RESEARCH REPORT

OzSET: The Australian SET-MH monitoring network

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Integration, analysis and publication of the Australian Surface Elevation Table-Marker Horizon dataset

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Executive Summary

Tidal wetlands (mangroves, tidal marshes and tidal forests) provide significant ecosystem services across the Australian coastal zone. These wetlands are at the forefront of climate change, being particularly vulnerable to the impacts of sea-level rise by virtue of the position in relation to tidal inundation and hydroperiod. The capacity of tidal wetlands to adjust vertically to sea-level rise has been the subject of extensive research, and a body of theory has developed concerning feedbacks between sea-level rise and the rate of sedimentation and new root production in wetlands. Allochthonous sediment inputs and autochthonous organic production increase wetland surface elevation, moderating the impacts of sea-level rise. The extent to which these processes operate globally, and between wetland types, is a subject of considerable research interest.

The Surface Elevation Table (SET) network has been developed over 30 years to answer these questions. The SET is a benchmark rod installed in wetlands against which wetland elevation change can be measured. At the time of installation, a feldspar layer is also introduced to the marsh surface, against which fresh sediment accretion is monitored. Periodic readings of the SET allow the trajectory of wetland elevation gain and sediment accretion to be measured over time. The difference between sediment accretion and elevation gain is a measure of subsidence, the auto-compaction of the upper marsh surface under the weight of sediment and water.

The global network of SET monitoring stations is concentrated in the North America, Europe and Australia, though SETs are found in Asia, Oceania, Central America and the Carribean, South Africa, South America, India. The Australian network is one of the largest, but has hitherto developed without national coordination.

This project collates the Australian SET data and provides an initial analysis of accretion and surface elevation trends. Specifically, the aim of the OZSET project was to:

1. Compile the existing SET dataset for Australia, including the location of SETs, the length of record and existing data.

2. Compile ancillary environmental data relevant to the interpretation of SET trends, including climate, geomorphic setting, tide range, dominant species, and the rate of local sea-level rise for the period of SET measurement.

3. Conduct preliminary analyses of SET-derived tidal wetland elevation trends in relation to key drivers

4. Disseminate SET and ancillary data through the NESP to national platforms.

The OzSET project identified and collated data for 268 SETs across four states and the Northern Territory. The network is clustered near major populations centres of Brisbane, Sydney, Newcastle, Wollongong, Melbourne, Perth and Darwin. SET installations are mostly in mangrove forests, but also cover a range of tidal marsh and tidal forest ecosystems.

Mangroves were found to have higher rates of accretion and elevation gain than all categories of tidal marsh, a result attributable to their lower position within the tidal frame (promoting higher rates of accretion) and higher biomass (with potentially higher rates of root

growth). While Australian tidal marshes show an increase in elevation over time, this elevation gain did not match the rate of water level increase at more than 80% of SET stations. High rates of accretion did not translate into high rates of elevation gain, because the rate of upper level subsidence increased with rate of accretion. This association between accretion and subsidence has been noted for tidal marshes in global syntheses, but was particularly strong in the Australian network, with 87% of variability in upper subsidence explained by the accretion rate.

The further development of the Australian SET network should focus on under-represented wetland types (specifically tidal forests) and geographic locations (Darwin Harbour and the Daintree being the only sites in the top end). Long-term datasets are required to clarify the strength of feedbacks between sea-level rise and marsh accretion, and while some of the Australian sites have records spanning two decades, many are new and ongoing effort in monitoring is required.

The Australian SET network is well placed to guide the development of landscape-scale sea-level rise visualisation tools. Products developed in Australia and publicly available currently lack distribution and accretion models for coastal wetlands. As a result, the resilience of coastal wetlands to sea-level rise scenarios is poorly represented, and landward translation not currently included in tools such as Coast Risk Australia. The sea level rise visualisation tool released in 2021 by the US National Oceanographic and Atmospheric Administration (NOAA) has both functionalities, allowing users to model the distribution of tidal wetland types under IPCC sea-level scenarios. The NOAA tool's marsh migration model (https://coast.noaa.gov/slr/#) is driven by accretion models derived from the United States SET network, and illustrations the potential for further development and application of the Australian network.

1 Introduction

1.1 Coastal wetlands and sea level rise

Tidal wetlands (mangroves, tidal marshes and tidal forests) are important coastal zone habitats. These three communities differ in structural characteristics and zonation in relation to the tidal frame. Mangroves are trees capable of growing and reproducing in sites frequently inundated by tidal waters, and have evolved to grow and reproduce in saline, anaerobic environments. In Australia, mangroves (typically *Rhizophoraceae, Avicenniaceae*) generally grow between mean high water and mean high water spring tides(Saintilan et al., 2019). Tidal marshes (or saltmarshes), consist of low growing herbs and grasses (common species include *Sporobolus virginicus, Sarcocornia quinqueflora, Samolus repens*, *Triglochin striata*), salt bushes (of the genus *Tecticornia, Atriplex*), and in more brackish to freshwater environments rushes (*Juncus, Phragmites*). Australian tidal marshes are more frequently found in upper intertidal environment, inundated by spring tides(Saintilan et al., 2019). Tidal forests (predominantly of the genus *Casuarina* and *Melaleuca*) are tolerant of infrequent tidal inundation and, if intertidal, occur between mean high water spring tidal levels and the highest astronomical tides (Kelleway et al., 2021).

Australian mangroves, tidal marshes and tidal forests make important contributions to a range of ecosystem services. The disproportionate contribution of these habitats to natural carbon sequestration has been demonstrated for all three habitats (Atwood et al., 2017), and they are the subject of emerging opportunities for blue carbon emissions reductions (Kelleway et al., 2020, Lovelock et al., 2022). The contribution of mangroves and tidal marshes to estuarine fisheries has also been demonstrated (Mazumder et al., 2006, Mazumder et al., 2011). They are important habitat for a number of endangered and vulnerable species of birds and mammals (Gonsalves et al., 2013, Kelleway et al., 2017).

The continued provision of the ecosystem services from coastal wetland environments is threatened by climate change. Several climate drivers influence survival and competitive interactions in tidal marshes, including temperature, elevated carbon dioxide concentrations, precipitation and sea-level rise. The proliferation of mangroves in higher latitudes, where they compete with tidal marshes, has been demonstrated on five continents and linked to all of these drivers. In Southeast Australia, tidal marshes have been converted to mangroves in most estuaries where long-term habitat dynamics have been studied, and the proportion of decline is consistent with sea-level trends over the period of observation (Saintilan et al., 2014).

While vulnerable to sea-level rise by virtue of their position in relation to tidal inundation, tidal marshes are capable of building elevation, ameliorating the impacts of increased water level. Indeed, the effect of sea-level rise and increased hydroperiod is to increase the rate of sedimentation, which is proportional to the depth and duration of inundation. Also, increased frequency of inundation can promote plant growth, which is limited higher in the tidal frame by higher porewater salinity and lower nitrogen concentrations (Feller et al., 2003). This increased biomass contributes to the building of root volume, an important component of marsh elevation gain (Morris et al., 2016, Morris et al., 2002). Also, the more anaerobic conditions created by increased inundation can lead to greater carbon preservation, enhancing the blue carbon efficacy of tidal marshes (Rogers et al., 2019).

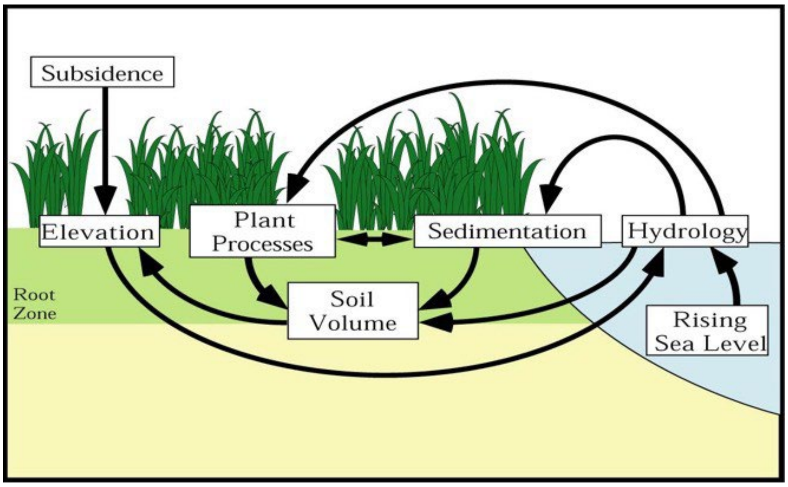

Figure 1: Processes creating a feedback between sea-level rise and marsh vertical accretion.

These considerations have given rise to models of marsh equilibrium with sea-level rise, whereby marshes rise or fall in the tidal frame to an optimal position, where increases in water level are balanced by increases in the elevation of the marsh (Cahoon et al., 2019), FIG 2). Modelling based on accretion responses in tidal marshes have suggested a robust response even to comparably high rates of sea-level rise, suggesting that the vulnerability of tidal marshes has been under-estimated in previous studies (Kirwan et al., 2016).

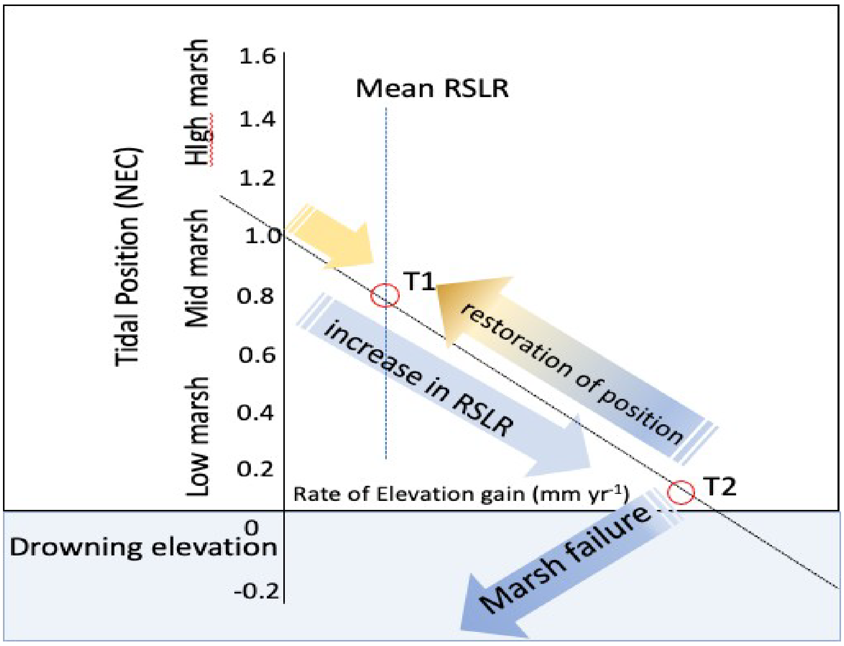

Figure 2: Marsh equilibrium model for coastal wetlands experiencing sea-level rise. Relative Sea Level Rise (RSLR) decreases the position of a marsh in the tidal frame (from T1 to T2), which enhances accretion, restoring the marsh to an optimal position in the tidal frame (mid-marsh). However, if the position of the marsh becomes too low, anoxic conditions lead to marsh drowning, rapid elevation loss and conversion to open water.

The extent and efficacy of feedbacks between water level rise and vertical accretion is still poorly understood. Recent syntheses from palaeo-stratigraphic observations of marsh responses to sea-level rise during the early Holocene, when rates of RSLR were higher than today, suggest that while marshes can track low rates of sea-level rise, this capacity is lost under rates exceeding 5-7mm year year (Horton et al., 2018, Saintilan et al., 2020). Contemporary observations of marsh responses to sea-level rise derived from accretion records (derived from radiometric and artificial markers) provide information on rates of sediment accumulation, but the extent to which this translates into elevation gain is critically important in determining marsh survival. Recently deposited sediment is subject to compaction, and ongoing accretion contributes to the compaction of sediment below (termed upper level subsidence: Figure 1). Upper level subsidence of accreting soil compromises the contribution of accretion to surface elevation gain and may be a key determinant of the resilience of wetlands under sea-level rise (Rogers and Saintilan, 2021, Saintilan et al., 2022). The relationship between accretion, subsidence and elevation gain is measured using the Surface Elevation Table, the operation of which is described in the following section.

1.2 The Surface Elevation Table technique

The Surface Elevation Table (SET) is a survey benchmark rod against which changes in the elevation of the marsh surface is measured. The rod is driven deep into the marsh (up to 30 metres), and measures are periodically made using a detachable arm, from which pins are lowered to the marsh surface. As the marsh accretes and the elevation of the marsh rises, the pins appear higher against the level arm. The arm is positioned on the benchmark rod to take readings in four compass directions, and nine replicate pins are used at each compass direction. These replicates of pins (9) and compass direction (4) are usually pooled in the estimate of marsh elevation change between readings.

Two SET designs have been commonly deployed globally. The original SET consisted of a hollow aluminium tube, manually slammed into the wetland to a maximum depth of 8 metres. An insert tube as concreted into the top of the SET pole, upon with the SET arm was attached (Figure 3). In a subsequent innovation a solid steel rod was used as the SET benchmark, allowing far greater depth of installation. This type of SET is termed the rod-SET, or rSET, and a smaller linear arm is used (Figure 3). Measurements are taken from a platform to minimise disruption to the SET plot and also reduce the influence of weight redistribution in the immediate vicinity of the reader. These platforms may be a permanent feature installed at the time of installation, but increasingly light weight portable platforms are used (Figure 3). As a result, between readings the SET is a visually unobtrusive fixture with negligible disruption to the wetland (Figure 4).

Figure 3 Measuring the rod Surface Elevation Table (left) and the original Surface Elevation Table (right). (Credit: Catherine Lovelock; Neil Saintilan)

At the time of installation, a feldspar horizon is often laid, against which sediment accretion can be measured. The accretion of sediment above the feldspar is gauged using shallow cores into the feldspar plots, usually dug with a knife. Shallow subsidence is inferred as the difference between vertical accretion measured against the feldspar marker horizon and elevation gain as measured from the SET benchmark rod. Shallow subsidence is defined as subsidence occurring between the surface and the base of the benchmark rod.

Figure 4. The head of the rSET benchmark rod amongst mangrove roots, Daintree River, Queensland (Credit: Catherine Lovelock)

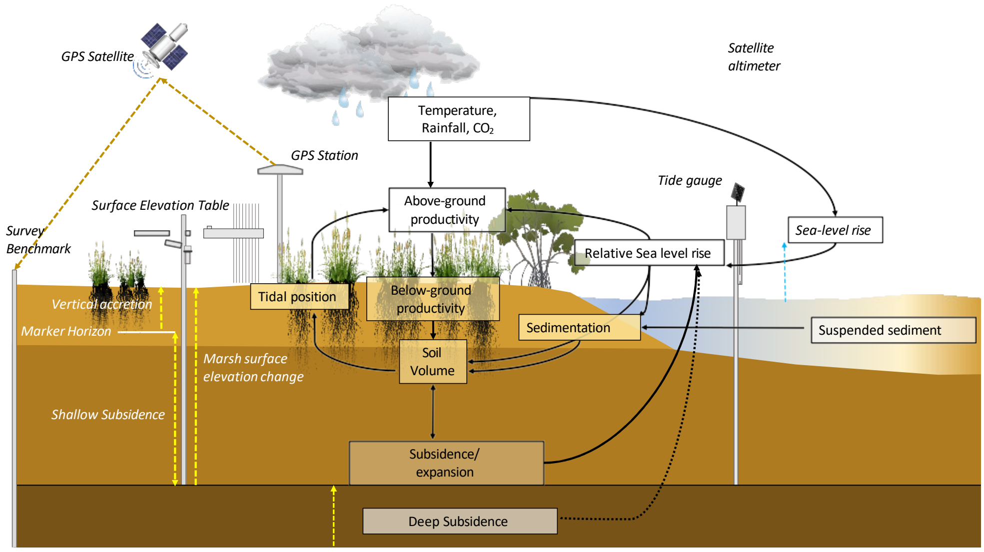

Figure 5: Operation of the SET-MH benchmark station, illustrating factors contributing to soil volume change.

SET measures are often compared to water level changes at nearby tide gauges (Figure 5). If the rate of water level increase exceeds the rate of elevation gain over the same period (termed the period of observation, or contemporaneous sea-level rise), then the marsh subject to an “elevation deficit”(Morris, 2006). Tidal marshes showing an elevation deficit are sinking in the tidal frame. Over time, the fate of such marshes will depend on the timing and strength of the negative feedbacks between water level rise and marsh vertical accretion described previously. For this reason, long-term SET measures are essential in order to capture feedback responses that may occur over decadal time periods. Syntheses of SET observations usually reject observation periods of less than three years.

1.3 The global SET network

The Surface Elevation Tables in their current form were developed by the US Geological Survey in the 1990’s initially to explore reasons for marsh break-up in the Mississippi delta (Cahoon et al., 2002, Cahoon et al., 1995). The Gulf of Mexico coastline is still one of the best-instrumented regions for SET measures in a network supporting several hundred installations (the CRMS network: https://www.lacoast.gov/CRMS/). The SET has been adopted by the US Fish and Wildlife Service as the standard method for monitoring the response of tidal wetlands to sea-level rise, and SETs are installed in most coastal National Estuarine Research Reserve system (NERR: https://coast.noaa.gov/nerrs/). As a result, the US coastline is extensively instrumented with SET stations, and these have informed the development of coastal inundation response models such as the Sea Level Affecting Marsh Model (SLAMM: https://coast.noaa.gov/digitalcoast/tools/□lam.html), which in turn has influenced the development of sea-level rise visualisation tools incorporating accretionary dynamics in lowlying sedimentary environments (for example the NOAA sea-level rise visualisation tool:https://coast.noaa.gov/slr/#).

To date, approximately 1000 SETs have been installed in over 40 countries worldwide (https://www.usgs.gov/centers/eesc/science/surface-elevation-table) . Important regional

SET networks include Europe (United Kingdom the European North Sea and Mediterranean coastlines), South Africa, Central America and the Caribbean, Asia (China, Vietnam, Indonesia), Oceania (New Zealand, Micronesia), and Australia. The technique has been described as the "global standard" for wetland monitoring against sea-level rise (Webb et al., 2013) and subject to important regional and global-scale synthesis reviews (Lovelock et al., 2015, Jankowski et al., 2017, Saintilan et al., 2022). While significant gaps in global coverage remain (Equatorial Africa, South America, Arctic coastline, Middle East) the network encompasses a range of bioclimatic zones, tidal ranges and rates of relative sea level rise (Figure 6).

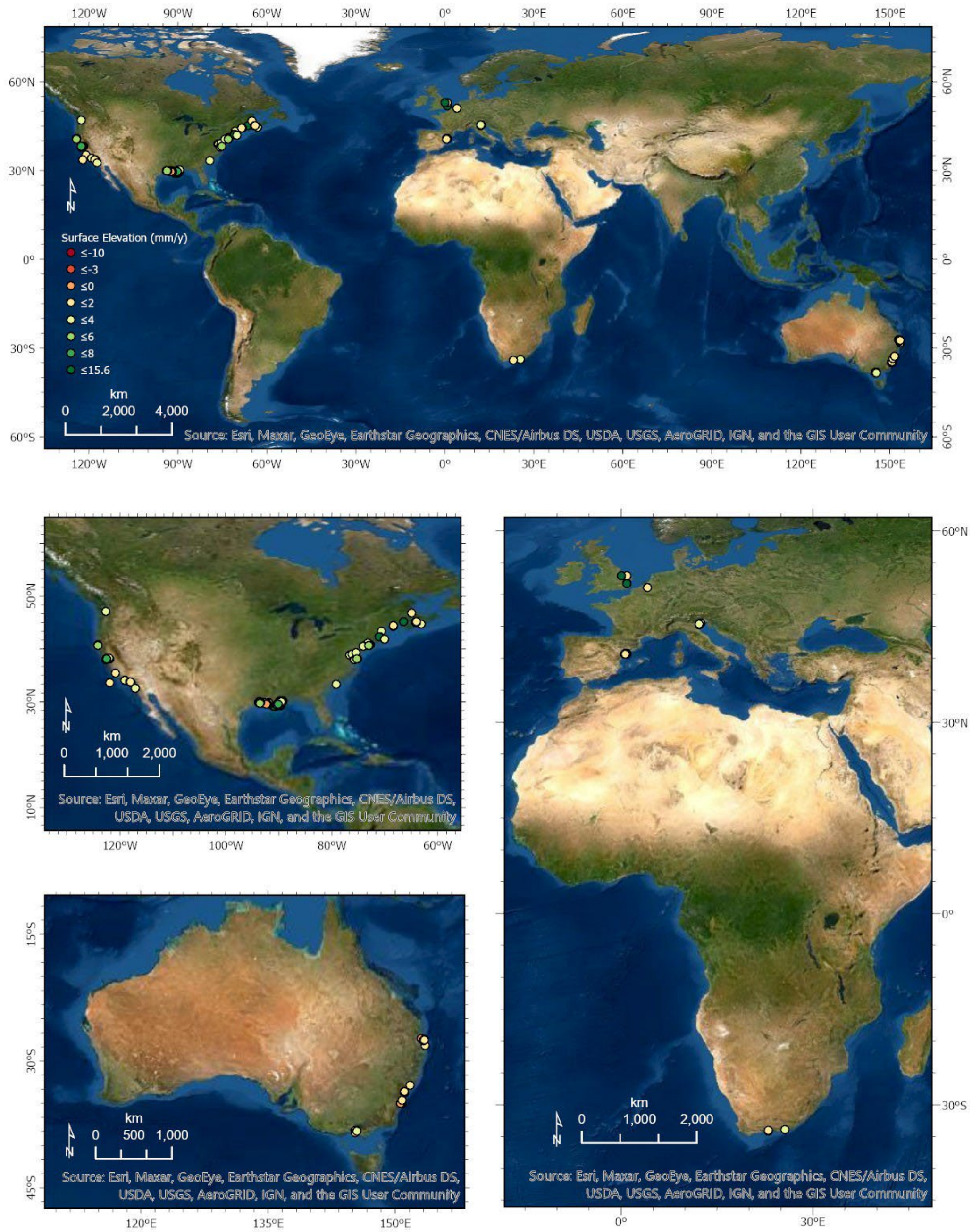

Figure 6: The global tidal marsh SET network. These sites, reported in Saintilan et al. 2022, consist of nearly 500 installations on four continents.

1.4 The Australian Network

Surface Elevation Tables were first installed in Australia in 2000-2002, funded by the Commonwealth's Coasts and Clean Seas Initiative, the Victorian and NSW State Governments, and several local councils. With assistance from the US Geological Survey, SETs were installed in 2000-2001 in NSW (Tweed River, Hunter River, Hawkesbury River, Parramatta River, Minnamurra River, Jervis Bay) and in Victoria (Westernport Bay). SET installation in Queensland commenced in 2007, initially in Moreton Bay, expanding to the Daintree River in 2014. Installation of SETs in Darwin Harbour commenced in 2016.

The Australian SET network consists of 268 benchmark Installations distributed across 30 sites (Table 1, Data S1, Figure 1). They are located in all coastal states and territories with the exception of Tasmania. While SET installations are numerically clustered around the major SE Australian population centres of Melbourne, Sydney, Newcastle and Brisbane, the network has expanded in recent years to several locations in Western Australia and the Tropical north (Darwin Harbour, Daintree, Low Isle and Woody Isle in the Great Barrier Reef).

Table 1. Location and sampling times of Australian SET-MH stations

Site	Coordinates	#SETs	First Sample Date	Last Sample Date	# years measured
New South Wales					
Cararma Inlet	-34.98, 150.78	6	02-08-2001	04-03-2020	18.6
Currambene Creek	-35.02, 150.66	9	03-02-2001	03-03-2020	19.09
Homebush Bay	-33.84, 151.07	9	15-08-2000	11-09-2020	20.09
Minnamurra River	-34.62, 150.84	6	11-09-2001	15-03-2017	15.52
Tweed River	-28.19, 153.55	6	30-11-2000	23-01-2018	17.16
Berowra Creek	-33.62, 151.12	6	11-12-2002	02-09-2017	14.74
MarraMarra Creek		6			
Kooragang Island	-32.85, 151.72	15	29-01-2002	03-02-2016	14.02
Tomago	-32.82, 151.77	9	01-10-2014	01-02-2019	4.34
Towra Point	-34.02, 151.16	12	15-04-2022	n/a	n/a
Victoria					
Kooweerup	-38.22,151.42	6	18-10-2000	12-11-2019	19.08

Quaill Island	-38.23, 145.31	6	16-10-2000	14-11-2019	19.09
Rhyll	-38.46, 145.28	6	17-10-2000	13-11-2019	19.08
French Island	-38.31, 145.43	6	15-10-2000	18-03-2022	21.4
Corner Inlet	-38.91, 146.30	12	14-03-2020	n/a	n/a
Queensland					
Tinchi	-27.29, 153.04	6	16-03-2007	11-10-2018	11.58
Nundah	-27.29, 153.04	6	19-03-2007	18-10-2018	11.59
Amity South	-27.43, 153.43	12	22-03-2007	13-11-2018	11.65
Adams	-27.52, 153.43	6	13-06-2007	08-11-2018	11.43
Halloran	-27.56, 153.29	6	13-06-2007	14-11-2018	11.43
Daintree River	-16.29, 145.40	18	10-08-2014	03-09-2021	7.07
Yandina	-26.56, 153.04	12	03-07-2020	n/a	n/a
Maroochy	-26.61, 153.05	3	25-08-2020	n/a	n/a
Woody Is./low is.	-16.38, 145.57	9	2022	n/a	n/a
Northern Territory					
Darwin Harbour	-12.48, 130.91	39	11-07-2016	24-12-2021	5.45
Western Australia					
Giralia	-22.49, 114.32	12	15-08-2011	n/a	6.84
Culham Inlet	-33.92, 120.05	3	15-04-2021	n/a	n/a
Oyster Harbour	-34.92, 117.97	3	15-04-2021	n/a	n/a
Leshanault	-33.21, 115.68	6	15-04-2021	n/a	n/a
Peel-Harvey Inlet	-32.75, 115.69	3	15-04-2021	n/a	n/a
Swan River	-31.92, 115.95	3	15-04-2021	n/a	n/a

1.5 Aims and Objectives of the project

The SET technique has been extensively applied to inform regional-scale models of sea-level rise in coastal lowlands in NSW ((Oliver et al., 2012, Traill et al., 2011, Rogers et al., 2012) and Queensland (Traill et al., 2011). Although we have national coverage with surface elevation tables in coastal wetlands in Australia (by research partners) these data have not been readily available to the research community or stakeholders as it resided with individual researchers. The purpose of the OzSET project was to

5. Compile the existing SET dataset for Australia, including the location of SETs, the length of record and existing data.
6. Compile ancillary environmental data relevant to the interpretation of SET trends, including climate, geomorphic setting, tide range, dominant species, and the rate of local sea-level rise for the period of SET measurement.
7. Conduct preliminary analyses of SET-derived tidal wetland elevation trends in relation to key drivers (Table 2)
8. Disseminate SET and ancillary data through the NESP to national platforms.

Table 2: Core data to be made publicly available (collated for each SET installation)

Rate of sediment accretion	Sediment accumulation above the baseline for each measurement period, and the linear trend through time
Rate of elevation gain	Elevation in relation to the benchmark (vertical position at installation) for each measurement period, and the linear trend through time
Rate of upper-level subsidence	Difference between the rate of sediment accretion and the rate of elevation gain
Elevation deficit	Difference between rate of sea-level rise and the rate of elevation gain

6. Methods

Data were compiled with the assistance of SET data custodians as set out in Table 2. Variables provided by data custodians included the rate of elevation gain (in mm per year) as a linear trend for the duration of the SET record, sediment accretion (in mm per year) as a linear trend for the duration of the accretion record (in some but not all cases). For each SET, relative pin height was calculated by subtracting baseline pin height from all subsequent readings. Relative pin heights were averaged hierarchically within each SET arm position and then across positions to integrate small-scale variation in surface elevation., the date of the initial reading and the most recent reading, and the dominant species found at the site. Rainfall and temperature variables were sourced from the Bureau of Meteorology (http://www.bom.gov.au/climate/data/) and sea-level trends calculated from the closest tide gauge in the Australian Baseline Sea Level Monitoring Network (http://www.bom.gov.au/oceanography/projects/abslmp/abslmp.shtml). A full list of variable names and their explanations are provided in Appendix 1. Simple and multiple linear regression were used to test relationships between quantitative variables. Paired t-tests were used to compare elevation trends between mangrove and tidal marsh SETs.

Table 3: Data custodians within the Australian SET network.

Custodian	Sites (see Table 1 for coordinates)	Contact
Prof Kerrylee Rogers, University of Wollongong Prof Neil Saintilan Macquarie University	Tweed River, Tomago Wetland, Kooragang Island, Berowra Creek, MarraMarra Creek, Homebush Bay, Minnamurra River, Currambene Creek, Cararma Intet, Kooweerup, Quaill Island, Rhyll, French Island	kerrylee@uow.edu.au neil.saintilan@mq.edu.au
Prof Catherine Lovelock University of Queensland	Tinchi, Nundah, Amity South, Adams, Halloran, Daintree River, Yandina, Maroochy, Giralia, Culham Inlet, Oyster Harbour, Leshanault, Peel-Harvey Inlet, Swan River	c.lovelock@uq.edu.au
Dr Madeline Goddard, Prof Linsay Hutley Charles Darwin University	Darwin Harbour	Lindsay.Hutley@cdu.edu.au
Dr Jeffrey KellewayUniversity of Wollongong	Corner Inlet, Towra Point, Woody Island, Low Island	jeffreyk@uow.edu.au

Sites were classified according to the geomorphic units using a typology that defines estuarine settings on the basis of dominance of river, wave and tide energy(Dalrymple et al., 1992): Barrier Estuarine (estuaries sheltered behind sand barriers along wave-dominated coastlines); Riverine Estuarine (sites associated with river systems where fluvial sedimentation is building active deltas); Tidal Estuarine (sites of meso-macro tidal range in which tidal deposition and erosion is a dominant process); Calcareous (sites associated with coral reef barriers); and Marine Embayment (sites protected from oceanic waves by shoreline configuration but for which fluvial influence is minor).

7. Results

7.1 Location and site characteristics

The network encompasses a range of geomorphic settings, though geographically the network is dominated by sites close to the population centres of Brisbane, Newcastle, Sydney, Wollongong, Melbourne, Perth and Darwin (Figure 7).

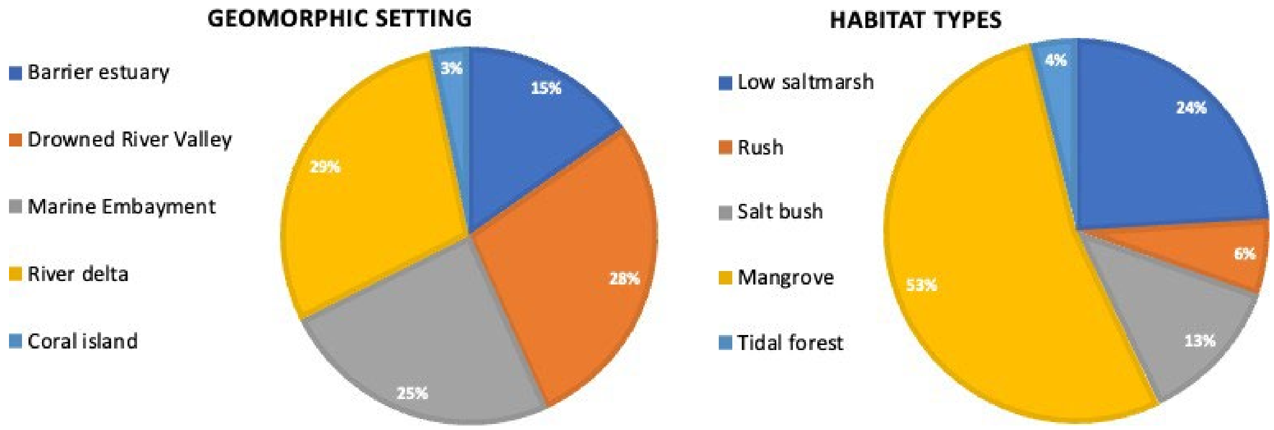

Figure 7. The proportion of SETs falling within defined geomorphic settings and habitat types

Australian SETs are equally divided between mangrove (53%) and tidal marshes and tidal forests, though tidal forests are under-represented in the network (4%). Being the most recent habitat sampled, tidal forest elevation and accretion data are not yet available. The network is also under-represented in the tropical north, though recent installations in Darwin Harbour (Northern Territory) and the Daintree River (Queensland) are providing early data.

7.2 Rates of elevation gain in relation to sea-level

The average rate of elevation gain for mangrove and tidal marsh sites is shown in Table 4 and Figure 8. These do not include sites recently established for which return readings have not been undertaken or for which the duration of record is too brief to derive a reliable trend (all of the Western Australian Sites, Corner Inlet in Victoria, the Tidal Forest sites at Towra Point NSW and the Woody Island and Low Island Great Barrier Reef sites). Data from these sites will be provided to the database as they become available.

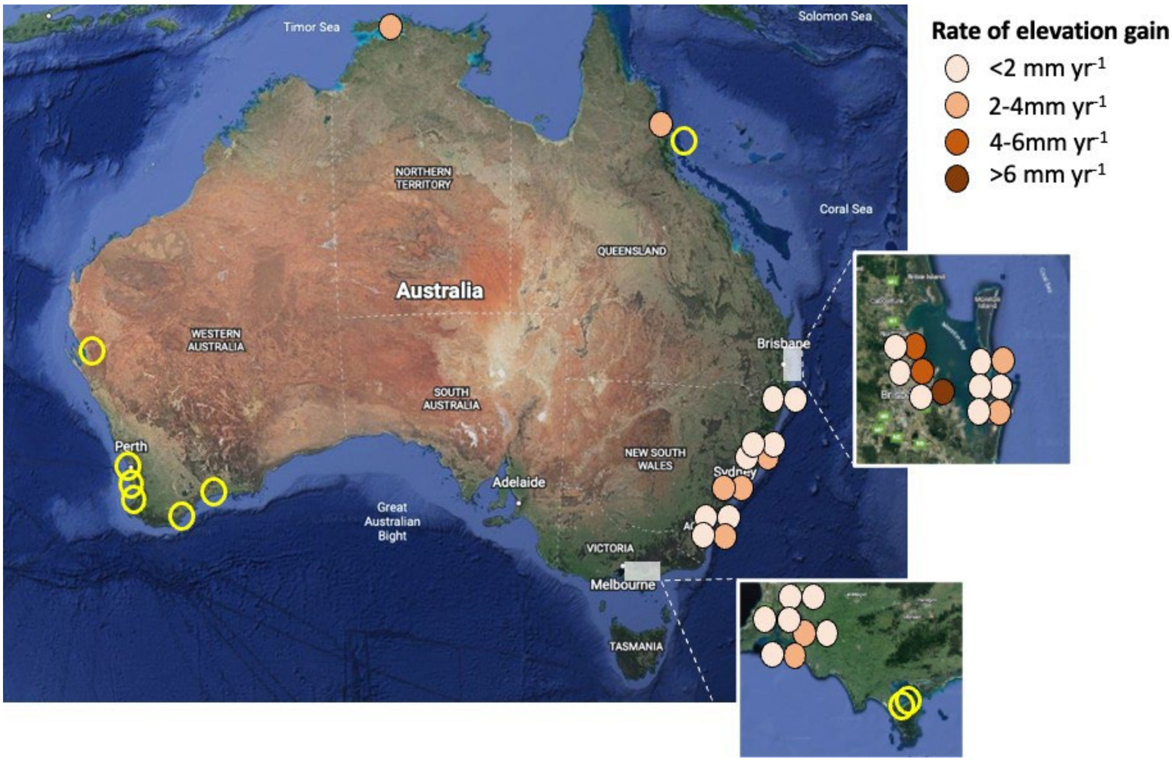

Figure 8. Distribution of the Australian SET network and rate of elevation gain. Locations are approximate (coordinates shown in Table 1). Yellow circles show recently installed SETs (no data). Paired sites show tidal marsh on the left and mangrove on the right.

Nearly all sites in the Australian SET network show a deficit in elevation gain compared to water level rises over the period of measurement (Table 4). Of 39 locations (sites with specific vegetation habitat) only four showed a surplus of elevation gain over sea-level rise averaged across SETs. Two of these were the only two restoration sites in the network (the French Island and Tomago tidal marshes).

Table 4: Rate of elevation gain* averaged by habitat type, compared to water level trends over the period of measurement (derived from nearest tide gauges). The elevation surplus (positive) or deficit (negative) is the difference between the rate of elevation gain and the water level trend. *several of the sites listed in Table 1 are too recent or have insufficient data to calculate an elevation trend.

Site	Elevation trend ($mm\ yr^{-1}$)	Water level trend ($mm\ yr^{-1}$)	Surplus (+) Deficit (-) ($mm\ yr^{-1}$)	Elevation trend ($mm\ yr^{-1}$)	Water level trend ($mm\ yr^{-1}$)	Surplus (+) Deficit (-) ($mm\ yr^{-1}$)
	mangrove			Tidal marsh		
New South Wales						

Cararma Inlet	2.183	2.38	-0.197	1.145	2.38	-1.235
Currambene	0.003	2.38	-2.377	-0.213	2.38	-2.593
Homebush Bay	2.923	5.4	-2.477	2.726	5.400	-2.674
Minnamurra	1.400	0.47	0.930	0.493	2.85	-2.357
Tweed River	1.807	4.9	-3.093	0.236	3.85	-3.614
Berowra Creek	2.456	3.42	-0.964	1.267	3.42	-2.153
MarraMarra	2.287	0.95	1.337	0.338	0.95	-0.612
Kooragang	0.887	3.11	-2.223	1.705	3.475	-1.770
Tomago				2.687	-4.03	6.717
Victoria						
Kooweerup	1.059	2.74	-1.681	0.247	2.028	-1.781
Quaill Island	0.407	3	-2.593	0.857	2.028	-1.171
Rhyll	2.293	3	-0.707	1.167	2.028	-0.861
French Island	0.937	2.74	-1.803	2.958	2.028	0.930
Queensland						
Tinchi	5.234	17.090	-11.856	0.027	3.850	-3.823
Nundah	5.896	17.090	-11.194	0.075	3.850	-3.775
Amity South	0.410	17.090	-16.680	0.152	3.850	-3.698
Amity North	2.338	17.090	-14.752	-0.010	3.850	-3.860
Adams	2.424	17.090	-14.666	0.415	3.850	-3.435
Halloran	6.224	17.090	-10.866	-0.025	3.850	-3.875
Daintree River	2.125	8.400	-6.275			
Northern Territory						
Darwin	2.924	9.313	-6.388			

Of the 267 SETs in the Australian network, 190 have elevation trend data, and for these elevation surplus or deficit has been calculated in relation to local water level trends for the period of measurement. Of these, 81% show a deficit between elevation gain and water level increase. If the Tomago and French Island tidal marsh restoration sites are removed from the analysis, 90% of SETs show an elevation deficit in relation to water level trends over the period of SET measurement. Of the mangrove SETs, 83% showed an elevation deficit, suggesting little difference in vulnerability between habitat types.

Mangroves have a high rate of accretion ($p<0.001$) and elevation gain ($p<0.001$) than tidal marshes, consistent with their lower position in the tidal frame (Figure 9).

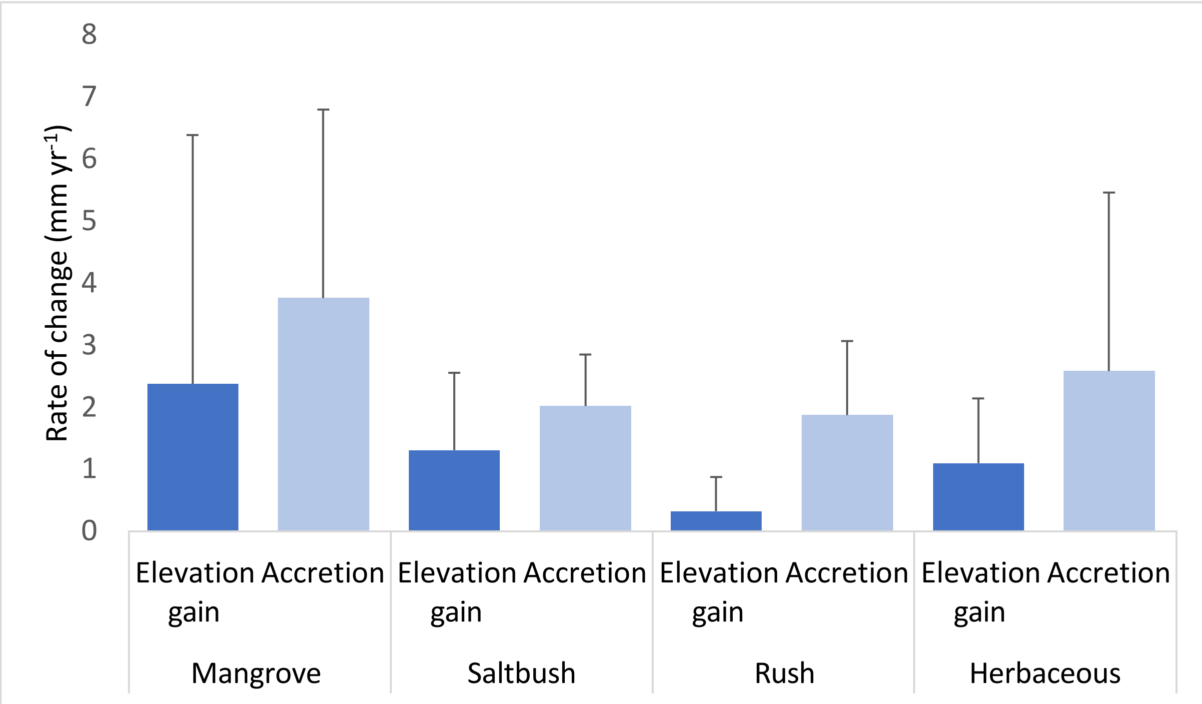

Figure 9: Comparison of the rate of accretion and elevation gain in mangrove compared to the four structural categories of tidal marsh.

7.3 Drivers of vertical accretion and elevation gain

Elevation gain was weakly correlated with the rate of sediment accretion ($p=0.028$, $r^2 = 0.04$). The relationship between the rate of accretion and sea-level rise was weak ($r^2 = 0.07$) but significant ($p=0.005$; $n=108$). Similarly, the relationship between elevation gain and sea-level rise was weak ($r^2 = 0.08$) but significant ($p=0.0006$).

The rate of subsidence was directly proportional to the rate of accretion ($r^2 = 0.76$), in a near 1:1 relationship (Figure 10). The implication of this result is that high rates of sediment accretion is not translating into elevation gain in Australian tidal wetlands.

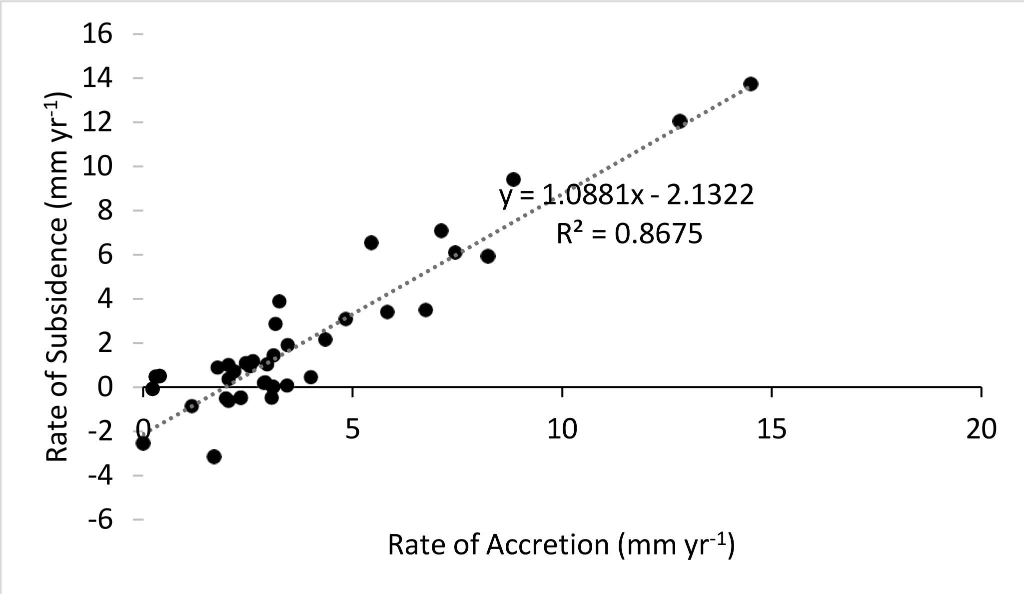

Figure 10: Relationship between the rate of sediment accretion above the feldspar marker horizon and the rate of upper-level marsh subsidence in Australian surface elevation tables (n= 108).

Because subsidence is reducing the contribution of accretion to elevation gain in direct proportion to the rate of accretion, a deficit between elevation gain and relative sea-level widens under high rates of relative sea-level rise (Figure 11).

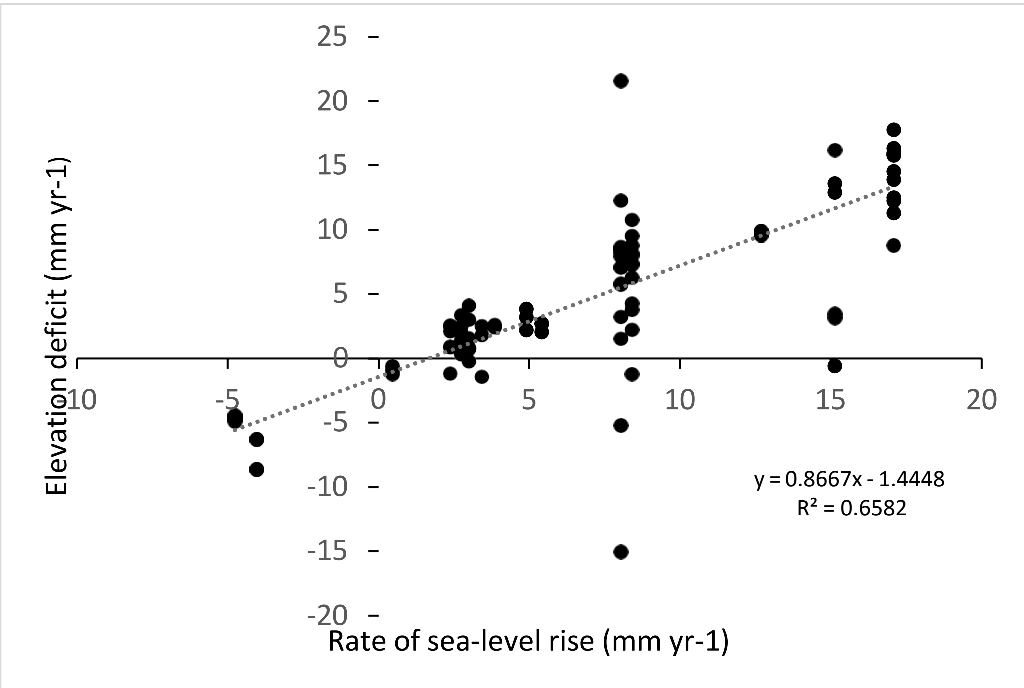

Figure 11: Relationship between RSLR and the deficit between RSLR and elevation gain in Australian tidal wetlands (n=183).

8. Conclusions

The Australian SET network has grown over two decades to include 268 installations across 30 sites. Habitats included in the network include mangrove (temperate and subtropical forests of Avicennia and tropical mangroves dominated by *Rhizophora* and *Bruguiera*), saltmarshes (incorporating the saltbushes, brackish rushes and herbaceous saltmarsh), and more recently tidal forests. The network covers 5 Australian states and territories, spanning geomorphic settings including macrotidal estuaries, drowned river valleys, microtidal barrier estuaries and coral islands.

The network has been established to explore the vertical adjustment of tidal wetlands to sea-level rise, and the processes influencing this adjustment. Results from the Australian SET network are largely consistent with other regional and global-scale syntheses. The relationship between accretion and upper-level subsidence, previously noted in Westernport (Rogers and Saintilan, 2021) and in global tidal marsh analyses (Saintilan et al., 2022), extended across the Australian network and was particularly strong ($r^2 = 0.867$). The result helps explain why Australian tidal marshes are showing a near ubiquitous deficit in relation to RSLR, and why the size of this deficit increases consistently with RSLR ($r^2 = 0.658$). Surface accretion appears to contribute to the subsidence of upper layers of sediment, introducing a negative feedback into the RSLR-accretion response.

Further work is required to better understand the response of Australian tidal wetlands to sea-level rise. The Australian SET network is heavily clustered to sites easily accessible to major population centres. This has helped maintain an appropriate frequency of measures, but has restricted sampling of some important wetland types. Until recently, arid-zone wetlands were poorly represented, but new SET installations in Western Australia will help to redress this issue. The macrotidal wetlands of northern Australia, the region of the greatest extent of tidal wetland in Australia, is represented by Darwin Harbour alone. Installations elsewhere in the top end would help interpret tidal wetland responses to climate change in this highly dynamic environment. Within the existing network, accurate survey of the elevation of SET installations in relation to fixed tidal datum would help interpret the implications of elevation deficits in relation to “elevation capital”, the elevation of the wetland above lower survival limits.

Finally, accessibility of the Australian SET data will help the research and management community develop better models of coastal lowland responses to sea-level rise. The US National Oceanographic and Atmospheric Administration (NOAA) has recently released a sea-level rise visualisation tool that includes a marsh accretion model based on SET data. This can be accessed at https://coast.noaa.gov/slr/#, and the marsh migration module showcases the potential application of dynamic elevation models in coastal planning.

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10. Appendix 1: Identifiers and Variables compiled.

Site.SET.identifier	Individual SET descriptor
Lead	Lead scientists responsible for readings and site data custodians
Site.label	Site identifier
Latitude	Latitude of individual SET in decimal degrees
Longitude	Longitude of individual SET in decimal degrees
Start	Date of first reading
End	Date of most recent reading
Years	Time between Start and End in years
elevation.rate	Rate of elevation gain (linear trend) from the SET record (mm yr^{-1})
RSLR.period.of.measure	RSLR for each site for the period of SET measurement (i.e. between Start and End). Linear trend (mm yr^{-1})
elevDeficit	Elevation Deficit, defined as RSLR period of measure minus elevation rate. (mm yr^{-1})
accretion	Rate of accretion above the feldspar horizon, linear trend (mm yr^{-1})
Subsidence	Rate of accretion – elevation rate (mm yr^{-1})
tidal.range	Difference between MHW and MLW (m)
tidalCat	Classification of tidal range as micro, meso, or macrotidal
maxTemp	Average daily maximum temperature of the warmest month of the year in degrees Celsius (sourced from the Bureau of Meteorology, nearest weather station)
rainfall	Average annual rainfall (mm) (sourced from the Bureau of Meteorology, nearest weather station)
Geomorphic Setting	Classification of geomorphic setting as: River deltaic, Tide Dominant, barrierLagoon, Barrier estuary, Embayment, Drowned River Valley
Dominant.vegetation	Dominant Genus or species in the vicinity of the SET station
shortGrassesHerbs	dominated by short grasses and herbs (*Sporobolus, Distichlis, Salicornia, Sarcocornia, Poa, Glaux, Borrichia, Puccinellia, Paspalum, Elymus, Impatiens*), binary
brackishRushes	dominated by brackish rushes (*Juncus, Baumea*)
saltbushes	dominated by saltbushes or shrubs (*Atriplex, Tecticornia*)
mangrove	Dominated by mangrove (*Avicennia, Rhizophora*, *Bruguiera, Ceriops*).