MANAGING WOODY BUSH ENCROACHMENT IMPACTING SOUTHERN WHITE RHINO (*CERATOTHERIUM SIMUM SIMUM*) HABITAT ON A PRIVATE RESERVE IN SOUTH AFRICA

by

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ABSTRACT

Managing woody bush encroachment impacting
southern white rhino (*Ceratotherium simum simum*) habitat
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Private nature reserves in South Africa have been a key contributor to the stabilization of southern white rhino (Ceratotherium simum simum) populations. However, woody bush encroachment is a widespread problem threatening the vital grasslands these rhinos rely on. This research aims to help UmPhafa Private Nature Reserve establish a bush encroachment management plan by identifying land cover changes over the past 18 years and by establishing key areas to restore to grasslands. UmPhafa's white rhino population was observed for six weeks during the summer months (Jan.-Feb, 2019) where limited-species quadrat surveys acquired the data on lemon bush (*Lippia javanica*), scented-pod acacia (*Vachellia nilotica*), sweet-thorn acacia (*Vachellia karroo*), paperbark acacia (*Vachellia sieberiana var. woodii*), and hook-thorn acacia (*Senegalia caffra*) concentrations near the rhino's summer habitat. These maps were combined with hotspot encroachment locations, ranger encroachment maps, and past seasonal rhino movements by to establish ten zones that encompassed 144.5 hectares for restoration. A weighted decision matrix was used to decide the prioritization of these zones based on their likely restoration impact towards increasing the rhinos' current grassland habitat. This study provides UmPhafa reserve managers with a guide to begin restoring grasslands that have been in steady declined since the rhinos were reintroduced to the land.

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Acknowledgements

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INTRODUCTION

By 1895, a mere 20-50 southern white rhinos (*Ceratotherium simum simum*) had survived after years of hunting and habitat loss had decimated their populations (Richard Emslie & Brooks, 1999). Today, after years of protection, they are largely considered a conservation success story. Their numbers have risen to around 20,000 individuals, with over 90% residing in South Africa (Carruthers, 2013; Richard Emslie & Brooks, 1999). Those rhinos living in South Africa can be found in government owned conservancies, such as Kruger National Park, or under private management which may cater to photographic tourism, trophy hunting, or to harvest rhino horn for profit.

Tragically, from 2008 to 2014, rhino poaching has increased by 9000% ("Poaching Numbers," 2019) and remains a very acute and devastating threat for our world's remaining rhinos. Habitat loss, however, continues to be a chronic and silent risk. As the human population rises, more and more land is utilized for homes, agricultural production, and logging ("Habitat Loss," 2019). To defend against this, many wildlife reserves and national parks have been established to protect Africa's unique wildlife from disappearing. Unfortunately for the southern white rhinos (Rhinos) living within these ecological islands, woody bush encroachment threatens to further diminish the only habitat they have left.

Bush encroachment is causing grasslands to transition into woodlands all over the world (Eldridge & Soliveres, 2014; Grellier et al., 2013; Liu et al., 2013; Soto-Shoender, McCleery, Monadjem, & Gwinn, 2018). As woody species replace grasses, the available grazing is therefore decreased for many animals (Grellier et al., 2013; Soto-Shoender et al., 2018). This process is often viewed negatively due to the ecosystem function changes it causes; such as the alterations to hydrological processes, fire patterns, and wildlife habitat (Scholtz, Polo, Fuhlendorf, & Engle, 2017).

While global woodland expansion has received greater attention in recent years, it still remains poorly understood (Scholtz et al., 2017). Factors that have been attributed with this phenomenon include changes to herbivory levels, changes to rainfall patterns and fire regimes, and an increase in atmospheric CO_2 (Milton & Dean, 1995; Roques, O'Connor, & Watkinson, 2001; Soto-Shoender et al., 2018; Wigley, Bond, & Hoffman, 2010). Just in the past two decades some southern African savannas have seen a decrease in grasslands by as much as 30% (Sirami & Monadjem, 2012).

On UmPhafa Private Nature Reserve (UmPhafa), the savanna grasslands which provide critical grazing habitat to their nine Rhinos — among many other grazing species — are being invading by *Lippia javanica*, a woody shrub, and four acacia shrub/tree species: *Vachellia sieberiana var. woodii*, *Vachellia nilotica*, *Vachellia karroo*, *Senegalia caffra*. In the time since the rhinos were reintroduced to this land in 2008, Landsat images and the personal accounts of staff members confirm that the grasses on the Gevonden — where the rhinos are restricted for security — are decreasing. Currently, the reserve managers hope to gain back ±250 hectares (ha) of savanna grasslands on Gevonden.

To assist with planning these restoration efforts, limited-species quadrat surveys were taken to estimate the concentration of *L. javanica* and acacia species near the Rhinos' summer habitat. This information was then combined with historic Rhino sighting locations and ranger restoration recommendation maps to establish ten key zones for woody encroachment removal.

This research directly contributes to UmPhafa's long-term management plan goals. With Goal 2 being to ensure the sustainable management for long-term wildlife conservation and Goal 3 to develop and manage reserve vegetation, the following sub goals that are critical to their success were established:

- 2A.3 – Improve management of encroachment and alien plants for removal (Bone & Spanton, 2019).
- 2D.1 – Main habitats that need expanding – Wetlands and Grasslands (Bone & Spanton, 2019).
- 2D.4 – Proper encroachment plan (Bone & Spanton, 2019).
- 3B – Rehabilitate vegetation and provide long-term habitat stability to the reserve (Bone & Spanton, 2019)
- 3B.1 – Encroachment plan (Bone & Spanton, 2019).

This research will assist UmPhafa managers by providing an encroachment plan to start expanding Gevonden's grasslands, however, the findings could also inform other reserves in the KwaZulu-Natal province how to better implement encroachment planning through threat mapping. This research also brings a new plant to the forefront as a problematic woody encroacher. While Acacia has been studied greatly ((Bester, 1996; De Klerk, 2004; Grellier et al., 2013; Okello, Young, Riginos, Kelly, & O'Connor, 2007; Skowno, Midgley, Bond, & Balfour, 1999) this research starts to take a new look into *L. javanica* and its effects on savanna grasslands.

LITERATURE REVIEW

The Southern White Rhino's Recovery

In 2001, Nelson Mandela proudly referred to the rhinoceros as the world's oldest land mammal ("KwaZulu-Natal Information," n.d.), as they are descendants of the great *Paraceratherium* which dates back 30 million years (Baraniuk, 2015). But sadly, we are quickly losing the few descendants left from the Oligocene period.

In 2010, the death of a juvenile Javan rhinoceros (*Rhinoceros sondaicus*) in Vietnam resulted in the extinction of the *annamiticus* subspecies (Brook et al., 2012). In 2011, the western black rhino (*Diceros bicornis longipes*) was declared extinct by the IUCN (Emslie, 2011). On March 19th, 2018 headlines around the world erupted to report the tragic news that Sudan, the last male northern white rhino (*Ceratotherium simum cottoni*), had passed away. Today there are only two females left of the species.

Even with all this devastating loss, there has been a remarkable comeback for one subspecies thanks to long-term conservation efforts. By the late 19th century, the southern white rhino (*Ceratotherium simum simum*) population had been reduced to a mere 20-50 individuals, all residing on the Hluhluwe Game Reserve in the KwaZulu-Natal province of South Africa (Emslie, 2012). After years of protection and translocations, their numbers have grown to approximately 20,160 animals, with South Africa home to around 93.2% of the total population (Emslie, 2012).

Southern White Rhino - Umkhombe

Physiology and Anatomy

Despite possible assumptions, the white rhino did not get its name due to its coloring. Possibly the most common belief is that the Afrikaans word "wyd" for wide, was misinterpreted as "white". Another theory suggests that the Rhinos may have first appeared white after wallowing in chalky mud. However, with roughly ten theories in total, no one can definitively say how or why the name came about (Naish, 2009).

Perhaps mistaking wyd for white is such an appealing premise, because of the white rhinos wide, square lip that is a distinguishing characteristic for the species when compared to the pointed, prehensile lip of the black rhinoceros (*Diceros bicornis*). Other physical differences between the two African species, seen in Figure 1, include the white rhino having a larger forehead, a pronounced neck hump when their head is raised, and being larger overall. Its large size also classifies it as a megaherbivore (body mass > 1,000 kg), with adult males weighing between 2,000-2,300 kg and females weighing approximately 1,600 kg (R. N. Owen-Smith, 1992). This also makes the southern white rhino (Rhino) is the second largest land mammal after the elephant family (*Elephantinae*) (Kingdon, 2015).

Over time, Rhinos have evolved to produce a short neck that is made up of a web of tendons, dense muscles, and tall vertebral spines (Kingdon, 2015). This gives them that signature neck hump, while also allowing the Rhino to be an efficient short-grass grazer (Kingdon, 2015). However, this adaptation does prevent them from lifting their heads above their backs (Furstenburg, 2013). Further perfecting their grazing abilities is their broad, flat lip which is approximately 20 cm wide.

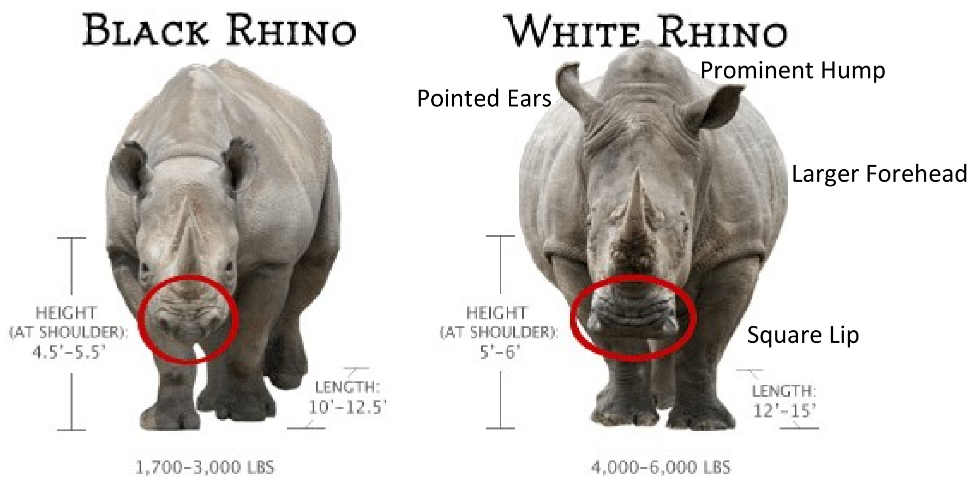


Figure 1. Anatomy differences between the white and black rhino. Adapted from Rhinoceros (Black & White Rhino) Facts. (2019). Retrieved March 27, 2019, from Hluhluwe Game Reserve website: https://hluhluwegamereserve.com/african-big-5/rhinoceros-black-white-rhino/.

Possibly the Rhinos most famous feature is their remarkable horns. Their horns are unique from many other ungulates like the impala (*Aepyceros melampus*) or cape buffalo (*Syncerus caffer caffer*), because they grow directly from the skin layer rather than containing a bone core (Hieronymus, Witmer, & Ridgely, 2006). The horns are comprised of a compact mass of tubular keratin fibers (Furstenburg, 2013), similar in composition to hoof walls, baleen plates, and cockatoo bills (Hieronymus et al., 2006). The average, accumulative mass for both horns on an adult Rhino ranges from 5.8-14.0 kg (Furstenburg, 2013), and while the IUCN's African Rhino Specialist Group does not recommend publishing the exact price of rhino horn, it has historically reached prices higher than the cost of gold on the black market, but the price may be dropping (WildAid, 2017).

Ecology and Diet

Bulls reach sexually maturity around eight to ten years of age, but will not begin breeding until around twelve once they've established a territory that ranges from 700-2600 ha (Furstenburg, 2013). Cows can have home ranges between 9,000-20,000 ha, and unlike the territory bulls, this region will overlap with other breeding female rhinos (Furstenburg, 2013). Their preferred habitat is savannas — areas of open grassland mixed with a range of wooded concentrations (Figure 2) — and despite grasses being their sole source of food, the woody component to their habitat is extremely important as well (Furstenburg, 2013). Open areas, with a low density of shrubs 0-2 m high are ideal for feeding when sweet grasses are present, while areas with moderately dense patches of vegetation, 2-4 m, provide refuge and occasional mixed grazing (Furstenburg, 2013). Lastly, scattered trees with canopies over 4 m offer shade from the sun or protection from storms (Furstenburg, 2013).

In order to focus on expanding suitable Rhino habitat, one should consider the species of grasses rhinos prefer. Studies have shown that white rhinos prefer to graze on short, high-quality grasses throughout the year (Shrader, Owen-Smith, & Ogutu, 2006). During the winter months when grasses contain less nutrition value, findings from Shrader et al. (Shrader et al., 2006) found that rhinos likely utilize fat and body reserves to overcome seasonal nutritional deficits. This debunked the previous hypothesis that Rhinos increase their mean food intake rate during the dry season to compensate for the poorer quality of grasses (Shrader et al., 2006). So, ensuring Rhinos have access to plenty of nutritional grasses during the wet, summer season may be imperative for helping them build up these reserves. Therefore, when evaluating woody bush encroachment on Rhino habitat, it could be more important to prioritize summer habitat over winter congregating areas.

Figure 2. Top Photo: Four rhinos grazing on an open area with a low density of small shrubs. Middle Photo: Two rhinos grazing among moderately dense patches of shrubs 2-4 m high. Bottom Photo: Two rhinos resting in the shade of acacia over 4 m high. Photos by Kelli Stephens.

Rhinos as Ecosystem Engineers

Grazing lawns are patches of grassland that remain in a near constant state of nutritious and productive juvenile growth from repeated grazing and trampling (Foster, 1965; R. Owen-Smith, 1988), and Rhinos can be essential for maintaining these systems (Waldram, Bond, & Stock, 2008). Waldram et al. (2008) found that when Rhinos are absent from mesic savanna grasslands, the grass swards can grow too tall for other short grass specialists, like the impala and wildebeest, to feed on. However, the opposite was true for semi-arid savanna grasslands where water is scarcer. In these systems where the productivity of grasses are already reduced due to lower rainfall levels, Rhinos may actually compete with other short grass grazers (Waldram et al., 2008). Short grass lawns have also been shown to increase biodiversity as Krook (2005) demonstrated their importance as critical habitat for the crowned lapwing (*Vanellus coronatus*), sabota lark (*Calendulauda sabota*), and African pipit (*Anthus cinnamomeus*) in Hluhluwe-iMfolozi Park.

While short grass systems are nutritionally beneficial to the grazers who maintain them and help increase biodiversity, they also create natural fire breaks. Their low biomass means there is insufficient fuel for fires, unlike areas comprised of tall, dense grasses and woody bushes (Waldram et al., 2008). In fact, when managing wildfires on private reserves, studies have shown that fires do not spread when an area is covered by more than 40% short grasses due to this low biomass (Turner, Gardner, & O'Neill, 2001). Grazing lawns can therefore help alter the size, spatial distribution, and frequency of fires on the landscape by creating natural fire barriers (Waldram et al., 2008). Thus, Rhinos as mega-grazers could be beneficial for preventing aggressive wildfires from spreading throughout reserves by helping to maintain short grass patches (Waldram et al., 2008).

Bush Encroachment

African savannas are characterized by wet summers, dry winters (De Klerk, 2004), and a diverse range of woody cover and grassland coexistence (van Langevelde et al., 2003). Due to this broad mix of trees and grasses, these ecosystems are considered highly unstable (Sankaran et al., 2005), and are extremely vulnerable to bush encroachment (Graw, Oldenburg, & Dubovyk, 2016).

In the 1980's, South Africans began to notice an increase in bush growth on savanna ecosystems (Graw et al., 2016), and the term "bush encroachment" became a commonly used designation for this ecosystem transition (Welz, 2013). Ward (2005) defines bush encroachment as the "suppression of palatable grasses and herbs by encroaching woody species", and unfortunately once this process starts to occur on savannas, it becomes extremely difficult to reverse (I. P. J. Smit & Prins, 2015).

Since the 1980's, 10-20 million hectares of land have been impacted by bush encroachment in South Africa alone (Ward, 2005). This transition is likely occurring due to a myriad of factors such as changes to herbivory levels, changes to rainfall patterns and fire regimes, soil moisture fluctuations, and an increase in atmospheric CO_2 (Milton & Dean, 1995; Roques, O'Connor, & Watkinson, 2001; Soto-Shoender et al., 2018; Wigley, Bond, & Hoffman, 2010). With all of these contributing factors, nature reserves that hope to manage their natural resources to be both productive and sustainable (Teague & Smit, 1992), must therefore include mitigating bush encroachment into their management plans. Without this, woody vegetation may continue to decrease palatable grasses on these lands (Welz, 2013), and ultimately decrease the carrying capacity of animals dependent on these ecosystems (De Klerk, 2004), such as the Rhino.

Controlling Bush Encroachment

For nature reserve managers to do want to combat bush encroachment, it's important to recognize of the factors contributing to it, which they can control, and which they cannot. For instance, little can be done directly by reserve managers regarding annual rainfall, droughts, or the increasing atmospheric CO_2, but managers are able to alter fire patterns, herbivory levels, and bush thinning through manual, chemical, or biological controls.

The Role of Fire

Fire is a natural disturbance that alters the vegetative structure of an ecosystem (W. J. Bond, Woodward, & Midgley, 2005). On savannas, rising tree densities have historically been mitigated by the presence of fires and sustainable herbivory levels (Sankaran et al., 2005). However, as natural fires became suppressed and the number of wild and domestic herbivores increased on lands from human involvement, so has the percent coverage of woody bush on savannas (Okello et al., 2007). When fires are suppressed too long in one area, it can lead to devasting effects. Due to the accumulated dry biomass after years of fire suppression, once a fire does ignite, it results in hotter, extremely intense fires that spread quickly over a large areas (Govender, Trollope, & Wilgen, 2006; Miranda, Sato, Neto, & Aires, 2009; Walters, Midgley, & Somers, 2004).

On private reserves, fires are often managed so that their intensity and size can be controlled for safety purposes (Price et al., 2015), but these controlled burns can also be used to reduce woody cover threatening open vegetation (Higgins et al., 2007). When considering fire as a means to control bush encroachment, the woody species of concern and its maturity will determine the ultimate success of its application. This is largely because many encroaching woody bush species demonstrate coppicing abilities. Coppicing enables plants to survive fires by producing new shoots from their root system

Figure 3. The image on the left shows Acacia coppicing (new growth) 5 months after a fire in Sept. 2018 caused the plant to be top killed. The image on the right shows a ranger standing amongst several *L. javanica* plants coppicing after being top killed. Photos by Kelli Stephens.

(De Klerk, 2004). When this regrowth occurs after a fire, the plant is considered to have been merely "top killed" (Okello et al., 2007). Both *L. javanica* and acacia species on UmPhafa have demonstrated significant coppicing after a fire in September of 2018 top killed the plants.

Besides coppicing, many plants survival rate after fires is determined by the intensity of the fire, the maturity of the plant, the type of bark around its stem, and the frequency of fires (De Klerk, 2004). Plants with thick, woody bark, like paperbark acacia (*Vachellia sieberiana var. woodii*), are highly resistant to fires as this bark protects the stem (De Klerk, 2004).

When prescribing fires to manage bush encroachment, a best practice is to burn hot, intense fires in the winter just before the spring rains arrive, as this will provide the most adverse effects on trees and shrubs without affecting grass regrowth (Alvarado, Silva, & Archibald, 2018; De Klerk, 2004; Govender et al., 2006). However, regardless of what season a fire is prescribed in or its intensity, a plants maturity can determine its ultimate survival rate.

Fire was once believed to eradicate all seedlings and saplings (Quan, Barton, & Conroy, 1994), but research has since proven that plant mortality after fire varies greatly between species, particularly among the wide range of acacia species (Vadigi & Ward, 2012). For instance, Vadigi and Ward (2012) demonstrated that when sweet thorn acacia (*Vachellia karroo*) saplings are exposed to fire, there was a 0% survival rate while 70% of paperbark saplings survived and displayed coppicing (average sapling height during experiment: 284 mm/sweet thorn; 226 mm/paperbark). However, most acacia species are considered highly resistant to fire mortality once its stems and branches are over 2 meters (m) high (De Klerk, 2004). Even of those plants under 2 m, 75-85% often survive fires and demonstrate dense coppicing soon afterwards (Bester, 1996). Thus, fire is best when used as a preventative measure to bush encroachment rather than curative, because while frequent fires can maintain the overall height of bushes, it will not remove bush once it has established itself (De Klerk, 2004; Scholtz et al., 2017).

Lippia javanica - Umswazi

L. javanica is commonly referred to as fever tea or lemon bush. It is indigenous to central, eastern and southern Africa and has become popular with gardeners for its aromatic leaves and low maintenance (Le Roux, 2004). It is an erect, woody bush standing roughly 1-2 m high with multiple stems shooting up from its root system (van Wyk, 2008). Small, cream flowers bloom year-round and can attract pollinators such as bees and butterflies (Le Roux, 2004). Perhaps the easiest way to identify *L. javanica* in the bush is by crushing its aromatic leaves. *L. javanica* leaves produce a strong, lemony fragrance (Xaba & McVay, 2010), that's easily recognizable to those familiar with it.

L. javanica is extremely adaptable and has been found in a remarkable variety of soil, vegetation, and climatic conditions such as woodlands, wooded grasslands, scrublands, riparian vegetation, dambos (shallow wetlands), swampy areas, and at altitudes from 0-2350 m above sea level (Maroyi, 2017). It can grow in both full sun or partial shade exposure (Xaba & McVay, 2010), and is a hardy plant that can withstand extreme conditions like droughts (Le Roux, 2004; Xaba & McVay, 2010). Being a pioneer plant, it will also take to disturbed soils quite willingly (Le Roux, 2004), and is considered to be a prolific weed in rangelands (Maroyi, 2017).

It is also highly resistant to browsers and insects, and is even been used to repel malaria sources, like mosquitos, away from communities (Malahlela, Adjorlolo, & Olwoch, 2019). Its essential oils have been studied extensively (Olivier et al., 2010), and are widely accepted as a reliable treatment for fevers, colds, and bronchitis (van Wyk, 2008). Studies also show that its oils produce moderate antimicrobial activities against respiratory pathogens (Viljoen, Subramoney, Vuuren, Başer, & Demirci, 2005), beneficial anti-inflammatory properties (Frum & Viljoen, 2006), and were even found to inhibit the HIV-1 reverse transcriptase enzyme (Mujovo et al., 2008).

While *L. javanica* research has focused on its medicinal benefits so far, its effects as a problematic woody bush encroacher have yet to be studied. This means that for wildlife reserve managers wanting to remove this encroacher and restore grazing lands, there is little research on effective removal methods to support these efforts. While *L. javanica* can be grown from seed, it will also root easily from cuttings (Le Roux, 2004), so cutting the plant in the field and leaving behind stems would not be advisable, as is often done after cutting acacia branches. Fire also appears to be an insufficient removal practice due to the coppicing displayed on burned *L. javanica* plants five months after a fire swept over two-thirds of UmPhafa's land in September of 2018. Chemical treatments like herbicide could be an option for removal. However, managing bush encroachment with herbicide is costly and often requires yearly treatments (Scholtz et al., 2017), and unless there is a targeted herbicide for the species to be removed, the herbicide will eliminate all surrounding plant species and could leach into water systems.

Acacia – Izihlahla Zameva

Acacia trees are often an iconic representation of Africa (Figure 4). However, new biochemical and molecular technologies have allowed botanist to break the once massive group of 1,500 *Acacia* species that spanned Australia, Africa, Asia, and the Americas into subgroups (Haddad, 2011). In 2011, after much debate, the controversial revised *Acacia* genus was approved by the International Botanical Congress and became a part of botanical literature moving forward (Boatwright, van der Bank, & Maurin, 2014). While 72% of the species remained unchanged, the genus *Acacia* now describes only plants native to Australia (Dyer, 2014), meaning African *Acacia*, aren't truly *Acacia* anymore. Instead, African *Acacia* have now largely been grouped into two genera, *Vachellia* and *Senagalia* (Dyer, 2014). While some have fully embraced this name change, the second edition of the *Field Guide to Trees of Southern Africa* (Braam van Wyk & Piet van Wyk, 2013) still uses the *Acacia* nomenclature when writing generally about the trees and listing the new scientific name in parenthesis. The staff members at UmPhafa also commonly refer to all these trees as "acacias", and because of this the term acacia will be used throughout this thesis as a common name.

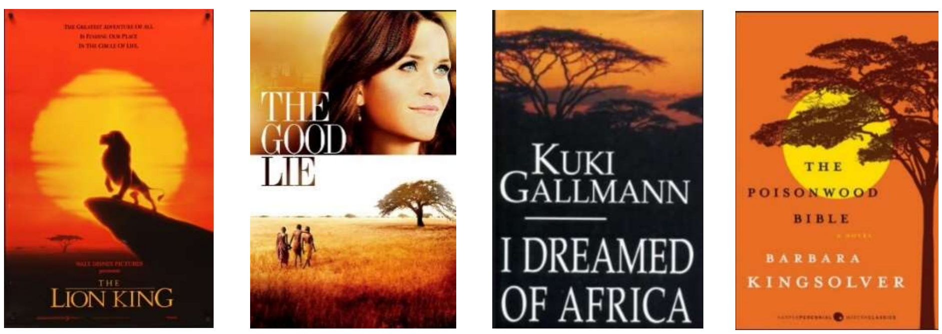


Figure 4. Various acacia tree species in modern pop culture depictions of Africa. From right to left: (1) 1994 movie poster from *The Lion King*, (2) 2014 movie poster from *The Good Lie*, (3) 1991 book cover for *I Dreamed of Africa*, (4) 2008 book cover for *The Poisonwood Bible.*

UmPhafa Private Nature Reserve is home to four acacia species seen in Figure 5: (1) paperbark acacia (*Vachellia sieberiana var. woodii)*, (2) scented-pod acacia (*Vachellia nilotica)*, (3) sweet-thorn acacia (*Vachellia karroo)*, and (4) hook-thorn acacia (*Senagalia caffra).* Paperbark acacia is a medium to large sized tree with spreading branches that form a flattened crown. The characteristic bark is a yellow or greyish brown that often flakes into papery pieces. The hook-thorn acacia ranges in size from a large shrub to a medium tree and is easily distinguishable from the other acacia species by its hooked thorns. The sweet-thorn and scented-pod acacias are the most similar in appearance, as they both range from small to medium sized trees with bright, yellow flowers. However, scented-pod acacia can be identified from sweet-thorn with its paler bark, spines that point backward, and unique pods.

Of these four species, sweet-thorn and scented-pod acacia are likely causing the most encroachment issues on UmPhafa. Prior to the 1990's, scented-pod acacia were observed to be the primary encroacher on grasslands, but recently there has been a shift towards sweet-thorn dominance (Bond, Smythe, & Balfour, 2001; Skowno, Midgley, Bond, & Balfour, 1999). This change is largely attributed to a decrease in fire frequency (Bond et al., 2001). However, for both species, low fire frequencies mixed with high rates of grazing allows a greater number of seedlings to reach maturity Bond et al., 2001; Skowno et al., 1999).

The biggest difference between these two species is their light requirement for seedling establishment. Scented-pod acacia seedlings do well on grazing lawns (Bond et al., 2001), where there is a low biomass of grass and subsequent high availability of light. However, the opposite is true for sweet-thorn acacia as they have been shown to benefit greatly from shade (O'Connor, 1995), unlike the majority of other acacia species (Smith & Shackleton, 1988). Sweet-thorn is also tolerant of drier areas, but truly flourishes where there are higher levels of rainfall (O'Connor, 1995). It can even establish seedlings in tall, dense grass swards, which often increase as fires are suppressed (O'Connor, 1995). It is believed that for these reasons, and its remarkable ability to thrive in various soils and climates , that sweet-thorn in now the most prominent grassland invader in South Africa (Csurhes, Weber, & Zhou, 2010; Du Toit, 1966).

Figure 5. Top left corner: Scented-pod acacia to the left of the giraffes, and sweet-thorn to the right. Top right corner: Giraffe in front of large paperbark acacia. Bottom: Close up of sweet-thorn (left side) and hook-thorn (right side) growing next to one another. Images by Kelli Stephens.

Conservation Decision Making

Scientists and conservation managers have long used spatial data for decision making for at-risk biodiversity (Wilson, McBride, Bode, & Possingham, 2006). More recently, mapping has evolved to include the distribution of threats along with the at-risk biodiversity (Allan et al., 2013). While threat mapping is useful, particularly as a public outreach tool, simple overlays to determine "hotspots" can be insufficient for determining the most cost-effective and pragmatic conservation decision (Tulloch et al., 2015).

A common business practice today is to create S.M.A.R.T goals in order to successfully execute improvement ideas. Simply put, these goals are: specific, measurable, attainable, realistic, and time bound. This creates manageable goals that can be quantifiably tracked to measure whether the original goal was achieved. Private reserves may benefit from adopting similar tools to this for their own goals. While keeping conservation ideals in mind, it is vital that planning and actions must work within the bounds of realism (Beale et al., 2013). All criteria should be evaluated for feasibility (Hobbs, Cramer, & Kristjanson, 2003) and what the likelihood of implementation effectiveness is (Knight, Cowling, Difford, & Campbell, 2010).

METHODS

Introduction

The main goal of this research is to aid in the establishment of UmPhafa's bush encroachment management plan, with emphasis toward their white rhino populations land usage. While all other animals can travel throughout the reserve's 5,800 hectares, the rhinos are restricted to approximately 1,000 hectares for safety purposes, making bush encroachment mitigation a priority for their continued health and consequent successful breeding. To achieve this goal, a comparison was made between Normalized Difference Vegetation Index (NDVI) values and land cover changes over the last 18 years. This analysis established where savanna areas have become dominated by woody bush, where desertification is occurring, and where savanna grasslands have recovered.

While this information provides important visual and statistical overview of land cover changes, field surveys were conducted the summer of 2019 to provide current ground conditions of woody bush encroachment on a finer scale for analysis. These onsite surveys allowed for rangers to be interviewed and provide firsthand insight on where woody bush encroachment has occurred during their tenure and displaced the rhinos from previously suitable habitat. Lastly, UmPhafa managers provided 2017 and 2018 sighting maps to offer further data on their rhino population's land usage. The ArcGIS Pro 2.3.2 software was then used to display and analyze all GIS data.

While intuition and personal knowledge is often used to make decisions, such as with the rangers' encroachment maps, a weighted decision matrix was used to measure and compare various factors and ultimately recommend the most efficient mitigation plan. This tool is beneficial for large groups as it allows for several people to quickly agree on a decision by using the mean value of their opinion for the weight and rate of each factor. This also establishes a value to the pros and cons of any potential solution to help guide decision makers into the best solution.

This chapter gives an overview of the study area, rhino population, survey methodology and representation, details on running NDVI and land cover classification 2D models, and personnel accounts from staff members. It also discusses how various plans, factors, and decisions were made through a weighted decision matrix. All results from the analysis described in this thesis are reported to UmPhafa Private Nature Reserve managers.

Study Area

The area of focus for this project covered 1,061 hectares on the Gevonden farm region of UmPhafa Private Nature Reserve (UmPhafa). The reserve was established in 2005 when the Colchester Zoo's Action for the Wild purchased three farms previously managed for cattle: Gevonden, Geluk and Veltek. In 2015, Sully farm was purchased, connecting the once divided reserve. UmPhafa, located in KwaZulu-Natal, South Africa now encompasses approximately 5,800 hectares with the Tugela River flowing along the southern border and the N3 to the west (Figure 6).

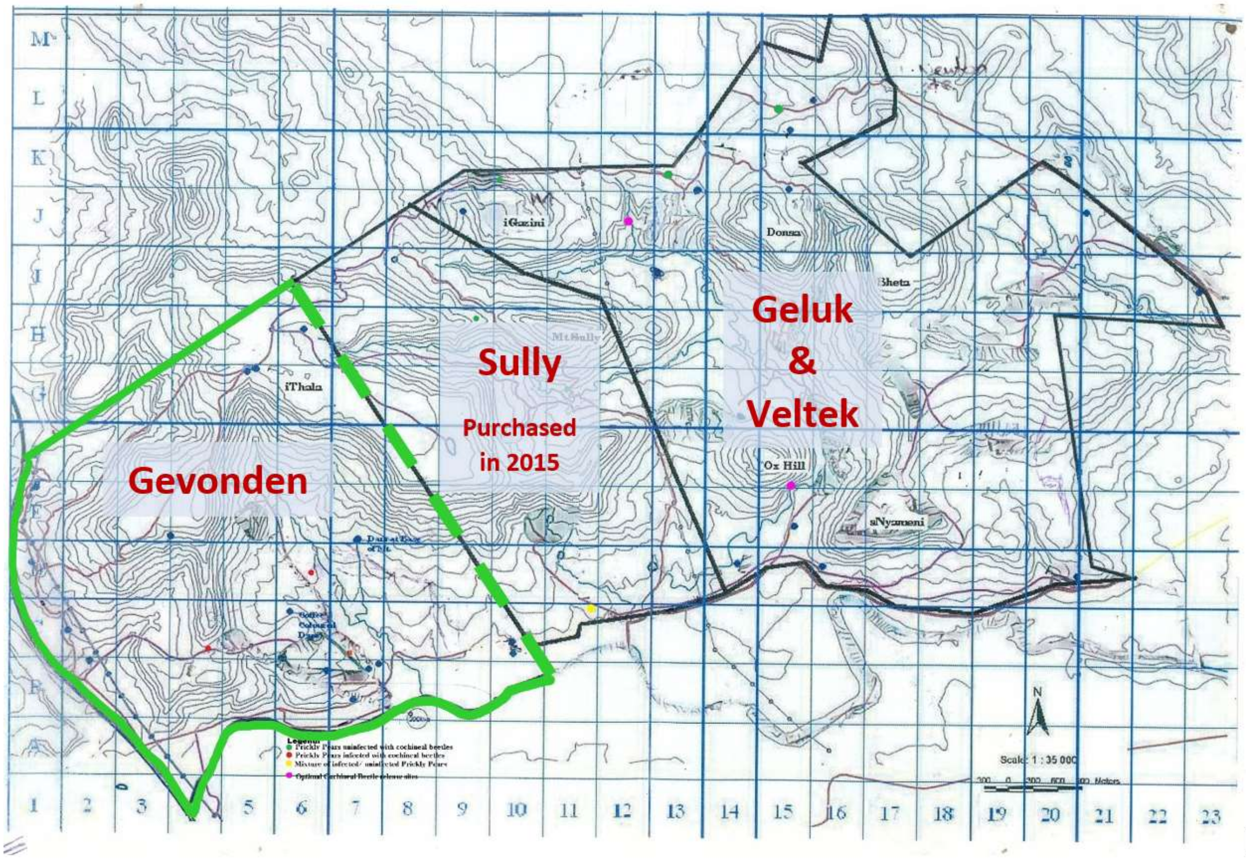


Figure 6. Elevation map of UmPhafa Private Nature Reserve. The green border outlines the Gevonden area, where the rhinos are kept for safety purposes. The green, dotted line designates the cable fence that all animals can travel through, except the rhinos.

To prepare the land for wildlife reintroduction, internal cattle fencing was removed, and an electrified perimeter fence was built around Gevonden. From 2006-2012 animals were introduced and kept in this area, until 2013, when the carrying capacity for certain species was reached, requiring management to relocate animals to Geluk and Vetrek to prevent overgrazing. However, after Sully was purchased and the internal fences were removed to allow the animals to move freely throughout the reserve, many found their way back to Gevonden and appear to view this area as "home" (Bone & Spanton, 2019). The abundance of grazing species, such as blue wildebeest (*Connochaetes taurinus*), plains zebra (*Equus quagga*) impala (*Aepyceros melampus*), and blesbok (*Damaliscus pygargus phillipsi*), on the Gevonden side of the reserve could impact the long-term health of its grasslands through overgrazing.

Rhino Population

Three southern white rhinos were reintroduced in 2008, and UmPhafa currently manages nine Rhinos, one being a dominant bull (Table 1). During the study, the three adult females, Scarface, Nomabonga, and Ambalo were often dispersed from each other. Vukela and Indodakazi were always observed together and were frequently seen accompanying Scarface and her calf, Assagai. Occasionally, Ambalo and her calf, Madikzela, would also join up with Scarface, Assagai, Vukela, and Indodakazi. Nomabonga was always with her calf, Imhlophe, and typically not with the other females. Bullitjie would roam around every day, spending time with various females or observed on his own.

Table 1. Demographics of UmPhafa's rhino population the summer of 2019. * designates that these rhinos were a part of the initial reintroduction group in 2008.

Name	Parents	Gender	Date of Birth
Scarface*	Unknown	Adult Female	≈2001-2003
Nomabonga*	Unknown	Adult Female	≈2002-2003
Ambalo	Scarface & Nkosi	Adult Female	Feb. 2011
Vukela	Nomabonga & Nkosi	Sub-adult Female	March 2012
Indodakazi	Scarface & Nkosi	Sub-adult Female	March 2013
Assagai	Scarface & Bullitjie	Yearling Male	June 2017
Imhlophe	Nomabonga & Bullitjie	Yearling Female	Dec. 2017
Madikzela	Ambalo & Bullitjie	Calf Female	March 2018
Bullitjie	Unknown	Adult Male	2006

Data Collection

Between January and February of 2019, 123 quadrat surveys were completed to measure the abundance and percent cover of *L. javanica* and acacia species near summer habitat rhino locations on UmPhafa. The quadrats were circular with a six-meter diameter, and to measure within this diameter, a metal stake was fabricated with a three-meter twine that could rotate 360 degrees. This allowed for ease of transport while walking approximately eight to sixteen kilometers a day and could be hammered various soils to mark the center of the quadrat.

The surveys began by tracking the Rhinos Monday – Saturday. Once an individual(s) was found, the rangers would designate a safe location to observe them, often downwind and from 30-70 meters away. Once this safe zone was established, a random number generator app was used on a phone to determine the center point of the quadrat. The app was utilized twice to move away from the safe point and decrease any personal bias from the researcher or rangers; the first attempt (numbers 1-5) would govern the direction of travel while the second (numbers 1-3) determined the distance to move (Figure 7). For safety purposes, surveys were ended if a rhino began moving towards the quadrat location, and partial surveys were not included in the final analysis. When time permitted, multiple surveys could be taken by moving to a new safe point around the rhinos.

On the days the Rhinos proved more difficult to locate, the rangers would advise the researcher on locations the rhinos were often seen. A rock would then be thrown by either the researcher, a ranger, or an intern, with closed eyes, to determine the initial start point followed by applying the random number generator to establish the quadrat's center point.

GPS waypoints (latitude and longitude) were taken at twenty-two "hot spot" locations where either *L. javanica*, acacia, or a combination of the two exceeded ≥90% land cover. These points were taken anywhere this was visually observed while tracking the Rhinos.

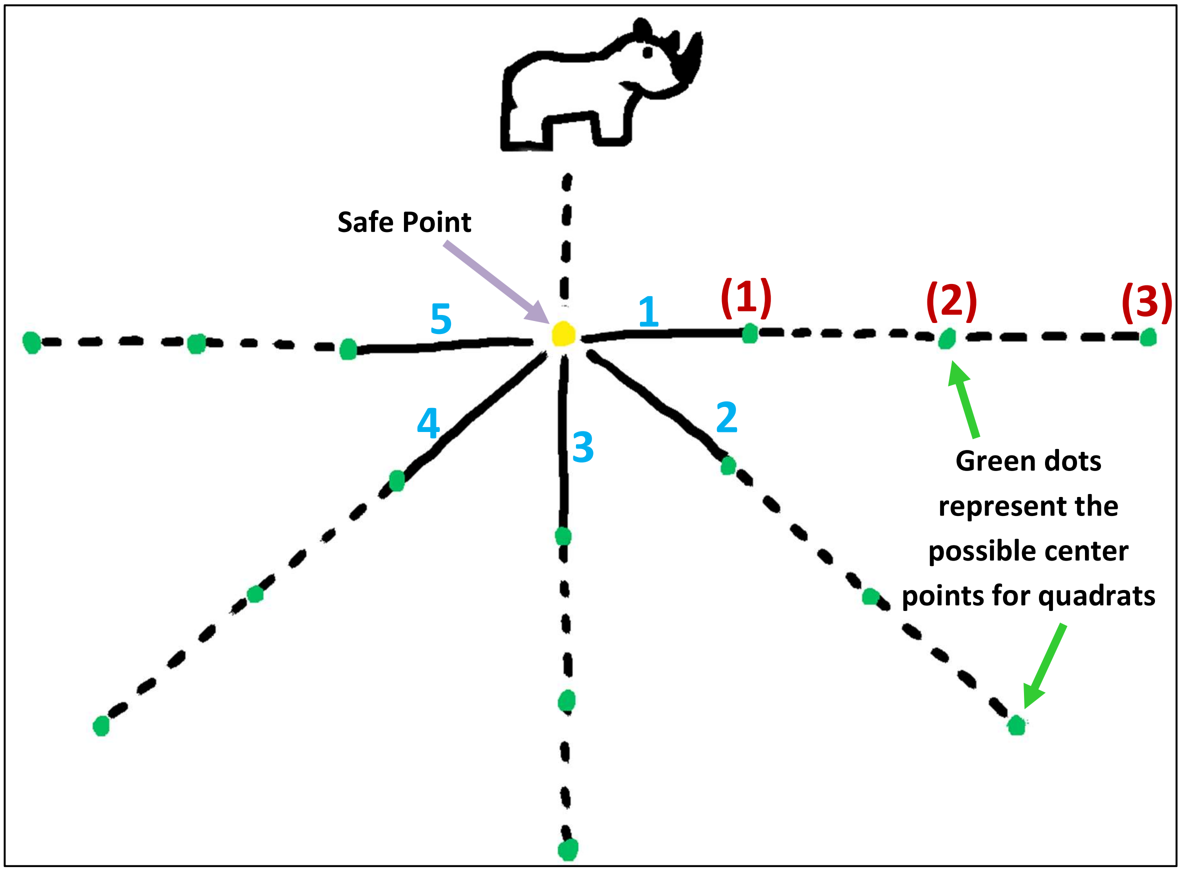


Figure 7. The center point of the quadrat was determined by using a random number generator app. First using numbers 1-5 (blue) to give the direction, always starting but looking perpendicular to the rhino(s) or their last known location if a rock was thrown: 1=0º Right, 2=45º Right, 3=90º, 4=135º Left, 5=180º Left. Secondly, numbers 1-3 (red) informed of the distance to travel: 1=Three m, 2=Six m, 3=Nine m.

Once the quadrat center point was determined a marker, often a rock, was set down to establish a rotational starting point. Rangers and the researchers would then move clockwise, counting the number of *L. javanica* plants in the quadrat. After counting *L. javanica*, the process was then repeated three more times to count acacia species. Each count was to measure the different size categories of acacia plants present in the quadrat. The size classifications determined by the reserve managers were; seedling (<0.5 m), small shrub (0.50-1.5 m), and tall shrub/trees (>1.51 m). Next, the percent cover of *L. javanica* and acacia over the total quadrat were estimated visually. Plants with their main stem system outside the quadrat were excluded from the plant count, but its leaves and branches were included in the percent cover category. Each quadrat was then given a unique ID consisting of the location from the grid map (Figure 6), date, and the sequential survey number for the day.

The aforementioned data was recorded in a field notebook. This information, along with the following, was then recorded on the researchers phone using the Survey123 app: (1) Date, (2) GPS Waypoint — taken from the quadrat center point, (3) Photograph of the quadrat and surrounding area, (4) How starting point was determined (rhinos vs. rock), (5) Rangers present, (6) Rhinos present, (7) Distance from rhinos (if applicable), (8) Comments (Figure 9).

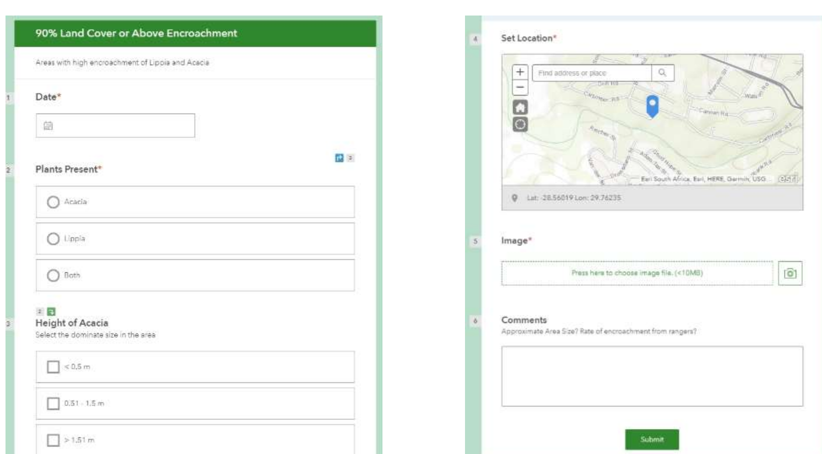
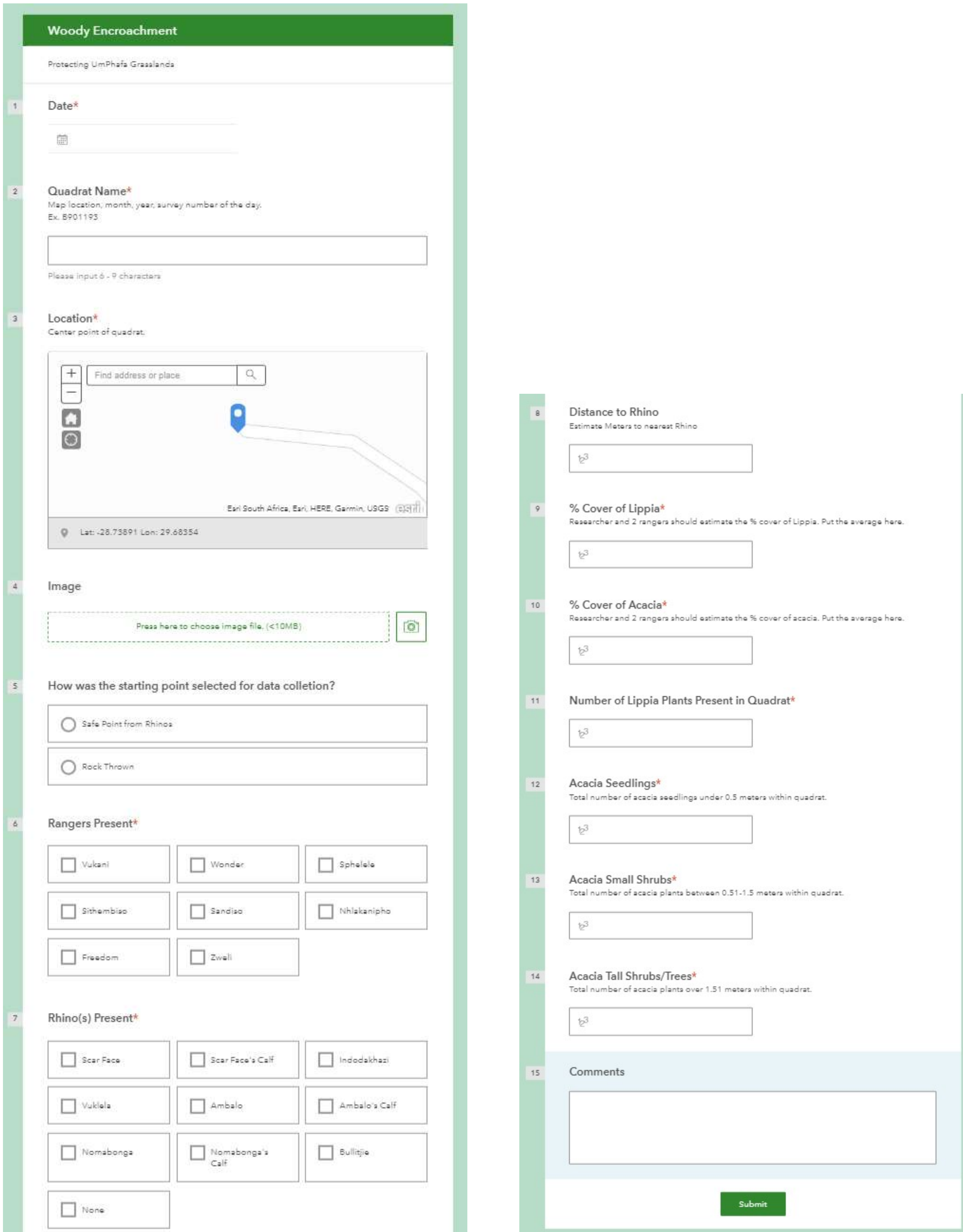


Figure 8. Visual of the "90% Land Cover or Above Encroachment" data collection form on Survey123


Woody Encroachment

Protecting UmPhafa Grasslands

1 Date*

2 Quadrat Name*
Map location, month, year, survey number of the day.
Ex. B901193

Please input 6 - 9 characters

3 Location*
Center point of quadrat.

Find address or place

Esri South Africa, Esri, HERE, Garmin, USGS

Lat: -28.73891 Lon: 29.68354

4 Image

Press here to choose image file. (<10MB)

5 How was the starting point selected for data colletion?

Safe Point from Rhinos

Rock Thrown

6 Rangers Present*

Vukani | Wonder | Sphelele
Sithembiso | Sandiso | Nhlakanipho
Freedom | Zweli

7 Rhino(s) Present*

Scar Face | Scar Face's Calf | Indodakhazi
Vuklela | Ambalo | Ambalo's Calf
Nomabonga | Nomabonga's Calf | Bullitjie
None

8 Distance to Rhino
Estimate Meters to nearest Rhino

9 % Cover of Lippia*
Researcher and 2 rangers should estimate the % cover of Lippia. Put the average here.

10 % Cover of Acacia*
Researcher and 2 rangers should estimate the % cover of acacia. Put the average here.

11 Number of Lippia Plants Present in Quadrat*

12 Acacia Seedlings*
Total number of acacia seedlings under 0.5 meters within quadrat.

13 Acacia Small Shrubs*
Total number of acacia plants between 0.51-1.5 meters within quadrat.

14 Acacia Tall Shrubs/Trees*
Total number of acacia plants over 1.51 meters within quadrat.

15 Comments

Submit

Figure 9. Visual of the "Woody Encroachment" data collection form on Survey123.

GIS Data Modeling

In order to assess bush encroachment changes on Gevonden, land cover conditions were examined between the time the area was operated as a cattle farm (2001), the year rhinos were reintroduced (2007), mid-points as animal population increased (2014 and 2016), and the current environment (2019). ArcGIS Pro 2.3.2 software was used to analyze all spatial data.

To model the Normalized Difference Vegetation Index (NDVI) and land cover classifications, Landsat and Sentinel-2 images were acquired from the USGS Global Visualization Viewer (GloVis) website. For 2001 and 2007, 30-meter resolution Landsat 4-5 Thematic Mapper images were used. These satellites collected very few images after November 2011, before being completely decommissioned in 2013. Therefore, to compare NDVI values at the same 30 m resolution, Landsat 8 images were used from 2014 and 2019 for analysis. In 2015, Sentinel-2 satellites began acquiring data at a 10 m resolution, so images were also analyzed from 2016 and 2019 to begin measuring NDVI and land cover changes over Gevonden at this finer scale. The last image obtained was an ASTER Global Digital Elevation Model (DEM), which was used to model the elevation within Gevonden. All the final images were chosen based on three factors: (1) maximum greenness, (2) minimal cloud cover, and (3) acquired between Feb. 23rd – March 30th of the respective year. All the images had 0% cloud cover, except the 2019 Landsat 8 image, which had a small cloud shadow over the northeast border of Gevonden, and minor interference on the 2016 Sentinel-2 image.

Satellite cameras capture all visible ranges in the form of bands (Gandhi, Parthiban, Thummalu, & Christy, 2015). In order to analyze the Landsat and Sentinel-2 images, a composite .TAR file was created of these bands.

NDVI

Measuring above-ground green biomass is commonly characterized using NDVI, which analyzes the differential reflectance of red and near infrared spectral bands (Saha, Scanlon, & D'Odorico, 2015) (Figure 10). As shown in Table 2, NDVI values range from −1 to +1, and while there aren't distinct boundaries for each land cover ("What is NDVI," 2017), they can be generalized into broad categories (Brecht, 2018).

To calculate NDVI levels over Gevonden, each image was first set to the band combination for *vegetation analysis* — Short-wave infrared (SWIR 1)/Near infrared (NIR)/Red (Figure 11). This rendering was then clipped to only include land cover within the Gevonden border and set for Dynamic Range Adjustment (DRA) to adjust the visible stretch as the image was zoomed in and out. Lastly, the NDVI raster analysis tool was then used to calculate pixel NDVI values for each year analyzed.

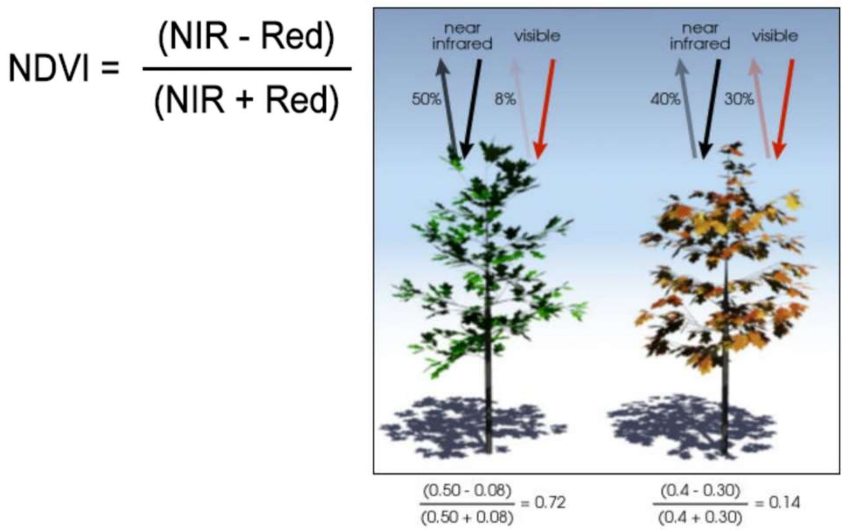


Figure 10. NDVI is calculated from the visible (Red) and near-infrared (NIR) light reflected by vegetation. Healthy or more dense vegetation (left) absorbs most of the Red light that hits it while reflecting most of NIR light. Unhealthy or sparse vegetation (right) reflects more Red light and less NIR light. Numbers on the NDVI scale range from −1 to +1. Adapted from NASA. (2000, August 30). Measuring Vegetation (NDVI & EVI), from https://earthobservatory.nasa. gov/features/MeasuringVegetation/measuring _vegetation_2.php

Table 2. The following numbers depict common NDVI values for various ecosystems. However, actual values can vary greatly by region and season.

Common NDVI Values	**Ecosystem**
Negative Values	Water
0	Urban
<0.1	Rock, Snow, Sand
0.1-0.2	Soils
0.2-0.5	Shrubs and Grasslands
0.5-0.8	Temperate and Boreal Forests
0.8-0.92	Rainforests

Table adapted from the text of Brecht, 2018

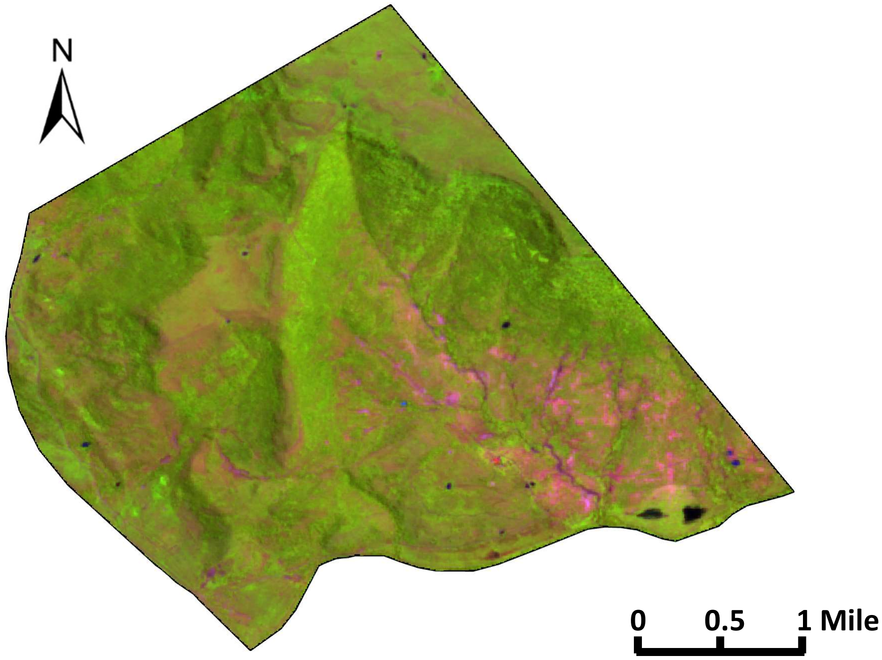


Figure 11. Example of the *Vegetative Analysis* band combination *SWIR 1/NIR/Red* on a 2019 Sentinel-2 composite image.

Land Cover Classification

To begin categorizing land cover, the *natural* band combination — NIR/ Red/Green — was applied to each Landsat and Sentinel-2 image (**Figure 12**). Next, a training sample was created for each year by manually creating polygons which designated pixels to their known land cover using a custom schema as seen in Figure 13. This step was performed over an unsupervised classifier to increase the categorization accuracy of the Maximum Likelihood Classification (MLC) geoprocessing script. Once the training classification was complete, a shapefile was created, and this was then reformatted into an ASCII signature file with a .gsg extension. This new file was used as the input signature file needed to run the supervised MLC. An output confidence raster was also created to analyze the tools sureness of correctly classifying the land cover for each pixel. Based on the confidence raster results, adjustments were made to the training sample as needed. The final image was then clipped to include only the land cover within the Gevonden border.

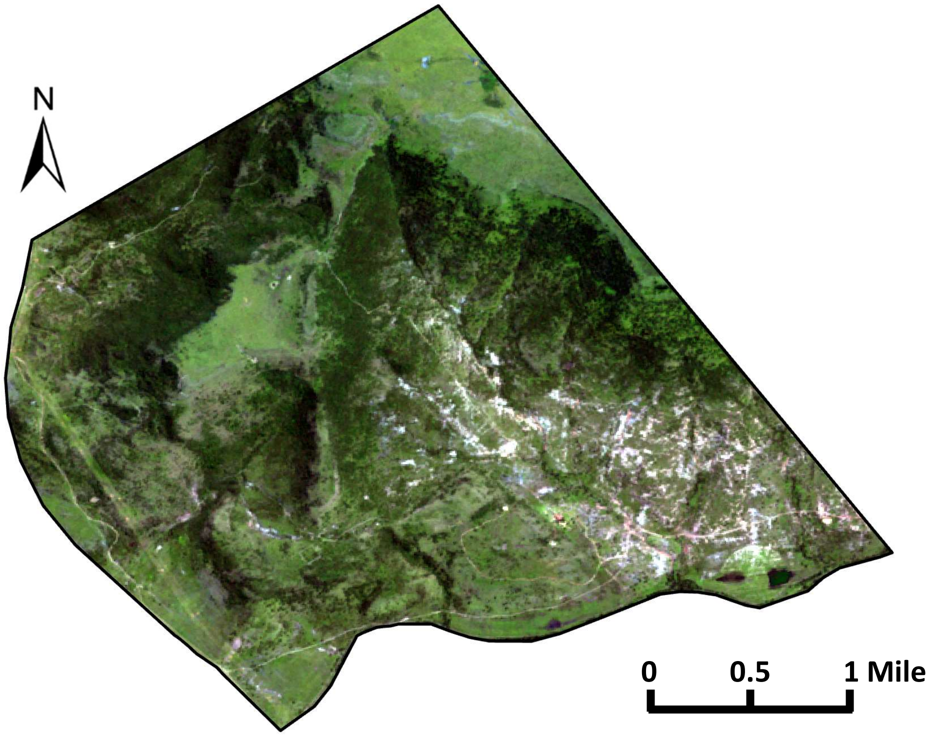


Figure 12. Example of the *Natural* band combination *NIR/ Red/Green* on a 2019 Sentinel-2 composite image.

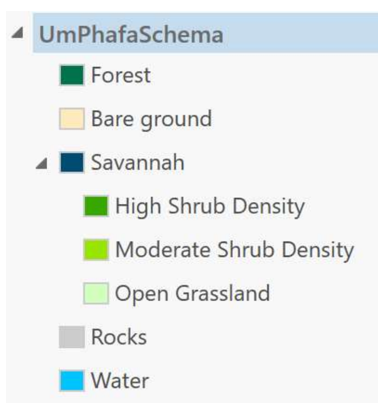


Figure 13. Custom UmPhafa Schema used to create each training sample.

Survey Representation

To view the Survey123 data in ArcGIS Pro, a hosted feature layer was created on ArcGIS Online. This layer was then superimposed onto a 2019 Sentinel-2 composite image set to the natural band projection. This basemap was layered with feature classes to display roads, buildings, and dams which could provide spatial reference on the 2D maps. Each map also included a layer which represented hotspots (≥90% land cover) of growth for *L. javanica*, acacia, or a combination of the two.

Quadrat survey results were displayed by selecting a combination of variables to manipulate with symbology. *L. javanica* and acacia quantities were visualized in four separate maps, while percent cover was displayed in two. Due to the high range of variability between the quantity of plants in each category, values were assigned to either a 0, low, medium, high, or very high classification assortment outlined in Table 3. *Classification ranges for the number of plants in each quadrat.*. For percent cover, values were broken into seven categories: 0%, ≤10%, ≤25%, ≤20%, ≤55%, ≤70%, and ≤100%.

Table 3. Classification ranges for the number of plants in each quadrat.

	Frequency Classification				
Plant Field	**0**	**Low**	**Medium**	**High**	**Very High**
Lippia	0	≤ 10	≤ 25	≤ 50	≤ 140
Acacia Seedlings	0	≤ 25	≤ 50	≤ 100	≤ 303
Acacia Shrubs	0	≤ 2	≤ 8	≤ 15	≤ 24
Acacia Trees	0	1	≤ 3	≤ 5	≤ 7

Weighted Decision Matrix

A weighted decision matrix (WDM) was used to evaluate and prioritize the different options for managing bush encroachment on Gevonden. This tool allows for several options to be evaluated based on any number of important factors. While it can be used by one person, it is also a great technique to use in a group, because the mean numerical value can be applied to factors when opinions vary.

To design the WDM, a list of location options for mitigating bush encroachment was listed in rows. The various factors which can impact the success or feasibility of these options are then listed as column headings. Each of these factors are then ranked on its importance: 1=Unimportant, 2=Neutral, 3= Somewhat Important, 4=Important, 5=Very Important. Next, each option is then scored on its ability to perform these factors by assigning a numerical value that corresponds to a five-point Likert scale: 1=Very Poor, 2=Poor, 3=Neutral, 4=Good, 5=Very Good.

Once everything has been rated the two scores are multiplied to create the combined weighted score. Lastly, adding the weighted scores in each row produces a total for each option. Those with the highest totals reveal the best options to proceed with.

RESULTS

Introduction

The results of this research first aim to answer if bush encroachment is occurring on Gevonden and to what degree using satellite images. This was achieved through analysis of mean NDVI values and the percent cover of various land classifications for five separate years: 2001, 2007, 2014, 2016, and 2019. While this provides insight into the severity of woodland expansion, it also visually displays where it has occurred.

This information was combined with ranger GIS encroachment maps (Appendix A) to allow for a more personal evaluation of changes to bush encroachment observed on Gevonden, with emphasis to its impacts to the Rhino's habitat. To further evaluate which locations near Rhino habitat are most at risk today, quadrat surveys (n=123) were conducted to map the current coverage and quantity of *L. javanica* and acacia seedlings, shrubs, and trees during the 2019 summer season. The results from this data were analyzed and displayed using ArcGIS Pro, which required a total of six maps.

To create a bush encroachment management plan, a weighted decision matrix was used to provide a clear reasoning for the results. This matrix can also be easily modified by the reserve managers as reserve goals and priorities may change.

NDVI Analysis

The mean NDVI values inside Gevonden's boundaries were as follows: (1) 2001 Landsat 5 image = 0.454, (2) 2007 Landsat 5 image = 0.457, (3) 2014 Landsat 8 image = 0.302, (4) 2019 Landsat 8 image = 0.391, (5) 2016 Sentinel-2 image = 0.627, and (6)

2019 Sentinel-2 image = 0.655. The NDVI renderings from ArcGIS Pro can be seen in **Figure 15**.

Due to spectral and spatial differences between Landsat 5, Landsat 8, and Sentinel-2 sensors, the mean NDVI values were not used to assume the dominate land cover or compared between the various satellites. Instead, it was used to measure if the mean NDVI has increased over the years which would indicate an increase in green biomass.

From 2001 to 2007 the NDVI value increased very slightly, by +0.003 which averages to a mean NDVI increase of +0.0005/year. From 2014 to 2019 the mean NDVI value increased by a total of +0.089 or +0.0178/year. This change equates to a 3,460% increase in the mean NDVI value by year. For the Sentinel-2 images, which acquire data at a higher resolution than the Landsat images (10 m vs. 30 m), the mean NDVI value increased by +0.028 or +0.007/year. These results are visualized in **Figure 14**.

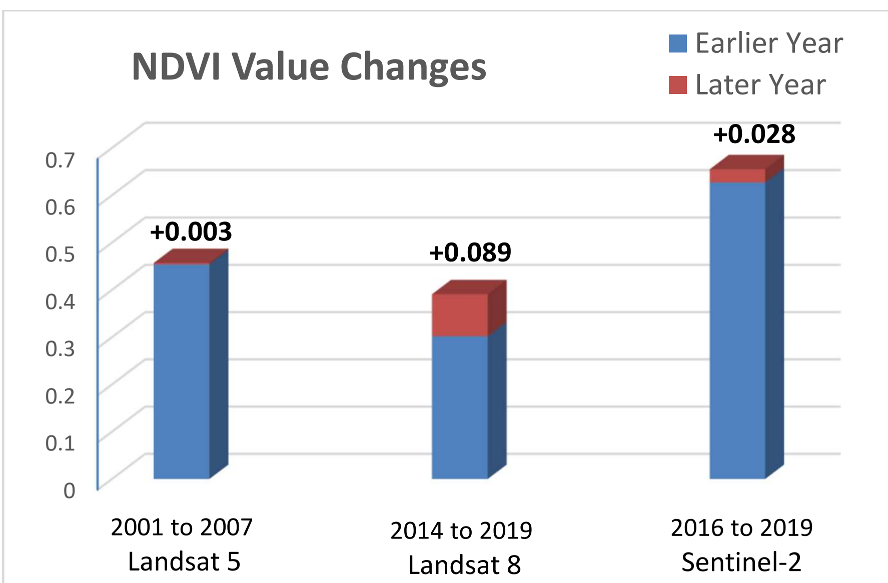


Figure 14. This graph displays the mean NDVI value changes between various satellite images over Gevonden.

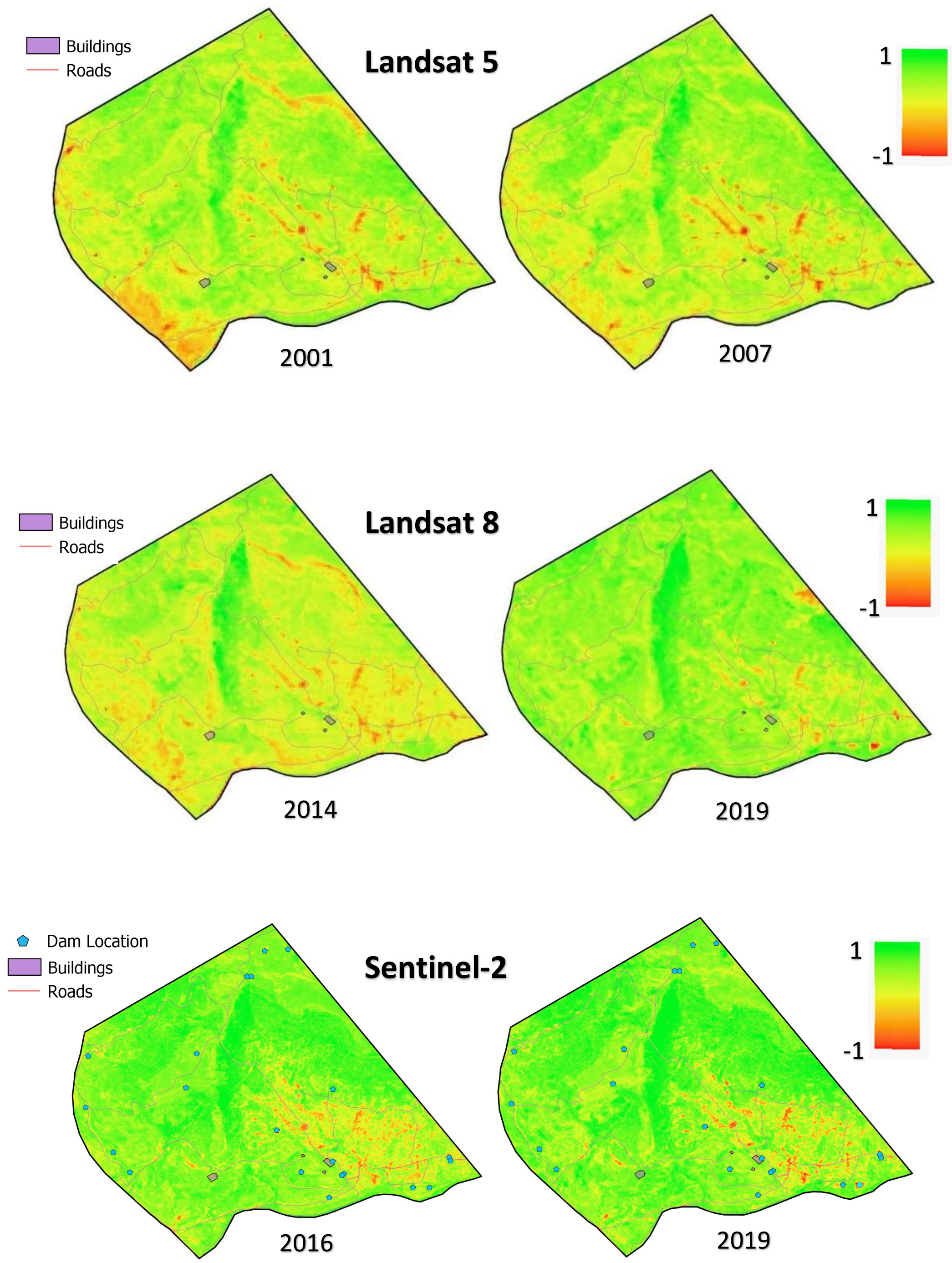


Figure 15. NDVI projections from Landsat 5, Landsat 8, and Sentinel-2 satellite images.

Land Cover Changes

Table 4 provides detailed results from the maximum likelihood land cover classification. The 2016 Sentinel-2 image was excluded from this group due to previously unseen atmospheric interference which decreased the classification accuracy.

For the rhinos on Gevonden, savannas with a moderate shrub density and open grasslands will provide the best habitat for grazing, while forests and high shrub density savannas offer protection from hot, sunny days or storms. These results help to determine the severity of bush encroachment by measuring grazing habitat losses and forest expansion over the past 18 years.

Starting with forest cover, the results indicate that this has been expanding steadily. Between the 30 m Landsat 8 image and 10 m Sentinel-2 image, the maximum likelihood tool estimates there to be around 27.65-30.42% forest land cover today. A cloud shadow on the eastern border could have increased this percentage slightly for the 2019 Landsat 8 image. High shrub density savanna land cover appears to have decreased around 2014, but its numbers have since risen again, with current coverage on Gevonden around 22.01-24%. Moderate shrub density savannas have been decreasing since 2007 and now cover approximately 20.5-21.54% of Gevonden. Open grassland savannas appear to have recovered slightly from 2007, and currently cover 18.55-19.54%. Bare ground has the most discrepancy for land cover classification in 2019. There is anywhere between 4.74-8.98% of bare ground land cover, which can stem from overgrazing, general erosion, or dongas (eroded ravines).

Looking at **Figure 16** we see that open grassland savannas appear to be recovering along the N3 (western) border of Gevonden. Some of this could be from the shrub and tree removal performed by the power company, as major power lines run through this area. The southwest corner was observed to be severely degraded in 2001, but this has improved greatly since then, possibly contributing to the rise and grassland cover. Forests and high shrub density savannas are expanding down iThala's slopes and to the south/southeast side of the boma, which is reducing moderate shrub and open grassland savannas in these areas. Lastly, the area north of the rye field and wetlands is degrading, likely due to overgrazing. Figure 17 displays the 2019 land cover classification results from the Sentinel-2 image at the 10 m resolution.

Table 4. Land cover percent changes over the past 18 years. Red cells indicate an undesirable change from the previous year, while green cells indicate a positive change. Forest and high shrub density savannas offer low quality grazing for rhinos, so increases in its percentages are undesirable while decreases in these land covers are desirable. For moderate shrub density and open grassland savannas the opposite is true, a decrease in coverage is undesirable while an increase is desirable. The S-2019 column represents the Sentinel-2 image at a 10 m resolution.

	2001	2007	2014	2019	S-2019
Forest	22.76%	23.15%	26.86%	27.64%	30.42%
High Shrub Savanna	24.03%	24.20%	17.42%	22.01%	24%
Mod Shrub Savanna	25.71%	29%	27.68%	21.54%	20.50%
Open Grassland Savanna	17.75%	17.05%	22.51%	18.55%	19.54%
Bare Ground	9.76%	6.38%	5.15%	8.98%	4.74%

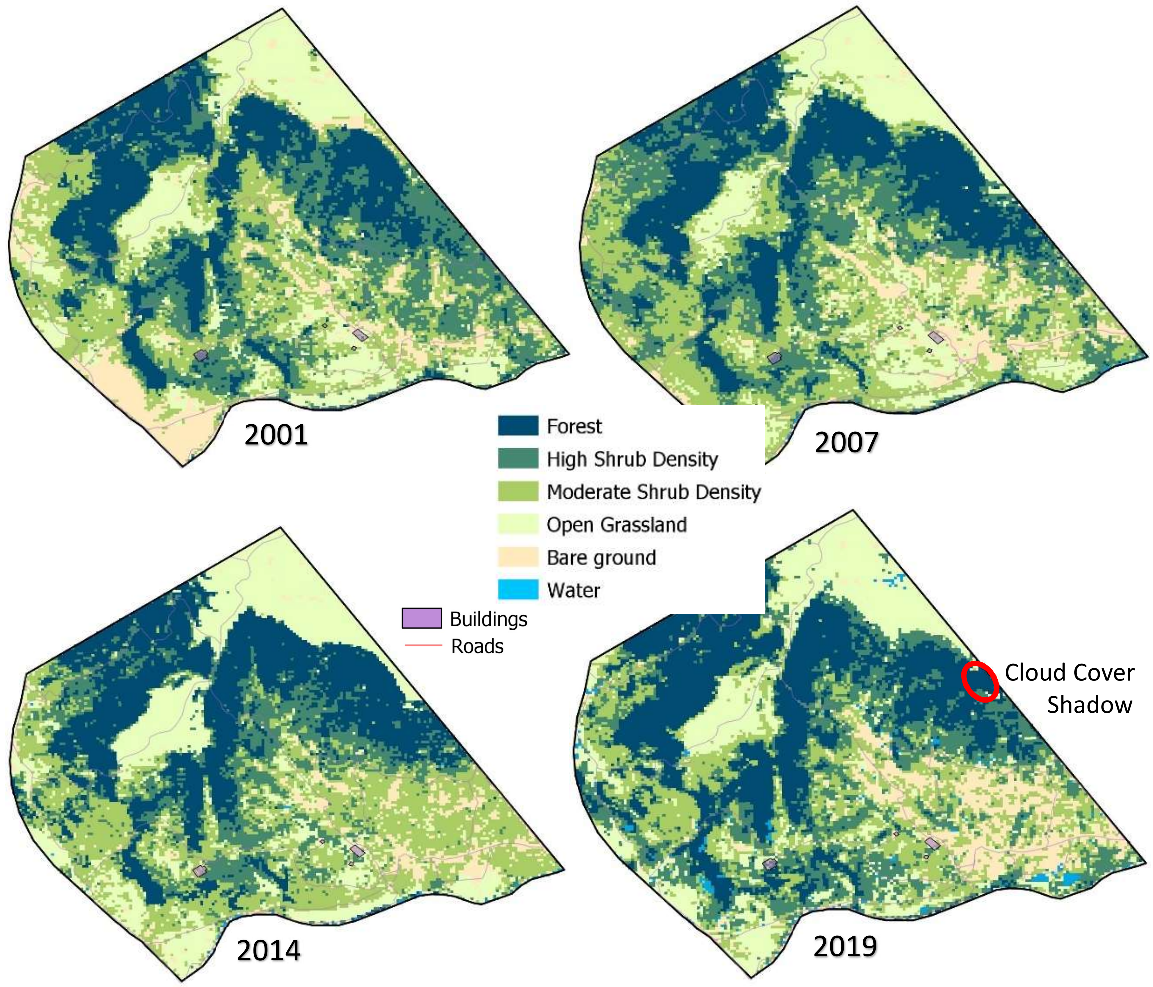


Figure 16. Land cover classifications at 30 m resolution.

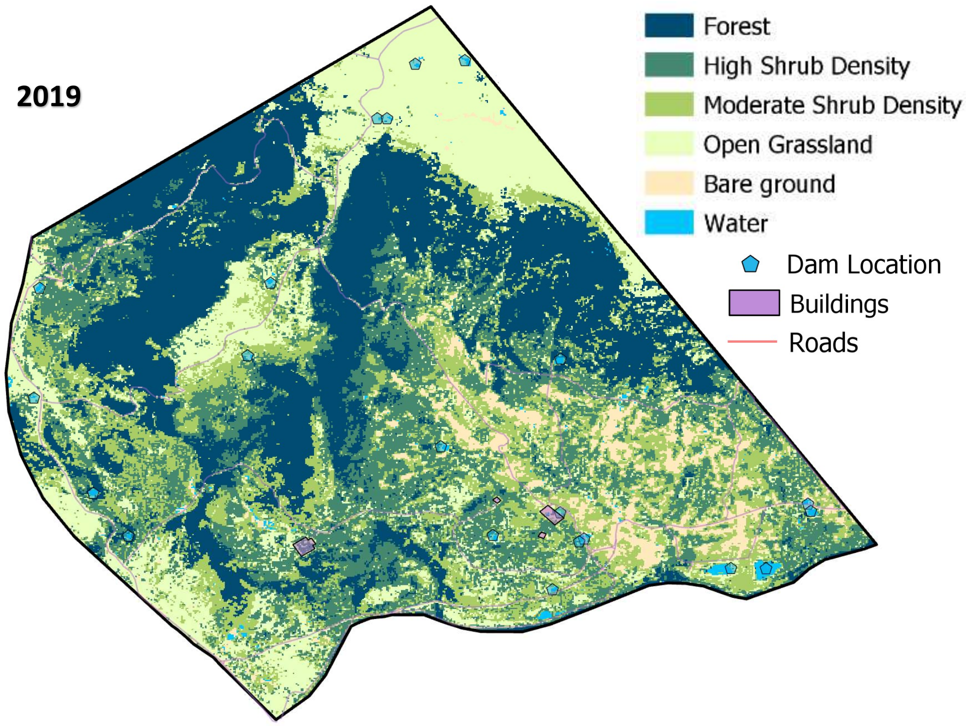


Figure 17. Land cover classification at 10 m resolution.

GIS Data Modeling

Lippia javanica

The percent coverage of *L. javanica* inside the quadrats ranged from 0-95% with a mean of 19.44% (Figure 18). The number of *L. javanica* plants found inside the quadrats ranged from 0-140 with a mean of 15.9 plants (**Figure 19**). 89.43% of the quadrats were found to have at least one *L. javanica* plant present. Several hotspots were found around the edges of iThala's plateaued summit and east of the N3 border. Hotspots were also found north of coffee dam in the amphitheater, and to the east of the iThala gorge.

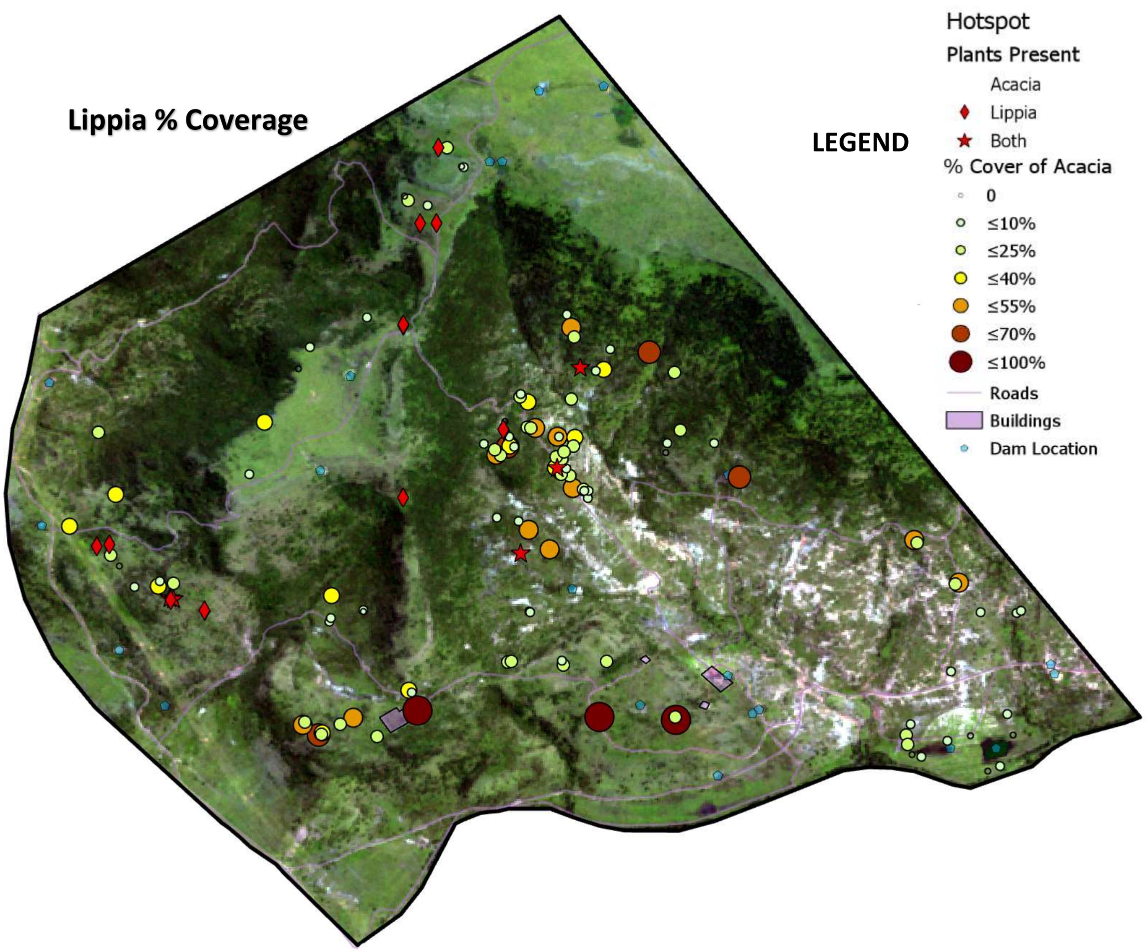


***Figure 18*.** ArcGIS Pro layer displaying the percent coverage of *Lippia javanica* inside circular quadrats near rhino sightings on Gevonden.

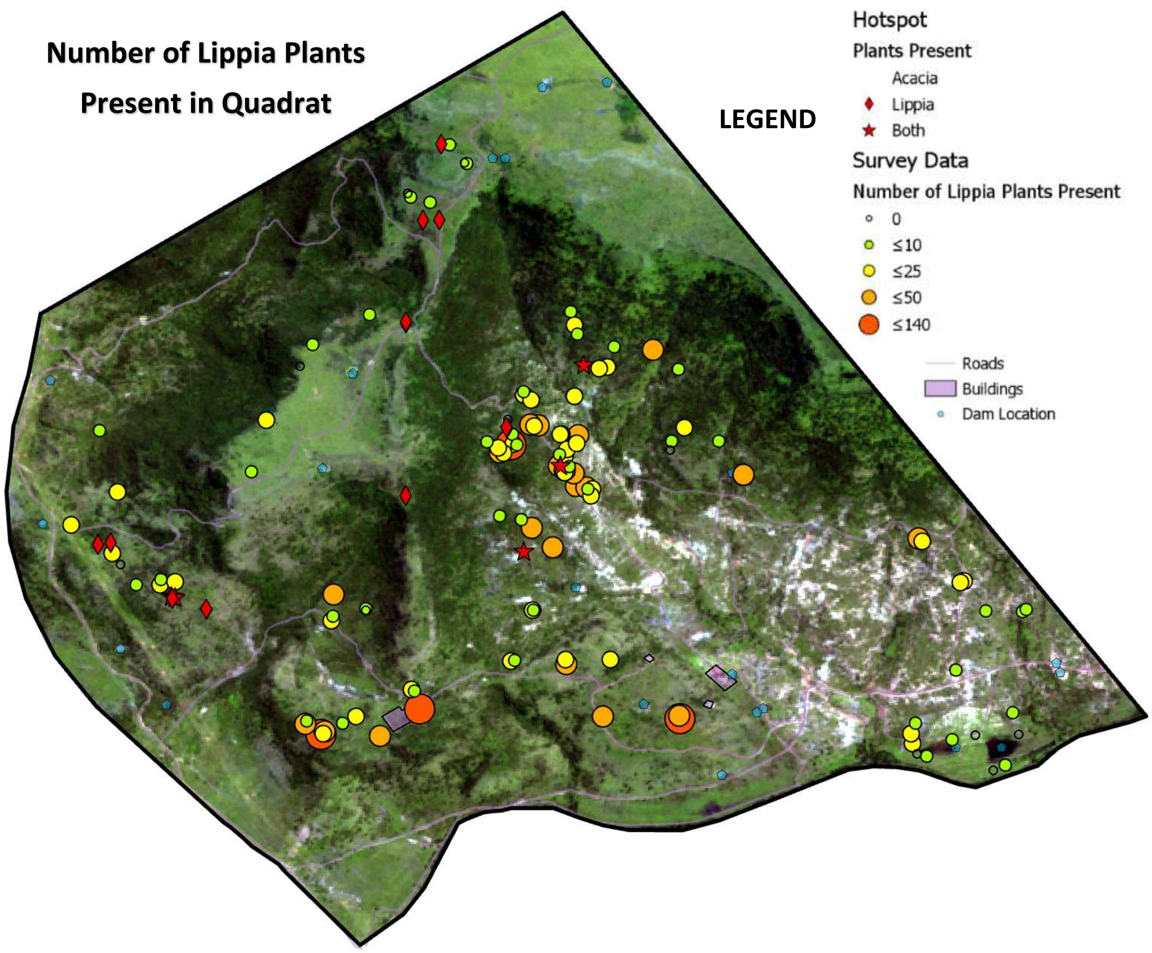


Figure 19. ArcGIS Pro layer displaying the number of *Lippia javanica* inside circular quadrats near rhino sightings on Gevonden.

Acacia

The percent coverage of acacia inside the quadrats ranged from 0-85% with a mean of 17.88% (**Figure 20**Figure 18). The number of acacia seedlings (<0.5 m) found inside the quadrats ranged from 0-303 with a mean of 37 seedlings (**Figure 21**). 92.68% of the quadrats were found to have at least one acacia seedling present. The number of small shrub (0.50-1.5 m) acacias found inside the quadrats ranged from 0-24 with a mean of 3.48 (Figure 22). 74.80% of the quadrats were found to have at least one small shrub acacia present. The number of tall shrub/trees (>1.51 m) acacia found inside the quadrats ranged from 0-7 with a mean of 0.90 trees (Figure 23). 38.21% of the quadrats were found to have at least one tall shrub or tree present. Several hotspots were found east of the N3 border, north of coffee dam, and to the east of the iThala gorge.

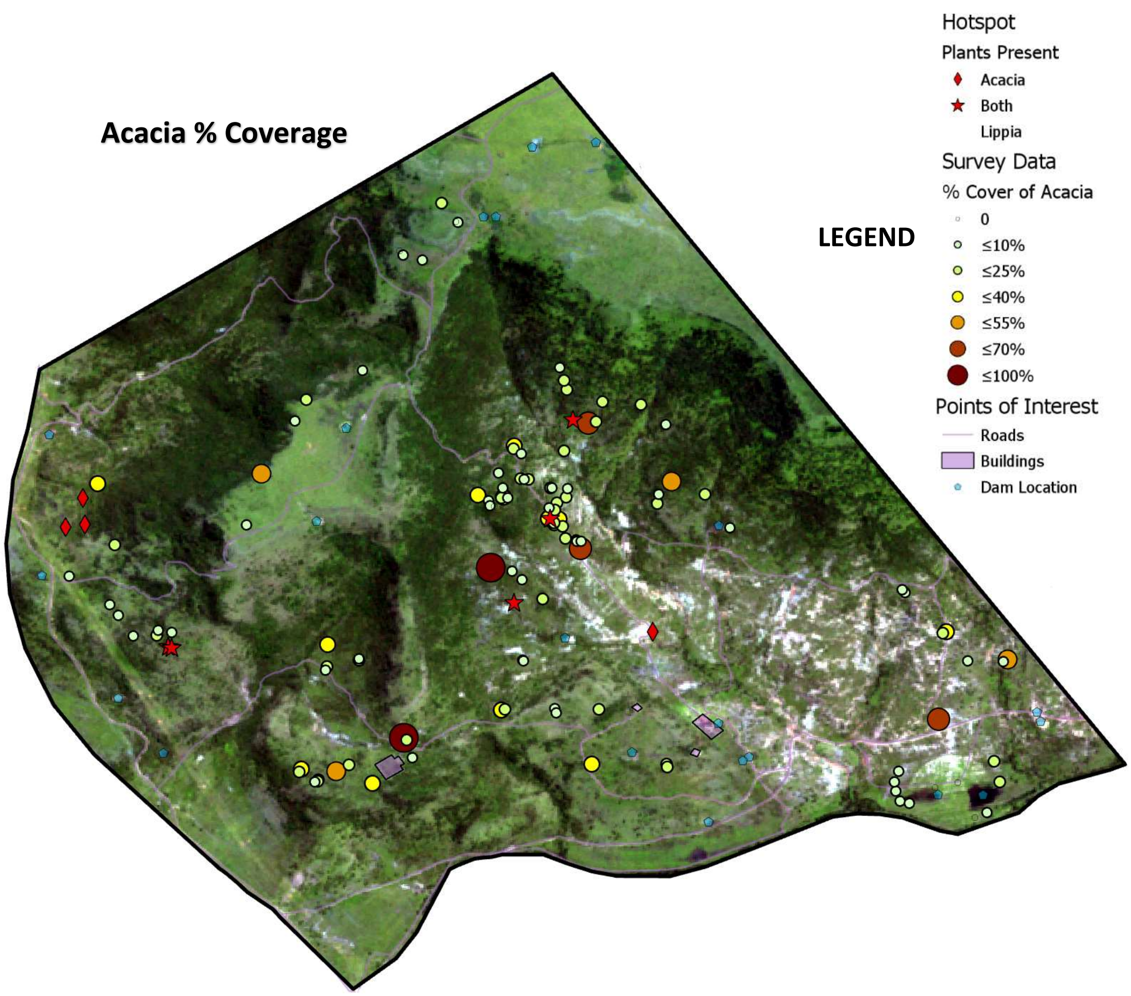


Figure 20. ArcGIS Pro layer displaying the percent coverage of acacia inside circular quadrats near rhino sightings on Gevonden.

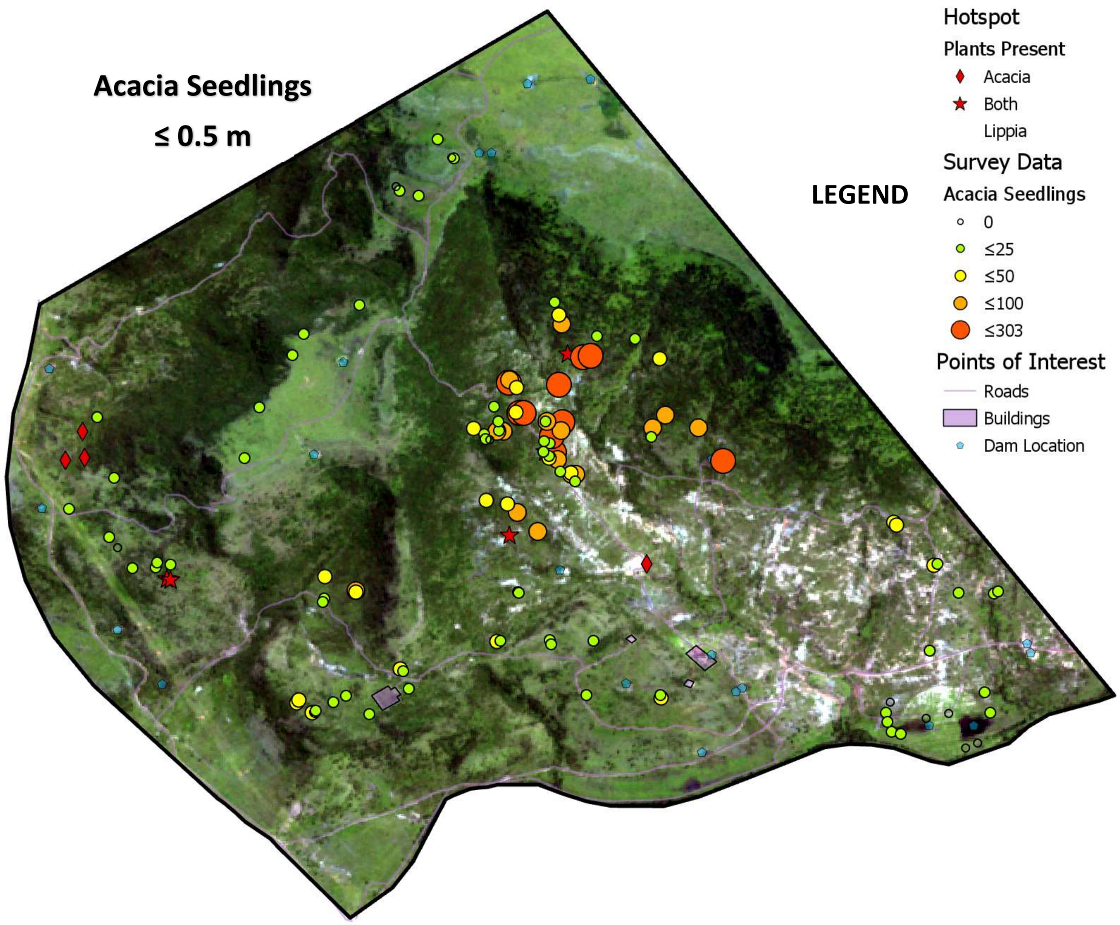


Figure 21. ArcGIS Pro layer displaying the number of acacia seedlings (<0.5*)* inside circular quadrats near rhino sightings on Gevonden.

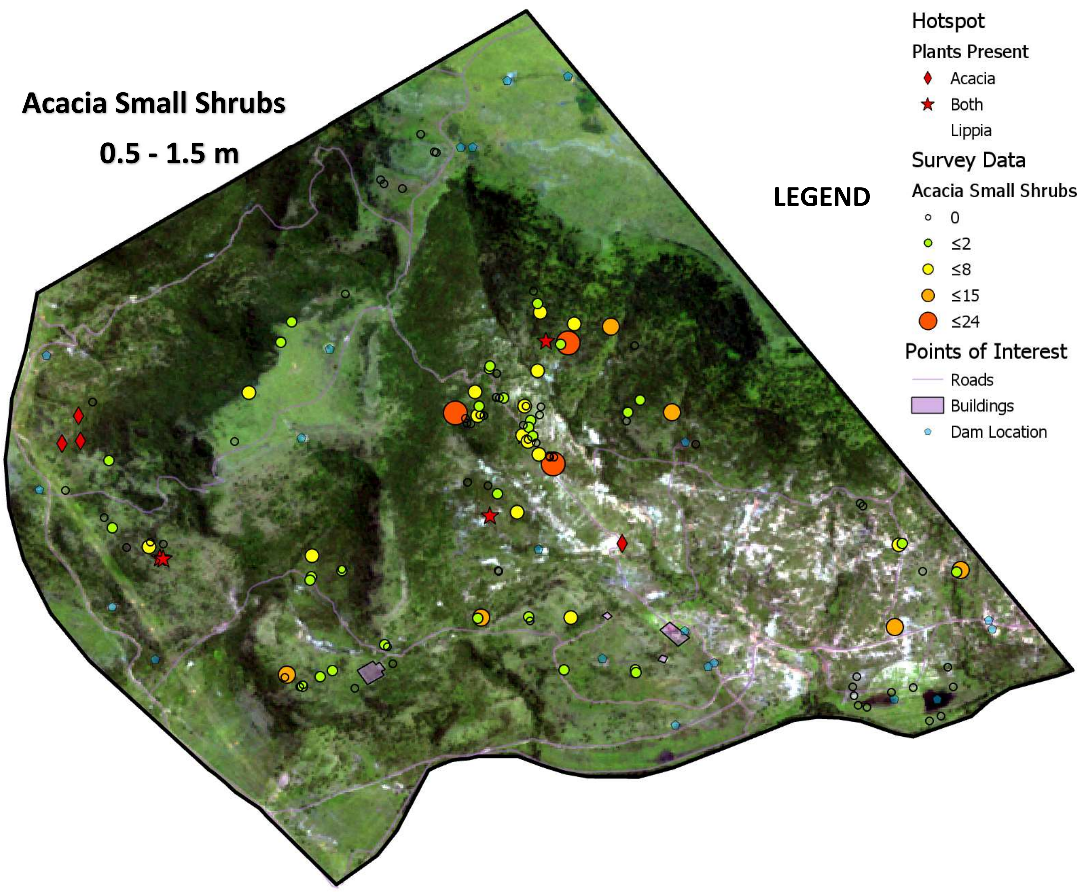


Figure 22. ArcGIS Pro layer displaying the number of small shrub acacias (0.50-1.5 m) inside circular quadrats near rhino sightings on Gevonden.

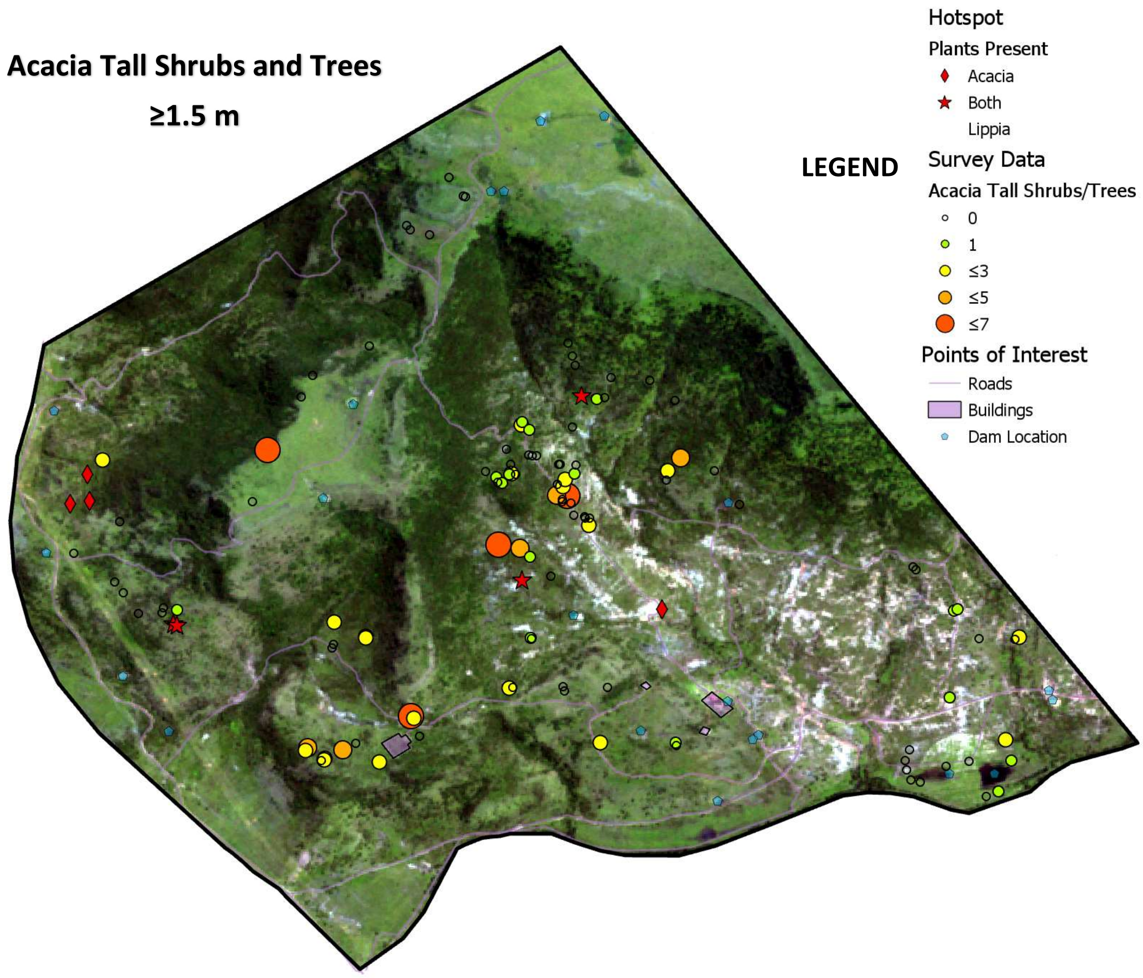


Figure 23. ArcGIS Pro layer displaying the number of tall shrub/trees (>1.51 m) inside circular quadrats near rhino sightings on Gevonden.

Restoration Priority Zones

Restoration priority zones (

Figure **24**) were created by evaluating the density of *L. javanica* and acacia flora near rhino summer habitat, hotspot locations for these plants, ranger encroachment maps (Appendix A), ranger comments on quadrat locations, and historic rhino habitat use maps (Appendix B). These areas range from 6.7 ha to 28.3 ha, and total 144.5 ha for grassland recovery.

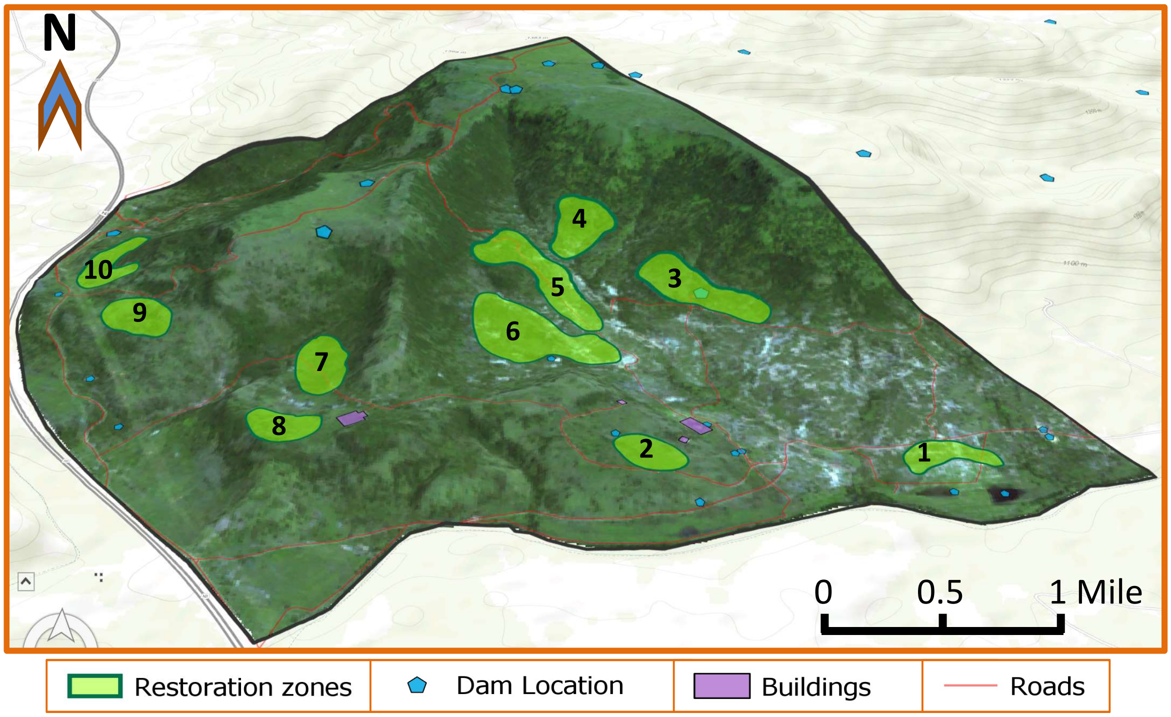


Figure 24. Ten priority zones to remove woody bush encroachment on savannas. (1) Rye Field Perimeter – 6.7 ha, (2) Bone Dam – 7.3 ha, (3) Mountain Dam – 19.3 ha, (4) Northeast Gorge – 14 ha, (5) iThala Road – 25.5 ha, (6) Amphitheater Coffee Dam – 28.3 ha, (7) Boma Valley East – 12.1 ha, (8) Boma Valley West – 8.6 ha, (9) N3 South – 10.2 ha, (10) N3 North – 12.5 ha.

Weighted Decision Matrix

Detailed results from the WDM are outlined in Table 7. For years where maintaining the current conditions (through fire treatment to kill seedlings <1 year and to inhibit the further growth of small shrubs) is all that can be managed due to various circumstances, Table 5 displays the recommended order of importance from the highest to lowest priority. Three zones were excluded from this WDM. Zone N3 north and Mountain Dam were excluded due to the high degree of encroachment which would require either manual removal or herbicide to significantly impact these areas. The Bone Dam location was excluded due to its proximity to housing on the reserve. I recommend to first reduce the plant biomass in this area through herbicide or manual removal to minimize the risk of an uncontrollable fire.

For grassland savanna restoration, Table 6 displays the zone prioritizations from highest to lowest impact. The N3 south region was not evaluated for its restoration effects due to its relatively new use by the rhinos. It was determined then that maintaining this area would be the most efficient land management practice.

Maintaining just the top four priority zones would protect 74.5 ha of land from further woody bush encroachment, while maintaining all the recommended zones protects 105.4 ha. To restore grazing lands for the rhinos on Gevonden, the top four priority zones would reestablish 58.3 ha of grassland savannas, and all nine would restore 134.3 ha.

Table 5. Results order for maintaining zones through fire management only.

Restoration Zone	**Score**	**Hectares (ha)**
Rye Field Perimeter	98	6.7
Northeast Gorge	93	14
iThala Road	93	25.5
Amphitheater – Coffee Dam	86	28.3
Boma Valley East	84	12.1
N3 South	84	10.2
Boma Valley West	75	8.6

Table 6. Results order for restoring zones through manual removal and fire management.

Restoration Zone	Score	Hectares (ha)
Rye Field Perimeter	89	6.7
iThala Road	84	25.5
Northeast Gorge	80	14
Boma Valley East	77	12.1
Amphitheater – Coffee Dam	65	28.3
Bone Dam	61	7.3
N3 North	60	12.5
Mountain Dam	59	19.3
Boma Valley West	49	8.6

Table 7. Weighted Decision-Making Table results. Recommended treatments types for each restoration zone are highlighted in the 'Manual Effort' column.

	Cost		Safety		Manual Effort		Likely Impact		Timeframe		Preferred Rhino Habitat		Total
Factor Ranking	**4**		**5**		**3**		**5**		**3**		**4**		
Options													
Maintain Grasslands	Score	Weighted	Score	Weighted	Score	Weighted	Score	Weighted	Score	Weighted	Score	Weighted	
Fire													
Rye Field Perimeter	5	**20**	4	**20**	5	**15**	3	**15**	4	**12**	4	**16**	**98**
NE Gorge	4	**16**	4	**20**	3	**9**	4	**20**	4	**12**	4	**16**	**93**
iThala Road	4	**16**	4	**20**	3	**9**	4	**20**	4	**12**	4	**16**	**93**
Amphitheater - Coffee Dam	3	**12**	3	**15**	3	**9**	5	**25**	3	**9**	4	**16**	**86**
Boma Valley East	4	**16**	3	**15**	4	**12**	4	**20**	3	**9**	3	**12**	**84**
Boma Valley West	4	**16**	3	**15**	4	**12**	3	**15**	3	**9**	2	**8**	**75**
N3 South	4	**16**	4	**20**	3	**9**	3	**15**	4	**12**	3	**12**	**84**
Restore Grasslands													
Clearing & Fire													
Herbicide & Fire													
Herbicide/Clearing/Fire													
Rye Field Perimeter	4	**16**	4	**20**	4	**12**	2	**10**	5	**15**	4	**16**	**89**
NE Gorge	2	**8**	3	**15**	3	**9**	4	**20**	4	**12**	4	**16**	**80**
Amphitheater - Coffee Dam	1	**4**	2	**10**	1	**3**	5	**25**	1	**3**	5	**20**	**65**
Boma Valley East	3	**12**	3	**15**	3	**9**	4	**20**	3	**9**	3	**12**	**77**
Boma Valley West	1	**4**	2	**10**	2	**6**	3	**15**	2	**6**	2	**8**	**49**
Moutain Dam	1	**4**	2	**10**	2	**6**	4	**20**	1	**3**	4	**16**	**59**
N3 North	3	**12**	3	**15**	3	**9**	2	**10**	2	**6**	2	**8**	**60**
Bone Dam	2	**8**	3	**15**	4	**12**	2	**10**	4	**12**	1	**4**	**61**
iThala North	2	**8**	3	**15**	3	**9**	4	**20**	4	**12**	5	**20**	**84**

DISCUSSION

Humans have rapidly altered landscapes around the world (Whitney, 1995), and these anthropogenic disturbances are the leading cause of biodiversity loss as habitats are destroyed and left fragmented (With, 2002). In South Africa, habitat loss coupled with poaching has forced rhino populations to reside on private lands and government-owned reserves. With so little space left for these megaherbivores, woody bush encroachment further degrades the vital grasslands within these already limited spaces. As chronic cattle grazing and fire suppression are considered the two of the leading causes contributing to bush encroachment (Chown, 2010; Lindsey et al., 2013; McGranahan, 2008; Pienaar, Rubino, Saayman, & van der Merwe, 2017; G. N. Smit, 2004), the history of cattle farming on UmPhafa's land has likely exacerbated the expansion of forest coverage today as well as a lack of controlled burns to abate new encroachment from establishing.

UmPhafa aims to create a naturally self-sustaining ecosystem with its long-term goals (Bone & Spanton, 2019), however management practices are often required to combat issues like bush encroachment or invasive species spread (Pienaar et al., 2017). A study by Pienaar et. al (2017) found that 57.1% of private game ranchers interviewed were actively controlling bush encroachment through the use of controlled burns, chemical applications, and manual removal. While controlled burns are great to use as a preventative tool, they will not restore grasses to land that is already bush encroached (De Klerk, 2004) due to the known fire resilience of mature acacia (Walters et al., 2004) and the observed coppicing *L. javanica* displayed during this research after fire.

Manual efforts to remove acacia is laborious and hazardous. Besides its protective thorns and the risks from using tools like panga machetes, loppers, or chainsaws, dangerous animals, like the puff adder (*Bitis arietans arietans*), can be found in these acacia groves. Applying chemical herbicides can also be hazardous for individuals applying it without personal protective equipment and may also leach into nearby water sources (De Klerk, 2004). However, despite all the potential hazards present from managing bush encroachment, inaction will certainly lead to further grassland degradation.

Results from analyzing NDVI and landcover classifications spanning the past 18 years, supports what UmPhafa employees had already believed; forest cover is increasing while grasslands are decreasing on Gevonden. For the rhinos restricted to this area for security purposes, this means that the grazing lawns they need for their continued health and survival are slowly disappearing. However, the current reserve managers are dedicated to preserving and restoring this habitat by establishing an encroachment management plan.

Recommended BE Management Plan

If the reserve managers find they have the means and budget to begin maintenance or restoration of the ten priority zones immediately, it is recommended to follow the order or importance from the results of the WDM. However, it is likely that due to annual budgeting and time constraints from projects already in place, that this will not be feasible in 2019. Nevertheless, I do advise that restoration of the Rye Field Perimeter begin this winter.

This zone came out as the top recommended area whether attempting to maintain or restore the land. Part of this is due to its high use by the rhinos, but as the smallest zone, it will also require the lowest financial cost, manual effort, and time to restore it which resulted in the highest weighted scores using the WDM. For this reason, I recommend that the manual removal of bush encroachment begin here this year. This will allow the reserve managers to estimate the time and energy it takes to thin the land of acacias to help improve restoration planning for the remaining zones.

Due to the high degree of bare ground and consequent low accumulation of plant biomass near the rye field, this area is also highly safe to begin implementing controlled burns after the acacia has been removed. Its proximity to the wetlands makes this area completely unsuitable for herbicide applications, but with few *L. javanica* plants present in this zone, this application should not be required.

Performing controlled burns has the added benefit of removing accumulated plant biomass which, when present, increases the risk of uncontrollable wildfires (Waldram et al., 2008). Therefore, systematic prescribed fires on Gevonden could help protect the housing and machinery by reducing the likelihood of an uncontrollable wildfire. Reserve managers should expect that most grazers, especially the Rhinos, will congregate to recently burned areas burned due to the flush of high quality grasses after the first rain (Waldram et al., 2008).

This research did fail to create zones totaling at least 250 ha, the original goal sought out by reserve managers for restoring grasslands. However, after creating the ten zones, which totaled 144.5 ha, I believed this would already provide an aggressive and demanding management plan for the reserve. Therefore, I recommend that the additional 105 ha of grassland restoration be implemented in a second phase of the bush encroachment management plan. Phase 2 can be established after the ten proposed zones in this research have been cleared of bush encroachment and only require prescribed burns for continued maintenance.

Future Research

L javanica bush removal will prove difficult for reserves as its consequences as a woody bush encroacher have yet to be studied. This gap in research, provides an opportunity for studies to measure its survival rate after disturbances, likely movements or rate of encroachment, and to study effective removal methods. During this research, questions also arose as to what affects it may have on enabling acacia encroachment by offering seedlings protection from large species that tend to completely avoid large groves of *L. javanica*.

Measuring the potential reduction in overgrazing after predator introductions is another area for further research on UmPhafa. The reserve managers have considered introducing cheetah (*Acinonyx jubatus*) and more spotted hyena (*Crocuta crocuta*), as there is currently one lone male. This potentially could encourage grazing herds of impala, blesbok, zebra, and blue wildebeest to spend less time on Gevonden's grasslands, which are critical for the Rhino's who remain there. This movement could then decrease overgrazing on Gevonden allowing for grass recovery and a slowing effect for additional bush encroachment.

CONCLUSION

Two-dimensional NDVI and land cover classification modeling using GloVis satellite images was used in this study to estimate the degree of woody bush encroachment on Gevonden over the past 18 years. This analysis confirmed that grasslands are decreasing, while the forests are expanding. Limited-species quadrat surveys investigated the concentration of *L. javanica* and acacia species near summer Rhino habitat using Survey123 to collect the data and acquire GPS coordinates for the quadrat center point. While tracking the Rhinos for quadrat surveys, GPS coordinates were also recorded for areas with aggressive *L. javanica* and acacia encroachment, >90% land cover. Four rangers also provided maps on where they have observed woody bush encroachment impacting Rhino habitat. Lastly, maps of historic Rhino sighting locations provided input on their seasonal movements. This information was combined to assess which grasslands are most at risk today from further degradation due to bush encroachment and ten priority restoration zones were established totaling 144.5 ha. Each of these zones was evaluated against six factors that could impacting the likelihood of restoration success using a WDM. These results provide a guide for how the reserve managers should begin organizing this monumental task.

It is important for any land manager to realize that, unfortunately, there is no quick solution for controlling and removing bush encroachment. Likewise, effective management of bush encroachment should not be considered a once-off event, but rather a long-term commitment (G. N. Smit, 2004). With forest cover on the rise and moderate shrub density savannas decreasing on Gevonden, suitable grazing habitat for their Rhinos is steadily decreasing. This trend will likely continue without the execution of manual, chemical, or fire controls (De Klerk, 2004).

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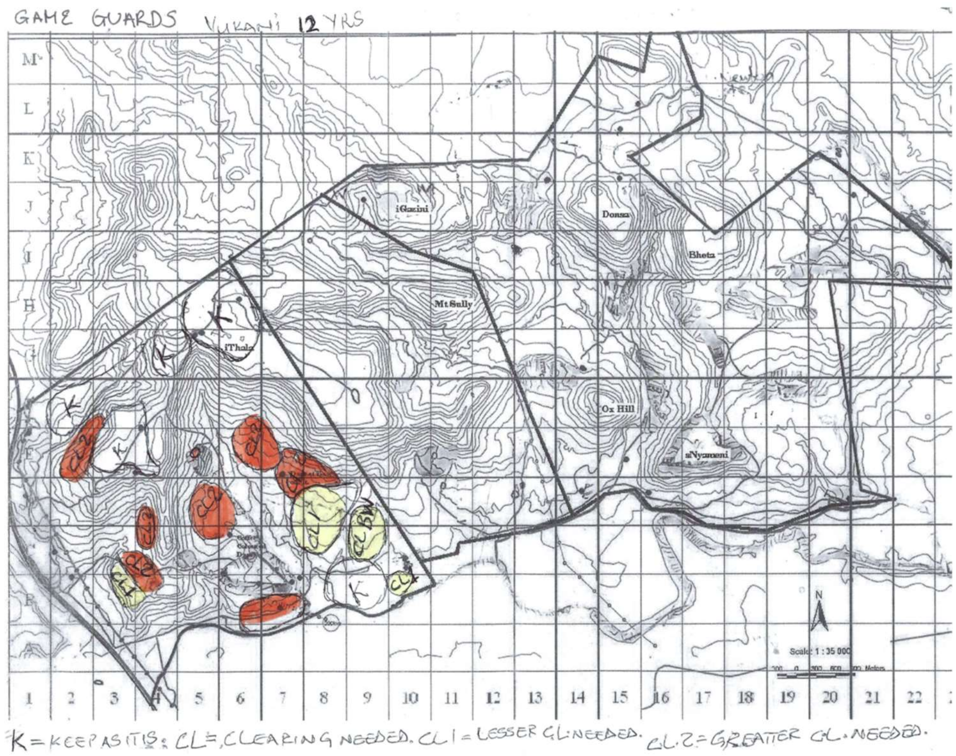
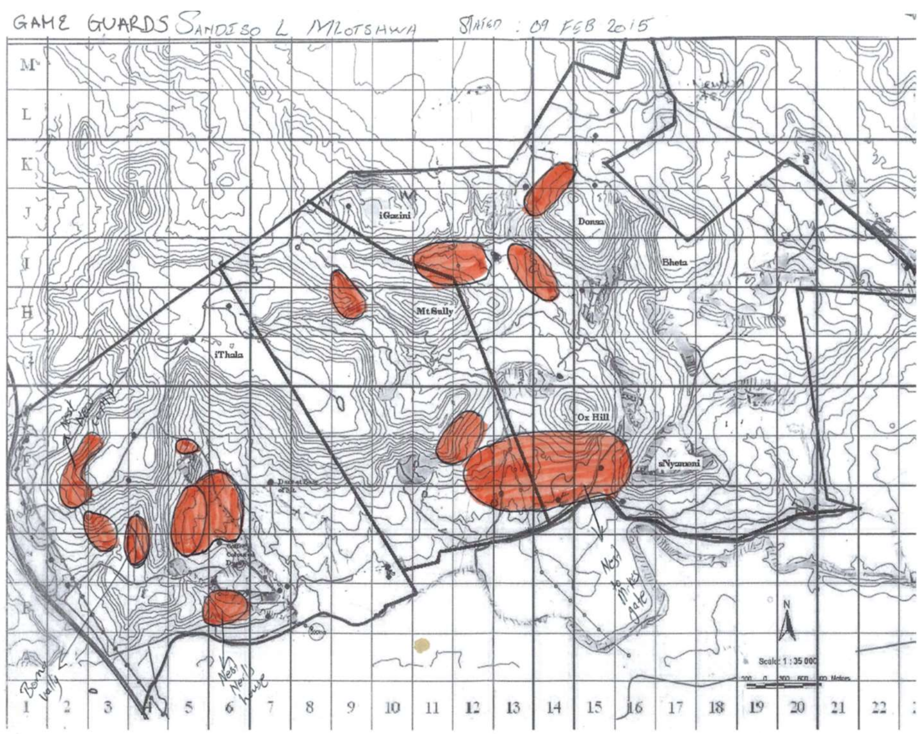
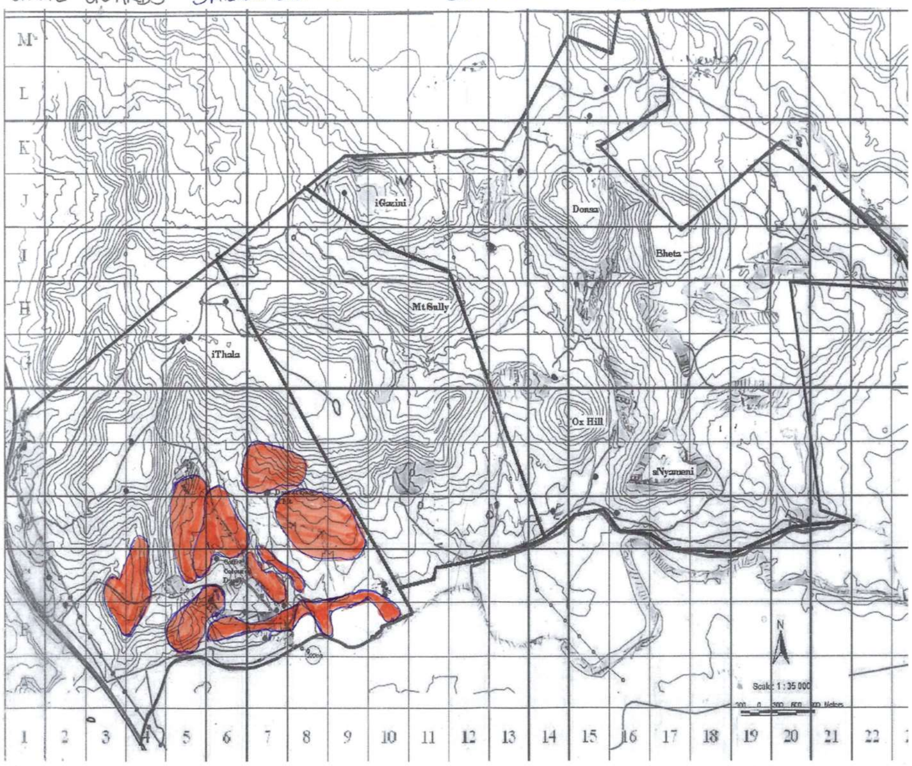
APPENDICES

Appendix A. Ranger bush encroachment problem area maps.

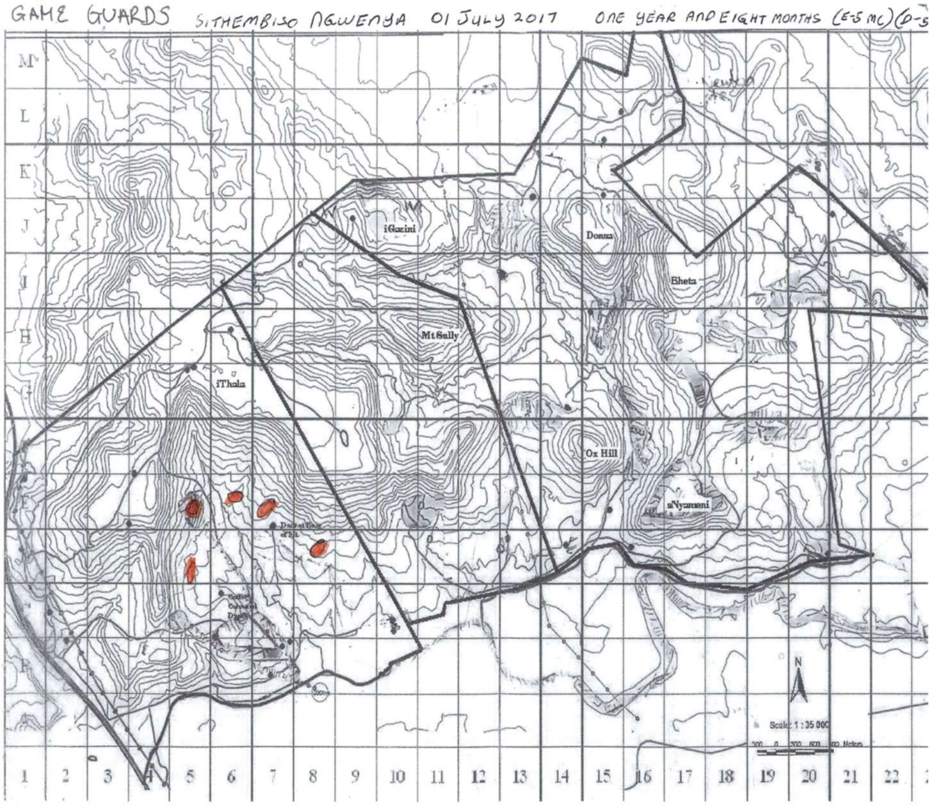




GAME GUARDS SPHELELE DLAMINI START DATE : 03 JULY 2017 (1 YEAR & 8 MONTH) -

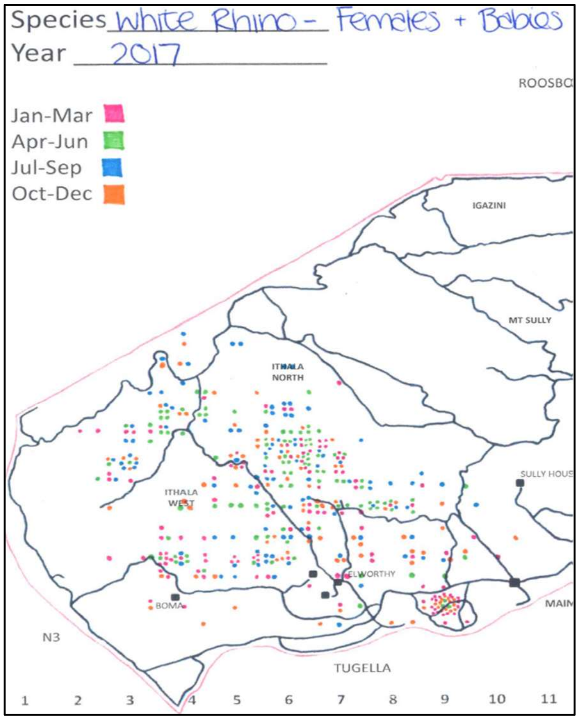


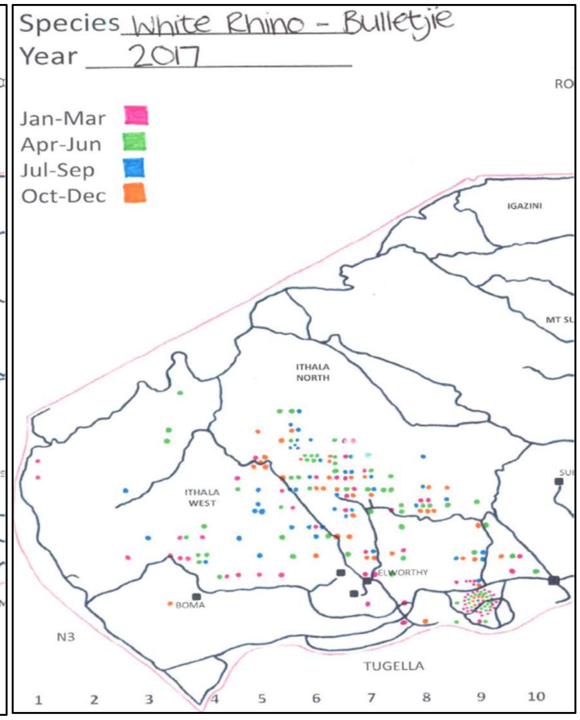
GAME GUARDS SITHEMBISO NGWENYA 01 JULY 2017 ONE YEAR AND EIGHT MONTHS (E-5 MC)(D-5

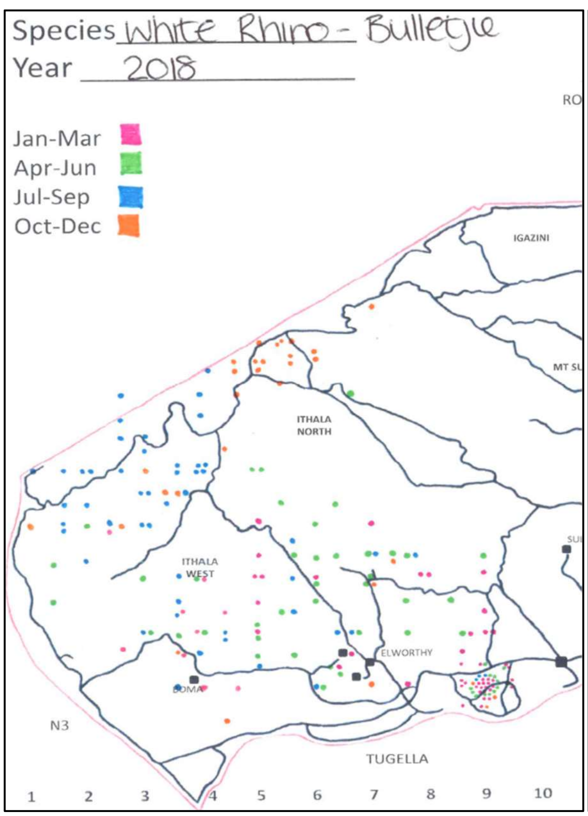


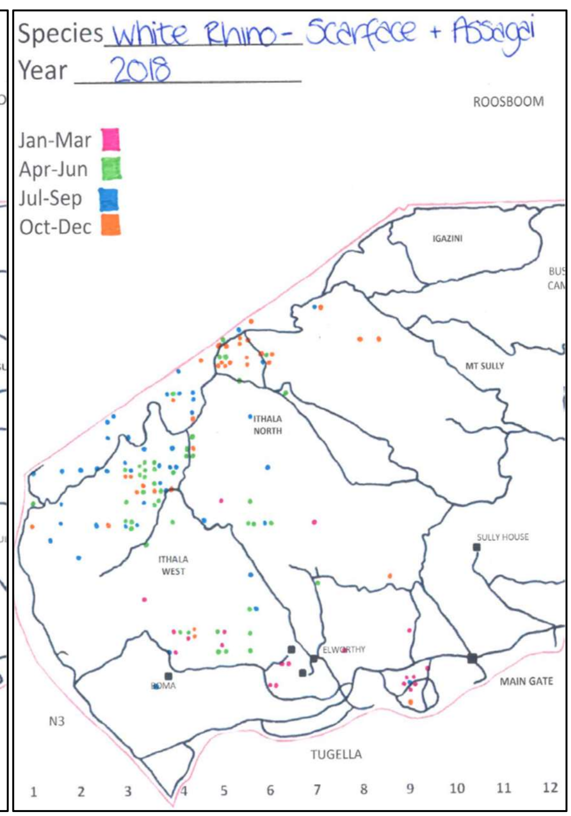
(E-7 ML)(E-6 MC)

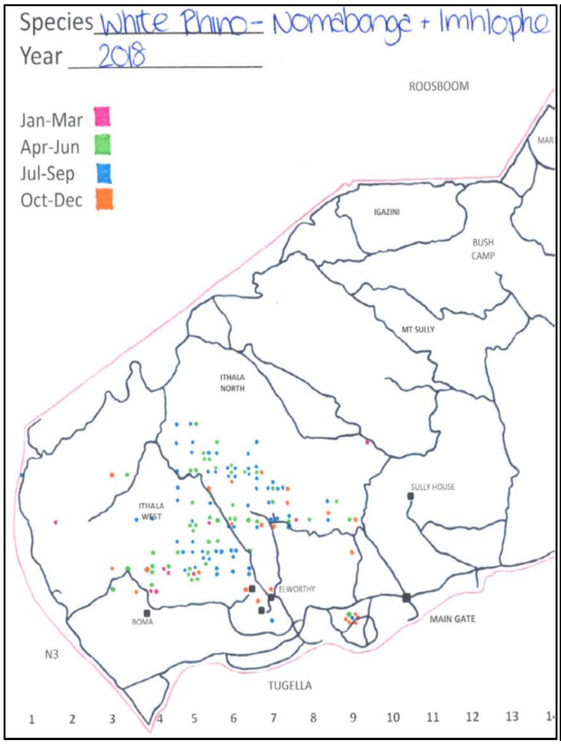
Appendix B. Historic rhino location maps.

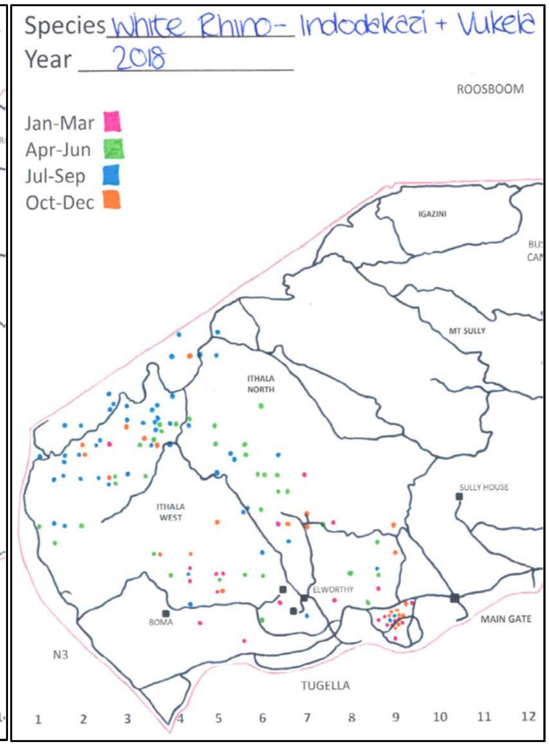


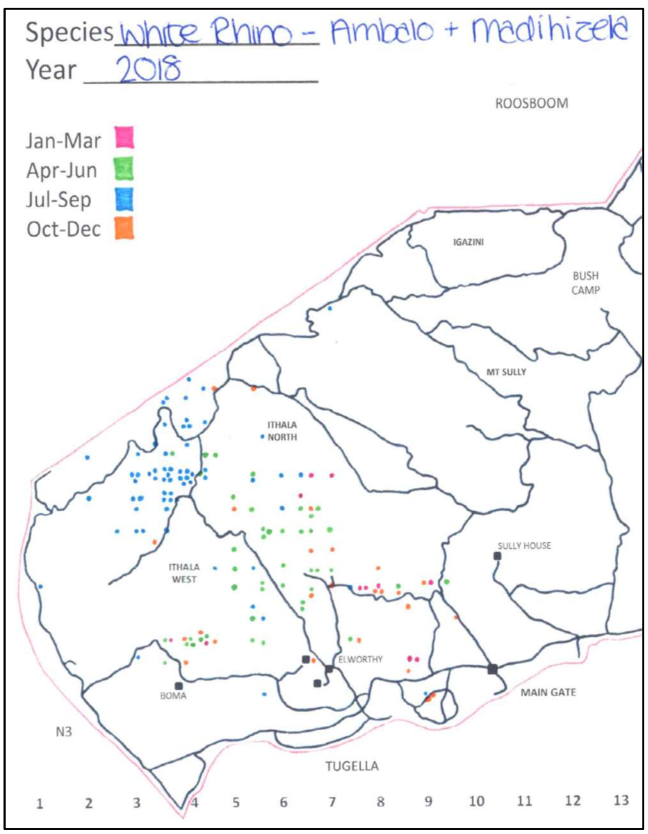







Species White Rhino - Nomabange + Imhlophe
Year 2018
Jan-Mar
Apr-Jun
Jul-Sep
Oct-Dec
ROOSBOOM
IGAZINI
BUSH CAMP
MT SULLY
ITHALA NORTH
ITHALA WEST
SULLY HOUSE
ELWORTHY
BOMA
MAIN GATE
N3
TUGELLA
1 2 3 4 5 6 7 8 9 10 11 12 13


Species White Rhino - Indodakazi + Vukela
Year 2018
Jan-Mar
Apr-Jun
Jul-Sep
Oct-Dec
ROOSBOOM
IGAZINI
MT SULLY
ITHALA NORTH
ITHALA WEST
SULLY HOUSE
ELWORTHY
BOMA
MAIN GATE
N3
TUGELLA
1 2 3 4 5 6 7 8 9 10 11 12


Species White Rhino - Ambalo + Madihizela
Year 2018
Jan-Mar
Apr-Jun
Jul-Sep
Oct-Dec
ROOSBOOM
IGAZINI
BUSH CAMP
MT SULLY
ITHALA NORTH
ITHALA WEST
SULLY HOUSE
ELWORTHY
BOMA
MAIN GATE
N3
TUGELLA
1 2 3 4 5 6 7 8 9 10 11 12 13