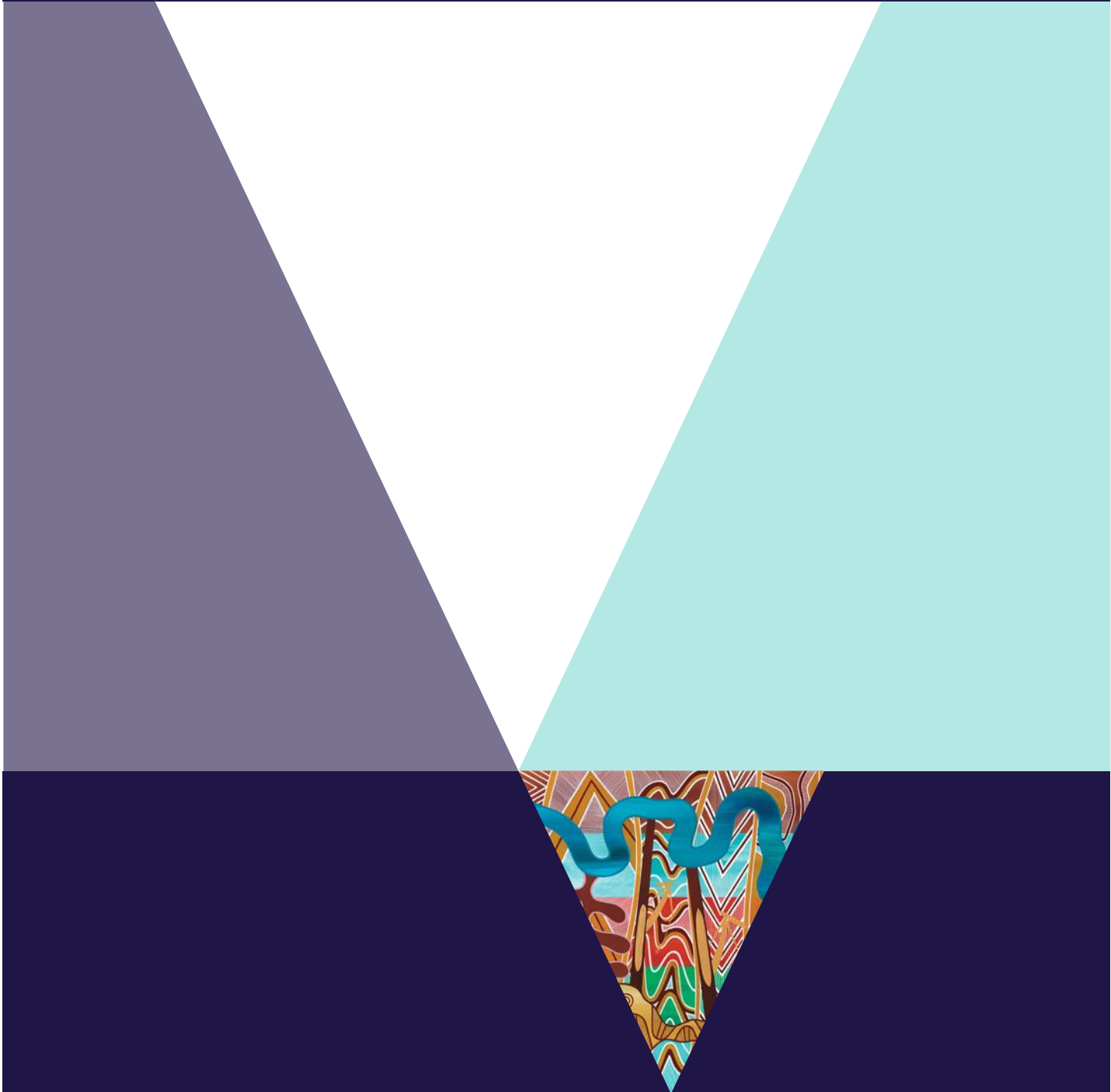


# Victorian Coastal Erosion Indicators

Design and Methods - Mar 2023  
Victorian Coastal Monitoring Program



Energy,  
Environment  
and Climate Action

OFFICIAL

## Acknowledgements

Acknowledgements to the academic partners within the Victorian Coastal Monitoring Program, including Deakin and Melbourne University, and thanks to the citizen scientists who have worked with the program.

## Author

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## Acknowledgment

We acknowledge and respect Victorian Traditional Owners as the original custodians of Victoria's land and waters, their unique ability to care for Country and deep spiritual connection to it. We honour Elders past and present whose knowledge and wisdom has ensured the continuation of culture and traditional practices.

We are committed to genuinely partner, and meaningfully engage, with Victoria's Traditional Owners and Aboriginal communities to support the protection of Country, the maintenance of spiritual and cultural practices and their broader aspirations in the 21st century and beyond.



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# Executive Summary

This report describes the development of erosion indicators for sites monitored by the Victorian Coastal Monitoring Program (VCMP). The aims of these tools and the report are to provide:

- A standardised indicator for reporting (e.g., in DEECA Environmental Management Plans).
- A draft format for a regular report summarising coastal change at VCMP sites.
- A reference for land managers, project managers and external users (consultants, academics).

The erosion indicator tools (Methods in Section 2) presented in this report are:

1. **Erosion Warning Indicator (EWI)**, used to **assess a site overall**, and for **comparing across sites** (Fig. E1), using four short-term and one long-term indicator.
2. **Erosion Hotspot Detector (EHD)**, used to **automatically identify** and assess recent (last 2 years) **high-erosion areas** (Fig. E2), providing a greater amount of detail to supplement the EWI.

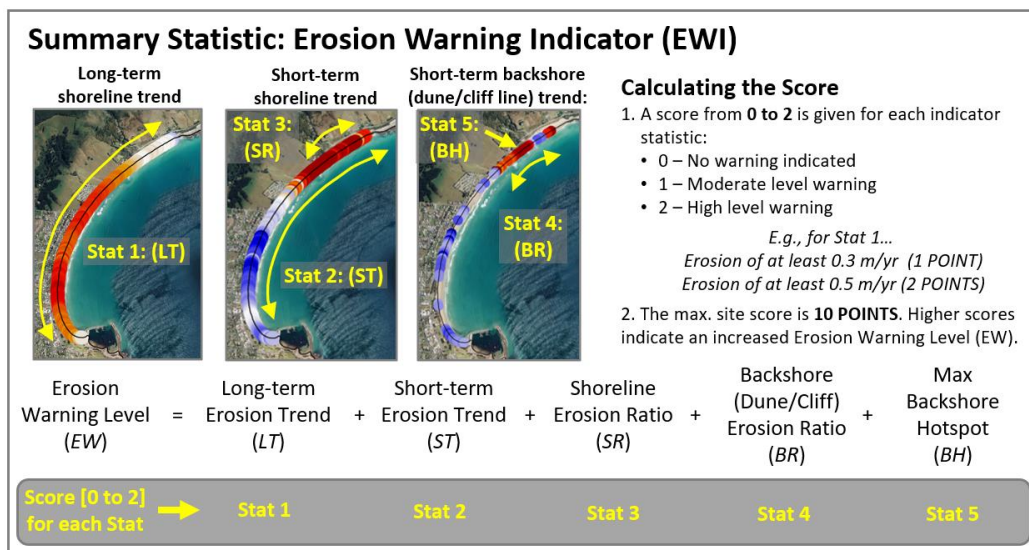


Figure E1. Erosion Warning Indicator tool.

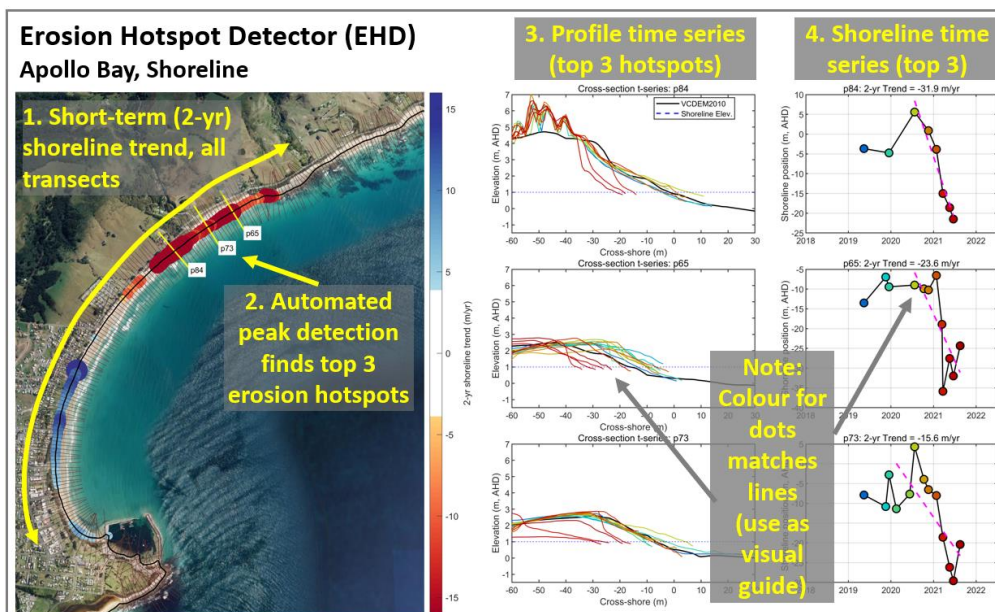


Figure E2. Erosion Hotspot Detector tool

No single metric can adequately describe the state of a beach, and users will be interested in different aspects of shoreline change, e.g., long-term vs. short-term erosion and widespread vs. localised hotspot erosion. The approach here is to use a multi-faceted assessment of erosion characteristics at a given site, which also allows for quantitative comparison across sites.

The Erosion Warning Indicator (EWI) was applied to all VCMP sites (Fig. E3; full Results for EWI in Section 3), with the highest EWI scores for **Marengo** and **Patterson River**, both scoring 6 out of 10. The Erosion Hotspot Detector (EHD) provides a higher level of detail for each site (as per the example in Fig. E2), with EHD results presented for all sites in Section 4. Limitations and suggested improvements are provided in Section 5, with some key limitations being:

- The erosion indicator tools assess hazard not risk (e.g., proximity to infrastructure is not assessed).
- The results presented are already out of date (ending in early 2022); however, the intent is to refine and provide an annual update.
- Some adjustments may be required to better capture cliff erosion volumes.

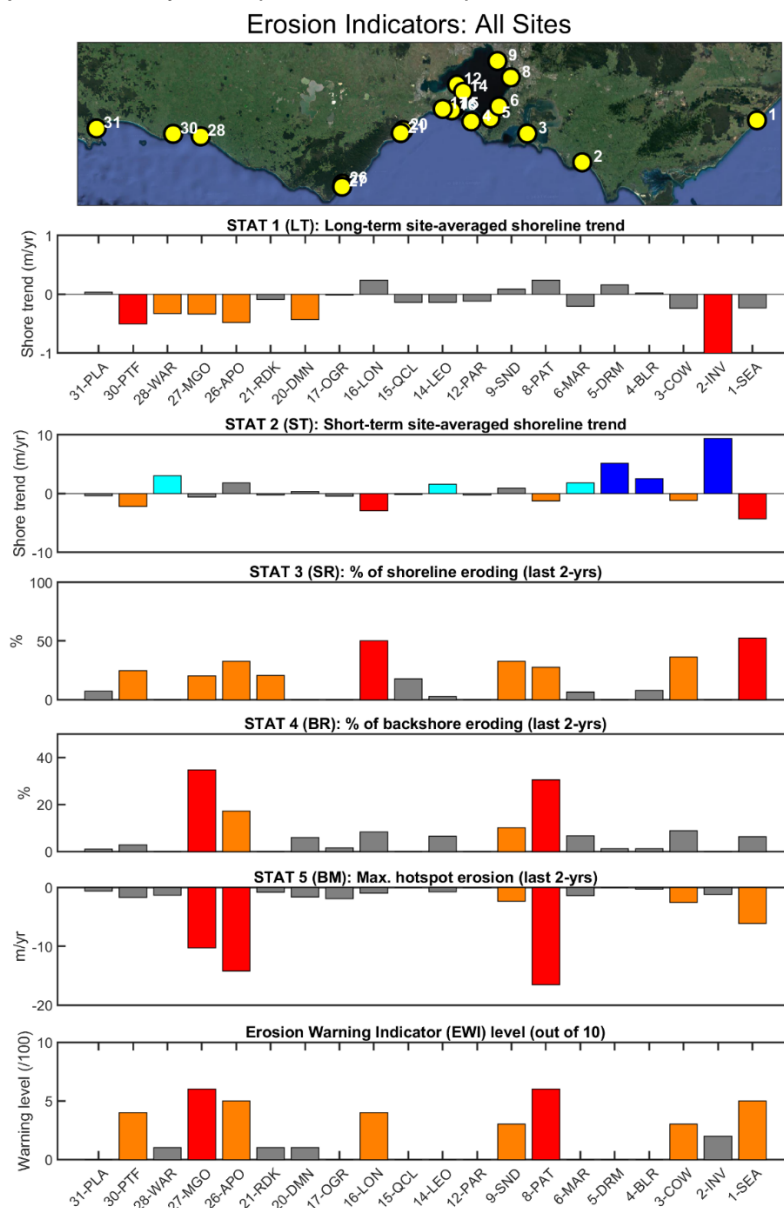


Figure E3. The Erosion Warning Indicator applied to VCMP sites with sufficient survey frequency and duration.

## Acronyms and Variables

**VCMP** – Victorian Coastal Monitoring Program

**DEA** – Digital Earth Australia (Coastlines), satellite derived annual mean shorelines, provided by Geoscience Australia.

**EWI** – Erosion Warning Indicator tool, calculated by summing 5 erosion statistics, each contributing up to 2 POINTS to the total warning level, for a maximum score of 10.

- LT – Statistic 1, Long-term (1988 – 2019) site-averaged shoreline trend, derived from DEA Coastlines
- ST – Statistic 2, Short-term (last 2 years) site-average shoreline trend, derived from VCMP drone surveys.
- SR – Statistic 3, Shoreline Erosion Ratio, the ratio of the shoreline that has significantly eroded in the last 2 years (VCMP data).
- BR - Statistic 4, Backshore (dune/cliff line) Erosion Ratio, the ratio of the backshore line that has significantly eroded in the last 2 years (VCMP data).
- BH – Statistic 5, Backshore Hotspot Maximum, the highest magnitude single point of backshore erosion (averaged over three adjacent 30-m spaced transects) in the last 2 years (VCMP data).

**EHD** – Erosion Hotspot Detector tool, uses an algorithm to identify the top 3 shoreline and backshore (dune/cliff line) erosion locations over the past 2 years. Uses VCMP drone data.

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# 1. Introduction

This report describes the methodological development and production of erosion indicators for sites monitored by the Victorian Coastal Monitoring Program (VCMP) (see Section 1.2). The purpose of an erosion indicator is:

- To provide regular (e.g., annual) feedback equivalent to existing environmental indicators (e.g., water quality) that are commonly made available by DEECA (e.g., through the Port Phillip Bay Environmental Management Plan).
- To provide a single product output from the VCMP to summarise the current state of all regularly surveyed sites, with regard to coastal erosion.
- As a reference to coastal land and project managers, in particular for sites they are responsible for.
- As a reference to coastal consultants and academics, e.g., to provide an overview of a site, prior to conducting a detailed coastal processes and/or hazard assessment.

The first aim is to produce a suite of indicators to convey the severity of erosion occurring to VCMP survey sites that identifies the various spatial and temporal occurrences of erosion, e.g., long-term vs. short-term erosion and widespread vs. localised hotspot erosion. Different users will be interested in different aspects of erosion, and the goal is to cater to this.

The second aim is to produce a more detailed tool designed to apply automated detection and analysis of the most severe erosion occurring at each site.

The two tools described in this report are:

- The **Erosion Warning Indicator (EWI)**, used to **assess a site overall**, and for **comparing across sites**.
- The **Erosion Hotspot Detector (EHD)**, used to **automatically identify and assess high-erosion areas in greater detail**.



Methods are described in Section 2, with results in Section 3 (EWI) and Section 4 (EHD).

### Notes of caution when using the indicator and hotspot tools

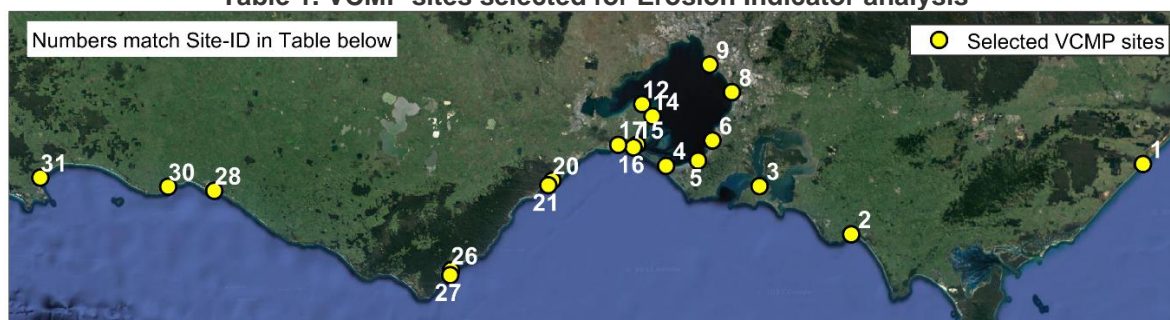
- The tools assess **erosion hazard** but **do not assess risk** (i.e., exposure and vulnerability). The tools will pick up on any erosion, regardless of proximity to infrastructure (this is possible, but is more complex and beyond the current scope).
- The tools are designed for statewide automated assessment, but will miss some fine details. Erosion events that have a small magnitude in terms of shoreline change, but a large impact due to high associated risk may not register.
- The results in this report are out of date at the time of release (most sites cut off in early 2022). An update will be provided by mid-2023, to include all data to the start of 2023.
- Positive sediment budget inputs like **beach renourishments** will be picked by the tools as short-term shoreline accretion, but no attempt is made to differentiate between shoreline change due to nourishment vs. “natural causes” (this is possible, but is more complex and beyond the current scope).

View the outputs according to the above caveats and also suggest things to improve ([jak.mccarroll@delpw.vic.gov.au](mailto:jak.mccarroll@delpw.vic.gov.au)). See Section 5 (Discussion and Conclusions) for further discussion of these issues.

## 1.1 VCMP Sites

As of 2022, VCMP had conducted drone surveys at 40 sites, with approx. 30 of these being regularly surveyed. For the purpose of an erosion indicator, a site must be regularly surveyed (minimum 4 surveys per year) and have a sufficiently long survey record (*preferably* over 2 years). For this report, **20 VCMP sites** had sufficient data to apply the erosion indicator methods (Table 1), based on minimum criteria of **7 surveys, covering at least one year**. Survey frequency at the selected sites ranges from **4 to 9 surveys per year**.

Table 1. VCMP sites selected for Erosion Indicator analysis



SITE-ID	LOCATION	ABBREV.	OPEN / BAY	N SURVEYS	START	END*
1	Seaspray	SEA	O	24	23/08/2018	3/11/2021
2	Inverloch	INV	O	26	22/08/2018	10/12/2021
3	Cowes	COW	B	25	24/08/2018	24/02/2022
4	Blairgowrie	BLR	B	10	3/12/2020	6/04/2022
5	Dromana-McCrae	DRM	B	10	3/12/2020	6/04/2022
6	Mt Martha	MAR	B	20	22/05/2019	22/02/2022

<b>8</b>	Patterson River	PAT	B	7	12/03/2021	15/12/2021
<b>9</b>	Sandringham	SND	B	10	4/12/2020	5/04/2022
<b>12</b>	Portarlington	PAR	B	25	6/06/2018	13/12/2021
<b>14</b>	St Leonards	LEO	B	31	6/06/2018	24/03/2022
<b>15</b>	Queenscliff	QCL	B	23	7/04/2018	8/02/2022
<b>16</b>	Point Lonsdale	LON	B	7	4/04/2019	24/03/2022
<b>17</b>	Ocean Grove	OGR	O	23	2/04/2019	13/12/2021
<b>20</b>	Demons Bluff	DMN	O	26	20/06/2018	21/10/2021
<b>21</b>	Point Roadknight	RDK	O	26	20/06/2018	10/12/2021
<b>26</b>	Apollo Bay	APO	O	37	1/06/2018	6/10/2021
<b>27</b>	Marengo	MGO	O	26	1/06/2018	29/11/2021
<b>28</b>	Warrnambool	WAR	O	30	6/03/2014	7/12/2021
<b>30</b>	Port Fairy	PTF	O	30	14/03/2018	31/01/2022
<b>31</b>	Portland	PLA	O	21	26/02/2018	28/01/2022

\* End date is limited to the most recent processed survey. An update will be completed to include 2022 surveys by mid-2023.

## 1.2 How to Quick-Check a Site Using This Report

This report has been designed to either to be read in order, as a standard document, or as a quick reference for users interested in a particular site.

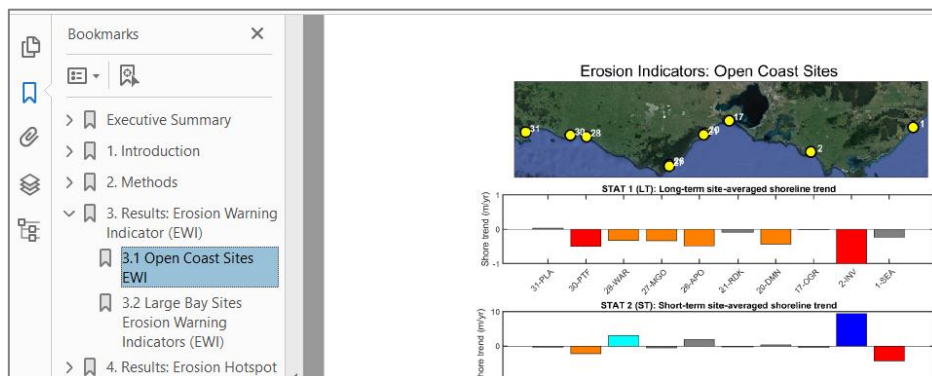
### Quick Check Steps...

1. If using Acrobat to view the pdf, open the bookmarks panel: “View > Show/Hide > Navigation Panes > Bookmarks”

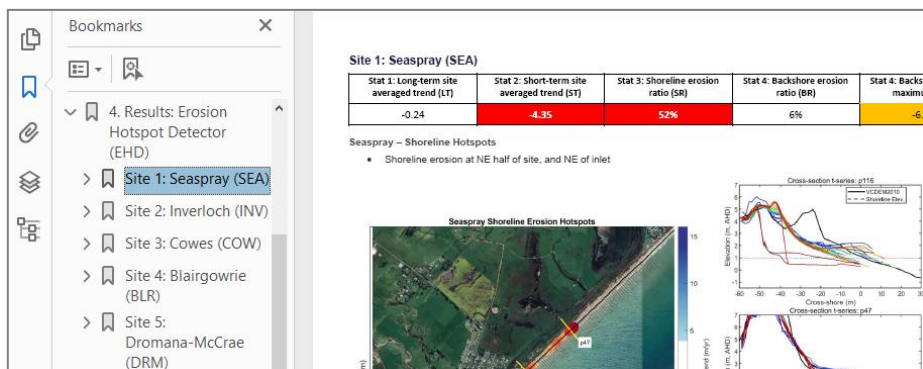


2. Get an overview of the site, compared to other VCMP sites, by checking the Erosion Warning Indicators (EWI). Using the Adobe Bookmarks, navigate to:

- Section 3.1 for Open Coast sites
- Section 3.2 for Large Bay sites



3. Check for more detailed analysis of high-erosion areas using the Erosion Hotspot Detector, with output for each site in Section 4.



## 2. Methods

### 2.1 Data Collection and Pre-processing

Prior to applying the Erosion Warning Indicator (Section 2.2) and Erosion Hotspot Detector (Section 2.3) methods, drone data is collected and processed as follows:

- Drone survey data collection is performed as described in (Pucino et al., 2021; Ierodiaconou et al., 2022).
- Data processing and quality control is conducted within the Propeller platform (<https://vcmp.prpellr.com>), with additional manual quality control checks, to achieve a horizontal-vertical uncertainty of 0.1 m or better (Pucino et al., 2021), with output products of Digital Surface Models (DSM) and orthomosaics.
- Analysis is conducted using a statewide framework of 30-m spaced transects.
- **Short-term VCMP drone survey outputs** include:
  - **Shorelines** for each survey, taking the ‘shoreline’ as the +1 m AHD contour for Open Coast sites, and +0.5 m AHD contour for Large Bay sites.
  - **Shoreline time series.**
  - Cross-sections (profiles) extracted at each transect, for each survey, which can be combined to produce a ‘**profile time series**’.
  - Shoreline change trends are determined for each transect, defining a ‘**short-term trend**’ as being based on the **last 2-years** of data.

Additionally, **long-term shoreline trends** are obtained for the period **1988 to 2019 (32 years)** using the satellite extracted, annually averaged shorelines from **Digital Earth Australia (DEA)** Coastlines (Bishop-Taylor et al., 2021).

All shoreline data (short-term VCMP drone and long-term DEA satellite) are **interpolated to the same set of 30-m spaced transects**, based on the DEA 2019 product.

### 2.2 Methods: Erosion Warning Indicator (EWI)

There is no one simple metric that can effectively describe the state of a beach. The approach here is to use a combination of statistics, and combine them into a single “Erosion Warning Indicator”. This gives a multi-faceted assessment of erosion characteristics at a given site, and allows for quantitative comparison across sites.

The 5 erosion statistics are:

1. Long-term shoreline change (1988 to 2019) – averaged across the site, using Digital Earth Australia satellite shorelines [*LT*]
2. Short-term change (last 2-years) – averaged across the site, using VCMP drone surveys [*ST*]
3. Ratio of shoreline eroding (last 2-years) - using VCMP drone data [*SR*]
4. Ratio of backshore (dune/cliff line) eroding (last 2-years) – using VCMP drone data [*BR*]
5. Max. backshore erosion (last 2-years, 3-point average alongshore) – VCMP drone data [*BH*]

The figures below demonstrate how the 5 statistics are calculated, using Apollo Bay and Inverloch as examples:

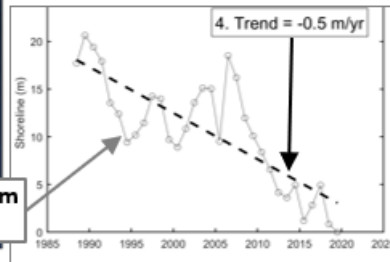
## Statistic 1: Long-term Shoreline Change (LT)



### Method

Uses DEA annual satellite shorelines (1988 – 2019)

1. Shoreline position at **transects** every **30 m** alongshore
2. Take the **site-averaged shoreline** for **each year**
3. Generate site-averaged shoreline **time series**
4. Fit single value for site-averaged **shoreline trend**

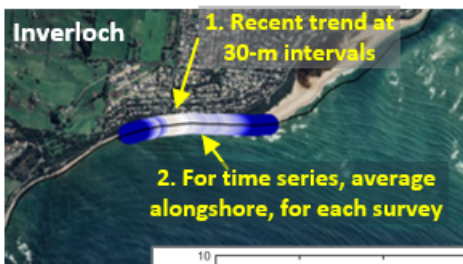


### Useful for identifying...

- Persistent erosion hotspots (map)
- Site-wide variability (time-series)
- Average sediment budget for the site (site-wide trend)

Figure 1. Erosion Statistic 1

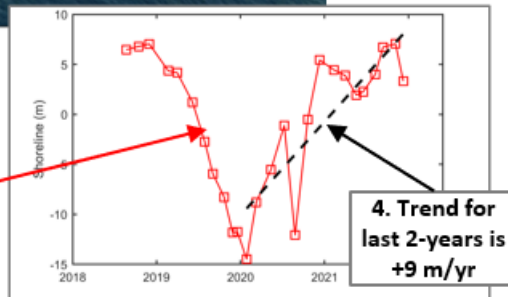
## Statistic 2: Short-term (2-year) Shoreline Trend (ST)



### Method

Uses VCMP drone surveys

1. Shoreline position (using 1-m AHD contour) every 30 m alongshore
2. Site-averaged shoreline for each survey
3. Site-averaged time series (inc. all VCMP surveys)
4. Find trend over last 2-years of data

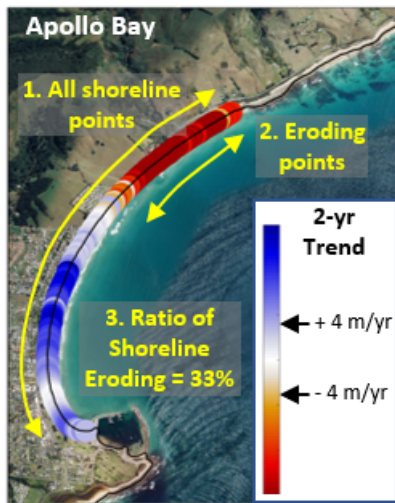


### Why take a 2-year trend...

- Pick out recent hotspots (map)
- Identify recent changes in behaviour across site (time series and 2-yr trendline)
- *E.g., Inverloch changes from short-term erosion to accretion after 2020*

Figure 2. Erosion Statistic 2

### Statistic 3: Ratio of Shoreline Eroding (last 2-years) (SR)



#### Method

Uses VCMP drone surveys

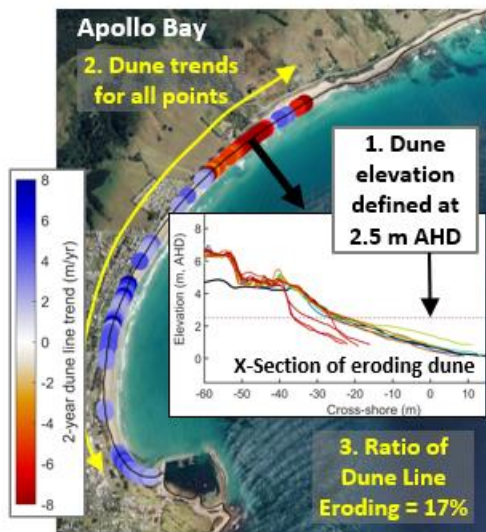
1. Find 2-year **shoreline trend** at each point alongshore (see Statistic 2), defining “shoreline” as:
  - 1 m AHD (Open Coast)
  - 0.5 m AHD (Large Bays)
2. Find points eroding at:
  - At least 4 m/yr (Open Coast)
  - At least 2 m/yr (Large Bays)
3. Shore erosion **ratio** = eroding points / total points

#### Useful for...

- Determining how much shoreline is impacted by recent erosion, even when the compartment as a whole is stable.
  - *E.g., ‘Beach Rotation’ at Apollo Bay, the NE has eroded while the SW has accreted.*

Figure 3. Erosion Statistic 3

### Statistic 4: Ratio of Backshore (Dune/Cliff Line) Eroding (last 2-years) (BR)



#### Method

Uses VCMP drone surveys

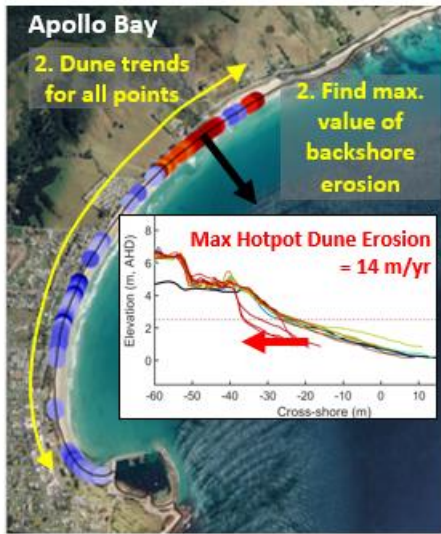
1. Define backshore (dune/cliff) line **elevation**
  - ~ 2.5 m AHD for Open Coasts
  - 1.5 - 2 m AHD for Large Bays
2. Determine 2-yr backshore **trend** at all points alongshore, and find points eroding at:
  - At least 2 m/yr (Open Coast)
  - At least 1 m/yr (Large Bays)
3. Backshore erosion **ratio** =  $n$  eroding points /  $n$  total points

#### Useful for...

- Determining when *beach erosion* (often just short-term fluctuations) turns to more serious *dune erosion*

Figure 4. Erosion Statistic 4

## Statistic 5: Max Backshore Hotspot Erosion (last 2-years) (MB)



### Method

Uses VCMP drone surveys

1. Determine backshore 2-year trend at all points alongshore (see Stat 4)
2. Find maximum erosion value (averaged across 3-points alongshore)

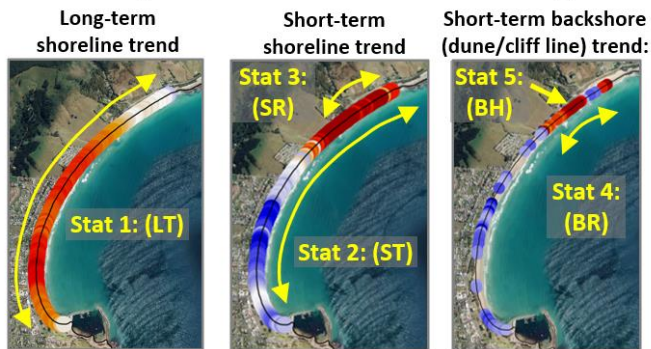
### Useful for...

- Finding the most extreme hotspots point of dune/cliff erosion
- **Hotspots are often a concern, even when most of the shoreline is stable**

Figure 5. Erosion Statistic 5

The 5 erosion statistics are then combined into an overall Erosion Warning Indicator [EWI, figure below]. Each individual statistic is given a score [0 – No warning; 1 – Moderate warning; 2 – High warning], and these scores are summed to a maximum value of 10. The higher the EWI value, the greater the severity of the warning. The rules for the scoring system are given in Table 2.

## Summary Statistic: Erosion Warning Indicator (EWI)



### Calculating the Score

1. A score from 0 to 2 is given for each indicator statistic:

- 0 – No warning indicated
- 1 – Moderate level warning
- 2 – High level warning

*E.g., for Stat 1...*

*Erosion of at least 0.3 m/yr (1 POINT)*

*Erosion of at least 0.5 m/yr (2 POINTS)*

2. The max. site score is **10 POINTS**. Higher scores indicate an increased Erosion Warning Level (EW).

$$\text{Erosion Warning Level (EW)} = \text{Long-term Erosion Trend (LT)} + \text{Short-term Erosion Trend (ST)} + \text{Shoreline Erosion Ratio (SR)} + \text{Backshore (Dune/Cliff) Erosion Ratio (BR)} + \text{Max Backshore Hotspot (BH)}$$

Score [0 to 2] for each Stat → Stat 1      Stat 2      Stat 3      Stat 4      Stat 5

Figure 6. Erosion Warning Indicator method

**Table 2. Summary of erosion statistics and Erosion Warning Indicator score (out of 10)**

Stat ID	Statistic description	Variable	Condition...	Contribution to EWI Score (/10)			
				Open Coast		Large Bays	
				1 POINT	2 POINTS	1 POINT	2 POINTS
1	Long-term site-averaged shoreline change (1988 - 2019)	LT	Erosion is at least...	0.3 m/yr	0.5 m/yr	0.3 m/yr	0.5 m/yr
2	Short-term site-averaged shoreline change (last 2-years)	ST		2 m/yr	4 m/yr	1 m/yr	2 m/yr
3	Ratio of shoreline eroding	SR	% shoreline eroding is at least...	20%	40%	20%	40%
4	Ratio of backshore eroding	BR		10%	20%	10%	20%
5	Max backshore hotspot erosion	BH	Max. erosion is at least...	4 m/yr	8 m/yr	2 m/yr	4 m/yr

The following colour coding is used throughout the report:

- Statistics contributing **1 POINT to EWI are in ORANGE**
- Statistics contributing **2 POINTS to EWI are in RED**
- For EWI TOTAL (out of 10), **MODERATE level warning (3 to 5 points) in ORANGE**, and **HIGH level warning (6 to 10 points) in RED**



## 2.3 Methods: Erosion Hotspot Detector (EHD)

In order to understand the detail of erosion occurring at a given site, an additional method is applied to identify “Erosion Hotspots”, using the following approach:

### Shoreline - Erosion Hotspot Detector

1. Determine Short-term Shoreline Trend (see Stat 2, Fig. 2) for all points alongshore for a site.
2. Use a peak finding algorithm to identify and rank a maximum of 3 peaks, using the following rules:
  - Minimum short-term erosion rate must exceed:
    - 4 m/yr for Open Coast sites
    - 2 m/yr for Large Bay sites
  - Minimum distance between peaks is 150 m (5 transects at 30-m spacing).
3. Generate time series of cross-section profiles at top 3 ranked erosion peaks (middle column in figure below).
4. Generate time series of shoreline position at top 3 hotspots (right column in figure below).

### Backshore (Dune / Cliff Line) – Erosion Hotspot Detector

1. Use the same approach as Shoreline Hotspots (above), with following thresholds:
  - Minimum short-term erosion rate must exceed:
    - 2 m/yr for Open Coast sites
    - 1 m/yr for Large Bay sites

Shoreline elevation is taken as 1 m AHD for Open Coast sites and 0.5 m AHD for Large Bays. The maps and hotspot time series are presented for each site in Section 4.

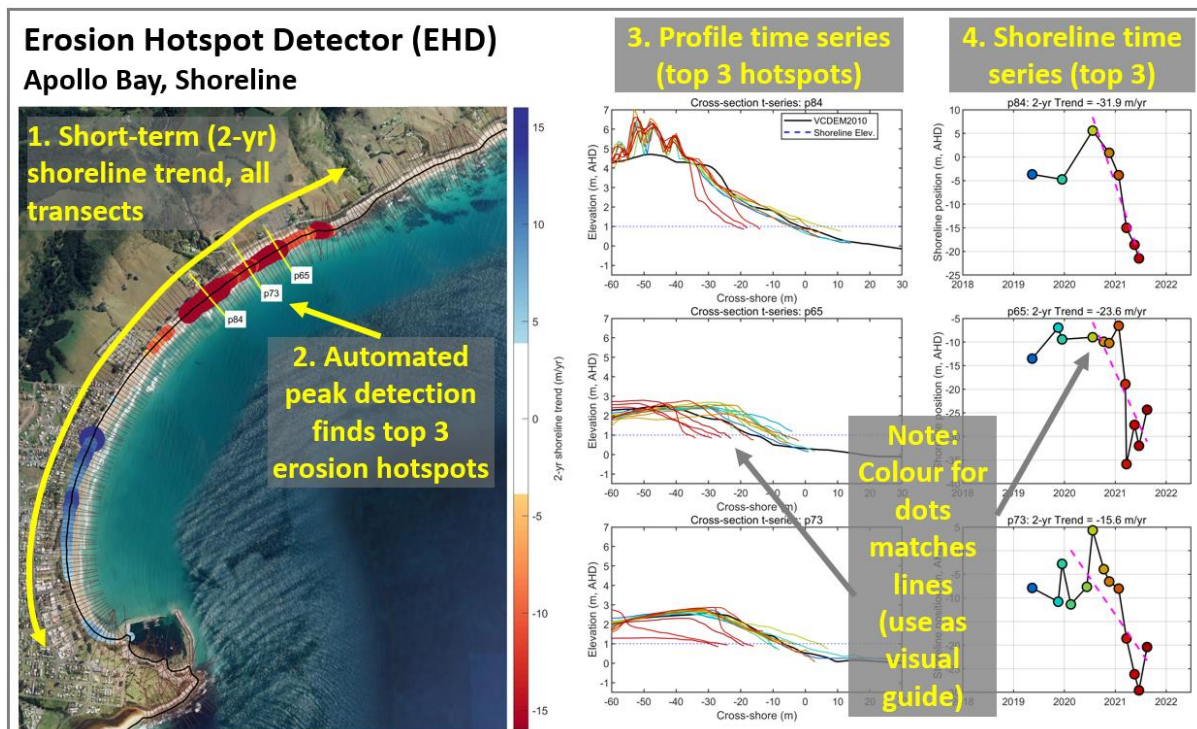


Figure 7. Erosion Hotspot Detector method

## 3. Results: Erosion Warning Indicator (EWI)

Summary results for application of the EWI are grouped by Open Coast sites (Section 3.1) and Large Bay sites (Section 3.2).

### 3.1 Open Coast Sites EWI

Open coast summary statistics and EWI level (as per methods in Section 2.1) are presented in Fig. 8. Additionally, a mosaic of shoreline trends for open coasts sites, in plan and time series view, are provided for long-term trends (Fig. 9) and short-term (2-year) trends (Fig. 10). Notable observations include:

- The **highest erosion warning level** is for **Marengo (27-MGO; EWI = 6)** due to the extent and magnitude of backshore (dune) erosion (Stat 4 and 5 in Fig. 8). This is the case despite a large nourishment accreting the mid-south section shoreline (see Section 4, Site 27), as the erosion statistics in this instance are triggered by erosion occurring away from the nourishment zone.
- Other sites with high erosion warnings include Seaspray (1-SEA) and Apollo Bay (26-APO), both with EWI = 5, and Port Fairy (30-PTF) with EWI = 4.
- Inverloch (2-INV in Fig. 8) has by far the worst long-term erosion (STAT 1, Fig. 8; Fig. 9), but has accreted in recent years (Fig. 10), and therefore has a relatively low EWI of 2 out of 10.
- Demons Bluff (20-DMN, Fig. 8) is known to experience frequent large volume cliff falls. For this reason, the site is considered high-risk and has been closed to the public. The EWI rating for Demons Bluff is low (2 out of 10) due to the *horizontal distance* of shoreline (STAT 3, Fig. 8) and cliff toe (STAT 4) erosion being relatively low. A better statistic to adequately capture the magnitude of cliffs falls would be *erosion volume* (this has some technical complexity if automating for all sites, and may be included in a future version).
- Portland (Dutton Way) does NOT show up as a long-term erosion site, despite historical erosion being a problem in that area. In this instance “long-term” only extends back to the start of the DEA satellite record in 1988 and this is NOT long enough to capture the initial phase of erosion around Dutton Way. Aerial imagery can provide a longer time series, but the extraction of shorelines (and backshore lines) is incomplete across the VCMP sites.

### Erosion Indicators: Open Coast Sites

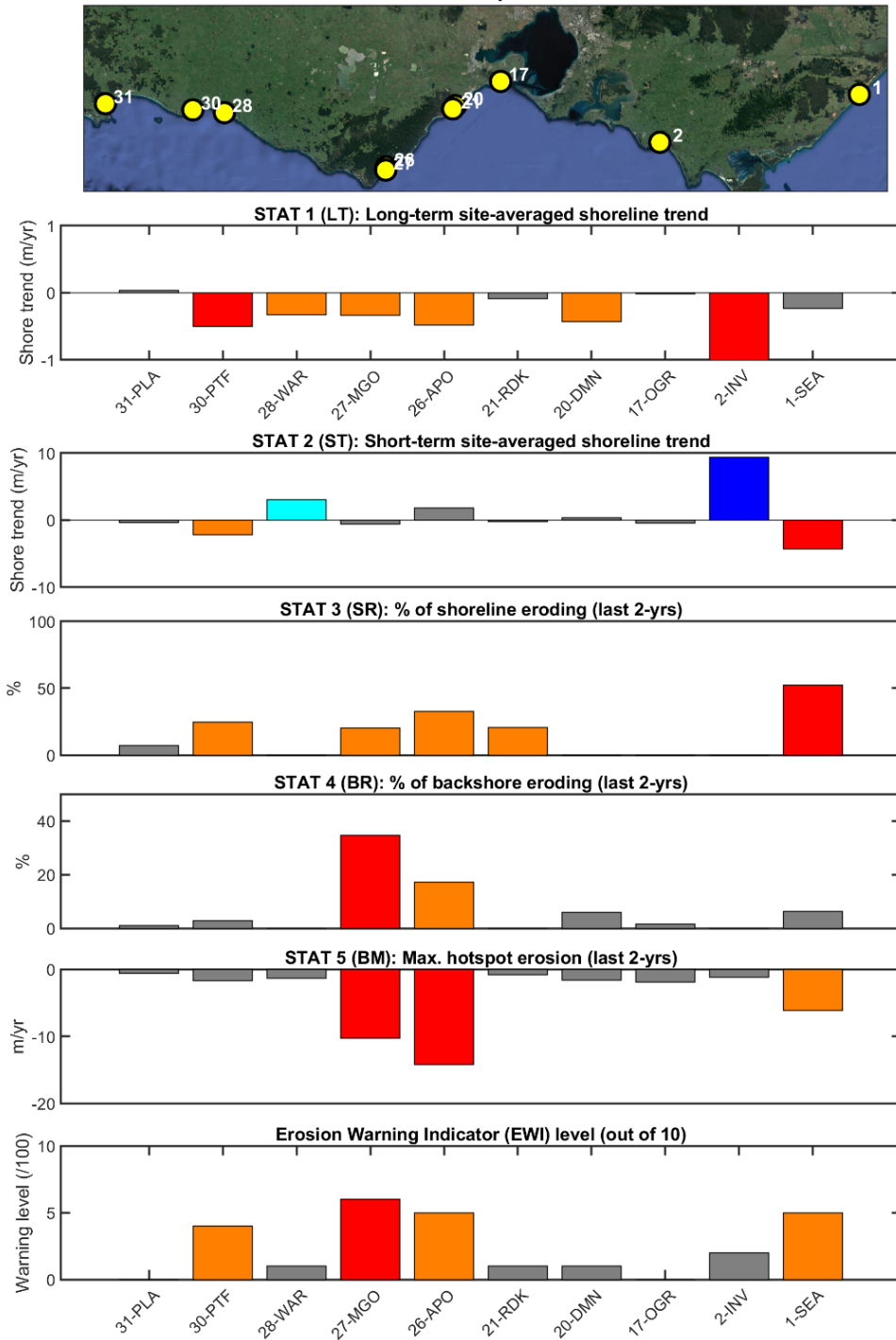


Fig 8. Open Coast site summary statistics and Erosion Warning Indicator levels.

Statistics contributing **1 POINT to EWI are in ORANGE**, and those contributing **2 POINT to EWI are in RED**.  
 For the overall EWI score (out of 10), **MODERATE levels (3 to 5 points) are ORANGE**,  
 and **HIGH levels (6 to 10 points) are in RED**.

## Open Coast Sites: Long-term (1988 – 2019) Shoreline Trend

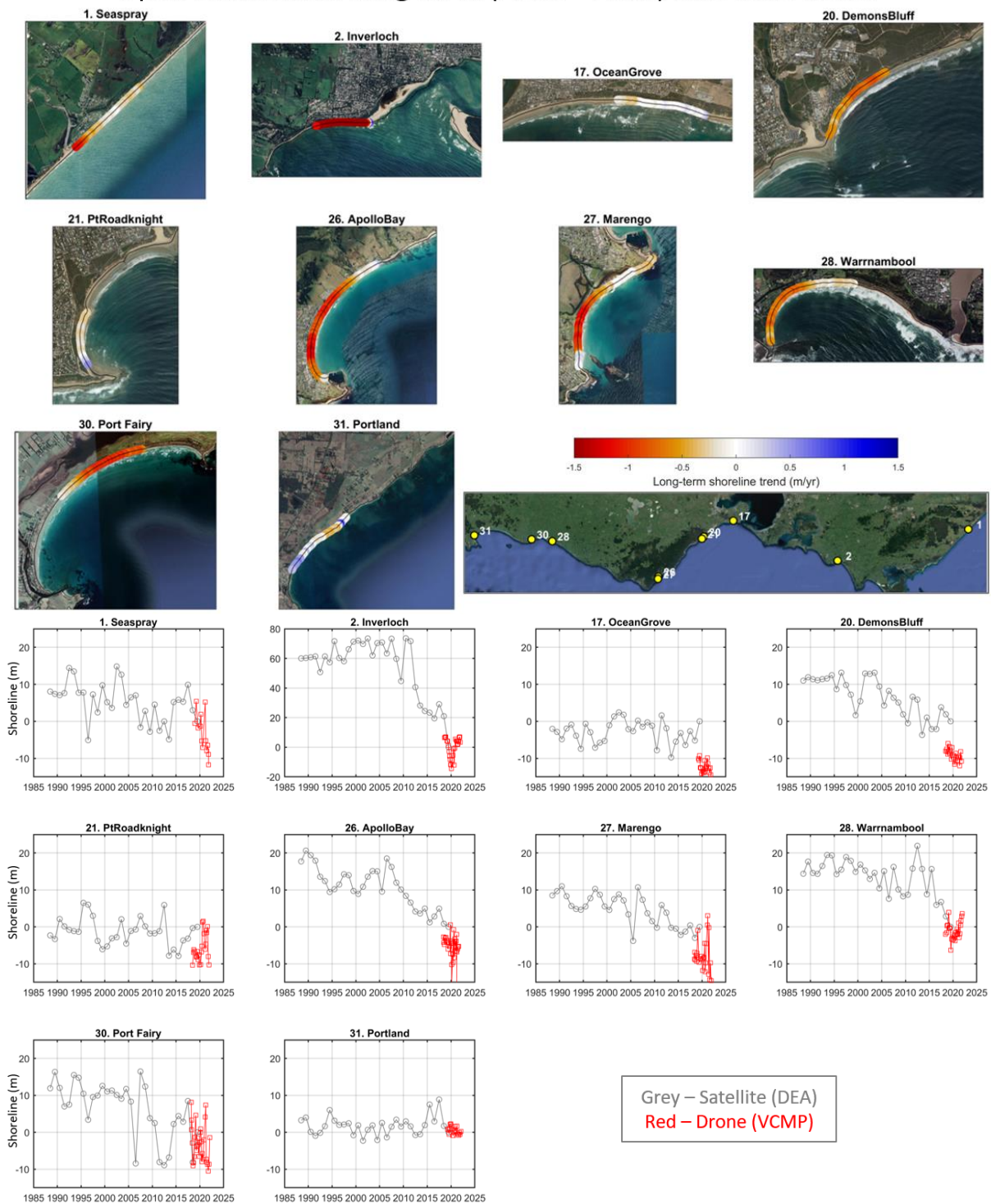


Fig 9. Open Coast long-term shoreline trend, using Digital Earth Australia satellite shorelines

## Open Coast Sites: Short-term (2-year) Shoreline Trend

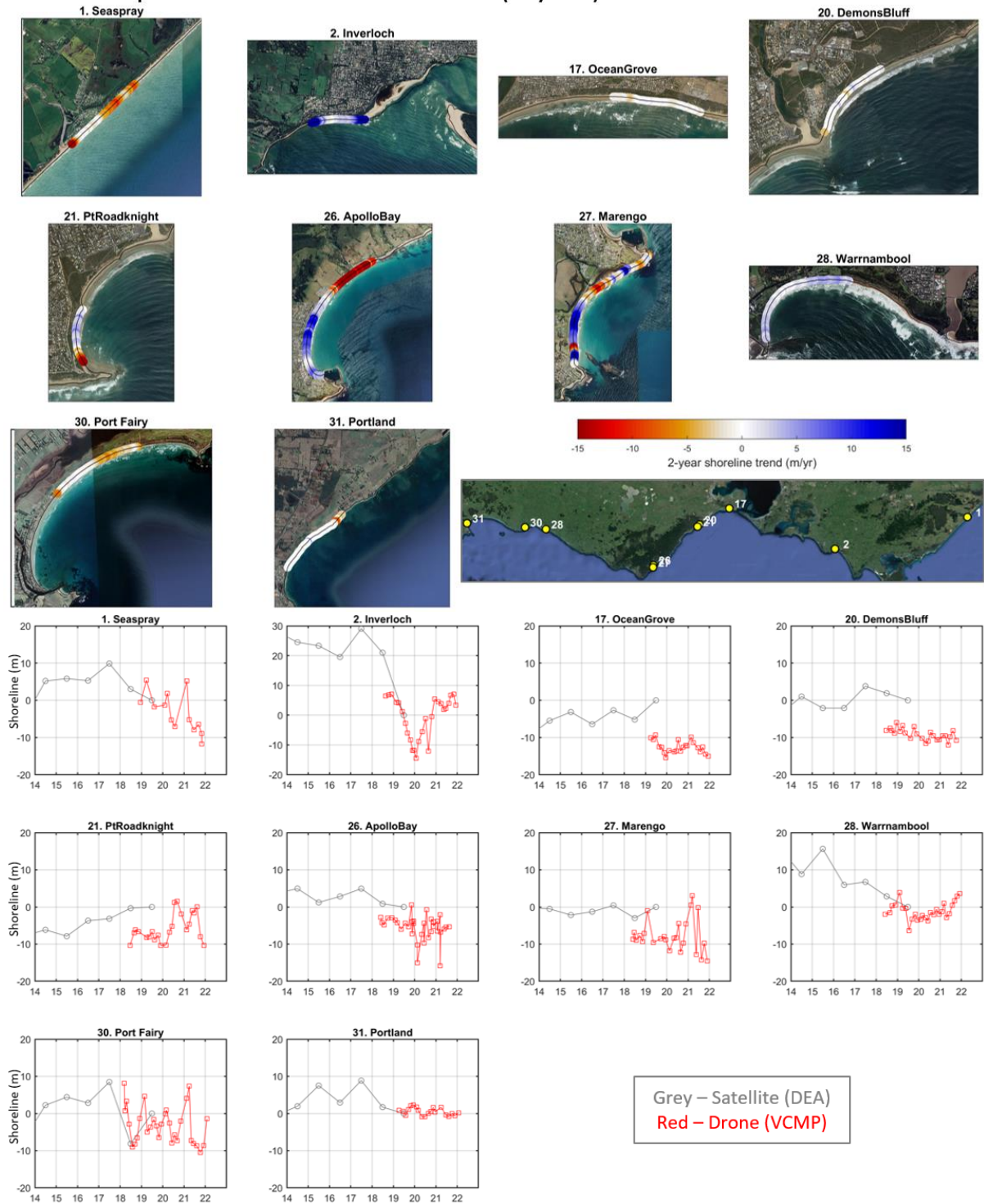


Fig 10. Open Coast short-term (2-yr) shoreline trend, using VCMP drone survey data.

**Why don't the grey and red lines always match up?** The DEA satellite (grey in time series) and VCMP drone surveys (red) use very different methods to define a “shoreline”. At some sites they line up well (e.g., Inverloch, Portland), at other sites there is an offset (Ocean Grove, Demons Bluff). This is to be expected.

### 3.2 Large Bay Sites Erosion Warning Indicators (EWI)

Large Bay sites summary statistics and EWI level (as per methods in Section 2.1) are presented in Fig. 11. Additionally, a mosaic of shoreline trends for bay sites, in plan and time series view, are provided for long-term trends (Fig. 12) and short-term (2-year) trends (Fig. 13). Notable observations include:

- The **highest erosion warning level** is for **Patterson River (8-PAT; EWI = 6)** due to the extent and magnitude of backshore (dune) erosion (Stat 4 and 5 in Fig. 8), as well as moderate shoreline erosion.
- Other bay sites with high erosion warnings include Point Lonsdale (16-LON; EWI = 4), Sandringham (9-SND; EWI = 3) and Cowes (3-COW; EWI = 3).
- None of the Large Bay sites exhibit sufficiently high long-term erosion to trigger a warning level (STAT 1, Fig. 11).
- Several Port Phillip Bay sites show positive short-term shoreline change, due to renourishments conducted over 2020-2022, these include Dromana (5-DRM), Blairgowrie (4-BLR) and St Leonards (14-LEO).

### Erosion Indicators: Large Bays Sites

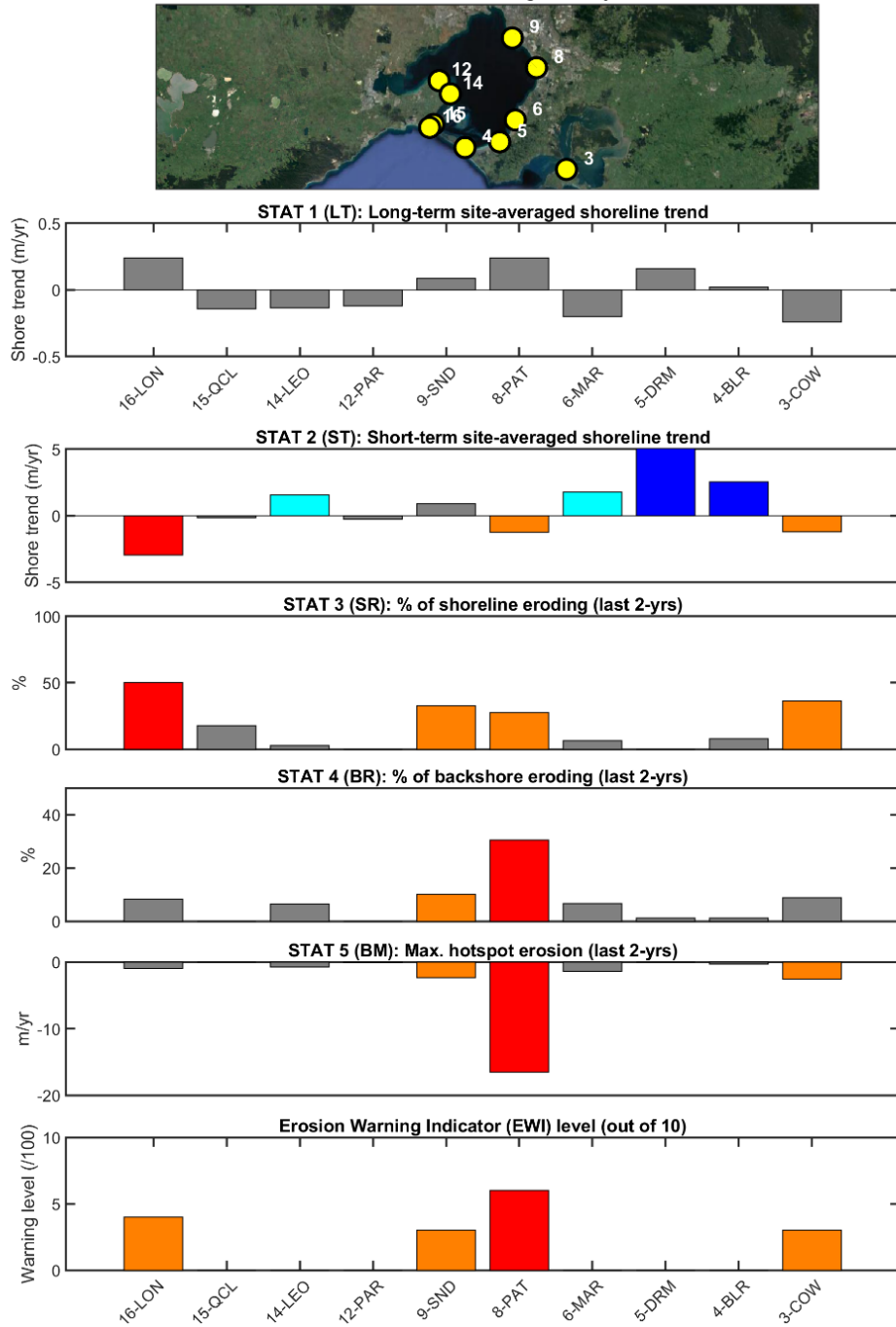


Fig 11. Large Bay site summary statistics and Erosion Warning Indicator levels.

Statistics contributing **1 POINT to EWl** are in **ORANGE**, and those contributing **2 POINT to EWl** are in **RED**.  
 For the overall EWl score (out of 10), **MODERATE** levels (3 to 5 points) are **ORANGE**,  
 and **HIGH** levels (6 to 10 points) are in **RED**.

## Bay Sites: Long-term (1988 – 2019) Shoreline Trend

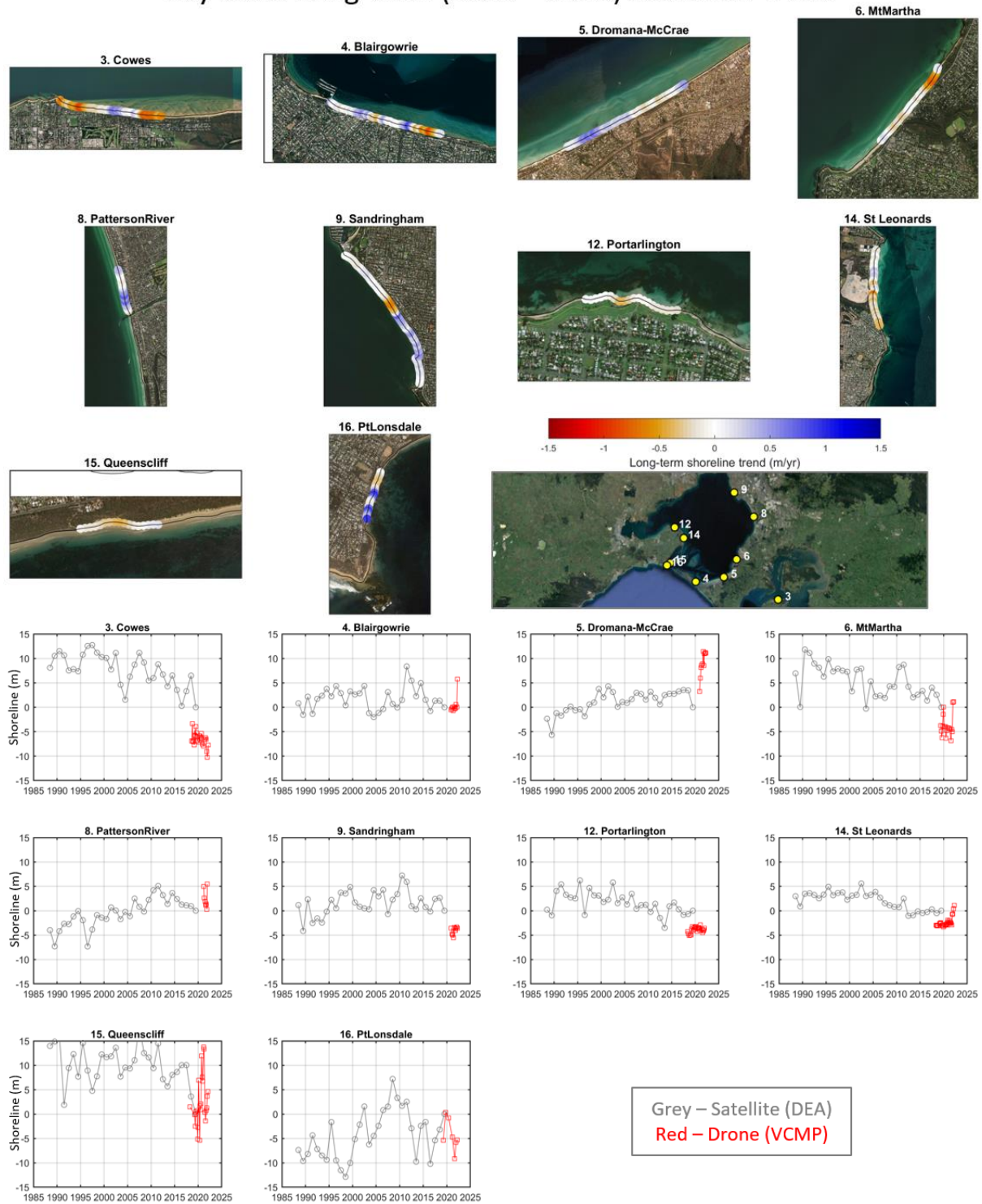


Fig 12. Large Bay sites long-term shoreline trend, using Digital Earth Australia annual satellite shoreline.



## Bay Sites: Short-term (2-year) Shoreline Trend

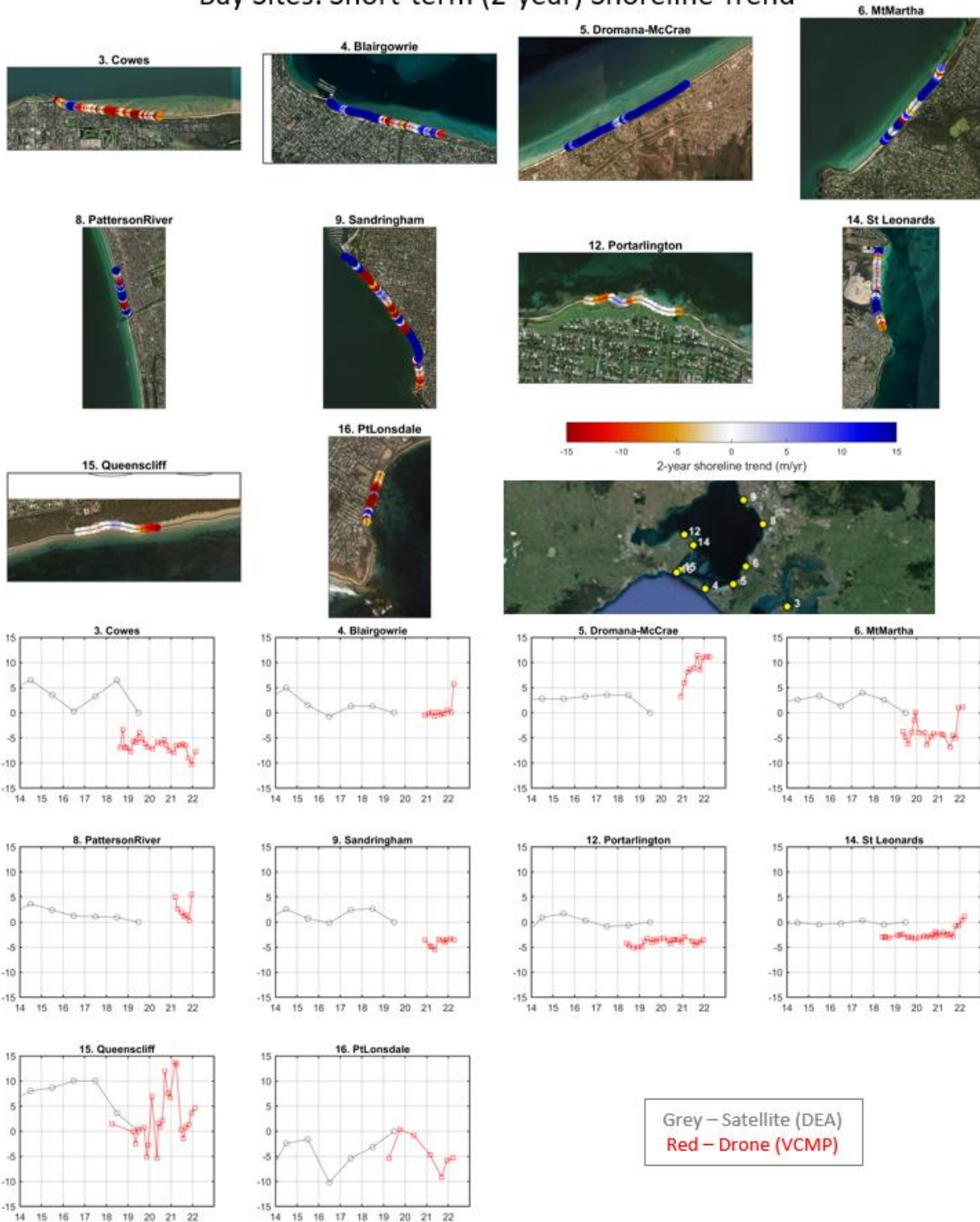


Fig 13. Large Bay sites short-term (2-yr) shoreline trend, using VCMP drone survey data.

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## 4. Results: Erosion Hotspot Detector (EHD)

This section contains results for the Erosion Hotspot Detector (EHD), each site contains:

- Tabulated results for first tool, the Erosion Warning Indicator (EWI, replicating the results in Section 3, Fig. 8 and 11).
- Colour coding for the EWI table is:
  - Statistics contributing **1 POINT to EWI are in ORANGE**
  - Statistics contributing **2 POINTS to EWI are in RED**
  - For EWI TOTAL (out of 10), **MODERATE level warning (3 to 5 points) are ORANGE**, and **HIGH level warning (6 to 10 points) are RED**
  - Details on the EWI scoring system are in Table 2 (Section 2.2)
- A full page figure for EHD top 3 SHORELINE erosion hotspots, with site map, profile time series and shoreline time series.
- A similar figure for EHD top 3 BACKSHORE (dune/cliff line) erosion hotspots.
- For all sites the coloured dots in the shoreline time series match up to the lines in the profile time series (for visual reference of profile evolution).

The intended use of this section is to:

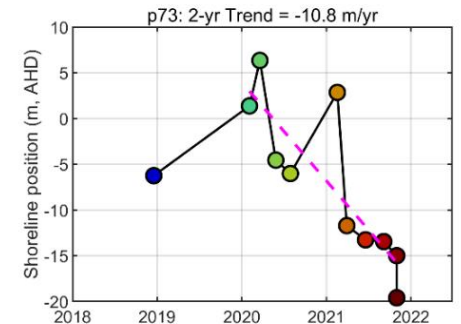
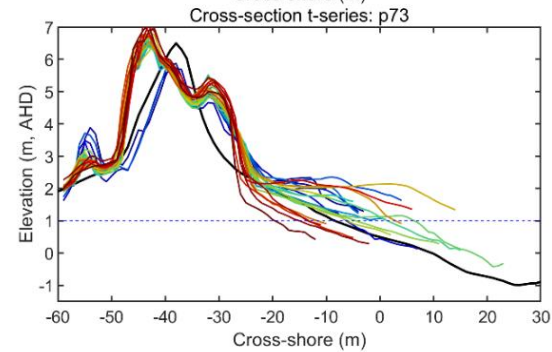
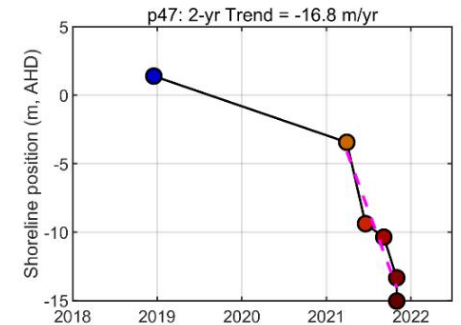
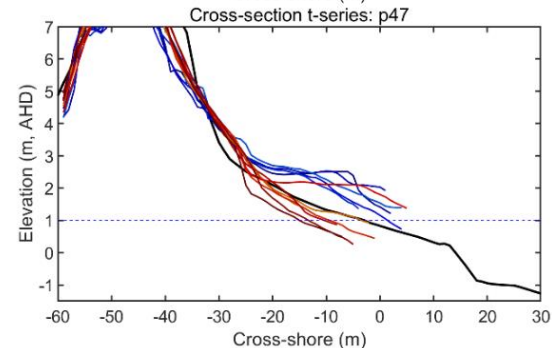
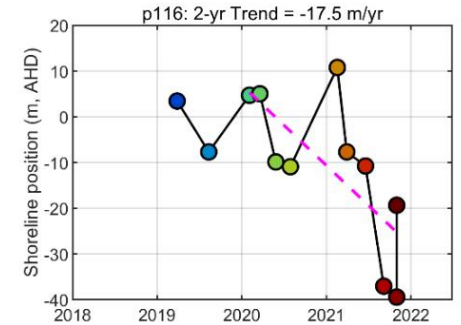
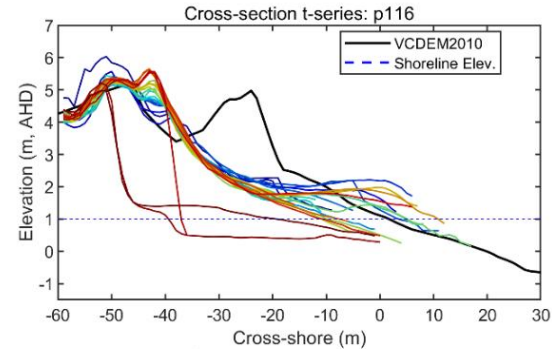
- Read the site overview in Section 3, using the EWI tool.
- Refer to individual sites in this section that are of particular interest.

# Site 1: Seaspray (SEA)

Stat 1: Long-term site averaged trend (LT)	Stat 2: Short-term site averaged trend (ST)	Stat 3: Shoreline erosion ratio (SR)	Stat 4: Backshore erosion ratio (BR)	Stat 5: Backshore hotspot maximum (BH)	Summary: Erosion Warning Indicator (EWI)
-0.24	<b>-4.35</b>	<b>52%</b>	6%	<b>-6.58</b>	<b>5 / 10</b>

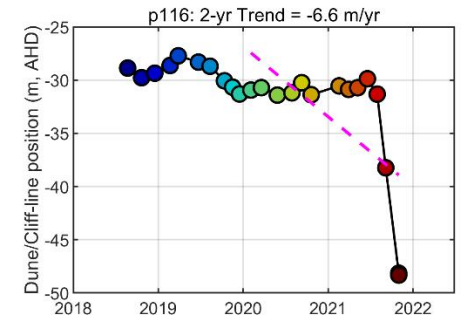
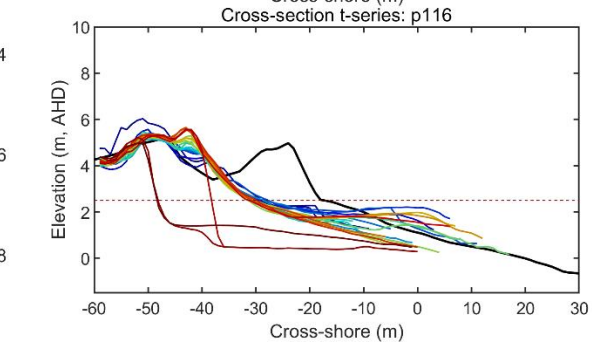
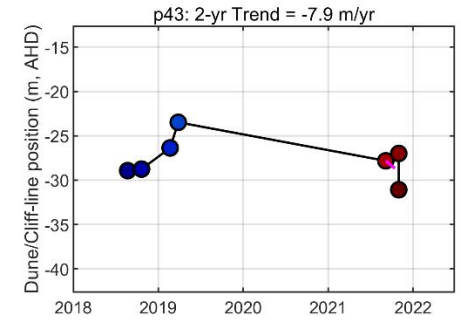
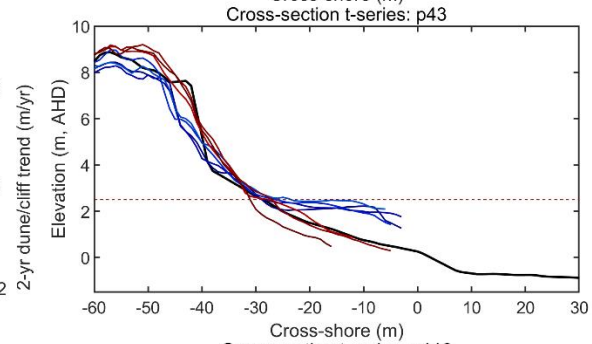
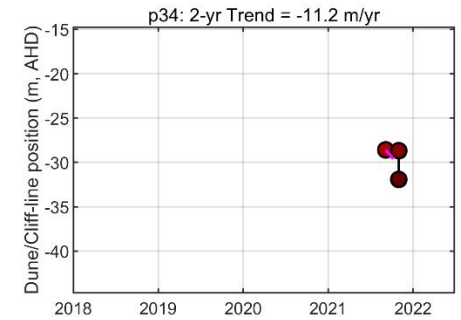
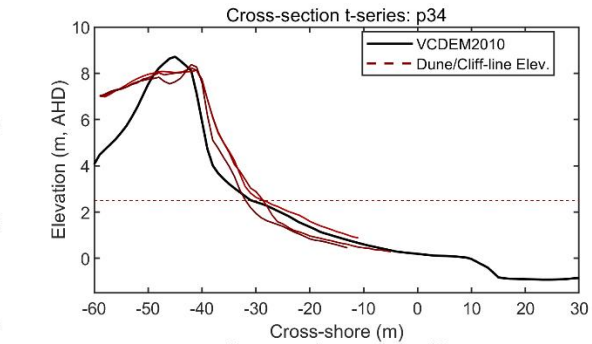
## Seaspray – Shoreline Hotspots

- Shoreline erosion at NE half of site, and NE of inlet



## Seaspray – Dune/Cliff-line Hotspots

- Isolated areas of dune erosion
- Aside from inlet area, no dune erosion around infrastructure



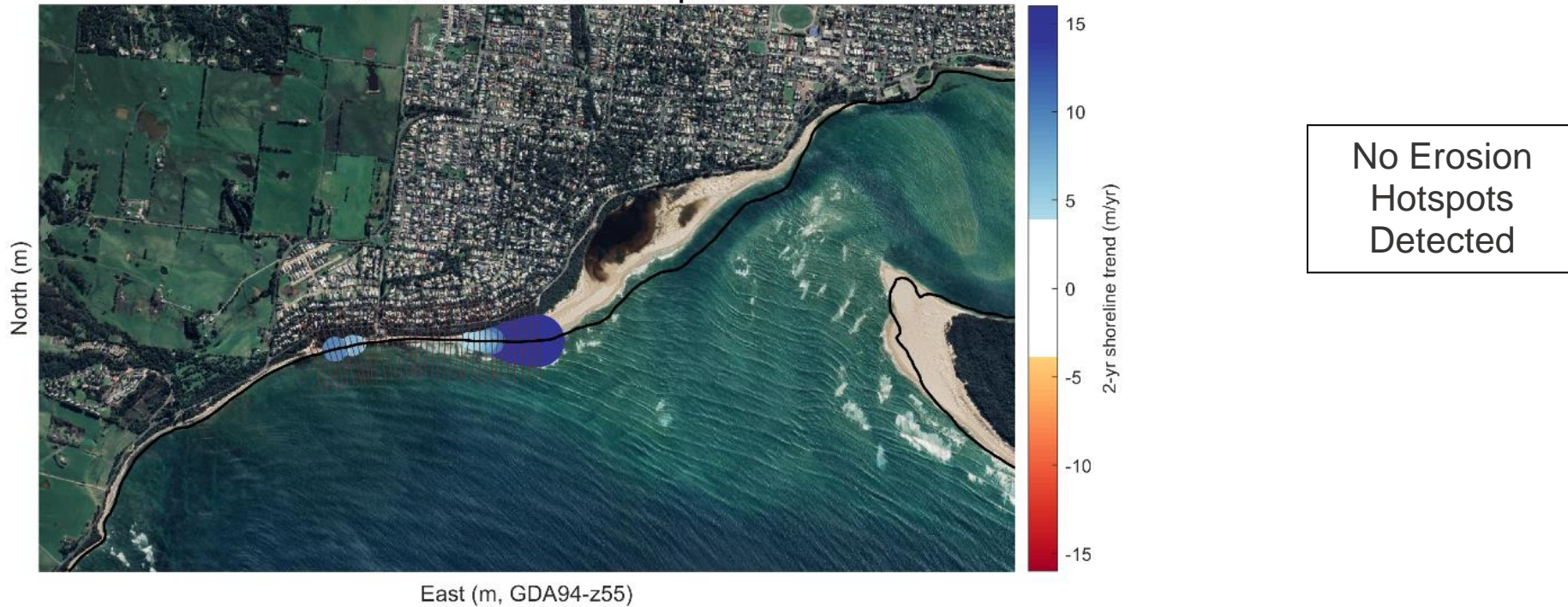
## Site 2: Inverloch (INV)

Stat 1: Long-term site averaged trend (LT; m/yr)	Stat 2: Short-term site averaged trend (ST; m/yr)	Stat 3: Shoreline erosion ratio (SR; %)	Stat 4: Backshore erosion ratio (BR; %)	Stat 5: Backshore hotspot maximum (BH; m/yr)	Summary: Erosion Warning Indicator (EWI)
-1.35	9.36	0	0	-1.48	2 / 10

### Inverloch – Shoreline Hotspots

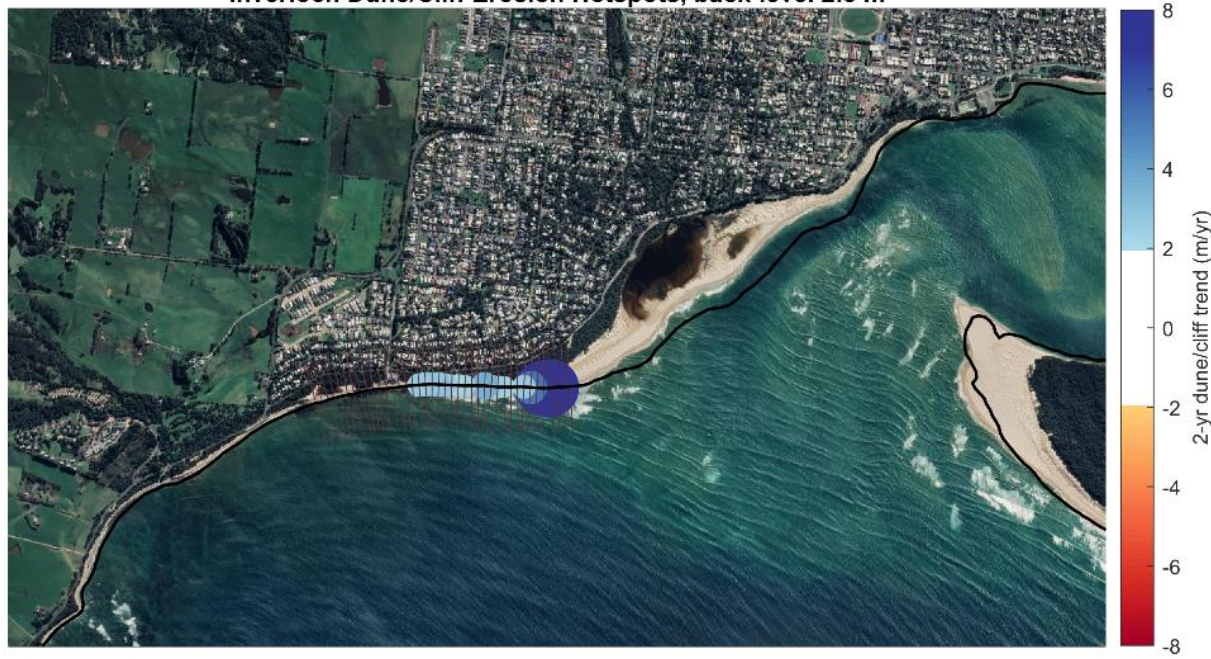
- No shoreline or dune line EROSION hotspots detected over past 2 years
- Shoreline and dune line around SLSC has been ACCRETING over this period

Inverloch Shoreline Erosion Hotspots



Inverloch – Dune/Cliff-line Hotspots

Inverloch Dune/Cliff Erosion Hotspots, back-level 2.5 m



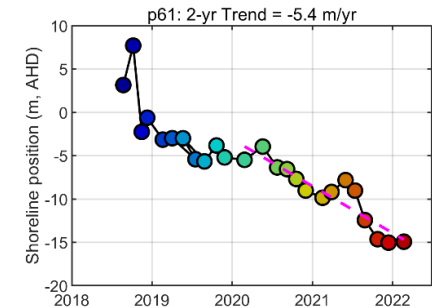
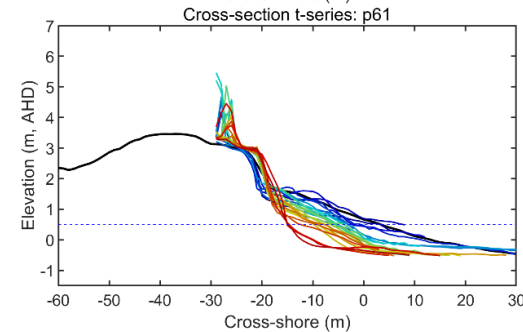
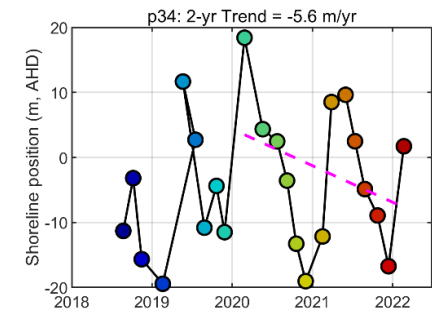
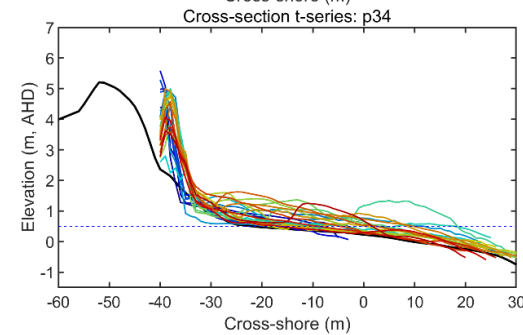
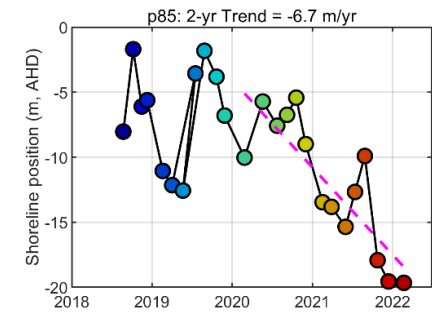
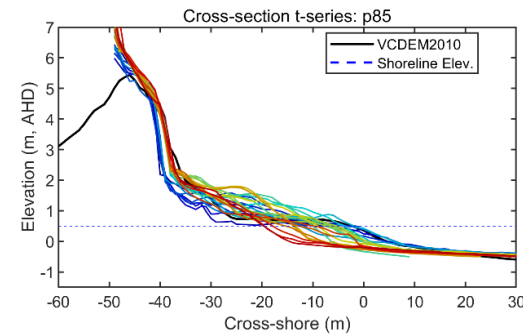
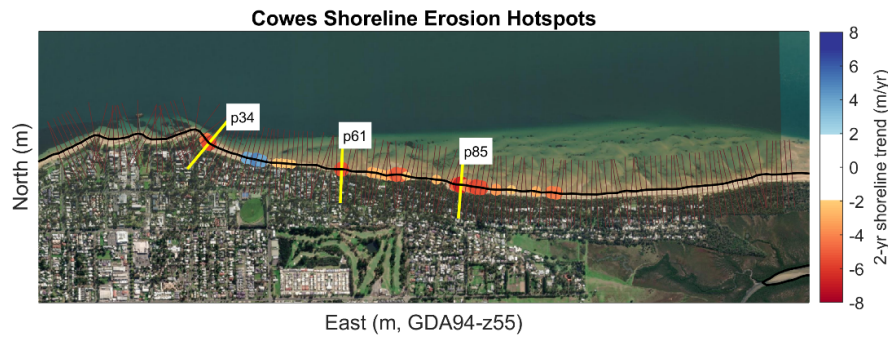
No Erosion Hotspots Detected

### Site 3: Cowes (COW)

Stat 1: Long-term site averaged trend (LT; m/yr)	Stat 2: Short-term site averaged trend (ST; m/yr)	Stat 3: Shoreline erosion ratio (SR; %)	Stat 4: Backshore erosion ratio (BR; %)	Stat 5: Backshore hotspot maximum (BH; m/yr)	Summary: Erosion Warning Indicator (EWI)
-0.24	-1.23	36%	9%	-3.47	3 / 10

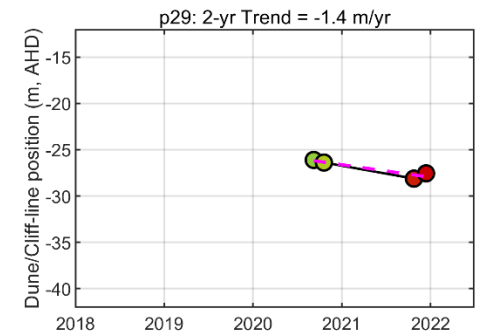
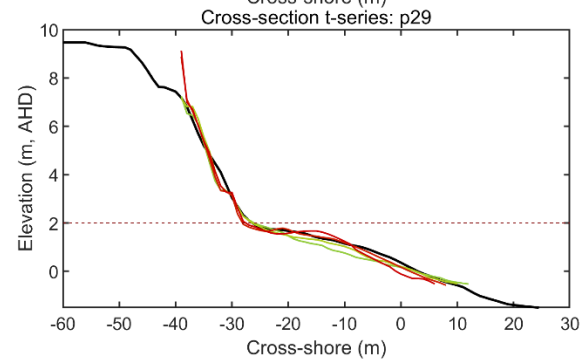
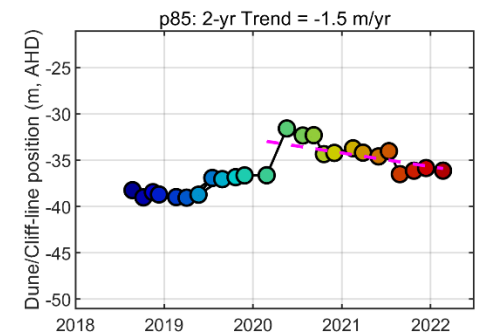
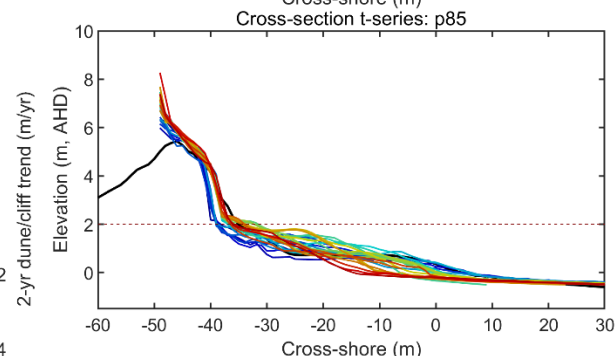
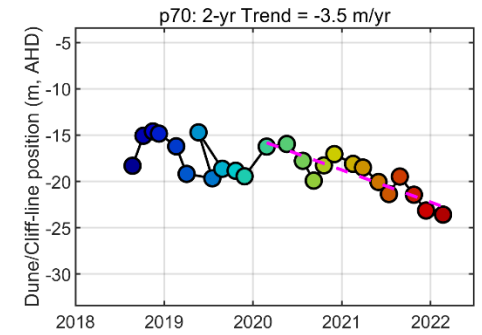
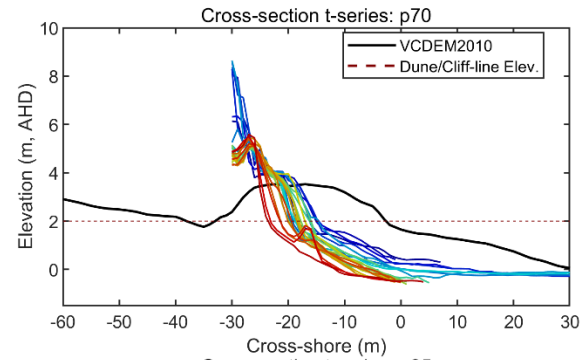
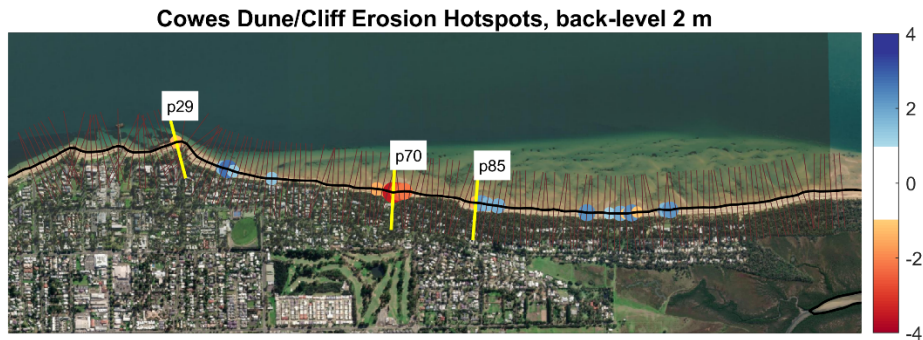
#### Cowes – Shoreline Hotspots

- p85 – Shoreline is moving onshore, beach face steepening
- p34 – Strong seasonal oscillation, trend is weak
- P61 – Steady long-term erosion with little seasonal variability





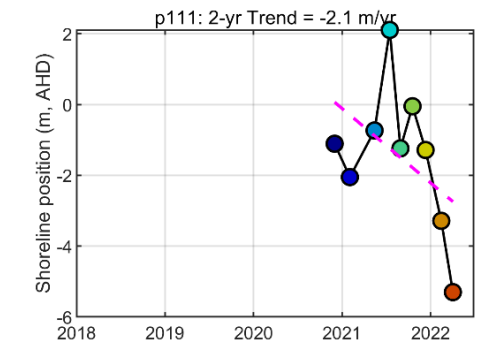
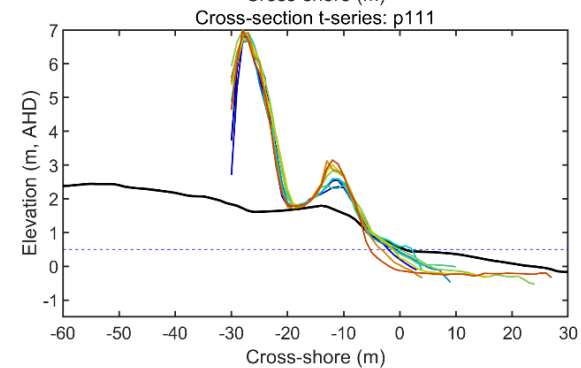
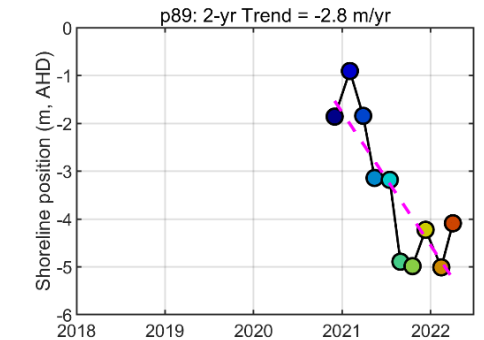
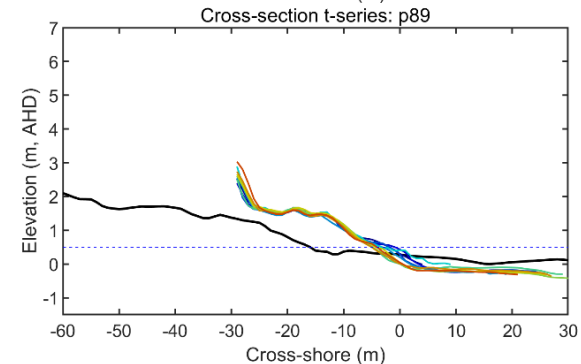
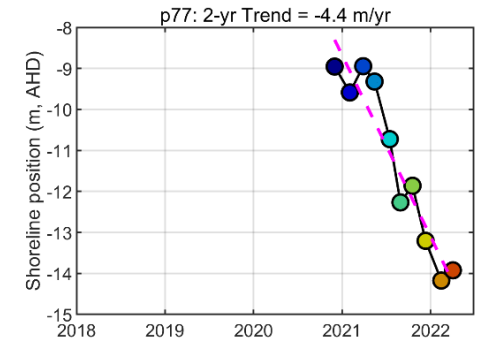
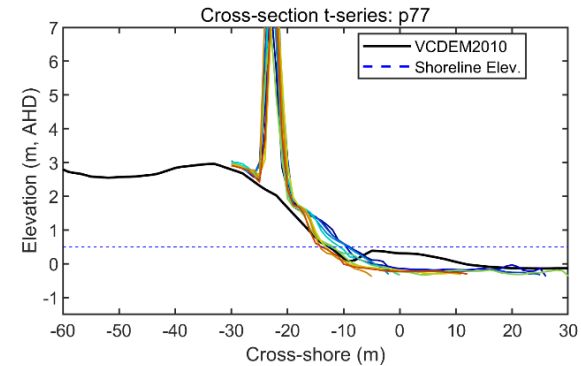
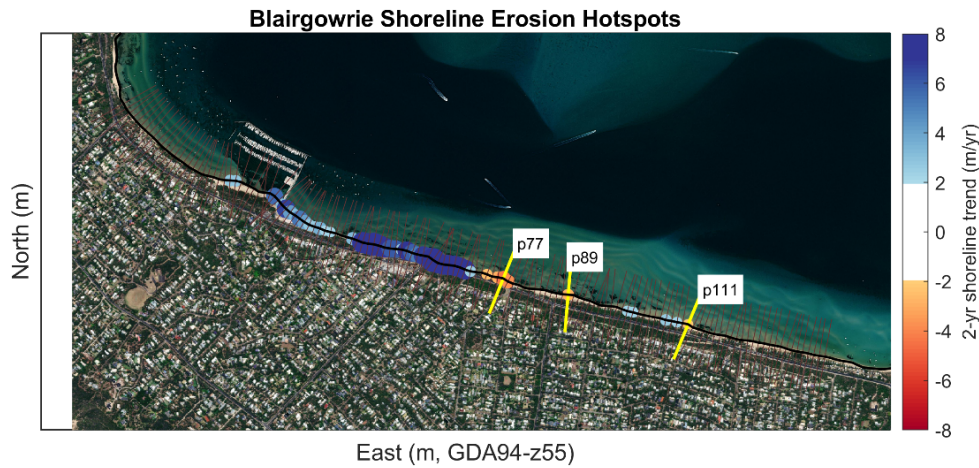
# Cowes – Dune/Cliff-line Hotspots



## Site 4: Blairgowrie (BLR)

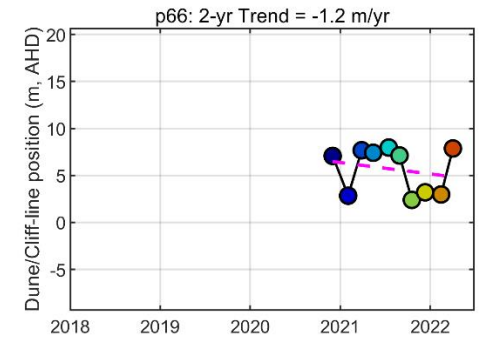
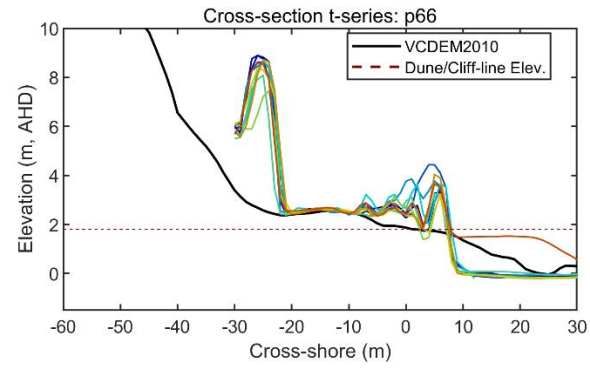
Stat 1: Long-term site averaged trend (LT; m/yr)	Stat 2: Short-term site averaged trend (ST; m/yr)	Stat 3: Shoreline erosion ratio (SR)	Stat 4: Backshore erosion ratio (BR; %)	Stat 5: Backshore hotspot maximum (BH; m/yr)	Summary: Erosion Warning Indicator (EWI)
0.02	2.54	8%	1%	-1.21	0 / 10

### Blairgowrie – Shoreline Hotspots



# Blairgowrie – Dune/Cliff-line Hotspots

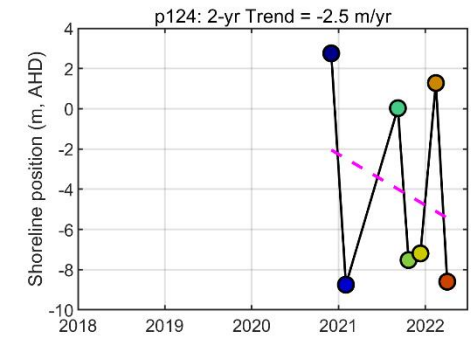
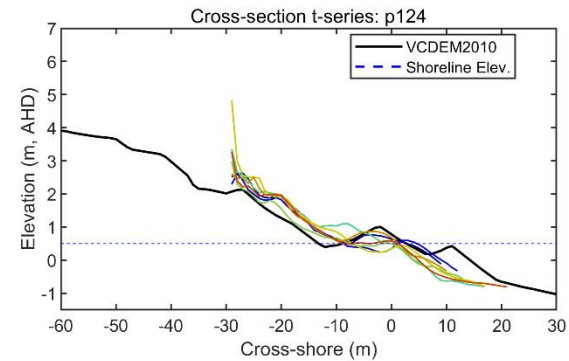
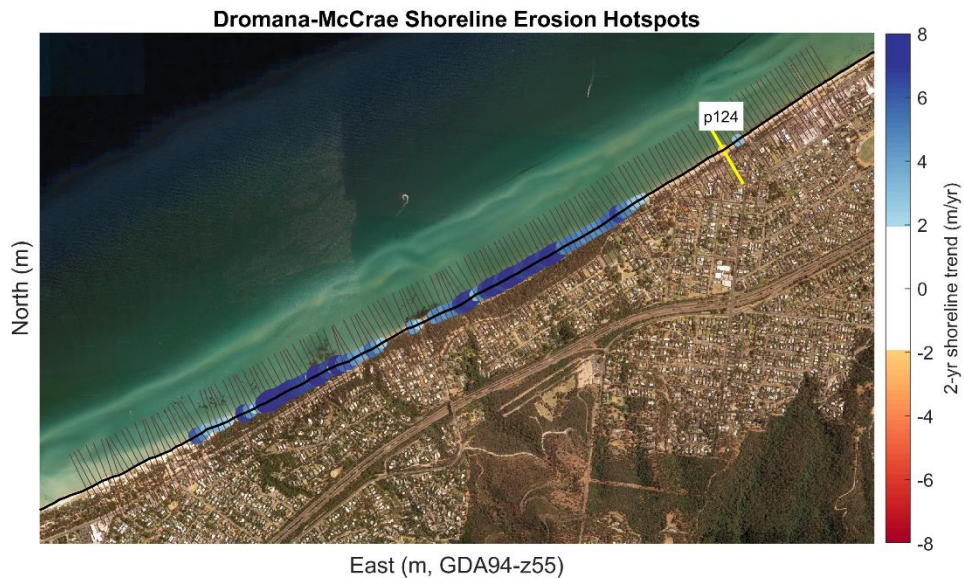
Blairgowrie Dune/Cliff Erosion Hotspots, back-level 1.8 m



## Site 5: Dromana-McCrae (DRM)

Stat 1: Long-term site averaged trend (LT; m/yr)	Stat 2: Short-term site averaged trend (ST; m/yr)	Stat 3: Shoreline erosion ratio (SR)	Stat 4: Backshore erosion ratio (BR; %)	Stat 5: Backshore hotspot maximum (BH; m/yr)	Summary: Erosion Warning Indicator (EWI)
0.16	5.10	0	1	-1.21	0 / 10

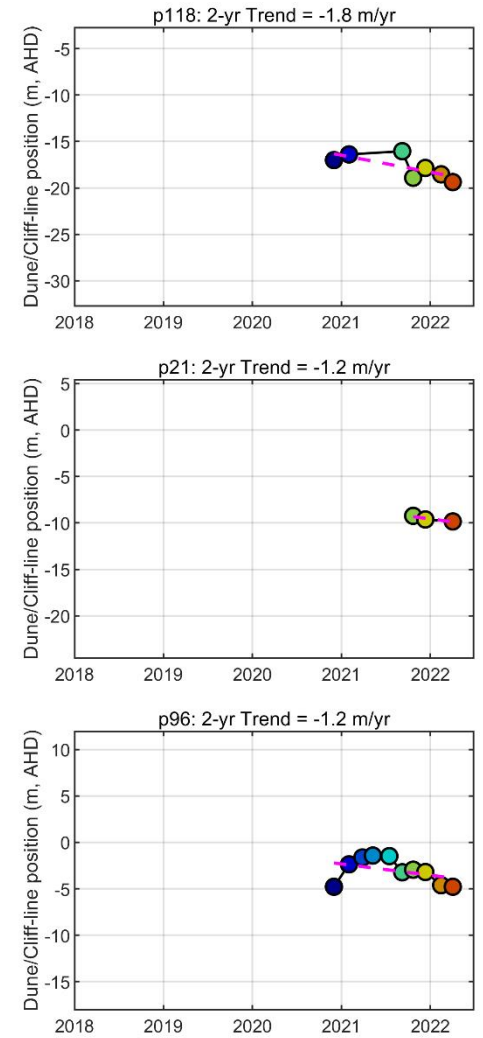
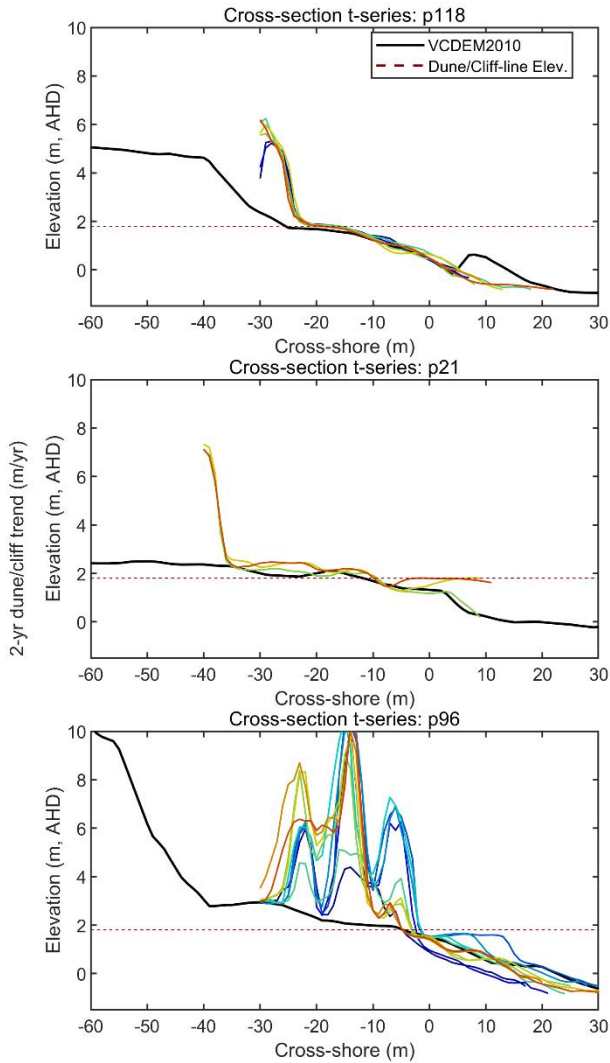
### Dromana-McCrae – Shoreline Hotspots



Only 1  
Hotspot  
Detected

# Dromana-McCrae – Dune/Cliff-line Hotspots

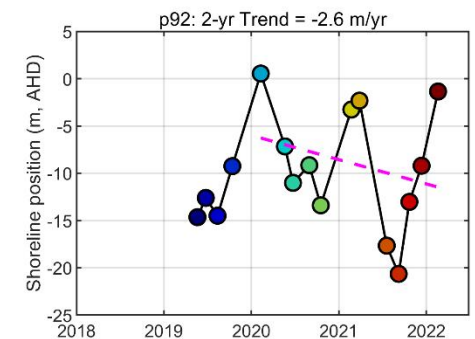
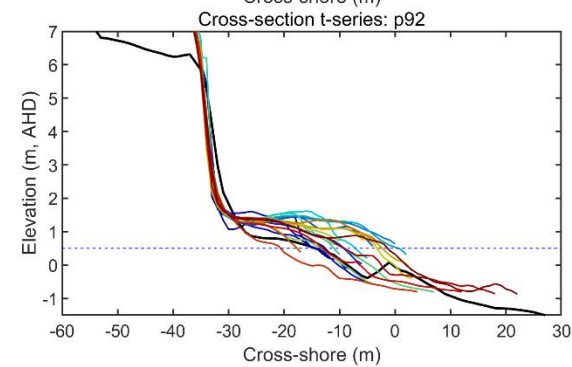
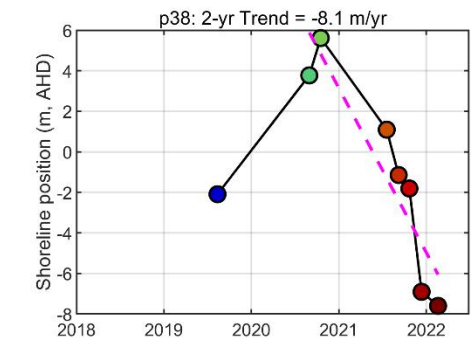
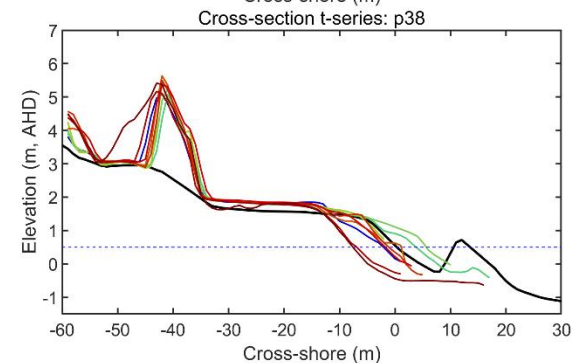
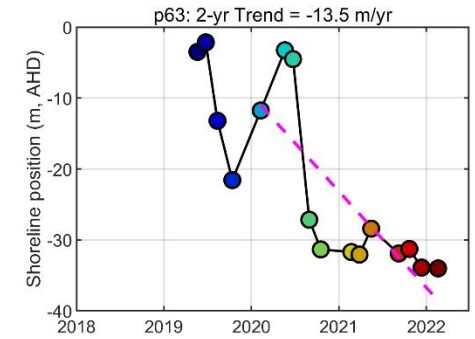
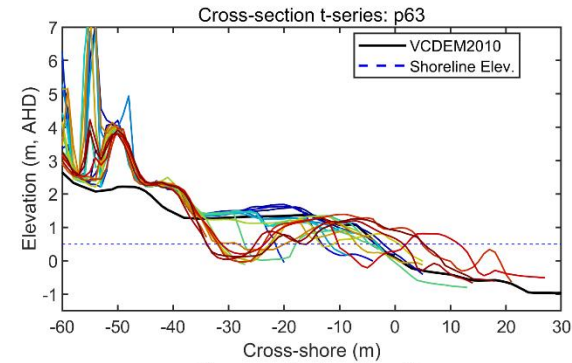
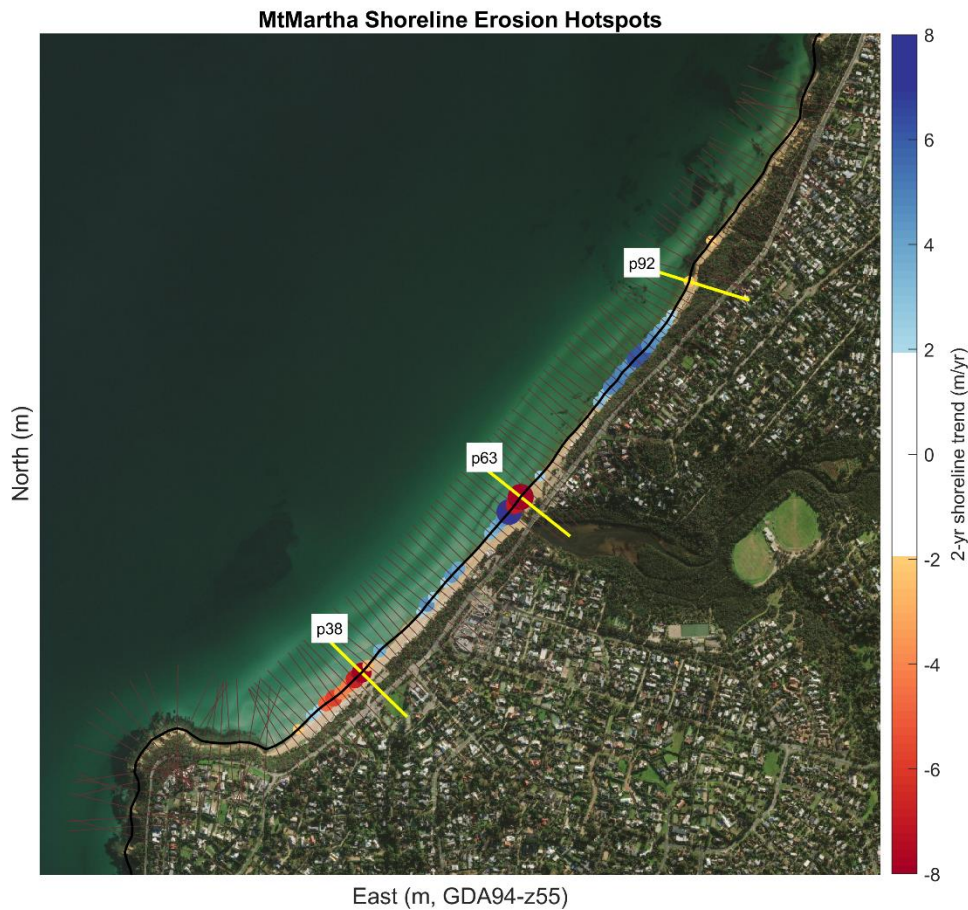
Dromana-McCrae Dune/Cliff Erosion Hotspots, back-level 1.8 m



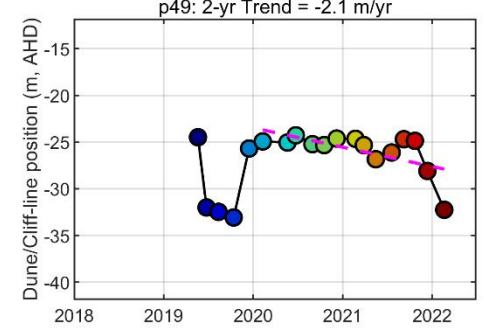
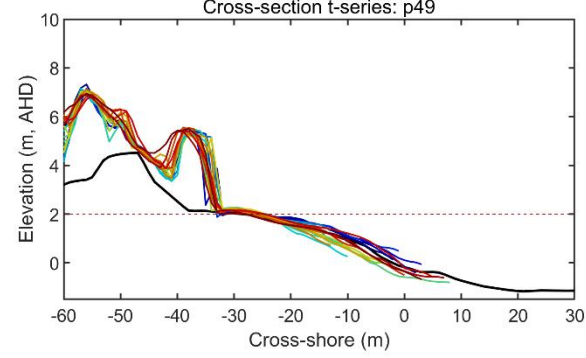
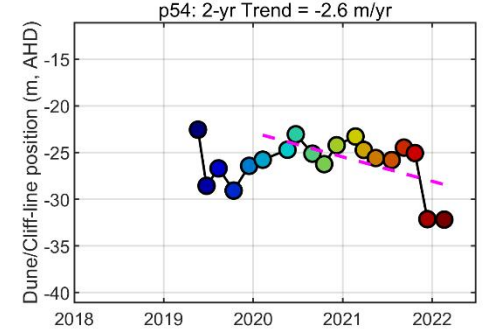
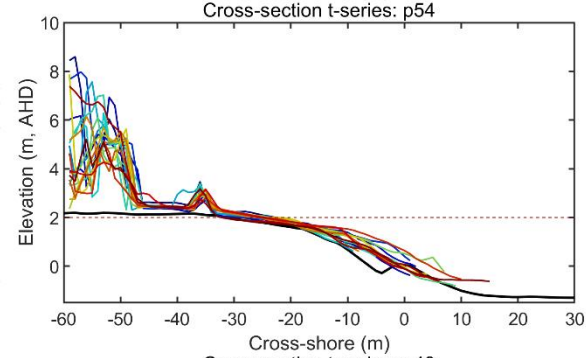
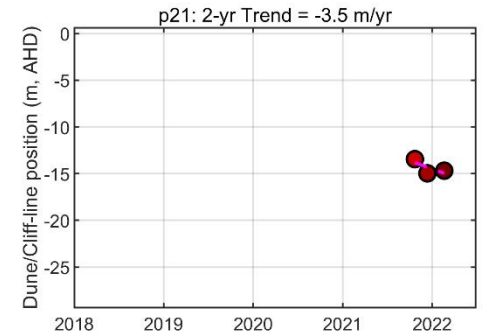
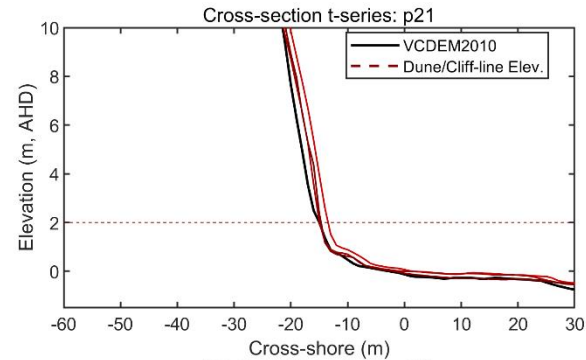
## Site 6: Mount Martha (MAR)

Stat 1: Long-term site averaged trend (LT; m/yr)	Stat 2: Short-term site averaged trend (ST; m/yr)	Stat 3: Shoreline erosion ratio (SR)	Stat 4: Backshore erosion ratio (BR; %)	Stat 5: Backshore hotspot maximum (BH; m/yr)	Summary: Erosion Warning Indicator (EWI)
-0.20	1.78	6%	7%	-2.60	0 / 10

### Mount Martha – Shoreline Hotspots



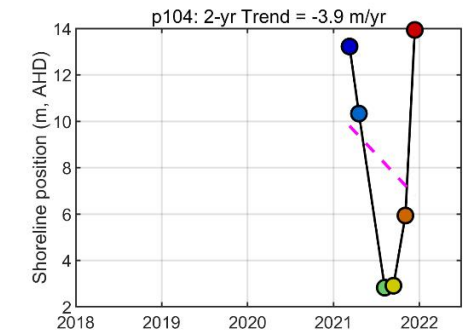
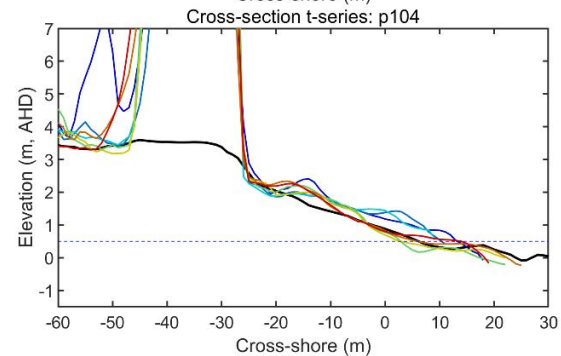
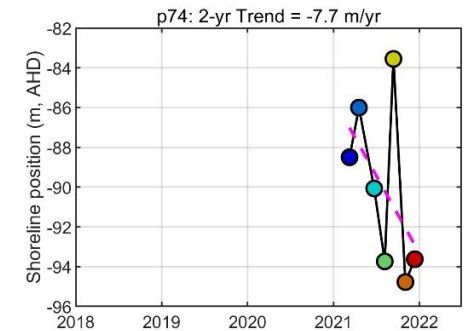
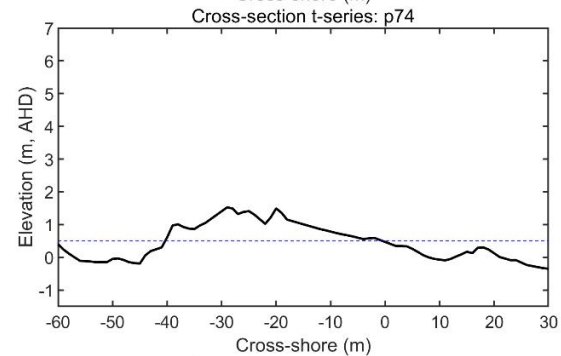
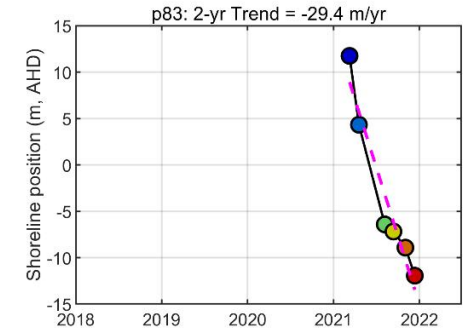
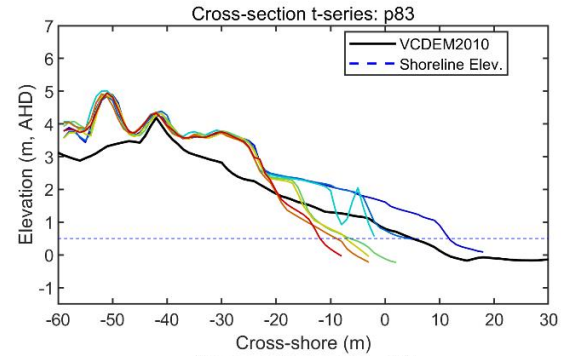
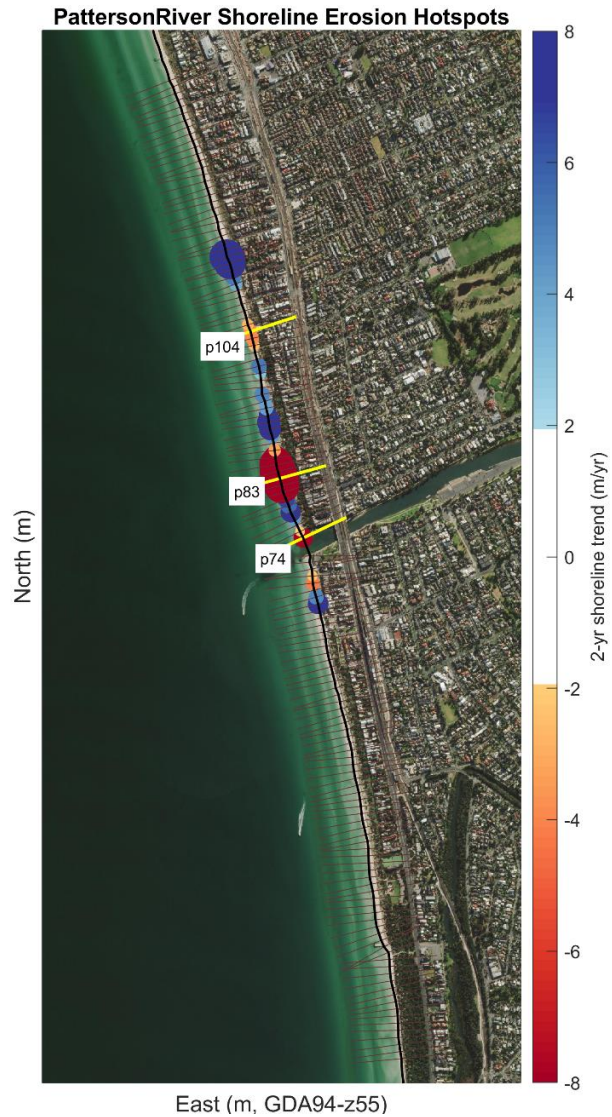
# Mount Martha – Dune/Cliff-line Hotspots



## Site 8: Patterson River (PAT)

Stat 1: Long-term site averaged trend (LT; m/yr)	Stat 2: Short-term site averaged trend (ST; m/yr)	Stat 3: Shoreline erosion ratio (SR)	Stat 4: Backshore erosion ratio (BR; %)	Stat 5: Backshore hotspot maximum (BH; m/yr)	Summary: Erosion Warning Indicator (EWI)
0.24	-1.24	28%	31%	-21.96	6 / 10

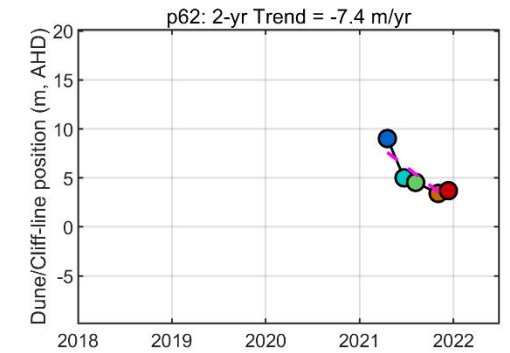
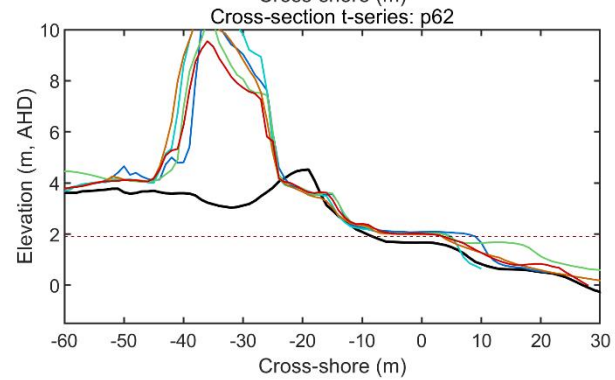
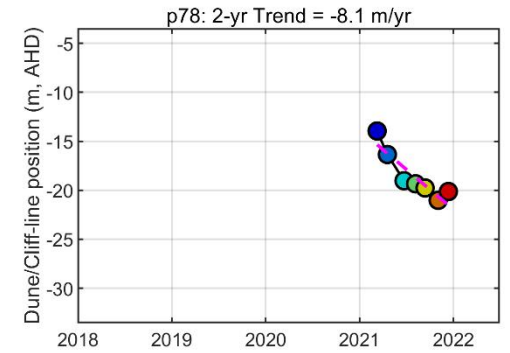
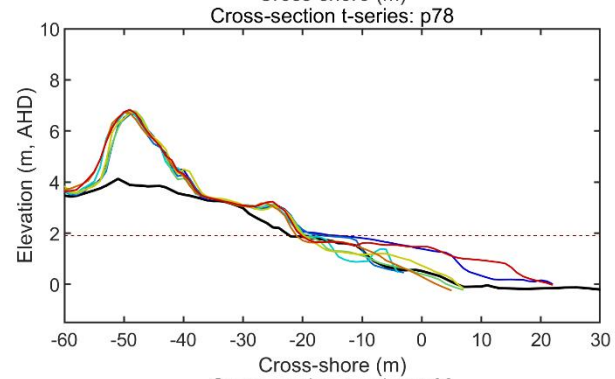
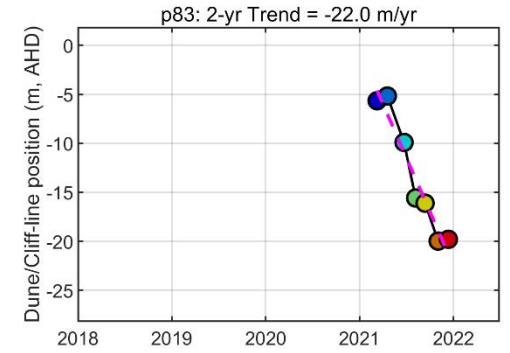
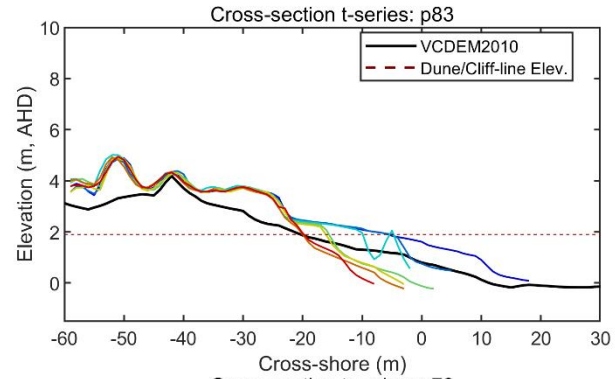
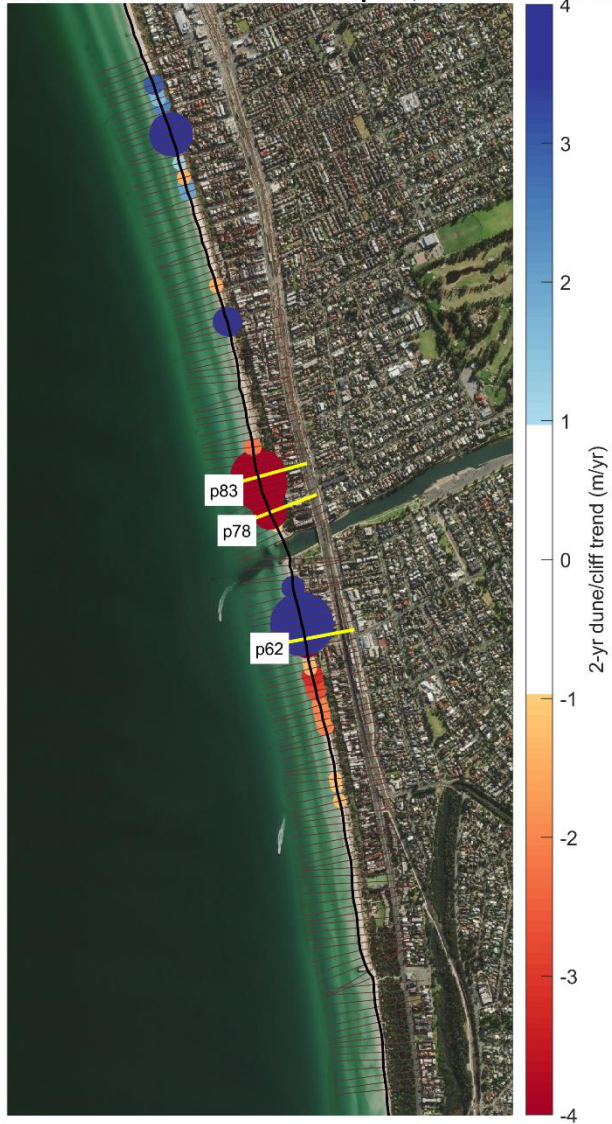
### Patterson River – Shoreline Hotspots





# Patterson River – Dune/Cliff-line Hotspots

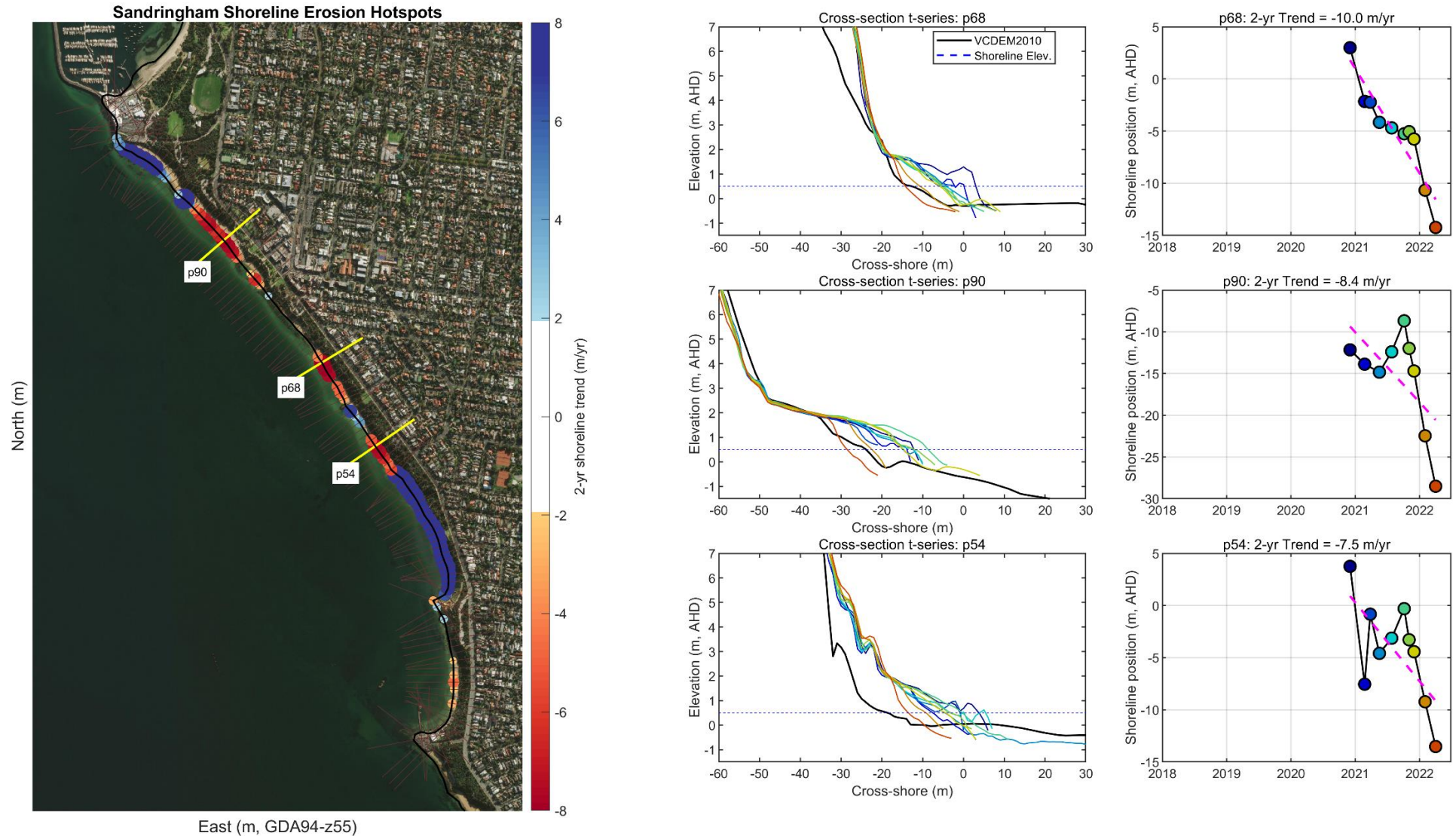
PattersonRiver Dune/Cliff Erosion Hotspots, back-level 1.9 m



## Site 9: Sandringham (SND)

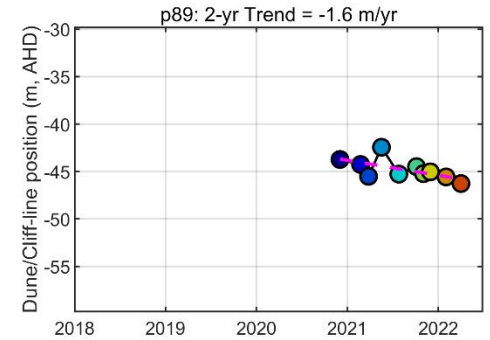
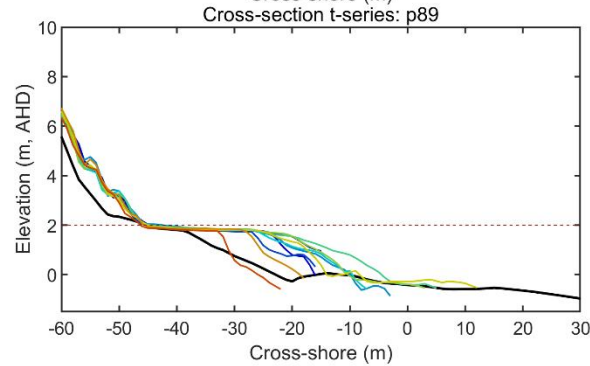
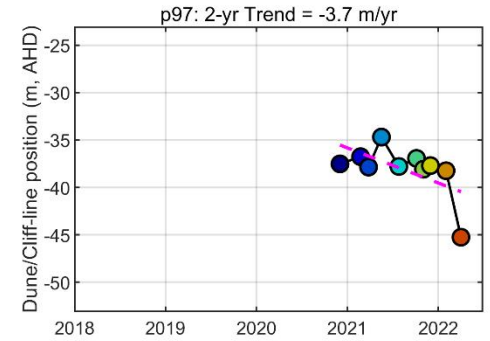
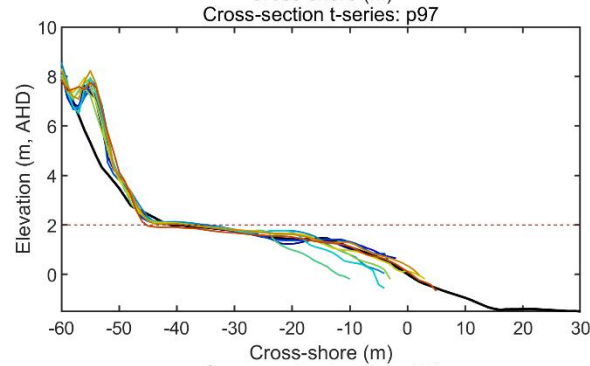
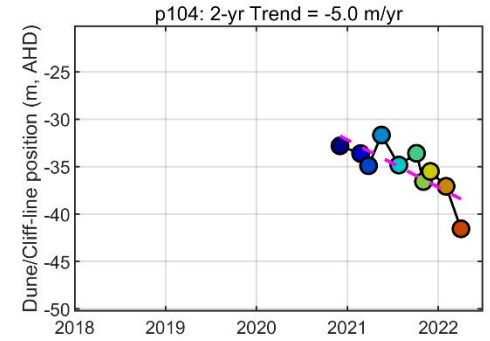
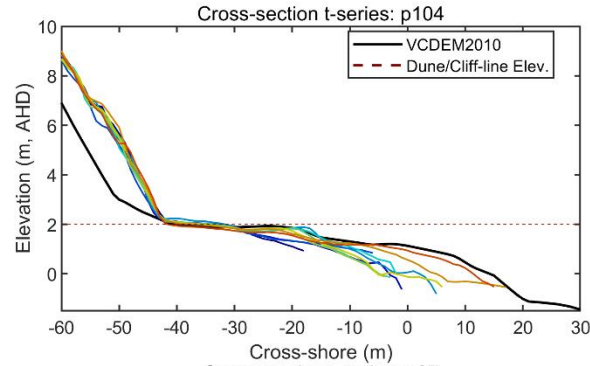
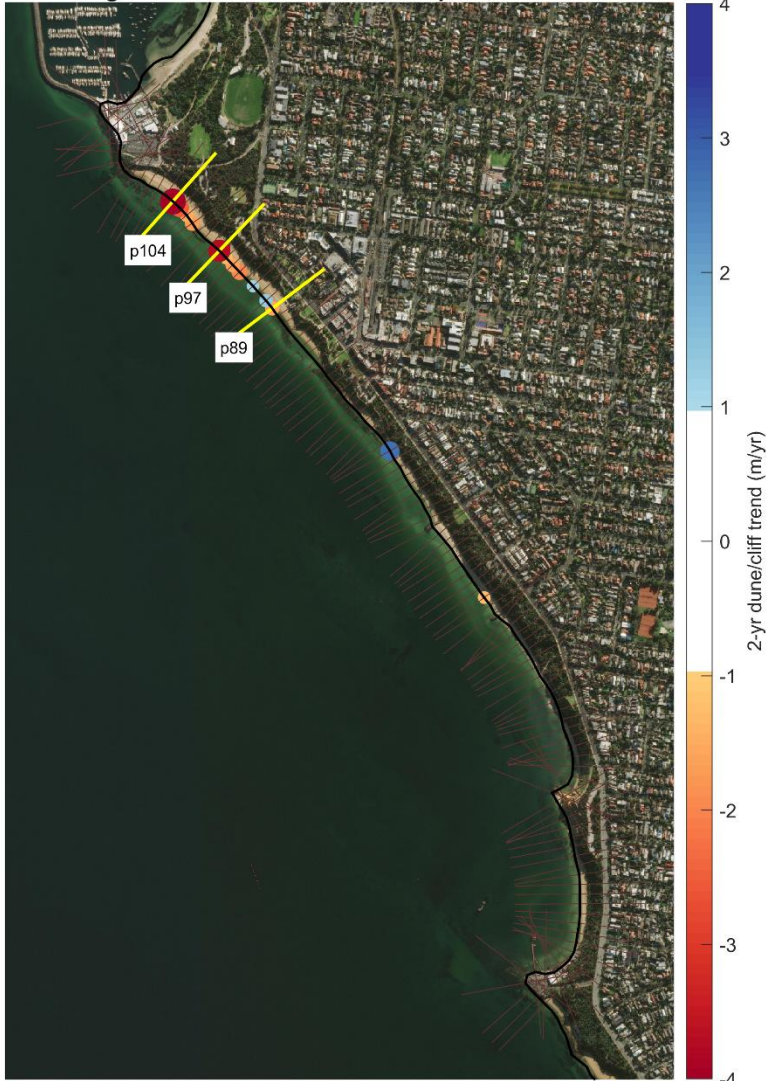
Stat 1: Long-term site averaged trend (LT; m/yr)	Stat 2: Short-term site averaged trend (ST; m/yr)	Stat 3: Shoreline erosion ratio (SR)	Stat 4: Backshore erosion ratio (BR; %)	Stat 5: Backshore hotspot maximum (BH; m/yr)	Summary: Erosion Warning Indicator (EWI)
0.09	0.91	0.33	0.10	-4.98	3 / 10

### Sandringham – Shoreline Hotspots



# Sandringham – Dune/Cliff-line Hotspots

Sandringham Dune/Cliff Erosion Hotspots, back-level 2 m



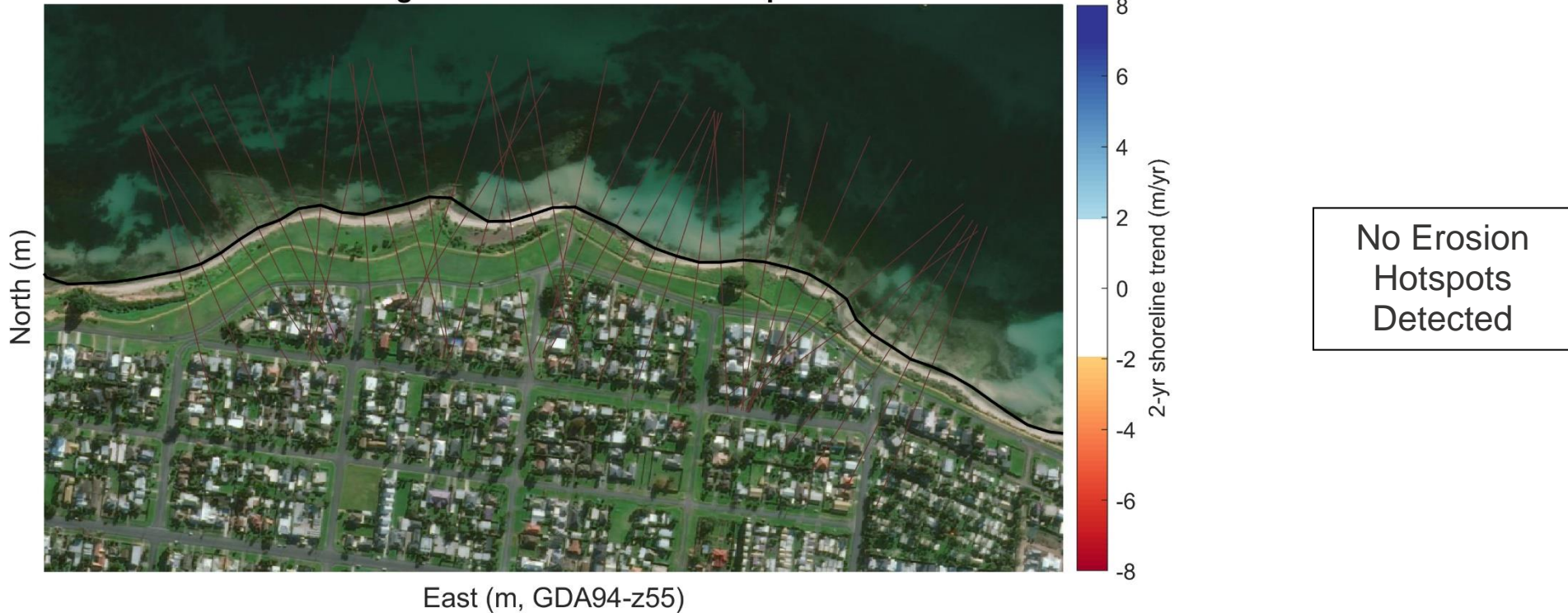
## Site 12: Portarlington (PAR)

Stat 1: Long-term site averaged trend (LT; m/yr)	Stat 2: Short-term site averaged trend (ST; m/yr)	Stat 3: Shoreline erosion ratio (SR)	Stat 4: Backshore erosion ratio (BR; %)	Stat 5: Backshore hotspot maximum (BH; m/yr)	Summary: Erosion Warning Indicator (EWI)
-0.12	-0.26	0.00	0.00	-0.53	0 / 10

### Portarlington – Shoreline Hotspots

- No EROSION or ACCRETION hotspots
- Stable shoreline with minimal variability

### Portarlington Shoreline Erosion Hotspots



Portarlington Dune/Cliff Erosion Hotspots, back-level 2 m

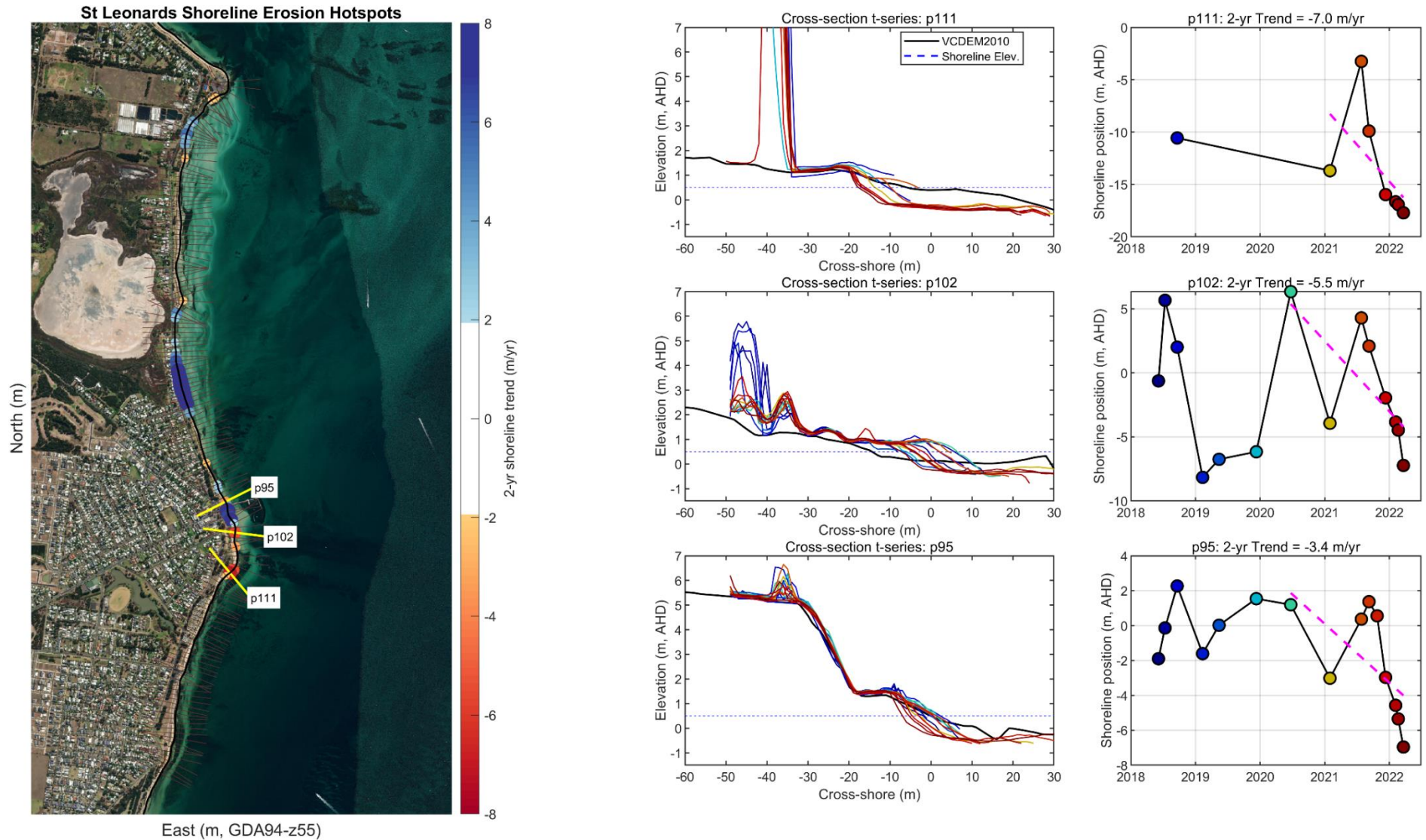


No Erosion  
Hotspots  
Detected

## Site 14: St Leonards (LEO)

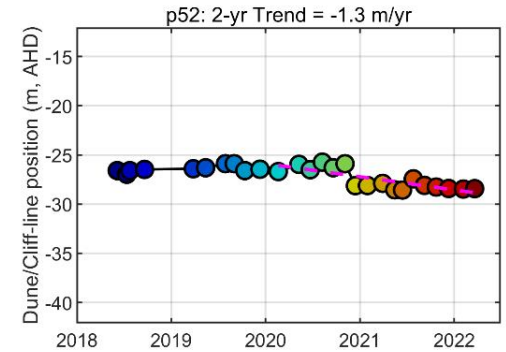
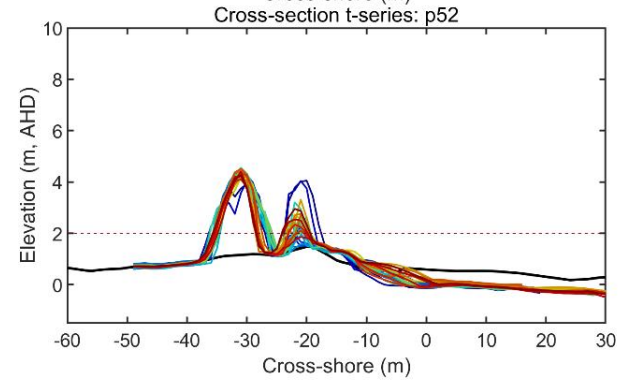
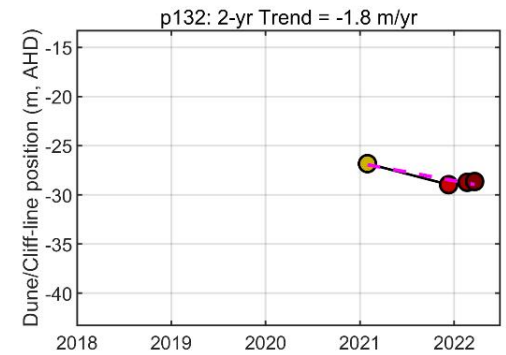
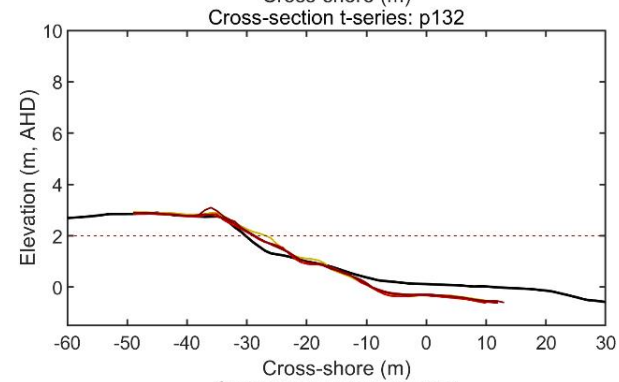
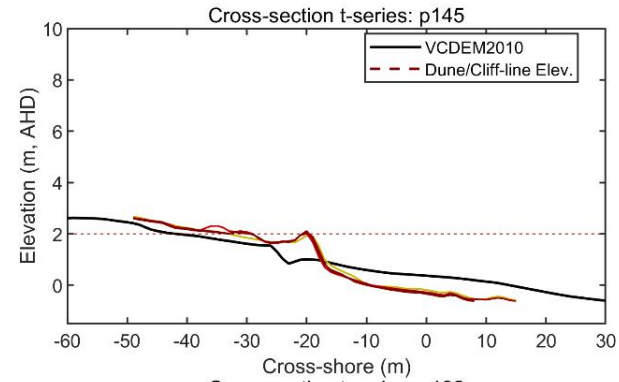
Stat 1: Long-term site averaged trend (LT; m/yr)	Stat 2: Short-term site averaged trend (ST; m/yr)	Stat 3: Shoreline erosion ratio (SR)	Stat 4: Backshore erosion ratio (BR; %)	Stat 5: Backshore hotspot maximum (BH; m/yr)	Summary: Erosion Warning Indicator (EWI)
-0.14	1.55	3%	6%	-1.33	<b>0 / 10</b>

### St Leonards (LEO) – Shoreline Hotspots



# St Leonards – Dune/Cliff-line Hotspots

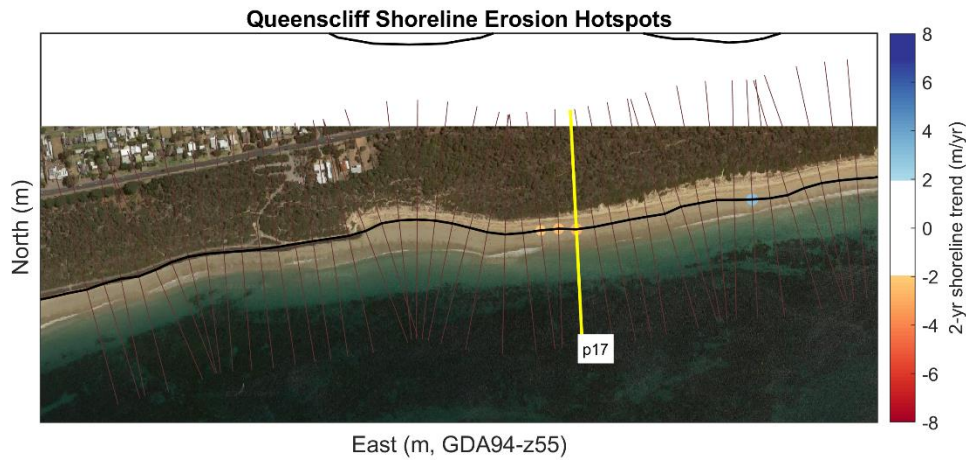
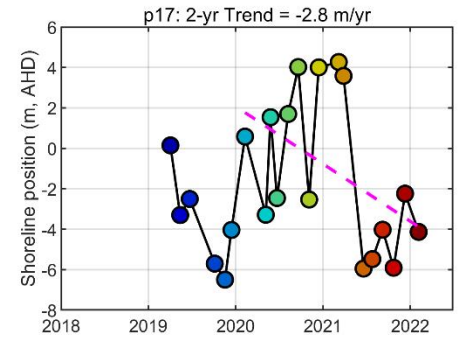
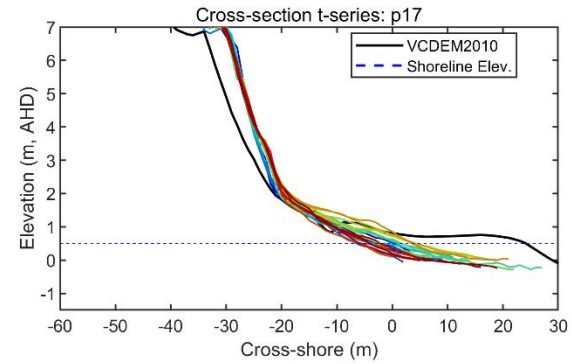
St Leonards Dune/Cliff Erosion Hotspots, back-level 2 m



## Site 15: Queenscliff (QCL)

Stat 1: Long-term site averaged trend (LT; m/yr)	Stat 2: Short-term site averaged trend (ST; m/yr)	Stat 3: Shoreline erosion ratio (SR)	Stat 4: Backshore erosion ratio (BR; %)	Stat 5: Backshore hotspot maximum (BH; m/yr)	Summary: Erosion Warning Indicator (EWI)
-0.14	-0.16	18%	0%	-0.06	<b>0 / 10</b>

### Queenscliff – Shoreline Hotspots

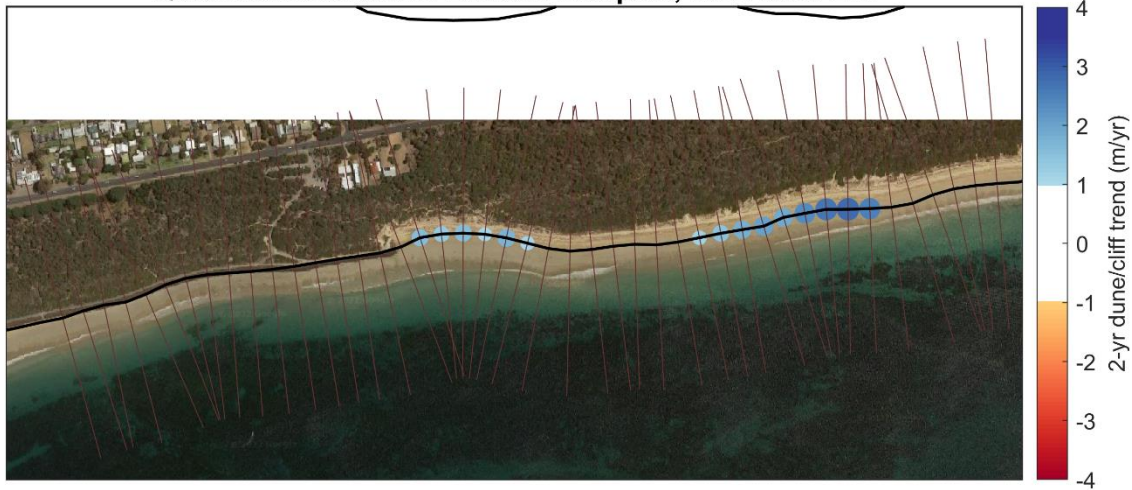


Only 1  
Erosion Hotspot  
Detected



Queenscliff – Dune/Cliff-line Hotspots

Queenscliff Dune/Cliff Erosion Hotspots, back-level 2 m

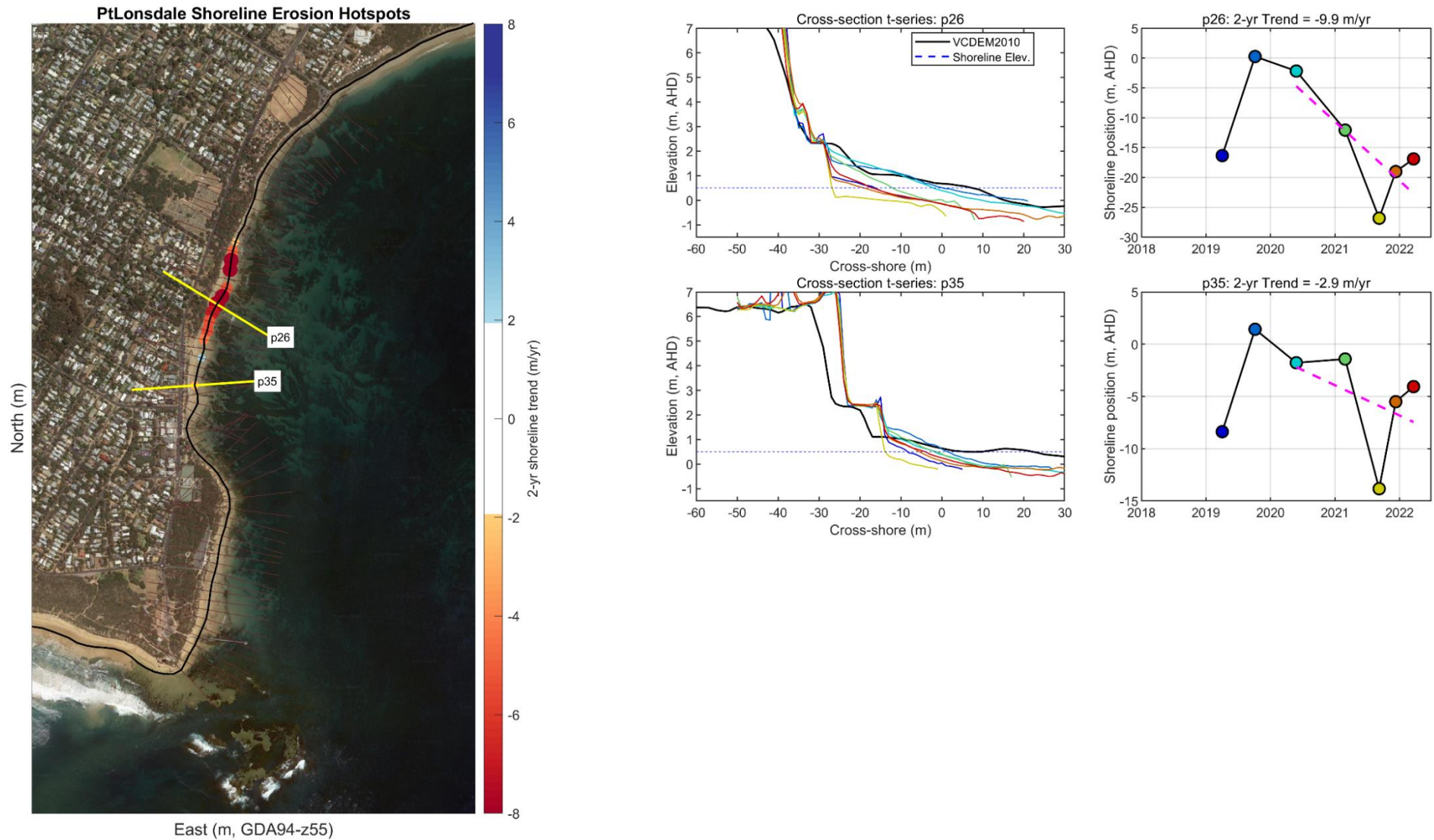


No  
Erosion  
Hotspots  
Detected

## Site 16: Point Lonsdale (LON)

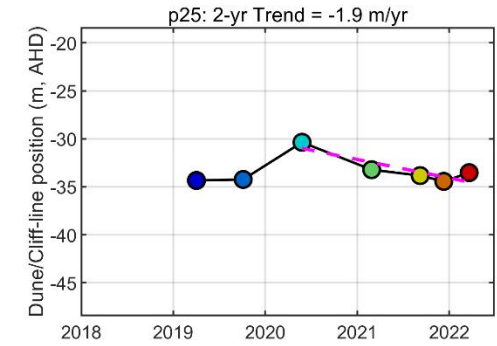
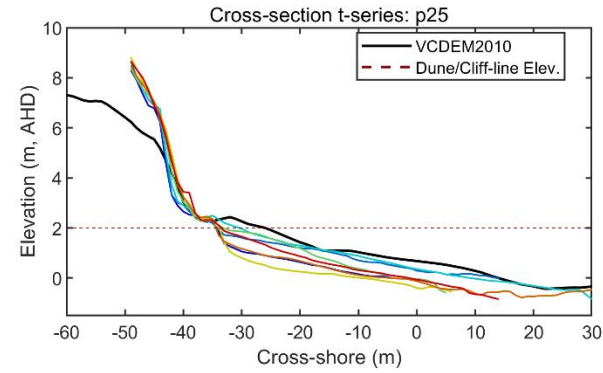
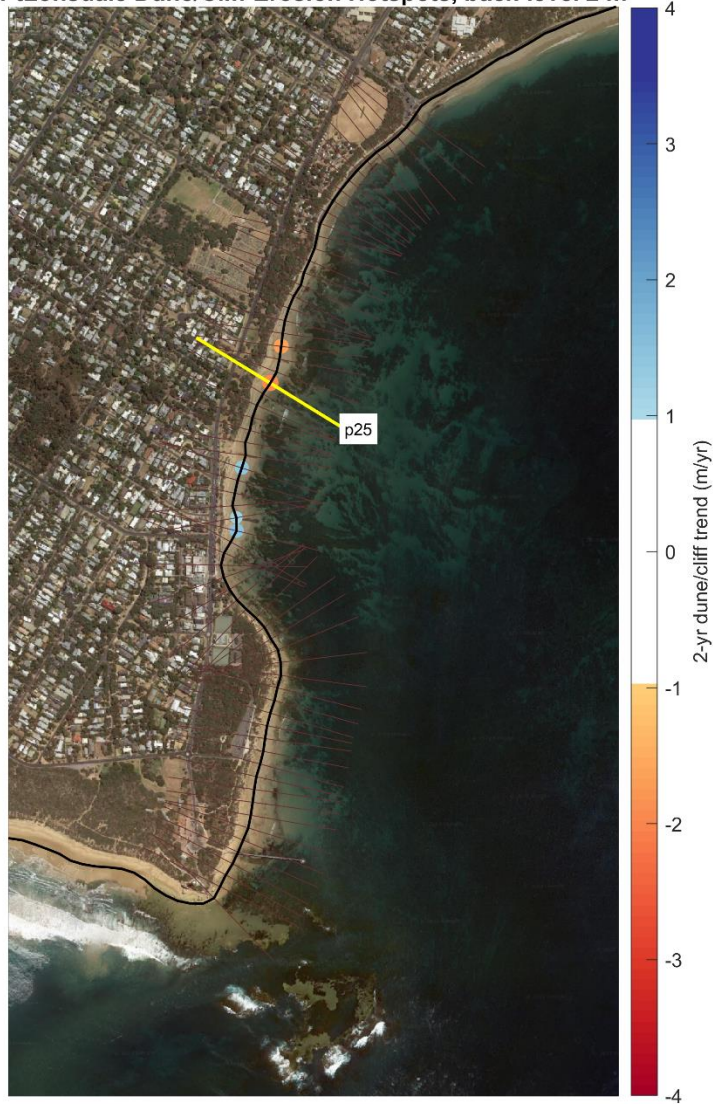
Stat 1: Long-term site averaged trend (LT; m/yr)	Stat 2: Short-term site averaged trend (ST; m/yr)	Stat 3: Shoreline erosion ratio (SR)	Stat 4: Backshore erosion ratio (BR; %)	Stat 5: Backshore hotspot maximum (BH; m/yr)	Summary: Erosion Warning Indicator (EWI)
0.24	-2.95	50%	8%	-1.93	4 / 10

### Point Lonsdale – Shoreline Hotspots



## Point Lonsdale – Dune/Cliff-line Hotspots

PtLonsdale Dune/Cliff Erosion Hotspots, back-level 2 m



Note: The algorithm has picked up on “dune line” erosion in front of a seawall, and adjacent to a groyne.

Despite there being a discontinuity between beach and dune in this instance (i.e., the wall), this seems like a legitimate application of the algorithm, as the back of the beach had temporarily reached an elevation sufficient to begin dune formation.

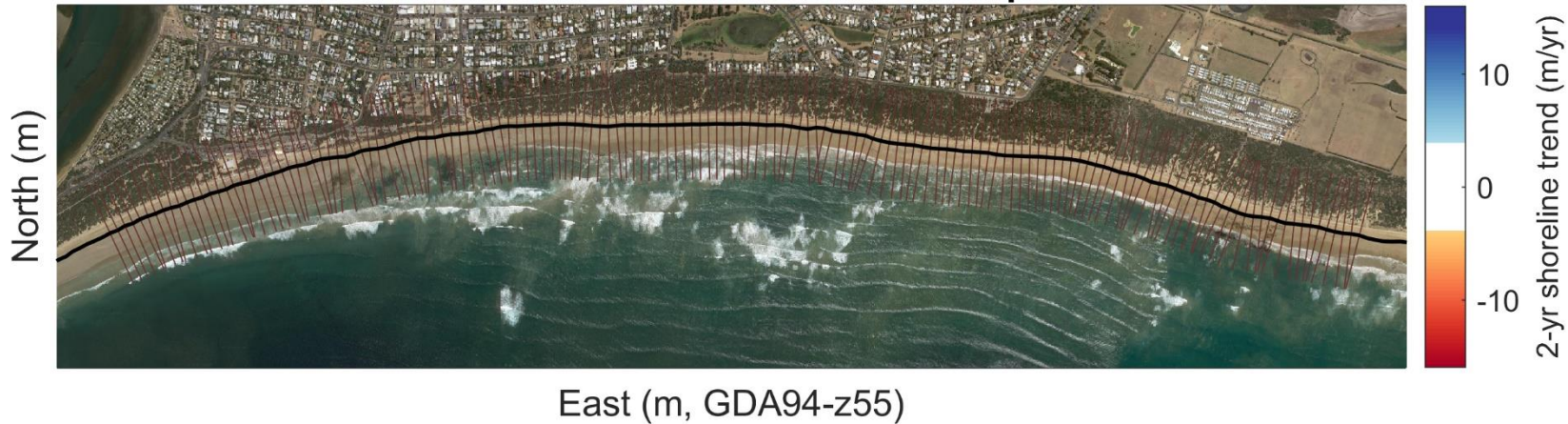
### Site 17: Ocean Grove (OGR)

Stat 1: Long-term site averaged trend (LT; m/yr)	Stat 2: Short-term site averaged trend (ST; m/yr)	Stat 3: Shoreline erosion ratio (SR)	Stat 4: Backshore erosion ratio (BR; %)	Stat 5: Backshore hotspot maximum (BH; m/yr)	Summary: Erosion Warning Indicator (EWI)
-0.01	-0.49	0	2%	-2.08	<b>0 / 10</b>

#### Ocean Grove – Shoreline Hotspots

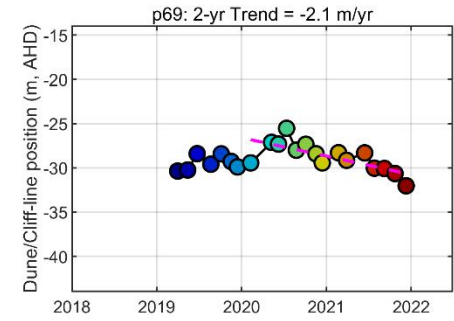
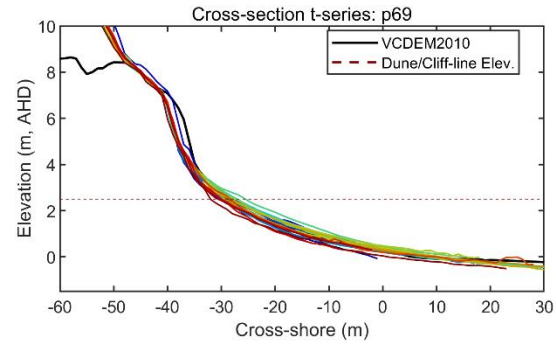
- No EROSION or ACCRETION shoreline hotspots
- One isolated area of minor dune erosion

### OceanGrove Shoreline Erosion Hotspots



No  
Erosion  
Hotspots  
Detected

# Ocean Grove – Dune/Cliff-line Hotspots



OceanGrove Dune/Cliff Erosion Hotspots, back-level 2.5 m



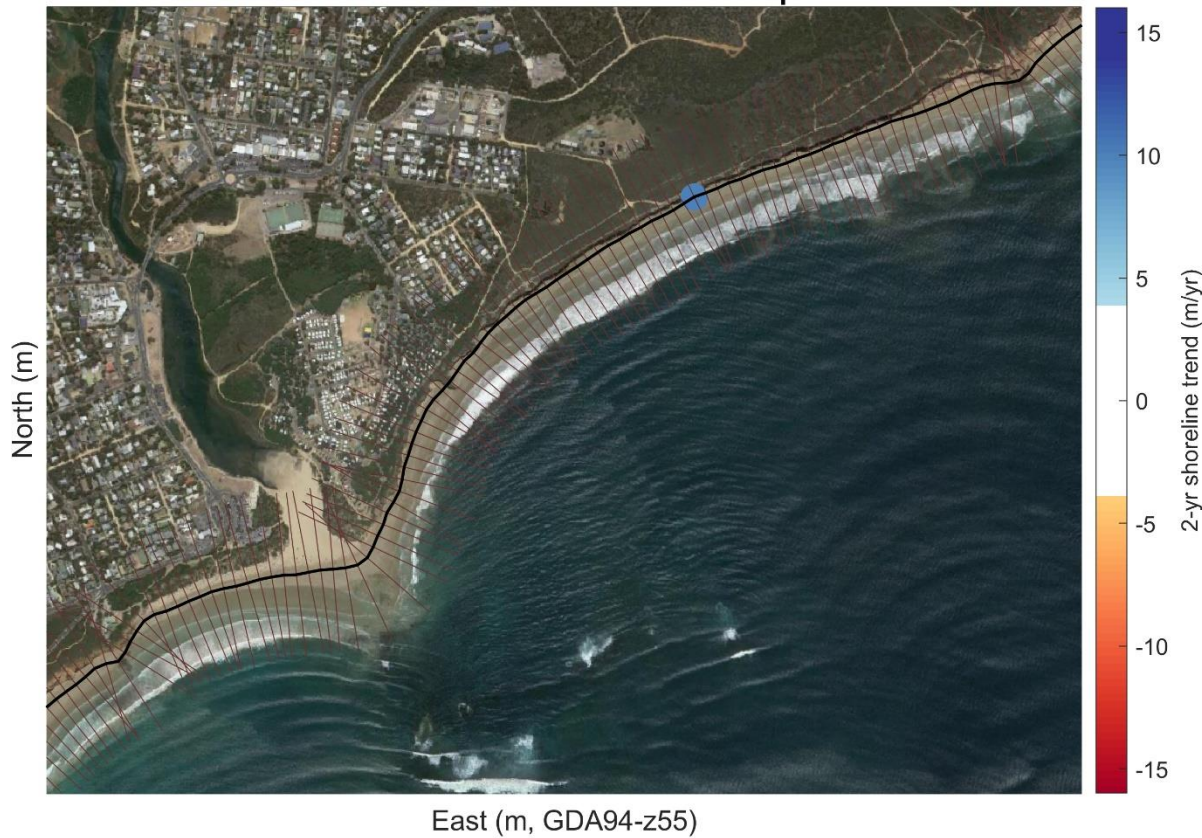
## Site 20: Demons Bluff (DMN)

Stat 1: Long-term site averaged trend (LT; m/yr)	Stat 2: Short-term site averaged trend (ST; m/yr)	Stat 3: Shoreline erosion ratio (SR)	Stat 4: Backshore erosion ratio (BR; %)	Stat 5: Backshore hotspot maximum (BH; m/yr)	Summary: Erosion Warning Indicator (EWI)
-0.43	0.34	0	6%	-4.72	1 / 10

### Demons Bluff – Shoreline Hotspots

- No shoreline erosion hotspots detected

#### DemonsBluff Shoreline Erosion Hotspots

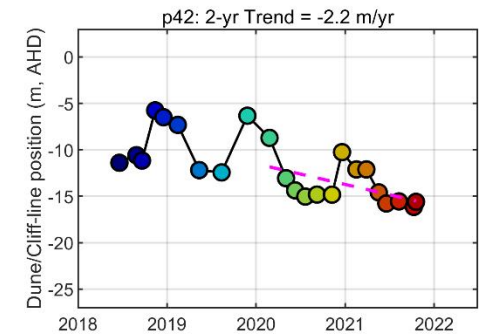
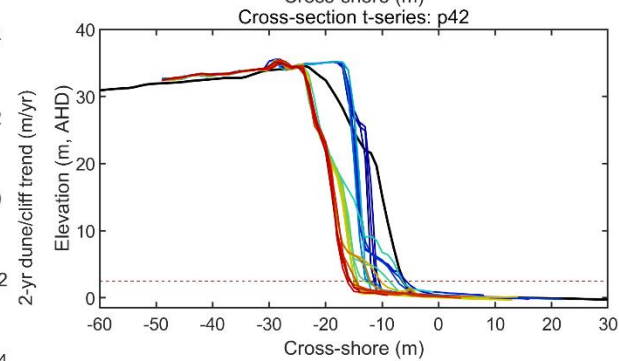
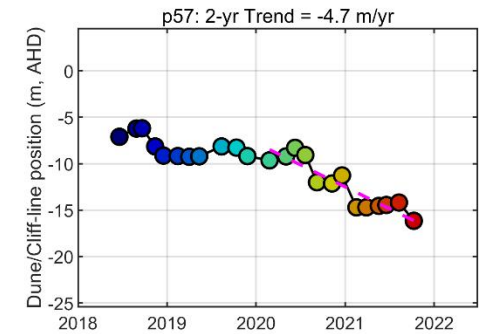
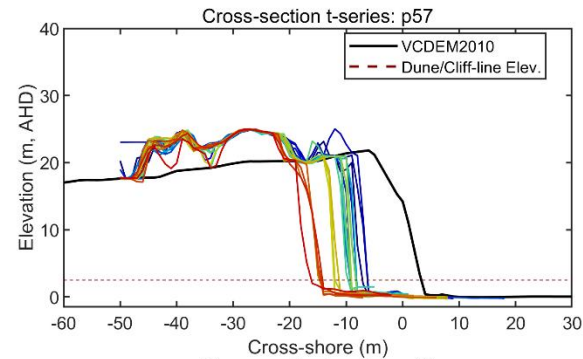
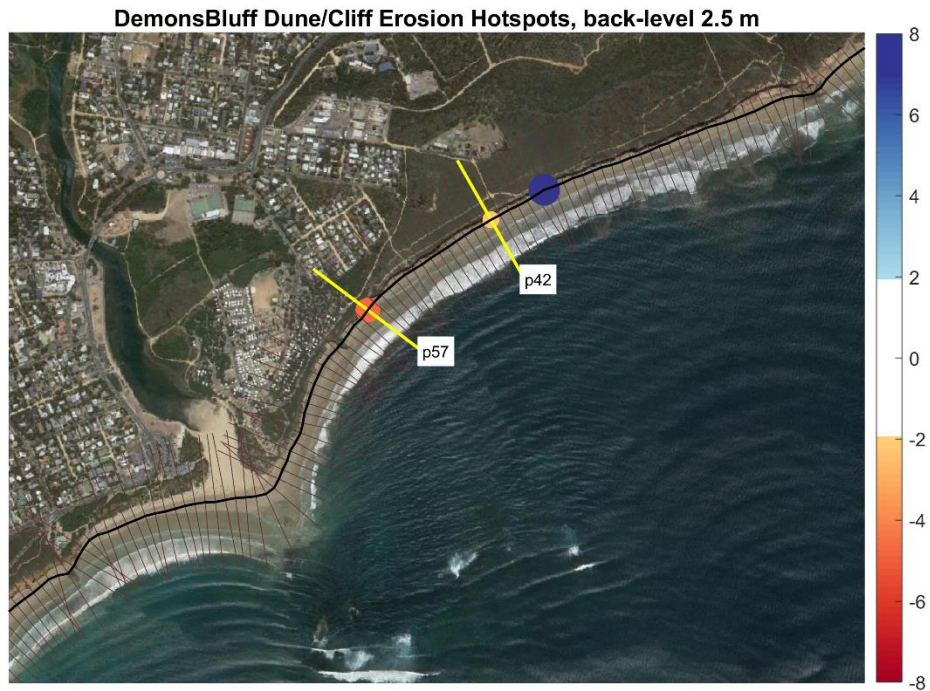


No SHORELINE  
Erosion Hotspots  
Detected

(see next page for cliff  
line erosion)

## Demons Bluff – Dune/Cliff-line Hotspots

- Two areas of rapid cliff retreat detected

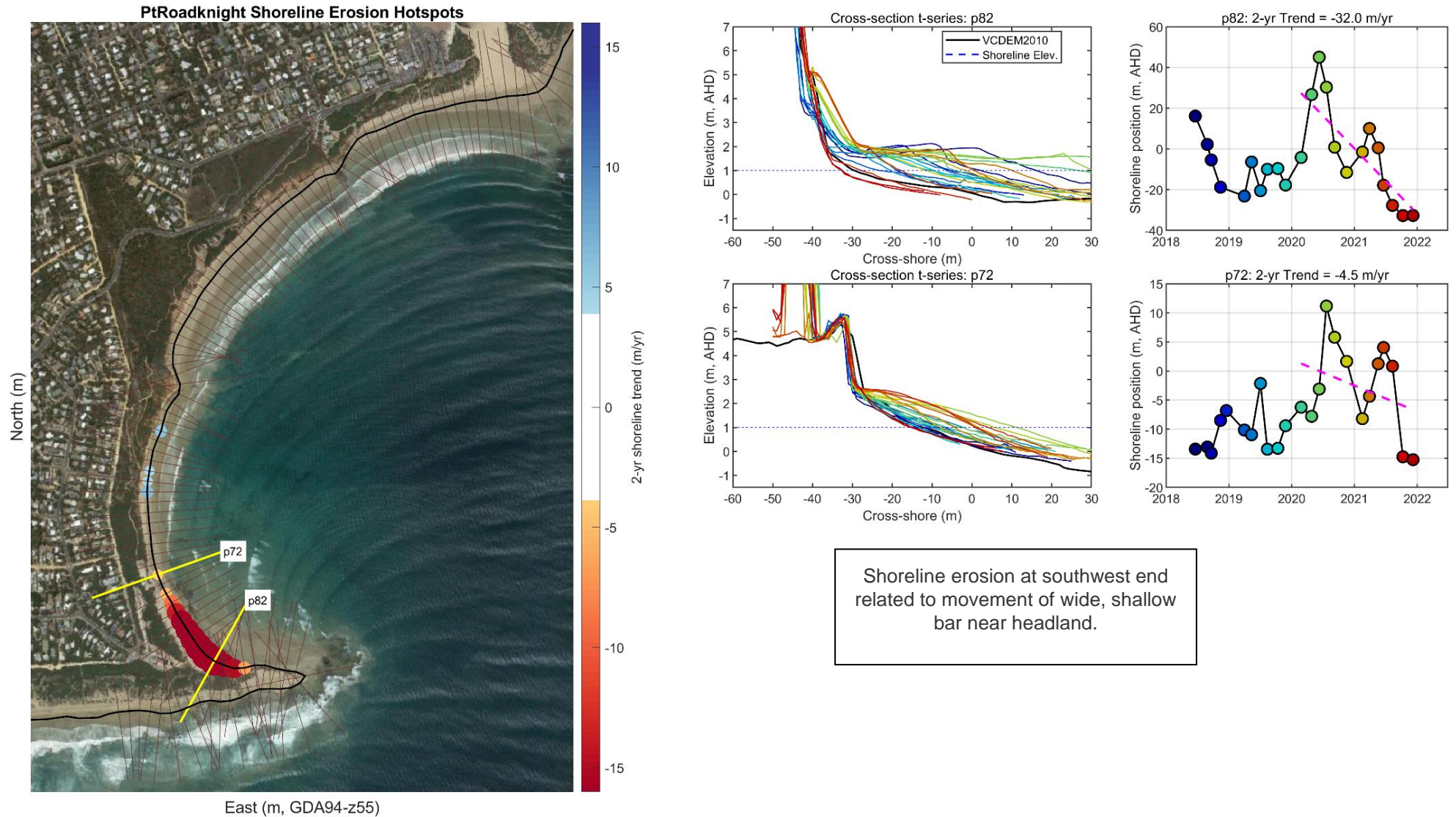


*NOTE: For Demons Bluff, and other sites with large cliff falls, the algorithm could be improved in future by using VOLUME change, instead of DISTANCE change (but this may be tricky).*

## Site 21: Point Roadknight (RDK)

Stat 1: Long-term site averaged trend (LT; m/yr)	Stat 2: Short-term site averaged trend (ST; m/yr)	Stat 3: Shoreline erosion ratio (SR)	Stat 4: Backshore erosion ratio (BR; %)	Stat 5: Backshore hotspot maximum (BH; m/yr)	Summary: Erosion Warning Indicator (EWI)
-0.09	-0.28	21%	0%	-0.91	1 / 10

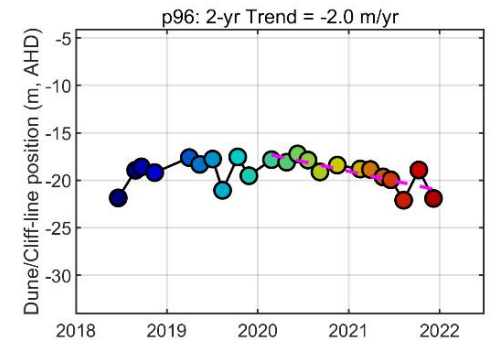
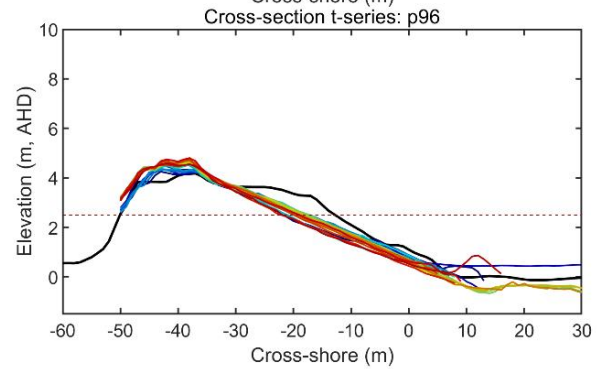
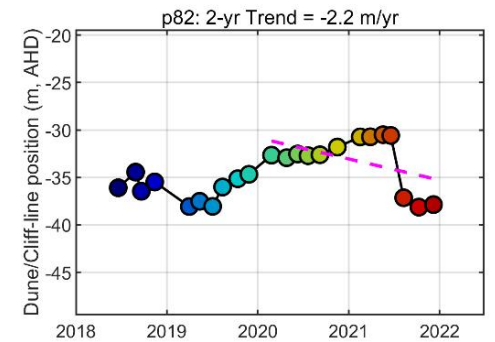
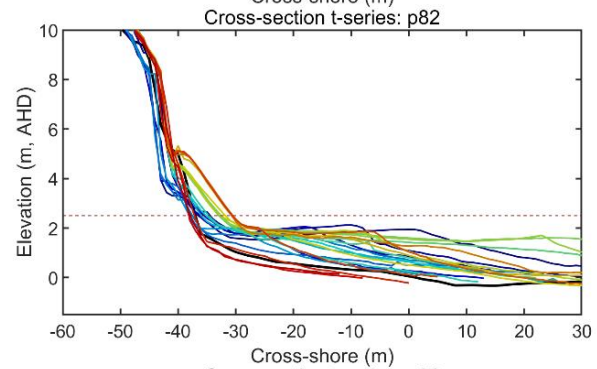
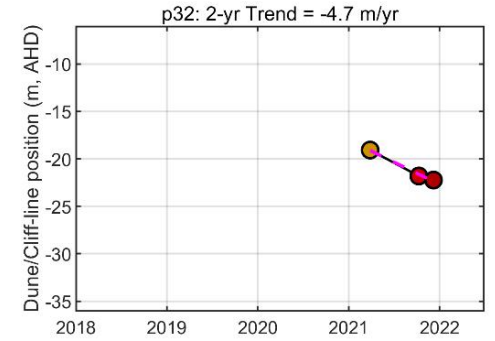
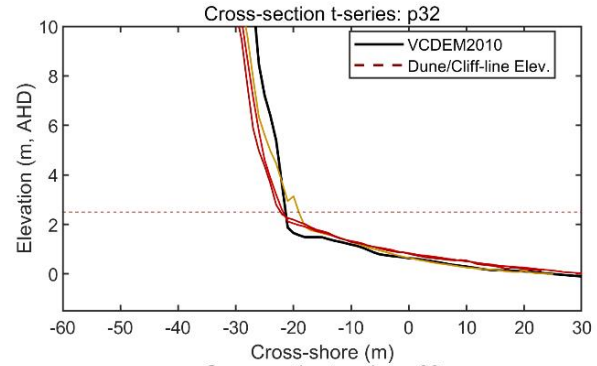
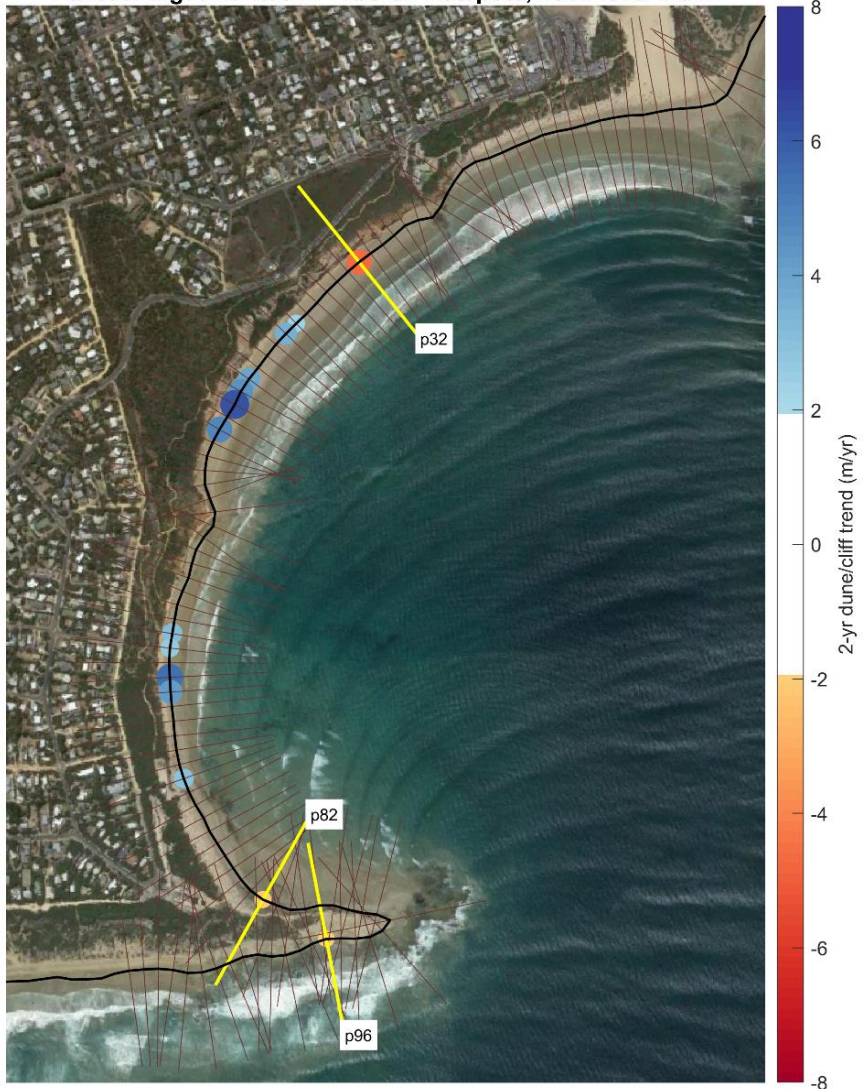
### Point Roadknight – Shoreline Hotspots





# Point Roadknight – Dune/Cliff-line Hotspots

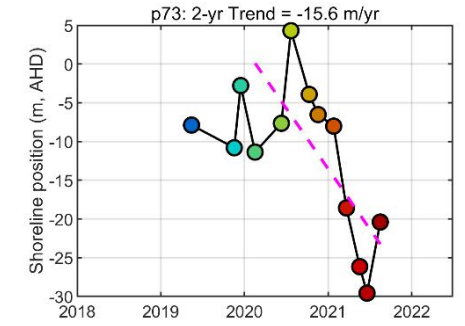
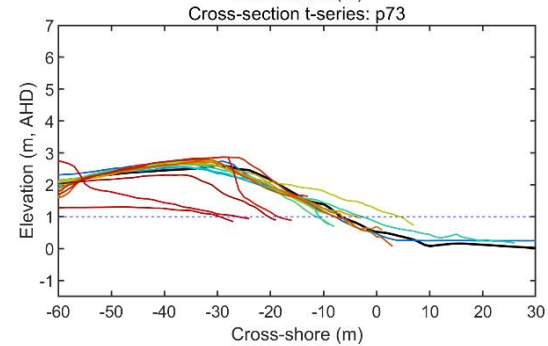
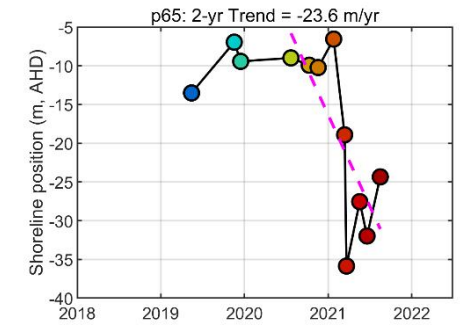
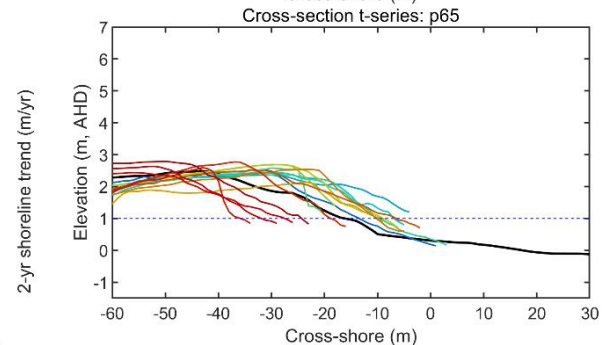
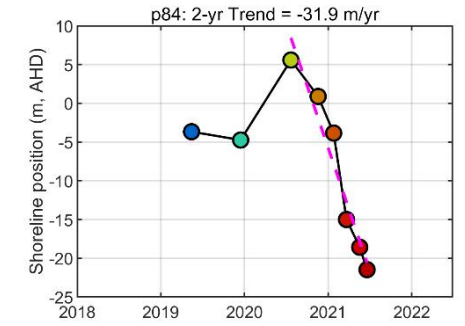
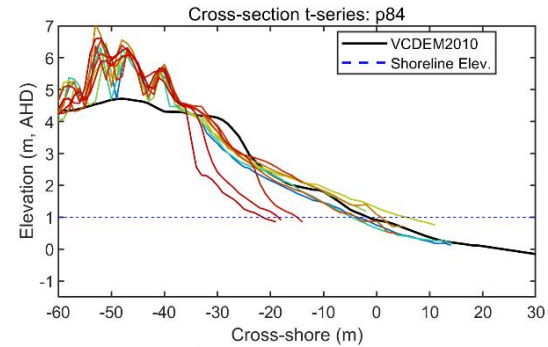
PtRoadknight Dune/Cliff Erosion Hotspots, back-level 2.5 m



# Site 26: Apollo Bay (APO)

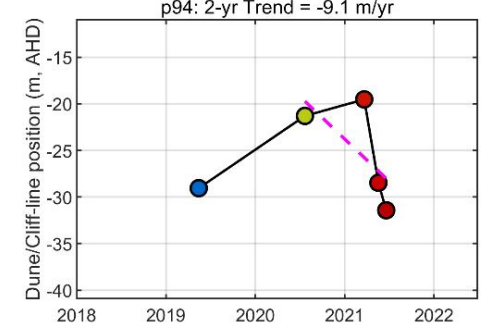
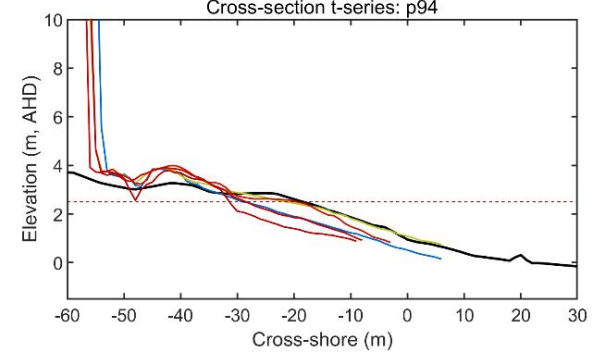
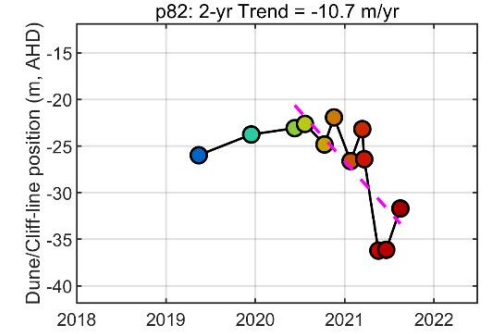
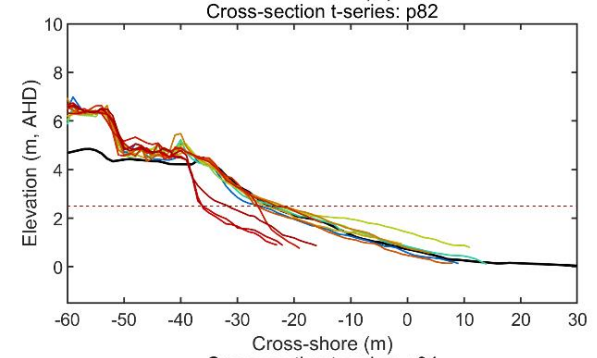
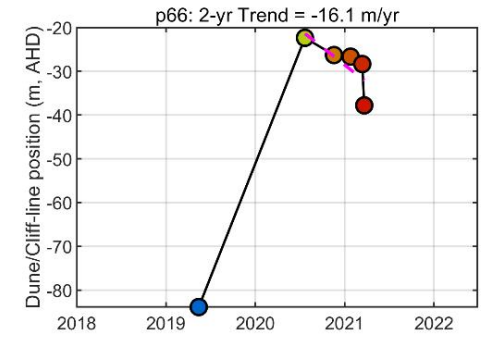
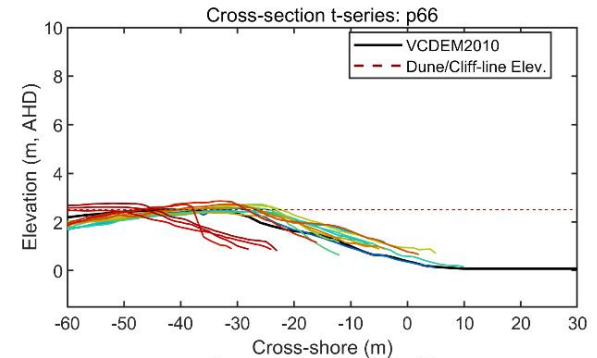
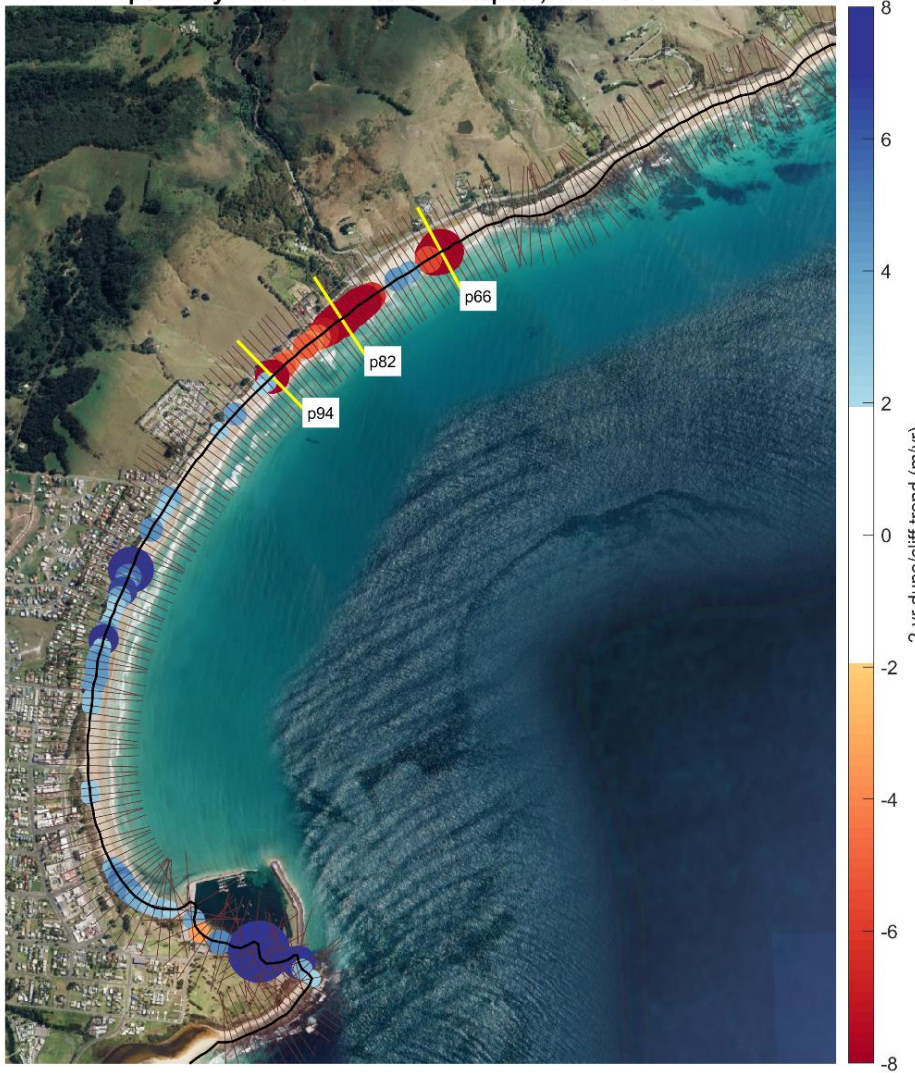
Stat 1: Long-term site averaged trend (LT; m/yr)	Stat 2: Short-term site averaged trend (ST; m/yr)	Stat 3: Shoreline erosion ratio (SR)	Stat 4: Backshore erosion ratio (BR; %)	Stat 5: Backshore hotspot maximum (BH; m/yr)	Summary: Erosion Warning Indicator (EWI)
-0.48	1.79	33%	17%	<b>-16.07</b>	<b>5 / 10</b>

## Apollo Bay – Shoreline Hotspots



# Apollo Bay – Dune/Cliff-line Hotspots

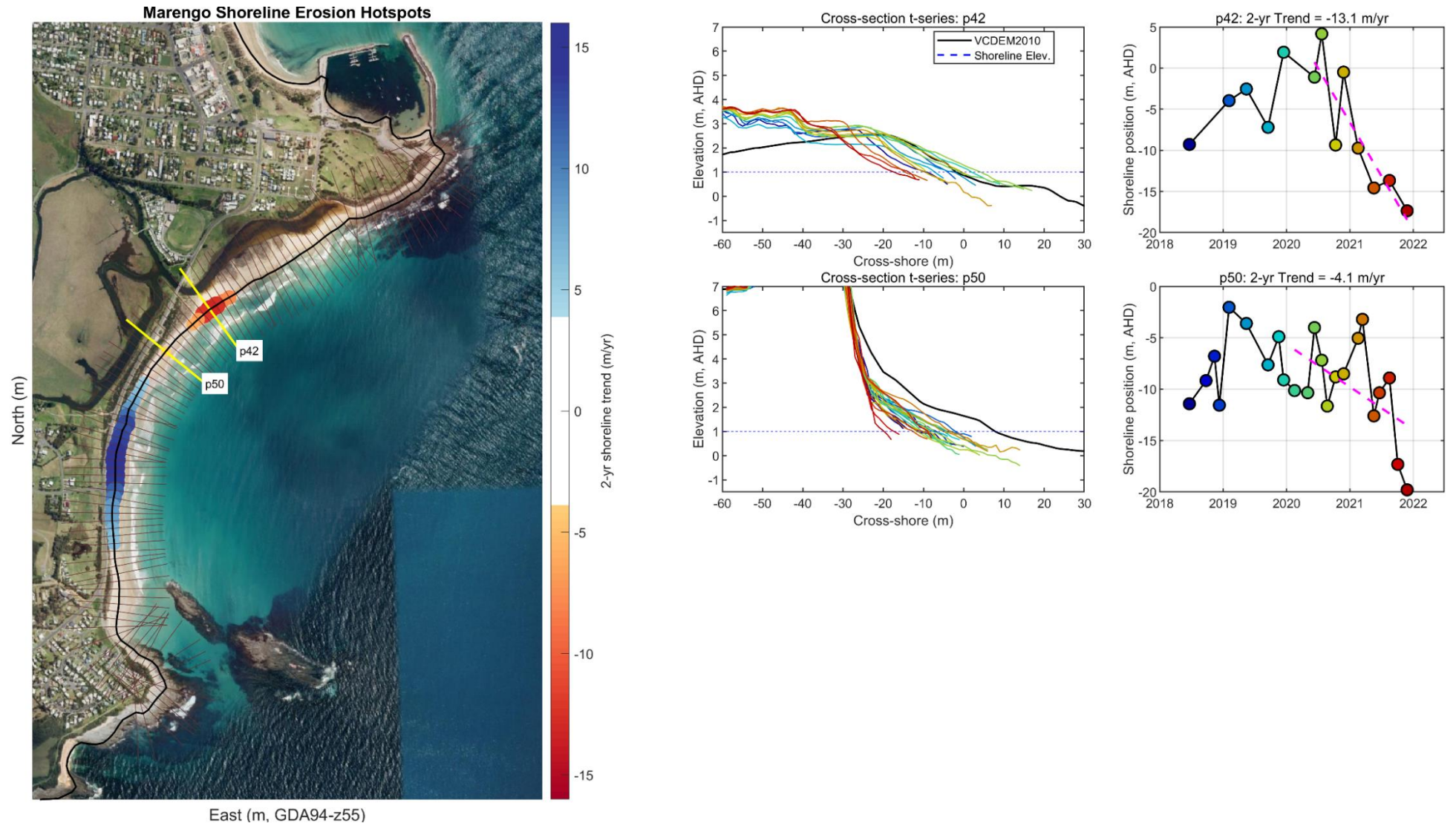
ApolloBay Dune/Cliff Erosion Hotspots, back-level 2.5 m



## Site 27: Marengo (MGO)

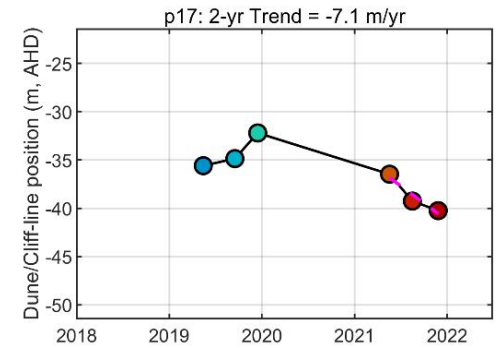
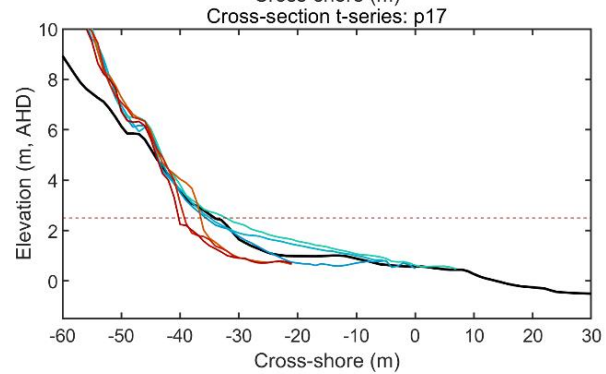
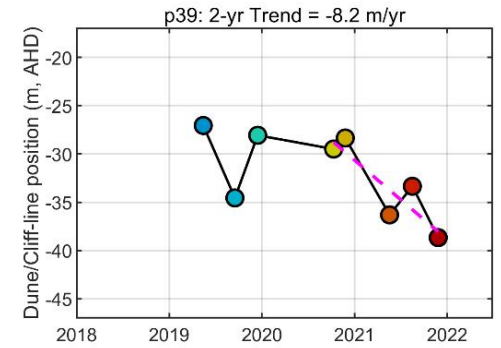
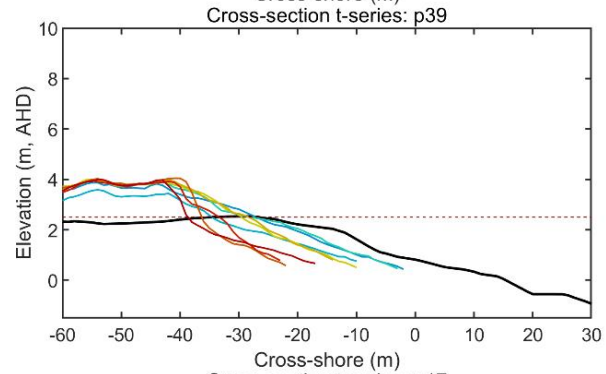
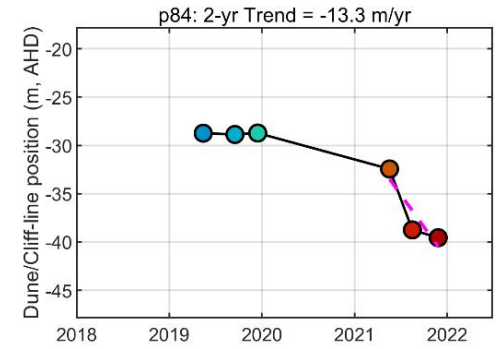
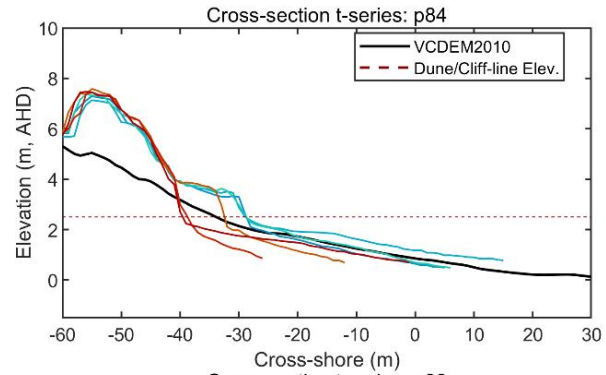
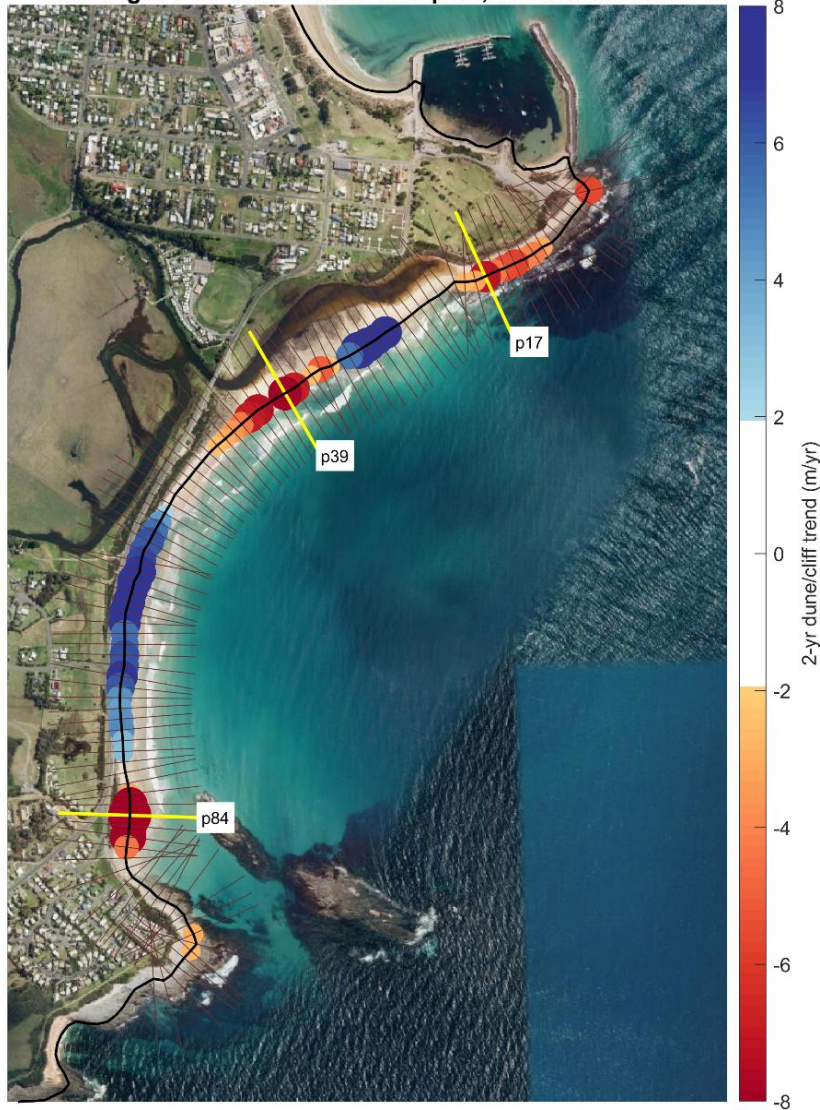
Stat 1: Long-term site averaged trend (LT; m/yr)	Stat 2: Short-term site averaged trend (ST; m/yr)	Stat 3: Shoreline erosion ratio (SR)	Stat 4: Backshore erosion ratio (BR; %)	Stat 5: Backshore hotspot maximum (BH; m/yr)	Summary: Erosion Warning Indicator (EWI)
-0.34	-0.58	21%	35%	-13.30	6 / 10

### Marengo – Shoreline Hotspots



# Marengo – Dune/Cliff-line Hotspots

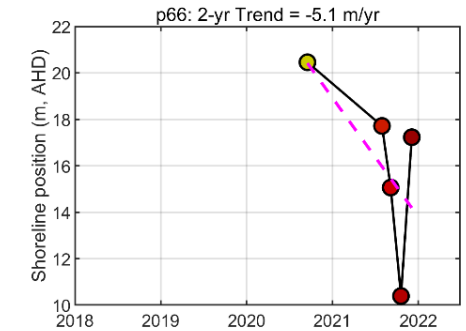
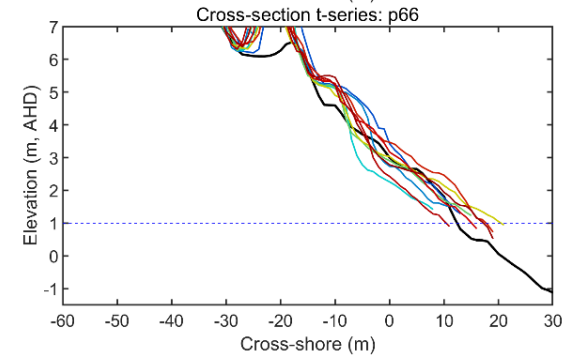
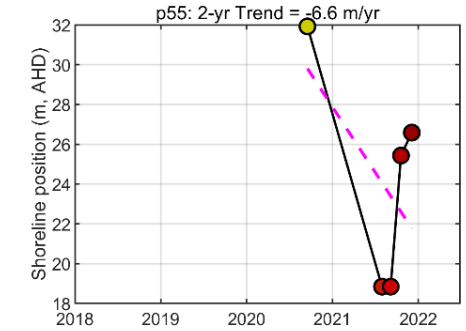
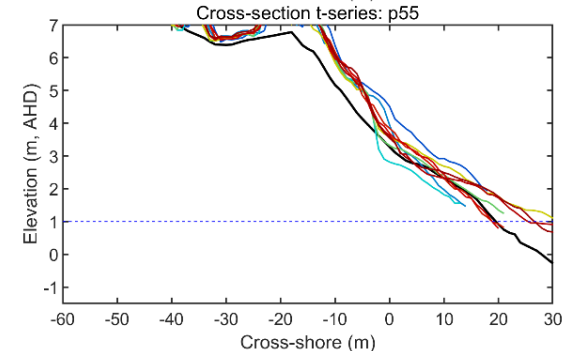
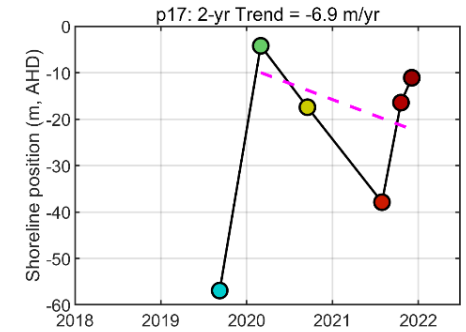
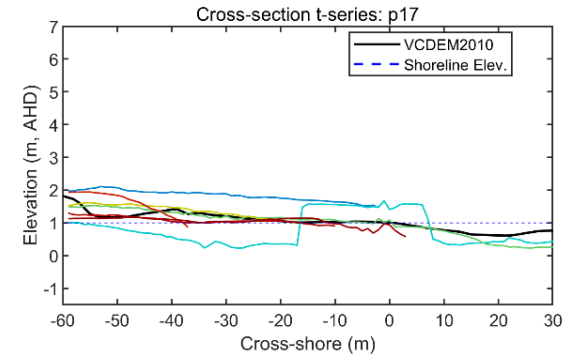
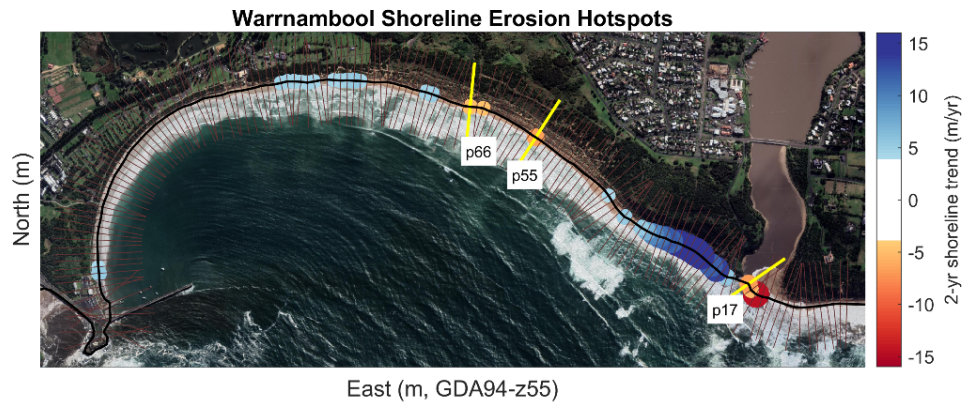
Marengo Dune/Cliff Erosion Hotspots, back-level 2.5 m



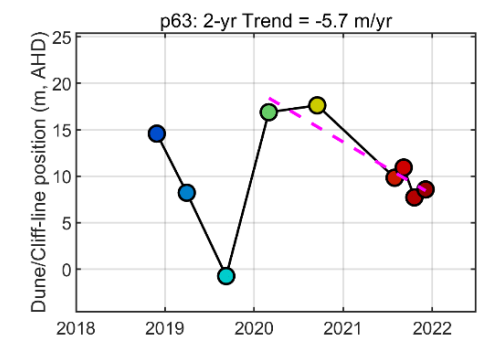
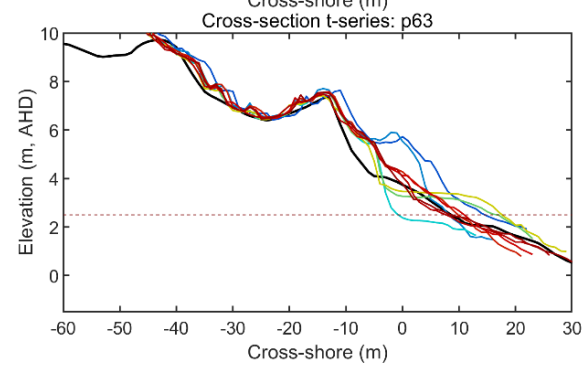
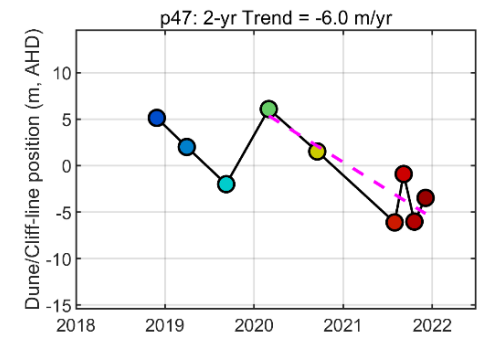
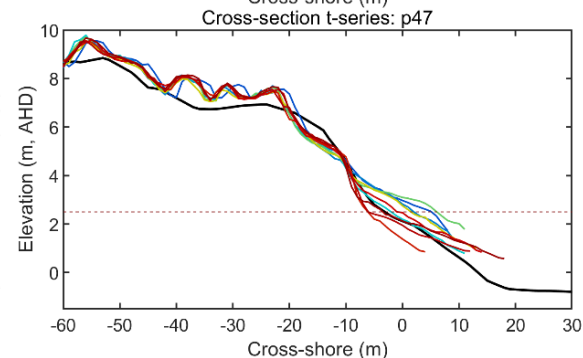
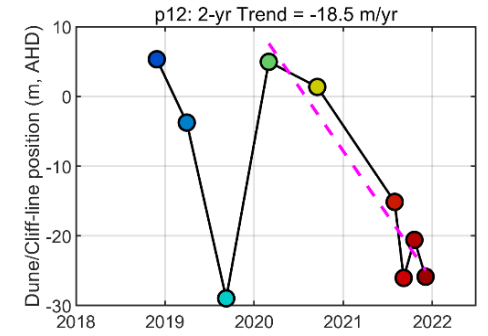
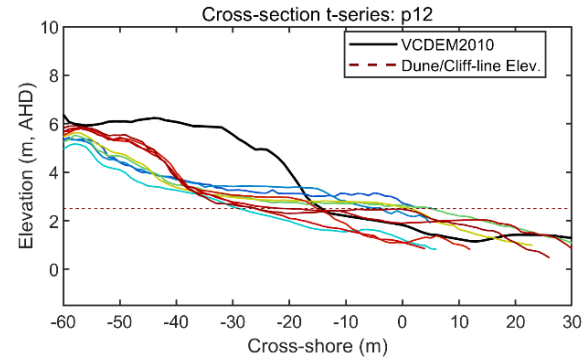
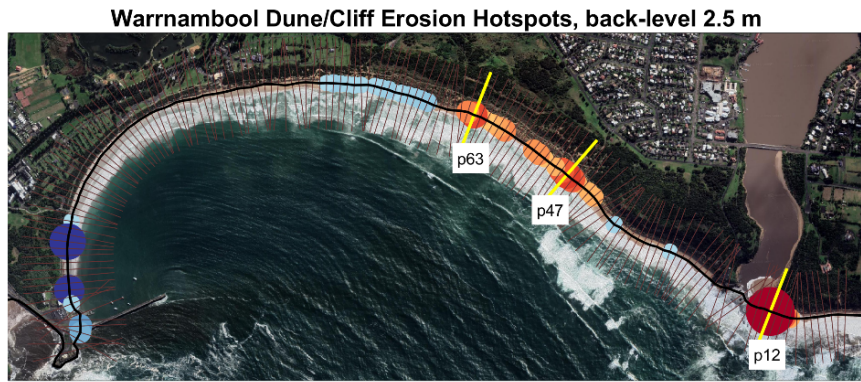
## Site 28: Warrnambool (WAR)

Stat 1: Long-term site averaged trend (LT; m/yr)	Stat 2: Short-term site averaged trend (ST; m/yr)	Stat 3: Shoreline erosion ratio (SR)	Stat 4: Backshore erosion ratio (BR; %)	Stat 5: Backshore hotspot maximum (BH; m/yr)	Summary: Erosion Warning Indicator (EWI)
-0.33	3.05	0%	0%	-1.70	<b>1 / 10</b>

### Warrnambool – Shoreline Hotspots



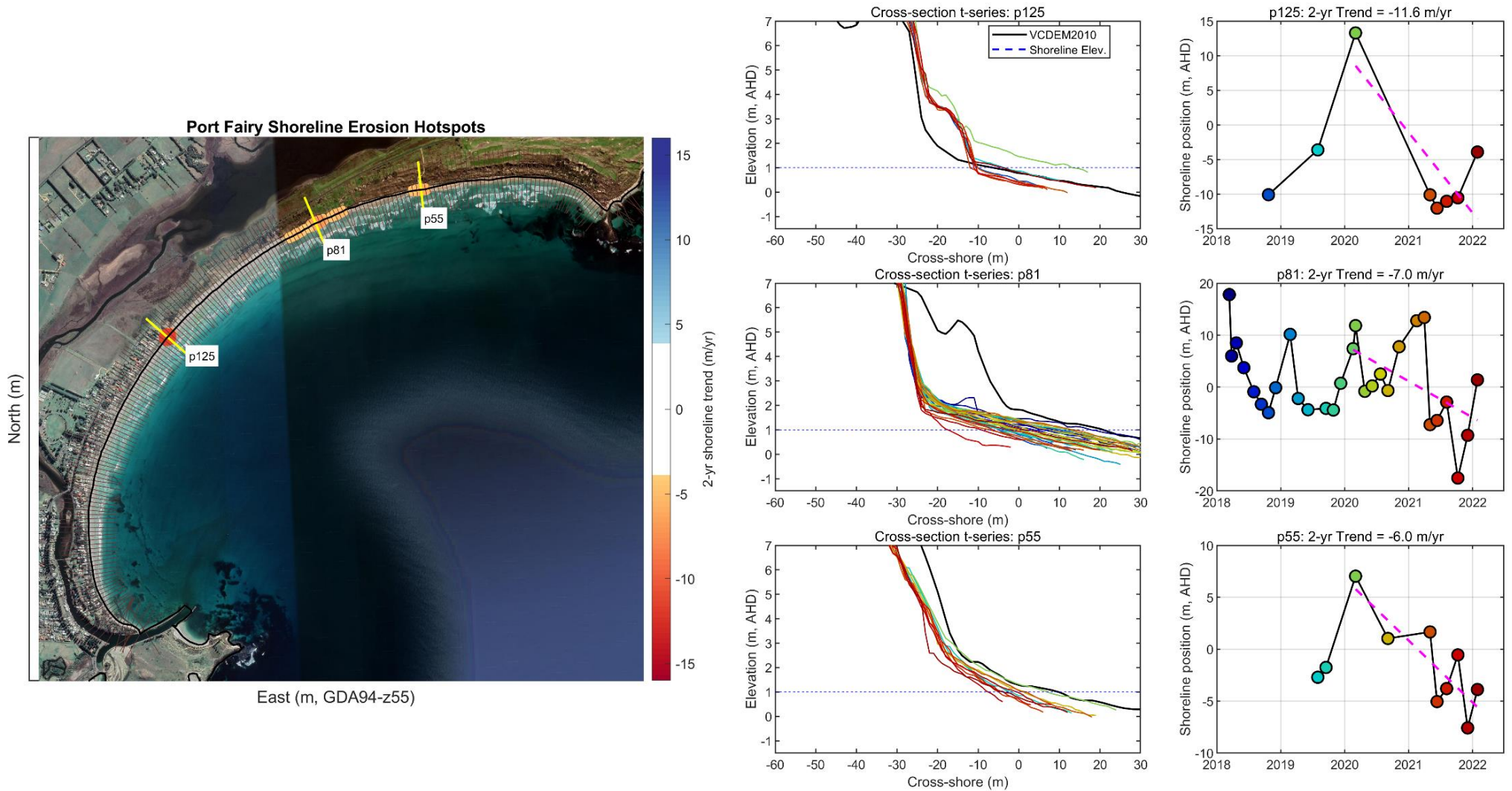
# Warrnambool – Dune/Cliff-line Hotspots



# Site 30: Port Fairy (PTF)

Stat 1: Long-term site averaged trend (LT; m/yr)	Stat 2: Short-term site averaged trend (ST; m/yr)	Stat 3: Shoreline erosion ratio (SR)	Stat 4: Backshore erosion ratio (BR; %)	Stat 5: Backshore hotspot maximum (BH; m/yr)	Summary: Erosion Warning Indicator (EWI)
<b>-0.51</b>	<b>-2.24</b>	<b>25%</b>	<b>3%</b>	<b>-2.46</b>	<b>4 / 10</b>

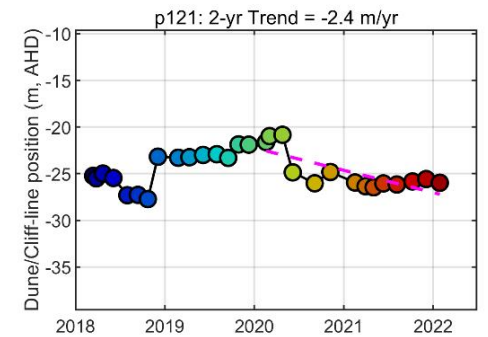
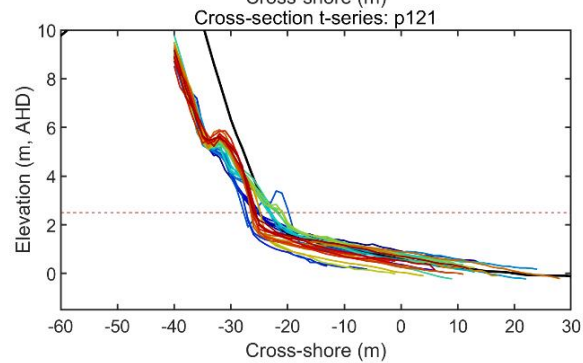
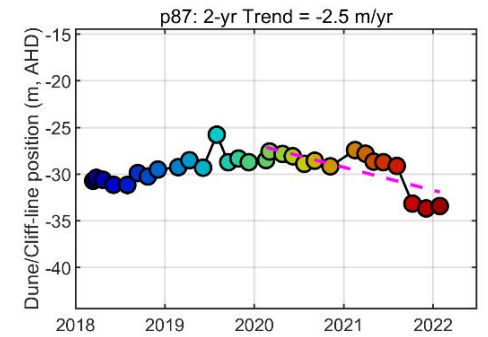
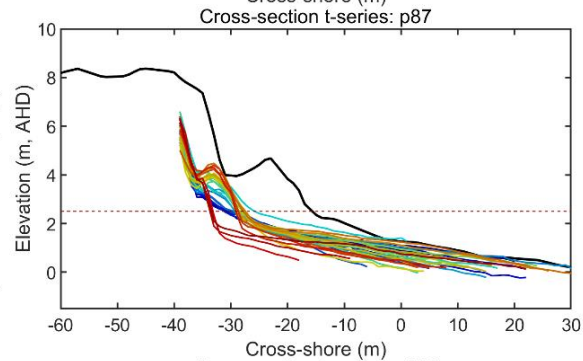
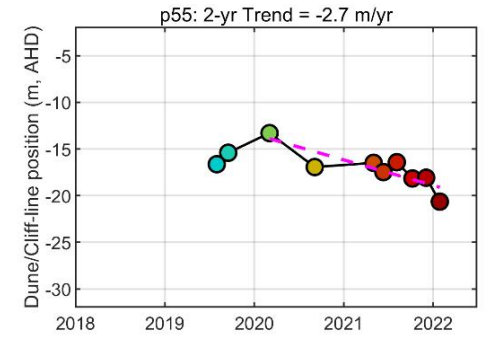
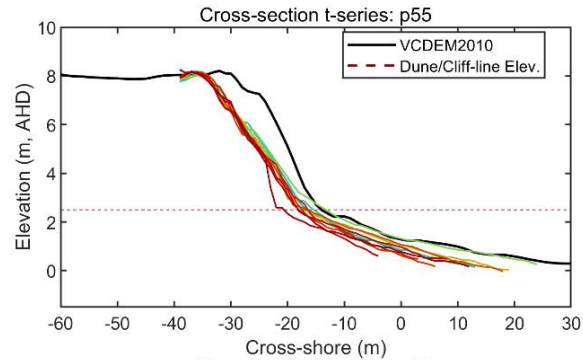
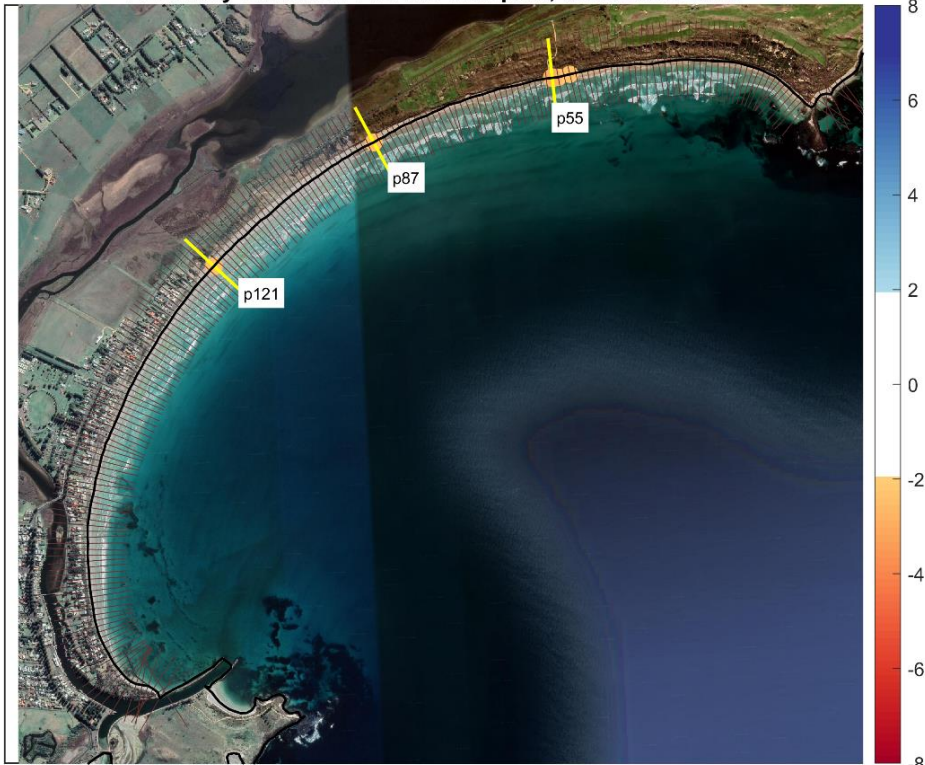
## Port Fairy – Shoreline Hotspots





# Port Fairy– Dune/Cliff-line Hotspots

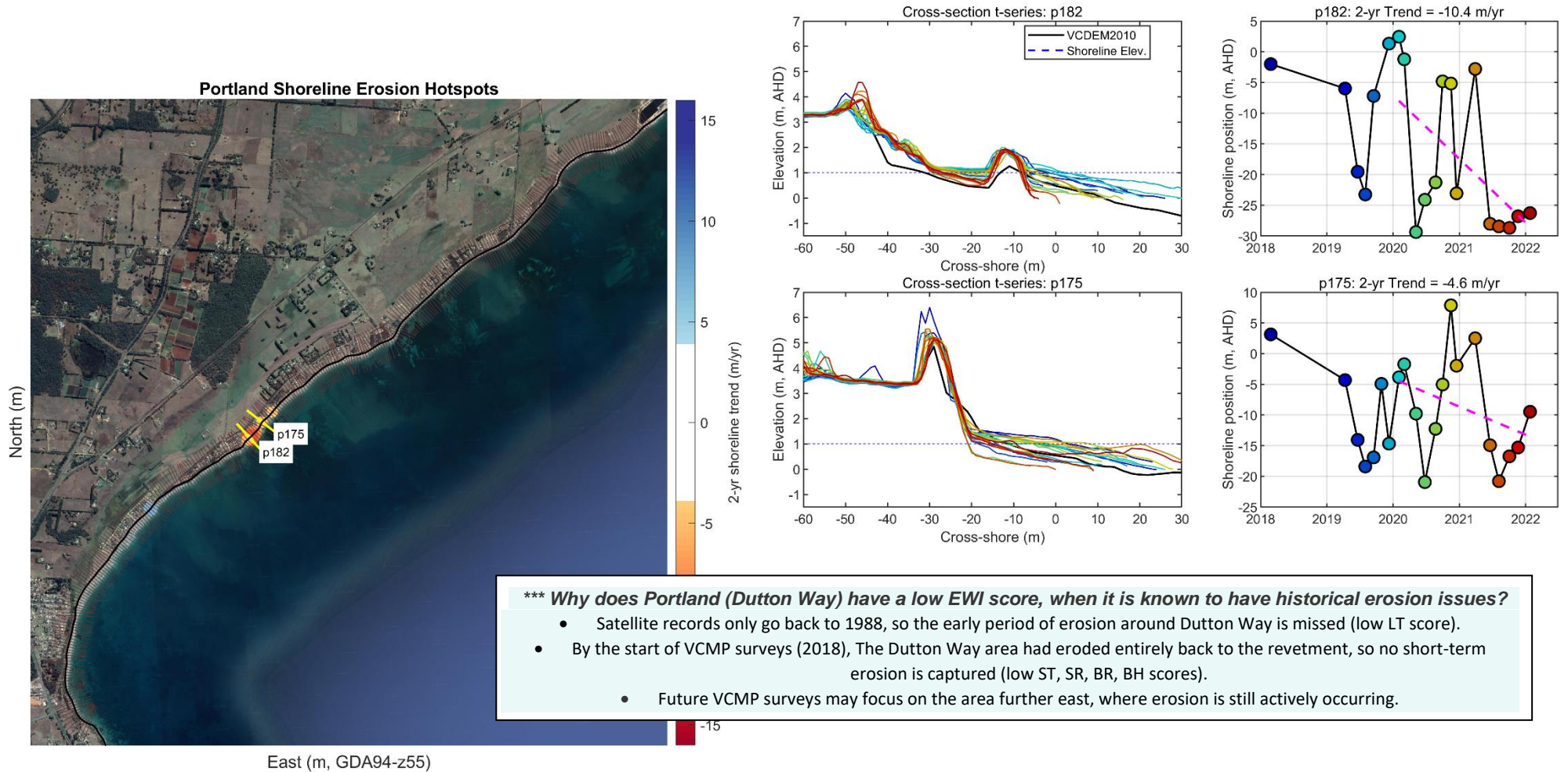
Port Fairy Dune/Cliff Erosion Hotspots, back-level 2.5 m



## Site 31: Portland (PLA)

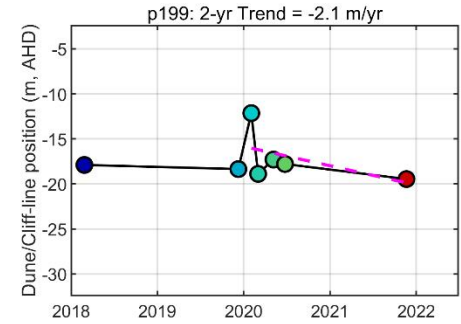
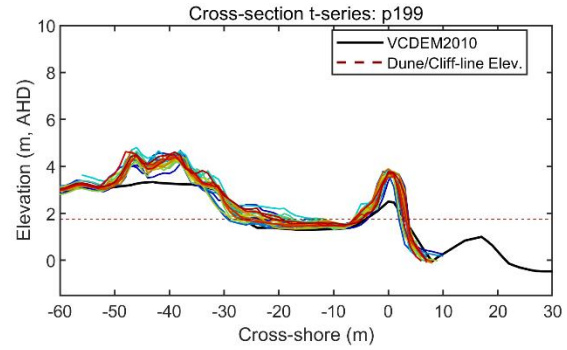
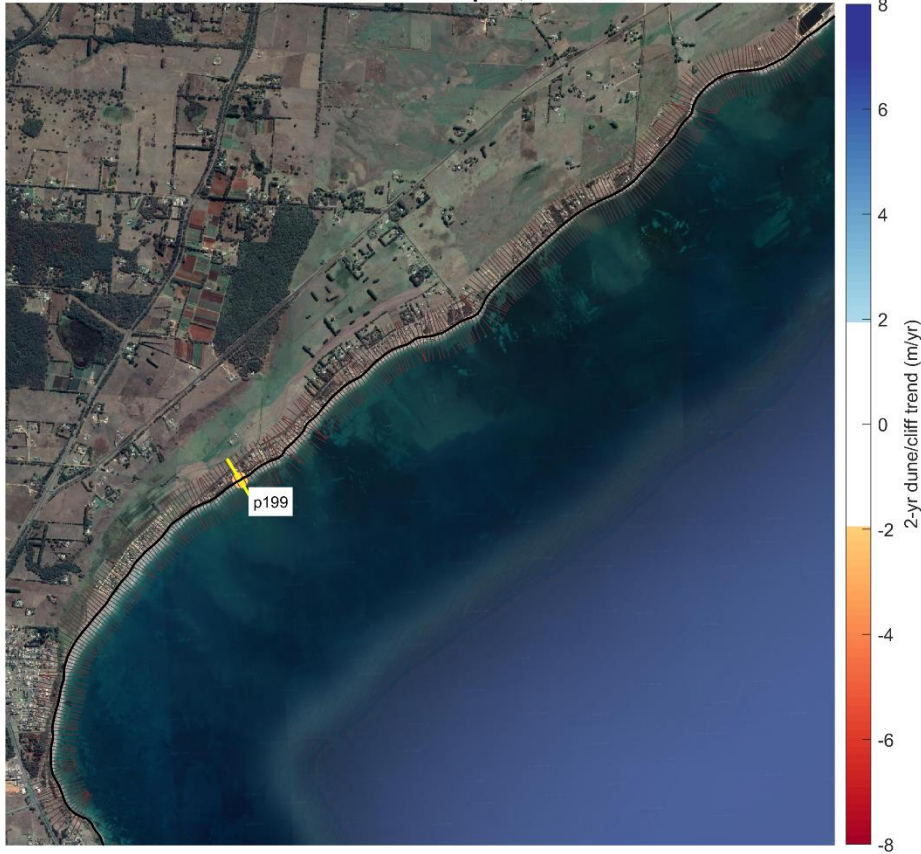
Stat 1: Long-term site averaged trend (LT; m/yr)	Stat 2: Short-term site averaged trend (ST; m/yr)	Stat 3: Shoreline erosion ratio (SR)	Stat 4: Backshore erosion ratio (BR; %)	Stat 5: Backshore hotspot maximum (BH; m/yr)	Summary: Erosion Warning Indicator (EWI)
0.04	-0.41	7%	1%	-2.14	<b>0 / 10***</b>

### Portland – Shoreline Hotspots



## Portland – Dune/Cliff-line Hotspots

Portland Dune/Cliff Erosion Hotspots, back-level 1.75 m



**\*\*\* Why does Portland (Dutton Way) have a low EWI score, when it is known to have historical erosion issues?**

- Satellite records only go back to 1988, so the early period of erosion around Dutton Way is missed (low LT score).
- By the start of VCMP surveys (2018), The Dutton Way area had eroded entirely back to the revetment, so no short-term erosion is captured (low ST, SR, BR, BH scores).
- Future VCMP surveys may focus on the area further east, where erosion is still actively occurring.

# 5. Discussion and Conclusions

This section focusses on issues around the usage and performance of the erosion indicator tools, with suggestions for future amendments and improvements.

## Limitations

- The tools (EWI and EHD) assess **erosion hazard** but **do not assess risk** (i.e., exposure and vulnerability). The tools will pick up on any erosion, regardless of proximity to infrastructure.
- The tools are designed for statewide automated assessment, but will miss some fine details. Erosion events that have a small magnitude in terms of shoreline change, but a large impact due to high associated risk may not register. The tools are not intended for local decision making, as this requires a local, place-based assessment of coastal hazards and risk.
- Positive sediment budget inputs like **beach renourishments** will be picked by the tools as short-term shoreline accretion, but no attempt is made to differentiate between shoreline change due to nourishment vs. “natural causes”.
- The DEA satellite record only goes back to 1988, which will fail to capture some known historical erosion that pre-dates this (e.g., Portland – Dutton Way). However, it may also be said that if erosion occurred >30 years ago, and is not recorded in more recent records, then it may not be relevant to current shoreline behaviour.
- The DEA satellite is reliable for long-open beaches with sand dunes, but is less reliable around rocky outcrops, headlands, and tall cliffs near the shoreline. E.g., discrepancies have been detected around Sandringham between the aerial imagery record and DEA satellite record. Recommendation: Be cautious with long-term (LT) statistic around cliffed and rocky areas, but also be aware it only makes up 20% of the EWI score (max. 2 out of 10 possible points). Also note that Geoscience Australia is working on this issue and there may be improvement in future releases.
- For cliffed sites prone to landslips (e.g., Demons Bluff), the tools do not adequately capture the severity of the hazard.

The results in this report are out of date at the time of release (most sites cut off in early 2022). An update will be provided by mid-2023, to include all data to the start of 2023.

## Suggested improvements

- A volume based method would pick up cliff falls, but is more complex from an automation perspective (e.g., vegetation is included in the VCMP drone surveys and will complicate backshore erosion calculations).
- Including aerial imagery as an alternative long-term record would alleviate / complement some of the shortcoming around satellite. However, shorelines and backshore lines have not been extracted for all VCMP sites, and this will need to be completed before an aerial imagery based statistic can be included.
- Coastal structures and infrastructure could be included in the algorithm, and this would allow the tools to be expanded to risk assessment. This is a significant task and could benefit from consultation with stakeholders (internal and external to DEECA).
- Using a single value (shoreline position change or volume change) effectively gives a single, all-inclusive estimate of sediment budget. The tool could be made to account for components of sediment budget. E.g., by separating out beach nourishment from other elements. This is also a significant task.

View the outputs according to the above caveats, and also suggest changes where something can be improved ([jak.mccarroll@delpw.vic.gov.au](mailto:jak.mccarroll@delpw.vic.gov.au)).

# References

- Bishop-Taylor, R., Nanson, R., Sagar, S., & Lymburner, L. (2021). Mapping Australia's dynamic coastline at mean sea level using three decades of Landsat imagery. *Remote Sensing of Environment*, 267, 112734.
- Ierodiaconou, D., Kennedy, D. M., Pucino, N., Allan, B. M., McCarroll, R. J., Ferns, L. W., ... & Young, M. (2022). Citizen science unoccupied aerial vehicles: A technique for advancing coastal data acquisition for management and research. *Continental Shelf Research*, 244, 104800.
- Pucino, N., Kennedy, D. M., Carvalho, R. C., Allan, B., & Ierodiaconou, D. (2021). Citizen science for monitoring seasonal-scale beach erosion and behaviour with aerial drones. *Scientific reports*, 11(1), 3935.

