Remote sensing evaluation of Cape parrot habitat in the Eastern Cape: implications for conservation

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Minor dissertation in partial fulfilment of the requirements for the degree of Master of Science in Conservation Biology

31st August 2022

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Acknowledgements

I would like to acknowledge my compassionate, patient and incredibly supportive supervisors. Thank you, Dr Vernon Visser, for dealing with my last-minute questions, and for your kind corrections that have taught me many skills and lessons I will take forward in life. Thank you, Prof Timm Hoffman, for your ever wonderful gentle demeanour, your support allowed me to overcome the worst of times and reminded me we are all only human. I am unbelievably grateful to have had you both as my supervisors.

To my support team.
Ethan, this thesis would not have been possible without your endless selflessness to put your life on hold, offering help and love at every turn. I have learnt so much from you and I am so overwhelmingly grateful to have you in my life. I love you. Thank you for being the person you are.
Sean, thank you for your never-ending motivation, and happiness. You have been a true friend and supporter and I could not have asked for a better person to have through the best and worst of times.
Mom and Dad, thank you for supporting me for the last six years of my life, allowing me to follow my passions and gain the confidence to be who I want to be. I owe you so much and I hope I continue to make you proud. I love you both.

To my fellow champions, thank you for bringing so much love and happiness to my life. I will forever cherish this time we have all spent together and hope we will have many more to come.

I would like to thank everyone who contributed to the development of this project. My Stutterheim family (and Dr Donna) for providing everything I could possibly need at short notice; I love and appreciate you all. Jess from the Cape Parrot Project team, Ian Taylor from AFC, and Louis Mostert from ALM Fire, thank you for welcoming me into your world and kindly helping me whenever I needed it.

Lastly, I would like to thank the Fitzpatrick Institute (and all involved with the CB class) for providing this amazing opportunity and unforgettable experience.

Contents

Abstract

The Cape parrot is the only endemic parrot of South Africa and is currently nationally threatened. One of the biggest threats to the Cape parrot is the past and present degradation of indigenous forest. The Amathole Mistbelt Forest in the Eastern Cape is the primary habitat for Cape parrot and has historically been heavily degraded. In order to conserve the Cape parrot effectively, there is a need to understand the spatial distribution of indigenous forest patches and their quality. There is currently not a sufficiently accurate landcover map available to fulfil this need. Thus, this study uses remotely sensed imagery at a 10 m resolution and random forest classification to (1) produce a land cover map of the indigenous forest in the Amathole region; (2) determine habitat quality of the indigenous forest, and (3) determine whether forest loss, as reported by Global Forest Watch (GFW), reflects the loss of indigenous forest or the clearing of plantations and woody alien invasives. The overall accuracy of the classification was very high at 82%. Cross validated accuracies were all high ranging from 95 – 100%, with water having the highest accuracy and indigenous forest, *eucalyptus* spp., pine spp., and infrastructure having the lowest accuracies. F1 scores ranged from 0.78 – 1.0, with indigenous forest ranking the second lowest at 0.80 and grassland ranking the second highest at 0.91. Indigenous forest covered 26% of the study area. Black wattle, pine spp. and *eucalyptus* spp. covered a combined 35% of the study area. The detailed map of indigenous forest shows the extent of its fragmentation and outlines some of the management implications associated with small forest patches. Secondly, habitat quality for Cape parrot is questioned as there is a lack of emergent canopy tree species and 30% of the matrix between forest patches is invaded by invasive alien species. Thus, it is suggested that a strong focus is put into clearing and managing invasive alien species. Lastly, GFW ‘forest cover loss’ is shown to be comprised primarily of plantation felling and invasive clearing. It is suggested that there has been little loss of indigenous forest in the last 30 years. Further research will include creating an open and accessible product in the form of a Google Earth Engine App to share with conservation managers in the area.

1. Introduction

One of the main priorities in conservation biology is the prevention of biodiversity loss and species population decline (Soule et al 1985; Kareiva and Marvier 2012). According to the World Wildlife Fund (WWF), species population sizes across numerous vertebrate taxa have seen an average decline of 68% between 1970 and 2016 (WWF Living Planet Report; 2020). During this period, the human population has grown exponentially, which has drastically increased the amount of land and resources needed to sustain various human activities. These human activities have posed direct threats to species habitats, primarily through habitat loss and degradation, as well as the invasion of alien species. Threats to species habitats are some of the main drivers behind species decline (Salafsky et al 2008 within Living Planet Report 2020). In Africa alone, over 50% of the threats to species are related to changes in land use, which involves habitat loss and degradation (Living Planet Report 2020).

South Africa is no different in terms of the impact that habitat loss and degradation has on biodiversity. For example, in 2017, range declines in half of South Africa's Forest dependent bird species were shown using bird atlas data (Cooper et al 2017). After four years, this trend is still being observed in South Africa (Mulvaney et al 2021). The main drivers of this decline include forest habitat loss, degradation, and the fluctuating matrix that exists between forest patches (Cooper et al 2017). This decline in forest dependent bird species was particularly prevalent in the Eastern Cape province of South Africa (Cooper et al 2017).

Most parrot (Psittaciformes) species are experiencing a decline in their populations with over a third of parrot species facing extinction. Habitat destruction is one of the most important drivers of this decline (Vergara-Tabares et al 2020). Habitat loss and degradation can reduce the amount of foraging area and the number of suitable breeding nest sites which can cause a decline in parrot reproduction success (Wirminghaus et al 1999). This can have knock-on effects for ecosystems since parrots provide important ecological functions in their habitats. These include the primary and secondary long-distance dispersal of mainly hard cover seeds from tall emergent tree species, and the provision of food to other animals via their food waste such as dropped food or fruit pulp (Blanco et al 2017).

1.1 The Cape parrot

The Cape parrot (*Poicephalus robustus*) is among the most threatened forest-dependent bird species in South Africa. It is South Africa's only endemic parrot species and is formally listed as endangered in the South African Red Data Book for Birds (Taylor et al 2015). The Cape parrot is a fairly large parrot species relative to other southern African parrots (30cm, 300g) (Taylor et al 2015). The current Cape parrot population size is estimated to be below 2000 individuals. Although low and having experienced large declines during the 20th Century, the population is currently considered stable (Downs et al 2019). Cape parrots have experienced a range decline of 58% from the 1990s to present, representing the largest range decline of any forest-dependent bird species in South Africa (Cooper et al 2017).

Cape parrots tend to remain in the same forest patch for life but do travel long distances in small flocks for feeding between forest patches *(*Wirminghaus et al 1999*)*. They are considered food specialists, and typically feed on the kernels of yellowwood species (*Afrocarpus* and *Podocarpus* spp.), while also intermittently feeding on other indigenous and alien fruits (Wirminghaus et al 2002). Cape parrots are secondary cavity nesters and nest in dying or dead emergent canopy trees, particularly yellowwoods, that are commonly reused every breeding season *(*Wirminghaus et al 1999*)*. Their primary habitat is Afromontane (Mistbelt) Forest, which is dominated by yellowwood species (Downs 2005).

Over 20 years ago, Wirminghaus et al (1999), highlighted probable causes of the declines in Cape parrots which he suggested were associated with habitat loss, degradation, fragmentation, low food and water availability, low availability of nest sites, disease, and the pet trade. Subsequently, Downs (2005) reported the same causes for the decline in this species but highlighted the Eastern Cape province as an area of particular concern. Moreover, habitat degradation, such as the removal of dead/dying trees from forests drastically reduces the availability of nesting sites and thus, facilitates low breeding success in populations that might already lack breeding individuals (Leaver et al 2020; Downs 2015). Due to their low population numbers, further habitat loss and degradation could greatly affect Cape parrot populations (Coetzer et al 2020).

The focus of Cape parrot conservation efforts has been on habitat protection and restoration (Wirminghaus et al 1999; Carstens et al 2020). One of the major problems with parrot and habitat conservation is the spatial distribution of the forest patches. The forest patches that Cape parrots inhabit occur on private land, nationally protected land, municipal protected land, and forestry land (Wirminghaus et al 1999). Thus, different forest patches are affected by different conservation regulations and management practices. Some Eastern Cape state forests, particularly in the Amathole region, have implemented sustainable harvesting which allows the removal of dead/dying trees. This, however, is detrimental for the breeding success of Cape parrots (Wirminghaus et al 1999; Mpisekaya and Kameni 2007). Efforts to estimate population numbers have relied heavily on citizen science datato estimate the size of the Cape parrot population for conservation management (Downs 2014). The largest sightings of Cape parrots over decades of observations have been in the Mistbelt forest patches in the Eastern Cape, with a population estimate of between 500 to 600 individuals (Downs 2014). Thus, the Eastern Cape Forest patches are considered a main source population for the species (Coetzer et al 2020). One of the largest clusters of Eastern Cape forest patches is situated between the towns of Stutterheim and Alice in the Amathole mountain region (Mucina and Geldenhuys 2006). The type of Mistbelt Forest that occurs in this region is categorised as the Southern Mistbelt Forest, and within the Amathole region, sub-categorised as the Amathole Mistbelt Forest (Mucina and Geldenhuys 2006). Thus, most conservation efforts are concentrated in the Amathole forests of the Eastern Cape

1.2 Indigenous forests of the Amathole

The Southern Mistbelt Forest group is distributed along the Great Escarpment at altitudes of 850-1600 m on south and southeast facing slopes and is comprised of the Eastern Mistbelt Forest, the Transkei Mistbelt Forest and the Amathole Mistbelt Forest, which all exist as fragments within the larger grassland biome (Mucina and Geldenhuys 2006). Vegetation is tall (15-20 m) and normally comprised of a multi-layered canopy consisting of two layers of trees (Upper- and Mid-canopy), a dense shrub understorey, and a dense herb layer (Mucina and Geldenhuys 2006). The Amathole Forest Complex is over 40 550 ha and occurs between 32°S and 33°S, and 26°E and 27°30'E (Thompson 1991). It is dominated by emergent trees (*Afrocarpus falcatus*) with several endemic and near endemic species (*Podocarpus henkelii*) as well as shrubs and herbs such as *Eugenia zuluensis* and *Plectranthus elegantulus* (Mucina and Geldenhuys 2006).

It has been argued that the Southern Afromontane Forest has not changed in distribution and range over the last 5000 years (Meadows and Linder 1988). However, there have been human linked negative impacts on its spatial extent in more modern times. Intensive deforestation occurred during the colonial era due to an expansion of agriculture and plantation forestry (Geldenhuys and MacDevette 1989). However, the large-scale commercial logging of indigenous forest ended in 1939 (Mpisekaya and Kameni 2007). It was observed that there was a lack of medium sized trees in forest patches, which was assumed to be due to historical colonial felling of timber and present-day harvesting by rural communities (Everard 1995; Wirminghaus et al 1999). However, it is unknown exactly how much timber was historically removed from the indigenous forest during the colonial era (Wells 1973). Yellowwood trees (*Afrocarpus* and *Podocarpus* spp.) were the most targeted species, making up 67% of the known timber used in building, mining, and wagon building - which was one of the largest industries in colonial South Africa (Wells 1973). Over 30 years ago, Cawe and McKenzie (1989b) suggested that forest patches had not recovered from commercial logging, which had ended 40 years earlier. This may have been due to the poor regeneration ability of these forests and the slow regeneration of canopy trees especially. Deterioration could also be attributed to livestock grazing, which can trample seedling growth, and gap invasion from invasive alien species (Wirminghaus et al 1999 and references therein)**.** The Amathole Forest is 8% statutorily conserved (Hogsback, Kologha, Isidenge, Kubusi), while 5% has been transformed for plantations (Mucina and Geldenhuys 2006*).* Most patches of forest are either managed and controlled by national government, provincial government, statutory bodies, or municipalities and this can determine the type and quality of forest management and possible impacts on conservation *(*Wirminghaus et al 1999; Mucina and Geldenhuys 2006). Current concerns are the associated threats that come with the uncontrolled harvesting of timber and non-timber forest products by local communities, the mismanagement of fire, and the potential that invasive alien species have to take over an area once established (Von Maltitz et al 2003). However, it is unclear how degradation and invasive aliens may be affecting the spatial distribution and habitat quality of the indigenous forest in Amathole.

1.3 Invasive Alien Species

The ever-increasing invasion of invasive alien species (IAS) is currently one of the largest threats to biodiversity and ecosystem functioning globally (De Wit et al 2001; Mostert et al 2017; Zengeya and Wilson 2020). In South Africa, IAS are a major concern and cost millions of rands a year to manage and control (Zengeya and Wilson 2020). Biological invasions have caused 25% of biodiversity loss, which makes it one of the largest threats to biodiversity in South Africa (Zengeya and Wilson 2020). Pines (*Pinus*), eucalypts (*Eucalyptus)*, and wattles (*Acacia*) are among the most widespread and damaging invasive species in South Africa. Pine, eucalypt, and wattle species were introduced into South Africa for the purposes of commercial forestry (De Wit et al 2001; Henderson 2001; Hoffman et al 2020). Although pines are still commercially planted, there has been debate over their ability to produce profit compared to wattle or *eucalyptus* (Louw 2006). *Eucalyptus* species are considered one of the most important commercial trees and contribute significantly to the forestry industry in South Africa (Bennet 2010; Hirsch et al 2020). The impact from pines, eucalypts, and wattles as invasives are relatively similar. Several pine species have become invasive in South Africa and can alter ecosystems and deplete water resources at a relatively fast rate if left unchecked (Henderson 2001). Out of the 200 *eucalyptus* cultivars cultivated in South Africa, only a few have become invasive. The main impact is their intense water usage which is very concerning in a semi-arid country such as South Africa (Hirsch et al 2020). Of the wattles which invade South Africa, black wattle (*Acacia mearnsii*) is one of the most worrying invasive wattle species, having invaded over 2 million ha (Le Maitre et al 2000). The Eastern Cape is thought to be the most affected of the provinces in South Africa by black wattle invasion (De Wit et al 2001). Black wattle has several negative impacts, including the reduction of water resources, biodiversity, grazing potential, and increased fire hazard (De Wit et al 2001).

The current total extent of different IAS across South Africa is unknown and acknowledged as a key gap in management (Zengeya and Wilson 2020). To achieve effective management, the monitoring of IAS distribution and an evaluation of interventions at local scales is critically needed (Zengeya and Wilson 2020). Without mapping the spatial distribution and extent of alien invasions, it is difficult to effectively implement early detection or rapid response processes to try and prevent their spread (Masemola et al 2020). Secondly, field collected data on spatial distribution and extent of invasive alien species, often used by managers in low resource areas, was found to either overestimate or underestimate the spatial extent of invasives, which can negatively impact management decisions (Cheney et al 2018). Thus, it was suggested by Cheney et al (2018) that systematic plot-based survey methods be used. However, with the improvement and accessibility of fine scale remote sensing imagery classification, reliable spatial distribution and extent data on invasive alien species can be provided with less intensive resource use.

1.4 Remote sensing

Remote sensing refers to the observation of the Earth's surface, usually by satellite or aircraft and is increasingly being recognised as a vital tool in conservation monitoring (Schowengerdt 2007; Rose et al 2019). It can be used to collect vast amounts of data in a very short period, which would otherwise be almost impossible to collect manually in the field. Depending on the resolution (spatial, temporal, spectral) of the remote sensing technology, data can be collected at varying scales which lends to both global and granular analyses. A benefit of this technology is the ability to accurately map different types of land cover and their spatial distribution and extent in a landscape using satellite imagery. This can assist in generating knowledge of a species habitat range, the change to that habitat over time, the size and distribution of the habitat, and various dynamics of the habitat such as above ground biomass, vegetation production, areas prone to erosion, areas prone to alien invasion, etc. (Rose et al 2019 and references therein). Remote sensing has also been used to monitor forest loss and gain in near real time at a fine scale resolution for the entire globe (Hensen et al 2013).

Currently, there are few accessible sources available to managers and conservationists when it comes to remotely sensed landcover maps of indigenous forest distribution in the Amathole region. One source is the National Vegetation Map (2018) developed for the whole of South Africa by the South African National Biodiversity Institute (SANBI 2018). This landcover map displays the different vegetation types across South Africa, including the distribution of the Amathole Mistbelt Forest. However, it does not show the distribution of invasive alien species. The National Vegetation Map is provided at a resolution of 30 m, which reduces the accuracy and the fine detail of the indigenous forest spatial distribution (Hernando et al 2017). An alternative source is the Global Forest Watch (GFW) platform which was launched in 2014 by the World Resource Institute. GFW provides a free, open access platform for visualising and monitoring forest cover change, with coverage from 2001 onwards (Hansen at al 2003). The dataset is comprised of 'forest cover loss' and 'forest cover gain' statistics per year since 2001 at a 30 m resolution and more recently at 10 m (Hansen et al 2013). However, GFW does not distinguish between the cover of indigenous forests, non-indigenous plantations, and woody invasive species. This may lead to misclassifications of forest loss when the felling of plantation trees or the clearing of invasive alien species occurs. Thus, more is needed to provide accurate information on the spatial distribution of the indigenous forest and surrounding woody invasives for the effective conservation of Cape parrot habitat.

1.5 Aim and Objectives

The overall aim of the study was to produce a land cover map, including classes for indigenous forest, black wattle, pine spp., and *eucalyptus* spp., of the Amathole region in which the largest Cape parrot population is found.

Four separate objectives for the study are as follows:

1. To map the extent of indigenous forest, the primary habitat for the Cape parrot, in the Amathole region;
2. To determine habitat quality of indigenous forest, specifically for Cape parrot, based on the canopy structure of indigenous forest, and landcover map of matrix between indigenous forest patches;
3. To evaluate whether forest loss as reported by GFW is loss of indigenous forest or the clearing of plantations/woody invasive alien species;
4. To describe management implications and possible interventions which arise from the findings of the study.

2. Methods

2.1 Study area

The study area covered approximately 1003 km^2 in the Amathole region of the Eastern Cape, South Africa. The focus of the study was on Amathole Mistbelt Forest, which is part of the Southern Mistbelt Forest (Mucina and Geldenhuys 2006). The area is a mixture of mountains dominated by indigenous forest, plantation forestry and grass covered hills mainly used as grazing land. The mean annual precipitation and temperature measures are 988 mm and 15.7 °C, respectively (Mucina and Geldenhuys 2006). The Amathole Mistbelt Forest is one of the coolest forests among the other forest types in South Africa but is slightly drier compared to the Northern Mistbelt Forest**.**

I used SABAP2 citizen science reports (Underhill et al 2017) of Cape parrot sightings to identify where Cape parrots occur in the Amathole area. I selected the Amathole Mistbelt Forest (National Vegetation Map 2018) within the larger, SABAP-derived region, and then derived a smaller study region therein including the indigenous forest and a 500 m buffer, which was used to determine field sampling sites. This became the final study area which includes indigenous forest, pine spp., grasslands, water bodies, infrastructure, and invasive alien stands of black wattle and *eucalyptus* spp.

2.2 General approach

The general approach of the project followed a step-by-step process to ensure the reproducibility of the project outputs (Figure 1). First, landcover classes were chosen for the study area for which landcover plots were collected and in addition, cover and height estimations were collected. Secondly, satellite imagery was acquired and processed to enhance classification accuracy. The results of the first two steps were combined with machine learning (Random Forest) classification processes to produce an assessed and validated landcover map, which was used in comparison with GFW 2021 'forest cover loss'. Cover and height estimations were combined with classification results to assess Cape parrot habitat quality of indigenous forest patches. The cape Parrots primary use of the forest occurs in the upper-canopy (emergent canopy); thus, habitat quality is determined by height and density of the upper-canopy, and the presence of an emergent canopy (~20 m) in the indigenous forest plots (Wirminghaus et al 1999). Habitat quality will also be influenced by the invasion of the surrounding matrix by woody alien invasives, as the woody invasives in the area (black wattle and eucalyptus spp.) can impact forest patches both negatively and positively.

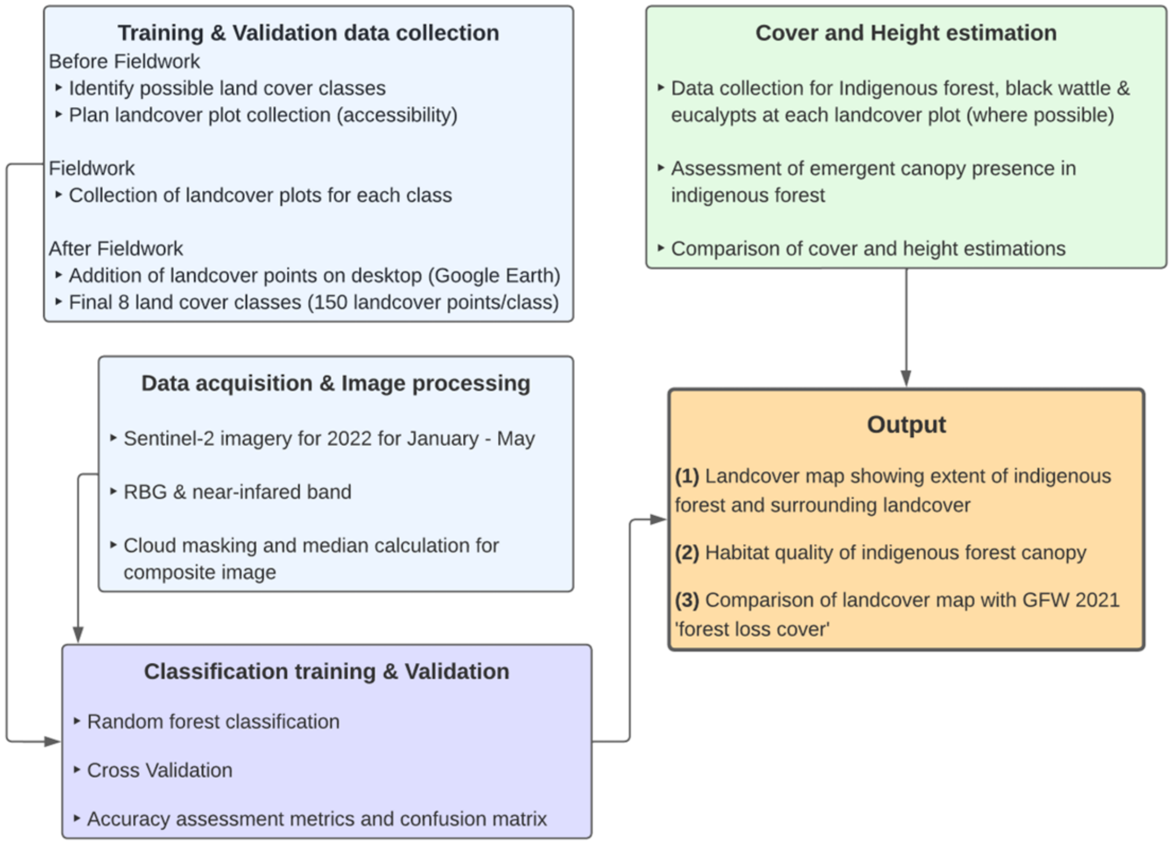


Figure 1. The general project approach used to map different land cover classes in the study area.

2.3 Land cover classes

Land cover classes were chosen by using the National Vegetation Map (2018) and choosing the dominant vegetation types for the study area as well as the most important in terms of indigenous forest and Cape parrot conservation (Table 1, Mucina and Geldenhuys 2006).

Table 1. Description of landcover classes, the total number of data points for each and the proportion of points generated in a desktop analysis.

Classes	Description	Overall points	Desktop
1. Indigenous Forest	Indigenous forest under the Amathole Mistbelt Forest type	150	0
2. Black wattle	Dense invasive stands of *Acacia mearnsii*	148	100
3. *Eucalyptus* spp.	Plantation and invasive stands of *eucalyptus*	150	98
4. Grassland	Grasslands/grazing land with an herbaceous layer.	150	140
5. Cleared	Specifically felled plantations or invasive clearing	150	150
6. Pine spp.	Commercial pine plantations of different pine species	150	100
7. Infrastructure	Gravel roads and buildings inside and between forest patches	150	150
8. Water	Dams that occur in the study area	120	120

2.4 Training data

2.4.1 Data collection: fieldwork

Landcover plots sampled in the field were predetermined using Google Earth to ensure all required permissions were identified and obtained, and to make sure plots were relatively easily accessible by choosing areas close to roads and not on steep mountain sides (Figure 2). Each plot was collected in the centre of a homogenous vegetation type spanning 10 x 10 m. A 20 m distance between each point was maintained to ensure each point was not overlapping. Field data collection was done between March and April 2022 and was associated with a period of heavy rainfall in the study area. Cover and height were estimated for the three woody vegetation classes out of the eight land cover classes. The woody vegetation classes include indigenous forest, *eucalyptus* spp., pine spp., and black wattle. Cover estimates were biased towards 100% cover due to the selection of points that had a homogenous cover of a particular class for better classification. Trees were selected based on the accessibility of sites for photography and Mid-canopy trees were also selected via visual estimation.

Indigenous forest is divided into three categories. These are: (1) Undergrowth which is comprised mainly of herbaceous plants growing beneath the canopy; (2) Mid-canopy comprised of trees taller than average human height, but shorter than those growing in the upper canopy, and which occur as a layer underneath the tallest trees; (3) Upper-canopy comprised of the tallest trees (emergent trees in some cases) in the forest.

The Mid-canopy layer changed between each forest patch, as there are subtypes of indigenous forest which change in structure and species composition. Some forest patches tended to have very little Mid-canopy growth compared to other patches. The identification of tree species also helped in distinguishing between Mid-canopy and Upper-canopy categories.

The height of each indigenous forest category was estimated by choosing a tree considered to reflect the average height of all trees in that canopy layer and then measuring the height of the tree using the photographic method. The photographic method includes using a camera device (cell phone) at a right angle to the tree from a distance, ensuring the entire tree is in the frame of the picture, and having a reference height object next to the tree (Fulkerson 2021). The picture is taken, and the tree height can be calculated by measuring (photoshop) how many reference objects (in this case an assistant of known height standing straight next to the base of the tree) fit into the height of the tree and multiplying that number by the height of the reference object. If done correctly, this method can be just as accurate as other tree height measurement methods and much easier to do in difficult terrain (Fulkerson 2021).

2.4.2 Data collection: desktop

Field landcover data collection was hindered due to time restraints and restricted access to certain areas (Figure 2). Therefore, Google Earth was used to collect more landcover plots. While in the field, GPS points were placed next to a patch of a specific vegetation type that was inaccessible, with a note on where the stand was in relation to the point, and other contextual information such as how homogenous the patch looked in cover and height. In Google Earth, these field GPS points were then used to locate the patches and placemarks were placed as ‘landcover plots’. I consistently ensured each patch looked homogenous and comprised of around 100% cover of the correct vegetation type while ensuring that landcover plots were 20 m apart using Google Earth's measuring tool.

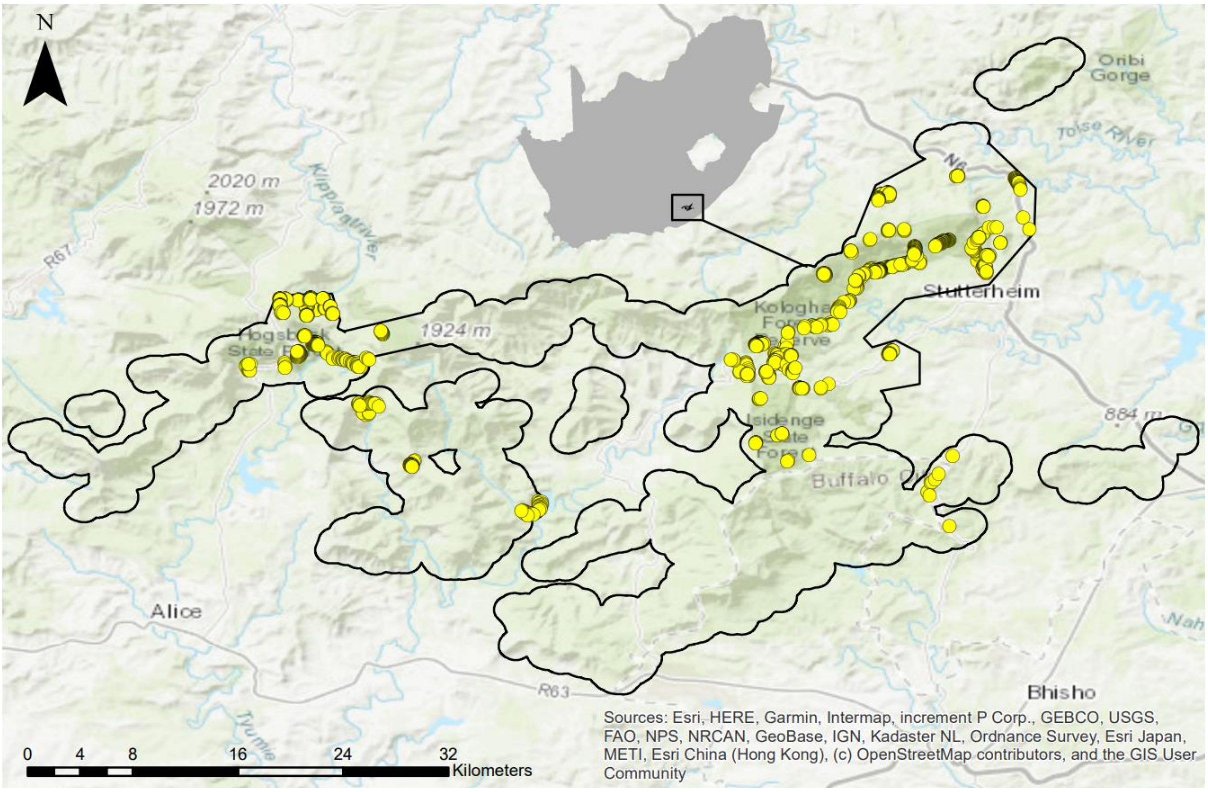


Figure 2. Field and desktop landcover plots collected in the study area between the months of March and April 2022

2.5 Satellite imagery

Sentinel-2 is a global, open access earth observation mission that includes two identical satellites (Sentinel-2 A and Sentinel-2 B) that launched in 2015 and 2017, respectively. Sentinel-2 has a relatively wide swath (290 km), a high spatial resolution of 10-60 m, a temporal resolution of at least five days and samples 13 spectral bands - four bands at 10 m, six bands at 20 m and three bands at 60 m resolution (Kramer 2002). Sentinel-2 data has been used in a variety of mapping applications, such as for soil moisture, water bodies, forest stress, land use, and landcover (Noi and Kappas et al 2017).

I used Sentinel-2 A, level-2A surface reflectance data for the landcover classification. Level-2A is a Bottom-Of-Atmosphere orthoimage produced from atmospheric correction of Top-Of-Atmosphere level-1C. Level 1-C products are geometrically corrected using sub-pixel multi-temporal registration between images (ground control units) with resampling using a 90 m

Digital Elevation Model (DEM) (Gascon et al., 2017). Level 1-C products are used with the Sen2cor (ESA) processor for atmospheric correction which uses sets of look-up tables from libRadtran (Gascon et al., 2017). This produces the Level 2-A product used in this study. The data was drawn from the Google Earth Engine (Gorelick et al 2017) data catalogue between 1 January and 31 May 2022. Initially, cloud filtering was applied to remove cloud cover percentage over 60%. Additionally, a function was developed using s2cloudless that defined the probability that a pixel was 'cloud'. Clouds were masked from individual images using this probability map. This prevented having to discard entire training images where a cloud only masked a portion of the study area. A single composite image was produced by calculating the median value per pixel. To ensure a classification resolution of 10 m, the four 10m bands of the 13 available spectral bands were used (red, green, blue and one near infrared).

In addition, the four 10m spectral bands were used to calculate two vegetation indices. Normalised Difference Vegetation Index (NDVI) is an index that utilises the Near-Infrared (NIR) and red channels in remote sensing data (B8 and B4 in Sentinel-2A, respectfully). It provides a good metric for vegetation as Chlorophyll found in leaves tends to reflect NIR more strongly as compared to other wavelengths. NDVI was calculated using the following formula NDVI = (B8 – B4) / (B8 + B4) and used as training data. Landsat Surface Reflectance-derived Enhanced Vegetation Index (EVI) was also used as training data. EVI is similar to NDVI in that it is used to quantify vegetation health. However, EVI corrects for atmospheric conditions which often influences NDVI. EVI was calculated using the following formula EVI = 2.5 * ((B8 - B4) / (B8 + 6.0 * B4 - 7.5 * B2 + 1.0)).

2.6 Classification and Validation

Random Forest (RF) was chosen to perform the classification as it consistently performs well in landcover classification and is the most commonly used classifier (Noi and Kappas et al 2017 and references therein). Essentially, a RF is a collection of individual decision trees that are trained on random samples of the original dataset, with replacement. When the trained RF receives input data, each individual decision tree predicts a class and the most voted class across all trees is given as the final class prediction (Breiman 2001). Some benefits of the RF model include its insensitivity to outliers, insensitivity to noise, and its ability to reduce overfitting, which is commonly found in decision trees (Breiman 2001).

Initially the data was spilt randomly with a set seed into training (70%) and test (30%) data. Training data was then split again in the random cross validation process where it was split (70/30) randomly up to 10 times. A random cross validation process allows the training and test data to be randomly sampled and trained up to 10 times to ensure representation. The model is trained on the random cross validation training split subset, and once this is completed, the model is validated with the validation subset. Finally, the model is tested against the initial unseen 30% test data. This provides an accuracy assessment on how well the model can predict unseen data (i.e., classifying new data points as the right cover class). An average of all the metrics were calculated using the produced sets of results. When working with spatial data, being wary of spatial autocorrelation is important. However, according to Wadoux et al (2021), spatial cross-validation approaches should not be used for assessing model accuracy due to a lack of theoretical underpinning that supports their use. Based on the results of this study, the random cross-validation approach was deemed appropriate for model validation. A grid search was conducted to derive the optimum parameter values (Mtry = 2, Ntree = 130). A variable importance assessment was obtained from the RF model; however, all variables were equally important (Supplementary material, Figure 1.)

3. Results

3.1 Cover and height estimates

Overall, black wattle has the densest cover with 95%, while indigenous forest is less dense with an average cover estimated at 87%. *Eucalyptus* spp. is the least dense of the tree classes at 83% (Table 2). The tallest average Upper-canopy height is in the indigenous forest at almost 16 m high, *eucalyptus* spp. is just below at 15 m. Black wattle had the lowest average canopy height at 10 m.

Table 2. The overall average and standard error of cover and height estimates for tree classes (sample size)

	Black wattle	***Eucalyptus* spp.**	**Indigenous forest**
Cover %	95.1 ± 0.8 (146)	82.5 ± 0.5 (149)	87 ± 1.1 (110)
Height (m)	10.2 ± 0.2 (97)	14.8 ± 2.8 (27)	15.7± 0.4 (110)

Overall, average cover decreased in the indigenous forest from undergrowth, Mid-canopy to Upper-canopy categories (Table 3). The undergrowth category in indigenous forest is almost entirely covered in herbaceous plant growth (75%). This layer has an average height of 30 cm. In the Mid-canopy cover - comprises of medium height tree species, emergent juvenile tree species and some large bush species - cover decreased to 57%, while the average height was 7.6 m. The Upper-canopy is comprised of tree species only and often includes emergent tree species, such as Yellowwoods, that rise above the forest canopy to heights of up to 15.7 m. However, cover decreased by over 20% in the Upper-canopy compared to the Mid-canopy. The tallest tree measured in the Upper-canopy was a Yellowwood species which was measured at 29.8 m.

Table 3. The overall average and standard error of cover and height estimates for indigenous forest categorised points (sample size)

	Undergrowth	**Mid-canopy**	**Upper-canopy**
Cover %	75.4 ± 2 (145)	57.3 ± 1.6 (145)	32.1 ± 1.4 (145)
Height (m)	0.3 ± 0.01 (145)	7.6 ± 0.3(108)	15.7 ± 0.4 (110)

In indigenous forests, the Mid-canopy had less variation in height compared to the Upper-canopy (Figure 3A). Most indigenous forest plots had an Upper-canopy between 10 - 20 m tall and a Mid-canopy between 5 – 10 m tall. In cover estimations, Mid-canopy had a much denser cover compared to the Upper-canopy (Figure 3B). Mid-canopy cover for most plots was between 50 – 75%, while Upper-canopy cover for the majority of plots was below 50%. Mid-canopy plots had more variation in cover density compared to Upper-canopy cover.

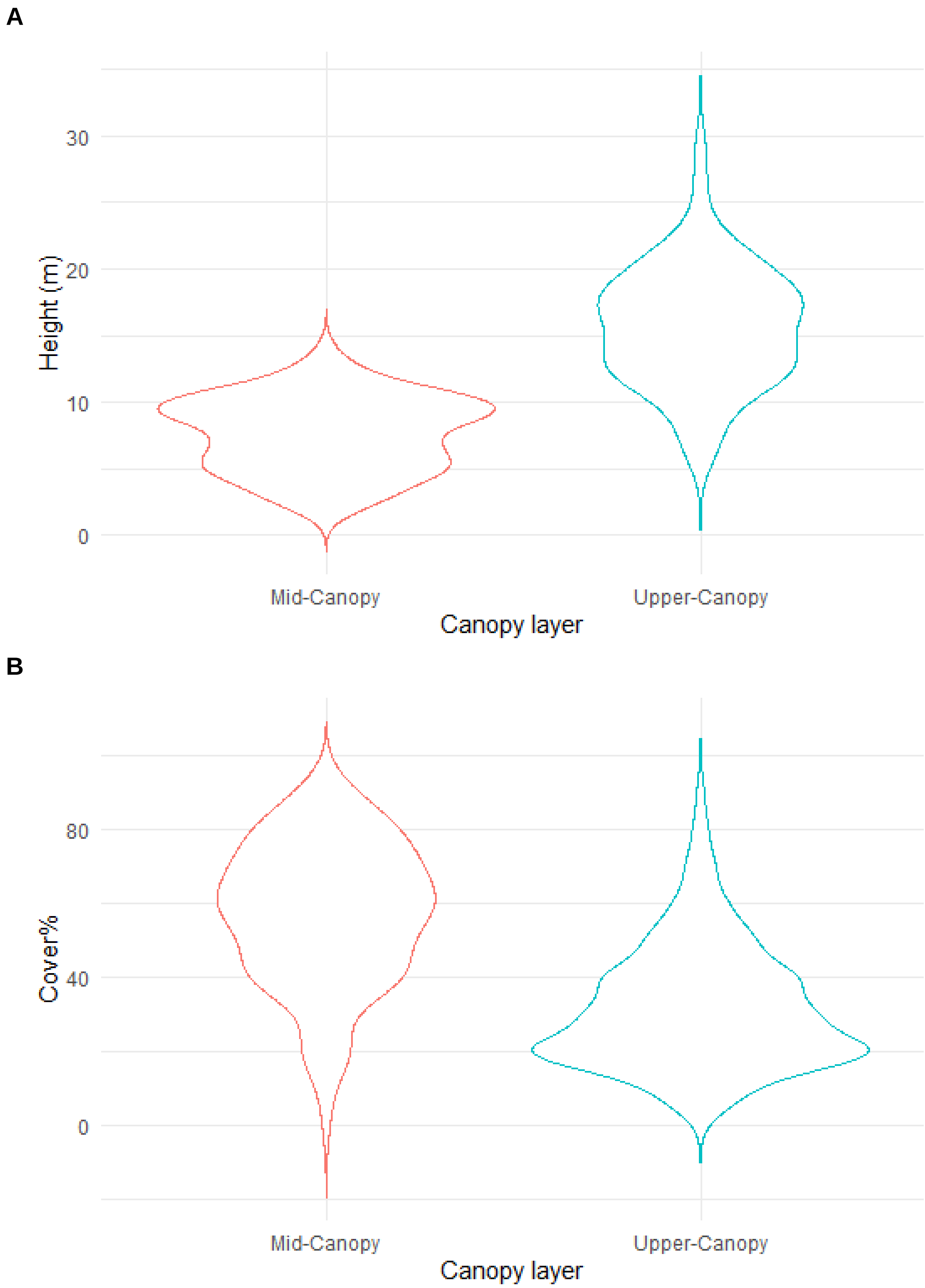


Figure 3. Height (A) and cover (B) estimations at indigenous forest landcover plots separated into Mid-canopy and Upper-canopy

3.2 Spectral profiles

The spectral profiles of most vegetation classes are similar. However, grassland differs most compared to the woody vegetation landcover classes, especially within the bands B2 and B3 (Figure 4). Woody vegetation classes were generally similar for the RGB bands but differed most at the near-infrared band (B8) (Figure 4). *Eucalyptus* spp. and pine spp. were very similar across all the bands (Figure 4).

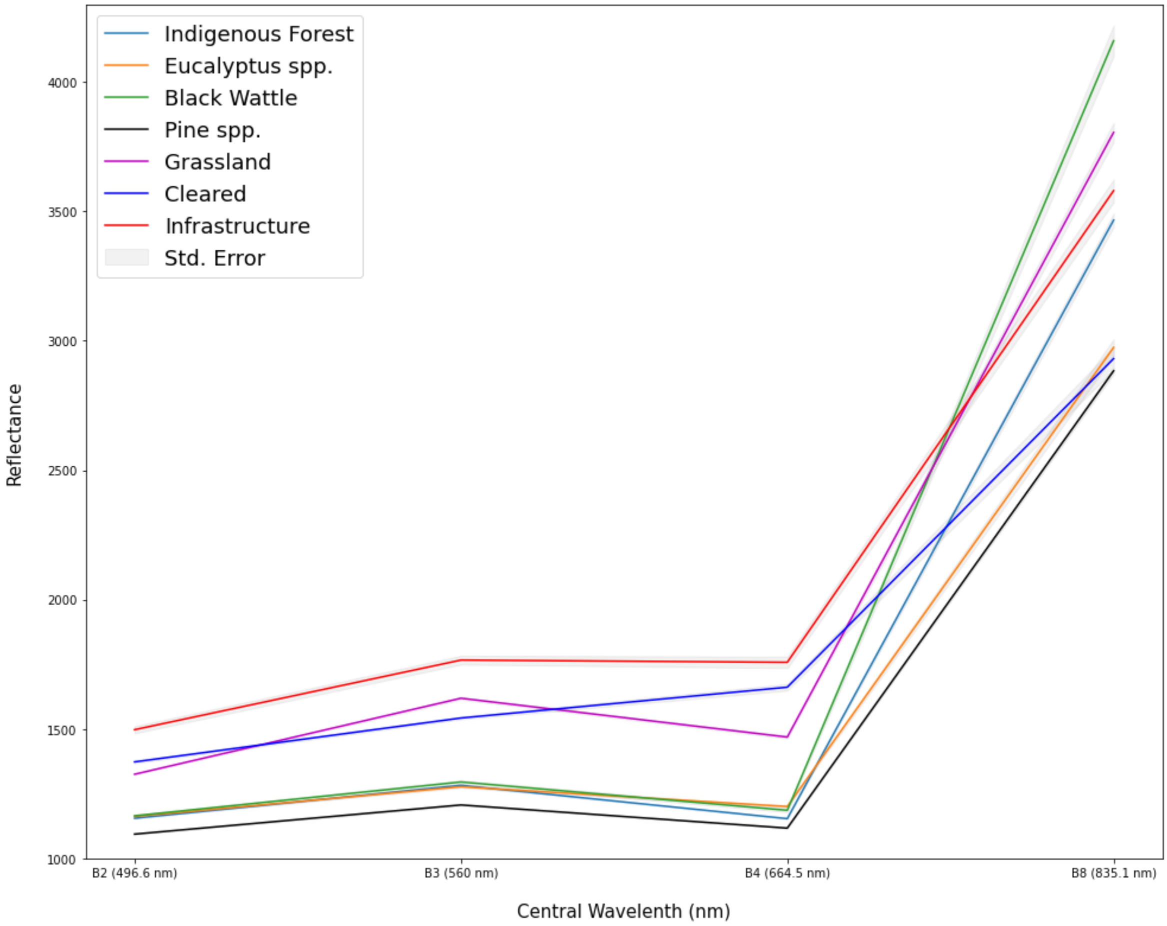


Figure 4. Spectral reflectance profiles of each landcover class for the bands used in classification. Average and standard error of Bands 2, 3, 4 (RGB) and Band 8 (near-infrared).

3.3 Model evaluation

The classes that were misclassified most often were indigenous forest, *eucalyptus* spp., cleared areas, and infrastructure (Table 4). Although they all had relatively high accuracies, their sensitivity and f1 scores were relatively low (Table 4). The confusion matrix shows that the *eucalyptus* spp. class were predicted at a relatively high percentage when it was actually indigenous forest plots, and vice versa (Figure 5). While most of the confusion in cleared areas was the misclassification of cleared plots as infrastructure (Figure 5, Table 4). There was relatively little confusion between black wattle and other classes, while grassland was misclassified as infrastructure relatively frequently (Figure 5).

	IF	BW	ES	GR	CL	PN	IN	WT
IF	370 79%	24 5%	36 8%			31 6%	1 0%	
BW	14 3%	422 84%	16 3%	4 1%	2 0%	5 1%	2 0%	
ES	44 9%	30 6%	409 86%	1 0%	11 2%	15 3%	16 4%	
GR		7 1%	5 1%	393 89%	20 4%		12 3%	
CL		4 1%	1 0%	13 3%	379 78%		21 5%	
PN	31 7%	3 1%	3 1%			436 90%		
IN	9 2%	12 2%	6 1%	30 7%	75 15%		332 86%	
WT								362 100%

Figure 5. Cross validated confusion matrix for landcover classes in the classification. IF – Indigenous forest, BW – Black wattle, ES – *Eucalyptus* spp., GR – Grassland, CL – Cleared, PN – Pine spp., IN – Infrastructure, and WT - Water.

Table 4. Accuracy assessment metrics for land cover classes in the classification

Class	Kappa	Sensitivity	Specificity	Accuracy	Precision	Recall	F1score
Indigenous forest	0.77	0.80	0.97	0.95	0.79	0.80	0.80
Black wattle	0.85	0.91	0.97	0.97	0.84	0.91	0.87
Eucalyptus spp.	0.79	0.78	0.98	0.95	0.86	0.78	0.82
Grassland	0.88	0.90	0.98	0.97	0.89	0.90	0.90
Cleared	0.81	0.91	0.97	0.96	0.78	0.91	0.84
Pine spp.	0.89	0.92	0.98	0.98	0.90	0.92	0.91
Infrastructure	0.75	0.72	0.98	0.95	0.86	0.72	0.78
Water	1.00	1.00	1.00	1.00	1.00	1.00	1.00

3.4 Overall classification landcover map

Overall accuracy for the classification was 82%. Cross validated accuracies were all high, ranging from 95 to 100%. Water had the highest accuracy, while indigenous forest and infrastructure had the lowest accuracies. Results for F1 scores were similar with water having the highest F1 score and roads the lowest F1 score. Indigenous forest had the second lowest F1 score at 0.80 (Figure 5, table 4). The study area covers 1003 km^2 (Figure 6). According to the classification, indigenous forest is relatively fragmented and covers an overall area of 264 km^2 (26%) of the study area, the highest percent cover of all the land cover classes (Figure 7). Black wattle covers an area of 122 km^2 (12%), *eucalyptus* spp. 187 km^2 (19%), pine spp. (mainly plantation) 42 km^2 (4%), grassland covers 197 km^2 (20%) and cleared areas cover 64 km^2 (6%). The rest of the area is covered by water and infrastructure.

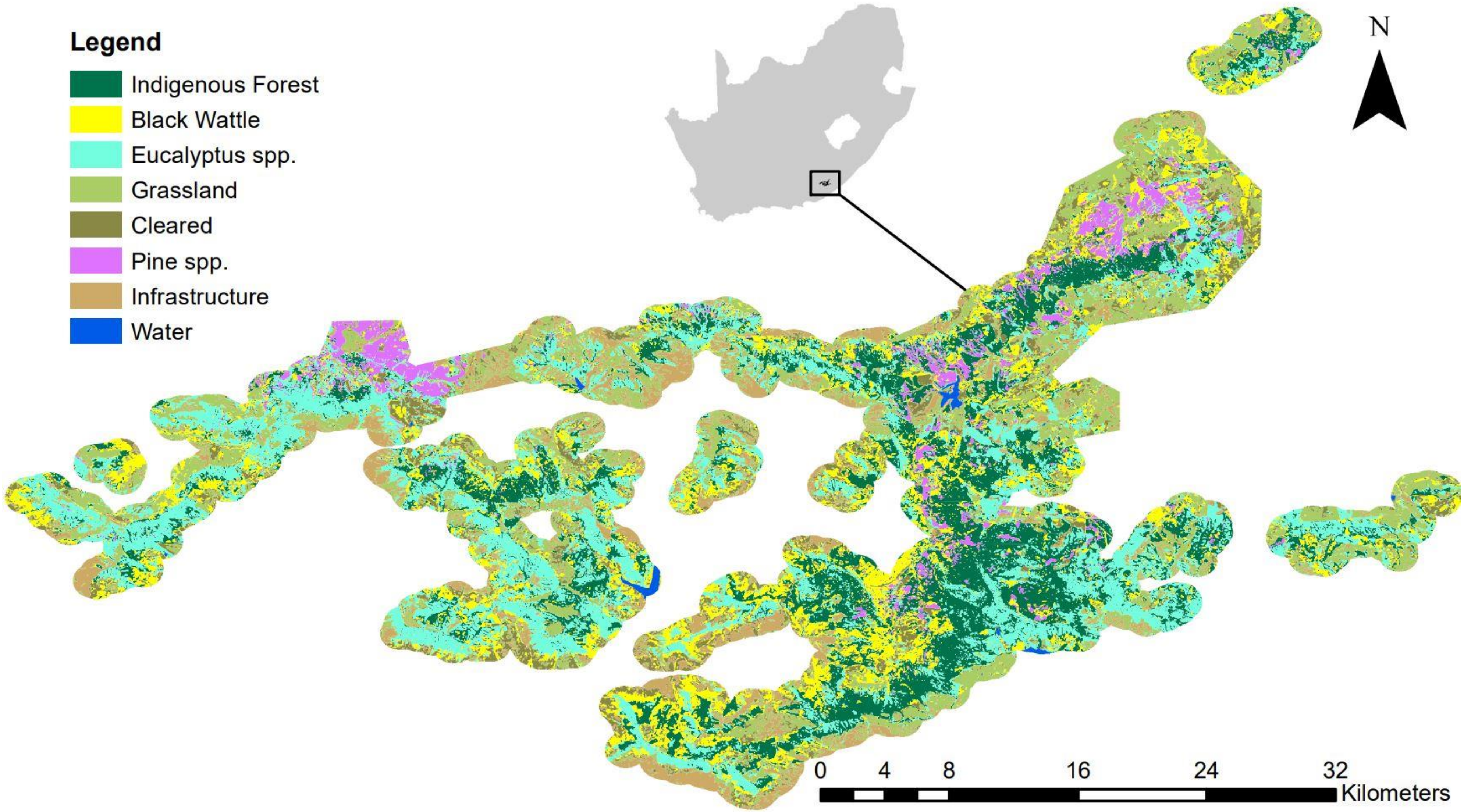


Figure 6. A classified map of the study area in the Amathole region of the Eastern Cape showing the distribution of seven landcover classes at 10 m resolution

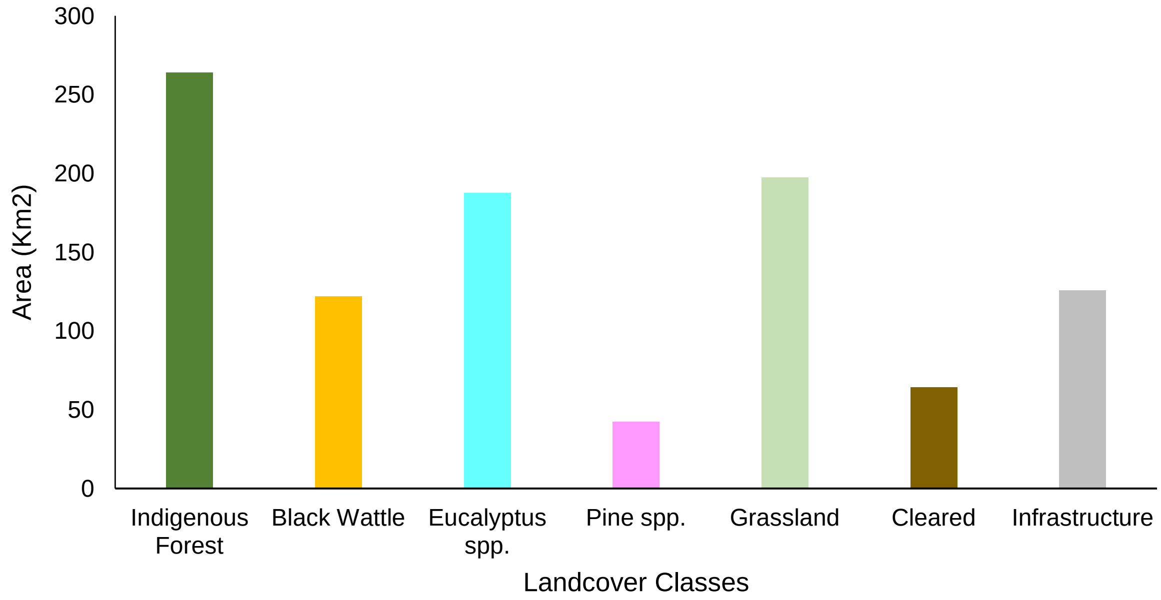
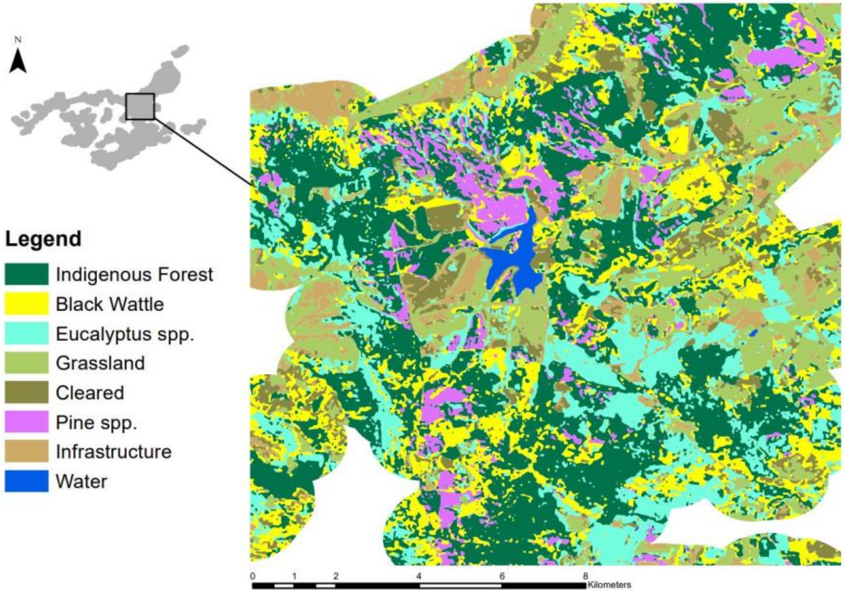


Figure 7. Area covered by landcover classes as determined by a Random Forest classification

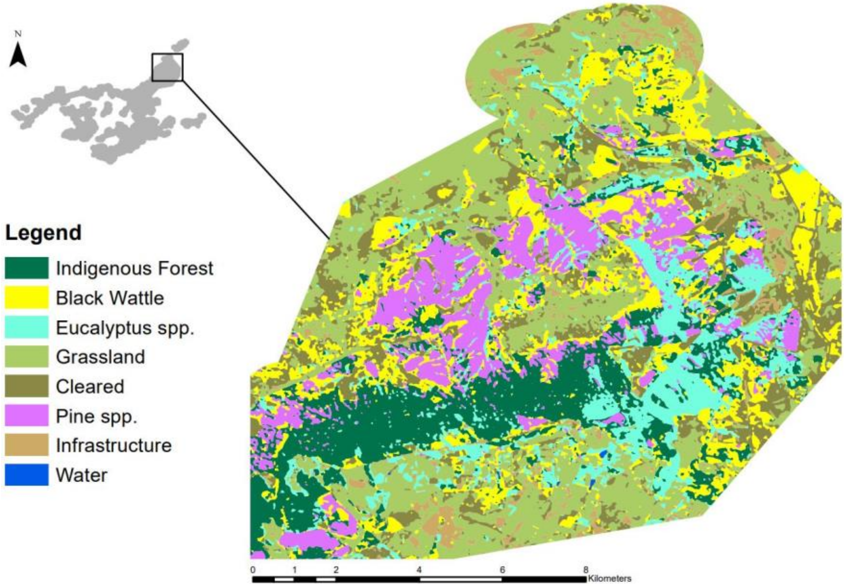
3.4.1 Landcover classes spatial distribution

Indigenous forest (Figure 8.1) is highly fragmented in the landscape, with forest patches separated by a mixed matrix of grassland, pine spp., cleared areas, and stands of black wattle and *eucalyptus* spp. There are also areas that display a large amount of alien invasion by *eucalyptus* spp. as well as *eucalyptus* spp. embedded within indigenous forest. Black wattle is one of the most accurately classified classes (Table 4), and generally occurs in large stands which have invaded grassland, especially on the edge of indigenous forests, and pine spp. or *eucalyptus* spp. stands (Figure 8.2). The cleared area landcover class occurs next to many large stands of black wattle (Figure 8.2). *Eucalyptus* spp. can occur as invaded stands as well as plantation compartments. *Eucalyptus* spp. often invade deep into the indigenous forest and typically occur between pine spp. plantation and indigenous forest. Pine spp. (figure 8.4) are generally seen in a regular pattern of patches that are plantation compartments. These compartments are often separated by *eucalyptus* spp., black wattle, or grassland. Large pine plantation compartments are mainly above the forest on the top of mountains while smaller compartments can be found inside the forest.

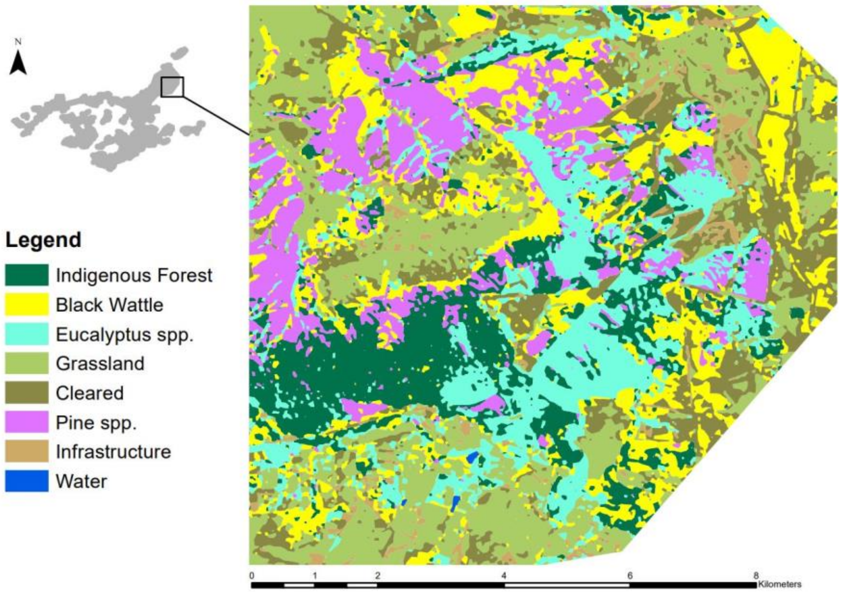
1. Indigenous forest



2. Black wattle



3. Eucalyptus spp.



4. Pine spp.

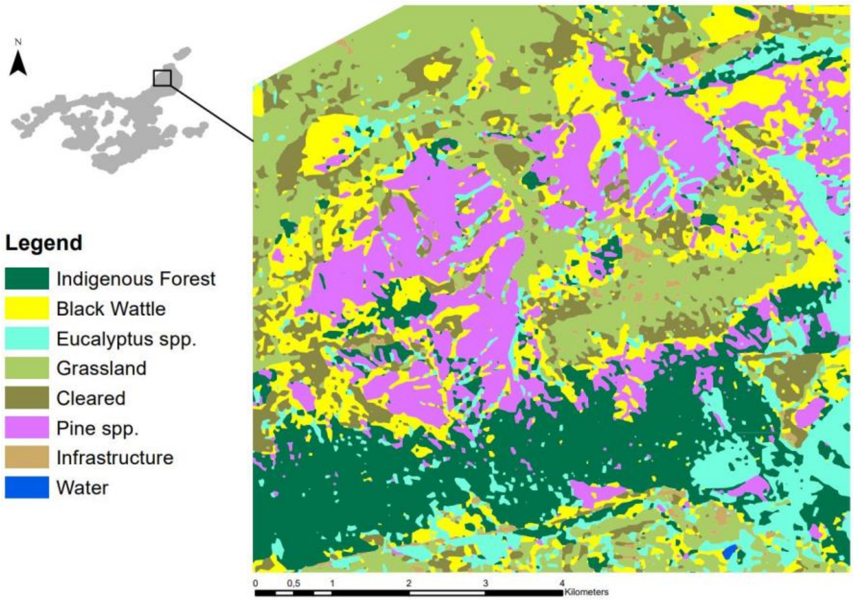
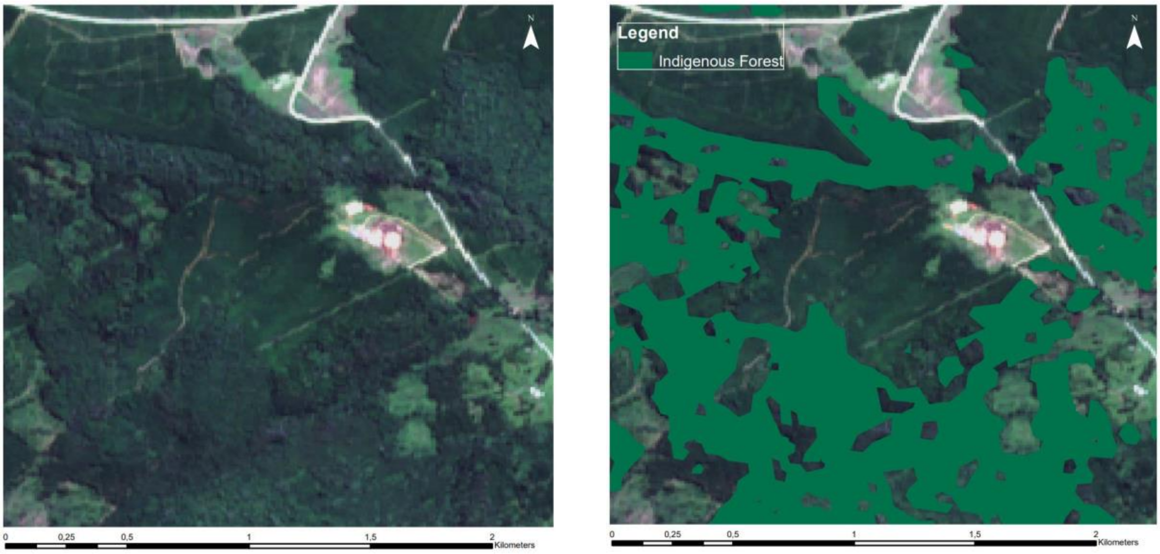


Figure 8. Spatial distribution of the woody vegetation landcover classes.

3.4.2 Quality of Classification

Indigenous forest classification performed well when the forest patch was relatively small and surrounded by a range of other landcover classes, such as the example of mainly *eucalyptus* spp. plantations and grassland (Figure 9A). These patches are generally more homogenous and on flatter land compared to forest patches closer to the mountain ranges (Figure 9B). In the latter case, the classification struggled with the variation that occurred because of steep elevation and a blue tinge was often present around large patches of indigenous forest. In many instances, indigenous forest landcover plots were incorrectly predicted as *eucalyptus* spp. and pine spp. (Figure 5).

A. Good Indigenous forest classification



B. Bad Indigenous forest classification

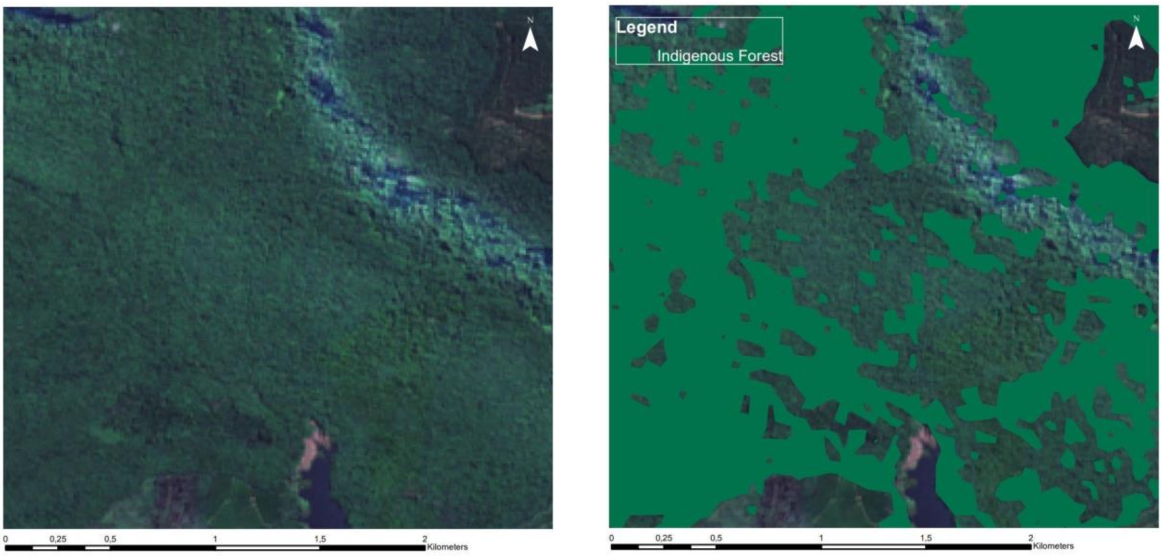
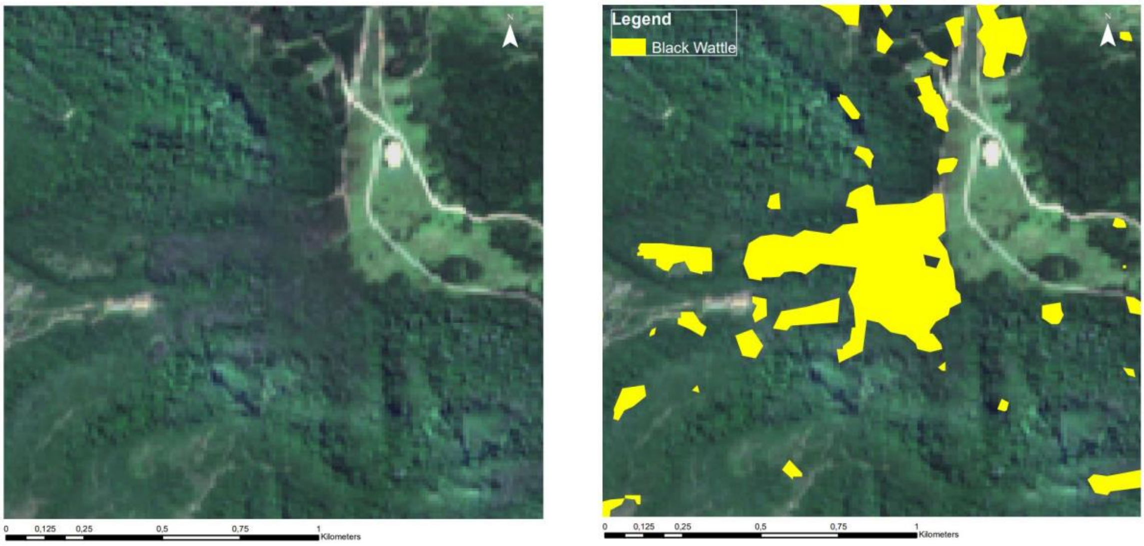


Figure 9. Colour image (RGB) compared to classified image for the landcover class Indigenous forest.

The classification of black wattle performed well when stands were surrounded by other woody vegetation landcover classes. This is especially true for when black wattle stands occurred in indigenous forest (Figure 10A). However, the classification struggled to classify the entire area covered by a stand of black wattle, resulting in patchiness in the classification. There was also confusion at times with felled areas when shrubby new growth was present, as seen in the example in Figure 10B.

A. Good Black wattle classification



B. Bad Black wattle classification

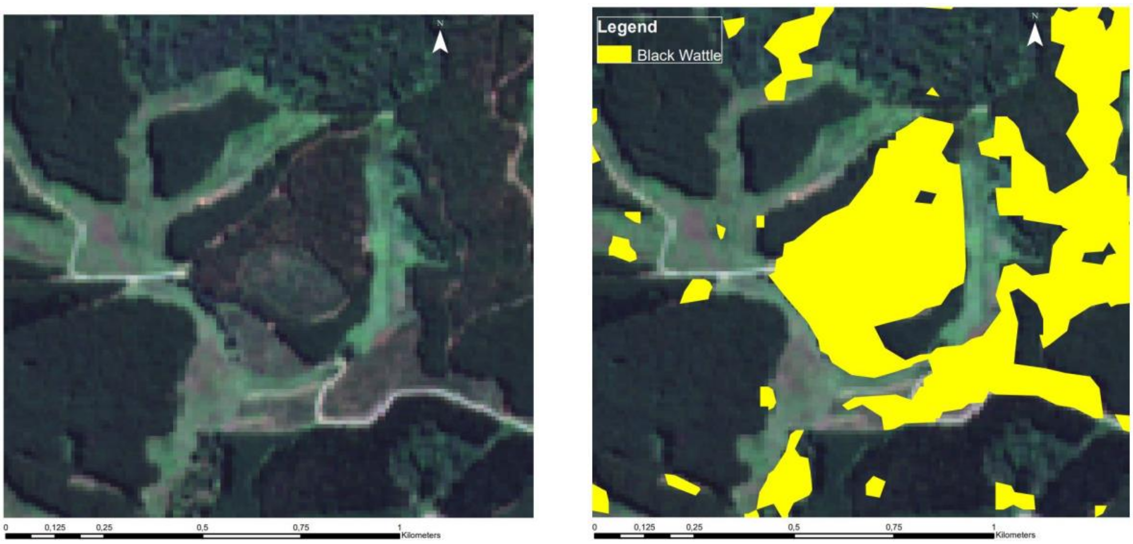
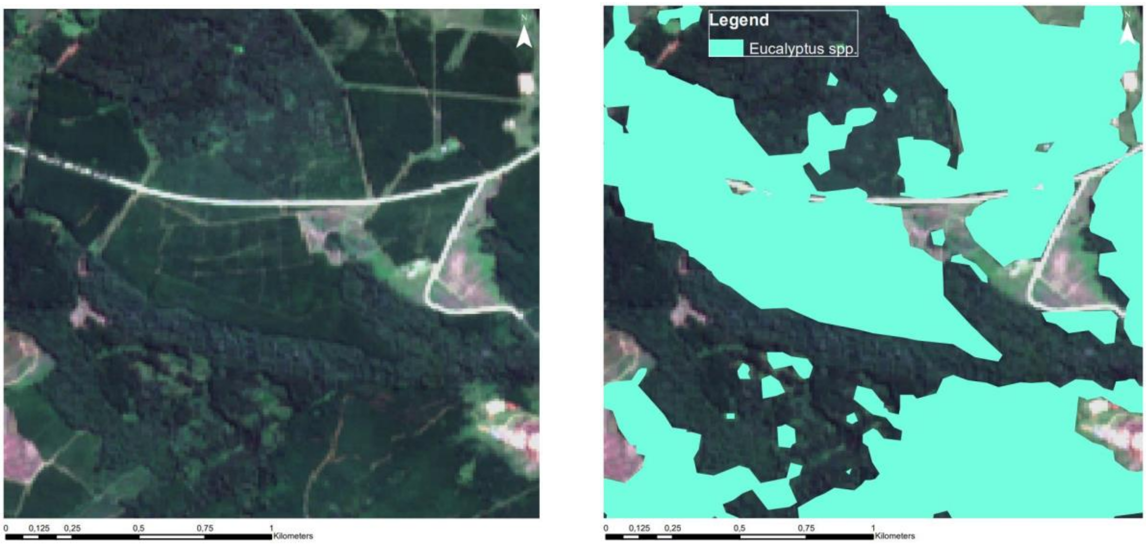


Figure 10. Colour image (RGB) compared to classified image for the landcover class Black wattle

Eucalyptus spp. stands were classified accurately when they occurred in large, homogenous plantations or stands as seen in Figure 11A. However, they were often confused with grassland and indigenous forest, especially when there was low cover or new grass growth as well as in the areas of steep elevation in indigenous forest (Figure 11B). Under these conditions, *eucalyptus* spp. landcover plots were predicted to be indigenous forest, black wattle, pine spp., and infrastructure when they were actually stands of *eucalyptus* spp. (Figure 5).

A. Good *eucalyptus* spp. classification



B. Bad *eucalyptus* spp. classification

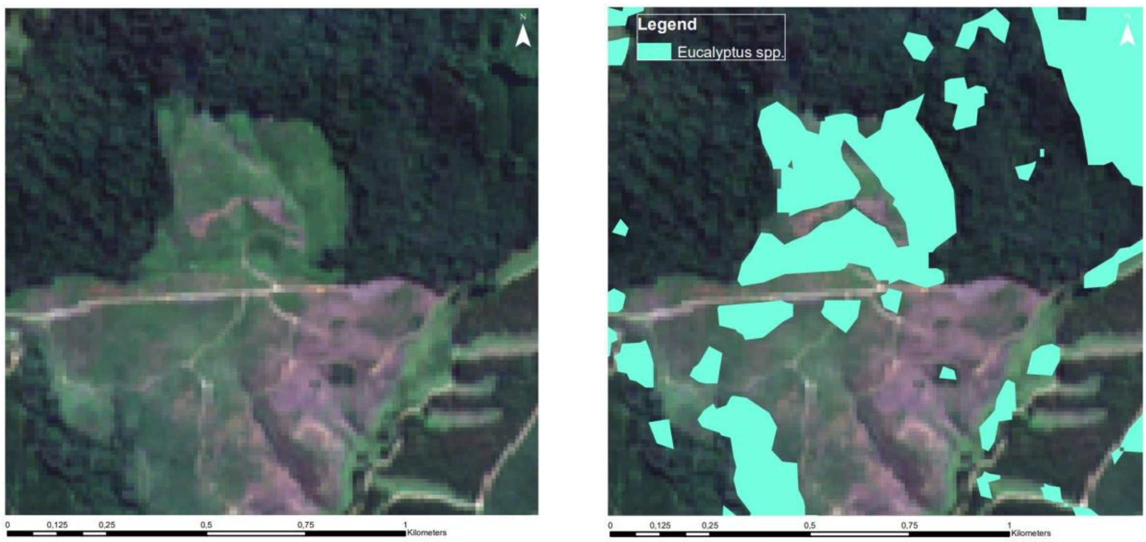
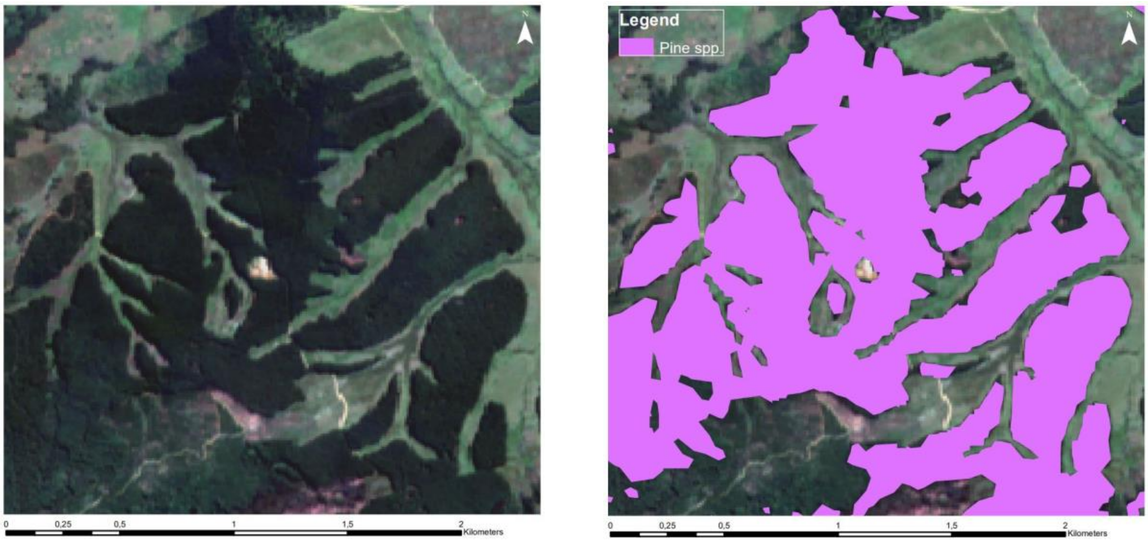


Figure 11. Colour image (RGB) compared to classified image for the landcover class *eucalyptus* spp.

The classification of pine spp. performed well especially when they occurred in plantation compartments that were separated by pathways of wetland/grassland areas and invasive species (*eucalyptus* spp. and black wattle – Figure 12A). The classification also performed well for pine spp. when plantation compartments occurred above the forest on the top of the mountain range compared to compartments on the slopes of the mountain between indigenous forest. The classification failed to capture the entire plantation compartment in these areas (figure 12B). Pine spp. landcover plots were predicted to be indigenous forest and black wattle when they were actually pine spp. (Figure 5).

A. Good pine spp. classification



B. Bad pine spp. classification

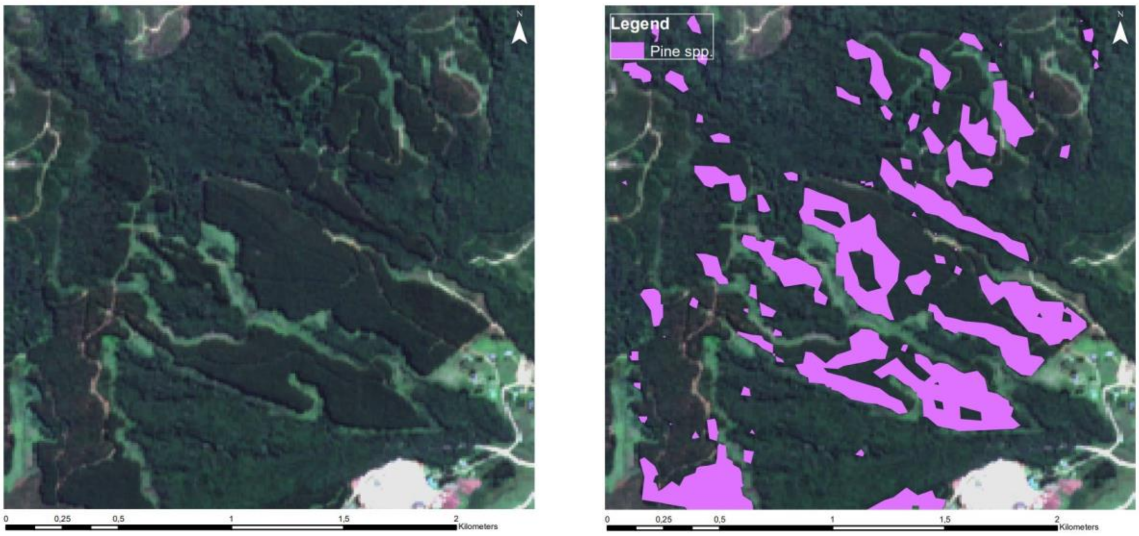


Figure 12. Colour image (RGB) compared to classified image for the landcover class pine spp.

3.5 Global Forest Watch

In 2021, estimates of forest cover loss by Global Forest Watch covered an area of 9.6 km^2 of the study area (Figure 14). When comparing this study with the GFW results, standing woody vegetation as determined in this study covered 44% of the GFW loss areas (Figure. 13). Standing *eucalyptus* spp. covered the largest GFW loss area (20%), followed by black wattle at 16%, indigenous forest at 6%, and pine spp. at 2% (Figure. 13). Cleared plantations covered the largest area of the GFW loss area at 30% (Figure. 13) and appeared to represent genuine tree cover loss (Figure 15). Infrastructure also covered a large area, although, this is most likely misclassified as cleared area (Figure 5).

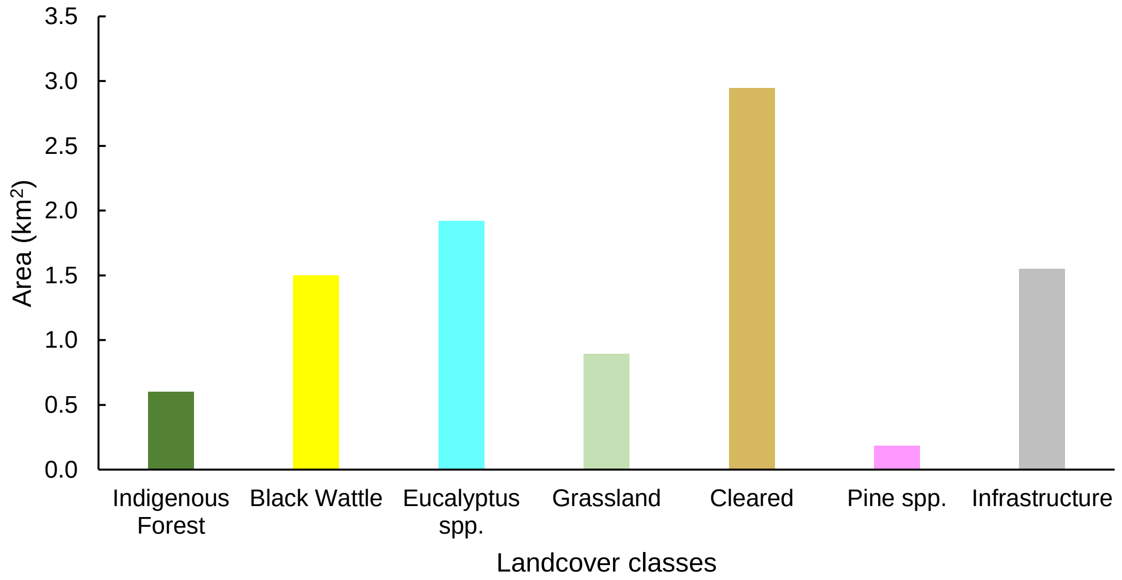


Figure 13. Area covered by landcover classes as determined by a Random Forest classification within the GFW forest cover loss of 2021.

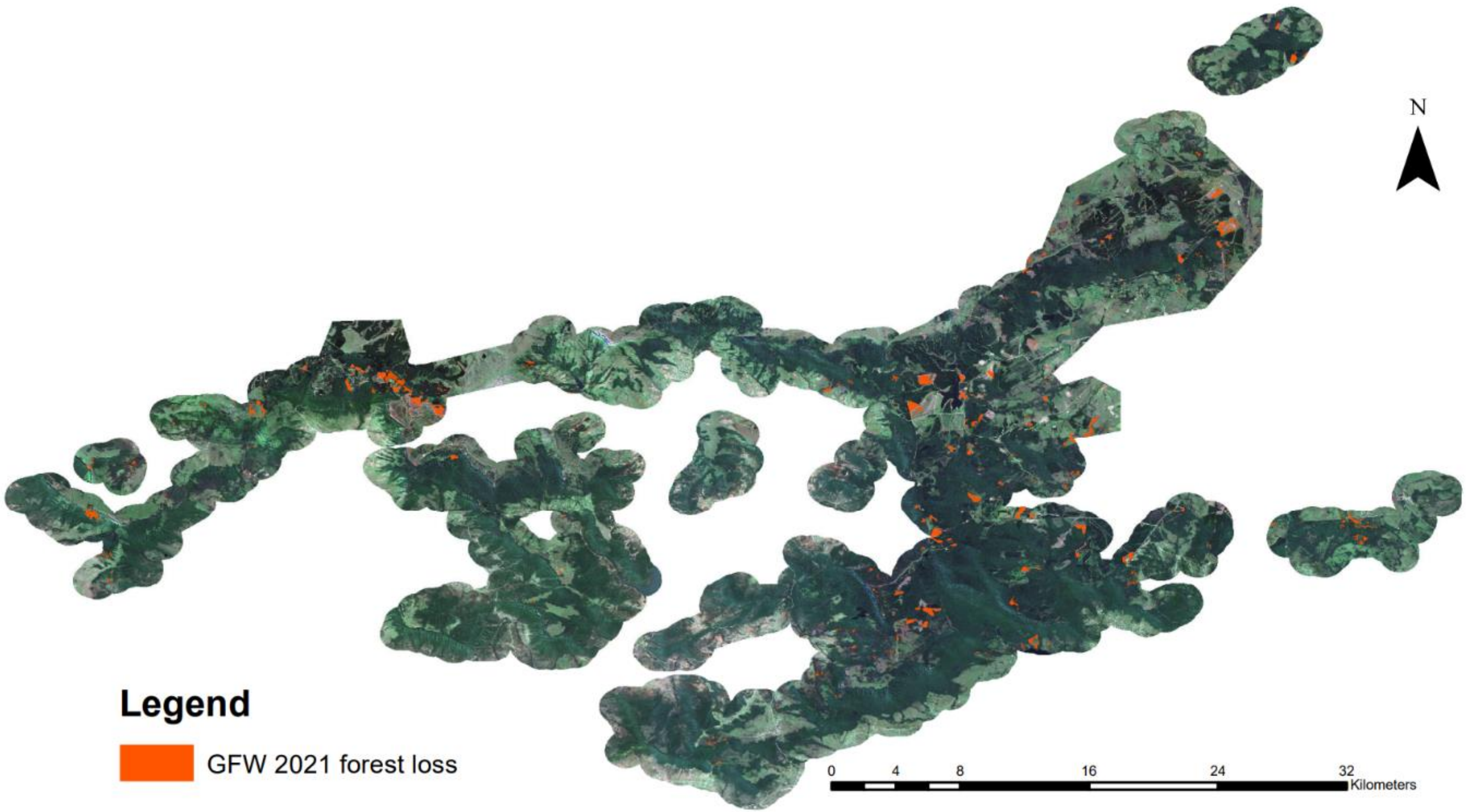


Figure 14. Forest cover loss for the study area during 2021 determined by Global Forest Watch (GFW).

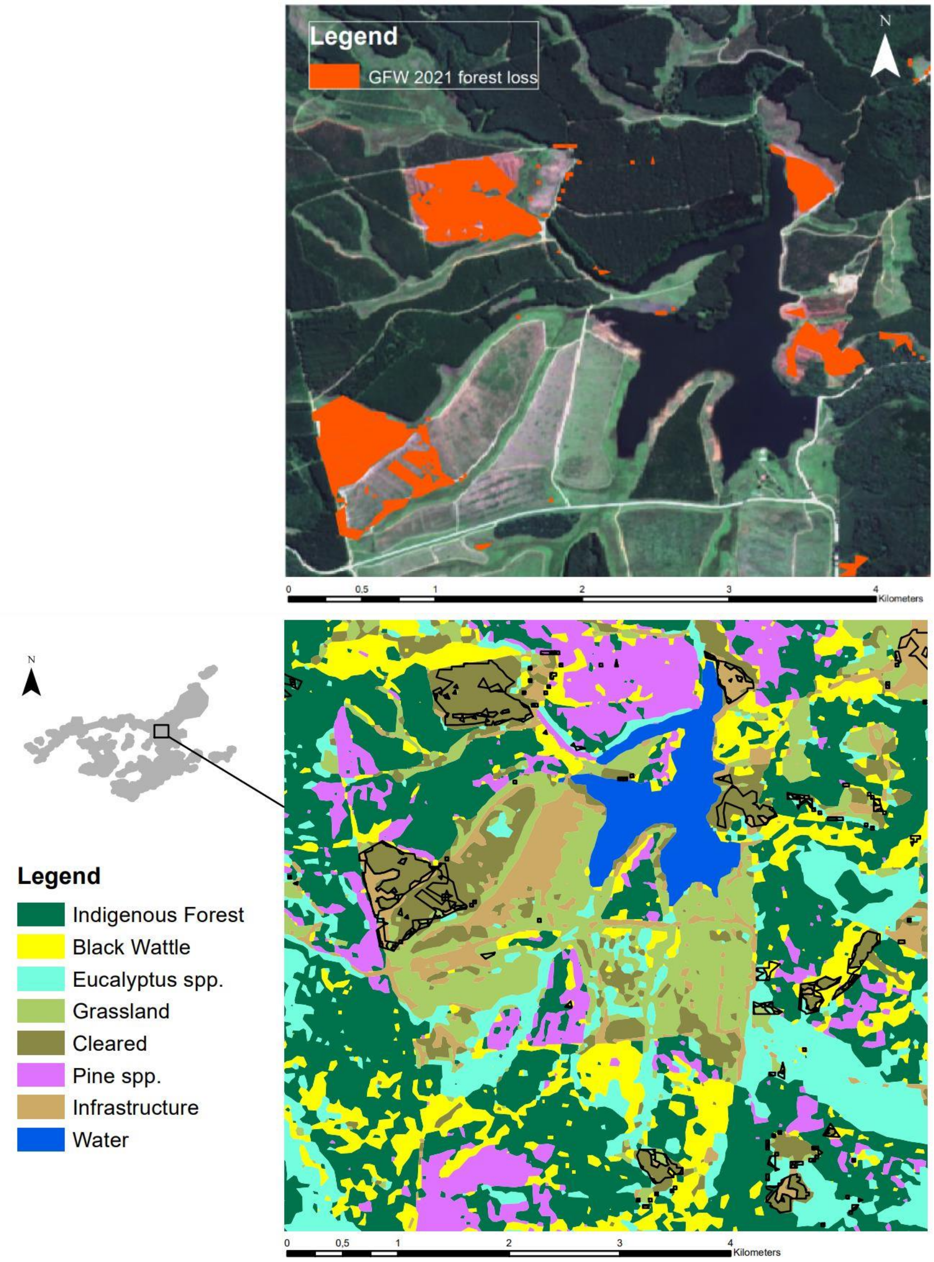


Figure 15. Example of GFW 2021 forest cover loss areas compared to classification of the same area.

When comparing the 2021 and 20-year (overall loss from 2001-2021) GFW forest cover loss with the boundaries of the plantation company in the study area, the extent of forest loss which occurred outside of the plantation areas can be determined. In 2021, 49% of forest loss occurred within the plantation boundaries (Figure 16). Over half (57%) of the forest cover loss that has occurred in the last 20 years has occurred within plantation boundaries (Figure 17).

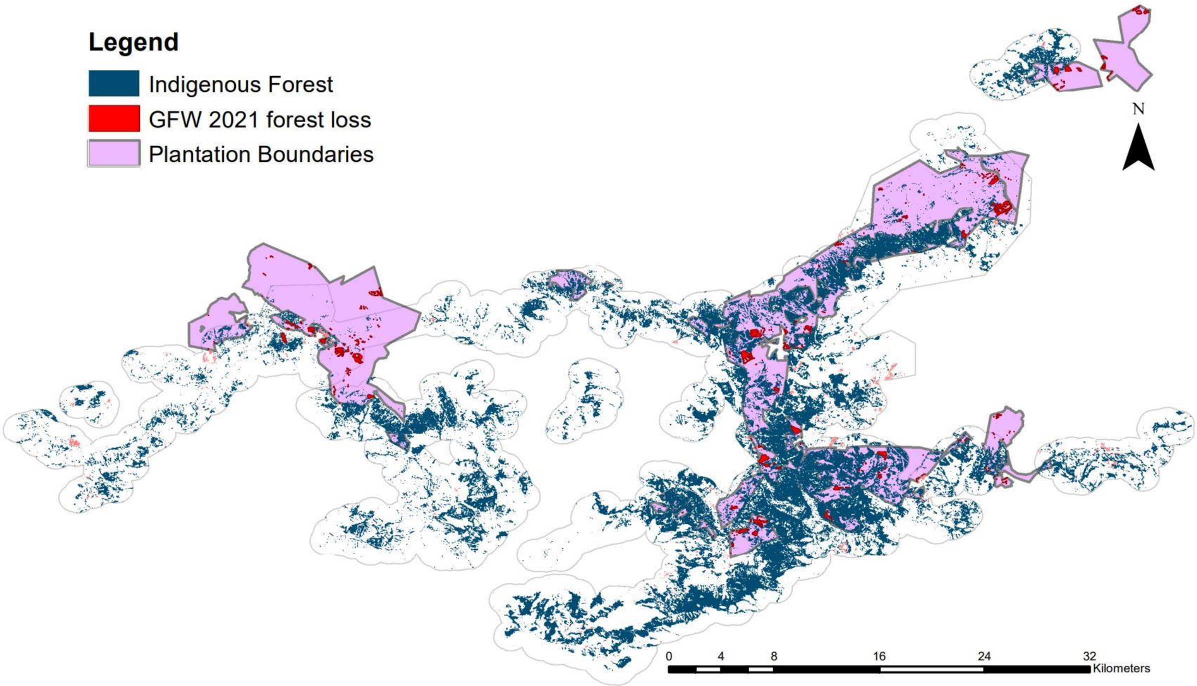


Figure 16. Forest cover loss captured by Global Forest Watch in 2021 and plantation company boundaries overlaid on landcover classes Indigenous forest and pine spp.

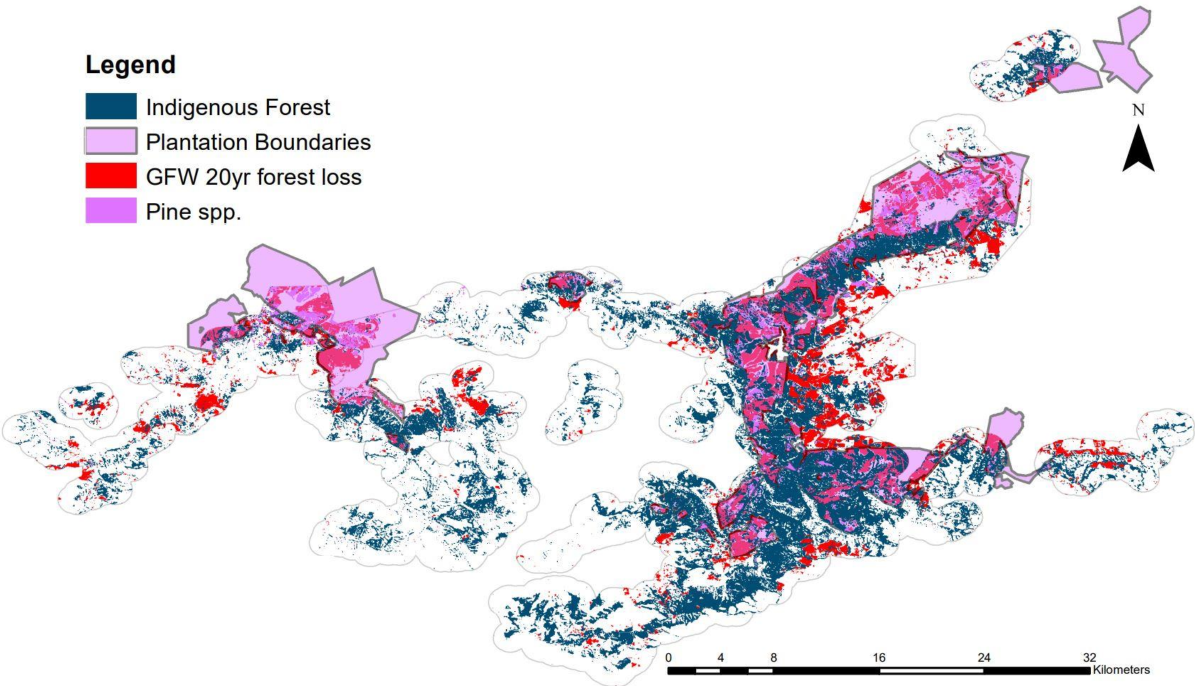


Figure 17. Forest cover loss captured by Global Forest Watch between 2001-2021, and plantation company boundaries overlayed on landcover classes Indigenous forest and pine spp.

4. Discussion

4.1 Landcover mapping of Cape parrot primary habitat

The preservation of Cape parrot habitat (Amathole Mistbelt Forest) is essential to the conservation of the species, particularly when the habitat area is the main source of their population. The Amathole Mistbelt Forest and surrounding landcover was accurately mapped in this study at a fine (10 m) resolution with distinction between the four main woody vegetation cover types: indigenous forest, pine spp., *eucalyptus* spp., and black wattle. This provides a much-improved landcover map for the area, as previously the only other available landcover maps did not distinguish indigenous forest from woody alien invasive cover. Further, it is an improvement on the National Vegetation Map (2018) because the boundaries between vegetation types are more accurately determined. Landcover maps that are too coarse reduce the ability to determine habitat vulnerability (Hernando et al 2017). This has created a knowledge gap in Cape parrot and indigenous forest conservation. The preliminary mapping of the indigenous forest and its surrounding vegetation can inform conservation management on the landscape level vulnerability of indigenous forest patches.

The classification of landcover classes in this study is considered as being ‘very good’, with an overall accuracy of 82%, and the classification of indigenous forest was even better with an accuracy of 95%. Given the high accuracy of indigenous forest classification in the study area, the distribution of indigenous forests can be interrogated in relation to local environmental and topographical features. Indigenous forest is mainly distributed on the slopes of the Amathole mountain range, with the largest patches occurring in the north-eastern side of the study area. Between large patches, the forest is very fragmented into small patches. These small patches are intersected and surrounded mainly by pine plantations, grassland, *eucalyptus* spp. stands, black wattle and cleared areas (Figure 8.1).

The spatial distribution of the indigenous forest can be attributed to climatic factors and historical human activities. In general, the forest biome in South Africa has been naturally fragmented for a long time due to ancient periods of climate change and regular fires (Geldenhuys 1989). Mistbelt Forests require high water availability and thus, tend to occur in the rain shadows of mountain ranges and along rivers and in valleys (Mucina and Geldenhuys 2006). This has resulted in the forest being naturally fragmented to a certain extent (Lawes 1990; Berliner 2005). However, due to historical logging during the colonial era, the forest became even more fragmented which has resulted in 5% of the Southern Mistbelt Forest having been converted into plantations (Mucina and Geldenhuys 2006). The indigenous forest landcover map produced by this study exceeds other maps in the granularity at which landcover types can be distinguished, both categorically (cover distinguishability) and in resolution. The distribution of the indigenous forest is seen to extend to the edges of the study area (Figure 6). This suggests that indigenous forest may extend outside of the study area, therefore, all areas covered by indigenous forest may not have been captured. Furthermore, the actual extent of the indigenous forest may be larger than what is presented in this study.

4.2 Habitat quality of indigenous forest patches

Landcover mapping can provide insight on the quality of indigenous forest habitat, in this case specifically for the Cape parrot. The landcover map produced in this study gives an indication of the general size of forest patches as well as the type of matrix that occurs between them, both of which can affect the quality of habitat for the Cape parrot. Small patches of forest are present and occur in a matrix of grassland and woody invasive aliens. Small forest patches (1 km^2) are more vulnerable to the threats of fire, invasion, and land degradation compared to large patches (10 km^2) (Von Maltitz et al 2003). It has been shown that small patches are significantly more vulnerable to fire compared to large patches especially when canopy cover is low (below 50%) (Guedes et al 2020). Furthermore, small patches are less suitable for avian forest specialists (such as the Cape parrot) as there are fewer resources and fewer niches available which can cause specialists to go locally extinct (Maseko et al 2020). Small patches have a higher edge to interior ratio, thus experience more edge effects, resulting in smaller trees and lower forest biomass at the edges (Echeveria et al 2007; Santana et al 2021). This could potentially mean small patches do not provide quality habitat for Cape parrot due to the lack of an emergent layer. This is also backed up by the fact that *Podocarpus* has been found to fruit for longer periods in larger patches, meaning more food is available to Cape parrots (Hart et al 2013).

One of the main indicators of habitat quality for the Cape parrot is the presence of an emergent canopy layer which they use as nesting sites (Wirminghaus et al 2002). Data collected in the field (cover and height estimates) can provide an idea on the quality of the emergent layer in the forests. There is evidence of an emergent layer in the collected data, with some indigenous forest landcover plots having multiple tree heights of over 20 m (Figure 3A). However, most indigenous forest plots did not show emergent heights (average height 15.7 m) and the cover for the Upper-canopy was the smallest on average (32%). This suggests that the Upper-canopy of the indigenous forest (at least in the areas where data was collected) is relatively sparse and does not contain many emergent canopy trees. This may be an artefact of historical logging (Cawe and Mckenzie 1989b), as it takes many years for emergent canopy tree species to get to such a height. In contrast, the Mid-canopy was relatively dense, which might represent the next cohort of emergent trees, but these have not yet had the time to grow to the height of an emergent layer. More intensive field work would be required to understand if this is the general trend for all indigenous forest patches or not. This will only be an estimation of the emergent layer quality for pristine undegraded forest patches, as this was where data collection was prioritized to ensure good landcover plots for the classification.

The matrix is mainly made up of grassland and cleared areas. Cleared areas were largely misclassified as infrastructure (Figure 6), and they, therefore, cover more area than what is predicted by the classification. However, invasive alien tree species such as black wattle, eucalypts and pines cover a large amount of the matrix area, comprising about 35% of the study area (Figure 7). Lawes et al (2009) found that in a naturally fragmented forest in the Kwa-Zulu Natal midlands, large forest patches surrounded by plantation forestry showed signs of interior degradation with a suggestion that there was a loss of large trees. They attributed this to the possibility of negative impacts from plantations upslope of indigenous forest patches, such as, decreased water availability, mechanical disturbance, and alien plant invasion (Lawes et al 2009). Wethered and Lawes (2003 and 2004) found that large forest patches surrounded by plantations have lower avian species richness compared to smaller patches, particularly in terms of forest specialists (such as the Cape parrot). Black wattle and *eucalyptus* spp. are common in large stands next to forest patches. This is concerning because the more invasive aliens there are in the matrix surrounding forests, the higher the chance of invasions moving into forest patches, especially in patches which have canopy gaps (Mavimbela et al 2018 and references therein). The landcover map highlights the importance of state protected forests which are the large patches of intact forest. Such areas don't appear to be as impacted by woody invasive aliens as the smaller forest patches which have woody invasive alien species growing along the edges (Figure 6). Edges are particularly vulnerable to alien plant invasions as there is higher species turnover and more sunlight, while large forest interiors are harder to invade (Harper et al 2004, references therein). Furthermore, the intrusion of roads into forest patches can influence the invasion of alien species into the forest interior. Thus, the building or maintaining of roads inside large indigenous forest patches should be avoided where possible (Puachard and Alaback 2006).

Invasive aliens do provide some benefits to forest patches and to the Cape parrot. Plantations have been found to act as a buffer to matrix/edge effects and aid in preventing Cape parrot local extinction in indigenous forest patches (Cooper et al 2017). However, this needs to be considered in conjunction with other avian forest specialists which are negatively affected by plantations and driven to local extinction (Cooper et al 2017). Another, repeated benefit of surrounding plantations is the extra security afforded to indigenous forest patches within plantation company boundaries which can prevent illegal harvesting (Cooper et al 2017). Pole harvesting of indigenous forest patches can negatively impact forest dependent birds, such as the Cape parrot (Leaver 2019). However, where there are black wattle stands, pole harvesting can be switched from indigenous forest to black wattle as black wattle is a preferential harvesting product (De Wit et al 2001). This indicates that black wattle stands in the area may be acting as buffers to indigenous forest harvesting.

4.3 Comparison to the Global Forest Watch estimates of forest loss

Previously, the Amathole Forest Complex was estimated to be around 40 000 ha (Thompson 1991). However, the classification map developed in this study shows that the extent of indigenous forest is only around 26 000 ha. However, about 20% of the forest landcover plots were misclassified and, therefore, the margin of error suggests that the extent may be up to 35 000 ha. Moreover, the study area was delineated based on forest patches where Cape parrots have been seen the most, and this does not cover the entirety of the Amathole Forest Complex. Given these complexities, the estimated forest extent of this study may not be that dissimilar to the estimates provided by Thompson (1991).

Global Forest Watch (GFW) captures forest cover loss at a 10 m resolution for the last five years and at a 30 m resolution before that from 2000 (Hansen et al 2013). They do not distinguish between different types of forest cover, such as indigenous forest, pine spp., *eucalyptus* spp. and other woody invasive species. Information around the potential drivers of forest cover loss is provided as either deforestation (permanent loss) or temporary loss (forestry/wildfire) at a 10 km^2 scale (Curtis et al 2018). In the Amathole area, GFW ‘tree cover loss’ was 13.6k ha between 2002 and 2021. GFW attributes this forest cover loss as temporary loss driven by forestry and shifting agriculture (Curtis et al 2018). However, due to the nature of the fragmented forest, a 10 km^2 resolution may be too coarse to accurately understand the drivers behind this forest cover loss.

In the landcover map produced, large areas mapped as forest loss by GFW clearly still contain tree cover which suggests that the loss is not indigenous forest loss. Most of the loss which has occurred is classified as “cleared”. The landcover class “cleared” represents areas where there has been felling of plantations or clearing of invasives. It can be assumed that a large amount of the loss captured by GFW for 2021 was the felling of plantations and the clearing of woody alien invasive stands, especially black wattle, as existing stands can often be seen surrounded by cleared area. This is backed up by the fact that almost half of the ‘forest cover loss’ occurred within the plantation company boundaries (Figure 16), further supporting the notion that loss was associated with plantation activities. Indigenous forests within the plantation company boundaries are well protected as a result of plantation security (Cooper et al 2017).

The findings presented here, that indigenous forest cover loss is not large, is supported by previous research. It is known that there was widespread indigenous forest deforestation, commercial logging and clearing of the forests for agriculture and plantations until 1939 (Geldenhuys and Macdevette 1989). This means that large scale loss of indigenous forest cover should not have occurred over the last 100 years. Controlled sustainable harvesting of indigenous trees was continued in large forest patches (such as the Amathole Forest Complex) from 1975 onwards, which has resulted in degradation of the forest in terms of habitat structure (Leaver and Cherry 2020), but very little deforestation of indigenous forest has occurred, specifically between 1990 and 2014 (Cooper et al 2017).

4.4 Management implications

An accurate landcover map can influence conservation management of the indigenous forest, Cape parrot habitat quality and the management of invasive alien species. This study highlights the utility of remote sensing to this end, as it would require extensive fieldwork to ascertain the extent of the indigenous forest, invasive alien species and to gain a better understanding of which areas are in greatest need of management (Royimani et al 2019). The main contribution of this work is to provide managers with a visual tool that informs them about the location, size, and vulnerability of indigenous forest patches, as well as the extent and location of specific invasive alien species. This information would go a long way to informing management decisions around vulnerability and prioritisation, which is extremely important in management of areas that have little to no resources to develop management plans (Jones et al 1999; Boyle et al 2014; Royimani et al 2019). Secondly, the provision of this tool along with accompanying research would render scientific knowledge more readily available for managers who lack the capacity to include research positions in their management team. The academic research associated with the production of the landcover map in this study can act as a nexus between forest managers, as knowledge concerning the conservation of forest and the complexities associated with invasive alien removal can be shared. My comparison with GFW highlights that global products might not always be suitable for local management purposes. In the future, GFW may be useful in determining if there is any long-term forest loss from selective harvesting that is not yet apparent. Secondly, findings of this study may suggest that focusing on woody invasive alien clearing may currently be more of a need than the strong focus on preventing indigenous forest harvesting.

4.5 Limitations and difficulties of landcover classification and data collection

4.5.1 Field data collection

Field data collection was limited as the time of the study coincided with high rainfall for the area. The heavy rainfall caused the mostly unpaved roads between forest patches to be inaccessible. Another constraint was accessibility into forest patches themselves, as early in the fieldwork it was proved inefficient to navigate in forest patches without paths. Isolated forest patches also had a higher security risk due to their remoteness and use by poachers. As a result, forest patches that had clear paths and that were more accessible were targeted. This resulted in a bias in the collection of forest landcover plot data to the northern half of the study area. Secondly, stands of invasive alien species, such as black wattle and *eucalyptus* spp., were either inaccessible due to stand thickness or occurrence on private land that could not be accessed. This was dealt with by collecting desktop points on Google Earth for areas where known stands of a particular species occurred in a homogenous area. The latter method was also used for landcover classes that were easily distinguishable in Google Earth (e.g., grassland, cleared land, infrastructure, and water) so as to save time and devote most of the field work to indigenous forest plots. This did, however, impact the number of plots for which cover, and height of black wattle and *eucalyptus* spp. could be estimated.

There were also some issues with cover and height estimates for indigenous forest plots. Firstly, plots were only located in relatively pristine, older forest patches to ensure good training data for the landcover classification. This method, however, means no data were collected in more degraded forests and thus may give an underestimation of forest degradation for the study area.

4.5.2 Classification

A potential issue with the classification is the spatial bias of landcover plots that may have affected classification accuracy. The classification had a high accuracy for the predicted landcover plots (30% test data) but these landcover plots were mostly on the eastern side of the study area, thus, variation for some landcover classes may have been missed. Lower classification accuracies may also be associated with the spectral reflectance of certain classes being very similar (particularly pine spp. and *eucalyptus* spp.).

4.6 Further research based on landcover classification

This study provides a building block for future study and research in the area, particularly on indigenous forest extent and its habitat quality for Cape parrots. Future research into the use of drone imagery would provide an interesting avenue to further understand the small-scale details of indigenous forest distribution and habitat quality (Onishi and Ise 2021). The variability within canopy height among indigenous forest plots suggests there may be differences in forest habitat quality and degradation between patches. Thus, future studies should explore this variability in more detail. Future studies could include additional information, such as using spectral indices and other remotely sensed information (topography, radar etc.) to get an even better classification. The Cape Parrot Project is intending to perform LiDAR over the indigenous forest in the near future (2023). This will not only provide important information about the structure and habitat quality of the forest but will also contribute to building a classification model that can distinguish between different tree species. Such an approach will better predict the extent of indigenous forest and invasive aliens (Shi et al 2020; Li et al 2021).

The landcover map and associated information will be made available to managers in the area by developing a Google Earth Engine app. This will allow for the improvement of management as well as promote communication between different managers and may be used as an easy tool to share information and plans with others. This study can also contribute to future research for monitoring and evaluation projects for both the indigenous forest, the Cape parrot and for invasive alien management. Lastly, this classified landcover map could be used as the basis of yearly monitoring of Cape parrot habitat.

5. Conclusion

The Amathole Mistbelt Forest and surrounding landcover was accurately mapped at a 10 m resolution distinguishing between indigenous forest, pine spp., black wattle, eucalyptus spp., grassland, cleared areas and infrastructure. It is suggested that there is reduced habitat quality in the emergent layer of indigenous forest patches. My landcover map provides knowledge about the quality of indigenous forest habitat for the Cape parrot and it highlights the increased vulnerability of small patches and potential alien species invasion. The matrix between indigenous forest patches is mainly comprised of grassland and invasive aliens such as black wattle and *eucalyptus* species. The study highlights how management of the matrix can influence habitat quality for Cape parrots in terms of forest cover loss. The felling of plantation trees and the clearing of invasive aliens is likely the ‘forest cover loss’ estimated by Global Forest Watch (GFW). No deforestation of indigenous forest has occurred in the area, and this is backed up by previous studies and understanding of forest degradation in the study area. This highlights the importance of local research as global products like GFW are not always suitable for local management purposes. Implications for management are the increased ability for managers to monitor and evaluate indigenous forest aspects such as patch size, spatial distribution, and matrix dynamics. Further information from the landcover map can also influence invasive alien clearing and prioritization.

6. Supplementary materials

Please contact me at: emmajwright2206@gmail.com for the sharing of classification model code.

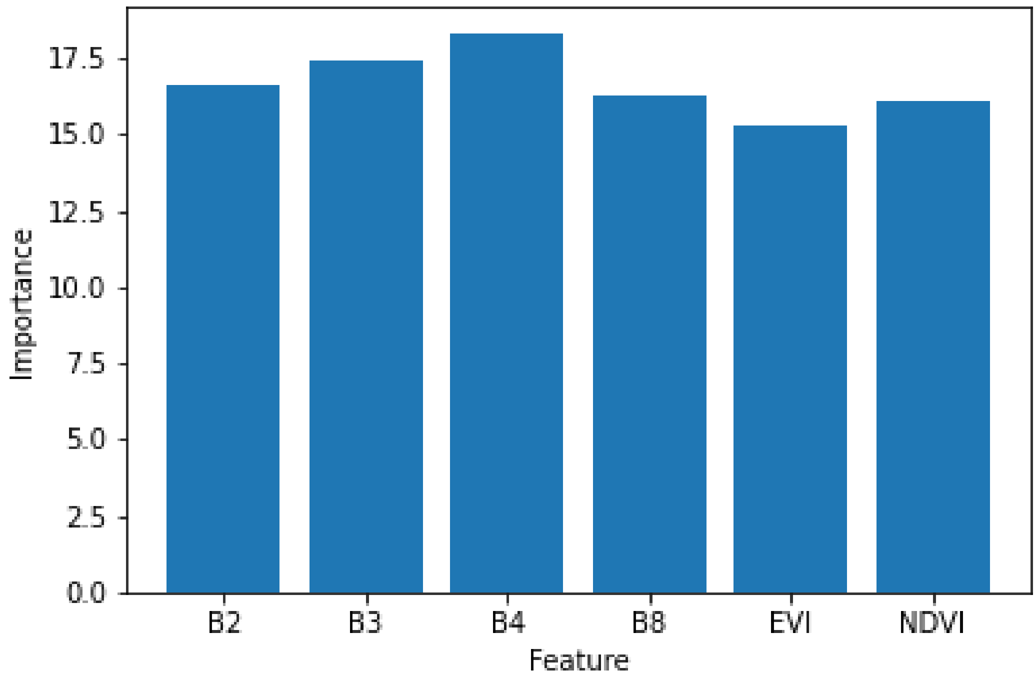


Figure 1. Feature importance derived from the random forest classification model

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