Mangrove dieback in the Gulf of Carpentaria: baseline for monitoring future trajectory in Queensland

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Prepared by:
Arnon Accad, Jiaorong Li, Ralph Dowling, John Neldner and Gerry Turpin
Queensland Herbarium
Department of Environment and Science
PO Box 5078
Brisbane QLD 4001

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Cover images:
Top: Dieback north of Karumba, August 2017.
Bottom: Seedling recover in transect N1 Karumba North, August 2017.

Executive summary

The mangrove dieback in the Gulf of Carpentaria was first detected in late 2015 to early 2016. The Queensland Herbarium, Department of Environment and Science (DES) has mapped the extent of mangrove dieback in 2017 in the Queensland portion of the Gulf of Carpentaria. This mapping of healthy mangrove, dieback of mangroves and the supratidal flat were derived from high resolution 20–30 cm RGB imagery captured by Airborne Research Australia (ARA) during August 2017 and 80 cm resolution Earth–I 2016 and 2017 imagery in areas not covered by the high resolution ARA capture.

The mapping has delineated a total of 2774 ha of dieback with 2295 ha of mangrove dieback in the Gulf Plains Bioregion and 479 ha of mangrove dieback in the Cape York Peninsula Bioregion. The primary mangrove species impacted by dieback was *Avicennia marina* subsp*. eucalyptifolia* (northern grey mangrove). Ground elevation data derived from the 2017 Lidar capture by ARA shows that the majority of the mangrove dieback within the Gulf of Carpentaria in Queensland occurs at the higher tidal levels of the mangrove habitats adjacent to the supratidal flats. The mangrove dieback was predominantly coastal in nature (as opposed to riverine) with 85% of the total mangrove dieback occurring within one kilometre of the coastline.

Field work was targeted in two location across the dieback area—Karumba and Pormpuraaw. The Karumba area exhibited major dieback to the north of the town while there is a minor area of dieback to the south-west. The area of dieback to the south of Pormpuraaw showed different levels and patterns of dieback severity within short distances. Permanent Corveg sites have been established in healthy mangrove areas and these will be used to set the benchmark to determine the level of recovery in areas affected by the dieback.

Historical assessment, both in the Karumba and Pormpuraaw areas, illustrates that the mangrove dieback has not discriminated on tree age with deaths occurring in trees as young as six-years old, to trees which were at least 47-years old. The majority of the mangrove dieback area south of Pormpuraaw was open ocean in 1969 with large areas not being colonised by mangroves until after 1998. This reflects the rapid dynamics of mangrove communities and their associated sediments in the Gulf of Carpentaria.

The twenty-nine catchments in the study area were analysed, with nine catchments each recording over 100 ha of dieback with the highest occurring in the Nicholson River Catchment (400 ha). An additional thirteen catchments had mangrove dieback extent from 2 ha to 86 ha. In seven of the catchments assessed there was no dieback of mangrove recorded. Each catchment was mapped and was assessed for a number of patch analysis parameters to illustrate the extent and severity of the dieback in each catchment.

Climate recordings in Karumba in the period prior to the dieback event illustrate that the monthly evaporation reached record levels and the monthly vapour pressure, monthly minimum temperature and monthly radiation have equalled past records and a derived water balance deficit can be calculated from these records. This water balance deficit was further impacted by the fact that the highest tides reached record low high tide levels due to sea level drop.

Some areas where dieback has occurred may reflect slightly higher ground elevation at the transition to supratidal flats, whereas other higher elevations may reflect recent sedimentation which was obvious in field work undertaken across the areas of dieback. It is currently unknown when precisely this sedimentation occurred but it is likely to have occurred during or just after the dieback event. It is also likely to be slowing down the recovery within these elevated areas.

The sedimentation event across the Queensland Gulf of Carpentaria both in Pormpuraaw and Karumba most likely occurred following three consecutive low pressure events between December 2015 and March 2016. Large Gulf floods, for example in 2009 and 2019, resulted in the transfer of large amounts of sediment into the intertidal zone and surrounding sea bed.

Large waves, some over four metres in height, in the shallow seas of the Gulf of Carpentaria can lead to large sedimentation events on the adjacent intertidal areas. While it is not clear if this sedimentation has caused the dieback it is known that elevated sediments levels result in the hindrance of mangrove recovery.

The prolonged water balance stress derived from the collective climatic factors presented above combined with sea level drops and the siltation events that have occurred are the most likely causes of the mangrove dieback within the Gulf of Carpentaria.

Field site measurements post the dieback event, coupled with accurate mangrove dieback mapping in 2017 provides a baseline for monitoring the future trajectory of mangrove dieback and or recovery in the Gulf of Carpentaria (Queensland).

Field sites will need to be revisited every three years and mapping should be undertaken every five years unless earlier global detection systems, such as the Queensland State Land and Tree Study (SLATS) woody cover change program or the Terrestrial Ecosystem Research Network (TERN) national mangrove observing system record a new large scale mangrove dieback event.

The report provides statistical information by catchment across the Queensland portion of the Gulf of Carpentaria and establishes a baseline to monitor the future trajectory of recovery or decline of the mangrove and associated communities within this area.

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Introduction

Mangrove dieback in the Gulf of Carpentaria was first detected in late 2015 to early 2016 (Duke et al 2017). The Queensland Herbarium has mapped the extent of mangrove dieback in 2017 in the Queensland portion of the Gulf of Carpentaria. This mapping of healthy mangrove (RE 2.1.3, 3.1.2a), dieback of mangroves and the supratidal flat (RE2.1.4, 3.1.6) were derived from high resolution 20–30 cm RGB imagery captured by Airborne Research Australia (ARA) during August 2017 and 80 cm resolution Earth–I 2016 and 2017 imagery in areas not covered by the high-resolution ARA capture.

Mangrove communities of Queensland are described in Neldner et al (2019). The remnant extent of mangrove communities in Queensland amounts to 476,271 ha and represents 98.7% of their pre-clearing (1950s) extent (Accad et al 2019). They are distributed around the Queensland coastal intertidal zone and are their represented in Bioregions: Cape York Peninsula (CYP; 32%), Gulf Plains (GUP; 21%), Brigalow Belt (BRB; 17%), Southeast Queensland (SEQ; 11%), Wet Tropics (WET; 10%) and Central Queensland Coast (CQC; 9%) see Figure 1.

The mangrove structural formation range from closed forest, closed scrub to low open shrubland. The mangrove communities have a higher diversity of species and complexity of structure from southern to northern Queensland. *Rhizophora* species and *Bruguiera gymnorhiza* dominate the most seaward locations. *Avicennia marina* and *Ceriops tagal* are generally dominant in more landward locations, and species such as *Excoecaria agallocha* and *Aegiceras corniculatum* dominate in the upper tidal reaches of rivers. Shrubs and herbs are rare in the mangroves, although very sparse *Tecticornia* spp. and *Sporobolus virginicus* may occur in the ground layer (Neldner et al 2019).Mangrove dieback in the Gulf of Carpentaria was first detected in late 2015 to early 2016 and was reported to impact areas around the Gulf of Carpentaria from Weipa in the north of Cape York Peninsula Queensland to Groote Eylandt, Northern Territory (Duke et al 2017). The Queensland Herbarium has developed a process to assess the extent of the recent 2016 mangrove dieback extent. This process uses the SLATS Landsat imagery and derived NDVI indices for 2014 and 2016 (Accad, 2016). This analysis estimated the area of potential dieback of about 1,400 ha (patches greater than 0.5 ha) with 900 ha in the Queensland Gulf Plains bioregion and a further 500 ha on the west coast of the Cape York Peninsula bioregion (Appendix II).

This report provides new findings of the 2017 extent of dieback in the Gulf of Carpentaria (Queensland) derived from detail mapping using high resolution captured imagery. This report describes a multi-level assessment methodology to determine future trajectory of mangrove communities in the Gulf of Carpentaria, Queensland. First level assessment applied at a site level over permanent monitoring transects established by the Queensland Herbarium in Karumba in 2017 and Pormpuraaw in 2018. Second level assessment applied by catchment level across each of the 29 catchments from the western tip of Cape York to the Northern Territory border.

The likely cause(s) of the mangrove dieback in the Gulf of Carpentaria during the late 2015 early 2016 period is also discussed.

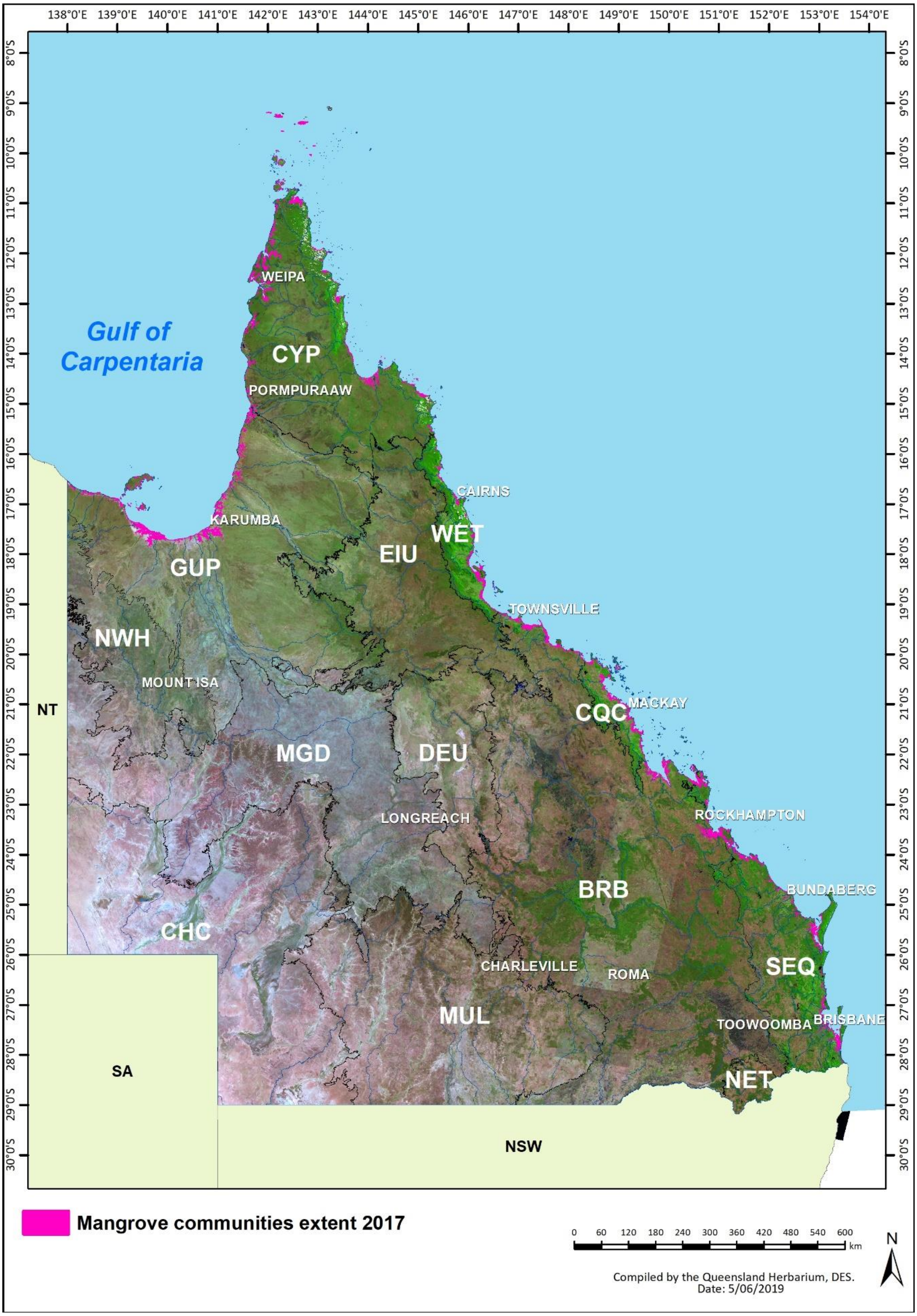

Figure 1 Mangrove communities extent 2017 in Queensland

Methodology

A program to monitor the future trajectory of the recovery of mangroves and associated communities within the Queensland portion of the Gulf of Carpentaria (from the western tip of the Cape York Peninsula to the Northern Territory border) was established in 2016. This program includes two phases:

1. the establishment of a network of permanent monitoring transects and
2. a program of change detection mapping of the mangrove dieback.

The first phase of the program was the establishment of eight permanent monitoring ground transects. Three monitoring transects were established in the Karumba area in 2017 and five south of the Chapman River, Pormpuraaw in 2018. The information gathered in each transect includes full floristic and structural information following the vegetation mapping methodology using CORVEG sites (Neldner et al 2015). Additional structural measurements of tree heights and diameter at breast height (dbh) as well as relative ground surface elevations were also captured. The aim is to revisit these sites every three years.

The second phase of the program was the mapping and change detection of mangrove dieback in the Queensland portion of the Gulf using large scale imagery (20 cm) and Lidar captured in August 2017 by Air Research Australia (ARA) and Earth–I 2017 satellite imagery (80 cm) in areas where the higher resolution imagery was not available. Budget and time constraints limited field assessment. The extent of the dieback classification followed the Broad Vegetation Group BVG 1:1 million classification (Neldner et al 2019). This allowed the classification of the areas of living mangroves, mangrove dieback and supratidal flats without the delineation of species dominancy. In the majority of the existing regional ecosystems (RE) mapping Queensland Herbarium (2018) was accepted while the mangrove dieback was digitised at 1:5000 scale. Future assessments of the extent of the dieback and/or recovery in the Queensland portion of the Gulf along with transect measurements will determine the trajectory of mangrove and associated communities within the study area.

Assessment of the age of the mangroves in the dieback and non-dieback areas was also conducted in the Karumba and Pormpuraaw areas to determine if the dieback was occurring in younger or older trees. The extent of mangrove dieback was assessed by examining historical aerial photography and digital imagery and is reported by catchment including detailed dieback extent and patch analysis.

Results

The mapping has delineated a total of 2774 ha of dieback with 2295 ha of mangrove dieback in the Gulf Plains Bioregion and 479 ha of mangrove dieback in the Cape York Peninsula Bioregion. This total of 2774 ha is almost double the original estimate of 1400 ha (Accad, 2016; see Appendix II). The primary mangrove species impacted by dieback is *Avicennia marina* subsp*. eucalyptifolia* (northern grey mangrove).

Historical assessment, both in the Karumba and Pormpuraaw areas, illustrates that the mangrove dieback has not discriminated on tree age with deaths occurring in trees as young as six-years old through to trees which were at least 47-years old. The majority of the mangrove dieback area south of Pormpuraaw was open ocean in 1969 with large areas not being colonised by mangroves until after 1998. This reflects the rapid dynamics of mangrove communities and their associated sediments in the Gulf of Carpentaria.

The twenty-nine catchments in the study area were analysed, with nine catchments recording over 100 ha of dieback: the Nicholson River (400 ha of dieback), Leichhardt River (378 ha), Upper Norman River (291 ha), Mitchell River (289 ha), Embley River (278), Cliffdale Creek (257 ha), Lower Norman River (215 ha), Edward River (124 ha) and Flinders River (122 ha). An additional thirteen catchments had mangrove dieback extent from 2 to 86 ha. In seven of the catchments assessed there was no dieback of mangrove recorded (Table 3).

The mangrove dieback was predominantly coastal in nature (as opposed to riverine) with 68% of the total mangrove dieback occurring within 500 m of the coastline and 85% of the total mangrove dieback occurring within one kilometre of the coastline. Of the 22 catchments where dieback was recorded, 12 catchments showed greater than 85% mangrove dieback within 500 m of the coast; ten had greater than 99% and six had greater than 85% mangrove dieback within one kilometre of the coast.

This report provides statistical information by catchment across the Queensland portion of the Gulf of Carpentaria and establishes a baseline to monitor the trajectory of recovery or decline of the mangrove and associated communities within this area. Each catchment was mapped (see example Nicholson River Figure 1) and was assessed for a number of parameters including: percent of total Gulf dieback, percent of mangrove dieback in the catchment, percent mangrove dieback in 500 m buffer, percent mangrove dieback in 500 m buffer of Landzone 1 (the intertidal zone). Extent and landscape position and graphed using a radar diagram to illustrate the extent and severity of the dieback in each catchment against the worse-case scenario for each parameter. The worse-case scenario for each parameter may be found in different catchments (Table 3). For example Nicholson River Catchment mangrove dieback, live mangrove and associated communities map (Figure 1) and the radar graph for the Nicholson River (Figure 2). Detailed analysis of each individual catchment can be found at Appendix I.

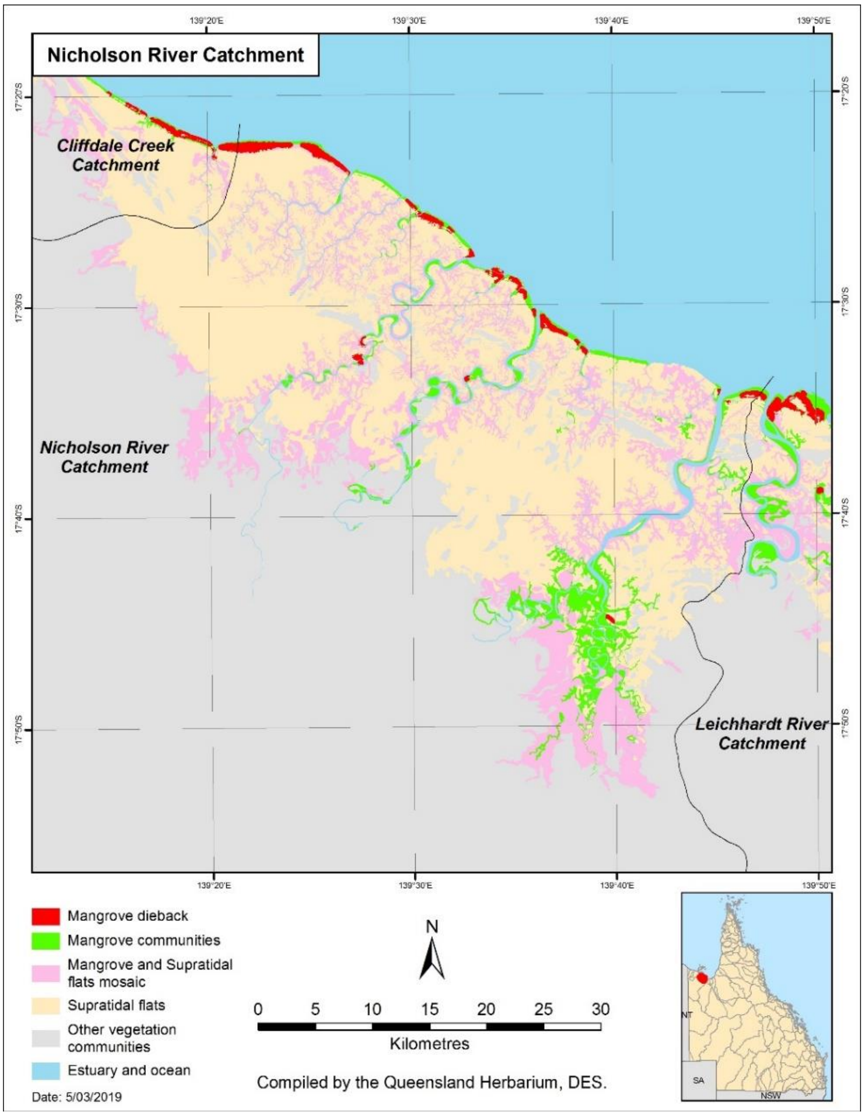

Figure 3 Nicholson River Catchment mangrove dieback, live mangrove and associated communities map

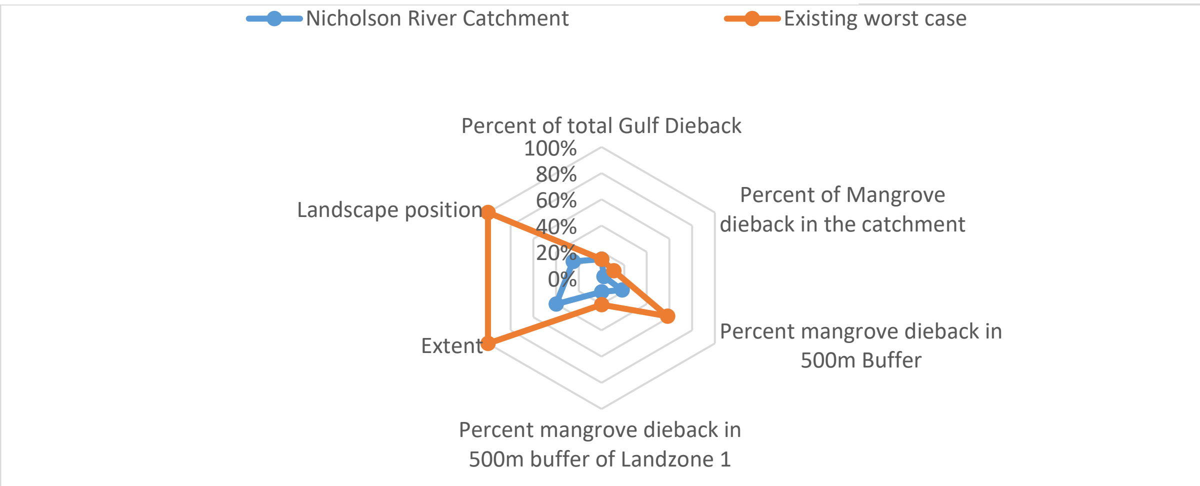

Figure 2 Nicholson River Catchment radar diagram to illustrate the extent and severity of each catchment against existing worst case (see Table 3). Landzone 1 is the intertidal zone.

Table 1 Nicholson River Catchment dieback assessment against the worst case scenario

Catchment	Percent of total Gulf dieback	Percent of mangrove dieback in the catchment	Percent mangrove dieback in 500 m buffer	Percent mangrove dieback in 500 m buffer of Landzone 1	Extent	Landscape position +
Nicholson River Catchment	14.415%	2.12%	18%	11%	40%	25%
Existing worst case	14.42%	10.81%	58%	20%	100%	100%

+ Landscape position: back (25%), front (50%), back and front (75%) and across from the back to the front (100%)

Table 2 Nicholson River Catchment mangrove dieback area and patch analysis

Catchment	Dieback area (ha)	Number of patches of mangrove dieback	Largest patch size (ha)	Smallest patch size (ha)	Average patch size (ha)
Nicholson River catchment	400	105	117	0.02	4

Table 3 Catchment analyses of the mangrove dieback in the Queensland portion of the Gulf of Carpentaria

Catchment	Indices										
	Mangrove Area (ha)	Dieback area (ha)	Dieback in catchment	Percent of Gulf Mangrove	2016 dieback	Ratio dieback to extent	Dieback within 500 m	Lz1 dieback within 500 m	Extent	Landscape position +	Supra-tidal flat (ha)
Nicholson River	18,471	**400**	2.17%	11.81%	**14.42%**	122.0%	18.13%	10.52%	40%	25%	97,729
Leichhardt River	7,163	378	5.28%	4.58%	13.63%	297.4%	23.18%	11.96%	50%	75%	24,997
Upper Norman River	13,645	291	2.13%	8.73%	10.49%	120.2%	25.47%	13.46%	100%	100%	47,156
Mitchell River	12,234	289	2.36%	7.82%	10.41%	133.1%	17.93%	9.20%	100%	100%	35,248
Embley River	10,209	278	2.73%	6.53%	10.03%	153.7%	8.13%	6.94%	30%	75%	3,241
Cliffdale Creek	3,228	257	7.96%	2.06%	9.26%	448.6%	23.43%	12.74%	72%	25%	35,672
Lower Norman River	6,944	215	3.10%	4.44%	7.75%	174.5%	22.05%	9.30%	90%	25%	35,256
Edward River	3,222	124	3.85%	2.06%	4.47%	217.0%	**58.22%**	16.26%	100%	100%	13,402
Flinders River	9,949	122	1.23%	6.36%	4.41%	69.4%	15.16%	6.86%	60%	25%	31,016
M Creek	1,078	86	8.02%	0.69%	3.11%	451.8%	19.78%	8.17%	30%	25%	32,088
Archer River	3,893	81	2.09%	2.49%	2.93%	117.8%	9.41%	7.00%	55%	25%	10,576
Lagoon Creek	832	42	5.09%	0.53%	1.53%	287.0%	25.78%	11.82%	40%	25%	12,593
L Creek	815	36	4.38%	0.52%	1.29%	247.0%	12.60%	4.69%	30%	25%	43,492
Mornington Island	4,266	35	0.81%	2.73%	1.25%	45.7%	30.56%	12.95%	50%	25%	9,696
Outer Islands	1,473	30	2.01%	0.94%	1.07%	113.3%	12.40%	8.22%	50%	25%	4,036
Staaten River	2,682	24	0.91%	1.71%	0.88%	51.4%	19.34%	6.74%	50%	75%	14,213
Lower Gilbert River	706	24	3.42%	0.45%	0.87%	192.9%	17.01%	9.08%	40%	75%	4,360
Eight Mile Creek	191	23	**12.11%**	0.12%	0.84%	**682.9%**	54.95%	**20.03%**	100%	100%	6,741
Coleman River	1,167	15	1.29%	0.75%	0.54%	73.0%	8.95%	5.01%	90%	25%	2,641
Watson River	4,046	11	0.28%	2.59%	0.41%	15.9%	5.29%	2.39%	20%	25%	4,021
Ducie Dulhunty River	10,990	9	0.08%	7.03%	0.33%	4.7%	30.11%	14.77%	90%	25%	2,100
Jackson River	6,872	2	0.03%	4.40%	0.07%	1.6%	6.92%	4.14%	1%	25%	3,329
Holroyd River	1,696	0	0.01%	1.08%	0.01%	0.5%	1.24%	0.33%	1%	25%	4,422
Jardine River	1,099	0	0.00%	0.70%	0.00%	0.0%	0.00%	0.00%	0%	0%	793
Kendall River	742	0	0.00%	0.47%	0.00%	0.0%	0.00%	0.00%	0%	0%	678
Mission River	17,062	0	0.00%	10.91%	0.00%	0.0%	0.00%	0.00%	0%	0%	6,928
Settlement River	332	0	0.00%	0.21%	0.00%	0.0%	0.00%	0.00%	0%	0%	7,393
Skardon River	2,589	0	0.00%	1.66%	0.00%	0.0%	0.00%	0.00%	0%	0%	1,770
Wenlock River	8,770	0	0.00%	5.61%	0.00%	0.0%	0.00%	0.00%	0%	0%	1,744
Worst case scenario	NA	400	12.11%	NA	14.42%	682.9%	58.22%	20.03%	100%	100%	
Total	156,365	2,774				1.77%					497,330

+ Landscape position: none 0%, land 25%, sea 50%, both land and sea 75% and right across the gradient 100%

The Queensland Herbarium established three permanent monitoring transects (150 m long) in the Karumba area in late August 2017. Two transects were established to the north and one transect to the south west of the Norman River. Results show that in the northern transects the dieback was both extensive and widespread in nature. In the south-west transect the dieback was limited and patchy in both nature and extent when compared to the northern transects.

In February 2018 the Queensland Herbarium received a copy of the Lidar data captured in August 2017 by Airborne Research Australia (ARA) for the Gulf of Carpentaria region. The Lidar data had initial processing undertaken by the Remote Sensing Centre, Department of Environment and Science. High resolution imagery was also captured at the same time as the Lidar data was captured. The Lidar data facilitated the comparison of both the ground elevation and tree heights between the dieback areas to adjacent live mangrove for each catchment (see Appendix I). For example, dieback within the Nicholson River Catchment has occurred in areas of a similar mean ground elevation to the adjacent living mangroves with very small deviation from the mean (Figure 3 left). Similarly the mean tree heights in the dieback areas and in the live mangroves are similar. The range of tree heights in the dieback transects relative to the trees in the living transects were less (Figure 3 right).

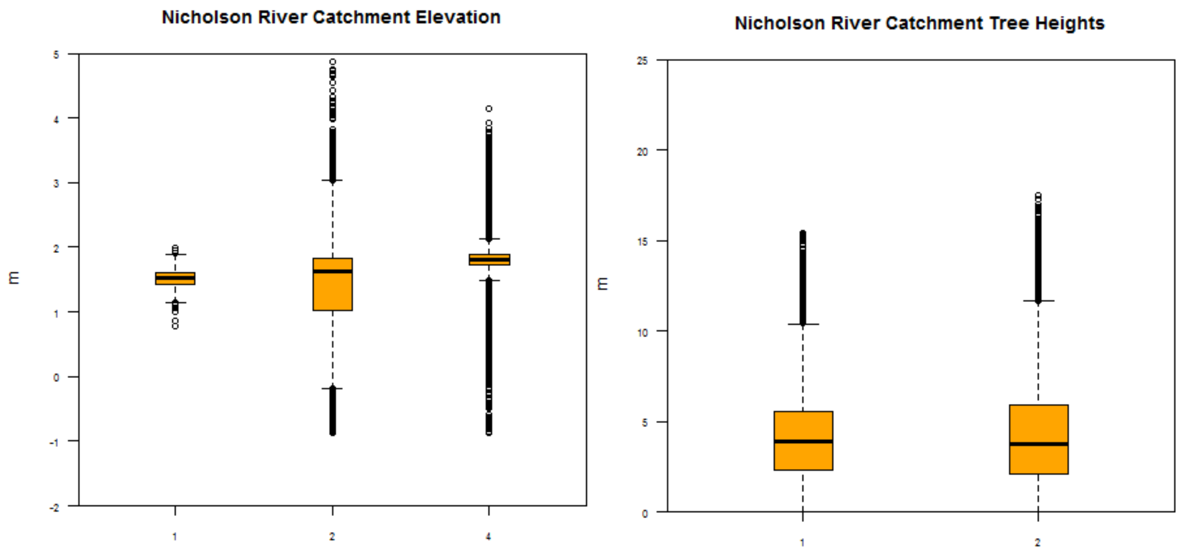

Figure 4 Nicholson River Catchment ground elevation and tree height comparison between 1. Mangrove dieback 2. Living mangrove and 4. Supratidal flats

Pormpuraaw in the coastal Melamen Plain area in July 2018. The transects are located 6.5 to 12.5 km south of the Chapman River and all are within six kilometres of each other. Results show that despite the close proximity of these transects to one another, different levels of dieback and recovery are reflected in each of the transects.

The mangrove dieback in the Queensland portion of the Gulf of Carpentaria was first detected in late 2015 to early 2016. The area has been subjected to a number of cyclones following the dieback. The area around the Norman River also had a major flood in February 2019.

Re-measurement of the permanent monitoring transects every three years will provide information on the trajectory of the affected mangrove areas. Similarly, regular mapping updates (every five years) of the intertidal zone in the Queensland Gulf of Carpentaria will provide the status and spatial extent of the dieback and will show the dynamic nature of the intertidal zone including: areas that have recovered, areas that have not recovered, new areas that have been colonised by mangrove and new areas that may have died. This process can be supported by using spatial data such as Landsat and sentinel to detect initial changes and further refinements using high resolution imagery, for example, Earth–I.

Mapping accuracy assessment

The accuracy of the polygon attributes was determined by generating a stratified random sample of 601 points with at least 150 metres from one point to another to remove autocorrelation, across the entire study area. There were 158 points to assess the areas of mangrove dieback, 258 points to assess the area of live mangrove and 185 points to assess the supratidal flats. While the mapping of the dieback was applied at the 1:5000 scale the assessment was conducted at the 1:1000 scale. The mapping accuracy of the three communities was 83% for live mangrove, 92% for mangrove dieback and 94% for supratidal flats. The inaccuracies were mainly due to scale issues inherited from the original Regional Ecosystems (RE) mapping Queensland Herbarium (2018) which was at 1:100,000 scale.

Historical assessment of mangrove extent

Karumba area

The area of mangrove dieback to the north of Karumba reflects the dynamic nature of mangrove communities in the area from the periods 1951, 1967, 2004, 2009 and 2017 (Figure 5). The 2015 mangrove dieback event that started in late 2015 to early 2016 was extensive in nature and occurred across the mangrove gradient from the seaward edge up to the boundary with the supratidal flats. The dieback event did not discriminate on the age of the mangrove community, affecting young mangroves (6, 11 and 15-years old) at the seaward edge and the supratidal flats boundary and older mangrove communities (21, 35 and 47-years old) in the centre of the transect (Figure 7A).

The area of mangrove dieback to the south west of Karumba reflects similar dynamics to the area to the north of Karumba as viewed in the 1951, 1967, 2004 2009 and 2017 imagery (Figure 6). The 2015 dieback to the south west of Karumba is not as extensive as that to the north of Karumba and affected mainly areas of mangrove stands at least 47 years old which occurred on the higher tidal areas adjacent to old clay pans (Figure 7B).

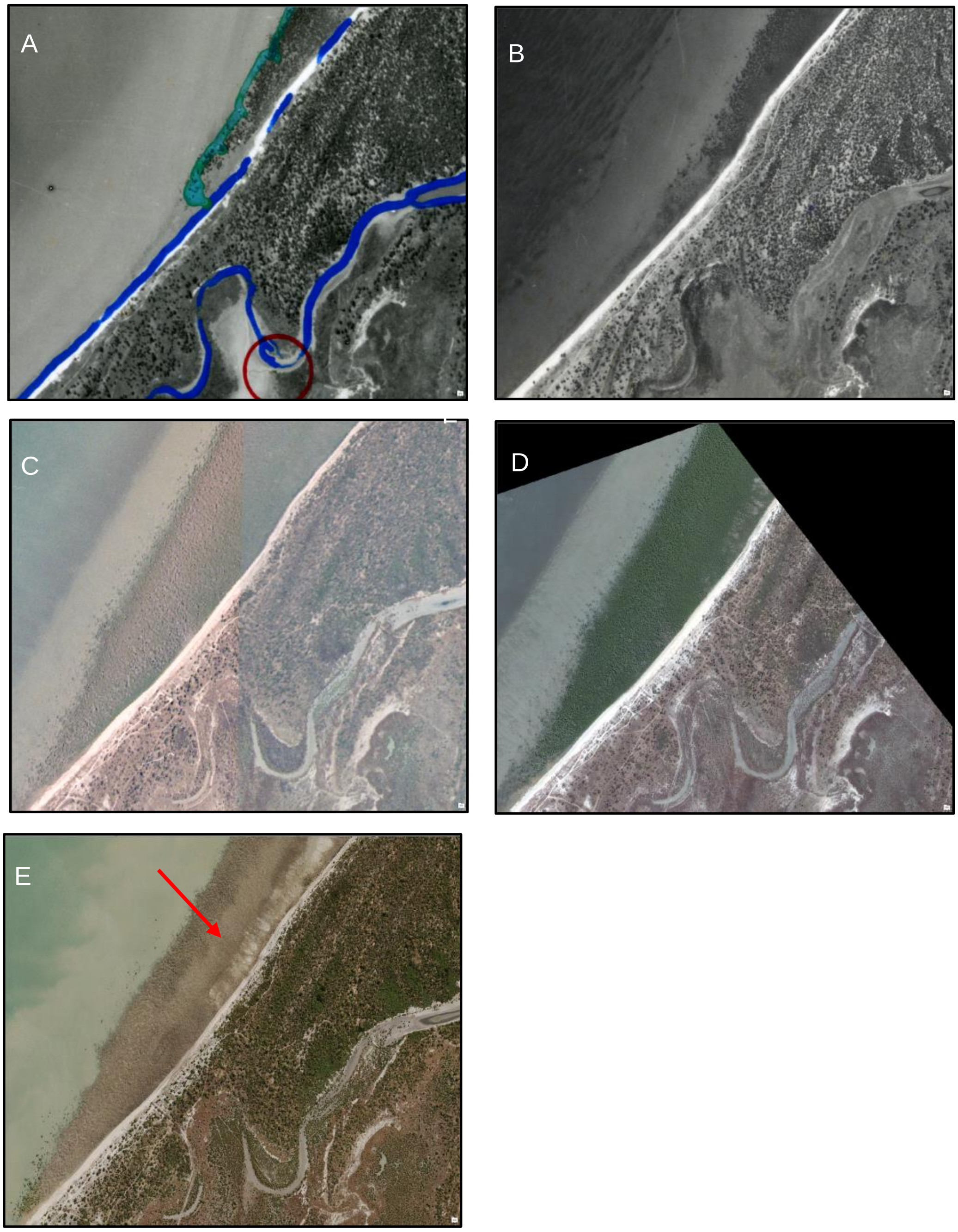

Figure 5 **Imagery of the area to the north of Karumba. A. 1951; B. 1967; C. 2004; D. 2009 E. 2017 Blue lines on A delineate mangrove extent and the red arrow in E. points to the 2015/2016 mangrove dieback**

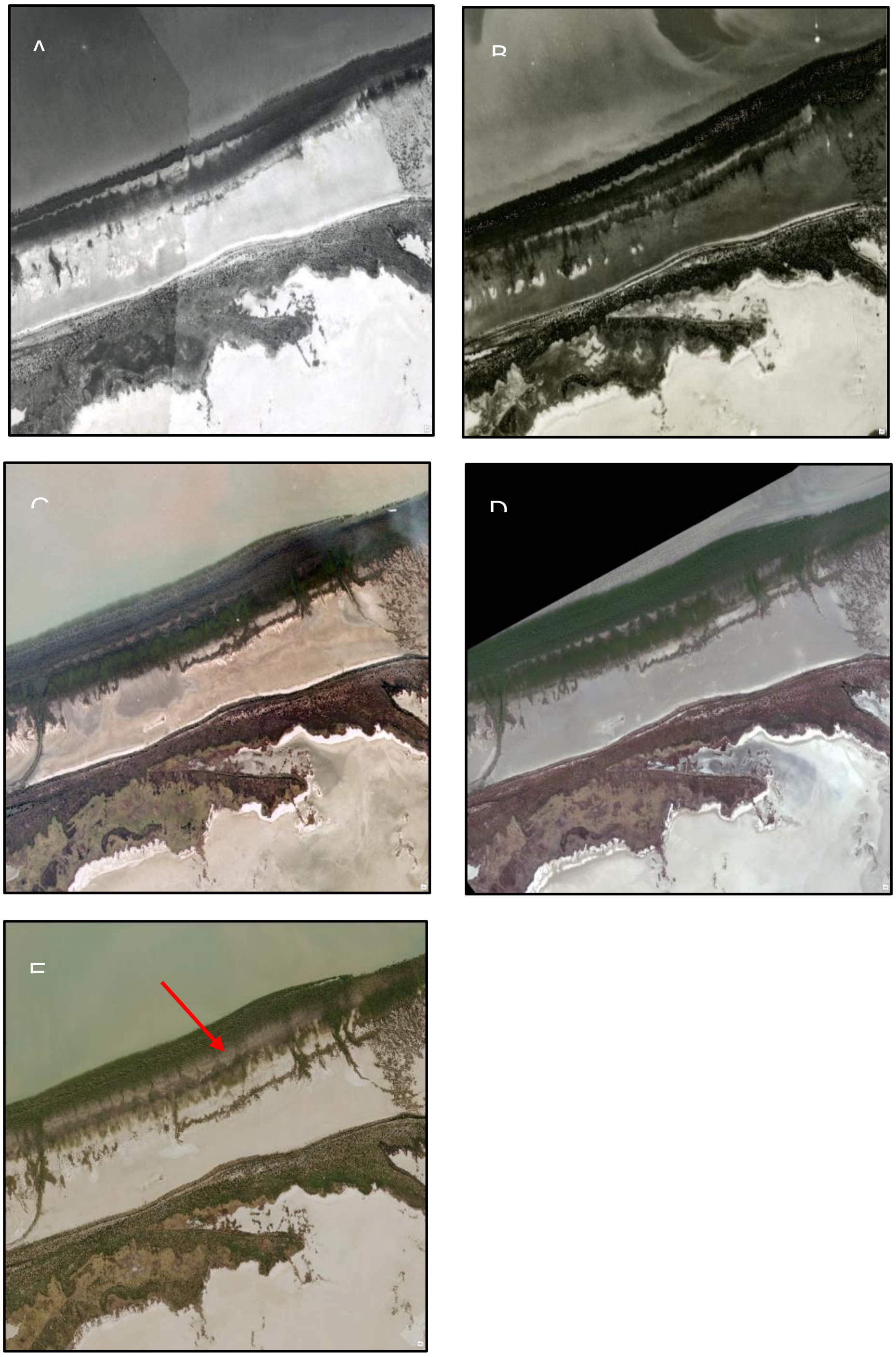

Figure 6 Imagery of the area to the south west of Karumba A. 1951; B. 1967; C. 2004; D. 2009 E. 2017 The red arrow in E. points to the 2015/2016 mangrove dieback.

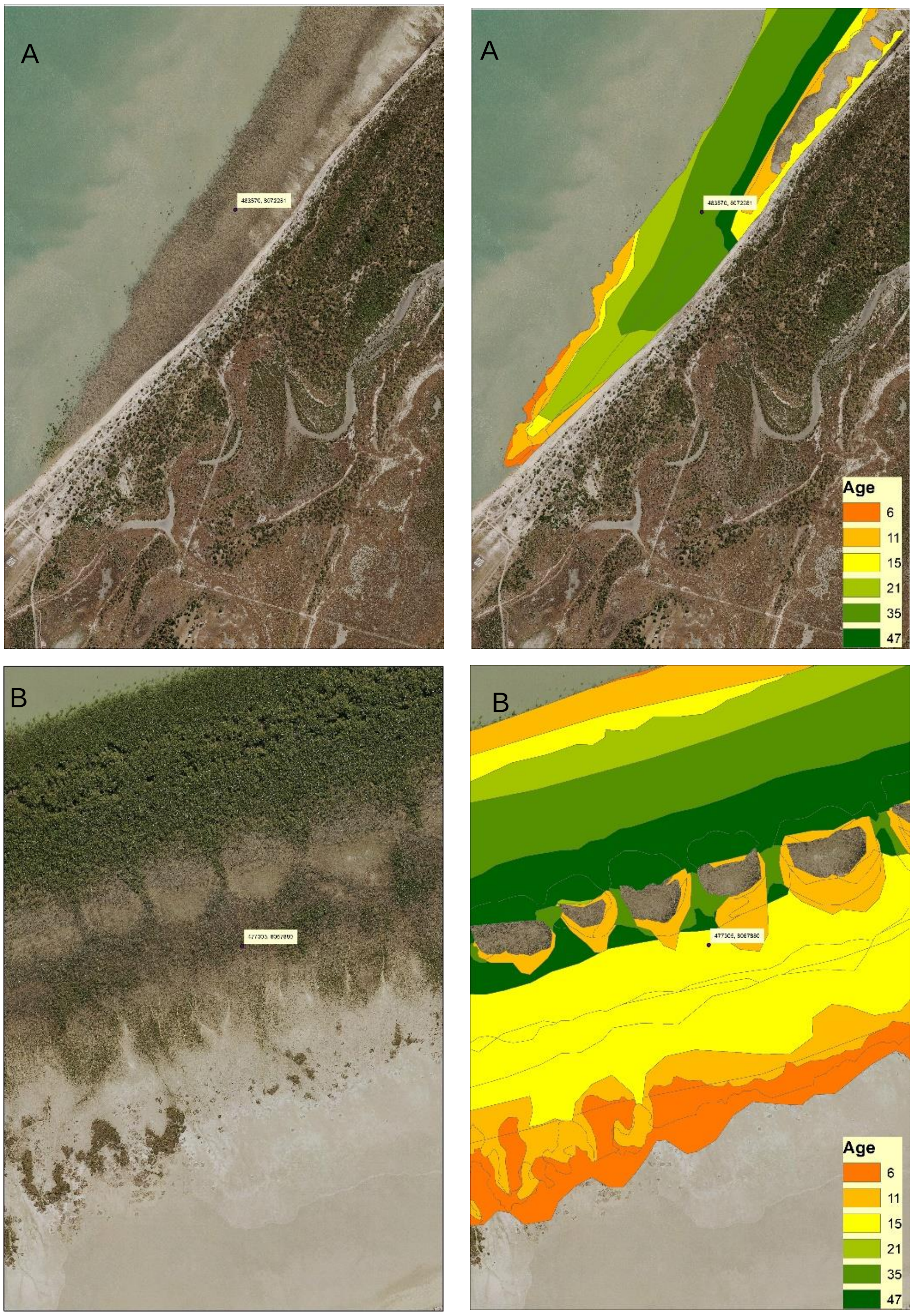

Figure 7 **Assessment of age of mangroves in the dieback at Karumba A. Area to the north of Karumba B. Area south west of Karumba**

Pormpuraaw area

The mangrove dieback to the south of Pormpuraaw and the west of the Melamen Plain reflect the dynamics of these coastal areas. Sedimentation has taken place on the coast between 1969 and 1998 facilitating mangrove expansion. The majority of area of mangrove dieback noted in the 2017 imagery was ocean in 1969 and large areas were not colonised by mangroves until after 1998 (Figure 8). As happened in the mangrove dieback in the Karumba area, the dieback has occurred across a range of tree ages with 20 to 50 years old mangrove trees being the most affected.

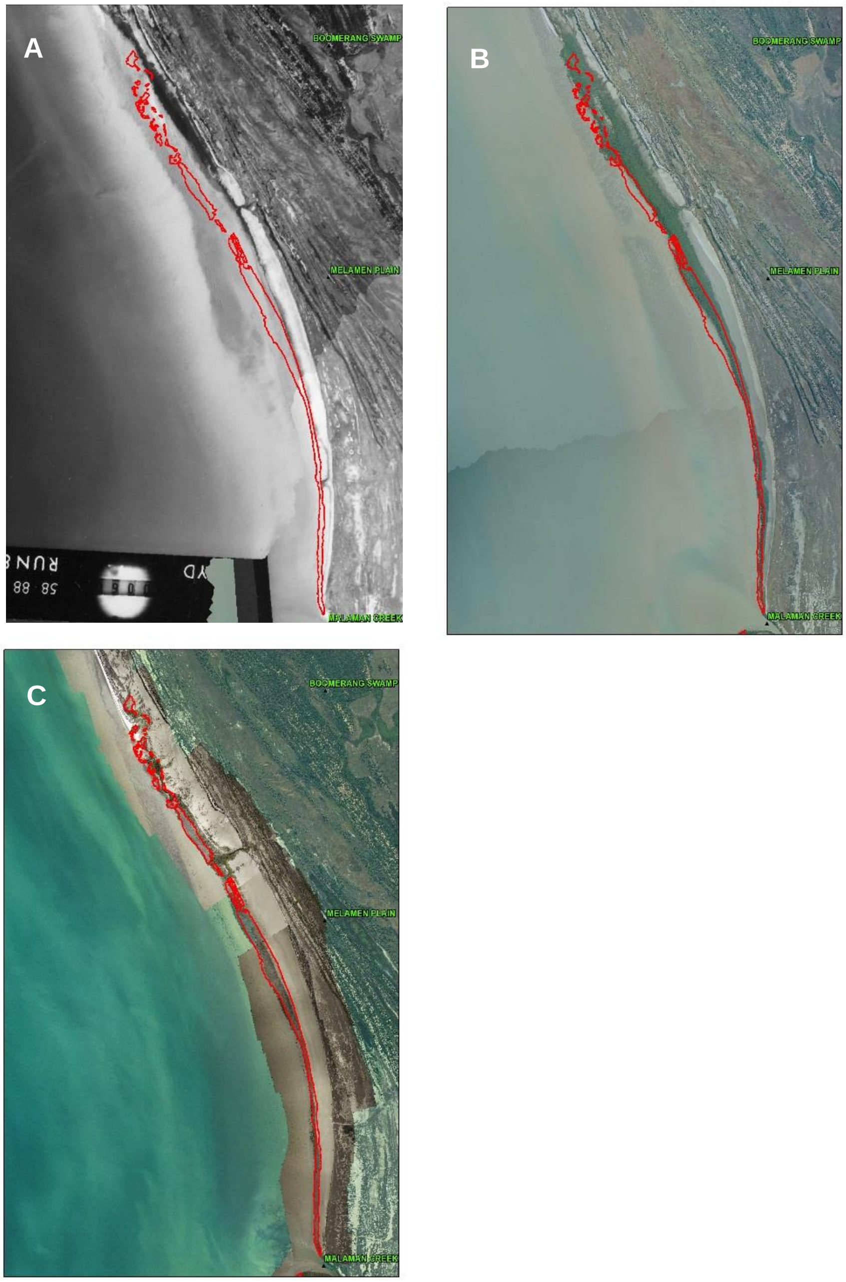

Figure 8 Melamen Plain south of Pormpuraaw. A. 1969; B. 1998; C. 2017

The red polygons on the maps show the extent of the 2015 mangrove dieback.

Mangrove dieback assessment across all catchments

The mapping of mangrove dieback within the Gulf of Carpentaria has delineated 2295 ha of mangrove dieback in the Gulf Plains bioregion and an additional 479 ha of mangrove dieback in the Cape York Peninsula bioregion. The total of 2774 ha is almost double the original estimate of 1400 ha of mangrove dieback within the Gulf of Carpentaria (Accad, 2016; see Appendix II).

The extent of the mangrove dieback in the Gulf Plains bioregion is a figure four-fold larger than the dieback in the Cape York Peninsula bioregion. The primary mangrove species impacted by the dieback based on the limited site information available is *Avicennia marina* subsp. *eucalyptifolia* (northern grey mangrove).

This mangrove community in the Gulf Plains bioregion is listed as RE 2.1.3 (tidal channels and associated levees, usually with mangroves) and in the Cape York Peninsula bioregion is listed as RE 3.1.2a (*Avicennia marina* low open forest). These areas are backed by supratidal flats RE 2.1.4 (Infrequently inundated clay plains and low samphire rises) and RE 3.1.6 (sparse herbland or bare saltpans on salt plains and saline flats). Areas of *Batis argillicola* dwarf shrubland usually with other halophytic species such as *Sesuvium portulacastrum* and *Tecticornia indica* (RE3.1.6x1) may occur on the supratidal flats adjoining the mangroves.

This report provides statistical information by catchment across the Queensland portion of the Gulf of Carpentaria and establishes a baseline to monitor the trajectory of recovery from the mangrove dieback. Each catchment was mapped and assessed for a number of parameters and graphed using a radar diagram to illustrate the extent and severity of the dieback in each catchment against the worst case scenario. Different catchments reflect the worst case scenario for different parameters (see Table 3).

The parameters, derived from the dieback mapping and reported on are:

- the percentage of mangrove dieback in each catchment of the total Queensland portion of the Gulf of Carpentaria dieback
- the percentage of mangrove dieback within the catchment
- the percentage of mangrove dieback to live mangrove within the catchment in the immediate proximity 500 m buffer around the dieback
- the percentage of mangrove dieback in the intertidal zone (Landzone 1—the intertidal zone potential habitat) within the catchment in the immediate proximity 500 m buffer around the dieback.

Patch analysis was conducted for each catchment with:

- the total area of mangrove dieback,
- the number of dieback patches and
- the largest, smallest and average patch size (Table 4).

In addition, two parameters were derived from a visual assessment of the most extensive dieback in each catchment:

- extent in percent across the mangrove gradient from land to sea, and
- landscape extent of dieback within this gradient. This is represented as a percentage to allow it to be graphed in the radar diagrams, where 25% is land end only, 50% is the sea end only, 75% land and sea end and 100% across the gradient (Table 3).

Comparison of all the Gulf catchments are presented in Tables 3 and 4 and in Figures 9–26). For detail analysis of each individual catchment see Appendix I.

Mangrove dieback distribution and extent analysis

Each catchment was assessed for the percentage of dieback within the catchment (live versus dead mangroves). The Nicholson River Catchment had the largest area of dieback in the Gulf (400 ha) amounting to 14.42% of the total mangrove dieback (Table3; Figures 9 and 10), while the area of mangrove dieback in the Eight Mile Creek catchment amounts to only 23 ha it represents over 12% of the catchments' mangrove extent (Table 3 and Figure 10).

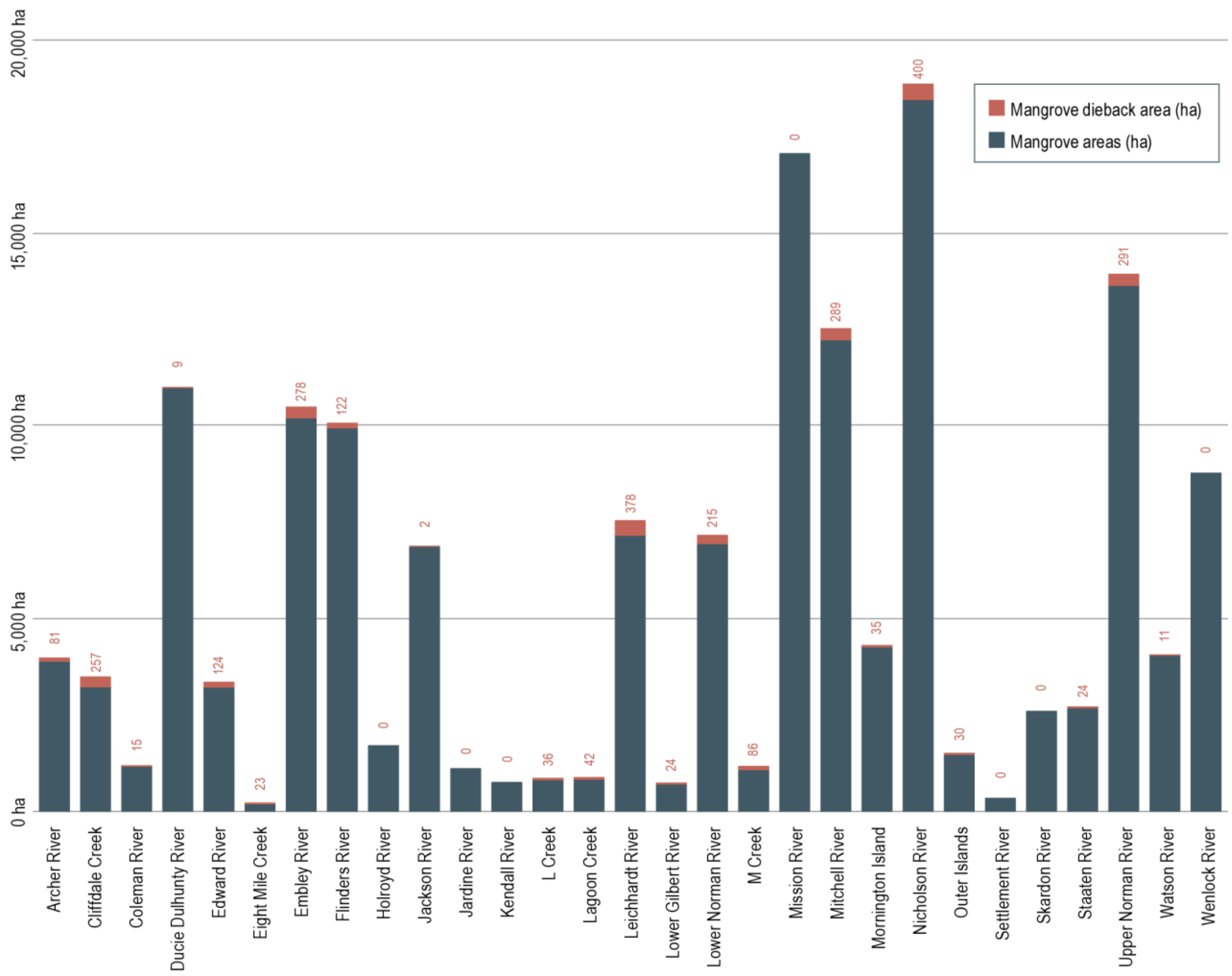

Figure 9 **Mangrove area and mangrove dieback area by catchment (labels showing the area (ha) of dieback)**

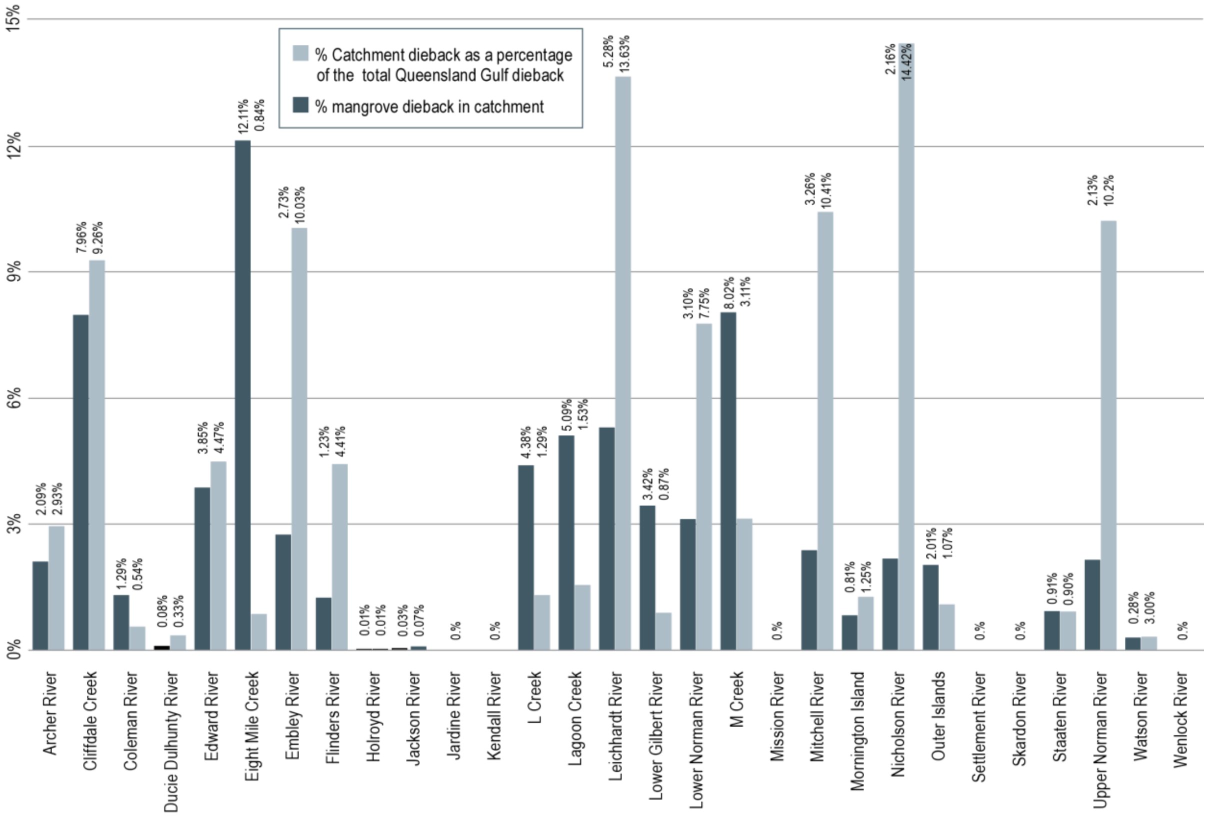

Figure 10 **Percent of mangrove dieback within each catchment and the catchment dieback as a percentage of the total Queensland Gulf dieback**

Patch size analysis

The Nicholson River Catchment recorded the largest area of dieback (400 ha) and the greatest number dieback patches (105) with the second largest dieback patch in the Queensland portion of the Gulf of Carpentaria (117 ha) (see Table 4 and Figures 11). The Nicholson River Catchment's average dieback patch is 4 ha with the smallest mapped dieback patch being 0.02 ha.

The largest dieback patch occurred in the Upper Norman River catchment north of Karumba and was 176 ha (see: Figure 12 catchment dieback area; Figure 13 number of mangrove dieback patches, Figure 14 smallest dieback patch, Figure 15 largest dieback patch and Figure 16 average dieback patch).

Table 4 Dieback patch analysis

Catchment	Dieback area (ha)	Number of dieback patches	Largest dieback patch size (ha)	Smallest dieback patch size (ha)	Average dieback patch size (ha)
Archer River	81	31	19	0.14	3
Cliffdale Creek	257	63	70	0.04	4
Coleman River	15	15	6	0.04	1
Ducie Dulhunty River	9	1	9	9.14	9
Edward River	124	26	70	0.03	5
Eight Mile Creek	23	2	17	6.33	12
Embley River	278	78	40	0.06	4
Flinders River	122	47	63	0.05	3
Holroyd River	0	1	0	0.15	0
Jackson River	2	2	2	0.32	1
Jardine River	0	0	0	0	0
Kendall River	0	0	0	0	0
L Creek	36	20	15	0.05	2
Lagoon Creek	42	7	20	0.76	6
Leichhardt River	378	76	107	0.02	5
Lower Gilbert River	24	4	13	2.80	6
Lower Norman River	215	26	52	0.75	8
M Creek	86	11	24	0.46	8
Mission River	0	0	0	0	0
Mitchell River	289	70	59	0.08	4
Mornington Island	35	8	18	0.40	4
Nicholson River	400	105	117	0.02	4
Outer Islands	30	8	8	0.74	4
Settlement River	0	0	0	0	0
Skardon River	0	0	0	0	0
Staaten River	24	11	6	0.59	2
Upper Norman River	291	33	176	0.19	9
Watson River	11	8	4	0.55	1
Wenlock River	0	0	0	0	0
Total	**2774**	**653**	**176**	**0.02**	**4**

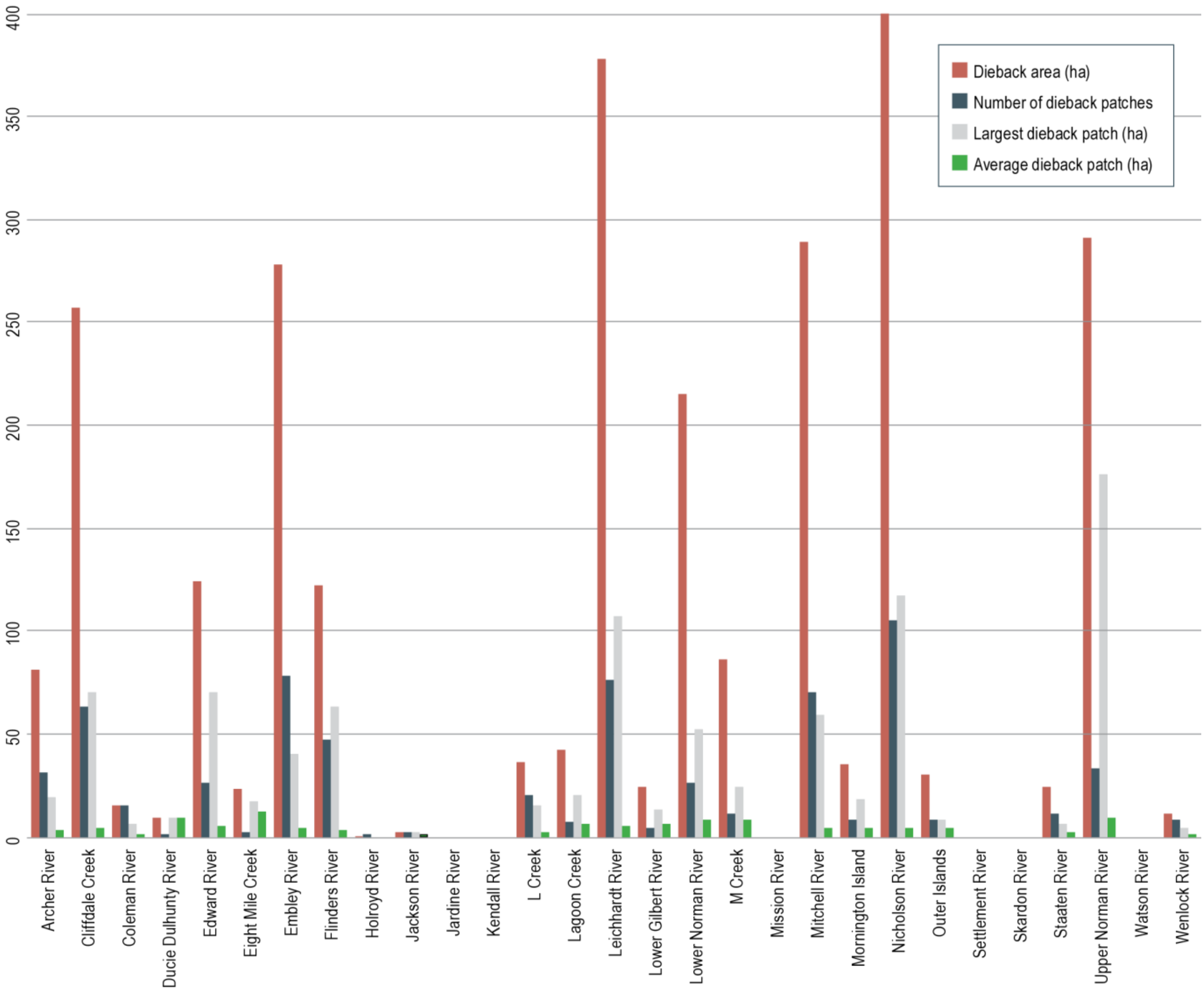

Figure 11 Dieback patch analysis including the area, number of patches, largest, smallest and average size

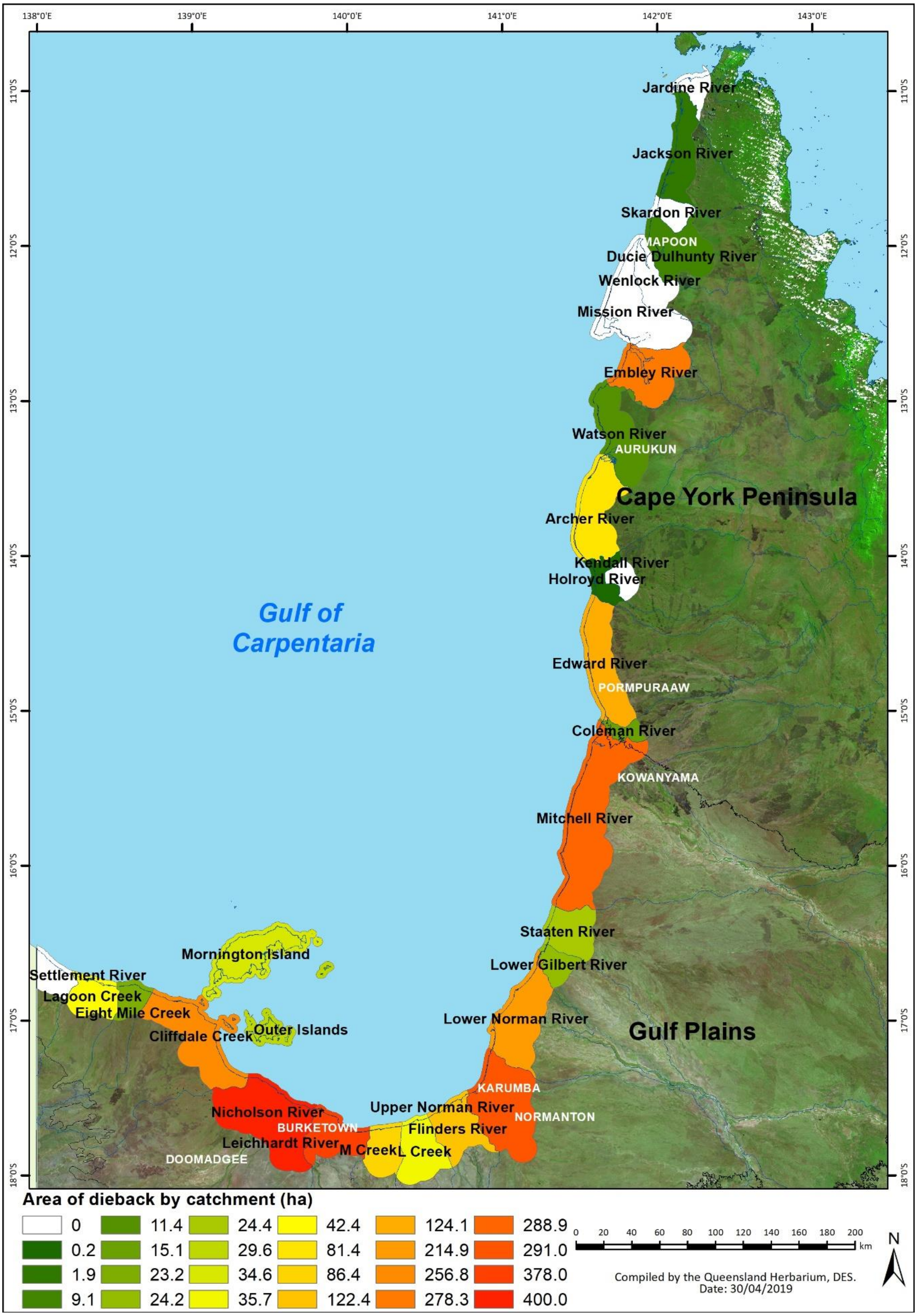

Figure 12 Area of dieback by catchment (ha)

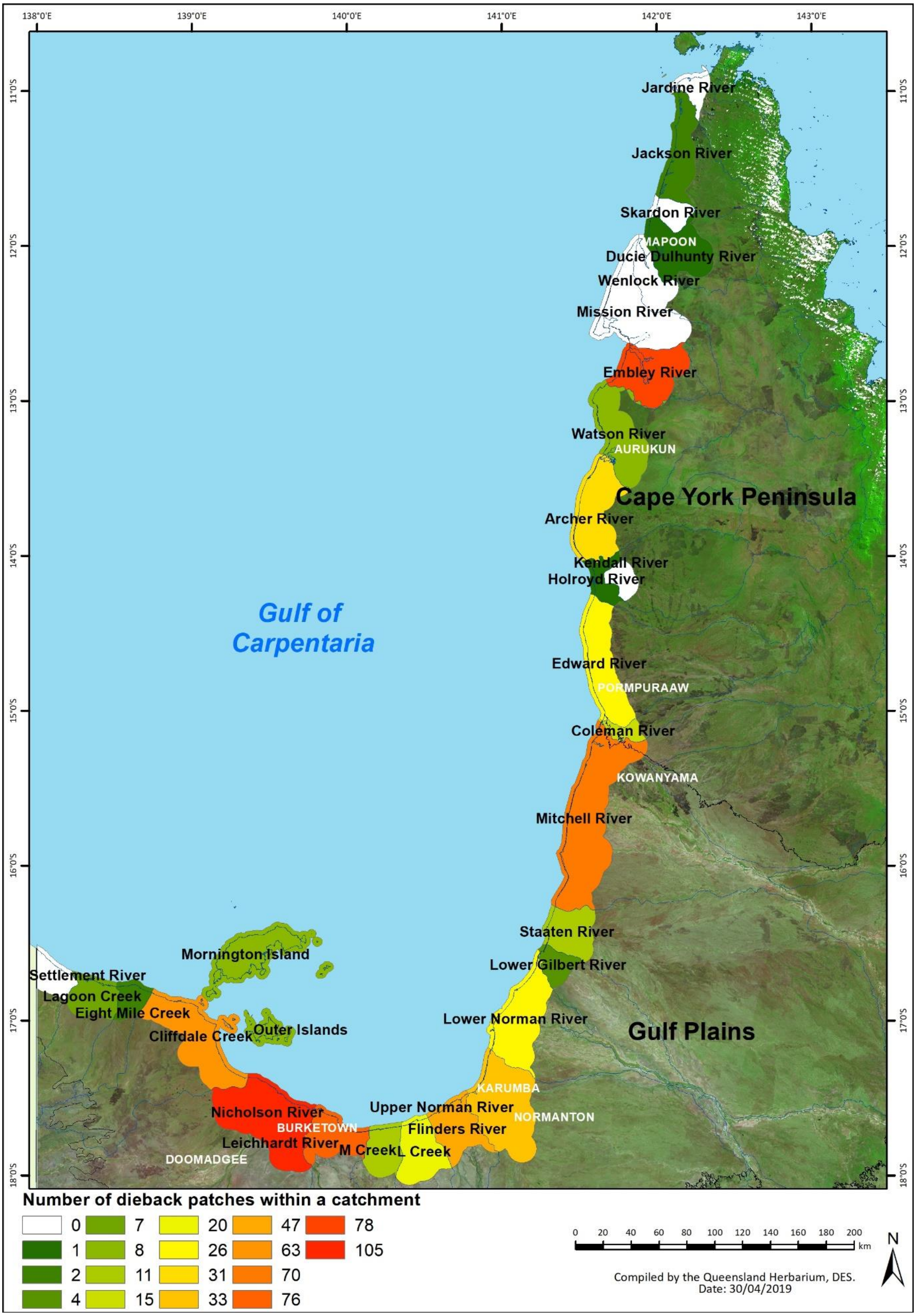

Figure 13 Number of mangrove dieback patches within a catchment

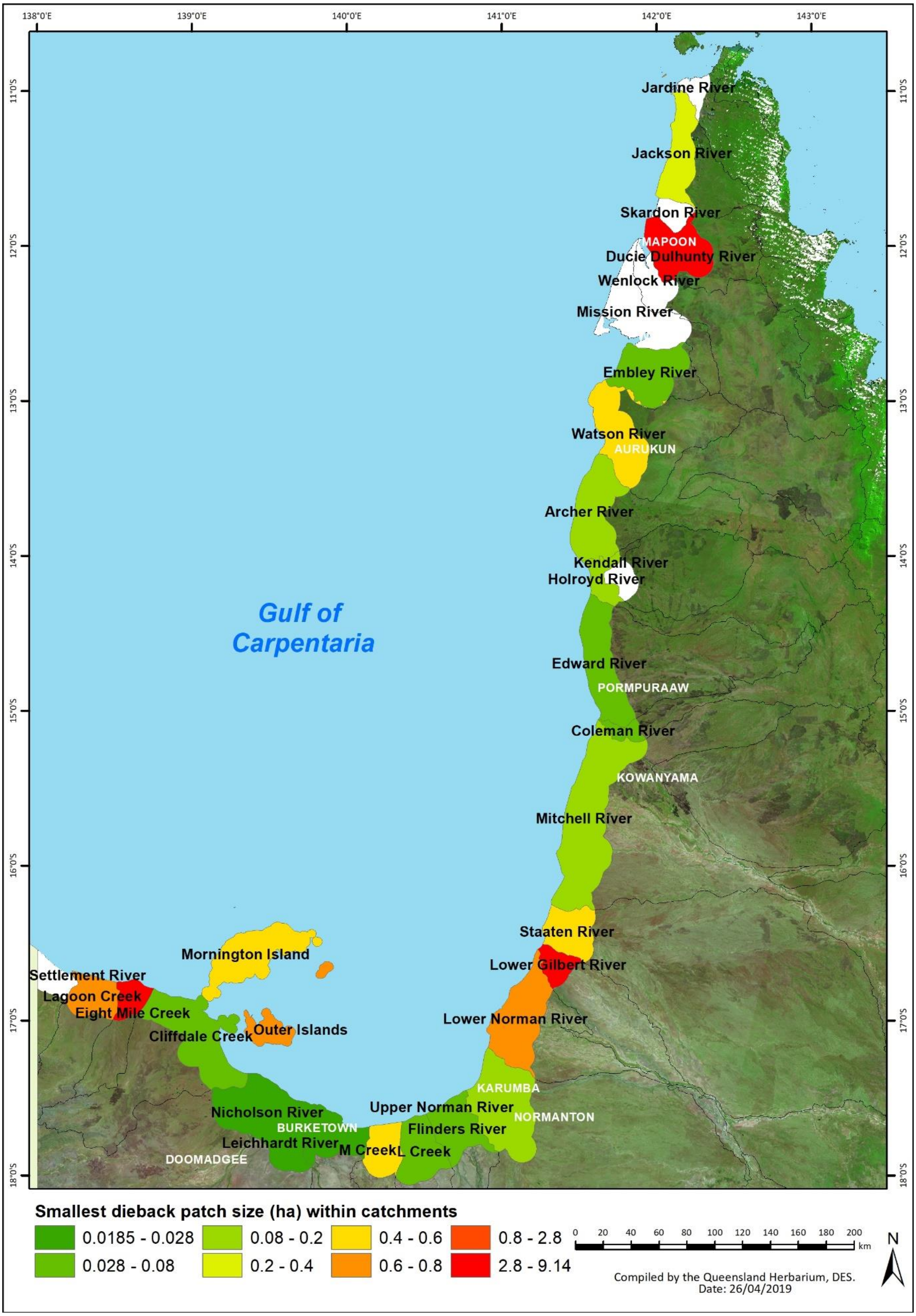

Figure 14 **Smallest dieback patch size (ha) within catchments**

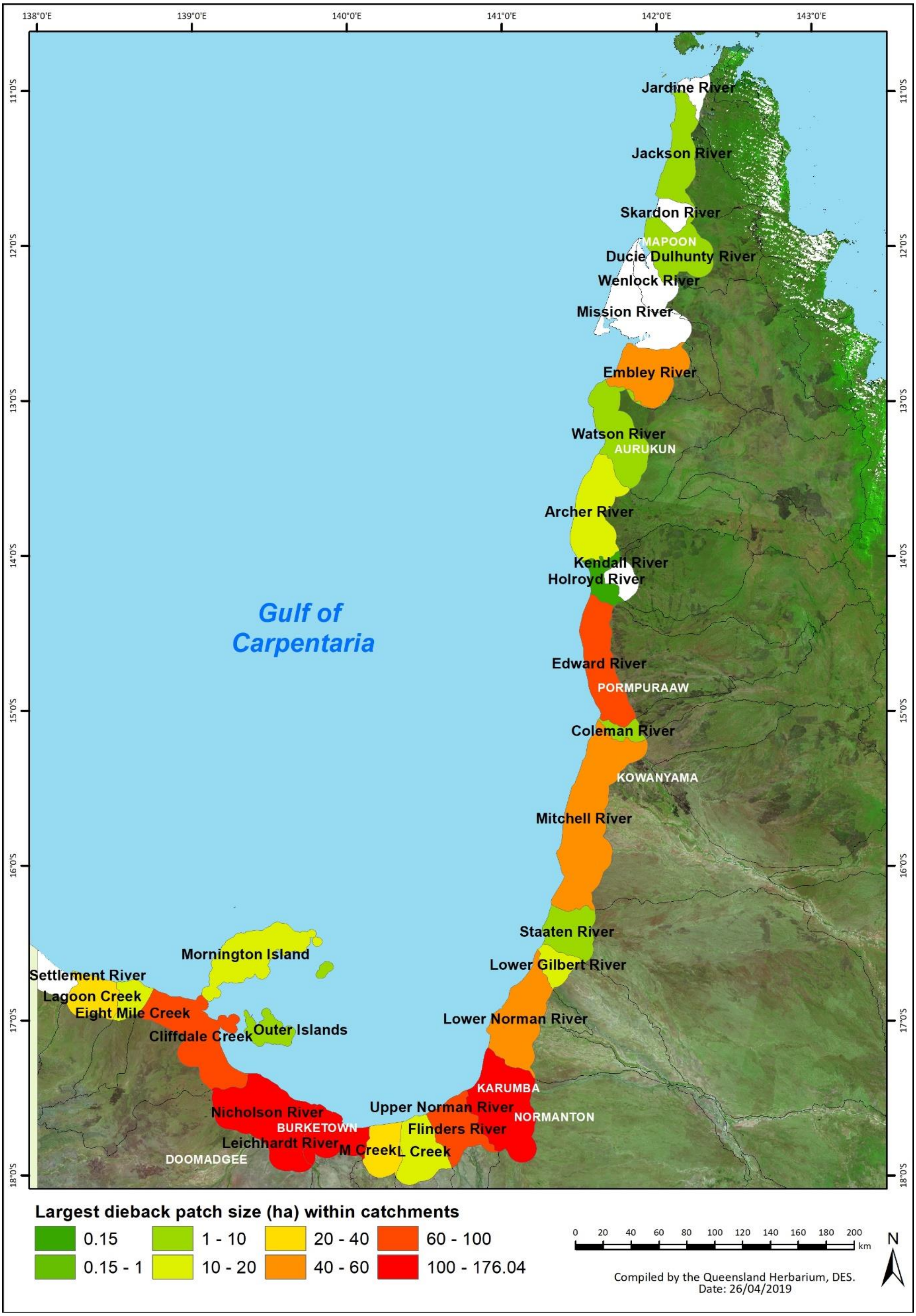

Figure 15 Largest dieback patch size (ha) within catchments

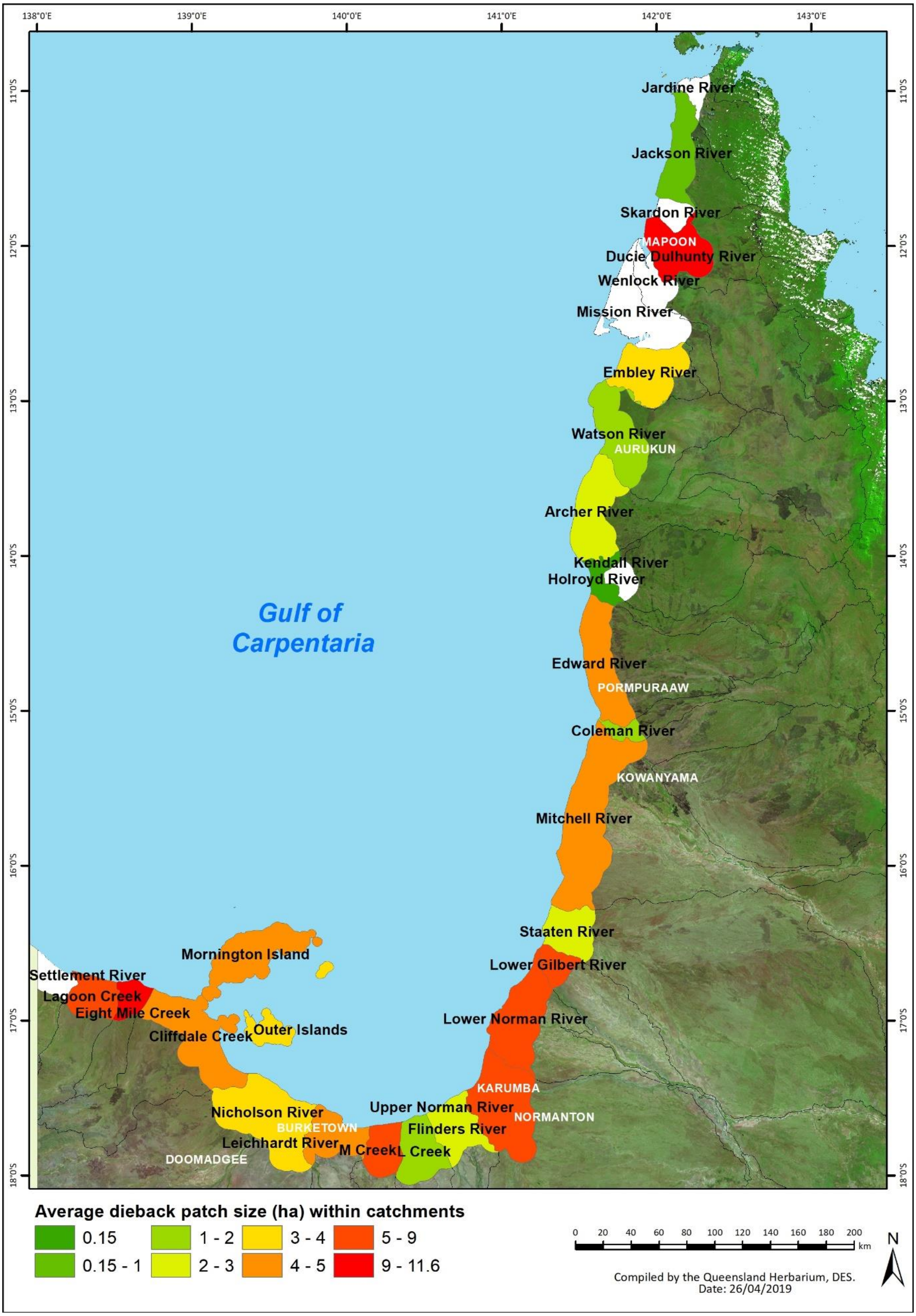

Figure 16 Average dieback patch size (ha) within catchments

Each catchment was assessed for the percent of the total mangrove dieback in the Queensland portion of the Gulf of Carpentaria (Figure 17) and the percent of dieback to live mangrove within the catchment (Figure 18).

A buffer analysis was applied to assess the impact of the dieback and the surrounding live mangroves. A 500 m buffer was applied to the dieback areas and this was assessed against the adjacent live mangroves as a percent dieback within 500 m (Figures 19 and 20). Similarly, a 500 m buffer around the mangrove dieback, was applied to the dieback and assessed against the area of Landzone 1 consisting of marine tidal clay plains (potential mangrove habitat) as a percentage (Figures 19 and 21).

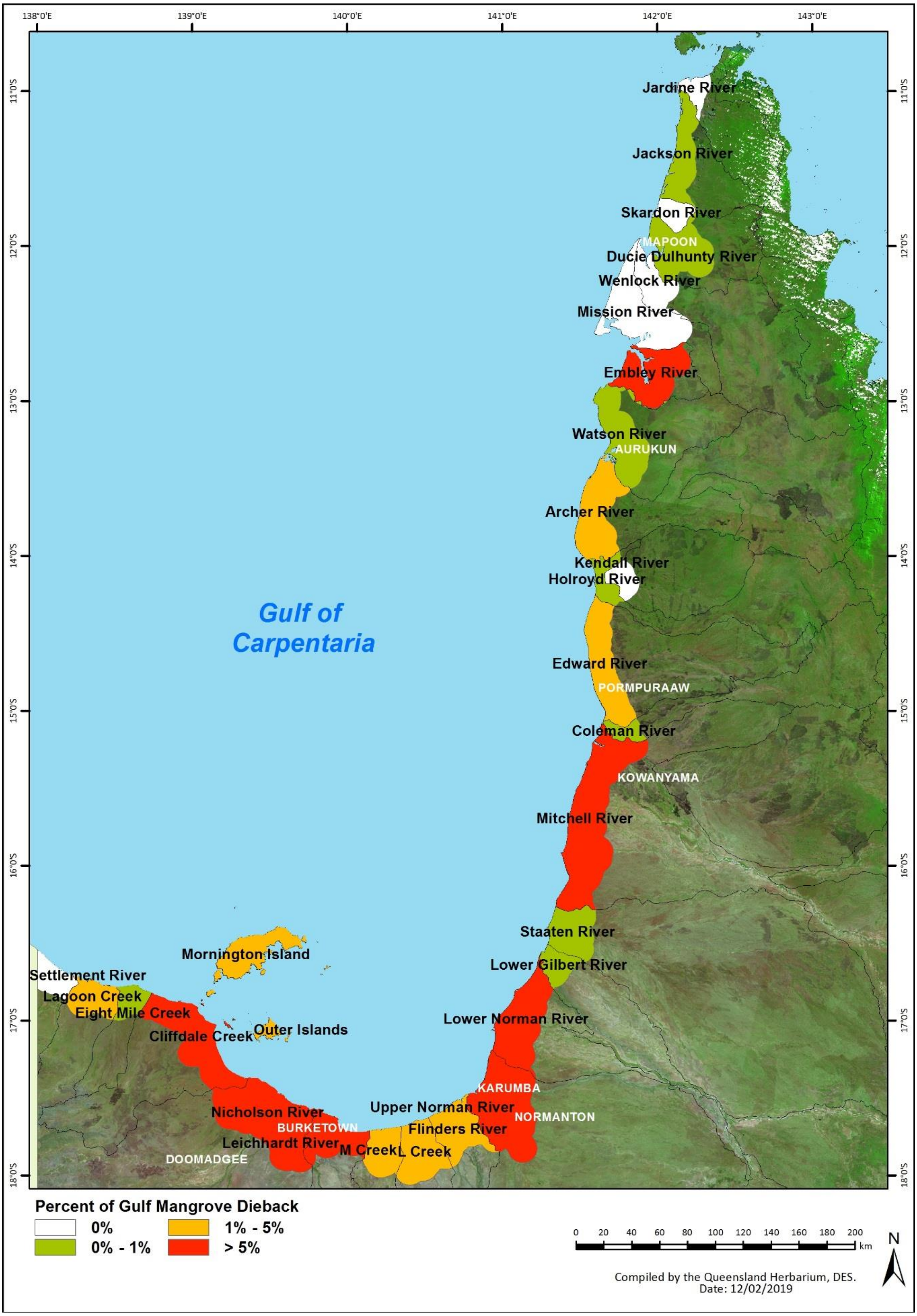

Figure 17 Percent of the total mangrove dieback within each catchment

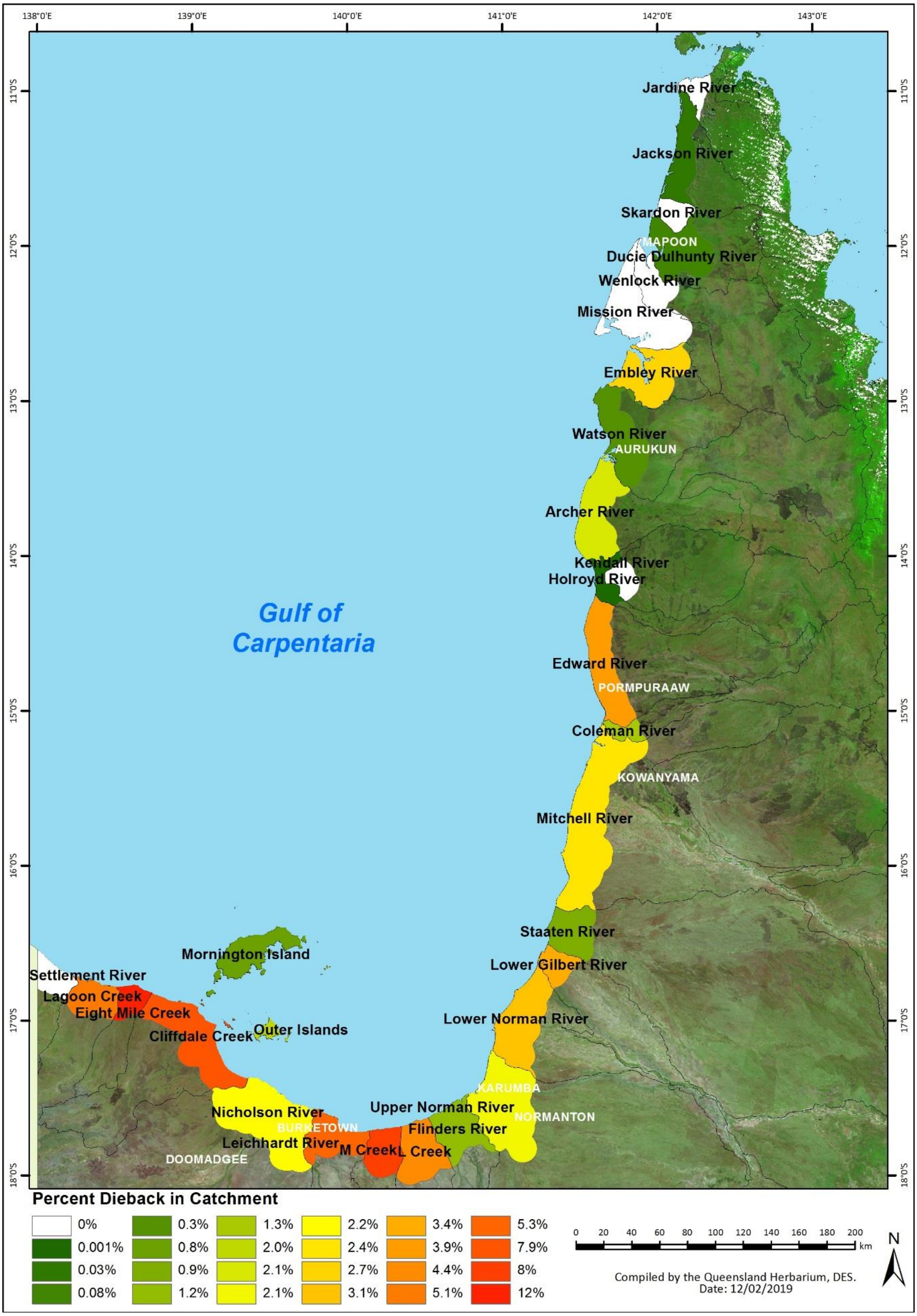

Figure 18 Percent of mangrove dieback within each catchment

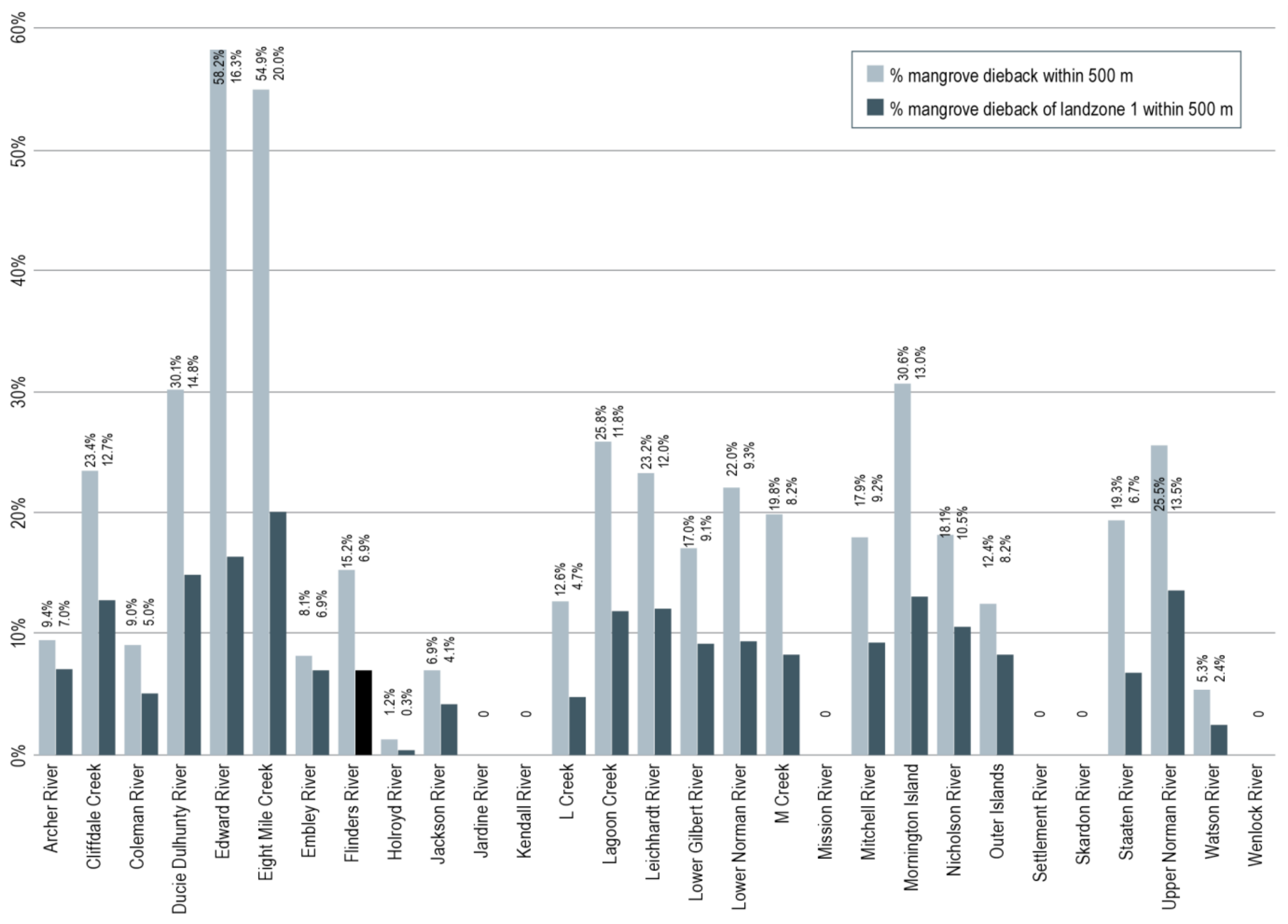

Figure 19 Percent of mangrove dieback in Landzone 1 (intertidal zone) within 500 m buffer within catchments

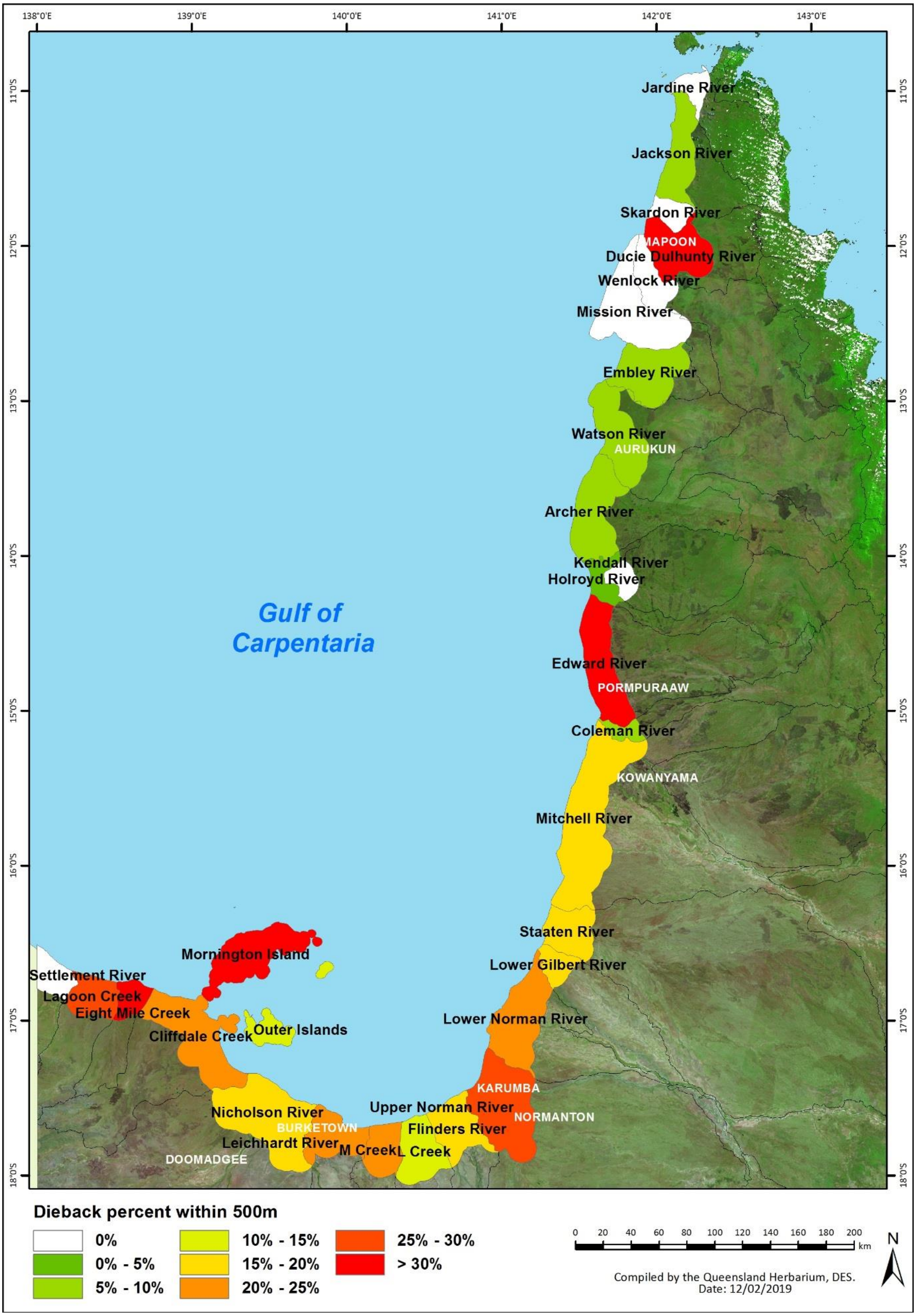

Figure 20 Percent of dieback within 500 m buffer of existing mangrove community within catchments

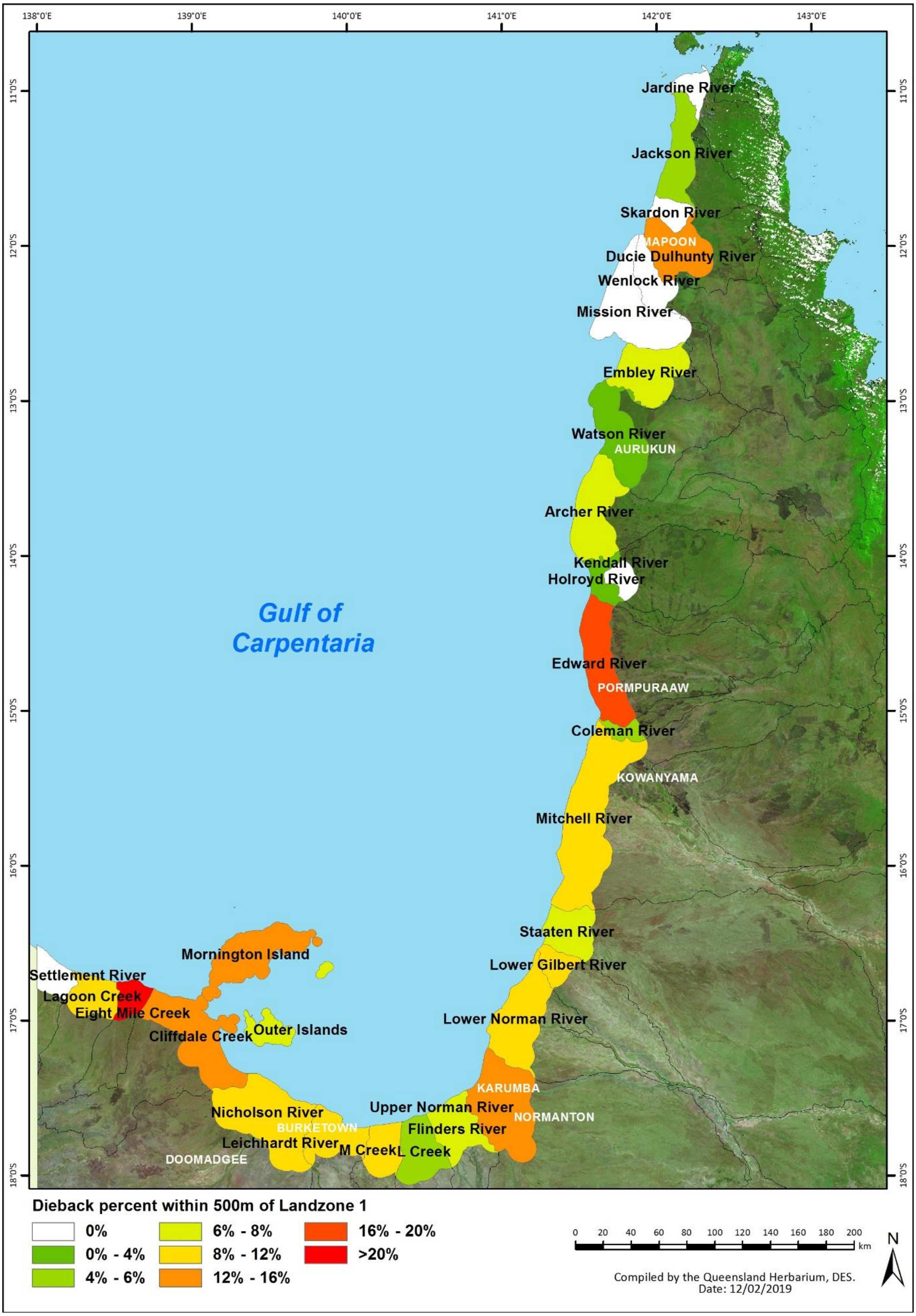

Figure 21 Mangrove dieback within 500 m buffer of Landzone 1 (intertidal zone) within catchments

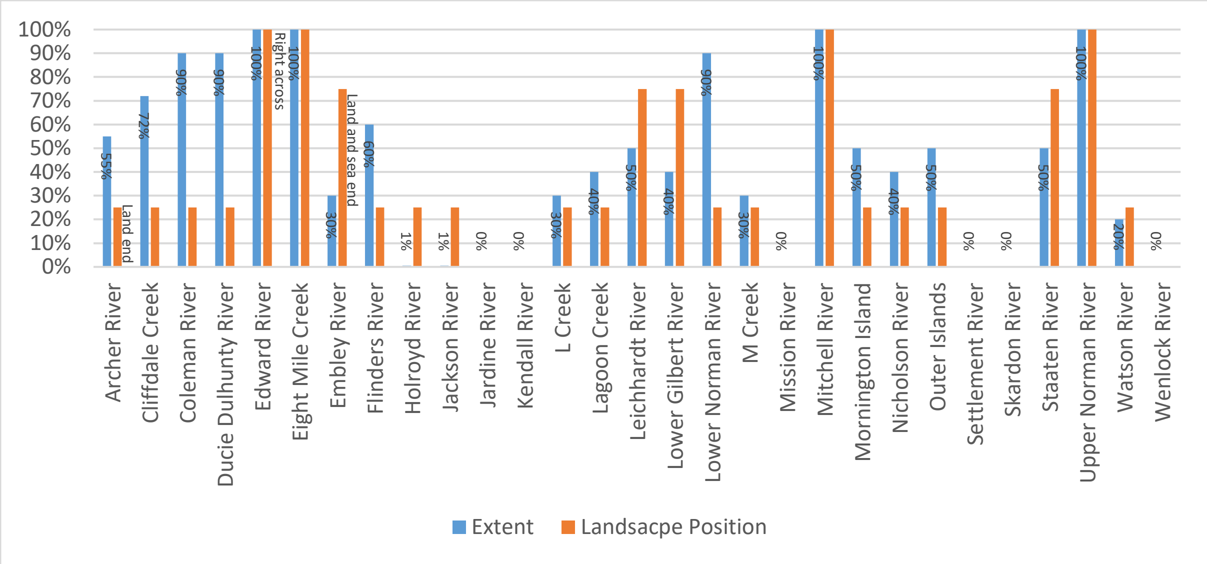

Figure 22 Extent and landscape position of mangrove dieback within catchments

A measure of the most extensive dieback in each catchment reported on the extent of dieback along the transect from supratidal flat to the coast and is presented as percent impact (Figures 22 and 23). Similarly, the landscape position location of dieback in each catchment was assessed across the gradient and it is represented as a percent to allow presentation in the radar graphs (none 0%, land 25%, sea 50%, both land and sea 75% and right across the gradient 100%) (Figure 22 and 24).

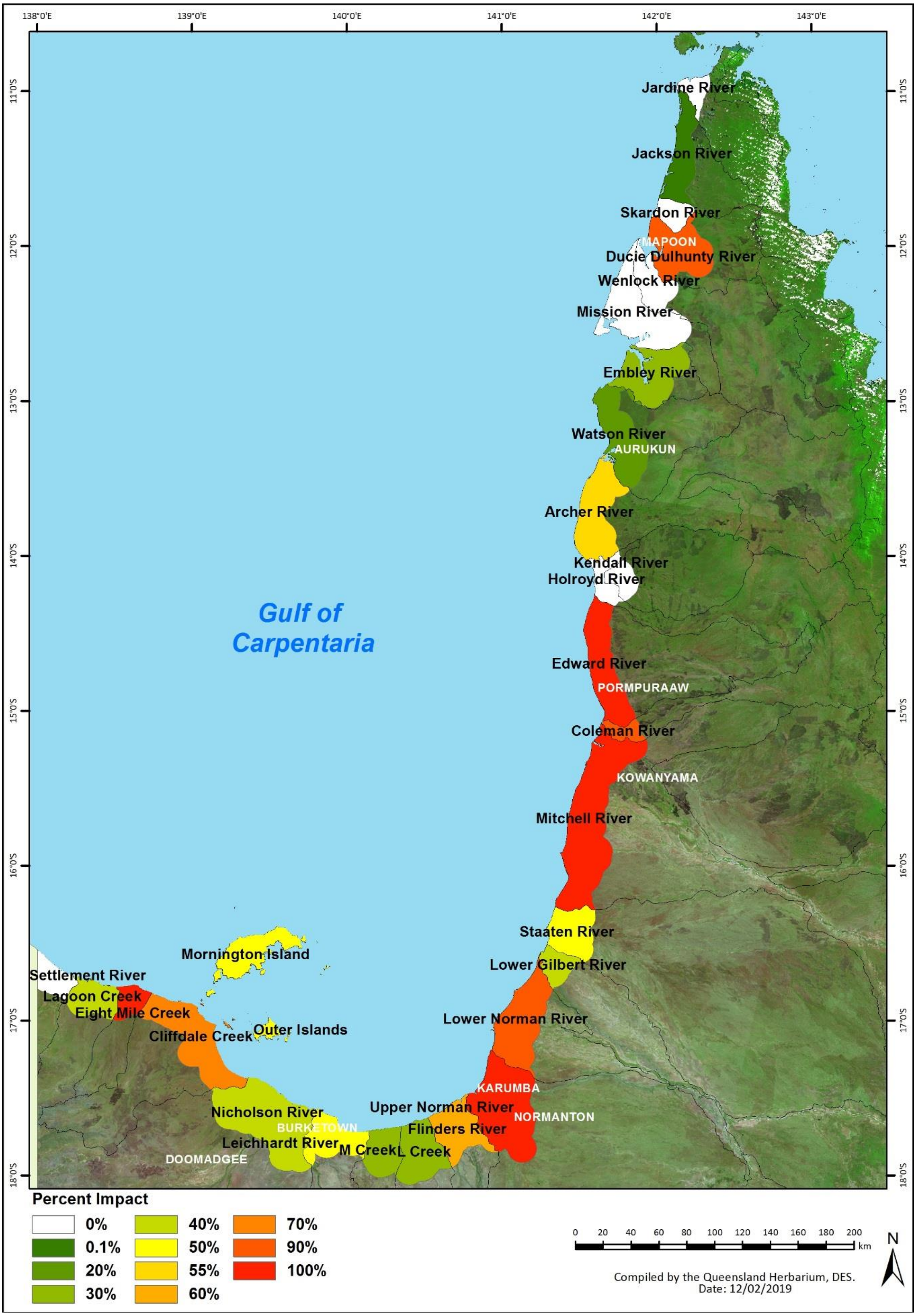

Figure 23 **Percent of worst transect impacted (extent across the transect) within catchments**

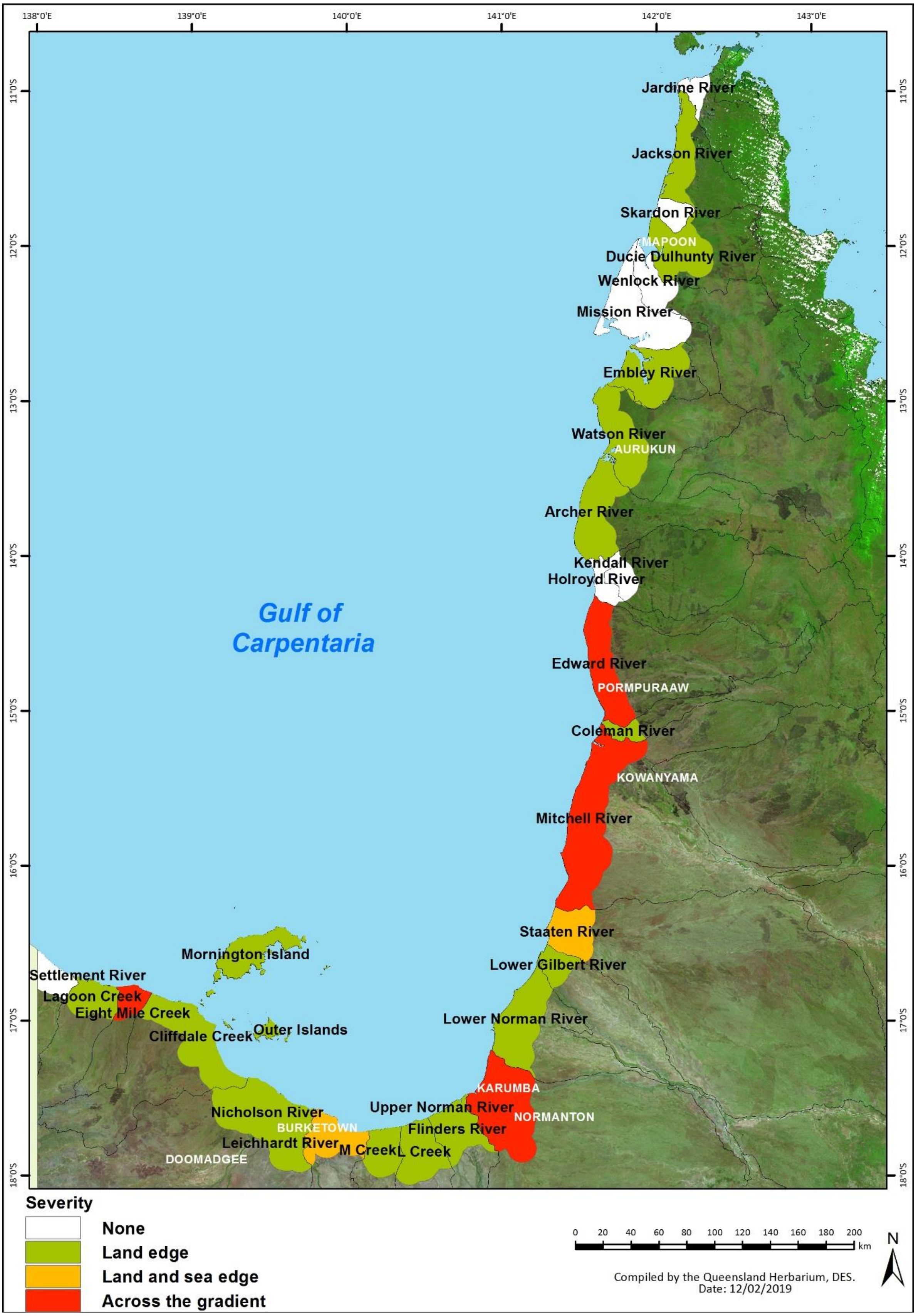

Figure 24 The landscape position of mangrove dieback within catchments

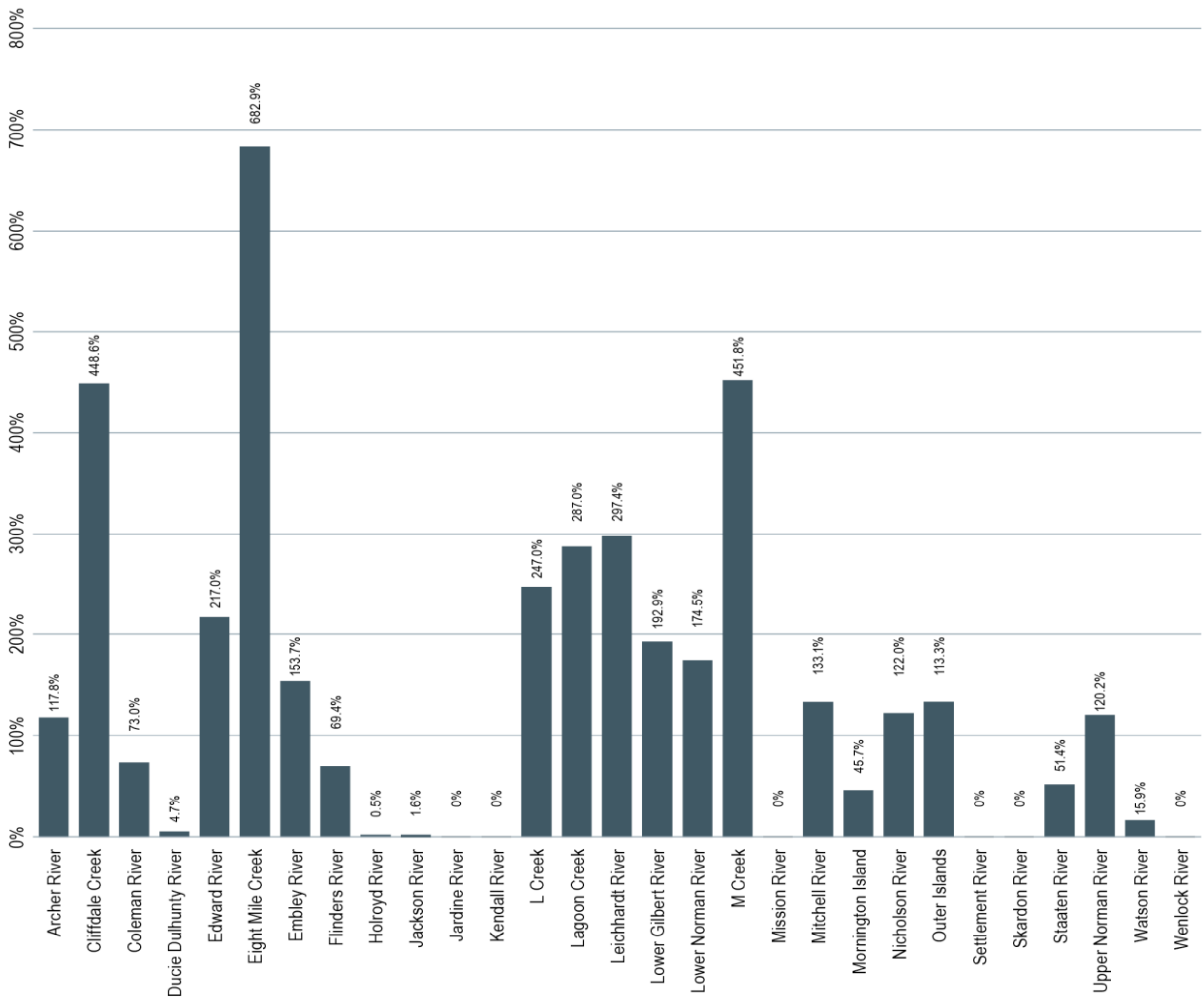

Figure 25 The ratio of gulf mangrove dieback and the extent by catchment

The ratio of the percent of the mangrove dieback to the percent of Queensland Gulf mangrove within each catchment provide another assessment of catchment dieback severity and shows that the dieback extent was not proportional to the mangrove extent present in each catchment (Figures 25 and 26).

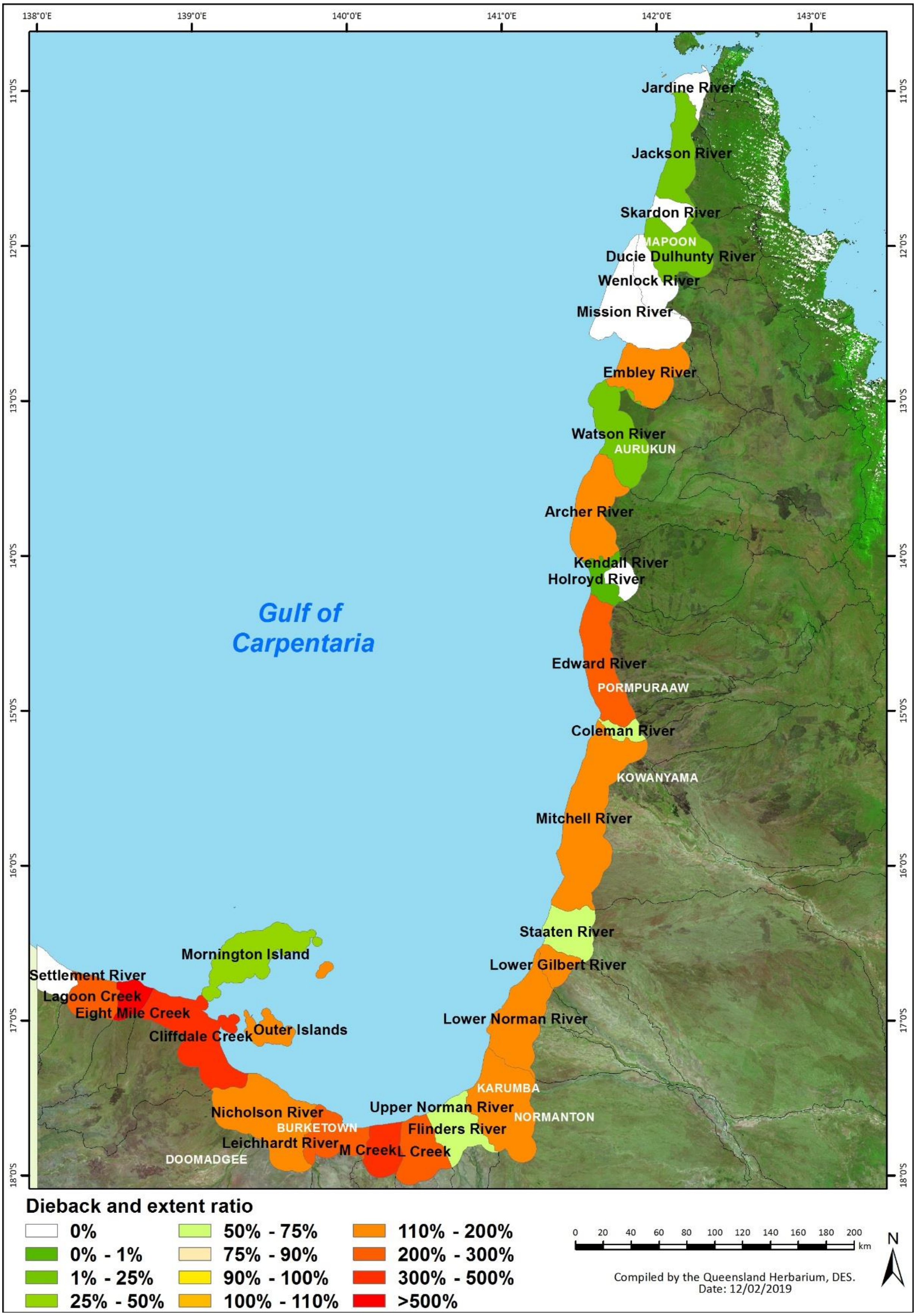

Figure 26 Map of the ratio of gulf mangrove % dieback and % extent by catchment

Lidar and high-resolution imagery capture and assessment

In August 2017 Airborne Research Australia captured Lidar data for the Gulf of Carpentaria region. Initial processing of this Lidar data was undertaken by the Department of Environment and Science Remote Sensing Centre at the Ecosciences Precinct, Dutton Park. A high-resolution three-band spectral RGB and Normalised Difference Vegetation Index (NDVI) imagery was also received from Airborne Research Australia.

The Lidar data capture provides a high-resolution baseline of mangrove extent, cover and height after the 2015–16 dieback event. This data is a fundamental data resource for both research and ongoing monitoring of the mangrove communities in the Gulf of Carpentaria.

The Lidar data capture provides physical measurements of both the ground elevation and the above ground vegetation over vast areas that are otherwise inaccessible. The correlation of ground information collected in the field with the Lidar and high resolution imagery allows for the extrapolation across the whole of the affected area within the Gulf.

The Lidar dataset consists of:

a) Point clouds in the form of Lidar data exchange File (LAS)

b) Digital terrain models (DTMs) at one metre spatial resolution and canopy height models (CHMs) at 0.5 m spatial resolution, and

c) High resolution RGB and NDVI imagery.

The raw data is available through the TERN data portal.

Figure 27 Extent of airborne LIDAR flights, Gulf of Carpentaria

Ground elevation data derived from the 2017 Lidar capture by Air Research Australia shows that the majority of the mangrove dieback within the Gulf of Carpentaria in Queensland occurs at the higher tidal levels of the mangrove habitats adjacent to the supratidal flats (Figure 28).

Across the region the dieback tree heights were 2.5 to 5 m tall with a mean tree height of 3.5 metres. Live mangrove tree heights were in the range of 2.5 to 7.5 metres with a mean of just under 5 metres (Figure 29).

The variability of the ground elevation in the living and dieback mangrove areas across the different catchments is very high (Figures 30 and 31). Some areas where dieback has occurred may reflect slightly higher ground elevation at the transition to the supratidal flats, whereas other higher elevations may reflect recent sedimentation which was obvious in field work undertaken across the dieback area. It is currently unknown when this sedimentation occurred but it is likely to have occurred during or just after the dieback event. It is also likely to be slowing down the recovery within these elevated areas.

The high variability of the elevations of the supratidal flats across the different catchments is presented in Figure 32.

Tree heights in the mangrove dieback and the living mangrove areas across the different catchments show high variability but overall the Lidar reflects lower tree heights in the mangrove dieback areas in comparison to the living mangroves (Figures 33 and 34). The lower tree heights in the dieback area are likely attributable to the lag of about a year and half, between the dieback event and the capture of Lidar data where the effected tree canopies were naturally trimmed as a result of dieback. This was evident at the time that field work was undertaken at Karumba and Pormpuraaw. The Lidar density over dead trees with no leaves may peak sub-canopy heights and therefore bias the dieback areas to lower tree heights.

The assessment of ground elevation and tree heights over dieback areas and live mangroves for each catchment is presented in Appendix I.

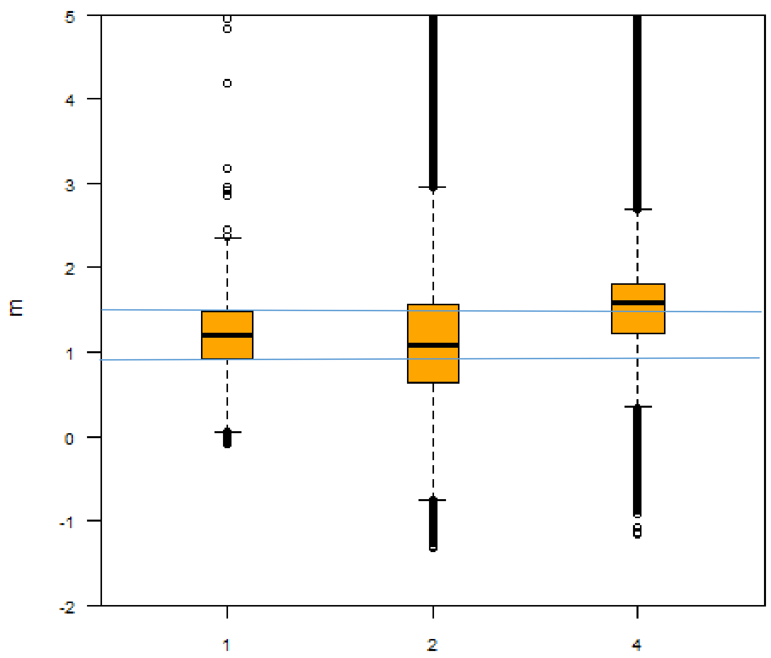

Figure 28 Ground elevation differences between: 1. mangrove dieback 2. live mangrove and 4. supratidal flats

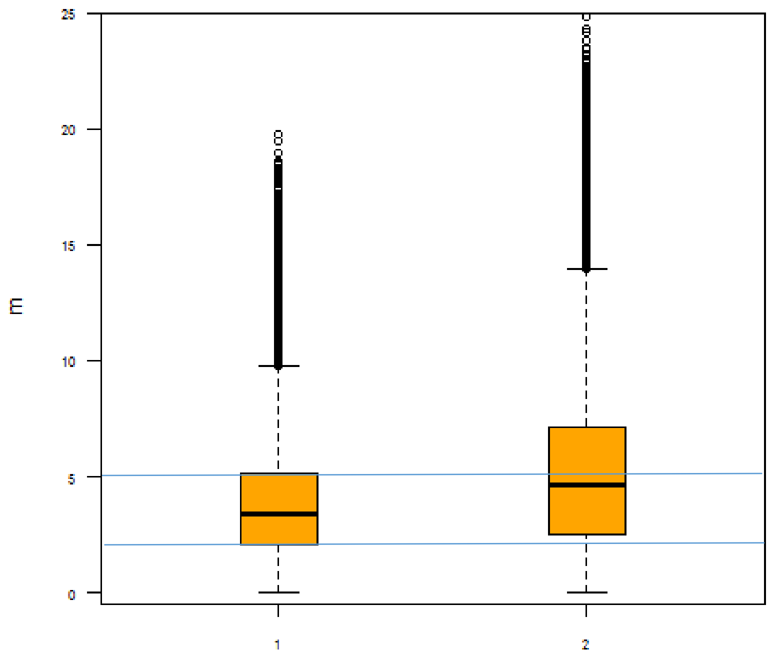

Figure 29 Tree height differences between: 1. mangrove dieback 2. live mangrove

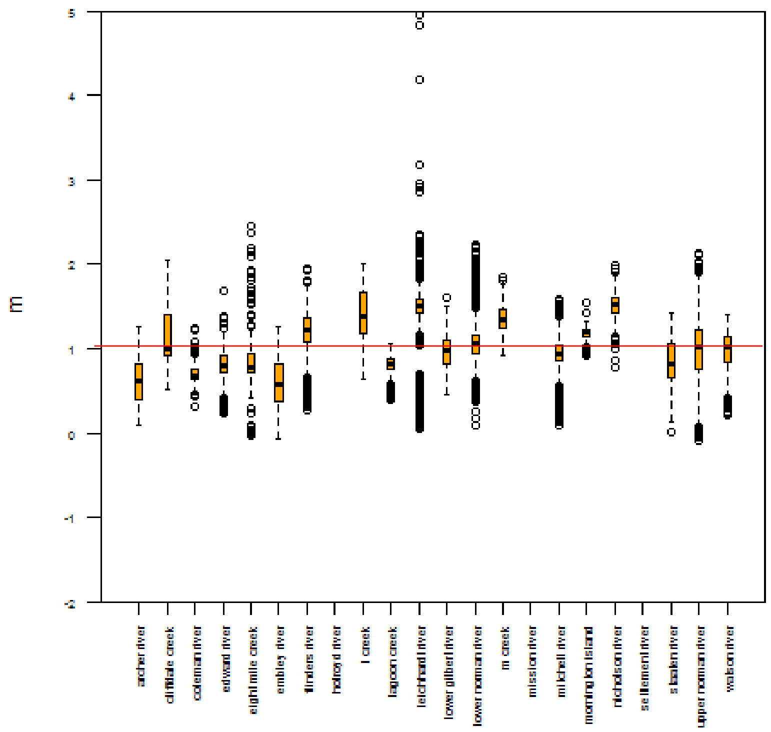

Figure 30 Mangrove dieback. Ground elevation across each catchment

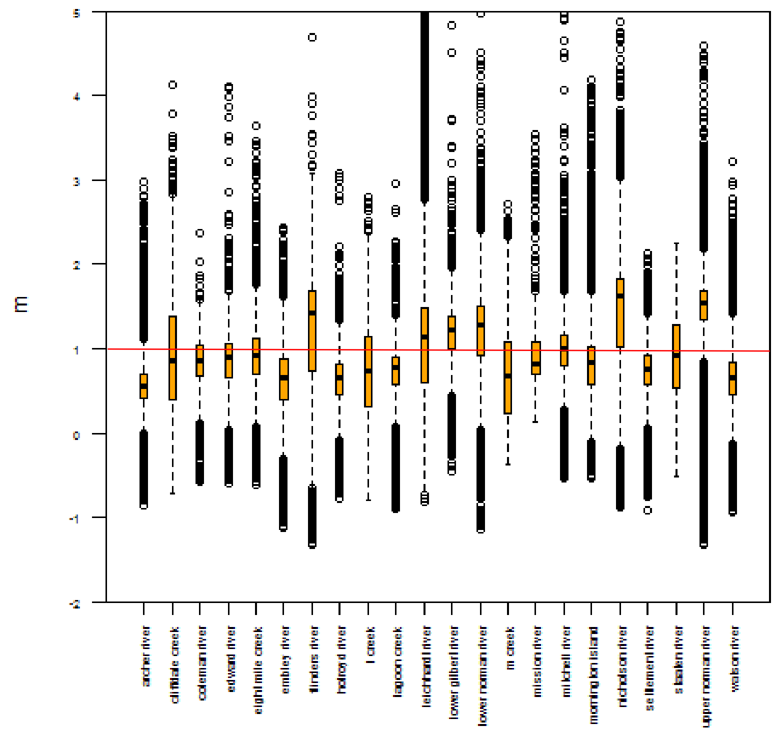

Figure 31 **Living mangrove. Ground elevation across each catchment**

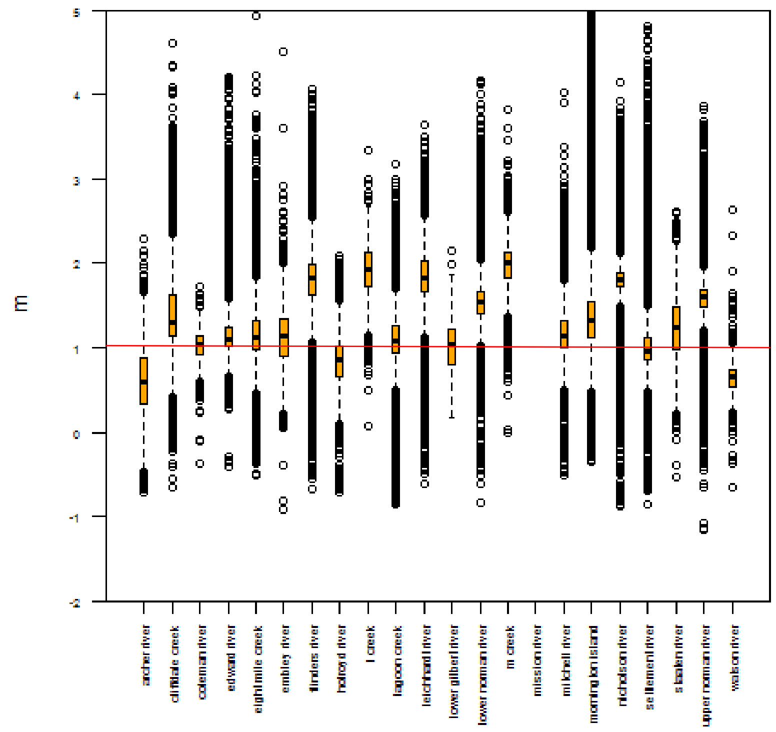

Figure 32 **Supratidal flat. Ground elevation across each catchment**

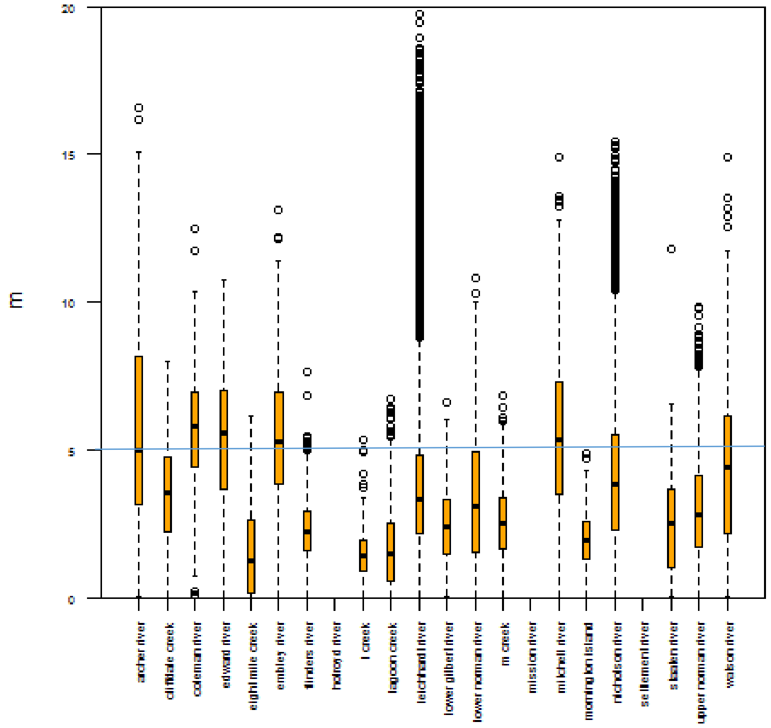

Figure 33 Mangrove dieback. Tree heights across each catchment

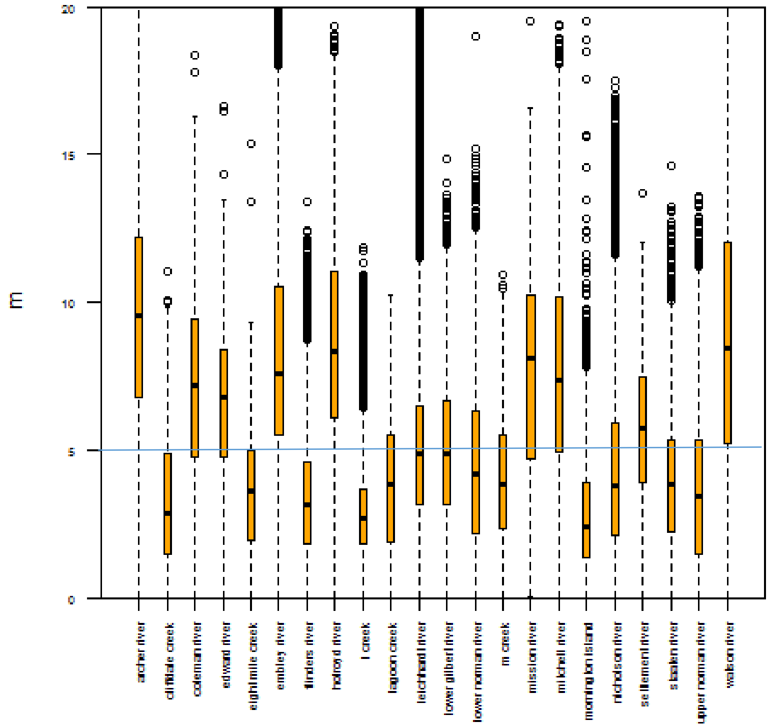

Figure 34 Living mangrove. Tree heights across each catchment

Field survey work

The Queensland Herbarium has targeted field work in two location across the dieback area, namely Karumba and Pormpuraaw. The Karumba area exhibited major dieback to the north of the town while there is a minor area of dieback to the south-west. The area of dieback to the south of Pormpuraaw showed different levels and patterns of dieback severity within short distances.

Field survey work carried out in each of the transects

At each of the two locations a number of transects were laid out and data collected. These transects follow the protocol as laid out in Neldner et al (2019).

1. Two CORVEG sites (50 m x 10 m) (Neldner et al 2019) were laid out with one site located in the area of mangrove dieback area and the other site in the adjacent living mangrove area.

2. The biomass (Tree heights and dbh) was recorded within the CORVEG sites. These biomass sites can be reduced to 50 m x 5 m, or further reduced to 25 m x 5 m depending on the density and each site's uniformity.

3. Pneumatophores were measured within the CORVEG transects at 10 m, 20 m, 30 m, 40 m and 50 m using 0.25 m x 0.25 m or 0.5 m x 0.5 m quadrats depending on the density of the pneumatophores.

4. Assessment of the recruitment of canopy species as well as other shrub and ground species across the 50 m x 10 m quadrat.

5. The soil surface elevation was taken across the CORVEG Plots at 10 m intervals starting at 0 m and extending to the end of the plots

6. Sediment cores were extracted and pH measurements were taken in the field at the Pormpuraaw transects. Samples were sent for laboratory analysis. Assessment of the laboratory results are beyond the scope of this current study.

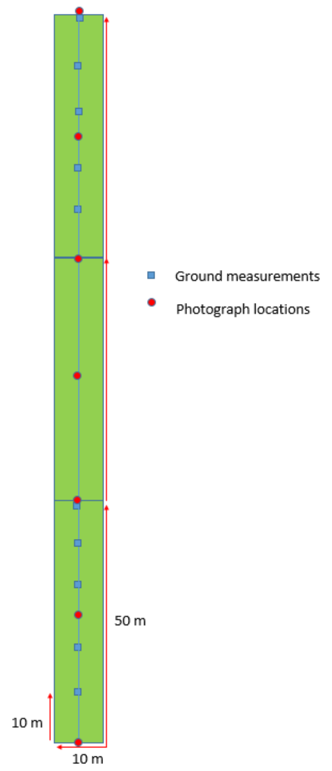

Figure 35 Monitoring transect

7. Photos covering 360^{O} were taken at every 50 m. Photos were also taken along the transect as far as possible towards the seaward edge and as far as inland as mangrove trees (live or dead) occurred. The locations where the vegetation changes (e.g. change from dead to alive or a change of species composition occurs) was marked and photos also taken at these locations.

Biocondition benchmarks

To assess the condition of each of the field sites and level of recovery this report has adopted the Queensland Herbarium biocondition benchmarks methodology (Eyre et al 2017). A Condition Assessment Framework for Terrestrial Biodiversity in Queensland provides the objective comparison of vegetation condition states within and between Regional Ecosystems. There are quantitative values for each assessable attribute in biocondition, and are derived as the average or median values from field data collected from reference, or best-on-offer, sites in the contemporary landscape, during optimal seasonal conditions as practicable (Eyre et al 2015).

Summary information for field work in Karumba and Pormpuraaw transects and preliminary findings are presented below. Further structural information and field measurements and photographs are given in Appendix IV Field Summary Structural Information Measurements and photographs.

Field work—Karumba

Three 150 m permanent monitoring transects were established in late August 2017 in the Karumba area. Two transects were established to the north and one transect to the south west of Karumba on the Norman River (Figure 27).

Preliminary findings Karumba area

In the northern transects the dieback was extensive and complete in nature while in the south-west transect, the dieback was limited and diffuse in nature and extent.

The recovery that is occurring at the seaward edge of the two **northern transects** is very strong. There is very low to little recruitment of seedlings or saltmarsh species in the landward end of the transects which indicates that in this area recovery is unlikely. This, combined with the siltation which has occurred in this area of the transects means that the area within the higher tidal limits is likely to convert to supratidal flat over time.

The landward end of **the south western transect** is adjacent the supratidal flat. The upper 30 m of this transect consists of a mixture of both living and dead shrubs of northern grey mangrove with a dense understorey of *Batis argillicola* (batis). The eastern side of the landward 30 m of the transect (which is adjacent to the supratidal flat) consists of an area of tall shrubs or low trees of northern grey mangrove, the majority of which are dead. However on the western side of the transect at this location the mangroves are alive and apparently healthy.

Elsewhere along the **south western transect** towards the coastline the mangroves are healthy and are not subject to dieback and consist of an open or low open woodland of grey mangrove. Because of the natural openness of this community it can, to the untrained eye, appear as dieback in aerial photography.

Karumba SW1A was used as the best on offer biocondition benchmark to assess the recovery of the other site measured in the Karumba area. Karumba SW1D which had very light dieback has scored the highest score (table 5).

Summary structural attributes of the Karumba transects including: tree density, tree heights, diameter at breast height, the percent of trees which are dead and the percent of trees which are reshooting from dead or dying stems are shown in Table 6. Seedling species and recovery density and heights are summarised for each site on the transect and is supported by the CORVEG field measurements (Table 7).

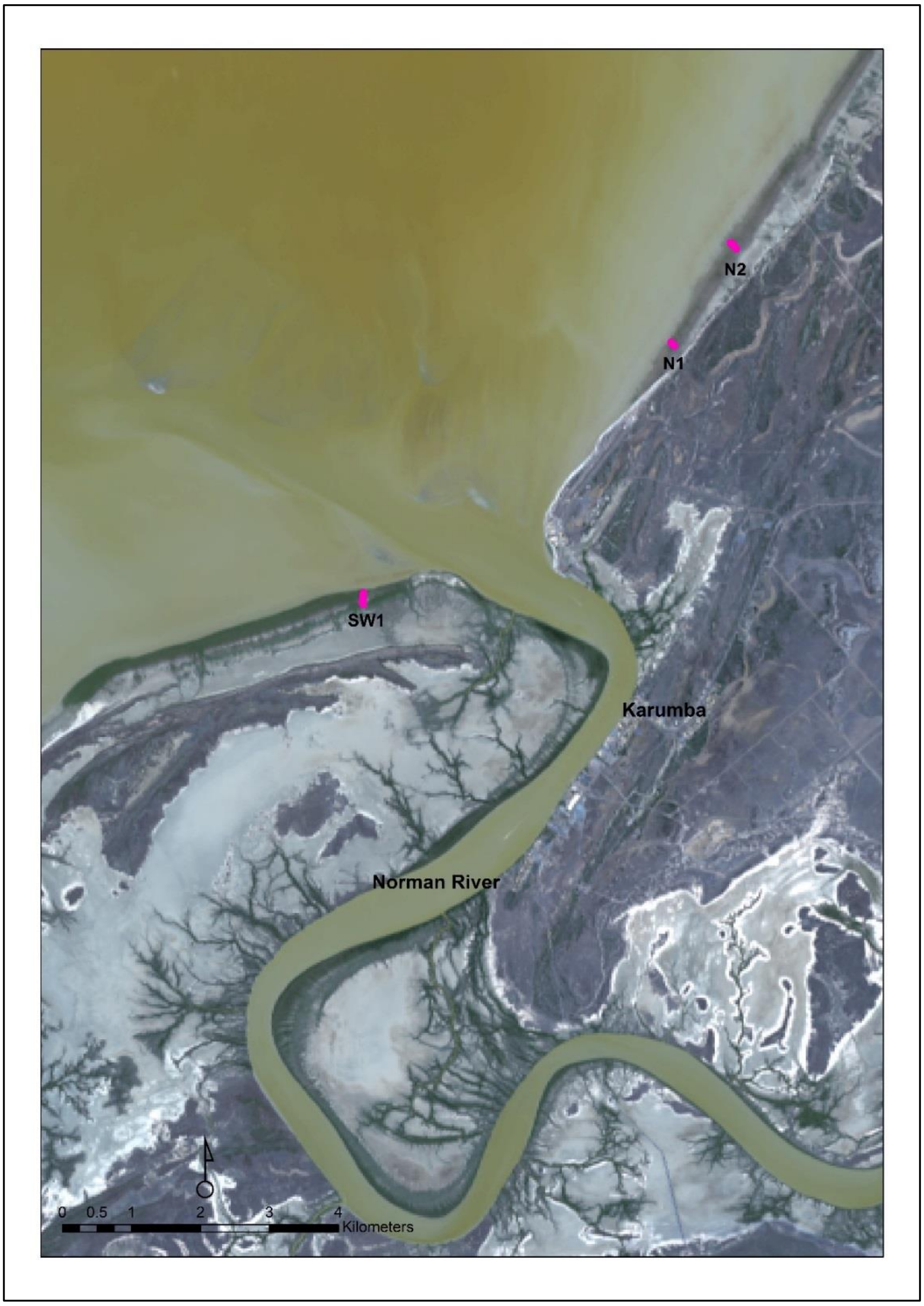

Figure 36 **Location of permanent monitoring transects established near Karumba in August 2017**

Table 5 Karumba mangrove biocondition scores

Site number	Tree canopy ht (m)	Tree canopy cover (%)	Large tree	Native shrub canopy	Tree spp. richness	Tree recruitment	Woody debris	Shrub spp. richness	Grass spp. richness	Forb other sppl. richness	Non-native plant cover	Native per grass grnd cover %	Litter grd cover %	Final biocondition score
Benchmark score SW1A	**5**	**5**	**15**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**10**	**5**	**5**	**80.0**
Score Karumba_SW1D	5	2	15	3	5	5	5	2.5	5	5	10	5	3	**20.5**
Score Karumba_N1D	0	0	15	0	5	5	5	5	5	5	10	5	3	**63.0**
Score Karumba_N1A	0	0	15	3	0	5	5	2.5	5	5	10	5	3	**58.5**
Score Karumba_N2A	0	0	15	3	0	5	5	5	5	5	10	5	3	**61.0**
Score Karumba_N2D	0	0	15	5	0	5	5	5	5	5	10	5	5	**65.0**

Table 6 Summary of structural attributes for Karumba monitoring transects

Site	Trees/ha	Mean tree height (cm)	Median tree height	Mean dbh (cm)	Median dbh (cm)	Percent dead	Percent re-shooting
N1A	120	533.42	605.00	92.93	81	92	0
N1D	7500	326.17	309.00	38.99	32	100	0
N2A	17-	449.53	464.00	95.53	90	100	0
N2D	600	380.42	400.00	49.45	44	100	0
SW1A	1920	308.25	297.50	81.08	53	8	0
SW1D	3142.86	284.20	253.00	61.91	37	53	0

Table 7 Summary of shrub layer 1 and 2 attributes for Karumba monitoring transects (CORVEG)

Site	0–50 m	100–150 m
N1 seedling species	Ba, Ae, Av, Ce*	Ae, Av
N1 seedling density	0.1%	40%
N1 seedling heights (cm)	10–40	10–60
N2 seedling species	Ae, Av, Ba	Ae, Av, Ba
N2 seedling density	4%	24.2%
N2 seedling heights (cm)	20–100	20–100
SW seedling species	Av, Ba	Ae, Av, Ba
SW seedling density	37.2%	5.1%
SW seedling heights (cm)	20–30	10–250

*Av: *Avicennia marina* subsp. *eucalyptifolia;* Ba: *Batis argillicola;* Ae: *Aegialitis annulata* (Club mangrove); Ce: Ceriops sp./spp.

Field work—Pormpuraaw

Five permanent monitoring transects (150 to 250 m long) were established in July 2018 south of Pormpuraaw. The five transects are located 6.5–12.5 km south of the Chapman River adjacent to the Melamen Plain and are located within 6 km from one another. (Figure 28).

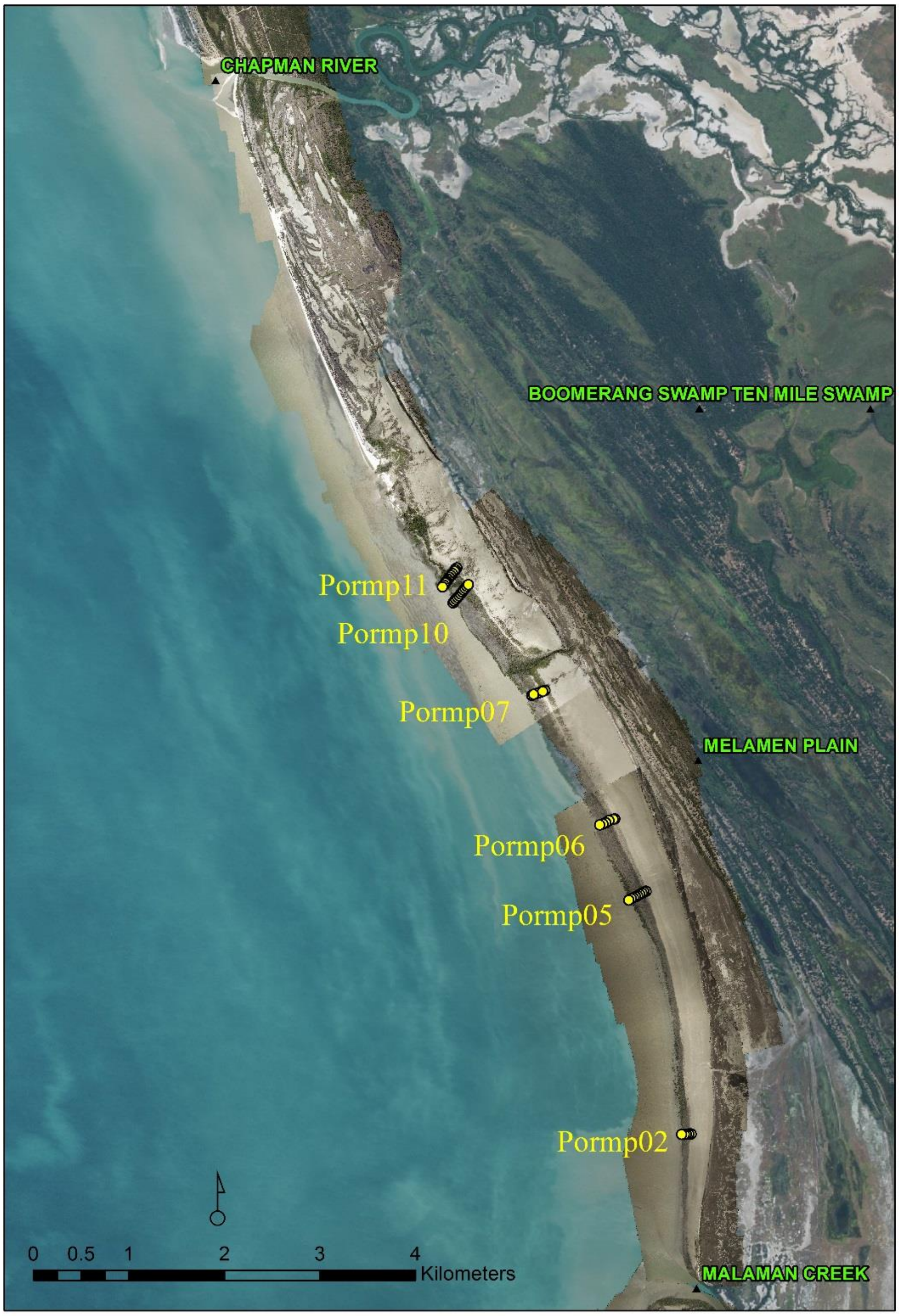

Figure 37 **Permanent monitoring transect locations south of Pormpuraaw**

Preliminary findings Pormpuraaw area

Despite the close proximity of the transects which lie to the south of Pormpuraaw, different levels of dieback and recovery are reflected in each of the transects.

Correlations between dieback areas and sedimentation covering the pneumatophores are obvious on the ground. Soil cores showed areas with mangrove dieback to have between 30 and 60 cm of sedimentation which covered most of the pneumatophores.

Table 8 Pormpuraaw biocondition scores

Site number	Tree canopy ht (m)	Tree canopy cover (%)	Large tree	Native shrub canopy	Tree spp. richness	Tree recruitment	Woody debris	Shrub spp. richness	Grass spp. richness	Forb other sppl. richness	Non-native plant cover	Native per grass grnd cover %	Litter grd cover %	Final biocondition score
Benchmark score SW1A	**5**	**5**	**15**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**10**	**5**	**5**	**80.0**
Score Porm_10_s5	5	5	0	3	5	5	5	2.5	5	5	10	5	5	**60.5**
Score Porm_10_s3	5	0	0	5	5	5	5	2.5	5	5	10	5	5	**57.5**
Score Porm_11_s3	5	0	0	3	5	5	5	2.5	5	5	10	5	3	**53.5**
Score Porm_05_s3	5	0	0	3	5	5	5	2.5	5	5	10	5	3	**53.5**
Score Porm_05_s1	5	0	0	5	5	5	5	2.5	5	5	10	5	3	**55.5**
Score Porm_02_s2	5	0	0	3	5	5	5	2.5	5	5	10	5	5	**55.5**
Score Porm_02_s1	0	0	0	0	0	5	5	2.5	5	5	10	5	5	**42.5**
Score Porm_5_s2	**5**	**2**	**0**	**3**	**5**	**5**	**5**	**2.5**	**5**	**5**	**10**	**5**	**3**	**55.5**
Score Porm_5_s4	**5**	**5**	**0**	**3**	**5**	**5**	**5**	**2.5**	**5**	**5**	**10**	**5**	**3**	**58.5**
Score Porm_7_s2	**5**	**5**	**0**	**5**	**5**	**5**	**5**	**2.5**	**5**	**5**	**10**	**5**	**3**	**60.5**
Score Porm_11_s2	**5**	**2**	**0**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**10**	**5**	**3**	**60.0**
Score Porm_11_s4	**5**	**5**	**0**	**3**	**5**	**5**	**5**	**2.5**	**5**	**5**	**10**	**5**	**3**	**58.5**

Best-on-offer sites with live mangroves in green shading in Table 7 were used to derive the biocondtion benchmark score for the Pormpuraaw site assessment. All sites besides Porm_2_s1 had some live canopy trees. All sites had recruitment occurring with two or three shrub species. Porm_05_s1 and Porm_02_s2 were the sites with the highest score for recovery while Porm_02_s1 had the lowest biocondition score for recovery. Summary structural attributes of the Pormpuraaw transects including: tree density, tree heights, Diameter at breast height, the percent of trees which are dead and the percent of trees which are reshooting from affected stems (Table 9). Assessment across each transect was conducted for the seedling species and recovery density (Table 10). Summary of structural attributes for Pormpuraaw monitoring transects and seedling information are presented in Tables 10 and 11.

Table 9 Summary of structural attributes for Pormpuraaw monitoring transects

Site	Trees/ha	Mean tree height (cm)	Median tree height (cm)	Mean dbh (mm)	Median dbh (mm)	% dead	% reshooting
Pormp02-S1	560	535.86	544	154.71	152	100%	**0%**
Pormp02-S2	2040	296.31	231	45.63	15	22%	**0%**
Pormp05-S1	1520	385.79	299	95.89	80	100%	**0%**
Pormp05-S2	1250	617.60	611.50	134.30	139	70%	**0%**
Pormp05-S3	560	532.14	614	140.29	93	100%	**0%**
Pormp05-S4	1120	814.36	863.50	105.29	104	7%	**0%**
Pormp07-S2	2720	732.87	789.50	78.01	71	12%	6%
Pormp10-S2	3700	817.49	872	72.76	70	11%	**0%**
Pormp10-S3	640	381.88	397.50	112.13	68	100%	**0%**
Pormp10-S5	400	1095	1095	127.75	127.75	**0%**	**0%**
Pormp11-S2	2720	794.03	845	76.26	75	6%	**0%**
Pormp11-S3	720	542.11	523	71.22	73	78%	**0%**
Pormp11-S4	1875	553.73	590	114.67	95	40%	**0%**
Pormp11-S5	400	532.90	528.50	100.40	78.5	60%	40%

Table 10 **Summary of shrub layer 1 and 2 attributes for Pormpuraaw monitoring transects (CORVEG)**

Site	0–50 m	50–100 m	100–150 m	150–200 m	200–250 m
Pormp02 seedling species	Av, Ba, Ae*	Av, Ba, Ae			
Pormp02 seedling density	0.6%	40.6%			
Pormp02 seedling heights (cm)	20–40	10–200			
Pormp05 seedling species	Ae, Av, Ba	Ae, Av, Ba	Av, Ae	Av, Ae	
Pormp05 seedling density	8.4%	1.3%	4.2%	1.4%	
Pormp05 seedling heights (cm)	15–60	30–160	50–100	10–25	
Pormp07 seedling species	Ba, Av, Ae			Av, Ae, Ba	
Pormp07 seedling density	77.4%			15.4%	
Pormp07 seedling heights (cm)	30–50			30–50	
Pormp10 seedling species		Av, Ae, Ba	Ae, Av, Ba +		Av, Ae
Pormp10 seedling density		5.4%	5.1%		1.1%
Pormp10 seedling heights (cm)		30–70	15–60		40–60
Pormp11 Seedling Species		Av, Ae, Ba	Av, Ae +	Av, Ae ++	Av, Ae
Pormp11 seedling density		9.8%	4.4%	23.6%	10.8%
Pormp11 seedling heights (cm)		30–40	20–60	40–800	30–80

*Av = *Avicennia marina* subsp. *eucalyptifolia;* Ba = *Batis argillicola;* Ae = *Aegialitis annulata* (Club mangrove)

+ 125–175 m instead of 100–150 m

++ 184–200 m instead of 150–200 m

Discussion and conclusions

The study has delineated a total of 2774 ha of mangrove dieback across dieback across twenty-nine catchments with 2295 ha of mangrove dieback occurring in the Gulf Plains bioregion and 479 ha of mangrove dieback occurring in the Cape York Peninsula bioregion. It has developed numerous patch analysis indices by catchment including: area of dieback, patch size statistics and percent dieback to living with no clear pattern explaining the cause or reason for the different dieback extents in the catchments.

The largest dieback areas occurred in three of the southern catchments in the Gulf Plains bioregion: the Nicholson River (400 ha of dieback), Leichhardt River (378 ha) and Upper Norman River (291 ha). The fourth largest dieback area occurred in the Mitchell River (289 ha) in the northern Gulf Plains bioregion and the fifth largest dieback area occurred in the Embley River (278 ha) in the Cape York Peninsula bioregion. The mangrove dieback was predominantly coastal in nature (as opposed to riverine) with 85% of the total mangrove dieback occurring within one kilometre of the coastline.

From limited ground site data it is presumed that the primary mangrove species impacted by dieback was *Avicennia marina* subsp*. eucalyptifolia* (northern grey mangrove). Historical assessment, both in the Karumba and Pormpuraaw areas, illustrates that the mangrove dieback did not discriminate on tree age with deaths occurring of trees as young as six-years old through to trees which were at least 47 years old.

A potential cause of the dieback in the Gulf of Carpentaria is discussed in Duke et al (2017) and to illustrate the climatic conditions occurring prior to the dieback event the long term climatic factors and sea level for the Karumba area are presented in: Climatic factors and sea level contributing to the Gulf of Carpentaria mangrove dieback Appendix III.

Climate recordings in Karumba in the period prior to the dieback event illustrate that the monthly evaporation reached record levels and the monthly vapour pressure, monthly minimum temperature and monthly radiation have equalled past records and a derived water balance deficit can be calculated from these records. This water balance deficit was further impacted by the fact that the highest tides reached record low high tide levels due to sea level drop (Duke et al 2017).

Some areas where dieback has occurred may reflect slightly higher ground elevation at the transition to supratidal flats, whereas other higher elevations may reflect recent sedimentation which was obvious in field work undertaken across the areas of dieback. It is currently unknown when precisely this sedimentation occurred but it is likely to have occurred during or just after the dieback event. It is also likely to be slowing down the recovery within these elevated areas. This is not a great surprise given that for example, the majority of the mangrove dieback area south of Pormpuraaw was open ocean in 1969 with large areas not being colonised by mangroves until after 1998. This reflects the rapid dynamics of mangrove communities and their associated sediments within the Gulf of Carpentaria.

The sedimentation event across the Queensland Gulf of Carpentaria both in Pormpuraaw and Karumba most likely occurred following three consecutive low pressure climate events between December 2015 and March 2016.

Wave plots from the buoy in Weipa illustrate large low pressure events centred on 26th December 2015, 2nd February 2016 and 19th March 2016 (Figures 38 and 39). These events correlate with large storm surge events both in Karumba and Pormpuraaw centred on 26th December 2015 and 19th March 2019 and smaller storm surge in 2nd February 2016 (Figures 40 and 41). Large Gulf floods, for example in 2009 and 2019, resulted in the transfer of large amounts of sediment into the intertidal zone and surrounding sea bed.

Large waves, some over four metres in height, in the shallow seas of the Gulf of Carpentaria can lead to large sedimentation events on the adjacent intertidal areas. While it is not clear if this sedimentation has caused the dieback it is known that elevated sediments levels result in the hindrance of mangrove recovery.

The prolonged water balance stress derived from the collective climatic factors presented above combined with sea level drops and the siltation events that have occurred are the most likely causes of the mangrove dieback within the Gulf of Carpentaria.

Field site measurements post the dieback event, coupled with accurate mangrove dieback mapping in 2017 provides a baseline for monitoring the trajectory of mangrove dieback and or recovery in the Gulf of Carpentaria (Queensland).

Field sites will need to be revisited every three years and mapping should be undertaken every five years unless earlier global detection systems, such as the Queensland State Land and Tree Study (SLATS) woody cover change program or the Terrestrial Ecosystem Research Network (TERN) national mangrove observing system record a new large scale mangrove dieback event (Lymburner et al 2019).

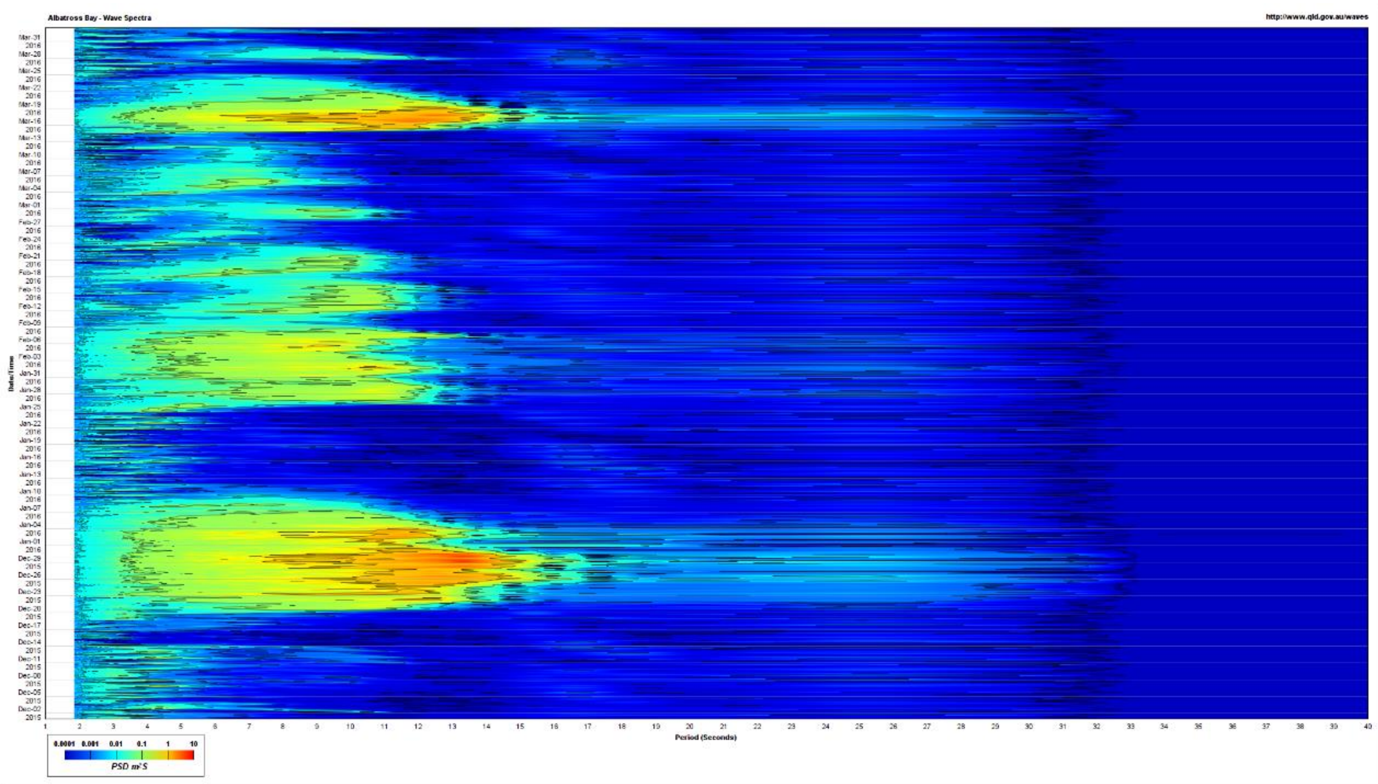

Figure 38 **Wave intensity plots from the wave buoy in Weipa blue (low) to red high**

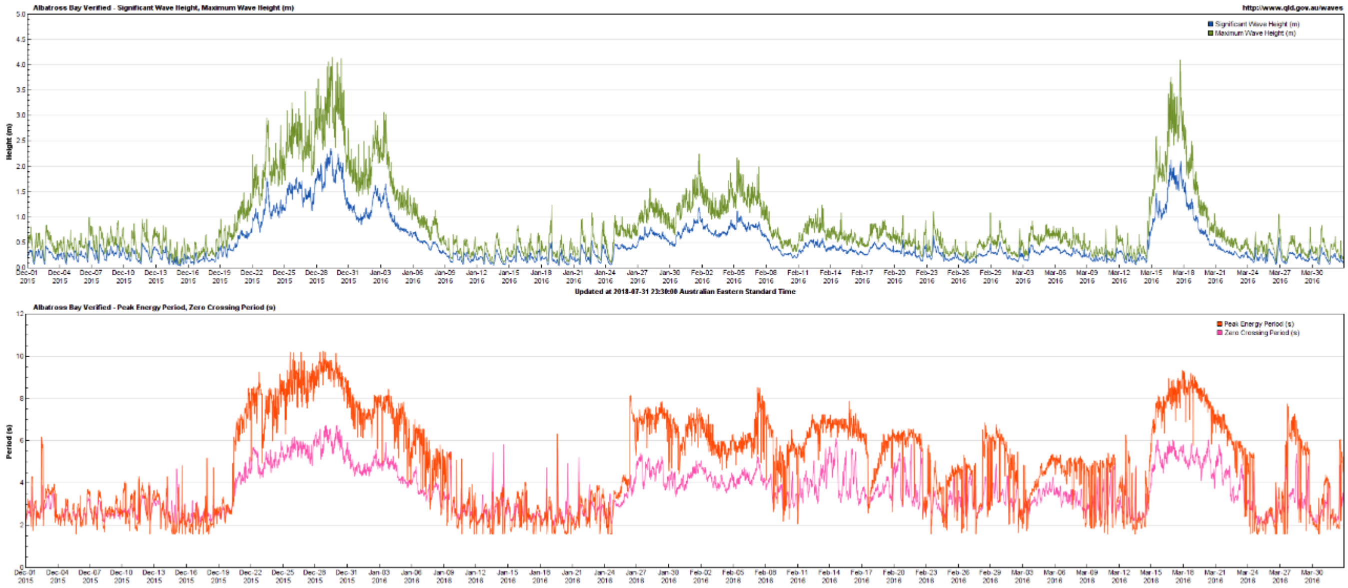

Figure 39 **Albatross Bay verified significant wave heights and peak energy period. Top. Blue: significant Wave Height (m); Green: Maximum Wave Height (m); Bottom. Orange: Zero Crossing Period (s); Pink: Peak Energy Period (s).**

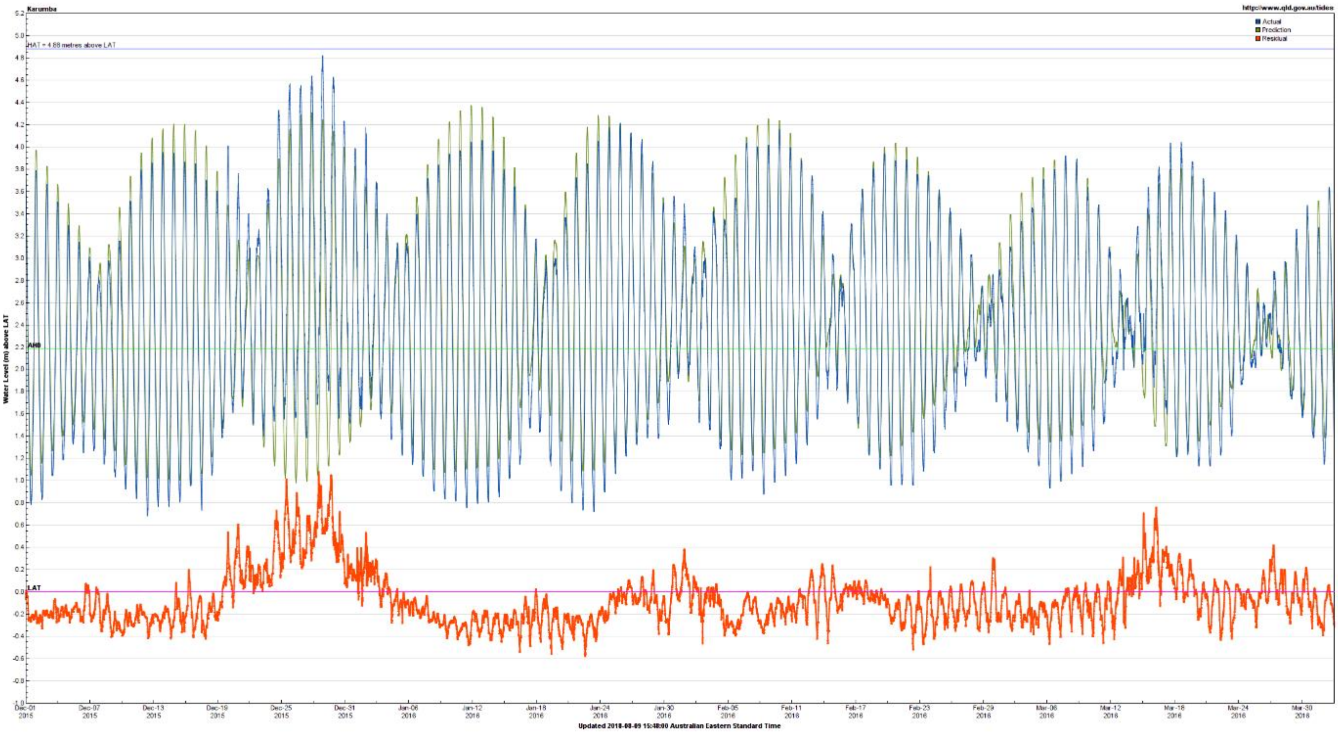

Figure 40 **Karumba storm surge (m). Blue: Actual; Green Predicted; Orange Residual**

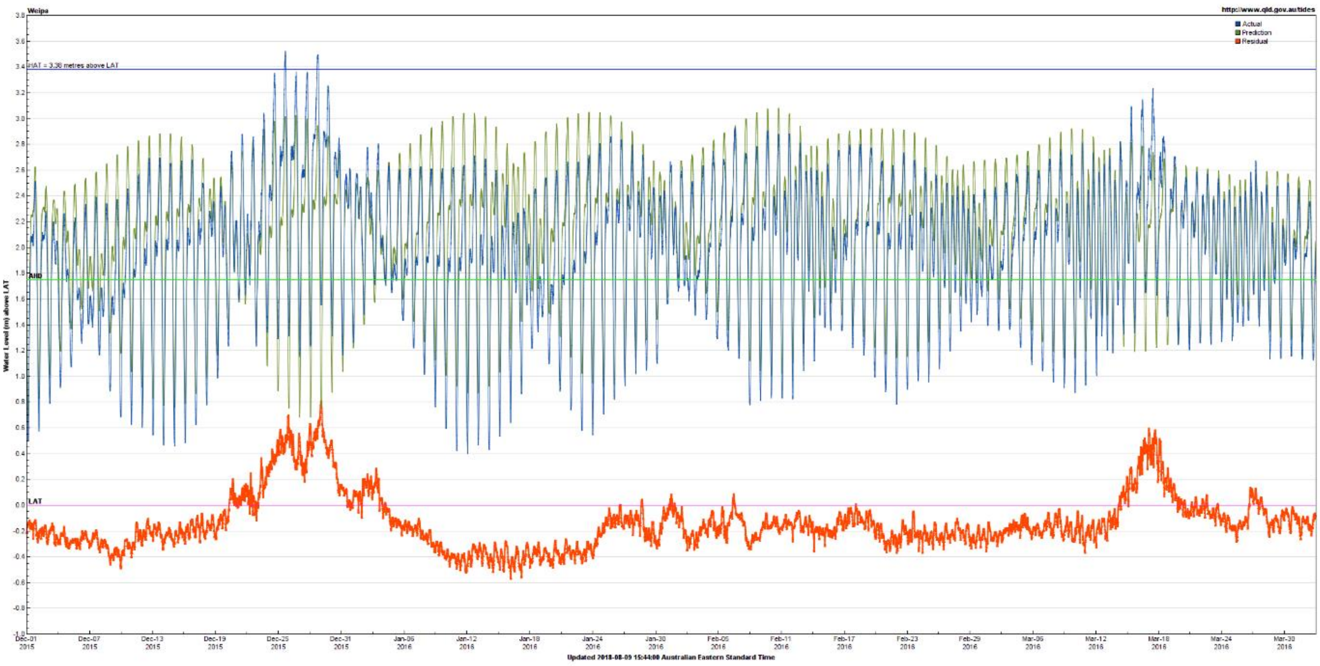

Figure 41 **Pormpuraaw storm surge (m). Blue: Actual; Green Predicted; Orange Residual**

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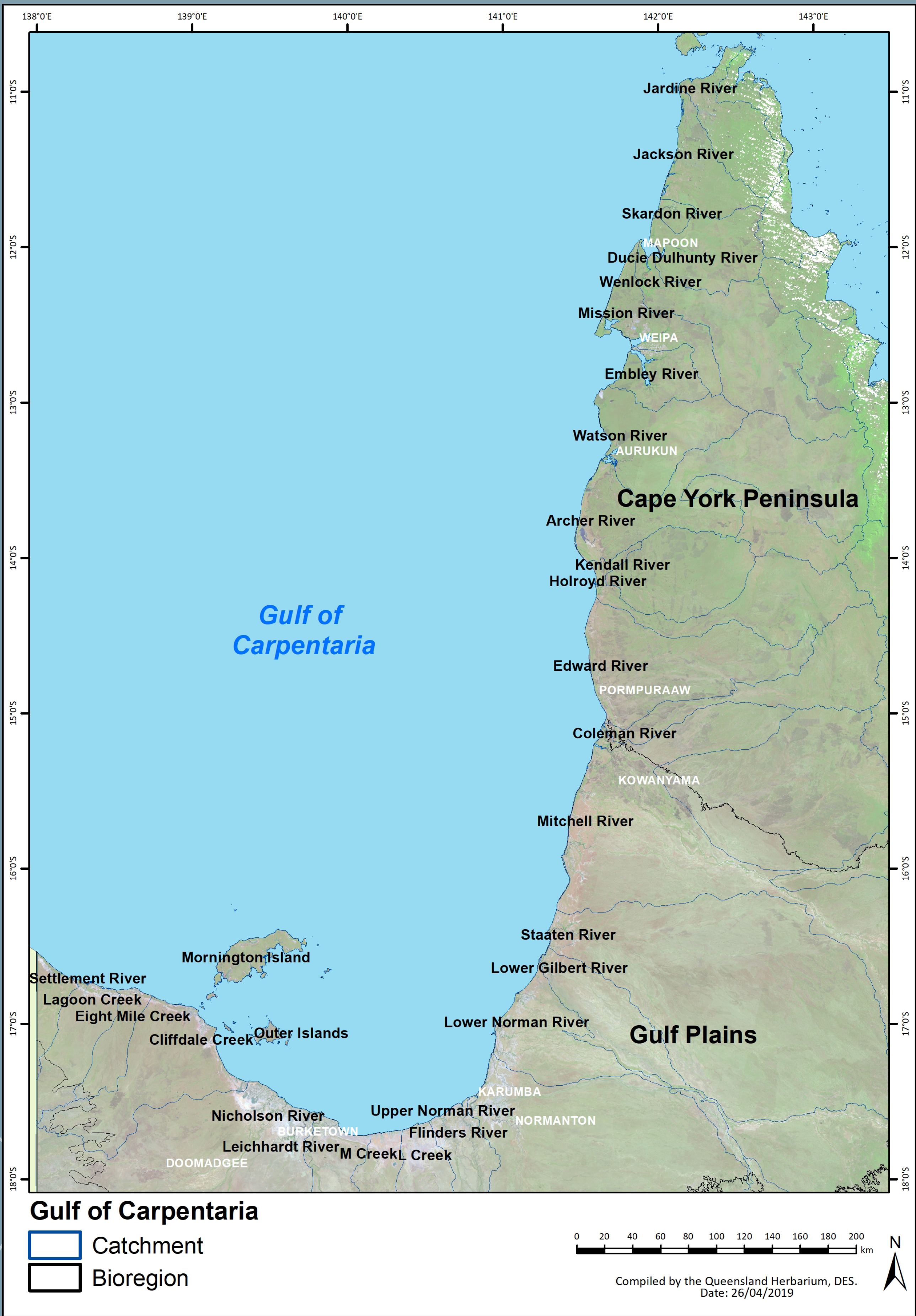
Queensland Herbarium
Brisbane Botanic Gardens
Mt Coot-tha Road
Toowong Qld 4066

+61 7 3199 7699
1300 QGOV (13 74 68)
queensland.herbarium@qld.gov.au
www.qld.gov.au/herbarium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Wenlock River
Mission River
WEIPA
Embley River
Watson River
AURUKUN
Cape York Peninsula
Archer River
Kendall River
Holroyd River
Gulf of Carpentaria
Edward River
PORMPURAAW
Coleman River
KOWANYAMA
Mitchell River
Staaten River
Mornington Island
Lower Gilbert River
Settlement River
Lagoon Creek
Eight Mile Creek
Cliffdale Creek
Outer Islands
Lower Norman River
Gulf Plains
KARUMBA
Nicholson River
Upper Norman River
NORMANTON
BURKETOWN
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