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Spatial Mapping of Vegetation Change on Big Island, Five Islands Nature Reserve, Port Kembla

Nial J. Roder

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Spatial Mapping of Vegetation Change on Big Island, Five Islands Nature Reserve, Port Kembla

Abstract
Anthropogenic influences have disturbed the natural functions and characteristics of ecosystems worldwide, and the restoration of such ecosystems is a common challenge faced by environmental managers. The Five Islands Group, Port Kembla, south of Wollongong City, has a long history of human interaction which has caused significant changes to the vegetation communities on the islands. The Five Islands were listed as a nature reserve in 1960 as they provide an important breeding habitat for many species of native seabirds. The largest of the islands, known as Big Island (17.7 ha), has shifted from an ecosystem supporting mainly native vegetation communities to one that is dominated by the exotic species Kikuyu grass and Coastal Morning Glory, resulting in severe habitat degradation for native seabirds that breed on the island. This project uses remote sensing and GIS techniques to map the distribution of native and exotic species on Big Island. High spatial resolution images were acquired using an unmanned aerial vehicle (UAV), which has emerged as a popular platform for remote sensing of the environment in recent years. Land cover classification maps were produced using a supervised maximum likelihood classification. As part of an ongoing seabird habitat restoration project, New South Wales National Parks and Wildlife Service conducted an aerial helicopter spray on Big Island in April 2017 to eradicate weeds. Thematic land cover maps were produced from images acquired before and after the aerial treatment.

A validation exercise was conducted and involved the collection of an independent georeferenced photographic dataset of the ground cover on Big Island to compare against the thematic content of the maps. The validation exercise yielded overall accuracies of 84% for pre-treatment classification and 75% for the post-treatment classification. The land cover maps provide the first detailed, high resolution pixel-based classification maps of Big Island, which can be used to establish a baseline against which future changes can be monitored. Land cover classes within the treated area before and after treatment were compared to assess the effectiveness of the spray in destroying the target species. The analysis revealed Kikuyu within the treatment area accounted for 66% of land cover before the treatment, and was reduced to 1% of land cover following treatment. Percentage cover of Coastal Morning Glory was reduced from 15% to 1% following treatment. Additionally, a series of historical aerial photographs were examined to estimate the trends of vegetation cover on Big Island. The aerial photographs revealed a rapid increase in vegetation cover following the introduction of Kikuyu grass to the island. Four additional permanent vegetation survey plots were established to supplement seven other previously established plots. A 20 × 20m quadrat was sampled at each plot location, following the NSW vegetation survey standards set out in the Native Vegetation Interim Type Standard (Sivertsen, 2009). All four sampled quadrats were dominated by exotics.

Vegetation mapping using remote sensing and GIS techniques has been recognised as a useful tool for monitoring the environment, and its applications will continue to improve with the development of higher quality spatial and spectral resolution sensors (such as UAVs). However, this should not deter from the benefits of field visits in understanding an ecosystem of interest.

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Nial Joseph Roder
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Abstract

Anthropogenic influences have disturbed the natural functions and characteristics of ecosystems worldwide, and the restoration of such ecosystems is a common challenge faced by environmental managers. The Five Islands Group, Port Kembla, south of Wollongong City, has a long history of human interaction which has caused significant changes to the vegetation communities on the islands. The Five Islands were listed as a nature reserve in 1960 as they provide an important breeding habitat for many species of native seabirds. The largest of the islands, known as Big Island (17.7 ha), has shifted from an ecosystem supporting mainly native vegetation communities to one that is dominated by the exotic species Kikuyu grass and Coastal Morning Glory, resulting in severe habitat degradation for native seabirds that breed on the island. This project uses remote sensing and GIS techniques to map the distribution of native and exotic species on Big Island. High spatial resolution images were acquired using an unmanned aerial vehicle (UAV), which has emerged as a popular platform for remote sensing of the environment in recent years. Land cover classification maps were produced using a supervised maximum likelihood classification. As part of an ongoing seabird habitat restoration project, New South Wales National Parks and Wildlife Service conducted an aerial helicopter spray on Big Island in April 2017 to eradicate weeds. Thematic land cover maps were produced from images acquired before and after the aerial treatment.

A validation exercise was conducted and involved the collection of an independent georeferenced photographic dataset of the ground cover on Big Island to compare against the thematic content of the maps. The validation exercise yielded overall accuracies of 84% for pre-treatment classification and 75% for the post-treatment classification. The land cover maps provide the first detailed, high resolution pixel-based classification maps of Big Island, which can be used to establish a baseline against which future changes can be monitored. Land cover classes within the treated area before and after treatment were compared to assess the effectiveness of the spray in destroying the target species. The analysis revealed Kikuyu within the treatment area accounted for 66% of land cover before the treatment, and was reduced to 1% of land cover following treatment. Percentage cover of Coastal Morning Glory was reduced from 15% to 1% following treatment. Additionally, a series of historical aerial photographs were examined to estimate the trends of vegetation cover on Big Island. The aerial photographs revealed a rapid increase in vegetation cover following the introduction of Kikuyu grass to the island. Four additional permanent vegetation survey plots were established to supplement seven other previously established plots. A 20 × 20m quadrat was sampled at each plot location, following the NSW vegetation survey standards set out in the Native Vegetation Interim Type Standard (Sivertsen, 2009). All four sampled quadrats were dominated by exotics.

Vegetation mapping using remote sensing and GIS techniques has been recognised as a useful tool for monitoring the environment, and its applications will continue to improve with the development of higher quality spatial and spectral resolution sensors (such as UAVs). However, this should not deter from the benefits of field visits in understanding an ecosystem of interest.
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1 Introduction

1.1 Background
The Five Islands Nature Reserve is a clustered island group between 0.5 kilometres and 3.5 kilometres off the coast of Port Kembla, south of Wollongong City (figure 1.1). Bass Islet, Rocky Islet, Martin Islet, Flinders Island, and Big Island comprise the Five Islands Group and collectively form an area of approximately 26 hectares (0.26 km$^2$). Coastal islands in Australia form unique ecosystems which have been vital in understanding factors of biogeography and evolution, including plant and animal distributions worldwide (Mills, 2014a). Coastal islands are less resilient than mainland ecosystems due to their geographic isolation from biotic source areas, limited habitat space and specialised dispersal pathways (Proske and Haberle, 2012). The Five Islands Group has a long history of human interaction, from being embedded in traditional Aboriginal dreamtime stories, to early European interactions such as introduced cattle grazing, and more recently conservation efforts. This chapter will provide a background to these historic themes of human interaction with the islands, which have played an integral role in the cultural and biological values which they possess today.

1.2 Geology of the Five Islands
The Five Islands vary slightly in their geological composition. Big Island, Rocky Islet, Martin Islet, and Bass Islet are all composed of Dapto-Saddleback trachybasalt, a Permian Flow, occurring at different stages of alteration (Chalmers, 1941). Chalmers (1941) proposed that Flinders Island was formed from a Bombo Flow, comprised of acidic and basic latites in various stages of deuteric alteration. The origin of Flinders Island was challenged by Carr (1983) who proposed it to be an outcrop of the Five Islands Latite Member, as part of the Gerringong Volcanics.

Four types of trachybasalts are found on Big Island (Chalmers, 1941). By far the most common is the Dapto-Saddleback trachybasalt, a black rock with abundant glassy feldspar and augite phenocrysts (Chalmers, 1941). Big Island also contains deuterically altered trachybasalt, an intrusion from the same magma which crystallised under different conditions, and a more carbonate-rich, more highly altered form of the intrusion (Chalmers, 1941). Above the igneous bedrocks there is recently compacted sandstone binded by iron oxides, and sandy topsoils across Big Island.

The Five Islands are considered continental islands because they were once adjoined to the mainland during periods of lower sea levels (Mills, 2015). Flinders and Bass Islets were separated from the mainland some 10,000 years ago during a gradual ‘drowning’ event of increasing sea levels. Big Island is sometimes subdivided into Big Island No. 1 and Big Island No. 2 because a wave-washed rocky isthmus absent of terrestrial vegetation is all that connects the islands. For the purpose of this project, Big Island No. 1 is herein referred to as “Big Island”, unless otherwise noted. Continual moderately rapid erosion of the isthmus between Big Island No.1 and No. 2 has made the time of their separation harder to quantify, though Davis et al. (1938) postulated that their isolation occurred
approximately 4000 years ago. This indicates that the Five Islands have been continuously habitable for terrestrial communities since the time of their isolation (Davis et al., 1938). Some communities have likely existed there since this time, while others have colonised the islands more recently.

Figure 1.1: Location of The Five Islands Nature Reserve, south-east Australia.
1.3 The Aboriginal Significance of the Five Islands
The Dharawal people were the original occupants of an extensive area stretching from Botany Bay in the north to Jervis Bay in the south. Their people were distinguished as either freshwater clans, such as those who lived above the escarpment on plateaus or inland river valleys, or salt water clans, who lived in coastal settings such as those who occupied the mainland adjacent to the islands (NSW National Parks and Wildlife Service, 2005). Through stories of historical culture and ongoing association, the Five Islands are significant to the Illawarra Aboriginal Community (Organ and Speechley, 1997). The islands feature in many different versions of Aboriginal dreamtime stories, which vary slightly depending on the Aboriginal group telling the story. Beyond dreamtime stories, historic cultural associations between Illawarra Aboriginal communities and the islands are evidenced by the remains of shell middens and stone artefacts on Big Island. These remains are likely to have been there since the last glacial period, when low sea levels would have meant that Big Island could be accessed by land. The subsequent isolation of the islands would have eroded much of the evidence of Aboriginal uses of the land, though middens and artefacts remain on Big Island and adjacent mainland at Hill 60 (NSW National Parks and Wildlife Service, 2005). These middens have been indirectly protected by restricting public access to the islands and a thick coverage of vegetation on Big Island. Throughout the management of the Five Islands Nature Reserve, these Aboriginal cultural values need to be considered and protected in best practice (NSW National Parks and Wildlife Service, 2005).

1.4 European Settlement of the Five Islands
Since the European discovery of The Five Islands, the physical and biological characteristics of the islands have been significantly altered. In 1770, Captain James Cook was the first European explorer to discover the islands, but was unable to differentiate between Big Island, Martin Island and the mainland, and so he called it Red Point. This name was transferred to the closest mainland point following European settlement of the area. Before 1861, cattle and rabbits had been introduced on Big Island for an unknown period of time. An advertisement published in the Illawarra Mercury in September 1861 confirms this, requesting the removal of all cattle on the island and cautioning of prosecution for anyone found destroying rabbits on the island (NSW National Parks and Wildlife Service, 2005).

From about 1866 to 1871, Edward Perkins, said to be a corruption of the surname Parkyns, and his family lived on Big Island. Mr Perkins was a fisherman who mostly caught sharks to be used for their oil. He used fishing, along with grazing goats and cattle, to provide for his wife and seven children on the island for approximately five years. The most notable changes to Big Island brought about by the presence of the Perkins family include the introduction of Buffalo Grass (Stenotaphrum secundatum) and reductions to soil stability as a result of grazing animals (Mills, 2015). It is important to note that, at this stage, the island’s vegetation communities remained largely dominated by native species. The
first reported introduced plant (Buffalo grass, *Stenotaphrum secundatum*) and the introduction of goats and cattle mark the first of a series of significant anthropogenic disturbances on Big Island.

In 1878 and 1884 there were two fires on Big Island which were believed to be deliberately lit. The first was described as being ablaze “for some hours... all over the island” in a notice appearing in the *Kiama Independent* and *Shoalhaven Advertiser* (Mills, 2015). The latter described in a letter to the editor of the *Illawarra Mercury* in 1884, whereby the author “was informed that the Government Stock Inspector, with his assistants... had set fire to the grass with the object of exterminating the rabbits which [had] been there for some years past.” Somewhere between a notice warning of prosecution for destruction of rabbits in 1861, and Government personnel conducting fires to destroy rabbits in 1884, the attitude toward this introduced species had changed (Mills, 2015).

In May 1925 a mining lease was granted for the removal of shell grit which was used to extract lime to make cement. The mining lease resulted in excavation of shell grit for a number of years, some of which was likely the remains of the Aboriginal middens. The lease was eventually cancelled in October 1947 (Mills, 2015). By this stage, the natural vegetation communities and ecosystem functions on Big Island had been significantly altered, driven by early European use of the island.

1.5 Conservation of the Five Islands Nature Reserve

The Five Islands were listed as a nature reserve in June 1960, following the exploitation of Big Island by means of grazing animals, the introduction and then eradication of rabbits, fire and mining. The Five Islands possess high biological and cultural heritage values and their preservation is of great significance. The islands provide breeding grounds for many species of seabird. Of particular importance for breeding seabirds is Big Island, which constitutes 17.7 hectares (0.177km²) of the 26-hectare nature reserve. Birds that breed on Big Island include Wedge-tailed Shearwaters (*Ardenna pacifica*, formerly known as *Puffinus pacificus*), Short-tailed Shearwaters (*Ardenna tenuirostris* formerly known as *Puffinus tenuirostris*), Sooty Oystercatchers (*Haematopus fuliginosus*; listed as a vulnerable species), Crested Terns (*Sternula bergii*), Silver Gulls (*Larus novaehollandiae*) and Australian Pelicans (*Pelecanus conspicillatus*) and Little Penguins (*Eudyptula minor*; figure 1.1)(NSW National Parks and Wildlife Service, 2005). Both the shearwaters and penguins dig burrows in the ground to lay their eggs and rear their chicks. These burrows are degraded by soil erosive processes and the presence of entangling weeds.

The Five Islands Nature Reserve has been designated by The International Union for the Conservation of Nature and Natural Resources (IUCN) as a Category 1a Reserve, a “Strict Nature Reserve”. This means that access is restricted to the public and only staff of National Parks and Wildlife Service (NPWS), volunteers of local land care groups, and researchers are permitted to access the islands. Big Island is the most frequently visited, and access to it is limited to relatively small swells, via a small
beach on the western side. The only infrastructure on any of the islands is a small research hut consisting of two shipping containers near the beach access on Big Island.

In addition to Australian legislation there are three international agreements which have been ratified by the Australian government placing obligations on NPWS concerning the management of migratory seabirds that visit the island. The international agreements include (Department of Environment and Energy):

- The Protection of Migratory Birds and their Environment, between the Australian Government and the Peoples Republic of China (CAMBA).

![Figure 1.2: Little penguin (Eudyptula minor) in its burrow on Big Island. (Photograph credit: Rowena Morris).](image)

Since the protection of the Five Islands as a nature reserve, the habitat conditions for the seabirds have continued to decline. This has been a major environmental concern for many years due to the increasing mortality rates of native seabirds on Big Island documented since 1979 (Gibson). Increased rates of seabird deaths have been caused by the transition of vegetation on Big Island from being
primarily native plant communities in the 1930s (Davis et al., 1938) to being dominated by introduced plant communities in the late 1980s (Mills, 1990) and beyond. The exotic vegetation that exists on Big Island causes entanglement and then death of burrowing seabirds that become trapped.

1.6 Seabird habitat restoration

NSW National Parks and Wildlife Service initiated the Big Island Seabird Habitat Restoration Project in 2014, with the primary objectives to eradicate weeds and restore the breeding habitat for burrowing seabirds on the island. In April 2014, a trial aerial helicopter spray was conducted on a 0.9 hectare treatment area (Area 1, figure 1.4) on the northwest side of the island. The main target species were Kikuyu grass (*Cenchrus clandestinus*, previously *Pennisetum clandestinum*) and Coastal Morning Glory (*Ipomoea cairica*). A glyphosate 360gL\(^{-1}\) mix was applied to the area using an aerial cone sprayer and the trial proved the glyphosate mix was effective in killing the target species. Following the initial trial spray there has been two more aerial spray events on the island. Area 2 (0.3 ha) was treated in April 2015 and replanted with native vegetation in July 2015. Areas 3, 5, and 6, approximately 3.1 hectares collectively, were treated in April 2017 and as yet have not undergone replanting. The vegetation management plan by Berrim Nuru Environmental Services of the Illawarra Local Aboriginal Land Council (2017) outlines the strategies involved in the vegetation regeneration program, including the planting schedule for Big Island. The revegetation scheme will be discussed in further detail in Chapter 2.

![Figure 1.3: View from the helicopter approaching Big Island for aerial spray treatment. Visible islands from foreground to background are Big Island 1, Big Island 2 and Martin Islet. The darker green ground cover on the northern end of Big Island 1 is Coastal Morning Glory, compared to the lighter green Kikuyu grass. Photograph credit: Jamie Erskine.](image-url)
Figure 1.4: Spray areas of Big Island as designated by NSW National Parks and Wildlife Service in accordance with the Big Island Vegetation Management Plan (Berrim Nuru, 2017).
1.7 Aims and Objectives
This project is a part of a long-term broader project being conducted by University of Wollongong and NSW National Parks and Wildlife Service involving spatial mapping of the Five Islands Nature Reserve terrestrial and marine environments, including island vegetation communities and rocky reefs. While seabird mortality has been documented to be increasing on Big Island for a long period of time (Gibson, 1979), only a small number of studies have investigated the impact caused by the dominance of exotic weeds. In this project, plant species distribution is mapped using remote sensing and geographic information systems (GIS) techniques. It is hoped that the maps produced may be used to assist informed management strategies, or work as supplements for future research projects on Big Island. This project will focus on the terrestrial vegetation communities of Big Island and aims to:

- Examine historical aerial photographs to describe past vegetation communities on Big Island
- Map the distribution of native and exotic plant species on Big Island
- Assess the effectiveness of the aerial weed spraying program conducted by NSW National Parks and Wildlife Service by comparing before and after vegetation communities in 2017.

2 Literature Review
2.1 Five Islands Vegetation
2.1.1 Overview
Davis et al. (1938) provide the earliest detailed account on the ecology of Big Island. A subsequent comprehensive vegetation study was not conducted until Dr Kevin Mills’ study (1990). Between these years Mr David Walsh had visited Big Island and taken notes on the vegetation that existed there for the years 1961, 1967, 1969 and 1976. This information was provided to Kevin Mills to assist in minimizing the knowledge gap of vegetation variances on Big Island through time, which ultimately influenced the development of kikuyu grass distribution maps. Mills (1990) developed maps of Big Island vegetation (No. 1 and No. 2) including the distribution of natives based on a series of sample plot surveys in 1989, and the distribution of Kikuyu grass for the years 1962, 1969, 1976 and 1989. A thesis paper by Wolhuter (1999) investigated the soil-stored seed bank of Big Island to assess the likeliness of native plant recolonization on the island. Since the initiation of the vegetation regeneration program in 2014, Kevin Mills has returned to Big Island regularly to conduct vegetation surveys and record notes regarding the island’s vegetation. He also published an extensive paper in 2015 which details the vegetation of Big Island and the history of its early exploration and exploitation. This paper is the first detailed, broad scale vegetation mapping exercise to be conducted on Big Island since Mills’ study (1990). The following sections examine existing literature describing the vegetation communities of Big Island, highlighting substantive findings by the acknowledged authors. It has been subdivided into three temporal periods based on the vegetation studies that have
been conducted on Big Island in the past. Additionally, it will explore the revegetation schemes of Big Island and Montague Island, New South Wales, and the remote sensing techniques pivotal to this project.

2.1.2 Big Island Vegetation in 1938

Davis et al. (1938) provide the first comprehensive vegetation study on Big Island, and thus the closest representations of the vegetation communities as they existed pre-European influence. It must be recognised, however, that European influence had already begun changing the ecology of the islands some seventy years prior to 1938. A mixture of native and exotic plants species is described. Davis et al. (1938) reported Big Island to contain nine different vegetation communities, with coverage ranging from small groups to widespread aggregates. The vegetation communities they describe on the island are: (1) The Correa-Westringia Community; (2) The Stenotaphrum Community; (3) The Sporobolus community; (4) The Scirpus nodosus community; (5) The Mesembryanthemum Community; (6) The Lomandra Community; (7) The Scalicornia Community; (8) The Spergularia-Claytonia-Portulaca Community; (9) The Scirpus cernus Community. These communities were reported to be in a highly unstable state of retrograde, due to gradual marine erosion, anthropogenic disturbances, introduced plants and animals, and burrowing seabirds.

The following native species were described as common on Big Island: Commelina cyanea (Scurvy Weed), Tetragonia tetragonioides (New Zealand Spinach; previously Tetragonia expansa), Lomandra longifolia (Spiny-head Mat-rush), Phragmites communis (Common Reed; locally common at a freshwater soak on the south-western side of Big Island), Ficinia nodosa (Knotted Club-rush; previously Scirpus nodosus).

Figure 2.1: Some native species that were common on Big Island in 1938: Carpobrotus glaucescens (pigface; left), and Lomandra longifolia (spiny-head mat-rush; right). (Lomandra photograph credit: Kevin Mills (2014b)).
Exotics that were described as common on Big Island include: Phytolacca octandra (Inkweed), Opuntia stricta (Prickly Pear; previously Opuntia inermis), and Stenotaphrum secundatum (Buffalo grass). Other exotics were described as rare or very rare.

Figure 2.2: Some exotic species that were common on Big Island in 1938: Opuntia stricta (prickly pear; left), and Stenotaphrum secundatum (Buffalo grass; right). Buffalo grass was the dominant grass species at this time. (Photograph credits: Kevin Mills (2014b)).

Davis et al. (1938) concluded that a total of 58 species were present on Big Island in 1938; of which 40 species were native and 18 species were exotic. Beyond the large presence of native species, Davis et al., (1938) also noted that Big Island maintained a considerable coverage of bare ground. They proposed that significant erosional “blowouts” occurred prior to European presence resulting from large numbers of burrowing birds. The states of the sand dunes were described as partially displaced by wind erosion. The northern slopes of Big Island contained bare sand drifts, void of vegetation, and a sand drift partially stabilized by plants existed on the south-eastern slopes. Where sandy soils remained, the main stabilizing species were Buffalo grass (Stenotaphrum secundatum) and Salt Couch (Sporobulus virginicus). Davis et al. (1938) reported that the sandy topsoils of Big Island are likely remnants of undulating sand dunes that existed prior to drowning, as they exist now on the adjacent mainland.
2.1.3 Big Island Vegetation in 1989

Mills’ study published in 1990 revealed a changed environment to the one described by Davis et al., (1938). From 1938 – 1989 three of the aforementioned vegetation communities disappeared entirely or almost entirely from Big Island; namely the Correa – Westringia, Scirpus nodosus and Scirpus cernuus communities. Importantly, the Correa – Westringia community dominated a large part of Big Island in 1938, and dwindled to only a few remaining shrubs by 1989. This is indicative of a trend that seems to have occurred over this 50 year period whereby there was a significant decline in the ratio of native species to exotics. This trend is illustrated well by Mills (1990), and is largely attributed to the introduction of Kikuyu grass (*Cenchrus clandestinus*). Kikuyu grass was first documented on Big Island in November 1969, and it is likely that it was intentionally introduced between 1968 and 1969 as a means of mitigating problems of soil erosion that were occurring at the time. In November 1968 the habitat condition of Big Island was described as: “Grass disappearing from all grassed areas on both islands. Up to 18” depth of soil has eroded from southern half and eastern side of Shearwater Rockery on West side of No. 1 [Big] island and up to 4 feet depth of soil has eroded from top of No. 1 island since December 1962. Shearwater burrows are collapsing. Some grass is regenerating in a few areas on No. 1 island but appears to be heavily grazed.” (report from Mr H. Battam, November 1968).

The scattered nature of its original occurrence supports the conclusion that it was intentionally planted, since it grows from nodes and does not produce viable seed (Mills, 1990). Figure 2.3 shows the distribution of *Cenchrus clandestinus* on Big Island for the years 1962, 1969, 1976 and 1989 as reported by Mills (1990).

![Distribution of Kikuyu grass on Big Island No 1. and No. 2 for the years 1962, 1969, 1976 and 1989 as reported by Mills (1990).](image-url)
Mills (1990) summarised the occurrence of native and exotic species on Big Island in 1938 and 1989 for comparison (Table 1).

**Table 1**: Summary of native, exotic and total species on Big Island for the years 1938 and 1989 as reported in Mills (1990).

<table>
<thead>
<tr>
<th></th>
<th>Shrub</th>
<th>Vines/Creepers</th>
<th>Forbs</th>
<th>Ferns</th>
<th>Grasses</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Native</strong></td>
<td>2</td>
<td>2</td>
<td>26</td>
<td>1</td>
<td>8</td>
<td>40</td>
</tr>
<tr>
<td><strong>Exotic</strong></td>
<td>0</td>
<td>3</td>
<td>14</td>
<td>29</td>
<td>2</td>
<td>18</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>2</td>
<td>5</td>
<td>39</td>
<td>30</td>
<td>10</td>
<td>58</td>
</tr>
</tbody>
</table>

While the total number of species only slightly increased from 58 to 64, the most notable shifts were the decline of natives from 40 species to 22 species, and the increase in exotics from 18 to 42 species. The native species that were present in 1989 were described as restricted in their distribution on the island. Mills (1990) attributed the limited distribution of natives to the complete dominance of Kikuyu grass. The northern and southern ends of Big Island become extremely exposed to salt spray in rough seas, which inhibits the growth of Kikuyu, assisting the colonisation of other species. It is in these salt-burden areas where most of the remaining native species occurred, and also where other exotics had spread significantly. Mirror bush (*Coprosma repens*) is a case in point. Mirror bush has expanded from a few shrubs to large shrub thickets covering the northern and southern ends of the island. Mirror bush is an introduced species of moderately high importance for removal from Big Island, however the established shrubs act as a buffer from winds and sea spray in Area 1, assisting the growth of adjacent natives.

### 2.1.4 Recent Years and Invasive Species

Introduced species are recognised as the second greatest threat to global biodiversity after the anthropogenic effects imposed on our ecosystems (Gooden et al., 2008). Presently, two species of vegetation are generating most concern for Big Island to be rehabilitated due to their destructive effects on native plant communities and seabird habitat (Mills, 2015): Kikuyu grass (*Cenchrus clandestinus*) and Coastal Morning Glory (*Ipomoea cairica*). A report from Mills (2014a) following the initial treatment of spray Area 1 states: “There is an urgent need to undertake follow-up spraying in the area to destroy the following weeds, before they become too difficult and expensive to treat. Most of these plants are in the northern one third of the sprayed area, although many seedlings of *Coprosma repens* occur elsewhere. Some of the larger stems of *Ipomoea cairica* are alive and are
producing shoots, none of the grass *Cenchrus clandestinus* seems to be alive – *Cenchrus clandestinus, Chrysanthemoides monilifera, Coprosma repens, Ipomoea cairica."

While there are many other exotic species identified on Big Island, *Cenchrus clandestinus* and *Ipomoea cairica* are ubiquitous and have been documented to adversely affect Australian seabirds due to entanglement of their feet and wings (Fortescue, 1999, NSW Department of Environment and Climate Change, 2008, Priddel, 2003, Smith and Battam, 1998, Weerheim et al., 2003). Many species of seabird return to the islands annually for breeding and food foraging. Breeding seabird species recorded on Big Island include: Sooty Oystercatchers, Little Penguins, Wedge-tailed Shearwaters, Short-tailed Shearwaters, Crested Terns, Silver Gulls, and the Australian Pelican (NSW National Parks and Wildlife Service, 2005).

Kikuyu grass (*Cenchrus clandestinus*) is a perennial grass that spreads via creepers along the ground, becoming dormant in winter and spreading aggressively when conditions for germination reach a favourable 15-20°C (NSW Department of Primary Industries). The extensive root system of Kikuyu grass has assisted the spread of the species on Big Island. Kikuyu is tolerant to trampling and grazing, reasonably tolerant to sand blast, and tolerant to waterlogging due to air channels contained in the stems and roots (NSW Department of Primary Industries). Manually removing Kikuyu grass should be avoided as this causes the rhizomes to break subsurface, resulting in rapid reshooting. The majority of Big Island is now covered in a dense sward of Kikuyu, over one metre high in places, making conditions less than favourable for burrowing seabirds.

The overwhelming dominance of Kikuyu grass has been attributed to a lack of competing species and high nutrient soils. The latter has been reported as an influence of thousands of nesting Silver Gulls contributing large deposits of nutrient-rich guano to the soils (Carlile et al., 2017, Gibson, 1979); an effective fertilising agent for perennial grasses such as Kikuyu (Mills, 1990). In contrast to burrowing seabirds, Kikuyu grass improves the habitat for the Australian Silver Gull populations on Big Island (Gibson, 1979, Smith and Carlile, 1992b). Increased Silver Gull populations are commonly attributed to an increasing urban population and associated food supplies such as waste disposal depots, parks, sewage outfalls, fishing boats and fish-processing plants (Furness, 2012). The major waste depot in Wollongong, just 12km away, provides a convenient food source which has influenced the extreme number of gulls on Big Island (Smith and Carlile, 1992b). Silver Gulls were not present on Big Island in 1938 (Davis et al.), but were estimated at 50,000 breeding pairs (Smith and Carlile, 1992a), making Big Island the largest breeding colony in NSW (Dolejska et al., 2015).
Sometimes referred to as “mile-a-minute” due to its ability to grow very rapidly, Coastal Morning Glory (*Ipomoea cairica*) is a perennial climber that was originally introduced to Australia and cultivated for garden ornamental purposes (NSW Department of Primary Industries, 2014). Its fast-spreading nature and tolerance to a wide variety of soils was quickly realized. Coastal Morning Glory spreads via seed dispersal which would have reached Big Island by floating across the water channel or deposited via bird guano (Mills, 1990). Coastal Morning Glory has a twining growth habit, exacerbating the dense mats of Kikuyu which inhibit seabirds from burrowing. Coastal Morning Glory is a climber which can reach canopy heights of up to 4.5m with the appropriate vertical support, and forms a dense mat of ground cover in the absence of vertical support (NSW Department of Primary Industries, 2014). There are no trees on Big Island which has resulted in fast, lateral spreading of Coastal Morning Glory. The dominance of Kikuyu and Coastal Morning Glory on Big Island has occurred synchronously with declining numbers of native seabirds on the island. Coastal morning glory is second to Kikuyu grass as a weed of high importance on Big Island (Mills, 1990).
2.1.5 Revegetation Scheme

NSW National Parks and Wildlife Service and Berrim Nuru Environmental Service of the Illawarra Local Aboriginal Land Council are the teams at the forefront of the spray program and revegetation of Big Island. The details of the project, including legal requirements such as the Environmental Impact Assessment and Threatened Species Assessment of Significance (7-part test) are outlined in the Review of Environmental Factors (NSW Office of Environment and Heritage, 2016).

Treatment Area 1 was the initial 0.9 hectare area of land that underwent aerial weed control using the application of glyphosate 360gL$^{-1}$ from a helicopter. Following spray treatment the thick layer of dead Kikuyu is left to mulch for approximately a year, which effectively works as a soil stabiliser and reduces surface runoff, hence minimizing the risk of inducing soil erosion. Wolhuter (1999) concluded that Big Island does not contain a viable soil-stored seed bank of native species for regeneration. However, inspection of the area several months after spraying had occurred revealed that three native species had colonised the area and were common (Mills, 2015). These three species were New Zealand Spinach (*Tetragonia tetrogonoides*), Wandering Sailor (*Commelina cyanea*) and Fishweed (*Einadia trigonos*). This indicates that there still remains a limited viable native seedbank (Berrim Nuru, 2017). These herbaceous species are short lived, and treated areas require additional planting.
Berrim Nuru (2017) outlines the revegetation scheme including the planting schedule for Big Island. In winter 2015, Berrim Nuru Environmental Service, with the assistance of NPWS staff and Friends of Five Islands volunteers, planted 3800 natives into the initial treatment Area 1. In July 2016, 4000 natives were planted mostly in Area 2 as well as infill planting in Area 1. Infilling was necessary to replace large patches of Wandering sailor that had died, which was expected of this short-lived coloniser species (Berrim Nuru, 2017).

The numbers of plants of each species that were ordered for planting in June 2017 are outlined in Table 2. These plants will supplement approximately 8000 plants that were planted into Areas 1 and 2 between 2015 and 2016. The most popular species for replanting is *Lomandra longifolia*. Since the first planting in 2014 this species has proven to survive well in Area 1 on Big Island with many plants growing up to one metre tall. Additionally, this species provides a perfect habitat for seabirds, and has proven effective in similar projects such as Montague Island (Department of Environment and Climate Change, 2009).

**Table 2:** Plants ordered for the June 2017 planting on Big Island (Berrim Nuru, 2017).

<table>
<thead>
<tr>
<th>Species</th>
<th>Number ordered</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Jamberoo Native Nursery</strong></td>
<td></td>
</tr>
<tr>
<td><em>Lomandra longifolia</em></td>
<td>1560</td>
</tr>
<tr>
<td><em>Westringia fruticose</em></td>
<td>0</td>
</tr>
<tr>
<td><em>Rhagodia candolleana</em></td>
<td>24</td>
</tr>
<tr>
<td><em>Carpobrotus glaucescens</em></td>
<td>0</td>
</tr>
<tr>
<td><em>Tetragonia tetragonoides</em></td>
<td>0</td>
</tr>
<tr>
<td><em>Poa poiformis</em></td>
<td>33</td>
</tr>
<tr>
<td><em>Correa alba</em></td>
<td>65</td>
</tr>
<tr>
<td><em>Monotoca elliptica</em></td>
<td>78</td>
</tr>
<tr>
<td><em>Myoporum boninense</em></td>
<td>160</td>
</tr>
<tr>
<td><em>Banksia integrifolia</em></td>
<td>80</td>
</tr>
<tr>
<td><strong>Menai Wildflower Garden</strong></td>
<td></td>
</tr>
<tr>
<td><em>Lomandra longifolia</em></td>
<td>400</td>
</tr>
<tr>
<td><em>Banksia integrifolia</em></td>
<td>100</td>
</tr>
<tr>
<td><em>Rhagodia candolleana</em></td>
<td>350</td>
</tr>
</tbody>
</table>

The planting schedule outlines that an additional 16,890 plants will be planted in June 2018. This will involve the initial planting of Area 3 and Area 6 that were sprayed in April this year, some planting in Area 4, and infilling of Area 2 where it is expected that Wandering Sailor will die back. Planting in 2019 will occur in Area 5 and consist of 9,000 plants, plus an additional 1,000 plants allowed for infilling of Areas 1, 2, 3, 4 and 6, as required. The planting layout of these areas will be largely determined by the distribution of the patches of regenerating native colonisers. In Areas 1 and 2, planting has been concentrated around and between the patches of colonising species to form an area.
of better condition vegetation, and this technique should be repeated for future planting operations (Berrim Nuru, 2017). Monitoring and maintaining any exotics that reshoot into the sprayed areas is also necessary. This involves spot spraying annuals or exotic grasses such as Kikuyu, stem scraping of Coastal Morning Glory, and hand weeding within and around natives, as required.

Figure 2.6: Shrubs of planted *Banksia integrifolia* in spray Area 1, standing at over 2m tall. Best growth has occurred where the plants are sheltered from wind and salt spray by developed Mirror bush shrubs.
2.2 Montague Island, New South Wales
Montague Island, an 82 hectare island located approximately 200 kilometres south of The Five Islands, has experienced similar habitat degradation due to anthropogenic effects. Montague Island represents the best case study from which management plans of Big Island can be adopted and refined. In 2004, NSW Department of Environment Climate Change and Water (DECCW) began the Seabird Habitat Restoration Project, aiming to control and reduce Kikuyu grass on Montague Island, and improve the native seabird breeding habitat (NSW Department of Environment and Climate Change, 2008). Prior to the initiation of the project, Kikuyu grass had spread across 45% of Montague Island and was likely to become a monoculture within 15 years if left unaddressed (NSW Department of Environment and Climate Change, 2008). Harris (2007) reported up to 300 Little Penguins (Eudyptula minor) were becoming entangled in the Kikuyu annually, as well as other species including Short-tailed Shearwaters, Wedge-tailed Shearwaters and Sooty Shearwaters. Through a combination of herbicide treatment and burning removal, the project successfully removed over 14.5 hectares of Kikuyu from the island, effectively halving its distribution. Over 60,000 native seedlings were planted where Kikuyu was removed which now support a dense cover of suitable nesting habitat for burrowing seabirds. Limited research had previously been conducted into effective control of Kikuyu grass in coastal ecosystems, and this project has proven successful control is possible with the appropriate management and monitoring regime.

2.3 Remote Sensing
2.3.1 Overview
In very simple terms, remote sensing refers to the acquisition of images of a desired subject without coming in to contact with that subject. In other words, remote sensing is the interpretation of measurements of electromagnetic reflectance or emittance of a particular area on the earth’s surface or atmosphere, from a distance (Mather, 1999). Early forms of remote sensing of the surface of the earth date back to the eighteenth and nineteenth centuries when cameras were sent into the air carried by balloons. In its more modern form, early twentieth century remote sensing was achieved by aircraft-mounted systems, initially for military purposes (Mather, 1999). However, the greatest advances in the remote sensing world have inarguably occurred in recent decades. This is attributable to the discovery of alternative remote sensing applications such as mapping, monitoring and modelling natural resources (Hamilton, 2017). Prior to the widespread applications of remote sensing, scientists interested in studying a natural phenomenon would generally be limited to visiting that geographic location, and then relying on direct observation or contact sensors to probe, for example, temperature, humidity, and soil pH. What remote sensing allows for, is a platform from which information can be acquired from a distance, without coming into direct contact with the object or phenomenon (Wilkie and Finn, 1996). Efficiency is another benefit of remote sensing, since it allows for a study site to be revisited frequently (e.g. by satellite) where revisiting by the analyst may be impractical. It also
enables in-situ observations to be scaled up to include much larger areas, and a continuous assessment of the landscape characteristics, for example, land cover. Continuous improvements in the field include but are not limited to: increasing numbers and improved specifications of satellite-borne sensors in orbit, refinements in the spectral, spatial, and temporal resolutions of datasets collected, developments in geographic information systems (GIS) technology for storing and analysing data collected.

Remote sensing allows scientists to overcome the main challenges associated with change detection and monitoring of ecosystems. The temporal scale (the time it takes to revisit an area of interest) of airborne and satellite-borne sensors can range from a matter of hours to decades. Thus, remote sensing provides the capacity to obtain imagery rapidly and repeatedly over large areas, allowing fast-paced phenomena such as storms, effluent discharge, and drought to be effectively monitored (Wilkie and Finn, 1996). Remote sensing has proved particularly useful for environmental applications for the following reasons (Wilkie and Finn, 1996):

- There is no observer interference; remote sensing of a phenomenon does not result in a change in that phenomenon.
- Data acquisition is almost instantaneous, consistent regardless of spatial scale, and data can be obtained frequently over long time periods.
- There are many sensors available with different spatial and spectral resolutions.
- Information can be efficiently collected on an entire system and the cost per unit effort is relatively cheap.

The following section describes in further detail the functions of remote sensing in the context of vegetation analysis.

2.3.2 Vegetation mapping using remote sensing
Remote sensing has provided conservation biologists and environmental managers with a powerful array of tools for mapping vegetation and monitoring the changes that ecosystems undergo. One fundamental characteristic of optical remote sensing instruments is that they collect reflectance data in multiple wavebands across the electromagnetic spectrum. Collectively, these wavebands provide a ‘spectral signature’ that can be analysed, and is often highly characteristic of the reflectance surface. Indeed, natural features such as sand, rock, and water have distinct spectral reflectance characteristics, and vegetation is no exception (figure 2.7).
Figure 2.7: Spectral signatures of dry bare soil, green vegetation and clear water body (Smith, 2001b).

Different types of vegetation (e.g. grasses, shrubs, crops, trees) have different reflectance characteristics (figure 2.8), which means they can be effectively mapped using remote sensing technology. In general, vegetation has low reflectance and low transmittance in the visible part of the electromagnetic spectrum. This is because pigments such as chlorophyll absorb wavelengths of violet-blue light and red light, and uses this energy for the process of photosynthesis (Wilkie and Finn, 1996, Mather, 1999, Verbyla, 1995). Typically, pigments in healthy vegetation absorb 70-90% of both blue and red light, with a reflectance peak between 0.5µm and 0.6µm, corresponding to visible green light (Mather, 1999). This is the reason why healthy vegetation appears green to us (Verbyla, 1995). It is spectral relationships like this that allow remote sensing to be particularly useful in the application of natural resource monitoring.
Figure 2.8: Reflectance spectra of different vegetation types. Different portions of the spectral curve are shaped by different components of the vegetation, as indicated at the top (Smith, 2001a).

With the increasing availability of improved temporal, spectral and spatial resolution data, expectations have developed that most types of rock, soil and vegetation should be remotely identifiable (Cochrane, 2000). However, plants exhibit spectral signature variation within a species, meaning comparison of spectral response between species can be quantitatively similar (Dennison and Roberts, 2003). The difficulties in spectral separability of vegetation arise because of the common chemical compositions of plants. For example, the composition and concentration of chlorophyll $a$, chlorophyll $b$ and carotenoids will determine the spectral response of vegetation in the visible wavelengths (400-700 nm) (Tucker and Garratt, 1977). The spectral response in the near-infrared wavelengths (700-1400 nm) are a function of the number and configuration of the air spaces that form the internal leaf structure (Danson, 1995).

Elvidge and Portigal (1990) demonstrated dramatic changes occurring in grassland vegetation spectral responses between seasons due to the decline in chlorophyll pigments and water absorption that occurs in drier months. They concluded that seasonal spectral changes occur at particular wavelengths on the spectral response curves including the chlorophyll red edge (0.95 $\mu$m), leaf water absorptions (1.15 $\mu$m), and lignin-cellulose absorptions (2.09 $\mu$m and 2.27 $\mu$m). Phenological developments of vegetation and associated spectral changes are difficult to measure with a narrow band instrument and are best detected with the use of a hyperspectral sensor (Dennison and Roberts, 2003). Hyperspectral
Imagers are remote sensing instruments that sample the electromagnetic spectrum in many (> 100) narrow wavebands in order to record a near-continuous representation of the spectral signature of a target (Hamylton, 2017). By contrast, multispectral sensors sample fewer, broader, discrete wavelength bands, resulting in less spectral detail per pixel (Colomina and Molina, 2014).

The widespread use of remote sensing emerged at a time when ecological monitoring was increasingly required. Monitoring involves repeated measurements of an area of interest, such as repeat mapping over time to establish change detection of land cover. Prior to the emergence of environmental monitoring applications of remote sensing, ecologists traditionally mapped vegetation using ground-based survey techniques. Initially, the acceptance of remote sensing for vegetation mapping purposes in its early years was not widespread among ecologists, and ground-based survey remained the stronger approach for gaining detailed information about vegetation cover and spatial variability, over localised areas (Alexander and Millington, 2000). However, the constraints of ground-based survey techniques were obvious: surveying of extensive areas is difficult to impossible (small spatial scale restrictions), difficult to access areas or terrain, high skill level requirements and impracticality for frequent revisits (Alexander and Millington, 2000). Alexander and Millington (2000) acknowledge that vegetation and land cover data acquired from ground surveys or from airborne and satellite-borne sensors may be combined to produce better results. This can be done at four stages of the mapping operation:

1. Airborne and satellite data can be used in the design of field sampling procedures
2. Ground reference data (or ground-truthing) is required to calibrate the models needed to interpret the remotely-sensed data. This is common for the purpose of selecting training areas for a supervised classification, as will be further discussed.
3. Ground reference data or airborne data is needed to validate information from satellite remote sensing.
4. Data from field survey may be combined with remotely-sensed data to create new information.

One of the most commonly used GIS tools for vegetation mapping is an image processing technique called image classification (Alexander and Millington, 2000). Image classification involves the transformation of raw data in the form of remotely sensed spectral radiance measurements, into mapped thematic representations of the composition of the land surface. For vegetation scientists, an image classification may be performed to obtain information about a key characteristic of interest, such as the floristic composition, structure, productivity, or species distribution on the ground surface (Alexander and Millington, 2000, Cochrane, 2000, Dennison and Roberts, 2003, Lewis et al., 2012).

Broadly, image classification techniques are divided into two types (Rees, 1999): supervised classification and unsupervised classification.
Figure 2.9: A flow diagram illustrating the application of a supervised classification algorithm to the raw bands of a satellite image of the western section of Aldabra Atoll to distinguish four ground-cover classes (Hamylton, 2017).
A supervised classification involves the input of user-defined areas of known ground-cover types, called ‘training areas’, to supply information about the spectral characteristics of that ground-cover type. Once the process is initiated, pixels are placed into classes based on the similarities of their spectral reflectance data with that of the training data (figure 2.9) (Alexander and Millington, 2000, Rees, 1999). Attention must be drawn to the fact that allocation of pixels into the appropriate class does not ensure a high classification accuracy for the overall image (Kershaw and Fuller, 1992). Training data should primarily consist of homogenous areas, well distributed across the scene in order to maximise the classification accuracy (Alexander and Millington, 2000).

In contrast, an unsupervised classification does not require user-defined training areas, but instead analyses the whole image by clustering to find distinguishable classes of pixels present (Rees, 1999). This relies on the inherent statistical properties of the image alone.

The maximum likelihood classifier is a supervised classification technique that quantitatively evaluates both the variance and covariance of the spectral response patterns of each category when classifying an unknown pixel. The statistical parameters involved are why the maximum likelihood classifier is one of the most accurate and widely used image classifiers (Conese and Maselli, 1992, Foody et al., 1992, Shalaby and Tateishi, 2007).

It is accepted practice that the results of an image classification are presented with an independent dataset to compare the output with data collected on the ground (Congalton, 1991). Broadly, the collection of field data to support remote sensing analysis is referred to as ground referencing or ‘ground-truthing’. When this data is used to assess the reliability of a map, it is referred to as a validation exercise (Hamylton, 2017). Associated errors are usually presented in the form of an error matrix (or confusion matrix). This is a necessary aspect of image classification if the results are to have any practical application (Alexander and Millington, 2000).

When interpreting the error matrix associated with an image classification, it is important to understand what information is given by the different statistical accuracies. For example, the overall accuracy is simply the number of correctly assigned pixels divided by the total number of pixels in the matrix. Accuracies of individual categories can also be calculated in two different ways. Firstly, producer accuracies are a measure of omission error, where the number of correct pixels in a category is divided by the number of pixels in that category according to the ground reference dataset (Congalton, 1991). This is a measure of the probability of a reference pixel being correctly classified. User accuracies are calculated by the number of correctly assigned pixels in a category divided by the total number of pixels assigned to that category. This a measure of the probability of a pixel classified on the map actually representing that class on the ground, or a measure of commission (Congalton, 1991).
Additionally, sample size of the validation data set is an important factor to be considered. When dealing with the error matrices of remote sensing image classifications, it is not simply a matter of a pixel being correct or incorrect. The analyst wants to know where the confusion is occurring between classes, and this can only be adequately represented with a sufficient sample size. However, there will never be enough time to acquire a ground reference point for every pixel in any analysis, and there will always be time, cost and practical limitations associated. Therefore, a balance should be found between what is statistically sound and what is practically attainable (Congalton, 1991).

2.3.3 Unmanned Aerial Vehicle (UAV) Technology for Remote Sensing

Until recent years, the applications of remote sensing in vegetation mapping have been restricted by the spatial and temporal resolution of the available sensor platforms (Lu and He, 2017). The spatially explicit data required for ecological spatial analyses have, for years, relied heavily on obtaining such data from satellite- or aircraft-mounted sensors (Anderson and Gaston, 2013). The spatial and temporal resolutions of imagery sourced by satellites are often inadequate for small-scale ecological investigations. Recent technological developments have expanded the availability and use of the unmanned aerial vehicle (UAV; otherwise known as unmanned aerial system (UAS), aerial robot, or most commonly ‘drone’), in environmental remote sensing applications. UAVs have proved to be an effective alternative for remotely sensed data acquisition in environmental monitoring applications since the development of small, fast, cost-effective and easily deployable systems (Colomina and Molina, 2014).

With respect to vegetation mapping, one particular advantage of the drone platforms is that revisit times can be aligned with the phenological cycles of the target species to be monitored (Anderson and Gaston, 2013). Additionally, UAVs have the capacity to operate at much lower altitudes than traditional remote sensing platforms such as manned aircraft or satellite, which can result in imagery with a very high spatial resolution, i.e. pixel sizes down to the centimetre-level. Such detailed datasets allow individual plants to be resolved (Anderson and Gaston, 2013, Colomina and Molina, 2014). This is because the spatial resolution of an image is a function of the distance between the sensor and the Earth (Hamylton, 2017). UAVs are controlled from the ground and have the capacity to be controlled remotely in real-time, or to fly autonomously based on pre-programmed flight plans, giving the pilot complete control of the area surveyed (Hamylton, 2017).

This project aims to classify species distribution of spectrally similar species (e.g. Kikuyu grass and Coastal Morning Glory), and the very high spatial resolution of drone-acquired imagery allows this to be effectively conducted.
3 Methodologies

3.1 Digitisation of Historical Aerial Photographs

A series of historical aerial photographs were provided by the Spatial Analysis Laboratory at the School of Earth and Environmental Sciences (University of Wollongong) for the purpose of this project. The series included black and white panchromatic images of Big Island for the years 1947, 1951, 1963, 1970, 1972, and 1984, and colour film images for the years 1977, 1981, 1990, 1994, 2001, and 2005.

The raw images were scanned and then georeferenced in ArcMap, a software component that forms a part of the Esri ArcGIS software. Georeferencing was necessary to provide spatial reference information to the images and assign the coordinate system of the data frame. The x,y coordinates of ground control points (i.e. distinguishable features of known locations in Google Earth) were transferred to the same features in the aerial photographs in ArcMap.

Colour images are usually best for plant species identification and land cover mapping, because reflectance values of the visible spectrum are often used in the interpretation of species and land cover. However, the spatial resolution of the aerial photographs deemed it impossible to conduct an effective pixel-based land cover classification on Big Island.

The 1981 aerial photograph has been provided as an example to show the spatial extent of the aerial images (figure 3.1). The aerial images were applied to a scale of 1:4000, which was used as a standard scale to produce a time series of comparable images. Despite the spatial resolution of the aerial photographs being inadequate for a species identification classification map, land cover could be easily distinguished between “vegetation” and “bare ground”. Areas containing vegetation were digitised with polygons in ArcMap. Then, the areas of digitised polygons were calculated using the “calculate geometry tool”, and expressed as a fraction of total island area (total vegetated area = 7.7 ha) to give a percentage vegetation cover result. Percentage vegetation cover for each year was then plotted through time on a scatter plot, giving an indication of the historical land cover trends of Big Island (figure 4.1).
Figure 3.1: Aerial photograph of Big Island in 1981 provided by the University of Wollongong. Islands in the frame include Bass Islet in the north, and Rocky Islet, Big Island, and Martin Islet respectively from west to east (centre frame). Details of the aerial survey are provided in the photo frame.

3.2 Field Survey

Prior to the initiation of this project, a series of permanent vegetation survey plots had been established by Kevin Mills and Phil Craven to monitor the vegetation before, during and after the helicopter aerial spraying program conducted by NPWS. Additional vegetation surveys were conducted on 20 April, 2017 to supplement the results of the previous surveys. An additional four plots were sampled, each measuring a $20 \times 20$ m quadrat (figure 3.2). A plot size of $20 \times 20$ m (0.04ha) is consistent with NSW government standards set out in (Sivertsen, 2009). The standard sampling plot size is adopted for sampling floristics to maximize compatibility with existing data (Sivertsen, 2009).
Figure 3.2: Locations of the permanent plots established for vegetation surveys on Big Island.
Each plot has been developed as a permanent plot for repeat sampling by placing a metal stake in the ground at each randomly selected location. Consistency in the orientation of each plot for repeat samples is maintained using a compass. The establishment of permanent plots is a very useful tool for long-term vegetation monitoring, as repeat surveys can help to distinguish between ecological trends and fluctuations, and give insight into the underlying mechanisms in the functioning of ecosystems (Bakker et al., 1996). A summary of the vegetation surveys that have been conducted on Big Island to date is provided in table 3. Repeat sampling of plots 01 – 07 was not achieved on Date 6 (20 April, 2017) due to time constraints.

**Table 3:** Summary of permanent plots for vegetation surveys on Big Island as reported by Mills (2017).

<table>
<thead>
<tr>
<th>Plot/Area</th>
<th>Peg</th>
<th>Date 1</th>
<th>Date 2</th>
<th>Date 3</th>
<th>Date 4</th>
<th>Date 5</th>
<th>Date 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>01/A1</td>
<td>NE corner</td>
<td>31.01.14</td>
<td>08.12.14</td>
<td>04.03.15</td>
<td>30.11.15</td>
<td>23.11.16</td>
<td>photo</td>
</tr>
<tr>
<td>02/A1</td>
<td>SE corner</td>
<td>31.01.14</td>
<td>08.12.14</td>
<td>04.03.15</td>
<td>30.11.15</td>
<td>23.11.16</td>
<td>photo</td>
</tr>
<tr>
<td>03/A2</td>
<td>SE corner</td>
<td>-</td>
<td>04.03.15</td>
<td>04.03.15</td>
<td>30.11.15</td>
<td>23.11.16</td>
<td>photo</td>
</tr>
<tr>
<td>04/A3</td>
<td>NE corner</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>23.11.16</td>
<td>-</td>
</tr>
<tr>
<td>05/A4</td>
<td>NE corner</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>23.11.16</td>
<td>-</td>
</tr>
<tr>
<td>06/A5</td>
<td>NE corner</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>23.11.16</td>
<td>-</td>
</tr>
<tr>
<td>07/A6</td>
<td>NE corner</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>23.11.16</td>
<td>-</td>
</tr>
<tr>
<td>08/A3</td>
<td>NE corner</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<td>20.04.17</td>
</tr>
<tr>
<td>09/A6</td>
<td>NE corner</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>20.04.17</td>
</tr>
<tr>
<td>10/A4</td>
<td>NE corner</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>20.04.17</td>
</tr>
<tr>
<td>11/A5</td>
<td>NE corner</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>20.04.17</td>
</tr>
</tbody>
</table>

### 3.3 Vegetation Analysis

**3.3.1 Drone Survey: aerial image acquisition**

For the purpose of developing land cover classification maps, a UAV (drone) was used to acquire aerial images. The drone was flown at approximately 70m above sea level, following an autonomous, pre-programmed flight path (*figure 3*). This was done to ensure the entire study area was included in the images captured by the drone. The first drone flight was conducted on 19 April, 2017 – just days prior to the Glyphosate 360 helicopter spray for the purpose of eradicating invasive species on Big Island. A second drone flight was conducted on 29 July, 2017, three months after the aerial spraying had occurred. All drone work above Big Island was permitted under the Scientific Licence SL101878. Flight dates were determined based on seabird breeding season and the weed treatment program.
The drone used to conduct the flights was a DJI Phantom 4, equipped with a stock DJI FC330 camera. The DJI FC330 camera has a 1/2.3” CMOS sensor and a Field Of View 94° 20mm (35mm format equivalent) lens, which captures images at 12.4 effective megapixels (MP). Images were captured at 90° (±0.02°) perpendicular to the ground surface.
3.3.2 Image Pre-Processing
The raw images of each flight were collated using Agisoft PhotoScan, a software product that performs photogrammetric processing of digital images. The processing resulted in an orthomosaic image for each of the drone flights. Manual georeferencing was not required for the orthomosaic images as the DJI FC330 camera records the x,y coordinates of the images it captures to an accuracy of ±0.3m with its vision positioning system engaged.

3.3.3 Image Classification
Vegetation changes on Big Island were assessed by comparison of multi-date land cover classifications produced in ArcMap. This was achieved by performing a supervised classification, which involves user input to create training areas to define areas of known land cover (figure 3.6). These user-defined areas are often referred to as regions of interest (ROIs). Each picture element, or pixel, is placed into one of the user-defined land cover classes based on its spectral reflectance properties. This differs from an unsupervised classification whereby less user input is required, and there are no training areas. Instead, the user simply defines the number of classes required, and the algorithm will naturally group pixels with similar spectral properties. The basic steps of a supervised and unsupervised classification are outlined in figure 3.5. A Maximum likelihood algorithm was employed as the supervised classification technique.

![Figure 3.5: Basic steps of: a) supervised classification that was used to produce land cover classification maps in this project. b) Unsupervised classification for comparison.](image-url)
3.3.4 Accuracy Assessment

With any form of spatial analysis there is some degree of uncertainty associated with the results, and no conclusions can be drawn from the results until the uncertainty has been recognised and reported (Hamylton, 2017). Evaluation of the errors leads to an understanding of the limitations on the ways in which the results can be used. A validation exercise was used to assess the accuracy of digital maps generated from the classification of remotely sensed images. This involved comparing the correlation of thematic map content to an independent variable dataset. In this case, the independent dataset used for validation was a series of photographs of the ground cover on Big Island (figure 3.7).
Photographs of the ground cover were collected at random sites across Big Island and the coordinates of each photograph were recorded using a handheld GPS for georeferencing each photograph. The ground reference datasets were acquired at two different dates – one immediately after the first drone image (for validation of the classification map prior to helicopter spraying), and one following the acquisition of the second drone image (for validation of the classification map after aerial spraying).

A point shapefile was created in ArcMap for each of the ground reference datasets, with both the x,y coordinates and actual land cover attributes included. As part of the validation exercise, these were independently viewed and assigned a class each, using a classification scheme that aligned with the digital maps. They were overlaid onto the land cover maps and the class assigned by the digital classification algorithm was exported. This allowed a comparison of actual land cover and classified land cover at each location. From this, pixels can be noted as correctly or incorrectly assigned, and several measures of accuracy can be derived. An error (or confusion) matrix was created for each validation dataset to quantify the user, producer, and overall accuracies of each classification map. Example images for each of the mapped vegetation classes are provided in figure 3.8.
Figure 3.8: Examples of mapped ground cover classes. A) Thick swards of Kikuyu grass (*Cenchrus clandestinus*) cover large areas of Big Island. B) Dead vegetation following Glyphosate treatment in Area 3. C) Established native vegetation in Area 1 (mainly visible is *Lomandra longifolia*). D) Shrubs of Mirror bush (*Coprosma repens*) stand up to 4m tall. E) Coastal morning glory (*Ipomoea cairica*).

3.3.5 Detailed assessment of cover change within treatment area

A multi-date comparison of land cover statistics was conducted to assess the effectiveness of the aerial spray of Areas 3, 5 and 6 that occurred in April 2017. Firstly, the treatment area was digitized as a polygon shapefile in ArcMap. The treated area polygon was then overlaid onto both of the land cover classification layers (before and after aerial spraying) that were produced by the maximum likelihood classifier. The clip tool is a raster data management tool that was carried out to isolate the area sprayed in each image (figure 3.9). The cell size of the pre-treatment classification was 5.994cm$^2$. The cell size of the post-treatment classification was 3.183cm$^2$. The cell count for each land cover class within the clipped treatment area was exported into a Microsoft Excel spreadsheet. Then, the area of each land cover within the treatment area was calculated using the formula (land cover class cell count × cell size = total area of land cover class). From this, a pie chart was produced to show the total area (m$^2$) and percentage cover of land classes within the treatment area, before and after treatment occurred.
Figure 3.9: Area sprayed in April 2017, isolated using the Clip tool in ArcMap. This allowed for a multi-date pixel analysis of the area to assess the effectiveness of the treatment in eradicating Kikuyu grass from the treated area.
4 Results

4.1 Historical Vegetation Communities

Figure 4.1: Top: Time series of Big Island (No. 1 & No. 2) produced from aerial photographs provided by the School of Earth and Environmental Sciences, University of Wollongong. Photographs were georeferenced in ArcMap and applied at the same scale for visual interpretation. Bottom: Graph illustrating the trend line for percentage vegetation cover on Big Island through time, as derived from the aerial photographs.
Figure 4.1 shows a time series of georeferenced aerial photographs of Big Island (No 1. and No. 2) for the years 1947, 1951, 1963, 1977, 1981, 1990, 1994, 2001 and 2005. The associated graph illustrates the trend of vegetation cover on Big Island over time. The general trend is an increasing percentage cover of vegetation. The most rapid increase in vegetation cover appears to have occurred between the years 1977 and 2001.

Figure 4.2: Map of land cover on Big Island in 2014 based off a vegetation map provided by Kevin Mills (see figure 4 in Mills, 2015).
Figure 4.2 represents the vegetation of Big Island in 2014. This map was reconstructed from the vegetation map provided by Mills (2015). It highlights the overall dominance of Kikuyu grass on Big Island, and the limited distribution of natives where sea-spray constrains Kikuyu growth.

4.2 Field Survey
Four additional vegetation monitoring plots were added to treatment Areas 3, 4, 5 and 6 (figure 2.4) and surveyed prior to the helicopter aerial spraying in April. The locations of the plots can be seen in figure 3.2. The survey design is consistent with NSW standards for vegetation monitoring, as described in (Sivertsen, 2009). The results of these surveys are summarised in tables 2-5. All survey results were accessed via the NSW BioNet web page (NSW Office of Environment & Heritage, 2017).

Table 4: Vegetation survey results of plot 08.

<table>
<thead>
<tr>
<th>Species Present: scientific name, (common name)</th>
<th>Percentage Cover (%)</th>
<th>Actual Abundance</th>
<th>Growth Form</th>
<th>Stratum</th>
<th>Native/ Exotic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cenchrus clandestinum (Kikuyu grass)</td>
<td>98</td>
<td>~500</td>
<td>Hummock Grass</td>
<td>Ground</td>
<td>Exotic</td>
</tr>
<tr>
<td>Bromus catharticus (rescuegrass)</td>
<td>2</td>
<td>47</td>
<td>Grass</td>
<td>Ground</td>
<td>Exotic</td>
</tr>
<tr>
<td>Sonchus oleraceus (sowthistle)</td>
<td>1</td>
<td>31</td>
<td>Forb</td>
<td>Ground</td>
<td>Exotic</td>
</tr>
<tr>
<td>Coprosma repens (Mirror bush)</td>
<td>2</td>
<td>5</td>
<td>Shrub</td>
<td>Mid</td>
<td>Exotic</td>
</tr>
<tr>
<td>Lycium ferocissimum (African boxthorn)</td>
<td>1</td>
<td>1</td>
<td>Shrub</td>
<td>Unspecified</td>
<td>Exotic</td>
</tr>
<tr>
<td>Chenopodium album (Fat hen)</td>
<td>1</td>
<td>1</td>
<td>Forb</td>
<td>Ground</td>
<td>Exotic</td>
</tr>
</tbody>
</table>
Table 5: Vegetation survey results of plot 09.

<table>
<thead>
<tr>
<th>Species Present: scientific name, (common name)</th>
<th>Percentage Cover (%)</th>
<th>Actual Abundance</th>
<th>Growth Form</th>
<th>Stratum</th>
<th>Native/Exotic</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Cenchrus clandestinum</em> (Kikuyu grass)</td>
<td>85</td>
<td>~500</td>
<td>Hummock Grass</td>
<td>Ground</td>
<td>Exotic</td>
</tr>
<tr>
<td><em>Ipomoea caírica</em> (Coastal Morning Glory)</td>
<td>20</td>
<td>100</td>
<td>Vine</td>
<td>Ground</td>
<td>Exotic</td>
</tr>
<tr>
<td><em>Chrysanthemoides monilifera subsp. rotundata</em> (Bitou bush)</td>
<td>15</td>
<td>15</td>
<td>Shrub</td>
<td>Mid</td>
<td>Exotic</td>
</tr>
<tr>
<td><em>Commelina cyanea</em> (Scurvy weed)</td>
<td>1</td>
<td>1</td>
<td>Forb</td>
<td>Ground</td>
<td>Native</td>
</tr>
</tbody>
</table>

Table 6: Vegetation survey results of plot 10.

<table>
<thead>
<tr>
<th>Species Present: scientific name, (common name)</th>
<th>Percentage Cover (%)</th>
<th>Actual Abundance</th>
<th>Growth Form</th>
<th>Stratum</th>
<th>Native/Exotic</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Cenchrus clandestinum</em> (Kikuyu grass)</td>
<td>40</td>
<td>100</td>
<td>Hummock Grass</td>
<td>Ground</td>
<td>Exotic</td>
</tr>
<tr>
<td><em>Coprosma repens</em> (Mirror bush)</td>
<td>70</td>
<td>50</td>
<td>Shrub</td>
<td>Mid</td>
<td>Exotic</td>
</tr>
<tr>
<td><em>Bromus catharticus</em> (rescuegrass)</td>
<td>1</td>
<td>22</td>
<td>Grass</td>
<td>Ground</td>
<td>Exotic</td>
</tr>
<tr>
<td><em>Sonchus oleraceus</em> (sowthistle)</td>
<td>1</td>
<td>1</td>
<td>Forb</td>
<td>Ground</td>
<td>Exotic</td>
</tr>
</tbody>
</table>

Table 7: Vegetation survey results of plot 11.

<table>
<thead>
<tr>
<th>Species Present: scientific name, (common name)</th>
<th>Percentage Cover (%)</th>
<th>Actual Abundance</th>
<th>Growth Form</th>
<th>Stratum</th>
<th>Native/Exotic</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Cenchrus clandestinum</em> (Kikuyu grass)</td>
<td>40</td>
<td>~500</td>
<td>Hummock Grass</td>
<td>Ground</td>
<td>Exotic</td>
</tr>
<tr>
<td><em>Ipomoea caírica</em> (coast morning glory)</td>
<td>60</td>
<td>500</td>
<td>Sedge</td>
<td>Ground</td>
<td>Exotic</td>
</tr>
<tr>
<td><em>Solanum nigrum</em> (black nightshade)</td>
<td>1</td>
<td>1</td>
<td>Forb</td>
<td>Ground</td>
<td>Exotic</td>
</tr>
<tr>
<td>Common Name</td>
<td>Rating</td>
<td>Native</td>
<td>Category</td>
<td>Growth Form</td>
<td>Origin</td>
</tr>
<tr>
<td>-----------------------------------</td>
<td>--------</td>
<td>--------</td>
<td>----------</td>
<td>-------------</td>
<td>--------------</td>
</tr>
<tr>
<td><strong>Tetragonia tetragonioides</strong></td>
<td>2</td>
<td></td>
<td>Forb</td>
<td>Ground</td>
<td>Native</td>
</tr>
<tr>
<td>(New Zealand spinach)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Eleusine indica</strong></td>
<td>5</td>
<td></td>
<td>Grass</td>
<td>Ground</td>
<td>Naturalised</td>
</tr>
<tr>
<td>(crowfootgrass)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Sonchus oleraceus</strong></td>
<td>1</td>
<td></td>
<td>Forb</td>
<td>Ground</td>
<td>Exotic</td>
</tr>
<tr>
<td>(sowthistle)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Bromus catharticus</strong></td>
<td>1</td>
<td></td>
<td>Grass</td>
<td>Ground</td>
<td>Exotic</td>
</tr>
<tr>
<td>(rescuegrass)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Chenopodium album</strong></td>
<td>1</td>
<td></td>
<td>Forb</td>
<td>Ground</td>
<td>Exotic</td>
</tr>
<tr>
<td>(Fat hen)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Solanum chenopodioides</strong></td>
<td>1</td>
<td></td>
<td>Forb</td>
<td>Ground</td>
<td>Exotic</td>
</tr>
<tr>
<td>(Velvety nightshade)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Einadia trigonos</strong></td>
<td>1</td>
<td></td>
<td>Forb</td>
<td>Ground</td>
<td>Native</td>
</tr>
<tr>
<td>(fishweed)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
4.3 Species Classification

Figure 4.3: UAV-acquired image of Big Island before aerial helicopter spraying of treatment Areas 3, 5 and 6. Image was captured on 19 April, 2017.
Figure 4.4: UAV-acquired image of Big Island after aerial helicopter spraying of Glyphosate 360. Image was captured on 30 July, 2017.

The land cover classification maps for drone images acquired in April 2017 and July 2017 are provided in figure 4.5 and figure 4.6, respectively. The maps were produced in ArcMap using a maximum likelihood classifier, as outlined in chapter 3. Error (or confusion) matrix associated with the output maps are provided in tables 8-9, each based on a ground reference dataset. Table 8 provides the user, producer, and overall accuracies associated with figure 4.5, and table 9 provides the accuracies associated with figure 4.6.
The overall classification accuracies of the maps are 84% (pre-treatment) and 75% (post-treatment). The highest producer accuracies of the pre-treatment map were for the classes Coastal Morning Glory, light rocks and dark rocks (100%). The lowest producer accuracy for the pre-treatment map was the class native/other vegetation (50%). The highest user accuracy for the pre-treatment map was for the classes Mirror bush/Bitou bush and dark rock (100%). Native/other vegetation yielded the lowest user accuracy for the pre-treatment map (33%). Producer accuracy of the post-treatment map was highest for the class dead vegetation (93%), while Coastal Morning Glory yielded the lowest producer accuracy for this map (40%). The highest user accuracy for the post-treatment map was dead vegetation (86%). Coastal Morning Glory yielded the lowest user accuracy for this map (57%). These measures of accuracy are useful in the assessment of a classification map, however, there are further considerations that need to be made when using these statistics, which will be further discussed in chapter 5.
Figure 4.5: Output map for land cover classification on Big Island, prior to the application of Glyphosate 360 which occurred in April 2017. Image classification was achieved in ArcMap using a supervised maximum likelihood classifier for pixel-based classification.
Figure 4.6: Output map for land cover classification on Big Island following aerial treatment of Glyphosate. Map was produced in ArcMap using a supervised maximum likelihood classifier for pixel-based classification.
Table 8: Classification Cross-Validation Results: Error (confusion) matrix associated with Figure 4.7 classification, showing the results of producer, user and overall accuracy assessments. Row labels are generated by the classification procedure, while column labels are assigned to an independent dataset for validation of pixel classification.

<table>
<thead>
<tr>
<th>Validation Class</th>
<th>Kikuyu Grass</th>
<th>Morning glory</th>
<th>Mirror/Bitou Bush</th>
<th>Dead Veg.</th>
<th>Light Rock</th>
<th>Dark Rock</th>
<th>Native/Other Veg.</th>
<th>Sum</th>
<th>User Accuracy (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kikuyu Grass</td>
<td>20</td>
<td>0</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>24</td>
<td>83</td>
</tr>
<tr>
<td>Morning glory</td>
<td>1</td>
<td>11</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>12</td>
<td>92</td>
</tr>
<tr>
<td>Mirror Bush</td>
<td>0</td>
<td>0</td>
<td>9</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>9</td>
<td>100</td>
</tr>
<tr>
<td>Dead Vegetation</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>75</td>
</tr>
<tr>
<td>Light Rock</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>7</td>
<td>71</td>
</tr>
<tr>
<td>Dark Rock</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>0</td>
<td>3</td>
<td>100</td>
</tr>
<tr>
<td>Native/Other Veg.</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>3</td>
<td>62</td>
<td></td>
</tr>
<tr>
<td>Sum</td>
<td>21</td>
<td>11</td>
<td>16</td>
<td>4</td>
<td>5</td>
<td>3</td>
<td>2</td>
<td>84</td>
<td></td>
</tr>
</tbody>
</table>

Overall Accuracy
Producer Accuracy (%) 95 100 56 75 100 100 50

Table 9: Error matrix associated with the image classification presented in figure 4.8, showing the results of user, producer, and overall accuracy assessments.

<table>
<thead>
<tr>
<th>Validation Class</th>
<th>Morning glory</th>
<th>Kikuyu Grass</th>
<th>Mirror Bush/Bitou</th>
<th>Dead Veg.</th>
<th>Native/Other Veg.</th>
<th>Sum</th>
<th>User Accuracy (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Morning glory</td>
<td>4</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>7</td>
<td>57</td>
</tr>
<tr>
<td>Kikuyu Grass</td>
<td>3</td>
<td>19</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>26</td>
<td>73</td>
</tr>
<tr>
<td>Mirror Bush/Bitou</td>
<td>0</td>
<td>3</td>
<td>10</td>
<td>0</td>
<td>2</td>
<td>15</td>
<td>67</td>
</tr>
<tr>
<td>Dead Vegetation</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>25</td>
<td>1</td>
<td>29</td>
<td>86</td>
</tr>
<tr>
<td>Native/other veg.</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>5</td>
<td>7</td>
<td>84</td>
<td>71</td>
</tr>
<tr>
<td>Sum</td>
<td>10</td>
<td>23</td>
<td>16</td>
<td>27</td>
<td>8</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Overall Accuracy
Producer Accuracy (%) 40 83 63 93 63

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4.4 Detailed assessment of cover change within treatment area

Presented in figures 4.7 - 4.8 is the analysis used to assess the effectiveness of the helicopter aerial spraying program that has been initiated by NSW National Parks and Wildlife Service. Figure 4.7 and figure 4.8 represent the area that underwent Glyphosate 360 gL\(^{-1}\) treatment in April 2017, before and after treatment had occurred, respectively. The top left images show the spray area as a polygon overlaid on to the drone images that were used for image classification. The treated area can be easily seen in the top left image of figure 4.8. The top right images reveal the image classification results within the treatment area, which were isolated using a clip tool in ArcMap. The pixel classifications of the treatment area are represented in the pie charts as land cover area (m\(^2\)) and land cover percentage. The percentage coverage of Kikuyu grass (*Cenchrus clandestinus*) in the treatment area before treatment occurred was 66%. Post-treatment Kikuyu grass cover fell to 1%. The percentage cover of Coastal Morning Glory (*Ipomoea cairica*) prior to treatment was 15%. Coastal Morning Glory cover fell to 1% post-treatment. The percent cover of native/other vegetation remained steady at 4%. Dead vegetation accounted for 6% of land cover pre-treatment and 88% post-treatment.
Figure 4.7: Land cover percentages of sprayed area (pre-treatment): Helicopter spray area, treated in April 2017 (top left). Land cover classes within the treatment area, before treatment occurred (top right). Pie chart displaying area in m² and percentage cover of each land cover class within treatment area (bottom).
Figure 4.8: Land cover percentages of sprayed area (post-treatment): Helicopter spray area, treated at April 2017 (top left). Land cover classes within treatment area as they occurred at July 2017, three months post-treatment (top right). Pie chart displaying area in m² and percentage of each land cover class within treatment area (bottom).
5 Discussion

In this project historical aerial photographs of the Five Islands were examined to describe the history of vegetation on Big Island. The aerial photographs in figure 4.1 provide a clear indication that the vegetation communities on Big Island have undergone drastic changes throughout the past 70 years. The aerial photographs can help to support findings by Davis et al. (1938) and Mills (1990). Visual interpretation of the 1947 aerial photograph would indicate that the dunes on Big Island were in a similar state as they were reported in 1938 (Davis et al.). The dunes at this stage were partially displaced by wind erosion. The northern slopes of Big Island contained bare sand drifts, void of vegetation, and a sand drift partially stabilized by plants existed on the south-eastern slopes (Davis et al., 1938). By 1947, the dune conditions appear to be in a similar condition, with some vegetation coverage also present on the north-western corner of the island. The difference in vegetation coverage is significant between the 1963 and the 1977 photographs. It was between these years that Kikuyu grass was introduced to Big Island. The 1977 aerial photograph shows what is most likely Kikuyu grass encroaching from the northern and southern ends of Big Island, with some bare soil remaining across the middle of the island. In the 1981 photograph, Kikuyu grass covers the central part of the island, while there is still some bare ground on the south-western corner and eastern side of Big Island. By 1990, the entirety of Big Island was covered in Kikuyu grass, as evidenced by Mills (1990).

The photographic time series also highlights the moderately rapid spread of Mirror bush (Coprosma repens). Mirror bush was first recorded on Big Island by Mills (1990), and would have reached the island via dispersal of its fleshy fruit carried by birds (Mills, 1990). Dark green shrubs of Mirror bush can be distinguished in the 1990 image and a single shrub occurs in the same location in the 1981 photograph. Two decades later, the 2001 photograph shows a widespread distribution of Mirror bush on the northern and southern ends of the island. Mirror bush distribution on Big Island in 2017 occurs in abundant clusters. Mirror bush is a salt-tolerant species which explains its colonisation on the northern and southern ends of the island, where sea-spray inhibits the growth of Kikuyu.

Field surveys were conducted on 20 April, 2017 at four newly established permanent vegetation survey plots. 20 × 20 m quadrats were established at each survey location, as outlined in section 3.2. Plots 8, 9, and 11 were established within the area that underwent aerial helicopter treatment days after the plots were sampled (figure 3.2). All of the surveyed plots were dominated by exotics. Replanting of natives will occur in Areas 3 and 6 (plots 4, 8, 9) in 2018, and in Area 5 (plots 6 and 11) in 2019, as outlined in section 2.1.5. Repeat surveys will be conducted to monitor the vegetation including growth and condition of planted and colonising natives, and any exotics that may reshoot in the treated areas.

The distributions of native and exotic species on Big Island were mapped using remote sensing and GIS techniques. High spatial resolution images were captured using a drone, and two maps were
produced using a supervised maximum likelihood classification – one prior to weed treatment and one three months post-treatment. The classification produced a total of eight land cover classes: Kikuyu grass, Coastal Morning Glory, Mirror bush/Bitou bush, dead vegetation, light rock, dark rock, and water. In this classification, Mirror bush and Bitou bush were collapsed into one category rather than assigned an individual class each. Both of these species have similar spectral reflectance characteristics which may cause confusion during classification (Dennison and Roberts, 2003, Foody et al., 1992). Similarities between the two species (e.g. both exotic species and account for the majority of shrubs on Big Island) mean that collapsing into one class will improve the classification accuracy without hindering the objectives of it. The main mapped classes in the pre-treatment classification map were Kikuyu grass and Coastal Morning Glory. This was expected as Kikuyu and Coastal Morning Glory are the two introduced species of greatest concern on Big Island. The map showed both species to have a widespread distribution across the island.

Following the aerial spray treatment that occurred across a large area of Big Island in April, 2017, significant changes occurred to the ground cover, as expected. The main mapped classes in the post-treatment classification were Kikuyu grass and dead vegetation. Similar coastal island projects, such as the Montague Island restoration project, have mapped the distribution of Kikuyu grass effectively, but did not map the distribution of other exotics. Their maps identified that 45% of Montague Island was covered in Kikuyu grass in 2000, and were used to inform the management strategies for controlling Kikuyu on the island. Over 14.5 ha hectares of Kikuyu were removed from Montague Island, and follow-up mapping revealed an 80% cover of natives after four years of rehabilitation works (NSW Department of Environment and Climate Change, 2008). Although the ongoing management strategies for Big Island have been planned out by Berrim Nuru (2017) and NSW Office of Environment and Heritage (2016), it is hoped that the maps produced herein may be used to establish a baseline against which future changes can be monitored. An accuracy assessment based on an independent ground reference dataset yielded overall accuracies of 84% for the pre-treatment classification and 75% for the post-treatment classification, which are considered quite high.

The maps are the first detailed, per-pixel vegetation maps of Big Island, which accurately represent the heterogeneous nature of the ground cover. They are also are a useful digital resource in their own right, that provide opportunities for further spatial analysis, such as mapping the distribution of individual plants on the island. Furthermore, the maps can supplement the ongoing research of the marine environments surrounding the Five Islands to improve the understanding of the evolution of this unique ecosystem.

The very high resolution imagery captured by the drone provides mapping opportunities that were previously unachievable. For example, with a pixel size of 3cm, individual Lomandra plants can be resolved and mapped. Additionally, there may be opportunity for the condition of individual plants to
be tracked. Changes to the phenology of plants, such as chlorophyll and water contents, influence the health of the vegetation, and may be compared across different temporal periods. This gives potential for highly detailed vegetation analyses previously hard to match. However, this would likely require the use of an improved spectral resolution sensor, as will be discussed in section 5.1.

Lastly, the effectiveness of the aerial helicopter spray program in eradicating the target species was assessed. This involved a comparison of land cover classes within the 2017 spray area, before and after treatment occurred. The assessment indicates that the glyphosate 360gL\(^{-1}\) mix that was applied to the area (NSW Office of Environment and Heritage, 2016) was highly successful in the destruction of Kikuyu grass and other exotic species. This is evidenced by the reduction of Kikuyu from 66% coverage of the area prior to treatment, to 1% coverage at three months post-treatment. Similarly, Coastal Morning Glory coverage declined from 15% pre-treatment to 1% post-treatment. The coverage of native/other vegetation remained steady at 4%. Mirror bush shrubs were not targeted during the aerial spray as they provide habitat for different species of fauna, and their removal will therefore require different management strategies (Berrim Nuru, 2017). The 5% reduction in coverage of Mirror bush/Bitou bush and the 2% increase in rock coverage were likely caused by spectral confusion. Spectral confusion as a limitation will be discussed in the following section. The high level of success of the application of glyphosate in the removal of exotic species is not surprising. The seabird habitat restoration project that was conducted on Montague Island also used glyphosate treatment for the removal of Kikuyu grass with high levels of success.

### 5.1 Limitations and Recommendations

Spectral confusion is common among land cover classifications due to the complexity of biophysical environments (Lu and Weng, 2007). Nichols (2012) and Yu et al. (2006) reported that very high spatial resolution imagery, such as the drone images used in this project, bring new challenges to the classification. While this higher spatial detail provides the opportunity for more accurate distinction of land cover boundaries, it is also increases intra-class spectral variability. In other words, pixels containing mixed land classes are reduced, but the spectral variation within land classes increases. The increase in spectral heterogeneity within a class can reduce the separability of classes (Lu and Weng, 2007, Yu et al., 2006). In addition, the effect caused by shadows is exacerbated in very high resolution imagery, adding to the amount of confused pixels (Yu et al., 2006).

There was significant confusion in the pre-treatment classification map where native Scurvy weed (*Commelina cyanea*) is mapped as Coastal Morning Glory, abundant in Area 2. Growth of natives in Area 2 have been successful, particularly the coloniser *Commelina cyanea* and planted *Lomandra longifolia*, and Coastal Morning Glory has not recolonised the area since treatment. There was also significant confusion in the post-treatment classification between dark rocks and water, with the map falsely indicating large areas of the rocky platform to be submerged. This did not affect the accuracy
of the map since ground reference points were not collected on the rocky platform for the post-treatment ground reference dataset. There were many breeding Silver Gulls on the western side of the island during the collection of ground reference data, making it difficult to access the rocky platform. Confusion between rocks and water will not hinder the purpose of this vegetation analysis project.

Spectral confusion may be improved by using alternative soft (‘fuzzy’) classifiers, subpixel classifiers or spectral mixture analysis that allow for spectral unmixing (Lu and Weng, 2007). Spectral unmixing is the decomposition of a mixed pixel into a collection of distinct spectra, or endmembers, and a set of fractional abundances that indicate the proportion of each endmember (Keshava and Mustard, 2002). Alternatively, the use of a handheld spectrometer for collecting more detailed spectral information in the field, for training data of known land cover classes would improve class separability.

There were also spectral limitations associated with the sensor used for image acquisition. The DJI FC330 camera only contains 4 wavelength bands; red, green, blue and alpha. This band combination is sometimes referred to as RGBA, which produces standard RGB colour images, with extra alpha channel information. The alpha channel is simply an opacity channel, acting as a transparency mask. Therefore, spectral response information in other wavelength bands that would improve species separation is not available. Species separation will be optimized when the greatest difference in the spectral signatures of those species are retrieved by the sensor. For example, figure 2.8 shows that the greatest difference between spectral signatures of different types of vegetation occurs in the near-infrared/infrared (NIR/IR) region of the electromagnetic spectrum. Additionally, reflectance values in this region may be used to compute useful vegetation indices such as the normalized distribution vegetation index (NDVI) that indicate the health of the vegetation. The use of a higher-standard multispectral or hyperspectral sensor would improve the classification accuracy results considerably. Ahmed et al. (2017) demonstrated classification accuracies fell 10-15% when spectrally less capable RGB sensors were used during a land cover classification using UAV acquired images. However, attaching a higher quality sensor would present additional issues to the UAV since such sensors are much heavier and would require a much higher carrier capacity (Lu and He, 2017).

Assumptions are often made that the ground reference dataset is truly correct, when there may be some errors involved. Errors in the ground reference data in this project could arise from misinterpreting the ground cover at a certain location, or location errors associated with a handheld GPS. Errors associated with the reference data are not quantified and would therefore be blamed on the digital classification, falsely lowering the accuracy of the classification map (Congalton, 1991).

A maximum likelihood classifier is mutually exclusive and exhaustive. That is, any area to be classified will be assigned to one class only, and all areas will be assigned to a class (Congalton, 1991). The exclusive nature of the classification means that only one species will be thematically mapped as present at any one particular location. The creeping growth form and fast lateral spreading
of Coastal Morning Glory has resulted in intertwined patches of this species and Kikuyu grass across Big Island. Similarly, where Coastal Morning Glory has found vertical support on Big Island it has covered the underlying vegetation. This is particularly the case for the northern and southern ends of Big Island where clusters of Mirror bush have been covered by Coastal Morning Glory. The reflectance values of the upmost vegetative layer (in this case Coastal Morning Glory), is what the sensor receives, and therefore these pixels will be classed as such, when in fact Mirror bush is also present. The separation of areas that contain more than one species may be improved by using alternative classifiers, such as those described for the potential reduction of spectral confusion. Alternatively, this could be achieved by the incorporation of ancillary data that describes the three-dimensional structure of vegetation. For example, a LiDAR-derived digital elevation model (DEM) would help to identify areas where Coastal Morning Glory is smothering underlying vegetation, particularly shrubs of Mirror Plant.

There is potential to adopt some management strategies from the successful project conducted on Montague Island, southern New South Wales. An integrated approach of chemical and fire control could be an effective strategy for weed removal. Controlled fire also reduces the risk of unplanned fire by removing biomass fire fuel. On Montague Island, weed control involving spraying, burning, then revegetating was more effective than spraying, then revegetating. This was the case in terms of both cover and diversity of revegetated natives, and controlling additional exotic species (NSW Department of Environment and Climate Change, 2008). However, the use of fire for vegetation management requires thorough planning and considerations. For example, burning would need to be conducted in small selected areas at a time to prevent it burning out of control across the island. This would require a 3-4m wide buffer around the burn zone to act as a fire break. Fire control would need to occur outside of seabird breeding and nesting seasons, when the birds have left the island. There is also potential to induce unwanted soil erosion by burning off dead Kikuyu that acts as a soil stabilizer. Additionally, cultural heritage values of the islands need to be considered, such as connections to the local Aboriginal people. If a fire management strategy was employed, it would need to ensure the protection of any Aboriginal artefacts such as the remains of shell middens.

6 Conclusion
Although there are limitations associated with the applications of vegetation mapping, the vegetation maps produced in this project represent a valuable dataset for the conservation of Big Island. The use of drones as a platform for acquiring high spatial resolution imagery in an efficient, repeatable and cost-effective manner has revolutionised the way we study landscapes and the environment in recent years. The ability to fly drone platforms at such low altitudes can result in imagery with pixel sizes down to the centimetre-level. For niche ecosystems, such as the Five Islands, this can facilitate the
development of detailed, high spatial and temporal resolution maps that have been previously unattainable due to spatial, temporal and cost restrictions of sensor platforms.

The first detailed, continuous vegetation maps of Big Island were produced to describe the distribution of native and exotic species. The area that underwent treatment in April 2017 was analysed to determine the ground cover before and after the treatment occurred. The application of glyphosate 360gL\(^{-1}\) was highly effective in destroying the target species of Kikuyu and Coastal Morning Glory. Future thematic land cover maps would facilitate an effective land cover change analysis for which the maps produced herein may be used as a baseline. This would be best achieved by establishing an ongoing image archive digital database to which a few images are added each year. As the technologies advance, higher quality spectral and spatial resolution sensors will provide the opportunity for highly detailed, highly accurate vegetation mapping. Image classification accuracies would be significantly improved by using a sensor that is optimised for mapping vegetation, i.e. receives spectral information in the NIR/IR regions of the electromagnetic spectrum. There is potential for individual plants to be mapped and the health condition of plant communities to be tracked. High-resolution image acquisition and thematic vegetation maps should be used in combination with ongoing field surveys throughout the duration of the revegetation scheme and beyond.

Similar coastal ecosystem studies involving the eradication of introduced Kikuyu grass are scarce. Montague Island, southern New South Wales represents the closest study from which insights can be gained in to best practice management strategies. A combination of chemical and fire treatment were used on Montague Island, successfully eradicating 14.5 ha of Kikuyu grass, halving its distribution. There is potential to adopt an integrated chemical and fire approach to remove dead Kikuyu biomass on Big Island, which would increase light penetration to the ground surface and stimulate the germination of colonising species. This approach would need to be carefully and thoroughly planned, as it would present additional risks to the ecosystem.
7 References


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