A comparative study of raster and vector based approaches in vegetation mapping on Five Islands off the coast of Port Kembla.

P B. Barlow

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A comparative study of raster and vector based approaches in vegetation mapping on Five Islands off the coast of Port Kembla.

Abstract
Remote sensing has facilitated extraordinary advances in the modelling, mapping and understanding of vegetation in remote Island ecosystems. With the unforgiving responses of Island ecosystems to anthropogenic influences, it is paramount that managerial strategies are put into place and vegetation conditions are quantified. The Five Islands group has an extensive history of anthropogenic alteration, resulting in widespread change in vegetation dynamics. In recent years introduced vegetation has overpopulated Big Island – The largest of the Island Nature Reserve – and made it inhabitable for protected burrowing and nesting seabird populations. As a result NSW National Parks and Wildlife Service (NPWS) are employing a 5-year rehabilitation plan to restore the Islands to their vegetation pre-human interference, in hope of the return of native seabird populations. This project in particular will utilize raster and vector based spatial mapping methodologies to resolve the following management questions: 1) How many Lomandra longifolia seedlings have survived, what is the health of the remaining plants and is there a correlation to distance from invasive Carpobrotus sp. 2) What are ideal Lomandra sp. densitys for areas that still need planting; 3) What vegetation is present on all Five Islands; 4) How effective was the weed treatment And 5) What is the spread of the invasive Carpobrotus sp between 2017 and 2018.

These management queries were answered through the acquisition of aerial imagery with a 4-band UAV drone camera followed by spatial analysis through ArcGIS technologies. Vector based spatial analysis included point digitization of Lomandra sp. as well as polygon digitization of exotic Carpobrotus sp. It was found that Lomandra sp. survival was low (19.74%). The digitization of exotic Carpobrotus sp. in 2017 and 2018 resulted in a calculated growth of 1.89m²/day and a correlation (r=0.47) was found between Lomandra sp. health and distance from Carpobrotus sp. The raster based supervised and unsupervised classifications of vegetation classes on the five Islands led to the distinguishing of vegetation into 5 vegetation classes determined by the dominating species. The weed treatment on Big Island was deemed highly effective with a loss of up to 88.89% of exotic species. Both raster and vector based methodologies were found to offer unique methods to spatially analyse vegetation ground coverage and can ultimately be used to solve broader managerial issues associated with delicate Island ecosystems.

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A comparative study of raster and vector based approaches in vegetation mapping on Five Islands off the coast of Port Kembla.

Pollyanna Beatrice Barlow

23rd October 2018

Submitted in part fulfilment of the requirements of the Honours degree of Bachelor of Science (Advanced)(Honours) in the School of Earth and Environmental Sciences, University of Wollongong 2018.
The information in this thesis is entirely the result of investigations conducted by the author, unless otherwise acknowledged, and has not been submitted in part, or otherwise, for any other degree or qualification.

Pollyanna Beatrice Barlow
23 October 2018
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**Abstract**

Remote sensing has facilitated extraordinary advances in the modelling, mapping and understanding of vegetation in remote Island ecosystems. With the unforgiving responses of Island ecosystems to anthropogenic influences, it is paramount that managerial strategies are put into place and vegetation conditions are quantified. The Five Islands group has an extensive history of anthropogenic alteration, resulting in widespread change in vegetation dynamics. In recent years introduced vegetation has overpopulated Big Island – The largest of the Island Nature Reserve – and made it inhabitable for protected burrowing and nesting seabird populations. As a result NSW National Parks and Wildlife Service (NPWS) are employing a 5-year rehabilitation plan to restore the Islands to their vegetation pre-human interference, in hope of the return of native seabird populations. This project in particular will utilize raster and vector based spatial mapping methodologies to resolve the following management questions: 1) How many *Lomandra longifolia* seedlings have survived, what is the health of the remaining plants and is there a correlation to distance from invasive *Carpobrotus sp.* 2) What are ideal *Lomandra sp.* densitys for areas that still need planting; 3) What vegetation is present on all Five Islands; 4) How effective was the weed treatment And 5) What is the spread of the invasive *Carpobrotus sp* between 2017 and 2018.

These management queries were answered through the acquisition of aerial imagery with a 4-band UAV drone camera followed by spatial analysis through ArcGIS technologies. Vector based spatial analysis included point digitization of *Lomandra sp.* as well as polygon digitization of exotic *Carpobrotus sp.* It was found that *Lomandra sp.* survival was low (19.74%). The digitization of exotic *Carpobrotus sp.* in 2017 and 2018 resulted in a calculated growth of 1.89m²/day and a correlation (r=0.47) was found between *Lomandra sp.* health and distance from *Carpobrotus sp.* The raster based supervised and unsupervised classifications of vegetation classes on the five Islands led to the distinguishing of vegetation into 5 vegetation classes determined by the dominating species. The weed treatment on Big Island was deemed highly effective with a loss of up to 88.89% of exotic species. Both raster and vector based methodologies were found to offer unique methods to spatially analyse vegetation ground coverage and can ultimately be used to solve broader managerial issues associated with delicate Island ecosystems.
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1. Introduction

1.1 Background

The five Islands nature reserve encompasses a small group of islands and islets located 450m offshore from Red point, Port Kembla, New South Wales Australia (Nicholas Carlile, 2017) (Figure 1.1). The island cluster is comprised of Rocky Islet, Bass Islet, Martin Islet, Flinders Island and Big Islands I and II, ranging from 0.5 to 19.8 ha respectively (NSW National Parks and Wildlife Service, 2005). Big Islands I and II are comprised of 10.7 ha of vegetation and are connected by a rocky isthmus that is susceptible to heavy seas. Big Island I is commonly referred to as “Big Island” and will be referred to as such throughout the remainder of this report unless stated otherwise.

1.2 Geology

The islands take on a harsh jagged appearance determined by their volcanic composition and geological history. They are considered a member of the Dapto latite sequence of the Gerringong Volcanic, Shoalhaven Group and consist of Permian volcanic rock (Mills, Illawarra Vegetation Studies. Big Islands, The Five Islands Group, 2015). Each island however varies in geological composition and has been categorized into types A-D shown in figure 1.2 (Chalmers, 1941).

Big Islands I and II are predominantly made up of Type A; Dapto Dolerite portraying a rusted red colour on its weathered surface and a black rock with residuous lustre, glassy feldspar and augite phenocrysts beneath. Type B; Deuterically altered trachybasalt makes up a majority of the remaining portions of Big Islands I and II and is an exposed dark grey colour from the surface (Chalmers, 1941). Type C; makes up small intrusions from the same magma crystallizing under different conditions. A

---

Figure 1.1: Map of Five Islands Nature Reserve off the coast of Port Kembla NSW (Office of Environment and Heritage, 2018)
thick dyke of basaltic nature intrudes the most northern point of Big Island I, which is composed of type D: heavily calcitized trachybasalt and is the only other rock type present on Big Islands I and II.

The Bombo Latite member found on Flinders Islet (figure 1.3) encompasses an assortment of Acid Latite, Devitrified Zeolitized Latite, Vesicular Latite and basic Latite which all occur readily on the Islet with an exception to the basic Latite Member which only occurs sporadically.

Martin and Bass Islets are largely composed of Dapto-Saddleback, a dolerite sequence occurring at varying stages of alteration. Martin Islet is composed of normal trachybasalt with inclusions of entirely black rock containing malachite, magnetite and labradorite stains as well as Copper and metamorphosed plagioclase feldspars. A specimen from Bass Islet however showed only normal trachybasalt and no presence of other rock types (Chalmers, 1941).

Rocky Islet is composed of volcanic sandstones from the Broughton Formation, which also comprise a portion of Big Island (David F. Branagan, 2000) (NSW National Parks and Wildlife Service, 2005). Although high rates of erosion have occurred, the larger sections of the island platforms are covered by relic sand dunes and highly fertile latite soil, resulting in dense plant growth and abundant wildlife.
1.3 Vegetation

1.3.1 Overview and Vegetative History
The Five Islands Group is comprised of four vegetated islands and one barren rocky Islet supporting no terrestrial vegetation due to oceanic and aeolian processes. Big Island alone represents 68% of the total comprising land area of 25.9ha and has been extensively altered due to anthropogenic processes. The smallest island, namely Flinders; and the two Islets, Bass and Martin, are difficult to land on and have been little affected directly by human interaction (Mills, Illawarra Vegetation Studies. Big Islands, The Five Islands Group, 2015). Vegetative Surveys are available for Big Islands No. 1 and No. 2 and Flinders Island. However the three Islets: Bass; Martin and Rocky are too hard to land on and have little published on their current vegetation.

Island ecosystems have proven to be particularly vulnerable to change, whether it is a construct of anthropogenic interference, effect of fire or a natural biological occurrence over time. The characteristics of size shape and degree of isolation result in unique island dynamics, and more often than not result in an interesting vegetative timeline. Big Island has undergone rapid vegetative change since first ecological accounts conducted by Davis et al. (1938). Common native species that were present on the Island in 1983 include *Commelina cyanea* (Scurvy Weed), *Tetragonia tetragonioides* - previously *Tetragonia expansa* (New Zealand Spinach), *Lomandra longifolia* (Spiny-head Mat-rush) (figure 1.4), *Phragmites communis* (Common Reed) and *Ficinia nodosa* - previously *Scirpus nodosu* (Knotted Club-rush).
Invasive species such as *Stenotaphrum secundatum* (Buffalo grass) were found to be abundant on the Island followed by *Phytolacca octandra* (Inkweed) and *Opuntia stricta* – previously *Opuntia inermis* (Prickly Pear) (figure 1.5). A total of 58 species of vegetation were recorded by Davis et al. on Big Island, 40 of which were native and only 18 to be exotic. The Island environment was also found to be composed largely of exposed rock, soil and sand dunes, making it ideal habitat for burrowing seabirds (Mills, Vegetation of the Oceanic islands of the NSW South Coast. 9. Big Island, The Five Islands Group, Illawarra Coast: Exploration, Exploitation and Conservation, 2015).

Figure 1.4: Images of three common native vegetation species found on Big Island in 1938. a) *Commelina cyanea* (Scurvy Weed); b) *Tetragonia tetragonioides* - previously *Tetragonia expansa* (New Zealand Spinach) and c) *Lomandra longifolia* (Spiny-head Mat-rush). (Images taken April 2018)

Figure 1.5: Images of three exotic vegetation species found on Big Island in 1938. a) *Stenotaphrum secundatum* (Buffalo grass); b) *Phytolacca octandra* (Inkweed) and c) *Opuntia inermis* (Prickly Pear). (Images a) and b) taken April 2018; Image c) photo credit: Kevin Mills, 2015)
Vegetative studies conducted by Kevin Mills in 1990 concluded the loss of three native vegetative communities: *Scirpus nodosus*, *Scirpus cernuus* and most importantly *Correa – Westringia*, which previously dominated large parts of Big Island. This loss of native species coincided with a dramatic increase in exotics, most significantly the introduction of *Cenchrus clandestinus* (Kikuyu Grass) shown in figure 1.6.

![Figure 1.6: LHS: Close range image of Cenchrus clandestinus (Kikuyu Grass) and RHS: A landscape image showcasing the extensive growth of Cenchrus clandestinus (Kikuyu Grass) on Big Island. (Images taken April, 2018)](image)

Considering *Cenchrus clandestinus* (Kikuyu Grass) grows from nodes not from the dispersal of seeds, the scattered nature of its original occurrence led to the hypothesis that the exotic grass was intentionally established to fight the erosional forces occurring on Big Island (Mills, 1990). Figure 2.10 depicts the rapid spread of *Cenchrus clandestinus* (Kikuyu grass) since its initial discovery in 1962.

![Figure 1.7: Distribution of Kikuyu Grass (Cenchrus clandestinus) on Big Islands I and II for the years 1962, 1969, 1976 and 1989. (Mills, 1990)](image)
It can be seen in figure 1.7 that the distribution of *Cenchrus clandestinus* (Kikuyu grass) is restricted towards the centre of the two Islands. This is likely due to the edges of the Islands, particularly the Northern and Southern most points being exposed to high winds and salt spray, which inhibits growth of Kikuyu. It was reported that the present Native species that existed in a restricted distribution and were found predominantly on the outer edges of the Island where they were shadowed by *Coprosma repens* (Mirror Bush) (figure 1.8). *Coprosma repens* is a dense and deep rooted exotic shrub that can withstand the exposure high winds and salt spray on the Island; and grows large enough to allow coverage for the limited amount of natives present.

![Image of Coprosma repens](image)

**Figure 1.8:** Photograph of *Coprosma repens* (Mirror Bush), an exotic shrub that lies on the outer edges of Big Island. They are dense, deep rooted shrubs that provide coverage for other plant species against harsh winds and salt spray. (Image taken May, 2018)

The dramatic increase in Exotic vegetation on Big Island and subsequent decrease in Native species was summarised by Mills and can be viewed in table 2.1 below. It can be seen in the table that between 1938 and 1989 there was a dramatic decrease in natives from 40 to 22 known species and contrastingly exotics were found to increase from 58 to 64 species.

| The Number of Plant Species recorded on Big Island in 1938 and in 1989. |
|-----------------------------------------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Shrubs | Vines/Creepers | Forbs | Ferns | Grasses | Total |
| Native | 2 | 2 | 3 | 0 | 26 | 16 | 1 | 0 | 8 | 4 | 40 | 22 |
| Exotic | 0 | 3 | 2 | 3 | 14 | 29 | 0 | 0 | 2 | 7 | 18 | 42 |
| Total | 2 | 5 | 5 | 3 | 40 | 45 | 1 | 0 | 10 | 11 | 58 | 64 |

**Table 1.1:** A table depicting the changes in exotic and native vegetation abundance between the years 1938 - 1989 (Mills, 1990)
1.3.2 Current Vegetation Found on Big Island No. 1 and No. 2

Plant invasion into a natural ecosystem is one of the most significant threats to the conservation of biological diversity across almost every biogeographical region of this earth (C. R. Veitch, 2002; Meyer, 2004). It is likely that the invasion of exotic species has been closely related to the evolution of humans and our associated movement, and thus has increased significantly in recent years in our advanced evolutionary state (Groves, 1998). This is definitely the case amongst the vegetation of The Five Islands, particularly Big Island, where the alteration of the vegetation from native to exotic species has been substantial. A complete List of all present Vegetation species identified between 1989 and 2015 and their abundance is documented in appendix A.

Vegetation surveys conducted by Kevin Mills as part of the NPWS vegetation rehabilitation scheme revealed that 90% of native vegetation on Big Island had completely disappeared by 2014, with only a small portion of natives occurring on the outer edges of the Island (Mills, Illawarra Vegetation Studies. Big Islands, The Five Islands Group, 2015). The observations were not dissimilar to that of vegetation surveys conducted in 1989, in that *Cenchrus clandestinus* (Kikuyu grass) dominated the Island. However, a few areas support the dense growth of low-growing exotic species including *Ipomoea cairica* (Coast Morning Glory), *Hydrocotyle bonariensis* (American Pennywort) and *Acetosa sagittata* (Turkey Rhubarb).

Thickets of woody weeds including: New Zealand coastal shrub *Coprosma repens* (Mirror Plant), with lesser amounts of *Chrysanthemoides monilifera* ssp. *Rotundata* (Bitou Bush) are found in greater abundance than in studies conducted in 1989 (Mills, 1990; Mills, 2015). The following woody exotic plants were found to be less common; *Lycium ferocissimum* (African Box-thorn), *Lantana camara* (Lantana) and *Lagunaria patersonia* (Norfolk Island hibiscus).

The only native shrubs occurring on Big Island since surveys conducted in 2004 are species that have been reintroduced by the NPWS vegetation rehabilitation scheme (Mills, Illawarra Vegetation Studies. Big Islands, The Five Islands Group, 2015). A detailed depiction of Natives that have been planted on Big Island is included in table 1.2.

**Table 1.2**

<table>
<thead>
<tr>
<th>Native Plant Species Planted on Big Island</th>
<th>2015</th>
<th>2016</th>
<th>2017</th>
<th>2018</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Banksia integrifolia</td>
<td>80</td>
<td>20</td>
<td>241</td>
<td>100</td>
<td>441</td>
</tr>
<tr>
<td>Carpobrotus glaucescens</td>
<td>288</td>
<td>50</td>
<td>0</td>
<td>0</td>
<td>338</td>
</tr>
<tr>
<td>Correa alba</td>
<td>22</td>
<td>20</td>
<td>150</td>
<td>450</td>
<td>642</td>
</tr>
<tr>
<td>Ficinia nodosa</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Hibbertia scandens</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Lomandra longifolia</td>
<td>2250</td>
<td>3172</td>
<td>2581</td>
<td>10525</td>
<td>18528</td>
</tr>
<tr>
<td>Monotoca elliptica</td>
<td>10</td>
<td>50</td>
<td>0</td>
<td>0</td>
<td>60</td>
</tr>
<tr>
<td>Myoporum boninense</td>
<td>10</td>
<td>0</td>
<td>161</td>
<td>0</td>
<td>171</td>
</tr>
<tr>
<td>Poa paiformis</td>
<td>30</td>
<td>100</td>
<td>240</td>
<td>0</td>
<td>370</td>
</tr>
<tr>
<td>Rhagodia condolleana</td>
<td>640</td>
<td>550</td>
<td>536</td>
<td>450</td>
<td>2176</td>
</tr>
<tr>
<td>Scaevola calendulacea</td>
<td>0</td>
<td>0</td>
<td>50</td>
<td>0</td>
<td>50</td>
</tr>
<tr>
<td>Tetragonia tetrogonoides</td>
<td>100</td>
<td>0</td>
<td>50</td>
<td>0</td>
<td>150</td>
</tr>
<tr>
<td>Themeda australis</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Westringia fruticosa</td>
<td>120</td>
<td>33</td>
<td>0</td>
<td>100</td>
<td>253</td>
</tr>
</tbody>
</table>
Often when the tide is low and the oceans are calm, a rocky bridge forms between Islands I and II, allowing for an extensive vegetation analysis to the second island. Surveys conducted on Big Island II revealed a sparse cover of natives, *Carpobrotus glaucescens* (including native Pigface) and *Tetragonia tetragonioides* (New Zealand Spinach) (figure 1.4; b). The native grass *Sporobolus virginicus* (Salt water Couch) was found to be healthy and in abundance particularly on the southern shore (Mills, Report on trip to Big Island, Port Kembla, 24 July and 2 August 2018, 2018) and native herbs *Atriplex australasica* (Saltbush) found on the northern side. Other common natives found on Island no. 2 include *Cotula australis* (Common Cotula), and *Cynodon dactylon* (Couch Grass), shown in figures 1.9: a); b) and c) respectively.

Recent surveys revealed a large loss of vegetation over the summit of Big Island II. This area has always been sparse of vegetation, however the extreme drought conditions that occurred particularly over April and May 2018 has exacerbated this situation (Mills, Report on trip to Big Island, Port Kembla, 24 July and 2 August 2018, 2018). The dry conditions resulted in mainly exotic species to be abundant on this section of the Island.

Exotics present on the island include thick woody shrubs *Lycium ferocissimum* (African Boxthorn) and *Coprosma repens* (Mirror Plant), small grass patches of *Cenchrus clandestinus* (Kikuyu Grass), *Stenotaphrum secundatum* (Buffalo Grass) and common occurrences of the creeping perennial herb *Hydrocotyle bonariensis* (Pennywort) and exotic succulent *Portulaca pilosa* (Akulikuli).

Figure 1.9: Images of three native plant species on Big Island No. 2 in July 2018. a) *Atriplex australasica* (Saltbush); b) *Cotula australis* (Common Cotula) and c) *Cynodon dactylon* (Couch Grass). (Source: Images a) and b) taken July, 2018; Image c) photo credit: Kevin Mills, 2015)

Figure 1.10: LHS: Photograph of *Hydrocotyle bonariensis* (Pennywort) and RHS: *Lycium ferocissimum* (African Boxthorn) common exotic species on Big Island No. 2. (Source: Images taken July, 2018)
1.3.3 Big Island Vegetation Management Plan

The big island revegetation scheme has effectively replanted an abundance of common natives that were previously present on the island (figure 1.11) and would support the nesting habits of burrowing seabirds currently and previously present. Table 1.2 gives a summary of the plants that have been planted between 2015 and 2018. The Berrim Nuru Vegetation Management Plan for Areas 1 – 6 on Big Island stated that the plants they have used had proven to be hardy and survived well (Nuru, Booiroodoong (Big Island) Vegetation Management Plan for Project Areas 1 – 6, 2017). This includes: *Lomandra longifolia* (spiny-headed mat-rush) which are becoming bushy and are just under one metre, *Myoporum boninense* (Boobialla) which are over one metre currently, *Carpobrotus glaucescens* (Native Pigface) which currently has a spread of around five metres, and *Banksia integrifolia* (Coastal Banksia), which has reached up to and in some plants over two metres after 20 months.

![Figure 1.11: Area 2 planted in 2016 to create suitable habitat for the nesting seabirds. Image taken 12th July, 2018 (Source: Rowena Morris)](image)

However, the red leaved pigface variety used in Area 1 is assumed to be a different variety to the same species that occurs naturally on the Islands. It has grown at a more rapid pace than the green variety and has larger, more succulent leaves. Berrim Nuru have since decided to stop planting the Unknown *Carpobrotus sp.* (exotic Pigface), and rather propagate the green native Pigface present on the Island (Nuru, Booiroodoong (Big Island) Vegetation Management Plan for Project Areas 1 – 6, 2017). The difference in the two varieties is distinguished in Figure 1.12.

The Unknown *Carpobrotus sp.* found on the island is considered a highly competitive invasive weed (Julie Chenot, 2018). They form monospecific carpets (Tomas Sintes, 2007) and spread swiftly over open areas, such as dunes, rocky coastlines and shrubland. The plant is particularly difficult to get rid of because it roots where each node contacts the soil, has multiple reproductive strategies, and forms in heavy mats up to 40cm in depth (D’Antonio 1990, 1993); meaning it will easily envelope other, less competitive native vegetation (Ana Novoa Luís González, 2013). The exotic *Carpobrotus sp.* also interacts indirectly with native shrubs and grasses by altering the soil chemistry; lowering the pH, Ca...
and Na content and increasing the organic content, salinity, Nitrogen and Phosphorus concentrations (Ana Novoa Luís González, 2013; Connor, 2009). This vastly inhibits the growth of adult native shrubs as well as native seedling germination (Albert, 1995). This species will be mentioned further in this paper and will be referred to solely by its genus: *Carpobrotus sp.* with its unknown species title presumed in this context.

**Figure 1.12:** LHS: Photograph of *Unknown Carpobrotus* (exotic Pigface) and RHS: *Carpobrotus glaucescens* (Native Pigface) on Big Island. Images taken July, 2018.
1.3.4 Current Vegetation Found on Flinders Island

The most recent vegetation survey conducted for Flinders Island was by Kevin Mills in 2014. In his analysis he found the Island to be dominated by exotic bushes: *Chrysanthemoides monilifera* (Bitou Bush), which was the most commonly occurring and *Coprosma repens* (Mirror Bush) (figure 1.8), which was mainly found on the cliffs around the edges of the plateau. Only two native shrubs can be found in limited abundance on the plateau; namely: *Correa Alba* (White Correa) and *waxtree* (Coast Rosmary) (Figure 1.13: b) and c)) (Mills, Vegetation of the Oceanic Islands off the NSW South Coast - Flinders Islet, Five Islands Group, Illawarra Coast, 2014).

![Figure 1.13](image1.png)

**Figure 1.13:** a) Photo of exotic bush *Chrysanthemoides monilifera* (Bitou Bush); b) native bush *Correa Alba* (White Correa) and; c) native bush *waxtree* (Coast Rosmary). (Photos taken on Big Island April, 2018)

Herbaceous plants were found to make up a majority of the vegetation on the Island; with 15 Natives and 11 exotics. They occur most commonly on the edges of the plateau in shallow soils that cannot support *Chrysanthemoides monilifera* (Bitou Bush), shown in figure 1.14. Other common exotics include *Opuntia stricta* (Prickly Pear) and *Eleusine indica* (Crowsfoot Grass). Common Natives include: *Plantago hispida* (Hairy Plantain), *Plectranthus parviflorus* (Cockspur Flower), *Commelina cyanea* (Wandering Sailor), *Tetragonia tetragonioides* (New Zealand Spinach), *Carpobrotus glaucescens* (Pig Face) and *Enchylaena tomentosa* (Ruby Saltbush) (Mills, Vegetation of the Oceanic Islands off the NSW South Coast - Flinders Islet, Five Islands Group, Illawarra Coast, 2014).

![Figure 1.14](image2.png)

**Figure 1.14:** Photograph on Flinders Island showing the Edge of the plateau which supports most of the native herbaceous plants. *(Source: Kevin Mills, 2014)*

20
1.4 Seabirds Inhabiting Big Island No. 1 and No.2

Big Island I and II are home to an abundance of avian wildlife including both nesting and burrowing seabird species (figure 1.17). The most common burrowing seabirds that inhabit Big Islands I and II include, but are not limited to: *Ardenna pacifica* (Wedge-tailed shearwater); *Ardenna tenuirostris* (Short-tailed Shearwater); *Eudyptula minor* (Little Penguin) and nesting Seabirds: *Chroicocephalus novaehollandiae* (Silver Gull) and *Thalasseua bergii* (Crested Tern). Figure 1.14 depicts the nesting habits and distribution of these avian species commonly found on Big Islands I and II. The Wedge-tailed Shearwater *Ardenna pacifica* can be found nesting independently on the plateaus and western slopes of Big Island or in loose colonies interspersed with the Short-tailed Shearwater *Ardenna tenuirostris* on the eastern slopes (Nicholas Carlile, 2017). The Short-tailed Shearwater *Ardenna tenuirostris* is only present in two minor areas on the north and east facing slopes of Big Island mixed with the Wedge-tailed Shearwater *Ardenna pacifica* and Little Penguin *Eudyptula minor*. The Silver Gull *Chroicocephalus novaehollandiae* has previously dominated Big Islands I and II, nesting on all available habitat not shielded by dense shrubs or occupied by Australian Pelican *Pelecanus conspicillatus* colonies. The Crested Tern *Thalasseua bergii* only populates a discrete area on the northern point of Big Island II, depicted in bright red in figure 1.15, and the exact nest location varies annually. The Little Penguin *Eudyptula minor* nests on the slopes and immediately inland on both Big Islands I and II, finding shelter under thick shrubs, grass, rock overhangs and in soil-covered burrows.

![Figure 1.15: Seabird nesting distribution on Big Islands I and II, Five Islands Nature Reserve, NSW (Nicholas Carlile, 2017).](image)

Burrowing seabirds require access to the soft topsoil as well as spacious vegetation to provide them with protection and stability for building burrows. The sturdy and capacious tussocks of *Lomandra longifolia* found on Big Island provide ideal nesting habitat for burrowing seabirds. However, with the overall increase in exotic and subsequent reduction in native vegetative species on Big Island, seabird colonization has become restricted. Densely matted vegetation such as Kikuyu grass *Cenchrus clandestinus* and Coastal Morning Glory *Ipomoea cairica* inhibits the ability of seabirds to burrow.
into top soils, entrapping them in the tangles of grasses and vines (figure 1.16) and ultimately resulting in their starvation and demise (Craven, 2014).

The direct effect of native vegetation loss on the nesting bird species can be seen in 2017 study conducted by Nicholas Carlile et. al. They found that prior to 1980, nesting Silver Gulls *Chroicocephalus novaehollandiae* dominated exposed areas of Big island I and II, and that habitat loss was a direct cause of breeding pair demise. Figure 1.17 shows the significant results of the study with an $R^2$ value above 0.5 and the obvious loss of breeding pairs between 1990 and 2015. Other burrowing seabird species including *Eudyptula minor* Little Penguins and three different breeds of shearwaters also struggle to nest in the dense exotic vegetation and as a result Carlile et. al. found their numbers to have subsequently dwindled on the island chain in recent years (Nicholas Carlile, 2017).

Figure 1.16: Image of entrapped Shearwater in Coastal Morning Glory *Ipomoea cairica* (photo: Rowena Morris)

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Figure 1.17: Estimated number of breeding pairs of Silver Gulls *Chroicocephalus novaehollandiae* on Big Island I and II from the 1980s to 2015. *(Nicholas Carlile, 2017)*
1.5 The History of the Five Islands

The Islands have an extensive history, being a place of legend amongst the Dharawal people, as the indigenous owners of this land. It was thought they lived off the coast of red point (figure 1.1) and would have swam to the islands regularly to access the rich food source of crustaceans, fin fish and seabirds as well as their eggs (Mills, Vegetation of the Oceanic islands of the NSW South Coast. 9. Big Island, The Five Islands Group, Illawarra Coast: Exploration, Exploitation and Conservation, 2015). The creation of the five Islands has since been accounted for by the descendants of the Dharawal people, in the form of dream time stories and legends as a medium for core Aboriginal spiritual belief.

In 1770 James Cook and the crew of the Endeavor were the first confirmed Europeans to view the Illawarra coast and The Five Islands, his crew members Bass and Flinders coining the name of the two north most Islands later in 1797 (Mills, Vegetation of the Oceanic islands of the NSW South Coast. 9. Big Island, The Five Islands Group, Illawarra Coast: Exploration, Exploitation and Conservation, 2015). European settlement brought about obvious anthropogenic changes to the Islands, having cattle, goats and rabbits being introduced to Big Island as early as 1849 (Mundy, 1852).

Big Island was then occupied by the Perkins family, who introduced Buffalo Grass Stenotaphrum secundatum to the Island and remained there between 1866 to late 1871, relying on the fishing of sharks for their oil as a main source of income (Illawarra Mercury, 1871). Fire, which was first recorded as early as 1849 as well as the inhabitation of the Perkins family on the Islands was the first of a series of major anthropogenic changes to the island. Fires were common on the island and were believed to be intentionally lit in the attempt of killing off the rabbits, which were now seen as a pest (Illawarra Mercury, 1884).

From 1925 to 1947, a mining lease was granted to allow for the extraction of shell grit from the Island, which were likely the remains of aboriginal middens. Lime was extracted from the shell grit and used in the making of cement. In June 1960 the Islands were then listed as a nature reserve; even though they had already been altered significantly from exploitation since early European settlement (Mills, Terrestrial Vegetation of Big Island, The Five Islands Group, Port Kembla, New South1938 - 1989. A Historical and Ecological Study.,, 1990).
1.6 Seabird Habitat Restoration Plan on Big Island

Big Island has an extensive cover of the vigorous weed species *Ipomoea cairica* (Coastal Morning glory) and *Cenchrus clandestinus* - previously *Pennisetum clandestinum* (Kikuyu grass), that grow through the spreading of runners to from dense mats. Because of its compact and tangled growing pattern, it is actively trapping nesting seabirds; including little penguins, shearwaters and petrels in their burrow entrances and resulting in their death from entrapment. The treatment of a 0.9 ha trial area commencing in 2014, involving the successful cone spray of a glyphosate 360 gL\(^{-1}\) mix over targeted weed species in Area 1, was the first attempt at eradicating the invasive weed species. Following the initial spray treatment; three more aerial spray events have occurred on Big Island.

Area 2, which equates to 0.3 ha, was treated in April 2015 and areas 3, 5 and 6, adding up to roughly 3.1 ha were treated in 2017 (Berrim Nuru, 2017). The aerial treatment to be conducted in 2018 re-sprayed over areas 3, 5 and 6 as well as areas east of the area 5 and 6 boundary. The area boundaries defined by NSW National Parks and Wildlife Service for the spray treatment and revegetation scheme are depicted in figure 1.18.

![Glyphosate area spray boundaries for 2017 and 2018 as defined by NSW National Parks and Wildlife Service (NPWS) in accordance with the Big Island Vegetation Management Plan (Berrim Nuru, 2018). Glyphosate treatment over 2018 also included a large area to the right of the Area 5 and 6 boundary.](image_url)
Weed treated areas then underwent a revegetation scheme as part of the vegetation management plan written by Birrum Nuru Environmental Services of the Illawarra Local Aboriginal Council. This involved replanting native plant seedlings in areas 1 and 2 over 2015 and 2016 respectively as well as the replanting within areas 3, 5 and 6 over 2017 and 2018. The revegetation scheme involved the planting of native plant communities that were previously found on the Island and would result in a suitable nesting habitat for seabird species. This included the replanting of species such as *Lomandra longifolia*, *Correa alba*, *Westringia fruticosa* and *Rhagodia condelleana* shrubs to name a few (Mills, Vegetation of the Oceanic islands of the NSW South Coast. 9. Big Island, The Five Islands Group, Illawarra Coast: Exploration, Exploitation and Conservation, 2015). The area boundaries for the Big Island Vegetation scheme are outlined in figure 1.19 below.

**Figure 1.19:** Area boundaries of Big Island as defined by NSW National Parks and Wildlife Service (NPWS) in accordance with the Big Island Vegetation Management Plan (Berrim Nuru, 2018).
1.7 Aims and Objectives

This paper functions as part of a broader long-term project being conducted by NSW National Parks and Wildlife Service (NPWS) and the University of Wollongong, revolving around the use of remote sensing techniques to map the flora and fauna of Five Islands Nature Reserve off the coast of Port Kembla, NSW. The overall purpose of this study is to assist NSW NPWS in vegetation analysis in relation to rehabilitating seabird habitat on Big Island, part of the Five Islands Nature Reserve. This study will also be assessing the effectiveness of the weed treatment to date.

NSW National Parks and Wildlife Service and the University of Wollongong are working together on a long-term project using remote sensing to map the flora and fauna of the Five Islands Nature Reserve located off the coast of Port Kembla, NSW. The mapping contributes to the seabird habitat rehabilitation project that commenced in 2014. This thesis contributes to the long-term project by creating the baseline mapping and data interpretation in relation to the weed infestation, weed treatment and planting of native species.

This project in particular will compare raster and vector based approaches to mapping island vegetation within a broader context of a 5-year rehabilitation management plan. In this study I will utilize raster and vector based spatial mapping techniques to resolve the following management questions:

- How many planted seedlings survived? Determine the success of *Lomandra longifolia* seedlings planted on Big Island by quantifying *Lomandra sp.* abundance in a subset of management regeneration areas where planting effort has been focussed. Success will be determined based on the association between current *Lomandra sp.* abundance and the record of individual seedlings planted.

- What areas still need planting? Assess current density patterns of fully grown *Lomandra sp.* on Big Island to determine an optimal distribution strategy when planting new individual seedlings.

- What vegetation is present on other islands? Map vegetation distribution and abundance on all islands within the Five Islands Nature Reserve through the use of spectral and spatial mapping techniques.

- How effective was the weed treatment? Analyse the drone images acquired from before and after the May 2018 aerial weed treatment.

- What is the health of the previously planted *Lomandra sp.?* Visually assess the health of *Lomandra sp.* by analysing individual tussocks based on colour, size and shape, and interpret the role of invasive Pigface species and tussock distribution in overall *Lomandra sp.* health.

- What is the spread of the “exotic” pigface? Map coverage and quantify changes in invasive South African Pig face species over time. Specifically focusing on the changes on Big Island between 2017 and 2018 using raster based remote sensing techniques.
2. Literature Review
   2.1 Remote sensing

2.1.1 Historical Overview of Remote Sensing
Remote sensing is defined as the ability to collect detailed information of an object or space without physically touching it (W.A Fischer, 1976). In the same way as we use our eyes to sense wavelengths of energy, we can use different types of sensors to convert electromagnetic energy into information which can be retained and utilised in a multitude of disciplines (Congalton, 2010). The ability to obtain knowledge without the need to be physically present is indispensable to the mapping process as it allows for a time efficient and more economically sound way to obtain information where the analysis on land may be physically unviable (Susan Kathleen Langley, 2001). Remote sensing also overcomes previous limitations such as analysing a large study area or enabling the user to frequently revisit a study site with minimal effort.

Although remote sensing technologies have been of rapid advancement in recent years, the ability to use areal imagery for human advantage was detected as early as 1858, in the use of analogue photography by balloon to take images of Paris from above (Jensen, 2007). The rapid evolution of analogue imagery to digital systems can be attributed to the extensive use of areal imagery during World War I and II, promoting the development of infrared, radar, and sonar technologies (Moore, 1979).

![Figure 2.1: An image of Thaddeus Lowe, a Civil War Aeronaut in 1862. This image shows men in the civil war preparing a hot air balloon for take-off, exemplifying the difficulty associated with early methods of remote sensing (Source: Mathew Brady, 1862).](image)

Analogue aerial imagery proved to be useful in defining geographical phenomenon and natural characteristics of a landscape. It allowed for the photo interpretation of an image in the same perception as the human eye, where features were identified via their size, shape, shadow, pattern, tone and texture (Congalton, 2010). However analogue photographs were limited to the wavelengths
of the electromagnetic spectrum that can only be sensed through film. These wavelengths were inclusive only of the visible portion of the spectrum as well as infrared and ultraviolet spectrum, however due to the three emulsion layer limitation of film, only one of these features could be detected at a single time.

A turning point for remote sensing technology was through the launch of the first Landsat satellite in 1972. Although the satellite itself was a failure, it was fitted with the first multispectral sensor and enabled the capturing of four wavelengths simultaneously (Congalton, 2010). The development of multispectral sensors coupled with the limitations of analogue photo imagery; drove the development of digital remote sensing. The development of remote sensing has since been driven by groups such as the National Aeronautics and Space Administration (NASA) and has greatly improved in quality and accessibility since the vast improvement of technologies and computer fields within the twenty first century (Blumenthal, 2013).

2.1.2 Remote Sensing and the Electromagnetic Spectrum
Remote sensing datasets commonly occur as digital images. Multispectral Scanner System (MSS) sensors were carried by the first 5 Landsat satellites which responded to the earth-reflected sunlight in four spectral bands to form a digital image. A standard visual sensor is able to recognise and collect red, green and blue wavelengths of light. This is also the case of multispectral sensors; however they are additionally capable of recognising infrared and ultraviolet radiation, which are non-visible to the human eye.

Remote sensing is dependent on the interactions between matter and energy, in the form of radiation that is present in the electromagnetic spectrum. The electromagnetic spectrum is divided into wavelengths of light that are travelling at the speed of light. The obtaining of reflectance data in multiple wavebands across the electromagnetic spectrum is what enables sensors to provide a unique ‘Spectral Signature’ that can be utilized for spectral analysis (Rencz, 2004).

A spectral signature can serve as an individual identifier for ground surface features, such as vegetation, soil and water that vary in their reflectance values. The greater the reflectance value the brighter the type of land cover appears in an image. As a passive process, visible and reflective infrared remote sensing relies on the reflected energy from the sun to exceed the earth’s own emitted energy. This region of the spectrum expands across 0.4 to 3 micrometers (µm) and incorporates the visible, near and mid-infrared sections of the electromagnetic spectrum. This is referred to as the solar-reflective spectral range (Schowengerdt, 2006).

It can be seen in figure 2.2 that the reflectance of water, soil and vegetation vary greatly in different wavelengths. In the visible spectrum between 380 nanometres (nm) and 760 nm the three reflectance values are not dissimilar, however the land cover types become more distinguishable as the wavelengths become longer in the near- and mid-infrared range. It can be seen that water only reflects in the visible light range, whereas vegetation and soil can be best identified in the near and mid-infrared wavelengths between 0.7-1.5 and 1.5-3.0 µm respectively (Schowengerdt, 2006; Schott, 2007).
The reflectance value of green vegetation is the most significant in the near-infrared range between 0.7 and 1.5 µm due to its photosynthetic properties. As a growing plant photosynthesizes, the present chlorophyll will absorb any visible blue and red light, however it will reflect the infrared light to avoid overheating through evaporation (Skidmore, 2002). Specifically, vegetation reflectance values within the visible wave-lengths are directly determined by the chlorophyll $a$, chlorophyll $b$ and carotenoids found within the leaf structure (Garratt, 1977). The response of the vegetation within the near- mid-infrared spectral wavelengths is attributed to the abundance and configuration of the air spaces present within the internal leaf structure (Danson, 1992). These features create a unique spectral signature for different vegetation types, meaning they have dissimilar reflectance values and in remote sensing we can use these characteristics to identify different vegetation types spectrally. Figure 2.3 shows the different reflectance values found amongst varying vegetative types commonly found in the agriculture industry.

**Figure 2.2:** Graph of reflectance values of water, soil and vegetation at different wavelengths. Water ranges approximately between 0.3 and 0.7 µm, vegetation between 0.7 and 1.5 µm and Soil between 1.5 and 0.3 µm on the spectrum. (*Source: Invalid source specified.*)

**Figure 2.3:** A graphical depiction of the reflectance values of different vegetation types at varying wavelengths to achieve a unique spectral signature (*Source: (Kyllo, 2003)*)
Plants and vegetation can also be identified by their health or vigor through the use of a vegetative index. A vegetative index is the comparison of the reflectance value at varying wavelengths, and is commonly used to determine plant vigor. Plant vigor is a measurement of the vitality, activity of health of a growing plant (Price, 1991). The most well-known vegetative index is the Normalized Difference Vegetative Index (NDVI), which utilizes the reflectance values of the red and Near Infrared portions of the electromagnetic spectrum to identify varying levels of plant vigor within fields. NDVI is dependent on the following formula:

$$\text{NDVI} = \frac{(\text{NIR} - \text{RED})}{(\text{NIR} + \text{RED})}$$

Where:

$$\text{NIR} = \text{Near Infra-red}$$

$$\text{RED} = \text{Red band}$$

Which results in a NDVI value ranging from low (-1.0) to high (1.0) vigor for each pixel in an image (A. R. Huete, 1992).

### 2.1.3 Image Classification of Digital Pixel-based Images

Images containing pixels of known or unique values can be processed in programs such as ArcGIS and can thus be classified into groups of pixels with similar values to create feature classes (Alexander and Millington, 2000). Feature identification through Pixel-based methodologies can included both an supervised and unsupervised classification procedure, which is summarised in figures 3.6 and 3.8 respectively. Both classifications can be developed from orthomosaics created from pre-processed raw images. Each image is made up of megapixels and each pixel contains data which is represented as a single numerical value across multiple spectral bands (Hamylton, Spatial Analysis of Coastal Environments, 2017). Objects that are built from clusters of pixels can be placed into defined groups called classes. A supervised classification will sort pixels into classes based on a user defined class, whereas an unsupervised classification will sort pixels into a respective class based on automatically found spectral properties alone. By classifying these pixel clusters into known classes, basic numerical values are given a context and therefore meaning.

### 2.1.4 Accuracy Assessment of Digitally Classified Images

Since Image classification through GIS is in some form a ‘predictive’ technology, it is necessary to couple the output with a known data set. In mapping, this dataset will often be derived from known points created from field data, which is referred to as ground-referencing or ‘truthing’ points. These points can be created from a georeferenced photograph, or a record of the ground cover type at a particular GPS location that has been assessed by the analyst for validation, this process is further discussed in chapter 3. This method is referred to as a ‘validation exercise’ and is necessary to prove the accuracy of an achieved output (Hamylton, Spatial Analysis of Coastal Environments, 2017). Validation can be achieved by employing an error, or ‘confusion’ matrix. An error matrix is a statistical cross examination of the known classification of the ground truthing points with their assigned or assumed classification (Congalton, 2010). The outcome of an error matrix will give a representation of the overall accuracy of the classification as a percentage, an example of this is shown in figure 2.4.
**Figure 2.4:** Error or confusion matrix showing the results of producer, user and overall accuracy assessments for Big Island II. Row values are allocated by the classification procedure whereas column values are allocated through the ground truthing dataset.

<table>
<thead>
<tr>
<th>Class</th>
<th>Exotic Bushes</th>
<th>Grass</th>
<th>NZ Spinach</th>
<th>Penny Wart</th>
<th>Dead Veg</th>
<th>Total</th>
<th>User's accuracy (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exotic Bushes</td>
<td>20</td>
<td></td>
<td>3</td>
<td></td>
<td></td>
<td>23</td>
<td>86.95652174</td>
</tr>
<tr>
<td>Grass</td>
<td>0</td>
<td>18</td>
<td>2</td>
<td></td>
<td></td>
<td>20</td>
<td>90</td>
</tr>
<tr>
<td>NZ Spinach</td>
<td>2</td>
<td>4</td>
<td>17</td>
<td></td>
<td></td>
<td>23</td>
<td>73.91304348</td>
</tr>
<tr>
<td>Penny Wart</td>
<td></td>
<td></td>
<td></td>
<td>20</td>
<td></td>
<td>20</td>
<td>100</td>
</tr>
<tr>
<td>Dead Veg</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>22</td>
<td>22</td>
<td>100</td>
</tr>
<tr>
<td>Total</td>
<td>22</td>
<td>22</td>
<td>22</td>
<td>20</td>
<td>22</td>
<td>108</td>
<td>89.81481481</td>
</tr>
<tr>
<td>Producers’ Acc</td>
<td>90.9090909</td>
<td>81.8182</td>
<td>77.272727</td>
<td>100</td>
<td>100</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
2.1.5 Raster and Vector Datasets

Information can be stored and utilized differently through geographic information system projections and depending on the type of information that needs to be represented one method may be better suited than another.

There are two fundamental approaches employed by GIS analysts to digitally portray geographic information either as fields or discrete objects. Discrete objects can be well defined in a space that would otherwise be unquantified, having unique spatial, temporal and thematic properties. Individual objects can be identified digitally as singular entities, such as vector points, lines or polygons that may share similar properties or vary greatly from their neighbouring points (Hamylton, Spatial Analysis of Coastal Environments, 2017). An analysis of discrete objects enables the user to answer distinctive questions about specific points; including information about its location, size, shape, distribution and abundance.

Conversely, phenomena described as one continuous dataset that falls within a boundary is best defined as a field, or in the form of raster data. Every possible location within a singular field would be identified with the same fixed value. This would be best utilized in a scenario defining a continuous feature that is to be identified with a singular value, such as: distinguishing a river from land, or the road from surrounding buildings and footpaths. Through identifying a particular feature as a field the user is able to answer questions based on what is there? as well as getting an overview of size and shapes of continuous features.

Once a feature is conceptualized, it is necessary to use the correct method to project the information in a way that is best suited to the phenomenon. Raster and vector data formats encompass two direct processes that can digitize geographic datasets in this way. Figure 2.5 exemplifies the different appearances and information content that can be illustrated by raster and vector datasets.

**Figure 2.5:** Three depictions of the different formats in which spatial data can be stored: (a) Drone acquired orthomosaic of the north-west side of Big Island, off the coast of Port Kembla; (b) A Digital Elevation Model (DEM), Illustrating a continuous raster surface of elevation in metres above sea level (masl); (c) Polygon and point Vector dataset representing individual *Lomandra longifolia* tussocks as well as mats of exotic Pigface – *Carpobrotus* sp.
Figure 1.8 demonstrates the appearance and the information available in raster and vector datasets. Figures (a) depicts a colour satellite image and figure (b) portrays a digital elevation model (DEM) of Big Island. Both of these figures are representative of a raster type dataset with their information stored in a georeferenced grid. Figure (c) portrays a vector based dataset that is representative of two vegetation types existing on Big Island. The elevation data layer stores an individual elevation value at each cell location within Big Islands II’s boundary. This is a continuous raster dataset that is represented by a grid of pixels accompanied by the corresponding elevation of each cell in the grid. The DEM is accompanied by an additional summary of the entire number of pixels that correspond to each elevation value and its georeferenced location. In comparison, the Vector based dataset is discrete and only identifies the individual features: Carpobrotus sp. (Exotic Pigface) and Lomandra longifolia which have been defined by the user. The lomandra longifolia tussocks are represented in a point vector format and each point corresponds to a row in an associated attribute table, for which multiple attributes can be listed, such as tussock colour, diameter and health. The same can be said for the Carpobrotus sp. bunches, which are represented in a polygon vector format that holds additional information such as surface area.

Vector datasets have been the most common method for representing phenomena throughout history (Maffini, 1987). By creating lines or “vectors”, cartographers would be able to portray roads and streams and define edges of features such as islands and oceans. Vector attributed information can be defined by a series of internal vertices defining the shape of a line and two nodes, or end points. Vector datasets specify Euclidean points in zero-dimensional space to a geographic location based on specified x, y – coordinates (Frank, 1996). Vertices can collectively form a georeferenced line in one-dimensional space and subsequently in two-dimensional space form a polygon. From the vertices and lines created within a vector dataset, it is possible to obtain additional information relating to locations of points, length of lines and complete perimeters plus area and section lengths for polygons. The creation of vertices and lines are however on some level subjective and inexact as real-world features need to be generalized to fit into these categories.

Digitisation is a common technique used in the construction of vector data, where an analyst will visually interpret features on an aerial photograph or a map, tracing over boundaries to create a digital record in the form of points, lines or polygons (Hamynton, Spatial Analysis of Coastal Environments, 2017). Euclidean points, lines and polygons, are non-existent in the natural geographic world at full scale and only at a certain spatial representation do they become an acceptable approximation. A vector based approach can be deemed highly subjective in the respect that no two people would interpret an ambiguous real life feature in the exact same way (Couclelis, 1992). Real world features can also sometimes be undefined, such as a continental edge that is endlessly changing as a result of the moving tide, and therefore need to be approximated based on subjective opinion. Because of this a vector based analysis would be best suited to define discrete data that has minimal change between features and can be individually distinguished (Davis, 2001). This is the case in figure 2.5 c), where individual Lomandra longifolia tussocks can be identified as well as mats of Carpobrotus sp. (exotic Pigface).

Contrastingly, a Raster model would be best suited to the projection of a continuous dataset, where information is organized in a grid of equally sized cells in rows and columns. Rows and columns usually align with the latitudinal and longitudinal planes to completely cover an AOI (Area of Interest) giving each cell a specific georeferenced location. Each georeferenced cell will also store one attribute value per cell, linking it to a known feature. The field (raster) DEM depicted in figure 2.5 b)
stores a singular value for every location within the Big Island II Boundary. This continuous representation of elevation within a grid of cells is accompanied by a dataset that provides the corresponding elevation of every grid point in the lattice, alongside a summary of the count of cells relating to each elevation value.

The cells within a raster grid can also be referred to as pixels, which stands for picture elements (Decker, 2001), and the level of detail depicted in a raster model is often defined by the cell, or pixel, size. This is commonly referred to as the spatial resolution of an image or raster based model. With a smaller pixel size a greater amount of detail can be achieved when assessing features and phenomena, resulting in higher resolution and greater spatial accuracy. A smaller cell size however, can greatly expand the storage space of a raster dataset, and result in a longer processing time and often significantly reduce the overall efficiency (Hengl, 2006).

Many factors come into play when deciding whether or not to employ a raster or vector representation. The decision is often dependant on; the nature of the features to be analysed, the type of analysis required, the storage space and processing capability of hardware and the level of precision that is required to represent the regions of Interest (ROI’s) (Hamylton, Spatial Analysis of Coastal Environments, 2017).

These factors can best be resolved through careful consideration of whether to employ raster or vector datasets for a given analytical objective that takes into account a range of advantages and disadvantages associated with each data format. For example; in a raster representation, attributes are attached to an individual grid cell, which means it can be very difficult to accurately express variation amongst geographical features that are small relative to the pixel size. A low spatial resolution may result in a large area on the ground relative to the actual area of interest. It may also result in a ‘pixelated’ representation of a feature that may have edges that do not fit into the shape of a 1:1m square, for example. Raster data is most commonly found amongst remote sensing satellite imagery and can be readily utilized for spatial analysis. Satellite images are composed entirely of a raster grid of pixels and each pixel contains a particular reflectance value, with no allowance for variation within a singular cell. This means that data cannot be continuous within a raster cell and all detail on reflectance variation is not represented. These features that are intrinsic of a raster based analysis commonly result in a depiction of a feature that is less precise than a vector based analysis. The advantages and disadvantages of Raster and Vector Datasets are listed in a comparative table (table 2.1) and can be considered when addressing each of the factors mentioned prior.

<table>
<thead>
<tr>
<th>Raster</th>
<th>Vector</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data stored as a grid of pixels organised into rows and columns with each containing a singular value.</td>
<td>Data stored as points, lines or polygons often georeferenced with an X, Y location to represent Regions of Interest (ROIs)</td>
</tr>
</tbody>
</table>

**Advantages**

- Features with continuous data are well represented through the use of multiple pixels that cover an entire area of interest in a continuous manner.
  For example, in a DEM (Digital elevation model) elevations change continuously over a surface and a raster model can portray this as a smooth blend

**Advantages**

- Data is independent to resolution; meaning it can be scaled to any size without losing precision.
- Data representation is more true to a features original shape and form without generalization.
- Since vector datasets are stored as points, lines or polygons, less information is
of shades or colours to show the gradual increase or decrease in elevation.
- Each cell assumes a geographic location relevant to its position within the matrix.
- Raster format is used to model satellite and other common remote sensing data, making it easy to program and quick to process.
- Raster format is also compatible with raster-based output devices including Cathode Ray Tube monitors (CRT’s) and Liquid Crystal Displays (LCD’s).
- Map algebra is efficient and easy to perform because quantitative analysis is intuitive with both discrete and continuous raster datasets.
- The one attributed nature of raster datasets is also well suited for mathematical modelling (Buckley, 1997).

Disadvantages
- Cell size contributes to graphic quality and determines data resolution; therefore raster datasets can be represented in a ‘pixelated’ quality.
- If a dataset has large dimensions and required high resolution – the file size will take a long processing time and large storage space.
- Raster datasets lack the ability to focus on one feature alone, in general building in data redundancy and making them a lot larger to store and take longer to process than vector equivalents.
- Linear features are difficult to represent and often, depending on cell resolution, precision is lost.
- Output maps in raster format commonly do not conform to high-quality cartographic needs.
- Does not contain an informative attribute table.

Disadvantages
- Since polygons are representative of one singular feature, spatial analysis within a polygon cannot be achieved.
- Continuous data cannot be represented effectively within a vector format due to no variation present within a singular polygon.
- The location of each feature needs to be stored independently.
- Manipulative algorithms and analytical functions are complex and may be processing intensive and time consuming. This limits the overall functionality for larger datasets (Buckley, 1997).
- Vector data needs to be converted into a topological structure for an accurate analysis. This has two implications:
  1) It is processing intensive and more often than not will require data cleaning which is time consuming.
  2) Topology is static; meaning any additional changes made to the dataset requires extensive re-building.

Table 2.1: A comparative table depicting the advantages and disadvantages of both raster and vector datasets.

Analysis through the use of Unmanned Aerial Vehicles (UAVs) is crucial in protected areas where ecosystem dynamics are highly volatile; and timely and accurate information is fundamental for environmental management. 2016 paper conducted by D. Ballari et al demonstrates the potential of UAV drone acquired images for monitoring the degradation of littoral vegetation in Puerto Villamil - Isabela Island, Galapagos, Ecuador (Figure 2.6). Due to an alienated Island environment and associated species endemism, 97% of the Galapagos is protected and ecosystems are vulnerable (D. Ballari, 2016; Gonzolo F Rivas-Torres, 2018). Littoral vegetation is crucial for both land and marine inhabitants, and with 5% of littoral vegetation reduction as a result of anthropogenic impacts, monitoring of this area is crucial. Species such as the critically endangered mangrove finch (*Camarhynchus heliobates*) and marine Iguanas are dependent on the vigorous vegetation on land as well as the non-vigorous algae present in the intertidal zone respectively. This study aimed to classify vigorous and non-vigorous vegetation in the hope to monitor overall littoral vegetation degradation over time. Highly vigorous vegetation was comprised of the littoral vegetation that was deemed healthy and thriving, whereas the less vigorous vegetation referred to littoral vegetation of compromised health and limited vitality.

![Figure 2.6: Location map for Galapagos Islands. LHS: In the context of the American Continent, and RHS: Puerto Villamil, Isabela Island](image)

Georeferenced images were captured using two camera sensors: Red Green Blue (RGB) and Infrared Red Green (NIR). The presence of vegetation was firstly conducted through the use of a Normalized Difference Vegetation Index (NDVI) and values between 0.6 and 0.025 NDVI were considered of high and low chlorophyll content respectively. From these identified areas they were able to classify regions of interest as either high or low vigor areas as well as give information of area and number of segments. A supervised classification was used and RIOs were validated through the use of training segments and the building of an error matrix. Figure 2.7 shows the classification results where a predominance of vegetation with high vigor (75%) and less presence of vegetation with low vigor (25%) was identified (D. Ballari, 2016).
This study explored the possibilities for using a UAV to assess littoral vegetation degradation on Isabela Island, an area of high vulnerability in the Galapagos Islands. Their results proved that image acquisition from UAVs is not only useful in overall image interpretation, however also performed in the generation of environmental thematic information where field work may not prove to be efficient or feasible.

**Figure 2.7: Top:** Classification of Regions of Interest into high or low vigor vegetation on Puerto Villamil, Isabela Island. **Bottom:** Table displaying vegetation distribution by class. (Source: (D. Ballari, 2016))

<table>
<thead>
<tr>
<th>Vegetation</th>
<th>Number of segments</th>
<th>Area (ha)</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>High vigor</td>
<td>10386</td>
<td>1.83</td>
<td>74.67</td>
</tr>
<tr>
<td>Low vigor</td>
<td>8429</td>
<td>0.62</td>
<td>25.33</td>
</tr>
<tr>
<td>Total</td>
<td>18815</td>
<td>2.45</td>
<td>100.00</td>
</tr>
</tbody>
</table>
3 Methodologies

3.1 Aerial Drone Survey of The Five Islands

A vegetation map was made using an Unmanned Aerial Vehicle (drone) as it has been proven to produce vegetation maps with a high spatial resolution and accompanied level of accuracy before (Roder, 2017). To create a detailed orthomosaic of the study area it is necessary to acquire multiple areal images that can then be merged to create an overall picture of the whole island. By combining multiple images, the UAV can be flown at a lower elevation and cover a greater ground area, resulting in a greater level of detail than what would be achievable with the use of a singular image. To collect images at a consistent height and distance apart whilst ensuring the entire island was captured, an autonomous flight path for the drone was set prior to conducting the drone flight. The conditions of the flight path are listed in the table featured in figure 3.1 and the flight path was coordinated through the use of Map Pilot, a phantom DJI compatible IPad application. The drone was set at 60masl (metres above sea level) to allow for an adequate spatial resolution whilst maintaining a large sample area.

Two perpendicular flight paths were created prior to the drone flight. The flight path chosen on the day would be dependent on the wind direction, as the flight path must be chosen the run perpendicular to the wind. In the case of no wind, the flight path that travels parallel to the largest part of land would be chosen to save time.

![Figure 3.1: The LHS figure depicts the drone flight path and conditions taken over Flinders Island at an EW direction. It contains a table depicting the flight path conditions such as distance, speed, the number of images taken and the storage space occupied. The image on the RHS depicts a NS flight path conducted over Flinders Island at the same flight conditions. (Screenshot from Map Pilot, 2018).]
Two separate drone flights occurred for Big Island. The first on the 23rd May 2018, before the aerial weed treatment, and the second on 7th July 2018, less than two months after the aerial treatment. Aerial weed treatment was conducted 2nd May through cone spraying by the NPWS service helicopter. The drone flights for the other islands occurred over two separate days, 29th June 2018 for Rocky Islet and 7th July 2018 for all other Islets, Martin, Flinders, Bass and Big Island II. The drone survey flight for Big Island on 23rd May 2018 and Rocky Islet on the 29th June 2018 was conducted from the nearby rock platform on Hill 60 (Figure 3.2). All other flights were conducted from a marine vessel located within 20 meters of each study site. All drone surveys were conducted under the Scientific Licence SL101878 and the flight times were determined based on the aerial weed treatment conducted by NSW NPWS as well as seabird breeding seasons.

The flight surveys were conducted using a DJI Phantom 4 (Figure 3.3) and the accompanying stock DJI FC330 camera. The DJI Phantom 4 has GPS Positioning horizontal accuracy of ±0.3 m with Vision Positioning and ±1.5 m with GPS Positioning. The DJI FC330 camera has a 1/2.3 inch complementary metal-oxide-semiconductor sensor and can capture 12.4M pixels effectively. The lens has a field of view of 94° 20 mm (35 mm format equivalent) f/2.8 focus at ∞ (Phantom 4 Specs, 2016). All images were captured at a 90° angle perpendicular to the ground with an accuracy of ±0.02°.

3.2 Image Pre-Processing

The raw images collected from the drone survey were then collated using Agisoft Photoscan Professional to create an orthomosaic and a DEM of the island (Agisoft LLC, 2018). To create both the orthomosaic and the DEM using multiple raw images the following workflow was followed:

- Align Photos
- Build Dense Cloud
- Build Mesh
- Build Texture
- Build Tiled Model
- Build DEM
- Build Orthomosaic
This creates a 3D orthomosaic which can be exported and used for analysis in Arc Map. The orthomosaic does not need to be georeferenced as the drones DJI FC330 standard camera is able to record the x, y coordinates of the location of each image captured to an accuracy of 0.3m.

### 3.3 Clipping of Images to Vegetation Extent

Prior to classification, each image was clipped to the extent of the vegetation, with allowance of small portions of exposed rock. This was to eliminate marine spectral classes and allow for a more stringent vegetation analysis based on the spectral properties of a targeted geographical subset of the image. A polygon was manually created to outline the extent of the island needed for classification. Through the use of the clip – data management tool, this polygon was assigned as the output extent of the feature class and subsequently clipped the input raster layer to the shape of the overlaying polygon (Figure 3.4).

![Figure 3.4: Process of defining classification layer through the use of the clipping tool in ArcMap 10.2 (Screenshots from ArcMap 10.2, 2018).](image)

**Figure 3.4:** Process of defining classification layer through the use of the clipping tool in ArcMap 10.2 (Screenshots from ArcMap 10.2, 2018).

[Diagram showing the process of clipping images to vegetation extent]

**Figure 3.5:** Defining the extent to undergo classification on big Island undergoing spray treatment (Screenshots from ArcMap 10.2, 2018).

![Figure 3.5: Defining the extent to undergo classification on big Island undergoing spray treatment (Screenshots from ArcMap 10.2, 2018).](image)
This process was also conducted on the before and after orthomosaics of Big Island to outline the extent of the spray area for 2018, shown in figure 3.5.

3.4 Digital Classification of Vegetation on the Five Islands

Feature identification through Pixel-based methodologies include both an unsupervised and supervised classification procedure. Both classifications were developed from the orthomosaics created from the pre-processed raw drone images of the Islands.

3.4.1 Supervised Classification

A supervised classification requires the use of pre-defined areas of geographic importance called regions of interest (ROI) or signatures. These areas acted as a spectral representation of the type of land cover that needs to be mapped. The steps used to run the supervised classification are outlined in figure 3.6 below.

![Figure 3.6: Simplified flow chart of steps used to run a supervised classification](Sarah Hamilton, 2017).

For the purpose of this study, up to five different signature classes were defined manually using the image classification toolbar. Each signature class was made up of approximately 20 training areas (ROIs), which were defined by drawing a polygon over each feature class (figure 3.7).

![Figure 3.7: Creating Training Areas (ROIs) to run Supervised Classification](Screenshot from ArcMap 10.4.1)
A signature file was developed using the training areas and was sub-sequentially used to run the maximum likelihood classification on the clipped orthomosaic. The resulting output would categorise each pixel into one of the user-defined land cover classes based on it having the same or similar spectral reflectance values.

### 3.4.2 Unsupervised Classification

An unsupervised classification is similar to a supervised classification in that it utilizes features with distinct spectral reflectance properties to classify pixels into different classes. However, an unsupervised classification does not require the manual identification of pixel classes through the use of ROIs to train the image classification algorithm. Instead, the unsupervised classification employs numerical procedures to logically group pixels into classes with the same or similar spectral properties without the need to create training areas (figure 3.8).

![Simplified flow chart of steps used to run an unsupervised classification](image)

**Figure 3.8**: Simplified flow chart of steps used to run an unsupervised classification *(Sarah Hamilton, 2017)*.

To perform the unsupervised classification of the islands, the clipped island raster image was processed through the isocluster function from the multivariate tool path in the spatial analyst toolbox in ArcGIS 10.4.1. Approximately 5 classes were defined, depending on the variation of the vegetation present in the area being analysed. The output of the unsupervised classified image is constructed from a series of numbered classes formed from the statistical values within the pixels of the original image. Therefore, interpretation of the image classes is necessary to define each class as a relevant land cover feature.

### 3.5 Majority Filter Classification Smoothing

The supervised and unsupervised classifications resulted in an output raster that appeared pixelated and “fuzzy”. To create a more cohesive raster layer the resolution was resampled to a coarser cell size with the neighborhood toolset. Neighborhoods can be either overlapping or non-overlapping, the focal statistics tools utilizes the overlapping neighbourhoods to calculate a specified statistic for the individual cells within a specified neighbourhood. A majority filter was used on the supervised and unsupervised vegetation maps at values of 3x3, 5x5 and 8x8 around every cell in the input raster. Figure 3.9 shows a section of the supervised classification for Big Island with the raw supervised classification (a) and the same area using an 8x8 neighborhood majority filter (b).
Figure 3.9: Figure a) depicts the area extent of the examples given and their location within Big Island. Both figures b) and c) depict a classified image of the vegetation on Big Island within the same area extent. b) Shows the classified image at full resolution with no smoothing. c) Shows the classified image with an 8x8 majority filter. (Extracts from ArcMap 10.4.1, 2018).
3.6 Accuracy Assessment of the Classified Images

Digital Maps classified from remotely sensed images will have some degree of uncertainty, and this uncertainty limits our ability to be able draw an accurate conclusion from their associated results. An understanding of the limitations can be drawn from an evaluation of the errors and subsequent accuracy assessment. A validation exercise was conducted to evaluate the correspondence of the remotely sensed images with a series of independent photographs taken in-situ. The independent data sets were derived from field collected data points, or ‘ground thruthing’ points. The ground truthing points were recorded as photographs (figure 3.10) with associated plant identification information and each was georeferenced using Avenza mobile A-GPS up to 5m accuracy. A point shapefile was created using the Georeferenced photographs into ArcMap (figure 3.11) and then used as reference points for the accuracy assessment. Since the accuracy of the hand held device can vary more than +/- 5m, the field data was visually checked for authenticity of the training sights and each point was manually adjusted with close visual scrutiny.

![Figure 3.10: Examples of ground cover classes used for ground truthing points. (Photos taken May, 2018)](image)

a) Single tuft of *Lomandra longifolia*.

b) Leaves of Mirror Bush (*Coprosma repens*).

c) Thickets of dead Kikuyu grass.

d) Thick swards of Kikuyu grass.

e) Leaves of the Native Forb New Zealand Spinach
Each Ground truthing point was assigned a class which directly corresponded with the class types identified in the digital classification; e.g. class 1 = Exotic_veg, 2 = Grass, 3 = Native_Forbs etc. The Ground referenced datasets at each location were then cross examined in an error or confusion matrix (table 3.1) with the classified pixels at the same point location on the map. Each column identifies the classes within the ground truthing points, whereas the rows identify the same classes derived from the classification. Each ground referenced point was manually entered into the error matrix, firstly by identification of the ground referenced point and then by placing the value of 1 in whichever row it was identified as by the classification.

The shaded boxes along the diagonal of the matrix represent the pixels that were assigned to the same class by the ground referenced dataset and classified map, and are ultimately deemed as correct. The overall accuracy of the map is then determined by the percentage of these correctly defined pixels out of the whole of the ground referenced data points.

**Table 3.1:** Error or Confusion matrix for vegetation classification on Big Island.

![Figure 3.11: Ground Truthing Points used to create error matrix in accuracy assessment of Big Island I. The field survey resulted in a total of 178 georeferenced points. (Screenshot from ArcMap 10.2)](image)
3.7 Manual Digitization of *Lomandra sp.* on Big Island
The *Lomandra sp.* were digitized by visually interpreting the tussocks on screen from the Big Island orthomosaic and turning them into digital vector data points. Firstly, to do this a point shapefile was created and given spatial referencing information to match that of the drone images. The shapefile was defined into datum D_WGS_1984 and coordinate system GCS_WGS_1984 to match the drone image.

Once zoomed to a resolution of 1:48 in ArcMap 10.4.1, each tussock can be visually interpreted clearly and recorded as a singular point through the use of the point editor toolset (figure 3.12). Tussocks were identified on a visual basis, meaning the size shape and colour were the main features considered in selecting which tussocks to digitize.

Fully grown *Lomandra sp.* were identified by a diameter of around 1.2 metres, earthy green colour and circular formation with a central vertex. Juvenile *Lomandra sp.* were included in the population count provided they were large enough to be easily identified from the aerial image. When presented in clusters, the *Lomandra sp.* distribution was estimated with careful consideration of individual plant size and shape to make an educated assumption of the positioning of each plant centre. These assumptions were supported by on ground reference photographs in most cases. Digital points were added consecutively and combined to create a new point shapefile of all *Lomandra sp.* points, which could then be counted and depicted digitally.

![Figure 3.12: Digitized point shapefile overlain onto *Lomandra longifolia* tussocks on Big Island I at scale 1:48. (Screenshot from ArcMap 10.4.1)](image)

3.9 Survival of *Lomandra sp.* Seedlings Planted on Big Island
To determine the overall success of the planted *Lomandra Longifolia* in Areas 1 and 2, as depicted in figure 1.7, the total amount of *Lomandra sp.* digitized was compared to the original amount planted. The *Lomandra sp.* were digitized as described in section 3.8 above for both areas. The total count of *Lomandra sp.* found in Area 1 was derived from one lot of digitizing and the total count of *Lomandra sp.* digitized in Area 2 was derived from an average obtained amongst 29 research assistants as described in section 3.10 below. Table 3.2 depicts the total amount of *Lomandra Longifolia* tussocks
that have been planted on Big Island so far in accordance with the Big Island Vegetation Management Plan (Berrim Nuru, 2018). As the figures provided by NPWS did not specify the individual count of *Lomandra longifolia* planted for each area, the total for Areas 1 and 2 was taken to show *Lomandra sp.* success. The total was calculated by finding the sum of *Lomandra sp.* planted in Area 1 over 2015, areas 1 and 2 over 2016 as well as Areas 1, 2 and 3 over 2017. The reason area 3 was included in the final addition of seedlings planted is because it is noted that it was only a small patch that was planted in area 3 in 2018 and there was also an additional small patch of 200 seedlings planted in areas 1 and 2 in 2018, which will not be counted to even out the totals calculated.

<table>
<thead>
<tr>
<th></th>
<th>2015</th>
<th>2016</th>
<th>2017</th>
<th>2018</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Lomandra longifolia</em> seedlings</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Areas</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td></td>
<td>1</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>(North hill)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>6</td>
<td></td>
<td></td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>(small Patch)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1&amp;2</td>
<td>1&amp;2</td>
</tr>
<tr>
<td>(infill 200 seedlings)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>18525</strong></td>
</tr>
</tbody>
</table>

*Table 3.2:* This table depicts the total number of *Lomandra longifolia* that were planted on Big Island between 2015 and 2018 in agreement with the Big Island Vegetation Management Plan (Berrim Nuru, 2018). Figures supplied by NPWS (National Parks and Wildlife Services, 2018).
3.10 Lomandra sp. Manual Digitisation Uncertainty

To test the uncertainty of the digitization of *Lomandra sp.* the probably of uncertainty from a statistical distribution was evaluated. To do this, 29 participants from University of Wollongong were asked to digitize all the *Lomandra sp.* points that could be found in area 2 of Big Island. The number of points digitized by the participants was then compared in an excel spreadsheet to find the following statistical metrics in table 3.3 as a multi-faceted investigation of statistical uncertainty:

<table>
<thead>
<tr>
<th>Measure</th>
<th>Definition</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean ($\bar{x}$)</td>
<td>A measure of central tendency, also known as the Statistical Average.</td>
<td>$\bar{x} = \frac{\sum x}{n}$</td>
</tr>
<tr>
<td></td>
<td>Calculated by dividing the sum of all values by the total number of data</td>
<td>Where: $\bar{x}$ = Mean</td>
</tr>
<tr>
<td></td>
<td>values summed.</td>
<td>$\sum x =$ sum of all data values</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$n =$ total number of values</td>
</tr>
<tr>
<td>Range ($R$)</td>
<td>Gives an estimate of the spread of the data. Can be found by taking the</td>
<td>$R = \text{Max} - \text{Min}$</td>
</tr>
<tr>
<td></td>
<td>minimum value away from the maximum value.</td>
<td></td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>A measurement that is used to quantify the amount of variation in a set</td>
<td>$\sigma = \sqrt{\frac{\sum(x - \bar{x})^2}{n - 1}}$</td>
</tr>
<tr>
<td>($\sigma$)</td>
<td>of data values.</td>
<td>Where: $\sigma$ = Standard Deviation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$\bar{x}$ = Mean</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$\sum x =$ sum of all data values</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$n =$ total number of values</td>
</tr>
<tr>
<td>Standard Error</td>
<td>A measurement of the statistical accuracy or variability in the sampling</td>
<td>$SE = \frac{\sigma}{\sqrt{n}}$</td>
</tr>
<tr>
<td>($SE$)</td>
<td>distribution of a statistic.</td>
<td>Where: $SE$ = Standard Error</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$\sigma$ = Standard Deviation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$n =$ total number of values</td>
</tr>
<tr>
<td>Median ($\hat{x}$)</td>
<td>The centre value that divides an array of data into two halves.</td>
<td>For odd numbers of observations ($n$):</td>
</tr>
<tr>
<td></td>
<td></td>
<td>the median is the value at position:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$\hat{x} = \frac{n + 1}{2}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>For an even number of observations ($n$):</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1) Find the value at positions:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$\frac{n}{2}$ and $\frac{n+1}{2}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2) Find the average of the two values to get the median.</td>
</tr>
<tr>
<td>95% Confidence</td>
<td>To find the Confidence interval for a normal distribution; the standard</td>
<td>$C.I. = \bar{x} \pm z \sigma$</td>
</tr>
<tr>
<td>Interval (C.I.)</td>
<td>deviation is multiplied by 1.96. As 95% confidence intervals are</td>
<td>Where: $C.I.$ = Confidence interval</td>
</tr>
<tr>
<td></td>
<td>obtained as 1.96 standard errors either side of the estimate.</td>
<td>$\bar{x}$ = Mean</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$z = 1.96$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$\sigma$ = Standard Deviation</td>
</tr>
</tbody>
</table>

Table 3.3: Identification of different statistical measures used to solve for the uncertainty in *Lomandra Sp.* Digitization. A description of each parameter as well as the subsequent formula used to solve for each statistical metric is included. (Agresti, 2017; Hamylton, 2017; Stern, 2001)
This data was then used to create a Frequency Histogram of the results by defining the Bin numbers between 0 and 840 and graphically analysing the frequency. A standard normal distribution Gaussian curve (figure 3.13) was then overlain onto the histogram to assess the nature of the distribution.

**Figure 3.13:** A Gaussian or standard normal distribution curve. The bell shape depicted indicates a normal distribution and below the bell equates to a value equal to one or 100%. The central limit theorem states that 95% of the area under the curve lies within ±1.96 standard deviations of the mean (Hamilton, Spatial Analysis of Coastal Environments, 2017).
3.11 Digitizing Carpobrotus sp. on Big Island

The Carpobrotus sp. were digitized by visual interpretation of the vegetation coverage on the Big Island Othomosiac and then the subsequent creation of vector polygons to represent these features. Both Aerial drone images from 19th July 2017 and 17th July 2018 were used in the digitization and two separate maps were produced for comparison. To do this a polygon shapefile was created and assigned the same spatial referencing information to match that of the drone acquired images. The shapefile was defined into datum D_WGS_1984 and coordinate system GCS_WGS_1984.

Once zoomed to a resolution of 1:200 in ArcMap 10.4.1, each area covered by the Carpobrotus sp. can easily be interpreted visually and traced around to create a polygon of each through the use of the polygon editor toolset. The Carpobrotus sp. was identified on a visual basis, with colour and shape being the main categorizing features. It can be distinguished by its darker green/purple toned foliage and its common matted formation, shown in figure 3.14. Digital polygons were added consecutively and combined to create a new shapefile of all Carpobrotus sp. polygons, which could then be depicted digitally.

Figure 3.14: LHS: Example of colour and coverage of Carpobrotus sp. on Big Island and RHS: Digitized polygon shapefile overlain over Carpobrotus sp. on Big Island at a scale of 1:200. (Screenshot from ArcMap 10.4.1)

3.12 Quantifying Lateral Growth of Carpobrotus sp. on Big Island.

To quantify the spread of the Carpobrotus sp. on Big Island, firstly the total area was calculated from the area occupied by the polygons. To do this the coordinates of the system was changed to an appropriate projected coordinate system, in this case GDA_1994_NSW_Lamberts_CC was applied. The Calculate geometry dialog box was then opened through the attribute table and the area field was calculated for both 2017 and 2018 Carpobrotus sp. the total areas were then compared in a excel spread sheet and Growth in m² per day was calculated by dividing the total difference by the amount of days between each aerial photograph.
3.13 Density analysis of *Lomandra sp.* on Big Island

To assess the density of the *Lomandra sp.* to one another a kernel density analysis was undertaken. This analysis was only conducted in rehabilitation area number two (figure 3.15) as this is where the prominence of healthy full grown *Lomandra sp.* are present.

![Figure 3.15: 2018 vegetation planting map showing the different area boundaries defined by NSW National Parks and Wildlife Service (NPWS).](image)

Firstly to assess density of the *Lomandra sp.* in area two of Big Island, the *Lomandra sp.* point file was clipped to the area extent using the clip spatial analyst toolset. The clipped *Lomandra sp.* point shapefile was then run through the spatial analyst; kernel density toolset with a search radius of 0.0001. Ideal *Lomandra sp.* density was then determined by the tussock distribution in the highest density areas.

### 3.14 Spatial Regression: *Lomandra sp.* Health vs. Distance from *Carpobrotus sp.*

To undergo a spatial regression of health of *Lomandra sp.* in relation to distance from Unknown *Carpobrotus sp.* information regarding tussock health, diameter and green auto was firstly collected.

To do this, additional fields were created in the *Lomandra sp.* attribute table for each characteristic: diameter; green auto and health. The diameter of each tussock was measured individually using the measure tool and green auto (total green present) was found by viewing the information for each point and its corresponding value in the green colour band.

The health of the *Lomandra sp.* was visually determined by factors including shape, size and colour and each tussock was assigned a number between one and five based on those factors. A rating of 1 would indicate extremely poor health where as a rating of 5 would indicate very good health. Table 3.4 below gives detail into the identification of each of the health classes 1-5 with a picture example of each occurring on Big Island. (*screenshots from Arcmap 10.4.1.*)
The distance between *Lomandra* sp. and *Carpobrotus* sp. was also determined as part of the overall spatial regression. To find the distance, the Euclidean Distance tool, found in the spatial analyst toolset in Arcmap 10.4.1 was used. It was then used in conjunction with a spatial regression model to show the relationship between *Lomandra* sp. and distance to *Carpobrotus* sp. as well its relationship with the attributes listed above. Because the *Carpobrotus* sp. is mainly present in north-west portion of Big Island, the analysis will be limited to the extent of area one, depicted in figure 3.14. To run the analysis the *Carpobrotus* sp. was input as the feature source data and the corresponding output was added to the *Lomandra* sp. attribute table as a separate field for regression analysis. This was performed using the extract surface data tool and adding a float field in the *Lomandra* sp. attribute table called distance. The outcome of the Euclidean distance is included in figure 3.16 below.

The information acquired from Arcmap 10.4.1 was then used to run a spatial regression to assess the relationship between the *Lomandra* sp. health, diameter and green auto to distance from Pigface Unknown *Carpobrotus* sp. The analysis was performed using GeoDa statistical analysis software. To run this analysis the *Lomandra* sp. shapefile created in Arcmap was opened in GeoDa software with all its original attributes. A classical (ordinary least squares) regression was then performed using the regress tool in the methods dropdown. The model was run with health as the dependant variable and distance; i.e. the Euclidean distance to pigface (figure 3.16) as the independent variable.

<table>
<thead>
<tr>
<th>1 (Extremely Poor health)</th>
<th>2 (Poor health)</th>
<th>3 (average health)</th>
<th>4 (good health)</th>
<th>5 (Very good health)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Description:</strong></td>
<td><strong>Description:</strong></td>
<td><strong>Description:</strong></td>
<td><strong>Description:</strong></td>
<td><strong>Description:</strong></td>
</tr>
<tr>
<td><strong>Colour:</strong> 100% discoloured.</td>
<td><strong>Colour:</strong> 75% discoloured.</td>
<td><strong>Colour:</strong> 50% discoloured or/ dull overall colour.</td>
<td><strong>Colour:</strong> 75% green with small amounts of discolouration.</td>
<td><strong>Colour:</strong> 100% green with no discolouration.</td>
</tr>
<tr>
<td><strong>Size:</strong> Average diameter smaller than 0.7 m.</td>
<td><strong>Size:</strong> Around 1m average diameter.</td>
<td><strong>Size:</strong> Average diameter between 1 – 1.5m.</td>
<td><strong>Size:</strong> between 1.5 – 2m</td>
<td><strong>Size:</strong> Between 1.5 – 2m</td>
</tr>
<tr>
<td><strong>Shape:</strong> Not circular in shape. Irregular radius from tussock centre.</td>
<td><strong>Shape:</strong> Not circular in shape. Irregular radius from tussock centre in some.</td>
<td><strong>Shape:</strong> Not always circular in shape. Irregular radius from tussock centre in some.</td>
<td><strong>Shape:</strong> circular in shape. Even radius from tussock centre.</td>
<td><strong>Shape:</strong> Circular in shape, even radius around tussock centre.</td>
</tr>
</tbody>
</table>

The information is presented in Table 3.4: *Lomandra Health Rating.*
The classical regression was then re-run as a spatial error model to find the association as a spatial regression. The model was re-run with health as the dependant variable and distance as the independent variable however this time with a weights matrix specified.

**Figure: 3.16:** A coloured depiction showing the euclidean distance from Pigface – Unknown *Carpobrotus* sp. Dark patches show the maximum distance of about 20m from the polygon whereas lighter patches depict location of the Unknown *Carpobrotus* sp. (screenshots from Arcmap 10.4.1)
3.15 Spatial Analysis: *Lomandra sp*. Health vs Distance from *Carpobrotus sp.*

A visual analysis was undertaken to assess distribution patterns of *Lomandra sp.* in relation to *Carpobrotus sp.* To do this the symbology of the *Lomandra sp.* was altered to show the varying attributes clearly, shown in figure 3.17. This was done in Arcmap 10.4.1 by going into the Layer properties of the *Lomandra sp.* point shapefile and changing the symbology to quantities in the symbology tab. The value field was then changed to that of an attribute of interest and each icon depicting a range within that field was changed to a distinctive colour and size. For example the *Lomandra sp.* points with a lower health rating would be defined with a small colourless symbol and the points with better health were defined by a larger different coloured symbol.

![Screenshot from Arcmap 10.4.1 showing Euclidian Distance (m²) and the associated digitized points depicting *Lomandra sp.* Health from 1-5. The Symbolgy used is from small pale green dots to large dark green dots to represent tussocks of low to excellent health respectively. (Screenshot from Arcmap 10.4.1)](image-url)
4. Results

4.1 Survival of *Lomandra sp*. Seedlings Planted on Big Island

<table>
<thead>
<tr>
<th></th>
<th>Digitized</th>
<th>Planted</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Lomandra Longifolia</em> in Area 1</td>
<td>968</td>
<td></td>
</tr>
<tr>
<td><em>Lomandra Longifolia</em> in Area 2</td>
<td>611.517</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>1579.517</td>
<td>8003</td>
</tr>
</tbody>
</table>

**Difference** 6423.483

*Table 4.1:* This table shows the values calculated for *Lomandra sp*. success. It depicts the total amount of *Lomandra longifolia* Digitized through the use of ArcMap 10.4.1 in Areas 1 and 2 as well as conveying the total number of seedlings planted in accordance with the revegetation scheme conducted by Berrim Nuru. The total number of *Lomandra sp.* digitized corresponds directly to the amount of tussocks that survived out of the seedlings planted. In other words, the total number of seedlings planted (8003) minus the total number digitized (1579.517) equals the total number of *Lomandra sp.* tussocks that did not survive (6423.483) accounting for the overall seedling Survival of *Lomandra longifolia*.

4.2 *Lomandra sp.* Manual Digitisation Uncertainty

*Figure 4.1:* A frequency histogram displaying the distribution of *Lomandra longifolia* abundance in Area 2 of Big Island, fitted with a Gaussian normal distribution curve. The Histogram was created from the individual number of *Lomandra sp.* digitized between 29 research assistants. The y-axis is composed of the number of Researchers whereas the x-axis portrays the Number of *Lomandra longifolia* tussocks identified. The key statistical values produced in the uncertainty analysis are depicted in the table on the RHS of the figure.
4.3 Density analysis of *Lomandra sp.* On Big Island

**Figure 4.2:** Results of Kernel density analysis for Area 2 on Big Island. The figure below features digitized *Lomandra sp.* points in a deep red colour as well as the expression of high (1 *Lomandra sp.* per 1m$^2$) density vs low density (0 *Lomandra sp.* per 1m$^2$) areas in red and green areas respectively. The regions between the high and low density areas are depicted by a gradual fading between red $\rightarrow$ orange $\rightarrow$ yellow $\rightarrow$ green as the *Lomandra sp.* tussocks become less dense.
4.4 Digital Classification of Vegetation on the Five Islands

4.4.1 Big Island: Supervised Classification

Figure 4.4.1: LHS: Output of supervised classification of land cover on Big Island in April 2018 before the aerial Glyphosate 360 treatment in May 2018. RHS: Output of supervised classification of land cover on Big Island in July 2018 after the aerial Glyphosate 360 treatment in May 2018. The output for both the before and after classification of Big Island was achieved using the maximum likelihood classifier in ArcMap 10.4.1 and shows the five vegetation classes: Exotic Bushes (21%; 16%), Grass (30%; 16%), Lomandra (9%; 19%), Dead Vegetation (32%; 45%) and Native forbs (8%; 4%) that were defined for the before and after spray classifications respectively. Both maps are presented with corresponding pie graphs depicting the percentages of the corresponding land cover types classified on Big Island.
4.4.2 Big Island II, Martin Islet and Rocky Islet: Supervised Classification

Figure 4.4.2: Top LHS: Output of supervised classification of land cover on Big Island II in July 2018. The map depicts five vegetation classes: Mirror Bush, Pennywort, NZ Spinach, Grass and Dead Vegetation that were defined for the classification. Top RHS: Output of supervised classification of land cover on Martin Islet in July 2018. The map depicts five vegetation classes: Dead Vegetation, Grass, Exotic Bushes, Unknown 1 and Unknown 2 that were defined for the classification. The output for both maps was achieved using the maximum likelihood classifier in ArcMap 10.4.1 Both maps are presented with corresponding pie graphs depicting the percentages of the corresponding land cover types classified on Big Island II and Martin Islet. Bottom LHS: Map of Rocky Islet. Shows lack of vegetation compared to other Islands.
4.4.3 Flinders Island and Bass Islet: Supervised Classification

Figure 4.4.3: 

**LHS:** Output of supervised classification of land cover on Flinders Island in July 2018. The map depicts five vegetation classes: Bitou Bush, Mirror Bush, Native, Rock and Dead Vegetation that were defined for the classification. 

**RHS:** Output of supervised classification of land cover on Bass Islet in July 2018. The map depicts five vegetation classes: Exotic Bushes, Unknown 1, Unknown 2, Grass and Dead Vegetation that were defined for the classification. The output for both maps was achieved using the maximum likelihood classifier in ArcMap 10.4.1. Both maps are presented with corresponding pie graphs depicting the percentages of the relating land cover types classified on Flinders Island and Bass Islet.
4.5 Effectiveness of Weed Treatment

**Figure 4.5.1: LHS: Top:** Output of supervised classification of land cover on Big Island in April 2018 before the aerial Glyphosate 360 treatment on 2nd May 2018. The output was achieved using the maximum likelihood classifier in ArcMap 10.4.1 and shows the five vegetation classes: Mirror Bush (9%), Coastal Morning Glory (9%), Dead Vegetation (48%), Grass – Kikuyu (27%) and Native forbs (9%). The associated pie chart depicts the percentages of the corresponding land cover types classified on Big Island in April 2018, prior the scheduled spray treatment.

**RHS: Top:** Output of supervised classification of land cover on Big Island in July 2018 after the aerial Glyphosate 360 treatment in May 2018. The output was achieved using the maximum likelihood classifier in ArcMap 10.4.1 and shows the five vegetation classes: Mirror Bush (7%), Coastal Morning Glory (1%), Dead Vegetation (84%), Grass – Kikuyu (7%) and Native forbs (1%). The associated pie chart depict the percentages of the corresponding land cover types classified on Big Island in July 2018, following the scheduled spray treatment.

**RHS: Bottom:** Table depicting the difference in vegetation coverage after the spray treatment.

<table>
<thead>
<tr>
<th>Class</th>
<th>Difference (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mirror Bush</td>
<td>- 22.22</td>
</tr>
<tr>
<td>Native Forbs</td>
<td>- 85.71</td>
</tr>
<tr>
<td>Coastal Morning Glory</td>
<td>- 88.89</td>
</tr>
<tr>
<td>Grass</td>
<td>- 74.07</td>
</tr>
<tr>
<td>Dead Vegetation</td>
<td>+ 75</td>
</tr>
</tbody>
</table>

60
4.6 Spatial Analysis: *Lomandra* sp. Health vs Distance from *Carpobrotus* sp.

**Figure 4.6.1:** A spatial depiction of the Euclidean distance of *Carpobrotus* sp. (exotic Pigface) to *Lomandra longifolia* tussocks with specific attention to *Lomandra* sp. health in Area 2 of Big Island in July, 2018. Dark blue sections of map indicate a distance of up to 20m away from *Carpobrotus* sp. whereas areas of light blue indicate presence of *Carpobrotus* sp.; *Lomandra longifolia* that range between low (1) and optimum health (5) are represented by small pale green points to larger dark green points respectively. The *Carpobrotus* sp. boundary is represented by the purple outline. **Bottom:** Table depicts the results of the spatial regression model **TOP:LHS:** Depicts the northern portion of Area 1, whereas the **TOP:RHS:** depicts the southern End of Area 1. Visual analysis of spatial distribution resulted in three conclusions:

1) Healthy *Lomandra* sp. are mainly present in clusters, whereas unhealthy *Lomandra* sp. are more commonly spread out and found standing alone.

2) *Lomandra* sp. that occur within a *Carpobrotus* sp. mat boundary are predominantly of poor health.

3) In areas of intermittent *Carpobrotus* sp. dispersal, *Lomandra* sp. present between *Carpobrotus* sp. clusters are of poor health.

4) *Lomandra* sp. of poor health appear to be widely spread and standing alone, whereas *Lomandra* sp. of greater health are localised and tend to occur in clusters.

<table>
<thead>
<tr>
<th>Summary of Output: Spatial Lag Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Observations</td>
</tr>
<tr>
<td>Lag coeff (Rho)</td>
</tr>
<tr>
<td>R-squared</td>
</tr>
<tr>
<td>W_Health</td>
</tr>
<tr>
<td>Distance_P</td>
</tr>
</tbody>
</table>
4.7 Spread of Exotic Pigface *Carpobrotus* sp. on Big Island between 2017 and 2018

**Figure 4.7.1:** Top LHS: Distribution of *Carpobrotus* sp. (exotic Pigface) in Area 1 of Big Island on the 29th July 2017. **Top RHS:** Distribution of *Carpobrotus* sp. on the 17th July 2018. Mats of the *Carpobrotus* sp. are outlined by the purple striped polygon in Arcmap 10.4.1. for both 2017 and 2018 maps. **Bottom RHS:** Table depicting areas calculated from the polygon area in Arcmap 10.4.1 for each year. The table also shows the results of the overall increase in *Carpobrotus* sp. distribution between the two aerial surveys as well as the calculated growth per day.
5. Discussion

In this project *Lomandra longifolia* were digitized by creating a point shapefile of each tussock that could be identified from the areal images acquired through the UAV. The points identified as being present over management Areas 1 and 2 (1580) were then compared with the Total amount of seedlings planted in these areas (8003) by Berrim Nuru under the provision of NPWS and OEH staff. The difference of between these counts (6423) indicated a low survival rate (19.74%) of *Lomandra longifolia* seedlings in these areas. There are multiple reasons for this large portion of *Lomandra sp.* being unaccounted for. The frequency histogram revealed a wide spread of data and revealed a relatively low confidence interval at 95% confidence (±169.02), meaning the vector based digitizing of *Lomandra sp.* presents a significant amount of user error. This could be because of the density of *Lomandra sp.*, as when the tussocks were presented in a close range to one another (1:1m²) they were difficult to distinguish as individual plants. It was also up to the user as to whether they considered Juvinille/small/or unhealthy species as a true *Lomandra longifolia* Tussock, as they appeared differently to the mature healthy plant and where difficult to correctly identify. The low survival of *Lomandra longifolia* seedlings may also be attributed to the harsh conditions on Big Island, such as: the threat of more competitive exotic species, namely *Carpobrotus sp.*, which vastly inhibit the growth of mature plants when in direct and indirect contact as well as prevent native seed germination (Albert, 1995; Ana Novoa Luis González, 2013; Connor, 2009; D’Antonio 1990, 1993; Julie Chenot, 2018; Tomas Sintes, 2007).

A notable spatial correlation was found between *Lomandra sp.* health vs. Euclidean distance from *Carpobrotus sp.* in both the spatial regression (R²=0.47) as well as the visual spatial analysis. The results of the spatial regression reveal that although there is a correlation, it is not as strong as predicted. This is because exotic *Carpobrotus sp.* cause the most detriment to a native species once they are in direct contact; as it will form large dense mats up to 40cm thick of layered dead and newly established material (D’Antonio, 2011) and grow directly over other native vegetation in its path. A comparison of areal images of Big Island between 2017 and 2018 show that healthy mature *Lomandra longifolia* tussocks in 2017 were completely replaced by *Carpobrotus sp.* the following year.

The low seedling survival could also be attributed to the harsh north coming winds and associated salt spray. The visual spatial analysis revealed the healthiest *Lomandra longifolia* were found in Areas protected by tall features: e.g. the management hut, and taller shrubs such as *Coprosma repens* (Mirror Bush); whereas *Lomandra sp.* tussocks on the north most facing hill had little to no visual endurance. This is because *Lomandra longifolia* are considered a type of heathland shrub that is usually found in the transitional zone; secondary or tertiary dune, or in the swale, rather than in the primary dune, fore dune or directly on the beach (Gillham, 1960; Kirkpatrick, 1989).

Although there was a large amount of uncertainty associated with vector based approaches to digitizing *Lomandra longifolia* tussocks, it was still deemed more appropriate than the raster based mapping, where Producer accuracy in the supervised classifications of Big Island Before and After spray analysis was lowest in *Lomandra longifolia* identification (59.09% and 53.85% respectively).

To assist management in knowing the ideal number of *Lomandra sp.* to plant per m² on the Island, a kernel density analysis was run through Arcmap 10.4.1. The kernel density analysis produced a result of 1 *Lomandra sp.* Tussock per m² as the maximum density as shown in figure 4.2 and therefore the ideal density of *Lomandra longifolia* to be planted in future operations. The maximum density was chosen as this will give the largest possible *Lomandra longifolia* seedlings to be planted in a given area while still guaranteeing they will be able to grow into healthy mature plants.

Both a supervised and unsupervised classification was run on all of the Five Islands in attempt to identify the vegetation present on each Island. The Supervised: maximum likelihood classification was considered the most accurate when put into a confusion matrix compared with the unsupervised:
iso-cluster classification. Visual analysis of the unsupervised classification revealed that non-significant features, such as shadows and light areas were considered an individual vegetation class. The raster based supervised classification was deemed very useful when there was a large area of unknown vegetation coverage, as each pixel could be digitally classified without the user knowing exactly what type of vegetation was present. Some difficulties were presented in that *Lomandra longifolia* had low producer accuracy in the Big Island classifications, as well as a large portion of *Chrysanthemoides monilifera* (Bitou Bush) being incorrectly classified as *Coprosma repens* (Mirror Bush) on Flinders Island (66.67% producer accuracy). However, both *Chrysanthemoides monilifera* and *Coprosma repens* have similar spectral reflectance properties which would have caused confusion during classification of Flinders Island (Dennison and Roberts, 2003; Foody et al., 1992). This was also the case in the classification of grass species present on the Islands, as they were placed into the same class even regardless of their invasive; e.g. *Cenchrus clandestinus* (Kikuyu Grass) or native; e.g. *Poa poiformis* (coast tussock-grass) status. It was also found that the running weed *Ipomoea cairica* (Coastal Morning Glory) was hard to distinguish from *Cenchrus clandestinus* (Kikuyu Grass) when creating ROI training areas on Big Island, as they were often tangled together and not in distinct enough patches to classify separately. This however, effectively highlighted the heterogeneous nature of the vegetation on Big Island and showed off the capabilities of Raster based analysis to distinguished small scale changes, where vector based analysis would only be able to consider these multifaceted areas as one class type. Regardless of these challenges the supervised classifications were deemed highly accurate, with total accuracy’s from 78.85-89.81% for Islands where ground surveys were available and 66.67-81.70% on islands of unknown vegetation.

The raster based classification proved to be a useful digital resource as it provides opportunities for further spatial analysis, such as mapping the distribution of individual plants on the island or incorporating other class features, such as plant vigor that was distinguished in the classification of littoral vegetation on the Galapagos Islands by D’Antonio (1990, 1993) and D’Antonio 1990, 1993; Ana Nova et al., 2013; Julie Chenot, 2018; Tomas Sintes, 2007), the growth was expected and...
proven to be rapid (1.89m$^2$/day). The use of vector based digital mapping allowed for the easy consolidation of data as well as simplified calculations to find area. Raster based mapping does not allow for straightforward field geometry calculations for parameters such as area; to do so a testing transformation must be conducted to turn raster into a vector format beforehand.

5.1 Limitations and Recommendations

Given the complex nature of digital spatial mapping; some unavoidable limitations were found to occur. However, with the fast growing and continuously expanding knowledge and development of spatial mapping and image classification methodologies, many of these limitations may be resolved in future analysis.

In this study, Lomandra sp. seedling survival was assessed by comparing the total amount of seedlings planted vs. the total number of Lomandra longifolia tussocks digitized in the aerial images. The resulting survival rate was lower than expected (19.74%), which could be explained largely by the large spread of data and relatively low confidence interval (± 196.02), indicating a high amount of user error. This process also took an extensive amount of time and would not be sustainable for a large data set. However, faster operations used in this study such as image classification would not give a count of individual tussocks and would only distinguish between vegetation classes present (Hamylton, 2017). Alternatively, Lomandra sp. digitization could be assisted through the implementation of recent advances in machine learning computer vision models in object detection. Compared to an image classification system, an object based detection system operates on a more fine-grained, granular, regional level where the useful signal apparent in an image is reserved, and the output would fundamentally reserve superior information on identification as well as location of objects of interest (J.Torres-Sánchez, 2015). The approach classifies not single pixels, but rather detects groups of pixels that represent an already pre-conceived object in a GIS database (Walter, 2004). Lomandra longifolia tussocks could be identified through the employment of a detection algorithm containing complex information on plant size, texture, colour, and shape that would be adjusted iteratively through a set of training samples (Zheng Song, 2011) (Constantine Papageorgiou, 2000). This would dramatically decrease the amount of inaccuracy associated with user error as well as reduce associated process time with larger data sets.

It should also be noted that Lomandra sp. seedling survival in Area 1 was compromised by the invasive Carpobrotus sp. as well as northerly winds, whereas Lomandra sp. survival in Area 2 was considerably less compromised and is presumed to have a higher rate of survival than Area 1. This promotes the notion that future research should be done into Lomandra longifolia seedling survival on the island, with particular note to Area 2 alone.

The point shapefile created for Lomandra longifolia was used further in this study to quantify the association between Lomandra sp. health and distance to Carpobrotus sp. The association found was not as significant as predicted, however through the visual spatial analysis an association was identified between Lomandra sp. health and location in relation to exposed and non-exposed areas on the island. This could be a direct response of Lomandra sp. to harsh environmental conditions such as wind and sea-spray found on the edges of the island. This hypothesized association could be tested in future studies through the use of the Euclidean distance feature in Arcmap10.4.1 to detect the association between Lomandra sp. health to island boundaries, specifically northerly winds, as well as coverage from features above a height of 1.2m, which is the height of a mature Lomandra longifolia tussock (Nabil M. Ahmad, 2018).

The challenge of spectral confusion became prominent throughout the duration of the classification process in mapping the vegetation on the Five Islands. Spectral confusion occurs when there is...
biophysical complexity in an environment; which is usually a result from optically similar signals as well as the mixing of different spectral classes (H. Holden, 1998). In the case of the Five Islands, vegetative classes such as *Ipomoea cairica* (Coastal Morning glory) and native forb *Commelina cyanea* (Wandering Sailor) have spectrally similar properties and were often confused in the spatial classification. This was detrimental to the accuracy of the results of the study, as the former is an introduced species and the latter is a native species, which needed to be correctly categorised into appropriate classes.

Spectral confusion also occurred in areas of high landscape heterogeneity, where the single pixel classifier would group vegetation into a pre-defined category; resulting in high intra-spectral variability (Dengsheng Lu, 2007). Usually this was found on Big Island where vines of *Ipomoea cairica* were tangled amongst swards of *Cenchrus clandestinus* and the output would result in the two vegetation types being classified as either one or the other. This process resulted in an output with reduced accuracy to the detriment of the overall reliability of the classification (G. M. Foody, 1998).

In this study the DHI FC33 camera was used for Aerial image acquisition. This camera only contains 4 spectral wavelengths distinguishing between Red, Green, Blue and Alpha (RGBA) spectral bands. The associated output only portrays wavelength variance within the visible spectrum (0.4–0.7 nm) with additional opacity information offered through the alpha band. It can be seen in figure 2.2 that most variation between vegetation spectral signatures occurs in the near-infrared to infrared region (NIR/IR) of the electromagnetic spectrum. Therefore the use of a multispectral or hyperspectral sensor would vastly improve the classification accuracy and reduce inter-spatial variability. Hyperspectral remote sensing utilizes hundreds of continuous narrow spectral bands between- 400 and 2,500 nanometres (nm), through the visible (0.4–0.7 nm), near-infrared (0.7–1 nm), and short wave infrared (1–2.5 nm) portions of the electromagnetic spectrum (Megandhren Govender, 2007; Chaichoke Vaiphasa, 2005). Hyperspectral remote sensing allows for a far greater range of discrimination between vegetation types that would be lost through the use of more limited sensors (K. S. Schmidt, 2003). The acquisition of hyperspectral data could be best obtained through the use of a hyperspectral airborne sensor coupled with a hand-held spectrometer. A handheld spectrometer is an optical device that collects detailed spectral reflectance values in the field and would create highly accurate training data of known land cover classes (Schmidt, 2003). This would ultimately allow for a classification with more vegetation classes and improve class separability.

Inaccurate classifications also occurred where one species would shelter another from the sensor, resulting in a single reflectance value being recorded from the top most species, with the vegetation beneath going undetected. This occurred in instances on Big Island where *Ipomoea cairica* grew completely over the top of *Coprosma repens* (Mirror Bush). As a result the classification categorised the *Coprosma repens* as *Ipomoea cairica* even though the *Coprosma repens* was a dominant species present. This error could be alleviated through the employment of ancillary Light Detection and Ranging (LiDAR) derived data. LiDAR sensors directly measure both the vertical extent and horizontal distribution of vegetation elements using the infrared and near infrared wavelengths (Edward W. Bork, 2007; Fowler, 2000). They operate on a pulse ranging principle to detect the digital elevation and range of elements from an airborne scanning LiDAR (Edward W. Bork, 2007). This would enable the separation of elements of distinguishable height. In this particular case, the much taller *Coprosma repens*, would be easily distinguished from the prostate perennial *Ipomoea cairica*. This would also allow for a more accurate analysis of the vegetation on Flinders Islet, where *Chrysanthemoides monilifera* (Bitou Bush) was incorrectly classified as *Coprosma repens*, as *Chrysanthemoides monilifera* is significantly shorter in habit.
Future analysis could include the further utilization of aerial imagery in the vector based digitization of animal inhabitants on the Islands. Visual analysis of Big Island and Martin Islet in particular, revealed a clear depiction of bird and seal species present on the islands. From the aerial imagery it was easy to distinguish between Ibis, Australian Pelicans, Silver Gulls and fur seals. This could lead to further research into the capabilities of using airborne methods to conduct ecological surveys assessing abundance and distribution patterns of fauna on the Five Islands.
6. Conclusions

In this study a comparison of raster and vector based approaches was utilized in order to quantify vegetation ground coverage in the Five Islands Nature Reserve, off the coast of Port Kembla, NSW. The project in particular functions within a broader context of a 5-year rehabilitation management plan being conducted by NSW National Parks and Wildlife Service (NPWS) and the University of Wollongong, revolving around the use of remote sensing techniques to answer fundamental management questions. The key conclusions of this study are summarised below:

- Vector based approaches allowed for the effective digitization of individual *Lomandra longifolia* points. Once the digitized points were compared with records of seedlings planted in Areas 1 and 2 of Big Island, a determination of species survival resulted in an outcome lower than expected (19.74%). The low seedling survival could be attributed directly to the competitive nature of the invasive *Carpobrotus sp.* present in treatment Area 1 on Big Island as well as the considerable user error associated with the digitization of points under human discretion. It is also hypothesized that the effect of northerly winds as well as salt-spray could also have effected *Lomandra sp.* survival.
- To determine the optimal distribution strategy for planting new *Lomandra longifolia* seedlings on Big Island, the kernel density toolset was utilized. The output of the kernel density analysis revealed that the maximum density amongst *Lomandra longifolia* tussocks in Area 2 of Big Island was 1 mature plant per m$^2$. Therefore the optimal distribution strategy would be to supply enough *Lomandra longifolia* seedlings to be planted within 1m$^2$ of one another to allow for the maximum amount to be planted in a given area.
- The use of drones as a platform for acquiring high spatial resolution imagery in remote settings has allowed for the effective acquisition of ground cover imagery of all Five Islands. The compilation of spatial imagery and Raster based classification methodologies proved to be a useful tool in the categorising of large areas of ground cover into the associated vegetation class. By utilizing the maximum likelihood classifier in ArcMap10.4.1 the associated distribution patterns and percentage vegetation cover of each class could be quantified for all Five Islands.
- The aerial spray treatment over Areas 3, 5, 6 and the eastern boundary margin on Big Island was deemed highly successful with a decrease in exotic vegetation species over the entire treatment area. The eradication of Invasive weeds; namely *Ipomoea cairica* (Coastal Morning Glory) and *Cenchrus clandestinus* (Kikuyu Grass) was highly successful with a reduction of 88.89% and 74.07% respectively. Raster-based classification techniques allowed for an extensive analysis of the change in vegetation classes before and after the spray treatment with accuracies of 88.89% and 90.91% respectively.
- The spatial analysis of *Lomandra longifolia* health and distance from *Carpobrotus sp.* resulted in a weak correlation ($r=0.47$). This was hypothesized to be caused by the effects of northerly winds and sea exposure having a considerable detriment to *Lomandra sp.* tussocks as well as the *Carpobrotus sp.* only harming plants once in direct contact.
- The exotic *Carpobrotus sp.* had a rapid growth rate in Area 1 of Big Island of 1.89 m$^2$ per day between 2017 and 2018. By creating a polygon feature class of the invasive *Carpobrotus sp.*, attributes like area were easily quantifiable and growth rate could easily be calculated.

Further Research into the remote sensing of the flora and fauna of Five Islands Nature Reserve off the coast of Port Kembla, NSW includes:
• The use of ancillary LiDAR data acquisition to distinguish between different plant height in the broader scope of quantifying *Lomandra longifolia* health in relation to protection from off shore winds and salt-spray.

• The acquisition of multi- or hyper-spectral data accompanied by training points from a hand help spectrometer to obtain vegetation coverage maps with greater accuracy and less spectral confusion. Hyperspectral data could also employ the use of normalized distribution vegetation index (NDVI) to assess plant vigor as discussed in chapter 2.1.6.

• Employ the vector based digitization of Seabird and Fur Seals present on the Islands, particularly Martin Islet. This would allow for a greater understanding of animal abundance and distribution on all five islands.

• The assessment used to find *Lomandra longifolia* seedling survival on Big Island should be contained to Area 2 alone, as this area was not prone to detriment from *Carpobrotus sp.* encapsulation and would give a more accurate outcome for species survival without competition.
7. References


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### 7. Appendices

Appendix A: All known plant Species in treatment Areas 1-6 on Big Island

<table>
<thead>
<tr>
<th>Species (natives first)</th>
<th>03.09.14</th>
<th>13.10.14</th>
<th>04.03.15</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commelina cyanea</td>
<td>rare</td>
<td>common</td>
<td>abundant</td>
</tr>
<tr>
<td>Etnadia trigonos</td>
<td>rare</td>
<td>common</td>
<td>common</td>
</tr>
<tr>
<td>Portulaca oleracea</td>
<td>rare</td>
<td>rare</td>
<td>rare</td>
</tr>
<tr>
<td>Tetragonia tetragonoides</td>
<td>common</td>
<td>common</td>
<td>common</td>
</tr>
<tr>
<td><em>Amaranthus viridus</em></td>
<td>-</td>
<td>rare</td>
<td>rare</td>
</tr>
<tr>
<td><em>Arayaia sericifera</em></td>
<td>-</td>
<td>-</td>
<td>rare</td>
</tr>
<tr>
<td><em>Baccharis pilosa</em></td>
<td>-</td>
<td>-</td>
<td>rare</td>
</tr>
<tr>
<td><em>Bromus cartharicus</em></td>
<td>common</td>
<td>abundant</td>
<td>abundant</td>
</tr>
<tr>
<td><em>Caltia maritime</em></td>
<td>-</td>
<td>rare</td>
<td>rare</td>
</tr>
<tr>
<td><em>Carpesium sp.</em></td>
<td>-</td>
<td>-</td>
<td>rare</td>
</tr>
<tr>
<td><em>Carica papaya</em></td>
<td>-</td>
<td>-</td>
<td>rare</td>
</tr>
<tr>
<td><em>Cenchrus clandestinus</em></td>
<td>rare</td>
<td>uncommon</td>
<td>abundant</td>
</tr>
<tr>
<td><em>Chenopodium album</em></td>
<td>rare</td>
<td>abundant</td>
<td>abundant</td>
</tr>
<tr>
<td><em>Chenopodium murale</em></td>
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<td>rare</td>
</tr>
<tr>
<td><em>Chrysanthemoides monilifera</em></td>
<td>rare</td>
<td>rare</td>
<td>rare</td>
</tr>
<tr>
<td><em>Cirsium vulgare</em></td>
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<td>rare</td>
<td>rare</td>
</tr>
<tr>
<td><em>Citrus lacinatis</em></td>
<td>-</td>
<td>-</td>
<td>uncommon</td>
</tr>
<tr>
<td><em>Conyza sp.</em></td>
<td>rare</td>
<td>rare</td>
<td>-</td>
</tr>
<tr>
<td><em>Coprosma repens</em></td>
<td>uncommon</td>
<td>common</td>
<td>rare</td>
</tr>
<tr>
<td><em>Cucumis melo</em></td>
<td>-</td>
<td>-</td>
<td>uncommon</td>
</tr>
<tr>
<td><em>Cucurbita pepo</em></td>
<td>-</td>
<td>rare</td>
<td>uncommon</td>
</tr>
<tr>
<td><em>Datura stramonium</em></td>
<td>rare</td>
<td>rare</td>
<td>-</td>
</tr>
<tr>
<td><em>Eleusine indica</em></td>
<td>-</td>
<td>uncommon</td>
<td>common</td>
</tr>
<tr>
<td><em>Eriothrina cristagalli</em></td>
<td>-</td>
<td>-</td>
<td>rare</td>
</tr>
<tr>
<td><em>Genotheta calvipes</em></td>
<td>rare</td>
<td>rare</td>
<td>-</td>
</tr>
<tr>
<td><em>Helianthus annuas</em></td>
<td>-</td>
<td>-</td>
<td>rare</td>
</tr>
<tr>
<td><em>Ipomoea carica</em></td>
<td>-</td>
<td>uncommon</td>
<td>common</td>
</tr>
<tr>
<td><em>Lepidium dixmianum</em></td>
<td>-</td>
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<td>-</td>
</tr>
<tr>
<td><em>Malva parviflora</em></td>
<td>-</td>
<td>rare</td>
<td>-</td>
</tr>
<tr>
<td><em>Melia azedarach</em></td>
<td>-</td>
<td>-</td>
<td>rare</td>
</tr>
<tr>
<td><em>Panicum miliaceum</em></td>
<td>-</td>
<td>-</td>
<td>rare</td>
</tr>
<tr>
<td><em>Passiflora edulis</em></td>
<td>-</td>
<td>-</td>
<td>rare</td>
</tr>
<tr>
<td><em>Phalaris minor</em></td>
<td>-</td>
<td>-</td>
<td>rare</td>
</tr>
<tr>
<td><em>Phytoleca octandra</em></td>
<td>rare</td>
<td>rare</td>
<td>uncommon</td>
</tr>
<tr>
<td><em>Ricinus communis</em></td>
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<td>-</td>
<td>rare</td>
</tr>
<tr>
<td><em>Senicio madagascariensis</em></td>
<td>-</td>
<td>rare</td>
<td>-</td>
</tr>
<tr>
<td><em>Sesilaria italic</em></td>
<td>-</td>
<td>-</td>
<td>rare</td>
</tr>
<tr>
<td><em>Solomon chenopodioides</em></td>
<td>-</td>
<td>rare</td>
<td>-</td>
</tr>
<tr>
<td><em>Solomon lycopersicum</em></td>
<td>-</td>
<td>rare</td>
<td>rare</td>
</tr>
<tr>
<td><em>Solomon nigrum</em></td>
<td>rare</td>
<td>uncommon</td>
<td>rare</td>
</tr>
<tr>
<td><em>Solfa sessis</em></td>
<td>-</td>
<td>rare</td>
<td>-</td>
</tr>
<tr>
<td><em>Sonchus oleraceus</em></td>
<td>common</td>
<td>abundant</td>
<td>uncommon</td>
</tr>
<tr>
<td><em>Sorghum bicolor</em></td>
<td>-</td>
<td>-</td>
<td>rare</td>
</tr>
<tr>
<td><em>Xanthium spinosum</em></td>
<td>-</td>
<td>rare</td>
<td>-</td>
</tr>
</tbody>
</table>

(Source: Mills, Illawarra Vegetation Studies. Big Islands, the Five Islands Group, 2015)
Appendix B: Accumulation of known breeding seabird species present on Big Islands I and II as detailed by Nicholas Carlile et. al, (2017)

**Common Seabirds Recorded on Big Islands I and II**

<table>
<thead>
<tr>
<th>Common Name</th>
<th>Scientific Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>White-faced Storm-Petrel</td>
<td><em>Pelagodroma marina</em></td>
</tr>
<tr>
<td>Wedge-tailed Shearwater</td>
<td><em>Ardenna pacifica</em></td>
</tr>
<tr>
<td>Sooty Shearwater</td>
<td><em>Ardenna grisea</em></td>
</tr>
<tr>
<td>Short-tailed Shearwater</td>
<td><em>Ardenna tenuirostris</em></td>
</tr>
<tr>
<td>Little Penguin</td>
<td><em>Eudyptula minor</em></td>
</tr>
<tr>
<td>Crested Tern</td>
<td><em>Thalasseus bergti</em></td>
</tr>
<tr>
<td>Silver Gull</td>
<td><em>Chroicocephalus novaehollandiae</em></td>
</tr>
<tr>
<td>Australian Pelican</td>
<td><em>Pelecanus conspicillatus</em></td>
</tr>
<tr>
<td>Australian White Ibis</td>
<td><em>Threskiornis molucca</em></td>
</tr>
<tr>
<td>Royal Spoonbill</td>
<td><em>Platalea regia</em></td>
</tr>
</tbody>
</table>

**Other Seabirds Recorded**

<table>
<thead>
<tr>
<th>Common Name</th>
<th>Scientific Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>White-faced Heron</td>
<td><em>Egretta novaehollandiae</em></td>
</tr>
<tr>
<td>Eastern Reef Egret</td>
<td><em>Egretta sacra</em></td>
</tr>
<tr>
<td>Little Pied Cormorant</td>
<td><em>Microcarbo melanoleucus</em></td>
</tr>
<tr>
<td>Pied Cormorant</td>
<td><em>Phalacrocorax varus</em></td>
</tr>
<tr>
<td>Little Black Cormorant</td>
<td><em>Phalacrocorax sulcirostris</em></td>
</tr>
<tr>
<td>Great Cormorant</td>
<td><em>Phalacrocorax carbo</em></td>
</tr>
<tr>
<td>Sooty Oystercatcher</td>
<td><em>Haematopus fuliginosus</em></td>
</tr>
<tr>
<td>White-fronted Tern</td>
<td><em>Thalasseus striata</em></td>
</tr>
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</table>
## Appendix C: Confusion Matrixes

### Big Island Before: Supervised Classification

<table>
<thead>
<tr>
<th>Mapped Class</th>
<th>Class</th>
<th>Validation Class</th>
<th>Total</th>
<th>User Accuracy (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Exotic Bushes</td>
<td>Grass</td>
<td>Native Forbs</td>
<td>Lomandra</td>
</tr>
<tr>
<td>Exotic Bushes</td>
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<td>4</td>
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<tr>
<td>Grass</td>
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<td></td>
</tr>
<tr>
<td>Native Forbs</td>
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</tr>
<tr>
<td>Lomandra</td>
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<td>Dead Veg</td>
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<td><strong>Total</strong></td>
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<tr>
<td><strong>Overall Accuracy</strong></td>
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<td><strong>Producer Accuracy (%)</strong></td>
<td>90.47619048</td>
<td>66.666667</td>
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### Martin Islet: Supervised Classification

<table>
<thead>
<tr>
<th>Mapped Class</th>
<th>Class</th>
<th>Validation Class</th>
<th>Total</th>
<th>User Accuracy (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Exotic Bushes</td>
<td>Grass</td>
<td>Forb 1</td>
<td>Forb 2</td>
</tr>
<tr>
<td>Exotic Bushes</td>
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<tr>
<td>Grass</td>
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<td>1</td>
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<tr>
<td>Forb 1</td>
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<td>11</td>
</tr>
<tr>
<td>Forb 2</td>
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<tr>
<td>Dead Veg</td>
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</tr>
<tr>
<td><strong>Total</strong></td>
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<td>13</td>
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<tr>
<td><strong>Overall Accuracy</strong></td>
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<td></td>
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<tr>
<td><strong>Producer Accuracy (%)</strong></td>
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### Bass Islet: Supervised Classification

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<th>Total</th>
<th>User Accuracy (%)</th>
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</thead>
<tbody>
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<td>Exotic Bushes</td>
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<td>Light Forb</td>
<td>Dark Forb</td>
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<td>Exotic Bushes</td>
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<tr>
<td>Grass</td>
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<td></td>
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<tr>
<td>Light Forb</td>
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<tr>
<td>Dark Forb</td>
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<td>Dead Veg</td>
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<td><strong>Total</strong></td>
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<td>15</td>
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<tr>
<td><strong>Overall Accuracy</strong></td>
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<td>18.75</td>
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### Big Island Spray Area Before: Supervised Classification

<table>
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<tr>
<th>Mapped Class</th>
<th>Class</th>
<th>Validation Class</th>
<th>Total</th>
<th>User Accuracy (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Exotic Bushes</td>
<td>CMG</td>
<td>Dead Veg</td>
<td>Grass</td>
</tr>
<tr>
<td>Exotic Bushes</td>
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<td>16</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>CMG</td>
<td></td>
<td>16</td>
<td>1</td>
<td>1</td>
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<tr>
<td>Dead Veg</td>
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</tr>
<tr>
<td>Grass</td>
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<td></td>
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</tr>
<tr>
<td>Native Forbs</td>
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<td>17</td>
</tr>
<tr>
<td><strong>Total</strong></td>
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<td>20</td>
<td>18</td>
<td>19</td>
</tr>
<tr>
<td><strong>Overall Accuracy</strong></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td><strong>Producer Accuracy (%)</strong></td>
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<td>100</td>
<td>78.94736842</td>
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</tbody>
</table>
Appendix D: Summary of Output: Spatial Lag Model – Maximum Likelihood Estimation

Data set : Lomandra_Area_1
Spatial Weight : Lomandra_Area_1_TD.gwt
Dependent Variable : HEALTH Number of Observations: 968
Mean dependent var : 2.3657 Number of Variables : 3
S.D. dependent var : 0.989898 Degrees of Freedom : 965
Lag coeff. (Rho) : 0.822978
R-squared : 0.471845 Log likelihood : -1096.31
Sq. Correlation : - Akaike info criterion : 2198.62
Sigma-square : 0.517538 Schwarz criterion : 2213.24
S.E of regression : 0.719401

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
<th>Std.Error</th>
<th>z-value</th>
<th>Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>W_HEALTH</td>
<td>0.8229776</td>
<td>0.02418649</td>
<td>34.02633</td>
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<td>CONSTANT</td>
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<td>DISTANCE_P</td>
<td>-0.001122965</td>
<td>0.00106469</td>
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<td>0.2915469</td>
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</table>

REGRESSION DIAGNOSTICS

DIAGNOSTICS FOR HETEROSKEDASTICITY

RANDOM COEFFICIENTS

TEST     DF     VALUE     PROB
Breusch-Pagan test  1  1.89307  0.1688561  

DIAGNOSTICS FOR SPATIAL DEPENDENCE

SPATIAL LAG DEPENDENCE FOR WEIGHT MATRIX : Lomandra_Area_1_TD.gwt

TEST     DF     VALUE     PROB
Likelihood Ratio Test  1  533.7504  0.0000000  

================================ END OF REPORT =================================