Dry Creek salt fields
vegetation impact mapping

Department for Environment and Water
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DEW Technical report 2021/14

Government of South Australia

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Summary

In late 2020 dieback of mangrove and saltmarsh habitats south of St Kilda was observed. In 2021, the Department for Environment and Water (DEW) developed a mapping approach based on best available datasets to measure the extent and composition of dieback across the Dry Creek salt fields. This work has been independently reviewed.

Key points: outputs

- **Approximately 24 hectares of vegetation dieback were mapped using new high-resolution multispectral aerial imagery captured in March 2021.**
- **The March 2021 data covers the entire Dry Creek salt fields area and adjacent habitats for the first time.**
- **Hyperspectral aerial imagery captured in January 2021 classified dieback mapping into types: mangrove, saltmarsh, bare ground and water.**
- **The new dieback boundary contains approximately 9 hectares of mangrove; 10 hectares of saltmarsh; and nearly 5 hectares of bare, sparsely vegetated, or aquatic ecosystems.**
- **The dead mangrove area represents 0.45% of the local Barker Inlet mangrove community; the dead saltmarsh area represents 1.4% of the local intertidal saltmarsh community.**
- **No major increase in dieback extent was evident between December 2020 and July 2021.**
- **Small areas of mangrove in poor health are detectable adjacent to the boundary of manual mapping of dead vegetation. The data shows areas of decrease in condition within approximately 50m of the boundary. A Spring recapture of multispectral aerial imagery will monitor this for change.**
- **Mangrove and coastal saltmarsh habitats in this area have shown variation in condition historically due to natural or other drivers.**
- **Historic 1997 mapping shows that saltmarsh adjacent to the Section 2 and 3 salt evaporation ponds were generally degraded or dieback.**
- **March 2021 data shows some patches of saltmarsh mapped as degraded in 1997 have died (e.g., near the mangrove boardwalk), while others require further research to understand current condition.**
- **March 2021 data shows some patches of mangrove mapped as degraded in 1997 (e.g., south of St Kilda) declined further, while other patches (e.g., north of St Kilda) recovered.**
- **Further high-resolution colour infra-red aerial imagery will be captured in October 2021 along with ground observations of vegetation condition.**
- **All new data captured forms a high-resolution baseline for future research on these habitats.**
- **There is high confidence that no major areas of dead vegetation remain undetected based on the integration of new mapping and spectral analysis.**

Key points: revised impact estimates

- **The total impact area estimates reported in January 2021 have been revised down from 45 hectares to 24 hectares based on outputs from the new March 2021 data.**
- **The revised mangrove dieback estimate is approximately 9 hectares, which is 1 hectare less than initially reported, due to different mapping techniques.**
- **The revised saltmarsh dieback estimate is approximately 10 hectares, which is 25 hectares less than the initial estimate due to different mapping techniques.**

1 Introduction

In late 2020 dieback of mangrove and saltmarsh habitats south of St Kilda was observed. In 2021 the Department for Environment and Water (DEW) developed a mapping approach based on best available datasets to measure the extent and composition of dieback across the Dry Creek salt fields.

The summary report presents high-level results and insights from the integrated analysis, while this technical report presents full results, insights, describes methods used and outlines next steps. This work has been independently reviewed. The Online Data Viewer lets users pan, zoom and compare datasets compiled and used in the analyses.

The Dry Creek Salt fields and adjacent coastal ecosystems are situated on Gulf St Vincent, near the northern suburbs of Adelaide (Figure 1). The area includes nearly 2700 hectares (ha) of mangrove and saltmarsh habitats alongside a series of salt evaporation ponds (over 3500 ha) that ceased operation, after many decades of production, in 2014. These habitats have been recognised for their high conservation value and are within the Adelaide International Bird Sanctuary National Park – Winaityinaityi Pangkara (AIBS) and Adelaide Dolphin Sanctuary, as well as Barker Inlet–St Kilda and St Kilda-Chapman Creek Aquatic Reserves.

The area of impact is on the seaward side of the Section 2 ponds where tides inundate the area twice daily via a series of tidal creeks that reach 1-2km into low lying areas (shown in Figure 16, Appendix 1). Mangrove forests occur in the lower elevations (up to approximately 1m AHD) and a variety of saltmarsh plant species occur up to the bunds at the margins of the salt evaporation pans (approximately between 1m and 1.4m AHD). Initial SA Government estimates were based on manual mapping, satellite and limited drone images. Initial indicative boundary mapping of the affected area at a broad scale is shown in Figure 1, initial estimate of the area of impact was around 45 ha (10 ha mangrove and 35 ha saltmarsh).

Department for Environment and Water used a variety of mapping techniques and datasets to more accurately measure the extent of dieback. This report details the results and insights from the integrated analysis. In March 2021 DEW contracted new high-resolution multispectral aerial imagery over the entire salt field area and manually mapped the impacts at a fine scale. Various remote sensing techniques were then used to assess and describe the impact on mangrove and saltmarsh habitats, including other land covers such as bare ground and open water, which are inherent within these settings.

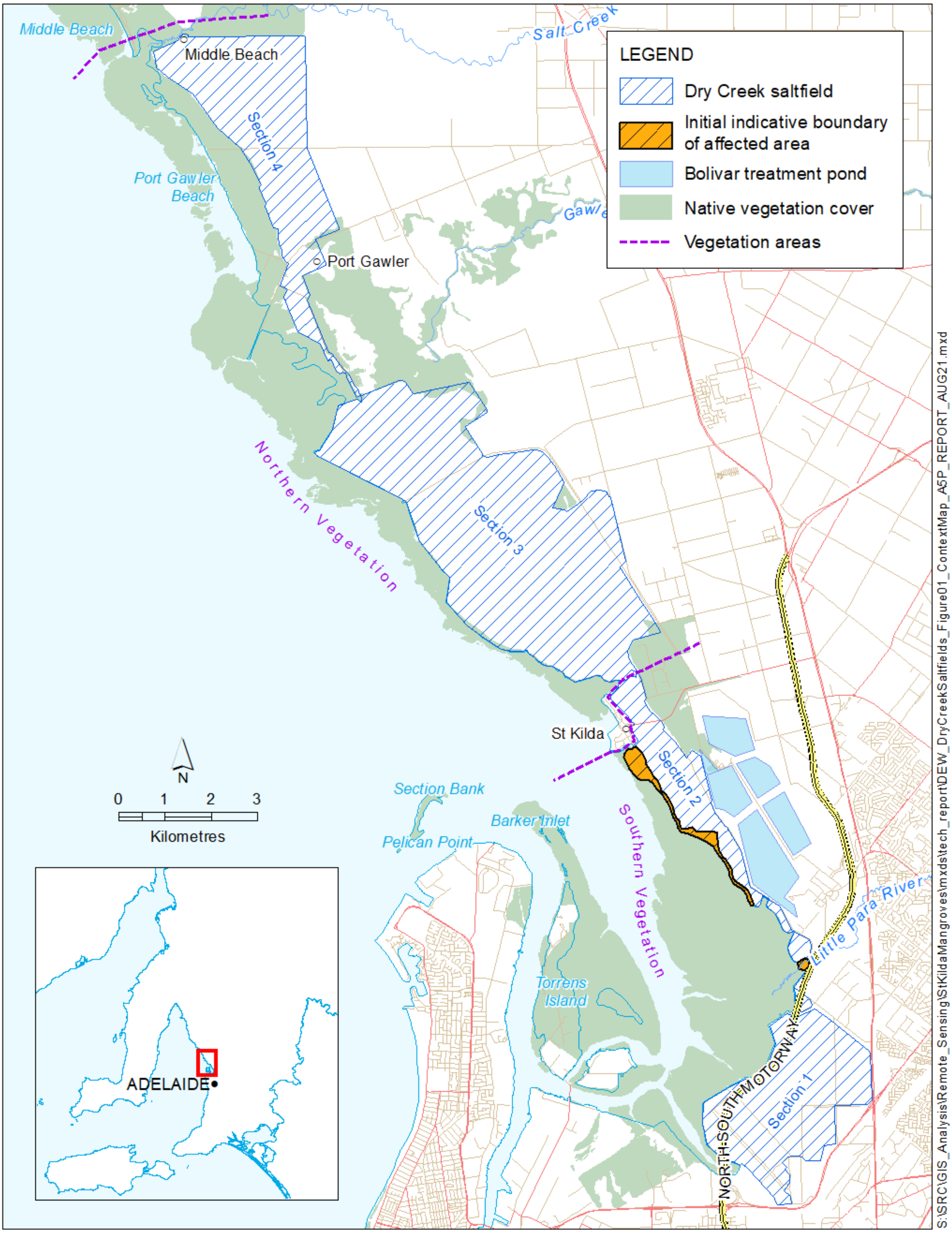

Figure 1 Site map of Dry Creek salt field on Gulf St Vincent showing; limits of the two vegetation areas considered in this report (northern and southern vegetation areas); initial indicative boundary of affected area and location of salt evaporation ponds (sections 1-4).

2 Aim and scope

The aim of this project was to map the extent and composition of recent native vegetation dieback in the area. Satellite images along with recent and new aerial photography were analysed alongside elevation, tide information and ground surveys of vegetation composition and health.

Specifically, the objectives were to:

- accurately map the extent of dead vegetation
- determine and map the extent of vegetation types affected
- compare current status of the vegetation with historic mapping
- inform future monitoring approaches and research investigations.

Description of vegetation related impacts are presented in terms of general vegetation community, which in this region is divided between mangrove areas and saltmarsh areas (see Table 1). Other land cover types (bare ground and open water) are included as they are inherent in these systems.

Vegetation Community	SA Vegetation Mapping Attributes			
	Species Description	Major Vegetation Group	Environmental Description	Vegetation Structural Form
Mangrove Forest	Avicennia marina ssp. marina low open forest over +/-Tecticornia sp., +/-Sarcocornia quinqueflora shrubs	Mangrove	Flats and Plains; Loam to Clay loam	low open forest
Saltmarsh	Sarcocornia quinqueflora, Tecticornia arbuscula, +/-Suaeda australis, +/-Sarcocornia blackiana low shrubland over Atriplex paludosa ssp., Lawrencia squamata, Distichlis distichophylla, +/-Maireana oppositifolia, +/-Samolus repens	Chenopod Shrub, Samphire Shrub and Forbland	Flats; varied soils ranging from heavy clay to loamy sand	low shrubland <1m

Table 1 Vegetation community descriptions from DEW (2021d)

3 Data and methods

The primary aim of this investigation is to describe in map form, the extent and composition of the dieback, which requires recent comprehensive aerial images. Previous mapping of the area then provides a historic understanding of the site for comparison. The resulting compilation of datasets and integration issues helps inform what and where to monitor in the future. Figure 2 shows the broad purpose within the investigation, for which each dataset was used.

This report discusses a range of interpretation issues relating to boundary delineation of dead mangrove and saltmarsh from multispectral imagery. It was determined that extent was most effectively mapped via a manual process of drawing boundaries using various high resolution spectral band visualisations. Composition of vegetation and land covers within that boundary were then identified using a variety of available datasets from multiple sensors. Historic and recent context of the vegetation condition was based on a 24 year old mapping dataset and a series of satellite images.

The range of analyses and data integration was undertaken using ESRI software. Python scripts are used to analyse, process, transform, combine and summarise datasets as needed. Scripting enables transparency and repeatability of methods. In other words, the flexibility to run and rerun analyses and testing of results.

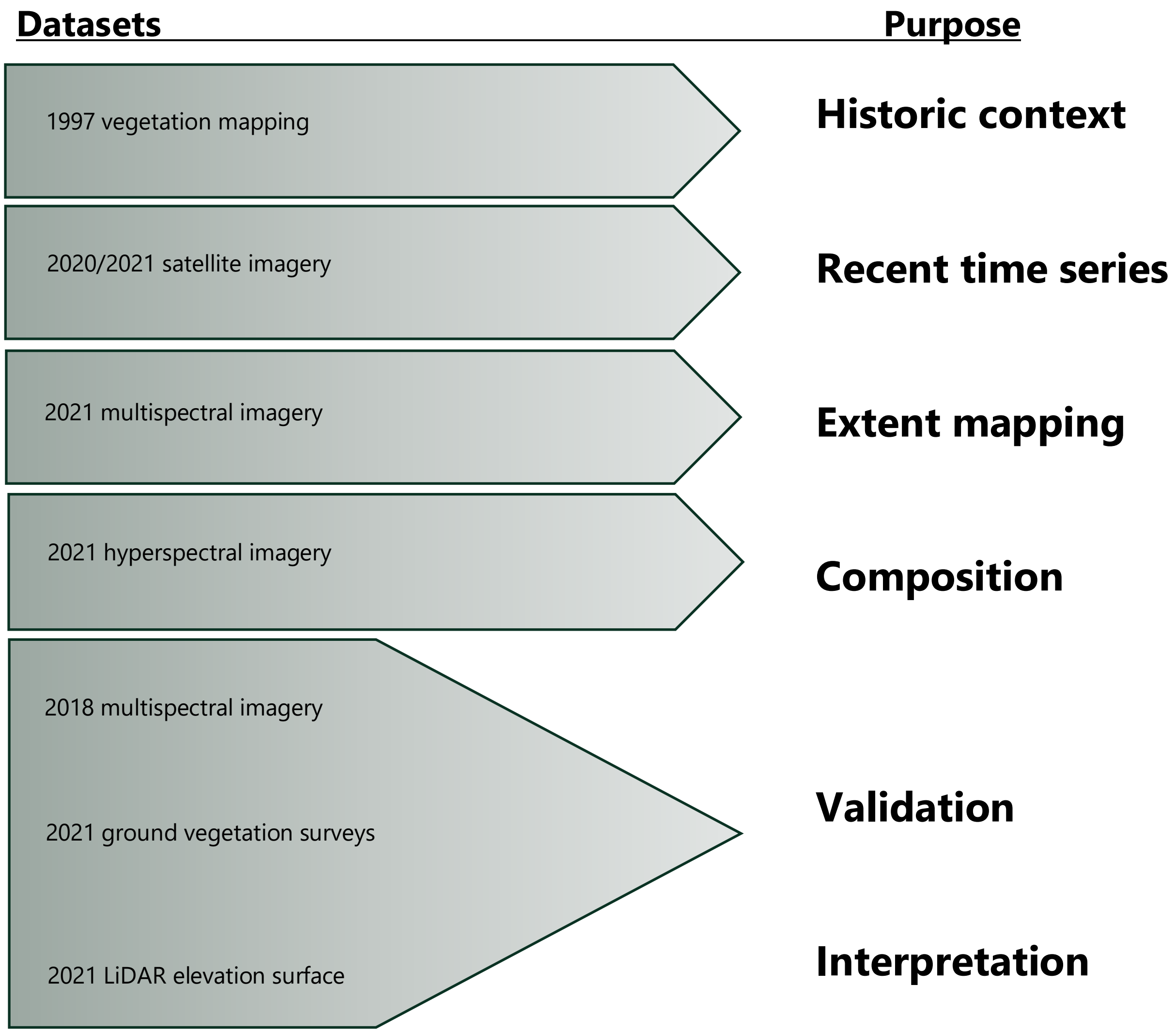

Figure 2 broad purpose for each of the input datasets

While mangrove areas are one of the easiest vegetation types to map from multi-spectral imagery, saltmarshes are one of the most difficult. This is due mainly to the low foliage cover of a range of constituent species and the presence of water. The latter being problematic to control for as tide times vary daily and even though they are predictable, our ability to synchronise capture times with inundation (via satellite or airplane) is quite restricted. In addition, inundation extents in these very flat landscapes, even with high precision elevation data, are a challenge to map. For these reasons, it was decided that instead of an image algorithm approach to delineating dead vegetation, a manual approach for an accurate overall extent would be more fit-for-purpose.

The manual mapping was then compared with hyperspectral and multispectral datasets to validate the boundaries and identify vegetation and land cover composition within. These datasets were chosen as most fit for this purpose on a basis of extent, resolution, re-visit and sensors used.

2021 hyper-spectral aerial imagery dataset (ARA 2021) was processed, tested and found to contribute the best available vegetation / land cover mapping to the analysis. These classes enable a useful description of the components within the mapped dead area derived from a dataset of comparable pixel resolution. The source dataset (DEW 2021a) had originally aimed to test the application of hyperspectral imagery to mapping specific plant species and their condition. Confidence in these kinds of outputs was low overall however this is likely to improve when adequate ground data is included. Despite this, broad vegetation types were found to be the best available source of vegetation mapping. In terms of non-vegetation composition, broad landcover classes with the addition of an enhanced open water class were also best available for the task.

It is acknowledged that a perfect representation of open water areas in a saltmarsh is challenging for the reasons mentioned and more, however this addition more appropriately delineated tidal creek lines and potentially informs future research into the topic. While only available for the section 2 area currently, this data is ideal for interpreting composition of the manual mapping.

This investigation used the following datasets and techniques:

3.1 1997 vegetation mapping

Coastal saltmarsh and mangrove mapping was undertaken in the area in the late 1990s (DEH 2006; DEW 2021d). This manual mapping was undertaken at 1:10,000 scale using 1997 aerial photography (see appendix 2, aerial-1 for specifications). The mapping published in 2006, was completed for the entire coastline of South Australia by the then Office for Coast and Marine (OCM), of the Department of Environment and Heritage (DEH) (see Figure 6Figure 7). Aerial photographs were interpreted based on tone, texture, colour and pattern. Knowledge of tidal processes and the effect this has on landform features of the area and characteristics of plant communities enabled informed decisions to be made concerning the placement of boundaries and appropriate coding. Field validation was undertaken.

At the coarsest level, this data distinguishes between broad vegetation groups. However, with a coastal focus it also infers degree of tidal connection (intertidal, supratidal), presence of acid sulphate soils, and importantly records a condition assessment of the vegetation groups (i.e intact, degraded, dieback). Table 2 details key attributes. Display of the full dataset can be found in NatureMaps (https://data.environment.sa.gov.au/NatureMaps)

Although part of a much larger relatively continuous strip of saltmarshes and mangroves from Adelaide around the top of Gulf St Vincent, the "Barker Inlet mangrove community" was identified as a local vegetation community stretching from Pt Gawler in the north (top of section 3 salt evaporation pans) to Dry Creek in the south.

Tidal Type
Stranded Tidal

Cover
Algal

Integrity
Intact

Supratidal
Intertidal
Non Tidal
Subtidal
Unknown

Bare
Casuarina
Cyanobacterial
Mangrove
Samphire
Samphire +/- Atriplex +/- Grassland
Sand
Seagrass
Seagrass / Algal
Sedges
Vegetated
Unknown

Dieback
Prograding
Degraded
Patchy
Uniform
Unknown

Table 2 vocabularies of 3 key attributes from 1997 mapping (DEH 2006), yellow highlights types of interest to this investigation.

3.2 2020-2021 Satellite vegetation and water indices

The Sentinel-2 satellite platforms are of value to this study owing to its regular repeat visits. Sentinel-2 mission consists of two satellites Sentinel 2A and 2B. Together it is possible to get repeat captures every 3 – 4 days with potential to collect numerous images per month. In practice, cloud cover can obscure part or all of images collected, affecting how regularly data over the salt fields is available, particularly in the winter months. At least one image in each month was acquired for analysis (SARA, 2021).

The repeat visit nature of the Sentinel 2 data provides some broader context around landscape (vegetation and water) dynamics. Albeit at a coarser scale, this data highlights some of the challenges and insights needed when interpreting remote sensing or earth observation data.

Sentinel-2 captures spectral bands that can produce vegetation and water indices at a relatively low resolution of 10m (see appendix 2, satellite-4 for specifications). Sentinel2 Satellite images were downloaded and processed into two time-series of indices:

- vegetation index: Normalised Difference Vegetation Index (NDVI) and
- water index: Normalised Difference Water Index (NDWI)

NDVI is a measure of the state of plant health based on how the plant reflects light at certain wavelengths. The NDVI (Rouse Jr. et al. 1974) was developed as an index of plant “greenness” and attempts to track photosynthetic activity. It has since become one of the most widely applied vegetation indices. It is also based on the principle that well-nourished, living plants absorb red light and reflect near-infrared light. As plants become stressed or “less healthy” the proportion of red light / near infra-red light changes. Stressed or dead vegetation absorbs comparatively less red light than healthy vegetation. NDVI at the pixel level is influenced by photosynthetic activity – related to stress or ‘health’, and canopy/foliage cover relative to exposure of background soil/water.

NDWI operates in a similar way to NDVI, contrasting reflectance/absorption in visible with longer wavelengths. Water absorption at longer wavelengths is the key factor influencing index values (Sagar et al 2017). . Values of both indexes range from -1 to +1.

The two indices were calculated on acquired images (see appendix 3 for formulas), and used to indicate broad change over time in vegetation growth and water levels in evaporation ponds respectivelyTo do this NDVI was thresholded at a value of 0.5, and NDWI was thresholded at a value of -0.1.

3.3 2021 dead vegetation mapping

Captured in March 2021, an aerial image dataset containing 4 spectral bands (see appendix 2, aerial-6 for specifications) was procured across the extent of all 4 sections specifically for this project and provides;

- visual images for manual mapping,
- an index baseline of vegetation condition, and
- an 'after' NDVI image for comparison with pre dieback imagery (see section 3.5)

A manual mapping approach (cartographer drawing boundaries) delineated the extent of dead vegetation based on the above multispectral imagery. On-screen digitising of boundaries occurred at a scale of 1:800. Boundary position was guided by alternating between true colour (i.e. natural colours) and false colour (i.e. where infra-red data is visible) views of the imagery. The NDVI version of this data also aided photo interpretation. Figure 3 shows an example of 1:800 scale on-screen view of false colour data. Note mangrove trees, water in creeks and light coloured bare ground are discernible whereas smaller saltmarsh species in upper part of figure, are less distinct in terms of form and colour.

This approach was performed by an experienced vegetation interpreter and mapped the visibly dead vegetation, Even though such mapping involves subjective interpretation especially at the margins of affected areas, use of a single vegetation digitiser minimised differences between operators. Other team members were consulted to provide quality assurance and review.

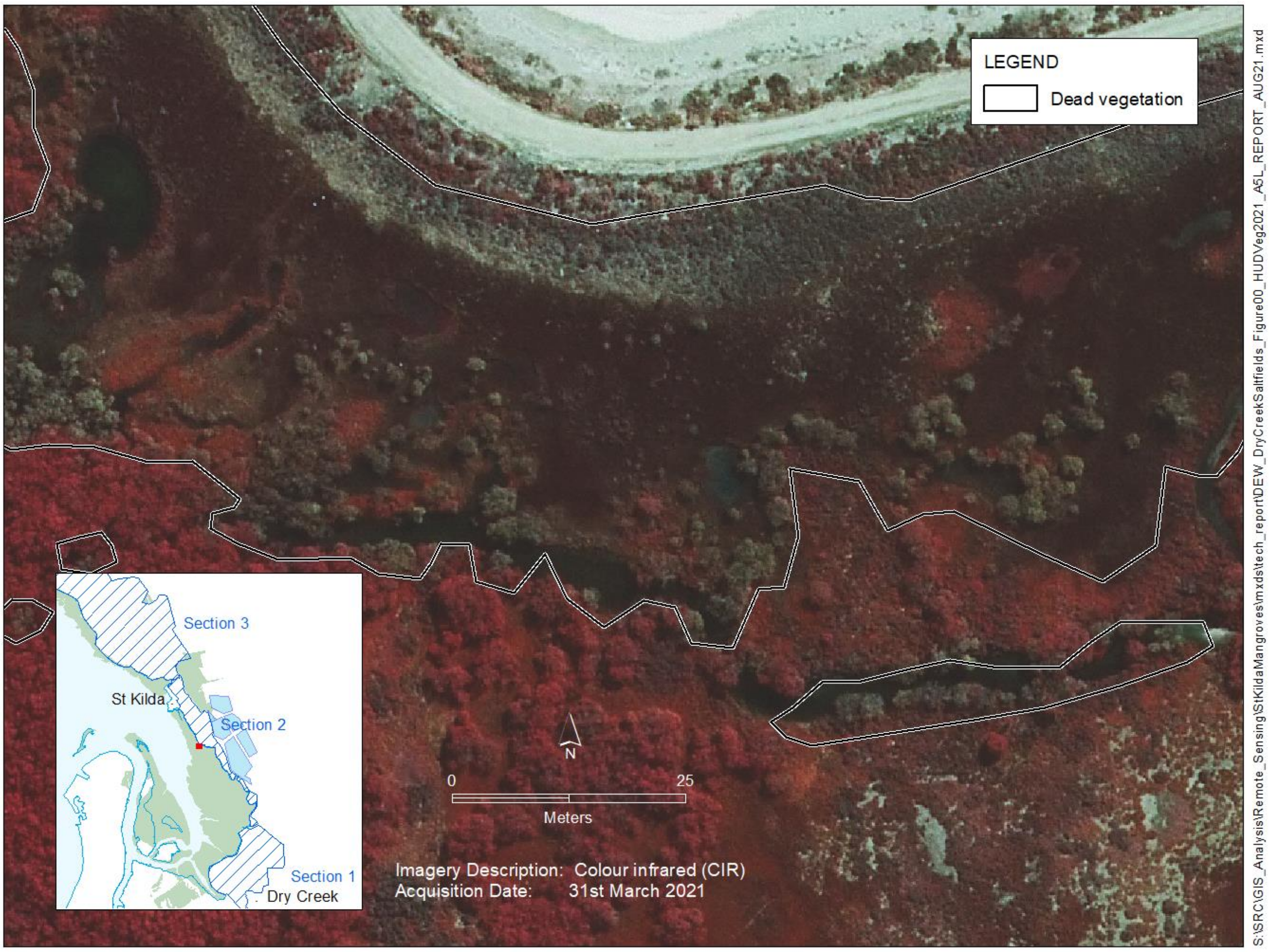

Figure 3 shows use of false colour (infra-red) image to delineate dead vegetation at screen scale of 1:800. Red tones are healthy vegetation, grey tones are dead. Note mangrove trees, water in creeks and light coloured bare ground are visible whereas smaller saltmarsh species are less distinct in terms of form and colour.

3.4 2021 hyperspectral dataset of vegetation types

The source dataset (DEW 2021a) originally aimed to test the application of hyperspectral imagery to mapping specific plant species and further, those in good or poor condition (see appendix 2, aerial-3 for specifications). This analysis was done using an unsupervised classification of the 62 spectral bands. Table 3 shows the resulting analysis classes of that classification. While this produced good species differentiation, the condition results were less accurate indicating further work is needed towards that outcome. Without ground observations for validation, this technique has some testing and development to go before showing confident results as a condition map. In addition, while it is successful in distinguishing between broad vegetation types (i.e., mangrove from saltmarsh),

In terms of land cover, this data again performed well except for open water where it showed a poorer coverage in comparison with 2021 imagery. Visual inspection of the analysis classes revealed an understatement of inundated areas for current purpose in creeks, small flood outs or depressions e.g. missing those areas where water is prevalent for enough of the time that more aquatic than terrestrial plants grow.

Due to tidal inundation, the level and distribution of water in the image is related to the times of capture of any given flight line as well as prevailing wind conditions. While general times of capture for the data are known, local weather conditions and capture times of individual flight lines is not recorded so actual extent of inundation or water influence is not known. After testing a number of methods to make up the shortfall, including addition of low lying areas from new LiDAR data, the most effective way came from adding pixels with NDVI < 0 from the March 2021 multispectral dataset.

So, in order to break down the manual extent mapping into vegetation and land cover components, the analysis classes were grouped as shown below in Table 3.

Data source	analysis class	vegetation/land cover
2021 hyperspectral	heathy mangrove	mangrove
	stressed mangrove	
	dead mangrove	
	healthy samphire	saltmarsh
	stressed samphire	
	dead samphire	
	bare earth	Bare ground
	jarosite	
	open water	water
2021 multispectral	NDVI < 0	

Table 3 shows the original 2021 hyper-spectral dataset analysis classes and the aggregated vegetation / land cover classes used in this study

3.5 2018 to 2021 NDVI change

The March 2021 NDVI dataset was used to inform the dead vegetation extent mapping, however additional information was required to determine which areas of low NDVI do not represent stressed or dead vegetation. An NDVI difference image was constructed from before and after images to assist validation and interpretation of dead vegetation mapping as water, soil and other non-living features also exhibit low NDVI, so must be distinguished from non-vegetated areas when interpreting NDVI outputs.

As described in section 3.3, this project acquired a new 4 band dataset covering the entire salt fields area in 2021. By chance, a 2018 capture (see appendix 2, aerial-2 for specifications) of 4 band imagery across metropolitan Adelaide happened to include the southern vegetation areas and the town of St Kilda (see Figure 4). So, while change detection between 2018 and 2021 could not be done in the northern vegetation section, we were able to create an NDVI difference map (dNDVI) to compare the datasets in the affected area south of St Kilda (Figure 17 in Appendix 5).

Both images were resampled to 20cm pixel size where the images overlap (i.e., all sections 1 and 2, small part section 3) then subtracted to generate the difference map (dNDVI). Resampling aligned pixels in the two images for the calculation. While slight variations in georeferencing result from resampling, they have no impact on any area calculations as this data is mainly used to assist validation and interpretation.

This NDVI differencing technique is best done when the two images have been captured using the same specifications of sensor (e.g., spectral bands, pixel resolution, radiometric calibration). Other ambient factors, more difficult to standardise must also be allowed for to interpret dNDVI (e.g., level of tidal inundation, sun angle and brightness). The two images used here were not captured using the same sensor method and were subject to variation in ambient factors, so care is needed to interpret dNDVI results. In areas of high foliage cover such as mangroves, interpretation is more straight forward, however in saltmarsh areas other factors come into consideration. In addition to areas of low foliage coverage due to leaf morphology of saltmarsh plant species, the influence of saturated or damp soil, presence of tidal flows and algae can lower NDVI values where healthy plants may be.

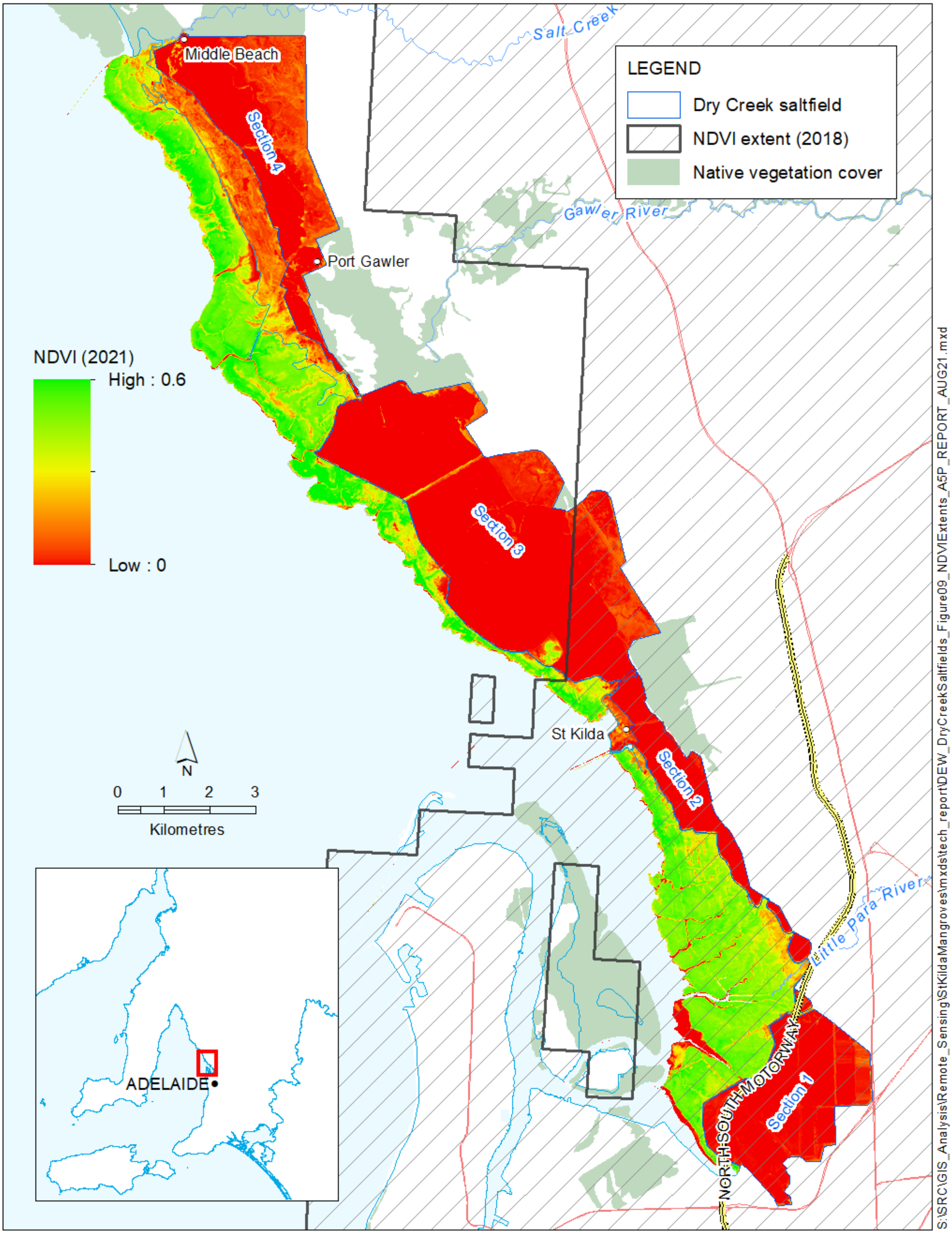

Figure 4 2021 High Resolution NDVI and boundary of comparable 2018 NDVI dataset.

3.6 2021 ground surveys of vegetation condition

With the aim of assisting aerial imagery interpretation, findings of recent vegetation surveys were used to validate vegetation impact mapping. Ground surveys were undertaken at 6 saltmarsh sites (see Figure 16 in Appendix 1) south of St Kilda in April 2021 (EPA, 2021). Transects aligned to EPAs local network of piezometers.

These provided the following in situ observations of ground elevation and plant species including condition. Figure 5 shows an example of how the 3 independent methods are co-located at one site.

a) elevation

Differential GPS methods record elevation (at sub-centimetre accuracy) at every metre. In addition, the distance along each transect of a consistent micro-ecosystem was recorded. I.e. number of metres along the transect before a change vegetation occurs

b) vegetation quadrats

Standard saltmarsh survey method (DEH, 2006) created 11 survey quadrats (30 x 30m) in saltmarsh areas on the seaward side of the section 2 ponds.

c) vegetation quadrat transects

Within each 30x30m quadrat, 2 tape measures forming a north-south/east-west cross were sampled every 60cm to record plant species and status of alive/dead

Ground survey data informs this investigation at multiple scales. Such fine grained floristic composition and condition measures enhance interpretation of NDVI data and validate hyperspectral analyses. This data confirmed the extent of the dead saltmarsh. Overall, plants at transects 16, 17, 18 were in the main dead, and in transects 19, 20, 21 were in a healthy state.

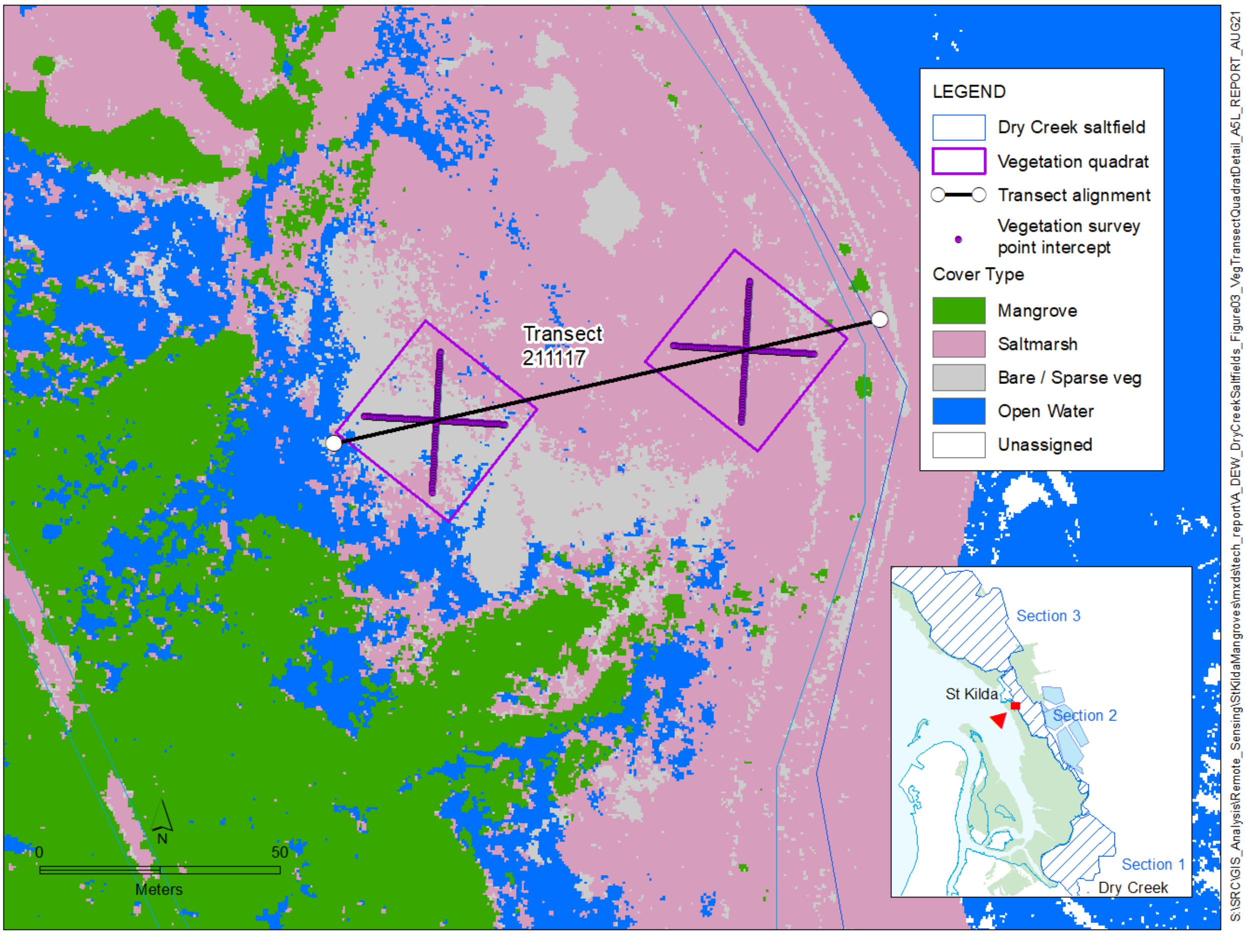

Figure 5 shows transect 17 to illustrate the co-location of quadrats and quadrat transects on elevation transects

3.7 LiDAR elevation surfaces

LiDAR imagery was collected in March 2021 across the same extent as the March 2021 multispectral imagery (see appendix 2, aerial-5 for specifications). It produced 10cm pixel resolution elevation data with vertical accuracy of +/- 5cm (e.g. Figure 16). Such elevation data can produce highly detailed topographic surfaces for drainage mapping, canopy models and broad land cover (DEW, 2021c).

4 Results

This section interprets the 2021 manual mapping through the lenses of the independent datasets, presenting summaries of key data and analysis outputs.

4.1 1997 vegetation mapping

The 1997 vegetation mapping provides an historic context to the condition of vegetation across the entire site. Combining this data with manual mapping provided an upper estimate of dead vegetation association areas due to the coarser scale of mapping produced with 1997 technology. This 1:10,000 scale mapping did not explicitly delineate bare ground and open water within the two main vegetation types.

This data shows distinctions between broad vegetated areas (e.g., mangroves, saltmarshes) at various levels of tidal inundation (e.g., intertidal, supratidal). Appendix 4 shows summary areas (in hectares) of all mapped vegetation groups by their condition grouped into the Northern and Southern Vegetation areas (as per Figure 1). Table 4 shows the same summary limited to the manual mapping area.

1997 mapping + condition	dead ha
Intertidal Mangrove - Dieback	0.3
Intertidal Mangrove - Intact	11.4
Intertidal Samphire - Degraded	9.0
Intertidal Samphire - Dieback	0.1
Intertidal Samphire - Intact	0.5
Supratidal Samphire - Intact	0.1
Chenier / Beach Ridge	0.5
outside mapping	1.5
total	23.4

Table 4 summed by 1997 vegetation type and condition summed within the manual mapping area

This data has captured the condition of the ecosystems at a point in time some 24 years ago. Changes since then are very informative about the pace and scale of change in these plant communities over time.

Figure 6 shows these summarised areas in focus area south of St Kilda. Of note are:

a) two dieback patches not mapped as dead in manual mapping method (see arrows pointing to hatched areas). The 2021 hyperspectral data shows one of these areas as open water among healthy mangrove and the other as bare ground (see matching arrows in Figure 11)
b) 95% overlap between 1997 degraded samphire and 2021 dead saltmarsh

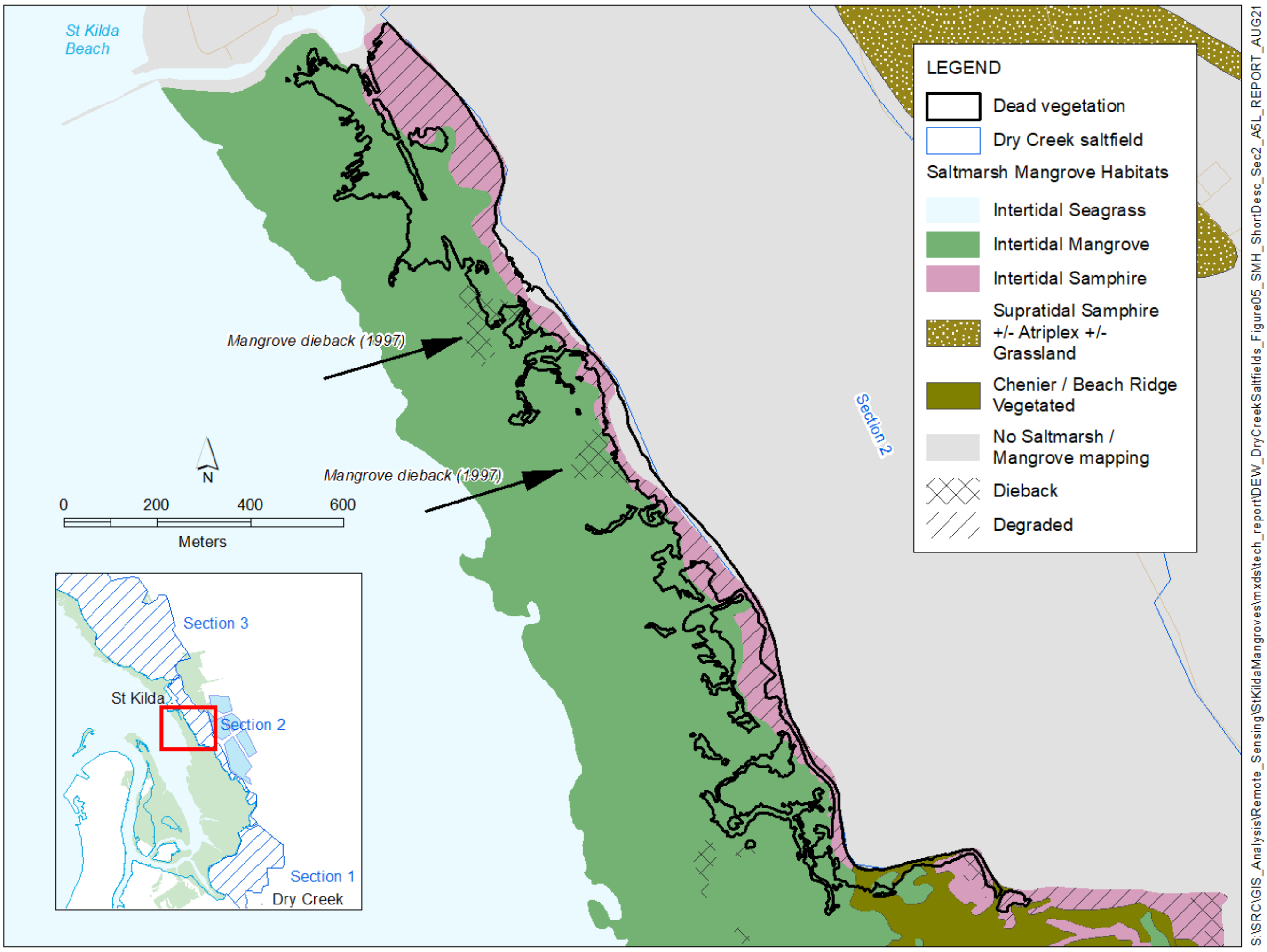

Figure 6 manual mapping area compared with 1997 condition polygons to the south of St Kilda. Arrows indicating areas mapped as mangrove dieback in 1997.

Figure 7 shows the 1997 condition mapping directly to the north of St Kilda. This shows that saltmarsh adjacent to the Section 2 and 3 salt evaporation ponds were generally degraded or dieback in 1997. Figure 15 discusses this further in relation to changes in condition since then.

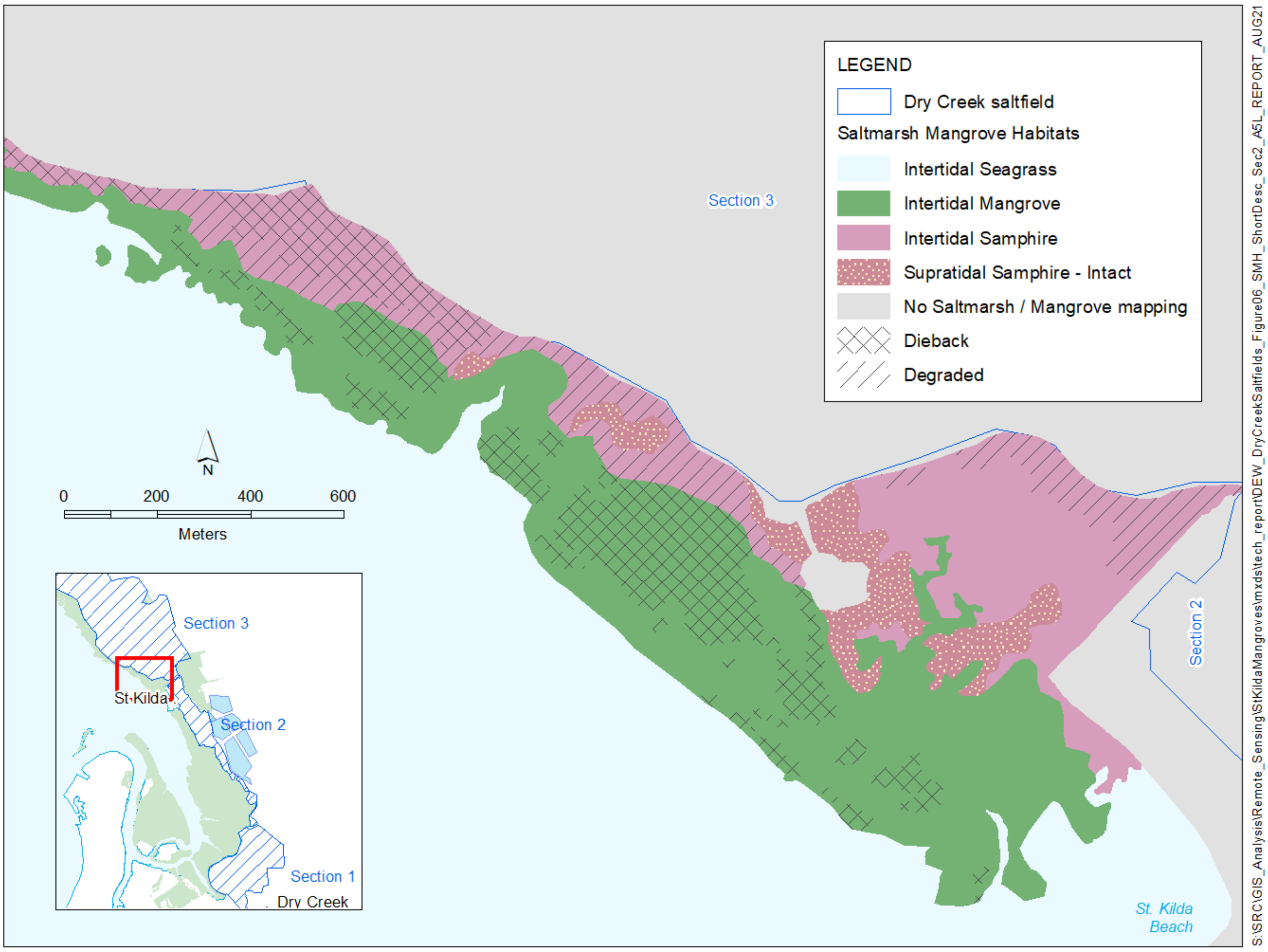

Figure 7 manual mapping area overlying 1997 condition polygons to the north of St Kilda.

4.2 Satellite indices

4.2.1 NDWI - Sentinel Water Index

Sentinel Water Indices show that in December 2019, the northern most ponds of section 2 (PA6 to PA 9) were empty and that from then through to April 2020, they started to fill (Figure 8). This analysis shows only the extent of water at the surface and does not indicate depth of the water. In wetter months, localised rainfall and water pooling at the surface can influence extents mapped by this index.

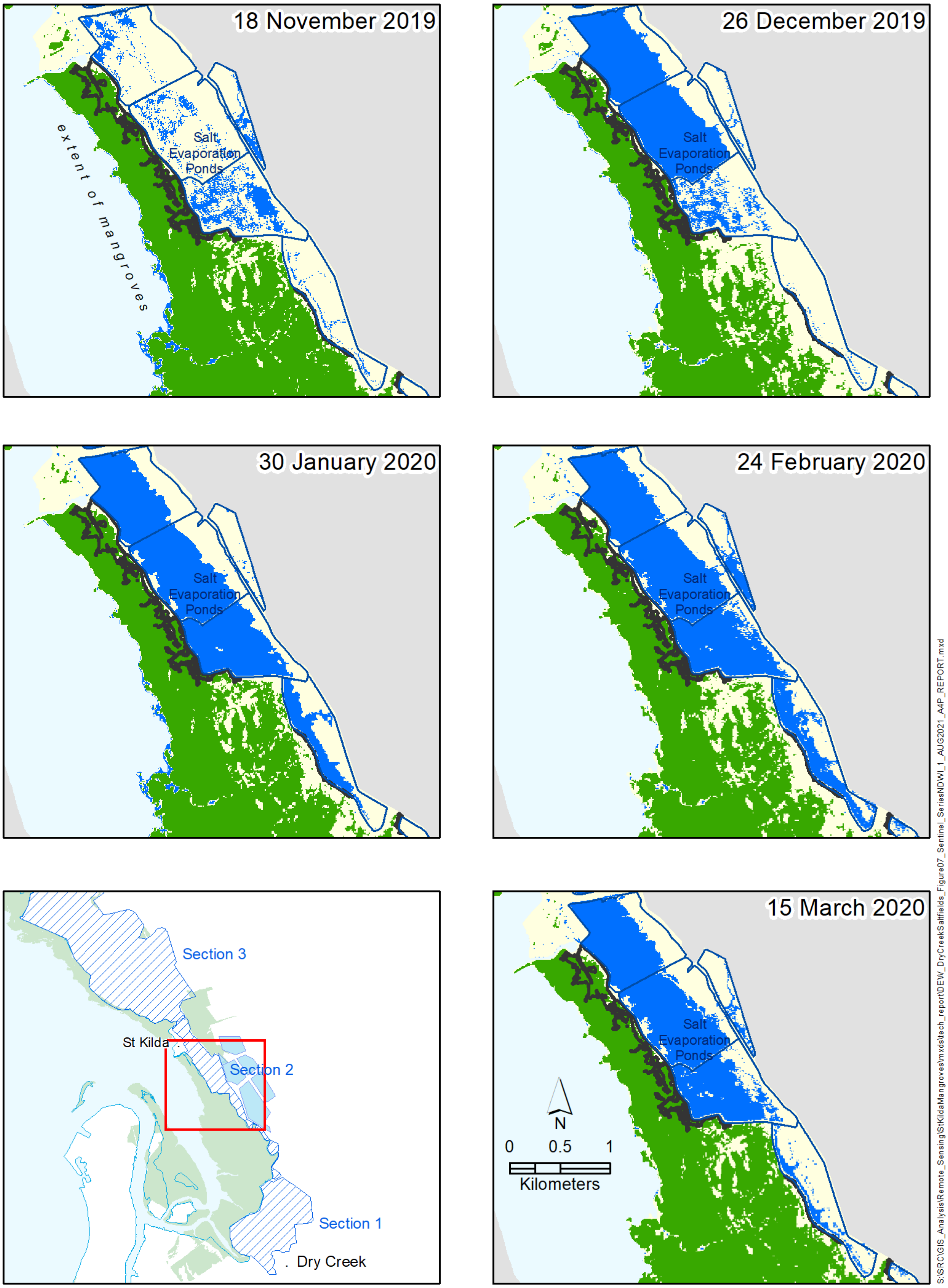

Figure 8 set of 6 frames showing open water in blue within salt evaporation ponds between November 2019 and April 2020. For context, green is high NDVI in the same month. Black line is March 2021 manual mapping of dead vegetation.

4.2.2 NDVI - Sentinel Vegetation index

NDVI maps are shown for the period June 2020 to February 2021 (Figure 9). The expansion of areas below the threshold within manual mapping shows that saltmarsh and mangroves started being impacted around August 2020, increasing in area to the maximum extent mapped around January 2021. Subsequent dates show no further expansion,

Similar to the water indices, interpretation of Sentinel NDVI is affected by the combination of pixel size, threshold value and the influence of surface water and localised rainfall. While the clear impacts of the dieback event on mangrove is evident at this scale, previous months of images show that in the saltmarsh areas, low photosynthetic activity (the subject of NDVI) occurs a) due to dryer landscapes in summer, and b) at higher elevations adjacent to bund walls and in the far south of section 2. This latter issue also suggests continued 'degraded' status of saltmarsh mapping from 1997.

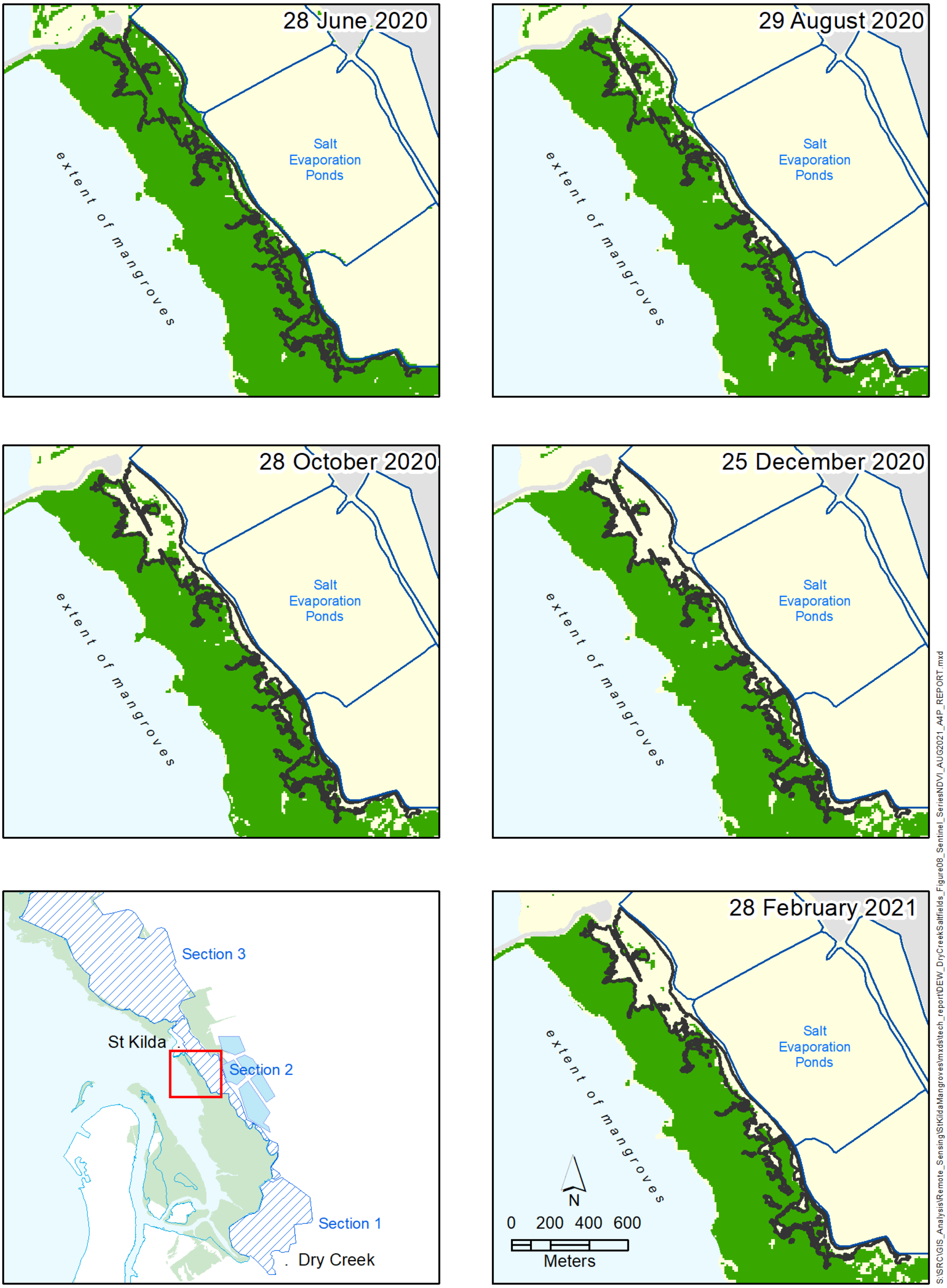

Figure 9 set of 6 monthly frames of Sentinel-2 NDVI between November 2020, and April 2021. Green is areas above the NDVI threshold, yellow is below. Black line is March 2021 manual mapping of dead vegetation.

4.3 Dead vegetation mapping

The manual mapping method identified a total extent of 23.4 hectares of visibly dead mostly vegetated areas (majority shown in Figure 10).

Using mapping derived from 2021 hyperspectral data, this divides into 8.3 ha of mangrove, 10.5 ha of saltmarsh and the remaining 4.6 ha is bare ground and open water.

Using the 1997 data, the manual mapping divides into 11.7 ha of mangrove, 9.7 ha of saltmarsh and the remaining 2 ha covers chenier / beach ridges or is outside the extent. 95% of the now dead saltmarsh area was mapped as degraded or dieback in 1997.

As described in section 3.1, the older mapping is at a much coarser resolution than the hyperspectral data and does not distinguish areas of mostly bare soil or more dominated by aquatic features. So the total area of impact remains the same, but we have a few different ways to describe ecological impacts.

In addition, the two vegetation mapping datasets used to describe components the manual mapping area are useful to interpret the change in NDVI data.

Note that outside the area of Figure 10, there is 1.2 ha of mapped dead vegetation which is included in the 23.4 ha total. These areas occur immediately adjacent ponds 9, 10 and 11 close to bund walls. They were delineated as per the method due to visibly grey (dead) canopies, and can be seen in Figure 14. They are not included in a number of the figures due to scale issues that would inhibit display of the focus area in north of section 2. In addition, as they are so high up in the saltmarsh elevation profile, and areas potential disturbed by bund construction and maintenance, their species composition is unclear.

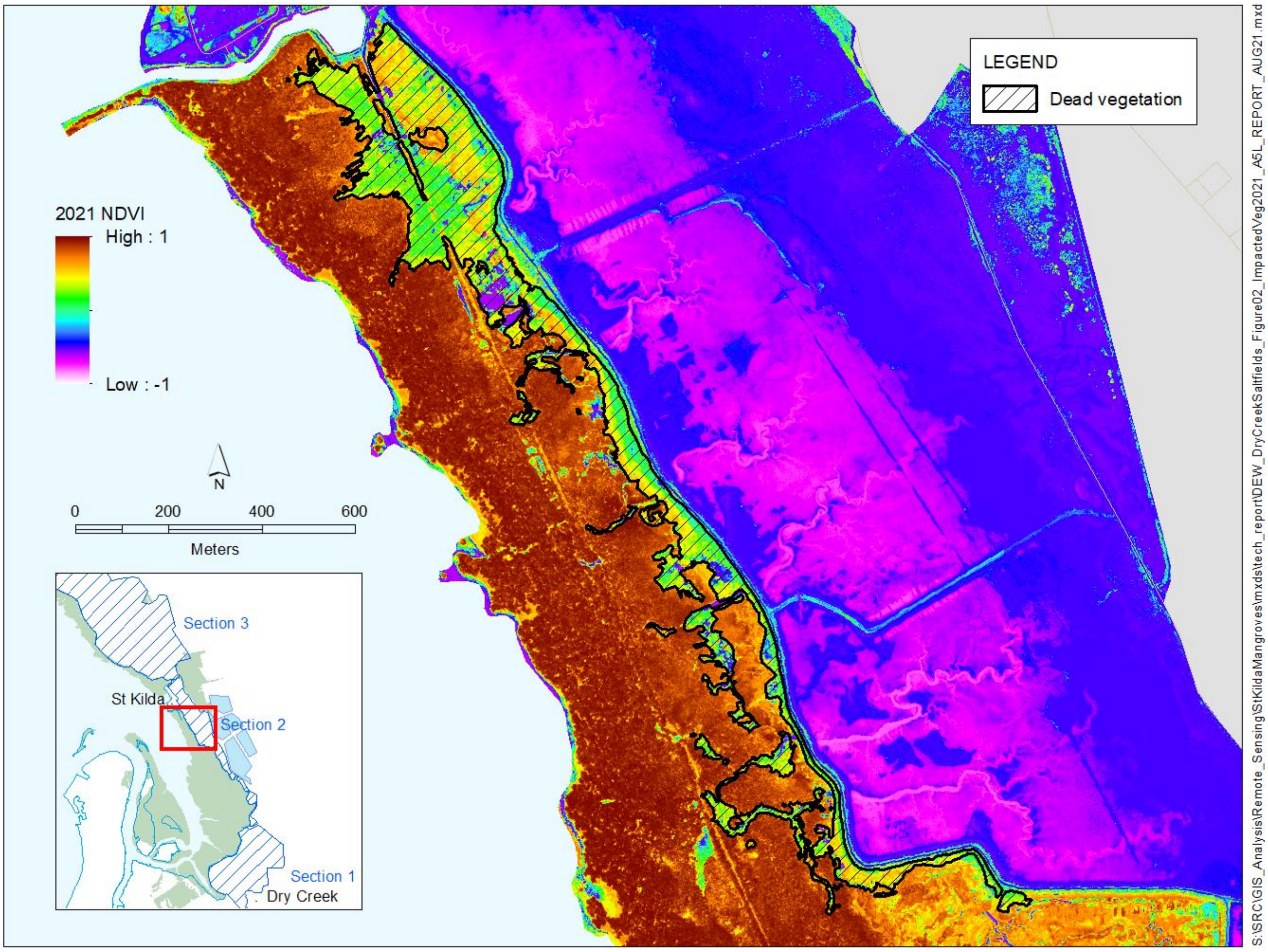

Figure 10 manually mapped area of dead vegetation overlying March 2021 NDVI.

4.4 Hyperspectral vegetation / land cover mapping

As mentioned in section 3, the aim of this mapping is to enable estimation of areas of impacted vegetation in terms of the two major vegetation associations (mangrove and saltmarsh), along with open water and bare ground. Table 5 shows this summary within the manual mapping.

vegetation/land cover	Dead ha
Mangrove	8.3
Saltmarsh	10.5
Bare Ground	1.8
Open Water	2.8
total	23.4

Table 5 manual mapping area summed by vegetation type / land cover from 2021 hyperspectral data.

Matching the above statistics, Figure 11 shows the manual mapping boundary overlying vegetation / land cover classes derived from the unsupervised classification.

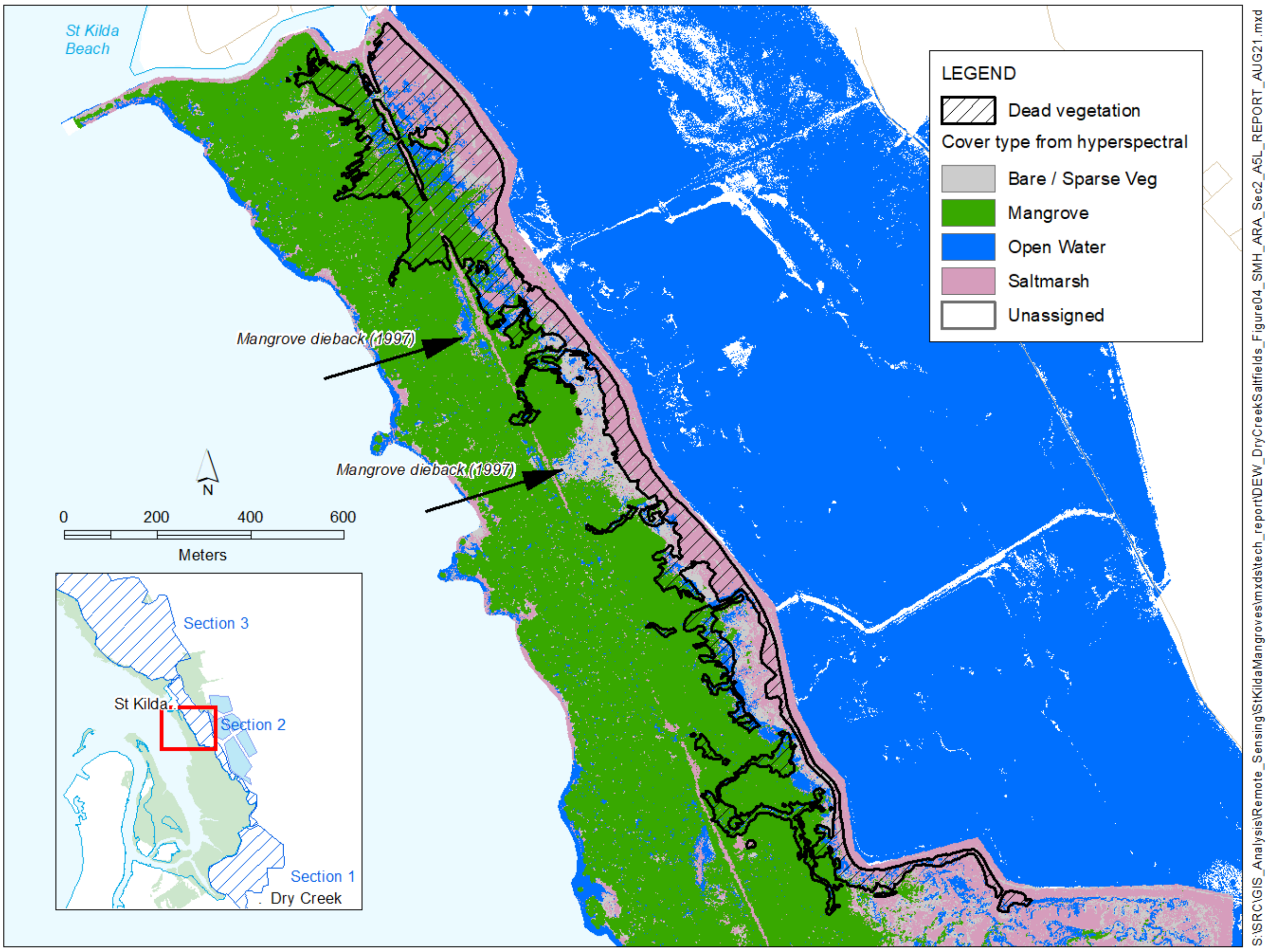

Figure 11 Manual mapped polygon over 4 vegetation / land cover classes derived from 2021 hyperspectral data. This provides the typology for dead vegetation area estimates. Arrows indicating areas mapped as mangrove dieback in 1997.

4.5 2018 to 2021 NDVI change

NDVI change mapping was used to validate and interpret the extent and composition mapping by indicating the magnitude and direction (up or down) of change in plant health.

In mangrove areas, significantly reduced NDVI aligns well with 2021 manual mapping of dead mangrove trees (orange and yellow tones in Figure 12). However in addition, this data shows as a detectable area of reduced NDVI adjacent to the mapped dead mangroves on the seaward side (e.g. see yellow at arrow in Figure 12). This small yet detectable drop in NDVI is evident indicating trees have not yet died, but their reduced condition (lower photosynthetic activity) is clear. This 'front' is commonly around 10m and up to 50m in some places, in advance of the manual mapping.

Slight decreases in NDVI are also seen in small patches within largely healthy mangrove forests further on the seaward side. This is picking up changes at individual tree level, and reflects natural population dynamics. Larger decreases at the very western (seaward) edge may indicate pressures on mangrove health from sea level rise, or edge effects where seagrass and other biota come into play and have been clipped out of this display.

In saltmarsh areas, results are less clear because both rises and falls in NDVI are apparent. This matches discussion in section 3.5 about challenges of spectral mapping of saltmarsh environments.

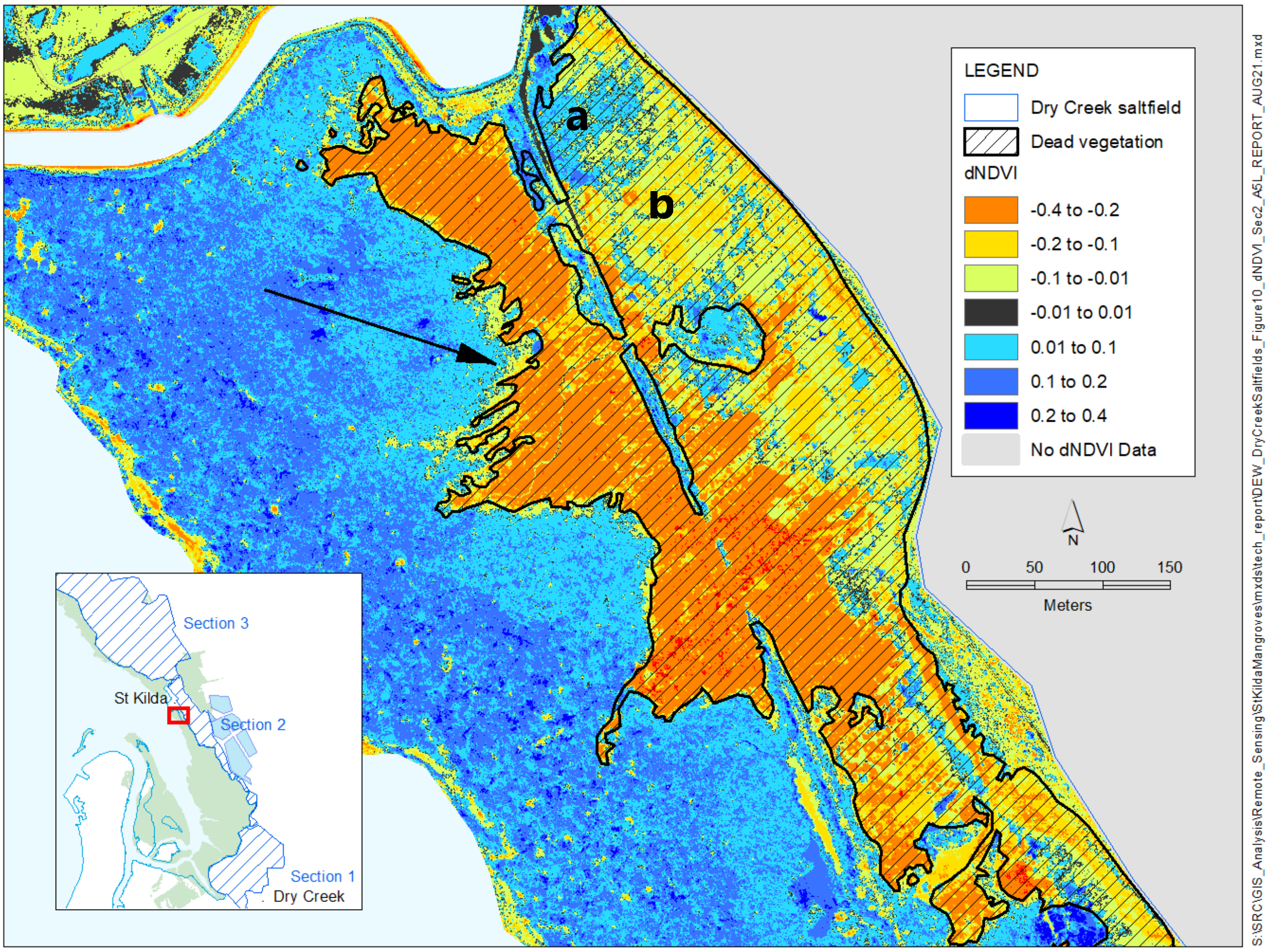

Figure 12 NDVI change mapping (dNDVI) between 2018 and 2021 showing alignment of manual mapping (black outline) with reduced NDVI (orange and yellow tones), plus the conundrum of both a rise in NDVI (blue tones at a) as well as a fall in NDVI (yellow tones at b) within the manually mapped dead saltmarsh.

In the end, this investigation found that a drop of at least 0.2 index units (dNDVI < -0.2) aligned with the manual delineation of dead mangroves, and that a drop of any size (dNDVI <= 0) aligned well with dead saltmarsh delineation from both manual mapping and ground surveys.

The final analysis then, combined the hyperspectral vegetation / land cover types with dNDVI values within the thresholds stated above. Figure 13 and Figure 14 show the resulting dataset classes of *Mangrove NDVI fall* and *Saltmarsh NDVI fall* aligning in extent with 2021 manual mapping of dead vegetation areas. While this investigation has found that a purely NDVI based delineation of vegetation condition does not completely match observed conditions, it has been used in conjunction with ground observations and other remotely sensed images to validate the manual mapping with confidence that no major areas of impact remain undetected.

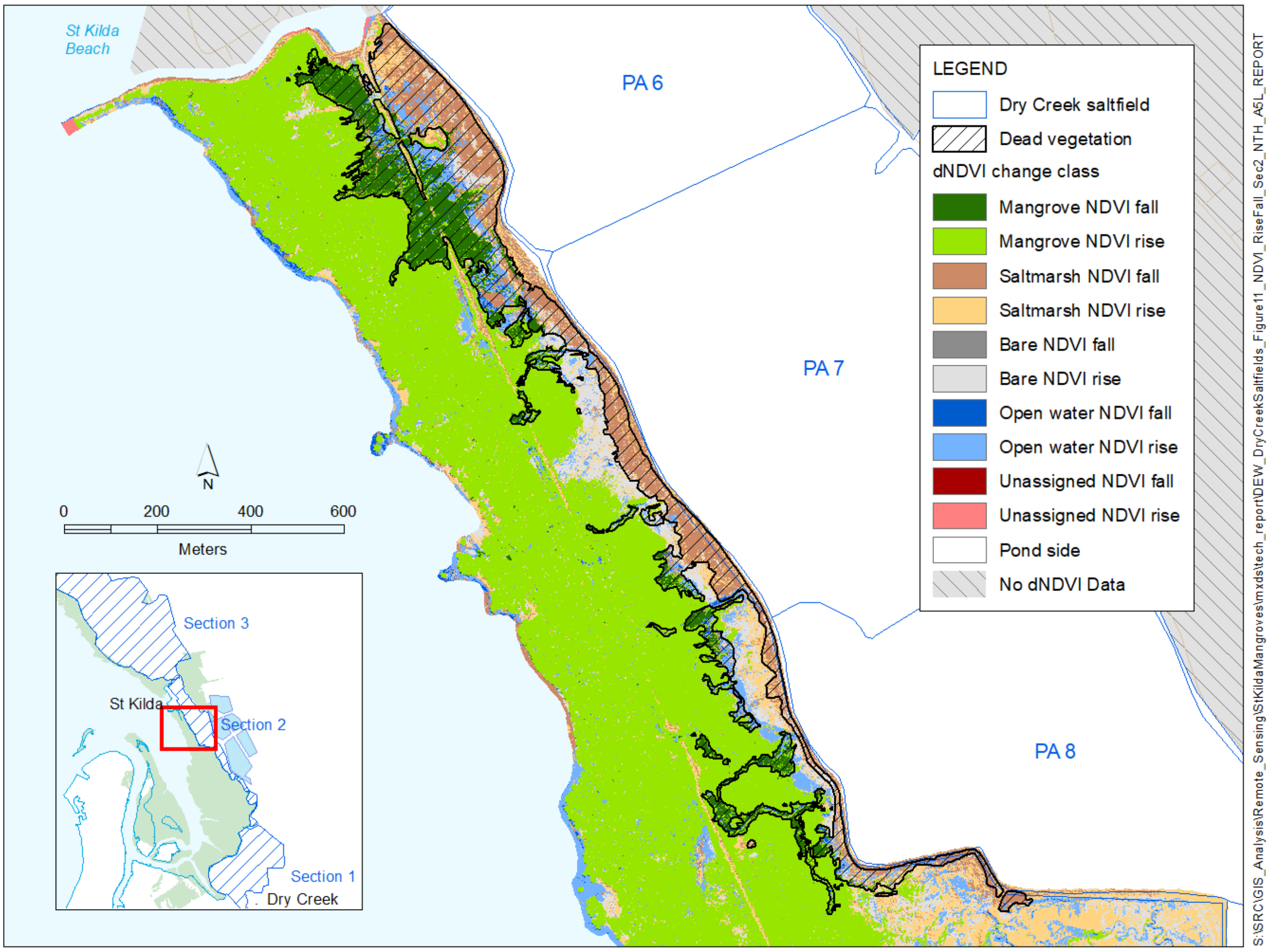

Figure 13 dNDVI thresholded hyperspectral vegetation/ land cover classes overlaid with manual mapping in northern parts of section 2.

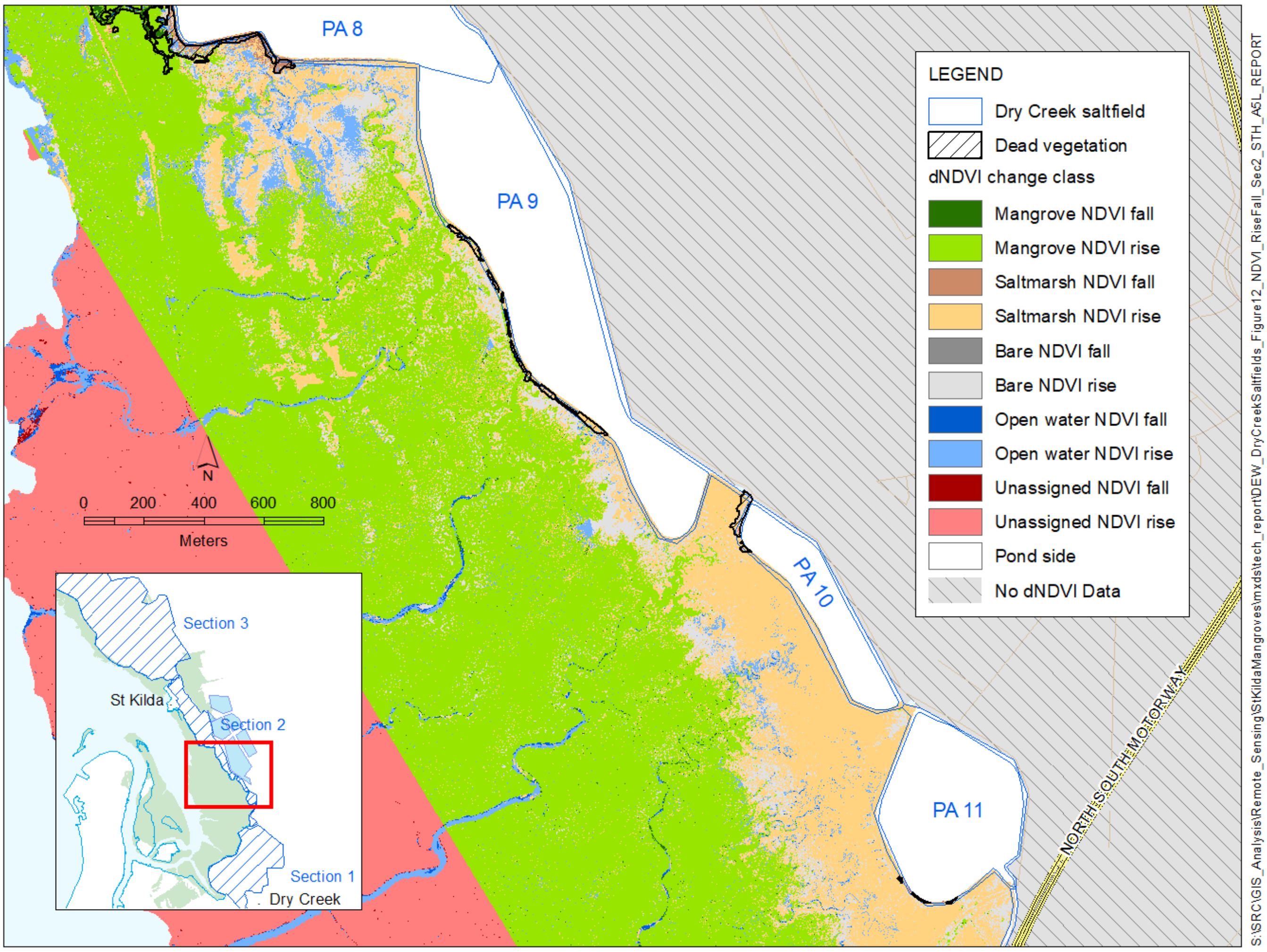

Figure 14 dNDVI thresholded hyperspectral vegetation/ land cover classes overlaid with manual mapping in southern parts of section 2.

4.6 LiDAR terrain model

It is evident that drainage pathways at and below the surface influence plant health and therefore NDVI values. For example, change in NDVI values near the mangrove trail suggest that transport of the hypersaline groundwater through the mangroves has been enabled by surface creeks and retarded by elevated ground.

A second example within saltmarsh in northern section 2, is where areas of slightly higher ground appears associated with 'islands' of healthy mangroves.

5 Discussion

In this section, the condition of vegetation to the north and the south of the township of St Kilda are discussed in terms of the data compiled. The data shows that southern vegetation adjacent to sections 1 and 2 ponds (see Figure 1) is where the most significant impacts can be seen from recent events. Northern vegetation (adjacent sections 3 and 4) shows no signs of recent decline in mangrove condition yet is data-poor in relation to recent condition of saltmarsh areas despite a highly informative baseline mapped in 1997.

5.1 Southern vegetation

In the late 1990's the entire coastline of SA was mapped to delineate coastal saltmarsh and mangrove habitats (DEH, 2006). The 1997 vegetation mapping for this area mapped 1,963 ha of mangrove and saltmarsh habitats south of St. Kilda. Nearly 1,900 ha of these habitats were mapped as being healthy, with a further 65 ha (3%) being mapped as in poor condition. This was mapped from contact aerial photography prints by hand at the time and is partly displayed in Figure 6.

Between June and December 2020, time series satellite data shows a significant drop in NDVI adjacent to section 2 ponds in both mangrove and saltmarsh areas (Figure 9). These impacted areas align with both 2021 manual mapping and high resolution NDVI change mapping. The time series shows that the area of impact within mangrove areas did not expand between December 2020 and February 2021. This was the case through July 2021, and will be monitored again in October 2021.

The high resolution NDVI difference mapping between 2018 and 2021 (dNDVI) provides more detail. In mangrove areas, significantly reduced NDVI aligns well with 2021 manual mapping of dead mangrove trees (orange and yellow tones in Figure 12). In addition, a smaller yet still noticeable drop in NDVI is evident just on the seaward side of the 2021 mapped boundary of dead trees. In this area, trees have not yet died, but their reduced condition (lower photosynthetic activity) is clear. This band is commonly around 10m and up to 50m in some places, in advance of the manual mapping (see arrow indicating yellow pixels between orange and blue tones on the seaward side of black line in Figure 12).

The fate of some 0.3 ha of mangrove dieback in 1997 mapping, is also of note as it is outside the main 2021 manually mapped dieback area. The arrows in Figure 6 indicate these old dieback areas. The northernmost indicated area shows regrowth and emergence of open water, while the southernmost indicated area has regressed further to predominantly bare soil (see Figure 11). Figure 6 also shows that the approximately 10 ha of dead saltmarsh aligns almost completely with the approximate 10 ha of degraded samphire mapped in 1997.

In saltmarsh areas, inconsistent NDVI values in relation to condition as discussed in the technical report are problematic to resolve. It is for this reason that NDVI change mapping is not used as a method to delineate saltmarsh that has died since 2018. However in the form of dNDVI it is used to validate 2021 manual mapping (see Figure 13 and Figure 14). A dNDVI fall of more than -0.2 describes the edge of dead mangroves, and any fall in NDVI (dNDVI < 0) aligns well with the edge of dead saltmarsh in the manual mapping and ground survey observations.

In addition, dNDVI at pixel level can be highly informative when considered in conjunction with other datasets. For example, a comparison with elevation data suggests that topographically driven drainage and flushing across tidal flats and creeks impacts NDVI values, and therefore dNDVI. Ground observations of species composition and plant health helps to interpret NDVI values and also explain why a single threshold approach across an image cannot be used to determine extent of impact. This is illustrated in Figure 12 by the conundrum of both rises in NDVI (blue tones at a) as well as falls in NDVI (yellow tones at b) within the manually mapped dead saltmarsh validated by ground survey.

The final analysis then combined the hyperspectral vegetation / land cover types with dNDVI values within the thresholds stated above (-0.2 for mangrove and 0.0 for saltmarsh). Figure 13 and Figure 14 show the resulting dataset classes of *Mangrove NDVI fall* and *Saltmarsh NDVI fall* aligning in extent with 2021 manual mapping of dead vegetation areas. Vegetation survey data also affirmed where the dead saltmarsh extended to. Overall, plants at transects adjacent ponds PA6, 7 and 8 were in the main dead, and in transects adjacent ponds PA9, 10 and 11 were in a healthy state.

While this investigation has found that a purely NDVI based delineation of vegetation condition does not comprehensively match observed conditions, it has been used in conjunction with ground observations and other remotely sensed analyses to validate the manual mapping with confidence that no major areas of impact remain undetected.

5.2 Northern vegetation

Of the 1,390 ha of saltmarsh and mangrove habitat mapped north of St Kilda in 1997, more than 1,200 ha was mapped as healthy, with around 10% (61 ha of mangrove and 67 ha of saltmarsh) in poor condition (impacted or dieback, see Appendix 4). In addition, this area recorded 209 ha of degraded chenier/beach ridges, which has mostly been used as a recreational off-road track for many years.

Between June and December 2020, time series satellite data in this area shows high NDVI across all mangrove areas, indicating no loss in condition over that time. A single NDVI image derive from the newly acquired March 2021 aerial imagery (Figure 4) concurs with the satellite-derived NDVI data in showing high NDVI values in mangroves. There is no 2018 NDVI over this area to compare with, except for the small area shown in Figure 15, south of XB8a. However, comparing the 1997 mapping with the March 2021 NDVI imagery found that, in some areas, mangroves mapped as in poor condition in 1997 are now healthy (see Figure 15 where 1997 dieback has blue tones in 2021).

Saltmarsh areas show varying NDVI across their range, in both the satellite derived data and the March 2021 NDVI image. The dNDVI image in Figure 15 shows the edge of NDVI change mapping and in saltmarsh areas, generally shows small rises in NDVI (blue tones) but also some falls (yellow tones). The 2021 aerial photograph shows that most of that saltmarsh is now bare soil with no vegetation. Without further detail to explain, this appears to challenge the general blue tone results from dNDVI.

Where there is no dNDVI (west of pond XB8a), there is saltmarsh and mangrove mapped as degraded and dieback in 1997. Aerial photography comparisons between 1997 and 2021 show improvement in many mangroves of these areas but are less able to inform a condition assessment of the saltmarsh areas without ground survey validation.

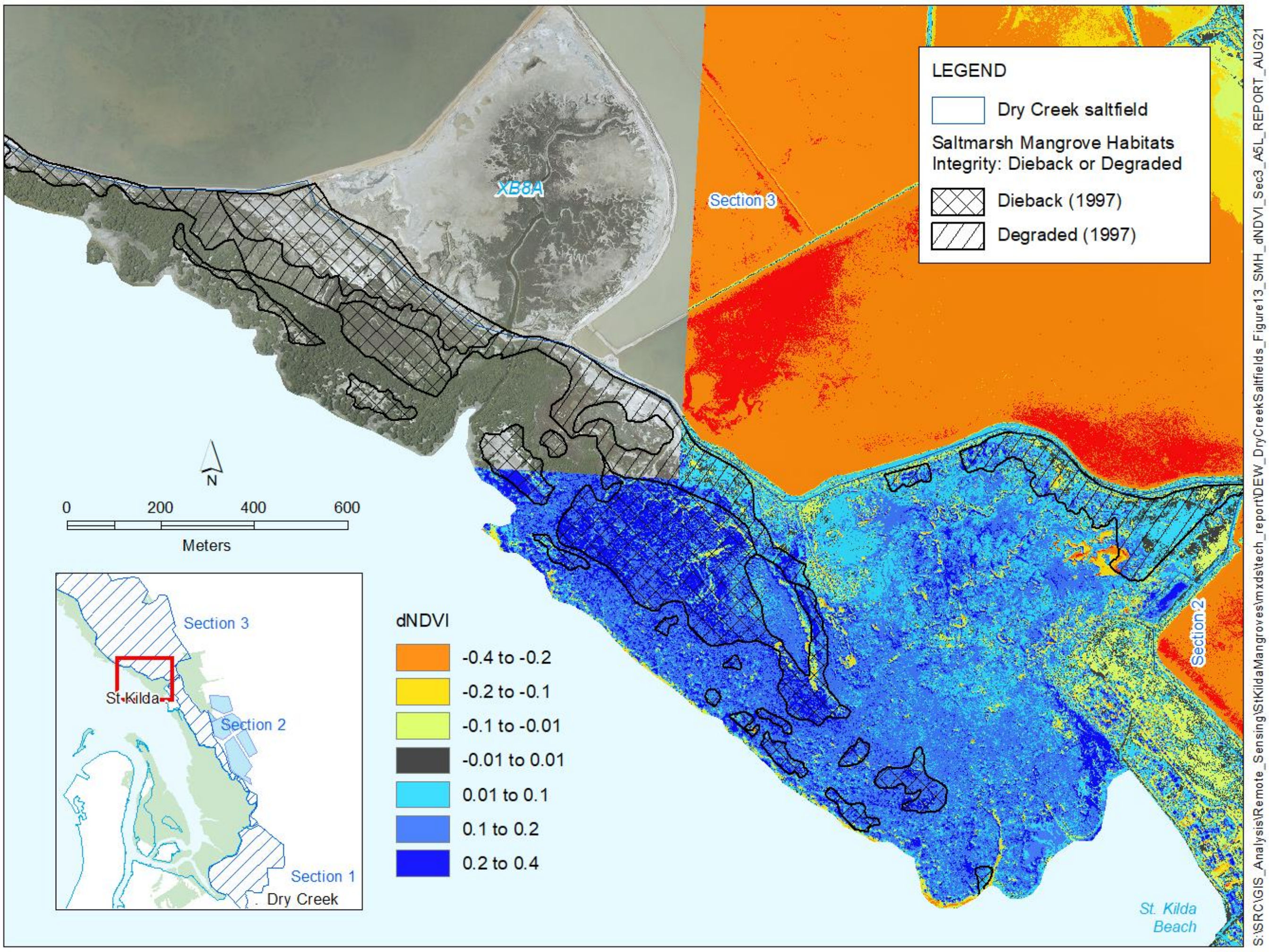

Figure 15 1997 polygon mapping in area immediately north of St Kilda. Refer to figure 7 for type.

6 Conclusion

In conclusion, we have used a variety of mapping techniques and datasets to determine that overall severe impact from the section 2 ponds refilling has been approximately 24 hectares. This can be represented as over 9 ha of mangrove, over 10 ha of saltmarsh and nearly 5 ha of bare, sparsely vegetated, or aquatic ecosystems.

In addition to this we have compiled a series of datasets that demonstrate a dynamic and naturally varying coastal ecosystem. Patches of dieback, large and small, appear and sometimes recover within an area of over 3,000 ha of mostly healthy mangrove and saltmarsh. However, there is a pattern of poor, degraded or dead saltmarsh adjacent to the salt evaporation ponds in sections 2 and 3.

New data acquisitions have captured a high-resolution baseline across the entire site for the first time. Comparing this with a spring recapture both from the air and on ground will be a valuable addition to the many research projects currently underway in the area.

6.1 Next steps

This project has captured a new 4 band imagery baseline for the whole site which will be repeated using exactly the same specifications in Spring (October) of 2021 to monitor future change.

Recommendations from these results will inform the aerial and ground monitoring approach concerning changes in vegetation condition and their relation to surface and groundwater movements.

Datasets from this and future monitoring will be made available to researchers as contribution to understanding these ecosystems, monitoring technologies and advising management actions.

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Appendix 1

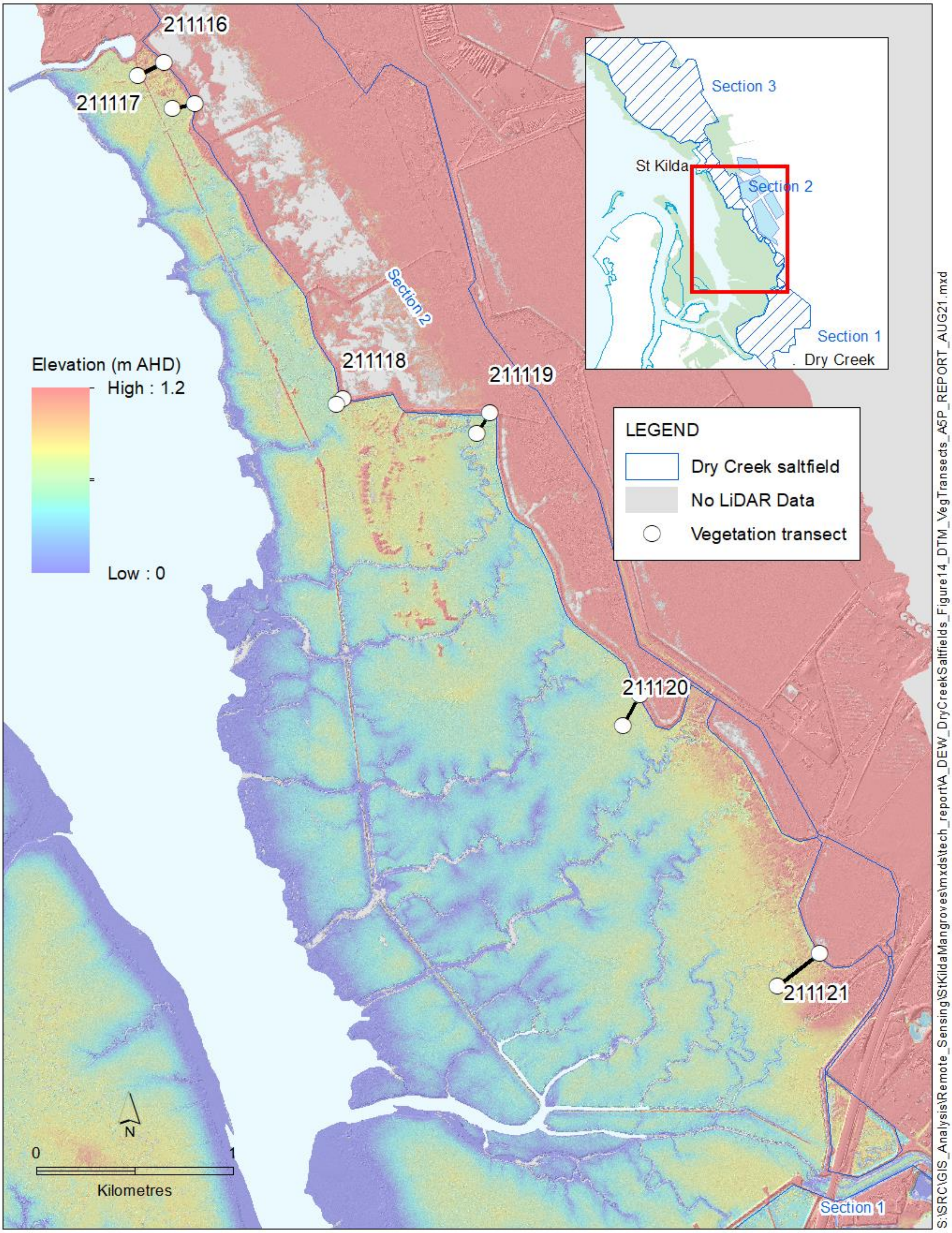

Figure 16 elevation map of saltmarsh and mangrove areas adjacent to Section 2 evaporation ponds, also showing location of 6 vegetation transects.

Appendix 2

Table showing details of imagery products used

Imagery-id	Sensor	Date	Spatial Resolution	Bands	Radiometric correction	Derived Products	Captured by	Comments
Aerial-1 (1997)	LMK 1000 analogue camera	9/4/1997	10cm	3 (RGB)	None	Georeferenced mosaic	SA Government	1:10000 colour aerial photography scanned and georeferenced using ground control from previously orthorectified aerial imagery
Aerial-2 (2018)	UltraCam Eagle Prime 210	24,25/9/2018	7.5cm	4 (RGBI)	Internal sensor corrections	Orthorectified mosaic NDVI	Aerometrex Pty Ltd	4 Band (RGBI) imagery not supplied to SA Government
Aerial-3 (Hyperspec)	Specim AISA 'Eagle 2' Hyperspectral Linescanner	16/1/2021	30cm	62 (VNIR)	Full including sensor and atmospheric corrections	Surface reflectance vegetation indices and unsupervised classification	Airborne Research Australia	Hyperspectral data had been collected for an in-house project. DEW engaged ARA to radiometrically correct and analyse the hyperspectral imagery. Necessary to investigate mangrove and saltmarsh regions separately.
Satellite-4 (Sentinel2)	Sentinel-2A/B MSI	28/6/2020 – 18/2/2021 (10 images)	10m	4 (RGBI)	Level 2A (Bottom of atmosphere reflectances)	NDVI, NDWI	European Space Agency	Downloaded from SARA (Sentinel Australasia Regional Access) https://copernicus.nci.org.au/sara.client/#/home
Aerial-5 (LiDAR)	Riegl Q680i-S Full waveform LiDAR	11-18/3/2021	10cm – 2m (Depending on product)	N/A	N/A	DTM, DSM, CHM, FCM, Intensity, Classified Point Cloud	Airborne Research Australia	Concurrent 3 Band (RGB) imagery captured by DSLR at 38cm resolution. Imagery has been geo-referenced and rotated to North. Digital Elevation Model available from Elvis (fsdf.org.au)
Aerial-6 (March 2021)	UltraCam Eagle Mk3	31/3/2021	15cm	4 (RGBI)	Internal sensor corrections	Orthorectified mosaic	Aerometrex Pty Ltd	Imagery and products supplied as part of St Kilda Mangroves 2021 project. Imagery is to be re-captured at same specifications in October 2021Natural colour orthorectified imagery supplied to SA Government as part of Adelaide Metro 2021 project

Appendix 3

Formulas:

Normalised Difference Vegetation Index (NDVI)

(NIR – Red) / (NIR + Red)

For the Sentinel-2 MSI imagery this is equivalent to: Band 8 = Near Infra-Red (NIR), Band 4 = Red.

(Band 8 – Band 4) / (Band 8 + Band 4)

Rouse Jr. et al (1974)

Normalised Difference Water Index (NDWI):

(Green – NIR) / (Green + NIR)

For the Sentinel-2 MSI imagery this is equivalent to: Band 3 = Green, Band 8 = Near Infra-Red (NIR)

(Band 3 – Band 8) / (Band 3 + Band 8)

Sagar et al (2017)

Appendix 4

TIDALCLASS	COVER	INTEGRITY	Northern Veg	Southern Veg	Grand Total
Intertidal	Algal	Intact	17		17
	Bare	Intact	11	1	12
	Cyanobacterial	Intact	1		1
	Mangrove	Dieback	61	14	75
		Intact	865	1543	2408
		Prograding	30	6	36
	Samphire	Degraded	40	41	81
		Dieback	27	10	37
		Intact	338	348	686
	Sand	Intact	127	21	148
	Seagrass	Patchy	2433	1132	3565
		Uniform	78	18	96
	Seagrass / Algal	Intact	22	207	229
Non-Tidal	Vegetated	Degraded		84	84
		Intact	2		2
Stranded Tidal	Bare	Intact	0	31	31
	Samphire	Degraded	2	76	78
		Intact	6	48	54
Subtidal	Bare	Intact	0	3	3
	Seagrass	Intact	102	1024	1126
Supratidal	Bare	Intact	130		130
	Casuarina	Intact	9		9
	Samphire	Degraded	3		3
		Intact	104	31	135
	Samphire +/- Atriplex +/- Grassland	Intact	577	187	764
	Sedges	Intact		4	4
	Vegetated	Degraded	209		209
		Intact	75	57	132
Grand Total (ha)			5269	4886	10155

Table 6 1997 vegetation mapping attributes summarised by Northern/Southern and shows areas of broad groups by condition.

Appendix 5

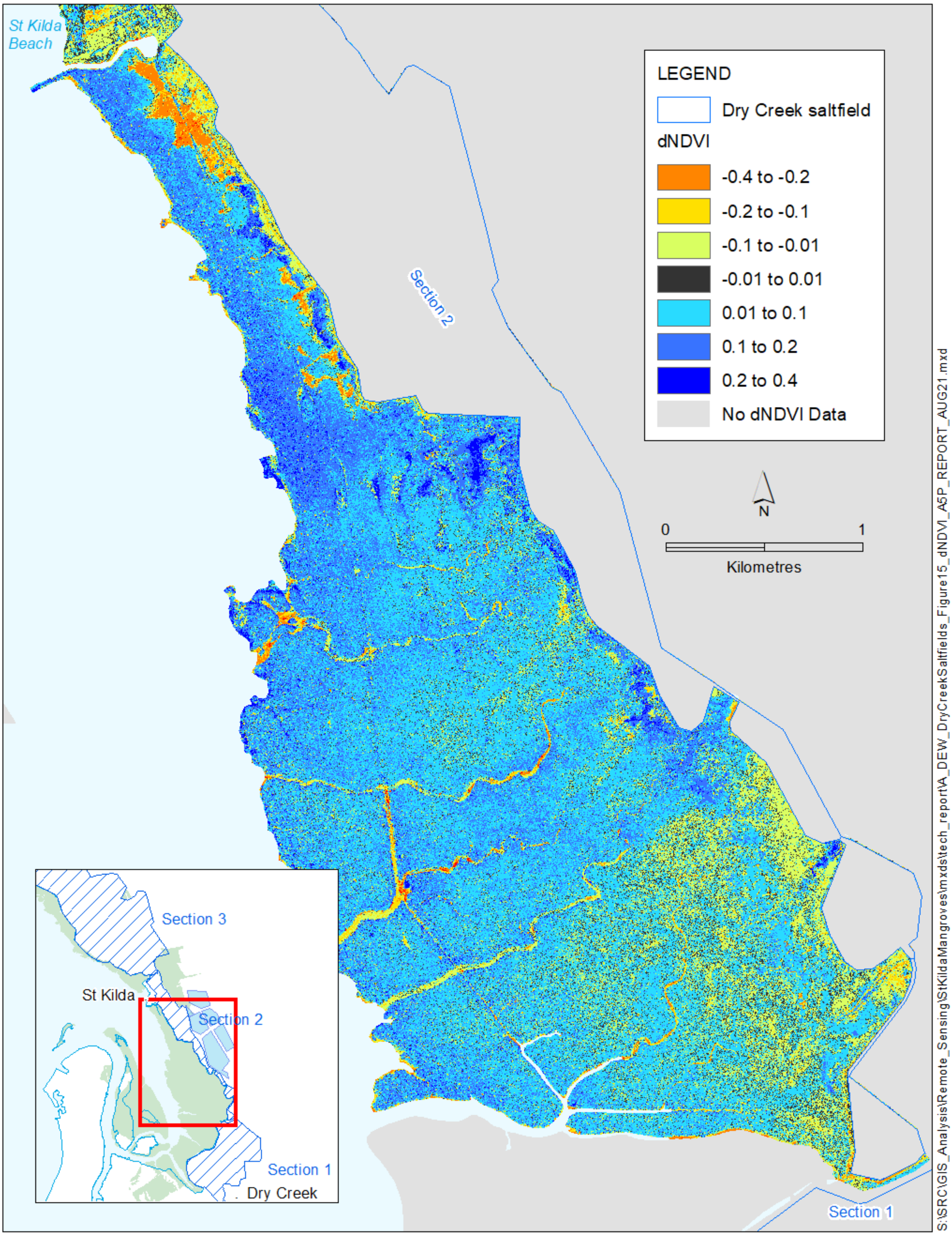

Figure 17 whole section 2 change in NDVI 2018-2021.

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