Gippsland Lakes Fringing Wetland Vegetation Mapping

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Citation: Brooks, S. and Hale, J. (2021) Gippsland Lakes Fringing Wetland Vegetation Mapping. A report to East Gippsland CMA.

Front cover photo: Wetland vegetation, Dowd Morass, Sean Phillipson.

Contents

1 Introduction

1.1 Context

The Gippsland Lakes are a series of coastal lagoons and fringing wetlands located approximately 300 kilometres east of Melbourne, extending from Sale Common east to Lake Tyers covering an area of approximately 60 000 hectares (Figure 1). The Lakes are of high conservation value, being listed as a wetland of international importance under the Ramsar Convention. The Lakes support a wide range of inundation dependent vegetation communities including:

- Seagrass – three species of seagrass occur in Lakes Victoria and King: *Zostera nigricaulis* in deeper areas, and *Zostera mulleri* in shallower, often intertidal, areas where the seagrass may be exposed at low tide, and *Ruppia spiralis*.
- Coastal saltmarsh – EPBC listed vulnerable community that occurs across many of the fringing wetlands as well as across the hypersaline Lake Reeve. Coastal saltmarsh includes a wide variety of plants differing greatly in their taxonomic, structure and life histories. In general, though, they occur in consistently saline environments and are generally dominated by low succulent chenopods (e.g. *Sarcocornia* spp.).
- Freshwater wetland vegetation – in Sale Common and MacLeod Morass. Includes a variety of emergent reeds, and sedges such as common reed (*Phragmites australis*), *Baumea* spp., *Bolboschoenus* spp., *Carex* spp., *Cyperus* spp., *Juncus* spp., *Schoenoplectus* spp.
- Variably saline wetland vegetation – which includes woody communities such as swamp paperbarks (*Melaleuca ericifolia*) as well as a variety of emergent salt tolerant rushes and sedges.

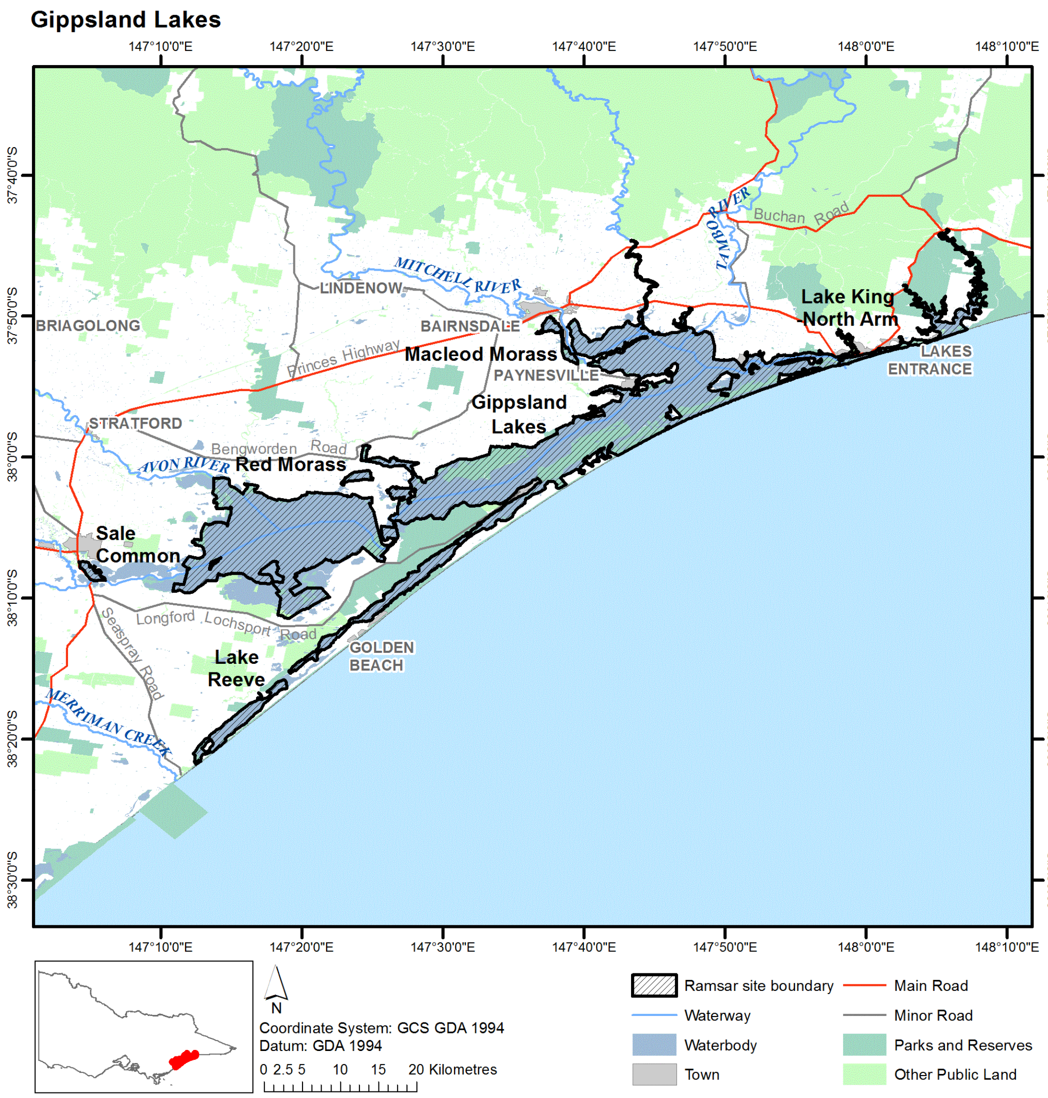

Figure 1. Gippsland Lakes Ramsar Site location.

1.2 Objectives

There have been several recent projects that have mapped inundation dependent vegetation in and around the Gippsland Lakes from remote sensed satellite data. This includes mapping of seagrass and saltmarsh within the Gippsland Lakes Ramsar Site boundary (Brooks and Hale 2021) and the freshwater vegetation in Sale Common and MacLeod Morass (Brooks and Hale 2020b). This project seeks to build upon this to provide a consolidated map of inundation dependent vegetation in the Gippsland Lakes. Specifically, the objectives of this project are to:

- Map the extent of inundation dependent vegetation and open water habitats across the Gippsland Lakes (within the Ramsar Site boundary and adjacent areas).
- Evaluate the status of ecological character, by comparisons with Limits of Acceptable Change (LAC) and Resource Condition Targets (RCTs).
- Compare current saltmarsh mapping with that conducted in 2011 (Boon et al. 2011) to determine if there has been a change in distribution.
- Compile all data and mapping of fringing wetland vegetation communities from this project and previous projects into a single data set.

1.3 Study area

There are numerous wetland areas that fringe the main waterbodies of the Gippsland Lakes, particularly Lake Wellington, although much of the area surrounding the lakes is either outside the Ramsar site boundary or only partially included. For example, Heart Morass, Dowd Morass, Clydebank Morass, Lake Coleman and Lake Morley are all dissected by the Ramsar site boundary with portions of the each within the Ramsar site and other portions outside it (Figure 2). There are some smaller (unnamed) wetlands between Clydebank Morass and Heart Morass on the western shore of Lake Wellington and between Lake Coleman and Lake Reeve, that are on private land and fully outside the Ramsar site. In addition, only small portion of the wetlands that fringe the lower reaches of the inflowing rivers that are within the Ramsar Site Boundary.

The study area for this mapping exercise includes all the wetlands that fringe the Gippsland Lakes (including those wholly or partially outside the Ramsar site boundary) from Sale Common to Lake Tyers.

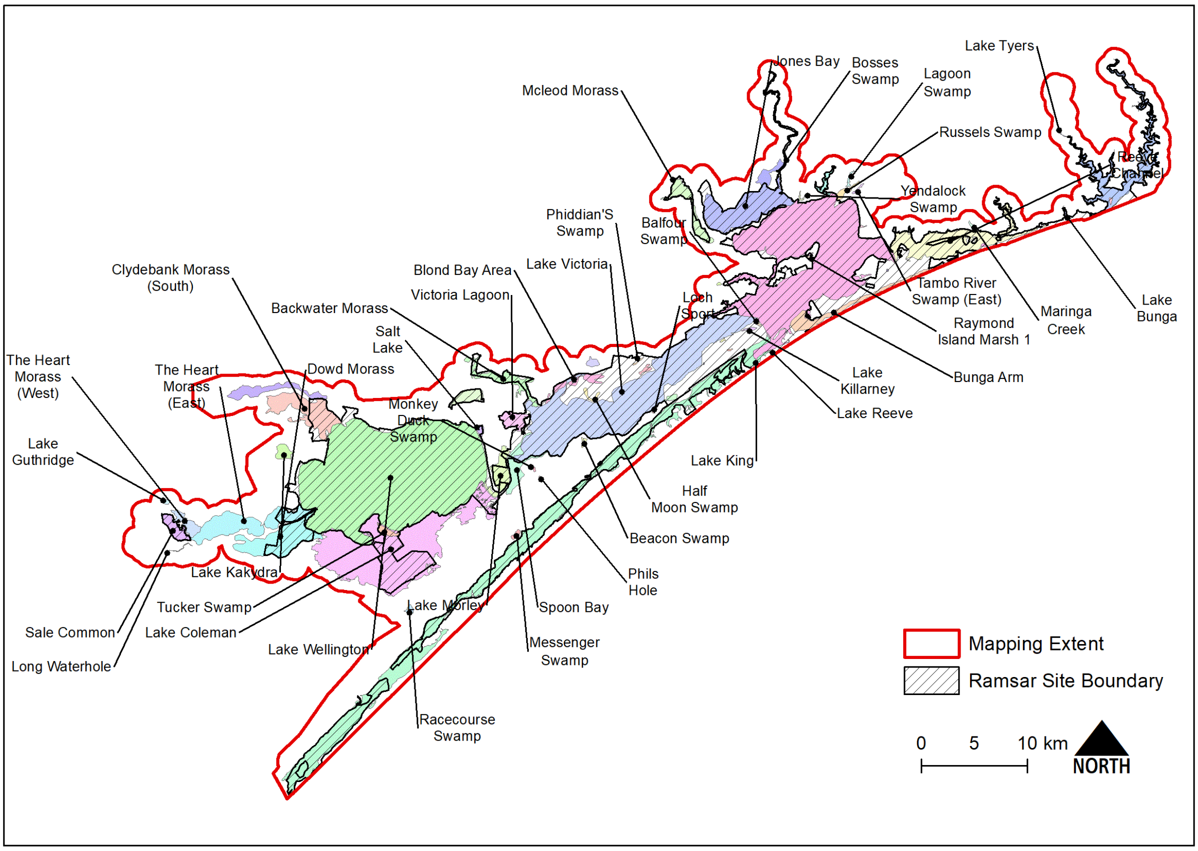

Figure 2: Mapping extent for this study showing the named wetlands and Ramsar boundary.

2 Approach – Sentinel-2 imagery

Remote sensing offers a cost-effective approach for mapping inundation dependent vegetation types over the entire site. Classification of Sentinel-2 satellite imagery has been used successfully to map freshwater wetland vegetation in MacLeod Morass and Sale Common (Brooks and Hale 2020b), seagrass and saltmarsh in the Gippsland lakes (Hale and Brooks 2019; Brooks and Hale 2021) and seagrass and saltmarsh in Corner Inlet (Brooks and Hale 2020a). Similar methods are used to map wetland vegetation and seagrass elsewhere (e.g. Kaplan and Avdan 2017; Traganos and Reinartz 2018; Bhatnagar et al. 2020).

In developing the Gippsland Lakes Seagrass Monitoring Framework (Hale and Brooks 2019), imagery from the Sentinel-2 satellite was compared to lower resolution Landsat imagery and higher resolution (and expensive / less available) Worldview imagery. It was concluded that Sentinel-2 was appropriate for image analysis and mapping to assess Gippsland Lakes Ramsar site LAC because it provides higher resolution than Landsat (10m vs 30m), has consistent coverage of the entire Ramsar site, is free of charge, is frequently available and will be accessible into the foreseeable future.

3 Method

The technical details of the method are provided in Appendix A. In summary, the mapping was derived from image classification of a single Sentinel-2 satellite image from 31 July 2020. This was the most recent cloud-free winter image. Winter was selected as the dominant species of reed beds in the Gippsland Lakes, common reed (*Phragmites australis*) and cumbungi (*Typha* spp.) seasonally senesce, turning brown in winter. This characteristic made them more easily discriminated from other vegetation communities that remain green throughout the winter months. Four steps were followed:

1. Sourcing and pre-processing of satellite imagery

Satellite imagery was inspected on National map and two cloud free Sentinel-2A multi-spectrum images from 31 July 2020 were downloaded from the Sentinel Australasia Regional Access (SARA) portal https://copernicus.nci.org.au and stitched together to cover the full extent of the site. The images were pre-processed using the Sentinel Application Platform (SNAP) to mask region of interest, improve resolution of non-visible wavelengths and add additional NDVI bands (normalized difference vegetation index) to enhance identification of green vegetation (e.g., swamp scrub) from the browned-off reed beds. See Appendix A for more detail.

2. Clustering and classification

A supervised maximum likelihood classification model was trained to identify nine land cover types in the imagery:

- Saltmarsh (saline communities mostly dominated by halophytic succulents such as glassworts)
- Reed beds (emergent macrophytes dominated mostly by common reed and / or cumbungi)
- Shallow marsh (emergent or floating macrophytes dominated by other species such as giant rush; *Juncus ingens*; spike-sedge; *Eleocharis* spp.; Azolla)
- Swamp scrub (paperbark dominated by *Melaleuca* spp.)
- Coastal scrub/heathlands
- Agricultural land
- Forest
- Bare ground (includes roads and rooftops)
- Open water

3. Review and clean-up

The resulting mapped outputs were reviewed, and smaller fragments (< 5 pixels) were removed to simplify the mapping (noise reduction). The shallow marsh/wet ground class was distributed across both freshwater wetlands and saltmarsh. Areas that intersected existing saltmarsh mapping (Boon et al. 2011) were reclassified as saltmarsh. Areas of saline aquatic meadow (shallow open water saltmarsh habitat; Figure 3, Figure 4) were excluded from the classification by the land-water masking process (refer Appendix A) but were added by intersecting the water mask with existing mapping of saline aquatic meadows from Boon et al. (2011).

4. Habitat areas and Ramsar limits of acceptable change

The area of each wetland habitat class was calculated for each of the named wetlands in the Victorian wetlands Inventory (DELWP 2018a) and for the portions of the Gippsland Lakes Ramsar site that have defined Limits of Acceptable Change.

Figure 3: Dry saltpan at Red Morass that is mapped as Saline Aquatic Meadow by Boon et al. (2011).

Figure 4: Saline Aquatic Meadow at Lake Reeve 2021 (D, Cook).

4 Results

4.1 Wetland vegetation extent

Over 20,000 hectares of wetland vegetation was mapped across the Gippsland Lakes study area, including over 12,000 hectares of saltmarsh, 3000 hectares of marsh and 5500 hectares of swamp scrub (Table 1; Figure 5 and Appendix B).

While the Victorian wetlands layer was a good indicator of open water (> 97% of the mapped open water was within a defined mapped wetland), it was less predictive of mapped wetland vegetation with only 73 % of saltmarsh and 61% of swamp scrub occurring within a mapped wetland unit.

Around 40% of all the mapped wetland vegetation was within the Gippsland Lakes Ramsar Site.

Table 1: Area of land cover classes (wetland habitat types shaded blue)

Category	Area mapped (ha) within study area	Area mapped(ha) within Victorian wetlands layer	Area mapped (ha) within the Ramsar Boundary
Saltmarsh	12,058	8,875	4,567
Reed bed	1,814	1,505	816
Shallow marsh	1,492	1,070	574
Swamp scrub	5,540	3,416	2,354
Open water	46,863	45,630	42,149
Agriculture	42,085	2,453	1,307
Coastal scrub	19,344	1,562	4,999
Bare/urban	6,765	3,072	3,237
Forest	9,708	516	1,103

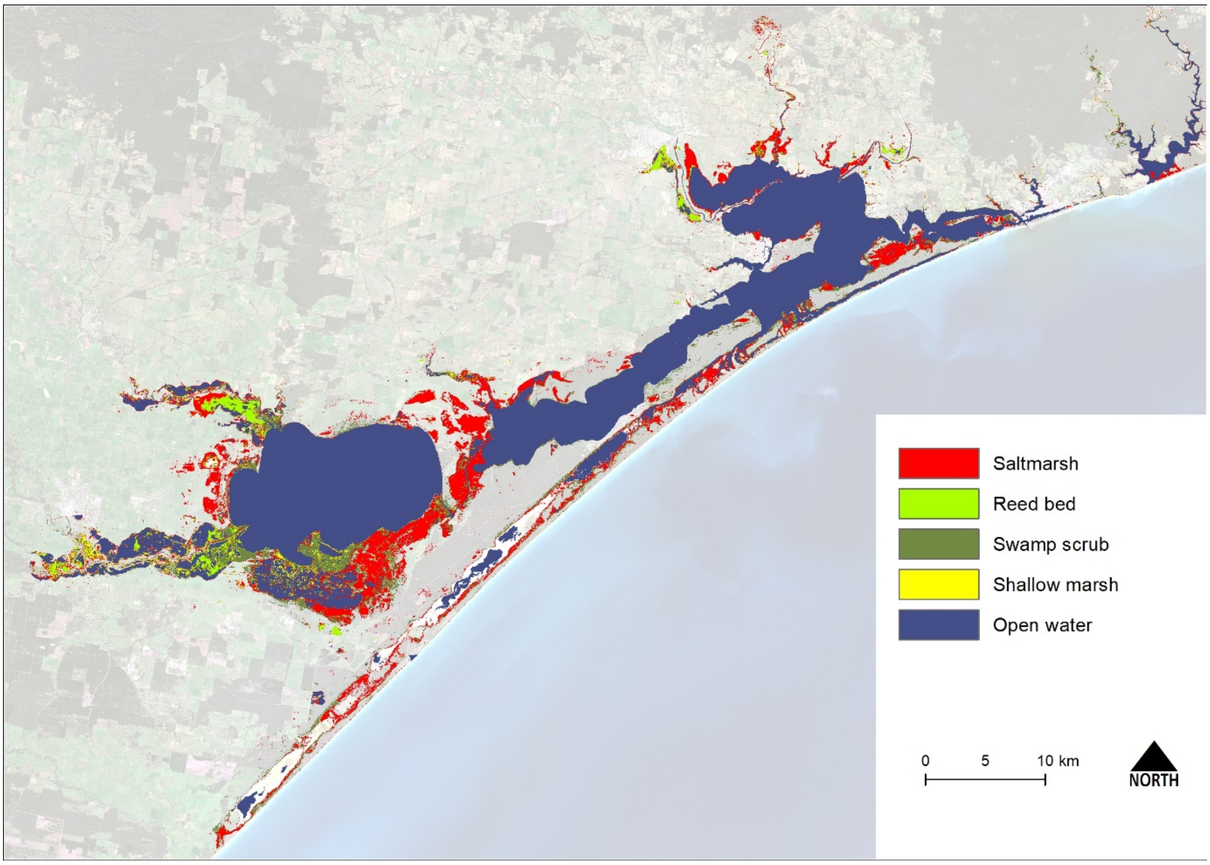

Figure 5: Distribution of wetland vegetation classes in the Gippsland Lakes study area classified from Sentinel-2 image 31/07/2020.

There are 56 named wetlands in the Victorian Wetlands Inventory that are within the study area. Areas of mapped classes within these wetlands are provided in Table 2. The winter period selected resulted in large areas of open water, that at other rime so of the year may have been dry (e.g., Lake Reeve). The majority of the fringing wetlands are dominated by saltmarsh and / or swamp scrub, reflecting the variably saline conditions. The wetlands with significant areas of tall and shallow marsh included the morass of Dowd Morass, Heart Morass, Macleod Morass and the southern section of Clydebank Morass.

Table 2: Area of wetland habitat classes classified from Sentinel imagery from 31 July 2020. Non-wetland classes grouped as "Other" include forest, agricultural land, bare ground and coastal scrub.

	Saltmarsh	Tall marsh	shallow marsh	Open water	Swamp scrub	Other	Total Area (ha)
Unnamed wetlands	2312.1	213.3	147.7	799.5	574.7	1850.4	**5897.6**
Backwater Morass	219.6	1.5	50.1	100.3	51.4	139.0	**561.8**
Balfour Swamp	6.6	0.1	0.0	0.3	3.6	2.8	**13.3**
Beacon Swamp	9.8	0	0.1	8.0	0.7	2.9	**21.5**
Big Plain Morass	1.7	0	0	0	0	70.9	**72.6**
Big Tussocky Swamp	0	0	0	0	2.4	3.5	**5.9**
Blond Bay Area	173.9	0.1	1.0	13.3	20.0	61.7	**269.8**
Blue Horizons Estate-Main Swamp	2.0	0	2.0	1.3	1.2	4.5	**11.0**
Bosses Swamp	167.0	28.1	11.1	1.9	16.2	25.7	**249.9**
Bunga Arm	38.2	0.2	9.8	519.1	50.0	33.0	**650.2**
Clydebank Morass (North)	73.4	25.0	6.7	246.9	21.3	165.2	**538.5**
Clydebank Morass (South)	304.3	504.6	11.8	284.2	124.4	101.4	**1330.8**
Cygnet Swamp	0.8	0	0	0.6	0.0	0.1	**1.5**
Dolomite Swamp	36.1	0.3	0	0	1.8	9.4	**47.5**
Dowd Morass	59.8	242.6	131.7	561.4	396.0	89.7	**1481.3**
Half Moon Swamp	42.6	0.7	0.2	1.8	6.3	9.0	**60.6**
Hickey Swamp	1.9	0	0.2	2.3	2.7	1.2	**8.3**
Jones Bay	15.7	1.2	1.0	1858.8	2.3	6.4	**1885.4**
Lagoon Swamp	3.1	4.5	0.6	2.7	0.1	16.5	**27.4**
Lake Bunga	0.6	0	1.8	11.3	0.1	2.6	**16.4**
Lake Coleman	2225.7	77.6	342.2	2045.2	1419.8	329.8	**6440.3**
Lake Guthridge	1.8	0	0.4	22.1	0	1.8	**26.1**
Lake Kakydra	76.3	13.5	14.5	3.8	5.9	57.6	**171.6**
Lake Killarney	20.3	0.1	0.2	0.2	3.3	1.3	**25.3**
Lake King	70.2	1.4	14.3	10115.3	80.6	251.0	**10532.8**
Lake Morley	391.5	0.7	13.8	18.2	76.6	27.9	**528.9**
Lake Reeve	1251.2	3.6	25.2	1998.7	228.9	3365.1	**6872.6**
Lake Tyers	44.5	0.2	21.1	1091.4	5.8	79.7	**1242.8**
Lake Tyers Swampland	10.8	0	0	2.4	0	0.0	**13.2**
Lake Victoria	14.9	0.1	5.4	7835.5	4.3	35.0	**7895.2**
Lake Wellington	17.1	12.0	13.9	14824.9	25.8	29.4	**14923.2**
Loch Sport	3.5	0	0	0.0	0.0	0.4	**3.9**
Long Waterhole	2.0	0	1.0	4.6	0.1	1.4	**9.1**

	Saltmarsh	Tall marsh	shallow marsh	Open water	Swamp scrub	Other	Total Area (ha)
Maringa Creek	8.0	0	0.9	4.6	5.8	2.2	**21.5**
MacLeod Morass	49.7	207.9	33.8	124.9	13.2	79.4	**508.8**
Messenger Swamp	13.1	0.1	0	0	0	21.8	**35.0**
Monkey Duck Swamp	1.7	0	0	0	0.6	8.3	**10.5**
Newlands Backwater	0.4	0	1.1	1.9	0.6	4.5	**8.6**
Phiddian'S Swamp	0.1	0	0	0	0	11.1	**11.1**
Phils Hole	0	0	0	0	0	2.4	**2.4**
Racecourse Swamp	0	0	0	0	0	42.2	**42.2**
Raymond Island Marsh 1	1.4	0	0.6	3.5	1.1	0.7	**7.4**
Raymond Island Marsh 2	3.4	0	0.3	0.0	0.2	0.5	**4.5**
Red Morass	164.7	4.2	0.2	0	2.6	96.9	**268.6**
Reeve Channel	67.9	2.3	7.3	1693.6	64.0	190.8	**2025.9**
Russels Swamp	56.5	2.0	3.2	12.9	0.3	17.2	**92.1**
Sale Common	42.5	35.0	82.3	31.0	9.4	75.6	**275.8**
Salt Creek Marsh	69.0	0	3.6	14.1	1.1	15.7	**103.6**
Salt Lake	50.7	0.8	0	0.1	0.3	16.8	**68.6**
Spoon Bay	288.0	0	4.4	11.8	58.7	119.6	**482.6**
Tambo River Swamp (East)	14.5	0	0.1	2.6	0.6	3.8	**21.4**
The Heart Morass (East)	93.7	116.3	94.0	1085.2	118.7	52.3	**1560.2**
The Heart Morass (West)	26.8	4.3	6.2	160.7	2.4	50.5	**251.0**
Tucker Swamp	1.3	0.0	1.1	101.5	2.6	0.0	**106.5**
Victoria Lagoon	286.8	0.1	0.1	1.0	1.6	5.3	**294.8**
Waddy Point Swamp	31.3	0.7	0.1	0.3	5.1	5.6	**43.0**
Yendalock Swamp	4.3	0	3.1	4.6	0.8	3.6	**16.4**
Grand Total	**8874.6**	**1504.8**	**1070.4**	**45630.1**	**3416.0**	**7602.9**	**68098.8**

5 Other considerations

5.1 Differences in mapping at different scales.

The mapping for this project was conducted at a very broad scale across the entire Gippsland Lakes region. The outputs of this broad mapping can be compared with previous recent mapping that was conducted using similar image classification techniques, but from smaller scales.

Brooks and Hale (2020b) used a Sentinel image from 18/06/2020 (approximately 6 weeks earlier than the current study) to map Sale Common and Macleod Morass using the same technique but with a more focussed scope that did not include terrestrial land outside the Ramsar boundaries. The results indicate that while similar areas of emergent macrophytes (reed bed and shallow marsh) were mapped on each occasion, the mapping completed for this project was less able to detect swamp scrub than the local mapping exercise (**Error! Reference source not found.** and **Error! Reference source not found.**). While the reasons for this are not known, it may be due to differences in the spectral signature of paperbark across the entire site resulting in a weaker classification of this vegetation community. Regardless, it is highly unlikely that there has been a dramatic decline in the extent of paperbark at either site.

This strengthens the argument for dividing the study area into regions for training of the classification to allow for better discrimination between vegetation classes at the smaller wetland scale.

Table 3: Macleod Morass. Areas of wetland classes comparing results of supervised classification of Sentinel-2 18/06/2020 image (Brooks and Hale 2020b) and this study 31/07/2020. Emergent macrophytes shaded green.

Vegetation categories	LAC categories	Brooks and Hale (2020b) 18/06/2020	This study 31/07/2020
Open water	Open water	98	122
Shallow marsh (giant rush)	Native emergent vegetation	84	30
Reed bed (Typha and common reed)	Native emergent vegetation	179	211
Swamp scrub / woodland (paperbark)	Woody vegetation	62	13
Other (bare ground)	Open water when inundated?	73	77
Sum of emergent macrophytes		**263**	**241**

Table 4: Sale Common. Areas of wetland classes comparing results of supervised classification of Sentinel-2 images in 20/10/2016 (wet phase) and 17/05/2020 (dry phase) (Brooks and Hale 2020b) and this study 31/07/2020 which is intermediate between dry and fully wet. Emergent macrophytes shaded green.

Vegetation class	LAC category	Brooks and Hale (2020b)		This study
		0/10/2016 (Wet Phase)	17/05/2020 (Dry Phase)	31/07/2020
Open water / tall marsh fragments	Open water	158	27	32
Shallow marsh, herbland	Native emergent vegetation	31	56	84
Reed bed	Native emergent vegetation	18	89	36
Swamp scrub / woodland	Woody vegetation	90	89	10
Other		10	49	102
Sum of emergent macrophytes		**49**	**145**	**122**

5.2 Changes in saltmarsh extent and distribution

The dual pressures of decreased freshwater inflows and increasing sea levels are resulting in increased salinity in Lake Wellington and potentially the fringing wetlands. There are predictions that this will result in shifts in vegetation communities with a die back of paperbark (Melaleuca ericofolia) and common reed (Phragmites australis) and their replacement with saltmarsh communities dominated by sea rush (Juncus kraussii) and beaded glasswort (Sarcocornia quinqueflora).

A comparison of the mapping undertaken as part of this study with that completed by Boon et al. (2011) has been completed with the aim of detecting shifts in saltmarsh distribution saltmarsh distribution to determine if there is any quantitative evidence of this change occurring. The results of this comparison need to be tempered by several factors including the difference in mapping technique and the lack of field validation of the current mapping. In addition, the spatial extent of the mapping by Boon et al. (2011) is not known, and it may be that mapping undertaken in this project is detecting saltmarsh in areas that they did not include in their mapping.

The current mapping comprises a total of 12,058 hectares of saltmarsh, compared with 10,136 hectares mapped in 2011 by Boon et al. 2011.

This 20% increase in total extent, however, masks significant variability in saltmarsh distribution between the two mapping events. While there is an overlap between the 2011 and 2020 mapping of around 7500 hectares, there are areas that have been detected as saltmarsh in 2020 that were not mapped as saltmarsh in 2011 and vice versa. There are several reasons for this including:

- Differences in the two methods with the mapping from detailed aerial photographs and field validation in 2011 resulting in differences in the delineation of the edges of saltmarsh that the current 10 metre pixel. This accounted for much of the difference between the two mapping extents.
- Highwater levels in July 2020, where some of the saltmarsh mapped by Boon et al. (2011) was underwater in 2020. This was evident in places like Lake Reeve, where a portion of the low-lying saltmarsh was underwater and not able to be detected from the image classification.

Nonetheless, the comparison has identified areas where there is evidence of potential saltmarsh expansion. This is particularly evident along the western shore of Lake Wellington (Figure 6) and east of Lake Coleman (Figure 7).

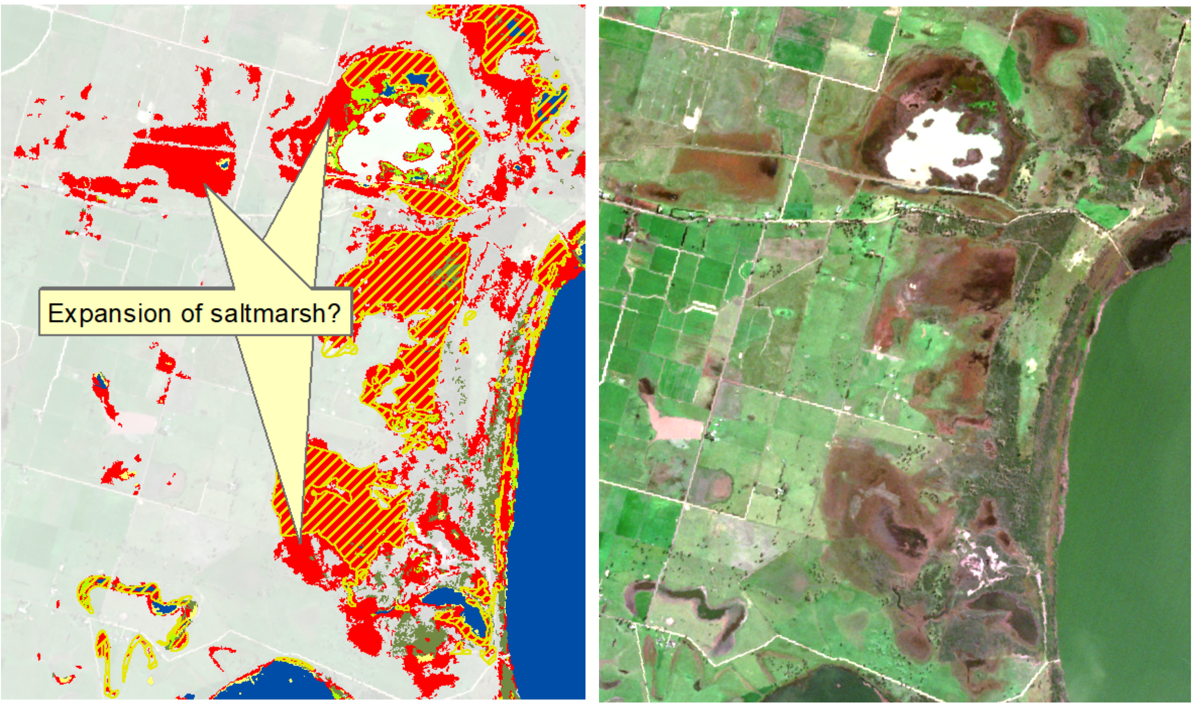

Figure 6. Western shore of Lake Wellington showing areas of potential saltmarsh expansion over the last decade beyond the limits mapped by Boon et al. (2011) (yellow hashed area; saltmarsh from this study in red).

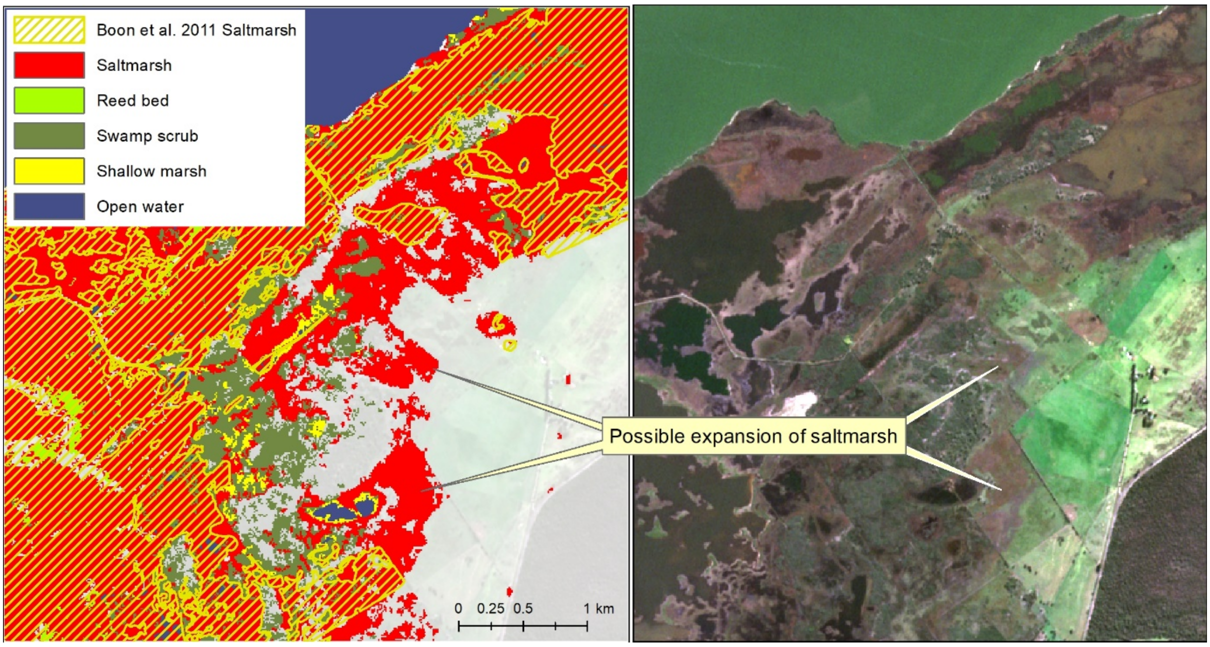

Figure 7. Eastern shore of Lake Coleman showing areas of potential saltmarsh expansion over the last decade beyond the limits mapped by Boon et al. (2011).

Future assessments of the expansion (or changes in the distribution) of saltmarsh would be aided by several things:

- Mapping of saltmarsh at periods of low water levels (most likely during late summer or autumn). This would minimise the amount of saltmarsh that is below the water level and not detected by image classification.
- Field validation of a portion of sites.
- Splitting the study area into a series of regions for training of the classification. This would account not only for differences in vegetation communities (e.g., the unique saltmarsh communities and Lake Reeve) but also account for the differences in the saturation and intensity of the satellite image from east to west over such a large area.
- Comparing mapped outcomes from comparable mapping methods.

6 Evaluating thresholds and targets

6.1 Evaluating the Ramsar LAC

There have been several projects completed on mapping of vegetation communities in the Gippsland Lakes Ramsar Site at different scales and at different times of the year (Brooks and Hale 2020b, 2021; and this report). This information has been consolidated here with respect to assessing against LAC, using the most accurate mapping to inform the assessment. In most instances, this is mapping that was conducted at the smaller scale, where training areas are more specific to the wetland / vegetation community, resulting in a more certain image classification.

Table 5: Assessment against LAC for mapped habitats.

CPS	LAC	Assessment
Seagrass	Total seagrass extent will not decline by greater than 50 percent of the baseline value of Robb and Ball 1997 (that is, by more than 2165 hectares) in two successive decades at a whole of site scale.	Total seagrass extent ranged from 2235 hectares in 2021 to 2854 hectares in 2019 (Brooks and Hale 2021). **LAC is met.**
	Total mapped extent of dense and moderate Zostera will not decline by greater than 80 percent of the baseline values determined by Robb and Ball (1997) in two successive decades at any of the following locations: • Fraser Island • Point Fullerton, Lake King o Point King, Raymond Island, Lake King • Gorcrow Point – Steel Bay, Lake Victoria • o Waddy Island, Lake Victoria	The areas stated in the Lac are not spatially defined and so an assessment against this portion of the Lac was not possible. **Unable to assess LAC.**
Saltmarsh	The total mapped area of salt flat, saltpan and salt meadow habitat at Lake Reeve Reserve will not decline by greater than 50 percent of the baseline value outlined in VMCS for 1980 (that is, 50 percent of 5035 hectares = 2517 hectares) in two successive decades.	In 2021 saltmarsh in Lake Reeve was 1176 hectares plus a further 3828 hectares salt flats / saltpan, which is a total of 5004 hectares (Brooks and Hale 2021). **LAC is met.**
Freshwater wetlands	The total mapped area of freshwater marshes (shrubs and reed wetland types) at Sale Common and Macleod Morass will not decline by greater than 50 percent of the baseline value for 1980 (that is, 50 percent of 402 hectares = 201 hectares) in two successive decades.	Freshwater marsh vegetation in MacLeod Morass and Sale Common was mapped in 2020. Total extent of reed and scrub wetland types across the two wetlands was 343 hectares. **LAC is met.**
Variably saline wetlands	The total area of common reed at Dowd Morass will not decline by greater than 50 percent of the 1982 baseline value (that is not less than 245 hectares) in two successive decades.	The mapping for Dowd Morass indicates 242 tall marsh and 131 shallow marsh, which is a total of 374 hectares of emergent macrophytes. What proportion of this is common reed, however, is not known **Unable to assess LAC.**

6.2 Evaluating the Resource Condition Targets

RCTs are established in the management plan for the site and are used to assess the effectiveness of management in maintaining or improving ecological character.

Table 6: Assessment against RCT.

Critical CPS	RCT	Assessment
Seagrass	The current extent and condition of seagrass in the Gippsland Lakes Ramsar Site will be maintained as indicated by the following: • Maintain extent of seagrass – 4000 to 5000 hectares. • Maintain medium-dense seagrass cover in 25 % of beds (measured as a long-term average over the 20 year timeframe).	While there was between 2235 hectares and 2854 hectares of seagrass present between 2017 and 2021, this falls short of the 4000 to 5000 hectares aspirational target. Current mapping (2017 to 2021) indicates 32 to 38% of the seagrass occurred as dense patches suggesting the RCT for density is being achieved.
Saltmarsh	Maintain the extent, diversity and condition of saltmarsh communities.	Over half the sites assessed in 2019 and 2020 had saltmarsh in good condition Brooks and Hale 2021). Without a benchmark to compare the RCT is unable to be assessed.
Freshwater wetlands	Maintain the extent, diversity and condition of freshwater vegetation communities	These RCTs are difficult to assess against as the benchmarks for maintaining or improving extent are not stated. In addition, current mapping data provides little information on diversity and condition. The mapping presented here, however, could be used to inform development of measurable RCTs for extent of wetland vegetation as part of the review of the Ramsar Site Management Plan.
Variably saline wetlands	Maintain extent, diversity and condition of native vegetation communities: swamp paperbark (*Melaleuca ericifolia*) woodland and common reed (*Phragmites australis*) emergent macrophyte beds.	
	Increase the extent and diversity; and improve the condition of native vegetation communities in and around the Heart Morass and other fringing wetlands on private land. Maintain extent of variably saline fringing wetlands.	

7 References

Bhatnagar, S., Gill, L., Regan, S., Naughton, O., Johnston, P., Waldren, S., and Ghosh, B. 2020. Mapping vegetation communities inside wetlands using Sentinel-2 imagery in Ireland. International Journal of Applied Earth Observation and Geoinformation **88**: 102083. doi:10.1016/j.jag.2020.102083.

Boon, P.I., Allen, T., Brook, J., Carr, G., Frood, D., Hoye, J., Harty, C., McMahon, A., Mathews, S., Rosengren, N.J., Sinclair, S., White, M., and Yogovic, J. 2011. Mangroves and Coastal Saltmarsh of Victoria: Distribution, Condition, Threats and Management. Victoria University, Melbourne.

Brodu, N. 2017. Super-Resolving Multiresolution Images With Band-Independent Geometry of Multispectral Pixels. IEEE Trans. Geosci. Remote Sensing **55**(8): 4610–4617. doi:10.1109/TGRS.2017.2694881.

Brooks, S., and Hale, J. 2020a. Corner Inlet Ramsar Site Habitat Mapping. West Gippsland CMA, Traralgon, Victoria.

Brooks, S., and Hale, J. 2021. Mapping of Seagrass and Saltmarsh Communities across the Gippsland Lakes. Bairnsdale.

Brooks, S.S., and Hale, J. 2020b. Vegetation mapping at Macleod Morass and Sale Common. Report for East Gippland Catchment Management Authority, Bairnsdale, Victoria.

Davis, J., and Brock, M. 2008. Detecting unacceptable change in the ecological character of Ramsar wetlands. Ecological Management & Restoration **9**(1): 26–32. doi:10.1111/j.1442-8903.2008.00384.x.

DELWP. 2017. Victorian Land Use Information System 2016/17. Department of Economic Development, Jobs, Transport and Resources, Victoria. doi:10.26279/5B96043F7BD02.

DELWP. 2018a. Victorian Wetland Inventory (Current). Department of Environment, Land, Water and Planning. Available from http://services.land.vic.gov.au/SpatialDatamart/dataSearchViewMetadata.html?anzlicId=ANZVI0803004912.

DELWP. 2018b. Native Vegetation - Modelled 2005 Ecological Vegetation Classes (with Bioregional Conservation Status). Department of Environment, Land, Water and Planning. Available from http://services.land.vic.gov.au/SpatialDatamart/dataSearchViewMetadata.html?anzlicId=ANZVI0803003495&extractionProviderId=1 [accessed 17 July 2021].

Department of the Environment, Water, Heritage and the Arts. 2008. National framework and guidance for describing the ecological character of Australian Ramsar Wetlands: module 2 of the National Guidelines for Ramsar Wetlands - implementing the Ramsar Convention in Australia. Dept. of the Environment, Water, Heritage and the Arts, Canberra. Available from http://www.environment.gov.au/water/publications/environmental/wetlands/pubs/module-2-framework.pdf [accessed 30 June 2013].

Gell, P.A., Finlayson, C.M., and Davidson, N.C. 2016. Understanding change in the ecological character of Ramsar wetlands: perspectives from a deeper time–synthesis. Marine and Freshwater Research **67**(6): 869–879.

Hale, J. 2016. Ecological Character Description Addendum - Gippsland Lakes Ramsar Site. Department of Environment, Land, Water and Planning, East Melbourne, Vic.

Hale, J., and Boon, P.J. 2017. Investigation into the resilience of Ramsar sites to large-scale drivers of change: Western Port. Department of Environment, Land, Water and Planning, Melbourne, Australia.

Hale, J., and Brooks, S. 2019. Gippsland Lakes Seagrass Monitoring Framework. Bairnsdale.

Kaplan, G., and Avdan, U. 2017. Mapping and monitoring wetlands using Sentinel-2 satellite imagery. ISPRS Ann. Photogramm. Remote Sens. Spatial Inf. Sci. **IV-4/W4**: 271–277. doi:10.5194/isprs-annals-IV-4-W4-271-2017.

Newall, P.R., Lloyd, L.N., Gell, P.A., and Walker, K.F. 2016. Implications of environmental trajectories for Limits of Acceptable Change: a case study of the Riverland Ramsar Site, South Australia. Marine and Freshwater Research **67**(6): 738–747.

Ramsar Convention. 2005. Resolution IX.1 Annex A. A Conceptual Framework for the wise use of wetlands and the maintenance of their ecological character.

Traganos, D., and Reinartz, P. 2018. Mapping Mediterranean seagrasses with Sentinel-2 imagery. Marine Pollution Bulletin **134**: 197–209. doi:10.1016/j.marpolbul.2017.06.075.

WGCMA. 2015. Vegetation map of the Lower Latrobe Wetlands. West Gippsland Catchment Management Authority.

Appendix A: Detailed methods

Introduction

The Sentinel-2 program of the European Space Agency (ESA) uses two satellites (Sentintel-2A launched June 2015 and 2B launched March 2017). Together they map the earth providing high spatial resolution imagery (10 m to 60 m pixels) with a combined return interval of 5 days. This typically provides at least one cloud-free view of the Gippsland Lakes every 6 months suitable for mapping current terrestrial vegetation or shallow water habitats. Each satellite has a multi-spectral sensor for wavelengths that are suited for water, vegetation and soils mapping (Table 7).

Image classification uses the information in the many wavelength bands to classify the spectral signature of the reflectance from different surfaces. Water, vegetation, soils, and urban areas each reflect light in different ways and the unique reflectance fingerprint can be used to map their distribution in satellite imagery. Vegetation absorbs red light and reflects infrared enabling combinations of wavelengths to distinguish different vegetation types. In contrast, water absorbs infrared, so water will appear black to an infrared camera.

Table 7. Sentinel-2 multi-spectral sensor bands.

Sentinel-2 bands	Sentinel-2A Central wavelength (nm)	Sentinel-2B Central wavelength (nm)	Spatial resolution (m)	Used for wetland vegetation mapping
Band 1 – Coastal aerosol	442.7	442.2	60	
Band 2 – Blue	492.4	492.1	10	Visible light - colour
Band 3 – Green	559.8	559	10	Visible light - colour
Band 4 – Red	664.6	664.9	10	Visible light - colour
Band 5 – Vegetation red edge	704.1	703.8	20	Differentially absorbed by pigments e.g. chlorophyll
Band 6 – Vegetation red edge	740.5	739.1	20	Differentially absorbed by pigments e.g. chlorophyll
Band 7 – Vegetation red edge	782.8	779.7	20	Differentially absorbed by pigments e.g. chlorophyll
Band 8 – NIR	832.8	832.9	10	Reflected by vegetation and bare soil
Band 8A – Narrow NIR	864.7	864	20	Reflected by vegetation and bare soil
Band 9 – Water vapour	945.1	943.2	60	
Band 10 – SWIR – Cirrus	1373.5	1376.9	60	
Band 11 – SWIR	1613.7	1610.4	20	Absorbed by water and wet soils
Band 12 – SWIR	2202.4	2185.7	20	Absorbed by water and wet soils

Pre-process

Sentinel-2 image data is freely available from the Sentinel Australasia Regional Access (SARA) portal https://copernicus.nci.org.au. While the return interval for Sentinel-2 is nominally 5 days there can be periods of several months of cloud cover interspersed with high turbidity and atmospheric reflections resulting on only a small number of images being suitable for mapping. Satellite images were screened by viewing on the https://nationalmap.gov.au/ website to select clear viewing dates when tall marsh had browned off for the winter making it easier to distinguish from green vegetation (Figure 8). This was found to be important in prior mapping at the site (Brooks and Hale 2020b).

Figure 8: Tall marsh is best mapped in late winter after the emergent growth has fully browned off providing strong contrast compared to other wetland vegetation (from Brooks and Hale 2020b).

Sentinel -2 images were pre-processed using the Sentinel Application Platform (SNAP) 8.0 https://step.esa.int/main/toolboxes/snap/:

1. SNAP was used to clip the Sentinel images to the extent of the Gippsland Lakes Ramsar site. The Ramsar site straddles the overlap between two tiles (Figure 9). A strip 2km wide was removed from the overlapping edge of the tiles to remove edge processing artefacts. The two overlapping sections were then mosaiced into a single multi-band image in GIS.
2. For mapping wetland vegetation a composite image was created for the 31/07/2020 using the Sentinel-2 visible, red-edge, near and short wave infrared (Bands 1, 2,3,4,5,6,7,8,11). The third party sen2res plugin for SNAP provides "super-sampling" resolution enhancement for Sentinel-2 using the information contained in 10m bands to sharpen the lower spatial resolution infrared bands from 20m to 10m (Brodu 2017).
3. NDVI (Normalized Difference Vegetation Index) was calculated and added as an additional band to help distinguish green vegetation (swamp scrub and sedgelands) from non-green vegetation (senesced tall marsh, *Sarcocornia* saltmarsh) or from bare ground. NDVI was also calculated for a cloud-free summer image (11 Feb 2021) and added to help isolate the spectral signature of tall marsh from other non-green vegetation classes (e.g. saltmarsh) or from agricultural land that displays the opposite pattern of green in winter and brown in summer (Figure 10).
4. Land and water areas were separately masked using the sen2coral SNAP plugin LandCloudWhitecapMask processor (Figure 11). Classification of saltmarsh was limited to the land area. Open water and saline aquatic meadows (shallow water salt marsh habitats) were effectively mapped by the water masking algorithm and were added to the mapping after the classification of land areas was completed.

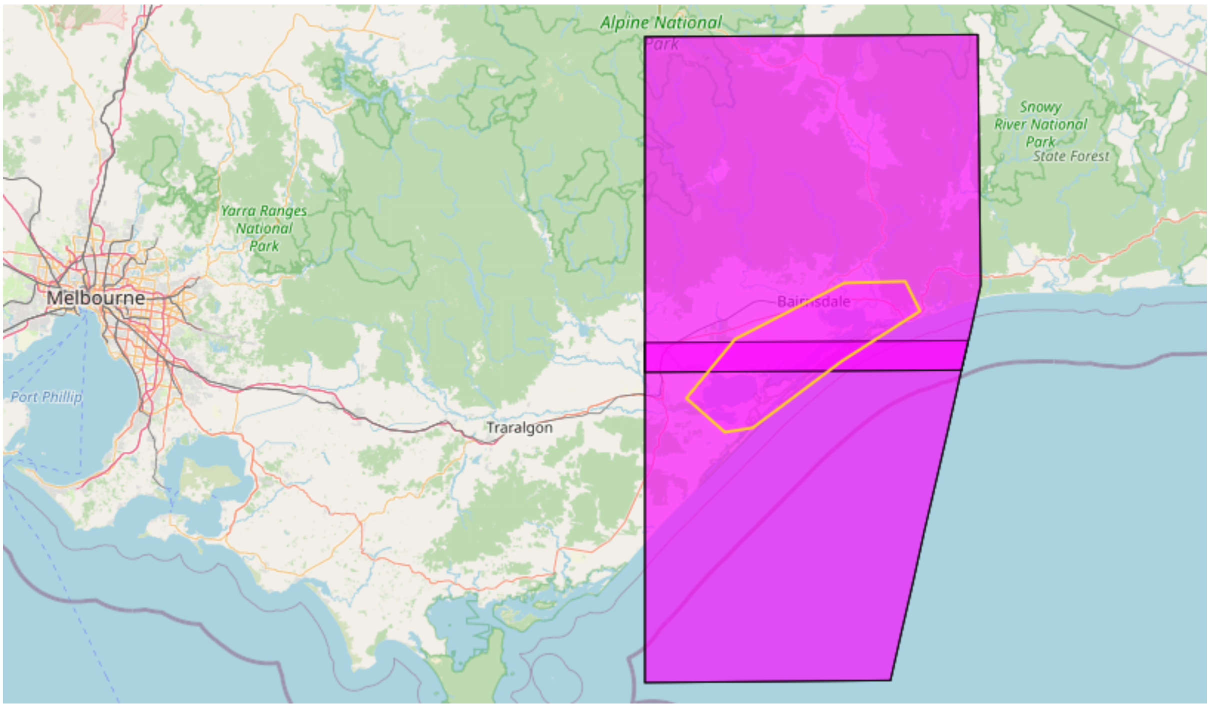

Figure 9 The Gippsland Lakes Ramsar Site straddles two Sentinel-2 image tiles (source: the SARA portal https://copernicus.nci.org.au)

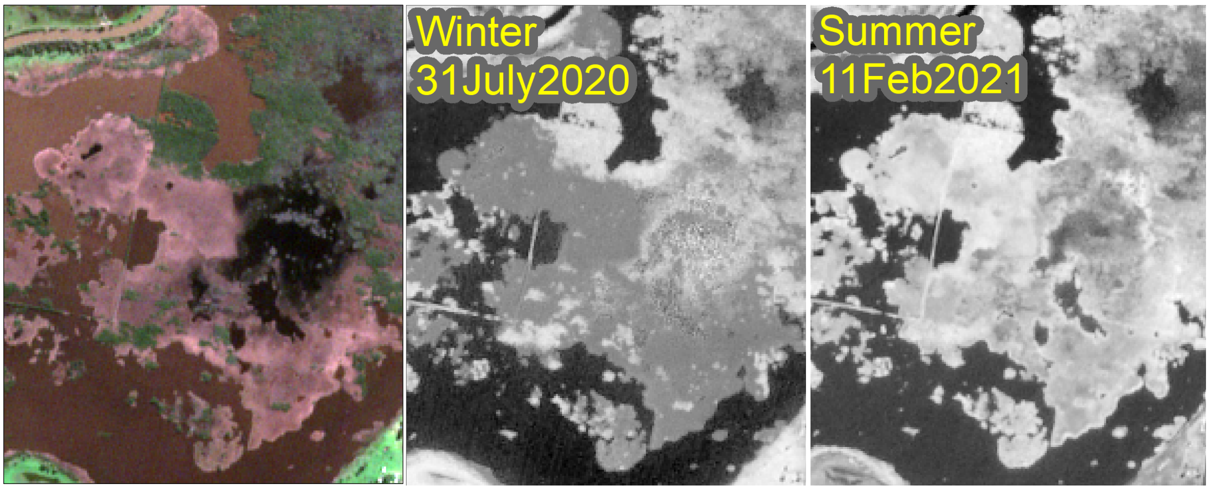

Figure 10: Tall marsh in Dowd Morass that has browned off in winter has a low NDVI (centre) compared to the same patch in summer. Including NDVI from both summer and winter in the classification improved discrimination of tall marsh vegetation from non-green vegetation such as saltmarsh.

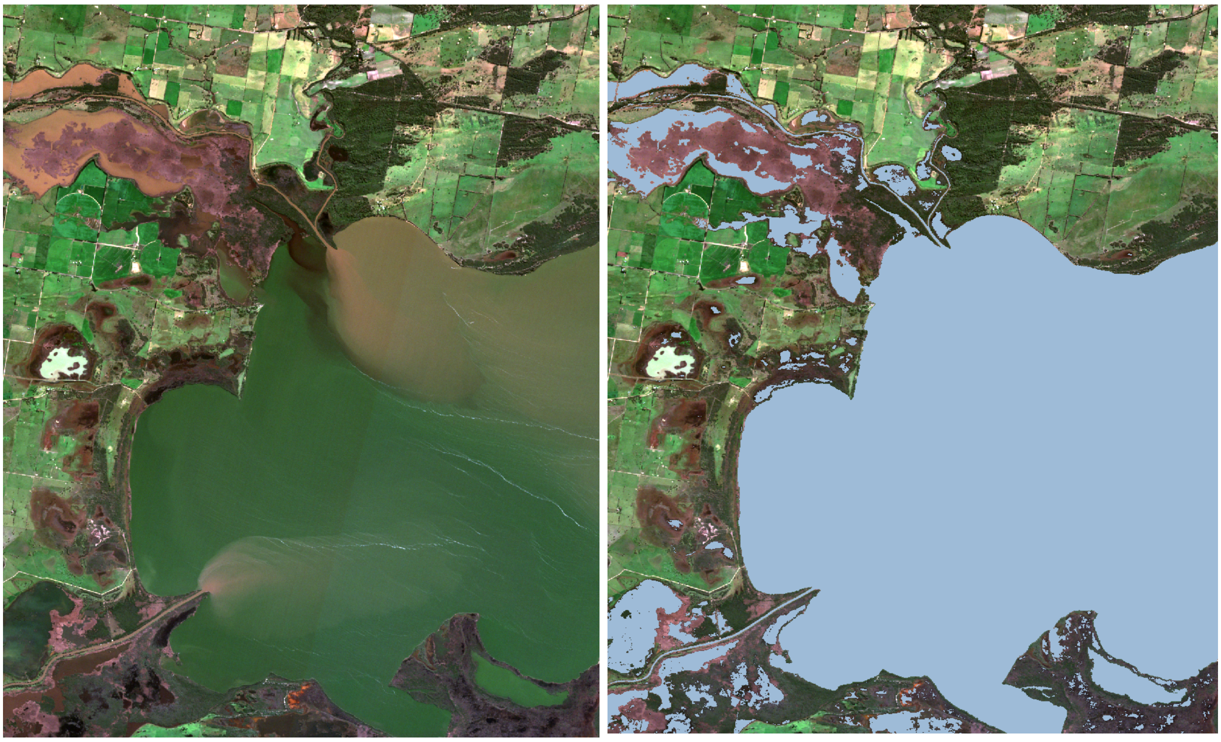

Figure 11: Turbid water from winter rains and different depths of the lakes and wetlands create a complex range of spectral reflectance (left) that reduce performance of the vegetation classification. Open water was masked to constrain the classification model to the land surface and was merged into the mapping as a final step.

The study area was defined by a 1km buffer around all wetlands in the Victorian wetlands inventory (DELWP 2018a) greater than one hectare in area and within 2km of the Gippsland Lakes Ramsar site boundary (Figure 12).

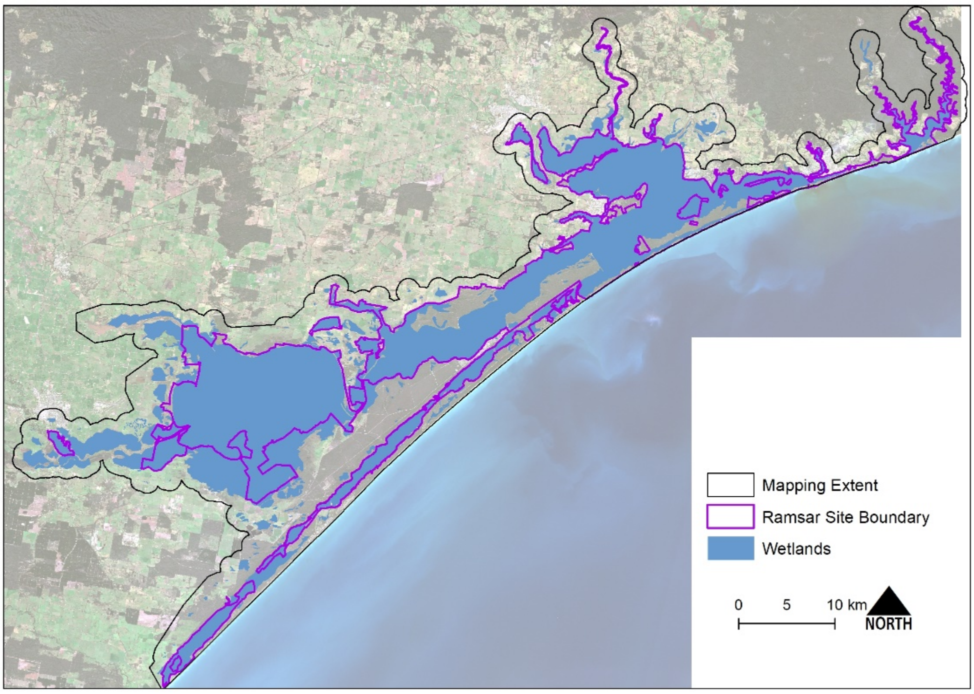

Figure 12: The mapping extent includes all wetlands from the Victorian wetland inventory within 2km of the Gippsland Lakes Ramsar Site boundary.

Image classification

A supervised maximum likelihood classification model was trained in ArcGIS to identify nine land cover types in the imagery (Table 8, Figure 13).

Table 8: Selection of areas used to train the maximum likelihood classification model.

Land cover class	Evidence used to identify known areas in which to train the model
Saltmarsh	Saltmarsh was mapped across the site by Boon et al. (2011).
Tall marsh (reed beds)	Past mapping of Macleod Morass and Sale common (Brooks and Hale 2020b), DELWP Lower Latrobe EVC mapping (WGCMA 2015), and higher resolution areal imagery in Google Earth.
Shallow marsh, wet ground	Past mapping of Macleod Morass and Sale common (Brooks and Hale 2020b). Areas in freshwater wetlands that were classified incorrectly in trial runs of the model.
Swamp scrub	DELWP EVC mapping (DELWP 2018b)
Coastal scrub/heathlands	DELWP EVC mapping (DELWP 2018b)
Agricultural land	Visual from imagery and the Victorian Land Use Information System (DELWP 2017)
Forest	DELWP EVC mapping (DELWP 2018b)
Bare ground (includes roads and rooftops)	Visual from imagery
Open water	Masked by SNAP water mask pre-processor

Saltmarsh was mapped across the site by Boon et al. (2011). This mapping has a number of different saltmarsh Ecological Vegetation Classes (EVC) that were aggregated into a single saltmarsh category (e.g. Coastal Saltmarsh, Wet Saltmarsh Herbland, Saline Aquatic Meadow, Wet Saltmarsh Shrubland). This guided the selection of training areas for saltmarsh on the Sentinel-2 image ensuring that all of the sub-types were represented (Figure 13).

Victorian EVC mapping provided guidance of other broad vegetation groupings (coastal heathlands, woodlands and forests). Agricultural land, bare ground and urban areas filled much of the area outside of wetlands within the study area. These land cover classes are not of interest but are included to give the classifier bins in which to allocate the areas that are not fresh or saline marshes or swamp scrub.

Open water was mapped by the land/water mask and was merged into the mapping after the land surfaces were classified into the wetland and non-wetland habitat classes. Open water includes the Gippsland lakes, inflowing rivers and open water of the adjacent freshwater wetland basins and saline aquatic meadows.

Saline aquatic meadows were identified by intersecting the open water patches with the Boom mapping layer. Patches of open water that aligned with the Boon mapping saline aquatic meadow polygons were merged with Boon mapping saline aquatic meadow polygons and added to the saltmarsh class. Generally the alignment of the water mask with the saline aquatic meadows was good (Figure 14), however, the merger of the two overlapping boundaries allowed the mapping to incorporate any expansion of saline aquatic meadow shorelines (2020 imagery is from a wetter period than when the Boon mapping was completed in 2010 at the end of the Millennium drought.

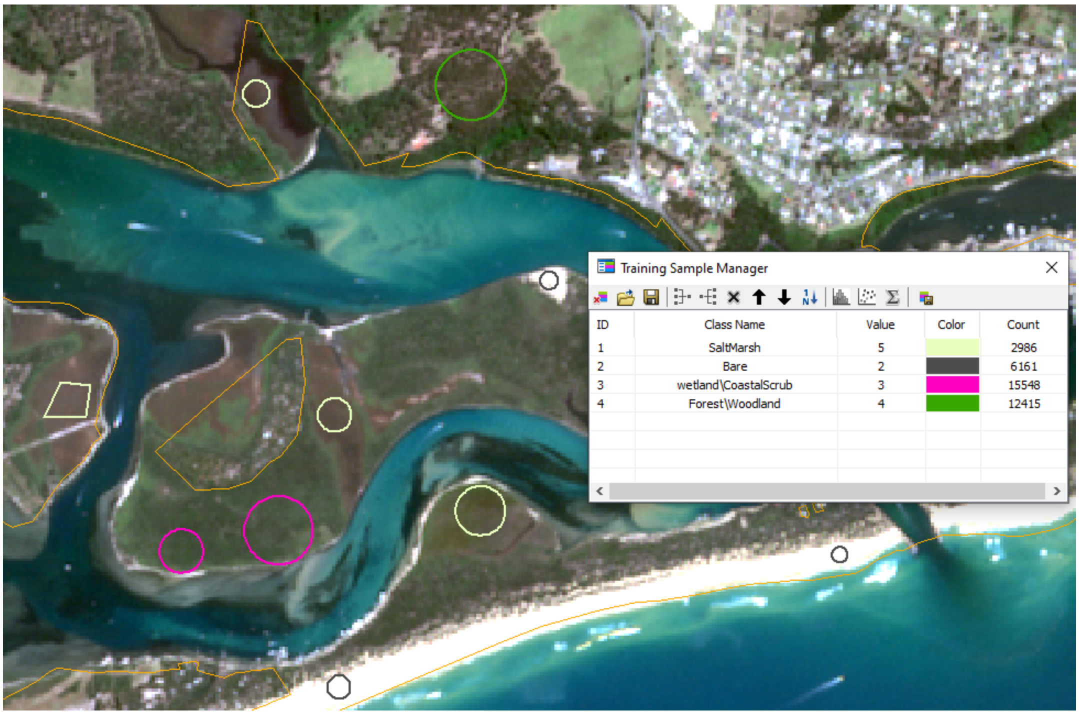

Figure 13. Defined training polygons for saltmarsh, bare ground, wetlands and heathlands and forests used to train the maximum likelihood classifier near Lakes Entrance.

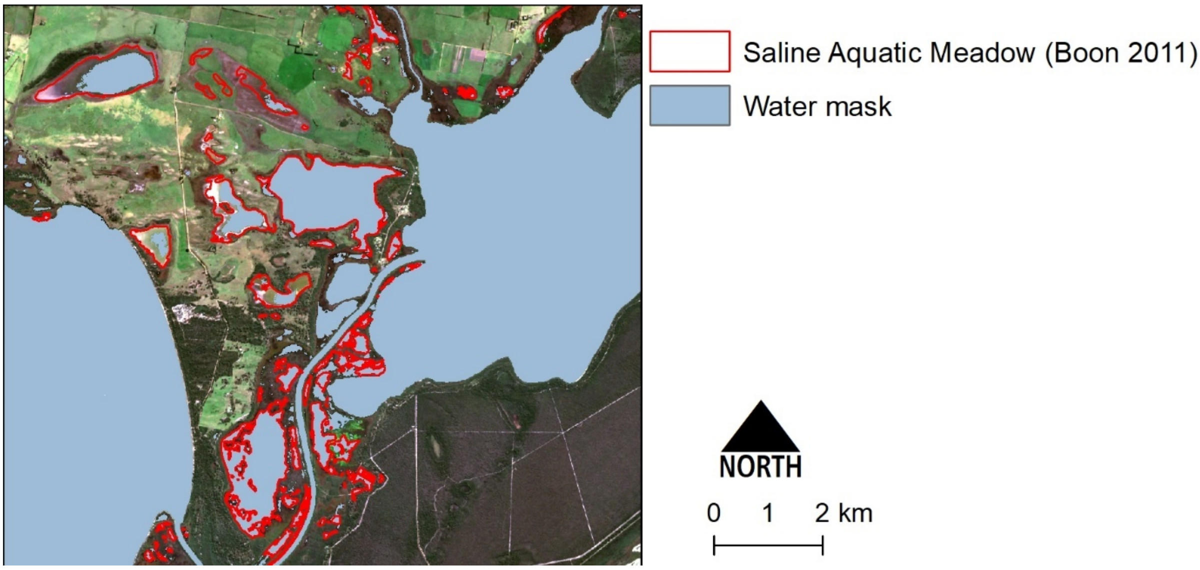

Figure 14. Saline aquatic meadows were added to the saltmarsh class as the union of the Boon mapping and the water mask to account for any changes in water level and/or basin geometry. Water areas that were not identified as saline aquatic meadows were added as "open water".

Mapping and Validation

The mapping produced in this study is a product of a desktop analysis with no recent field verification supporting the model training nor testing the outputs. The resulting maps should be used with caution. EGCMA and experts with local knowledge are expected to review the outputs further. On a visual assessment there is generally good agreement with past mapping in Macleod Morass, the Lower Latrobe Wetlands and the Boon 2011 saltmarsh mapping (Figure 15). Saltmarsh was likely overestimated in the predominantly freshwater wetlands of Sale Common and Long Waterhole (Figure 16). Small isolated fragments of saltmarsh were classified outside of all known wetlands, particularly in urban areas and along roadways where different combinations of surfaces mimic the spectral reflectance of these classes (visible in Figure 15 and Figure 16). No manual clean-up was undertaken in the current project to remove misclassified pixels as the areas are generally small and are outside the wetland boundaries.

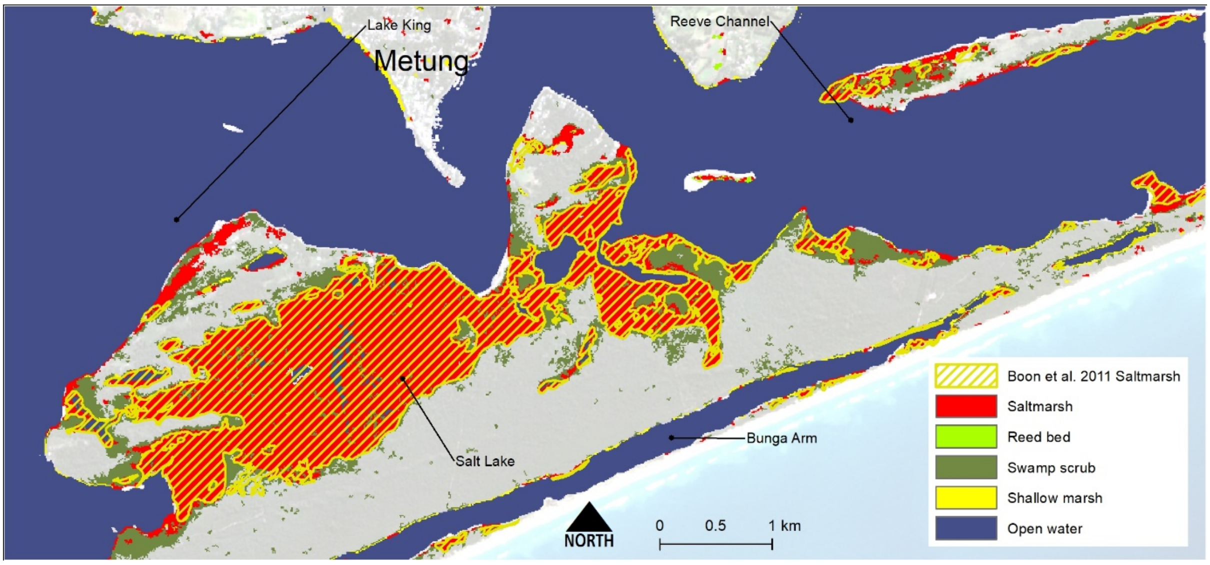

Figure 15: Existing ground validated saltmarsh mapping by Boon et al. 2011 overlaying the results of the image classification showed good agreement within wetland areas. Some misclassified fragments of saltmarsh and shallow marsh are visible within the built area of the town of Metung (top of figure).

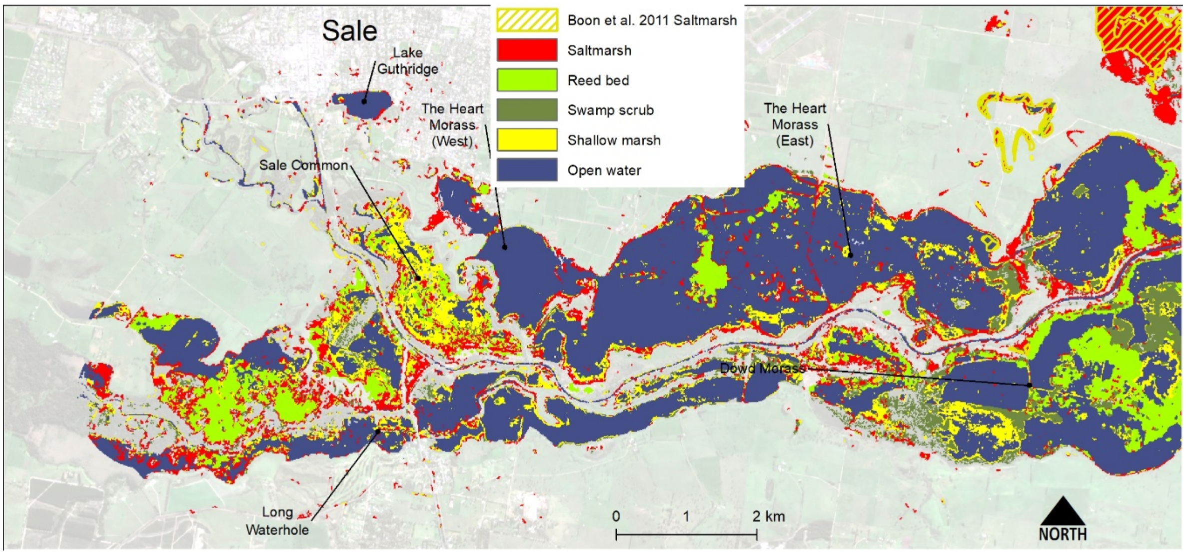

Figure 16: Potential overestimation of saltmarsh at Sale Common and Long Waterhole which are predominantly freshwater habitats. Lower Latrobe Wetlands mapping by DELWP indicates there is some fringing saltmarsh within Heat Morass. Small fragments of saltmarsh were also classified within the township of Sale.

Appendix B: Mapped outputs

Areas of land cover types are summarised in Table 9 and wetland habitat types (saltmarsh, reed bed, shallow marsh, swap scrub and open water) are mapped in Figure 17 to Figure 22.

Table 9: Area of land cover classes (wetland habitat types shaded green)

class	Area (Ha) in study area	Area (Ha) in Vic wetlands	Area (Ha) in the Ramsar Boundary
Saltmarsh	12,058	8,875	4,567
Reed bed	1,814	1,505	816
Shallow marsh	1,492	1,070	574
Swamp scrub	5,540	3,416	2,354
Open water	46,863	45,630	42,149
Agriculture	42,085	2,453	1,307
Coastal scrub	19,344	1,562	4,999
Bare/urban	6,765	3,072	3,237
Forest	9,708	516	1,103

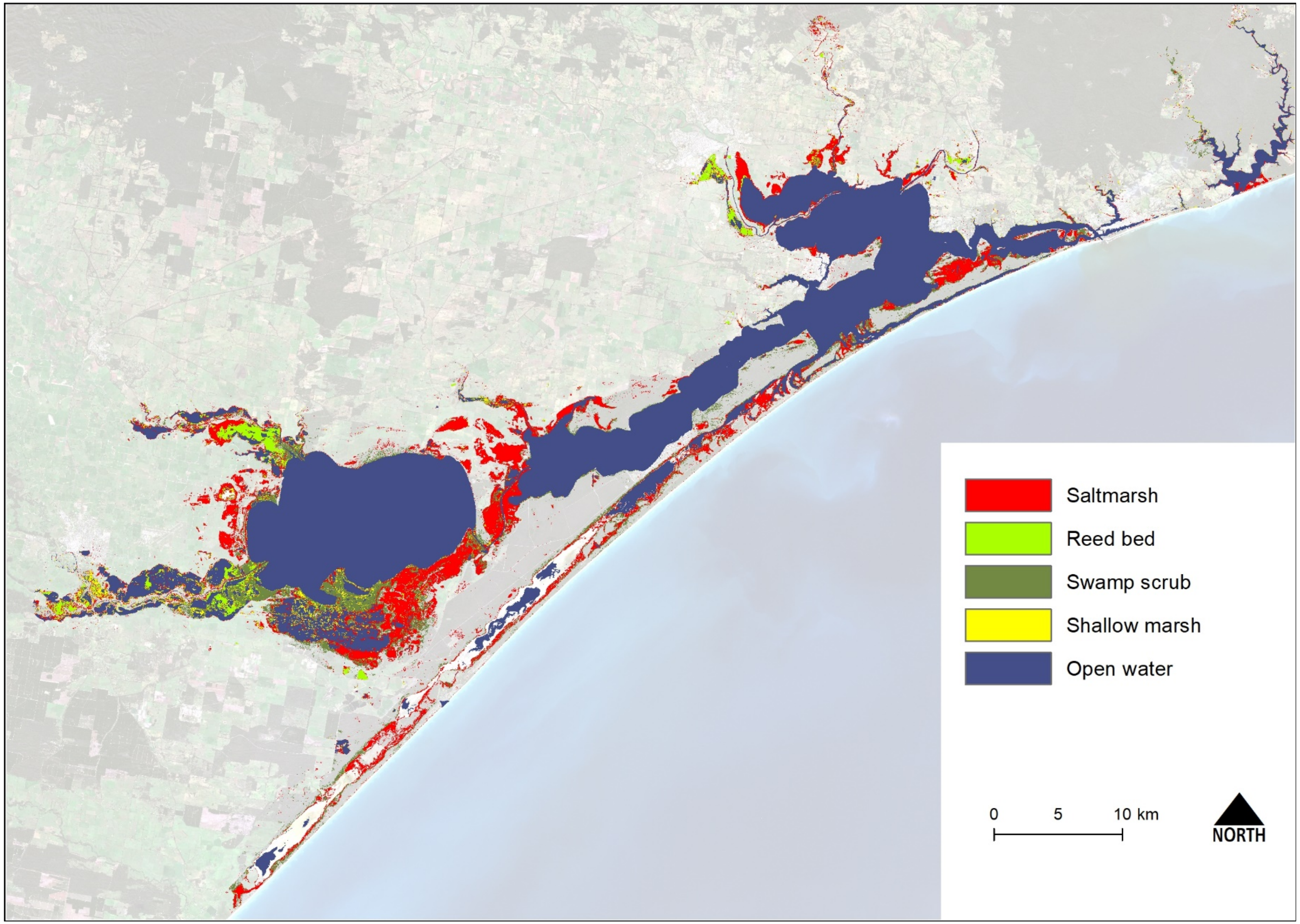

Figure 17. Wetland habitat classes in the study area classified from Sentinel-2 imagery from 31 July 2020.

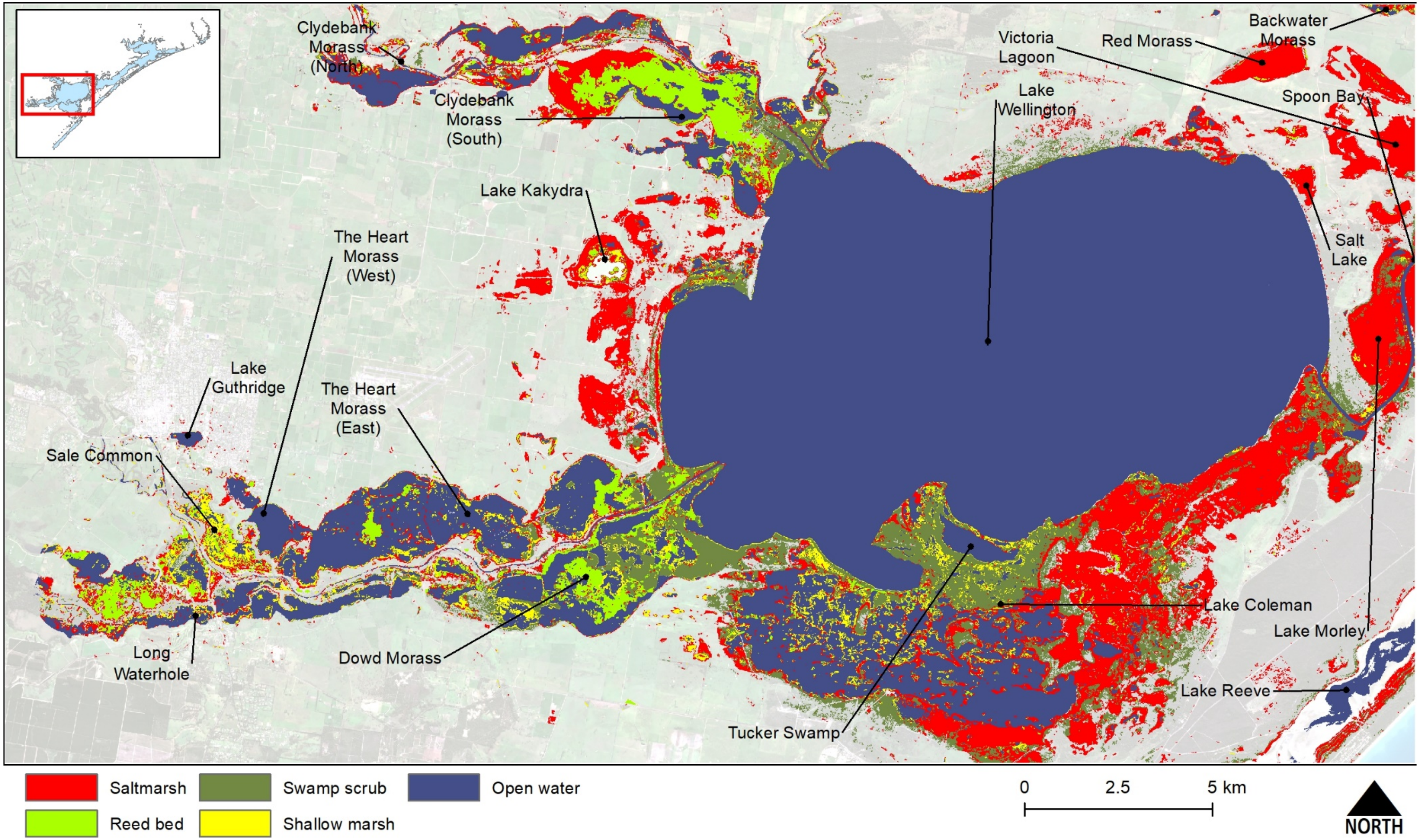

Figure 18. Wetland habitat classes around lake Wellington showing the extensive Avon River wetlands including Clydbank Morass (top middle) and Lower Latrobe wetlands including Dowd Morass and Heart Morass (lower left) classified from Sentinel-2 imagery from 31 July 2020.

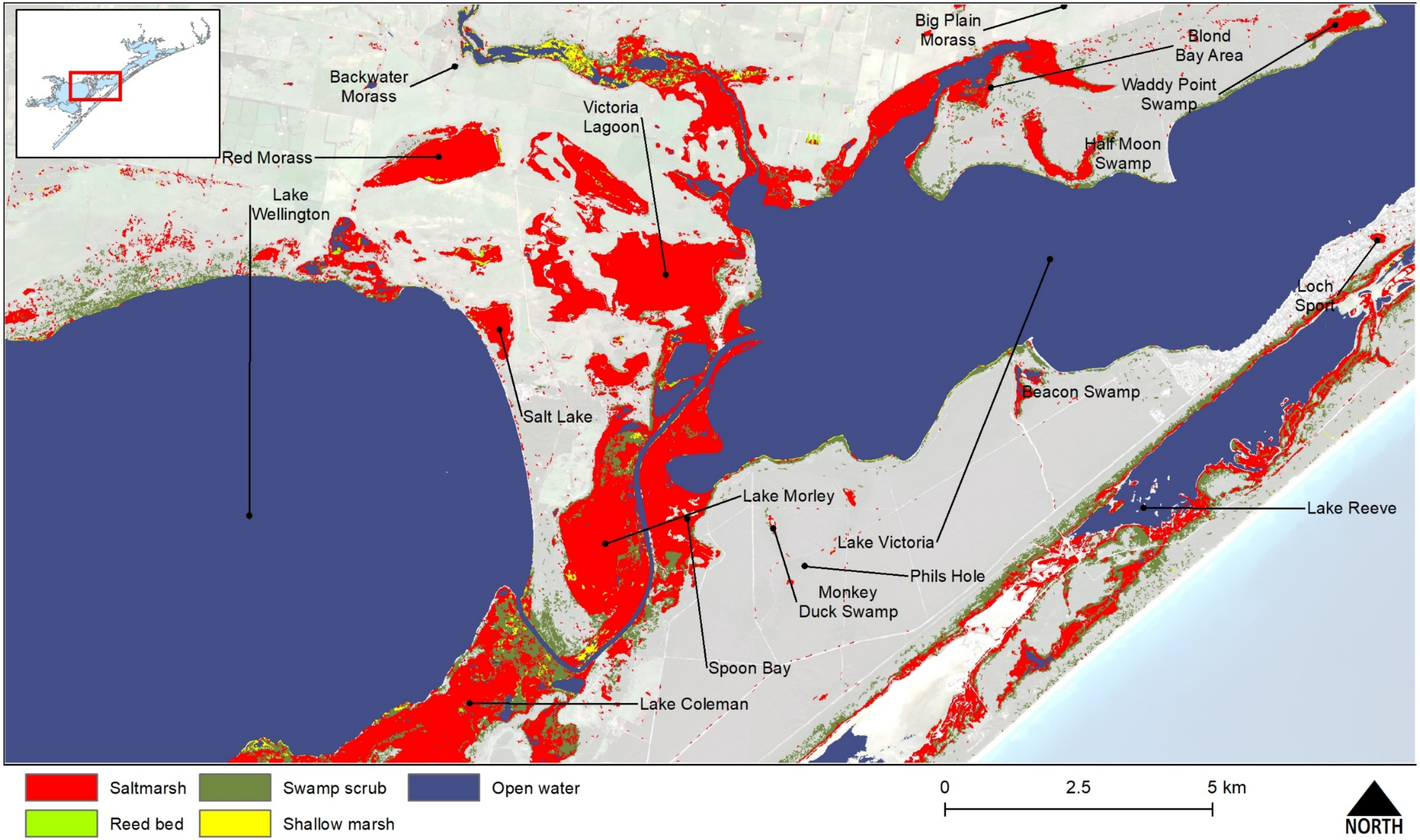

Figure 19. Wetland habitat classes showing extensive saltmarsh habitat between Lake Wellington and Lake Victoria classified from Sentinel-2 imagery from 31 July 2020.

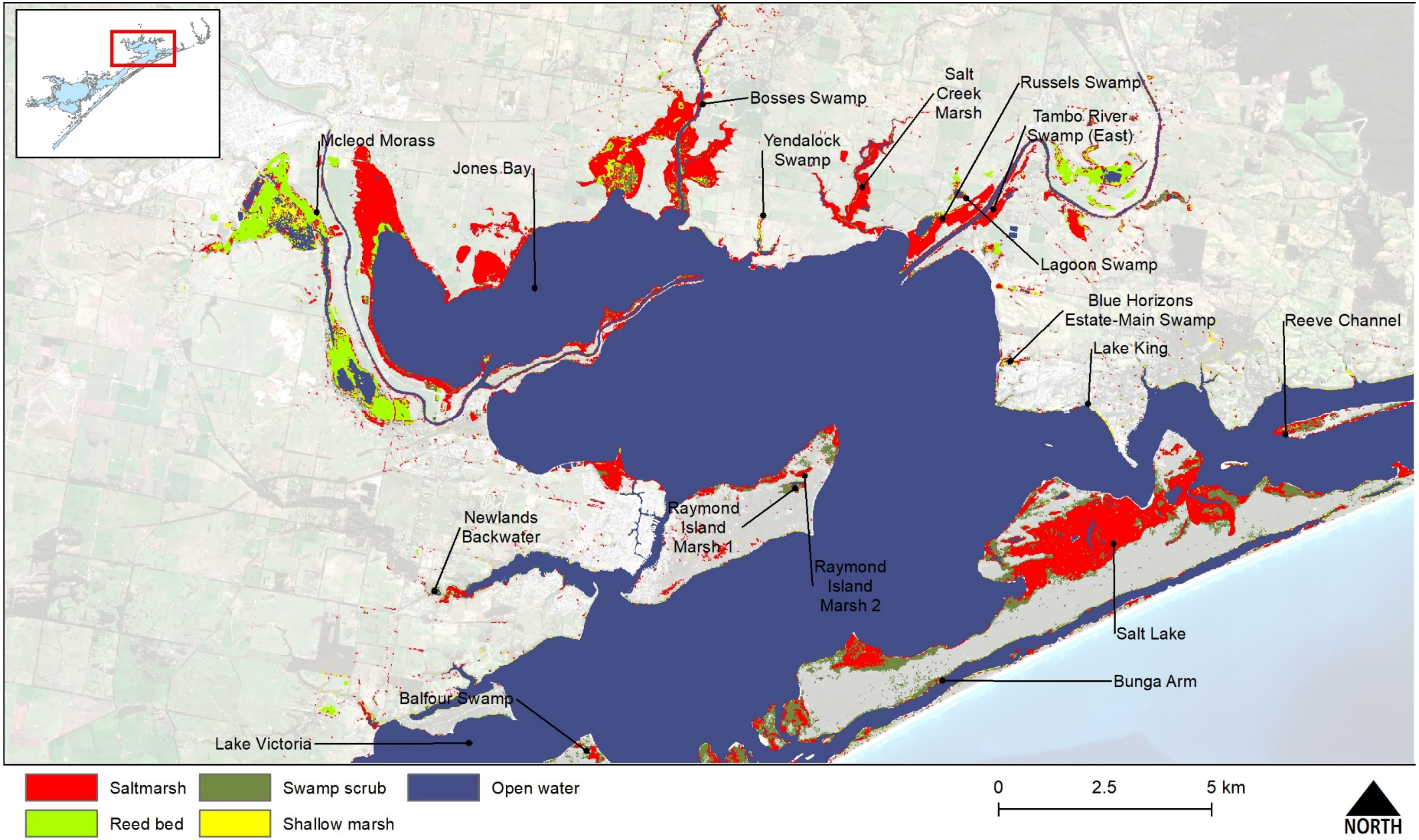

Figure 20. Wetland habitat classes in MacLeod Morass and around Lake King classified from Sentinel-2 imagery from 31 July 2020.

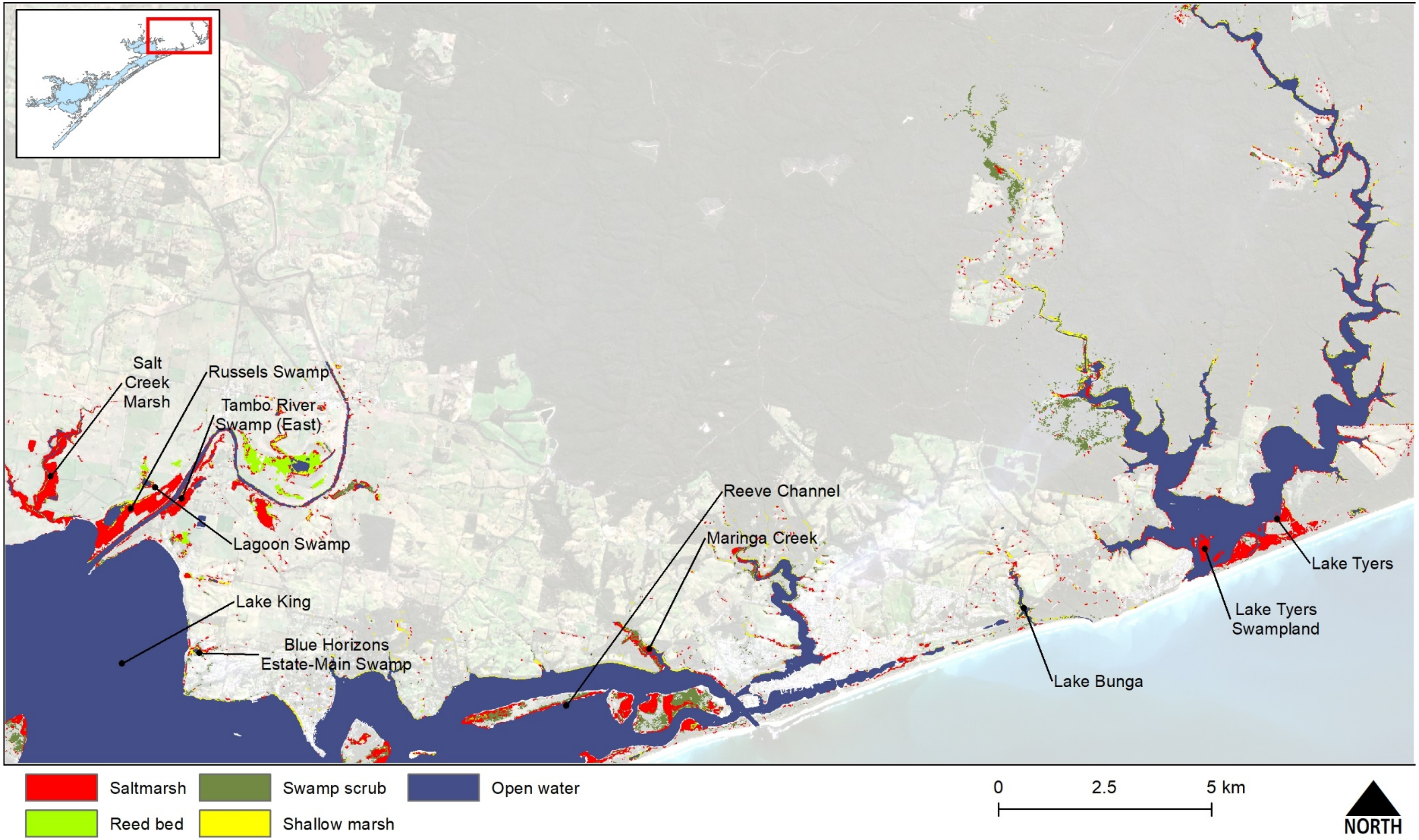

Figure 21. Wetland habitat classes near Lakes Entrance and Lake Tyers classified from Sentinel-2 imagery from 31 July 2020.

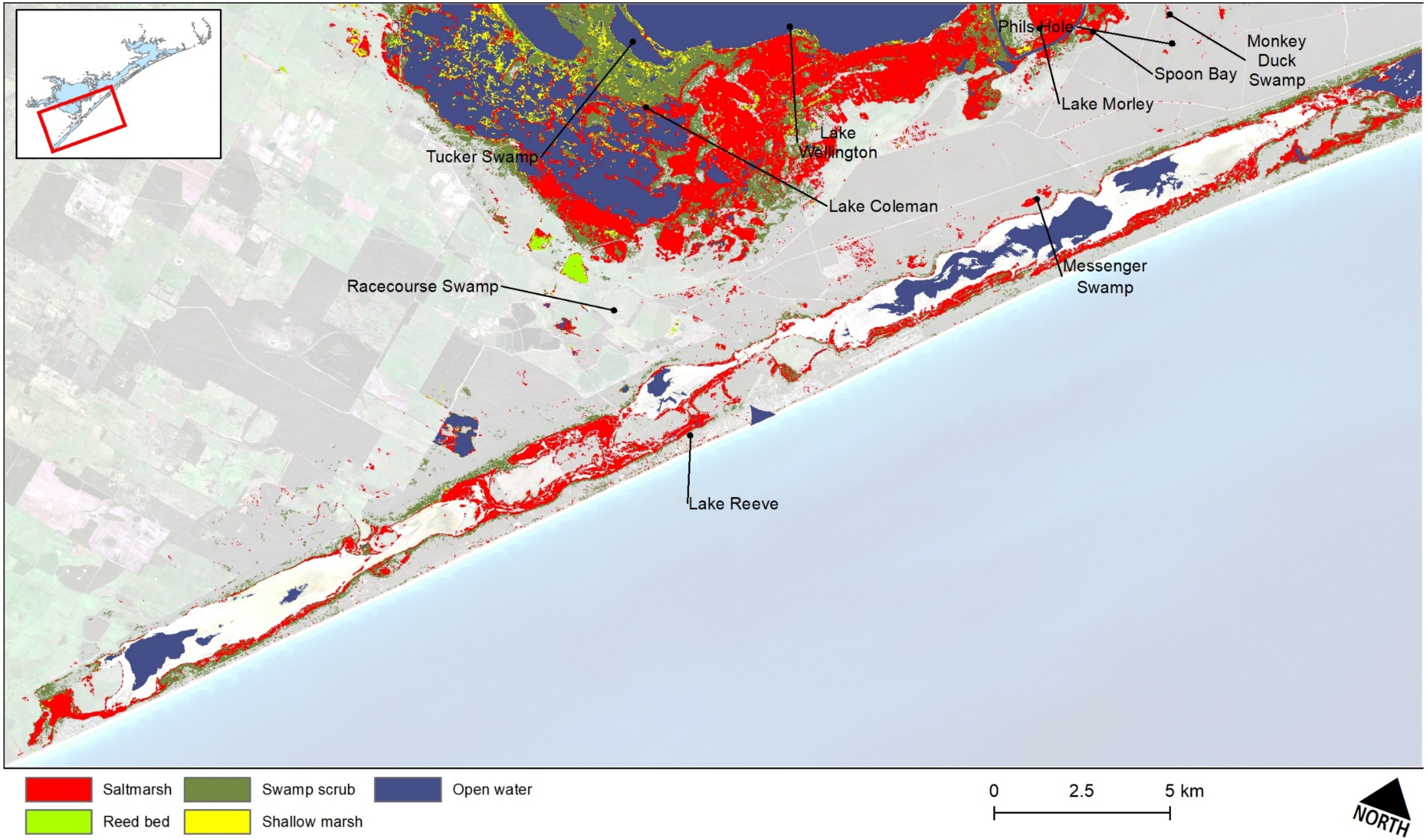

Figure 22. Wetland habitat classes in the vicinity of Lake Coleman and Lake Reeve classified from Sentinel-2 imagery from 31 July 2020.