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Environmental Sensing Technologies and Research

Eramurra mapping
Horseflats PEC – Remote Sensing

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Document Information

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Addendum produced. Project development envelopes changed slightly, requiring recalculation of some parameters. More in-situ validation data were provided. We caried out further validation.	July 2023
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1. Background: Horseflat PEC

We report here the potential of satellite remote sensing, specifically Sentinel-2 A/B data, for mapping the spatial extent of a Priority Ecological Community (PEC) in the Horseflat land system located within the Roebourne Plains of northwest Western Australia. The maps and data derived from this feasibility study are to support monitoring and management of environmental state currently, and possibly change from recent times, within the context of potential industrial development in the region.

Payne and Tille (1992) reported an inventory and condition survey of the Roebourne Plains in 1992 and named 5 land systems, Cheerawarra, Horseflat, Mallina, Sherlock and River, also stating these land systems support most of the districts productive pastures (see Figure 1). van Vreeswyk et al. (2004) tabulated over 100 land systems in their inventory and condition survey of the Pilbara region. The Roebourne plains, with an area of 1261 km^2 (van Vreeswyk et al. 2004), are themselves part of the western Pilbara region and are located in the north eastern North-West Division of Western Australia. The Horseflat land system is described as comprising 8 land units (Payne and Tille, 1992):

1. Stony rise and low hills,
2. Calcrete plains,
3. Gilgaied plains,
4. Non gilgaied, sometime stony plains,
5. Alluvial plains,
6. Dissected slopes,
7. Linear drainage depressions,
8. Channels and minor river terraces

van Vreeswyk et al. (2004) defined a larger number of land types to describe the characteristics of the Pilbara regions, and identified Alluvial plain Roebourne Plains grassland (ARPG) as the most extensive site type on the Horseflat land system, and Aluvial plain tussock grassland (APTG) as common within the Horseflat land system (van Vreeswyk et al. 2004). DBCA (2021) list PECs in WA and include Roebourne Plains coastal grasslands with gilgai microrelief on cracking clays, Chenopod vegetation associations of the Roebourne Plains, and Horseflat land system of the Roebourne Plains. The Horseflat land system of the Roebourne Plains is described as “extensive, weakly gilgaed clay plains dominated by tussock grasslands on mostly alluvial non-gilgaid plains, red clay loams or heavy clay loams”. It is also described as incorporating Unit 3 (gilgae plains), Unit 5 (alluvial plains) with some Unit 7 (drainage depressions).

The expectation is that the general colouration of the PEC communities would be distinctly red, particularly in comparison to adjacent non-PEC systems. However, the descriptions of these PEC type land systems also include the presence of vegetative cover comprising *Sorghum sp.* and *Eragrostis xerophila* (Roebourne Plans grass) along with other native species on the Roebourne Plains, with the Horseflat system dominated by *Eragrostis xerophila* and other *Eragrostis* spp., *Eriachne* spp. and *Dichanthium* spp. with annual grasses including *Sorghum* spp. and rare *Astrebla* spp. (DBCA, 2021). van Vreeswyk et al. (2004) provide a detailed overview of the climate across the region, noting that the Pilbara rangeland falls within two bioclimate regions, semi-desert: tropical characterised by 9 to 11 months of dry weather, and desert: summer rain characterised by up to 12 months of dry weather. They also note that plant growth is determined by availability of moisture together with soil characteristics.

For this work we are investigating the potential of satellite-based remote sensing for mapping the extent of Horseflat PEC. Remote sensing instruments measure the spectral reflectance, or colour, of land surfaces. Based on the descriptions of the PEC and adjacent land systems presented above, we expect PEC to be characterised by a generally bright red colour when vegetation cover is sparse (dry periods), but also displaying a high vegetation index cover for intermittent short periods where rainfall has enabled significant growth of vegetation.

The classification of PEC within the 8 listed land units suggests topography and surface slope may influence the likelihood of land being classed as PEC. For this work we expect PEC to occur on low gradient surfaces. Also, the distinction between PEC occurring in some Unit 7 (Linear drainage depressions) and not in Unit 8 (Channels and minor river terraces) suggests locations of known rivers and streams may be useful in mapping PEC.

The aims of this project are to:

1. study the feasibility of satellite remote sensing data from Sentinel-2 A/B in mapping the PEC in the Horseflat land system (see extent defined in Figure 2).
2. develop a methodology to identify the Horseflat PEC from the satellite data and generate a PEC map to inform the extent of and recent changes to the PEC in the study region.

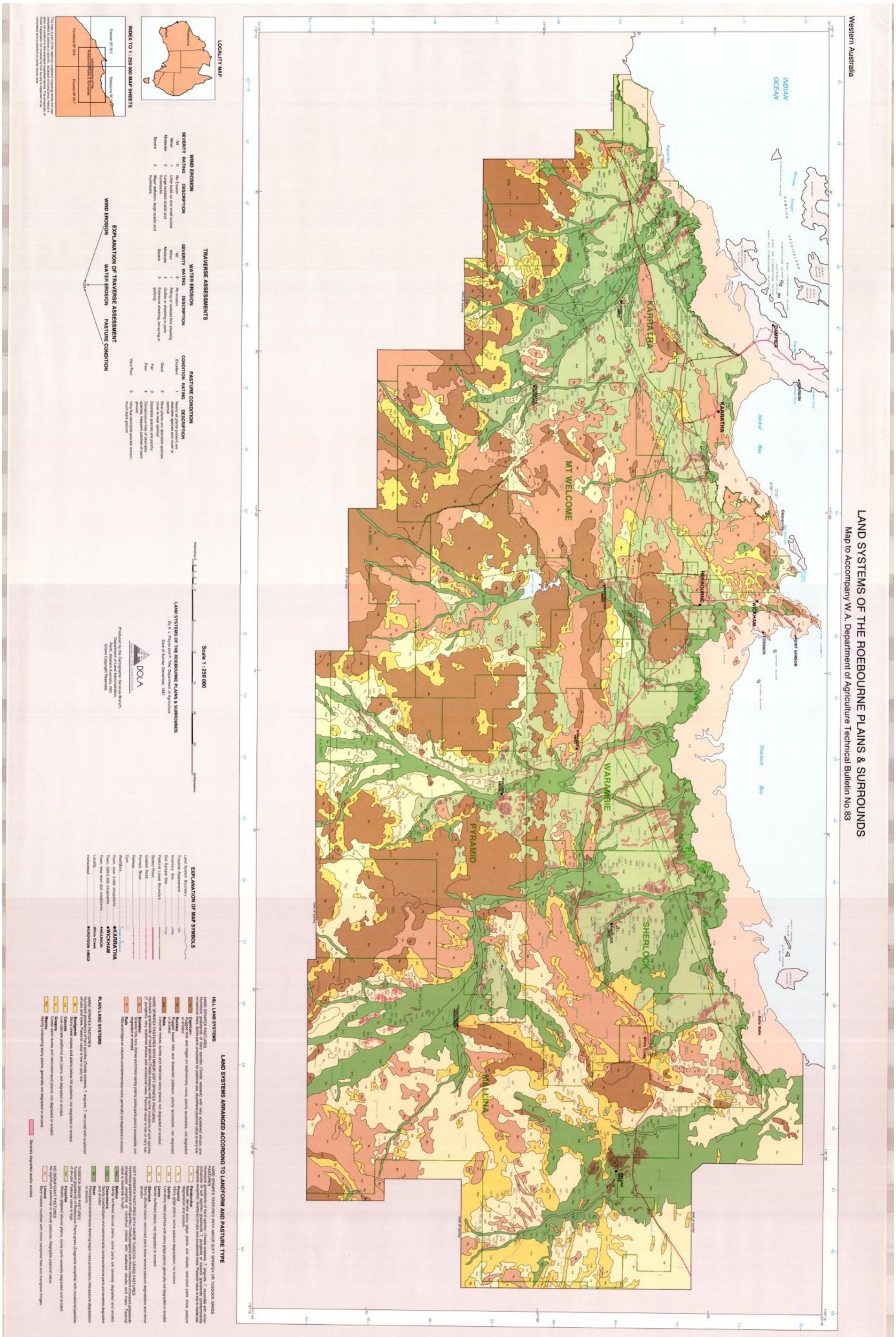

Figure 1. Land system map from Payne and Tille (1983). Horseflat land system is indicated by pale green.

2. Study Sites

The Horseflat land system is indicated on Figure 2 by green boundaries, based on Department of Agriculture 1987 data (Zappelli, 2004). The Horseflat area of interest (AOI) for this aspect of the work is a subregion of a larger regional AOI, shown in Figure 2, extending from the southern extent of Exmouth Gulf to approximately 118 degrees east. A localised area of interest (AOI) representing the focus of this study is indicated in Figure 2 by a magenta rectangle (Eramurra AOI). The approximate extent of the Horseflat AOI is indicated by a yellow boundary (Horseflat AOI).

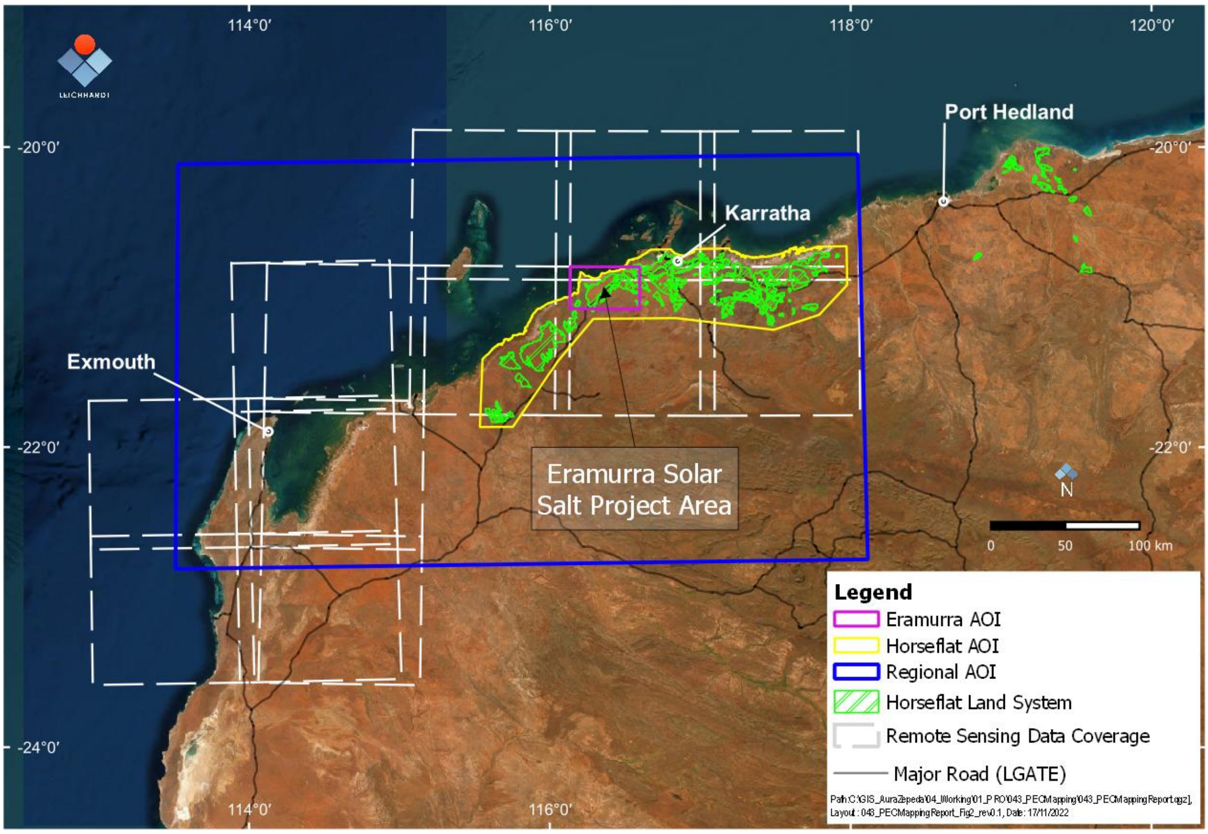

Figure 2. Regions of interest for remote sensing-based mapping. Regional AOI (blue), Horseflat AOI yellow), and Eramurra AOI (magenta). Image proved by Leichhardt.

3. Data

The ground truth locations for the PEC sites provided by Leichhardt Salt Pty Ltd and Satellite remote sensing data from the Sentinel-2 A/B data are used in this study.

3.1 In-situ Data

The *in-situ* validation data provided by Leichhardt, used to identify locations as PEC and not-PEC, was collected sporadically across 2015, 2017, 2018, 2019 and 2020. In total, data from 89 sites were sampled and provided but we rejected two sites, one because the point was located outside the Horseflat region and the other due to a missing label to identify as PEC or not. The final 87 *in-situ* sites identified 35 as PEC. All 35 sites were located within the area identified as the Horseflat (see Figure 3).

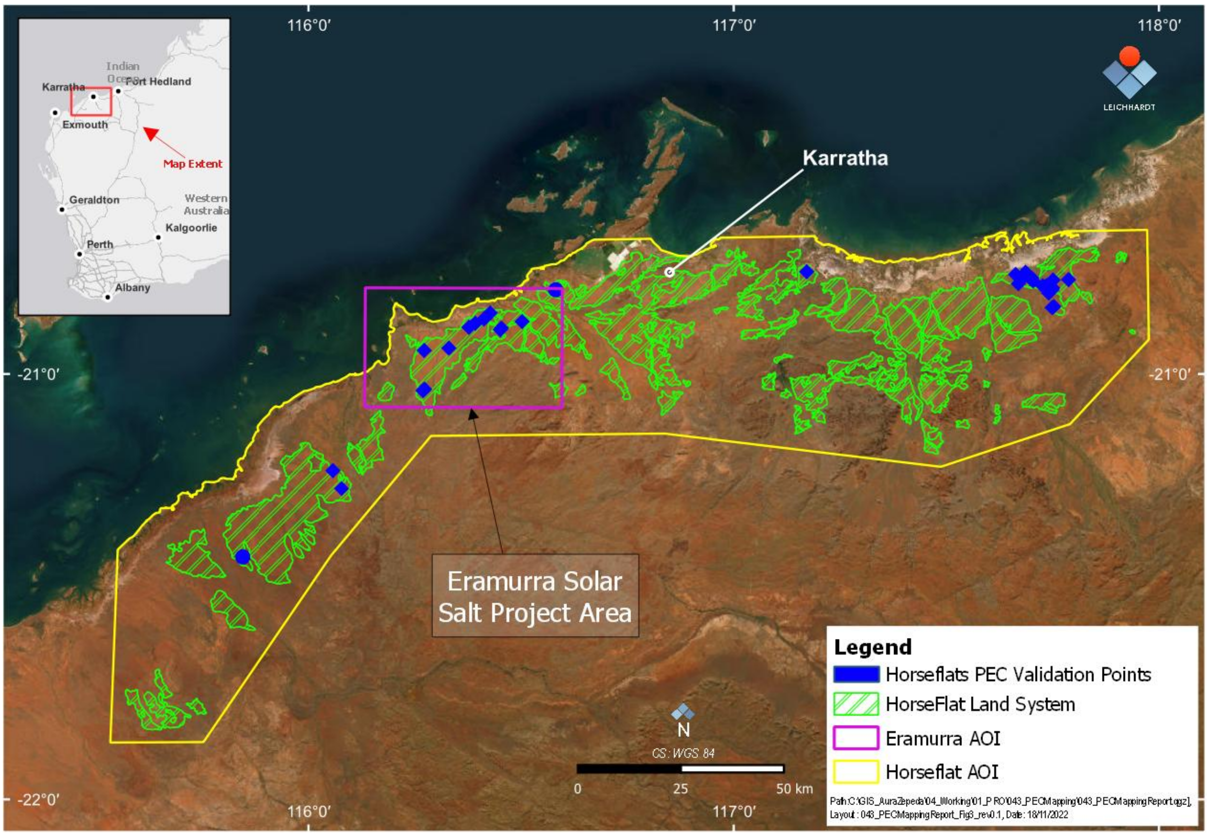

Figure 3. The in-situ PEC "validation" points (blue). Green polygons are areas identified as the Horseflat land system.

3.2 Satellite Remote Sensing Data

The Sentinel-2A and 2B each provide 10 day repeat views of the globe, interleaved to provide views of the earth at intervals of 5 days. Sentinel 2A began operation in June 2015 and Sentinel 2B in March 2017. Spatial resolution varies from 10 m to 60 m across 13 visible and infrared spectral bands (see Table 1). For this work we used the Sentinel-2 data from 1st January 2018 to 31st of December 2021 for PEC mapping. The core data for this work included the Normalized Bottom of Atmosphere Reflectance and Terrain corrected (NBART) product from Sentinel-2 A/B and cloud mask data generated using a python implementation of the `fmask` algorithm by Zu and Woodcock (2012) and Zhu et al. (2015). The NBART products are preferred over the top of the atmosphere reflectance because NBART products have the atmospheric and terrain effects corrected to account for atmospheric, sun and satellite angles. Inconsistencies can arise between the satellite images at different time periods because of variation in atmospheric conditions, sun and satellite angles and terrain slope and aspects (Li et al, 2010). The NBART product allows for accurate comparison of imagery at different locations and seasons.

Table 1. Sentinel-2 Multi-spectral Instrument (MSI) band information.

	wavelength	spatial resolution (m)
Band 1 – Coastal aerosol	443	60
Band 2 – Blue	492	10
Band 3 – Green	560	10
Band 4 – Red	665	10
Band 5 – Vegetation red edge	704	20
Band 6 – Vegetation red edge	740	20
Band 7 – Vegetation red edge	783	20
Band 8 – NIR	833	10
Band 8A – Narrow NIR	865	20
Band 9 – Water vapour	945	60
Band 10 – SWIR – Cirrus	1373	60
Band 11 – SWIR	1614	20
Band 12 – SWIR	2202	20

3.3 Topographic and drainage data

Shuttle radar Topographic Mission (SRTM)-derived 1 Second Digital Elevation Model (DEM)Version 1.0 data (Gallant et al., 2011) were used in this study to produce a gradient map to analyse the relationship between PEC and slope in the PEC area delimitation. The DEM is derived from SRTM data acquired by NASA in February 2000 and publicly released under Creative Commons licensing from November 2011. The DEM is derived from lidar surveys and gridded to ~ 30 m horizontal resolution and represents ground surface topography and excludes vegetation features.

River and stream data incorporated into this study were accessed from the Western Australian Land Information Authority (Landgate) (Govt. Western Australia, 2022). River and stream data were incorporated to analyse and exclude river channels from low slope areas.

4. Methodology and Results:

The methodology to map PEC from Sentinel-2 data is built upon the preliminary investigation conducted by Leichhardt. In the preliminary investigation, Leichhardt showed that the ratio Sentinel-2 Band4/Band2 highlights the Horseflat land system. The ratio Band4/Band2 has been dubbed the Red Soil Index (RSI) in this study, because a higher RSI index highlights a red coloured land system more prominently.

In addition to the RSI, additional indices listed in Table 2, commonly used in mapping vegetation and soils, were investigated for the feasibility in mapping the PEC. The vegetation indices were included to allow identification of vegetation during the intermittent growth following wet periods.

Table 2. Sentinel-2 indices that were investigated.

Modified Bare Soil Index (MBSI)	$MBSI = \frac{Band11 - Band12 - Band8}{Band11 + Band12 + Band8}$	Nguyen et al. (2021)
Enhanced Vegetation Index (EVI)	$EVI = 2.5 * \frac{Band8 - Band4}{(Band8 + 6.0 * Band4 - 7.5 * Band2) + 1}$	Huete et al. (2002)
Normalised Difference Vegetation Index (NDVI)	$MBSI = \frac{Band4 - Band8}{Band4 + Band8}$	Rouse et al. (1974)
Simple Ratio Clay Index (SCRI)	$SCRI = \frac{Band11}{Band12}$	Bousbih et al (2019)

Normalized Difference Vegetation Index (NDVI) and Enhanced Vegetation Index were both useful in highlighting the vegetation covered surfaces. Likewise, the Red Soil Index and the

Modified Bare Soil Index (MBI) were beneficial in identifying the bare earth surfaces. MBSI and EVI were deemed redundant in identifying the PEC because the NDVI and RSI were providing similar information. Thus, only NDVI and RSI were used in mapping the PEC land system.

4.1 All Years Combined Monthly Statistics of Different Land Surfaces

To develop a methodology to identify or classify pixels we need to understand the natural variability of indices for pixels identified as PEC and also pixels classified as non-PEC. We visually identified a number of land surfaces using high-resolution Google Earth satellite imagery, extracted NDVI and RSI values from those locations for time series spanning 2018 to 2021, and generated monthly statistics for the different land surface types in the study region. The land surface types identified were named based on simple visual inspection and included blue mud, white mud, grey mud, mudflat at higher ground, sandbar, PEC and mangrove. Monthly box-plots for the different land surface types are presented in Appendices 1-3. For all plots the data for each month is an amalgamation of data for that month across all years from 2018 to 2021.

From the monthly statistics of the different surface types, we observe that the RSI of PEC is consistently higher than the other land surface types. The RSI median values of PEC across all the months were all greater than ~2.75, while the median values for other land surfaces were all less than ~2.5. The difference and separability of the RSI values between PEC and other land surface types shows that the RSI can be used in distinguishing the PEC from the other land surface types assessed here.

There was not significant difference in NDVI values between the PEC and other land surface types, except for mangrove which was significantly higher with NDVI greater than ~0.6 across all the months. However, it is interesting to note that the median NDVI values for PEC locations across all the months varied minimally between ~0.12 and ~0.17, while other land systems varied by significant margins across different months. The details of the results can be ascertained from Appendices 1-3.

4.2 Yearly Monthly Median Time Series Analysis of PEC Sites

The NDVI and RSI indices were computed for each satellite pass individually after masking the clouds. For all 35 PEC validation locations and for every satellite pass, the median of 3 x 3 pixels was extracted from the NDVI and RSI data. The median of 3 x 3 pixels was selected to account for spatial variability and effects of pixel adjacency. To generate continuous time series with little or no missing data due to clouds, monthly median composite sets of NDVI and RSI were generated. The time series plots of the median NDVI and RSI values through time are shown in Figures 4 and 5 respectively. For each vertical set of points (1 month) there are typically 35 data points. Different colours indicate different PEC locations.

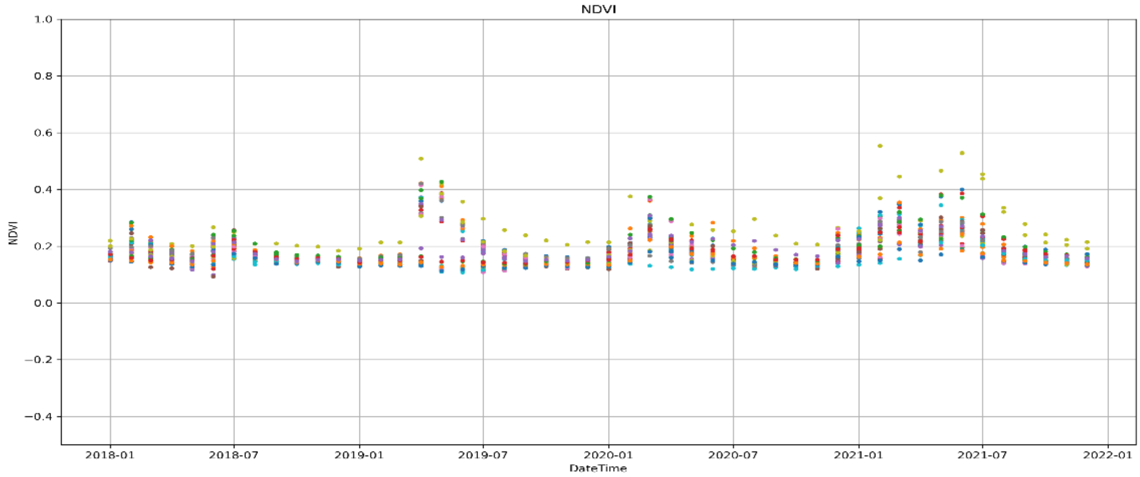

Figure 4. Time series plot of NDVI for the PEC validation locations.

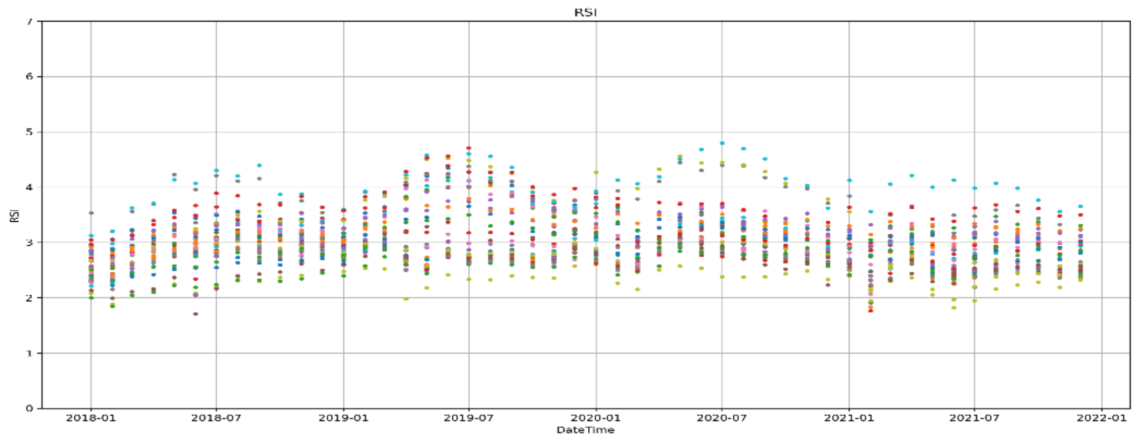

Figure 5. Time series plot of RSI for the PEC validation locations.

After producing monthly composites of NDVI and RSI indices for the years 2018 to 2021, a statistical summary of the indices at the PEC sites was generated. The statistical summary generated from the 35 PEC sites is presented in Table 3.

Table 3. Statistical summary generated from PEC sites using monthly median data.

Index/Stats	Mean	Median	Max	Min	Standard Deviation	Percentile (%)				
						2.5	5.0	90.0	95.0	97.5
NDVI	0.18	0.16	0.55	0.09	0.06	0.12	0.13	0.26	0.30	0.36
RSI	3.20	2.94	4.79	1.71	0.49	2.21	2.33	3.68	4.02	4.23

4.3 RSI Index Thresholding using Monthly Median Composite

From the NDVI time series plot in Figure 4, we see that there are some months, most noticeably in April-June 2019, February-March 2020, and February-July 2021, where there were higher NDVI values across nearly all the PEC sites. This is interpreted as an indication of significant increases in vegetation growth. The RSI time series plot in Figure 5 shows that there were yearly trends in RSI values for many locations, with the RSI values for many sites increasing from low in December-January to peaks around June-August. The RSI time series data shows that many PEC sites exhibit a range of RSI values throughout the year.

The approach to classify individual pixels as PEC or not-PEC was to define threshold index values which would be compared to individual image pixels to produce maps of PEC. From the time series observations, we inferred the NDVI and RSI thresholds should be generated from data from all years and months combined to form a robust threshold representative of all seasons. The long-term median values of NDVI and RSI presented in Table 3, which were generated using all the PEC sites across all the months from 2018 – 2021, were used as thresholds. A subset of the study sites with PEC validation locations and shapefiles/boundaries indicative of the Horseflat land system was used as a test case to see how effective the RSI threshold was in identifying the pixels within the Horseflat shapefile. The map generated from the median of data across all the years with RSI greater than or equal to the median RSI value of 2.94 is presented in Figure 6. From Figure 6 we observe that the pixels above the RSI threshold, displayed as red, are generally quite consistent with the extent and boundaries of the areas defined as Horseflat. Pixels above the RSI threshold but outside the polygon of the Horseflat PEC do not necessarily indicate classification errors. These pixels may identify land of similar characteristics to, but located outside, the Horseflat land system. Note, for example, the descriptions of some land systems in Figure 1 include mention of tussock grass pastures, gilgaid plains and alluvial plains. These may produce reflectance spectra very similar to the Horseflat system. Also, for this figure we have not assessed the optimum RSI threshold or included information about the NDVI, therefore this is only an indicative map of the effectiveness of the RSI alone.

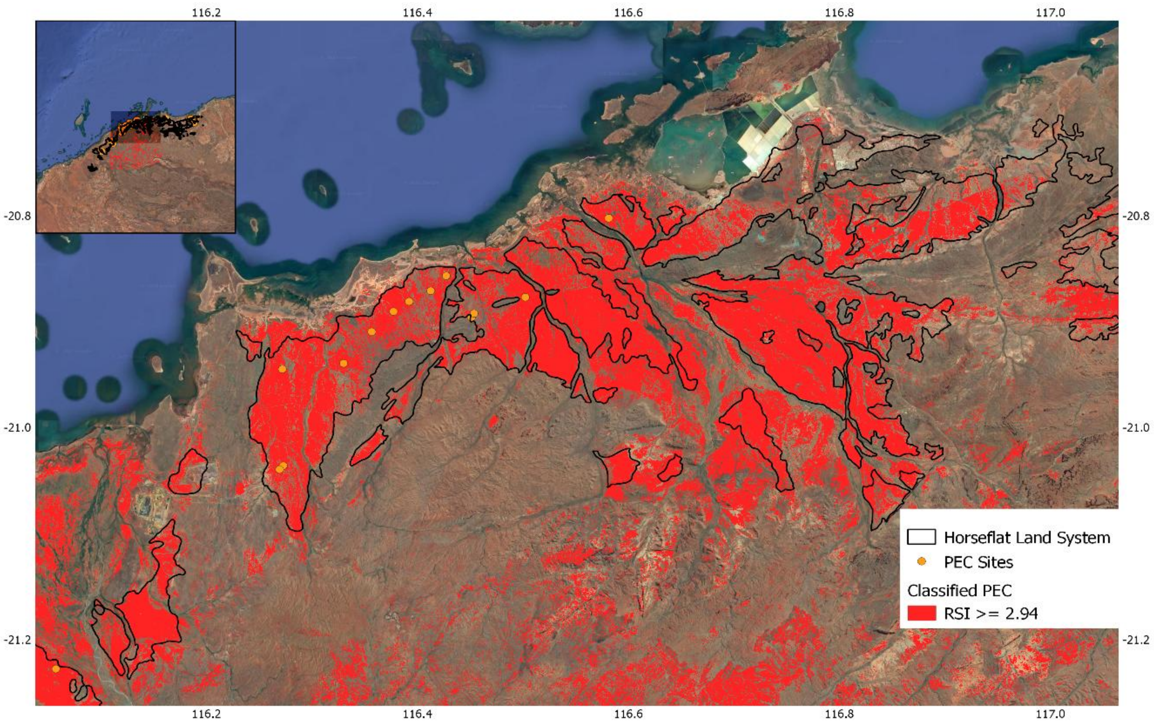

Figure 6. Map generated using median across all the RSI data for pixels with RSI >= 2.94.

4.4 NDVI through time

The Sentinel 2 data were used to calculate individual NDVI data, then used to calculate median NDVI images for each year. The median NDVI was then used as a threshold to determine the number of months in each year that each pixel exceeded the threshold value. A small study region is shown here to demonstrate the information displayed by the NDVI monthly count data. Figure 7 shows the study region, indicated by a white polygon, overlayed on a Google Earth image of the coastal region near Karratha. Figure 8 to Figure 11 shows the NDVI month counts for the years 2018 to 2021. The general trend compared to 2018 is that 2019 displays significantly lower monthly counts of NDVI, meaning there were less months in the year where vegetation cover exceeded the median of all years. The years 2020 and 2021, in general, show higher counts for months exceeding the median of all years.

Figure 7. Google Earth image showing the region (white polygon) selected to demonstrate the NDVI maps for 4 years, shown in Figures 8 to 11.

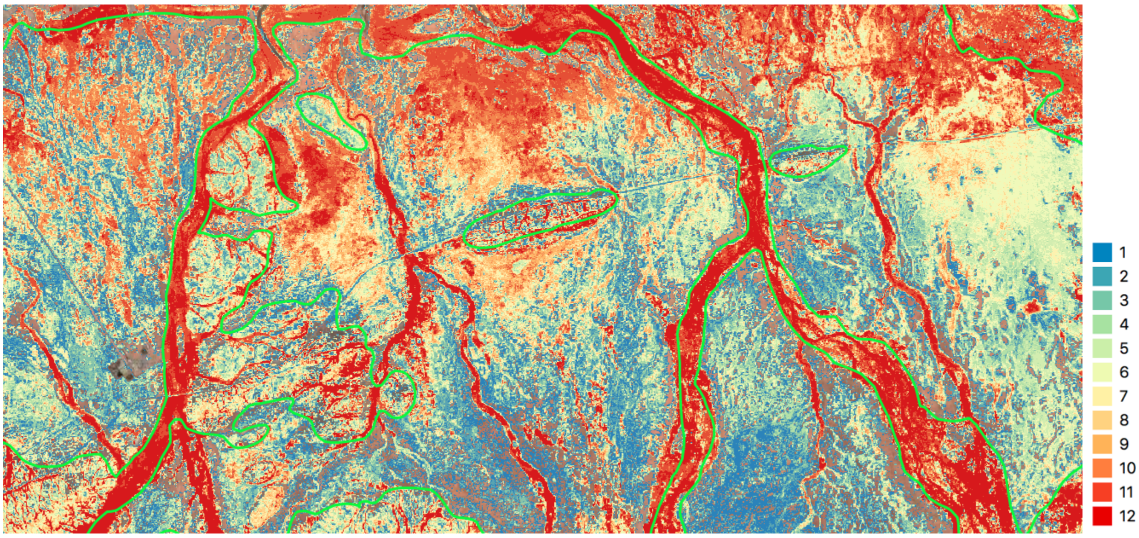

Figure 8. NDVI monthly count 2018 for the region shown in Figure 7.

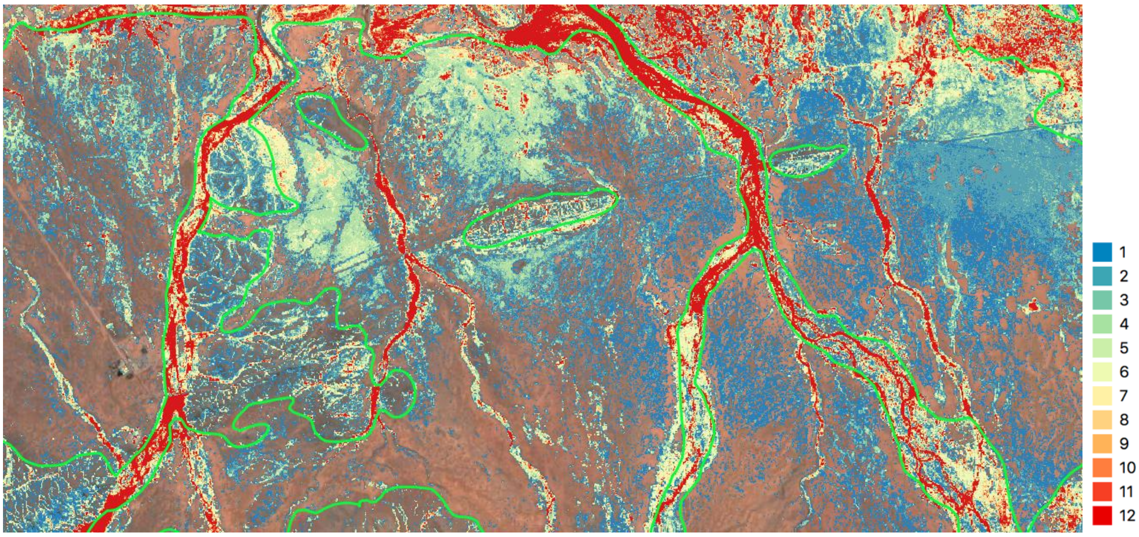

Figure 9. NDVI monthly count 2019 for the region shown in Figure 7.

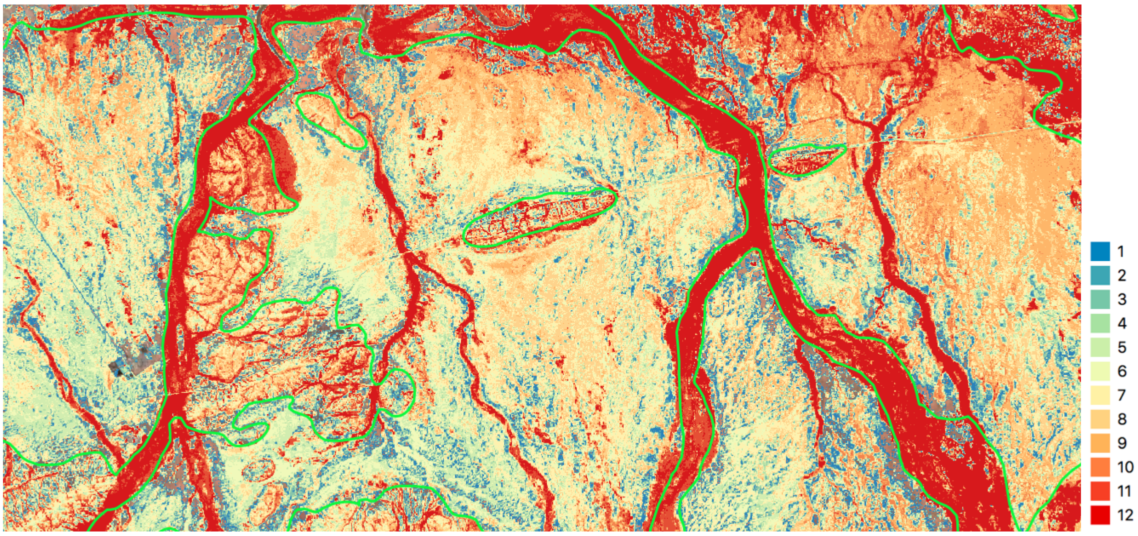

Figure 10. NDVI monthly count 2020 for the region shown in Figure 7.

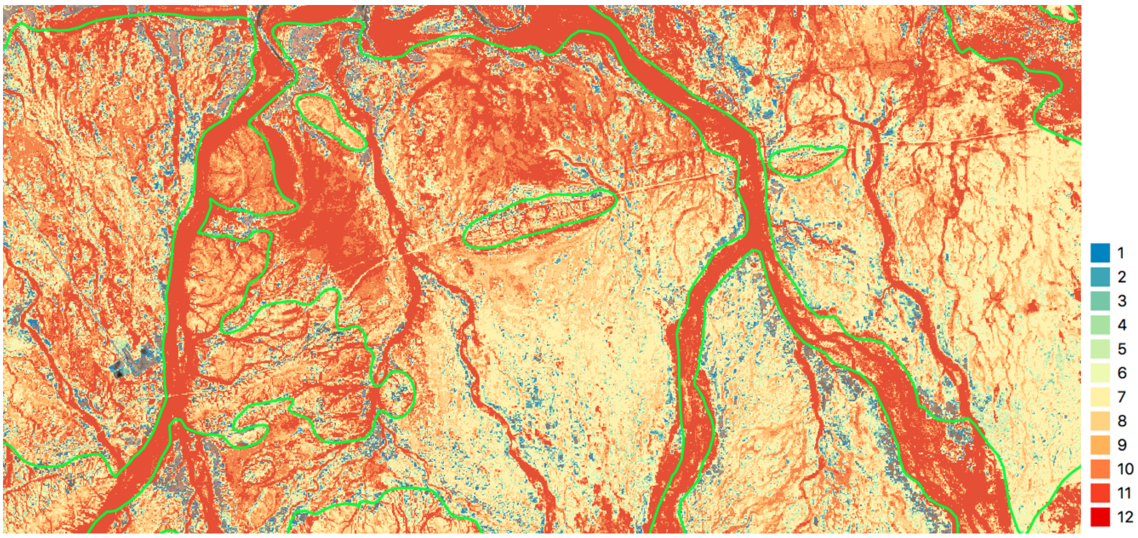

Figure 11. NDVI monthly count 2021 for the region shown in Figure 7.

4.5 RSI and NDVI Based Thresholding using Monthly Composites

From the information presented in Sections 4.2 and 4.4, we observed that the PEC land system can be covered with vegetation as indicated by high NDVI values at PEC sites during some of the months. These high monthly median NDVI values in PEC sites were observed noticeably higher in some years than others. To include the presence of vegetation, indicated by high NDVI values at PEC sites, there was a need to identify the minimum number of times the PEC sites may be covered by vegetation. The PEC validation sites are assumed to have high RSI if not covered by vegetation and low otherwise, thus, the RSI threshold does not have to be exceeded in every month.

We examined a brute force method to identify the number of months where NDVI and RSI values were above or equal to the threshold to produce the lowest classification error. We used 35 PEC sites and 846 not-PEC sites to validate the results of the brute force method. A subset of all the results is shown in Table 4. The first three rows correspond to the results with the highest accuracy, the fourth and fifth rows correspond to 20^{th} and 30^{th} percentiles respectively (see Appendix 4) in the number of months PEC sites were above the PEC threshold and the minimum number of months PEC sites were above the NDVI threshold, respectively.

Table 4. Results of brute force method in identifying number of months NDVI >= NDVI threshold and RSI >= RSI threshold with least error.

Counts (RSI, NDVI)	PEC Accuracy (%)	Not-PEC Accuracy (%)	Not-PEC Identified as PEC (%)	PEC Identified as Not-PEC (%)	Total Accuracy (%)
(1, 1)	*91.43*	*95.12*	*54.29*	*0.40*	*94.96*
(2, 1)	*91.43*	*95.25*	*53.62*	*0.40*	*95.09*
(2, 7)	*91.43*	*95.76*	*50.77*	*0.40*	*95.58*
(6, 7)	80.0	96.41	50.0	0.92	95.70
(10, 7)	*77.14*	*96.66*	*49.06*	*1.05*	*95.82*

From Table 4, we observe that when the RSI and NDVI exceeds one and two months within the total of 48 months (2018 – 2021) these count thresholds produce the highest PEC accuracy of 91.43%. PEC accuracy is the number of PEC sites correctly identified as PEC. We should note that highest PEC accuracy results also have high commission error (Not-PEC sites identified as PEC) between 50.55% – 54.29%.

For this work we have chosen to investigate PEC maps using a threshold of at least 2 months of RSI equal to or above the RSI threshold and at least 1 month of NDVI equal to or above the NDVI threshold.

4.6 Topography and rivers

Figure 12 shows the DEM data (Gallant et al., 2011) used to calculate the gradient of land within the Horseflat land system. Figure 13 shows the regions within the Horseflat land system with gradients less than 3°.

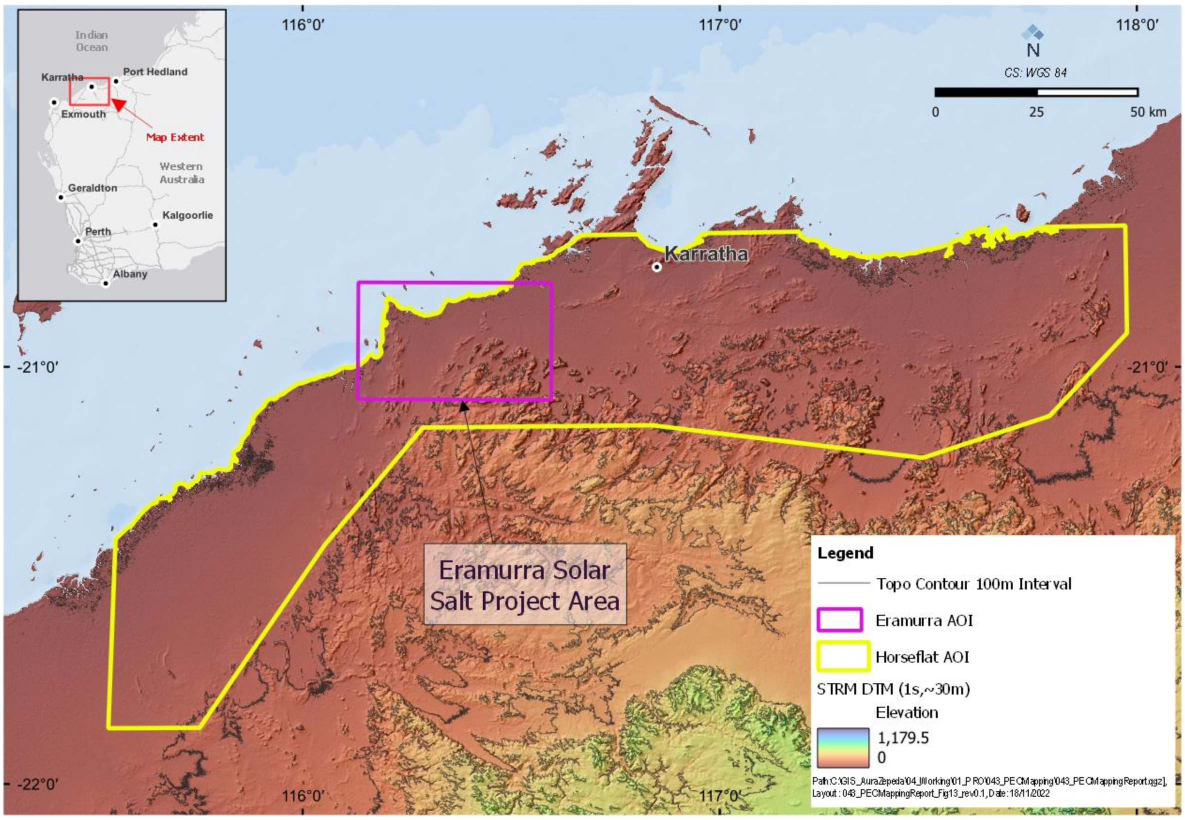

Figure 12. SRTM-derived 1 Second Digital Elevation Model (DEM) Version 1.0 (Gallant et al. 2011).

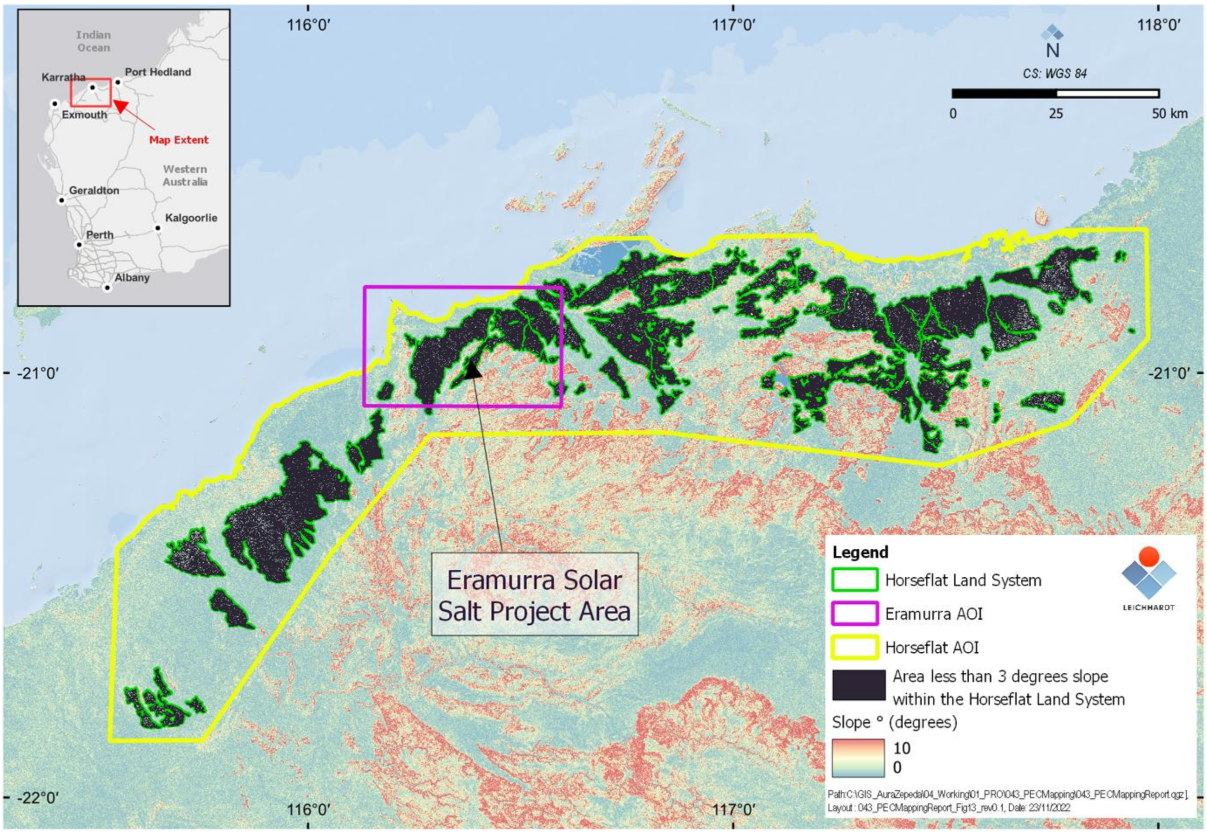

Figure 13. Map highlighting gradients less than 3 ° within the Horseflat land region. Gradients were calculated from DEM data (Gallant et al. 2011).

Figure 14 and Figure 19 show Google Earth images of sections of the study region with water courses (Govt. Western Australia, 2022) overlaid in blue. The yellow lines perpendicular to the water courses indicate the locations of profile plots, shown below. The mapped water courses often align with features visible in the satellite image, however there are cases where visual inspection does not identify any obvious feature to indicate the presence of a water course.

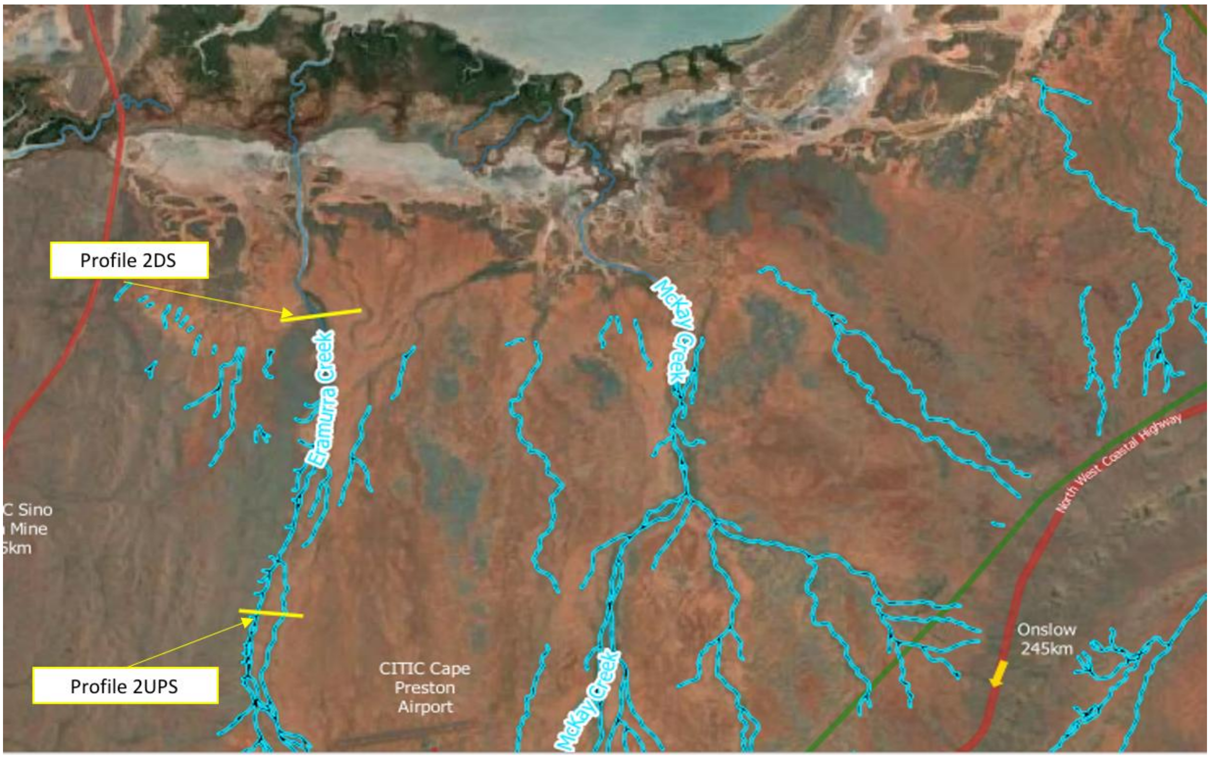

Figure 14. Overview of Eramurra Creek and profile lines.

Figure 15 and Figure 17 show details of the upstream and downstream locations of the profiles on Eramurra Creek, plotted in Figure 16 and Figure 18. The yellow curve represents the land surface profile where the gradient of all sections is less than 1° unless otherwise indicated as between 2° and 3° or between 3° and 4°. Vertical blue lines indicate the locations of the mapped water courses. Vertical black lines indicate distances of 20 m either side of the water course. It is interesting to note that water courses do not occur in all the depressions and the water courses do not necessarily occur at the lowest points of the profile.

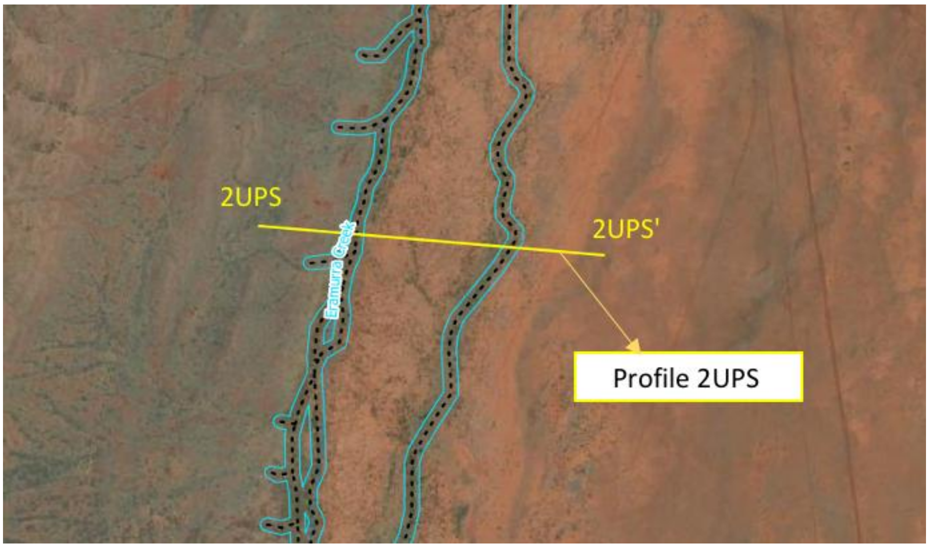

Figure 15. Upstream location along the Eramurra Creek. The profile, indicated by the yellow line, is plotted in Fig. 16.

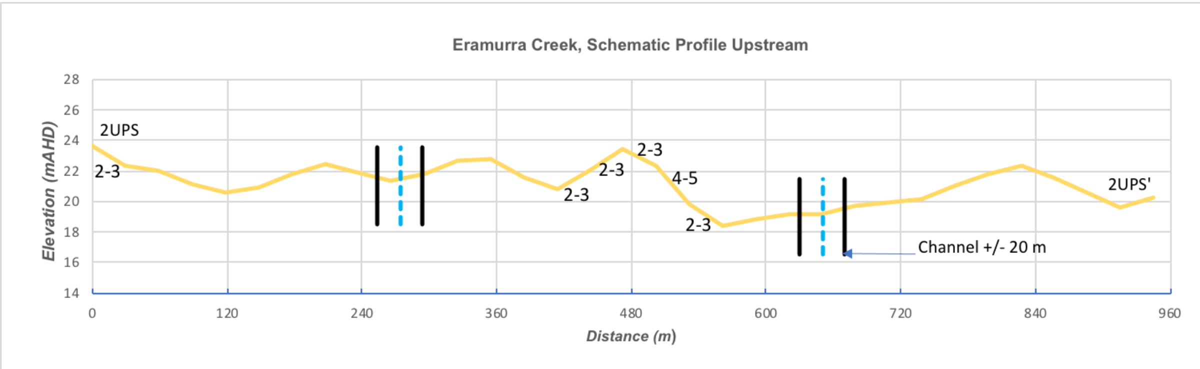

Figure 16. Eramurra Creek Profile from DEM data showing locations of mapped water courses in upstream locations. Vertical lines indicate a width of +/- 20 m from the water course. Gradients of all sections are less than 2° unless indicated as between 2° and 3° (2-3), or between 4° and 5° (4-5).

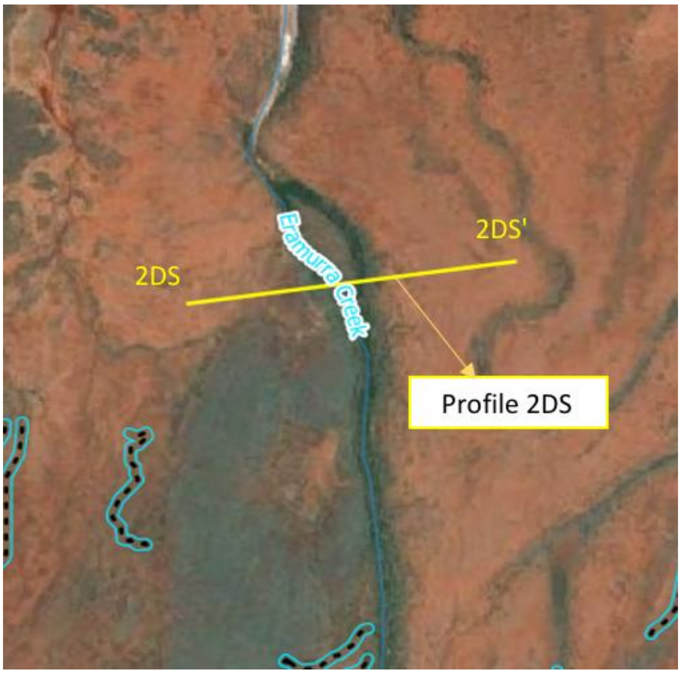

Figure 17. Downstream location along the Eramurra Creek. The profile, indicated by the yellow line, is plotted in Fig. 18.

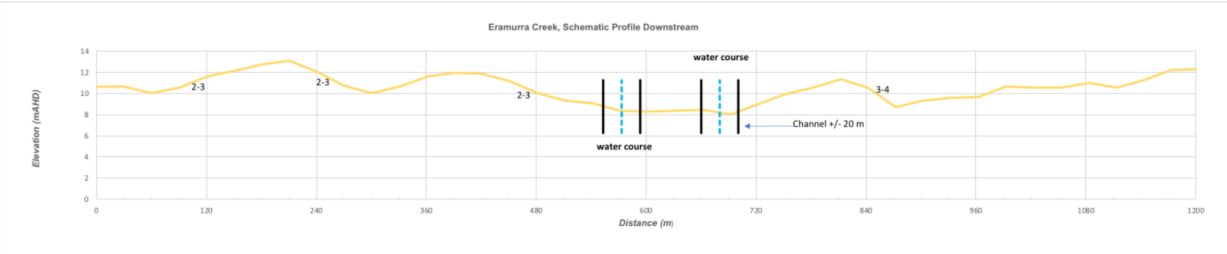

Figure 18. Eramurra Creek Profile from DEM data showing locations of mapped water courses in downstream locations. Vertical lines indicate a width of +/- 20 m from the water course. Gradients of all sections are less than 2° unless indicated as between 2° and 3° (2-3), or between 3° and 4° (3-4).

Figure 20 and Figure 22 show details of the upstream and downstream locations of the profiles on McKay Creek, plotted in Figure 21 and Figure 23.

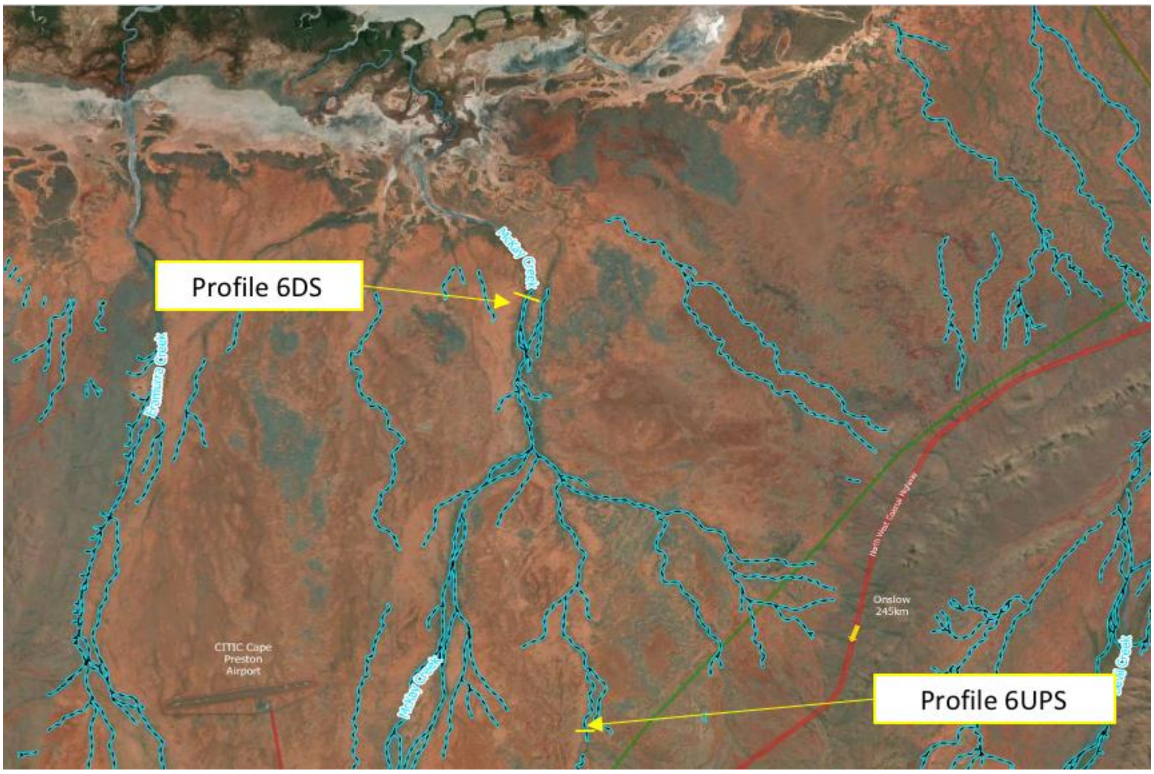

Figure 19. Overview McKay Creek and profile lines.

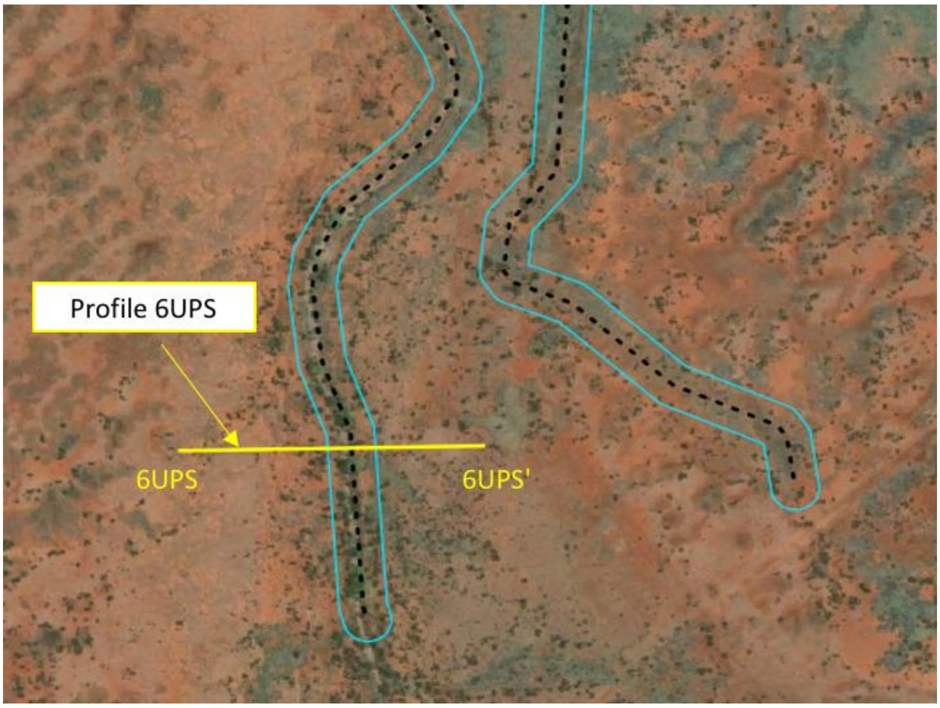

Figure 20. Downstream location along the McKay Creek. The profile, indicated by the yellow line, is plotted in Fig. 21.

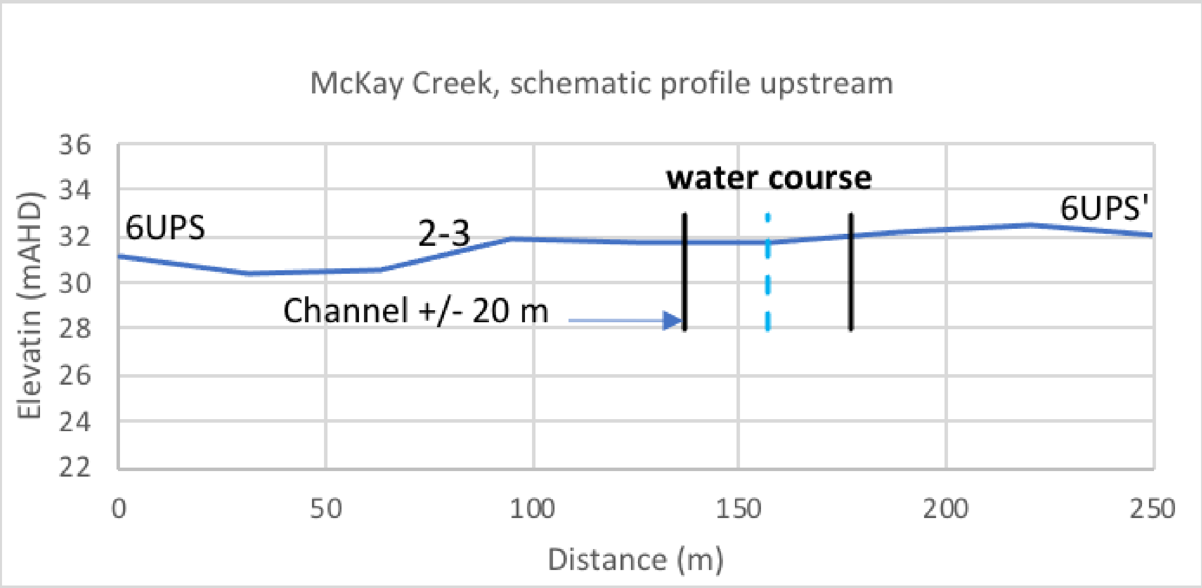

Figure 21. McKay Creek Profile from DEM data showing locations of mapped water courses in upstream locations. Vertical lines indicate a width of +/- 20 m from the water course. Gradients of all sections are less than 2° unless indicated as between 2° and 3°.

Figure 22. Downstream location along the McKay Creek. The profile, indicated by the yellow line, is plotted in Fig. 23.

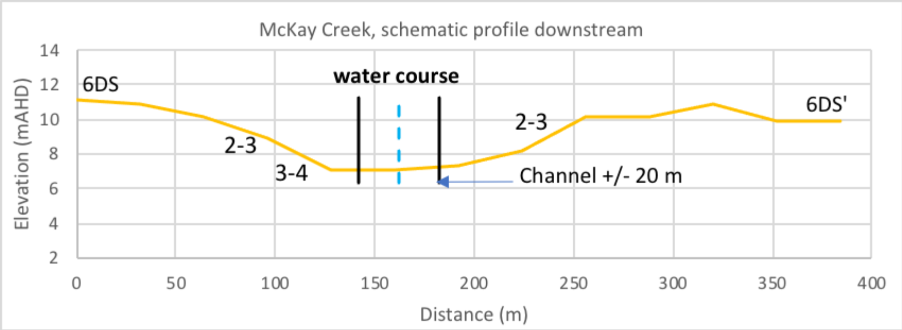

Figure 23. McKay Creek Profile from DEM data showing locations of mapped water courses in downstream locations. Vertical lines indicate a width of +/- 20 m from the water course. Gradients of all sections are less than 2° unless indicated as between 2° and 3° (2-3) or between 3° and 4° (3-4).

4.7 PEC Map

We have chosen 4 parameters to apply to classify Sentinel pixels as either PEC or not-PEC: Number of months RSI is greater than 2.94, number of months NDVI is greater than 0.16, ground surface gradient, and distance from water courses. The choice for number of months, based on data presented in Table 5, is not definitive, but we have chosen the RSI monthly count threshold as 2 and the NDVI monthly count threshold as 1. Also, the gradient limit to distinguish PEC from not-PEC is not defined, and the distance from water courses is not defined. Table 5 shows the percent PEC within the Horseflat land system for a number of scenarios. The intention here is to demonstrate the impact of changing classification thresholds on the percent cover of PEC mapped. Option A represents the row from Table 4 where RSI must be greater than or equal to the threshold for at least 2 months across the 4 years, and the NDVI must be greater than or equal to the threshold for at least 1 month across the 4 years. Option A then includes results for slope limits of 2°, 3° and 4°, and distance from water courses of 0 m, 20 m and 60 m. Option B presents the same types of results but for the fourth row in Table 4 where RSI must be greater than or equal to the threshold for at least 6 months across the 4 years, and the NDVI must be greater than or equal to the threshold for at least 7 months across the 4 years. Options A and B represent “good” and “poor” validation results.

Table 5. Percentage PEC cover within the Horseflat land system for different values of RSI monthly count, NDVI monthly count, slope, and distance from water courses.

Option	Sub-Option	RSI >=	NDVI>=	Slope <=	Distance from River/Stream (m)	Total Area PEC (km^2)	% of PEC within HorseFlat (AOI)
A	A1	2	1	2	20	1513	50
	A2	2	1	2	60	1353	45
	A3	2	1	3	20	1950	65
	A4	2	1	3	60	1746	58
	A5	2	1	2	0	1592	53
	A6	2	1	3	0	2050	68
	A7	2	1	4	0	2186	72
B	B1	6	7	2	20	1296	43
	B2	6	7	2	60	1161	38
	B3	6	7	3	20	1668	55
	B4	6	7	3	60	1496	49
	B5	6	7	2	0	1364	45
	B6	6	7	3	0	1754	58
	B7	6	7	4	0	1868	62

The mean percentage of PEC within the Horseflat land region for option A is 59% (min=45%, max = 72%). For option B the mean percentage of PEC is lower, at 50% (min = 38%, max=62%). This shows that the impact of choosing poor RSI and NDVI monthly thresholds will tend to underestimate the percent cover, on average, by approximately 10% in this case. The ranges of percent cover, 45% to 72% and 38% to 62% are much larger than the 10% impact caused by RSI and NDVI monthly thresholds. These larger ranges are a combination of choices of ground slope thresholds and distance from water courses combined.

Figure 24 shows the resultant percent cover of PEC in the Horseflat land region for different land slope thresholds. The blue curve represents option A results. If a maximum slope of 2° is imposed, the resultant PEC area is 53%. As we allow PEC with higher slopes the PEC cover increases through 68% at 3° to 72% at a 4° slope limit. The red curve, representing option B, shows the same trend. Note option B PEC area is less than option A. For this work we have chosen a slope limit of 3° when mapping PEC and suggest that changing the slope limit by +/- 1° may equate to a variation in mapped % PEC cover of roughly +/- 10%, but potentially a larger impact at 1° compared to 4°.

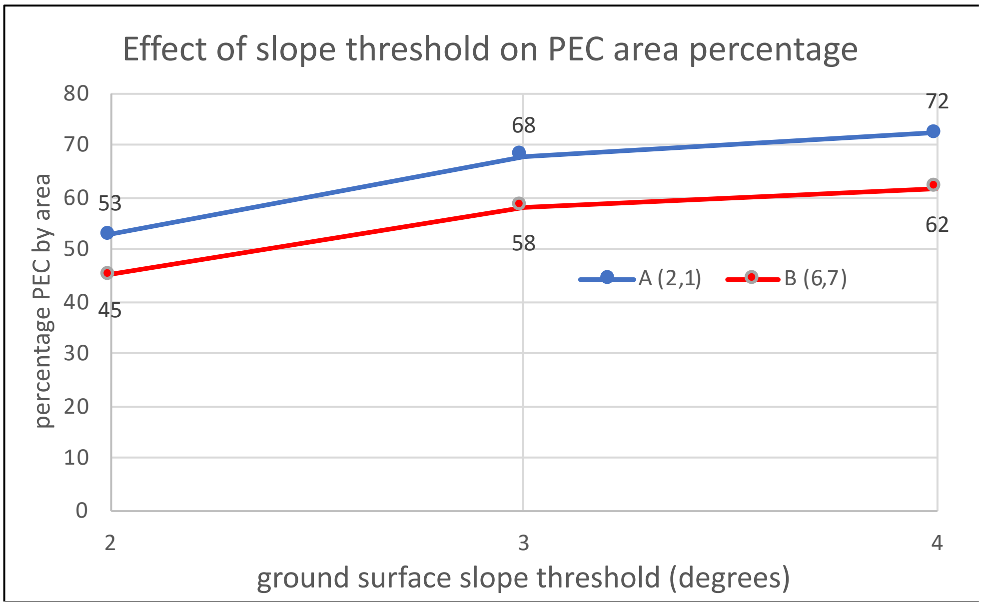

Figure 24. Effect of slope threshold on PEC classification and subsequent calculation of PEC percent cover in the Horseflat land region.

Figure 25 shows the effect of imposing a distance offset for PEC from water courses. Figures 16 to 23, admittedly a very small sample size, showed the width of water courses vary considerably. It is unlikely a single threshold distance is appropriate, but in this case a fixed distance limit is considered reasonable if applied consistently and with an understanding of the impact. The blue curve represents results for Option A. If there is no offset accounted for then the percent area of PEC is 53%. By imposing an offset of 20 m, the estimated PEC area is decreased to 50%. At an offset of 60 m the PEC area is decreased to 45%. For each change in distance offset of 10 m the estimated PEC area changes by only a few percent. For this work we have chosen 20 m as the PEC offset for water courses.

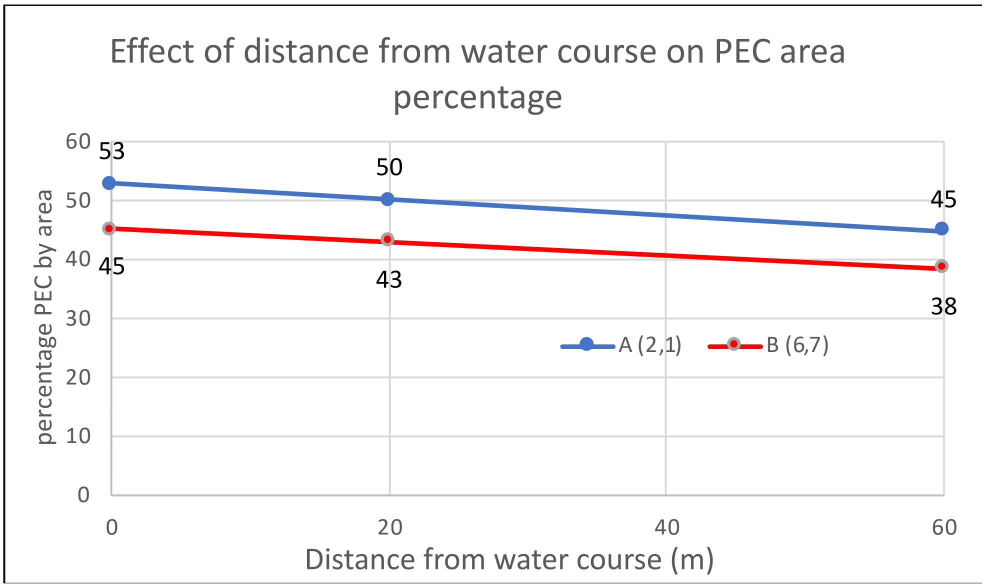

Figure 25. Effect of distance from water course on the mapped % PEC

Based on the selection of classification thresholds, we can now produce a map of PEC for the Horseflat region. Figure 26 shows a PEC map with thresholds RSI >= 2.94 for at least 2 months across the 4 years, NDVI >= 0.16 for at least 1 month across the 4 years, ground slopes have to be less than or equal to 2°, and PEC can’t occur closer than 20 m to water courses.

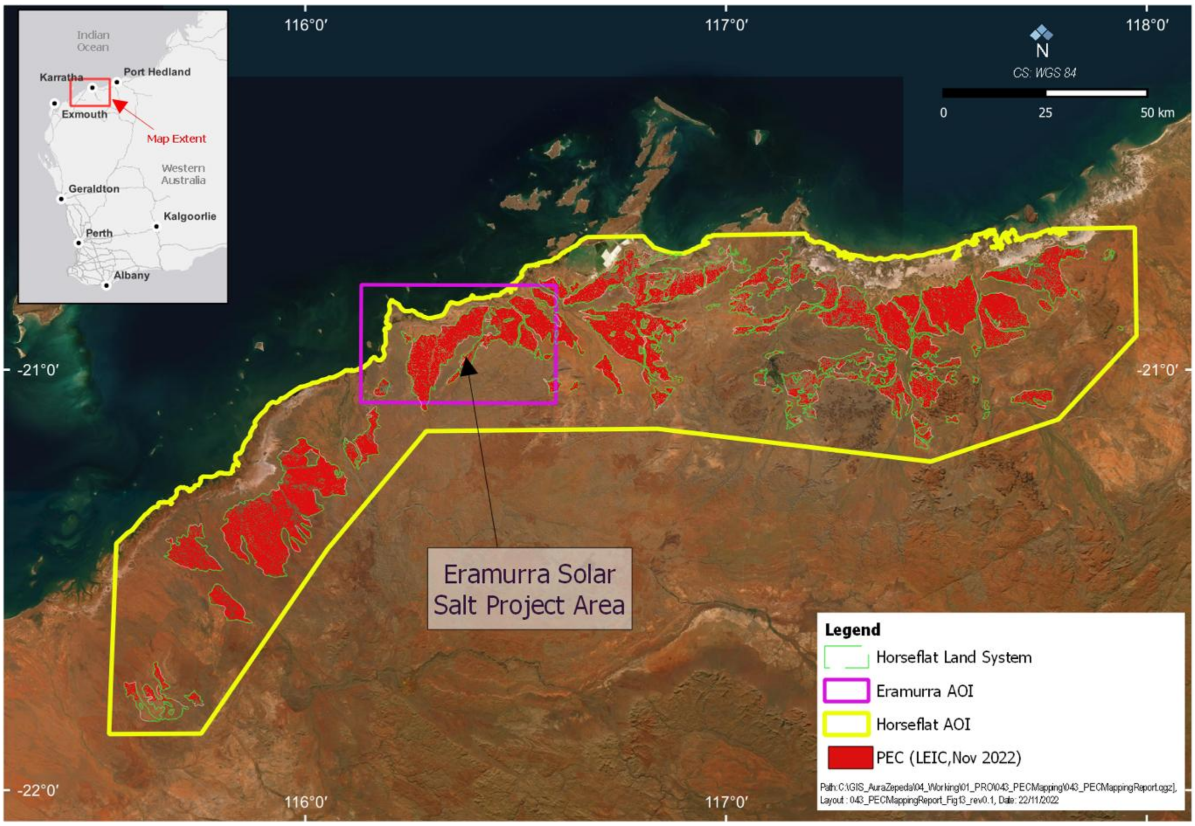

Figure 26. Map of PEC in the Horseflat land system based on RSI, NDVI, land gradient and offset from water courses.

The spatial resolution of Figure 26 suggests some regions are 100% classified as PEC. The following figures show “zoomed in” areas to give a better impression of spatial density of the classification. Figure 27 shows a region of the Horseflat land system in the vicinity of Karratha with Sentinel-derived PEC areas highlighted in black. Figure 28 shows a closer view of the inset indicated in Figure 27. As the extent is zoomed, the patchiness of the classification is more evident.

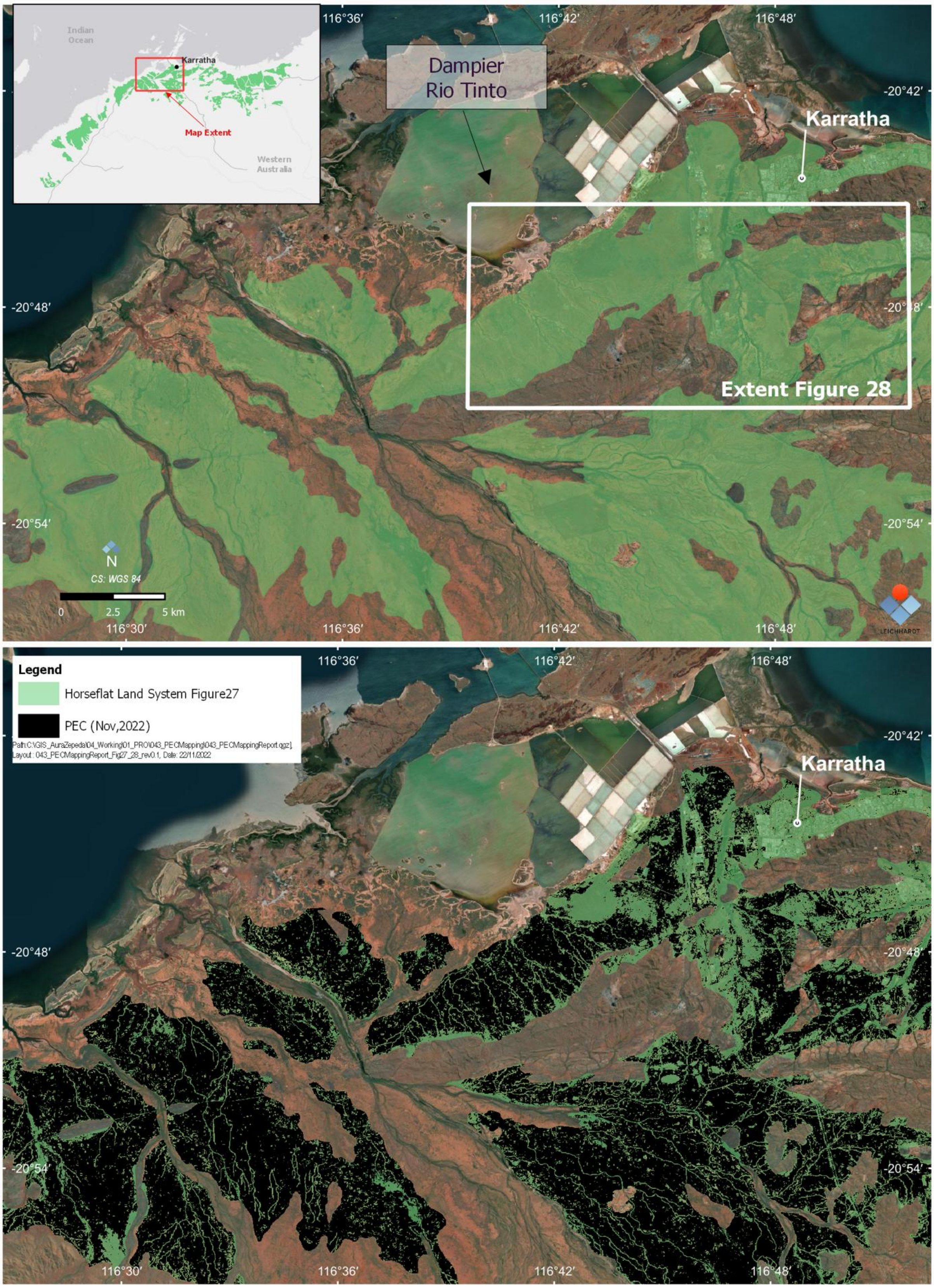

Figure 27. Part of the Horseflat land system in the vicinity of Karratha (top). Areas classified as PEC overlayed on the Horseflat land system (bottom).

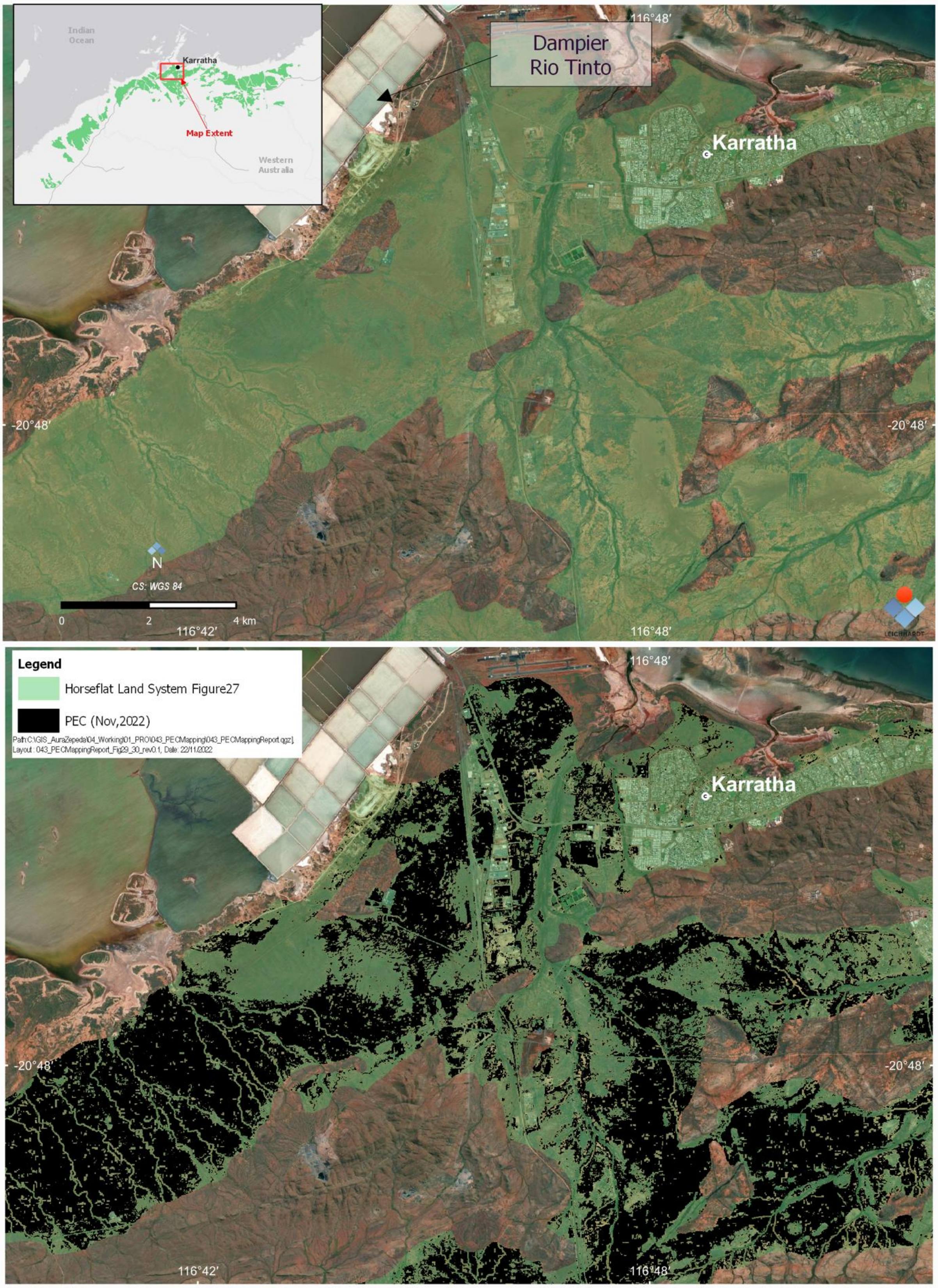

Figure 28. Slightly "zoomed" region indicated in Figure 27 showing the Horseflat land system in the vicinity of Karratha (top). PEC area within the Horseflat land system (bottom).

4.8 PEC quality through time

There is interest in assessing change in PEC "quality" through time. In the remote sensing case we can infer vegetative cover or "productivity" by analysing spatial temporal patterns in NDVI. Mapped data showing monthly counts of NDVI exceeding the threshold of 0.16 (see examples from Figure 8 to Figure 11) was used to calculate the area of vegetation cover in the PEC area already defined and shown in Figure 26.

Table 6 shows the total area of the Horseflat PEC that is considered productive based on exceeding the NDVI threshold for at least 1, 3, 5 and 7 months across the four years from 2018 to 2021.

Table 6. Total area of vegetation within the Horseflat PEC area based on NDVI monthly thresholds 1, 3, 5 and 7 for years 2018 to 2021.

Year	NDVI>=	Area NDVI (km²)	% Area within PEC
2018	1	1757	90
2019		1207	62
2020		1588	81
2021		1934	99
2018	3	1403	72
2019		930	48
2020		1359	70
2021		1857	95
2018	5	1068	55
2019		664	34
2020		1185	61
2021		1738	89
2018	7	725	37
2019		410	21
2020		895	46
2021		1485	76

Figure 29 shows the data in Table 6 plotted as curves. Each curve is for a different monthly count threshold. The blue curve, showing the largest vegetated area for each year, is based on pixels only requiring a high NDVI value once in the 4 years. The yellow curve, showing the smallest areas for each year, is based on pixels requiring a high NDVI value for at least 7 months across the 4 years. As stated earlier, we expect PEC to display a high vegetation index cover for intermittent short periods where rainfall has enabled significant growth of vegetation. In fact, instances may occur where vegetation is only present for one month across the 48 months studied here. Nonetheless, this very low productivity may be still classified as PEC and would be included in the data for the blue curve.

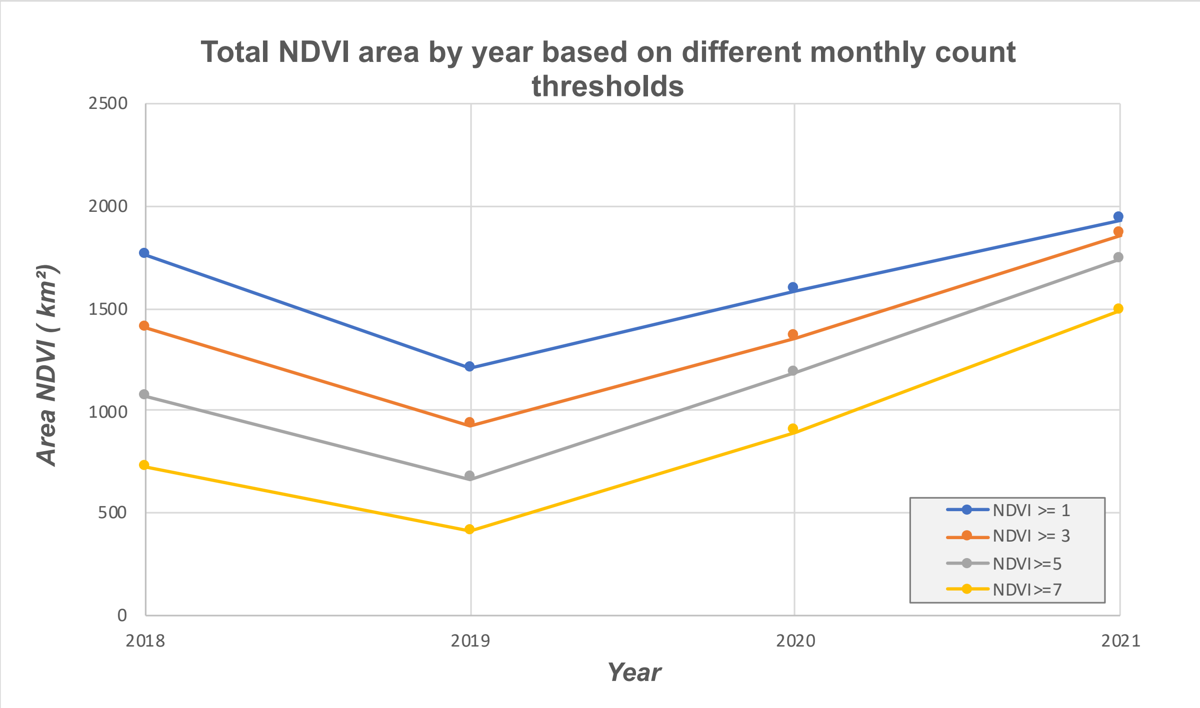

Figure 29. Annual vegetation cover for the Horseflat PEC for 2018 to 2021. Each curve represents estimated areas based on different monthly NDVI count thresholds, 1, 3, 5 and 7 months (Data from Table 6).

Figure 29 also shows that, independent of the monthly count threshold chosen, 2019 tended to be a lower vegetation cover year, 2018 and 2020 were similar, and 2021 was higher in vegetation cover.

We may further describe the quality of the PEC by combining the total area of PEC and the number of months of vegetation cover, based on exceeding the NDVI threshold. We term this combined monthly count and area the “productivity”. One may also consider this an estimate of relative biomass. More area covered in vegetation and vegetated for more months may equate to a larger biomass available for grazing, for example (time x area). The units for this metric are km^2 month. Table 7 shows the total productivity of the Horseflat PEC for the years 2018 to 2021. These same data are also displayed in Figure 30.

Table 7. Productivity of Horseflat PEC for years 2018 to 2021.

Year	Total km^2 months
2018	10473
2019	6522
2020	10875
2021	16459

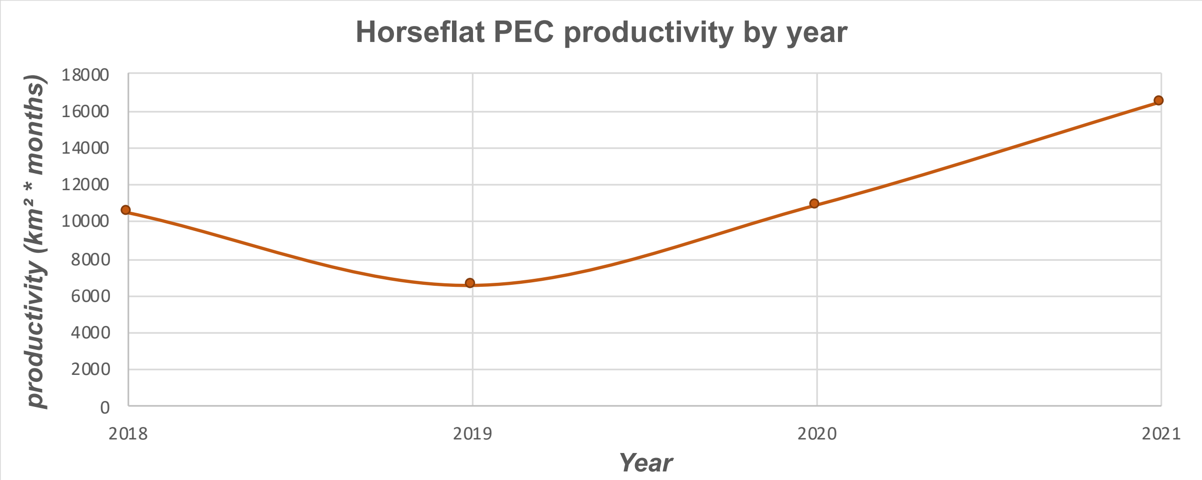

Figure 30. Productivity of Horseflat PEC for years 2018 to 2021.

5. Discussion

We only had 35 PEC validation points. Initially we used the set of 89 PEC/non-PEC points from the PEC_HorseFlatLandSystemPECandNonPECSites_JL_20210824.shp file. We achieved very high PEC classification accuracy (77%-92%) and very high not-PEC accuracy (95%-96%,) depending on the number of months above classification threshold criteria, however classification of non-PEC as PEC was poor with approximately 50% confusion. It is interesting to consider the accuracy of the validation with respect to confidence in classifying ecosystem type based on whatever methods were used. Appendix 5 lists a subset of the columns from the PEC_HorseFlatLandSystemPECandNonPECSites_JL_20210824.shp file. For this work we relied on the PEC vs non-PEC as listed in the column headed "RF_photo_c". However, there are three columns "manual_che", "RF_photo_c" and "auto_check" that indicate the PEC classification and the result across all three columns are not consistent. Also, some classes are described with some uncertainty by "unlikely" and "possible PEC". In fact, there is also a column headed "tecpec_nam" that labels some points as "Horseflats PEC" but is not always consistent with the other PEC classification columns.

The columns describing soil colour, soil texture, habitat and site description also display quite variable description across both PEC and non-PEC sites.

The development of the Sentinel-based PEC mapping methodology was focussed on the Horseflat land system. It is clear, particularly from visual inspection of satellite images of the NW of WA that the appearance of the land changes dramatically along the full extent of the Regional ROI. The RSI and NDVI thresholds tuned for the Horseflat region are not necessarily optimum for other regions. We observed a very high density of PEC classified pixels in some distant regions of the Regional ROI (results not shown). The methodology for mapping PEC type ecosystems is sound, however thresholds would need to be tuned for other regions.

Although the choice of classification thresholds has an impact on the resultant classification map extent, we believe the data are reliable for monitoring relative change through time as long as thresholds remain unchanged. Uncertainties in absolute areas have been described with respect to threshold choices.

We have demonstrated the effectiveness of Sentinel 2A/B data in classifying PEC-like pixels within the Horseflat land system. The coverage is well aligned with the historical mapping of the Horseflat system, and there is detail within the extent of the Horseflat system that appears to be aligned with some features such as drainage channels or rocky terrain.

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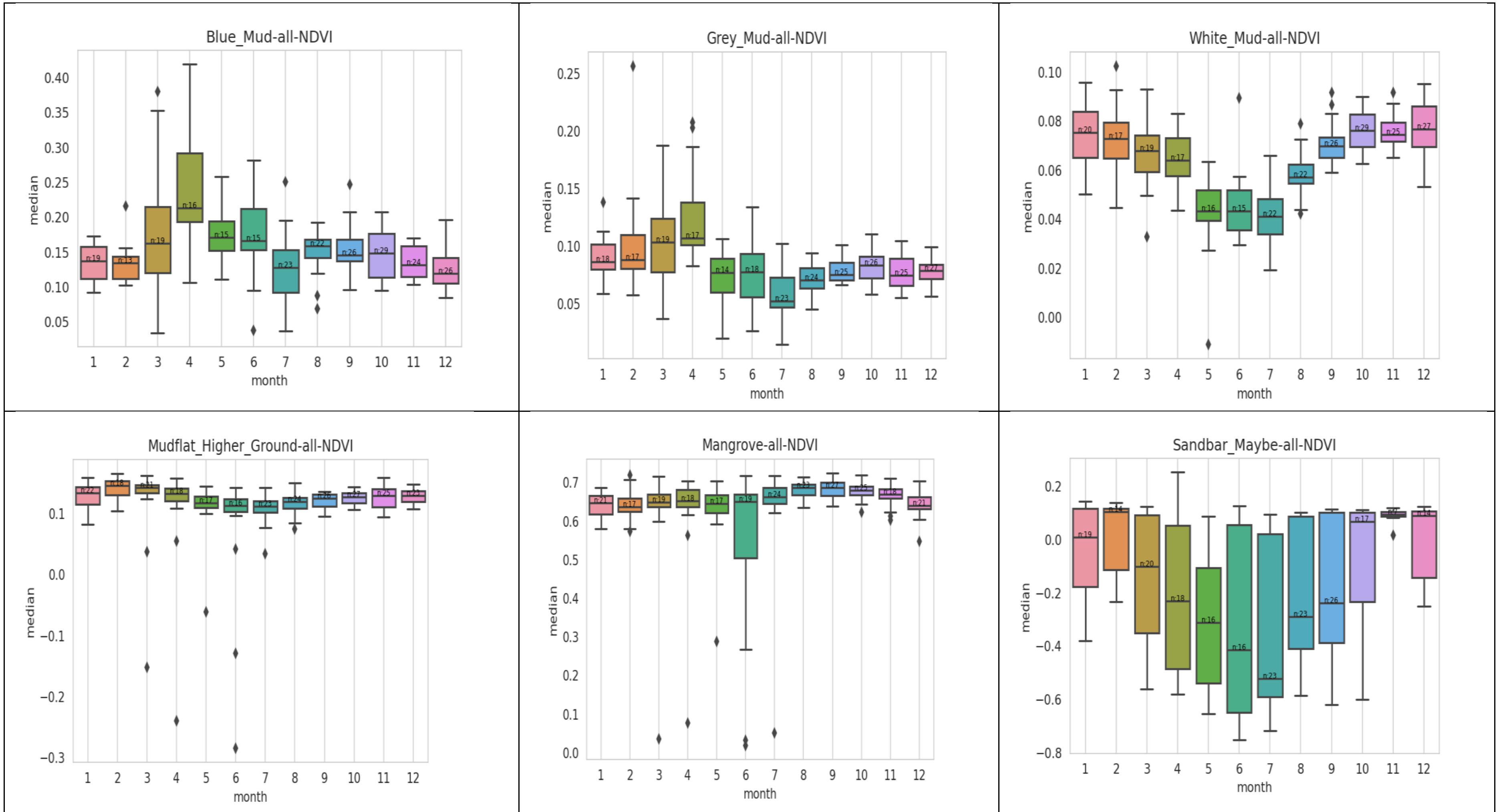
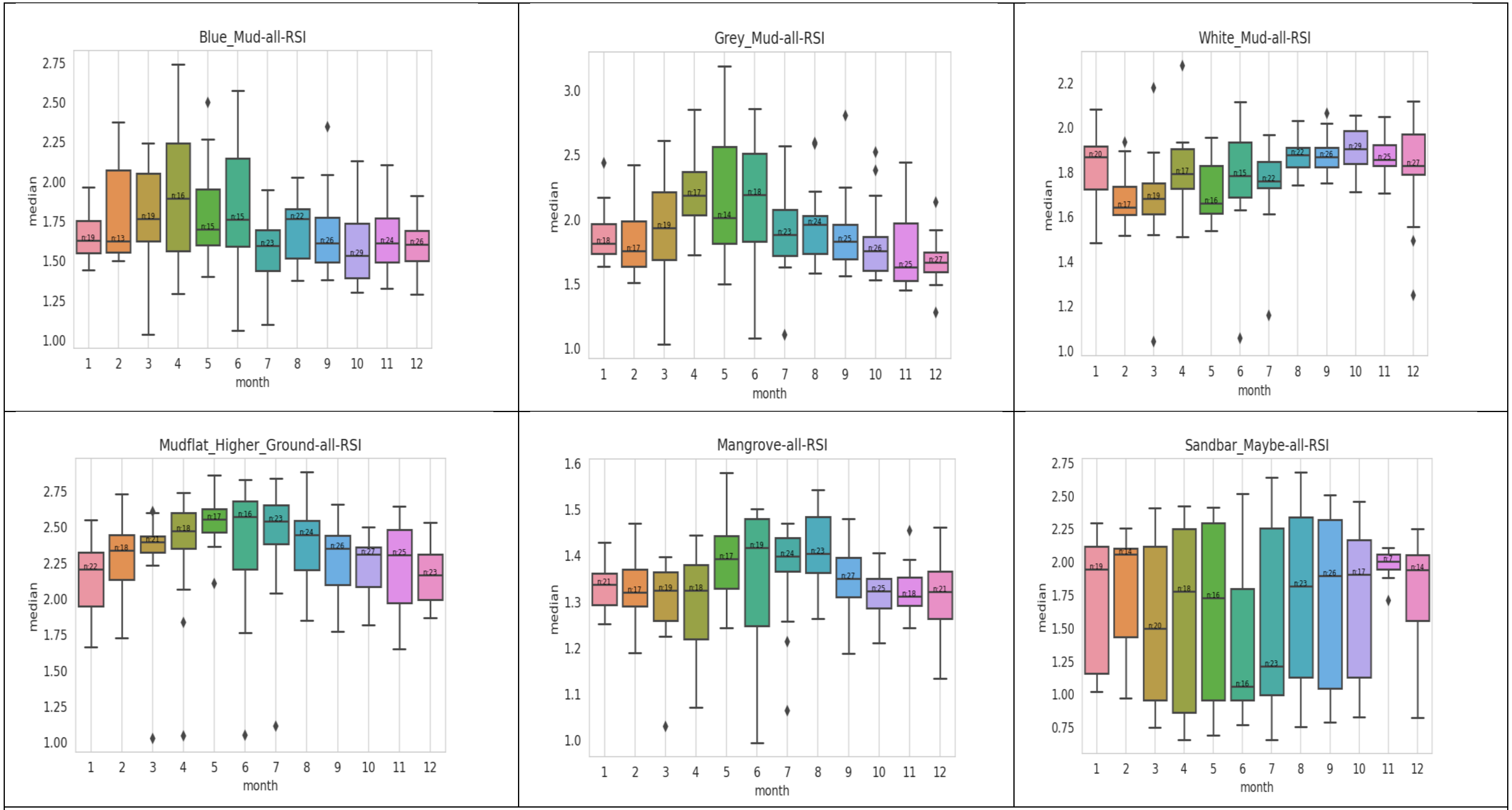
Appendix 1:



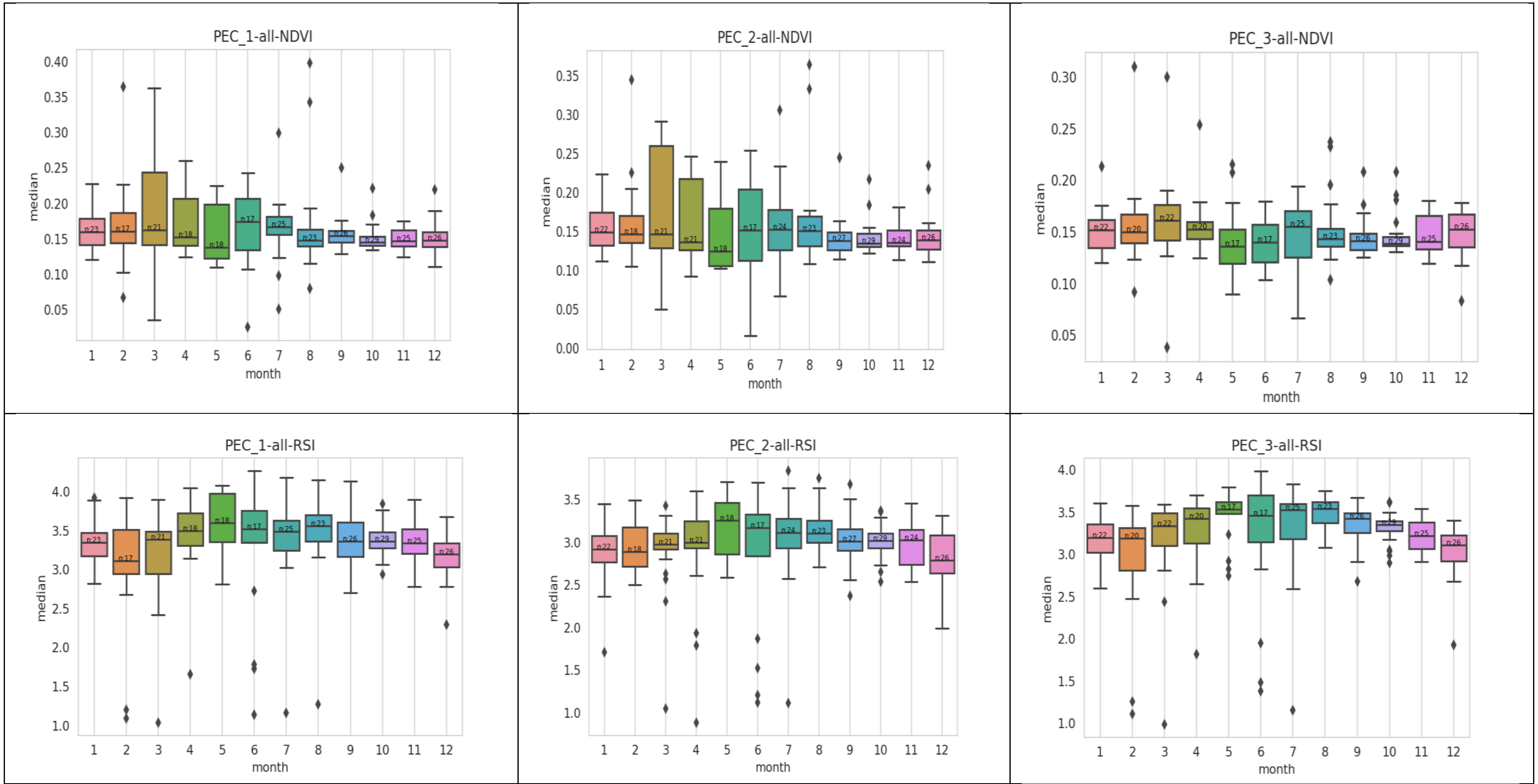
Box plots of the monthly median NDVI. Blue Mud (top left), Grey Mud (top middle), White Mud (top right), Mudflat Higher Ground (bottom left), Mangrove (bottom middle), and Possible Sandbar (bottom right)

Appendix 2:



Box plots of the monthly median RSI. Blue Mud (top left), Grey Mud (top middle), White Mud (top right), Mudflat Higher Ground (bottom left), Mangrove (bottom middle), and Possible Sandbar (bottom right)

Appendix 3:



Box plots of the monthly median NDVI (top row) and RSI (bottom row) for PEC. PEC-1(left), PEC-2 (middle), PEC-3 (right)

Appendix 4: The PEC site's statistics showing the number of times NDVI, and RSI was >= respective threshold across 48 months.

Statistics	**NDVI Counts**	**RSI Counts**
Mean	23.8	24.8
Median	25	26.0
Max	48	48.0
Min	7.0	0.0
One Standard Deviation	9.1	17.3
Percentile 2.5	7.8	0.0
Percentile 5.0	8	0.0
Percentile 7.5	9.6	1.1
Percentile 10.0	12.6	2.8
Percentile 20.0	17.8	5.8
Percentile 30.0	18	10.4
Percentile 40.0	20.0	15
Percentile 50.0	25.0	26
Percentile 60.0	26.0	35.8
Percentile 90.0	34.0	47
Percentile 95.0	35.6	47.3
Percentile 97.5	38.65	48

Appendix 5: Subset of selected columns from the file PEC_HorseFlatLandSystemPECandNonPECSites_JL_20210824.shp

soil_textu	soil_colou	tecpec_nam	manual_che	RF_photo_c	auto_check	site_descr	habitat
ALUV	BLK	Horseflats PEC	PEC	PEC	possible pec	Isolated plants of Rhynchosia minima and Streptoglassa bubakii, over a low tussock grassland of Eragrostis xerophila.	Grass plain
clay loam	red-brown	Horseflats PEC	Not PEC	Not PEC		Mid open shrubland of Acacia sclerosperma subsp. sclerosperma and Carissa lanceolata, over low isolated shrubs of Ptilotus obovatus and Cleome viscosa over low sparse tussock grassland of	shrubland
clay loam	red-brown	Horseflats PEC	PEC	PEC	possible pec	Isolated low shrubs of Acacia bivenosa over isolated plants of Rhynchosia minima and Streptoglassa bubakii over a low open tussock grassland of Eragrostis xerophila.	grassland
sand	red-brown		Possible PEC	Not PEC		Woodland of Eucalyptus victrix over mid open shrubland of Acacia sclerosperma subsp. sclerosperma, Acacia coriacea subsp. pendens, over open hummock grassland of Triodia epactia.	riparian zone
clay loam	red-brown	Horseflats PEC	PEC	PEC	possible pec	Isolated plants of Rhynchosia minima and Streptoglassa bubakii over a low tussock grassland of Eragrostis xerophila.	grassland
loam	brown		Not PEC	Not PEC		Mid open woodland of Corymbia hamersleyana and Eucalyptus victrix and over tall shrubland of Acacia trachycarpa over mid isolated shrubs of Carissa lanceolata and Cajanus cinereus	shrubland
clay loam	red-brown	Horseflats PEC	PEC	PEC	possible pec	Isolated plants of Rhynchosia minima and Streptoglassa bubakii over a low tussock grassland of Eragrostis xerophila.	grassland
clay loam	red-brown	Horseflats PEC	PEC	PEC	possible pec	Isolated plants of Cleome viscosa, Rhynchosia minima and Streptoglossa bubakii over a low tussock grassland of Eragrostis xerophila and Dicanthium sericium subsp. humilius.	grassland
sandy loam	red-brown		Not PEC	Not PEC		Mid open woodland of Eucalyptus victrix and Corymbia hamersleyana, over mid open shrubland of Acacia coriacea subsp. pendens, Acacia pyrifolia and Acacia sclerosperma subsp. scle	riparian zone

clay loam	red-brown		Possible PEC	Not PEC	possible pec	Isolated shrubs Acacia synchronicia and Acacia pyrifolia over a hummock grassland of Triodia epactia.	spinifex grassland
loam	red-brown		Possible PEC	Not PEC	possible pec	Mid open shrubland of Acacia inaequilatera over isolated shrubs of Carissa lanceolata, Corchorus walcottii and Solanum lasiophyllum over an open hummock grassland of Triodia epactia.	shrubland
loam	red-brown	Horseflats PEC	PEC	PEC	possible pec	Isolated plants of Dichanthium sericeum subsp. humilius, Rhynchosia minima and Neptunia dimorphantha over a low tussock grassland of Eragrostis xerophila.	spinifex grassland
loam	red-brown		Possible PEC	Not PEC	possible pec	Mid open shrubland of Acacia sclerosperma subsp. sclerosperma and Acacia inaequilatera over isolated shrubs of Carissa lanceolata, Corchorus walcottii and Solanum lasiophyllum	shrubland
clay loam	red-brown		Possible PEC	Not PEC	possible pec	Mid isolated shrubs of Acacia synchronicia over a hummock grassland of Triodia epactia.	spinifex grassland
clay loam, stones	red-brown	Horseflats PEC	PEC	PEC	possible pec	Horseflat land system of the Roebourne Plains PEC (P3iii) Low isolated Acacia xiphophylla shrubs over owEragrostis xiphophylla, Aristida latifolia,	grassland
clay loam (minor cracking clay evident)	red-brown		Unlikely	Not PEC		Not PEC. Open Acacia xiphophylla shrubland over Eragrostis xerophila, Dichanthium sericeum, *Cenchrus ciliaris and Rhynchosia minima	shrubland
clay loam	red-brown		Possible PEC	Not PEC	possible pec	Not PEC. Low closed Triodia epactia and Sorghum plumosum grassland.	grassland
clay loam	red-brown		?	Not PEC		Not PEC. Open Acacia xiphophylla shrubland over Eragrostis xerophila, Dichanthium sericeum, and *Cenchrus ciliaris grassland over	shrubland

clay loam, stones	red-brown		Possible PEC	Not PEC	possible pec	Not PEC. Open Acacia xiphophylla shrubland low open Enneapogon caerulescens , Eragrostis xerophila, Dichanthium sericeum and Trio	shrubland
clay loam	red-brown		Possible PEC	Not PEC	possible pec	Not PEC. Isolated low Acacia sp. and *Prosopis pallida. (WoNS) shrubs over low open Eragrostis xerophila, Dichanthium sericeum, <	grassland
clay loam (cracking clays evident)	red-brown	Horseflats PEC	PEC	PEC	possible pec	Horseflat land system of the Roebourne Plains PEC (P3iii). Low open Eragrostis xerophila and Dichanthium sericeum grassland over isolated low Ptilotus sp. an	grassland
loam, clay loam, stones	red-brown		Possible PEC	Not PEC	possible pec	Not PEC. Reduced dominance of Eragrostis xerophila .Triodia spp. present. Increasing presence of herbs such as Ptilotus spp. Acacia sclerosperm	shrubland
sandy clay	red-brown		?	Not PEC		River and drainage line of open woodland of Eucalyptus victric, over tall shrubland of Melaleuca dusty tip, Melaleuca callistemon, over patchy grassland of Cenchrus setiger and Cenchrus echinatus.	riparian zone
sand	brown, whitish		Unlikely	Not PEC	possible pec		riparian zone
			?	Not PEC			
loam	red-brown		Possible PEC	Not PEC	possible pec	Mid to tall open shrubland of Acacia bivenosa, over hummock grassland of Triodia wiseana with mixed herbs.	shrubland
sandy clay	red-brown		Possible PEC	Not PEC	possible pec		shrubland
gravel / alluvial, clay	red-brown		Possible PEC	Not PEC	possible pec		grassland
clay loam	red-brown	Horseflats PEC	PEC	PEC	possible pec	Tussock grassland of Sorghum timorens, Eragrostis spike, and Dactylon radulans, with mixed herbs.	grassland
clay loam	red-brown		Possible PEC	Not PEC	possible pec	Low open shrubland of Acacia xiphophylla, over tussock grassland of Eragrostis spike, Sorghum timorense, and Dicanthium sericeum.	shrubland

clay loam	red-brown	Horseflats PEC	Not PEC	PEC		Tussock grassland of Eragrostis spike with mixed herbs.	grassland
clay loam	red-brown		Possible PEC	PEC	possible pec	Grassland of Sorghum Timorese and Eragrostis spike with mixed herbs.	grassland
loam	red-brown		Possible PEC	Not PEC	possible pec	Low open to scattered shrubland of Acacia pruinocarpa, over grassland of Eragrostis spike, Paraneurachne muelleri, and Hypolaena grass with mixed herbs.	shrubland
clay	brown		Possible PEC	PEC	possible pec	Tussock grassland of Eragrostis spike with Ptilotus exaltatus, Rhyncarhena minima, and Fascicle weed.	grassland
sandy loam	red-brown		Possible PEC	PEC	possible pec	Stony plain of mixed grasses.	grassland
sandy loam	red-brown	Horseflats PEC	PEC	PEC	possible pec	Mixed grassland of Eriachne pulchella and Aristida contorta with mixed herbs of Goodenia occidentalis, Euphorbia drummindia and Sida fibulifera	grassland
clay loam	red-brown	Horseflats PEC	PEC	PEC	possible pec	Open tussock grassland of Eragrostis spike, Hypolaena spike, and Paracalaena muelleri, with mix of herbs.	grassland
loam	red-brown		Possible PEC	Not PEC	possible pec	Low open shrubland of Acacia xiphophila, over mixed herb land of Amaranth white bunches, Pterocaulon sphacelatum, over grassland of Sorghum Timorense and Triodia wiseana.	shrubland
loam	red-brown		Unlikely	Not PEC	possible pec	Mid open shrubland of Acacia bivenosa, Senna glutinosa, Acacia arida, over low open for land of Roepeara macrocarpa and floppy sandpaper, over hummock grassland of Triodia wiseana and Triodia horridum.	shrubland
clay loam	red-brown		Unlikely	Not PEC	possible pec	Drainage line of mid open shrubland of Acacia curled segment and Acacia single pod over tussock grassland of paranurachne mullerii and Eragrostis spike and dicanthium serissium	shrubland
clay loam	red-brown		Unlikely	Not PEC	possible pec	Draining line of tall open shrubland of acacia inequilatera over mid open shrubland of Acacia curvy segment and grevillea pyrimadalis, over mixed grasslandof Triodia wiseanna, Austrostipa half Black.	shrubland
			?	Not PEC			

sandy clay,	red-brown,		Unlikely	Not PEC		Tall open Acacia bivenosa, A. inaequilatera and A. xiphophylla shrubs over open Triodia wiseana grassland and Eragrostis xerophila tussock grassland	shrubland
sandy clay,	red-brown,		Unlikely	Not PEC		Tall Prosopis glandulosa x veluntia and Hakea chordophylla shrubland over Eragrostis xerophila grasses	shrubland
sandy clay,	brown,		Not PEC	Not PEC		Tall open Prosopis glandulosa x veluntia, Acacia synchronicia and A. inaequilatera shrubland over low isolated Eragrostis xerophila grasses	shrubland
gravel / alluvial, clay loam, clay,	red-brown,		Not PEC	Not PEC		Tall open Acacia citrinoviridis, A. coriacea subsp. pendens and Erythrina vespertilio shrubland over sparse mid Acacia xiphophylla shrubland over low open Cenchrus ciliaris	riparian zone
sandy clay,	brown,		Possible PEC	Not PEC	possible pec	Tall isolated Vachellia farnesiana and Prosopis glandulosa x velutina shrubs over mid Triodia longiceps hummock grassland over isolated clumps of low Schenkia coementii forbs.	spinifex grassland
clay loam,	red-brown,		Unlikely	Not PEC	possible pec	Low open Eucalyptus victrix woodland over tall open Acacia synchronicia and Prosopis glandulosa x velutina shrubland over low closed Eragrostis xerophila tand Cenchrus ciliaris tussock gra	open woodland
clay loam,	red-brown,		Not PEC	Not PEC		Tall open Prosopis glandulosa x velutina and Acacia xiphophylla shrubland over isolated mid Acacia glaucocaesia shrubs over isolated low Eragrostis xerophila,Cenchrus ciliaris and	shrubland
clay loam,	red-brown,		Possible PEC	PEC	possible pec	Low closed Eragrostis xerophila , Cenchrus ciliaris and Enneapogon caerulescens grassland over isolated low Corchorus tridens, Rhynchosia minima and Euphorbia drummondii forbs.	grassland
clay loam,	red-brown,	Horseflats PEC	PEC	Not PEC	possible pec	Isolated clumps of mid Acacia xiphophylla and A. inaequilatera shrubs over low Eragrostis xerohpila, Cenchrus ciliaris and Triodia epactia grassland over sparse low Corchorus tridens, Ipomoe	grassland
clay loam	red-orange, brown	Horseflats PEC	PEC	PEC	possible pec	Tussock grassland of Eragrostis xerophila, and Sorghum timorenseover a sparse herbland of Rhynchosia minima on flat plain.	grassland

clay loam	red-orange, brown	Horseflats PEC	PEC	Not PEC	possible pec	Isolated trees of Acacia inaequilatera over a sparse herbland of Rhynchosia minima and Indigofera trita in tussock grassland of Eragrostis xerophila, and Sorghum timorenseon flat plain	grassland
clay loam	orange-brown	Horseflats PEC	PEC	PEC	possible pec	Tussock grassland of Eragrostis xerophila, over a sparse herbland of Rhynchosia minima on flat plain	grassland
clay loam	red-orange		Possible PEC	Not PEC	possible pec	Acacia bivenosa and Acacia xiphophylla mid sparse shrubland over Triodia epactia tall sparse hummock grassland over Aristida contorta, Enneapogon caerulescens and Eragrostis	grassland
clay loam	red-orange		Possible PEC	Not PEC	possible pec	Acacia inaequilatera and Capparis spinosa var. nummularia mid isolated shrubs over Triodia wiseana low sparse hummock grassland over Cenchrus ciliaris, Enneapogon caerulesce	grassland
clay loam	red-orange		Possible PEC	Not PEC	possible pec	Acacia ancistrocarpa and Acacia inaequilatera tall sparse shrubland over Corchorus walcottii and Polymeria calycina low sparse shrubland over Triodia wiseana tall sparse hummock grassland over Amphipo	grassland
clay loam	red-orange		Possible PEC	Not PEC	possible pec	Acacia xiphophylla mid isolated shrubs over Aristida contorta, Eragrostis xerophila and Sporobolus australasicus low tussock grassland over Ptilotus helipteroides, Ptilotus r	grassland
clay loam	red-brown		Possible PEC	Not PEC	possible pec	Acacia aff. sclerosperma subsp. sclerosperma, Acacia inaequilatera and Prosopis glandulosa tall sparse shrubland over Acacia bivenosa, Ere	shrubland
clay loam, clay	red-brown	Horseflats PEC	PEC	PEC	possible pec	Low Eragrostis xerophila, Cenchrus ciliaris and Poaceae sp. 2 dry sterile tussock grassland over isolated low Ptilotus nobilis and Sclerolaena bicornis forbs.	grassland
clay loam, clay	red-brown	Horseflats PEC	PEC	PEC	possible pec	Low Eragrostis xerophila tussock grassland over isolated low Ptilotus nobilis and Sclerolaena costata forbs.	grassland
clay loam, clay	red-brown	Horseflats PEC	PEC	PEC	possible pec	Low Eragrostis xerophila and Poaceae sp. 4 dry sterile tussock grassland over isolated low Ptilotus nobilis and Sclerolaena costata forbs.	grassland
				PEC			

				PEC			
				Not PEC			
				PEC			
				Not PEC			
				Not PEC			
				PEC			
				PEC		Our PEC	
Red brown sandy clay loam				PEC		G+ Eragrostis xerophila, Dichanthium sericeum subsp. Humilius tussock grass	
Brown clay with gilgais				PEC		G+ Eragrostis xerophila,Vigna sp. Hamersley Clay (A.A. Mitchell PRP 113) tussock grass, vine	
				Not PEC		Not PEC, but is Tussock Grassland	
Red brown sandy clay loam				PEC		G+ Eragrostis xerophila,Dichanthium sericeum subsp. Humilius tussock grass	
				Not PEC		Not PEC, but is Tussock Grassland	
Brown clay with gilgais				PEC		G+ Eragrostis xerophila tussock grass	
				Not PEC		Not PEC, but is Tussock Grassland	
				PEC		Our PEC	
				PEC		Our PEC	
				PEC		Our PEC	
				PEC		Our PEC	
				Not PEC		Not PEC, but is Tussock Grassland	
sandy clay	red			Not PEC			grassland
clay	red			Possible PEC			shrubland
clay	red			PEC			grassland

sandy loam	red			Not PEC			open heath
loamy clay with rocks	red-brown			Not PEC			
clay loam	red			Not PEC			

Site and Regional Horseflat PEC Flora Survey

17th-20th April 2023

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Contents

Table of Figures

1 Introduction

Following on from significant wet weather events within the Karratha/Mardie regions, a flora photography survey was organised for the Eramurra Solar Salt Project (ESSP) site and identified regional Horseflat Land System of the Roebourne Plains, to assist with validation of the remote-sensing model for the Priority Ecological Community.

2 Survey Areas

2.1 Overall areas

Figure 1 shows the overall target area for the collection of flora photographs across the ESSP site and the Horseflat Land System (shaded areas)

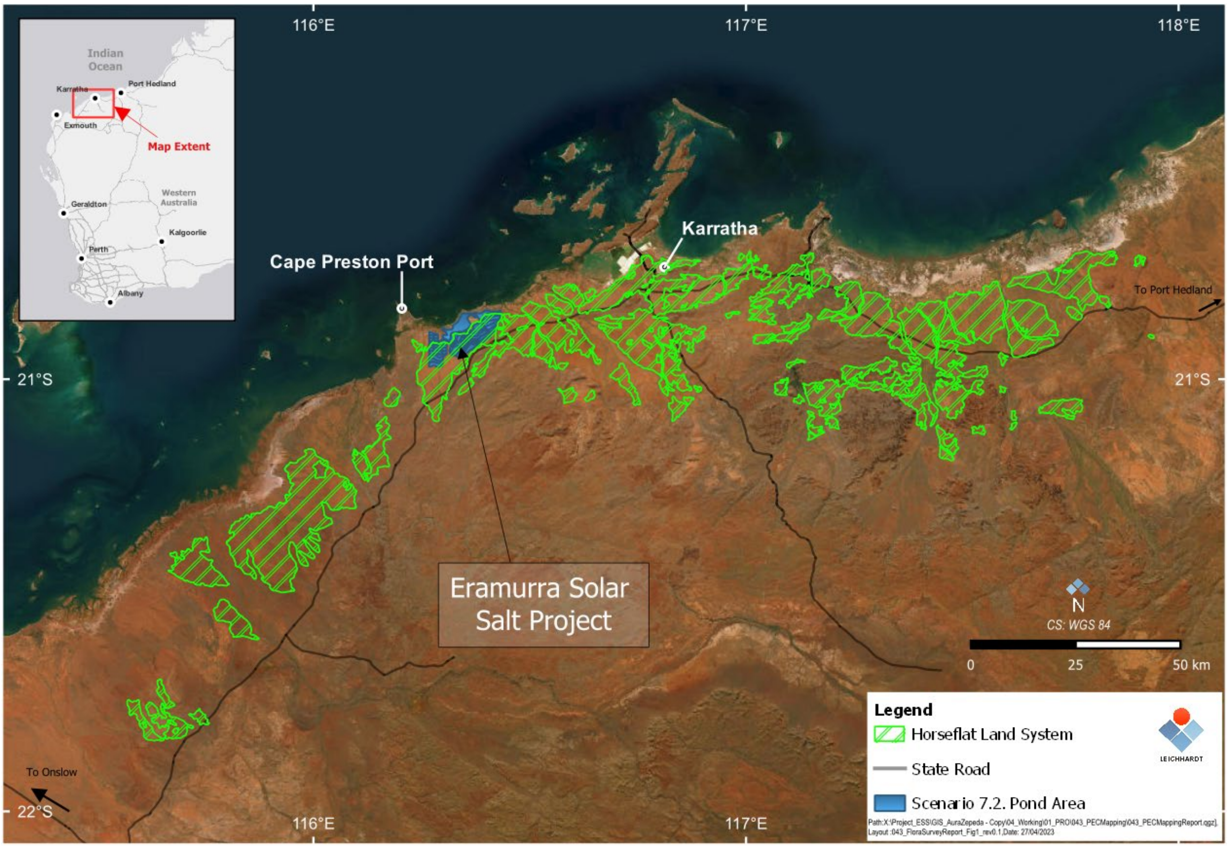

Figure 1: Regional survey area of the Horseflat Land System.

2.2 ESSP Site survey points

A grid was developed representing the development area of the site with validation points at approximately 1.7 km apart as shown in Figure 2. The site was surveyed in April 2023.

To ensure comprehensive coverage of the target survey area at the ESSP site, a grid of validation points was established with points spaced approximately 1.7 km apart, as illustrated in Figure 2. Field data collection was conducted on April 17th and 18th, 2023, using the Mergin maps application to record location points and flora photographs. Two mobile devices (Galaxy tablets) were used for the survey, enabling simultaneous data collection by each surveyor at different locations. A high-resolution image of the site, along with regional access roads and tracks from Landgate, served as a base map layer to facilitate data collection. Data collected at each point included positional coordinates (x, y, z) and five photos taken in different orientations (north, east, south, west, and ground).

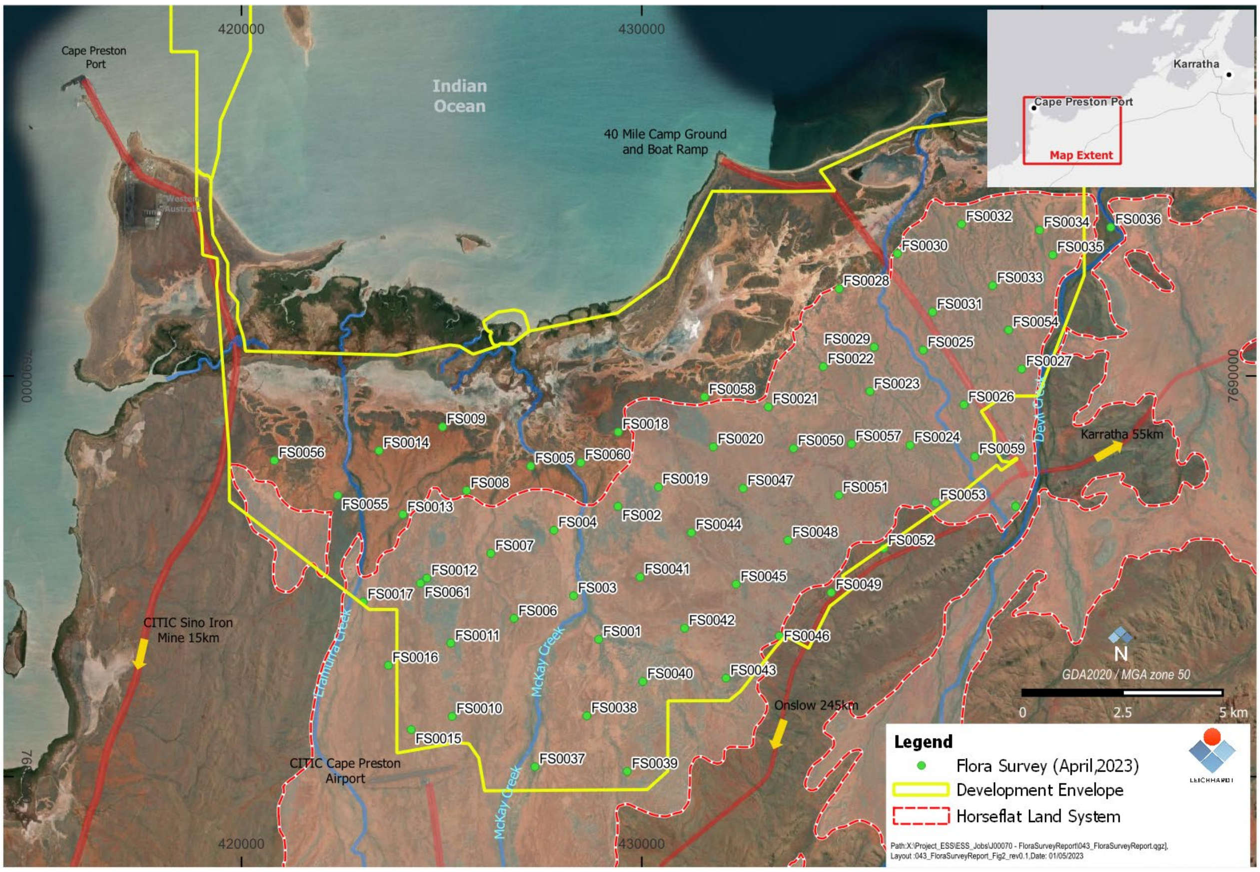

Figure 2: ESSP survey grid

2.3 Regional Horseflat Land System survey points

The surveyors used the main highway to access unsealed roads where possible or took points just off the main highway for regional data collection across the broader Horseflat Land System. Intervals between points were around 5-10 km.

Whim creek to the 40 Mile Beach Road (FMBR) was surveyed on the 19th April and from FMBR to the southwest extent beyond Fortescue river crossing, on the 20th April.

2.4 Survey methodology

The following guidelines for photography was used:-

- 1 x geo-refenced photo facing north with horizon in top third of the image;
- Then 1 x photo looking down to capture ground with top of photo at 5m distance from the GIS location;
- This should be north. Scale to be added, eg, GPS Logger or Compass or Ruler;
- Then 1 x photo at 90 degrees (ie, east), with horizon in top third of the image;
- Then 1 x photo at 180 degrees (ie, south) with horizon in top third of the image; and
- Then 1 x photo at 270 degrees (ie, west) with horizon in top third of the image.

A compass app was used to determine North with a square base plate positioned at the feet of the surveyor to determine East, South and West foot positions. See Figure 3 below.

Figure 3: Survey process using base plate.

The photos were captured on galaxy devices using the mergin maps app (Section 2.2) which collected the coordinates. A drop down list was used to identify each of the five photos per point with N, S, E and W picked for the compass points and 'Ground' picked for the ground photo. A 1.2 m stake was positioned in the ground photo for scale on the site points with a 0.9 m stake (accidently broken by vehicle) on the regional flora points.

2.5 Survey locations

A total of 61 images from the ESSP site and a further 37 across the regional extent of the Horseflat Land System were captured.

Figure 4 shows the photographic survey points that were taken for the regional extent of the Horseflat Land System to validate the model.

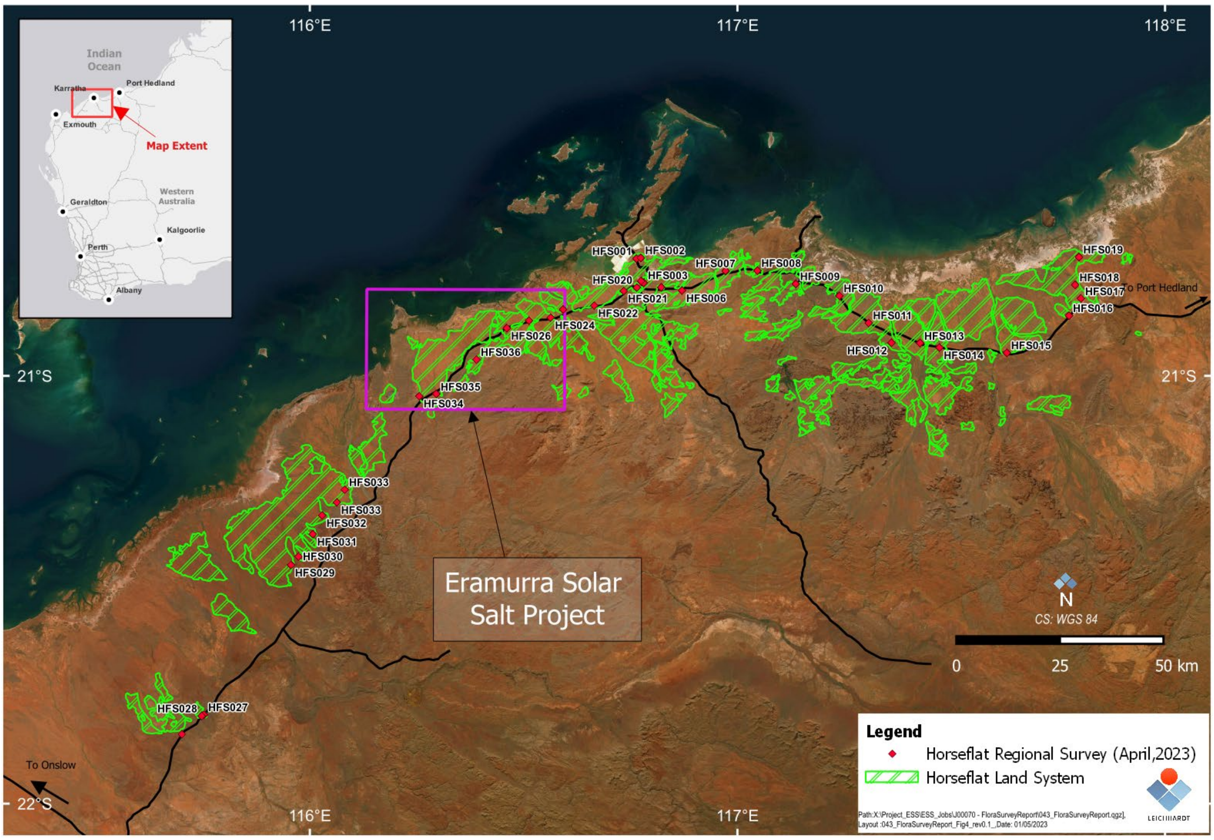

Figure 4: Regional and local survey points of the Horseflat Land System.

3 Data handling and use

Upon capturing the photographic data, the images and location points were initially stored on the devices and then were automatically synced to a cloud service when WiFi was available. The GIS team in Leichhardt office then performed quality control and validation of the data, after which it was published on the company web map as point layer. The collected point layer, along with the attached photographs, were made available for review and assessment by an expert on the PEC, to determine whether the vegetation community was representative of the Priority Ecological Community of the Horseflat Land System of the Roebourne Plains.

This information will be used to assist with validation of the remote-sensing model for the Priority Ecological Community.

Addendum 1: PEC Model Validation

This addendum is associated with **EnSTaR Technical Report, Eramurra Mapping, Horseflats PEC – Remote Sensing, RL004a, February 2025.**

Since the original mapping work reported in RL004a we were provided with more in-situ information collected within the Horseflats region. We used this new information to undertake further validation of the PEC mapping model described in RL004a.

Validation Data

The validation data supplied consisted of 2 sets of results of manual photo-interpretation of photographs collected at specified latitude/longitude positions. For set A, comprising 479 points, photographs were obtained by pointing the camera downwards at the location (data labelled as "ground") and by pointing the camera to the north, south, east and west. The extent of the view in each of the NSEW photos was taken as providing assessment of a Sentinel pixel adjacent to the location of the "ground" location (see Figure 1).

	North	
West	Ground	East
	South	

Figure 1. Representation of the sentinel pixels used in conjunction with field-collected photographs.

For set B, comprising 158 points, latitude/longitude locations were provided, but no indication of camera orientation was recorded. One record was discarded because of an incomplete data record. An overview of the photographic validation data is shown in Table 1.

Table 1. Overview of photographic field validation data.

Set A – Ground, N, S, E, W	
PEC	177
Not PEC	233
Possible PEC	69
Set B – no orientation	
PEC	70
Not PEC	64
Possible PEC	23

For the validation exercises reported here we discarded points labelled as “Possible PEC”.

For this validation exercise we have also incorporated 794 validation data points collected prior to the Horseflats photographic survey, representing surface types from regions surrounding the Horseflats extent. These “Not PEC” classes include diverse surface types such as mangrove and mudflat.

The PEC model development described in Section 4.5 of RL004a included an assessment of the model accuracy for a range of RSI and NDVI threshold values (Table 4 in RL004a). Threshold values (RSI,NDVI) of (1,1), (2,1) and (2,7) were identified as the highest PEC accuracy. The values (2,1) were chosen for all subsequent mapping work. We also reported accuracy for threshold values of (6,7) and (10,7) to demonstrate the accuracy of the 20^{th} and 30^{th} percentiles respectively.

PEC model validation with pixel offset

Table 2 shows the accuracy statistics for the same RSI,NDVI threshold values as reported in Table 4 of PL004a.

Table 2. Accuracy statistics for RSI, NDVI threshold values. All validation data from sets A and B plus previous non-PEC data, camera directions N,S,E,W one pixel offset.

Counts (RSI, NDVI)	PEC Accuracy (%)	Not-PEC Accuracy (%)	Not-PEC Identified as PEC (%)	PEC Identified as Not-PEC (%)	Total Accuracy (%)
(1, 1)	*94.33*	*85.33*	*40.71*	*5.67*	*87.00*
(2, 1)	***94.33***	***86.80***	***38.20***	***5.67***	***88.19***
(2, 7)	*93.52*	*88.73*	*34.75*	*6.48*	*89.61*
(6, 7)	*93.52*	*89.83*	*32.46*	*6.48*	*90.51*
(10, 7)	*89.88*	*91.57*	*29.30*	*10.12*	*91.26*

PEC model validation with no pixel offset

The validation assumption was that all N, S, E, W views represented the state of Sentinel pixels adjacent to the pixel at the specified camera latitude/longitude. In an attempt to demonstrate the effect of uncertainty in the actual photograph view we have calculated the accuracy statistics where the Sentinel pixel for all N, S, E, W views is taken as the specified latitude, longitude of the photo. Essentially, all validation points are taken as "ground". The in-situ dataset used for validation contained a total of 637 points with three classification types: PEC, "Not PEC," and "Possible PEC." One point was discarded due to an incomplete record. The distribution of the remaining points is as follows:

- PEC points: 247
- "Not PEC" points: 297
- "Possible PEC" points: 92

Since there was uncertainty in classifying the "Possible PEC" points as either PEC or "Not PEC," those points were discarded from the validation process. Therefore, the final dataset used for validation consisted of 247 PEC points and 1091 "Not PEC" points which included 794 points previously identified as "Not PEC". The results in Table 3 indicate the accuracy of the PEC model when validated using the in-situ dataset and a selected set of RSI, NDVI thresholds.

Table 3. Accuracy statistics for RSI, NDVI threshold values. All validation data from sets A and B plus previous non-PEC data, camera directions N,S,E,W no pixel offset.

Counts (RSI, NDVI)	PEC Accuracy (%)	Not-PEC Accuracy (%)	PEC Commission Error (%)	PEC Omission Error (%)	Total Accuracy (%)
(1, 1)	*94.33*	*84.63*	*41.90*	*5.67*	*86.42*
(2, 1)	***94.33***	***86.46***	***38.85***	***5.67***	***86.91***
(2, 7)	*93.52*	*88.47*	*35.29*	*6.48*	*89.40*
(6, 7)	*93.52*	*89.75*	*32.65*	*6.48*	*90.45*
(10, 7)	*91.09*	*92.13*	*27.65*	*8.91*	*91.94*

Comments

The validation assessment undertaken in RL004a was based on 87 ground-truth data points, 35 PEC and 52 not-PEC. The updated PEC model validation reported in this Addendum was based on 1338 validation points.

We have considered the uncertainty in photographic location and orientation by considering two analysis methods, one where we ascribe the photographic descriptions taken by aiming the camera “looking into the distance” to adjacent Sentinel pixels, and the second method where all photographic descriptions are ascribed to the pixel at the location of the camera.

For both methods of validation, the PEC accuracy has improved slightly compared to the assessment in the original report (94% cf. 91%). The not-PEC accuracy is slightly lower (87% cf. 95%), not-PEC identified as PEC is improved (38% cf. 53%) and PEC identified as not-PEC slightly higher (6% cf. 0.4%). Total accuracy is slightly lower (88% cf. 95%).