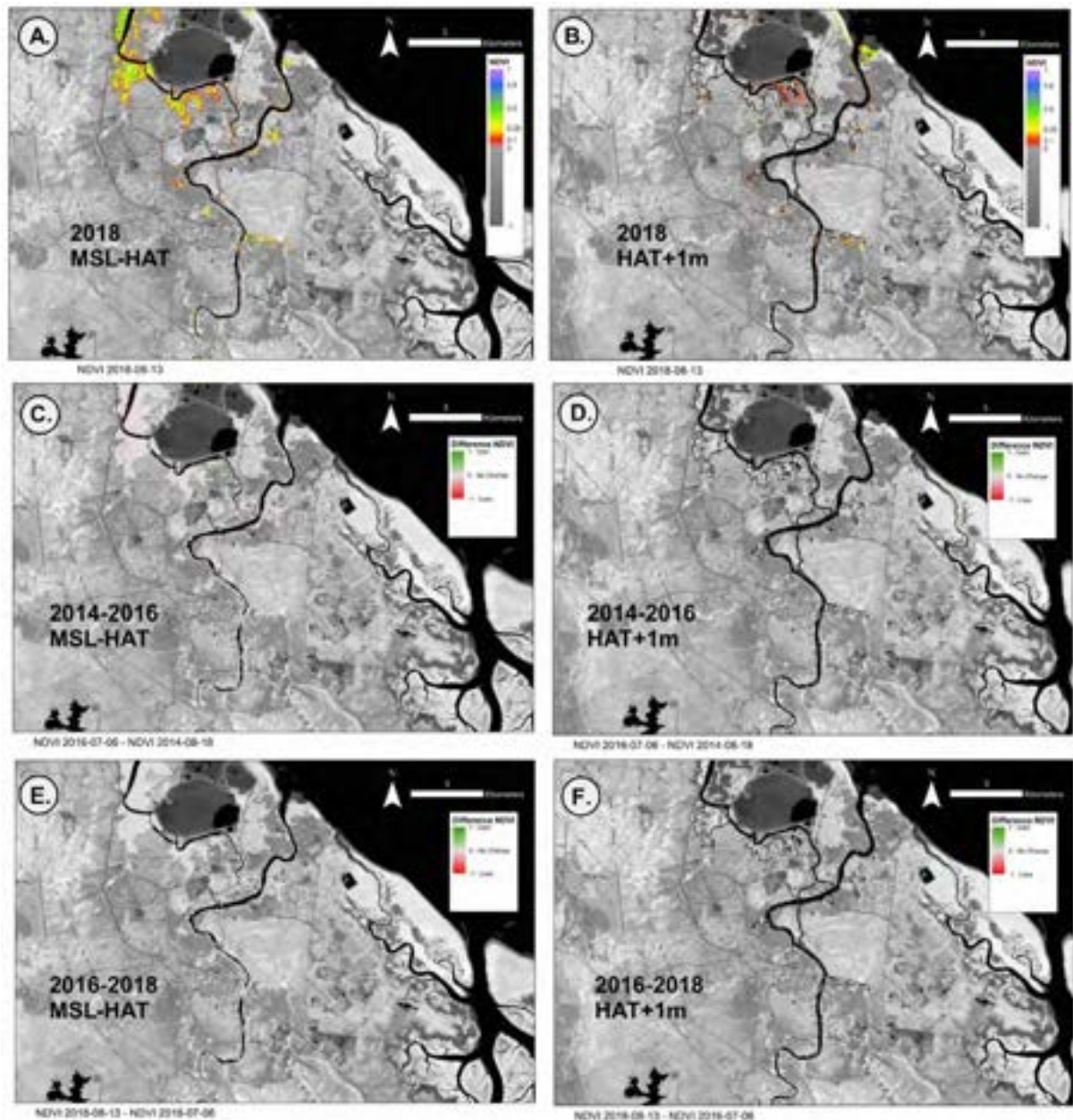


Figure 45: Satellite images of the Boyne River estuarine areas showing NDVI measures of vegetation condition for tidal wetlands (MSL-HAT) and supra tidal zone (HAT +1m) for 2018 (A & B), and two change detection periods 2014-2016 (C & D) and 2016-2018 (E & F).

A first evaluation of changes to vegetation cover was made using vegetation indices (like NDVI) from satellite imagery (Fig. 45). The indices for specific dates represent measures of sub-lethal condition at the time (A & B for 2018 – for tidal wetlands, and supra tidal areas respectively). Colours towards the red end of the scale show vegetation in relatively poor condition while that at the green-blue end is notably healthier. In the 2018 views, tidal wetlands and supra tidal vegetation were in poor condition throughout the estuary. When change detection was done comparing scenes from two different time periods (C-F), the scales from red to green indicate relative losses or gains. Comparison of two time periods show notably different responses where losses suffered in one time period might show gains with recovery in a subsequent time

period. The time periods shown in the figure include 2014-2016 (C & D) and 2016-2018 (E & F). By comparing C & E, it can be seen that tidal wetlands downstream were damaged and lost in the first period while in the second period these same areas showed no detectable change. These differences represent severe disturbance event in the first period with flooding and cyclonic conditions causing damage to vegetation cover throughout the estuary. And, these damaged areas showed no recovery was taking place one-two years afterwards. The supra tidal areas had no noticeable change.

Management issues registered at community workshops

Key issues flagged at 2016 and 2017 community workshops included cattle grazing, lack of buffer zones, and a proposed new bridge (see Fig. 46).



Figure 46: Digitised outcomes of the workshop community-based participatory mapping of Boyne River tidal wetland management issues.

Environmental management issues in the Boyne estuary

- Altered Hydrology – Restricted Flows
- Altered Hydrology – Waterway Barriers
- Direct damage – Vehicle access
- Mangrove Removal/ Trimming - Direct damage – reclamation, landfill loss
- Direct damage – Stock grazing
- Chemical Inputs – Herbicides & excess nutrients

The Boyne estuary is protected by the Queensland Government as a Fisheries Closed Waters designated area. This is legislated under the Fisheries Regulations 1995 and the Fisheries (East Coast Trawl) Management Plan 1999. This applies to all fishery species and all commercial fishing nets for an annual period of closure from 1 September to 30 April.

Specifically, the closure applies to most of the Boyne River estuary and the waterways joining it. The system is however heavily exploited by recreational fishers.

The Boyne catchment is dominated by the Awonga Dam that has restricted flows downstream in the estuary and greatly changed the way the whole system functions. There is an urgent need to re-evaluate the benefits derived from the impacted estuarine areas and to adequately cater for these valuable but threatened habitats.

These estuarine habitats are in a really bad state following recent severe flooding on top of the general neglect of a number of other management matters, like vehicle access, cattle grazing, runoff of agricultural chemicals, and the lack of riparian vegetation. Most of these issues can be managed locally. If successfully managed it seems possible to increase the resilience of these habitats

Recommended management actions:

- Extend Queensland Government Fisheries Closed Water restrictions
- Mitigate flood damaged areas and protect these areas from further damage
- Restore tidal wetlands along estuary banks in combination with re-establishment of riparian buffering vegetation
- Restore natural hydrological conditions to tidal wetlands
- Reduce herbicide runoff to the Boyne River estuary
- Increase public awareness regarding the importance of mangroves and riparian vegetation to reduce cutting and clearing.

Drivers of change up to 2018

Boyne River estuary – chief drivers, condition & threats – a summary			
Drivers of Change	Severity*	Scale*	Score**
Direct Human Drivers			
Direct Damage - Cutting/ Removal	5	1	5
Direct Damage – Stock Damage	4	1	4
Direct Damage - Vehicle Damage	3	2	6
Indirect Human Drivers			
Altered Hydrology - Restricted Flow	3	2	6
Altered Hydrology - Waterway Barriers	4.5	3	13.5
Pollutants – Nutrients	1	1	1
Natural Drivers			
Bank Erosion	3	3	9
Saltpan Scouring	2	1	2
Depositional Gain	1	1	1
Terrestrial Retreat	2	1	2
Light Gaps	4	1	4
Upland Migration	4	1	4
Flood Damage	4	4	16
Human Impact Score:			35.5
Overall Condition Score:			73.5
* ranking of 5 condition levels – minimal to high impact			
**overall measure is the multiple of severity and scale scores			
Future threats to tidal wetland condition:-			
1. Proximity to major urban area - encroachment			
2. Pollution from urban and agricultural runoff			
3. Future extreme climatic & weather events – flooding, rising sea levels			

Descriptions of management issues and drivers of change

Direct Human Drivers

Direct Damage - Cutting/ Removal (Fig. 47)

The accumulation of multiple small constructions (with encroachment and urban expansion) has amounted to the massive and progressive deterioration of the entire estuarine system affecting not only it's overall health but also, it's resilience and capacity to recover and repair itself after being damaged by large-scale catastrophic events, like severe flooding. Direct losses were observed along most of the Boyne River estuary ranging from things like cutting

of riparian vegetation, installation of boat ramps, construction of bridges, and verge hardening with rock walls, encroachment and landfill replacement of tidal wetlands associated with urban expansion. This factor was observed along much of the Boyne estuary.



Figure 47: Where urban meets estuary, there appears the estuary often losses.

Direct Damage – Stock Damage (Fig. 48)

There are few if any fenced grazing properties along the waters' edge of this estuary. Cattle and other grazing stock have free access to intertidal areas where their presence causes serious impacts to mangrove and saltmarsh vegetation. Observations show the detrimental presence of footprints and tracks as well as direct grazing impacts on foliage, bark, stems and branches. There are even evidence of preferential grazing on *Avicennia* trees with other species trampled in order to get to individual trees.



Figure 48: Young mangrove seedlings after the flood event have a hard time when they can be easily grazed upon by hungry cattle.

Direct Damage - Vehicle Damage

Human access tracks were observed in many places along this estuary. Some were official and well-constructed, but there were many others consisting of little more than a cleared track through mangroves to the waters' edge. Further to these instances, there were places also

where vehicle access onto saltpan-saltmarsh areas had caused runnelling, damage to saltmarsh vegetation and unnatural ponding across expansive areas also littered with abandoned rusting vehicles. The damage to the integrity of the soil and vegetation is extensive.

Indirect Human Drivers



Figure 49: Access paths cut through the mangrove verge offer little protection for surrounding plants during the flood event.

Altered Hydrology - Restricted Flow (Fig. 49)

Also notable during the field surveys was the number of constructions affecting the natural flows of tides and river runoff. These have sometimes quite noticeable consequences with either sometimes dramatic effects like severe erosion, or sites of massive sediment deposits. These might arise after a particularly extreme flow event or storm, but they also occur during relatively benign weather conditions after some significant change has impacted natural runoff. Some examples observed along the estuary include ponded pastures, fish farm ponds, road and bridge verges, drain paths, and encroachment and land fill across tidal flats, and construction of bund walls and roads without adequate drainage.

Altered Hydrology - Waterway Barriers (Fig. 50)

Structures like the dam upstream combined with the number of breakwaters and constructed drains are all affecting the estuary. The impacts resulting from the dam range from: reduced flows into the estuary, less flushing during peak flow events, increased sediment deposition, and depositional gain. The observation made show that the impacts of this driver dominate the Boyne River estuary.



Figure 50: Boat ramps are common – so is the damage to connectivity and stability of estuary shorelines.

Pollutants – Nutrients (Fig. 51)

There were only a few field observations listing the presence of possible pollutant sources at places along the estuary. These mostly listed the presence of green algae covering exposed mud flats fronting mangroves. This is considered an indicator of excess nutrients in surrounding waters.



Figure 51: Exposed mud flats often have green surfaces where algae flourishes with the extra light and nutrients.

Natural Drivers

Climate and Weather Impacts

Bank Erosion

Bank erosion refers to the collapse and erosion of river banks. The frequency of this occurrence largely determines whether this is natural or not. For instance, where there is a corresponding amount of depositional gain (=expanding bank) as a direct counter process, used to quantify the net result of overall erosion or deposition of banks throughout the system. In this case, the erosion appears to be exceeding deposition. Bank erosion is accelerated in areas lacking riparian vegetation, the presence of fires damaging vegetation, vehicles damaging vegetation, and changes to the hydrology, including rising sea levels.

Saltpan scouring

Saltpan scouring was observed in many lower estuarine areas. It involves the sheet erosion of surface sediments across saltpans removing saltmarsh plants and establishment of broad drainage channels. This process is accelerated by vehicle damage, drought conditions and rising sea levels.

Depositional gain (Fig. 52)

Depositional gain is seen as the counter process to bank erosion along estuarine shorelines. It occurs where sediments accumulate in estuarine systems for other reasons like catchment vegetation clearing, tilled agriculture in the catchment, installation of weirs and dams blocking the normal tidal and river flow hydrology. The indicator for depositional gain is the occurrence of young seedlings in front of established frontal mangrove trees. The age of the young stand is indicative also of when new sediment levels on the mud bank exceed mean sea level making the site available for natural mangrove colonisation. As such, depositional gain is driven by sediment supply.



Figure 52: It may not be depositional gain, but there are patches of young plants growing on exposed banks in many places representing flood damage recovery. They only need a few years before they become more secure and less vulnerable.

Terrestrial retreat & upland migration

Loss of low-lying, terrestrial edge trees were noted in a few places. These were also associated with the upland establishment of young mangrove plants, often also accompanied by the

erosion of terrestrial verges around the highest tide levels. The indicators of terrestrial retreat were noted as the presence of eroding upland margins.

Light gaps

Few light gaps were observed along the Boyne shoreline. These unusual forest gaps are formed naturally by lightning strikes killing trees in small circular patches (Duke 2001). These patches are normally common and there is a distinct and ordered recovery process as the gaps are colonised by seedlings that progressively grow and fill the gap, returning the canopy to its uniform condition. The frequency of gaps observed in the Boyne estuary is low but normal.

Flood damage (Figs. 53 - 54)

Flood damage was notable along most of the Boyne estuary. The indicators observed were dead trees, standing and lying angled downstream and often covered in silt and occasionally either undermined or with roots buried under sediments. Flood damage recorded in the Boyne system dominates the overall condition of this heavily impacted estuary. More than half (57%) of fringing mangroves along the Boyne were severely impacted by flooding in 2013. Some of these areas have not since recovered.



Figure 53: Flood damage dominates most mangrove stands fringing the estuary.

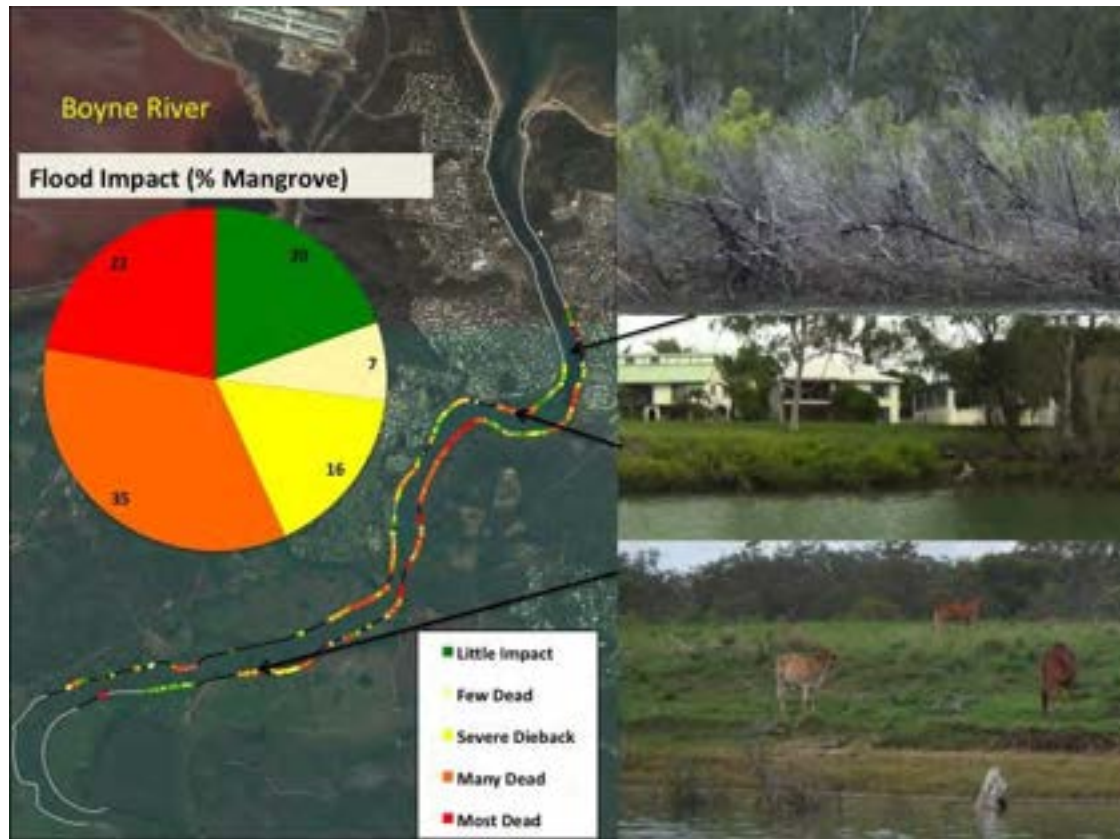


Figure 54: Flood damage was notable in the Boyne estuary. Shoreline video assessment method (S-VAM) surveys quantify mid-estuary sections with severe damage and loss of mangroves.

5.0 BAFFLE CREEK ESTUARY

Burnett Mary region

Mouth location:	-24.514920; 152.056042
Condition:	Near pristine, river & tide dominated
Area of tidal wetlands (Mackenzie & Duke 2011)	
Mangroves:	927 ha
Tidal saltmarsh and salt pans:	282 ha
Total tidal wetland:	1,209 ha
Wetland Cover Index:	80.0%
Mean Annual Rainfall (25yr mean):	1,054 mm
Catchment Area:	2,562 km ²



Figure 55: The mouth of Baffle Creek viewed looking upstream in 2008.



Figure 56: Achievements regards successful field surveys undertaken in the Baffle Creek estuary in collaboration with Gidarjil Rangers up to late 2018. Tracks (yellow lines) are shown on satellite images for 2017 and 2018.

Summary Description

Baffle Creek is a near pristine estuary located in a busy agricultural area (Fig. 55). The catchment has a diversity of natural habitats and some modified landscapes, including: seven threatened and endangered regional ecosystems, valuable freshwater wetlands, forestry and productive agricultural lands. Agriculture, primarily cattle grazing, is the primary land use. This relatively low-intensity agriculture has allowed much of the catchment to remain well vegetated. The river system is one of the last remaining larger systems not to have a significant waterway barrier. These qualities are reflected in the relatively good water quality throughout the system. The environmental values of downstream estuarine areas are protected by two Conservation Parks at the estuary mouth, and its declaration as a Fish Habitat A (DPI&F 2003). The habitat conditions of this estuary make it a popular location for local, recreational fishing-based tourism. Careful management is required to preserve these high conservation values. The estuary was surveyed in 2017 and 2018 by the Gidarjil Rangers (see Fig. 56).

Estuary Features

Physical setting. Baffle Creek estuary is a river-dominated system with a tide dominated delta. This estuary type has high sediment trapping efficiency with well mixed circulation and a low risk of habitat loss due to sedimentation (NLWRA 2002). Low turbidities are likely due to both the sandy substrate and unimpeded natural flows to reduce fine mud deposition. Proposed intensive landuse within the catchment puts Baffle Creek estuary at risk of high siltation rates and muddy sediment deposition directly threatening natural wetland habitats. The mouth of Baffle Creek estuary is dynamic and shifting north with bank erosion, sand deposition and channel infilling. Upstream, the estuary is characterised by steep banks, with a relatively narrow main channel flowing through high-cut rocky banks. A number of smaller creeks flow directly into Baffle Creek estuary including Eulielah Creek, Bottle Creek upstream and Duck Creek downstream. Overall there is currently a net loss of bank habitat within the estuary.

Estuarine zones (Fig. 57). Steep rocky cliffs dominate the estuary upstream of Sheep Station Creek. The morphology of these banks does not support sediment accretion and cause a narrowing of the channel resulting in higher flow velocities. These banks of low erosion risk also provide minimal habitat for tidal wetland colonisation upstream. Erosion was recorded as being high in the mid and lower estuary. High scores in the mid estuary are likely the result of bank destabilisation from cattle grazing as well as the effect of drought on estuarine hydrology. Most mid estuary erosion was observed to be inactive. Large depositional islands are a feature of the lower-mid sections of the estuary. These areas indicate that the freshwater-saltwater mixing zone in this estuary is much further downstream than in most nearby estuaries, highlighting the importance of freshwater flows to the natural hydrodynamics and estuarine ecology of Baffle Creek. A number of large remnant terrestrial islands which appear to have been historically connected to the mainland are another feature of the lower-mid estuary zone. Depositional islands within the estuary are mostly accreting on the downstream side, again highlighting that the estuary is primarily influenced by riverine flow. Tidal wetlands and seagrass rapidly colonise these depositional banks. A number of rocky outcrops, such as the rocky bar at Ferry Crossing, exist within the mid to lower sections of the estuary, adding to habitat complexity in the lower-mid zone.

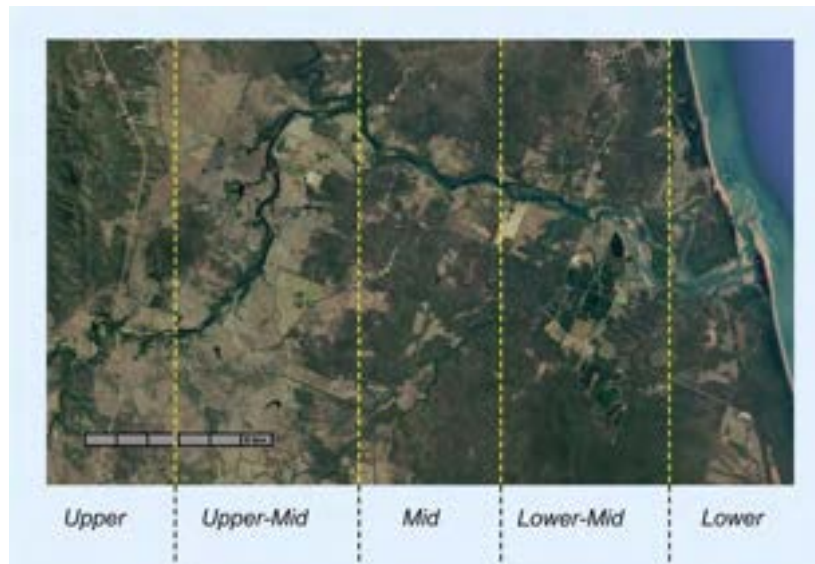


Figure 57: Estuary zones of Baffle Creek.

Changes to natural habitats. Changes to natural habitats are driven by a combination of human and natural drivers of change. Overall there has been a net loss of bank habitat within the estuary. Bank habitat loss may have implications for future coastal development planning. Urban development of the southern bank at Winfield had led to low-level bank modification, mostly in the form of erosion control. In other sections of the estuary, bank modification occurs widely as boat ramps and access points, indicating its high recreational use. Low levels of mangrove dieback and crown retreat were recorded throughout most of the estuary, particularly the lower and upper sections (Mackenzie and Duke 2011). Past drought conditions were likely to have stressed fringing mangroves communities. Upstream mangroves also were affected by frost. This was most noticeable with large patches of dead *Rhizophoras* recorded in 2008-9. More recent flooding has altered the relative area of these habitats (Duke et al. 2019) along with changes caused by direct human impacts.

Tidal wetland vegetation

Mangrove habitat (Fig. 58). Baffle Creek has moderate mangrove species diversity (Table 4). The estuary features all 11 local mangrove species (Duke 2006). This high species diversity is indicative of a large, undisturbed estuary with largely unimpeded freshwater flows. The dominant mangrove community type within the lower estuary are dense closed *Rhizophora* with fringing *Avicennia* communities backed by *Ceriops* stands. In the upper estuary the mangrove fringe consists mostly of *Avicennia-Aegiceras* with occasional plots of *Excoecaria*. Upstream, large areas of dead stands of *Rhizophora*, *Aegiceras* and *Excoecaria* appeared indicative of frost damage. A notable tidal wetland species in the estuary is the mangrove *Xylocarpus granatum*. Only one relatively young tree was found in the estuary (Mackenzie and Duke 2011). The closest known stand of this species is 100km to the south in the Burrum River. The area surrounding the tree was heavily grazed and this limited occurrence is notably threatened. Tidal wetland vegetation, with an 80% WCI, shows that it is dominated by mangroves more than would be expected for an estuary receiving low to moderate rainfall (see Duke et al., 2019). The area of mangrove (based on 2004 imagery) was expected to have

started to decrease in response to declining rainfall associated with ongoing drought over the previous decade.

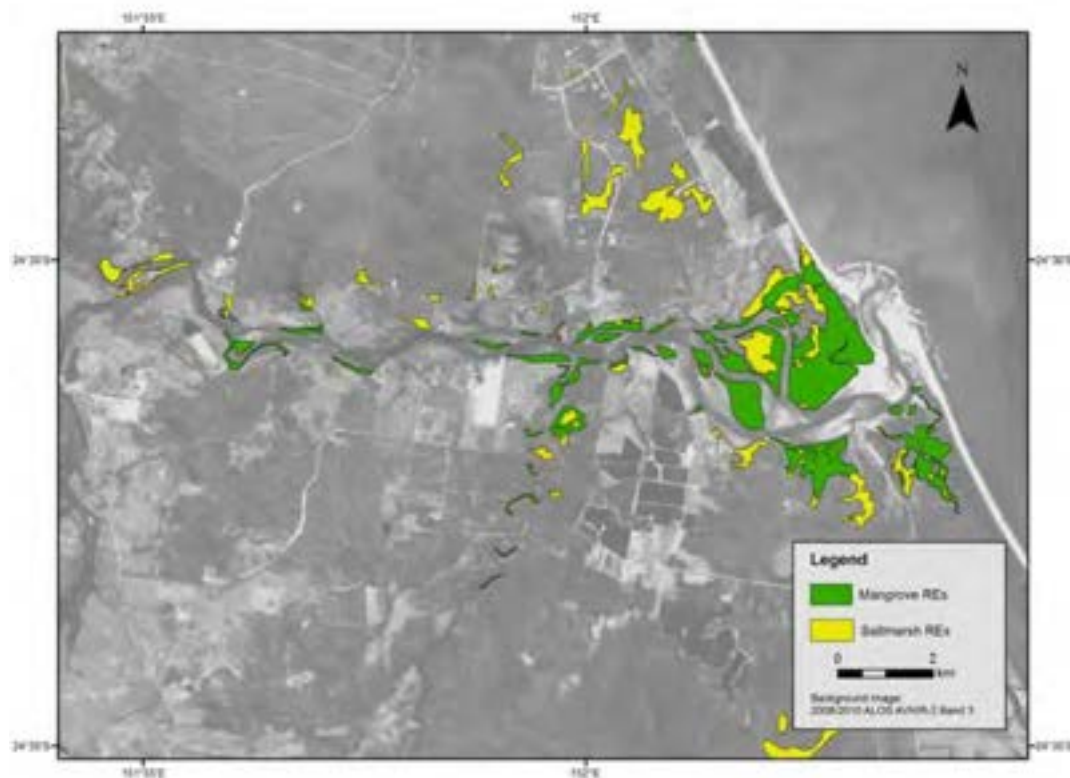


Figure 58: Baffle Creek showing mangrove and saltmarsh areas.

Saltmarsh-saltpan habitat. (Fig. 58). Baffle Creek has high saltmarsh species diversity (Table 4), but many species are limited to isolated patches within the estuary (Mackenzie and Duke 2011). The estuary features 13 of the 16 locally occurring saltmarsh species (Johns 2010). Saltmarsh extent in this estuary is limited by the steep tidal profile present throughout much of the estuary. The saltmarsh vegetation, dominated by *Chenopods* with few rushes present, is typical of estuaries receiving low to moderate rainfall and with limited groundwater influence at the terrestrial fringe. Dry salt pans dominate the majority of upper-intertidal areas of Baffle Creek, while *Sporobolus* is the dominant saltmarsh species. Most saltmarsh-pan areas are located in the lower estuary along Duck Creek, both on and opposite Long Island. Two uncommon saltmarsh species are present, *Atriplex semibaccata* and *Salsola australis*. One individual of each was observed in sandy upper-intertidal areas on the north bank. The saltmarsh-pans of Baffle Creek are severely impacted by cattle, and the intensive grazing and trampling has reduced vegetation coverage in most saltmarsh-pan areas.

Table 4: Tidal wetland plants recorded for the estuary of Baffle Creek (Mackenzie and Duke 2011).

Mangrove Species	Saltmarsh Species
<i>Acrostichum speciosum</i>	<i>Atriplex semibaccata</i>
<i>Aegialitis annulata</i>	<i>Baumea juncea</i>
<i>Aegiceras corniculatum</i>	<i>Fimbristylis ferruginea</i>
<i>Avicennia marina</i>	<i>Fimbristylis polytrichoides</i>
<i>Bruguiera gymnorhiza</i>	<i>Salsola australis</i>
<i>Ceriops australis</i>	<i>Sarcocornia quinqueflora</i>
<i>Excoecaria agallocha</i>	<i>Sesuvium portulacastrum</i>
<i>Lumnitzera racemosa</i>	<i>Sporobolus virginicus</i>
<i>Osbornia octodonta</i>	<i>Suaeda australis</i>
<i>Rhizophora stylosa</i>	<i>Suaeda arbusculoides</i>
<i>Xylocarpus granatum</i>	<i>Tecticornia halocnemoides</i>
	<i>Tecticornia indica</i>
	<i>Tecticornia pergranulata</i>

Biomass of tidal wetlands of the Baffle Creek estuary

Tree heights were recorded in satellite imagery and verified in field surveys. The overall height of mangrove vegetation across the broad tidal wetland areas of the Calliope River are relatively low, around 3-5 m or less. This is consistent with areas of relatively low rainfall. Taller stands were notably observed in most upstream tributaries, as depicted in maps and imagery (Fig. 59).

The zone immediately above the tidal wetland zone (i.e., 1m > HAT) refers to the supra tidal zone. The vegetation in this zone is considered vulnerable to a number of human and natural factors, including vehicle access, reclamation damage, severe storms, flooding, feral pigs, exotic weeds, and sea level rise. The patterns described in tidal wetlands appeared matched by cover heights of the supratidal vegetation.

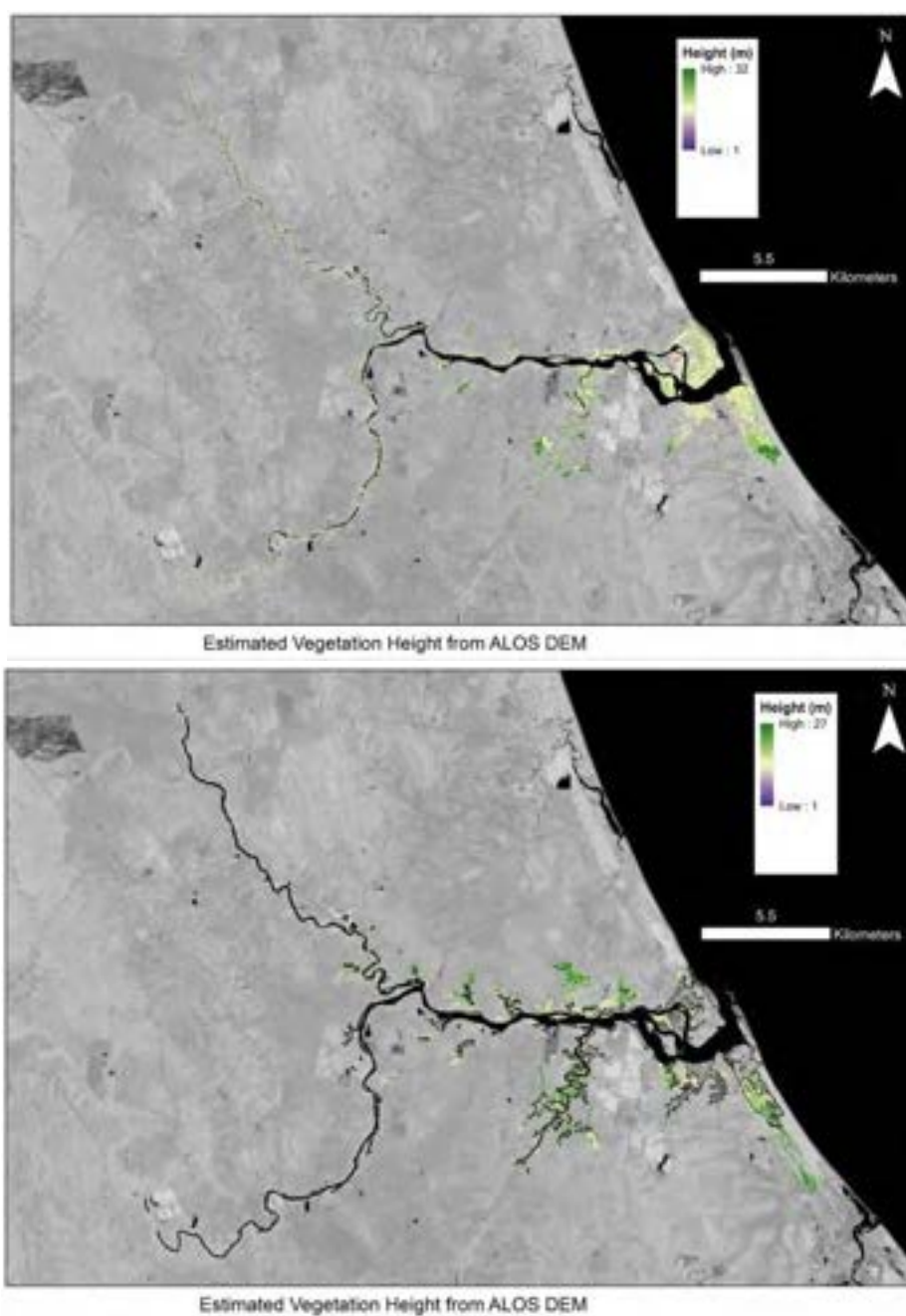


Figure 59: Satellite images of Baffle Creek estuarine areas showing height of vegetation for A) tidal wetlands (MSL-HAT) and B) the supra tidal zone (HAT +1m) for 2010 using ALOS DSM.

Changes taking place in tidal wetlands of Baffle Creek estuary

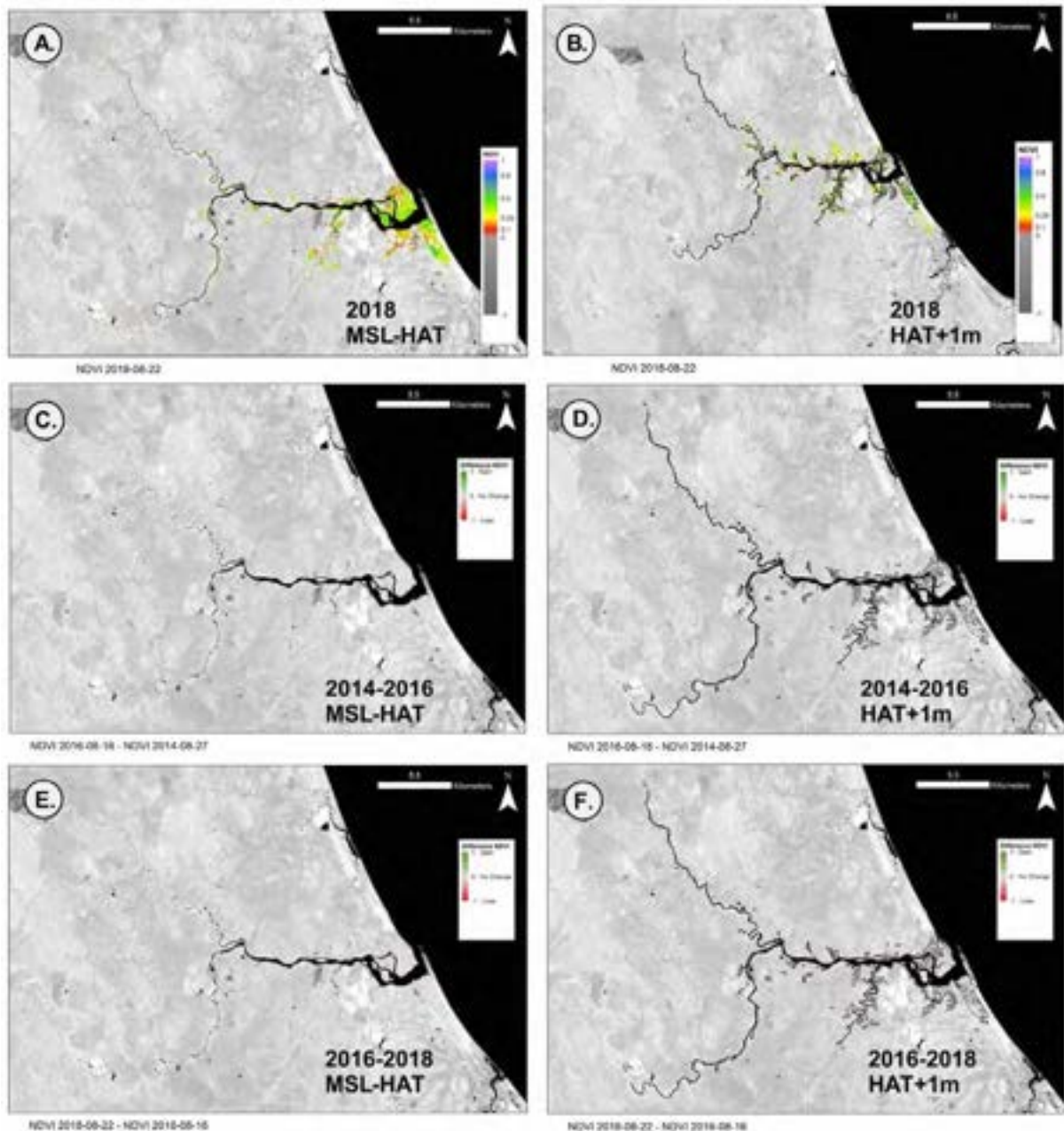


Figure 60: Satellite images of the Baffle Creek estuarine areas showing NDVI measures of vegetation condition for tidal wetlands (MSL-HAT) and supra tidal zone (HAT +1m) for 2018 (A & B), and two change detection periods 2014-2016 (C & D) and 2016-2018 (E & F).

A first evaluation of changes to vegetation cover was made using vegetation indices (like NDVI) from satellite imagery (Fig. 60). The indices for specific dates represent measures of sub-lethal condition at the time (A & B for 2018 – for tidal wetlands, and supra tidal areas respectively). Colours towards the red end of the scale show vegetation in relatively poor condition while that at the green-blue end is notably healthier. In the 2018 views, tidal wetlands and supra tidal vegetation were in poorer condition upstream and along upper landward margins. When change detection was done comparing scenes from two different time periods (C-F), the scales from red to green indicate relative losses or gains. Comparison of two time periods showed notably different responses where losses suffered in one time period might show gains with

recovery in a subsequent time period. The time periods shown in the figure include 2014-2016 (C & D) and 2016-2018 (E & F). In this case, there appeared to be similar responses during both periods. In each period, the tidal wetlands downstream showed overall low levels of loss. The supra tidal response however was mixed with some notable gains in the first period, and losses in the second notably at mid-stream sites.

Management issues registered at community workshops

Key issues flagged at 2016 and 2017 community workshops included cattle grazing, vehicle access damage and dieback of *Avicennia* mangroves (see Fig. 61).

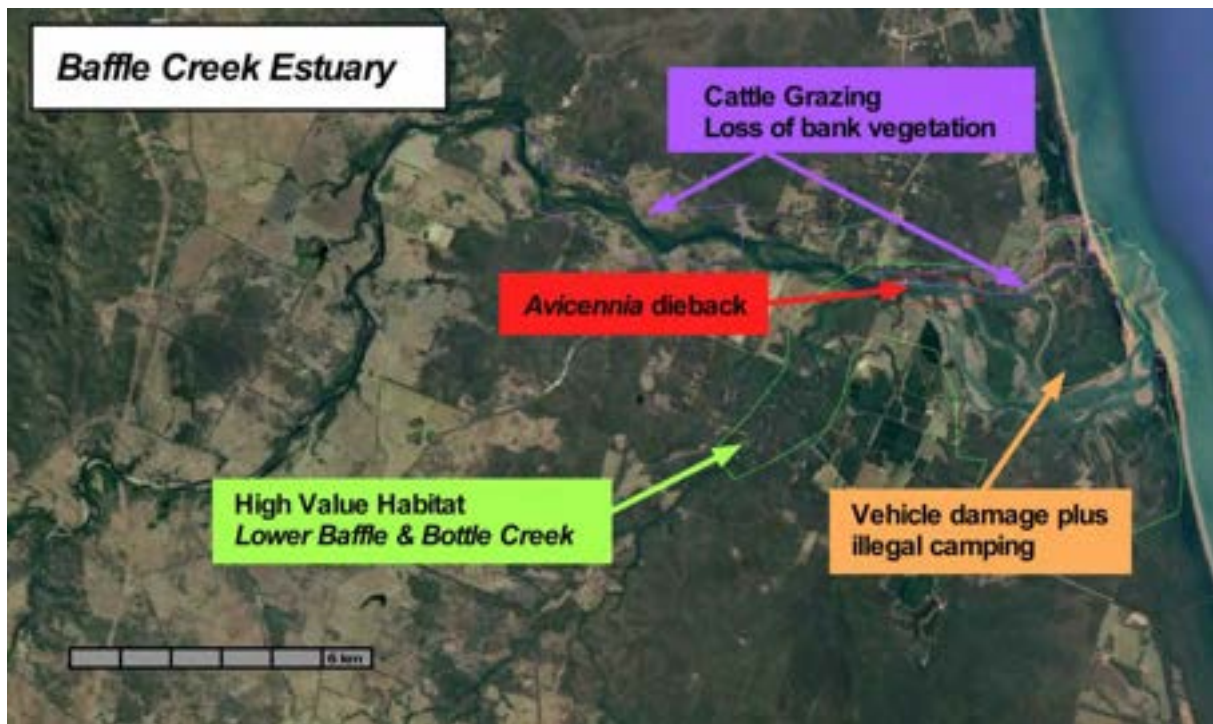


Figure 61: Digitised outcomes of the workshop community-based participatory mapping of Baffle Creek tidal wetland management issues.

Baffle Creek is a sand dominated estuary with fine oceanic sand present at the mouth, sandy mud banks in the mid estuary and coarse sand and mud upstream. The mouth of Baffle Creek is highly dynamic, moving north and widening. Rapid erosion has resulted in a significant loss of tidal wetland and dune vegetation on the northern bank. It is estimated that the main river channel has moved north by almost 50m in the last 15 years. Consequently, many logs and trunks litter the mouth of the estuary, creating a navigational hazard.

Oceanic influence, increased through recent drought conditions, has contributed to a net loss of bank through erosion in the lower estuary. This bank erosion is coupled with increased siltation at the entrance of tidal channels on both sides of the lower estuary. Siltation has greatly altered the hydrological regime of these channels, reducing tidal flow and exacerbating siltation upstream. Tidal wetland condition and water quality within these channels is consequently affected. Orange water, often a sign of acid leaching from acid sulphate soils,

was observed during aerial surveys in the upper reaches of Mullet Creek, located in the southern Mouth of Baffle Creek Conservation Park.

Large depositional islands (Fig. 62) are a characteristic feature of the lower-mid sections of the Baffle Creek estuary. These areas indicate that the freshwater/saltwater mixing zone in this estuary is much further downstream than in most nearby estuaries, highlighting the importance of freshwater flows to the natural hydrodynamics and estuarine ecology of Baffle Creek. A number of large remnant terrestrial islands which appear to have been historically attached to the mainland are another feature of the lower-mid estuary zone. Depositional islands within the estuary are mostly accreting on the downstream side, again highlighting that the estuary is primarily influenced by riverine flow. Tidal wetlands and seagrass rapidly colonise these depositional banks. A number of rocky outcrops, such as the rocky bar at Ferry Crossing, exist within the mid to lower sections of the estuary, adding to habitat complexity in the lower-mid zone.



Figure 62: Large depositional banks are common throughout Baffle Creek estuary. Note the dieback (grey tinge) of fringing *Casuarina* as a result of drought.

Steep rocky cliffs with rocky outcrops dominate the estuary upstream of Sheep Station Creek. The morphology of these banks does not support sediment accretion and cause a narrowing of the channel resulting in higher flow velocities. These banks also provide minimal habitat for tidal wetland colonisation upstream.

The rocky banks of the upper estuary result in low erosion risk. Erosion was recorded as being high in the mid (3) and lower (1) estuary. High scores in the mid estuary are likely the result of bank destabilisation from cattle grazing as well as the effect of drought on estuarine hydrology. Most mid estuary erosion was observed to be inactive, and it is likely that erosion in the mid estuary zone is counteracted by instream deposition, a factor not recorded during the RAP survey.

At the mouth of the estuary the northern bank is a site of rapid active erosion. Significant bank loss has occurred over the past 15 years, possibly resulting from increased oceanic influence linked to low freshwater flows. Whilst deposition was not recorded on the alternate southern bank, infilling of the tidal channel in the Mouth of Baffle Creek Conservation Park was observed.

Overall there is currently a net loss of bank habitat within the estuary; however the rate of loss is not a current issue of concern within Baffle Creek. Bank habitat loss may nonetheless have implications for future coastal development planning. Urban development of the southern bank at Winfield has generated some low level bank modification, mostly in the form of erosion control. In other sections of the estuary, bank modification is widely boat ramps and access points, indicating the high recreational value of the river.

Environmental management issues in the Baffle Creek estuary

- Cattle grazing in the intertidal zone (Fig. 63).
- Litter and erosion control
- Agricultural intensification
- Increased urbanization
- Increased water extraction and proposed water storage
- Catchment modification



Figure 63: Cattle amongst the mangroves in the mid estuary.

Baffle Creek estuary has high conservation value. However, these values are threatened by both direct and indirect anthropogenic drivers of change present within and adjacent to the estuary. The primary direct threat to the estuary environment is cattle. Heavy grazing of saltmarsh and mangroves has significantly reduced the resilience of these habitats to natural pressures such as drought and frost. Cattle trampling disturbs tidal wetland sediments, leading to increased erosion, raised turbidity and hence lowered water quality both within the estuary and extending to the nearby southern Great Barrier Reef. Cattle dung in the tidal zone is also likely to contribute to nutrient import into the estuary during high tides, contributing epiphytic algae growth on seagrass. Whilst some efforts have been undertaken to restrict cattle grazing in declared conservation zones, more effort must be made to limit cattle grazing in intertidal

areas adjacent to private land. This is obviously a complex issue, but one that is necessary if the ecological values of Baffle Creek are to be maintained.

Near urban areas, local residents concerned about bank erosion have utilised low-cost, macro refuse such as tyres and concrete slabs to control erosion. Residents should be discouraged from using macro-refuse to buffer erosion as these rarely work and create an eyesore, reducing the aesthetic value of the river. Alternatives such as groynes and baffles, integrated with mangrove gardens, should be encouraged and investigated further.

Recent expansion of intensive forestry production (macadamias; Fig. 64) and increased population pressure within the Baffle Creek area have the potential to threaten the ecological integrity of the estuary if careful management and planning are not in place. Freshwater and groundwater extraction can limit freshwater flows into the estuary, affecting tidal wetlands that are reliant on groundwater and periodic freshwater flows. Agricultural and urban runoff has the potential to reduce water quality values within the estuary if not managed adequately, threatening all estuarine habitats.



Figure 64: Macadamia farm adjacent to the Baffle Creek estuary.

Increased water extraction and proposed water storage

Water storage impoundments and restricted freshwater flows within the estuary and upstream should be avoided as the estuarine habitats, particularly seagrass, are heavily reliant on continuous flow to maintain estuary flushing.

Catchment modification

Riparian vegetation upstream and catchment vegetation should be maintained to limit sediment and nutrient flows into the estuary. Drought conditions have the potential to mask the effects of catchment land use intensification until rainfall events. Continued water quality monitoring, with particular emphasis on event based monitoring is required to detect catchment degradation and apply the appropriate management response.

Recommended management actions:

- Reduce cattle grazing and cattle access in tidal wetland areas by exclusion or adoption of a grazing management plan.
- Limit freshwater and groundwater extraction
- Provide legislative protection to Baffle Creek to prevent future construction of water storage facilities along Baffle Creek.
- Establish a protective buffer zone along the estuary to limit intensive urbanization of estuary banks.

Drivers of change up to 2018

Baffle Creek estuary – chief drivers, condition & threats – a summary			
Drivers of Change	Severity*	Scale*	Score**
<i>Direct Human Drivers</i>			
Direct Damage - Cattle Grazing	5	4	20
Direct Damage - Vehicles	2	2	4
Direct Damage – Cutting/Clearing	5	2	10
<i>Indirect Human Drivers</i>			
Faunal Damage (Bats)	3	1	3
Depositional gain	1	2	2
Bank Erosion – Riparian Clearing	4	2	8
<i>Natural Drivers</i>			
Bank Erosion	5	2	10
Altered Hydrology - Channel infilling	1	1	1
Drought - Ecotone Shift	5	1	5
Frost	2	2	4
Flood Damage	4	3	12
Human Impact Score			47
Overall Condition Score:			79
* ranking of 5 condition levels – minimal to high impact			
**overall measure is the multiple of severity and scale scores			
Threats to tidal wetland condition:-			
1. Cattle Grazing			
2. Extreme weather events – flooding, drought and frost			
3. Cutting and clearing of mangroves			

Descriptions of management issues and drivers of change

Direct Human Drivers

Direct Damage - Cattle Grazing (Fig. 65).

Cattle grazing was observed in most accessible mangrove areas and all saltmarsh areas within Baffle Creek. The impact of grazing is severe and ongoing. Trampling of saltmarsh areas has greatly reduced vegetation cover and *Sporobolus* saline grasslands are heavily grazed with vegetation height being only a few millimetres. Sediment disturbance is likely to have resulted in saltmarsh surface erosion during flooding. Grazing of mangrove margins following flooding limits mangrove recovery and exacerbates erosion risk during extreme flood events. Cattle grazing therefore limits ecosystem resilience to natural climate events

It has previously been reported that stocking rates along the Baffle Creek estuary are high leading to reduced ground cover and impacts to freshwater and marine wetland ecosystems. Heavy stocking rates are likely to contribute to elevated sediment inputs to the estuary during high-rainfall events contributing to the extensive levels of sediment deposition within the estuary and offshore transport to the southern GBR.



Figure 65: Cattle grazing mangrove margins threatens mangrove flood recovery and increases erosion risk.

Direct Damage - Vehicle Damage

Vehicle tracks were observed in the saltmarsh/saltpan areas near the township of Winfield. The vast majority of tracks were from trail bikes. Density of tracks was low, suggesting minimal use. Small roads have been created through tidal wetlands along much of the estuary to access the water and boat ramps. The observed impact of these roads was minimal, but such roads are likely to be influencing surface flows and local hydrology.

Direct Damage – Cutting/Clearing (Fig. 66).

Mangrove trimming and clearing of mangroves for shoreline access is apparent along much of the lower and mid estuary. Following flooding, opportunistic mangrove removal and seedling removal appears to be occurring adjacent to settlements and campsites. There appears to be an increasing number of uncontrolled access points along the river. Direct damage to mangroves following flood events limits mangrove recovery leading to reduced shoreline

mangrove cover. Habitat fragmentation for shoreline access decreases habitat resilience to flood events and limits fish habitat values. Uncontrolled access points are also sites of sediment erosion leading to increased sediment loads in the estuary. Preventing mangrove establishment following flood events is likely to lead to an overall loss of shoreline mangrove habitat. There is at least one instance of an abandoned vessel resulting in direct mangrove damage



Figure 66: Recent mangrove removal for shoreline access

Indirect Human Drivers

Wildlife Displacement – Bats (Fig. 67).

A large colony of flying foxes have colonised a tall mangrove stand ~800m² in an area on the north bank near the estuary mouth. Bat populations have increasingly been taking up residency in mangroves as a result of habitat destruction elsewhere. Bats can cause significant damage to mangroves by causing foliar leaf loss and increasing sediment anoxia with droppings. Species not able to withstand physical damage, such as those in the *Rhizophoraceae* family will die if the colony persists over an extended period. The colony in Baffle Creek is within a mixed *Avicennia/Rhizophora* community and will therefore likely cause a change in species composition within that area. The bat colony has been present in this location for over 10 years and appears to be increasing in size.



Figure 67: Flying fox colony, Baffle Creek.

Bank Erosion (Fig. 68).

Riparian vegetation removal and cattle grazing along estuary banks has contributed to bank destabilisation in the estuary resulting in bank erosion during flood events. Narrow mangrove margins in the upper estuary are not sufficient to prevent this erosion and shoreline retreat contributes to a loss of mangrove habitat. Estuary bank erosion is likely a significant contributor to sediment loads from Baffle Creek entering the southern GBR. These estuary banks are particularly vulnerable following severe flood damage to the remnant mangrove margin. Camp sites and uncontrolled access further contribute to shoreline erosion risk. Some areas of recent shoreline erosion are recovering with new mangroves present along the shoreline leading to some level of stabilisation.



Figure 68: Bank erosion along poorly vegetated and grazed shoreline in Eulilah Creek.

Depositional Gain (Fig. 69).

Islands within the estuary are expanding through sediment deposition and mangrove colonisation. Recently low flows and less frequent flood events have enabled mangrove colonisation and stabilisation of these depositional banks. *Rhizophora* on these banks were aged using the leaf-node scar count method to identify the age of the banks. The oldest trees were recorded as being 10-15 years old, consistent with the recent drying period.



Figure 69: Depositional bank of riverine sediments with mangrove colonisation, Baffle Creek.

Natural Drivers

Bank Erosion (Fig. 70).

The mouth of Baffle Creek is a highly dynamic zone. Severe active erosion is limited to the mouth of the estuary. Oceanic influence appears to be increasing in this zone, potentially exacerbated by recently lower flows and less frequent flood events associated with low rainfall.



Figure 70: Bank erosion in the lower estuary with channel migration into upper-intertidal mangrove forest.

The estuary mouth is rapidly moving (Fig. 71) eroding large areas of mangrove. Further upstream, exposed eroding banks are present opposite depositional islands which have narrowed and shallowed the main channel. Shoreline erosion and associated mangrove loss is likely to increase with rising sea levels.



Figure 71: The mouth of Baffle Creek estuary in 2002 (left) and 2018 (right) showing coastal shoreline retreat and development of depositional islands.

Altered Hydrology - Channel infilling (Fig. 72)

The movement of the estuary mouth to the north and recent low rainfall has resulted in subsequent infilling of the south tidal channel in the Mouth of the Baffle Creek Conservation Park. Some mangrove dieback of older trees was observed along the channel, but mostly rapid mangrove colonisation was occurring, predominantly *Aegialitis*.



Figure 72: Natural sand deposition at the entrance of a creek running through the southern Mouth of Baffle Creek Conservation Park is affecting tidal flows to tidal wetland areas in the park area.

Frost Damage.

Frost impacts upstream mangroves. Frost has been known to significantly influence *Rhizophora* distribution and more frequent frosts are likely to influence this species' distribution within Baffle Creek.

Ecotone Shift (Drought) (Fig. 73).

Past drought conditions greatly affected mid-estuary mangrove communities at the landward fringe and saltmarsh vegetation, causing an increase in unvegetated saltpan area. However, it is very likely that the effects of drought were exacerbated by cattle grazing, trampling and sediment disturbance. Ecotone shift was most evident on and adjacent to Long Island and in Duck Creek, near Winfield. It appears that past observations of negative ecotone shift have since recovered due to higher rainfall conditions and rising sea level over the last decade.

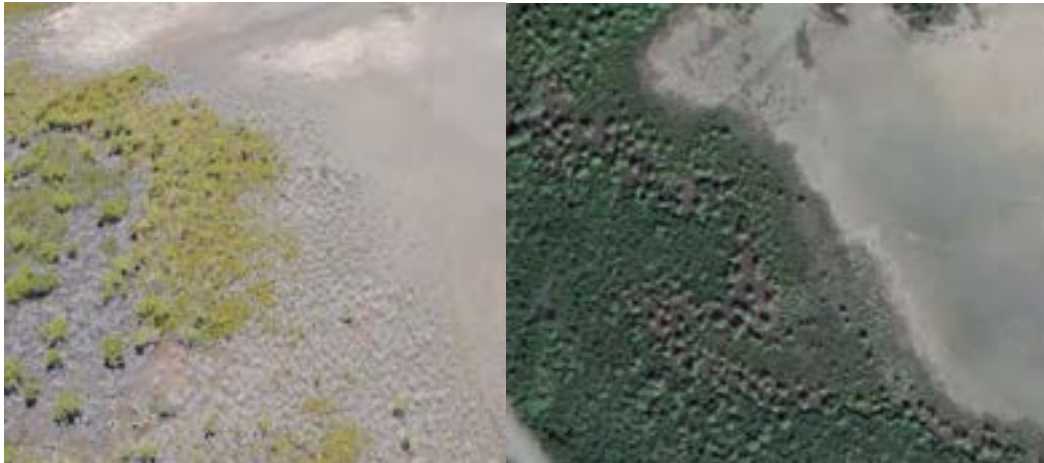


Figure 73: Drought induced mangrove dieback on the landward fringe, indicative of negative ecotone shift; mangrove to saltpan-saltmarsh in 2008 (left) and the same area showing positive ecotone shift and recovery in 2018 (right; image: Google Earth).

Flood Damage (Fig. 74).

Recent severe flooding has greatly impacted fringing mangroves along Baffle Creek throughout the estuary. Most narrow fringing mangroves in the mid and upper estuary which were inundated by flooding were either physically damaged by floodwaters, experienced extended inundation periods beyond physiological tolerance or had root systems exposed by erosion or smothered with sediment. Large-scale erosion of mangroves has occurred along the northern lower estuary. Flood-related mangrove losses may be offset by the formation of mud deposits in the mid estuary, suitable for mangrove colonisation. There is evidence that some mangrove areas are recovering following flooding.



Figure 74: Flood impacted mangroves in 2017 showing recovery (left) and limited recovery (right).

6.0 KOLAN RIVER ESTUARY

Burnett Mary region

Mouth location:	-24.666562; 152.204764
Condition:	Modified, river-tide dominated
Area of tidal wetlands (Mackenzie & Duke 2011)	
Mangroves:	858 ha
Tidal saltmarsh and saltpans:	111 ha
Total tidal wetland:	969 ha
Wetland Cover Index:	89.0%
Mean Annual Rainfall (25yr mean):	963 mm
Catchment Area:	2,902 km ²



Figure 75: The mouth of Kolan River and the Kolan River Conservation Park in 2008.



Figure 76: Achievements regards successful field surveys undertaken in the Kolan River estuary in collaboration with Gidarjil Rangers up to late 2018. Tracks (yellow lines) are shown on satellite images for 2013, 2016 and 2018.

Summary Description

The Kolan River estuary was declared a Fish Habitat Area (B) in 1983 (DPI&F 2008) (Fig. 75). This declaration recognises the value of the estuary as an important fish habitat. Another significant feature of the Kolan River estuary is the 622ha Mouth of Kolan River Conservation Park. Despite these conservation measures, the catchment area has been notably altered by intensive agriculture, in particular sugarcane production and widespread cattle grazing. Significant hydrological changes include installation of the weir have severely affected water flows and natural connectivity. These changes affect the significant water resources of the Kolan noting deterioration in water quality, area of tidal wetlands and estuarine habitat condition throughout the system. For instance, the river estuary is characterised by unusual and extreme sedimentation. In summary, both tidal wetland habitat complexity, and the quality of habitat condition are low. Agricultural runoff and hydrological changes have made these tidal wetlands particularly vulnerable to the anticipated impacts of climate change and rising sea levels. The estuary was surveyed in 2013, 2016 and 2018 by the Gidarjil Rangers (see 76).

Estuary Features

Physical setting. Agriculture and waterway barriers along the Kolan River and its major tributaries have been severely and detrimentally managed, seriously degrading natural water flows and water quality. Where this river system is one of the most highly modified systems in the region, it is also considered a major contributor of harmful sediments and nutrients to southern Great Barrier Reef waters. Large sections of the estuary have been cleared of riparian vegetation. Agricultural landuse has in some places expanded to the edge of the tidal zone and tidal areas have been reclaimed for cropping. Most agricultural land in this estuary lacks a significant environmental buffer. As a result, there is increased bank erosion and slumping which contributes to sedimentation of the estuary. Historical clearing of freshwater wetlands and restriction of natural freshwater flows for agricultural purposes have contributed to decreased water quality in the estuary. The Kolan is characterised by high levels of nutrients, high turbidities and low flows. Chemicals such as the herbicides Diuron and Atrazine have also been recorded at high levels within the estuary (Prange & Duke 2005; GBRMPA 2001).

Estuarine zones (Fig. 77). The mouth of the Kolan estuary is sand-dominated and dynamic. The estuary downstream is characterised by depositional mud banks and shallow bars. A long sandy spit at the entrance provides some protection but much of these deposits have eroded and shifted northward. On the southern bank, the depositional areas are rapidly accreting as the mouth shifts northwards. On the northern bank, a rock wall and groins have been constructed to protect Miara caravan park. Sediment deposition within the river has left the river shallow and lacking a significant navigation and flow channels throughout the lower estuary. Accreting depositional banks have formed on most inside bends of the river and these provide suitable habitat for tidal wetland expansion and colonisation. Upstream, banks become steeper with evidence of significant bank slumping caused by the removal of riparian vegetation and cultivation of the river edge. Exposed rock is present on some banks and closer to the barrage. Exposed rock anchors the formation of small mangrove islands in the upper estuary near the tidal barrage. The length of the estuary has been significantly reduced by the tidal barrage.



Figure 77: Estuary zones of the Kolan River

Changes to natural habitats. Changes to natural habitats are driven by a combination of human and natural drivers of change. Of primary importance for the Kolan River estuary, the presence of the tidal barrage so close to the mouth is likely to have reduced its resilience to climatic shifts and extremes. For instance, recent drought conditions resulted in a reversing of the salinity profile upstream (Mackenzie and Duke 2011). The increased salinities, exceeding seawater levels, upstream severely affected fringing mangrove communities. It is likely that fish populations and other aquatic species would have been even severely impacted. This situation exemplifies the reasons for conserving environmental flows, even during drought conditions. Many of the environmental issues in the Kolan estuary are further exacerbated with there being little or no riparian buffers between agricultural activities and estuary waters. The issue of bank erosion and sediment, nutrient and chemical pollution, could be ameliorated rapidly with the successful establishment of vegetation buffers and bank restoration for the damaged tidal wetland margins.

Tidal wetland vegetation



Figure 78: Kolan River estuary showing mangrove and saltmarsh areas.

Mangrove habitat (Fig. 78). The Kolan River has moderate mangrove species diversity (Table 5) with eight of the 11 locally occurring mangrove species (Duke 2006) being represented within the estuary (Mackenzie and Duke 2011). All eight of these species occur within the tidal wetland area around the mouth. Three are present further upstream, where *Avicennia*, *Aegiceras* and *Excoecaria* are tolerant of the high and low salinity extremes associated with the influence of the barrage. The dominant species within the estuary are *Avicennia marina* and *Aegiceras corniculatum*. The most dominant is *A.marina* in all but upstream sections of the estuary where *A.corniculatum* dominates. The dominance of *A.marina* in these near tropical latitudes is indicative of highly stressed tidal wetland habitats. Three species are notably absent from the Kolan River including: *Acrostichum speciosum*, *Bruguiera gymnorhiza* and *Xylocarpus granatum*. The first two would have been effectively lost from the system following construction of the barrage with its influence on salinity extremes in upstream sections of the estuary. On the other hand, *Xylocarpus* was not well-represented in any of estuaries north of Great Sandy Straits. And, the Kolan River lacks the upper-intertidal, riparian habitats needed to support this species.

Table 5: Tidal wetland plants recorded for the estuary of the Kolan River (Mackenzie and Duke 2011).

Mangrove Species	Saltmarsh Species
<i>Aegialitis annulata</i>	<i>Fimbristylis polytrichoides</i>
<i>Aegiceras corniculatum</i>	<i>Sarcocornia quinqueflora</i>
<i>Avicennia marina</i>	<i>Sesuvium portulacastrum</i>
<i>Ceriops australis</i>	<i>Sporobolus virginicus</i>
<i>Excoecaria agallocha</i>	<i>Suaeda australis</i>
<i>Lumnitzera racemosa</i>	<i>Suaeda arbusculoides</i>
<i>Osbornia octodonta</i>	<i>Tecticornia halocnemoides</i>
<i>Rhizophora stylosa</i>	<i>Tecticornia indica</i>

Saltmarsh-saltpan habitat (Fig. 78). Saltmarsh vegetation is under-represented in the Kolan river system (Table 5). The estuary is considered poor in saltmarsh species since the habitat conditions does not suit these species. Saltmarsh in the Kolan system is dominated by *Sporobolus* grasslands or patchy *Tecticornia* communities present on drier saltpans. In some areas where freshwater inputs to the tidal wetland area have been restricted, there has been a recent increase in saltpan area. This was observed at the upstream portion of the Mouth of the Kolan River Conservation Park (Mackenzie & Duke 2011).

Biomass of tidal wetlands of the Kolan River estuary

Tree heights were recorded in satellite imagery and verified in field surveys. The overall height of mangrove vegetation across the broad tidal wetland areas of the Calliope River are relatively low, around 3-5 m or less. This is consistent with areas of relatively low rainfall. Taller stands were observed in upstream reaches of smaller tributaries, as depicted in maps and imagery (Fig. 79).

The zone immediately above the tidal wetland zone (i.e., 1m > HAT) refers to the supra tidal zone. The vegetation in this zone is considered vulnerable to a number of human and natural factors, including vehicle access, reclamation damage, severe storms, flooding, feral pigs, exotic weeds, and sea level rise. The majority of stands surrounding the estuary appeared to be of very short stature except for a few isolated patches.

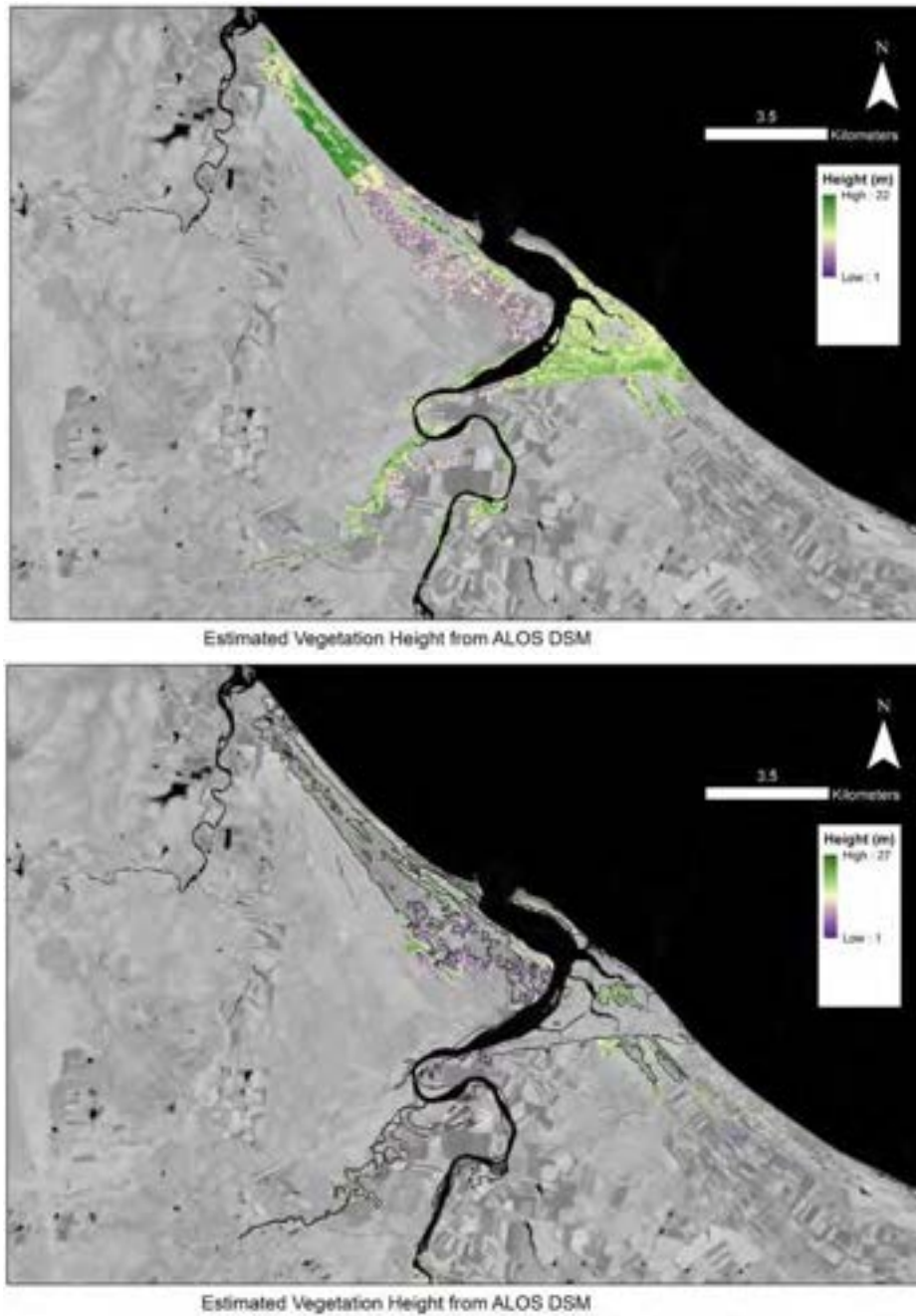


Figure 79: Satellite images of the Kolan River estuarine areas showing height of vegetation for A) tidal wetlands (MSL-HAT) and B) the supra tidal zone (HAT +1m) for 2010 using ALOS DSM.

Changes taking place in tidal wetlands of the Kolan River estuary

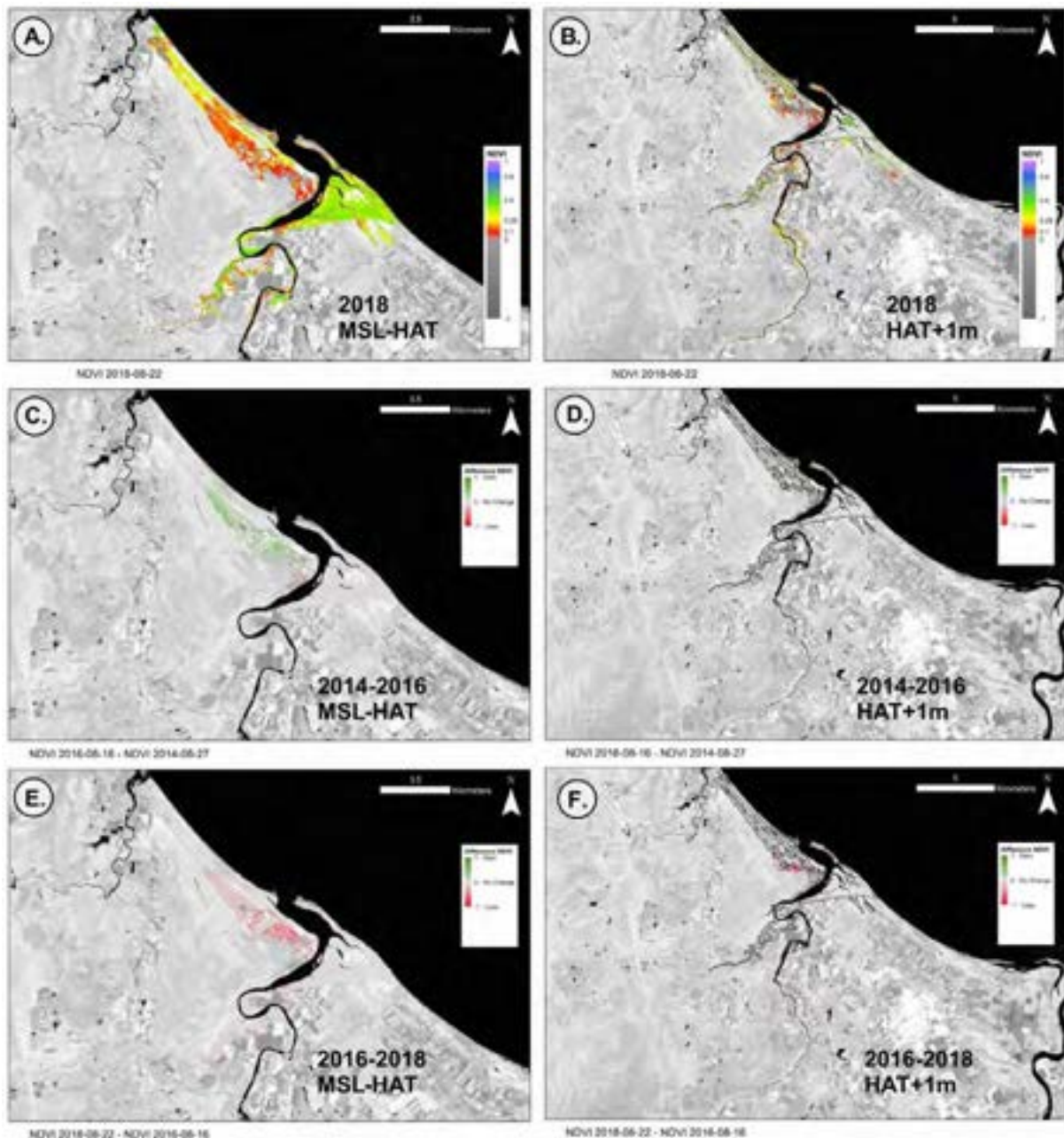


Figure 80: Satellite images of the Kolan River estuarine areas showing NDVI measures of vegetation condition for tidal wetlands (MSL-HAT) and supra tidal zone (HAT +1m) for 2018 (A & B), and two change detection periods 2014-2016 (C & D) and 2016-2018 (E & F).

A first evaluation of changes to vegetation cover was made using vegetation indices (like NDVI) from satellite imagery (Fig. 80). The indices for specific dates represent measures of sub-lethal condition at the time (A & B for 2018 – for tidal wetlands, and supra tidal areas respectively). Colours towards the red end of the scale show vegetation in relatively poor condition while that at the green-blue end is notably healthier. In the 2018 views, the observations are mixed. While there is considerable stress amongst tidal wetland and supra tidal stands north of the mouth, those to the south appear to be in good condition. Upstream there appears to be greater stress on upper tributary stands.

When change detection was done comparing scenes from two different time periods (C-F), the scales from red to green indicated relative losses or gains. Comparison of two time periods showed notably different responses where losses suffered in one time period might show gains with recovery in a subsequent time period. The time periods shown in the figure include 2014-2016 (C & D) and 2016-2018 (E & F). By comparing C & E, it can be seen that the stressed tidal wetland and supra tidal areas to the north of the mouth and upstream appeared to become prominent in the recent period while the areas south of the mouth appeared to have little or no change.

Management issues registered at community workshops

Key issues flagged at 2016 and 2017 community workshops included direct loss, cattle grazing, vehicle access damage, lack of buffers and dieback of saltmarsh (see Fig. 81).



Figure 81: Digitised outcomes of the workshop community-based participatory mapping of Kolan River tidal wetland management issues.

Environmental management issues in the Kolan River estuary

- Erosion and sediment deposition
- Altered hydrology
- Climate change
- Chemical and nutrient pollution

The Kolan River is one of the most modified estuaries in the Burnett Mary region. The primary environmental management issue in the Kolan River are bank erosion and sedimentation. Whilst there is evidence to suggest that these processes are natural to some extent, they have most certainly been exacerbated by historical landuse practices and the construction of a tidal barrage. The historic removal of tidal wetland and freshwater wetland area through reclamation and clearing of riparian vegetation for cropping, removed effective environmental buffers in much of the mid and upper estuary. Consequently, intensive cropping has direct connectivity

to the estuary, contributing sediments, nutrients and chemicals to the estuarine environment and southern Great Barrier Reef. Without extensive efforts to restore riparian vegetation to the estuary banks, bank slumping and erosion will continue with associated sediment inputs to the estuary. Continued sedimentation will reduce the navigability of the estuary and may block tidal flow into the large tidal wetland area at the mouth.

The presence of a tidal barrage so close to the mouth is likely to reduce the resilience of the estuary to climatic shifts and extremes due to limiting freshwater supply to the estuary during low rainfall periods.

Many of the environmental issues in the Kolan estuary are associated with there being little or no environmental buffer between agriculture and the estuary. The issue of bank erosion and sediment, nutrient and chemical pollution, may be ameliorated with the inclusion of a vegetation buffer and tidal wetland restoration in some areas.

It is concerning that in the decade since the publication of the *State of the Mangrove Report* (Mackenzie & Duke 2011), little to no action has been taken to protect and restore tidal wetlands in the Kolan estuary.

Recommended management actions:

- Develop and implement a shoreline erosion management plan which includes innovative integration of hard and soft engineering strategies, including mangrove gardens.
- Reduce sediment, nutrient and chemical inputs to the estuary through the establishment of vegetation buffers and tidal wetland restoration.
- Maintain or increase environmental freshwater flows to the estuary.
- Implement a tidal wetland restoration program at the Miara boatramp to protect threatened sub-tropical saltmarsh habitat.
- Educate estuary landholders of the importance of tidal wetlands to local and regional economies (Figs. 82 - 83).



Figure 82: A typical mangrove shoreline stand in the Kolan River dominated by *Avicennia* with scattered *Rhizophora* and *Aegiceras*.



Figure 83: Tidal wetlands along the Kolan estuary have high fish habitat value that support regional recreational and commercial fisheries.

Drivers of change up to 2018

Kolan River estuary – chief drivers, condition & threats – a summary			
Drivers of Change	Severity*	Scale*	Score**
<i>Direct Human Drivers</i>			
Direct Damage – Habitat Fragmentation	5	2	10
Direct Damage - Cattle	3	2	6
Direct Damage – Vehicles	3	1	3
Direct Damage – Mowing	3	1	3
<i>Indirect Human Drivers</i>			
Altered Hydrology – Waterway Barrier	3	3	9
Altered Hydrology – Restricted Flow	3	3	9
Depositional gain	1	4	4
Bank Erosion – Loss of Riparian Veg.	2	4	8
Pollution – Herbicide	1	2	2
Agricultural Encroachment	1	4	4
<i>Natural Drivers</i>			
Drought - Estuarine Shift	1	2	2
Flood Damage	4	4	16
Altered Hydrology – mouth shift	4	2	8
Human Impact Score			58
Overall Condition Score:			84
* ranking of 5 condition levels – minimal to high impact			
**overall measure is the multiple of severity and scale scores			
Threats to tidal wetland condition:-			
1. Altered Hydrology			
2. Chemical and Nutrient Pollution			
3. Bank erosion and flooding events			

Descriptions of management issues and drivers of change

Direct Human Drivers

Direct Damage – Clearing & Habitat Fragmentation (Fig. 84)

Mangrove habitat fragmentation and removal for shoreline access and river views is occurring along the Kolan estuary and Yandaran Creek. Following recent flooding it appears that mangrove re-colonisation has been prevented in some locations. Habitat fragmentation

reduces mangrove resilience to future flood events, reduces sediment and nutrient trapping capacity and increases sediment export to the southern GBR.



Figure 84: Shoreline habitat fragmentation for shoreline access in the lower-mid estuary.

Direct Damage – Cattle (Fig. 85).

Cattle grazing is impacting tidal wetlands at the Miara boat ramp and along Yandaran Creek. At the Miara boat ramp it is apparent that cattle are grazing on *Avicennia* reducing tree height and also causing sediment instability in adjacent saltmarsh. This area is also affected by altered hydrology and vehicle damage. Along Yandaran Creek, cattle are grazing saltmarsh habitat and *Avicennia* seedlings. In both instances cattle grazing reduces tidal wetland resilience to sea level rise and flood impacts, and disturbs tidal wetland sediments reducing sediment trapping capacity and increasing sediment export to the adjacent southern GBR waters.



Figure 85: *Left*: Damage to saltmarsh resulting from cattle near the Miara boat ramp. Note also the wooden barrier to restrict tidal flow. *Right*: Evidence of cattle grazing and browsing saltmarsh and mangroves along Yandaran Creek.

Direct Damage – Vehicles (Fig. 86).

Vehicle damage is evident at the Miara boat ramp where vehicles turn around on adjacent saltmarsh and saline grassland. Vehicle impacts are also present in saltmarsh behind the Miara Caravan Park. These areas are small however damage could easily be prevented if appropriate measures were taken. Given that there is limited remnant saltmarsh habitat in the Kolan estuary and that sub-tropical saltmarsh is an EPBC listed endangered regional

ecosystem, efforts should be undertaken to limit impacts to these areas. Vehicle damage in this area was first reported in 2008 (Mackenzie & Duke, 2011) and more recent observations suggest little has changed in the past 10 years.



Figure 86: Vehicle damage to saltmarsh at the Miara boat ramp in 2008 (Left) and an aerial view of the same location in 2017 showing increased habitat degradation (Right).

Direct Damage – Mowing (Fig. 87)

A small area of saltmarsh was observed to be frequently mown behind the Miara Caravan Park. Mowing reduces tidal wetland resilience to sea level rise preventing upland migration of habitat.



Figure 87: Mowing of saltmarsh at Miara Caravan Park.

Indirect Human Drivers

Altered Hydrology - Waterway Barriers

The primary driver of change affecting tidal wetlands within the Kolan River is altered hydrology. Barrage construction on both the Kolan River and Yandaran Creek reduces freshwater flow into the estuary. During periods of drought as was experienced in the past decade, salinity extremes occur within estuary causing mangrove death and stress. In 2008 large scale dieback of *Aegiceras* in the upstream section of the estuary was observed (Mackenzie & Duke 2011). It was noted that the resilience of the tidal wetlands to further external stressors in the upper estuary had been reduced as a result of altered hydrology. Upper estuary mangroves were severely impacted during the recent flood events. The

extensive loss of upper estuary mangroves during the flood events is indicative of the compounding effects of multiple natural and anthropogenic pressures (Fig. 88).



Figure 88: Fringing *Aegiceras* suffering severe drought stress 2008 and the same area in 2018 showing complete loss of habitat following flooding with evidence of habitat recovery.

Altered Hydrology - Restricted Flow (Fig. 89).

Freshwater impoundment associated with agriculture is contributing to change within the estuary. In areas where water impoundment is present rate of saltmarsh expansion is elevated, suggesting such alterations to hydrology can cause significant changes to plant community structure. In the Kolan estuary it is apparent that the large mangrove to saltmarsh area ratio is maintained by overland and groundwater freshwater inputs. The low canopy density and mangrove retreat occurring during drought conditions suggests that minor changes to hydrological flow in this estuary are likely to have a significant influence on the area of mangrove and saltmarsh.



Figure 89: Irrigation impoundments restrict freshwater flows to tidal wetland areas and exacerbates drought conditions as can be seen by the dying area (top right).

There are two areas within the Kolan River where restricted freshwater flow has had an obvious effect on tidal wetlands. These include the area of mangrove near the Miara boat ramp where a wall has been constructed to restrict flow, and in the upstream portion of the Conservation Park where freshwater inputs have been impounded for irrigation.

Both restricted flow and waterway barriers increase the risk of estuarine habitat loss associated with sea level rise as they limit upriver and upland shifts in tidal wetland distribution.

Depositional Gain (Fig. 90)

Vegetation removal both within the catchment and adjacent to the estuary has led to increased sediment loads in the Kolan River estuary. During periods of low flow, much of this sediment is deposited within the estuary where it remains as a result of reduced estuarine flushing capacity associated with the construction of the barrage. This sediment has made the estuary shallower, as well as encouraging the formation of accreting banks consisting of deep, nutrient rich anoxic mud. These banks provide perfect habitat for mangrove colonisation, where *Avicennia* and *Aegialitis* are dominant species. It is possible that rapid sediment deposition creates conditions that favour some species and not others. In this instance it is likely that *Avicennia* and *Aegialitis* can quickly become established on downstream depositional banks whereas *Rhizophora* cannot. Plant community structure clearly has the potential to be altered by increased sediment deposition within an estuary. The reduction of *Rhizophora* fringing communities within an estuary greatly influences fish habitat quality as *Rhizophora* stands are structurally more complex than *Avicennia* stands, making *Rhizophora* forests high quality fish habitat.



Figure 90: Downstream depositional banks colonised by seedlings, signalling future mangrove expansion in this section of the estuary.

Bank Erosion – Loss of Riparian Habitat (Fig. 91).

Significant bank erosion is present along much of the upper and lower Kolan River estuary. Riparian vegetation removal and historical agricultural encroachment into wetland areas has greatly increased the rate and risk of erosion in the estuary. Estuary bank erosion potentially represents a significant sediment source to the lower estuary resulting in estuary shallowing and depositional bank formation and may be a significant source of sediment to the southern GBR. Bank erosion is also leading to loss of agricultural land and threatens infrastructure, including homes.

Local efforts to limit bank erosion in the mid and lower estuary appear ineffective. In some areas, bank erosion has been exacerbated by mangrove removal and fragmentation.

Elevated nutrient and sediment runoff to the estuary may limit the capacity of mangroves to reduce bank erosion during flood events. Elevated nutrient loads and anoxic fine sediment deposits result in mangroves having lower root to shoot ratios making them more vulnerable to erosion and toppling.

Following recent flood events, significant bank erosion has occurred along the estuary near the mouth of Yandaran Creek. An erosion control plan has been designed and is intended to be implemented by Gidarjil Development Corporation with other partners in the near future.



Figure 91: The absence of a riparian buffer and cropping to estuary margins increases erosion risk and estuary sediment loads.

Pollution – Herbicide (Fig. 92).

Both Diuron and Atrazine have been recorded at moderate levels within the estuary. These herbicides are known to impact mangroves and have likely contributed to reduced mangrove resilience to both flood and drought impacts.



Figure 92: Dead (grey) *Avicennia* and *Aegiceras*. The cause of death is related to herbicide runoff.

Agricultural Encroachment – Sea level squeeze

Agriculture directly adjacent to tidal wetlands, with little or no natural buffer zones greatly increases the risk of future tidal wetland loss due to sea level rise.

Natural Drivers

Flood Impacts (Fig. 93).

Recent severe flooding in the Kolan estuary severely impacted shoreline mangrove habitats throughout the estuary. These impacts were most severe in the upper estuary where large areas of mangroves were completely lost as a result of flood impacts.

Mangrove resilience to flooding is likely to have been reduced by historical high nutrient and sediment inputs to the estuary, agricultural impacts and altered hydrology.

Mangrove recovery following severe flooding is evident in the lower and mid estuary. Newly deposited mudbanks are now colonised with mangrove seedlings. A new mangrove channel was created opposite Yandaran Creek. In some locations, flood recovery has been impeded by human mangrove removal, bank hardening and cattle grazing.

More frequent severe flood events in this estuary will likely see the loss of upstream mangrove habitats in the future as a result of bank erosion exacerbated by agricultural encroachment.



Figure 93: Flood impacted mangroves showing recovery (left) and lack of recovery (right).

Drought - Estuarine Shift

Estuarine shift is a function of long term climatic change (either climate change, or natural events such as drought), whereby species distributions within an estuary are altered. Noticeable effects of estuarine shift occur at the margins of species tolerance to factors such as salinity or where optimal conditions for species colonisation are extended. Recent drought conditions in the region have reduced freshwater flows into the Kolan estuary. This has resulted in increased salinity further upstream. In this instance estuarine shift is affecting *Aegiceras* and *Aegialitis*. Large stands of *Aegiceras* in the upper estuary were observed to have high levels of crown retreat, indicative of stress. *Aegialitis* was observed to be colonising depositional banks in the upper-mid estuary where few adult trees of this species were present. Successful recruitment in the upper estuary would greatly increase the upstream range of this species in the Kolan estuary.

It is likely that estuarine shift in the Kolan River estuary has been exacerbated by the presence of a barrage (Fig. 94), which restricts freshwater flow. The ecological implications of these

waterway barriers are more obvious during climatic extremes. Under natural scenarios of drought, species shifts would occur, with less salinity tolerant species reducing in range. However, with the presence of the barrage, the upstream estuary has effectively been removed. This reduces the capacity of these species to retract to areas which are fresher and may ultimately cause them to die out in the estuary, as was likely the case with *Bruguiera* and *Acrostichum*.



Figure 94: The barrage is likely to exacerbate estuarine shift in the Kolan River.

Altered hydrology – natural (Fig. 95)

Recent severe weather events in the region resulted in the formation of new estuary entrance at the Kolan River mouth. This dramatic change to the estuary morphology has altered estuary hydrology and hydrodynamics increasing tidal flow and seawater exchange at the estuary mouth. Shoreline and tidal wetland habitats in this area are undergoing natural adjustment to these changes. Large-scale erosion of shoreline habitats is now occurring at the estuary mouth resulting in a loss of habitat. The changes currently being experienced in the Kolan estuary may be indicative of how estuaries will respond to future sea level.



Figure 95: Kolan estuary mouth in 2005 (left) and 2018 (right) (*Images from Google Earth*).

7.0 BURNETT RIVER ESTUARY

Burnett Mary region

Mouth location:	-24.755957; 152.398608
Condition:	Extensively modified, river-tide dominated
Area of tidal wetlands (Mackenzie & Duke 2011)	
Mangroves:	391 ha
Tidal saltmarsh and saltpans:	148 ha
Total tidal wetland:	540 ha
Wetland Cover Index:	72.5%
Mean Annual Rainfall (25yr mean):	938 mm
Catchment Area:	33,235 km ²



Figure 96: The mouth of the Burnett River looking upstream in 2008.



Figure 97: Achievements regards successful field surveys undertaken in the Burnett River estuary by Gidarrji Rangers up to late 2018. Tracks (yellow lines) are shown on satellite images for 2013, 2016 and 2018.

Summary Description

The Burnett River catchment is the largest within the Burnett Mary Region (Fig. 96). The catchment extends from the Burnett Range and flows 420km to the mouth at Burnett Heads (EPA 2006), flowing directly through the City of Bundaberg. The river has been extensively modified by urban, agricultural and industrial development (Van Manen 1999). These factors have altered river flow and increased nutrient and sediment loads from the surrounding catchment. Consequently, water quality of the river is low and the river is in poor condition (Esselmont *et al.* 2006). Tidal wetlands in the estuary appear healthy, but are species poor and habitat diversity and quality are low. With the exception of Burnett Heads, tidal wetlands in the estuary are limited to fringing stands of *Avicennia marina*. Estuary eutrophication and sedimentation has caused the fast growth and expansion of mangroves along estuary margins, but these stands are highly vulnerable to storms, floods and climatic events. Although much of the Burnett estuary has been extensively modified there remain some areas of environmental value. The tributaries of Splitters Creek and McCoy's Creek remain relatively undisturbed and their connectivity with the Burnett has been maintained. Splitters Creek is an important habitat for the EPBC listed Lungfish (WetlandCare 2008). At the mouth, Barrubra Island adjacent to the Burnett River is also an area of significant environmental value. The island maintains healthy tidal wetland mangroves and saltmarsh despite significant hydrological alterations. The estuary was surveyed in 2013, 2016 and 2018 by the Gidarjil Rangers (see Fig. 97).

Estuary Features

Physical setting. The Burnett River estuary is river-dominated with a tide dominated delta. This estuary type is said to have low sediment trapping efficiency, naturally high turbidity, well mixed circulation and at low risk of habitat loss due to sedimentation (NLWRA 2002).

Construction of the Ben Anderson barrage in 1976 and alterations to the river mouth during 1958 have dramatically altered the hydrology of the estuary (Heidenreich and Lupton 1999). At the mouth, oceanic influences were enhanced with construction of a training wall on the north bank and subsequent dredging of the shipping channel for the Bundaberg Port. The rock training wall effectively isolated Barrubra island from the main channel such that it is no longer connected hydrologically to the Burnett system, despite a small break in the wall for fish passage (Heidenreich & Lupton 1999). Reclamation of tidal wetlands for expansion of the port and the development of the marina coupled with bank hardening at the mouth and narrowing of the channel to encourage its natural scouring (Bruinsma & Danaher 2000).

Construction of the Ben Anderson barrage greatly reduced freshwater flow into the Burnett estuary and effectively reduced the tidal prism by 40% (Heidenreich & Lupton 1999). Since construction, sediment delivered to the estuary via creeks and direct run-off is no longer flushed regularly from the system. As a consequence, accreting depositional banks and siltation in the upstream sections of the estuary are common, which in turn reduces tidal flow into adjacent creeks and channels.

Estuarine zones (Fig. 98). The Burnett River is a mud dominated system owing to a strong riverine influence, high sediment input and altered hydrology which affects salinity and

sediment flocculation. The majority of banks along the mid to upper estuary are either stable or depositional. However, these banks have a relatively steep profile that limits the width of the tidal range. Erosion is more evident in the lower estuary. The mouth of the estuary is sand dominated resulting from oceanic influence. Much of the north bank consists of the training wall and the southern bank has been hardened for port development. Inside the mouth of the estuary the river becomes mud dominated.



Figure 98: Distribution of zones within Burnett River estuary.

Changes to natural habitats. Changes to natural habitats are driven by a combination of human and natural drivers of change. The human induced changes to the Burnett River catchment have severely altered the hydrology of the river. These hydrological alterations have led to many changes in plant community structure, species composition and ecological function of the tidal wetland communities of the Burnett River. Depositional mud banks become more frequent upstream and are most prevalent near the barrage, where extensive channel infilling has occurred. These depositional banks have a high surface benthic microalgae cover suggesting high nutrient load associated with the sediment. Very little bank erosion is occurring upstream. However, there are some locations in the estuary where bank erosion is a major issue. Severe erosion is mostly present on the North bank near the old ferry crossing where mangroves are being undercut by wave action and boat-wash. Erosion is also associated with bank vegetation removal and agricultural encroachment on the north bank near Fairymead.

Tidal wetland vegetation

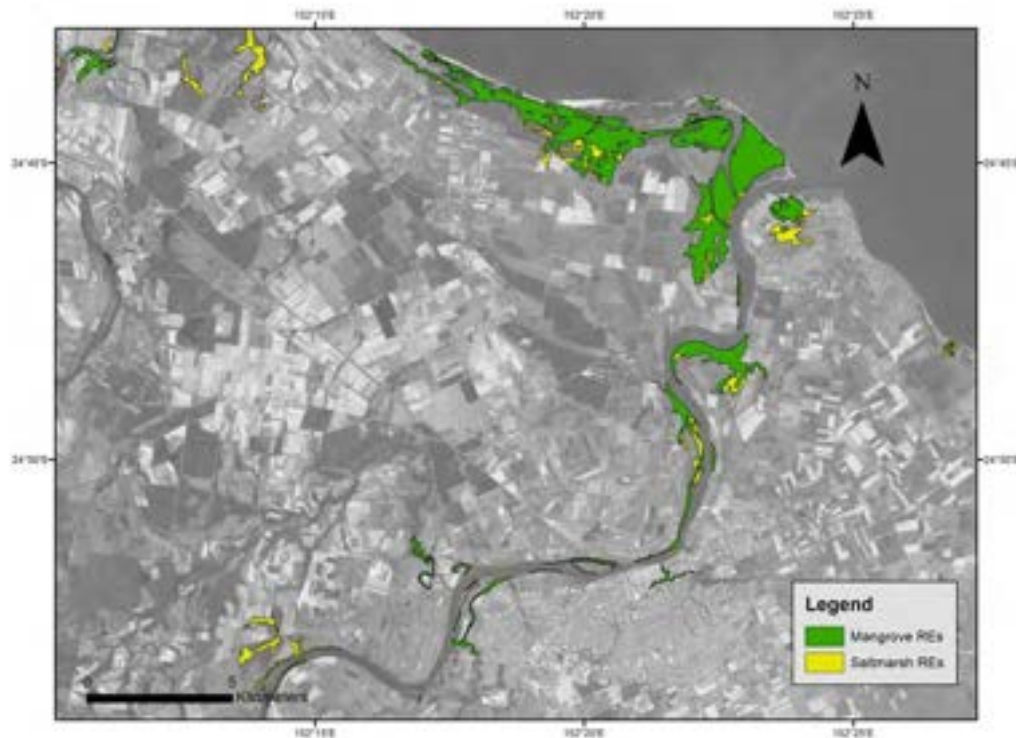


Figure 99: Burnett River showing mangrove and saltmarsh areas.

Mangrove habitat (Fig. 99). The Burnett River estuary is the most species poor for mangroves in the region (Mackenzie & Duke 2011), with only six out of the 12 locally occurring species present (Table 6). There are only three significant stands of mangrove forests remaining on the Burnett River. These are located at Fairymead, Rubyanna Creek and Burnett Heads. Most of the remaining tidal wetlands area is comprised of fringing mangrove forests that line the river banks. Generally, *Avicennia marina* and *Aegiceras corniculatum* were the dominant mangrove species of the Burnett River estuary. The most dominant, *A.marina*, occurred in all sections of the estuary. Other species were more restricted. For example, *Aegialitis annulata* was restricted to a stand at Burnett Heads. And *Rhizophora* was only present at relatively low abundances compared to neighbouring estuaries. This species also oddly occurred as an under canopy to *Avicennia* stands. There were no continuous stands of *Rhizophora* in this estuary. The Burnett estuary was therefore unique as the only local estuary without *Rhizophora*-dominated sections along the estuary. This was a notable distinguishing factor separating northern and southern mangrove stands where *Rhizophoras* usually dominated estuarine shorelines north of Tin Can Bay (-25.796378; 152.982432). It is likely that the combination of increased sediment load and elevated nutrient supply enabled *Avicennia* to gain a competitive advantage in this estuary. Low mangrove species diversity is likely due to altered hydrological regime combined with significantly reduced habitat availability and limited freshwater inputs. Species normally associated with freshwater flows such as *Bruguiera gymnorhiza* and *Acrostichum speciosum* may have been lost with the reduced tidal prism following construction of the Ben Andersen barrage, coupled with mouth opening and reduced groundwater infiltration. *Xylocarpus granatum* is often rare within northern estuaries of the

region, and *Lumnitzera racemosa* is typically a high intertidal fringing species and may have been lost with riparian buffers with urban and agricultural encroachment.

Table 6: Tidal wetland plants in Burnett River estuary.

Mangrove Species	Saltmarsh Species
<i>Aegialitis annulata</i>	<i>Fimbristylis polytrichoides</i>
<i>Aegiceras corniculatum</i>	<i>Salsola kali</i>
<i>Avicennia marina</i>	<i>Sarcocornia quinqueflora</i>
<i>Ceriops australis</i>	<i>Sesuvium portulacastrum</i>
<i>Excoecaria agallocha</i>	<i>Sporobolus virginicus</i>
<i>Osbornia octodonta</i>	<i>Suaeda australis</i>
<i>Rhizophora stylosa</i>	<i>Suaeda arbusculoides</i>
	<i>Tecticornia indica</i>

Saltmarsh-saltpan habitat (Fig. 99). Saltmarsh plant diversity and area were very low within the Burnett estuary (Table 6). While the majority of saltmarsh species were represented, these were greatly restricted in their distribution. This was shown overall by the mangrove to saltmarsh ratio being relatively high (~72.5%) compared to the predicted cover ratio based on regional rainfall. This implied there were unusual circumstances involved. It suggested that saltmarsh in the Burnett estuary was lost either by direct destruction with reclamation, or with mangrove encroachment facilitated by increased nutrient and freshwater delivery from adjacent agriculture. The latter argument is least tenable since mangrove areas only appeared to have increased in the upper estuary due to rapid colonisation of depositional banks that did not involve saltmarsh loss. Two functional saltmarsh-pan areas remained in the river estuary. These were located at Rubyanna Creek and Burnett Heads. Some saltmarsh and brackish swamps remain in Splitters Creek. The remaining saltmarsh was predominately *Sporobolus* saline grassland which were infrequently inundated by high tides.

Biomass of tidal wetlands of the Burnett River estuary

Tree heights were recorded in satellite imagery and verified in field surveys. The overall height of mangrove vegetation across the broad tidal wetland areas of the Calliope River are relatively low, around 5m – with taller stands in the downstream area north of the mouth. This is consistent with areas of relatively moderately low rainfall. The taller stands were notably observed surrounding lower elevation shorelines just above mean sea level, as depicted in maps and imagery (Fig. 100).

The zone immediately above the tidal wetland zone (i.e., 1m > HAT) refers to the supra tidal zone. The vegetation in this zone is considered vulnerable to a number of human and natural factors, including vehicle access, reclamation damage, severe storms, flooding, feral pigs, exotic weeds, and sea level rise. Vegetation in this zone is virtually non-existent except for a few isolated remnant patches in the conservation area north-west of the mouth.

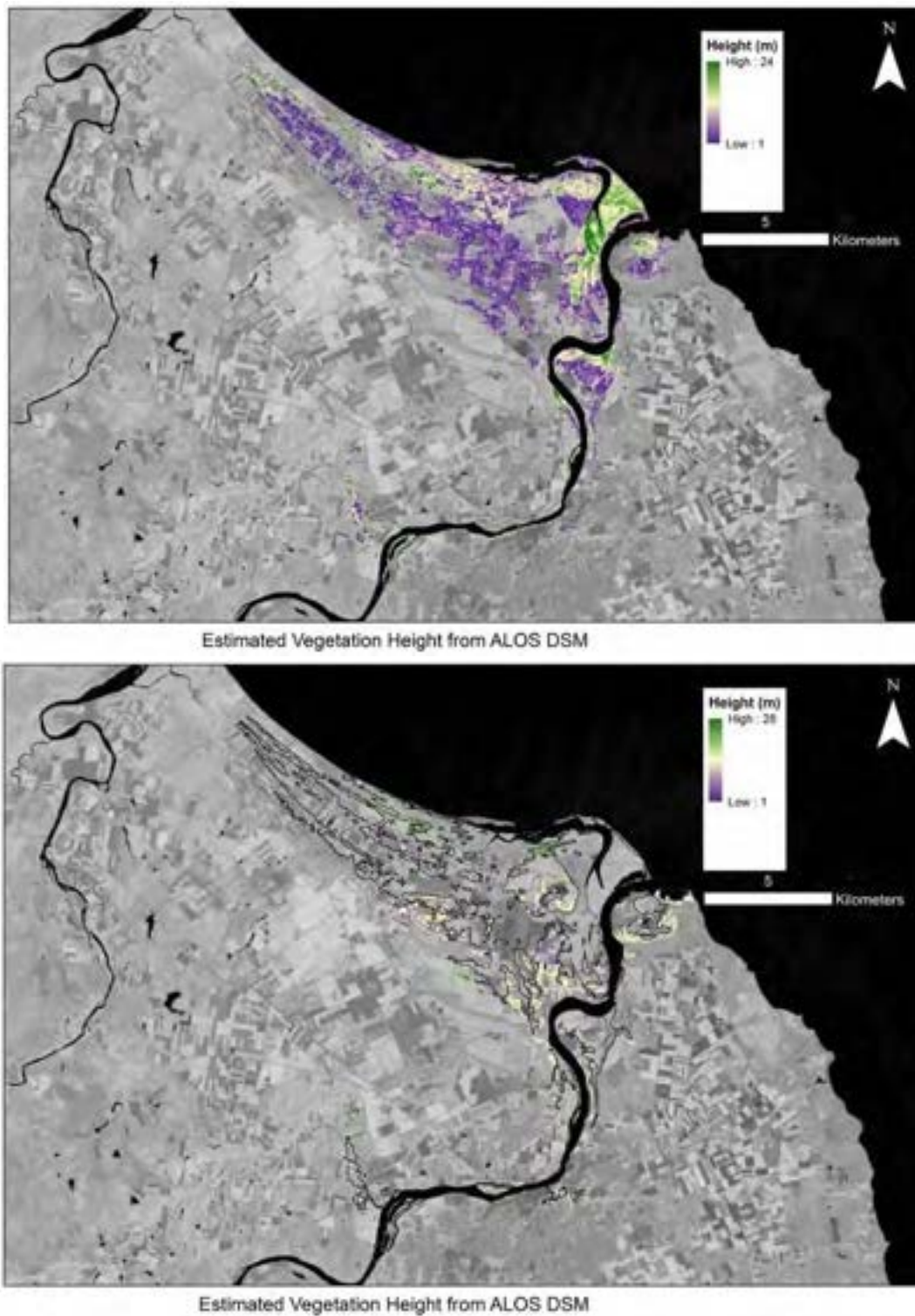


Figure 100: Satellite images of the Burnett River estuarine areas showing height of vegetation for A) tidal wetlands (MSL-HAT) and B) the supra tidal zone (HAT +1m) for 2010 using ALOS DSM.

Changes taking place in tidal wetlands of the Burnett River estuary

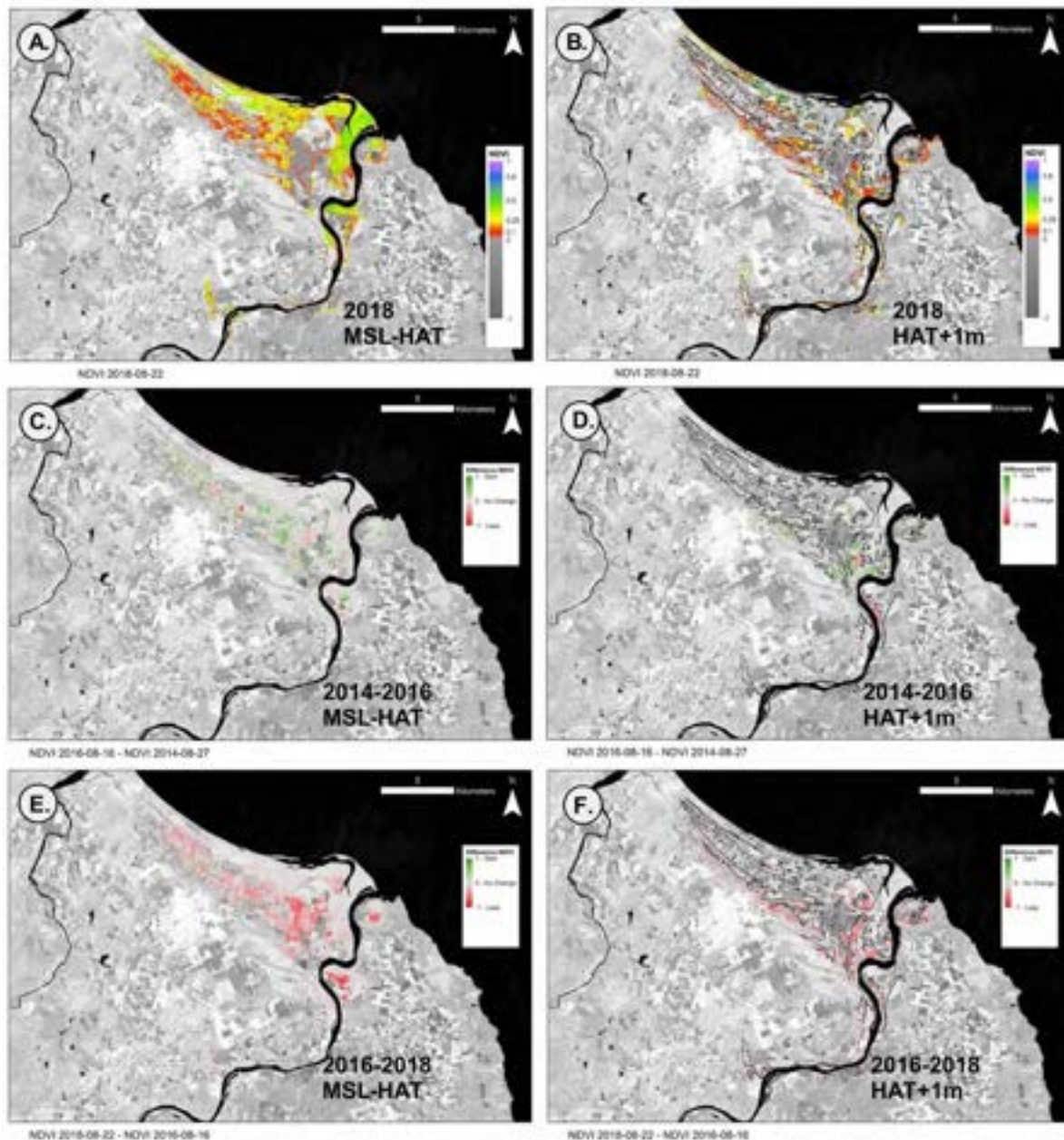


Figure 101: Satellite images of the Burnett River estuarine areas showing NDVI measures of vegetation condition for tidal wetlands (MSL-HAT) and supra tidal zone (HAT +1m) for 2018 (A & B), and two change detection periods 2014-2016 (C & D) and 2016-2018 (E & F).

A first evaluation of changes to vegetation cover was made using vegetation indices (like NDVI) from satellite imagery (Fig. 101). The indices for specific dates represent measures of sub-lethal condition at the time (A & B for 2018 – for tidal wetlands, and supra tidal areas respectively). Colours towards the red end of the scale show vegetation in relatively poor condition while that at the green-blue end is notably healthier. In the 2018 views, tidal wetlands and supra tidal vegetation were in poorer condition at upland margins, particularly those around the mouth. When change detection is done comparing scenes from two different time periods (C-F), the scales from red to green indicate relative losses or gains. Comparison of two time periods show notably different responses where losses suffered in one time period

might show gains with recovery in a subsequent time period. The time periods shown in the figure include 2014-2016 (C & D) and 2016-2018 (E & F). By comparing C & E, it can be seen that tidal wetlands downstream around the mouth were damaged and lost chiefly in the second period while they were mixed in the first period. The effects on supra tidal areas matched the conditions observed in tidal wetlands.

Management issues registered at community workshops

Key issues flagged at 2016 and 2017 community workshops included altered hydrology, removal of mangrove stands, lack of edge buffer vegetation, vehicle access damage, and high value wetlands (see Fig. 102).

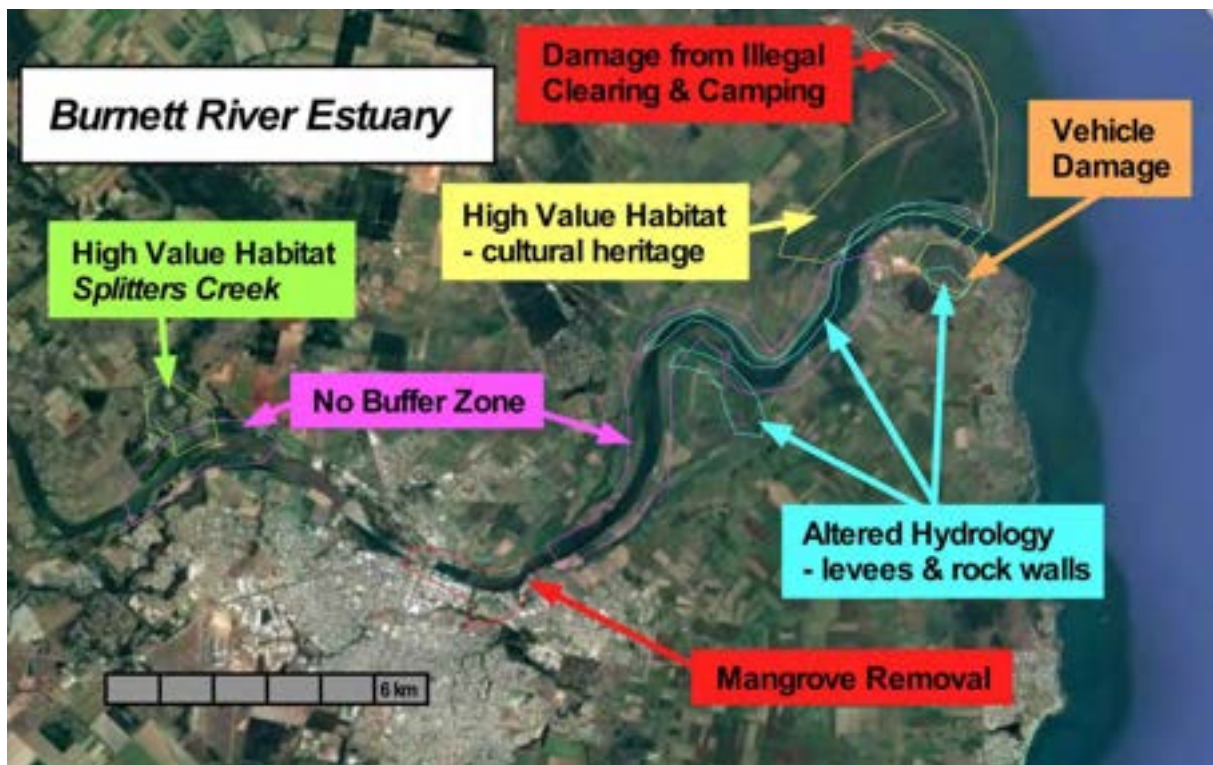


Figure 102: Digitised outcomes of the workshop community-based participatory mapping of Burnett River tidal wetland management issues.

Environmental management issues in the Burnett River estuary

- Sediment deposition and mangrove expansion
- Altered hydrology
- Chemical and Nutrient Pollution
- Mangrove Removal/ Reclamation

The Burnett River is the most modified estuary in the region. Most of the issues influencing the river can be attributed to the presence of urban and intensive agricultural land use with direct connectivity to the estuary. The primary issue for the estuary is increased sedimentation and siltation in the river resulting from riparian vegetation removal, urbanisation and altered

hydrology These factors have resulted in the formation of depositional banks along the mid and upstream reaches of the estuary. The sediment deposits are high in nutrients, creating a perfect environment for mangrove establishment and growth, particularly *Avicennia marina* (Grey Mangrove) and *Aegiceras corniculatum* (River mangrove). The expansion of mangroves within the river has led some sections of the public to label mangroves as the cause of sedimentation leading to a negative perception of mangroves in the Bundaberg area. This attitude can lead to increased levels of mangrove destruction and removal (direct damage) by some local residents living adjacent to mangrove areas, as well as efforts to have local management authorities remove large areas of vegetation. This perception is however incorrect. Mangrove removal will only lead to increased sediment mobilisation and decreased nutrient and pollutant buffering capacity in the estuary, not to mention the removal of scarce fish habitat.

The majority of tidal wetland communities in the Burnett River are severely altered from natural conditions and there is therefore a great need to preserve the few large stands that remain. Whilst some areas of mangroves within the estuary, particularly the Town Reach, appear healthy and vibrant, elevated nutrient loads and herbicide inputs to the estuary threaten the resilience of the tidal wetland ecosystem, reduce biodiversity and decrease ecosystem service provision. Boat wake and bank erosion also contribute to the decline of tidal wetland ecosystem health in some areas. Unfortunately, there is little that can be done to restore natural ecosystem function from a management perspective. However, the condition of the Burnett River estuary and reduced ecosystem service provision of the tidal wetlands should serve as a warning about the effects of altered hydrology, decreased water quality and mangrove removal when planning estuary modifications in nearby relatively unaltered estuaries.

Recommended management actions:

- Reduce sediment, nutrient and chemical inputs to the estuary through the establishment of vegetation buffers upstream and tidal wetland restoration.
- Increase environmental freshwater flows to the estuary.
- Ensure the continued protection of the Bundaberg Port Authority mangrove area.
- Increase community awareness regarding the benefits of tidal wetland ecosystems and the underlying causes (nutrients and sediments) of mangrove expansion in the estuary.

Drivers of change up to 2018

Burnett River estuary – chief drivers, condition & threats – a summary			
Drivers of Change	Severity*	Scale*	Score**
Direct Human Drivers			
Reclamation – habitat loss	5	2	10
Direct Damage – Vehicles	3	1	3
Direct Damage – Cutting	4	1	4
Direct Damage – Cattle	4	1	4
Indirect Human Drivers			
Altered Hydrology – Waterway Barrier	2	5	10
Altered Hydrology – Restricted flow	2	3	6
Depositional Gain	1	4	4
Bank erosion – lost riparian veg	2	4	8
Pollution – Pesticides	1	1	1
Pollution – Nutrients	1	2	2
Shoreline Erosion – Boat Wake	3	2	6
Faunal Displacement – Bats	3	1	3
Natural drivers			
Drought – Ecotone Shift	4	2	8
Storm Damage – Wind	4	1	4
Flood Damage	4	4	16
Human impact score:			61
Overall condition score:			89
* ranking of 5 condition levels – minimal to high impact			
**overall measure is the multiple of severity and scale scores			
Future threats to tidal wetland condition:-			
• Extreme weather events – storms, wind, floods. • Removal and reclamation • Pollution – nutrients, pesticides, herbicides • Shoreline erosion plus severe flooding			

Descriptions of management issues and drivers of change – Burnett River estuary

Direct Human Drivers

Direct Damage - Reclamation

Reclamation of mangroves around the port area is has occurred recently and will most likely continue to occur with port development and expansion. However, this process is offset with the protection of a large area of mangroves at Burnett Heads. The port could also consider integrating 'mangrove gardens' in rock wall constructions to improve habitat diversity along the estuary margins at the river mouth.



Figure 103: Vehicle damage to Walkers Creek tidal wetlands (*Aerial image: Qld Globe*).

Direct Damage - Vehicle Damage (Fig. 103).

Damage to tidal wetlands caused by vehicle access is ongoing at Walkers Creek. The damage is restricted to the saltmarsh area where fisherman gain access to the creek. This issue was first reported in 2008 (Mackenzie & Duke, 2011) and has not yet been addressed. This vehicle damage is resulting in sediment export to the estuary and a loss of tidal wetland function. A mangrove boardwalk and associated access management is currently in development by Gidarjil Development Corporation.

Direct Damage - Removal/ Cutting (Figs. 104-105)

Following severe flooding there was a local management response to cut and remove dead mangroves from some areas of shoreline along the town reach.



Figure 104: Poisoning of surviving mangroves and adjacent riparian buffer adjacent to urban land.

This approach was taken in the interests of public safety. Some of these areas have not since re-established with mangroves. Some shoreline residents took advantage of the damaged state of mangroves along shore frontage to remove mangroves and it is likely that active mangrove seedling removal to prevent mangrove re-establishment is occurring in some locations. Trimming and removal of mangroves continues along the estuary for view maintenance and access.



Figure 105: Dead mangroves being cut following flooding in 2013 (left) and the same area showing little recovery in 2016 (right).

Direct Damage – Cattle Grazing (Fig. 106)

Cattle grazing along the Burnett estuary shoreline and in tidal wetland areas limits habitat function, increases sediment and nutrient export to the estuary via tidal flows and limits flood recovery. Shoreline fencing and off-shore watering points should be encouraged.



Figure 106: Cattle grazing was recorded close to and including intertidal vegetation.

Indirect Human Drivers

Altered Hydrology - Waterway Barriers (Fig. 107)

The primary driving factor affecting tidal wetlands within the Burnett River is altered hydrology. Barrage construction and alterations to the river mouth have dramatically altered flow regimes. This has consequently altered sediment deposition within the estuary and potentially increased erosion on some banks. The construction of the training wall separating Barrubra Island has dramatically altered the natural hydrological conditions within this large mangrove area. The reduced frequency of freshwater flows resulting from the presence of the Ben Anderson Barrage limits the flushing capacity of the estuary resulting in the accumulation of sediments, nutrients and pollutants within the estuary, all of which can influence tidal wetland ecology and ecological integrity.

The presence of the barrage within the estuary will restrict upstream mangrove estuarine shift as sea levels rise.



Figure 107: The training wall at the mouth of the Burnett River severely impacts natural flow.

Altered Hydrology - Restricted Flow (Fig. 108).



Figure 108: Mud banks created after the installation of the weir restricting flows have become sites of depositional gain as young mangrove plants spread across them.

Restricted flow from the construction of roads and dams is a major driver of change in the Burnett estuary. Dam construction in the upper Rubyanna Creek is likely to have altered freshwater flow into this area and affected tidal plant community structure. Roads and pond development in the upstream section of the river at McCoys Creek have also altered the hydrology of the tidal wetland system in this area. Restricted flow has affected mangroves in the Burnett Heads mangrove area. Restricted flows limit freshwater flows to the estuary during periods of low rainfall and result in elevated salinities within the upper estuary. The highly

variable salinity conditions influence both fish habitat and fisheries resources and reduce tidal wetland ecosystem resilience to climate impacts such as drought and severe flooding.

Depositional Gain

The Ben Anderson barrage greatly reduces the freshwater flow into the river. Since construction, the river has become dominated by tidal influx from the mouth, effectively trapping sediment in the upper estuary and generating large depositional banks and shallow water depth. The shallowing of the estuary was a likely contributor to flood levels. Urban and agricultural development in the estuary has increased sediment runoff into the river. The formation of nutrient rich depositional banks provided perfect growing conditions for *Avicennia* and *Aegiceras*. It was previously reported that these banks were unstable and that a large flood would likely result in loss of mangrove habitat due to the low resilience of mangroves that grow in high nutrient and anoxic fine sediment conditions. This is exactly what occurred. The depositional banks in the estuary are likely to re-develop leading to rapid mangrove expansion once again if sediment loads to the estuary are not significantly reduced.



Figure 109: Bank erosion associated with wave action undermining unconsolidated shorelines downstream in the Burnett estuary.

Bank Erosion (Fig. 109)

Significant bank erosion occurred along the estuary following flooding. Erosion was likely exacerbated by estuary siltation, loss of riparian vegetation and low mangrove resilience related to high nutrient loads. Bank erosion threatens both agricultural and urban land, and tidal wetlands. Of particular concern is bank erosion that is impacting threatened sub-tropical saltmarsh on the northern bank at Fairymead. There is little remnant saltmarsh vegetation in the Burnett River system and efforts should be undertaken to protect remnant areas where possible. A shoreline protection strategy for this area has been developed and is awaiting funding for implementation by Gidarjil Development Corporation.

Erosion control using shoreline bank hardening (Fig. 110) is a common feature along the estuary. It is recommended that all future shoreline erosion management strategies include consideration of shoreline vegetation and promote natural engineering approaches.



Figure 110: Bank hardening has been undertaken without regard for tidal wetlands or riparian margins in many areas bordering the Burnett estuary.

Pollution – Pesticides and others (Fig. 111)

Herbicide and pesticide runoff from agricultural and urban land threatens both tidal wetland habitat and associated fisheries resources.



Figure 111: Crustaceans like mud crabs are sensitive to pesticide pollution.

Chemical Inputs – Nutrients

There is limited natural buffer between urban and agricultural land use along the Burnett estuary (Fig. 112). Flood damage to the mangrove fringe has resulted in a loss of natural capacity in the estuary to trap and filter nutrients present in runoff. Now, more than ever, there

is a need to establish vegetation buffers along the estuary and where feasible encourage mangrove growth adjacent to urban and agricultural land to reduce nutrient inputs to the estuary.

In the past, high levels of nutrient availability in the estuary led to significantly reduced mangrove resilience to flooding. Mangroves in high nutrient environments have lower root to shoot ratios and shallower root systems and are more susceptible to flood impacts. Future nutrient loads to the Burnett estuary should be reduced not only to protect offshore reef systems, but also to protect estuary habitat values provided by shoreline mangrove habitats.



Figure 112: There is limited natural buffer between agricultural and urban land use along the estuary.

Natural Drivers

Flood Damage (Figs. 113 - 114)

Burnett River estuary mangroves have experienced flood impacts from consecutive severe flood events. More than half of the shoreline mangroves in the estuary were severely damaged by flooding, including 25% shoreline habitat loss. One-third of the total mangrove area in the estuary was severely damaged, with 70% of upstream mangroves lost. The flood events reset mangrove area in the estuary to 5% less than were present prior to the construction of the Ben Anderson Barrage in 1971. Whilst this may seem like a natural reset, the loss of mangroves needs to be considered in the context of the surrounding land use change within the estuary. In 2016, it was observed that only 27% of damaged shoreline mangroves were showing positive recovery, with 19% experiencing further degradation.

The Burnett estuary is a highly modified system and shoreline mangrove habitat provides important ecosystem services that maintain estuary ecological, social, economic and cultural values. In the current landuse context, such a significant loss of mangroves, represents a significant loss of ecosystem function, particularly nutrient and sediment trapping capacity that in the past have likely moderated water quality in the estuary, protecting the nearby southern GBR.



Figure 113: Mangroves prior to flooding in 2009 (top left), immediately after flooding in 2013 (bottom left) and showing signs of recovery in 2018 (right).

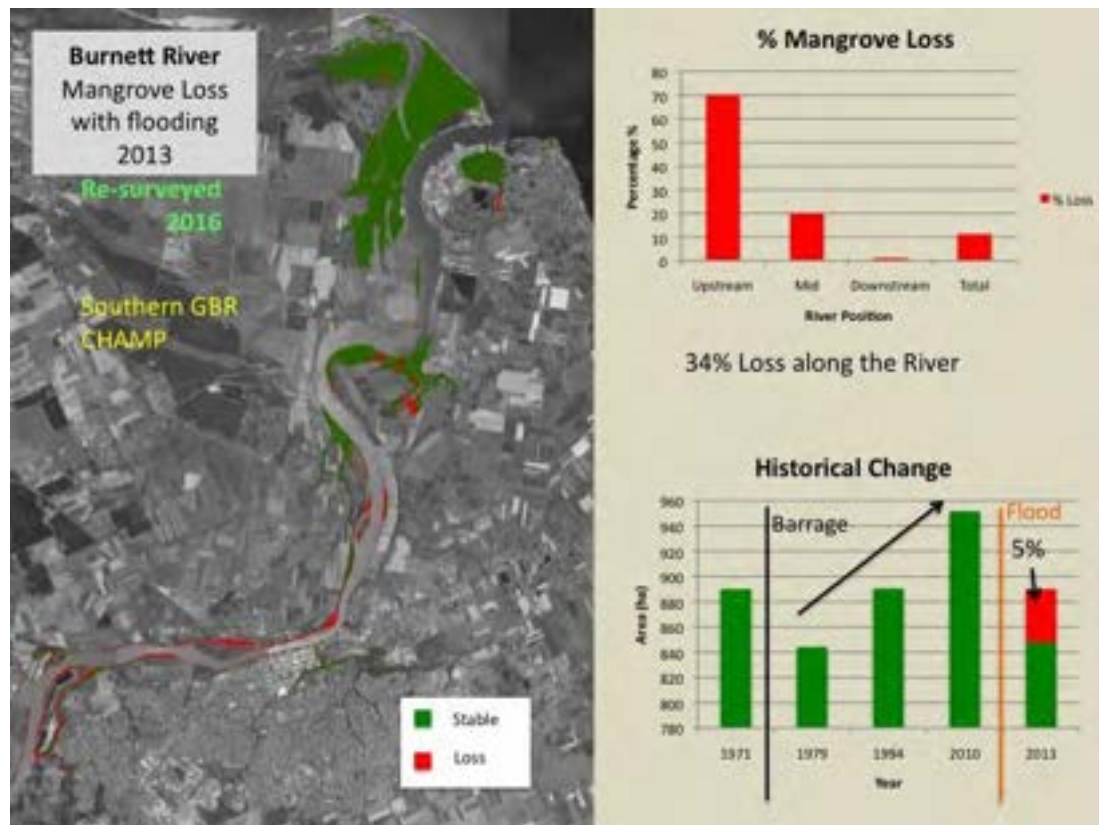


Figure 114: An image of the Burnett River estuary showing the severe impact of the 2013 floods on mangroves upstream. While there was little change at the mouth, it is clear that upstream stands fluctuate widely in response to flooding events and alterations to hydrology like the installation of the barrage upstream. More recent surveys with the NESP TWQ Hub S-GBR project show the longer term status of this event.

8.0 ELLIOTT RIVER ESTUARY

Burnett Mary region

Mouth location:	-24.927511; 152.485112
Condition:	Largely unmodified, river-tide dominated
Area of tidal wetlands (Mackenzie & Duke 2011)	
Mangroves:	434 ha
Tidal saltmarsh and saltpans:	154 ha
Total tidal wetland:	589 ha
Wetland Cover Index:	74%
Mean Annual Rainfall (25yr mean):	947 mm
Catchment Area:	388 km ²



Figure 115: Looking upstream from the mouth of the Elliott River in 2008. Note the channel is to the north of the central rocky bar.



Figure 116: Achievements regards successful field surveys undertaken in the Elliott River estuary in collaboration with Gidarjil Rangers up to late 2018. Tracks (yellow lines) are shown on satellite images for 2013, 2016 and 2017.

Summary Description

The Elliott River is the northernmost river system within the Burrum Basin, flowing into the Great Sandy Marine Park (Fig. 115). The river has previously been identified as having high conservation value as it is one of a few unregulated coastal river systems in South-East Qld (Bruinsma & Danaher 2000). The estuary is recognised as a highly important fish habitat area with a number of EVR listed freshwater species recorded in the upper reaches and the lower reaches serving as a nursery ground for many commercially important fishery resources (Lupton 1993). The freshwater reach of the Elliott River is a series of intermittently flushed waterholes (Rogers et al. 2004), while the lower estuarine section meanders through extensive mangroves before widening into a sandy tidal delta. The Elliott River has high groundwater inputs with over 50% of freshwater runoff entering the aquifer, resulting in a low frequency of freshwater flows through the river system (Mackenzie & Duke 2011). The estuary was surveyed in 2013, 2016 and 2018 by the Gidarjil Rangers (see Fig. 116).

Estuary Features

Physical setting. The Elliott river estuary is a sandy tide-dominated tidal creek system (NLWRA 2002). The estuary flows intermittently into the coral sea, exiting through a sandy beach ridge to the south and the southern end of the Woongarra volcanic coastal formation to the north. The river and estuary are groundwater dependent systems, with groundwater flows driving hydrological conditions 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 and ecological integrity. These ecosystems are threatened by excessive groundwater extraction, altered terrestrial hydrological connectivity and eutrophication. The Elliott River is a unique estuarine system with high conservation value. The hydrology of the estuary is seasonally determined, with groundwater discharge driving flow during drier periods and riverine flow in wetter periods. Consequently, the estuary entrance is a highly dynamic zone. Recent sudden widening of the entrance resulted in increased sand deposition causing the main channel to become shallower. Local users were concerned this would create a navigational hazard. These conditions were expected to improve if riverine flows increased. Increasing bank erosion and loss of habitat on the southern bank in the lower estuary was also an issue of concern for local residents (Rogers et al. 2005). Increased water extraction was considered likely to contribute further to reduced river flows and increased oceanic influence with higher current velocities. Water quality within the estuary was reportedly good with low turbidity, although increasing levels of nutrients have been recorded within the past decade, possibly from more intense agricultural practices (Rogers et al. 2004).

Estuarine zones (Fig. 117). The Elliott River has a sand dominated lower estuary with a rocky mid-section and mud and coarse sediment forming banks upstream. Within the estuary mouth are many dynamic sand bars. The dynamic nature of sand movement within the estuary mouth is highlighted by the recent movement of the channel to the south of Dr Mays Island. Sandbag groins have been placed on the southern side of the estuary to reduce erosion in this zone. Extensive tidal wetland habitats in the lower estuary have developed an extensive peat layer on top of the sandy sub-surface substrate. Upstream of the Riverview boat ramp in the lower-

mid estuary on the north bank, steep banks with exposed natural rock are present with mangroves growing on porous sandstone and sand deposits. Ephemeral sand banks are present along the estuary margins and within the main estuary. In the mid estuary, the bottom substrate remains sand, but bank substrate becomes sandy mud. These banks are mostly stable and depositional. Upstream of Yellow Waterholes Creek, the estuary intersects a small sandstone ridge, creating some areas of steep exposed rocky substrate. The presence of depositional mud banks increase upstream, with 97% of the upper estuary banks being mud. Unlike the Burnett estuary to the North, these muddy banks have low clay content and consist of humic organic material and coarse-grained riverine sediments. This estuary does not have significant sediment inputs and the majority of sediment runoff is trapped within upstream mangrove forests and deposited inside the many bends of the estuary. Within the upper estuary, the channel significantly narrows and becomes highly sinuous. In many places, the estuary bypasses river bends at high tide and flows directly through extensive tidal wetlands. This highlights that the estuary has historically had low to moderate flow associated with the high groundwater recharge in the catchment.



Figure 117: Estuary zones of the Elliott River (referred to throughout the chapter)

Changes to natural habitats. Changes to natural habitats are driven by a combination of human and natural drivers of change. The Elliott River catchment already has the highest population density for all major catchments in the Burnett Mary Region. The effects of agricultural and urban development were apparent in tidal wetland areas (Mackenzie & Duke 2011). Historically, tidal wetland areas were reclaimed for agricultural development. Agricultural and aquaculture runoff directly to tidal wetland areas in Yellow Waterholes Creek increased nutrient loads and freshwater supply, altering tidal wetland plant communities. Such effects were expected to increase in the future. These impacts were likely enhanced further by increased groundwater extraction associated with agricultural and urban development. In the upper estuary, a large tidal wetland area of tall *Bruguiera* (Orange mangrove) and *Acrostichum* (mangrove fern) - an important fish habitat area, appeared impacted by prevailing drought conditions. This rare plant community was reliant on periodic freshwater flows to moderate saline tidal waters. Increased extraction of groundwater during dry periods was therefore likely

to have further reduced the capacity of this important tidal wetland area to resist drought and other stressful events. The high density of irrigated cropping within the estuary has led to presence of a large number of impoundments. Many of these impoundments occur at the headwaters of streams flowing directly into the estuary. They were believed to have greatly modified freshwater flows to the river and they may also have affected groundwater recharge. Consequently, estuarine hydrology was also likely to have been affected. Adjacent to the estuary, most stream headwater flows were modified, particularly on Yellow Waterholes Creek plus two other small creeks running through Riverview and Elliott Heads. These water storage impoundment areas had a significant impact on tidal wetland ecology in downstream tidal areas, with increased saltpan formation and loss of mangrove area post-construction (Mackenzie & Duke 2011). The impoundments had reduced the capacity of these areas to resist drought effects. Terrestrial flows into tidal wetland areas appeared likely to be essential for tidal wetland ecology.

Tidal wetland vegetation

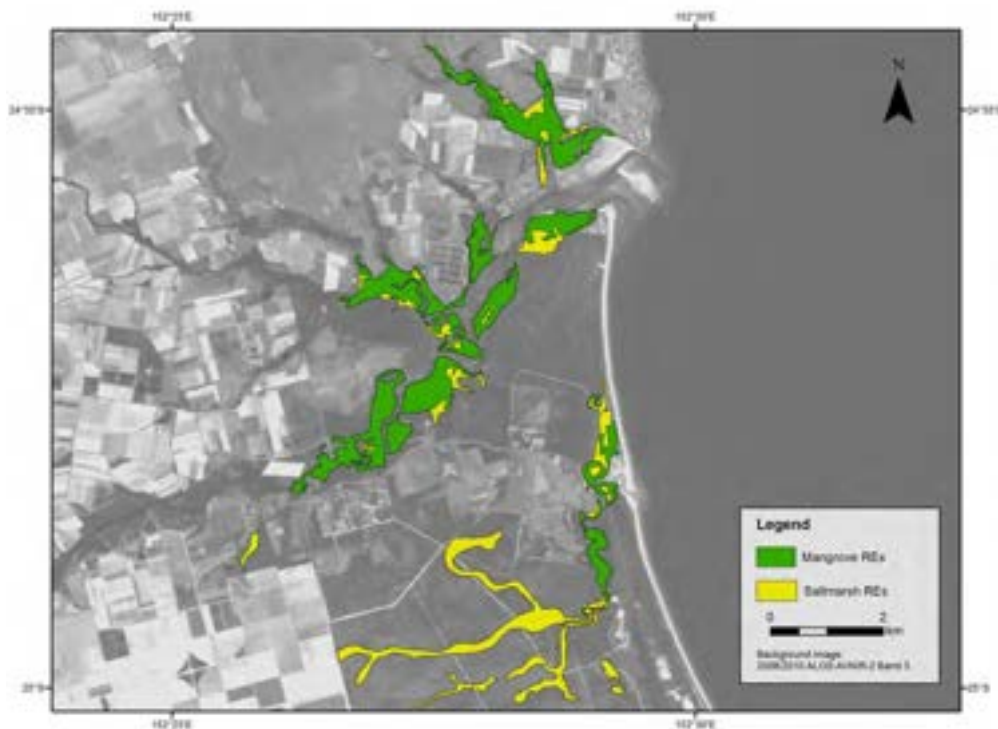


Figure 118: Elliot River estuary showing mangrove and saltmarsh areas.

Mangrove habit (Fig. 118). The Elliott River had a high diversity of mangrove species with 10 out of the 11 locally occurring species present within the estuary (Table 7). All these species occurred throughout the estuary, highlighting the diversity and complexity of tidal wetlands in this estuary. *Rhizophora*, *Avicennia* and *Aegiceras* each occurred at high abundances throughout most of the estuary, although *Rhizophora stylosa* was the least abundant upstream, and *Aegiceras corniculatum* was least abundant downstream, being consistent with their upstream distributional patterns elsewhere (Duke et al., 1998). Similarly, *Bruguiera gymnorhiza* was absent from the mouth of the estuary, presumably because of the lack of

groundwater inputs. *Osbornia* and *Aegialitis* were present throughout most of the estuary except the most upstream reaches influenced by freshwater. *Lumnitzera* and *Excoecaria* were present in the estuary, but only as individuals scattered along the mangrove-terrestrial interface. The estuary lacked *Xylocarpus granatum* only – a species often found only in larger estuaries north of Great Sandy Strait. The dominant species within the Elliott estuary was *Avicennia*, as with many estuaries in the region. However, *Rhizophora stylosa* was the most dominant species in mid estuarine zones and was notably dominant at the mouth. *Ceriops australis* was also a dominant species within the estuary in all but the most upstream reaches with their eroded banks. The upstream part of the estuary was dominated by *Avicennia* and *Bruguiera*, with some areas dominated by *Acrostichum*, the Mangrove fern.

Table 7: Tidal wetland plants in the Elliott River estuary.

Mangrove Species	Saltmarsh Species
<i>Acrostichum speciosum</i>	<i>Atriplex semibaccata</i>
<i>Aegialitis annulata</i>	<i>Baumea juncea</i>
<i>Aegiceras corniculatum</i>	<i>Dyspahnia littoralis</i>
<i>Avicennia marina</i>	<i>Fimbristylis ferruginea</i>
<i>Bruguiera gymnorhiza</i>	<i>Fimbristylis polytrichoides</i>
<i>Ceriops australis</i>	<i>Salsola australis</i>
<i>Excoecaria agallocha</i>	<i>Sarcocornia quinqueflora</i>
<i>Lumnitzera racemosa</i>	<i>Sesuvium portulacastrum</i>
<i>Osbornia octodonta</i>	<i>Sporobolus virginicus</i>
<i>Rhizophora stylosa</i>	<i>Suaeda australis</i>
	<i>Suaeda arbusculoides</i>
	<i>Tecticornia halocnemoides</i>
	<i>Tecticornia indica</i>
	<i>Tecticornia pergranulata</i>

Saltmarsh-saltpan habit (Fig. 118). The Elliott estuary had a high diversity of saltmarsh species. All common species were represented (Table 7) including rarer ones such as *Dyspahnia littoralis*, *Atriplex semibaccata* and *Salsola australis*. The presence of these rarer species reflected the broad habitat diversity and complexity of tidal wetland ecosystems of this river estuary. These included both wet and dry saline grassland, brackish swamps and wet and dry vegetated and unvegetated saltpan and samphire saltmarsh. Extensive areas of algal mat community were associated with seasonally wet saltpans contributed to high productivity levels in the estuary as well as providing nutrients to adjacent mangrove communities. The estuary also had a large areas of brackish sedge swamp which is of high ecological value.

Biomass of tidal wetlands of the Elliott River estuary

Tree (vegetation) heights were recorded in satellite imagery and verified in field surveys. The overall height of mangrove vegetation across the broad tidal wetland areas of the Calliope River are relatively low, around 3-5 m or less. This is consistent with areas of relatively low

rainfall. Slightly taller stands were notably observed along lower elevation shorelines just above mean sea level, and in upstream reaches, as depicted in maps and imagery (Fig. 119).

The zone immediately above the tidal wetland zone (i.e., $1\text{m} > \text{HAT}$) refers to the supra tidal zone. The vegetation in this zone is considered vulnerable to a number of human and natural factors, including vehicle access, reclamation damage, severe storms, flooding, feral pigs, exotic weeds, and sea level rise. There were taller vegetation in upstream areas compared to those in lower estuarine areas.

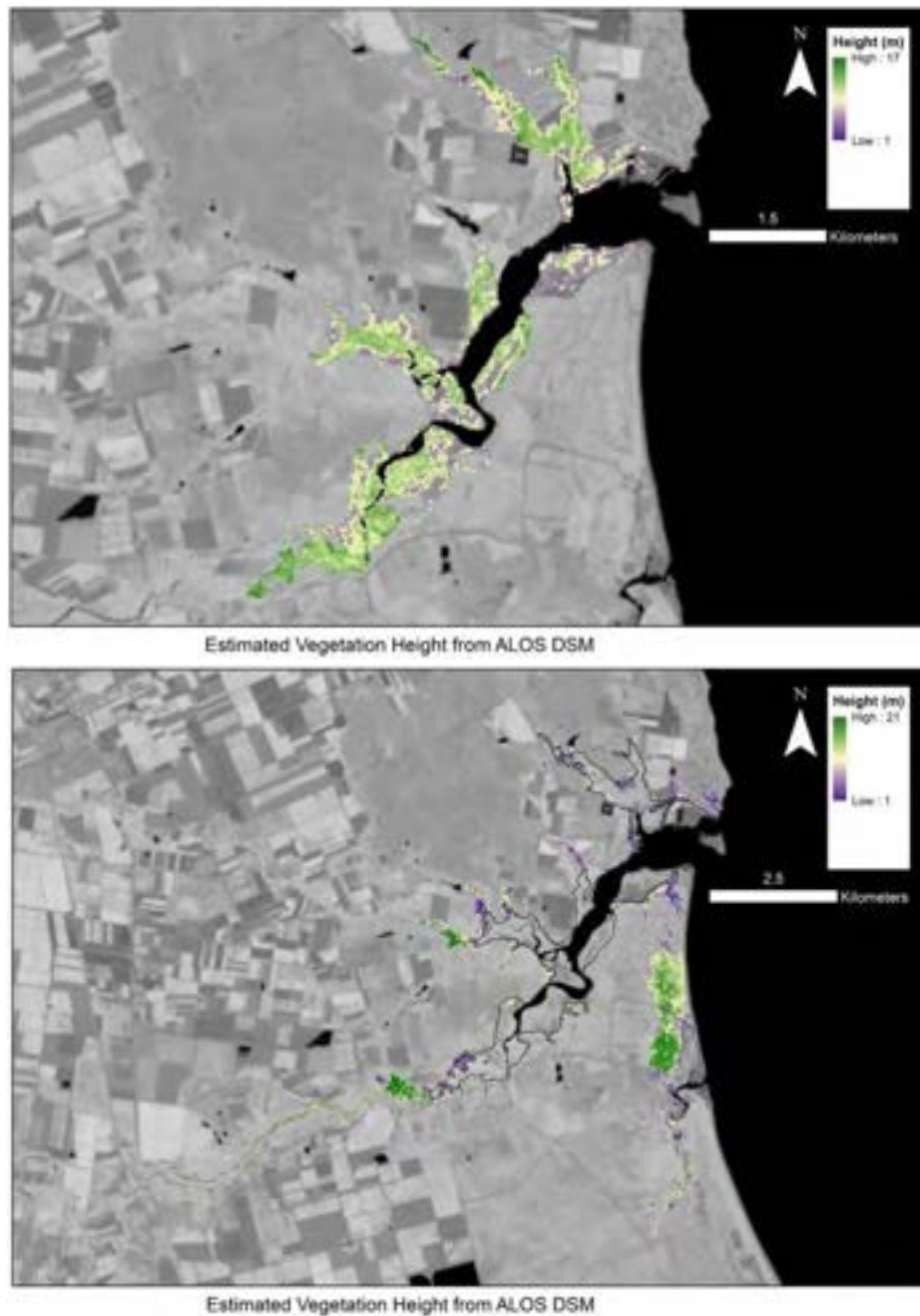


Figure 119: Satellite images of the Elliott River estuarine areas showing height of vegetation for A) tidal wetlands (MSL-HAT) and B) the supra tidal zone (HAT +1m) for 2010 using ALOS DSM.

Changes taking place in tidal wetlands of the Elliott River estuary

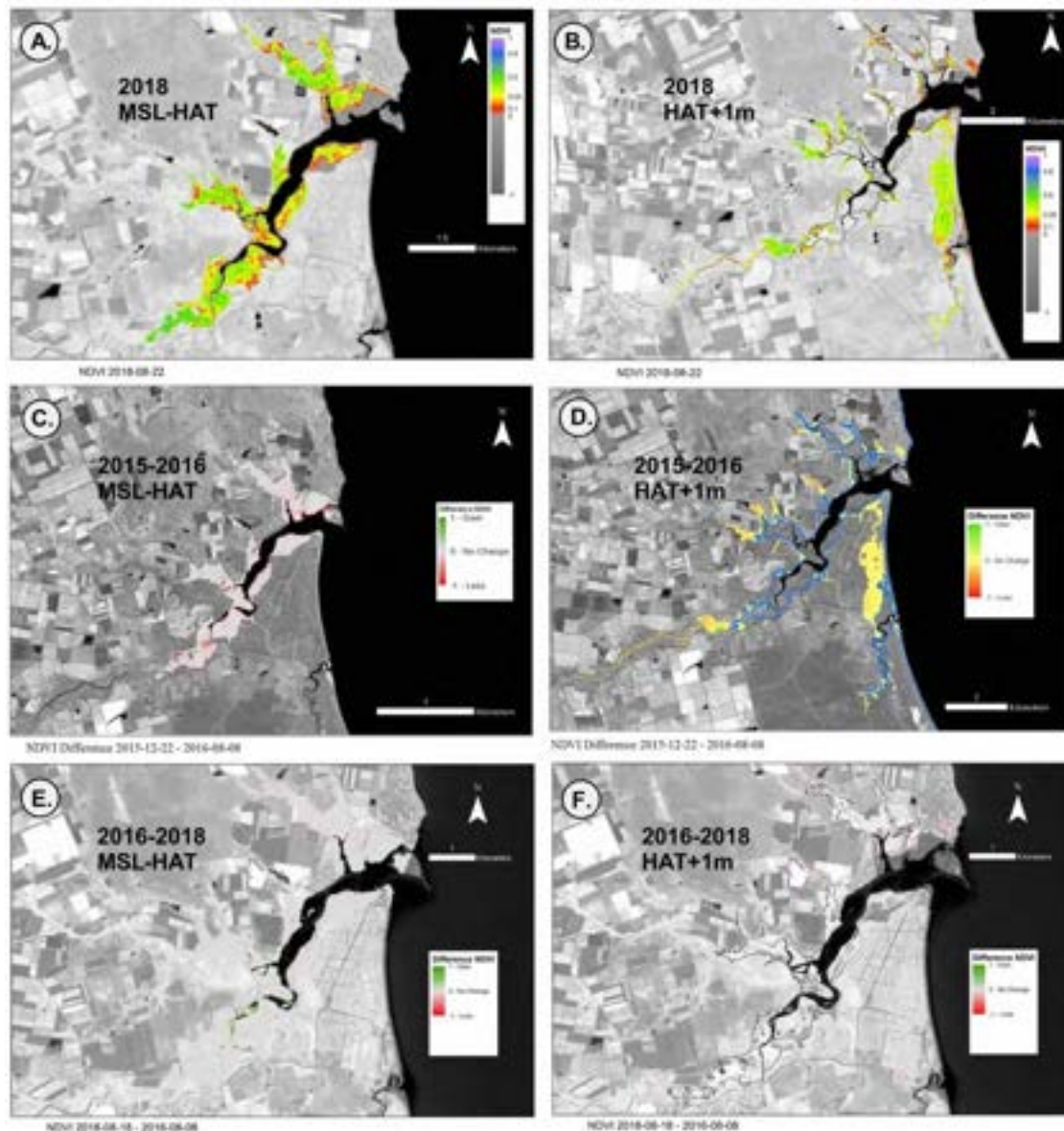


Figure 120: Satellite images of the Elliott River estuarine areas showing NDVI measures of vegetation condition for tidal wetlands (MSL-HAT) and supra tidal zone (HAT +1m) for 2018 (A & B), and two change detection periods 2015-2016 (C & D) and 2016-2018 (E & F).

A first evaluation of changes to vegetation cover was made using vegetation indices (like NDVI) from satellite imagery (Fig. 120). The indices for specific dates represent measures of sub-lethal condition at the time (A & B for 2018 – for tidal wetlands, and supra tidal areas respectively). Colours towards the red end of the scale show vegetation in relatively poor condition while that at the green-blue end is notably healthier. In the 2018 views, tidal wetlands and supra tidal vegetation were in poorer condition in downstream areas than for stands further upstream. There also appeared to be a relatively high proportion of upper fringing areas showing stress. In supratidal stands this was most evident in lower estuarine areas.

When comparing these change scenes for two different time periods (C-F), the scales from red to green indicate relative losses (red) or gains (green). These time periods shown in the

figure include 2015-2016 (C & D) and 2016-2018 (E & F). Comparison of two periods showed notably different responses where losses suffered in one time period might show gains with recovery in a subsequent time period. By comparing C & E, it could be seen that tidal wetlands throughout the estuary were damaged and lost in the first period while in the second period these same areas (especially those upstream) showed detectable gains. These differences represent severe disturbance event in the first period with flooding and cyclonic conditions causing damage to vegetation cover. The effects on supra tidal areas were noticeable in the more recent time period, and mostly in downstream areas.

Management issues registered in community workshops

Key issues flagged at 2016 and 2017 community workshops included vehicle access damage, cattle grazing, pollution & excess nutrients, runoff, direct losses, lack of a buffer, damage to saltmarsh, and high value wetlands (see Fig. 121).

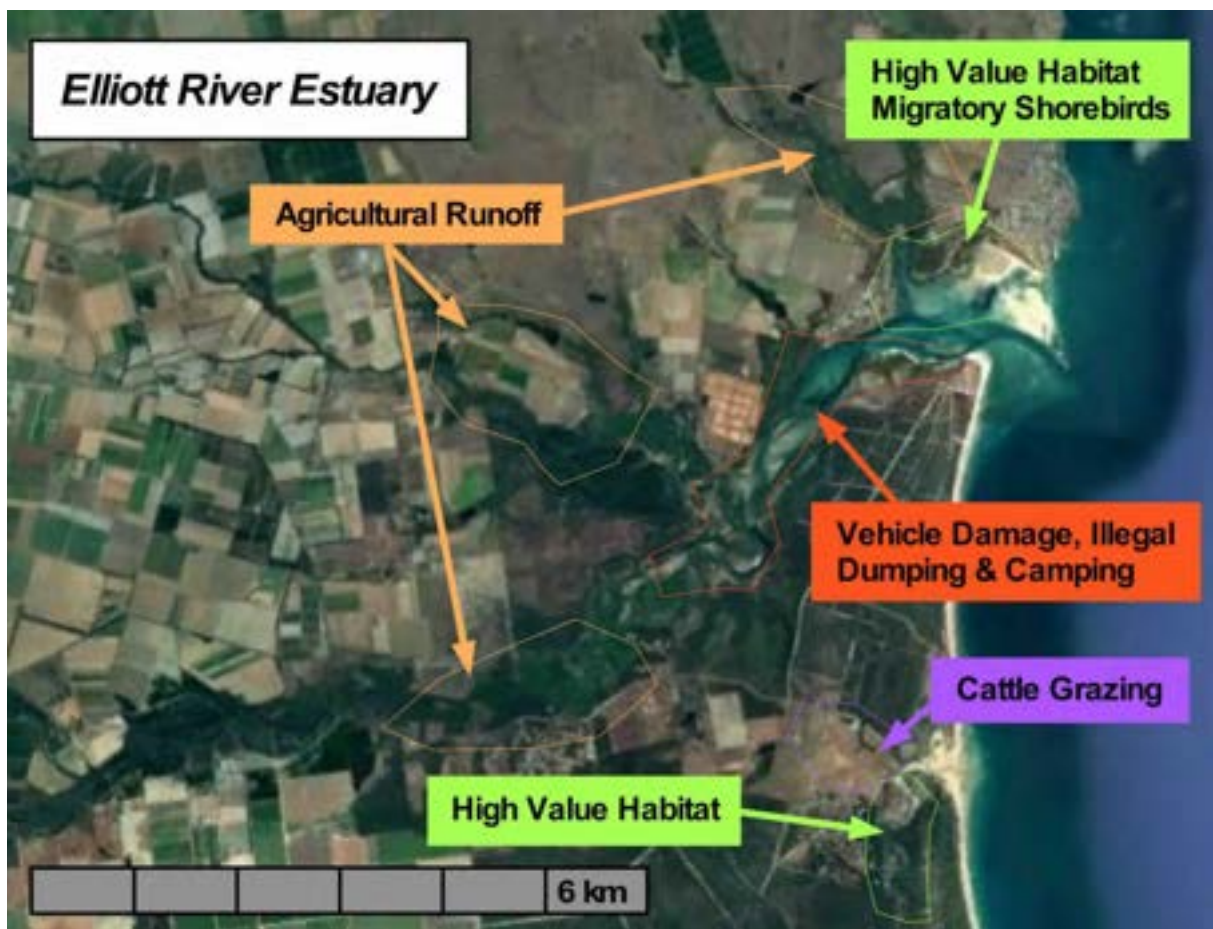


Figure 121: Digitised outcomes of the workshop community-based participatory mapping of Elliott River tidal wetland management issues.

Environmental management issues in the Elliott River estuary

- Groundwater Extraction
- Altered Hydrology – Restricted Flow
- Agricultural Intensification and Urbanisation
- Estuary modification

The tidal wetland ecosystems, riparian vegetation and freshwater wetlands in and adjacent to the Elliott River system are groundwater dependent ecosystems (SKM 2005). Groundwater outflows into the river drive hydrological processes during dry periods (SKM 2005). Unregulated over-extraction of groundwater occurs within the catchment, which influences the ecological function of the Elliott River system and surrounding habitat. In the upper estuary, a large tidal wetland area consisting of tall *Bruguiera* (Orange mangrove) and *Acrostichum* (mangrove fern) filters upstream river flow and provides an important fish habitat area. This tidal wetland plant community is unique for the region. Both *Bruguiera* and *Acrostichum* rely on direct freshwater flow to moderate saline tidal waters. As this tidal wetland area is present above where the aquifer is less than 1m from the surface (SKM 2005), it is highly likely that this plant community is groundwater dependent. During surveys conducted in 2008 this area appeared to be impacted by prevailing drought conditions, with large areas of *Acrostichum* dying back or dead. Over-extraction of groundwater during dry periods is therefore likely to severely effect the capacity of this important tidal wetland area to resist drought effects and may also influence resilience capacity. Given its importance for the economic and ecological values of the whole Elliott River estuary, efforts should be made to ensure its protection through regulation of groundwater extraction.

Hydrology of the Elliott River is dependent on groundwater flow (SKM 2005). Reduction of groundwater flow during dry periods will influence tidal flow into the estuary and oceanic influence. Recent changes to the estuary opening and channel infilling may be influenced by over-extraction of groundwater in the catchment. Before large-scale engineering solutions are implemented to modify the estuary opening, the specific role of groundwater flow and its effect on physical processes within the estuary should be investigated.

The high groundwater recharge capacity of the catchment places this estuary at high risk of from agricultural and urban runoff. The loss of fertile lands surrounding Bundaberg will likely place increased agricultural pressure on this estuary. Population growth in the region will also likely increase urban development in the catchment, particularly adjacent to the estuary. Consequently, there is an increased risk of pesticide, herbicide and nutrient runoff to the estuary.

The Elliott River catchment already has the highest population density for all major catchments in the Burnett Mary Region. The effects of agricultural and urban development are already apparent in tidal wetland areas. Historically, tidal wetland areas have been reclaimed for agricultural development. Agricultural and aquaculture runoff directly to tidal wetland areas in Yellow Waterholes Ck appears to have increased nutrient loads and freshwater supply, altering tidal wetland plant communities. Such effects are likely to increase in the future. These impacts are in addition to the likely increase in groundwater extraction associated with agricultural and urban development.

Due to the high risk of groundwater contamination specific attention should be afforded to reducing herbicide, pesticide and fertiliser application in the catchment, particularly adjacent to tidal wetlands.

Estuary Modification

The construction of a training wall at the southern entrance of the estuary and dredging of the main channel, may have perverse outcomes for tidal wetland areas upstream and the high ecological values of the estuary. Specific attention must be given as to how such modifications will influence erosion of banks upstream and water quality. Engineering solutions to modify estuary entrances in nearby estuaries appear to have contributed to habitat loss and altered physical processes. Erosion is a natural process within the Elliott River system and the tidal wetland plant communities present along the southern bank suggest this area of the estuary is naturally dynamic. This is supported by viewing historical aerial photographs. The need for open water access from the estuary mouth must be balanced with appropriate assessment of the environmental impact to the estuary, with alternate approaches considered.

Drivers of change up to 2018

Elliott River estuary – chief drivers, condition & threats – a summary			
Drivers of Change	Severity*	Scale*	Score**
Direct Human Drivers			
Reclamation/ Removal	5	1	5
Direct Damage – Vehicle Damage	4	3	12
Indirect Human Drivers			
Altered Hydrology – Terrestrial Barriers	3	3	9
Pollution – Herbicides plus Nutrients	1	3	3
Depositional Gain	1	1	1
Bank Erosion – lost riparian veg.	2	4	8
Natural Drivers			
Ecotone Shift	3	3	9
Altered Hydrology – mouth changes	4	2	8
Bank Erosion	4	2	8
Flood Damage	4	4	16
Human Impact Score			38
Overall Condition Score:			79
* ranking of 5 condition levels – minimal to high impact			
**overall measure is the multiple of severity and scale scores			
Future Threats to Tidal Wetland Condition			
1. Continued and increased groundwater extraction			
2. Continued recreational vehicle use of tidal wetland areas			
3. Bank erosion and loss of riparian vegetation			
4. Severe weather events			

Descriptions of management issues and drivers of change

Direct Human Drivers

Direct Damage - Reclamation/Replacement (Fig. 122).

Fringing mangroves have been removed from a few isolated locations along the estuary margins. Mostly mangroves are removed to maintain access to boat ramps, jetties and fishing spots. The largest incident of mangrove removal is the construction and maintenance of intake/outtake pipe for the large aquaculture facility upstream of Riverview. Whilst, these incidents are isolated, continued and increased mangrove removal associated with intensified

development adjacent to the estuary will add up to have a significant ecological impact on the estuary.



Figure 122: Mangrove removal for aquaculture intake/outlet pipes.



Figure 123: Left and right images show extensive damage to tidal wetlands on the southern bank.

Direct Damage – Vehicle Damage (Fig. 123).

Intense recreational vehicle use of tidal wetland areas on the southern bank is causing extensive and possibly irreparable damage to these valuable ecosystems. Vehicle damage is causing degradation of the saltmarsh substrate which has caused increased sediment compaction, increased pooling and erosion. This has increased the susceptibility of tidal wetland areas in an around damaged areas to drought conditions causing saltpan expansion and increased mangrove retreat. The resilience capacity of damaged areas to recover from drought is now greatly reduced and it is unlikely that these areas will recover during wetter periods. There is an urgent need to reduce vehicle access and establish restoration efforts where required, with ongoing monitoring of recovery.

Indirect Human Drivers

Altered Hydrology – Terrestrial Barriers (Fig. 124).

Intensive agriculture relying on irrigation is the dominant landuse surrounding the estuary. To provide consistent water for irrigation supplies, many creek headwaters have been impounded. The loss of terrestrial hydrological connectivity is impacting tidal wetlands and freshwater wetlands within the creeks and the Elliott River. During drought periods small freshwater flows are important for maintaining ecological function in wetland ecosystems. Impoundment has reduced freshwater flows and freshwater availability to downstream tidal wetlands. Consequently, the effects of drought have been exacerbated in these areas, with increased rates of mangrove retreat. The presence of terrestrial barriers to freshwater flow greatly reduces the resistance capacity of tidal wetlands to drought.



Figure 124: Restricted flow in stream headwaters has increased drought effects in freshwater wetlands and reduced tidal wetland - terrestrial connectivity.

Pollution – Nutrients and Herbicides (Figs. 125 - 126).

The effects of direct nutrient runoff to the estuary are visible in tidal wetlands adjacent to some areas of intensive agriculture and aquaculture. The estuary is susceptible to eutrophication through groundwater pollution. Additionally, large areas of agricultural land have minimal vegetation buffer zones between crops and tidal wetland areas.



Figure 125: Direct connectivity between intensive agriculture and tidal wetlands without a significant tidal buffer increases risk of eutrophication.

Nutrient runoff, usually also associated with increased freshwater flow has an initial positive effect on tidal wetland productivity. In Yellow Waterholes Creek and another creek upstream of Riverview, nutrient runoff has caused mangrove expansion into saltmarsh areas and increased height and vigour of fringing mangroves. However, nutrients also decrease the capacity of tidal wetland areas to withstand environmental variability, such as drought, storm events or loss of nutrient supply. Eutrophication also encourages development of monotypic mangroves forests, which decreases habitat complexity and species diversity. Direct nutrient runoff to tidal wetland areas in Elliott River should be monitored and new nutrient sources should be restricted. The reduction of current nutrient supply will likely have a significant impact on affected tidal wetland areas, with slow recovery to natural conditions. Care should be taken to reduce perverse outcomes of nutrient runoff management in the form of mass mangrove mortality.



Figure 126: Species-specific dieback of *Avicennia marina* was recorded in the Elliott estuary. This is indicative of herbicides in runoff waters from agricultural lands.

Dieback of particularly sensitive mangrove trees of *Avicennia marina* is caused by herbicides in runoff from agricultural lands. These effects can be reduced with the greater use of buffering stands of vegetation between the fields and estuarine waters.

Depositional Gain (Fig. 127).

There were notable areas of expanding shoreline margins with fields of young seedlings taking advantage of sediment deposits reaching mean sea levels. These sediments are the result of a combination of clearing of ground cover in the catchment, tillage agriculture and soil disturbances, and the installation of dams and weirs blocking normal flushing flows.



Figure 127: Lots of seedlings growing in front of established shoreline trees is indicative of depositional gain.

Natural Drivers

Flood Damage (Fig. 128).



Figure 128: Recent flooding has damaged and killed mangrove vegetation in several places along the estuary.

The estuary has been affected by severe flooding in recent years. This is marked by the presence of mangrove dieback and dead wood. Changes have also been taking place at the mouth (Fig. 129).



Figure 129: Significant changes have occurred at the mouth of the estuary. Note the closure of the northern main channel and the opening of a southern channel south of the small islet.

Bank Erosion (Fig. 130).

Bank erosion is considered an issue of concern in the Elliott River estuary. Extensive and severe erosion of tidal wetland areas and coastal ecosystems are occurring on the southern bank in the lower estuary. This process is occurring in conjunction with southward migration of the estuary entrance. Based on observations of fringing tidal wetland plant communities (upper-intertidal closed *Cerriops*), it is apparent that erosion in this area has been occurring for quite some time.

As such, this process should be considered to be entirely natural. However, it is likely that drought conditions resulting in reduced freshwater flows and groundwater supply to the estuary is causing increased oceanic tidal influence in the lower estuary. Again, excessive groundwater extraction in the Elliott River catchment is likely to have exacerbated these conditions. Understandably there is concern that shoreline erosion and concurrent deposition within the estuary main channel is creating a navigational hazard and reducing access to and from the estuary.

Large-scale engineering modifications to the estuary mouth are proposed to alleviate this problem. But, before this occurs, the situation should be monitored now that flows have been increased due to rain. Assessment of potentially perverse outcomes in the form of habitat loss upstream resulting from altered hydrology should also be examined. Examination of the connection between groundwater extraction and estuary hydrology should also occur before extensive modification occurs.



Figure 130: Bank erosion in the lower estuary with channel migration into upper-intertidal mangrove forest.

Potential Future Threats to Tidal Wetland Condition:

- **Continued and increased groundwater extraction**
 - Reduced ecosystem resistance and resilience due to flooding
 - Altered hydrological conditions
- **Agricultural and urban intensification surrounding estuary**
 - Risk of groundwater contamination – nutrients and herbicides
- **Continued vehicle use of tidal wetland areas**
 - Reduced ecosystem resistance and resilience
 - Irreparable damage to saltmarsh ecosystems and fish habitat
- **Flooding events**

9.0 BURRUM RIVER ESTUARY

Burnett Mary region

Mouth location:	-25.179229; 152.616557
Condition:	Largely unmodified, river-tide dominated
Area of tidal wetlands (Mackenzie & Duke 2011)	
Mangroves:	491 ha
Tidal saltmarsh and saltpans:	153 ha
Total tidal wetland:	644 ha
Wetland Cover Index:	76%
Mean Annual Rainfall (25yr mean):	944 mm
Catchment Area:	910 km ²



Figure 131: Looking upstream from the entrance to the Burrum River in 2008.



Figure 132: Achievements regards successful field surveys undertaken in the Burrum River estuary in collaboration with Gidarjil Rangers up to late 2018. Tracks (yellow lines) are shown on satellite images for 2013, 2016 and 2018.

Summary Description

The Burrum River estuary is the receiving waters of the Burrum, Cherwell, Isis and Gregory rivers that combine before flowing into northern Hervey Bay (Fig. 131). The estuary has high ecological, economic and cultural values. There are limited tidal wetland areas along the estuary owing to its steep topography along upper-intertidal estuarine shorelines. These areas have moderate habitat diversity, with mangrove areas being predominantly monotypic and saltmarsh-pan areas being mostly small saltpans. Despite the low complexity of these areas, they contribute important ecological services that support fishing and recreation-based tourism and protect important habitat for endangered marine fauna within the estuary and within Hervey Bay. The estuary remains largely unmodified, however the effects of waterway barriers, altered hydrology, human population growth and intensive landuse in the Gregory and Isis Rivers have reduced the ecological integrity of the estuary and reduced the resistance and resilience of its tidal wetlands to future changes in climate and sea level. The estuary was surveyed in 2013, 2016 and 2017/18 by the Gidarjil Rangers (see Fig. 132).

Estuary Features

Physical setting. The Burrum River estuary is classified as largely unmodified (NLWRA 2002) and the estuary is river-dominated and high in mud content. It is ~26km long and extends from the town of Howard at Burrum Weir #1 to Burrum Heads, where it flows into northern Hervey Bay. The broad lower estuary flows through extensive Holocene chenier dune ridges (Barry & Martin 2004) while the upper part cuts through older sedimentary rocks (Walker 2008). Both substrates have high porosity, low moisture retention and low nutrient retention capacity, making them poor soils for agriculture. Within the lower estuary are extensive alluvial deposits, sand bars and islands of coarse sedimentary material. Many of the depositional sand islands have been stabilised by mangrove with dense vegetation suggesting they have been present for hundreds of years. The primary landuse has been cattle grazing, low density residential and conservation. Riparian vegetation along the estuary remained mostly intact, with some clearing associated with residential housing and grazing lands (Bruinsma & Danaher 2000).

Estuarine zones (Fig. 133). The hydrology of the Burrum River is largely riverine influenced with high sediment loadings. The lower estuary is highly dynamic and susceptible to erosion with large sand deposits forming extensive shoals that extend into Hervey Bay (Walker 2008). The estuary substrate has increased mud content with distance from the mouth. At the mouth, the estuary is largely tidally-influenced, and susceptible to oceanic sand re-deposition (Brizga *et al.* 2002). The surrounding geology is dominated by Holocene sand ridges (Barry & Martin 2004). Upstream from the mouth, the banks are mostly sand, while further upstream, there are rocky outcrops and sedimentary layers exposed much of the time. In mid and upper reaches, many rocky areas have been covered with recent mud deposits. At mid estuary, near the confluence of the three major river systems, there were many depositional islands and sand bars. These banks and islands consist of coarse sedimentary deposits washed down from eroded upstream landforms.

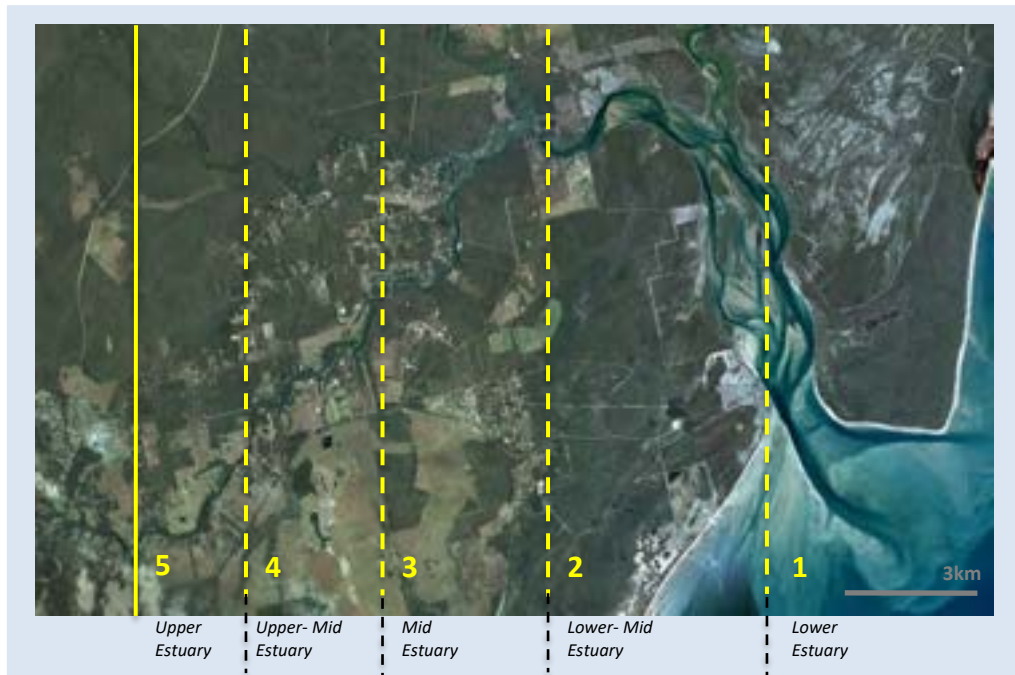


Figure 133: Estuary zones of the Burrum River.

Changes to natural habitats. Changes to natural habitats are driven by a combination of human and natural drivers of change. Recent alterations to river flows had significantly altered the hydrology of the estuarine system following the installation of barriers that trapped coarse material and blocked environmental connectivity. Two major structures, Lenthalls Dam and Burrum Weir #1, exemplified the resulting impacts to the estuary. Upstream in the upper estuary, greater sedimentation corresponded with erosion and increased tidal influence in the mid and lower estuary downstream. Similar observations were recorded for other tributaries, like the Cherwell and Isis. For these and other instances, the installation of waterway barriers led to increased sedimentation upstream and erosion downstream. The natural salinity gradient was also altered, with more variable and higher salinities upstream causing the loss of upstream brackish environments (Walker 2008). The proposed further raising of Lenthalls Dam was expected to further exacerbate these changes (Brizga *et al.* 2002). A large increase in residential landuse along the mid and upper Burrum and lower Cherwell and Isis rivers had significant environmental consequences. The increased population coupled with the increased amount of low density residential housing resulted in a number of minor modifications to estuary banks for pontoon installations, access paths and removal of vegetation for views. More intensive modifications were also done in the lower Burrum estuary at Walkers Point, Buxton and Burrum Heads. Here, estuary banks were hardened with rock wall structures to prevent erosion. Erosion had been an ongoing and serious issue for Burrum Heads township (Hegerl 1993; Brizga *et al.* 2002). Urban expansion was reported for Burrum Heads, where the urban footprint increased with sea-change retirees and increased tourism. However, surrounding these townships, most remaining land was protected within the Burrum Coast National Park. And, upper estuary catchments of the Burrum, Isis and Cherwell rivers had been mostly protected under State Forestry Reserve.

Tidal wetland vegetation

Mangrove habit (Fig. 134). The Burrum River estuary has a high species diversity and low complexity of tidal wetland plant communities (Table 8). All local species, except the mangrove fern, *Acrostichum speciosum*, were recorded within the estuary. The presence of *Brugueira gymnorhiza* and *Xylocarpus granatum* in the estuary was limited to a few isolated stands and were likely remnant stands from historically wetter conditions. *Lumnitzera racemosa* was present throughout most of the estuary, but it was limited to upper-intertidal margins. There were notably four dominant mangrove plant communities in the estuary. Open *Osbornia* and *Aegialitis* stands occurred on newly formed banks on coarse sedimentary islands in the lower estuary. Closed *Rhizophora* was present also on these islands and also along fringing banks in the lower and lower-mid estuary. Closed *Cerriops* occurred on exposed eroding banks in the lower estuary, with some isolated stands upstream. Closed *Avicennia* with fringing *Aegiceras* and upper-intertidal *Excoecaria* were present along most estuary banks upstream from Buxton. There was a change in dominant fringing mangrove species from *Rhizophora* to *Avicennia* around that point. Of interest, was the presence of tall (>20m) stands of *Rhizophora* at the upper-intertidal margins of mid-estuary *Avicennia* forests. These mangroves were some of the tallest *Rhizophora* recorded for this region, and they appear to be unusually old trees. As such, these stands may be remnant occurrences from a period of higher sea-level, possibly up to 500 years ago.

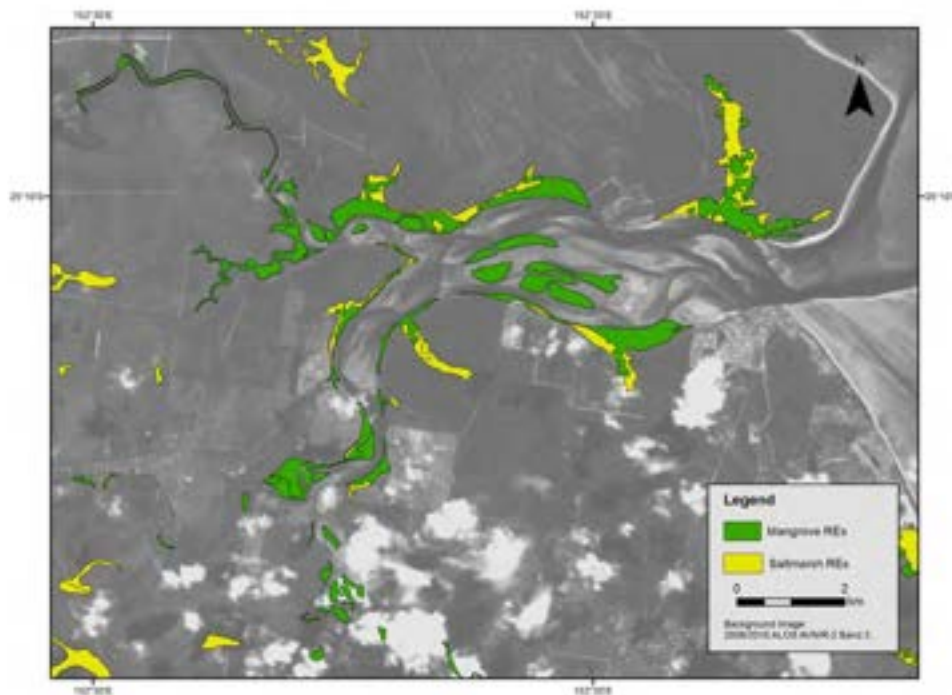


Figure 134: Burrum River estuary showing mangrove and saltmarsh areas.

The removal of upper-estuarine habitat and increased salinisation of upstream habitat, in combination with low rainfall effectively removed upstream brackish environments that had possibly supported the mangrove fern. Much of the lower estuary tidal wetland area were too dry to provide suitable habitat for this species. Extensive fringing mangroves were present in the Isis, Gregory and Cherwell rivers. The main areas of tidal wetlands were the mangroves

growing on sedimentary mid-stream islands at the mouth of the estuary and at the confluence of the major tributaries upstream. Steep banks of hard sedimentary rock along much of the estuary prevented the formation of broad tidal areas.

Table 8: Tidal wetland plants in the Burrum River estuary.

Mangrove Species	Saltmarsh Species
<i>Aegialitis annulata</i>	<i>Baumea juncea</i>
<i>Aegiceras corniculatum</i>	<i>Enchylaena tomentosa</i>
<i>Avicennia marina</i>	<i>Fimbristylis ferruginea</i>
<i>Bruguiera gymnorhiza</i>	<i>Fimbristylis polytrichoides</i>
<i>Ceriops australis</i>	<i>Limonium tetragonum</i>
<i>Excoecaria agallocha</i>	<i>Sarcocornia quinqueflora</i>
<i>Lumnitzera racemosa</i>	<i>Sesuvium portulacastrum</i>
<i>Osbornia octodonta</i>	<i>Sporobolus virginicus</i>
<i>Rhizophora stylosa</i>	<i>Suaeda australis</i>
<i>Xylocarpus granatum</i>	<i>Suaeda arbusculoides</i>
	<i>Tecticornia indica</i>
	<i>Tecticornia halocnemoides</i>
	<i>Tecticornia pergranulata</i>

Saltmarsh-saltpan habit (Fig. 134). Saltmarsh vegetation in the estuary (Table 8) was restricted to five locations; north Burrum Coast National Park, downstream of Burrum Heads, some small patches of saltpan on depositional islands at the estuary mouth, at the mouth of the Gregory River and a small saltmarsh area opposite Buxton. These saltmarsh areas have sparse vegetation cover, dominated by *Tecticornia* spp. *Sporobolus* areas are restricted to a thin band at the upper-intertidal margin with less salt tolerant sedge species such as *Fimbristylis* spp. and *Baumea juncea* limited to within the upper-intertidal mangrove fringe. The primary drivers of saltmarsh vegetation zonation was low rainfall (Duke et al. 2019), porous substrate and steep topography which limited the conditions for vegetation colonisation.

Biomass of tidal wetlands of the Burrum River estuary

Tree heights were recorded in satellite imagery and verified in field surveys. The overall height of mangrove (tidal wetland) vegetation across the broad estuarine areas of the Burrum River was relatively low, especially downstream in lower estuarine reaches and vegetation was notably taller in upstream zones (Fig. 135). There were few broad areas of tidal wetlands. The zone immediately above the tidal wetland zone (i.e., 1m > HAT) refers to the supra tidal zone. The vegetation in this zone is considered vulnerable to a number of human and natural factors, including vehicle access, reclamation damage, severe storms, flooding, feral pigs, exotic weeds, and sea level rise. There were few indications of how this vegetation cover has responded over time.

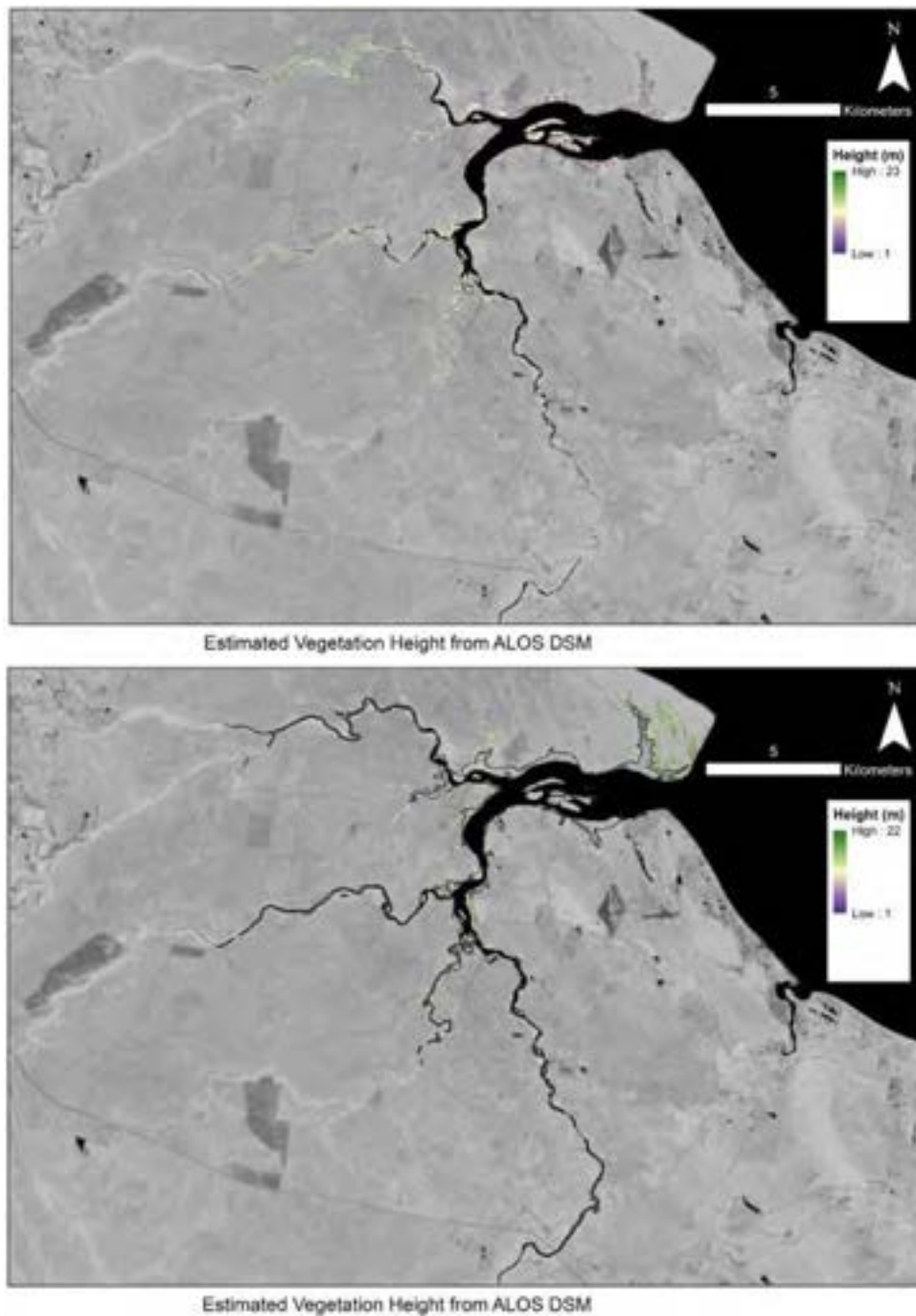


Figure 135: Satellite images of the Burrum River estuarine areas showing height of vegetation for A) tidal wetlands (MSL-HAT) and B) the supra tidal zone (HAT +1m) for 2010 using ALOS DSM.

Changes taking place in tidal wetlands of the Burrum River estuary

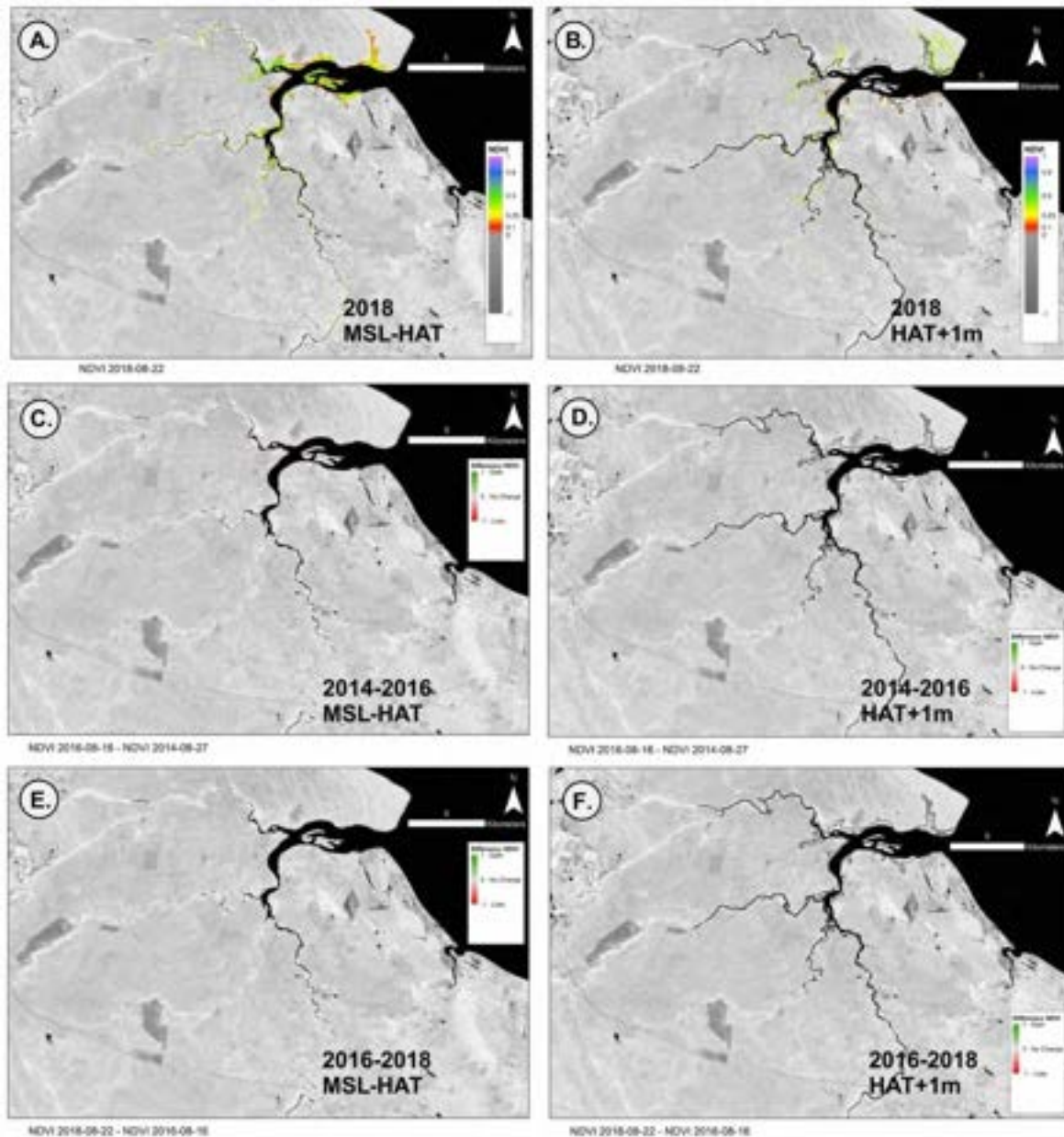


Figure 136: Satellite images of the Burrum River estuarine areas showing NDVI measures of vegetation condition for tidal wetlands (MSL-HAT) and supra tidal zone (HAT +1m) for 2018 (A & B), and two change detection periods 2014-2016 (C & D) and 2016-2018 (E & F).

A first evaluation of changes to vegetation cover was made using vegetation indices (like NDVI) from satellite imagery (Fig. 136). The indices for specific dates represent measures of sub-lethal condition at the time (A & B for 2018 – for tidal wetlands, and supra tidal areas respectively). Colours towards the red end of the scale show vegetation in relatively poor condition while that at the green-blue end is notably healthier. In these views, tidal wetlands and supra tidal vegetation showed very few differences along the entire estuary. When change detection was done comparing scenes from two different time periods (C-F), the scales from red to green indicate relative losses or gains. The time periods shown in the figure include 2014-2016 (C & D) and 2016-2018 (E & F). Comparison of two time periods showed overall low losses for each time period notably for vegetation around the lower estuary. The effects

on supra tidal areas were similar. These observations were consistent with observations of declining rainfall levels over recent years.

Management issues registered at community workshops

Key issues flagged at 2016 and 2017 community workshops included altered hydrology, direct losses, lack of a buffer, and high value wetlands (see Fig. 137).

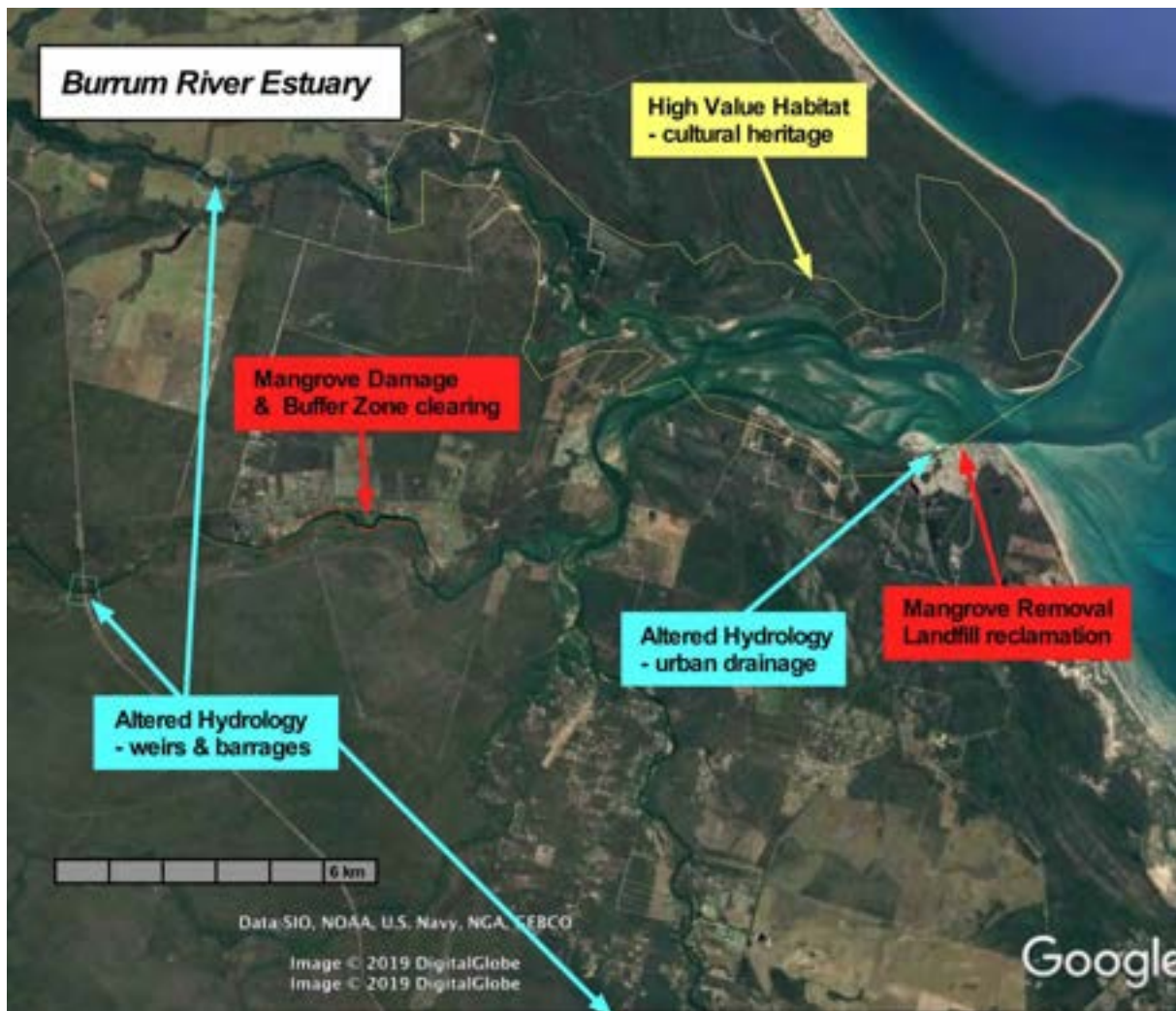


Figure 137: Digitised outcomes of the workshop community-based participatory mapping of Burrum River tidal wetland management issues.

Environmental management issues in the Burrum River estuary

- Altered Hydrology
- Shoreline Erosion
- Mangrove Removal/ Trimming & Habitat Fragmentation
- Flood impacts
- Climate Change

Tidal wetlands of the Burrum and adjacent estuaries have been impacted by severe flooding. But, the estuary exhibits good natural resilience to these events, with signs of positive recovery throughout the estuary. In some locations, mangrove recovery has been limited by bank hardening, structures, mangrove removal and cattle grazing.

Severe flood impacts to mangroves in the upper estuary were likely exacerbated by sediment deposition related to altered hydrology which facilitated rapid mangrove growth. Mangroves growing on fine sediment deposits are likely less resilient to flooding having lower root to shoot ratios making them more susceptible to flood impacts. Shoreline erosion is a major issue of concern in the Burrum estuary and is causing significant loss of mangrove and coastal habitat. The shoreline erosion issue will continue to worsen with rising sea levels. Management actions are required to protect high value tidal wetland assets at the estuary mouth.

Mangrove damage and impacts to mangroves related to altered hydrology is present near the Burrum Heads township. Population growth and urban expansion will see direct and indirect impacts to mangroves increase with appropriate management (Fig. 138). There are a number of abandoned vessels present in the estuary that are impacting mangrove habitat. Litter and rubbish was frequently observed in mangrove habitat along the estuary. Although this does not directly impact mangrove habitats, it is an issue of concern for other marine wildlife, particularly sea turtles which are known to utilise mangroves within the Burrum estuary.

A previously reported issue relating to altered hydrology impacting tidal wetlands in the Burrum Coast National Park (Mackenzie & Duke 2011) has since been addressed by restoring some level of natural flow, but it is unclear at this stage whether there has been a significant improvement to tidal wetland function as a result. Any proposals to remove or impact mangroves in the estuary should be considered in light of existing mangrove stresses, and likely future mangrove loss associated with flood impacts and shoreline erosion.



Figure 138: Mangrove removal is common along the Burrum estuary.

Recommended management actions:

- Increase environmental freshwater flows to the estuary
- Reduce sediment inflows to the upper estuary
- Increase public awareness regarding the importance of mangroves and riparian vegetation to reduce cutting and clearing.
- Develop and implement a shoreline erosion management plan that incorporates natural and hard engineering approaches (Fig. 139).
- Remove abandoned vessels impacting mangroves.

Drivers of change up to 2018

Burrum River estuary – chief drivers, condition & threats – a summary			
Drivers of Change	Severity*	Scale*	Score**
<i>Direct Human Drivers</i>			
Direct Damage - landfill	2	1	2
Direct Damage - Cutting/ Removal	4	2	8
Direct Damage - Cattle Grazing	3	1	3
Direct Damage - Vehicle Damage	2	1	2
Direct Damage – Abandoned Vessels	3	1	3
<i>Indirect Human Drivers</i>			
Altered Hydrology - Terrestrial Barrier	2	2	4
Altered Hydrology - Waterway Barrier	2	5	10
Depositional Gain	1	3	3
Pollutants – Herbicides	2	2	4
<i>Natural Drivers</i>			
Bank Erosion	4	3	12
Root Burial – Storm Damage	2	1	2
Flood Damage	4	3	12
Human Impact Score:			39
Overall Condition Score:			65
* ranking of 5 condition levels – minimal to high impact			
**overall measure is the multiple of severity and scale scores			
Future Threats to Tidal Wetland Condition:-			
1. Increased population density and urban expansion			
2. Shoreline and bank erosion			
3. Extreme weather events – floods and drought			



Figure 139: Large-scale bank erosion in the mid-section of the Burrum River estuary.

Descriptions of management issues and drivers of change

Direct Human Drivers

Direct Damage - Cutting/Removal (Fig. 140).

Mangroves along the Burrum, Cherwell and Isis rivers are increasingly being trimmed and removed to enhance views, create access to pontoons and because of a negative attitude towards these trees by some residents. The removal and trimming of mangroves at an individual location may appear to be an ecologically insignificant impact, but when this is considered in the broader context of the estuary and the frequency of occurrence, there is likely to be an effect. Bank erosion is already an issue within the Burrum River and removal of mangroves is likely to increase bank erosion rates and risk of erosion. The trimming of mangroves reduces arboreal habitat and productivity. The creation of 'holes' in the mangrove fringe from cutting and trimming reduces the visual amenity value of the river. Without education to change attitudes and enforcement of legislation protecting marine plants there is high likelihood of increased mangrove removal and mangrove trimming, especially with an increase in the number of residential properties adjacent to the estuary. Between 2013 and 2018, shoreline modification along the Burrum estuary has increased by 4.3% and 21 new structures built within the mangrove shoreline fringe. The number of structures built represents an 18% increase in habitat fragmentation.



Figure 140: Boat ramp cutting through the mangrove fringe, Burrum River.

Direct Damage - Cattle Grazing (Fig. 141).

Low levels of environmental impact from cattle grazing were observed in a small saltmarsh area upstream of the Isis River entrance. The stock density in the tidal wetland area appeared to be low. Given the small area of saltmarsh/saltpan complex within the Burrum River, these areas should be provided with greater protection through fencing to reduce the risk of damage from increased stock access. Stock access to shoreline habitats is limiting natural habitat recovery following flooding.

Direct Damage - Vehicle Damage

Recreational 4WD/ motorbike activity was observed during aerial surveys to be damaging a small area of saltmarsh upstream from the Burrum Heads township, adjacent to private property. The small area of this saltmarsh area limits the extent of the damage and limits usage. However, given the small area, it is highly susceptible to damage. The Burrum River has a low saltmarsh and saltpan area and existent areas should be protected from damage resulting from vehicle use.



Figure 141: Grazing by stock plus access and vehicle use has contributed to tree death and loss of saltmarsh vegetation in the Burrum mid estuary.

Direct Damage – Abandoned vessels (Fig. 142).

A number of abandoned vessels are present in the lower estuary near Burrum Heads. Although these vessels have a limited impact area, they represent a lack of management oversight in the estuary as they are relatively easy issue to rectify. It is recommended that abandoned vessels are removed as soon as practical.



Figure 142: Abandoned vessels impacting mangroves near Burrum Heads.

Indirect Human Drivers

Altered Hydrology - Terrestrial Barrier (Fig. 143).

A small dam constructed in upper-intertidal tidal wetland on the southern bank upstream of Burrum Heads has reduced terrestrial connectivity and freshwater supply. The dam appears to be associated with a bund wall that restricts cross-flow tidal influence. It appears that the dam was initially constructed on saltmarsh/saltpan habitat causing a loss of tidal wetland area. The alteration to hydrology in this area appears to have caused reduced vegetation cover, with loss of mangroves and an expansion of saltpan relative to the adjacent unaffected tidal wetland areas. The severe ecological impact of this construction highlights the sensitivity of tidal wetland areas to hydrological change from terrestrial barriers to flow.



Figure 143: Altered hydrology caused by restricting freshwater flow and influencing tidal flow impacts tidal wetland areas.

Altered Hydrology - Waterway Barrier

Lenthalls Dam, Burrum Weir #1 and the Isis and Gregory weirs reduce freshwater flow volume and frequency to the lower estuary. These waterway barriers caused large-scale ecological change when they were constructed and continue to effect downstream estuarine environments. Increased sediment deposition in the upper estuary from reduced flows has enabled increased mangrove colonisation, whereas reduced riverine influence downstream, in combination with reduced sediment supply has caused increased erosion and loss of fringing tidal wetlands. Erosion also restricts mangrove colonisation and establishment on fringing banks, especially where vegetation has been removed. Reduced flows and sedimentation reduce the capacity of tidal wetlands to resist drought and exacerbate drought effects. Small to moderate freshwater flows are important during droughts, as these flows limit salinity. Weirs and dams restrict low flow events, and consequently salinity increases upstream. Increased salinity reduces plant productivity and can cause increased mangrove mortality. Mangroves that establish on high nutrient anthropogenically sourced sediment deposits are more susceptible to drought and water stress (Fig. 144), leading to an increase in mortality and loss in productivity during low rainfall periods (Lovelock *et al.* 2009). It is recommended that improving environmental flows during drought be considered when assessing future water usage and storage in the catchment.



Figure 144: Depositional gain is common along banks showing that sediments have accumulated and been colonised by mangroves.

Altered Hydrology - Increased Freshwater Flows

The construction of a high density residential housing area in Burrum Heads has increased freshwater and possibly nutrient runoff to a small creek flowing into the Burrum estuary upstream of Burrum Heads. Mangroves have now extensively colonised this area (Fig. 145). The area is protected from erosion by a small sand ridge running parallel to the shore. Whilst increasing mangrove area in the river may have some positive ecological effects, their presence is decreasing the visual amenity and recreational values of the area. The mangroves however should remain as they are required to buffer pollutants possibly entering the Burrum estuary from the residential area. Due to the rapid colonisation of mangroves, it is highly likely the water from the creek has a high nutrient load. The water quality in this stream should be investigated further.



Figure 145: New sapling growth sites mark locations of depositional gain.

Pollutants – Herbicide (Fig. 146).

Avicennia throughout the Gregory River estuary appear to be experiencing greater levels of dieback compared to the nearby Isis river system. From aerial surveys this effect appeared similar to that previously observed in the Pioneer River system near Mackay which was shown to be the result of herbicide contamination in mangrove sediments (Duke *et al.* 2005). High levels of Diuron, Ametryn and Simazine, all agricultural herbicides, have previously been reported in surface waters of the Gregory River (McMahon *et al.* 2005). Herbicide pollution has the potential to severely reduce mangrove ecosystem productivity (Duke *et al.* 2005) and increase susceptibility to drought. Flows from the Gregory River with high herbicide concentration is also likely to impact upon adjacent seagrass beds in the Burrum River and Hervey Bay (McMahon *et al.* 2005). Flow based sampling of water entering the Gregory River over the weir should specifically test for herbicide contamination. There is increasing pressure within the Gregory catchment to intensify agricultural production in response to conversion of fertile lands surrounding Bundaberg to housing. This will increase the risk of herbicide contamination. Strategies to reduce herbicide application and farm runoff should be implemented within the Gregory catchment to protect estuarine tidal wetland and seagrass habitat.



Figure 146: Species specific dieback of *Avicennia marina* whilst other species appear healthy.

Natural Drivers

Flood Damage – drowned dead trees (Fig. 147).

Recent flooding has caused notable damage to shoreline vegetation. This is often dead and layered in sediment.



Figure 147: Damage from recent flooding shows dieback of lower elevation vegetation, and the leaning dead stems are largely unidirectional.

Bank Erosion (Fig. 148).



Figure 148: Eroding bank, exposing upper intertidal closed *Ceriops* forest, Burrum River mouth.

Bank erosion is a natural process. The overall frequency of eroded banks in the Burrum River (41%) is comparable to adjacent estuaries of a similar size. However, erosion in the lower estuary and mid-estuary may be exacerbated by the effects of waterway barriers. Reduced flow from the three major tributaries of the lower estuary is likely to have increased oceanic influence at the mouth, resulting in altered current patterns, greater current velocities and increased sand import. These factors would all contribute to higher rates of erosion. On the northern bank (the black banks) of the lower estuary, loss of tidal wetlands as a result has

been recorded to be approximately one meter per year (C. Bussey pers comm.). In the mid-estuary mud and sediment deposition and accumulation from reduced flushing, may cause a shallowing of the estuary and a localised sea-level rise effect. Banks in this area of the estuary are susceptible to erosion, having sheer or steep profiles with loosely compacted sedimentary rock substrate.

Storm Damage – Root Burial (Fig. 149).

An area of mangroves on the northern bank in Burrum Coast NP appears to have experienced significant sand deposition in the past. It's likely this occurred resulting from a climatic event such as a cyclone or large flood. The event is likely to have taken place more than 50 years ago. Mangroves in this area are now recovering with colonisation and expansion of *Osbornia* and *Aegialitis* occurring. The volume of sand deposited in the area shows the extent to which natural events can dramatically alter ecological systems and the risk these events pose to coastal urban areas.



Figure 149: Sand deposition and root burial within the highly dynamic lower estuary.

Potential Future Threats to Tidal Wetland Condition

- **Increased Population Density**
 - Increased mangrove trimming and mangrove removal for view improvement and shoreline access
- **Agricultural Intensification in the Gregory and Isis catchments**
 - Increased risk of herbicide contamination
 - Increased sediment delivery to the estuary
 - Increased water extraction and reduced flows
- **Future extreme climatic events – drought**
 - Increased effect of droughts and severe flooding reduce the resilience of tidal wetland ecosystems - especially when they must also deal with altered flows associated with upstream waterway barriers

10.0 SHORELINE VIDEO ASSESSMENT METHOD (S-VAM) RECORDS – A BASELINE DATASET OF SIGNIFICANT VALUE FOR FUTURE EVALUATIONS OF ESTUARINE TIDAL WETLAND HABITATS

The detailed imagery and data collected by Gidarjil Rangers, as described in this report, has significant, immense and lasting value for environmental managers. This is not just for the observations presented and discussed with each estuarine system, but it also extends to the continuous sequences of geo-tagged images capturing all these shorelines on two or more occasions from 2013 and 2018.

These images have at least two fundamental values. One is their value as time and place referenced images for display and comparison. In this sense, they represent an historical record. The other value, of arguably greater importance and immense value, is their use in scoring or measuring specific features seen or not seen along the shorelines filmed. In this way, it is possible using these images to quantify the condition and the changes taking place along every metre of shoreline, and throughout each estuarine system. For example, this assessment can not only show each site of erosion but also quantify the level of impact so high risk sites can be prioritised for mitigation works or other conservation measures.

These enhanced assessment outcomes require further processing and evaluation, but it is considered a cost-effective strategy where data already gathered has immense additional value. The observations only need to be scored to tap into this opportunity. And, in doing so, this will further enhance the already remarkable achievements made by the Gidarjil rangers. The observations contained in these records hold an invaluable account of habitat condition for each of the eight estuarine systems during the period from 2013 to 2018. The records document the condition and the changes taking place during this time. At very least, these data represent a substantive baseline from which to evaluate future change. For these reasons, it is a top recommendation of this project that this primary baseline resource be assessed further for each of the eight estuarine systems.

While this undertaking was not possible in this current project, it has been possible to make a preliminary evaluation to demonstrate its value. A brief example of the level of detail is shown for the Burrum River estuary in Figure 150. The tracks surveyed are those shown in Figure 132. These observations taken in 2013, 2016 and 2018 were each scored at the intervals 100m apart along the entire estuary. Our analysis involved looking at each frame and scoring a selection of features – in this case related to shoreline habitat condition and presence of mangroves. Mangrove presence also identified species type (see Table 8 using abbreviated initials) as well as density, patch size, openness and sparsity.

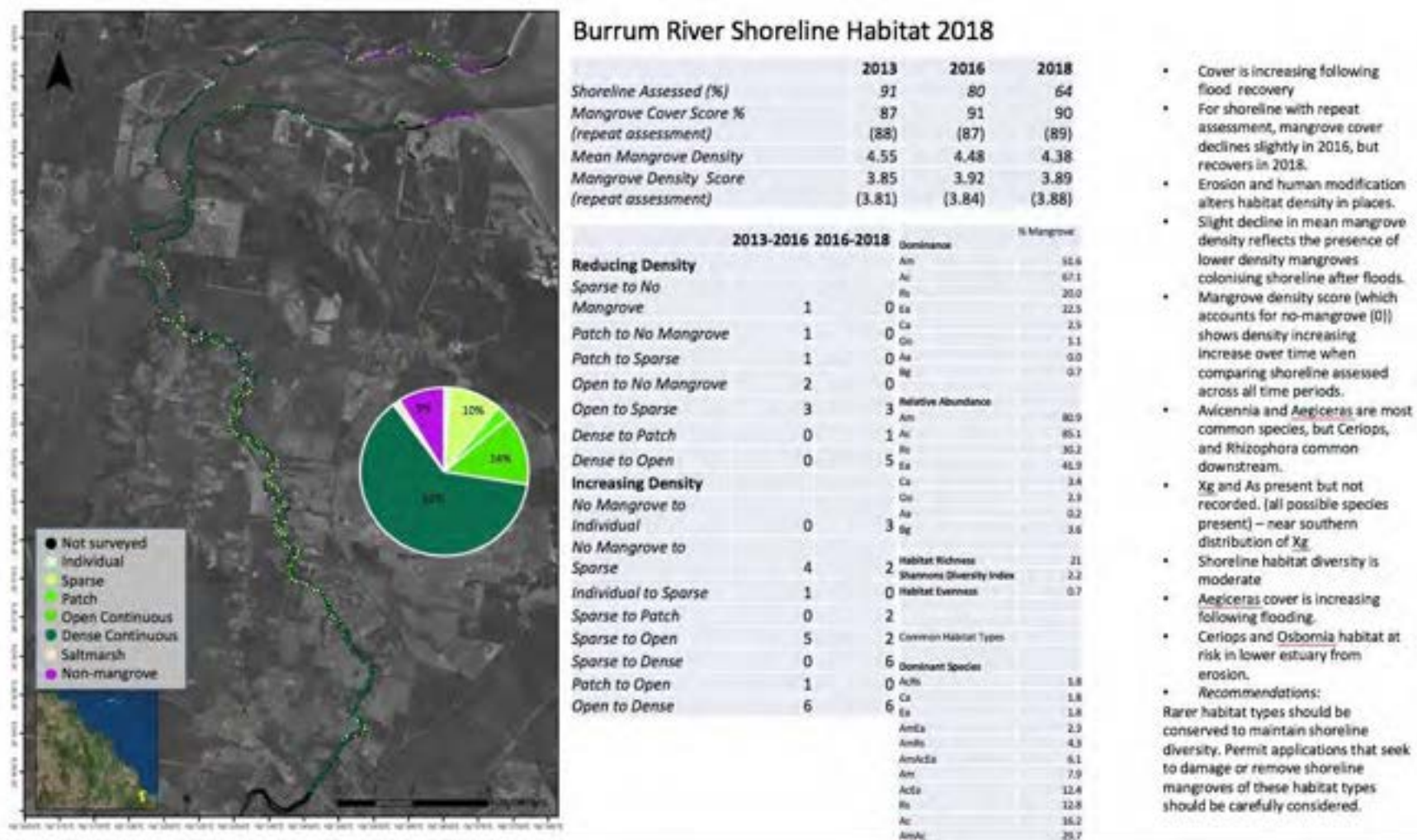


Figure 150: Mangrove condition scores derived from the detailed field data of the Burrum River estuary.

A few observations gained from this evaluation of shoreline condition included:

- 1) Mangrove stands were sparse and patchy along the lower estuary, while they were denser upstream;
- 2) Mangrove presence during two time periods (2013-2016 & 2016-2018) showed limited recovery after flood damage, and human modifications affected density; and
- 3) Mangrove species diversity was dominated by *Avicennia marina* (Am = grey mangrove) and *Aegiceras corniculatum* (Ac = river mangrove).

It remains only to be said that the Gidarjil Rangers are keen to continue this work. While, there have been some ups and downs, overall it has been a most rewarding experience for all concerned.

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