Mesquite Invasion in the Pilbara, Western Australia.

Applied Remote Sensing

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1. Introduction

Mesquite is known as one of the most invasive weeds in Australia, adapting from seasonal spreading events to utilising the livestock to distribute fertilised seeds, it has become one of the most prolific and expensive weeds to control in the Pilbara. Prosopis is the scientific name for Mesquite, branches into four primary species and multiple hybrids (Australian Association of Bush Regenerators, 2003). It was introduced in Western Australia (WA) in the 1930s on Mardie Station, a cattle and sheep pastoral station located near the Fortescue River in the Pilbara. Initially reported in low numbers until a major cyclone flooded of the Fortescue River, damaging facilities at Mardie Station along with spreading the seed pod throughout the floodplain of the Fortescue River, resulting in the infestation across the whole station which remain in the area to present day. Multiple control methods over the last ~70 years have been applied to the area, including a biological control agent, introduced in 1998 which caused defoliation and dieback in mesquite (Australian Association of Bush Regenerators, 2003). As one of the most invasive and prevalent weed species in Australia, it is important to study the controls that have been implemented over time to determine how best to mitigate the spreading of invasive species. As methods have varied in effort over the early decades, this report will provide comparison of techniques used before and after the introduction of the biological controls in 1998. The years incorporated in the analysis are taken from 1988, 1998 (pre-biological control), 2008, 2018 and 2023. Using satellite imaging from these periods, image differencing, change vector analysis and multidate change classification methods will be applied to study Mardie Station. Using the different change detection methods, the objective of this report is to determine which control methods should be emphasised moving forward to reduce and maintain mesquite invasion in the Pilbara, historically, what control methods have failed to contain the Mesquite resulting in large scale infestation.

1.2. Study Area

Mardie Station is primarily a livestock station comprising sheep and cattle, with recent development of an open cut mine site. The study area seen in figure 1, shows the location of the study area for this report (with spatial reference to the open cut mine site and the Mardie Station homestead/facilities in red). Mardie Station is located outside the southwestern section of the study area and the mine site on the north-eastern side. The main river system seen running through the study area is the Fortescue, it is important to note that there are multiple smaller water systems which vary in size due to seasonal change (Davis, O'Keeffe, & Long, 2003). These smaller scale systems can be visually identified in figure 1, looking at concentrated zones of green vegetation which follow the same distribution patterns of a river system. The floodplains of the river systems and coastline are an important feature of the study area, the Pilbara coast, since 1910 averages roughly one cyclone every two years (Bureau of Meteorology, n.d.). Averaging winds more than 90km/h, statistically over this period, this section of the coast is the most susceptible in Australia regarding cyclone frequency (Bureau of Meteorology, n.d.). There have been multiple recorded flooding events associated to the floodplains of the Maitland, Sherlock, Robe, and the Fortescue River (Bureau of Meteorology, n.d.). An extreme example is an event in 1894, when a flooding event caused the river to reach a few metres from the Mardie homestead (highlighted as Mardie Station in figure 1), resulting in hundreds of livestock getting washed away and facility damage (Bureau of Meteorology, n.d.).

Figure 1. Overview of the Study Area (green) in Mardie Station. Mardie Station Homestead and work facilities highlighted with red circle; Sino Iron Ore Mine Site highlighted in red box.

The climate of the region is classified as hot arid, with average maximum temperatures of 28 degrees Celsius in July and 38 degrees Celsius in January (Bureau of Meteorology, 2023). The region has even recorded multiple 50-degree Celsius daily maximums in both 1998 (19th February) and 2022 (Bureau of Meteorology, 2023). The cyclone that is considered to cause the initial outbreak of Mesquite occurred on the 6th of March 1945 (Bureau of Meteorology, n.d.), there is limited information on the flooding event in historical record of the Bureau of Meteorology (n.d.), winds were recorded at >170 km with noted flooding of the Harding River. Inferring what flooding may have potentially in the floodplain of the Fortescue River, all large-scale cyclones in this region historically overlap just off the coast of Karratha, just northeast of the study area, then cut inland over Mardie Station (Bureau of Meteorology, n.d.). Looking at other major flooding events between 1910 to 2017, a comparison could be done to that of Cyclone Monty, which has more available data regarding flooding areas. Cyclone Monty (Burton & Davidson, 2014), which occurred in late February and early March of 2004 (similar time of year), at the end of a long drought. Although Cyclone Monty is considered more severe, it travelled over Mardie station on the 2nd of March, recording winds of 154 km the station the highest flood on record for the Fortescue, Maitland, and Robe Rivers (Burton & Davidson, 2014). The exact value of rainfall at Mardie is an under-estimation as the gauge was found overflowing at a record value of 393 mm, therefor could be considerably greater. This introduces one of initial issues with weed containment and what made the species so prevalent in the area in a short time. The Fortescue River is recorded at 760 km long, therefor whenever there is a large-scale flooding event, seed pots can effectively be deposits all over the sub catchment areas with low elevation, seen in teal and light yellow in figure 2.

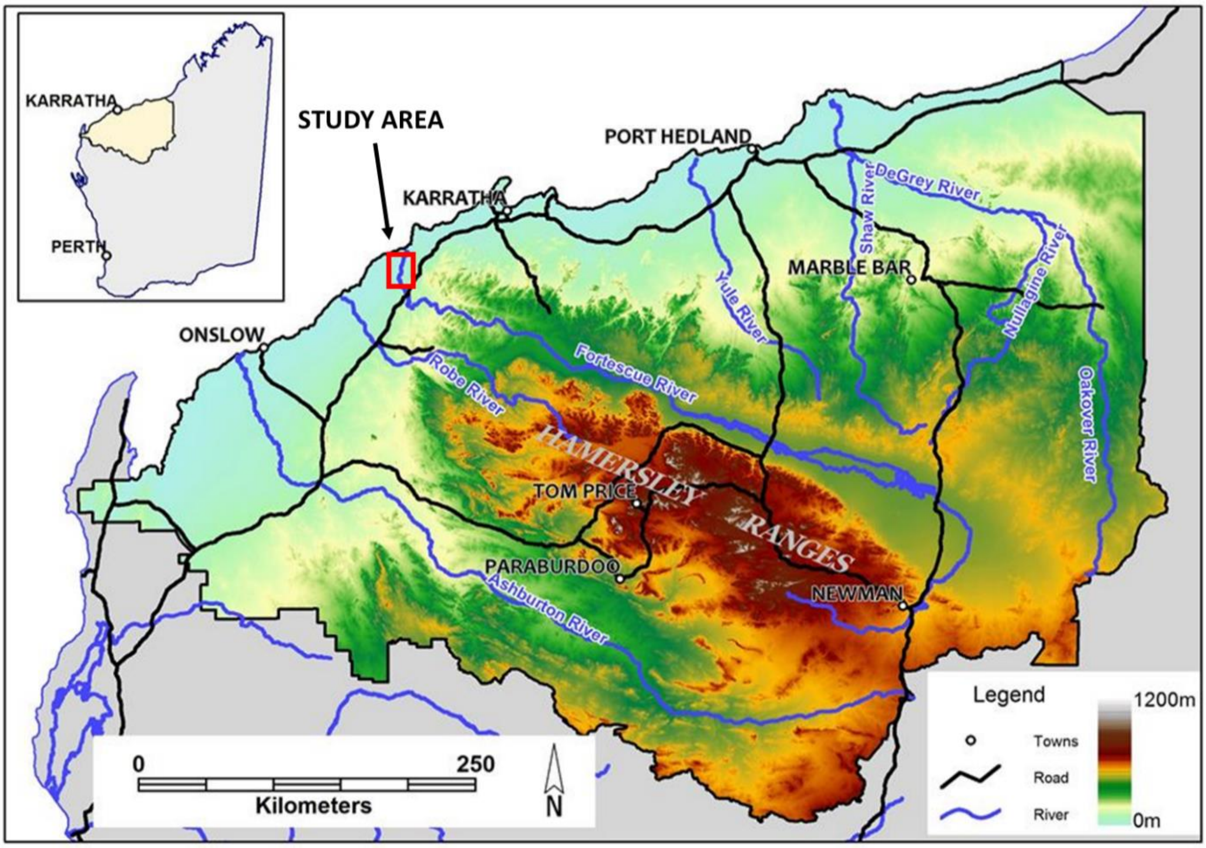

Figure 2. Elevation of the Pilbara region including major river systems. Study area highlighted in red. Retrieved from (Department of Primary Industries and Regional Development, 2021)

Mesquite forms in thickets, distributed densely around water sources which become impenetrable for livestock, resulting in infections from the wounds caused by the thorns and poisoning from overconsumption of the seed pods (Australian Association of Bush Regenerators, 2003). They very in shape and size dependant on species, ranging from 3 to 15 m tall (figure 3A), the branches are defined by their zig-zag structure, thorns are placed at node points with fern like leaves, seen in figure 3B. The seed pods can record sizes of 200 mm in length and can produce up to 20 viable seeds per pod (figure 3C). The taproot of the plant can grow to depths of 20 m, with mature trees exceeding 50 m (Australian Association of Bush Regenerators, 2003). Resulting in the morphology and physiology being a key reason how prolific it became.

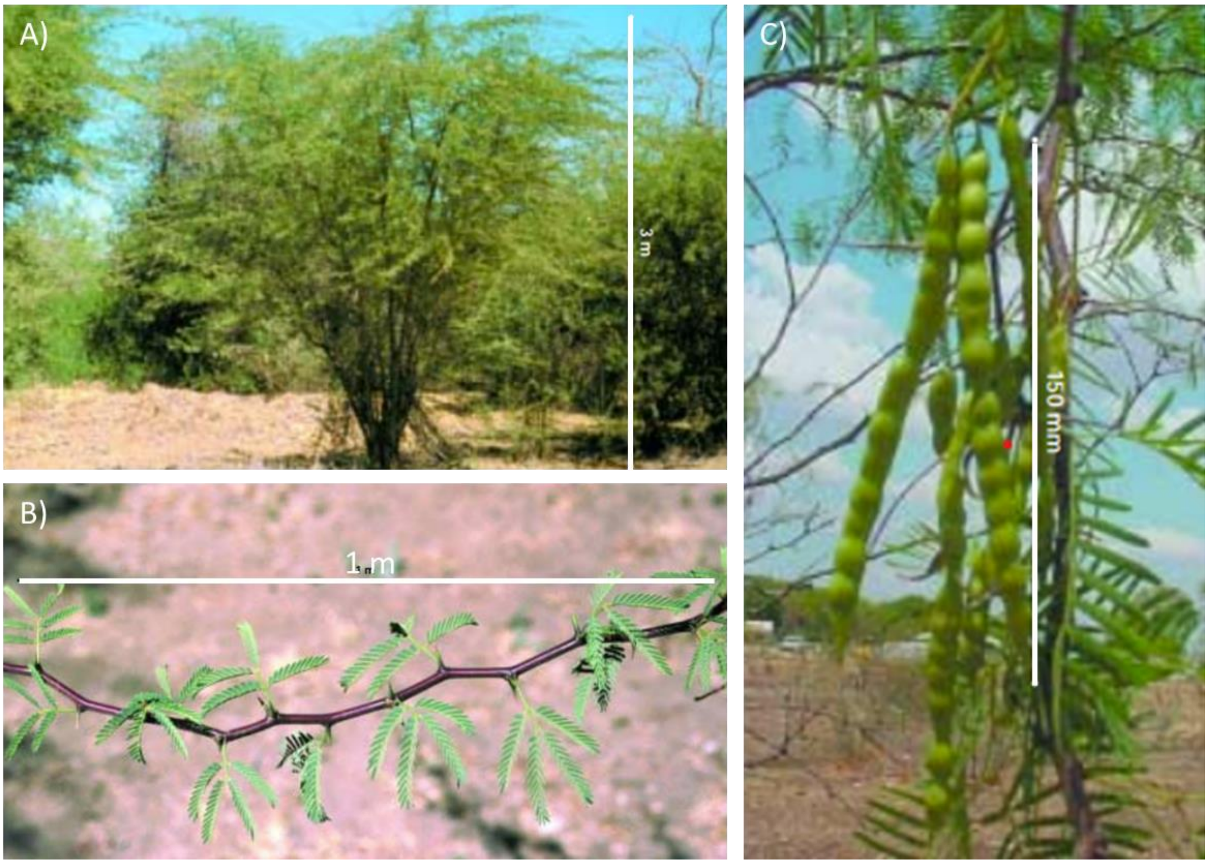

Figure 3. A) Typical Mesquite bush structure, scalebar = 3 m. B) structure of zig zag branches and thorns, scalebar = 1 m C) structure of typical seed pod, scalebar = 150 mm. Images retrieved from (Australian Association of Bush Regenerators, 2003).

To understand how Mesquite spread so prolifically in the Pilbara it is important to understand the typical growth pattern the species. Seen in figure 4, the general growth pattern and growth pattern under suitable conditions have been recorded (Australian Association of Bush Regenerators, 2003). To understand the patterns for germination and dormancy, the conditions and environment of the study area need to be assessed to determine if they match the Prosopis species. As previously stated, the

Pilbara's climate is arid, with varying levels of rainfall in the wet season. Prosopis, native to the subtropics and tropics of America, Africa, and the west and south regions of Asia, evolved to be suited to arid soil, resistant to droughts (Australian Association of Bush Regenerators, 2003). Prosopis species are well suited to areas north of 28 degrees south latitude, (Australian Association of Bush Regenerators, 2003); with typical environments such as open grassland, rangeland and along banks of rivers and water bodies. Therefor Mesquite is well suited to thrive in the Pilbara, as it is north 28 degrees south in latitude, the terrains are typical of that were they are native based around the Fortescue River, and they are extremely drought tolerant so the prolonged dry summers the Pilbara receives will not affect the weed. This has resulted in the loss of native habitat due to erosion; the grassland cattle and sheep would habit have also been converted to weedy shrubland. Increasing the amount of habitat for feral animals, which also feed off the seed pods resulting in a negative feedback loop for native habitat. As noted with the feral species, the native animals and livestock feed on the seed pods, which assists in dispersion of the seeds.

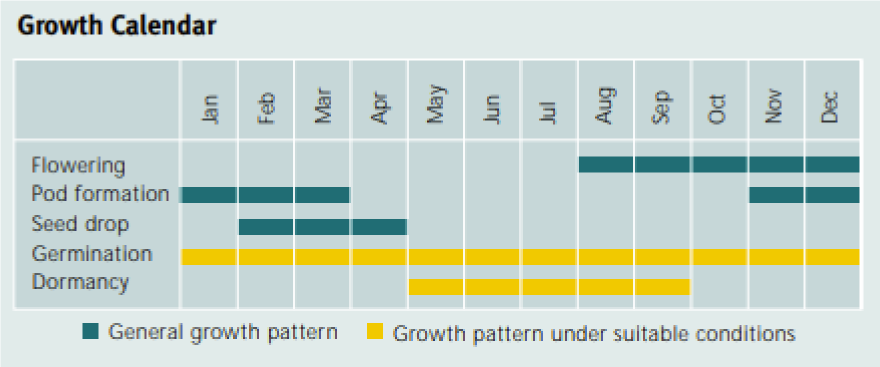

Figure 4. Growth Calendar of Mesquite. Retrieved from (Australian Association of Bush Regenerators, 2003).

As there are multiple species of Prosopis the germination for the seeds is all year round provided the environment has suitable conditions. Most regions of the study area consist of the suitable conditions, the germination is likely annual, with long dormancy periods between May and September. Flowering occurs between August and December, with pod formation occurring between November to March. The seeds will drop between February and April, which is a reason for the prevalence for the weed. As seen in figure 5, February and March, since 1910 – 2017 have recorded the most Cyclones in the Karratha and Dampier region, lining up with the period in which Mesquite drops seeds (Bureau of Meteorology, n.d.). Resulting in increased spreading and successful distribution of the plant.

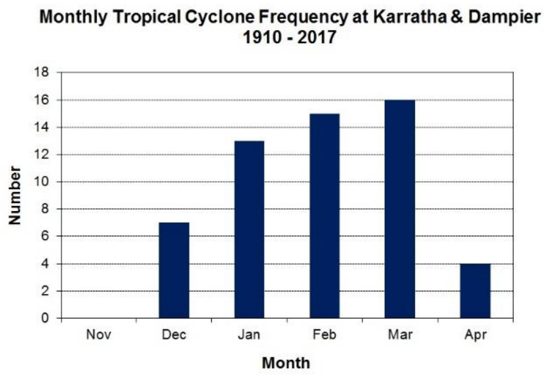

Figure 5. Monthly Tropical Cyclone Frequency at Karratha and Dampier, 1910 to 2017. Retrieved from (Bureau of Meteorology, n.d.).

With assisted transportation from cyclones, it is important to note that the pods require breaking of the seed casing to allow germination to occur. Conditions such as cyclones or fire (controlled or wild) can cause the pods to break although on Mardie Station the primary method of distribution for Mesquite has been identified as through the digestive track of animals (Australian Association of Bush Regenerators, 2003), where the pod is broken down, and deposited into nutrient-rich dung acting as a fertiliser. As previously stated, the seed pods are eaten by native, feral and livestock animals as it provides a protein rich and sugar rich meal. Mardie Station has a current holding capacity of roughly 7500 cattle (Commercial Real Estate, 2023), when cattle are exposed to the seed, they are isolated in select paddocks until they have passed the seed into dung. Along with having to relocate livestock, overconsumption of the seeds can result in poisoning and the thorns can lead to infections, resulting in potential financial loses. The next section will discuss why grazing management is important to do prior and post control management.

There are several forms of management outside of grazing management, varying in chemical, mechanical and biological controls. Management strategies have been implemented dependant of the characteristics of the mesquite infestation. As the plant varies in hardiness due to variables such as size, maturity, and habitat. For a cost-effective approach, traditional strategies integrate herbicides with controlled burns and grazing management. The herbicide is applied to the stump of a freshly cut Mesquite, effectively dealing with the smaller bushes all year round. Bulldozers are cheap and effective methods of removal, either using the cutter bar mounted on the front or a blade plough dragged behind. The use of fire needs to have several parameters monitored to be successful, their needs to be enough fuel to generate the required heat to kill a mesquite, although the hybrids found in the Pilbara require careful preparation to mitigate damage to non-targets. Biological controls such as the two introduced into the Pilbara was initiated by CSIRO (Australian Association of Bush Regenerators, 2003). Releasing a leaf tying moth (Evippe sp #1) that caused defoliation and a leaf sucking bug that caused dieback in the area in 1999 (Anderson et al., 2006). Understanding these different approaches to control management, it is critical to remove grazing after control efforts to encourage perennial grasses and native grow and reduce grazing if burns are required to allow sufficient fuel.

To relate this information on how mesquite has become so prevalent as a weed at Mardie Station, the densest growth in the study area is located along the floodplain of the Fortescue River, on heavy alluvial clays, saline muds and around water stations for cattle. As further discussed in the later sections of the report, it is unlikely these areas will ever be fully recovered. With the combination of cyclone frequency and flooding risk along with mesquites ability to spread effectively, it is important to focus on areas less dense, around the livestock and station boundaries with potential to be dispersed outside of the station via the floodplains of the local river systems.

2. Materials and Methods

The data analysed in this report was provided by the United States Geological Survey (USGS). The acquisition data was recorded by the Landsat 5 and 8 satellite. The path/row geocoding method was used to identify the study area, isolating the path location of 114 and row location of 75. Cloud cover range was adjusted to 0 – 5% and date of acquisition for data is taken from the month of February, as mentioned in the previous section, at this stage there has been significant rainfall (figure 5), as well as being too early to show defoliation in leaves from leaf tying moth for the data provided post introduction and within the period of pod formation (figure 4). The data acquired from 1988 was on the 18th of February and the 1998 data was acquired on the 4th of February. The data acquired after the biological controls was the 9th of February 2008, the 20th of February 2018, and the 18th of February 2023. The 5 acquisition dates were determined as they represent almost decade length change from the 1980s to present day. This 40-year period has seen the decommission of Landsat 5, therefor the data recorded in 2018 and 2023 were acquired with the Landsat 8 satellite. Therefor to accuracy assess change the two satellites data cannot be compared. To achieve a representative change assessment, there is two datasets prior biological control, one dataset a decade later using the same acquisition sensors, and two datasets to represent the current change.

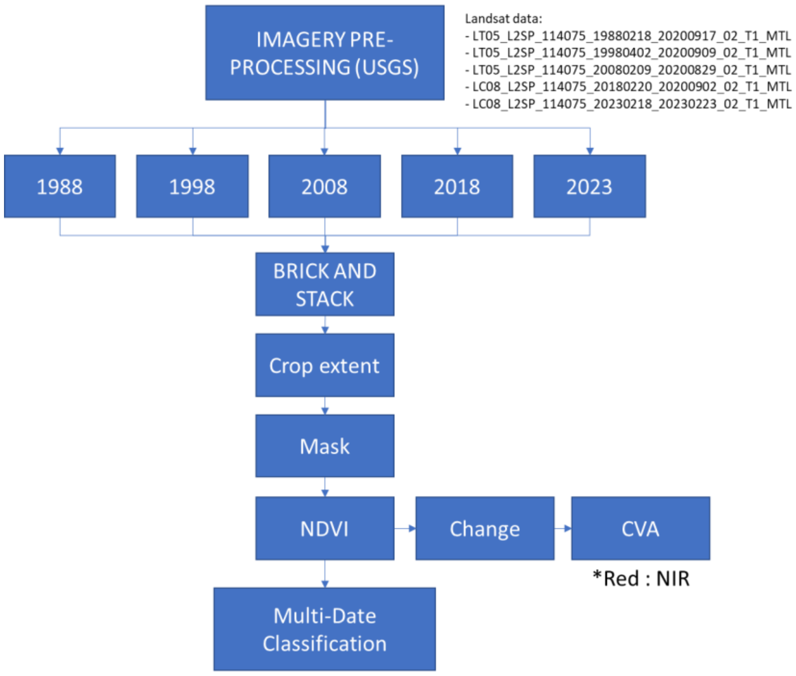

Figure 6. Structure chart used for image pre-processing for the 4 Landsat datasets.

Imagery pre-processing was done using the R software package (version 4.2.2). With three datasets, 1988, 1998 and 2008 acquired with the Landsat 5 satellite and two acquired with the Landsat 8 satellite (2018 and 2023), modifications were made to optimise change detection processing methods. The Landsat 5 satellite uses the MSS and TM sensor to acquire data, whereas Landsat 8 uses OLI and TIRS. They both differ in radiometric resolution as Landsat 8 has 12 bits whereas Landsat 5 has 8 bits, the thermal resolution on Landsat 8 is 100 to the 120 resolutions on Landsat 5. With the difference in satellite data, Landsat 5 analysis will not be compared with Landsat 8 data. There will be analysis comparison of 1988 with 1998 along with 2018 with 2023 will be used to compare representative data from the two acquisition sources although as they have been acquired with different instruments, therefor trends may be related to different equipment. To do prepossessing of the imaging, the required R packages are Raster, RStoolbox, and sf. There are to considerations made at this stage, the current RStoolbox has issues with identify and processing Landsat 8-9 data, along with this pixel scaling differs between collection 1 and 2 Landsat data, therefor all datasets required are to be collection 2 level 2 data, which each band is then bricked and stacked into their respective dataset. This process removes the ability to apply atmospheric corrections (COS(thetaz)), which is not essential as the elevation of the study area is low; cloud masking will also be unavailable. This was taken into consideration when filtering for datasets on the USGS website, where only acquired data with cloud percentages <5 was used. Due to the inability to access metadata, the change detection algorithms were modified to adjust to the introduced variables. Masking was applied to crop to the boundaries of the study area, using a shapefile of the study area (seen in figure 1).

The change detection algorithms used was image differencing, multi-date classification and change vector analysis. It is important to note that change vector analysis requires atmospheric correction to perform a Tasselled Cap Transformation, the red and NIR bands were substituted into the place of the brightness and greenness (x and y values) to calculate angle and magnitude. With change vector analysis, the production of plots that displayed the angle and magnitude relating to mesquite populations in the study area can be applied to the dates post and prior biological control (1988 – 1998 and 2018 – 2023). The vector taken from this algorithm informs about the type of change, vegetation expansion, vegetation loss, moisture gain and moisture loss, using the older date as an azimuth. With the stacked datasets, image differencing was applied using NDVI (normalised difference vegetation index) images that the 1998 was subtracted by the 1988 dataset and the 2023 dataset was subtracted by the 2018 dataset. To plot the change, a calculation was applied to each NDVI plot to avoid double negatives. The change data provided histograms which plotted the distribution of change seen in the NDVI values between the data prior biological control method were implemented and post implementation.

Training data was then applied to the change data to classify landcover change over the 4 time periods. These four classes were identified as mesquite_mesquite, mesquite_soil, soil_mesquite and soil_soil. The four classes represent the two main land cover changes present in the study area. The sample size of the training data was 1000 with a set.seed value of 100. The training data was then ran through a supervised random forest classification.

3. Results

The Landsat datasets were plotted to confirm that there was no clear cloud coverage or artifacts founds within the imaging, seen in figure 7. As the 2018 and 2023 data was captured with the Landsat 8 satellite, the RGB plot looks different to the other three, as well as being captured in a different resolution. With no cloud cover or artifacts found within the plots, masking applied to the study area along with extent cropping to filter out the unnecessary pixel data.

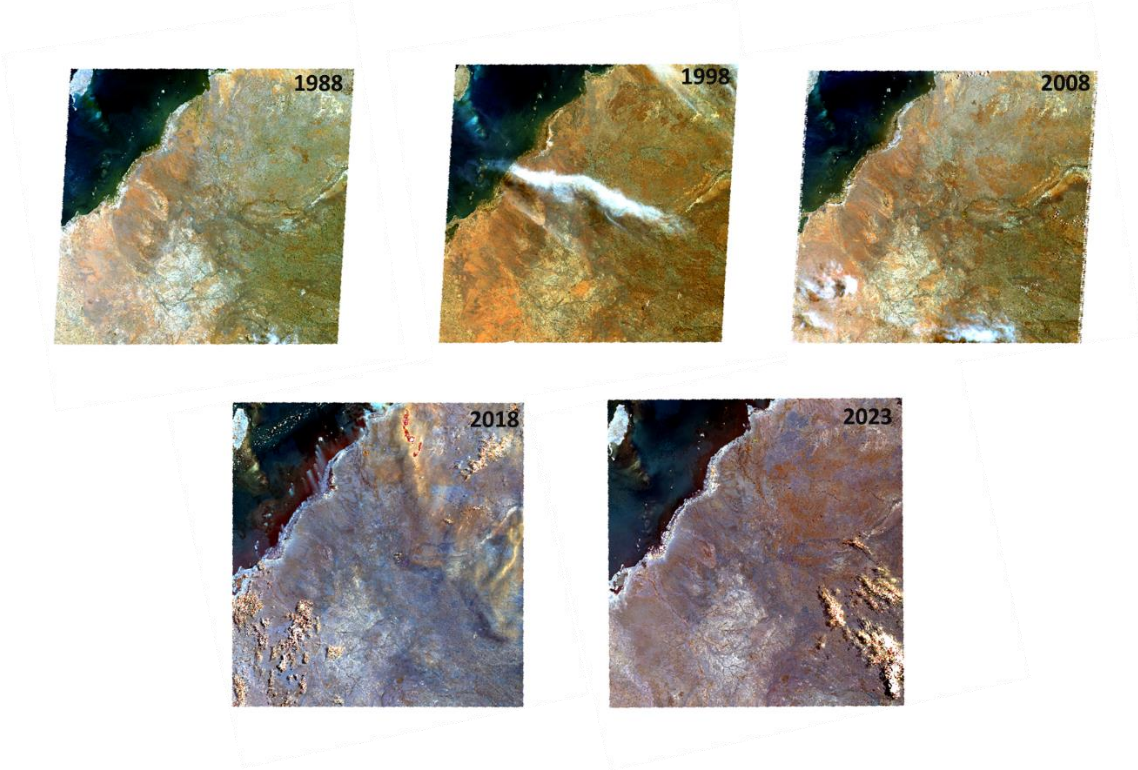

Figure 7. RGB plots of the 5 datasets used for pre-processing.

An NDVI was applied, a slope-based indices to the 5 datasets. Figure 8 displays the vegetation identified in the study area, A) and B) share most vegetation features (seen in green), with C) displaying more variation between 0 - 0.15 in areas that recorded values representative of bare soil in 1998 and 1988, indicating potential new growth post 1998 in central zones of the study area. As the 1988 and 1998 data have similar distribution, there are few noticeable differences in bare ground identified around the coastline at the mouth of the Fortescue River, seen in 1998. Along with more vegetation appearing closer to the Mardie Homestead (identified as Mardie Station in figure 1). Plot C), appears to have similar distribution patterns to 1988 and 1998, although the maximum value has been adjusted to 0.25, whereas 1988 and 1998 have maximum values of ~0.4, indicating overall health of vegetation is decreasing. Plot C) mirrors the trends present in the 2 prior datasets, with slight increase in vegetation in areas which were bare soil prior, it is identified that the health of densely clustered mesquite is worse in 2008 since introduction of biological control. Plot D) indicates the vegetation has become more stress than the previous plots with vegetation around the river systems converting to bare soil and more stressed vegetation dispersed throughout the centre of the study area. With a maximum value of 0.15 the vegetation index is much lower than the three other plots, Plot E) displays similar trends as seen in plot D), although the vegetation seen throughout is less saturated. The trends apparent thought 1988 - 2008 images indicate that the areas of greatest change are localised to the lower elevation zones along the coast and clustered around water bodies, with mesquite populations clustered around waterbodies will increase dispersion throughout the central sections of the study area. Whereas the areas of greatest change between 2018 - 2023 is the increase of bare soil around the waterbodies, with more vegetation found in the central region of the study area.

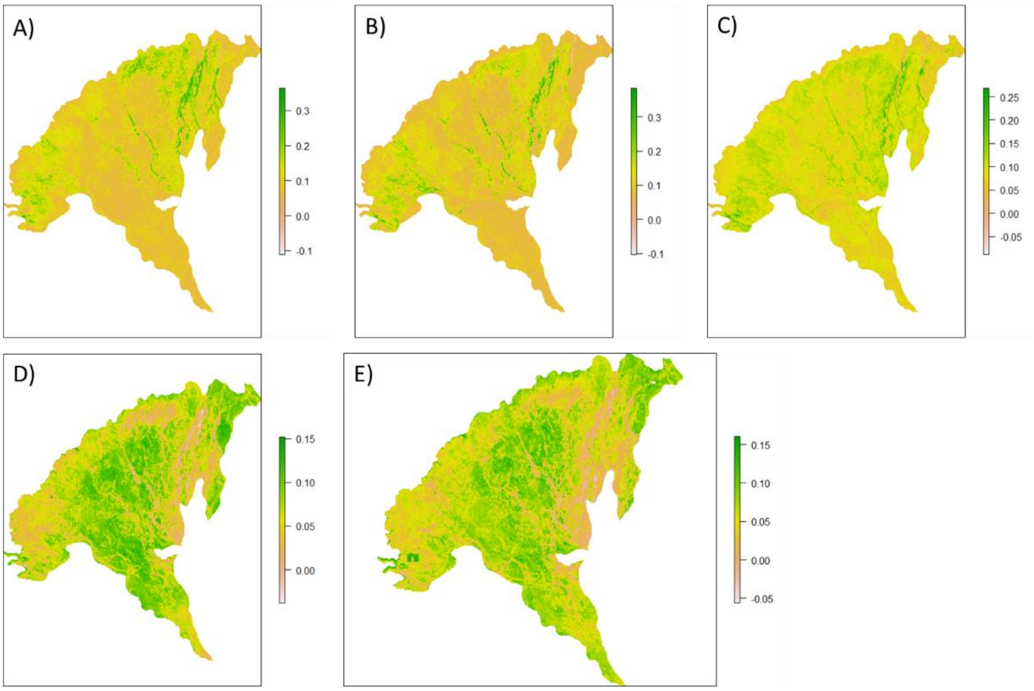

Figure 8. NDVI plots of the 5 masked datasets. A) 1988, B) 1998, C) 2008, D) 2018 and E) 2023.

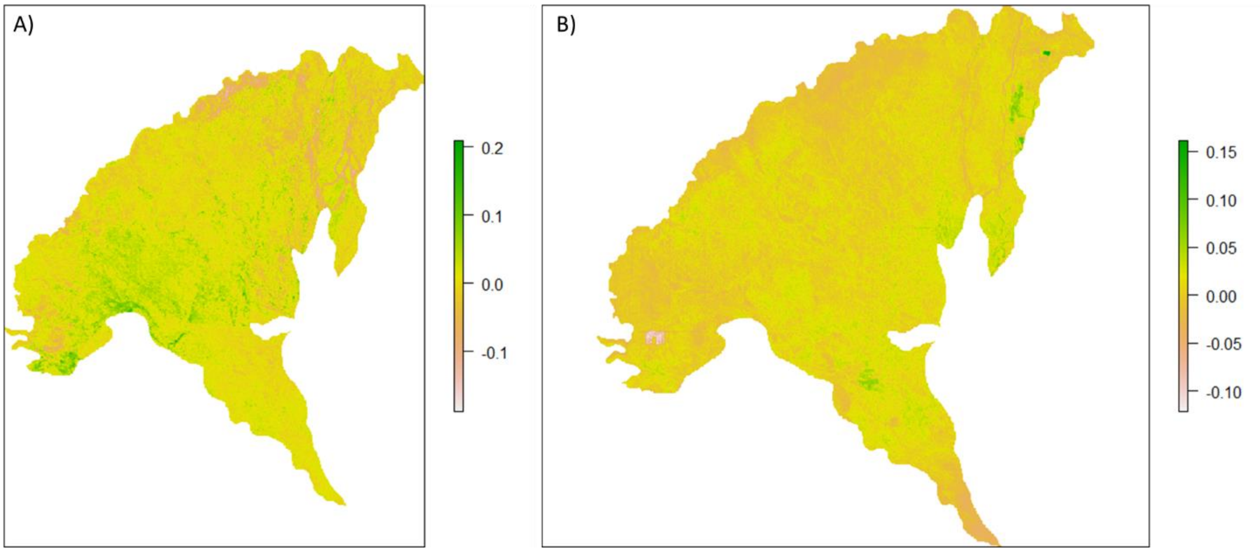

Figure 9. Change plots done with NDVI images. A) 1988 – 1998 and B) 2018 - 2023.

Change maps were plotted to look at the differences in NDVI values prior and post biological control was introduced. Seen in figure 9, A) shows the change from 1988 - 1998, the green areas seen around the farmstead indicates areas in that period that were likely invaded by mesquite. There are very low levels of vegetation change found either side of the Fortescue River. The change from 2018 - 2023, the mesquite invasion looks to be more localised to the west of the iron ore open pit, in sections of the Fortescue River floodplain. There are some increases in prevalence along the southern section of the Fortescue River, with one isolated cluster seen in the southern section of the study area. Both change plots indicate change in mesquite in those periods were related to livestock (1988 – 1998) and increased effort in controls (2018 – 2023). Figure 10 displays the data presented as a histogram, comparing the distribution of change done with the NDVI change plots (figure 9). Both are relatively balanced although there is a net increase of vegetative cover in both change maps.

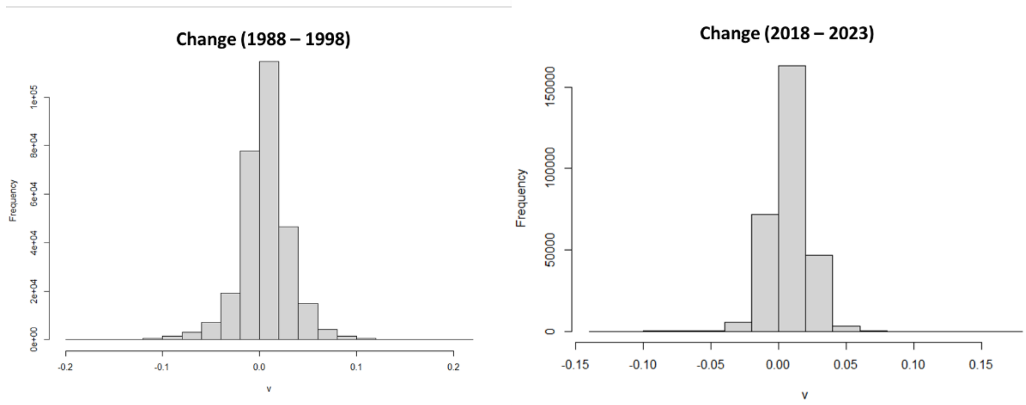

Figure 10. Histograms of distribution of change done with the NDVI change plots.

The final component of the change vector analysis is the angle and magnitude plots of both compared periods. The angle plot provides the following information, values between 0 – 90 = Moisture loss, 90 – 180 = Vegetation loss, 180 – 270 = Moisture gain and 270 – 360 = Vegetation gain. The magnitude plots provide information where the most significant change is occurring. The angle plot for the 1988 - 1998 change data indicates varying amounts of moisture loss around the Fortescue River, sections along the coast and a zone east of the homestead. Vegetation loss is seen in proximity to the Fortescue River, and to the west of the homestead. Moisture gain is prevalent throughout the central section of the study area and coastline. Vegetation gain is seen in localised clusters in proximity to the Fortescue River and the homestead. The magnitude of growth is identified in proximity to the Fortescue River with isolated high magnitude clusters on the southern section of the river and along the coastline in proximity to the homestead. There are low levels of magnitude dispersed throughout the study area which are the result of livestock.

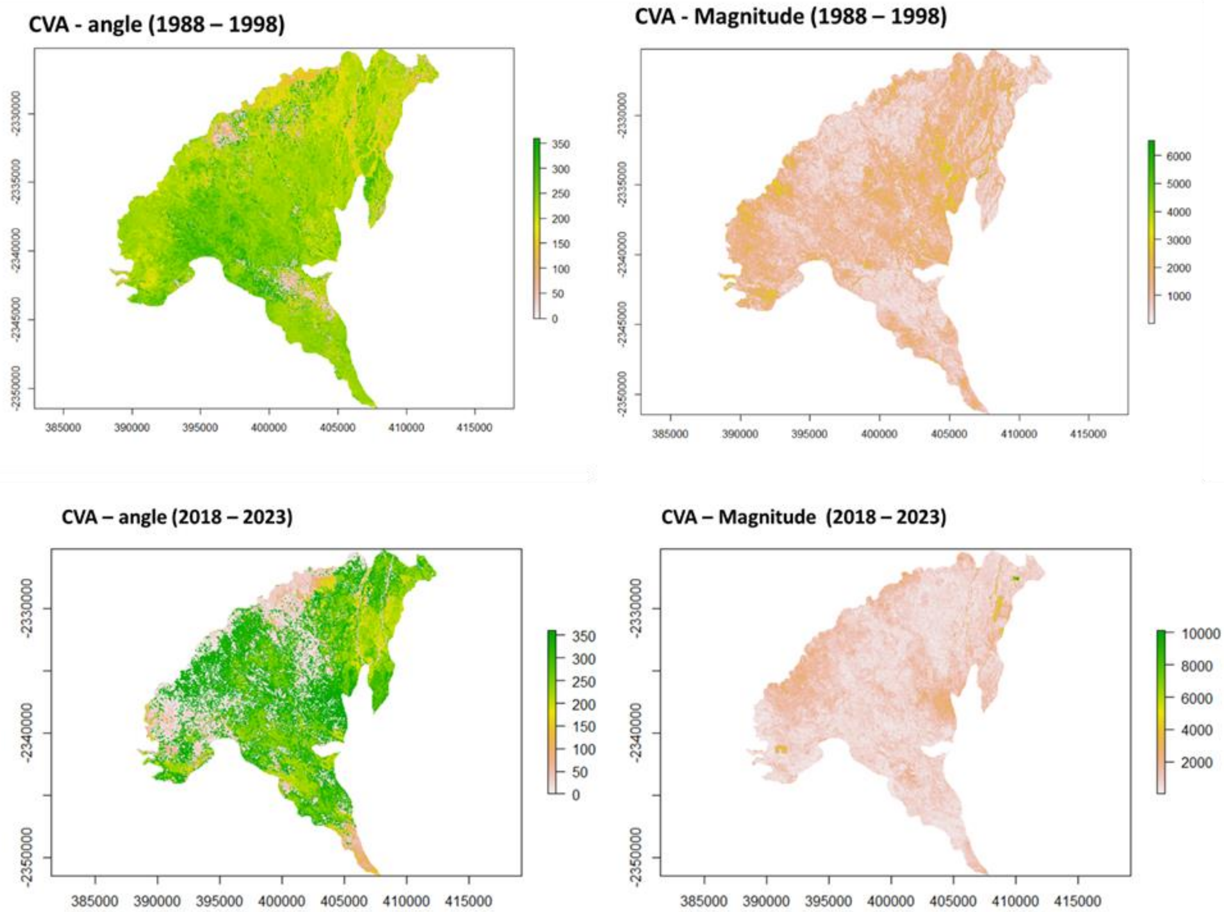

Figure 11. Change vector analysis plots displaying angle and magnitude from 1988 - 1998 and 2018 - 2023.

The angle plot for the 2018 - 2023 change data indicates varying amounts of moisture and vegetation loss around the southern tip of the study area, the coastline in proximity to the homestead and to the west of the river mouth of the Fortescue River. There is also noticeable vegetation loss on the eastern section of the Fortescue River. Moisture and vegetation gain is seen disseminated throughout the centre of the study area. The lower magnitude change is seen more so throughout the boundaries of the study area with a few isolated high magnitude zones dispersed in proximity to the Fortescue River. With more isolated high magnitude zones and less lower magnitude zones indicates more effective control methods with less distribution from livestock.

Multidate classification was completed on both the 1988 - 1998 and 2018 - 2023 change data plots which separated the pixel values into 4 classes. Seen in figure 12, the areas of moisture gain and moisture lost seen in the angle plot (figure 11) is represented as best with the soil/soil and mesquite/soil classes. A lot of the data with angle values ~270 are classified as soil/mesquite with values ~350 classified as mesquite/mesquite. Magnitude values <2000 also reflects the distribution soil/mesquite class. With some of the higher angle values >270, not fully representative of the mesquite/mesquite classification it is likely that there were mesquite populations already prevalent in the same areas identified in the change vector analysis. Most of the mesquite populations are associated with waterbodies, with an increase in change from soil to mesquite the areas surrounding.

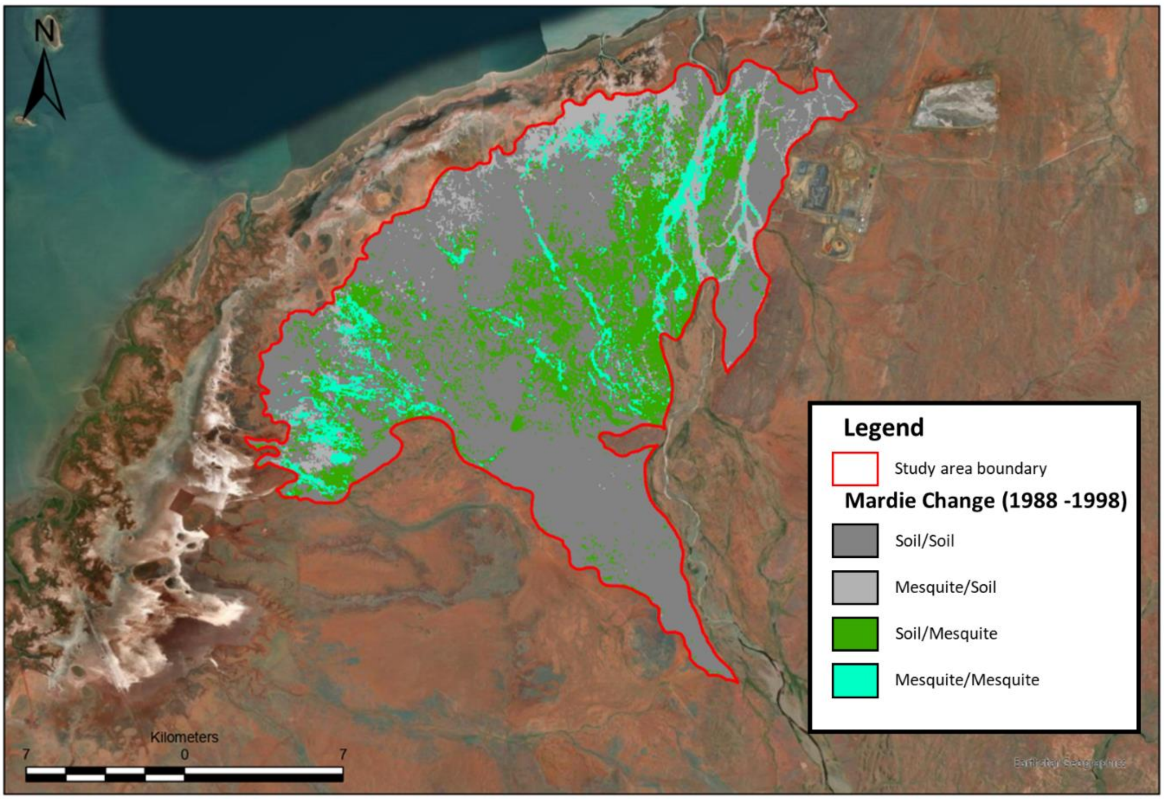

Figure 12. Multidate classification of change data between 1988 - 1998.

In comparison to figure 12, the change identified between 2018 - 2023 was an increase in soil/mesquite and a decrease in mesquite/mesquite. Still prevalent around the Fortescue River the mesquite/mesquite populations have declined along the coastline, in particularly in proximity to the homestead. More mesquite populations have formed in the southern point of the study area, in proximity to a bend of the Fortescue River, although the central part which had increases in soil/mesquite between 1988 - 1998 has declined between waterbodies. Similar trends are seen with the magnitude plots, where the lower values are distributed in similar patterns to the soil/mesquite classification.

The statistics from the two figures (figure 12 and 13) were quantified and portrayed in the bar graph seen in figure 14. The recorded change for mesquite/mesquite between 1988 and 1998 was 2044 hectares, mesquite/soil was 2183 hectares, soil/mesquite was 5632 hectares and soil/soil was 16,425 hectares. The change in area recorded for mesquite/mesquite between 2018 - 2023 was 1686 hectares, mesquite/soil was 2410 hectares, soil/mesquite was 7030 hectares and soil/soil were 15,212 hectares. 2018 - 2023 recorded the most change from mesquite to soil, the lowest mesquite to mesquite, the second highest increase of soil to mesquite and the second highest soil to soil. 1988 - 1998 recorded the lowest mesquite to soil and soil to mesquite and the highest mesquite to mesquite, and soil to soil.

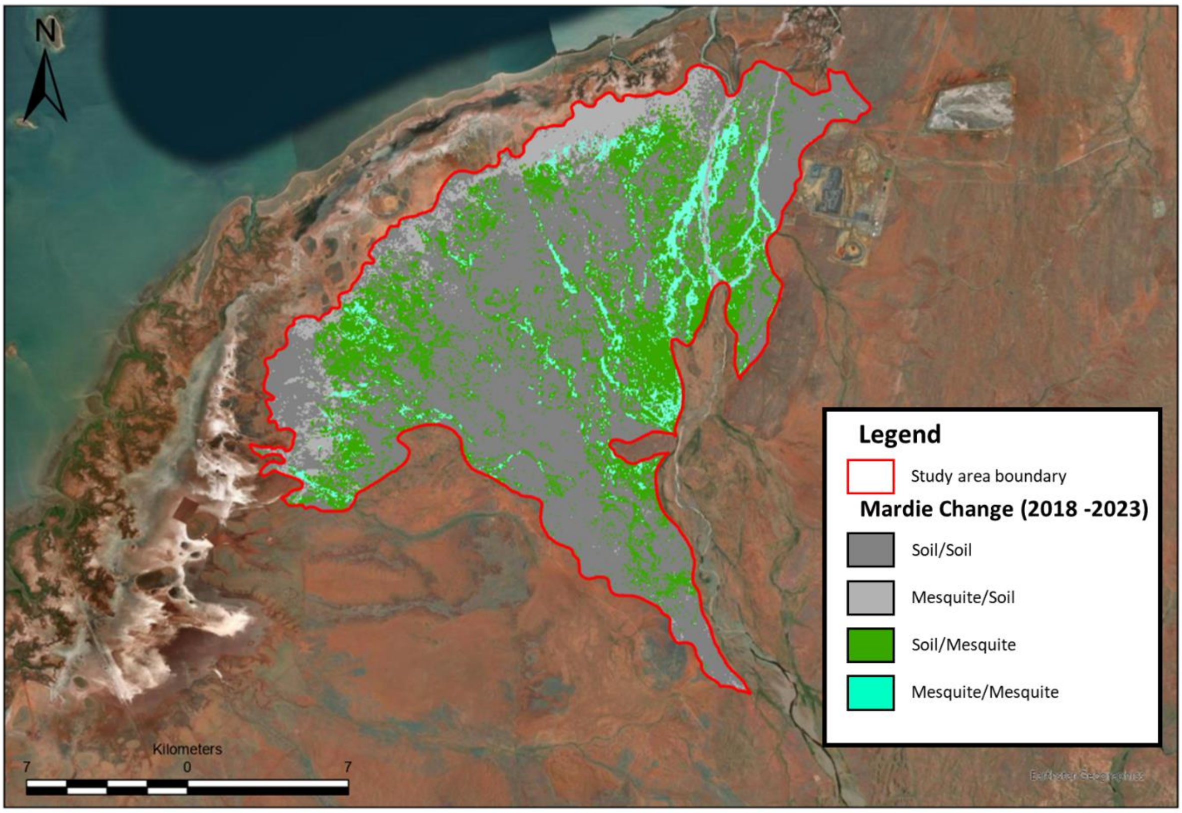

Figure 13. Multidate classification of change data between 2018 - 2023.

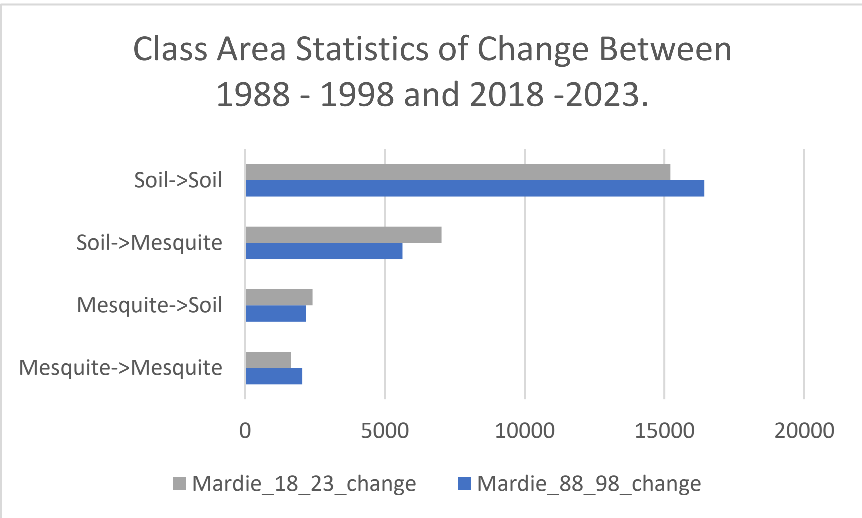

Figure 14. Class Area Statistics of Change Between 1988 – 1998 and 2018 - 2023.

4. Discussion

A NDVI plot does not minimise the artifacts created from soil background, it does plot heavy vegetated areas well as they appear overly saturated, this creates clear boundaries for this analysis, as sparse vegetation which is typical of native Pilbara bushland is less likely associated with the high saturated zones. This needs to be considered as disseminated vegetation throughout may record lower values due to the index used. For example, new growth recording values between 0 - 0.15 seen in 2008 (figure 8C), does indicate that the vegetation is stressed, although this is primary seen distributed throughout areas which were previously bare soil, therefor due to resolution and index, the value for this vegetation is not as representative as the clusters around the river systems. Water (river systems) are identified easily using the NDVI, as NIR is absorbed by water therefor the red band value is higher. Values that are less than 0 (negative) can be classified as water. The re-emission of the sun's energy is dependent on the amount of chlorophyll in the plant, stressed plants are not making enough chlorophyll and therefor have more red band reflected. NDVI compares the two bands to determine the relative biomass. Green leaves strongly reflect NIR, values of 1 indicate the health of that of a rainforest and anything close to that as a healthy plant, stressed plants record values closer to 0. The healthiest vegetation zones found in the NDVI plots compiled with Landsat 5 (figure 8A, B) is that in association with the Fortescue River and along the coast, these are areas recording values <0.3. This presence of Mesquite is relatively healthy, as noted in the summary of the study area, it is ideally located along the floodplain of the Fortescue, on heavy alluvial clays and saline muds. The NDVI plot compiled with Landsat 8 (figure 8D, E) data show dispersion throughout the central parts of the study area, are likely caused by livestock related outbreaks, as seen in the NDVI plots, they range around 0.15 which is classified as unhealthy vegetation. Overall, the biological control looks to have been effective, as the vegetation is more stress in the 2008 plot, then significantly reduced in the 2018 and 2023 plots. Additional work from 2008 to present time is apparent as the floodplain of the Fortescue River is more representative of stressed vegetation and bare soil and the distribution throughout is less dense.

The change plots (figure 9) indicate prevalent infestation around the farmstead and an increase in population throughout the central region. This can be further confirmed by plot C) from 2008, displaying similar distribution of vegetation with the increased infestation areas from 1988 - 1998. This would be a direct result from distribution through livestock and distribution from Cyclone Monty. The material that was dense around the Fortescue River before 1988 did not change over the following decade. The change plot for the 2018 - 2023 period displays isolated infestations along the Fortescue

River. The increase in infestations trends seen in the 1988 - 1998 data do not appear in the 2018 - 2023 change plot. As seen in the 2018 - 2023 change plot, management techniques have shown effective mitigation techniques, isolating the invasion points to isolated areas around the Fortescue River. The great variation in magnitude and change seen from 2018 – 2023 to all the data prior is in relation to the management systems put in place over the last 15 years, which will be covered in the following paragraphs. Finally, both periods 1988 - 1998 and 2018 - 2023 recorded net positive vegetation cover change, as seen in the histogram. Looking at the distribution patterns of the change plots, it is likely that the change is related to mesquite invasion associated with waterbodies including water stations for livestock as they are distributed in high concentration clusters. A net positive vegetation cover does not indicate that the weed is not being supressed, it may just be associated to dense or low risk zones. It does indicate that it is unlikely to recover areas which are dense, and that control should be in relation to containment and isolation rather than population control.

Figure 11 displayed vegetation loss in proximity to the Fortescue River, along the coastline, at the southern tip of the study area and to the west of the homestead. Vegetation gain was dispersed throughout at low magnitude with clusters, in proximity to the Fortescue River and along the coastline. Moisture gain is prevalent throughout the 1988 - 1998 map, where as a lot of these locations are considered vegetation gain in the 2018 - 2023 map. The only distribution trend that can be inferred from this map is a location of vegetation loss, a section of coastline west of the Fortescue River that registered vegetation loss, has also recorded vegetation loss in 2023. Which could indicate that this area is prone to seasonal patterns. It is likely that the distribution patterns of magnitude seen in the 1988 – 1998 plot is related to livestock as it primarily resides in grazing fields, which looks to have been minimised in the 2018 – 2023 plot. It can also be a fair assessment to assign the Fortescue floodplain to be at risk of invasion, although exact locations at risk can't be identified in a change vector analysis. Increases in magnitude around existing infestation sites does indicate successful growth patterns in these areas. To forecast trend patterns to determine angle and magnitude from the present onwards, the increase of dataset to include annual change or change over 2 - 5-year periods would more accurately reflect the health and growth patterns of the weed.

The multidate change classification provided valuable information on what the true representative data of change is of the study area over the two change periods. To determine if the changes are the result of good control methods, it is important to discuss what methods were used over those time periods.

The control methods used between the 1950s - 1980s began with the use of chemical spray (2,4,5-Trichlorophenoxyacetic acid), this was ineffective against mature plants (Robinson, Van Klinken, & Metternicht, 2008). Basel barking along with diesel was applied to the weeds, which was very effective although it was at a high cost, due to the required work force needed to treat the infestation along with the price of diesel and herbicide (Robinson, Van Klinken, & Metternicht, 2008). Large scale mechanical treatment was used in the late 1950s on the denser mesquite thickets, using bulldozers and ploughs results were initially positive (Robinson, Van Klinken, & Metternicht, 2008). Although over the following three decades leading into the 1980s the recovery of infested land and spreading was not achieved (Robinson, Van Klinken, & Metternicht, 2008).

The eradication of Mesquite in the Pilbara is now identified as unachievable. The Pilbara mesquite management committee, formed in April of 2002, is primarily focused on the prevention of further infestation outside of Mardie Station (Australian Association of Bush Regenerators, 2003), ideally isolating the spread to just the one farm. Since 2000, there has been a 2 km wide containment line around the current infestation. The station staff quarantine livestock in designated paddocks if Mesquite has been consumed, making sure that the weed is isolated before it is passed through the gut before release. Additionally thorough cleaning is done to the heavy machinery that is used at the station (Australian Association of Bush Regenerators, 2003). The staff also works alongside the Conservation Volunteers Australia to chemically treat mesquite that is in proximity of the containment line or that is likely to break beyond the boundary of the station (Australian Association of Bush Regenerators, 2003).

Between the years 2007 to 2009 Rangelands NRM ran a project on mesquite management (Pilbara Mesquite Management Committee, n.d.). This project identified fire not being an appropriate control tool for hybrid species present at Mardie Station, as the fuel load required is not achievable to effectively remove the weed. The biological control reduced annual flower production over 49% and mature pod production by 9% within the first 6 years of introduction (Pilbara Mesquite Management Committee, n.d.). The high concentration areas of mesquite still have plants which produce large amounts of viable seed pods in areas which sustain high levels of the leaf moth. It was recorded that the seed banks of mesquite hybrids found in the soil profile at Mardie Station were in association with the watering points for livestock and the animal tracks. There was little identified associated with the infestation zones (Pilbara Mesquite Management Committee, n.d.). Between 2010 and 2012 there has been focus on mechanical control for hybrid mesquite using front mounted blade ploughs, using a

10,000-hectare area on Mardie Station, 17 photographic monitoring sites were established to use the plough on hybrid species (Pilbara Mesquite Management Committee, n.d). With funding from Citic Pacific Mining and pastoral management from Mardie Station created a herbicide control program, which commenced in 2011 with a 10 year commitment put in place Pilbara Mesquite Management Committee, n.d). Using a phenoxyacetic acid herbicide (BCI Minerals, 2019) data was recorded from the first 4 years of use, recording a total area of treatment over this period at ~20,000 hectares, controlling ~435,000 mesquite plants, this study also treated Parkinsonia (a similar weed species), between the two weed types, over 489,000 plants were killed (Pilbara Mesquite Management Committee, n.d). Currently, the goal for the station is to reduce and maintain densities of the weeds in the Fortescue Catchment area by 2025 and continue surveillance (Greening Australia, 2018). Nqurrawaana Rangers have used dieback fungus on weeds along the Fortescue River as early as 2017 (Greening Australia, 2018). Sections of Robe River, on the Mardie station has noted extensive infestation from the Yarraloola (neighbouring farm) – Mardie Boundary to the coastline, there has been no active management plan as the area is remote (Greening Australia, 2018), there is high chances of seed spreading due to proximity of infestation with river catchment. With the Robe River on the Yarraloola Station being actively controlled with chemicals, the risks of seeds moving downstream are limited. The control efforts along these boundaries at the time of publication (Greening Australia, 2018), indicate that the control efforts along the buffer zones between the two stations have resulted in a reduction of Mesquite. Suggesting current methods are working well to contain the infestations.

There was more change seen between 1988 to 1998 (figure 12) with soil to mesquite than mesquite to soil by more than double the hectares which follow trends related to livestock distribution. Change from mesquite to mesquite over the 1988 – 1998 period was 2044 hectares, which are likely the highest density zones around the Fortescue River and Farmstead. This is also seen in the figure 13 for the period of change between 2018 – 2023, where the mesquite-to-mesquite areas are in proximity to river systems which are unable to contain, the amount of overall mesquite to mesquite change has decreased between the two analysed time periods with the 2023 change indicating 1686 hectares. Mesquite to soil was higher in the 2018 – 2023 period at 2410 hectares, this is likely due to the leaf moth and the areas in proximity to the boundary or at risk of spreading to the buffer zone created in the early 2000s. Soil to mesquite is recorded at 5632 hectares between 1988 to 1998, whereas in the 2018 – 2023 period was 7030 hectares. This may be in relation to updated management plans, as there is a primary focus on reducing risk of outbreak on surrounding farms rather than reducing populations on Mardie Station. This resulted in an increase of Mesquite in high density areas, as the high concentration areas can still produce large amounts of viable seed pods with the biological controls present, this can be identified visually in figure 13, as the mesquite/mesquite areas are located around the Fortescue River. Figure 14 summarised the total gain and loss of the four classes. Out of the 26,284 hectares used in the 1988 - 1998 classification, 62.5% of the land was recorded as soil/soil. Out of the 26,338 hectares used in the 2018 -2023 classification, 57.8% of the land was recorded as soil/soil. Looking at the mesquite to soil classification in figures 12 and 13, there is clear evidence that populations are decreasing along the coastline boundary, although there is more soil to mesquite change disseminated throughout the study area in 2023, which will be important to monitor as it likely related to livestock distribution through consumption, although they are less likely to contribute to contamination of other farms than the dense infestations around the floodplains, on the clay and mud soil types or around the station boundaries.

5. Conclusion

Using multiple change detection methods, 4 decades of Mardie Stations long history were analysed to further understand the nature of mesquite and other hybrid weed species in the area. The period analysed between 1988 - 1998 marked the end of over half a century of attempts to control the infestations prevalent along the Fortescue River and throughout the coast of Mardie Station. The dominant trends of this period were that of dense mesquite populations in the floodplains. As time progressed, the biological controls were seen in effect in the 2008 data which displayed stressed vegetation, with NDVI trends continuing to 2023 with vegetation stress increasing. At present time, mesquite is distributed primarily though livestock, as the biological control, herbicide programs and diligent farm management systems have effectively kept populations from increasing and invading other sections of the Pilbara. With image differencing and change vector analysis the habits of the invasive species over that period involved the infestation of new land surrounding already prevalent infestation zones with regressions taking place along the boundaries closest to the Indian Ocean. Utilising livestock and weather patterns, the species can traverse the Station following either the patterns of the water feeders or the floodplains of the Fortescue River. This is further confirmed in the periods from 2008 - 2023, with the same dense infestations along the Fortescue River and the appearance of new mesquite dispersed throughout the study area. With significant funding from the government, mining and agricultural industries, there have been multiple studies done over the last 15 years to understand the best practices to apply to mitigating the risk of outbreak outside of Mardie Station. These projects are key contributors to the success, along with the use of biological controls to understand how to deal with large scale infestation. With the acknowledgement of not being able to reclaim the land lost to dense infestation, the implementation of grazing techniques along with the appropriate teaching and support to the staff at the station, and the maintenance of the 2 km safe zone is the most effective ongoing control technique to mitigate further spread. There is always going to potential of a spreading event to occur in the future, as the coastline is prone to flooding therefore preparation should be done on a case-by-case basis as the area is historically known to have significant cyclone events every few decades. With continued contributions from mining, pastoral management and government bodies, mesquite should be effectively limited within the boundaries of Mardie Station.

6. References

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7. Appendix

R Code

```
library(RStoolbox)

> library(raster)

Loading required package: sp

> library(sf)

Linking to GEOS 3.9.3, GDAL 3.5.2, PROJ 8.2.1; sf_use_s2() is TRUE

Warning message:

package ‘sf’ was built under R version 4.2.3

> library(ggplot2)

> library(rgdal)

Please note that rgdal will be retired during 2023,

plan transition to sf/stars/terra functions using GDAL and PROJ

at your earliest convenience.
```

See https://r-spatial.org/r/2022/04/12/evolution.html and https://github.com/r-spatial/evolution

rgdal: version: 1.6-5, (SVN revision 1199)

Geospatial Data Abstraction Library extensions to R successfully loaded

Loaded GDAL runtime: GDAL 3.5.2, released 2022/09/02

Path to GDAL shared files: C:/Users/barle/AppData/Local/R/win-library/4.2/rgdal/gdal

GDAL binary built with GEOS: TRUE

Loaded PROJ runtime: Rel. 8.2.1, January 1st, 2022, [PJ_VERSION: 821]

Path to PROJ shared files: C:/Users/barle/AppData/Local/R/win-library/4.2/rgdal/proj

PROJ CDN enabled: FALSE

Linking to sp version:1.6-0

To mute warnings of possible GDAL/OSR exportToProj4() degradation,

use options("rgdal_show_exportToProj4_warnings"="none") before loading sp or rgdal.

```
> wd<-setwd("C:/Users/barle/OneDrive/Desktop/Data/88")
>
> wd<-setwd("C:/Users/barle/OneDrive/Desktop/Data/88")
> a1<-brick('LT05_L2SP_114075_19880218_20200917_02_T1_SR_B1.tif')
> a2<-brick('LT05_L2SP_114075_19880218_20200917_02_T1_SR_B2.tif')
> a3<-brick('LT05_L2SP_114075_19880218_20200917_02_T1_SR_B3.tif')
> a4<-brick('LT05_L2SP_114075_19880218_20200917_02_T1_SR_B4.tif')
> a5<-brick('LT05_L2SP_114075_19880218_20200917_02_T1_SR_B5.tif')
> a6<-brick('LT05_L2SP_114075_19880218_20200917_02_T1_ST_B6.tif')
> a7<-brick('LT05_L2SP_114075_19880218_20200917_02_T1_SR_B7.tif')
>
> eighteight<-stack(a1,a2,a3,a4,a5,a6,a7)
> plotRGB(eighteight, r = 3, g = 2, b = 1, stretch = "lin")
>
> wd<-setwd("C:/Users/barle/OneDrive/Desktop/Data/98")
> wd<-setwd("C:/Users/barle/OneDrive/Desktop/Data/98")
>
> b1<-brick('LT05_L2SP_114075_19980402_20200909_02_T1_SR_B1.tif')
> b2<-brick('LT05_L2SP_114075_19980402_20200909_02_T1_SR_B2.tif')
```

```
> b3<-brick('LT05_L2SP_114075_19980402_20200909_02_T1_SR_B3.tif')
> b4<-brick('LT05_L2SP_114075_19980402_20200909_02_T1_SR_B4.tif')
> b5<-brick('LT05_L2SP_114075_19980402_20200909_02_T1_SR_B5.tif')
> b6<-brick('LT05_L2SP_114075_19980402_20200909_02_T1_ST_B6.tif')
> b7<-brick('LT05_L2SP_114075_19980402_20200909_02_T1_SR_B7.tif')
>
> nineeight<-stack(b1,b2,b3,b4,b5,b6,b7)
> plotRGB(nineeight, r = 3, g = 2, b = 1, stretch = "lin")
>
>
> wd<-setwd("C:/Users/barle/OneDrive/Desktop/Data/08")
> wd<-setwd("C:/Users/barle/OneDrive/Desktop/Data/08")
>
> c1<-('LT05_L2SP_114075_20080209_20200829_02_T1_SR_B1.tif')
> c2<-('LT05_L2SP_114075_20080209_20200829_02_T1_SR_B2.tif')
> c1<-brick('LT05_L2SP_114075_20080209_20200829_02_T1_SR_B1.tif')
> c2<-brick('LT05_L2SP_114075_20080209_20200829_02_T1_SR_B2.tif')
> c3<-brick('LT05_L2SP_114075_20080209_20200829_02_T1_SR_B3.tif')
> c4<-brick('LT05_L2SP_114075_20080209_20200829_02_T1_SR_B4.tif')
> c5<-brick('LT05_L2SP_114075_20080209_20200829_02_T1_SR_B5.tif')
> c6<-brick('LT05_L2SP_114075_20080209_20200829_02_T1_ST_B6.tif')
> c7<-brick('LT05_L2SP_114075_20080209_20200829_02_T1_SR_B7.tif')
>
> zeroeight<-stack('c1,c2,c3,c4,c5,c6,c7')
Error in .rasterObjectFromFile(x, objecttype = "RasterBrick", ...) :
  Cannot create a RasterLayer object from this file. (file does not exist)
In addition: Warning message:
c1,c2,c3,c4,c5,c6,c7: No such file or directory (GDAL error 4)
> zeroeight<-stack(c1,c2,c3,c4,c5,c6,c7)
>
>
```

```
> wd<-setwd("C:/Users/barle/OneDrive/Desktop/Data/18")
> wd<-setwd("C:/Users/barle/OneDrive/Desktop/Data/18")
>
> d1<-brick('LC08_L2SP_114075_20180220_20200902_02_T1_SR_B1.tif')
> d2<-brick('LC08_L2SP_114075_20180220_20200902_02_T1_SR_B2.tif')
> d3<-brick('LC08_L2SP_114075_20180220_20200902_02_T1_SR_B3.tif')
> d4<-brick('LC08_L2SP_114075_20180220_20200902_02_T1_SR_B4.tif')
> d5<-brick('LC08_L2SP_114075_20180220_20200902_02_T1_SR_B5.tif')
> d6<-brick('LC08_L2SP_114075_20180220_20200902_02_T1_SR_B6.tif')
> d7<-brick('LC08_L2SP_114075_20180220_20200902_02_T1_SR_B7.tif')
>
> oneeight<-stack(d1,d2,d3,d4,d5,d6,d7)
>
> plotRGB(zeroeight, r = 3, g = 2, b = 1, stretch = "lin")
> plotRGB(oneeight, r = 3, g = 2, b = 1, stretch = "lin")
>
>
>
> e1<-brick('LC08_L2SP_114075_20230218_20230223_02_T1_SR_B1.tif')
> e2<-brick('LC08_L2SP_114075_20230218_20230223_02_T1_SR_B2.tif')
> e3<-brick('LC08_L2SP_114075_20230218_20230223_02_T1_SR_B3.tif')
> e4<-brick('LC08_L2SP_114075_20230218_20230223_02_T1_SR_B4.tif')
> e5<-brick('LC08_L2SP_114075_20230218_20230223_02_T1_SR_B5.tif')
> e6<-brick('LC08_L2SP_114075_20230218_20230223_02_T1_SR_B6.tif')
> e7<-brick('LC08_L2SP_114075_20230218_20230223_02_T1_SR_B7.tif')
>
> twothree<-stack(e1,e2,e3,e4,e5,e6,e7)
> plotRGB(twothree, r = 3, g = 2, b = 1, stretch = "lin")


> crop_extent<-extent(388366, 412378.3, -2351449, -2325259)
```

```
>
> Mardie88<-crop(eighteight, crop_extent)
> Mardie98<-crop(nineeight, crop_extent)
> Mardie08<-crop(zeroeight, crop_extent)
> Mardie18<-crop(oneeight, crop_extent)
> Mardie23<-crop(twothree, crop_extent)

> ed<-setwd("C:\Users\barle\OneDrive\Desktop\Data")
Error: '\U' used without hex digits in character string starting ""C:\U"
> ed<-setwd("C:/Users/barle/OneDrive/Desktop/Data")
> wd<-setwd("C:/Users/barle/OneDrive/Desktop/Data")
> wd<-setwd("C:/Users/barle/OneDrive/Desktop/Data")
>
> yamerina<-st_read('boundary1.shp')
Reading layer `boundary1' from data source
`C:\Users\barle\OneDrive\Desktop\Data\boundary1.shp' using driver `ESRI Shapefile'
Simple feature collection with 1 feature and 1 field
Geometry type: POLYGON
Dimension:     XY
Bounding box:  xmin: 388366.6 ymin: -2351449 xmax: 412378.3 ymax: -2325259
Projected CRS: WGS 84 / UTM zone 50N
> Mardie88<-mask(Mardie88, yamerina)
> Mardie98<-mask(Mardie98, yamerina)
> Mardie08<-mask(Mardie08, yamerina)
> Mardie18<-mask(Mardie18, yamerina)
> Mardie23<-mask(Mardie23, yamerina)
> plotRGB(Mardie88, r = 7, g = 4, b = 1, stretch = "lin")
>
> plotRGB(Mardie98, r = 7, g = 4, b = 1, stretch = "lin")
>
> plotRGB(Mardie08, r = 7, g = 4, b = 1, stretch = "lin")
```

```
>

> plotRGB(Mardie18, r = 7, g = 4, b = 1, stretch = "lin")

>

> plotRGB(Mardie23, r = 7, g = 4, b = 1, stretch = "lin")


> Mardie88_msk<-mask(Mardie88, yamerina)

> Mardie98_msk<-mask(Mardie98, yamerina)

> Mardie08_msk<-mask(Mardie08, yamerina)

> Mardie18_msk<-mask(Mardie18, yamerina)

> Mardie23_msk<-mask(Mardie23, yamerina)

> wd<-setwd("C:/Users/barle/OneDrive/Desktop/Data/Mask")

> wd<-setwd("C:/Users/barle/OneDrive/Desktop/Data/Mask")

>

> writeRaster(Mardie88_boa_msk, filename="Mardie88_boa_msk.tif",
options="INTERLEAVE=BAND",overwrite=TRUE)

Error in h(simpleError(msg, call)) :

  error in evaluating the argument 'x' in selecting a method for function 'writeRaster': object
'Mardie88_boa_msk' not found

> writeRaster(Mardie88_msk, filename="Mardie88_msk.tif",
options="INTERLEAVE=BAND",overwrite=TRUE)

>

> writeRaster(Mardie98_msk, filename="Mardie98_msk.tif",
options="INTERLEAVE=BAND",overwrite=TRUE)

> writeRaster(Mardie08_msk, filename="Mardie08_msk.tif",
options="INTERLEAVE=BAND",overwrite=TRUE)

> writeRaster(Mardie18_msk, filename="Mardie18_msk.tif",
options="INTERLEAVE=BAND",overwrite=TRUE)

> writeRaster(Mardie23_msk, filename="Mardie23_msk.tif",
options="INTERLEAVE=BAND",overwrite=TRUE)

> Mardie88_msk<-brick('Mardie88_msk.tif')

> Mardie98_msk<-brick('Mardie98_msk.tif')

> Mardie08_msk<-brick('Mardie08_msk.tif')

> Mardie18_msk<-brick('Mardie18_msk.tif')
```

```
> Mardie23_msk<-brick('Mardie23_msk.tif')

> Mardie88.NDVI<-(Mardie88_msk$layer.4 - Mardie88_msk$layer.3) / (Mardie88_msk$layer.4 + Mardie88_msk$layer.3)

> plot(Mardie88.NDVI)

> Mardie98.NDVI<-(Mardie98_msk$layer.4 - Mardie98_msk$layer.3) / (Mardie98_msk$layer.4 + Mardie98_msk$layer.3)

> plot(Mardie98.NDVI)

> Mardie08.NDVI<-(Mardie08_msk$layer.4 - Mardie08_msk$layer.3) / (Mardie08_msk$layer.4 + Mardie08_msk$layer.3)

> plot(Mardie08.NDVI)

> Mardie18.NDVI<-(Mardie18_msk$layer.4 - Mardie18_msk$layer.3) / (Mardie18_msk$layer.4 + Mardie18_msk$layer.3)

> plot(Mardie18.NDVI)

> > Mardie18.NDVI<-(Mardie18_msk$layer.4 - Mardie18_msk$layer.3) / (Mardie18_msk$layer.4 + Mardie18_msk$layer.3)

> plot(Mardie18.NDVI)

> NDVI_88<-Mardie88.NDVI +1

> NDVI_98<-Mardie98.NDVI +1

> NDVI_08<-Mardie08.NDVI +1

> NDVI_18<-Mardie18.NDVI +1

> NDVI_23<-Mardie23.NDVI +1

>

> NDVI_change<-(NDVI_98)-(NDVI_88)

> NDVI_change_prior<-(NDVI_98)-(NDVI_88)

> NDVI_change_post<-(NDVI_18)-(NDVI_08)

> plot(NDVI_change_prior)

> plot(NDVI_change_post)

> hist(NDVI_change_prior)

> hist(NDVI_change_prior)

> hist(NDVI_change_prior)

> hist(NDVI_change_post)

> hist(NDVI_change_prior)
```

```
> cva<-rasterCVA(Mardie88_msk[[3:4]], Mardie98_msk[[3:4]])
>
> cva1<-rasterCVA(Mardie08_msk[[3:4]], Mardie98_msk[[4:5]])
>
>
> plot(cva$angle)
> plot(cva1$angle)
> plot(cva$magnitude)
> plot(cva1$magnitude)
>
> cva<-rasterCVA(Mardie88_msk[[3:4]], Mardie98_msk[[3:4]])
> plot(cva$angle)
> plot(cva1$angle)
> plot(cva$angle)
> plot(cva$magnitude)
>
>
> NDVI_18<-Mardie18.NDVI +1
> NDVI_23<-Mardie23.NDVI +1
> NDVI_change_landsat8<-(NDVI_18)-(NDVI_23)
> plot(NDVI_change_landsat8)
> hist(NDVI_change_landsat8)
> hist(NDVI_change_landsat8)
>
>
> cva2<-rasterCVA(Mardie18_msk[[4:5]], Mardie23_msk[[4:5]])
>
> plot(cva2$angle)
> plot(cva2$magnitude)

> wd<-setwd("C:/Users/barle/OneDrive/Desktop/Data/Training")
```

```
> wd<-setwd("C:/Users/barle/OneDrive/Desktop/Data/Training")
>
> mesquite_classes<-readOGR(dsn = ".", layer = "training")
OGR data source with driver: ESRI Shapefile
Source: "C:\Users\barle\OneDrive\Desktop\Data\Training", layer: "training"
with 8453 features
It has 2 fields
Integer64 fields read as strings:  ID
Warning messages:
1: OGR support is provided by the sf and terra packages among others
2: OGR support is provided by the sf and terra packages among others
3: OGR support is provided by the sf and terra packages among others
4: OGR support is provided by the sf and terra packages among others
5: OGR support is provided by the sf and terra packages among others
6: OGR support is provided by the sf and terra packages among others
> plot(mesquite_classes)
> ourClasses<-unique(mesquite_classes$class)
> ourClasses
[1] "mesquite_mesquite" "soil_mesquite"     "mesquite_soil"     "soil_soil"
> set.seed(100)
> for (i in 1:length(ourClasses)) {
+ class<-subset(mesquite_classes, mesquite_classes$class == ourClasses[i])
+ classpts<-spsample(class, type = "random", n = 1000)
+
+ classpts$class<-rep(ourClasses[i], length(classpts))
+
+ if (i == 1) {
+ training<-classpts }
+ else {
+ training<-rbind(training, classpts)
+ }}
```

```
> show(training)
class       : SpatialPointsDataFrame
features    : 4000
extent      : 388389.7, 412256.6, -2350973, -2325499  (xmin, xmax, ymin, ymax)
crs         : +proj=utm +zone=50 +datum=WGS84 +units=m +no_defs
variables   : 1
names       :             class
min values  : mesquite_mesquite
max values  :         soil_soil
>
> wd<-setwd("C:/Users/barle/OneDrive/Desktop/Data/Mask")
> wd<-setwd("C:/Users/barle/OneDrive/Desktop/Data/Mask")
>
> Mardie88_msk<-brick('Mardie88_msk.tif')
> Mardie98_msk<-brick('Mardie98_msk.tif')
> Mardie08_msk<-brick('Mardie08_msk.tif')
> Mardie18_msk<-brick('Mardie18_msk.tif')
> Mardie23_msk<-brick('Mardie23_msk.tif')
> Mardie88_msk<-dropLayer(Mardie88_msk, "layer.6")
> Mardie98_msk<-dropLayer(Mardie98_msk, "layer.6")
> Mardie08_msk<-dropLayer(Mardie08_msk, "layer.6")
> Mardie18_msk<-dropLayer(Mardie18_msk, "layer.6")
> Mardie23_msk<-dropLayer(Mardie23_msk, "layer.6")
> wd<-setwd("C:/Users/barle/OneDrive/Desktop/Data/Training")
> wd<-setwd("C:/Users/barle/OneDrive/Desktop/Data/Training")
>
> Mardie_88_98<-stack(Mardie88_msk, Mardie98_msk)
> Mardie_08_08<-stack(Mardie08_msk, Mardie18_msk)
>
> Mardie_88_98_change<-superClass(Mardie_88_98, model = "rf", trainData = training, responseCol
= "class")
```

```
Loading required package: lattice

>

> Mardie_08_18<-stack(Mardie08_msk, Mardie18_msk)

> Mardie_08_18_change<-superClass(Mardie_08_18, model = "rf", trainData = training, responseCol = "class")

> Mardie_18_23<-stack(Mardie18_msk, Mardie23_msk)

> Mardie_18_23_change<-superClass(Mardie_18_23, model = "rf", trainData = training, responseCol = "class")>


> plot(Mardie_88_98_change$map)

> plot(Mardie_08_18_change$map)

> plot(Mardie_18_23_change$map)


> writeRaster(Mardie_88_98_change$map, filename="Mardiechange_Prior99.tif", options="INTERLEAVE=BAND", overwrite=TRUE)

> writeRaster(Mardie_08_18_change$map, filename="Mardiechange_post99.tif", options="INTERLEAVE=BAND", overwrite=TRUE)

> writeRaster(Mardie_18_23_change$map, filename="Mardiechange_2023.tif", options="INTERLEAVE=BAND", overwrite=TRUE)

>

> Mardie_88_98_change.freq<-freq(Mardie_88_98_change$map, useNA = "no")

> Mardie_88_98_change.freq[,"count"] * 30^2/10000

[1]  2044.44  2183.67  5632.74 16425.81

> Mardie_08_18_change.freq<-freq(Mardie_08_18_change$map, useNA = "no")

> Mardie_08_18_change.freq[,"count"] * 30^2/10000

[1]  1686.06  2325.78  8015.85 14258.97

Mardie_18_23_change.freq<-freq(Mardie_18_23_change$map, useNA = "no")

> Mardie_18_23_change.freq[,"count"] * 30^2/10000

[1]  1633.05  2410.56  7030.35 15212.70
```