Mapping of Seagrass and Saltmarsh Communities across the Gippsland Lakes

Shane Brooks and Jennifer Hale, April 2021

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Front cover photo: Saltmarsh, Morley Swamp, Damien Cook.

Contents

1 Introduction

The Gippsland Lakes Ramsar Site is a complex of coastal lagoons and fringing wetlands located approximately 300 kilometres east of Melbourne. The site extends from Sale Common east to Lake Tyers covering an area of approximately 60 000 hectares (Figure 1). The Ramsar site supports extensive areas of both seagrass and saltmarsh, which are critical to the ecological character of the Ramsar Site, and the current status of ecological character with respect to these two vegetation communities is assessed via Limits of Acceptable Change (LAC).

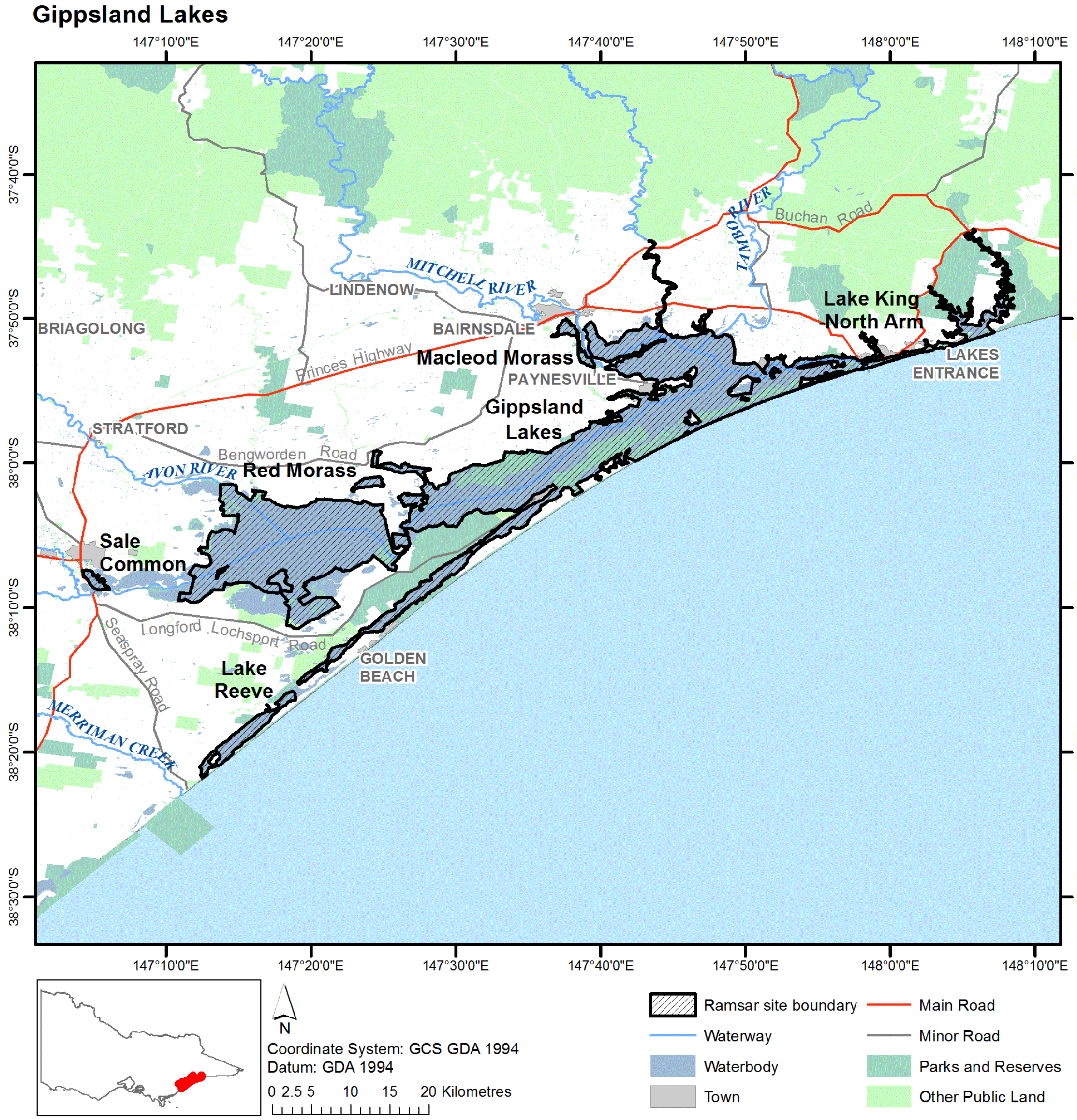

Figure 1. Gippsland Lakes Ramsar Site location.

The original Ecological Character Description (ECD) for the Gippsland Lakes Ramsar Site contains the following LAC relevant to seagrass and saltmarsh (BMT WBM 2011):

- *Total seagrass extent will not decline by greater than 50 percent of the baseline value of Roob and Ball 1997 (that is, by more than 2165 hectares) in two successive decades at a whole of site scale.*
- *Total mapped extent of dense and moderate Zostera will not decline by greater than 80 percent of the baseline values determined by Roob and Ball (1997) in two successive decades at any of the following locations: Fraser Island, Point Fullerton, Lake King, Point King, Raymond Island, Lake King, Gorcrow Point – Steel Bay, Lake Victoria, Waddy Island, Lake Victoria.*
- *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*.

Updated LAC for the Gippsland Lakes Ramsar Site are being developed as part of a review process, and it is these revised LAC that are forming the basis of current Ramsar reporting. The revised LAC for seagrass and saltmarsh are (DELWP in prep.):

- *Total seagrass extent will not decline below 2000 hectares for a period of greater than 20 continuous years.*
- *Greater than 15 percent of the total seagrass extent will have a density of "medium" or "dense".*
- *The total mapped area of saltmarsh at Lake Reeve will not decline below 600 hectares.*
- *Total saltmarsh extent across the entire Ramsar site will not decline below 3000 hectares.*

In addition, the Ramsar Site Management Plan for the site contains resource condition targets (RCTs) that are aspirational targets against which the effectiveness of management actions is evaluated. The RCTs for seagrass and saltmarsh are (East Gippsland CMA 2015):

- *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).*
- *Maintain the extent, diversity and condition of saltmarsh communities.*

East Gippsland CMA (EGCMA) requires a map of seagrass and saltmarsh extent and an assessment of saltmarsh condition in the Gippsland Lakes Ramsar Site to meet Ramsar reporting requirements.

2 Approach – Sentinel-2 imagery

Assessing the LAC requires mapping of total extent of saltmarsh and seagrass. Remote sensing offers a cost-effective approach for mapping these vegetation types over the entire site. Classification of Sentinel-2 satellite imagery has been used successfully to map seagrass in the Gippsland Lakes (Hale and Brooks 2019) and seagrass and saltmarsh in Corner Inlet (Brooks and Hale 2020). 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), Sentinel-2 imagery 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 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

3.1 Seagrass and saltmarsh mapping

The technical details of the method are provided in Appendix A. In summary, the mapping of vegetation involved four steps.

1. Sourcing and pre-processing of satellite imagery

Four clear images were downloaded from the Sentinel Australasia Regional Access (SARA) portal https://copernicus.nci.org.au. The images were pre-processed using the Sentinel Application Platform to mask regions of interest and to improve resolution of non-visible wavelengths (see Appendix A for more detail).

2. Clustering and classification

Supervised classification of the Sentinel-2 images was used with maximum likelihood models trained to detect the spectral signatures of saltmarsh and seagrass

The mapping was improved by separately classifying terrestrial habitats (saltmarsh) that can be classified using both visible and non-visible reflectance (e.g., infrared), and sub-tidal habitats (seagrass) that were classified using visible reflectance only (due to the fact that infrared light is absorbed by water).

A small number of saltmarsh locations (22 sites) were assessed in the field to confirm the saltmarsh type and qualitatively assess condition (refer section 3.2). These locations informed training site selection for saltmarsh mapping but the majority of training sites were selected using aerial photography and past mapping. We did not conduct any new on-ground surveys or ground-truthing to map seagrass. Model training for image classification was informed primarily by previous mapping.

- Seagrass distribution was mapped in 2016 (Kitchingman 2016).
- Saltmarsh were mapped across the whole 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).
- Local experts reviewed preliminary seagrass maps from a trial of the mapping method concluding that the mapping was appropriate to support evaluation of seagrass extent at the whole-of-site scale (Hale and Brooks 2019)

3. Review and clean-up

The resulting mapped outputs were reviewed, and small, isolated fragments representing < 5 pixels (500m^2) were removed or merged into adjacent mapped areas. A small number of areas that were obviously classified incorrectly were excluded from the final mapping. These were primarily along the shoreline of Bancroft Bay opposite Flannagan and Rigby Islands where tree shadow into deep water was detected as seagrass. Classification of Jones Bay and near the outflow of the Tambo River was poor on 20/04/2019 due to turbid inflows on this date and these areas were excluded from the mapping for this date.

It was not possible to map one category of saltmarsh (Saline Aquatic Meadow). This category proved problematic for Boon et al. (2011) due to extreme temporal variation. At times they may appear as bare ground (Figure 2), while at other times they are covered by open water that may or may not contain submerged plants (Figure 3). Boon et al. (2011) mapped any areas of bare ground or water surrounded by other saltmarsh communities as Saline Aquatic Meadow, and it accounted for a large proportion (almost 25%) of the saltmarsh in the Ramsar site. Classification of imagery from Sentinel was not able to distinguish bare ground that Boon classified as Saline Aquatic Meadow from other bare surfaces and if the area was submerged, the water changed the spectral properties disrupting the classification. To account for this and to allow comparisons with LAC, the areas mapped by Boon et al. (2011) as Saline Aquatic Meadow were integrated into the new 2021 mapping.

4. Comparison with Limits of acceptable change

The area of each class of habitat was calculated and compared against the defined LACs and RCTs.

Figure 2: Dry saltpan at Red Morass that is mapped as Saline Aquatic Meadow by Boon et al. (2011).

Figure 3: Saline Aquatic Meadow at Lake Reeve 2021 (D, Cook).

3.2 Saltmarsh condition assessment

In 2019, Greening Australia conducted assessments of the condition of saltmarsh communities across parts of the Gippsland Lakes. The method used as a rapid assessment, based on the habitat hectares approach and recommended by Boon et al. (2011). We extended this condition mapping to areas not covered by the 2019 assessment in the west and south of the Ramsar Site (Figure 4). Twenty-two sites were assessed in February 2021; accessed via walking, kayak or small boat. At each site, the most widespread EVC was identified for assessment; several assessments were conducted if a site supported large areas of different EVCs. A one-hectare plot was selected in an area of EVC that was of homogenous condition.

Data collected by Greening Australia did not include point locations nor the EVC type of saltmarsh being assessed. As a result, analysis of condition with respect to EVC was not possible.

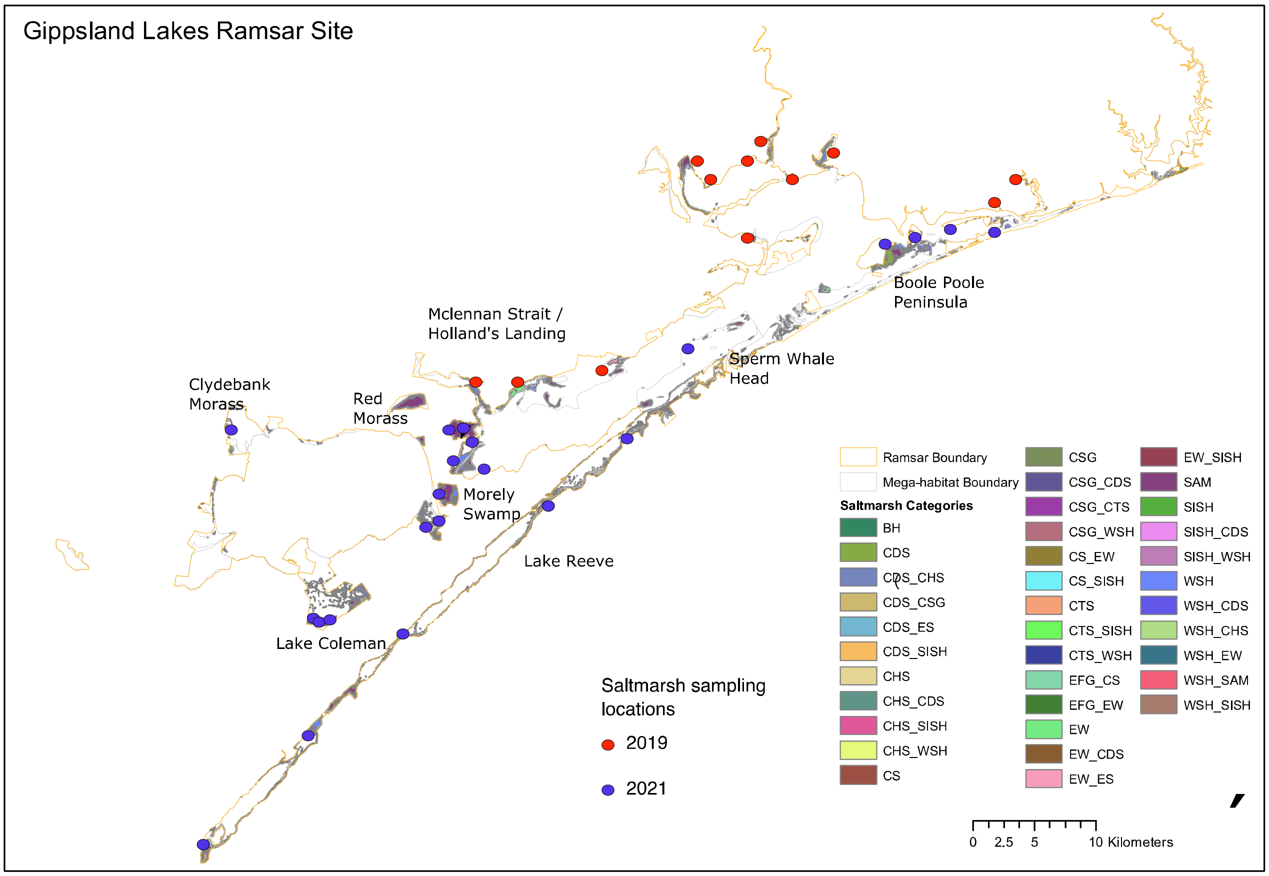

Figure 4: Location of saltmarsh assessment sites from this study and Greening Australia 2019

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4 Results

4.1 Seagrass extent

Seagrass was mapped on four dates to evaluate change over time. The Sentinel image archive is relatively new commencing in late 2016. The four dates represented the clearest cloud-free images with best water clarity following the spring-summer growth period to maximise visibility for mapping:

- 09/03/2017
- 20/04/2019
- 15/03/2020
- 24/01/2021

Lake Wellington and Lake Tyers were excluded from the mapping. Lake Wellington is too fresh and there was no evidence of seagrass in imagery. Lake Tyers exhibits a uniform dark substrate in all imagery with only some sandbanks near the mouth (Figure 5) which is currently closed to the ocean by sand. Seagrass was not able to be distinguished from this imagery. More suitable conditions when water levels are lower and water clarity is higher, may provide an opportunity to map seagrass in this section.

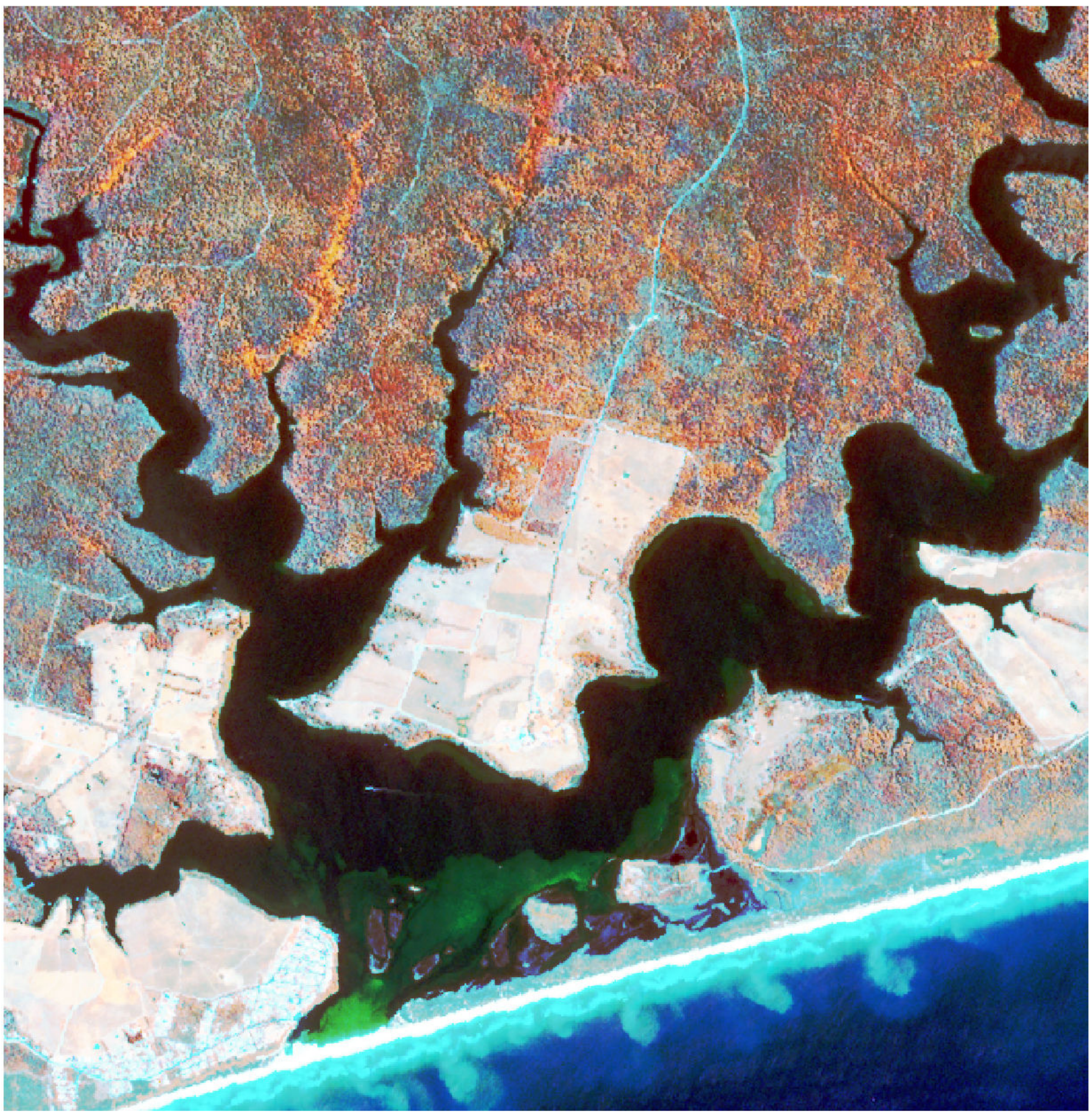

Figure 5: The most recent clear image of Lake Tyers from the Sentinel record (January 9, 2021).

Table 1. Seagrass extent 2017 to 2021

Category	2017	2019	2020	2021
Dense Seagrass	896	920	892	838
Sparce Seagrass	1866	1934	1724	1396
total (ha)	**2762**	**2854**	**2616**	**2235**

While total seagrass extent did not vary substantially over the four time periods, there are distributional differences with 2017 having more seagrass in Jones Bay and less in the western end of Lake Victoria in comparison to the other years (Figure 6).

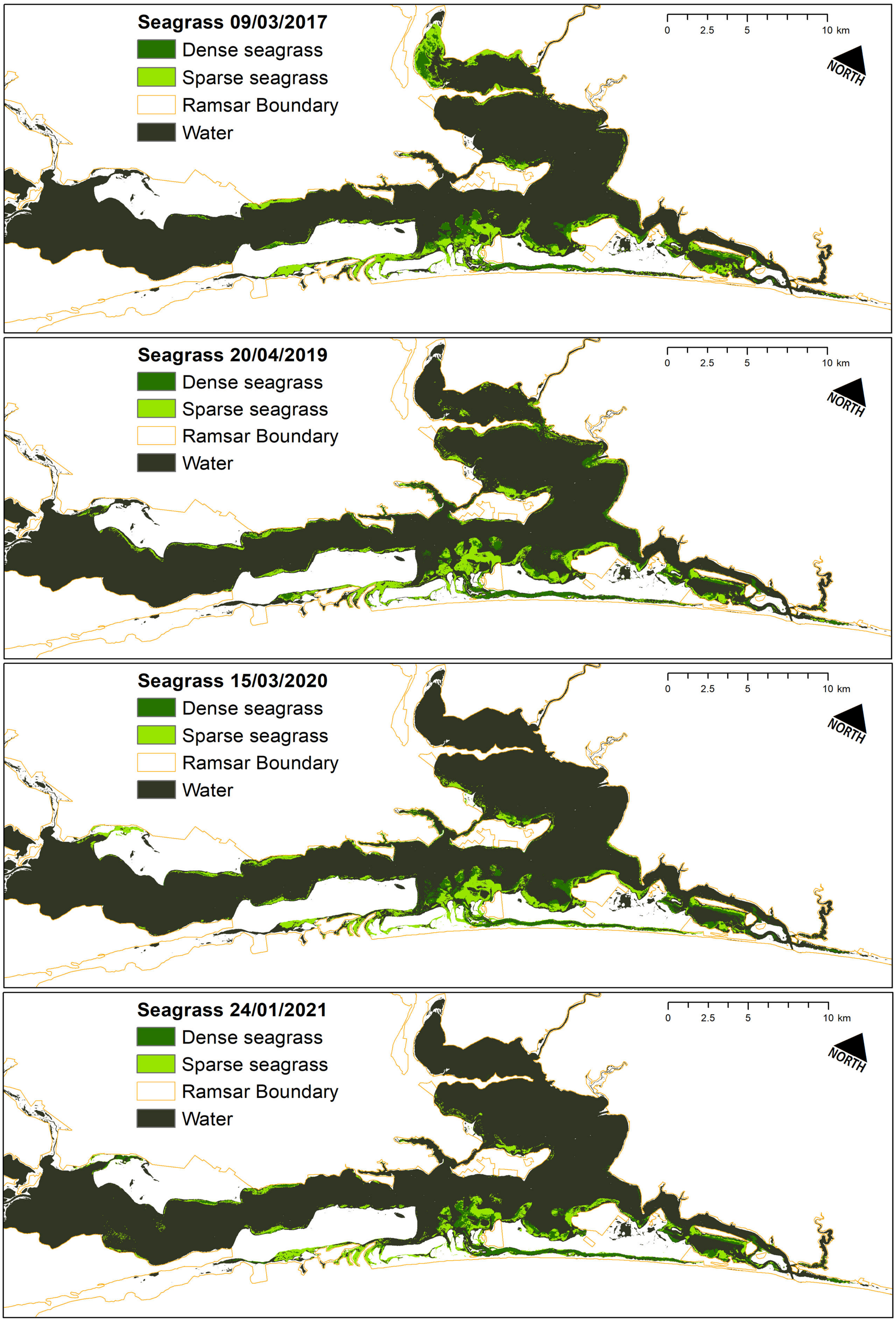

Figure 6: Distribution of seagrass in the Gippsland Lakes Ramsar site in 2017-2021.

4.2 Saltmarsh extent

A total of 4666 hectares of saltmarsh was mapped across the whole site as one collective group integrating different saltmarsh EVC (e.g., dry coastal saltmarsh, hypersaline saltmarsh, wet saltmarsh herbfields; Figure 7). This includes 1261 hectares of saltmarsh at Lake Reeve. There is a further 3719 hectares of exposed unvegetated salt flat at Lake Reeve.

4.3 Saltmarsh condition

Saltmarsh condition varied considerably across the site. Sites assessed in 2021, Coastal Dry Saltmarsh, Coastal Hypersaline Saltmarsh, Saline Aquatic Meadow and Wet Saltmarsh Herbland were all in good condition. Estuarine Scrub, however, was consistently assessed as being in very poor condition (Table 2).

Vehicle damage and rubbish dumping were observed at sites located in Victoria lagoon (Figure 9) and in the south west end of Lake Reeve.

Table 2: Condition of saltmarsh assessed in 2021.

Location	EVC	Condition score	Condition category
Lake Reeve	Coastal Dry Saltmarsh	95	Good
Lake Reeve site	Coastal Dry Saltmarsh	100	Good
Victoria Lagoon	Coastal Dry Saltmarsh	95	Good
Lake Reeve	Coastal Hypersaline Saltmarsh	100	Good
Lake Reeve	Coastal Hypersaline Saltmarsh	95	Good
Lake Reeve	Coastal Tussock Saltmarsh	95	Good
Clydebank Morass	Estuarine Reedbed	85	Good
Flannagan Island	Estuarine Scrub	36	Very Poor
Lake Coleman	Estuarine Scrub	41	Very Poor
South-east corner of Lake Wellington	Estuarine Scrub	36	Very Poor
McLennan Strait	Estuarine Scrub	36	Very Poor
West of Spoon Bay	Estuarine Scrub	36	Very Poor
Lake Coleman	Estuarine Wetland	43	Very Poor
Lake Coleman	Estuarine Wetland	85	Good
Morley Swamp	Estuarine Wetland	100	Good
South-east corner of Lake Wellington	Estuarine Wetland	60	Poor
Trouser Swamp, Sperm Whale Head	Estuarine Wetland	95	Good
Lake Reeve	Saline Aquatic Meadow	100	Good
Victoria Lagoon	Saline Aquatic Meadow	100	Good
Boole Poole (east)	Wet Saltmarsh Herbland	100	Good
Boole Poole (west)	Wet Saltmarsh Herbland	100	Good

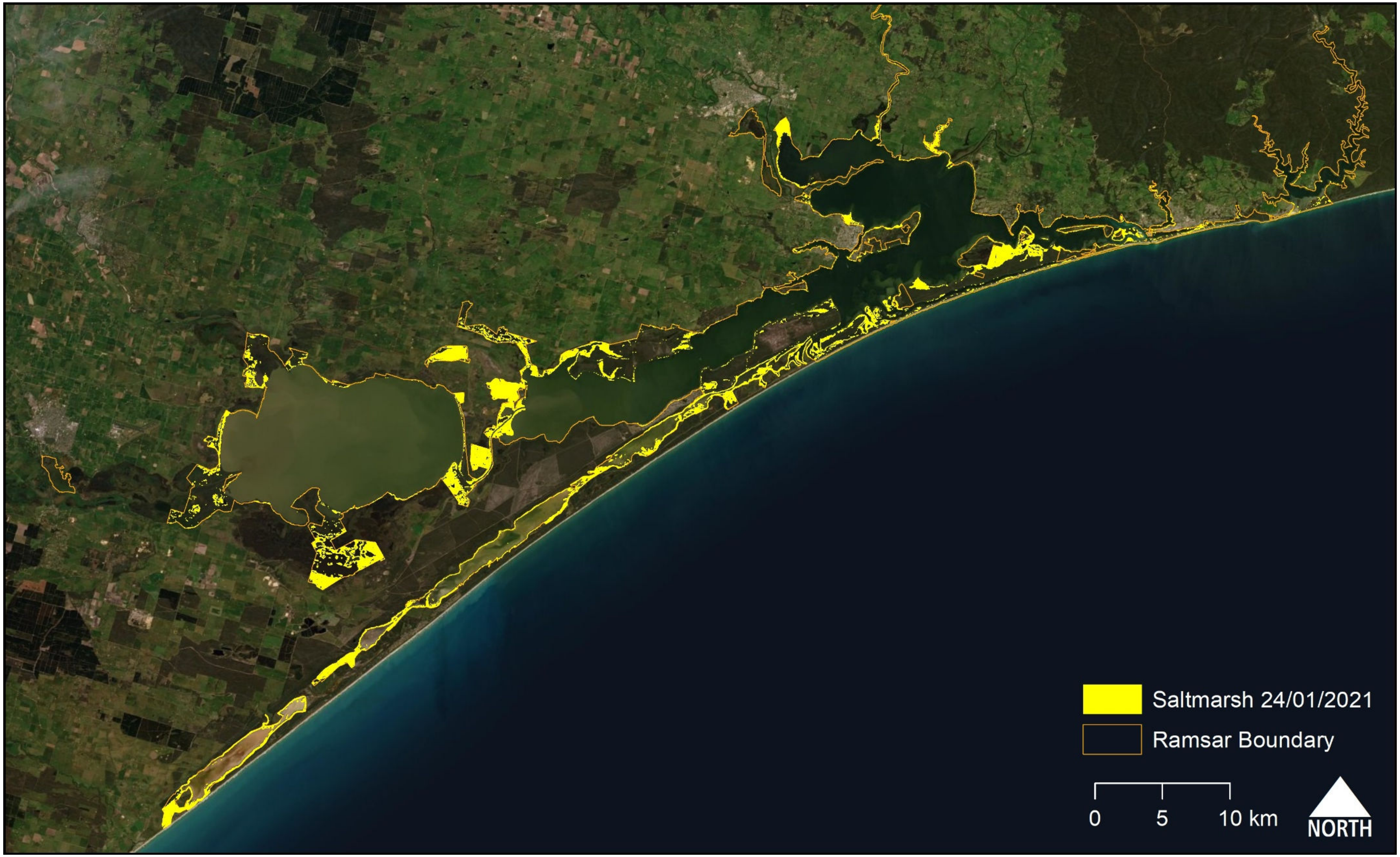

Figure 7: Distribution of saltmarsh in the Gippsland Lakes Ramsar site

Figure 8: Example of good condition Coastal Dray Saltmarsh in Lake Reeve (D. Cook).

Figure 9: Vehicle damage and rubbish dumping at saltmarsh in Victorian Lagoon (D. Cook).

The combined 2019 and 2021 dataset resulted in 23 sites being assessed as in “good” condition (55% of sites assessed); three sites were assessed as fair, eight as poor and six as very poor (see Appendix B).

4.4 Evaluating the LAC

4.4.1 Seagrass

Seagrass mapping from this project has been used to assess against the original and revised LAC; all of which are met (Table 3).

Table 3: Assessment against LAC for seagrass.

Source	LAC	Assessment
Original ECD (BMT WBM 2011)	Total seagrass extent will not decline by greater than 50 percent of the baseline value of Roob 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. **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 Roob and Ball (1997) in two successive decades at any of the following locations: Fraser Island, Point Fullerton, Lake King, Point King, Raymond Island, Lake King, Gorcrow Point – Steel Bay, Lake Victoria, Waddy Island, Lake Victoria.	In 1997, 50% of seagrass was considered to be in dense patches (Roob and Ball 1997). The current project could only distinguish two categories of seagrass density[1] and between 32 and 38% was considered dense. In 2016, 60% of the seagrass was considered dense (Kitchingman 2016). As the decline in density below the 40% threshold has persisted for just five years. **LAC is met.**
ECD Addendum (DELWP in prep.)	Total seagrass extent will not decline below 2000 hectares for a period of greater than 20 continuous years.	Total seagrass extent ranged from 2235 hectares in 2021 to 2854 hectares in 2019. **LAC is met.**
	Greater than 15 percent of the total seagrass extent will have a density of “medium” or “dense”.	Current mapping (2017 to 2021) indicates 32 to 38% of the seagrass occurred as dense patches. **LAC is met.**

4.4.2 Saltmarsh

Saltmarsh mapping from this project has been used to assess against the original and revised LAC; all of which are met (Table 4).

Table 4: Assessment against LAC for saltmarsh.

Source	LAC	Assessment
Original ECD (BMT WBM 2011)	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	Saltmarsh in Lake Reeve was 1261 hectares plus a further 3405 hectares salt flats / saltpan, which is a total of 4666 hectares. **LAC is met.**
ECD Addendum (DELWP in prep.)	The total mapped area of saltmarsh at Lake Reeve will not decline below 600 hectares.	Mapped extent of saltmarsh in Lake Reeve in 2021 was 1261 hectares. **LAC is met.**
	Total saltmarsh extent across the entire Ramsar site will not decline below 3000 hectares	Total extent of saltmarsh in 2021 was 4666 hectares. **LAC is met.**

[1] It should be noted that the satellite mapping does not map density classes in the same way as the original Roob and Ball (1997) mapping. The 10 metre pixels from Sentinel imagery result in an average density over each 100 m^2 area, while the field collection of Roob and Ball (1997) distinguished density by the closeness of individual seagrass plants.

4.5 Evaluating the RCT

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. The RCTs for seagrass are quantitative and while the RCT for density is being achieved, the RCT for extent of seagrass is not yet realised (Table 5).

The RCT for saltmarsh is qualitative and requires a benchmark against which change in condition can be assessed. There is no benchmark for saltmarsh condition established for the time of listing. Future assessments could, however, be evaluated against the condition assessments in this report and Greening Australia (2019).

Table 5: Assessment against RCT for saltmarsh and seagrass.

Critical CPS	LAC	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 had saltmarsh in good condition. Without a benchmark to compare the RCT is unable to be assessed.

5 References

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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 6).

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 6. Sentinel-2 multi-spectral sensor bands.

Sentinel-2 bands	Sentinel-2A	Sentinel-2B		Used for wetland vegetation mapping
	Central wavelength (nm)	Central wavelength (nm)	Spatial resolution (m)	
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, algal blooms and atmospheric reflections resulting on only a small number of images being suitable for mapping seagrass in a year (Figure 10, Figure 11). Satellite images were screened by viewing on the https://nationalmap.gov.au/ website to select dates where seagrass was clearly visible. The summer period (Dec to April) was chosen because following the spring-summer growth period the above ground biomass of seagrass would be greatest making it easier to see and map in the satellite imagery. Four dates were chosen (Table 7).

Table 7 Image dates for Sentinel-2 used for mapping seagrass and saltmarsh

EPOC	Image Date	Comments	Saltmarsh mapping	Seagrass mapping
2016/17	09/03/2017	Silty water flowing from Lake Wellington obscures the western end of Lake Victoria but very few seagrass patches in this area in other images	n/a	✓
2017/18	-	No image located – high cloud cover combined with cyanobacteria blooms in the Gippsland Lakes	n/a	✗
2018/19	20/04/2019	generally clear	n/a	✓
2019/20	15/03/2020	Elevated turbidity from recent rain showing as plume out of the entrance into the sea. Shallow areas with seagrass still visible.	n/a	✓
2020/21	24/01/2021	clearest image – some high-level cloud over Lake Tyers but not over any know seagrass or saltmarsh locations.	✓	✓

Figure 10. Example of reflection from the water surface obscuring details of Seagrass (image date 24/12/2018)

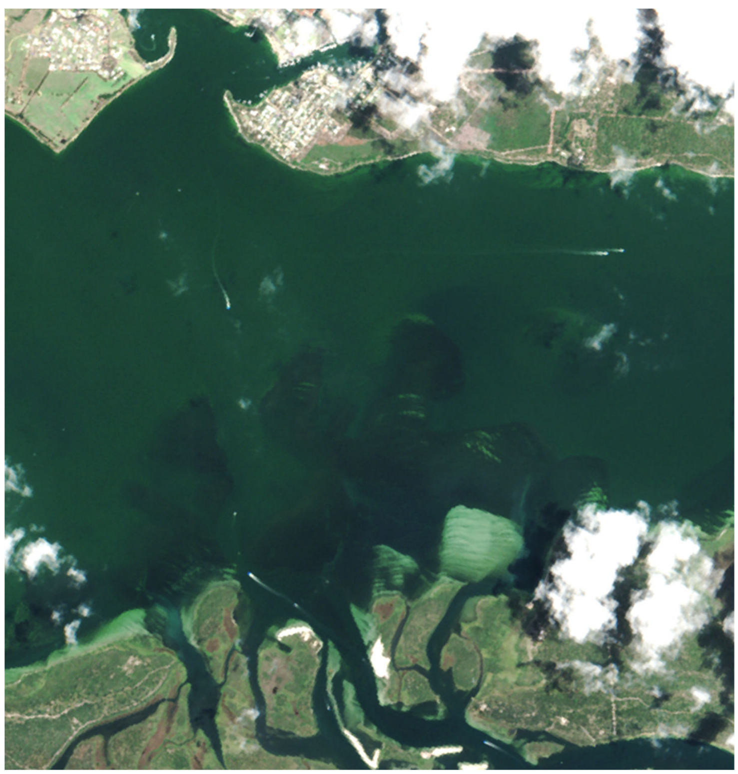

Figure 11 Cyanobacteria bloom 05/01/2018 obscuring the seagrass south of Raymond Island along with some cloud cover

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

1. 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).
2. 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 12). 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 ArcGIS 10.
3. Land and water areas were masked using the sen2coral SNAP plugin LandCloudWhitecapMask processor (Figure 13) using a reference value of 0.05 and masking all negative values. Classification of saltmarsh was limited to the land area. The classification of seagrass was constrained to water areas only, with additional areas deeper the 4m excluded to further reduce the number of possible groupings from which to identify seagrass (Hale and Brooks 2019).

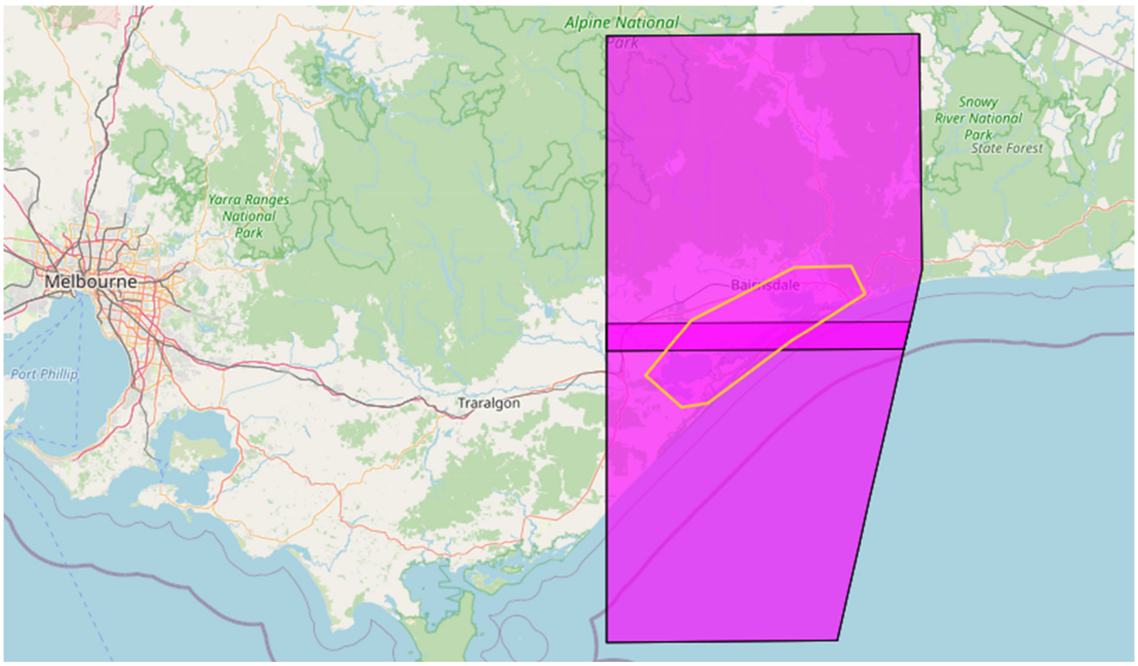

Figure 12 The Gippsland Lakes Ramsar Site straddles two Sentinel-2 image tiles (source: the SARA portal https://copernicus.nci.org.au)

Saltmarsh

For mapping saltmarsh a composite image was created using the Sentinel-2 visible, red-edge, near and short wave infrared (Bands 1, 2,3,4,5,6,7,8,8a,11,12) with the lower resolution bands super-sampled to the same consistent resolution of 10m. The image from 24/01/2021 was them masked to isolate the terrestrial area during the classification (Figure 15).

Seagrass

For mapping seagrass, the first five visible light and red-edge (Bands 1, 2,3,4,5) were used. Water attenuates the infrared bands making them unsuitable for mapping seagrass. The red-edge 704nm (Sentinel Band 5) was included as it is a narrow band that is strongly reflected by chlorophyl and is useful for distinguishing seagrass from accumulated detritus and dark sediments (Figure 14). Water areas shallower than 4m within the site where seagrass is expected to be found were isolated using the water mask and 4m bathymetry contour supplied by DELWP (Figure 16).

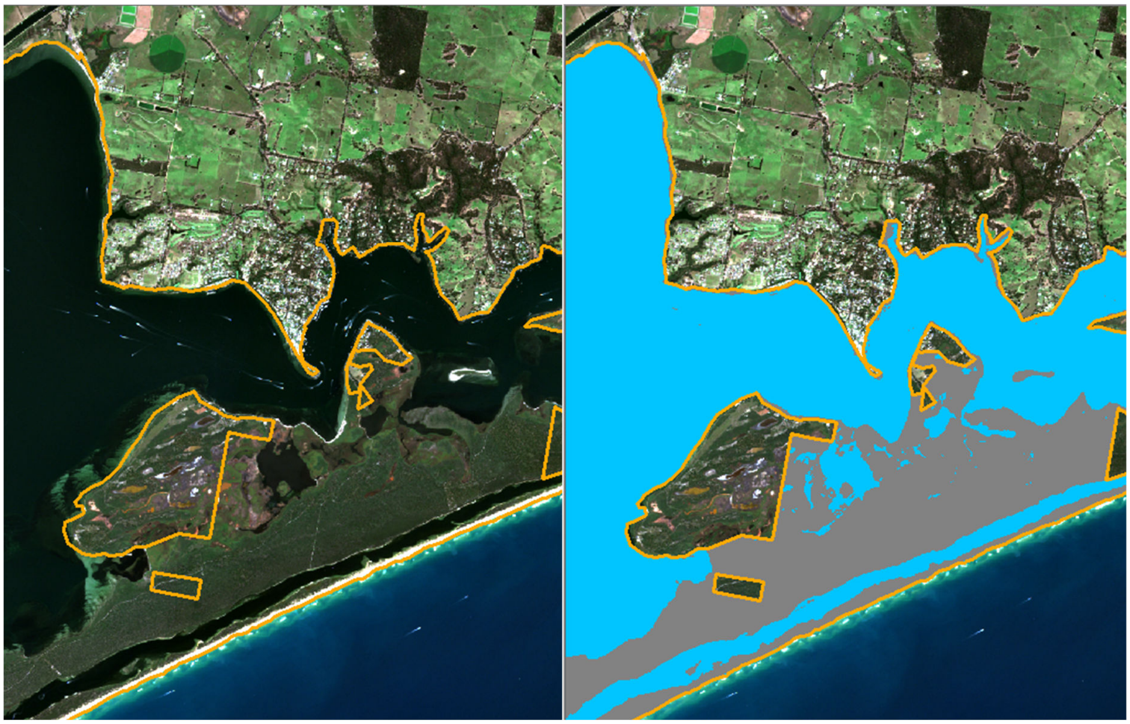

Figure 13: Separate water and land masks (right) limit the classifier to terrestrial environments for saltmarsh or aquatic habitats for seagrass within the Ramsar boundary.

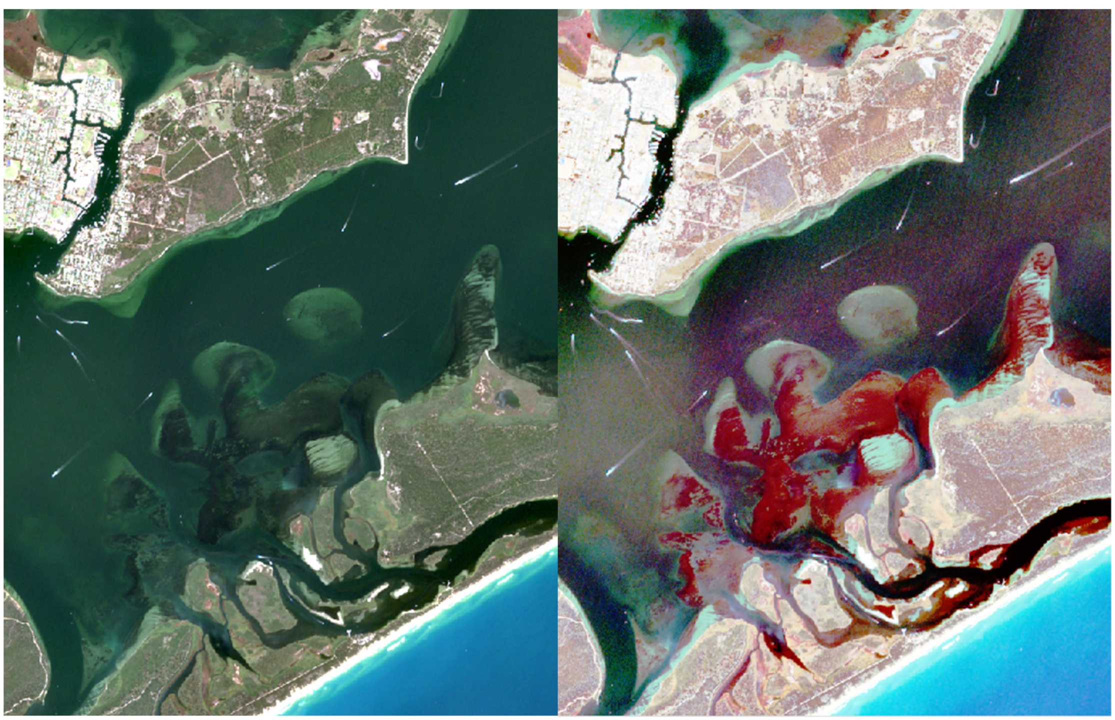

Figure 14: Normal red,blue,green (RGB) image of seagrass south of Paynesville/Raymond Island (left side) compared to a false colour image (right side; red edge sentinel band5 substituted for red). Equalising colour histograms helps visualise the seagrass beds as bright red patches from which to collect training data and to check classification outputs.

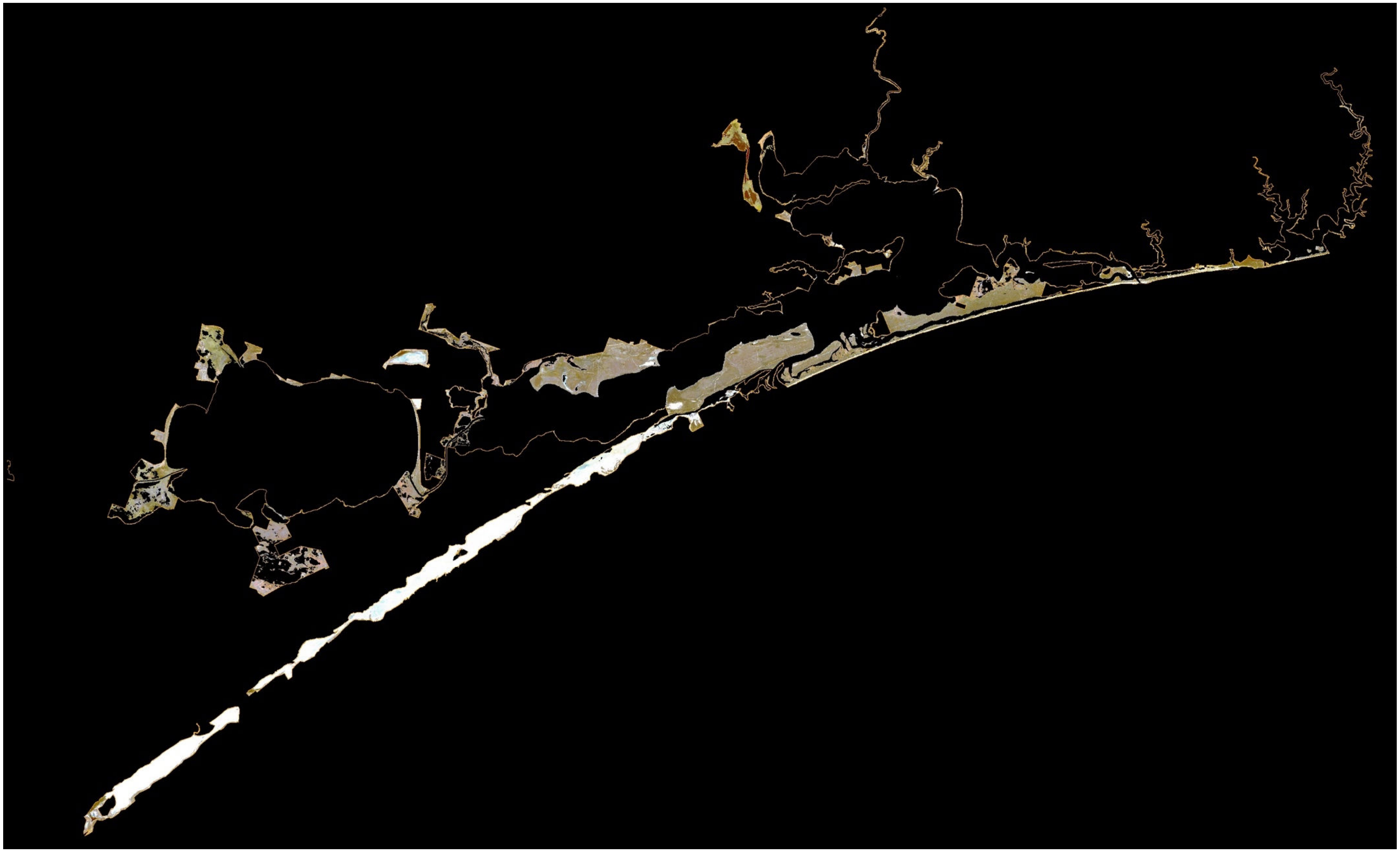

Figure 15. Land areas of the Gippsland Lakes Ramsar Site 24/01/2021 that saltmarsh habitat was mapped in.

Figure 16. False colour image of the saline water region of the Gippsland Lakes Ramsar Site that seagrass was mapped in. False colour red-edge, green, blue histograms equalised shows seagrass beds as red patches (image date 24/01/2021).

Classification of saltmarsh

Classifying saltmarsh required additional classes to accommodate other terrestrial habitat types found within the site. The classifier was trained for:

- saltmarsh
- bare soil/sand
- coastal scrub
- forest and woodlands
- swamp scrub

Saltmarsh was mapped across the whole 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 on the Sentinel-2 image (Figure 17). Victorian EVC mapping provided guidance of other broad vegetation groupings (wetlands, heathlands and forests). These are not of interest and are included only to give the classifier bins in which to allocate the areas that are not saltmarsh. The different reflectance from the largely dry Lake Reeve required this area to be trained and classified separately with results merged afterwards. For Lake Reeve a “wet” class was added for patches of lake bed that appeared to have shallow water that was isolated by the land/water masking process. A supervised maximum likelihood classification was performed in ArcGIS 10 and resulting classes were compared to Boon et al. (2011). Training was adjusted iteratively to seek the best alignment (Figure 18).

The maximum likelihood classification identified 4,666 ha of saltmarsh across the whole of the Gippsland Lakes Ramsar site (Figure 7)

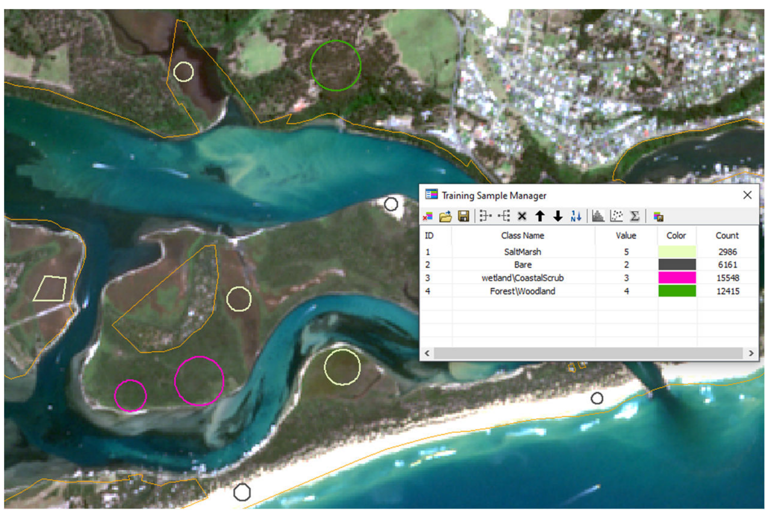

Figure 17. Defined training polygons for saltmarsh, bare ground, wetlands and heathlands and forests used to train the maximum likelihood classifier near Lakes Entrance.

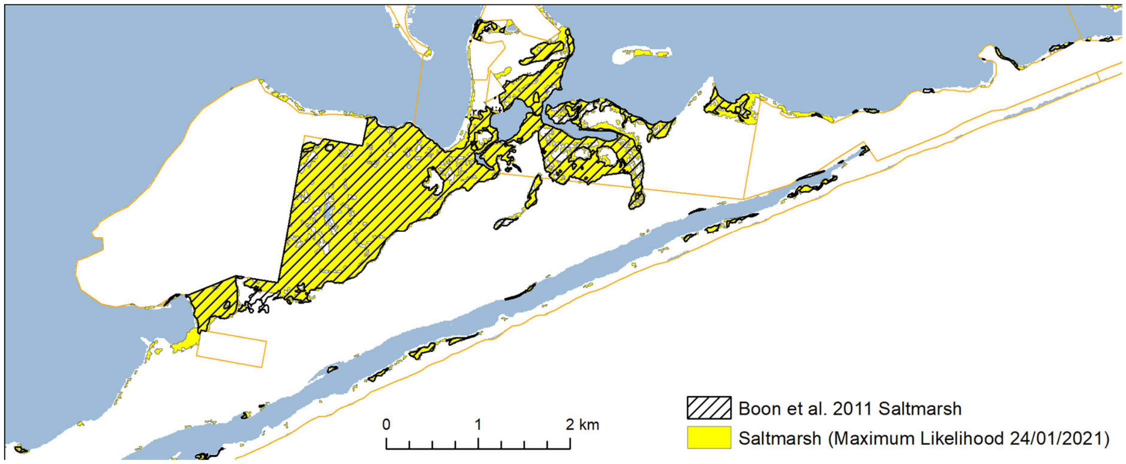

Figure 18. Close agreement of image classification of saltmarsh from Sentinel-2 imagery 24/01/2021 with Boon et al. 2011 saltmarsh mapping opposite Metung

Classification of seagrass

Seagrass was classified using four categories (Dense seagrass, sparse seagrass, bare/sand, and deep water) as described in the Gippsland Lakes Seagrass Monitoring Framework (Hale and Brooks 2019). The current day seagrass extent was mapped from the same Sentinel-2 image 24/01/2021 used for saltmarsh by extracting only the visible wavelengths, coastal aerosol and red edge Bands 1-5.

To assess inter-year variability, four mid-late summer images spanning 2017 to 2021 were mapped (Table 7). A clear image was not found for the summer of 2017/18 because of protracted cloud cover and persistent blue-green algae blooms (Figure 11).

The water areas were divided into four zones that stratify differences in water colour and turbidity that influence the spectral signature of seagrass (Figure 19). Separate maximum likelihood classification models were trained and run for each zone with the final maps merging the four model outputs.

There was also considerable variation in reflectance spectra among images from different years which reduced the ability of training signatures of seagrass in one year being sufficiently reliable to map seagrass in another year. Models were therefore retrained for each year including moving training areas to realign with the shifting distribution of seagrass at each time.

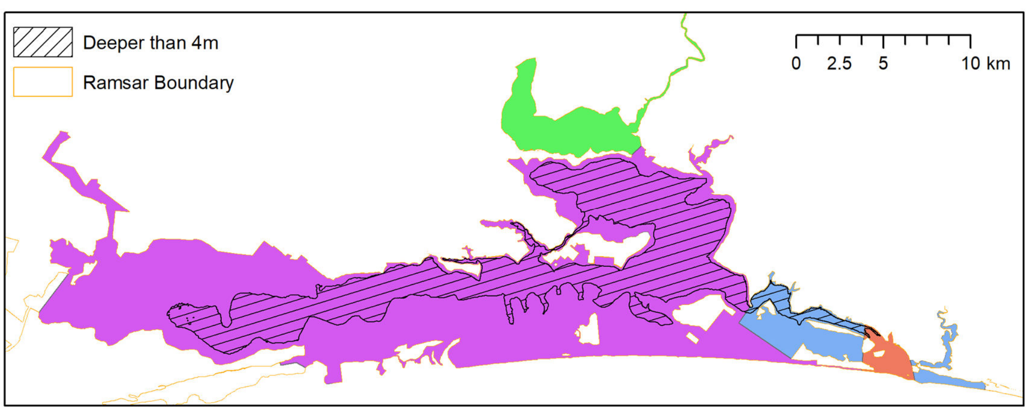

Figure 19. Separate image classification models were trained and run for each of four zones on any sample date to stratify differences in water colour and turbidity. The four maps were then merged.

Mapped outputs were reviewed, and smaller fragments representing < 5 pixels were removed or merged into adjacent mapped areas. A small number of areas that were obviously classified incorrectly were excluded from the final mapping, these were primarily along the shoreline of Bancroft Bay opposite Flannagans and Rigbys Islands where tree shadow into deep water was detected as seagrass. Classification of Jones Bay and near the outflow of the Tambo River was poor on 20/04/2019 due to turbid inflows and these areas were excluded.

The resulting seagrass extents are presented below in Table 8 and mapped in Figure 20 to Figure 23.

Table 8. Seagrass extent 2017 to 2021

	2017	2019	2020	2021
Dense Seagrass	896	920	892	838
Sparse Seagrass	1866	1934	1724	1396
total (ha)	**2762**	**2854**	**2616**	**2235**

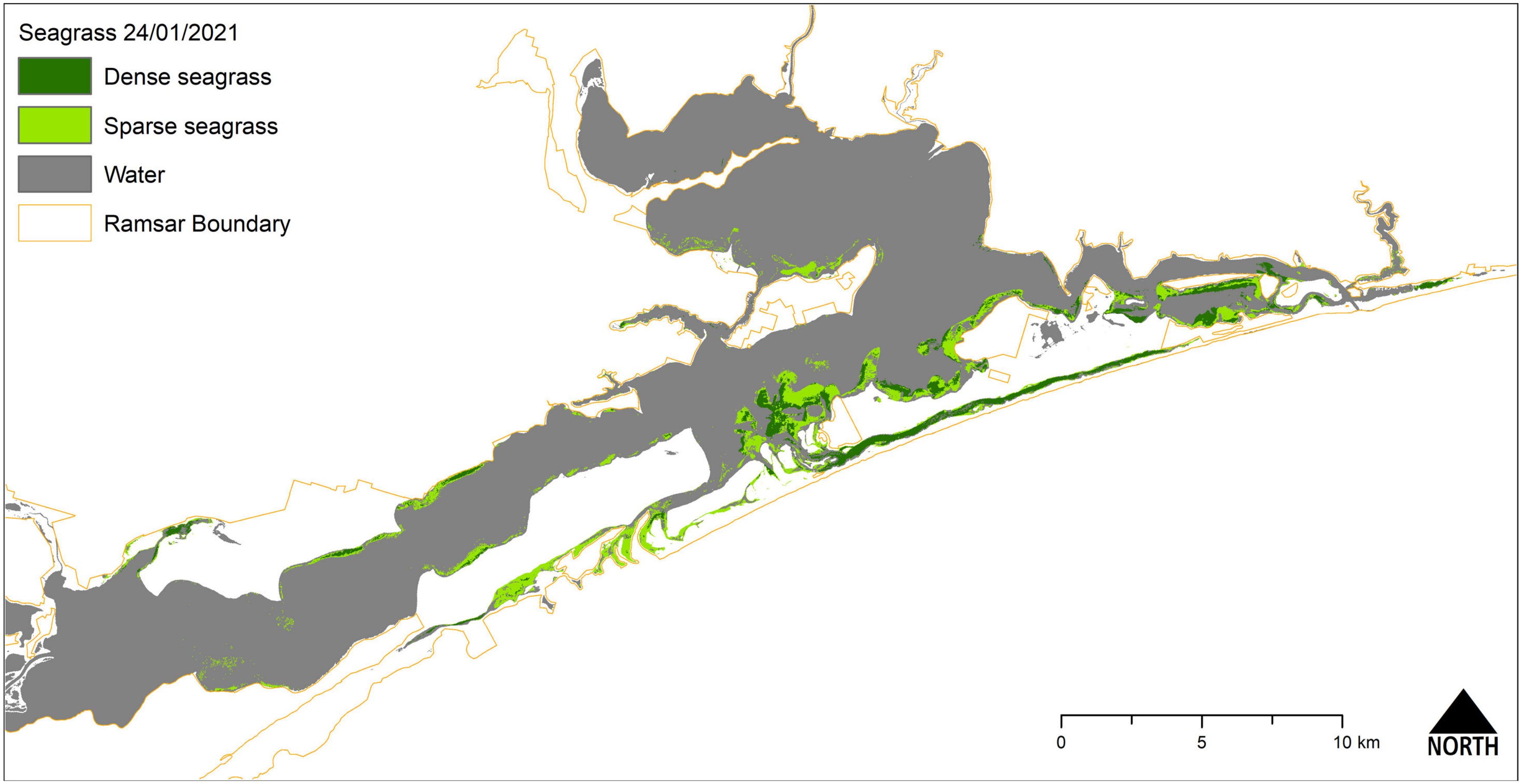

Figure 20: Extent of seagrass in the Gippsland Lakes Ramsar site mapped from Sentinel-2 image 24/01/2021.

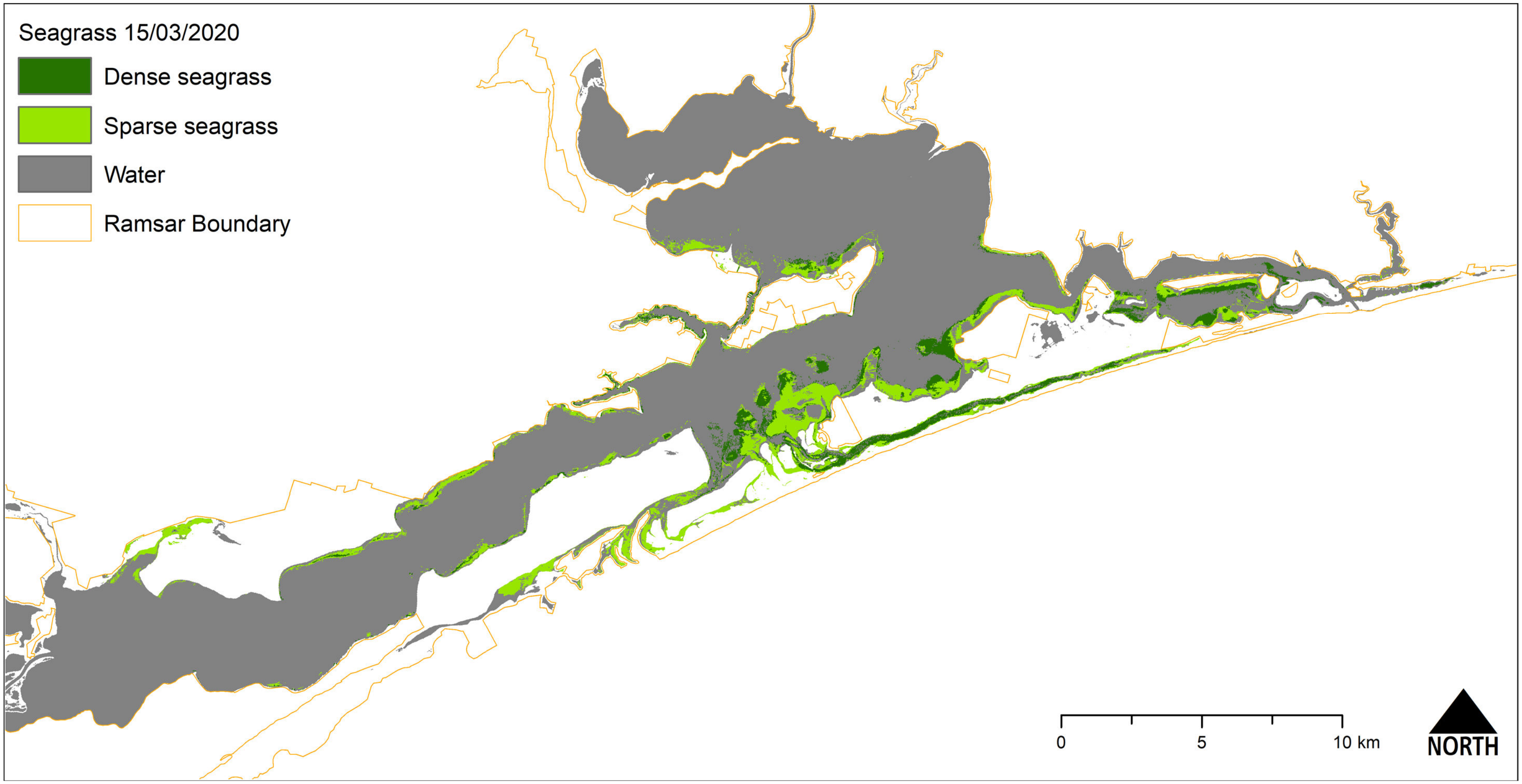

Figure 21: Extent of seagrass in the Gippsland Lakes Ramsar site mapped from Sentinel-2 image 15/03/2020.

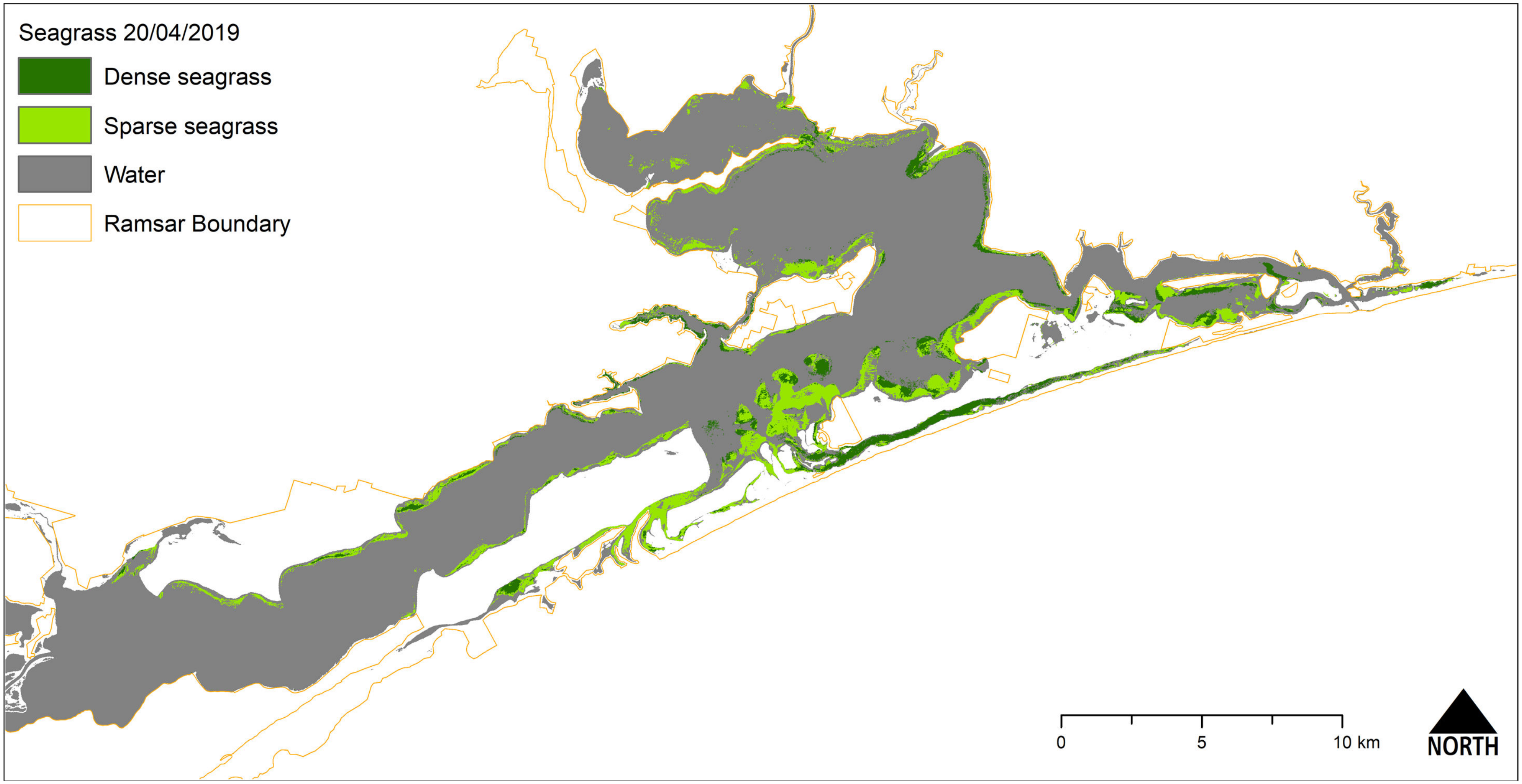

Figure 22: Extent of seagrass in the Gippsland Lakes Ramsar site mapped from Sentinel-2 image 20/04/2019.

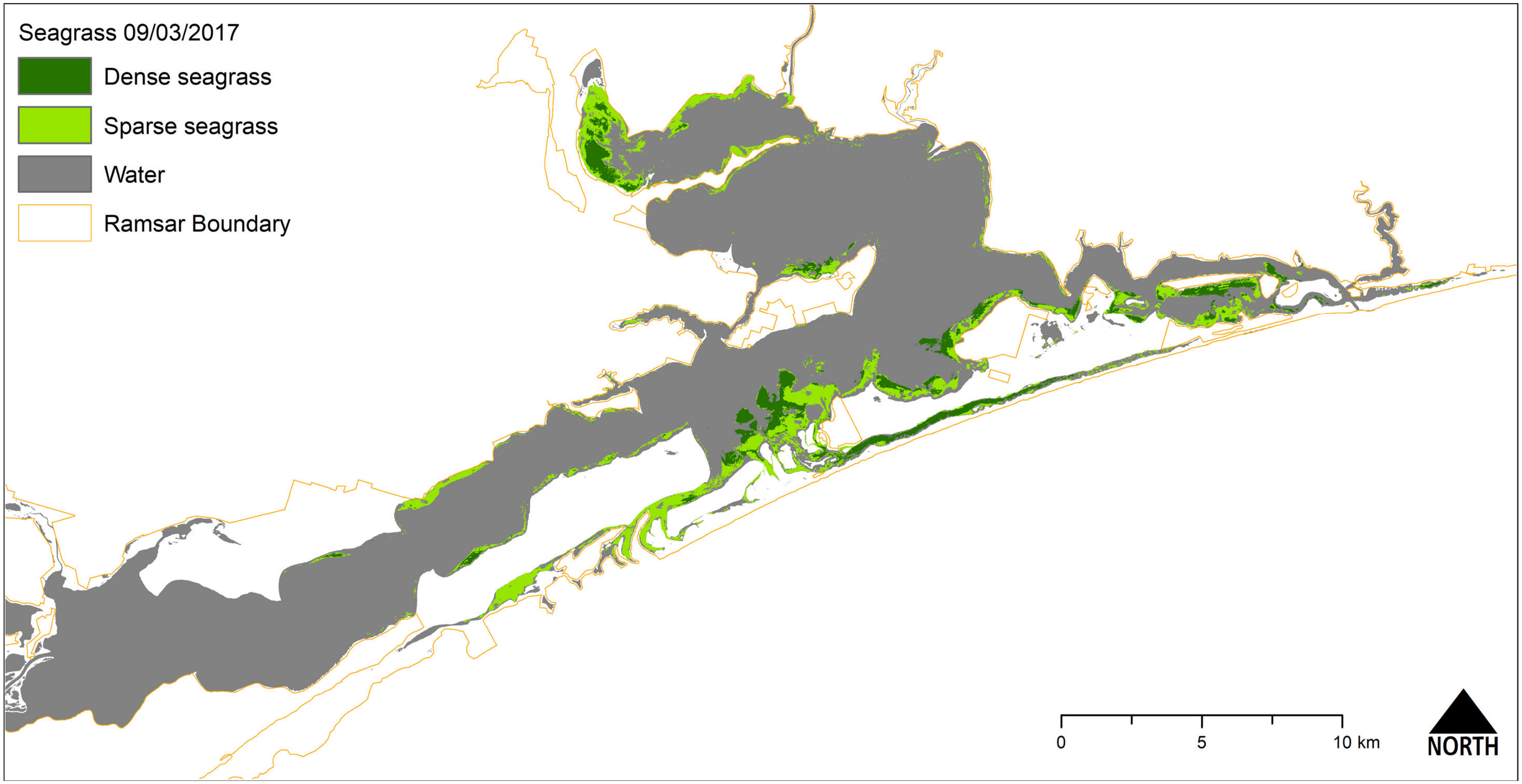

Figure 23: Extent of seagrass in the Gippsland Lakes Ramsar site mapped from Sentinel-2 image 09/03/2017.

Appendix B: Saltmarsh Condition

Condition scores for sites collected n 2019 (Greening Australia) and this study. Note that location and EVC name is not available for the 2019 data.

Location	Latitude	Longitude	EVC	Condition score	Condition category
Boole Poole east	-37.8988	147.8725	Wet Saltmarsh Herbland	100	Good
Boole Poole west	-37.8967	147.8559	Wet Saltmarsh Herbland	100	Good
Clydebank Morass	-38.0314	147.1911	Estuarine Reedbed	85	Good
Flannagan's Island	-37.8899	147.8957	Estuarine Scrub	36	Very Poor
Lake Coleman site 1	-38.1812	147.3146	Estuarine Wetland	43	Very Poor
Lake Coleman site 2 (small island within lake)	-38.1801	147.3180	Estuarine Wetland	85	Good
Lake Coleman site 3	-38.1795	147.3061	Estuarine Scrub	41	Very Poor
Lake Reeve site 1A	-38.3489	147.2160	Coastal Tussock Saltmarsh	95	Good
Lake Reeve site 1B	-38.3499	147.2162	Saline Aquatic Meadow	100	Good
Lake Reeve site 2	-38.1946	147.3908	Coastal Hypersaline Saltmarsh	100	Good
Lake Reeve site 3	-38.2622	147.3231	Coastal Dry Saltmarsh	95	Good
Lake Reeve site 4	-38.0950	147.5264	Coastal Hypersaline Saltmarsh	95	Good
Lake Reeve site 5	-38.0401	147.6133	Coastal Dry Saltmarsh	100	Good
Morley Swamp	-38.0851	147.4263	Estuarine Wetland	100	Good
Rigby Island	-37.8884	147.9497	Wet Saltmarsh Herbland	100	Good
South-east corner of Lake Wellington site 1	-38.1127	147.4237	Estuarine Scrub	36	Very Poor
South-east corner of Lake Wellington site 2	-38.1152	147.4172	Estuarine Wetland	60	Poor
Trouser Swamp, Sperm Whale Head	-37.9822	147.6575	Estuarine Wetland	95	Good
Victoria Lagoon overflow to Lake Wellington (site 3)	-38.0536	147.4581	Estuarine Scrub	36	Very Poor
Victoria Lagoon site 1	-38.0481	147.4411	Coastal Dry Saltmarsh	95	Good
Victoria Lagoon site 2	-38.0473	147.4501	Saline Aquatic Meadow	100	Good
West of Spoonbay Campground	-38.0810	147.4550	Estuarine Scrub	36	Very Poor
Simpson				65	Poor
Backwater morass				70	Fair
Dahlsons Wetland				85	Good
Blond Bay Pig Holes				85	Good
Blond Bay Half Moon				70	Fair

Location	Latitude	Longitude	EVC	Condition score	Condition category
Blond Bay East				95	Good
Dawson Cove				90	Good
Point Fullerton				85	Good
Jones Bay				95	Good
Norgate Point				65	Poor
Bosses Swamp				70	Fair
Ford Nicholson River				65	Poor
Nicholson River East				80	Fair
Reef Point				60	Poor
Slaughterhouse Creek				75	Good
Russells Wetland				60	Poor
Tambo River East				60	Poor
Hillview				85	Good
Howlett				55	Poor
Maringa Creek				85	Good