SCIENTIFIC REPORT

Mangrove Dieback Monitoring in the Hawkesbury River Estuary

using Remote Sensing and GIS following July 2022 major flood event



Source: NSW National Parks and Wildlife Service (n.d.).

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01 Introduction

1.1 Background and environmental monitoring problem

Mangrove forests are ecologically important intertidal ecosystems that support coastal biodiversity, provide nursery habitats for aquatic species, stabilise shorelines and contribute to carbon sequestration (Kuenzer et al., 2011). However, their location along dynamic coastlines and estuaries makes them vulnerable to changes in hydrology, sedimentation and extreme weather events. Monitoring mangrove conditions is therefore essential for identifying ecological stress and potential recovery. Satellite remote sensing provides a spatially extensive and repeatable approach to monitoring these ecosystems, particularly where regular field surveys are difficult (Tran et al., 2022).

The Hawkesbury River estuary in New South Wales experienced several significant floods during 2021 and 2022. The July 2022 flood was particularly severe in the lower Hawkesbury River, with exceptionally high water levels recorded at Wisemans Ferry (Infrastructure NSW, 2023). This study focuses specifically on the July 2022 event. Previous investigations documented mangrove canopy deterioration and identified associations between severe dieback and substantial sediment deposition (Hughes, 2023). However, distinguishing genuine vegetation decline from changes caused by tides, seasonal variation and satellite observation conditions remains challenging (Zhang et al., 2017).

Multispectral satellite imagery enables vegetation assessment using the Normalised Difference Vegetation Index (NDVI), a widely applied indicator of vegetation condition (Tran et al., 2022). PlanetScope imagery, with approximately 3 m spatial resolution, is particularly suitable for monitoring narrow and fragmented mangrove stands. However, differences between satellite sensor generations may affect NDVI consistency (Huang & Roy, 2021), requiring careful interpretation of temporal changes.

This project aims to evaluate changes in mangrove vegetation conditions around the meander bend of the lower Hawkesbury River estuary in New South Wales, Australia adjacent to the locality of Singletons Mill (NSW 2775) following the July 2022 flood, using multitemporal PlanetScope imagery and GIS.

The specific objectives are to:

1. Characterise mangrove vegetation conditions using suitable pre-flood and post-flood PlanetScope imagery.
2. Quantify spatial and temporal changes in NDVI to identify areas of vegetation decline, stability or potential recovery.
3. Evaluate the reliability of observed changes by considering image quality, tidal and seasonal variation, sensor consistency and available independent evidence.
4. Assess the suitability of the monitoring approach for repeatable mangrove-condition assessment.

1.2 Research question and scope

Primary research question:

How did satellite-derived NDVI values change across mangrove vegetation in the selected Hawkesbury River estuary study area before and after the July 2022 flood?

Supporting research question:

How suitable is the applied PlanetScope NDVI and GIS workflow for repeatable monitoring of mangrove vegetation condition, considering its limitations and operational costs?

The study focuses on vegetation-index changes within a consistent mangrove study area. NDVI differences will be interpreted as indicators of spectral vegetation change rather than definitive evidence of mangrove mortality or flood-induced damage without supporting observations.

02 Literature Review

2.1 Mangrove disturbance and the need for monitoring

Mangrove ecosystems are sensitive to changes in hydrological and sedimentary conditions. Their intertidal distribution complicates monitoring because vegetation conditions may vary with inundation, sediment deposition and shoreline dynamics (Kuenzer et al., 2011). Radabaugh et al. (2021) linked altered hydrology with signs of mangrove stress, highlighting the importance of combining remote sensing with independent ecological observations.

These issues are relevant to the Hawkesbury River estuary, which experienced significant flooding during 2021 and 2022 (Infrastructure NSW, 2023). Hughes (2023), reporting for Hornsby Shire Council, combined field observations, PlanetScope imagery and NDVI differencing to investigate deterioration associated with sediment deposition. Approximately 11.9% of the mapped mangrove area showed negative vegetation-index change between 2021 and 2023. This establishes a local monitoring need, although spectral decline alone does not confirm mortality.

2.2 Remote sensing and vegetation indices for mangrove assessment

Satellite remote sensing enables repeated monitoring of mangrove vegetation across large areas where regular field surveys may be difficult. Kuenzer et al. (2011) highlighted its effectiveness in assessing mangrove distribution, environmental change and ecosystem condition.

The Normalised Difference Vegetation Index (NDVI), calculated using near-infrared (NIR) and red reflectance, offers a simple, repeatable indicator of vegetation greenness. Tran et al. (2022) reported that NDVI was used in 82% of the reviewed mangrove studies, demonstrating its widespread application. However, NDVI reflects spectral vegetation characteristics and should not be interpreted as a direct measurement of mangrove health or mortality (Tran et al., 2022).

Other indices provide complementary information. The Enhanced Vegetation Index (EVI) improves sensitivity in dense vegetation, where NDVI saturation is problematic (Huete et al., 2002). The Normalised Difference Moisture Index (NDMI) uses near-infrared and shortwave-infrared reflectance to examine moisture-related variation (Wilson & Sader, 2002). Additional approaches address different monitoring needs. SAVI reduces soil-background effects in sparsely vegetated pixels (Huete, 1988), while MVI combines green, near-infrared and shortwave-infrared reflectance to distinguish mangroves from other land covers (Baloloy et al., 2020). SAR provides observations through cloud cover and can complement optical mapping, as demonstrated by the integration of ALOS PALSAR and Landsat in Global Mangrove Watch (Bunting et al., 2018). However, radar interpretation must account for inundation and scattering conditions. SAVI could be evaluated using the existing PlanetScope imagery, whereas MVI requires another dataset containing SWIR.

NDVI was selected for this study because it enables straightforward, repeatable comparison of relative vegetation greenness within a consistent mangrove boundary using the available PlanetScope red and NIR bands. Its use in the council assessment also provides a relevant local methodological precedent (Hughes, 2023). Converting continuous NDVI differences into decline, stability and increased classes makes results easier to map and summarise. However, class areas depend on the selected thresholds. These classes should therefore be interpreted as operational categories of spectral change until supported by independent reference observations.

2.3 Satellite selection and temporal change detection

Satellite selection involves trade-offs between spatial detail, observation frequency, spectral coverage and cost. Landsat provides long-term observations but its 30 m resolution limits the detection of narrow mangrove stands (Nardin et al., 2016). Sentinel-2 offers freely accessible imagery with 10 m visible and NIR bands, making it suitable for low-cost vegetation monitoring (European Space Agency, n.d.).

PlanetScope provides imagery at approximately 3 m spatial resolution and frequent observations, allowing more detailed monitoring of narrow and fragmented mangrove areas (Planet Labs PBC, 2026). However, Huang and Roy (2021) identified systematic differences in NDVI between PlanetScope sensor generations, which may affect temporal comparisons.

NDVI differencing between satellite acquisition dates can identify spatial patterns of vegetation decline or improvement. However, reliable change detection requires consistent image alignment, analysis masks and acquisition conditions. Comparisons between selected dates cannot independently establish the timing or continuity of vegetation recovery.

2.4 Environmental uncertainty, validation and research gap

Intertidal conditions introduce uncertainty into satellite-based mangrove monitoring. Zhang et al. (2017) demonstrated that tidal variation influences mangrove spectral signatures and classification accuracy. Consequently, differences in tidal conditions between satellite acquisitions may produce apparent NDVI changes unrelated to vegetation deterioration. Selecting images from comparable seasons and tidal conditions can improve temporal comparability. Future comparison of NDVI with EVI or SAVI, discussed in Section 2.3, could additionally assess sensitivity to index choice.

Sensor consistency also requires attention. Huang and Roy (2021) identified NDVI differences between the first two PlanetScope sensor generations, supporting checks of sensor metadata before temporal comparison. Repeatability alone does not establish accuracy: documented processing supports repetition, while accuracy assessment requires independent reference observations. Olofsson et al. (2014) recommend probability-based sampling and error matrices for evaluating change classifications. Field observations or aerial imagery representing the compared dates could support this assessment.

Building on the previous Hornsby Shire Council assessment (Hughes, 2023), this study examines mangrove vegetation changes within the Hawkesbury River estuary between Laughtondale and Spencer using pre-event, event-period and post-event PlanetScope imagery. The study aims to assess whether NDVI-based change detection provides a reliable and repeatable approach for monitoring mangrove conditions following the July 2022 flood.

03 Methodology

In this study, remotely sensed data were used with digitisation of the boundary layer to map vegetation change and dieback within mangrove stands near Singletons Mill, lower Hawkesbury River, NSW. PlanetScope imagery was selected because its 3 m spatial resolution suits the narrow mangrove fringes of the study area, where coarser sensors such as Landsat or Sentinel-2, whose 10 to 30 m pixels would be dominated by mixed pixels along such thin fringes (Kuenzer et al., 2011; Nardin et al., 2016).

3.1 Study area

The study area comprises approximately 38.5 ha of mapped mangrove around the meander bend of the lower Hawkesbury River estuary in New South Wales, Australia, adjacent to the locality of Singletons Mill (NSW 2775), the closest suburb to the area of interest. The site is about 2-3 km from Wisemans Ferry Road.

Mangrove stands fringe the outer and inner banks of the bend, separated by cleared floodplain land and a small number of buildings on the western side. The digitised mangrove polygons define the area of interest (AOI) used for the analysis as shown on figure 1 below. They were digitised on screen in ArcGIS Pro on 19 October 2026 using Esri World Imagery and Google Earth Pro imagery as visual references.

The selection of the AOI was mainly based on its high flood vulnerability. The lower Hawkesbury River flooded repeatedly in March 2021 and in March, July and October 2022. The mangrove stands near Singletons Mill sitting on the inside of a tight river bend, a point-bar setting where flood sediment builds up. This area was identified as one of the most impacted sections of the estuary by Council monitoring, which makes it a strong candidate for tracking dieback (Hughes, 2023).

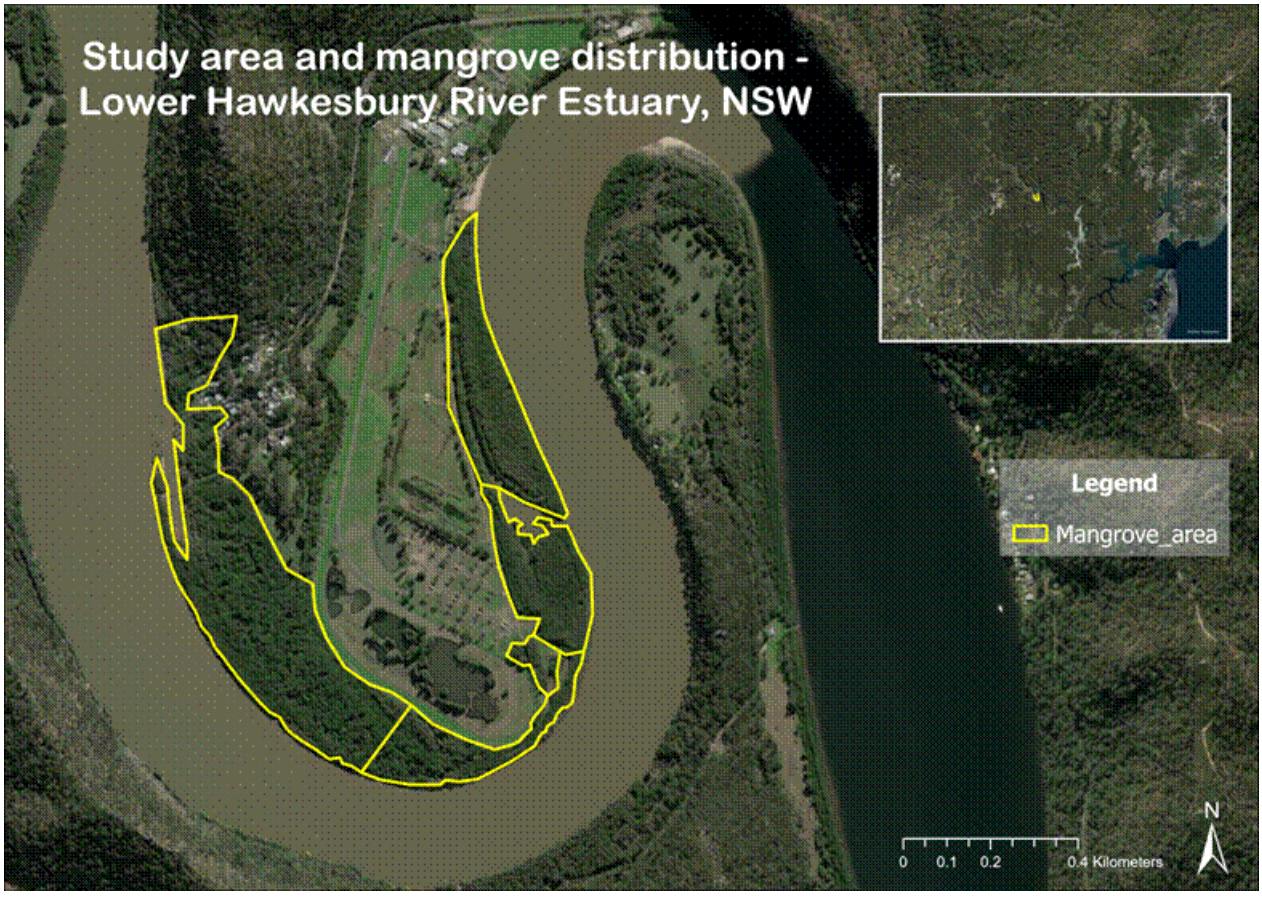


Figure 1: Study area and mangrove distribution in the lower Hawkesbury River estuary, NSW. Yellow polygons show the digitized mangrove extent used as the analysis mask

3.2 Satellite datasets and acquisition strategy

Table 1: Remote-sensing input datasets and acquisition/quality specifications.

PERIOD	SENSOR + PROCESSING LEVEL	DATE	PIXEL SIZE / BANDS	SOURCE	QUALITY
Pre-event	PlanetScope Analytic Surface Reflectance	2022-06-15	3 m / 8 bands	https://docs.planet.com/data/imagery/planetscope/	Cloud cover ≤30%; AOI coverage 100%
Event-period	PlanetScope Analytic Surface Reflectance	2022-08-30	3 m / 8 bands	https://docs.planet.com/data/imagery/planetscope/	Cloud cover ≤30%; AOI coverage 100%
Post-event	PlanetScope Analytic Surface Reflectance	2023-06-17	3 m / 8 bands	https://docs.planet.com/data/imagery/planetscope/	Cloud cover ≤30%; AOI coverage 100%

3.3 Pre-processing

Three PlanetScope analytic surface reflectance scenes, representing the pre-event, event-period and post-event conditions were used to map mangrove dieback (refer table 1). PlanetScope imagery was obtained through the Planet Explorer platform. A broader search extent was initially used to ensure adequate satellite coverage, while the subsequent GIS analysis was restricted to mapped mangrove polygons to exclude surrounding terrestrial vegetation and open water. Imagery searches were limited to PlanetScope multispectral scenes containing near-infrared (NIR) and red bands required for NDVI calculation. Scenes were selected based on low cloud cover (30%), 100 % AOI coverage and image quality to minimize atmospheric interference and missing observations. Eight-band Surface Reflectance products were downloaded in GeoTIFF format with accompanying Usable Data Masks (UDM2) to support consistent spectral analysis and shadow masking. Since the imagery was already supplied as surface reflectance, no further atmospheric correction was applied. The June 2022 and June 2023 acquisitions were selected to improve seasonal comparability, while August 2022 provided an observation of vegetation conditions following the July 2022 flood .

3.4 Processing

Each scene was clipped to the AOI using the digitised mangrove shapefile in ArcGIS Pro, producing three clipped rasters (Before_clip, During_clip and After_clip) that restricted the analysis to mangrove pixels only.

The Normalised Difference Vegetation Index (NDVI) was then calculated for each clipped image using Band 6 (Red) and Band 8 (near-infrared) of the eight-band PlanetScope imagery. This gave three NDVI rasters (Before_NDVI, During_NDVI and After_NDVI). The formula applied was:

$$NDVI = \frac{NIR - RED}{NIR + RED}$$

The symbology was changed to show spatial pattern differences using a green to red gradient, with higher NDVI values indicating greater spectral greenness.

And the change in vegetation condition was quantified by differencing the NDVI-based layers between dates to create two change rasters: dNDVI_Before_During (pre-event to event-period) and dNDVI_Before_After (pre-event to post-event). This allows for determining the vegetation loss or gain within the study period, which is used to study land-cover changes.

$$dNDVI = NDVI_{(Before)} - NDVI_{(During\ \&\ After)}$$

Each dNDVI raster was then reclassified into three vegetation classes (regrowth, remain same, dieback) using the Reclassify tool with manually defined intervals, set by inspecting the dNDVI histograms and comparing against the basemap imagery. Finally, the rasters were converted to polygons using the Raster to Polygon tool, and polygons with a gridcode of 3 (dieback) were extracted using Select by Attributes.

3.5 Post-processing

After selecting the dieback polygons (gridcode = 3), their total area was obtained using the Sum statistic for the Shape_Area field in square metres. This value was then divided by 10,000 to convert the area to hectares to make it easier to compare.

ArcGIS Pro was used to produce three layout maps. For the study area map, the clipped mangrove boundary was overlaid on satellite imagery of the lower Hawkesbury River estuary. The appropriate legend, scale bar, and north arrow were added, along with an inset map showing the site's location within the wider estuary.

For the two outcome maps, the dNDVI was displayed within the same mangrove boundary. The first map compared the event period (Aug 2022) with pre event (Jun 2022), and the second compared post event (Jun 2023) with pre event (Jun 2022). Both maps used the same legend. Light green showed increased greenness (regrowth), dark green showed little change (remains same), and red showed decreased greenness (dieback). Each map included a north arrow and scale bar.

3.6 Outputs and Interpretation

The outputs produced from the methodological workflow are:

1. Clipped PlanetScope rasters and NDVI layers for the pre-event (15 June 2022), event-period (30 August 2022) and post-event (17 June 2023) dates, showing the distribution of vegetation condition within the mangrove area.
2. Reclassified dNDVI layers, in which dNDVI values were grouped into three vegetation classes (regrowth, remains same, dieback) using manual intervals, so that conditions could be compared consistently between dates.

Combining these outputs allows both spatial analysis and quantitative interpretation. Linking the spectral indices to the digitised mangrove boundary keeps the results specific to mangrove stands and gives council a repeatable, measurable way to track mangrove health after flood events.

04 Results

4.1 Spatial pattern of NDVI Change

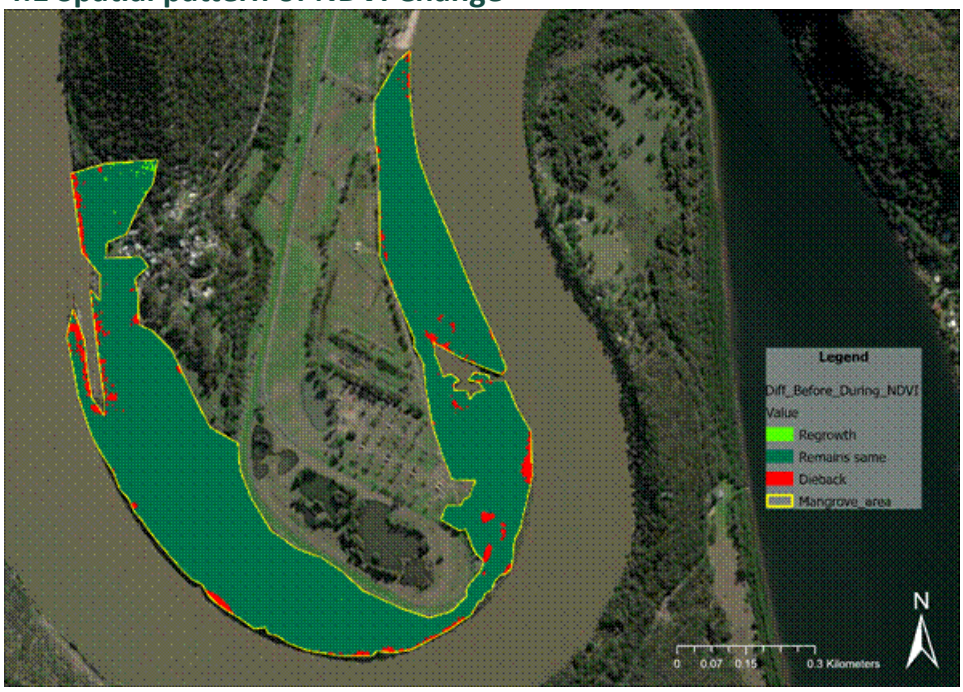


Figure 2 Mangrove vegetation change between June and August 2022, PlanetScope, Singletons Mill, NSW. Basemap: Esri, ArcGIS (captured 19 October 2026).

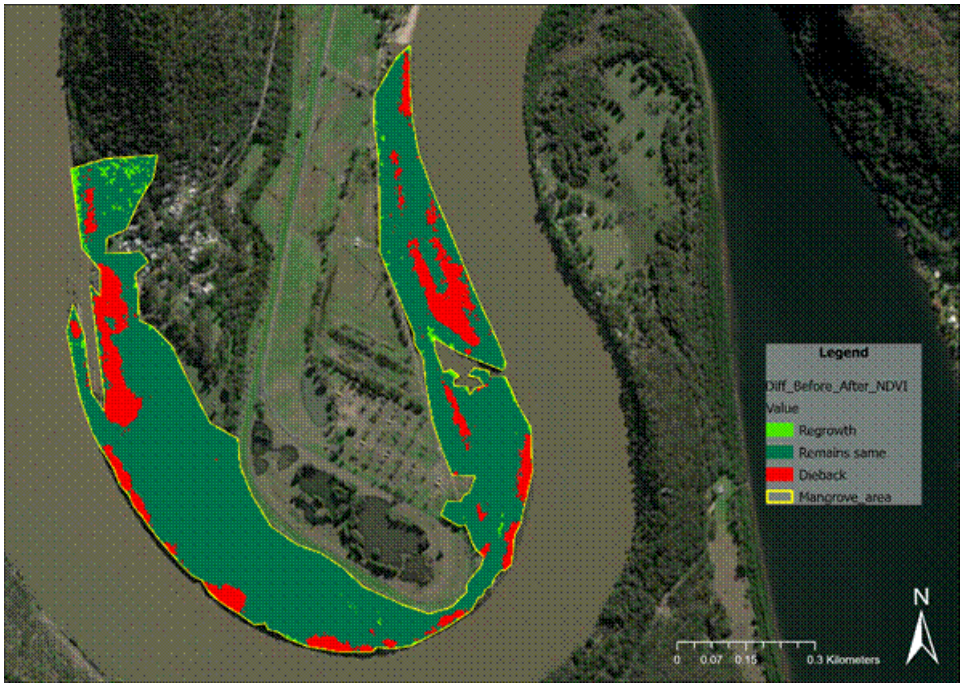


Figure 3 Mangrove vegetation change between June 2022 and June 2023, PlanetScope, Singletons Mill, NSW. Basemap: Esri, ArcGIS (captured 19 October 2026).

Figures 2 and 3 show the distribution of vegetation change classes within the mapped mangrove area. Most of the area was classified as remaining stable in both comparisons. The June–August 2022 map showed relatively small, scattered patches classified as dieback, whereas the June 2022–June 2023 map showed larger and more extensive patches. Areas classified as regrowth were limited in both comparisons.

4.2 Change detection and area statistics

Table 2: Area of each vegetation condition in the mangrove AOI from dNDVI analysis.

Class	Before → During (ha) (Jun – Aug 2022)	% of condition	Before → After (ha) (Jun 22 – Jun 23)	% of condition
Dieback	*1.3*	*3.3*	*5.7*	*14.8*
Remain same	*37.1*	*96.6*	*32.2*	*83.8*
Regrowth	*0.04*	*0.1*	*0.5*	*1.4*
Total	***38.5***	***100***	***38.5***	***100***

The dNDVI showed that most of the 38.5 ha mangrove AOI remained spectrally stable. The area classed as dieback grew from 1.3 ha (3.3%) between June and August 2022 to 5.7 ha (14.8%) between June 2022 and June 2023, while regrowth stayed below 2% in both intervals.

4.3 Comparison with Hornsby council report

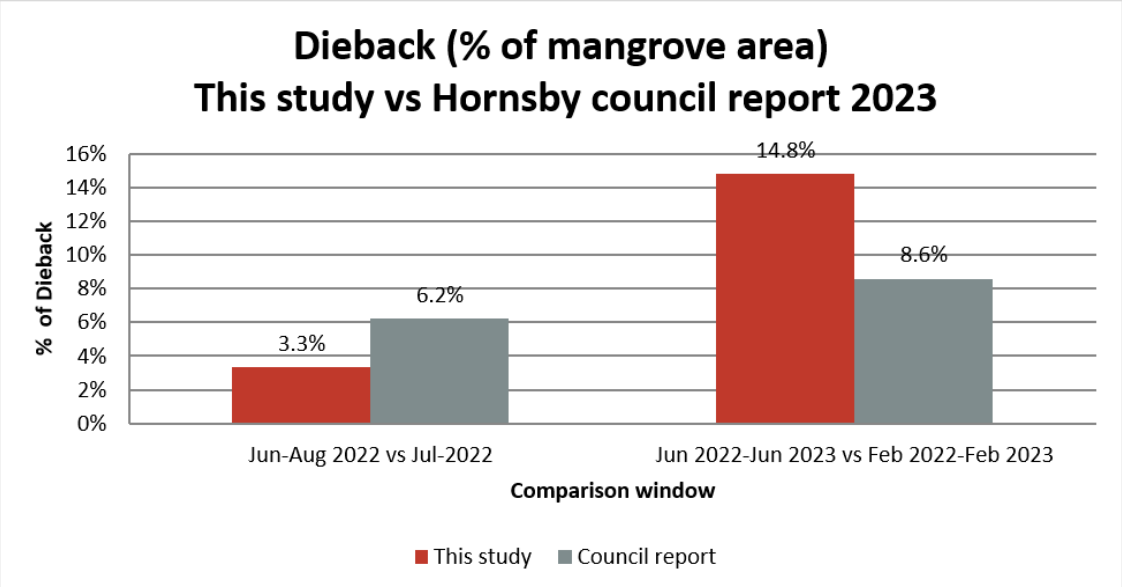


Figure 4. Dieback as a percentage of mangrove area in this study compared with the Hornsby council report 2023. (Note: Study area, image dates and classification thresholds differ between this study and the council report (Hughes, 2023), so values are indicative only.)

The proportion classified as dieback in this study was 3.3% for June–August 2022, compared with 6.2% in the council's July 2022 flood comparison. For the longer intervals, this study recorded 14.8% between June 2022 and June 2023, compared with 8.6% in the council's February 2022–February

2023 comparison. These percentages provide regional context rather than a direct validation because the study boundaries, observation windows and classification methods differ.

05 Discussion

5.1 Overview: Value and limitations for remote sensing for mangrove monitoring

Remote sensing offers a spatially extensive and repeatable way to monitor mangrove condition, particularly where field surveys are difficult because of muddy, waterlogged or remote sites (Kuenzer et al., 2011; Tran et al., 2022). Spectral indices such as NDVI are the most widely used tool for this purpose. High-resolution sensors add further value to narrow fringing stands. PlanetScope's 3 m pixels and near-daily revisit allow finer detection of canopy variation than Landsat's 30 m pixels (Nardin et al., 2016) and make it more likely that suitable scenes can be found before, during and after a flood.

Despite these benefits, satellite derived change needs to be interpreted with care. Intertidal conditions affect spectral values, so differences in tidal height between dates can produce apparent NDVI changes unrelated to canopy conditions (Zhang et al., 2017). NDVI itself measures spectral greenness, not mortality, so independent ecological evidence is needed to confirm what a decline means (Radabaugh et al., 2021). These factors, along with the commercial cost of high-resolution imagery, influence both how the results of this study are read and how far the approach can be applied operationally.

Attribution to individual floods is a further limitation. The July 2022 flood was selected as the focal event because its peak water level at Wisemans Ferry exceeded those of the preceding 2021–2022 floods and the subsequent October 2022 event (Hornsby Shire Council, n.d.), suggesting potentially greater disturbance. However, a higher flood peak alone does not establish greater mangrove damage. The June 2022 baseline may already reflect impacts from earlier floods, while the June 2023 observation also encompasses the October 2022 flood. Consequently, the observed NDVI changes cannot be attributed exclusively to July 2022, and cumulative or delayed effects of multiple floods cannot be excluded. Comparison with the council report provides additional context, but differences in study boundaries, image dates and classification thresholds mean that the reported percentages are indicative rather than directly comparable and do not constitute independent validation.

5.2 Analysis of the results

As shown in table 2, the minimal early change in dieback seems reasonable as canopy loss often occurs over months and the August image was captured only about eight weeks after the July 2022 flood peak. The Before→After (Jun 22 – Jun 23) interval extends to include the October 2022 flood, but the flood peak water level was much lower than in the July 22 flood (Hughes, 2023). The July flood is therefore more likely to be the larger event in the window of time, though the two events are indistinguishable. Due to lack of confirmation with field observations, the results are interpreted as a spectral decline that is consistent with, but does not prove, flood related dieback (Radabaugh et al., 2021).

5.3 Feasibility

The approach provides a practical basis for repeatable mangrove monitoring for four reasons.

· Narrow fringing stands are well resolvable by 3 m pixels Planet scope, while 10 m or 30 m sensors would blend these into "mixed pixels" (Kuenzer et al., 2011; Nardin et al., 2016).

· NDVI is the most frequently used index in mangrove research, and all these three scenes are 8-band surface-reflectance products, which minimizes the artificial NDVI differences reported between sensor generations (Huang & Roy, 2021, Tran et al., 2022).

· The workflow uses standard ArcGIS Pro operations within a fixed mangrove boundary including clipping, NDVI calculation, differencing, reclassification, conversion to polygons, dieback class selection and area summarisation. It can be repeated following flood events when suitable imagery is available.

· The PlanetScope satellites together pass over most places on Earth almost every day which make the council choose event scenes that meet a quality gate.

Routine implementation would require suitable imagery access, an ArcGIS Pro licence and staff able to process imagery and check the outputs. Costs and processing time should be assessed before adopting the workflow as a monitoring service. A proposed schedule could combine comparable seasonal observations with additional acquisitions following major floods. Each monitoring cycle would produce change maps and area statistics to identify locations for field inspection.

5.4 Further improvements

Several improvements would strengthen the monitoring cycle. First, adding scenes for each season and before and after each flood would help distinguish changes occurring between events and track potential recovery. Each scene should be matched for tide and season, with the tide height recorded at acquisition (Zhang et al., 2017). Change classes should be checked against field observations or suitable aerial imagery, with quantitative accuracy assessed where independent labelled reference samples are available. The sensitivity of the manual thresholds should be compared with the council's statistical method (Hughes, 2023). Finally, other indices such as Enhanced Vegetation Index (EVI) and Normalised Difference Moisture Index (NDMI) and Sentinel-2 as a lower-cost option should be considered along with NDVI (Tran et al., 2022).

06 Conclusion

This study demonstrated a repeatable PlanetScope and GIS workflow for mapping vegetation change and identifying potential mangrove dieback near Singletons Mill. Most of the approximately 38.5 ha study area remained spectrally stable, but the dieback class covered 1.3 ha (3.3%) in the June–August 2022 comparison and 5.7 ha (14.8%) in the June 2022–June 2023 comparison. These findings address the project's objectives by locating and quantifying vegetation decline and showing how the workflow could guide monitoring and field inspections. However, three observation dates and the absence of site-specific validation prevent confirmation of mortality or attribution solely to the July 2022 flood. Future monitoring should use imagery acquired under comparable tidal and seasonal conditions, supported by targeted field checks of canopy condition and sediment depostion.

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A Data flow diagram

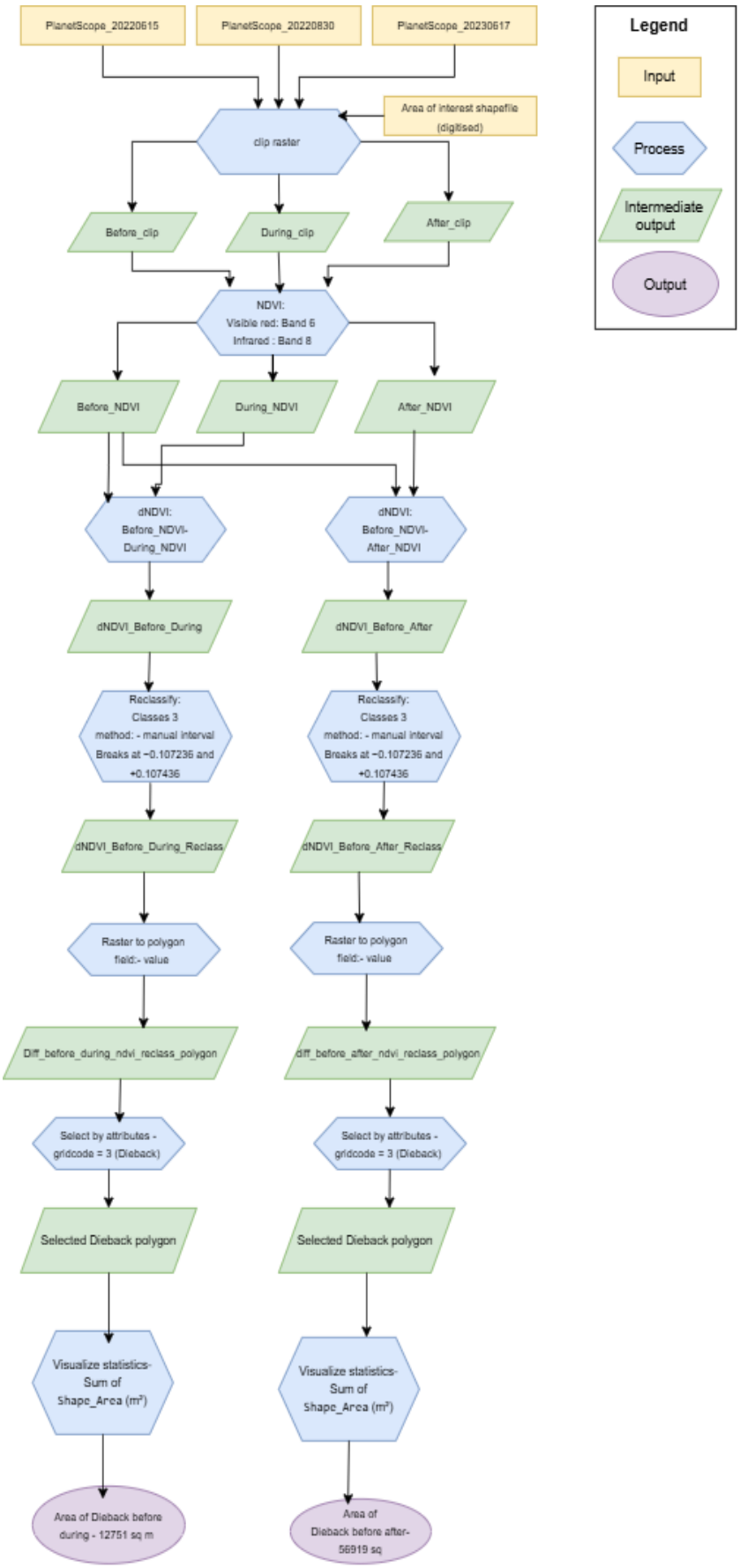


Figure A1. Data flow diagram showing the PlanetScope NDVI differencing, change classification and area calculation workflow used to assess potential mangrove dieback.

B Project timeline and group contributions

Project timeline

Project task	Sept W3-4	Oct W1	Oct W2	Oct W3	OctW4-5	Nov W1
literature review; subscription to PlanetScope	■					
AOI definition + data selection		■				
report draft; data from PlanetScope; confirmation of dates		■	■			
NDVI & digitizing data -report writing; DFD			■			
dNDVI and area calculation; producing map; DFD Completion				■	■	
Report writing; referencing and final check					■	■

Table B1. Planned group workflow and milestone schedule.

Statement of Contribution

GROUP MEMBER	CONTRIBUTION PART	HOURS SPENT ON THE PROJECT
Madina Azelitskaia	Introduction + DFD + Editing and reviewing	30 hours
Md Fahim Rahman	Literature Review	30 hours
Jathushan Vasanthan	Methodology + Results + Discussion	30 hours
Mozna Aslam	DFD + Results + Conclusion	30 hours
ALL	GIS analysis	14 hours