



**Utilising GIS and Remote Sensing to assess the impacts of the  
invasive *Rubus cuneifolius* on veld grazing capacity.**

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degree of  
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## PREFACE

This research work was conducted from April 2018 at the School of Agricultural, Earth and Environmental Sciences, University of KwaZulu-Natal, Pietermaritzburg, South Africa, under the supervision of Professor Kevin Kirkman and Dr Mbulisi Sibanda.

I would like to declare that the research work presented in this thesis has never been submitted in any form of degree or diploma to any other institution. This work represents my original work except where due acknowledgements are made.

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Signed  Date: December 2023

As the candidate's supervisors, we certify the above-mentioned statement and have approved this thesis for submission.

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Publication 1

Publication 2

Publication 3

etc.

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## **DEDICATION**

This dissertation is dedicated to my daughters, Ayabonga and Inamandla. Thoughts of not failing you kept me going until this dissertation was complete.

## ABSTRACT

This study was motivated by the heavily invasion of *Rubus cuneifolius* (bramble) in the Mistbelt grasslands of KwaZulu-Natal province of South Africa, particularly at Wakefield Farm. When not effectively managed, bramble invasion results in dire consequences, including the reduction of veld grazing capacity. The initial steps in managing invasive alien plants (IAPs) in rangelands involves understanding their distribution and extent. This requires a suitable satellite data with optimal temporal, spectral and spatial resolution, a task that necessitates accurate and feasible mapping of IAPs. In this regard, this study aimed to assess the utility of Sentinel-2 multispectral imager in mapping the spatial distribution of bramble and assessing its impact on veld grazing capacity. This overarching aim was addressed using two specific objectives. The first objective was to test the capabilities Sentinel-2 Multispectral Imager (MSI) in detecting and mapping bramble during the senescence period. To address this objective, four sets of spectral features (all spectral bands, *m*NDVI, *m*SR and combined inputs) and the Discriminant Analysis algorithm were used to test the utility of Sentinel-2 MSI's in detecting bramble during the senescing stage. Inputs were tested when red edge bands were included in the analysis (inclusive bands) compared to when they were excluded from the analysis (exclusive bands). The second objective was to assess the impacts of bramble invasions on grass production, species diversity and dominance. To address this objective, grass biomass and species data we gathered and dry weight rank (DWR) and double sampling techniques were utilised. A relationship between the estimated biomass and the actual biomass was determined in the invaded and the uninvaded patches. Then, Shannon-Wiener diversity index and the Simpson's Index were used to calculate species diversity and dominance, respectively. Results showed that bramble could be detected using Sentinel-2 MSI to an overall accuracy of 89.33% with red edge derived *m*NDVI being the most influential discrimination variable. Furthermore, results showed a significant relationship between the estimated and the actual biomass as well as a higher total biomass in the invaded patches. In uninvaded patches, species diversity was higher while dominance was lower and in the invaded patches species diversity was lower while dominance was higher. This study highlights that Sentinel-2 MSI's red edge bands are well-suited for discriminating invasive alien plants, particularly bramble, in rangelands during annual senescence. Additionally, it emphasizes that bramble invasion diminishes the value of rangelands by reducing the productivity of palatable grass species.

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## LIST OF ABBREVIATIONS

AIS	Alien invasive species
ANOVA	Analysis of Variance
DA	Discriminant analysis
DWR	Dry weight ranking
GIS	Geographic information system
GPS	Global positioning system
GSI	Ground sampling interval
IAP	Invasive alien plants
KZN	KwaZulu-Natal
MSI	Multispectral instrument
<i>m</i> NDVI	modified Normalised difference vegetation index
NEMBA	National Environmental Management: Biodiversity Act
NIR	Near infrared
OA	Overall accuracy
OLI	Operational land imager
PA	Producer accuracy
RS	Remote sensing
SA	South Africa
SASSCALL	Southern African Science Service Centre for Climate Change and Adaptive Land Management
<i>m</i> SR	modified Simple Ratio

SPOT	Satellite Pour l'Observation de la Terre
SWIR	Shortwave infrared
UA	User accuracy
VI	Vegetation Index
VIS	Visible

## CHAPTER 1: GENERAL INTRODUCTION

### 1.1. Introduction

Rangelands can be described as land where natural vegetation is predominantly dominated by grass, grass-like plants, forbs, and shrubs that are grazed or have the potential to be grazed. They can also be characterized as natural ecosystems that are managed for livestock grazing and wildlife habitat (Lesoli et al., 2013). From an agricultural perspective, rangelands are considered a major feed source for livestock as grasses, forbs, and shrubs that grow on them are an important source of forage for grazing animals (Ali et al., 2016). More than 70% of the earth's terrestrial surface is covered by rangelands (grasslands, savannas, thickets and karroid shrubland vegetation). Grasslands, being the most expansive terrestrial ecosystems in the world, cover 31.5% of the global land and play a significant role in regulating the carbon cycle as well as providing support for plant and animal biodiversity. In South Africa, grassland is the second largest biome and covers 29% of South Africa's land area, providing a plethora of ecosystem services. Grassland ecosystems also provide excellent habitats to the extant mammalian megafauna and support billions of people who directly rely on them (Sinha et al., 2022). Veld condition (where veld is a local term for grassland or rangeland) is a measure of the health of grass, where good veld condition refers to sustainable forage production and resistance of veld to soil erosion. In South Africa, development techniques for veld condition assessments have proven to be valuable for assessing current veld condition and for formulating veld management practices such as stocking rates, rotational grazing and resting as well as burning (Trollope et al., 1989). It is estimated that 60% of the grazing veld in South Africa is in a bad state, 30% in an intermediate state and 10% in a good condition (Van de Pol & Jordaan, 2008). Tainton (1981) states that overgrazing and selective utilization of grass species is the main reason for degradation. But according to Lesoli et al. (2013), productivity in rangelands is mostly threatened by soil erosion and alien plant species.

Alien species introductions generally occur within the context of a complex socio-political environment (O'Connor & van Wilgen, 2020). Many species were intentionally introduced to rangelands for purposes beneficial to humans. For example, some species such as *Opuntia ficus-indica*, *Prosopis* spp., and *Eucalyptus* spp., were introduced in rangelands for purposes such as providing forage for livestock, shade, erosion control, ornamental uses (Belnap et al., 2012). Invasive alien plants (IAPs) have been widely renowned for their adverse impact on the production and biodiversity of native species, altering rangeland processes and functions (Davies & Johnson, 2011). More studies have established a relationship between the loss of

native plant diversity and high exotic abundance when there is an implied connection to competitive displacement (Davies, 2003; Keddy, 2001; MacDougall & Turkington, 2005). Rapid rangeland invasions by some IAPs critically impedes on grazing and cause stock losses due to injury and poisoning (Zimmermann & Moran, 1991).

*Rubus cuneifolius*, commonly known as American bramble is native to North America and is one of the alien invasive species that adversely impacts on rangeland condition (Hansen, 2015). It is a deciduous perennial shrub from the *Rosaceae* family that forms dense thickets that are extremely difficult to penetrate. It is characterized by curved, prickly shoots, leaves occurring in groups of three or five and white flowers that develop fruits in the second year of growth (Hansen, 2015). Bramble was first introduced to South Africa in the early 1900s for the purpose of making jam from its fruits (blackberries) (Erasmus & van Staden, 1983; Wager, 1947). In South Africa, it was proclaimed a noxious weed in 1962 (Erasmus & van Staden, 1983). Although the area of infestation has expanded, no control measure for eradication has proven entirely successful (Erasmus & van Staden, 1983). *Rubus cuneifolius* is listed under category 1b on South Africa's National Listed Invasive Species. According to the National Environmental Management Biodiversity Act (NEMBA), Act no. 10 of 2004 – Alien Invasive Species (AIS) Regulations, species like bramble must be controlled and wherever possible should be removed and/or destroyed. It also means that there is a strict prohibition of this weed being planted or traded. Dense infestations of bramble result in a decrease in grazing capacity and they also limit access to infested areas with thorn-covered canes causing natural barriers (Erasmus & van Staden, 1984). Bramble exhibits a robust ability for reproduction, dispersion, and resource utilization (including water, mineral elements, and light) (Masson et al., 2015). The thriving weed status of this plant in the KwaZulu-Natal (KZN) province can be attributed to its apparent optimal environmental conditions and the absence of natural competitors and predators (Erasmus & van Staden, 1983). Therefore, it is very common in commercial grassland and forests of the KZN Midlands (Hansen, 2015).

The KZN Mistbelt grassland, an indigenous grassland vegetation unique to KZN, is currently a top priority in conservation efforts. This is due to the irreversible transformation of over 90% of this biome, leaving only 0.3% formally designated as conservation areas (Reynolds & Symes, 2013; Scott-Shaw, 2001). The Mistbelt grassland holds significance not only due to its rarity as a biome but also because its decline has substantial implications for biodiversity. For example, the decline in suitable habitat and associated wetlands in the Mistbelt grassland is directly linked to the critical endangerment of avian species in South Africa, including the Blue

Swallow and Wattleed Crane (Barnes, 2000; Reynolds et al., 2012; Wakelin & Hill, 2007). The encroachment of *Rubus cuneifolius* (bramble) poses a significant threat to specialized grassland taxa, potentially resulting in the further conversion of grasslands into communities characterized by woodlands (Reynolds & Symes, 2013). Bramble amongst other IAPs is considered a threat to rangelands because it reduces the productivity of herbaceous plants and increases bush cover (Lesoli et al., 2013; Ward, 2005). In the long term, these affect the livestock industry by reducing forage species diversity, yield and quality, interfering with grazing accessibility, and poisoning animals (Lesoli et al., 2013). Techniques to manage established invaders in rangelands often succeed but have been constrained by being point-based and time-consuming. However, addressing these constraints could benefit from more fundamental research, encompassing basic spatially explicit advancements in monitoring technologies to advanced ecological modeling, and the utilization of low-cost remote sensing techniques (Simberloff et al., 2005).

The value of remote sensing to distinguish plant species and communities on rangelands is well established (Booth & Tueller, 2003; Hunt et al., 2003). Over the past decades, the integration of remote sensing (RS), geographical information systems (GIS), and global positioning system (GPS) technologies has been utilized for detecting, mapping, and monitoring the distribution of noxious rangeland plants (Hunt et al., 2003; Niphadkar & Nagendra, 2016). Mapping has become more accurate and feasible, thanks to significant advances in the spatial, temporal coverage, and spectral resolution of earth observation sensor technologies (Huang & Asner, 2009; Rowlinson et al., 1999).

Remote sensing applications are replacing traditional survey-based methods, which are both expensive and time-consuming (Govender et al., 2008). Numerous Earth observation sensors have been demonstrated to be effective in detecting and mapping IAPs (Dorigo et al., 2012; Laba et al., 2008; Royimani et al., 2019). For instance, Laba et al. (2008) utilised high-resolution 2.4m Quickbird imagery to detect *Phragmites australis*, *Lythrum salicaria*, and *Trapa natans* in a diverse wetland environment. They achieved an overall accuracy of  $\geq 65\%$  using a Maximum Likelihood classifier, underscoring the reliability of multispectral resolution sensors for mapping IAPs. Meanwhile, Fuller (2005) used IKONOS imagery with a 4m spatial resolution to detect paperbark trees when the cover was more than 50%. Despite achieving optimal accuracies in these studies, it is crucial to note that IKONOS and QuickBird, being fine spatial resolution commercial sensors, are associated with exorbitant image acquisition

costs. Therefore, there is a need to explore and assess other new-generation Earth observation sensors with comparable resolutions.

The Sentinel-2 Multispectral Instrument (MSI) is among the new generation of Earth observation sensors, featuring optimal resolutions ideal for detecting and monitoring IAP invasions, such as bramble, in rangeland ecosystems (Main-Knorn et al., 2017). Sentinel-2 satellites are equipped with the Multispectral Instrument (MSI), capable of recording 13 wide-swath bands at various resolutions ranging from 10 to 60 meters. The 13 bands cover the Visible-Near infrared/shortwave infrared (VNIR/SWIR) spectral regions and introduce two additional spectral bands in the red edge region. The new red edge bands make Sentinel-2 MSI unique from its predecessors such as Landsat, as this region of the electromagnetic spectrum is significant in vegetation mapping and analysis for several reasons. For instance, it is highly sensitive to chlorophyll content in plant leaves, which is crucial for assessing vegetation health (Bramich et al., 2021; Clevers & Gitelson, 2013b). Also, it is renowned for exhibiting minute variations in the spectral signatures of different species and vegetation types. Finally, this region is very sensitive to unique phenological variations of plants (Liu et al., 2021). This makes Sentinel-2 more suitable for characterizing IAPs like bramble in complex vegetated areas such as savanna rangelands.

Spectrally robust information, combined with advanced algorithms, has emerged as a critical tool in quantifying spectrally different land covers including the detection and mapping of IAP (Okujeni et al., 2014). Numerous algorithms such as discriminant analysis have been widely used to detect and map alien invasive species. For instance, (Lottering et al., 2020) utilized the discriminant analysis (DA) to map the invasive *Solanum mauritianum* in commercial forest plantations to optimal accuracies of 77%. Although other numerous studies have been conducted using a wide range of machine learning algorithms to assess bramble, there is a need to extend such research efforts by evaluating algorithms such as the DA in conjunction with Sentinel-2 MSI. In this regard, this study sought to explore the capability of Sentinel-2 MSI with red edge bands to detect and map the spatial distribution of bramble in a grassland ecosystem during the senescence stage of growth. It also sought to investigate the impact of bramble on the species productivity, dominance, and diversity of native grass species.

## 1.2. Aim and research objectives

The aim of this study was to explore the capability of Sentinel-2 MSI in mapping the spatial distribution of bramble (*Rubus cuneifolius*) and assessing its impact on veld species grass quantity, diversity, and dominance at farm scale in KwaZulu-Natal province, South Africa.

## 1.3. Specific objectives

The overarching aim of this study was addressed using the following specific objectives:

- To test the potential and strength of Sentinel-2MSI's red edge spectral data in discriminating the alien invasive *Rubus cuneifolius* during its senescent stage based on DA algorithm in the Mistbelt region of KwaZulu-Natal, South Africa.
- To evaluate the effect that bramble (*Rubus cuneifolius*) on diversity, dominance, and the overall biomass of native grass species.

## 1.4. Thesis structure

The main objective of this study was addressed through four chapters in a paper format. The first and last chapters serve as an introduction and synthesis, respectively, while the second and third chapters are standalone papers. Consequently, there are irreconcilable overlaps between these chapters. Specifically,

- **Chapter one** is an introductory chapter, providing the overall literature review of the study.

Chapters two and three are data chapters that are presented as independent research papers, formatted for submission to a peer-reviewed journal.

- **Chapter two** investigates the robustness of Sentinel-2 MSI's red edge bands in discriminating bramble (*Rubus cuneifolius*) in a senescent grassland ecosystem. Four sets of spectral features were used (spectral wavebands, modified normalized difference vegetation index (*mNDVI*), modified simple ratio vegetation index (*mSR*) and the combination of input variables) as classification inputs to discriminate bramble from other land cover types. All classification inputs were tested with red edge bands included (inclusive bands) against red edge bands not included (exclusive bands) in the analysis.
- **Chapter three** investigates the effect of the invasive bramble (*Rubus cuneifolius*) on rangeland grass production, species diversity and dominance. A method of estimating biomass was used to compare against the actual biomass in a patch invaded by bramble and in an uninvaded patch adjacent to it. All grass species were recorded and used to calculate species diversity and dominance for both patches.

- *Chapter four* provides a synoptic review of the study's objectives and the associated conclusions. It also highlights the implications of the study, the major conclusions as well as limitations of the study and recommendations for future research.

## **CHAPTER 2: EVALUATING THE ROBUSTNESS OF SENTINEL-2 MSI'S RED-EDGE BANDS IN DISCRIMINATING AN ALIEN INVASIVE BRAMBLE (*RUBUS CUNEIFOLIUS*) IN A SENESCENT GRASSLAND ECOSYSTEM**

### **Abstract**

Bramble (*Rubus cuneifolius*) is one of the most serious invasive alien plants (IAPs) in the Southern African grasslands, costing an estimated \$50.5 million worth of destruction per year. Earth observation facilities offer a cheap and efficient method of mapping the distribution of aggressive alien invasive plants such as bramble over large areas. The main objective of this study was to test the utility of red edge bands of Sentinel-2 multispectral instrument (MSI) satellite data in mapping the distribution of bramble in a grassland ecosystem during the annual senescence. Specifically, we compared the performance of all spectral bands (inclusive of red edge bands) in relation to selected spectral bands (exclusive of red edge bands). Four sets of spectral features were used as classification inputs to discriminate bramble from other land cover types. These were: (1) spectral wavebands, (2) modified normalized difference vegetation index (*mNDVI*), (3) modified simple ratio vegetation index (*mSR*) and (4) the combined optimal variables derived from the preceding three stages based on discriminant analysis (DA) algorithm. For all the spectral features, all spectral wavebands were compared with selected wavebands (exclusive of red edge) hereafter termed exclusive wavebands. The overall classification accuracies were 84.62% based on all spectral wavebands, 87.18% using exclusive wavebands, 89.33% for the *mNDVI* of all spectral wavebands, and 85.39% based on *mNDVI* derived from exclusive wavebands, 83.43% using *mSR* of all spectral wavebands, and 84.57% using the SR derived from exclusive wavebands. When all optimal wavebands were combined an overall accuracy of 85% was obtained. The most optimal wavebands for mapping bramble during the grass senescence stage were Bands 2, 3, 7, 11 and 12. These results underscore the optimal influence of Sentinel-2 MSI's visible, red edge and shortwave infrared (SWIR) wavebands in discriminating rangeland alien invasive species such as bramble during the senescing stage.

**Keywords:** Multispectral remote sensing, invasive alien plants, vegetation indices, discriminant analysis, Mistbelt grasslands.

## 2.1. Introduction

Ecosystems and economies worldwide have been threatened by invasive alien plants (IAPs) (Bradley & Mustard, 2006; Vitousek et al., 1996). The spread of IAPs at an alarming rate has displaced several native species, impacting ecosystem function and biodiversity, leaving systems heavily impacted (Pimentel et al., 2005). In rangeland ecosystems, these invasions are mostly due to inappropriate management practices such as overgrazing and fire suppression (van Wilgen et al., 2001). IAPs in rangelands can be grasses (annual, biennials and perennials), herbaceous perennials, shrubs or trees and are often associated with significant impacts on both humans and the environment (van Wilgen et al., 2001). IAPs in South Africa have decreased water resources by 7% over the past 20 years and this has resulted in an estimated cost of R600 million a year in attempts to clear them (van Wilgen et al., 2001). Some competitive invasive species can outcompete and replace high yields of favorable grass species thus reducing pasture quality (Pimentel et al., 2005).

One of the problematic invasive species in the South African mesic grasslands and savannas is a perennial shrub endemic to North America *Rubus cuneifolius* commonly known as the American bramble (Hansen, 2015). It was initially introduced for berry production but now has naturalized and invades a number of areas, mostly grasslands, plantations, forest edges, river banks and roadsides (Erasmus, 1984b). The efficient proliferation of bramble has left large areas infested with dense stands (Hansen, 2015) that are difficult, costly and time-consuming to control (Chappelka, 2002). This plant spreads by vegetative propagation and with its fine network of extensive roots can form extensive thickets which cause serious problems in areas it invades (Chappelka, 2002). It also rapidly expands invasion through long-distance seed dispersal by frugivorous avian and mammalian species (Denny & Goodall, 1991). It impacts species richness and diversity, grazing capacity, hydrology and other ecosystem functions. Bramble has rapidly invaded the cool, moist eastern parts of South Africa, particularly KwaZulu-Natal (KZN) and Mpumalanga provinces (Erasmus, 1984b). In the Mistbelt region of KwaZulu-Natal, it is considered one of the most severe woody plant invader species and has naturalized due to a lack of predators as well as favorable environmental conditions in the area (Erasmus, 1984b). For example, Reynolds & Symes (2013) noted that grass species diversity and richness were lower in bramble-invaded sites than in sites clear of bramble in the KZN Mistbelt grasslands. In addition, bramble has the potential to reduce rangeland productivity as well as grazing capacity. Therefore, proper condition assessments of rangelands maintained for grazing are crucial for the determination of long-term grass productivity since it is the main

source of animal feed and provides resources for rural communities (Pickup et al., 1994; Pullanagari et al., 2012; Ramoelo et al., 2015). In order to assess the environmental impacts as well as possible control options for IAPs such as bramble, there is a need for rapid and efficient data and tools that could be used to accurately determine their current distribution and extent.

In recent years, traditional field surveys have been replaced by efficient and timeous technologies such as remote sensing techniques for detecting and mapping plant species over large areas (Mutanga et al., 2004; Peerbhay et al., 2016). Remote sensing-based rangeland assessments are less costly while offering near-instant results when compared with conventional field-based techniques (Pickup et al., 1994). In addition, satellite data can be archived which is an added advantage, especially for long-term monitoring. Multispectral remote sensing, in particular, is a cost-effective source of obtaining spatial information on alien infestations rapidly and over large areas (Dube et al., 2017; Feilhauer et al., 2013). Many of the alien invasive species with unique growth forms and phenologies have been identified using this technique (He et al., 2015). New optical missions such as Sentinel-2 Multispectral Instrument (MSI) and Landsat 9 operational land imager (OLI) are increasingly becoming relevant to the field of biological conservation and ecology, offering researchers optimal spatial resolution imagery that can be freely accessed with global coverage (He et al., 2015). Furthermore, such sensors can yield high classification accuracies and can be successfully applied to rangeland management (Sibanda et al., 2016).

Sentinel-2 MSI satellite data offers a high multispectral resolution with improved data availability, complementing and ensuring the continuity of Landsat and SPOT (Clevers & Gitelson, 2013; Delegido et al., 2011; Drusch et al., 2012; Frampton et al., 2013). Sentinel-2 MSI offers data with a high spectral resolution ranging from 10m to 60m ground sampling distance and covering global land surfaces (Drusch et al., 2012). Additionally, the high-resolution spatial information is attributed to an orbital level of approximately 800km, with a swath width of 290km and a 5-day revisit time at the equator, allowing near-real time multi-temporal data suitable for mapping IAPs such as bramble (Atzberger & Richter, 2012; D'Odorico et al., 2013; Drusch et al., 2012). The red edge wavebands are among the 13 bands that form part of the electromagnetic spectrum along with visible, near-infrared and shortwave infrared (Drusch et al., 2012). The presence of red edge bands and the incorporation of the shortwave infrared in the spectral configuration of Sentinel-2 MSI is important for vegetation assessment and monitoring and is comparable with RapidEye and WorldView-2 satellite data (Ramoelo et al., 2015). Meanwhile, the inclusion of these red edge wavebands in the Sentinel-

2 MSI sensor enhances its capacity for distinguishing between various vegetation types, setting it apart from its predecessors, Landsat 8 and 9 (with OLI1 & 2 sensors), which lack these critical spectral bands and offer a lower spatial resolution of 30 meters. The four bands within the red edge region (Band 5, 6, 7 and 8A) of Sentinel-2 MSI have been reported to provide better discrimination and identification of species at large scales by widening the spectral window (Shoko & Mutanga, 2017). Furthermore, these wavebands are invaluable in estimating chlorophyll content at ranging scales for enhanced plant productivity assessments (Clevers & Gitelson, 2013; Schuster et al., 2012). Other than the optimal spectral resolution of this sensor, a robust spectral derivative could provide robust information suitable for discriminating IAPs such as bramble. Spectral derivatives such as vegetation indices have been renowned for their optimal performance. Vegetation indices such as normalized difference vegetation index (NDVI) and simple ratio vegetation indices (SR) from its five narrow spectral bands sampling the regions between 0.6- 0.9 $\mu$ . have been extensively proven to be robust and to exhibit optimal discrimination accuracies (Ramoelo et al., 2015). For example, Shoko & Mutanga (2017) illustrated that the vegetation indices extensively improve the classification accuracies when discriminating between *Festuca* and *Themeda* in a natural grassland of Drakensberg mountains. It is widely hypothesised that the combination of Sentinel-2 MSI's vegetation indices, red edge wavebands as well as its optimal spatial resolution could significantly improve the accuracy of mapping the invasive bramble from a plot to landscape scales. Although there have been attempts at this, the relative performance of modified vegetation indices (VI) has not been extensively tested in discriminating IAPs such as bramble, especially during senescence stage.

However, many studies conducted on IAPs focused on discriminating them from other vegetation species only during the growing and greening up phenological. For example, Rajah et al. (2018) successfully explored the potential of two freely available multispectral sensors, including Sentinel-2 MSI, in mapping bramble during the flowering phenological stages (spring and summer). Features of Sentinel-2 MSI satellite data offer a platform for exploring and understanding the spatial distribution of bramble or any other IAPs especially during the senescent stage of grasslands when livestock forage is critically required.

In that regard, this study sought to test the potential and strength of Sentinel-2MSI's red edge spectral data in discriminating the alien invasive *Rubus cuneifolius* during its senescent stage based on DA algorithm in the Mistbelt region of KwaZulu-Natal, South Africa. Monitoring senescing grasslands using Sentinel-2 MSI could be particularly useful, especially when

conducting long-term or seasonal research on the effects of grassland ecosystems, considering forage availability.

## **2.2. Materials and methods**

### *2.2.1. Study site*

This study was conducted at Wakefield Research Farm in Fort Nottingham (Figure 2.1.), classified as Drakensberg foothill moist grassland in KwaZulu-Natal province of South Africa (Mucina and Rutherford 2006). The area is located at 29°29'13.23"S and 29°53'52.73"E. Wakefield Farm specialises in beef production from indigenous grasslands. The study area experiences a distinct climate pattern with summer rainfall spanning from October to April, followed by dry and cold winters from May to September. The vegetation is dominated by highland sourveld grasslands with *Themeda triandra*, *Tristachya leucothrix*, patches of indigenous bush clumps, and moist grasslands of the Drakensberg foothill and Mooi River highland grassland. The temperatures range from 9°C to 32°C with 975 mm average annual rainfall occurring mostly in summer. It snows occasionally and frost is common for at least four months in a year. This region has an altitude range of 800 to 1 860 m above sea level. The terrain is mountainous with undulating hills, wetlands and river gorges (Mucina and Rutherford 2006). Domestic livestock and wildlife species are found in this area. Urban sprawl, cultivation and plantation are the major causes of the approximated 20% transformation of this region. In addition, *Rubus cuneifolius* is considered as one of the most severe invader plants in this area along with *Solanum mauritianum* and *Acacia mearnsii* (Mucina and Rutherford 2006).

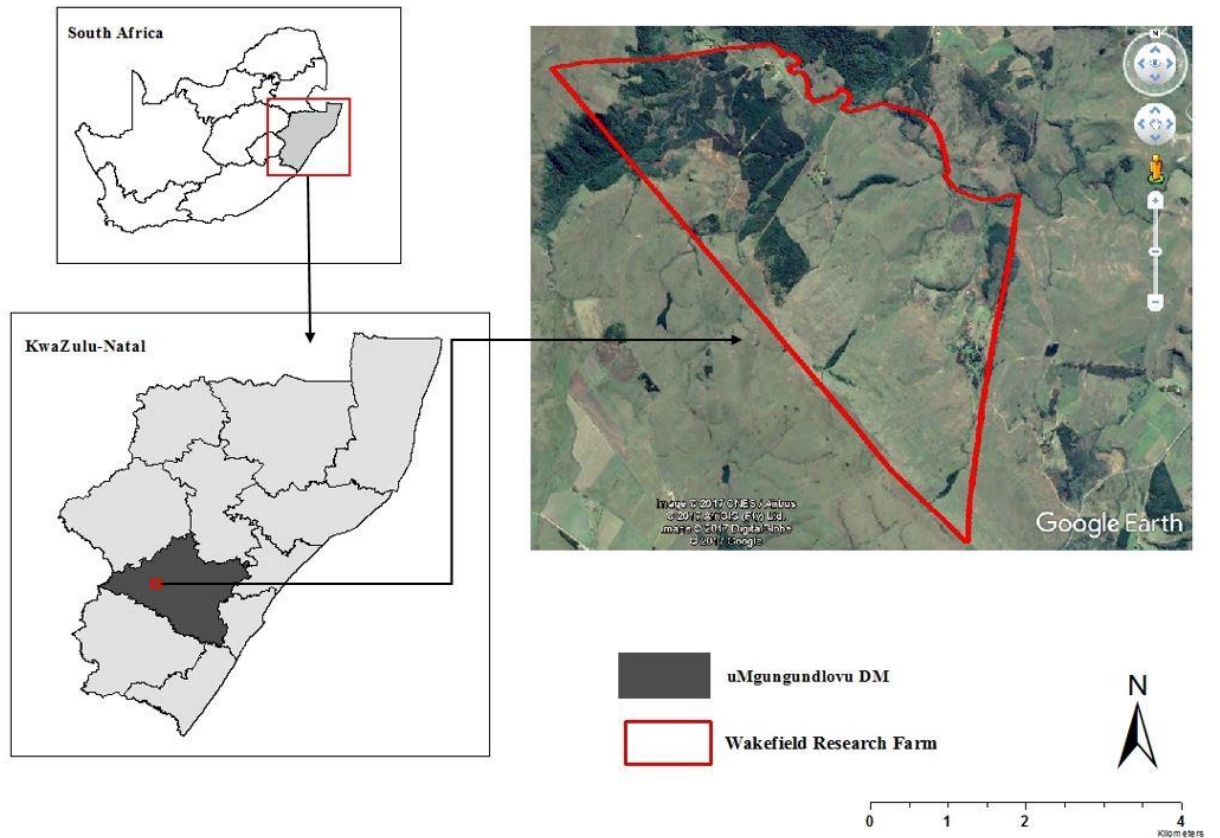


Figure 2.1.: Wakefield Research Farm, uMgungundlovu District Municipality

### 2.2.2. Field data acquisition

A field survey was conducted in May 2017. To map the distribution of bramble in Wakefield Farm, a handheld Garmin eTrex10 GPS, with an accuracy of  $\pm 5$  m, was used to capture the locations of senescing bramble (Figure 2.2.) and other land cover types captured randomly within the farm. The GPS data were recorded in a Microsoft Excel spreadsheet and were imported into ArcGIS 10.4 software as a point shapefile. In total, six classes were recorded from Wakefield Farm including bramble (163), built-up (19), water (22), grass (22), forest (21) and riparian vegetation (20). An average of 20 points were recorded per land cover class with a higher number for bramble, adding up to a total of 267 points.



Image by: everyday nature trails

Figure 2.2.: A typical image of bramble leaves yellowing during the senescent stage of growth

### *2.2.3. Remotely sensed data and image processing*

A cloud-free Sentinel-2 MSI image was also downloaded in May 2017, coinciding with the field data collection. The 13 spectral bands of this sensor cover the coastal aerosol, blue, green, red, red edge, NIR, and SWIR spectrums (Table 2.1.). For the purpose of this study, bands 1, 9 and 10 were excluded as they are not relevant for vegetation assessments. The imagery was freely accessed from the USGS Earth Resources Observation and Science Centre archive (<https://earthexplorer.usgs.gov/>). The Sentinel-2 MSI satellite data were pre-processed using Sen2Cor toolbox version 2.3.0, a third-party plugin tool from European Space Agency used for atmospheric correction before analysing them. The terrain and cirrus correction were also conducted using Sen2Cor. After image pre-processing, spectral signatures of each point were extracted using the spatial analyst tool in ArcMap 10.4 for each of the Sentinel-2 MSI bands used.

Table 2.1.: Sentinel 2 MSI band characteristics

Band	Resolution (m)	Wavelength (nm)
<b>Band 1 (Coastal aerosol) *</b>	60	443
<b>Band 2 (Blue)</b>	10	490
<b>Band 3 (Green)</b>	10	560
<b>Band 4 (Red)</b>	10	665
<b>Band 5 (Vegetation Red Edge)</b>	20	705
<b>Band 6 (Vegetation Red Edge)</b>	20	740
<b>Band 7 (Vegetation Red Edge)</b>	20	783
<b>Band 8 (NIR)</b>	10	842
<b>Band 8a (Vegetation Red Edge)</b>	20	865
<b>Band 9 (Water Vapour) *</b>	60	940
<b>Band 10 (SWIR-Cirrus) *</b>	60	1375
<b>Band 11 (SWIR)</b>	20	1610
<b>Band 12 (SWIR)</b>	20	2190

\* Represents bands that were not used in the classification analysis

Modified normalized difference vegetation index (*mNDVI*) and modified simple ratio vegetation index (*mSR*) were then computed using two possible band combinations from the preprocessed Sentinel-2 MSI bands. The *mNDVI* was calculated based on the formula  $(\text{Band1} - \text{Band2}) / (\text{Band1} + \text{Band2})$  while *mSR* was calculated using the formula  $\text{Band1} / \text{Band2}$  where Band1 and 2 are two different Sentinel-2 MSI bands exclusive of Bands 1, 9 and 10. To evaluate the importance of red edge wavebands in mapping bramble, four sets of spectral features were used as classification input to analyze extracted spectral data (Table 2.1). Particularly the red edge derivatives were separated from others and used as detailed in Table 2.2.

Table 2.2.: Spectral features used for the classification of bramble. \*Exclusive wavebands (bands used in the analysis except for bands 5,6,7 and 8a)

Analysis	Input variables
Analysis 1	Spectral bands data, all spectral wavebands (including red edge bands) vs exclusive wavebands (excluding red edge bands)
Analysis 2	NDVI (all spectral wavebands vs exclusive wavebands)
Analysis 3	SR (all spectral wavebands vs exclusive wavebands)
Analysis 4	The combination of all the above input variables (all spectral wavebands vs exclusive wavebands)

#### 2.2.4. Discriminant analysis

Before conducting the classification, descriptive statistics which include analysis of variance (ANOVA) were conducted to explore and understand the data. For instance, ANOVA was used to assess whether there were windows of spectral separability between the classes using Sentinel-2 spectral settings. Specifically, we tested whether there were significant differences between the reflectance of different classes considered in this study. To discriminate bramble from other land cover types in the study area, a discriminant analysis (DA) algorithm was used. DA is a multivariate statistical technique in XLSTAT 2017 software which is an add-in tool for Microsoft Excel. DA is an algorithm developed in 1936 by R.A. Fisher for classification. It evaluates the variability between classes, thereby obtaining better separation between classes. In addition, data classes are modelled with the aim of reclassifying an object with low error risk (Amaral et al., 2004). Classification accuracy was done for each of the variable inputs that were investigated in this study. In conducting classification accuracy assessment particular attention was drawn to determining models (Table 2.2.) and specific variables that yielded the highest accuracy. Those with higher accuracies were regarded as better at discriminating bramble from other land cover types. ANOVA was used to determine the reflectance characteristic of the land cover types obtained from the DA algorithm. This classifier was chosen because it is used by researchers when trying to explain the dependent and the independent variables.

### 2.2.5. Image classification accuracy assessment

Prior to the analysis, the spectral dataset was randomly split into 30% testing and 70% training samples. Error matrix tables were generated from each classification. The matrix tables for each of the inputs were used to calculate the producer accuracy (PA), user accuracy (UA), overall accuracy (OA). Allocations of agreement and disagreement (omission and commission errors) between field data and classification results were generated using Pontius and Millones allocation spreadsheet (Jr and Millones).

## 2.3. Results

### 2.3.1. Spectral characterization of land cover types

Based on ANOVA exploratory data analysis, bands from the red edge and the short-wave infrared illustrated spectral separability between bramble and other land cover types. Figure 2.3. shows the best regions of spectral separability between bramble and other land cover types. It can be observed that bramble could be optimally differentiated from other land cover types when using wavebands 7, 11 and 12. The discrimination of bramble from other land cover types was highest at 783nm and between 1610 and 2190 nm.

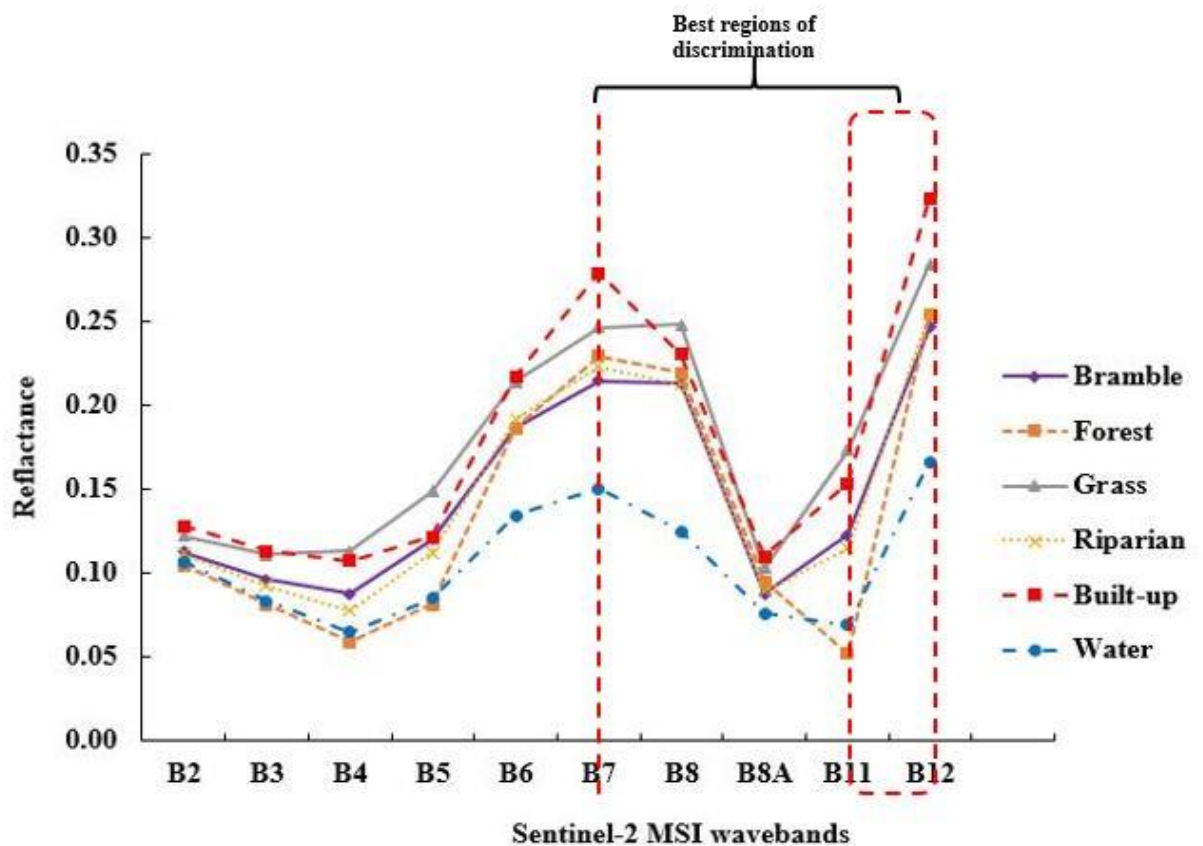


Figure 2.3.: Spectral characteristics of bramble and other land cover types based on ANOVA

### 2.3.2. Image classification accuracy assessment

Tables 2.3. to 2.8. shows confusion matrices derived from Sentinel-2 MSI in conjunction with the DA algorithm. Tables 2.3. to 2.8. display overall accuracies ranging from 83 to 89% based on wavebands (inclusive and exclusive of red edge bands) as well as derived vegetation indices. It can be observed that *mNDVI* derived from all spectral wavebands exhibited the highest overall classification accuracy of 89.33% whereas the *mSR* of exclusive wavebands exhibited the lowest overall accuracy of 83.43%. For all the classification input variables, higher accuracies were obtained when red edge bands were included in the analyses. Figure 2.4. illustrates that bramble was mapped to a user accuracy (UA) of 98% and producer accuracy (PA) of 88%. Grass and forest classes were classified with 100% PA. Built-up was classified by 100% of both user and producer accuracies.

### 2.3.3. Analysis of spectral features

#### 2.3.3.(i) Spectral bands data

When all spectral wavebands (inclusive bands) were used, an accuracy of 85% was obtained and an accuracy of 87% was then obtained when red edge bands were excluded from the analysis (Figure 2.6.). Therefore, the generic VIS, NIR and SWIR wavebands were better at classifying bramble when the red edge bands were excluded from the analysis. Based on the Pontius and Millones (2008) classification accuracy assessment (Figure 2.5. (b)), the omission error was higher followed by the agreement error in classifying bramble. There were no allocations for classification errors for built-up and so 100% user and producer accuracies were obtained (Figure 2.4.). Figure 2.5. (a) is variable importance scores showing that VIS (Band 2 and 3), red edge (Band 7 and 8A) and SWIR (Band 12) were the most influential bands in discriminating bramble from other land cover types.

#### 2.3.3.(ii) Vegetation indices

The *mNDVI* derived from inclusive bands was more robust at discriminating different land cover types from bramble whereas *mSR* derived from exclusive wavebands better discriminated bramble from other land cover types (Figure 2.5.(b)). When using vegetation indices to discriminate bramble from other land cover types, *mNDVI* exhibited a highest Overall classification accuracy of 89% when red edge bands were included in the analysis. Across all inputs the *mSR* displayed the lowest percentage for all analyses (83%).

### 2.3.3.(iii) Combination of inputs

The combination of all the spectral inputs from the preceding analysis stage showed that there was no relative difference between the inclusion and exclusion of red edge bands in the analysis. A classification accuracy of 85% was obtained for both the exclusive and inclusive data for combined variables.

### 2.3.4. Production of distribution map

Figure 2.7. displays the distribution of bramble in a grassland ecosystem of Wakefield Farm during the senescence stage from a Sentinel-2 MSI satellite data. To generate the map, the input that yielded the highest classification accuracy was used which was *m*NDVI inclusive of red edge bands.

Table 2.3.: Discriminating bramble from other land cover types using all spectral (inclusive) wavebands.

from \ to	Bramble	Forest	Grass	Riparian	Settlement	Water	Total	% correct
Bramble	45	0	0	1	0	0	46	97.83%
Forest	0	4	0	0	0	3	7	57.14%
Grass	1	0	4	0	0	0	5	80.00%
Riparian	4	0	0	3	0	1	8	37.50%
Settlement	0	0	0	0	4	0	4	100.00%
Water	2	0	0	0	0	6	8	75.00%
Total	52	4	4	4	4	10	78	84.62%

Table 2.4.: Discriminating bramble from other land cover types using exclusive wavebands

from \ to	Bramble	Forest	Grass	Riparian	Settlement	Water	Total	% correct
Bramble	45	0	0	1	0	0	46	97.83%
Forest	0	4	0	0	0	3	7	57.14%
Grass	1	0	4	0	0	0	5	80.00%
Riparian	3	0	0	4	0	1	8	50.00%
Settlement	0	0	0	0	4	0	4	100.00%
Water	1	0	0	0	0	7	8	87.50%
Total	50	4	4	5	4	11	78	87.18%

Table 2.5.: Discriminating bramble from other land cover types using *m*NDVI computed from inclusive wavebands

from \ to	Bramble	Forest	Grass	Riparian	Settlement	Water	Total	% correct
Bramble	112	0	1	0	0	0	113	99.12%
Forest	0	16	0	1	0	1	18	88.89%
Grass	4	0	11	0	0	0	15	73.33%
Riparian	3	1	0	4	0	0	8	50.00%
Settlement	3	0	1	0	6	1	11	54.55%
Water	1	0	1	0	1	10	13	76.92%
Total	123	17	14	5	7	12	178	89.33%

Table 2.6.: Discriminating bramble from other land cover types using *m*NDVI of exclusive wavebands

from \ to	Bramble	Forest	Grass	Riparian	Settlement	Water	Total	% correct
Bramble	111	0	2	0	0	0	113	98.23%
Forest	0	16	0	0	0	2	18	88.89%
Grass	4	0	11	0	0	0	15	73.33%
Riparian	5	1	0	1	0	1	8	12.50%
Settlement	3	0	1	1	5	1	11	45.45%
Water	3	1	1	0	0	8	13	61.54%
Total	126	18	15	2	5	12	178	85.39%

Table 2.7.: Discriminating bramble from other land cover types using *m*SR computed from inclusive wavebands

from \ to	Bramble	Forest	Grass	Riparian	Built-up	Water	Total	% correct
Bramble	101	0	2	2	0	0	105	96,19%
Forest	0	9	0	2	0	0	11	81,82%
Grass	7	0	11	0	0	0	18	61,11%
Riparian	5	1	0	8	0	0	14	57,14%
Built-up	5	0	0	1	5	2	13	38,46%
Water	1	0	0	1	0	12	14	85,71%
Total	119	10	13	14	5	14	175	83,43%

Table 2.8.: Discriminating bramble from other land cover types using *mSR* of exclusive wavebands

from \ to	Bramble	Forest	Grass	Riparian	Settlement	Water	Total	% correct
Bramble	103	0	1	1	0	0	105	98.10%
Forest	0	9	0	1	0	1	11	81.82%
Grass	6	0	12	0	0	0	18	66.67%
Riparian	8	1	0	3	0	2	14	21.43%
Settlement	3	0	0	0	8	2	13	61.54%
Water	1	0	0	0	0	13	14	92.86%
Total	121	10	13	5	8	18	175	84.57%

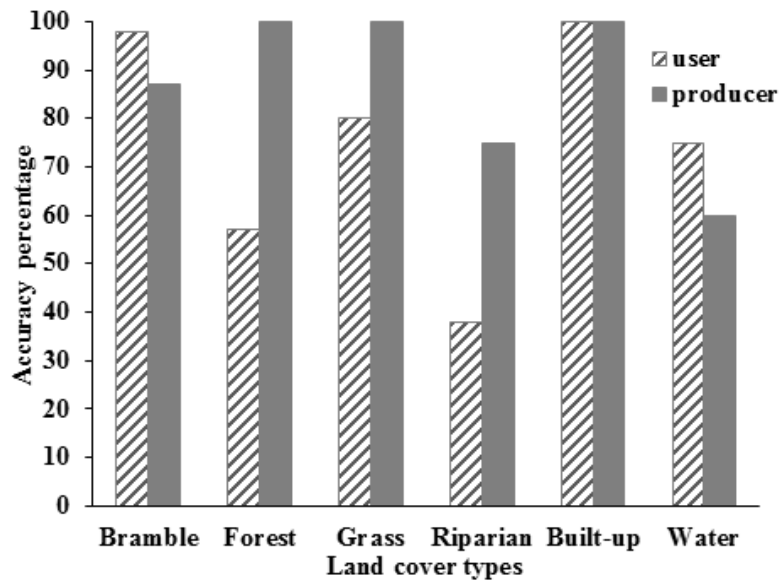


Figure 2.4.: Percentages of user and producer accuracy from the matrix table

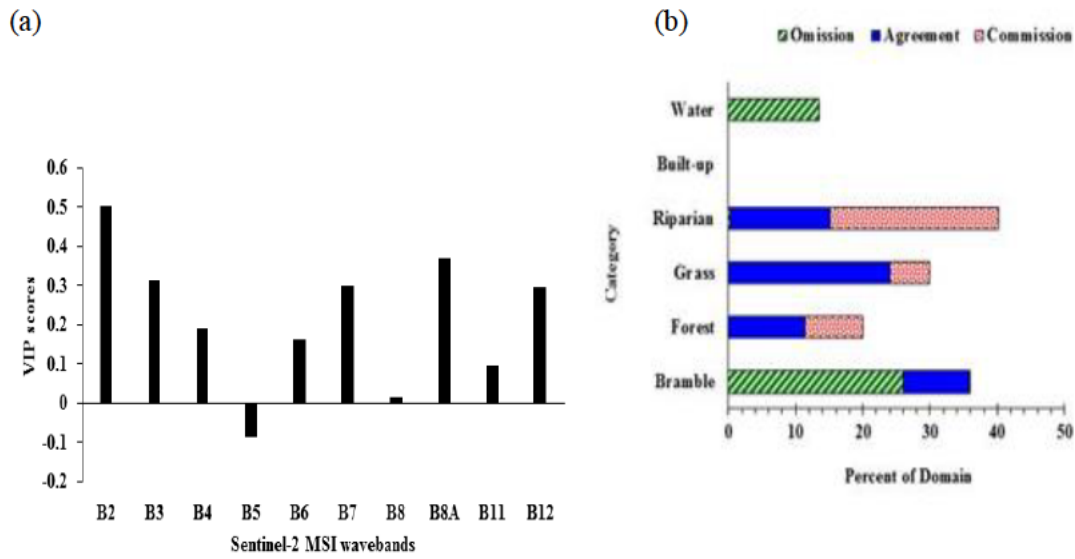


Figure 2.5.: (a) Variable importance scores of Sentinel-2 MSI's most optimal bands in classification based on DA. (b) Classification accuracies of Sentinel-2 MSI satellite data

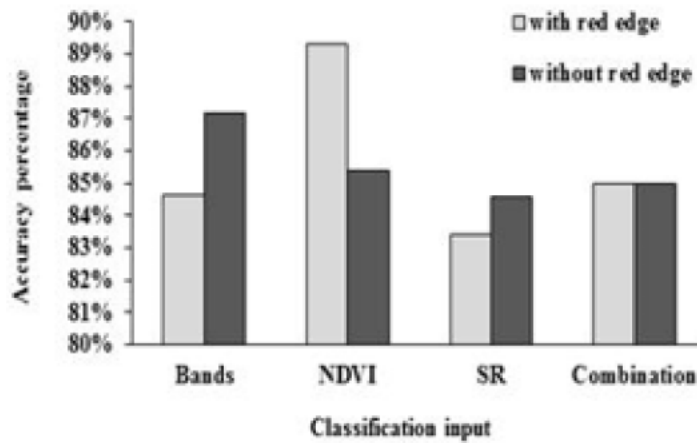


Figure 2.6.: Overall accuracy percentages of classification input variables analyzed

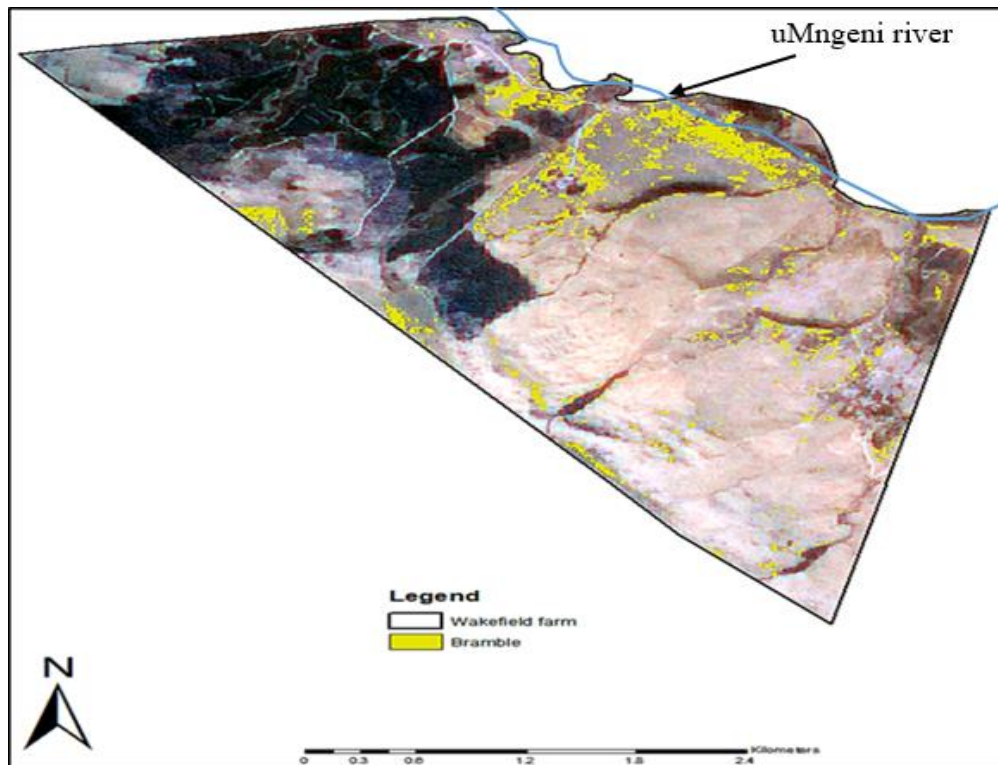


Figure 2.7.: The distribution of bramble from a Sentinel-2 MSI satellite data in a grassland ecosystem during the senescent phase

#### 2.4. Discussion

The main objective of this study was to test the robustness of Sentinel-2 MSI satellite data in discriminating bramble in a grassland ecosystem during its senescent state of growth. Furthermore, this study sought to determine the strength of Sentinel-2 MSI's red edge bands in mapping the invasive bramble. Accurate mapping of alien invasive species is critical, especially for management, eradication as well as sustainable control (Dube et al., 2017).

The results demonstrated that Sentinel-2 MSI combined with the DA algorithm optimally discriminated bramble from other land cover types during its senescence state in a grassland ecosystem. The distribution of bramble in this state was effectively detected at a high accuracy (Overall accuracy = 85%), based on the DA algorithm. This means that the classification of the senescent bramble from other land cover types of this grassland ecosystem is not dependent on the presence or absence of red edge bands. For this study, bramble leaves lacked chlorophyll during the classification process and thus displayed an orange-yellow colour. Filella & Penuelas (1994) and several authors have described red edge bands to be sensitive to chlorophyll concentration. This implies that the red edge bands were not influential in detecting the senescent bramble leaves. Literature indicates that it is often easier to detect a target plant

species if it has different phenological attributes from its community members. For example, *Euphorbia esula* was optimally detected in the visible section of the electromagnetic spectrum because of its spectrally yellow-green leaves which are unique from other vegetation species in the vicinity (Evangelista et al., 2009).

When spectral bands data was used (Analysis 1), the performance of wavebands was higher than when the red edge bands were excluded from the analysis (87.18%). Nevertheless, this difference was not significant when compared to the analysis that included the red edge bands, resulting in an accuracy of 84.62%. These results suggest that red edge wave bands are not influential in mapping bramble during the early stages of senescence. When comparing all the inputs analysed, *mSR* produced the lowest classification results (83.43% with red edge and 84.57% without red edge) and *mNDVI* computed the highest classification results (89.33% with red edge and 85.39 without red edge). This implies that spectral bands and *mNDVI* were better discriminators of bramble from other landcover types during the senescence stage when compared with *SR* in this study.

Earlier studies implied that *NDVI* can be used to distinguish different vegetation species as well as estimate different plant attributes such as above ground biomass and leaf area index (*LIA*) between seasons and across different phenological stages (Pettorelli et al., 2005). The optimal performance of *NDVI* could be attributed to the fact that it is sensitive to bramble whereas it optimally suppresses atmospheric noise, view/sun angle, soil background as well as topographic effects (Sibanda et al., 2020). Furthermore, vegetation indices are derived from two or more bands that are more robust in detecting vegetation characteristic variations when compared with single bands which are more susceptible to background effects (Bannari et al., 1995), hence its optimal performance in discriminating bramble in this study. *NDVI* derived from all spectral wavebands yielded the highest accuracy (89.33%) when compared to all other inputs. Since the data were collected during the dormant season, *NDVI* was anticipated to exhibit lower classification accuracies. Our results illustrate the robustness of *NDVI* considering its optimal performance in discriminating bramble from other land cover types in its senescent state (discolored and yellow leaves).

The optimal wavebands derived in this study to characterize bramble were bands 2, 8A, 3, 7 and 12, in order of importance (Figure 2.5. (a)). The *VIS* spectrum, specifically, Band 2 was the optimal band compared to other Sentinel-2 wavebands in discriminating bramble. The Blue Band 2 is described as a waveband that is sensitive to senescing vegetation, carotenoids, and

vegetation browning (ESA, 2010). The optimal performance of the visible spectrum of the electromagnetic spectrum indicated in this study is in agreement with the findings by Carter (1993), who noted that the reflectance of plants on visible wavelengths (i.e., Blue and Red regions) increases with the increase in the stress levels on the leaves of vascular plants. Moreover, Band 2 is among the four finer resolution wavebands (10 m bands) which could explain its optimal performance when compared to other optimal wavebands. Fine spatial resolutions facilitate the detection of minute changes in vegetation properties in relation to coarse spatial resolutions. Band 8A and 3 which are the red edge and the green wavebands, respectively were also among the optimal bands that optimally discriminated bramble from other land cover types in this study. This could be attributed to their sensitivity to chlorophyll loss due to vegetation senescence. Subsequently, wavebands in the green and red edge (band 3 and 8A) can be used as a SR index combination to discriminate the senescing vegetation (ESA Sentinel online, 2018). The SWIR bands also optimally contributed to the discrimination of bramble. As noted by Reynolds & Symes (2013), it can be observed from Figure 2.7. that bramble mostly invaded moist areas at proximity to uMgeni River which runs adjacent to the farm. Bramble is known to also have dense stands found in valley and along water courses (Erasmus, 1984b)

## **2.5. Implications and conclusion of the study**

The main objective of this study was to investigate the robustness of Sentinel-2 MSI's red edge bands in discriminating bramble during senescence based on DA algorithm. Mapping *Rubus cuneifolius* in grasslands during the senescing stage of growth was an unfamiliar approach compared to other studies that have been conducted to map this invasive plant. Findings suggest that the Sentinel-2 MSI sensor is important for mapping bramble during its browning phase, and it is most optimal when red edge bands are included in NDVI analysis based on DA algorithm. Also, based on the findings of this study we conclude that bramble can be better discriminated from other grassland ecosystem plants using Sentinel-2 MSI data's visible (Band 2), short wave infrared bands (Bands 11 and 12) and red edge (Band 8A) wavebands during the senescence stage in relation to red-edge bands. Although Sentinel-2 MSI data has proven to be invaluable in discriminating bramble during the dry season in a grassland ecosystem it still has to be tested in mapping other grassland IAPs. In this regard, this freely available sensor offers an opportunity for the investigation of IAPs and their effects on grass availability as well as grazing capacity in grassland ecosystems. Such sensors can also be successfully applied for

long-term monitoring activities that are not dependent on season for informed decision-making with regards to the management of IAPs as such bramble.

## **2.6. Acknowledgements**

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### CHAPTER 3: THE EFFECT OF THE INVASIVE BRAMBLE (*RUBUS CUNEIFOLIUS*) ON RANGELAND GRASS PRODUCTIVITY, SPECIES DIVERSITY AND DOMINANCE.

#### Abstract

Rangeland managers globally are faced with a problem as the value of grazing land is reduced due to invasive alien plants (IAPs). They change the composition, structure and functions of grassland systems by displacing important native species. Limited research has been conducted on the effect of IAPs on livestock production and grass productivity, particularly at local scales in the context of Southern Africa. Therefore, this study sought to investigate the effect of the invasive bramble (*Rubus cuneifolius*) on rangeland biomass, species diversity and richness using the dry weight rank (DWR) and double sampling techniques. Two patches were investigated, one invaded with bramble and an adjacent patch that was clear of bramble based on the DWR technique. A Shannon Wiener Diversity Index was used to calculate species diversity and a Simpson's Index was used to calculate species dominance between studied patches. To achieve the above objectives, the study tested (i) if there was a significant relationship between the estimated biomass and the actual dry matter yield, and (ii) whether there were significant differences in the amount of grass above-ground biomass and species diversity between the invaded patch and the uninvaded patch. It was hypothesised that the production and species diversity would be higher in the uninvaded patch than in the invaded patch. A significant relationship was obtained between the estimated biomass and the actual dry matter yield in both the invaded and the uninvaded patches ( $R^2$  of 0.8028 and 0.8407, respectively). A test of proportions showed that there were statistically significances (alpha at 0.05) in the amount of biomass between the two patches. The total biomass was higher in the invaded patch (2136 kg/ha) when compared to the uninvaded patch (1887 kg/ha). However, relatively more palatable species were recorded in the uninvaded site in relation to the invaded site. *Eragrostis curvula* contributed the highest biomass percentage in the invaded site while *Hyparrhenia hirta* was highest in the uninvaded site. There was higher species diversity and lower species dominance in the uninvaded patch. In the invaded patch there was a lower species diversity and higher dominance. Desirable grassland species are diminishing and clearing the problematic bramble should be a priority for a sustainable rangeland. The results of this study underscore the notion that bramble invasion reduces the value of rangeland by decreasing the productivity of palatable grass species.

**Key words:** Grass biomass, dry weight rank, species, double sampling, Mistbelt grassland, invasive alien plants.

### **3.1. Introduction**

There is increasing concern about the impact of biological invasions (Mooney, 2005; van Wilgen et al., 2012). They are globally the most serious and increasingly destructive phenomenon for many ecological systems, including rangelands (D'Antonio & Meyerson, 2002). In South Africa, about 10 million hectares (more than 10%) of land area is currently impacted by invasive alien plants (IAPs). As a result, the integrity of natural and agricultural systems has been threatened by IAPs (Callaway & Aschehoug, 2000; Gwate et al., 2016). They have the ability to competitively eradicate neighboring native plants by aggressive competition (Gordon, 1998; Hoffmann et al., 2004). Sometimes a species may not be invasive but can have the ability to significantly alter the structure, composition as well as the normal functioning of a certain plant community (D'Antonio & Vitousek, 1992; Gordon, 1998; Gwate et al., 2016). High interspecific competition of IAPs is one of the major attributes which facilitate their successful invasions (Vilà & Weiner, 2004). According to Parker & Reichard (1998) and Vilà & Weiner (2004) there is evidence produced from field observations that suggests that competition from IAPs is the main reason for the decrease in native species populations. Native biodiversity provides environmental services that are a driving force of ecosystem functioning and stability (Masocha & Skidmore, 2011). In a variety of contexts, including rangelands, species richness and species diversity have been identified as two indicators of ecosystem health (Symstad & Jonas, 2011).

The primary productivity of species is influenced by species richness (Wilsey & Wayne Polley, 2006). Therefore, as reported by Rapport et al. (1985) species loss should be an indicator of stress in an ecosystem. The abundance of productive and palatable grass species is also a good indicator that the veld is suitable for carrying grazing livestock. Different grass species react differently to grazing pressure and so species diversity is a good indicator of veld condition in rangelands. Grass species composition and abundance of important species are some of the most important elements of veld condition monitoring. The underlying management problems in rangelands are often visible with the presence and spread of IAPs (Masters & Sheley, 2001b). Symstad & Jonas (2011) believe that IAPs can either have negative or positive impacts on the species diversity and richness as some alien species add diversity or richness to the ecosystem with little or no impacts on the native species. The Working for Water programme, which is aimed at reducing the density of terrestrial IAPs in catchments and waterways envisages that

clearing IAPs provide opportunities for increased water and grass productivity for rangeland farmers (Gwate et al., 2016).

On natural rangelands, livestock farming is globally the most common type of land use (Driscoll et al., 2014; Macdonald, 2004) since they occupy up to 30% of the land area (Steinfeld, 2006). In that regard, as population growth and consumption per capita increase, there is a growing demand for livestock production and, therefore, it is expected to increase by more than 50% by 2020. But rangeland farmers are concerned with the reduction in the value of grazing land by aggressive IAPs (Macdonald, 2004), which in turn will result in a reduction in livestock production and, therefore, the reduction in the economy and in food security. The economy of human enterprises such as grazing, forestry and agriculture have been largely affected by IAPs (Shackleton et al., 2007). South Africa has had little focus on the study of the IAP impacts on livestock production, especially at local scales (Shackleton et al., 2015; Yapi et al., 2018). However, several examples have been presented where native species have been displaced by AIPs.

American Bramble (*Rubus cuneifolius*) is one of the IAPs that cause serious impacts on the productivity of native grass species in grassland ecosystems of Southern Africa. It was originally introduced to South Africa from America for berry production in the 1900s (Erasmus, 1984b). This bramble has since become naturalized and is now prolific in the eastern parts of South Africa, especially KwaZulu-Natal and Mpumalanga provinces. This is not surprising since the Natal Midlands in KwaZulu-Natal province is ranked second of the most stressed areas in the country due to alien invasive species after the Cape Floral Kingdom (Binns et al., 2001). Bramble is currently listed under the category of invasive species of South Africa that should be controlled, destroyed or removed as soon as the infestation is spotted (category 1b). It mostly invades grasslands, forests and grows prolifically in disturbed sites (Hansen, 2015). It restricts access to grasslands and forests with its impenetrable and prickly dense stands. It also limits grazing and water access for livestock and wild animals in grasslands (Erasmus, 1984b).

In this paper, the major objective is the evaluation of the effect that American Bramble (*Rubus cuneifolius*) on grassland ecosystems has on the productivity of native grass species. This will be achieved by evaluating the effect that bramble has on the diversity, dominance as well as overall biomass of grass species in a rangeland ecosystem. It is hypothesised that invaded patches will have less production and species diversity when compared to the uninvaded patch.

## 3.2. Materials and methods

### 3.2.1. Study Area

This study was conducted at Wakefield Farm near Fort Nottingham (29°29'13.23"S; 29°53'52.73"E) in KwaZulu-Natal province, South Africa. The farm occupies 527 ha of land and is used for beef production. Wildlife and domestic livestock are found grazing off indigenous grasses in this area. The study area falls within the Drakensberg Foothill Moist Grassland, Veld type Gs10 of (Mucina & Rutherford, 2006). This mountainous and incised area is dominated by short bunch grasses including *Themeda triandra* and *Tristachya leucothrix* (Mucina & Rutherford, 2006). The area is characterized by a warm-temperate climate associated with warm summers with approximately 890 mm of rainfall and cold winters. This rangeland was chosen for study because it is intensively invaded by bramble. The fern *Pteridium aquilinum* and alien shrubs such as *Solanum mauritianum* were present and may become invasive over time if not properly managed.

### 3.2.2. Field data collection

Fieldwork was conducted in April 2018. A large patch that was visually heavily invaded by bramble was compared to an adjacent patch that was uninvaded. Because there was only one patch of bramble large enough to sample, this limited the opportunity for spatial replication. Fifty quadrats (50cm × 50cm) were placed randomly within each patch studied and the total biomass was estimated. In a patch where bramble heavily invaded, quadrats were placed randomly but where there was visibly grass to sample. A method called dry weight rank (DWR) technique was used to estimate grass biomass and species composition. The DWR is a method that rapidly estimates the total yield species composition to ground level without harvesting a great part of the studied site (Friedel et al., 1988; Tothill et al., 1992). This method has been widely applied in a range of pasture types (Tothill et al., 1992) and was introduced by 't Mannelje & Haydock (1963) and later improved by Jones & Hargreaves (1979). For biomass estimation, from a scale of 1 to 10, the total biomass of grass was estimated by identifying all grass species within the studied patch for each quadrat. Species were identified and allocated with a ranking 1, 2 or 3 based on decreasing order of dominance. Ranking 1 was given to a species that occupied at least 70% of the quadrat, ranking 2 was given to a species that occupied ~20% of the quadrat and ranking 3 was given to a species with 10% or less in the quadrat. For species diversity and dominance purposes, all grass species present in the quadrat were recorded. In a technique called double sampling, 10% of the quadrats were clipped 6-8 cm from the ground and placed in a labeled paper bag. The samples were oven dried at 75°C and each

sample weighed for biomass using an analytical balance in order to calibrate the estimation technique.

### 3.2.3. Data analysis

An Excel spreadsheet was used to derive a calibration equation using the estimated biomass and the actual biomass using a linear regression of the form  $y = a + bx$ . Data from the linear regression, double sampling technique as well as the DRW were used to measure dry matter as well as species composition using a program that was developed to process such data. From the program, the actual species dry weight was derived as well as the dry weight percentage of each species. This analysis was done for both patches for comparison purposes. The difference in biomass proportions of the studied patches was tested using the two-sample z-test in Excel. For a descriptive measure of grass communities in the two studied patches, species diversity and dominance were calculated. To evaluate diversity in grass population based on dry weight values and using a Shannon-Wiener Index ( $H'$ ), where  $H' = -\sum \left[ \left( \frac{n_i}{N} \right) x \ln \left( \frac{n_i}{N} \right) \right]$ . Species dominance was also calculated to evaluate the dominance of grass species based on their dry weight values using a Simpson's Index ( $\lambda$ ) where  $\lambda = \sum \frac{n(n-1)}{N(N-1)}$ .

### 3.3. Results

#### 3.3.1. Estimating grass productivity

When comparing the estimated biomass with the actual dry matter yield of each of the 50 quadrats, 0.8028 was the regression coefficient that was obtained in the invaded patch and the uninvaded patch, the value of 0.8407 was obtained (Figure 3.1. (a) and (b)).

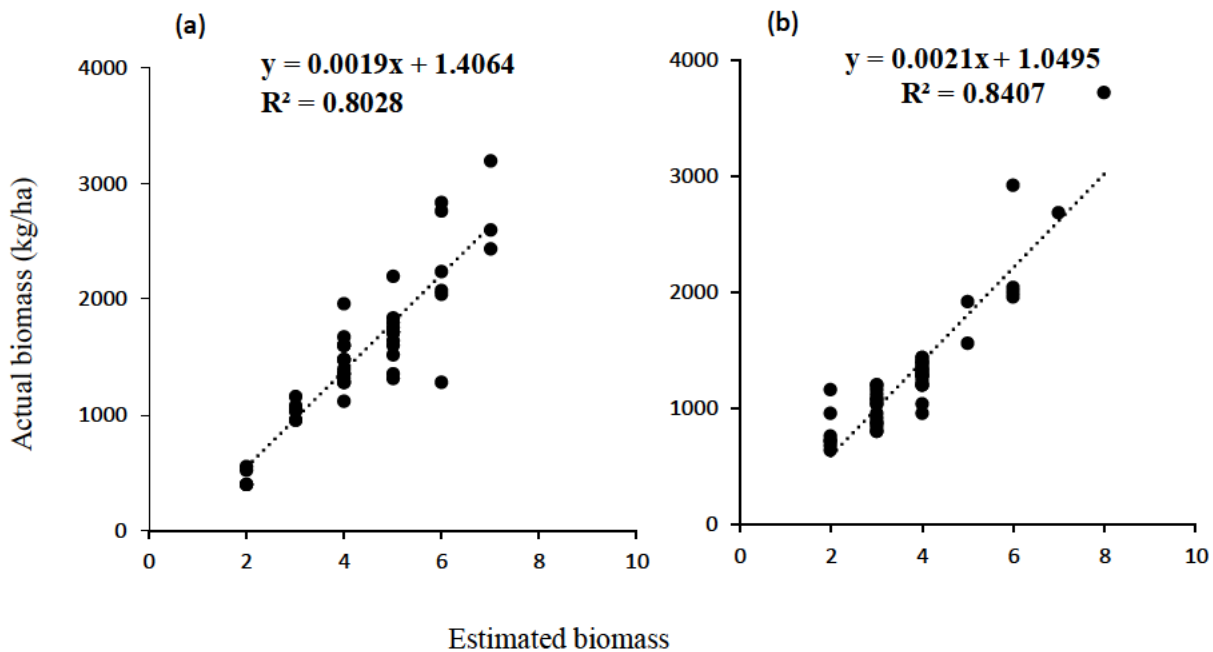


Figure 3.1.: Estimated biomass with the actual biomass (kg/ha) in a) invaded patch and b) uninvaded patch

Figure 3.2. shows that the invaded patch had a higher grass biomass (2136 kg/ha) than that measured in the uninvaded patch (1887 kg/ha). Table 3.1. below shows that based on the two-sample z-test the p-value obtained (0.054) was greater than the alpha 0.05 suggesting that grass biomass values are not statistically significant between the invaded patch and the uninvaded patch. The calculated z-value (-1.93) also agrees with the difference in biomass proportions between studied patches.

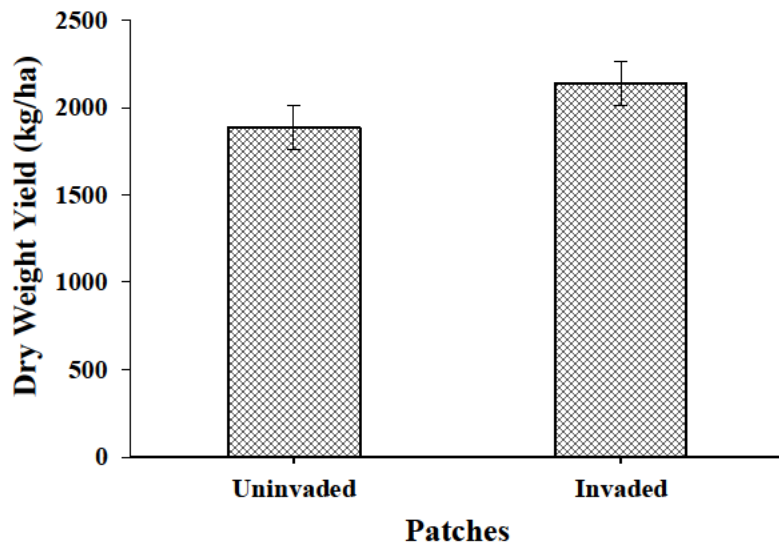


Figure 3.2.: The total dry yield of grass in the two patches

Table 3.1.: The difference in grass biomass means between the invaded patch and the uninvaded patch based on the two-sample z-test

	<i>Uninvaded patch</i>	<i>Invaded patch</i>
Mean	32.58	38.28
Known Variance	206.0445	229.8384
Observations	50	50
Hypothesized Mean Difference	0	
z	-1.930522831	
P(Z<=z) one-tail	0.026771045	
z Critical one-tail	1.644853627	
P(Z<=z) two-tail	0.053542089	
z Critical two-tail	1.959963985	

### 3.3.2. Grass species diversity and dominance

Figure 3.3. shows that there were six grass species in total that were found in the bramble-invaded patch with *Eragrostis curvula* contributing the highest percentage in the total dry matter yield (77.64%). The rest of the species that were found in this patch each accumulated less than 10% of dry matter. In the uninvaded patch, there was a total of seven grass species that were recorded with *Hyparrhenia hirta* contributing the highest percentage of dry matter (61.91%). The rest of the species in the uninvaded site each contributed less than 15% of dry matter. More palatable species were found in the uninvaded site than there were in the invaded site and more unpalatable species were found in the invaded site.

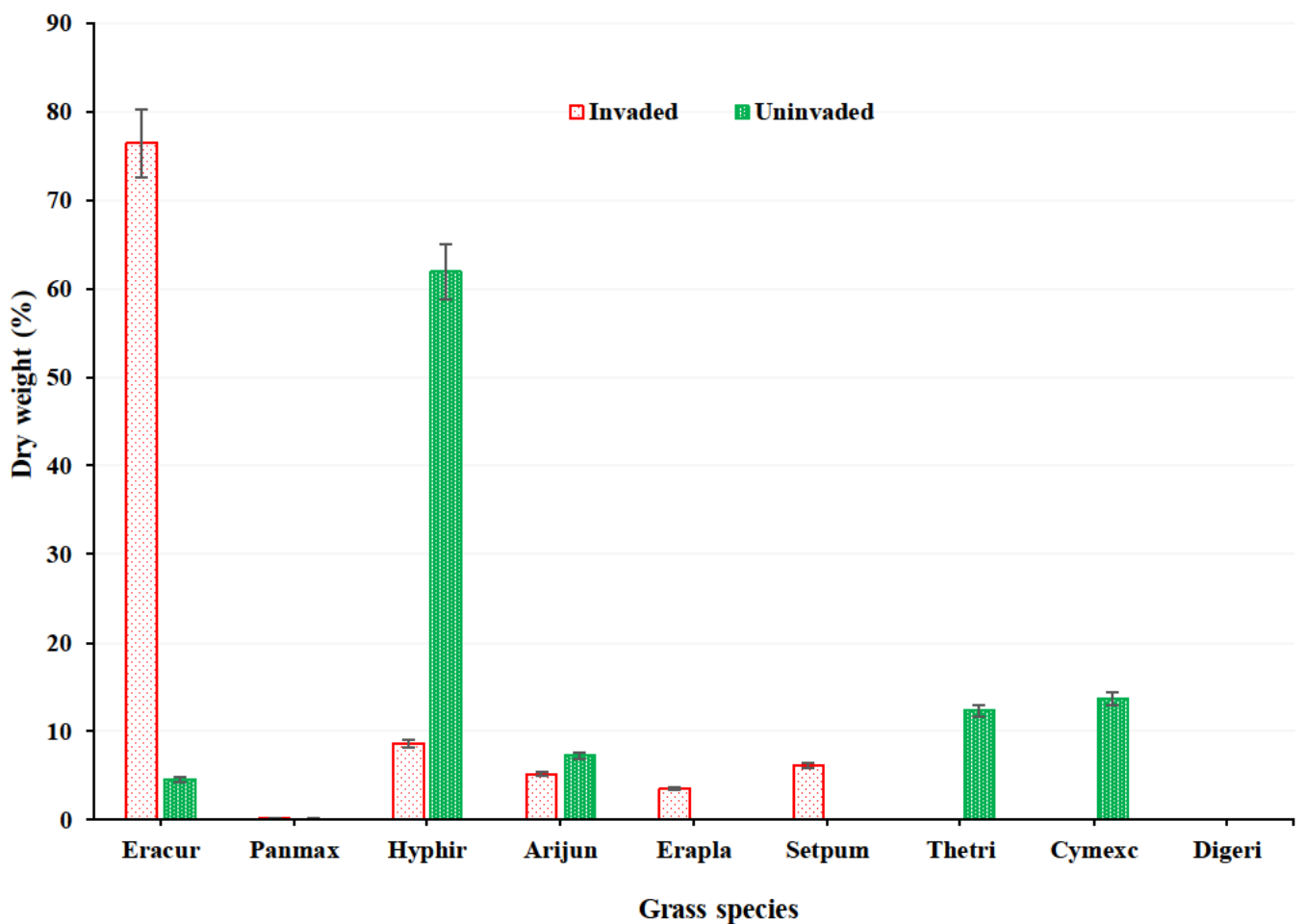


Figure 3.3.: Dry weight percentage per grass species found in the studied patches

**Grass species key:** **Eracur** - *Eragrostis curvula*      **Panmax** - *Panicum maximum*      **Hyphir** - *Hyparrhenia hirta*  
**Arijun** - *Aristida junciformis*      **Erapla** - *Eragrostis plana*      **Setpum** - *Setaria pumila*  
**Thetri** - *Themeda triandra*      **Cymexc** - *Cymbopogon excavatus*      **Digeri** - *Digitaria ariantha*

Table 3.2. presents all the grass species that were found in both patches, the grazing value and their grazing status. Table 3.3. shows that based on the calculations from the Shannon-Weiner index, there is relatively higher species diversity (1.17) in the uninvaded patch than there was in the invaded patch (0.87). It also shows that based on Simpson's index, the invaded patch held a relatively higher species dominance (0.59) when compared to the uninvaded patch (0.42).

Table 3.2.: Grass species found in the uninvaded and the invaded patches, their grazing value (palatability) and grazing status

Grass species	Grazing value	Grazing status
<i>Eragrostis curvula</i>	Average	Increaser II
<i>Panicum maximum</i>	High	Decreaser
<i>Hyparrhenia hirta</i>	Average	Increaser I
<i>Aristida junciformis</i>	Low	Increaser III
<i>Eragrostis plana</i>	Low	Increaser II
<i>Setaria pumila</i>	Average	Increaser II
<i>Themeda triandra</i>	High	Decreaser
<i>Cymbopogon excavatus</i>	Low	Increaser I
<i>Digitaria eriantha</i>	High	Decreaser

Table 3.3.: The measure of species diversity and dominance on grass community at Wakefield Farm using Shannon-Wiener Index and Simpsons index respectively

Index	Uninvaded patch	Invaded patch
<b>Shannon-Weiner</b>	1.17	0.87
<b>Simpson's</b>	0.42	0.59

### 3.4. Discussion

The aim of this study was to investigate the effect of the invasive bramble on rangeland native grass species biomass production, diversity as well as dominance. Several successful IAPs have contributed to both plants and animal native population decline (Dukes & Mooney, 2004). The known adverse impacts of bramble include the reduction of rangeland carrying capacity as well as the succession of other natural plants (Rajah et al., 2018). We had predicted less grass biomass in the site where bramble invaded. The results of this study, however, show that the biomass of grass species was higher in the patch that was invaded with bramble compared to the patch clear of bramble. This might have been because sampling took place towards the bramble reaching the senescent stage of growth the dominant grasses were striving in growth. The invaded area was not excluded from grazing, therefore these results could also be explained by that this patch was probably largely protected from grazing, due to inaccessibility, while the uninvaded area had been grazed during the season. These results are despite the fact that the proportion of grass in the invaded patch is reduced by the bramble cover per unit area when compared to the uninvaded patch where grass production is well presented. Our results were different from those obtained by Shackleton et al. (2017) where they found that the invasions of *Lantana camara* reduced the presence of native grasses and reduced more than 50% forage available to livestock. Again, Ndhlovu et al. (2011) found that *Prosopis* invasion decreased forage production by 34% which was improved by 110% in six years of clearing. Similarly, Gwate et al. (2016) investigated the effect of an invasive tree *Acacia mearnsii* on grass productivity and found that there was an immense decline in grass production with grass cover decreasing to below 10% where *Acacia* infested.

The uninvaded patch being more diverse means that it can provide forage for a variety of grazing animals, community stability as some species can work together to survive drought, insect plagues and disease outbreaks in an interaction called commensalism. In this study, where bramble invaded there was a decrease in the number of native grasses. Similar to our result, Belcher & Wilson (1989) did a study looking at the composition of native prairie as a function of leafy spurge abundance over a large area and within a single infestation. They found on both large scale and at single infestation that leafy spurge was related to a decline in the abundance of dominant species in native prairie. Lower numbers of the most common native species in leafy spurge stands were recorded and one native grass species was not recorded at all. There was a negative correlation between the cover of common native species and the cover of common alien species, indicating that native species were being replaced by alien species.

There was also a significantly higher species richness in native prairie than there was in stands of leafy spurge (Belcher & Wilson, 1989). Also comparable to this study, Vilà et al. (2011) investigated the ecological impacts of IAPs on ecosystems, communities and species and found that the average number in richness and diversity of resident plants decreased in invaded areas whereas there was a significant increase in primary production and other ecological processes. Similar to this study, Reynolds & Symes (2013) found higher species abundance and lower diversity in the bramble-invaded site than in the site clear of bramble. Species abundance and dominance have been proven to increase as species diversity decreases (Dornelas et al., 2011).

Moreover, grass species we found in the uninvaded patch were relatively more palatable than those that were found in the invaded patch. Our results could be explained by that grazing cattle cannot get access into the bramble-invaded patch because of the thorny barrier created by bramble, also explaining the higher grass biomass in between bramble. *Hyparrhenia hirta* was the most dominant in the uninvaded patch. *Hyparrhenia hirta* is an Increaser I species that is palatable when it is not tall (du Toit, 2009). When this grass is at its younger state of growth it is selectively grazed by sheep and usually has higher crude protein and dry matter yield in heavily grazed sites than in sites with light grazing (Lodge et al., 2005). *Themeda triandra* was the third most dominant in the patch that was not invaded by bramble. If this species is not grazed or burnt it can accumulate forming dense stands and litter accumulation because of its tall stature (Lunt, 1990). It is a Decreaser species that is regarded as one of the most important grasses in South Africa. Where this species dominates, the veld is said to be in good condition (Trollope, 1990; Westoby et al., 1989). It also appears in sites where fire and defoliation are frequent (du Toit, 2009). *Eragrostis curvula* dominated the invaded patch. It is an Increaser II species that dominates along roadsides, in disturbed sites as well as in poor condition pastures that are particularly in sandy soils. A dense infestation of *Eragrostis curvula* increases fuel load and is highly flammable which could be hazardous during the dry seasons (Fact sheet index, 2018). This species is unpalatable for grazing, and it has been noted that where it dominates, grazing management should be at its greatest level (Fact sheet index, 2018). In this study, the results from the Simpson's index illustrated higher species dominance calculated in the invaded patch, which translates to lower species richness.

In the uninvaded site, *Themeda triandra* and *Digitaria eriantha* were two Decreaser species that were recorded, whereas no Decreaser species was recorded in the invaded site. Other palatable grass species like *Digitaria eriantha* were also found in small proportions in the uninvaded site. Decreaser species are dominant in a veld that is in very good condition (Foran

et al., 1978; Scott-Shaw & Morris, 2015; Van Oudtshoorn, 2002; Vorster, 1982). However, in this case, Decreaser species had a very small percentage of the total biomass even in the patch with no bramble invasion. This might be because larger areas are dominated by bramble and so the uninvaded patches are now over-utilized. This, therefore, means that the veld is not in good condition and might be under serious threat over time as these species are unable to withstand heavy grazing (Coughenour et al., 1985; Trollope, 1990).

### **3.5. Implications and conclusion of the study**

The IAPs have ecological and economic related consequences in rangelands and such transformations should be examined with the aim of eradicating them and increasing grass production. There is a relatively low productivity of rangelands and biodiversity intactness due to IAPs and these impacts are expected to increase at exponential growth if these are not properly managed. From the results of this study, it can be concluded that the invasion of bramble greatly affected the grazing capacity in this grassland ecosystem. The invasive bramble poses a significant threat to the richness as well as the diversity of native grasses available for livestock in this rangeland. Specialist grassland species are decreasing with the invasion of bramble, and it is a cause for concern to rangeland farmers. The clearing of this detrimental species will restore the rangeland's original structure and grazing productivity. Better and informed decisions can be made when the magnitude of changes that are brought forward by IAPs is known.

### **3.6. Acknowledgements**

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## CHAPTER 4: SYNTHESIS

### 4.1. Introduction

For all ecosystems worldwide, invasive alien plants (IAPs) are recognized as a major threat to ecosystem functions (Masters & Sheley, 2001a). Past mistakes and current invasion crises consume the time and resources of rangeland managers and make proactive land management increasingly difficult (Belnap et al., 2012). A species such as *Rubus cuneifolius*, if not managed at an early stage can encroach in grasslands until a closed canopy shrub thicket occurs. This can then influence changes in vegetation species composition and in turn threaten the sustainability of livestock production, wildlife habitat, and grassland birds. Grass productivity can also be significantly reduced by encroaching species through replacement, competition, shading, and allelopathic effects (Lesoli et al., 2013). To effectively manage such IAPs, spatial data plays a crucial role in identifying areas that require swift and efficient eradication (Rowlinson et al., 1999). Techniques to manage established invaders often succeed but have been constrained by accessibility and inconsistent funding. However, more fundamental research can improve these constraints, including simple advances in control technologies to more sophisticated remote sensing techniques (Simberloff et al., 2005). The Sentinel-2 Multispectral Instrument (MSI), with its optimal spatial and spectral capabilities, is well-suited for evaluating and monitoring management practices related to grassland productivity (Sibanda et al., 2016; Vundla et al., 2020). Testing its ability to discriminate bramble in the KZN Mistbelt grassland is essential, presenting an alternative technique for mapping and monitoring rangeland IAPs. The aim of this study was to explore the capability of Sentinel 2 MS in mapping the spatial distribution of bramble (*Rubus cuneifolius*) and to assess its impact on veld species diversity, dominance and grass quantity at farm scale in KwaZulu-Natal, South Africa. This aim was addressed through two specific objectives:

1. To test the potential and strength of Sentinel-2 MSI's red edge spectral data in discriminating the alien invasive *Rubus cuneifolius* during its senescent stage based on the DA algorithm in the Mistbelt region of KwaZulu-Natal.
2. To evaluate the effect that American Bramble (*Rubus cuneifolius*) on grassland ecosystems has on the productivity, diversity and dominance of native grass species.

This chapter gives a synoptic review of the study's objectives and the associated conclusions. It also highlights the implications of the study, the major conclusions as well as limitations of the study and recommendations for future research.

## 4.2. Review of the findings and specific conclusions

The first objective of this study was to test the capability of Sentinel-2 MSI for mapping the distribution of bramble during the senescence phase in a Mistbelt grassland livestock farm. Four sets of spectral features were used as classification inputs to discriminate bramble from other landcover types using the DA algorithm. These were: spectral wavebands, modified NDVI, modified SR and combined variables. All inputs were tested when red edge bands were included and when they were excluded from the analysis. From the results of this study, we found that Sentinel-2 MSI is well suited for mapping the distribution of bramble during senescence. Bramble was accurately discriminated from other classes with high accuracies. Furthermore, there were higher user and producer accuracies when red edge bands were included for all the inputs. The overall classification accuracies were as follows: 84.62% for all spectral wavebands, 87.18% using exclusive wavebands, 89.33% for the *m*NDVI of all spectral wavebands, 85.39% based on *m*NDVI derived from exclusive wavebands. Additionally, 83.43% accuracy was achieved using *m*SR of all spectral wavebands, and 84.57% using *m*SR derived from exclusive wavebands. Combining all optimal wavebands resulted in an overall accuracy of 85%. The most optimal wavebands for mapping bramble during the grass senescence stage were Bands 2, 3, 7, 11, and 12. These results highlight the significant influence of Sentinel-2 MSI's visible, red edge and shortwave infrared (SWIR) wavebands in discriminating rangeland alien invasive species such as bramble during the senescing stage.

The second objective of this study sought to evaluate the effect that bramble has on the diversity, dominance as well as overall biomass of native grass species in a rangeland ecosystem at a farm scale. Quadrats were placed randomly within the bramble-invaded and the uninvaded patches to estimate the overall grass biomass. In the invaded patch, quadrats were placed where there was visibly grass to be sampled as most area was infested with bramble. It was hypothesised that the bramble-invaded patch would have less grass biomass, diversity and dominance when compared to the uninvaded patch. All grass species were recorded for both invaded and uninvaded patches and used to measure species diversity and dominance. The results of this study from the dry weight rank and double sampling methods revealed that in a bramble-invaded patch the overall grass biomass was relatively higher when compared to the uninvaded patch. These results could be explained by that the bramble invaded patch was probably largely protected from grazing, due to inaccessibility, while the uninvaded area had been grazed throughout the season. Grass production in the invaded area was higher despite there being a proportion of bramble covering/displacing grass species thus reducing the grass

area compared to the outside of the invaded area which was entirely covered with grass. There were relatively more palatable/ desirable species such as *Hyparrhenia hirta*, *Themeda triandra* and *Digitaria eriantha* found in the uninvaded patch. In the invaded patch undesirable species such as *Eragrostis curvula* dominated which is said to dominate in disturbed sites and in pastures that are said to be in poor conditions. This is a clear indication that the invasion by bramble leaves mostly undesirable grass species in pastures which therefore means this decreases the grazing capacity for grazing animals.

#### **4.3. Implications of the study**

When the magnitude of changes brought forward by IAPs is known, better and more informed decisions can be made. The findings of this study demonstrated the unprecedented opportunity for deriving reliable near real-time information for mapping the spatial distribution of bramble. The extent of bramble as well as the effects it has on grass species productivity and diversity in Wakefield Farm is now realized and control options can be initiated. The rangelands in this farm are utilized for livestock farming and provided crucial information from this research, farm managers can make knowledgeable decisions and take actions to keep rangelands producing large amounts of preferred native grass species that will keep veld in a healthy condition.

#### **4.4. Conclusion of the study**

Due to the realization that *Rubus cuneifolius* causes huge problems in rangelands, specifically in the KZN Mistbelt grasslands, this study sought to explore the capability of Sentinel-2 MSI in mapping the spatial distribution of bramble (*Rubus cuneifolius*) and to assess its impact on veld species diversity and grass quantity at Farm scale in KwaZulu-Natal, South Africa. In conclusion, the study underscores the adverse impact of bramble invasion on grazing capacity by fostering the prevalence of undesirable grass species in pastures. Additionally, the findings highlight the instrumental role of Sentinel-2 MSI's visible, red edge and shortwave infrared (SWIR) wavebands in accurately discerning rangeland alien invasive species, particularly bramble, during the senescing stage. These insights contribute to a comprehensive understanding of the ecological consequences of bramble invasion, emphasizing the need for effective management strategies to mitigate its negative effects on rangeland ecosystems.

#### **4.5. Limitations of the study and recommendations for future research**

The study has certain limitations, primarily stemming from a constrained spatial replication. To enhance the reliability of results, it is recommended that future research expands to larger spatial scales, allowing for increased spatial replication. This approach would offer a more comprehensive understanding of the dynamics associated with bramble invasion. Additionally, considering the known extent of bramble, future studies could explore opportunities for effective control and monitoring. For other problematic IAPs such as *Lantana camara* and *Acacia mearnsii*, especially in Mistbelt grasslands, mapping efforts using newly introduced Earth observation sensors should be explored. Furthermore, to gain a comprehensive view, future research could investigate the applicability of the Sentinel-2 sensor or other capable sensors in mapping IAPs throughout all seasons of the year for comparative analysis.

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