The Invasion Potential of Selected *Berberis* Species in South Africa

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DECLARATION

I declare that the dissertation hereby submitted by me for the Magister Scientiae in Botany degree at the Faculty of Natural and Agricultural Sciences at the University of the Free State is my own independent work and has not previously been submitted by me at another university/faculty. I furthermore cede copyright of the dissertation in favour of the University of the Free State.

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Jan-Hendrik Keet Date

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SUMMARY

Invasive alien species are a serious threat to global biodiversity. They have considerable negative effects on the economy and the environment, using up valuable natural and monetary resources. Every year new species are introduced into South Africa and with that the list of potentially new invasive species grows. These emergent invasive species should receive a very high priority in terms of assessing their invasion potential and possible impacts.

No formal study has been conducted regarding the invasion potential of any species in the genus *Berberis* within South Africa, even though it has been a popular horticultural genus for many decades and is known to have invasive species. The current study focussed on four key points, namely: 1) the elucidation of all *Berberis* spp. that have been historically and are currently cultivated within South Africa, 2) assessing the size, extent and reproductive age of any naturalized/invasive *Berberis* populations, 3) determining potential habitable areas of naturalized/invasive *Berberis* species and 4) determining whether any *Berberis* species should be officially listed under the National Environmental Management Biodiversity Act.

A total of 30 *Berberis* species/cultivars/hybrids were found to have been cultivated in South Africa in the past and present (11 species, 11 cultivars, 8 hybrids). Three of these species are widespread invasives in other parts of the world, namely *B. darwinii*, *B. thunbergii* and *B. vulgaris*. The KwaZulu-Natal Province has the highest diversity of species/cultivars/hybrids stocked by nurseries/private/wholesale growers, while *B. thunbergii* and *B. thunbergii* var. *atropurpurea* were found to be the most widely stocked species.

Two invasive *Berberis* populations were found. The first population was from the species *Berberis aristata* and occurs in the Woodbush State Forest (Limpopo Province; 23.8192°S 29.9608°E). This population has an extent of occurrence of 115 ha and an area of occupancy of 1.58 ha. A total of 5 725 individuals were geotagged and the population was found to be highly reproductively active, with more than 40% of the population able to flower and set seed. The second population was from the species *B. julianae* and occurs at the Glen Reenen rest camp in the Golden Gate Highlands National Park (Free State Province; 28.5049°S 28.6187°E). This population has an extent of occurrence of 0.42 ha and an area of occupancy of 0.02 ha. It was also found to be highly reproductively active with 38% of the population able to flower and set seed. A few minor occurrences of this species were found at the Alma

Ranger Station, also in the Golden Gate Highlands National Park. A total of 473 individuals of this species were geotagged.

Bioclimatic modelling revealed that substantial parts of South Africa are suitable for both *Berberis aristata* and *B. julianae*. The former species was found to be more suitable to the mountainous regions while the latter has a higher suitability to the central parts of the country. The situation regarding future climate scenarios (2020) was the same, although a range contraction was found for both species. Weed risk assessments revealed that both *B. aristata* and *B. julianae* would have failed a pre-border screening (score of 27 and 22, respectively, according to the Australian Weed Risk Assessment system), indicating that both species pose an environmental risk. Herbicide trial clearing revealed that three chemicals can be used for the successful control of *Berberis* spp., namely metsulfuron-methyl, triclopyr and glyphosate.

The final outcome of the study is the following recommendations: *Berberis aristata* should be listed as a category 1a invasive species in the National Environmental Management Biodiversity Act, while *B. julianae* should be listed as category 1b in non-urban areas and not listed in urban areas.

Key terms: *Berberis*, invasive, bioclimatic modelling, weed risk assessment, early detection, eradication.

OPSOMMING

Uitheemse indringer plante is ‘n ernstige bedreiging vir wêreldwye biodiversiteit. Hulle het aansienlike negatiewe effekte op die ekonomie en die omgewing en gebruik waardevolle natuurlike en geldelike hulpbronne. Nuwe spesies word elke jaar in Suid-Afrika ingevoer en veroorsaak dat die lys van potensiële nuwe indringer spesies ook groei. Hierdie opkomende indringer spesies moet ‘n hoë proiriteit ontvang in terme van die assessering van hulle indringingspotensiaal en moontlike impakte.

Geen formele studie was al gedoen oor die indringingspotensiaal van enige spesie in die genus *Berberis* in Suid-Afrika nie, al is dit ‘n populêre tuinboukundige genus wat al vir dekades lank gekweek word en is bekend om indringer spesies te hê. Die huidige studie het gefokus op vier sleutel punte, naamlik: 1) die toeligting van alle *Berberis* spp. wat in die verlede en in die hede gekweek is in Suid-Afrika, 2) die assessering van die grootte, omvang en voortplantingsouderdom van enige genaturaliseerde/indringende *Berberis* populasies, 3) die bepaling van potensiële bewoonbare areas van genaturaliseerde/indringende *Berberis* spesies en 4) om te bepaal of enige *Berberis* spesies amptelik gelys moet word in die Nasionale Omgewingsbestuurs Biodiversiteitswet.

‘n Totaal van 30 *Berberis* spesies/kultivars/hibriede was gevind om in kweking te wees gedurende die verlede sowel as die hede (11 spesies, 11 kultivars, 8 hibriede). Drie van hierdie spesies is wydverspreide indringerplante in ander dele van die wêreld, naamlik *B. darwinii*, *B. thunbergii* en *B. vulgaris*. Die KwaZulu-Natal provinsie het die hoogste diversiteit gehad in terme van spesies/kultivars/hibriede wat aangehou word deur kwekerye/privaat/groothandel kwekers, terwyl *B. thunbergii* en B. *thunbergii var. atropurpurea* die mees wydverspreide gekweekte spesies is.

Twee indringer populasies van *Berberis* was gevind. Die eerste populasie was van die spesie *Berberis aristata* en kom voor in die Woodbush State Forest (Limpopo Provinsie; 23.8192°S 29.9608°E). Hierdie populasie het ‘n mate van voorkoms van 115 ha en ‘n area van besetting van 1.58 ha. ‘n Totaal van 5 725 individue was gegeotag en daar was gevind dat die populasies hoogs voortplantingsgereed is, meer as 40% van die populasie is alreeds in staat om te blom en saad te skiet. Die tweede populasies was van die spesie *B. julianae* en kom voor in die Golden Gate Hoogland Nasionale Park (Vrystaat Provinsie; 28.5049°S 28.6187°E). Hierdie populasie het ‘n mate van voorkoms van 0.42 ha en ‘n area van besetting

van 0.02 ha. Die populasie is ook hoogs voortplantingsgereed, met 38% van die populasie in staat om te blom en saad te skiet. ‘n Paar geringe voorvalle van die spesie was gevind by die Alma Wildbewaarder Stasie, ook in die Golden Gate Hoogland Nasionale Park. ‘n Totaal van 473 individue van dié spesie was gegeotag.

Bioklimatiese modellering het getoon dat ‘n aansieklike klomp dele van Suid-Afrika geskik is vir beide *Berberis aristata* en *B. julianae*. Die eersgenoemde spesie is meer geskik tot die bergagtige dele terwyl die laasgenoemde meer geskik is tot die sentrale dele van die land. Die situasie in terme van toekomstige klimaat (2020) was dieselfde, alhoewel ‘n reeks-inkrimping vir beide spesies gevind was. Onkruid risiko assesserings het getoon dat beide *B. aristata* en *B. julianae* ‘n voorgrens analise sou druip (telling van 27 and 22, onderskeidelik, na aanleiding van die Australiese Onkruid Risiko Assessering sisteem) en dat beide van hulle dus ‘n omgewingsrisiko is. Onkruiddoder toetse het gewys dat drie chemikalieë gebruik kan word vir die suksesvolle beheer van *Berberis* spp., naamlik metsulfuron-metiel, triclopyr and glifosaat.

Die finale uitslag van hierdie studie is die volgende voorstelle: *Berberis aristata* moet gelys word as ‘n kategorie 1a indringer spesie in die Nasionale Omgewingsbestuurs Biodiversiteitswet, terwyl *B. julianae* gelys moet word as kategorie 1b in nie-stedelike gebiede en nie in stedelike gebiede gelys moet word nie.

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Chapter 1: Introduction

One of the current biggest threats to global biodiversity is the invasion of native habitats by alien species (Vitousek *et al.*, 1997; Mack *et al.*, 2000). These invasive alien species are a result of on-going and increasing human re-distribution of species and include all kinds of organisms (pathogens, plants, insects, molluscs, birds, mammals, etc.) (Van Wilgen *et al.*, 2008). The expansion of transport and commerce (i.e. global trade) in the past 500 years has directly affected the geographic scope, frequency and number of species that have been introduced into countries outside of their native environment (Vitousek *et al.*, 1997; Mack *et al.*, 2000; Meyerson & Mooney, 2007). Taxa have always been migrating, but the rate at which human-assisted introductions occur are several orders of magnitude (100 000 times the natural arrival rate) higher today than in the past (Tye, 2001; Rejmánek *et al.*, 2006). Over the past 20 years the rate of species introductions has been about 10 species per year (Tye, 2001). Moreover, the magnitude of introductions is increasing globally (Levine & D'Antonio, 2003; Hulme, 2009). As a consequence, there are very few habitats left on earth that do not contain species introduced by humans (Mack *et al.*, 2000).

Species are never intentionally introduced to become invasive; rather they are introduced for their uses (e.g. ornamental plants) and from there on some of them start invading. Unfortunately, of the species that have become invasive, the majority were deliberately introduced and some of them are now the worst pests known to man (e.g. water hyacinth *Eichhornia crassipes*, *Melaleuca* spp. and salt cedar *Tamarix* spp.) (Mack *et al.*, 2000). Many of these invasive alien plant species (IAPs) can alter the structure and functioning of ecosystems and thus become problematic. For example they can change ecosystem processes such as primary productivity, decomposition, hydrology, geomorphology, nutrient cycling and/or disturbance regimes (Vitousek *et al.*, 1997; Levine & D'Antonio, 2003). The impacts of these species can eventually lead to considerable economic costs, for example agricultural forage losses (pasture losses), the need for control measures (chemical, biological, mechanical, physical), loss of water and loss in ecotourism (Pimentel *et al.*, 2000; Le Maitre *et al.*, 2011).

Not all plant species, however, are equally threatening to a new environment should they be introduced. One of the main objectives in invasion ecology is to understand and explain why certain taxa possess the ability to invade more successfully than others (Richardson *et al.*, 2000). Only a small portion of all taxa that are introduced actually reproduce and proliferate over vast areas, the majority of them fail at some stage or other (Richardson *et al.*, 2000). The reason is that for alien species to become invaders they have to persevere through several successive elimination stages, which constitutes a bottleneck of physical and biological constriction, meaning that with each new barrier fewer species able to overcome and continue to the next one (Mack *et al.*, 2000; Richardson *et al.*, 2000).

The invasion process can be summarized as follows (Figure 1.1) (Mack *et al.*, 2000): (1) transport to a new environment, (2) arrival, (3) survival and reproduction, (4) germination, seedling emergence and survival of descendants, (5) ability to persist and naturalize and finally (6) ability to spread unaided and effectively over large areas to invade new habitats. The invasion process can be debilitated at any one of these stages. It can be characterized in relation to the different biotic and abiotic barriers that are (or are not) overcome (Richardson *et al.*, 2000; Blackburn *et al.*, 2011). These barriers are considered to be limiting factors in the spread of an introduced taxon (Richardson *et al.*, 2000).

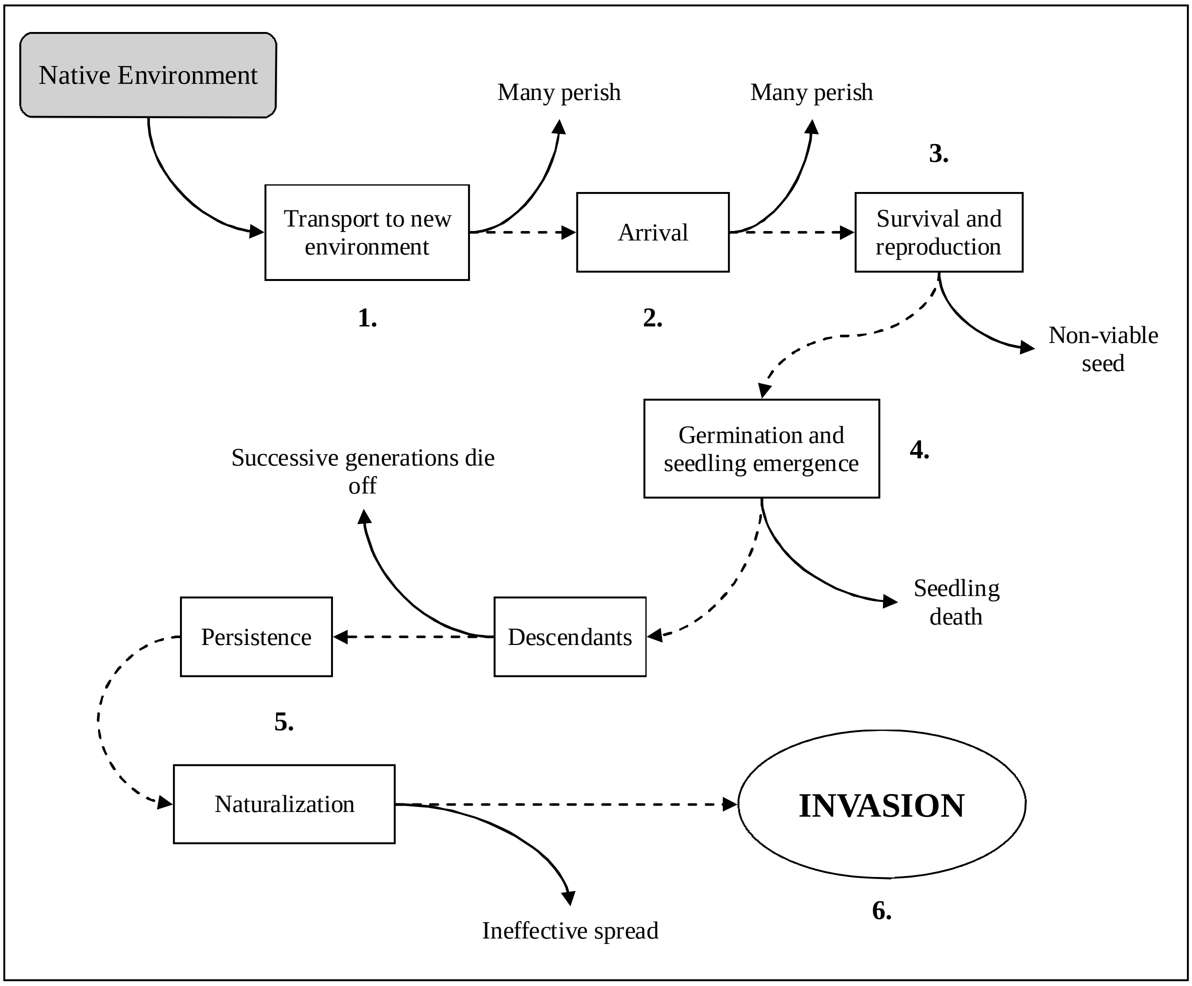


Figure 1.1: Biotic invasions are the least likely outcome of a multistage process that starts off with the transportation of species to regions outside of their natural geographical range. The

solid lines represent the most likely outcome of each successive stage while the dotted lines represent the least likely outcome. Numbers are discussed in the text. The diagram is not intended to be exhaustive of all possibilities. ***(drawn and interpreted from Mack et al., 2000)***

The phases and definitions characterizing the invasion process are as follows (Figure 1.2) (Richardson *et al.*, 2000): **introduction** occurs when a plant or its propagule(s) is able to overcome a major geographical barrier (A) through human assistance. The term **casual** is applied to introduced taxa that are able to reproduce sexually or vegetatively but are unable to maintain their populations in the long term. If local environmental barriers (B) no longer prevent individuals from surviving and reproductive barriers (C) are overcome, naturalization starts to occur. Thus, a taxon that overcomes barriers A, B and C can be considered successfully **naturalized**. The process of **invasion** occurs when introduced taxa are able to overcome dispersal barriers (D) and also cope with the abiotic environment and the biota (E) that occurs in the new region. This constitutes invasion into disturbed, semi-natural communities. To invade successionally mature and undisturbed communities taxa must overcome a barrier (F) made up of different resistance factors than for a disturbed community.

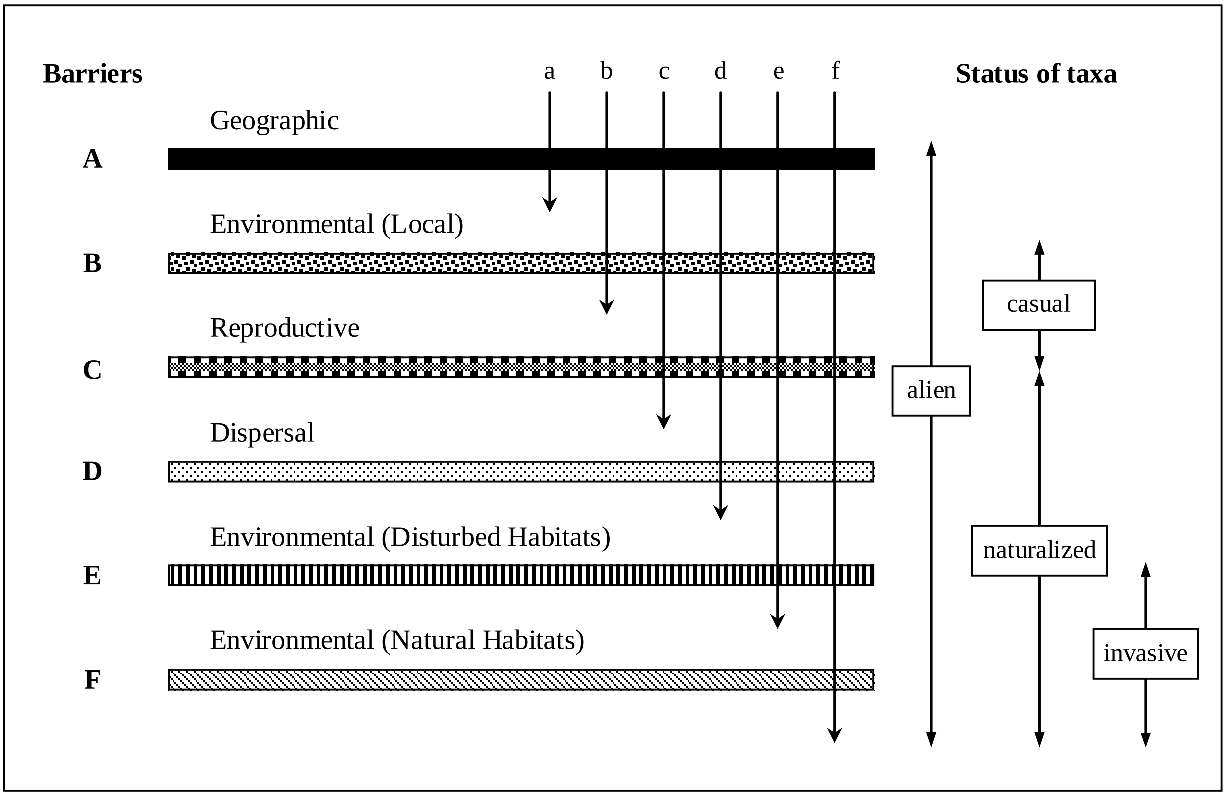


Figure 1.2: Diagram of the different major barriers that restrict the spread of introduced plants together with terms that correlate with different phases in the invasion process. Arrows a through to f signify the routes that taxa need to take in order to reach the different states from introduced to invasive in natural vegetation *(redrawn and adapted from Richardson et al., 2000)*

It is important to define the concepts of "naturalization" and "invasion" and to distinguish between the two. These two terms are often used loosely and interchangeably which can complicate matters in terms of interpretability (Richardson *et al.*, 2000). Taxa might persist temporarily after having escaped cultivation or they can be fully naturalized and invasive, with an entire continuum in between (Richardson *et al.*, 2000; Blackburn *et al.*, 2011). The difference between naturalized and invasive may also signify the point where notable ecological and economic consequences start to become apparent (Richardson *et al.*, 2000; De Lange & Van Wilgen, 2010). In this document the following definitions of *naturalized* and *invasive* regarding plants are adopted, as recommended by Richardson *et al.* (2000) (see Appendix A for more definitions):

- **Naturalized –** "Alien plants that reproduce consistently … and sustain populations over many life cycles without direct intervention by humans (or in spite of human intervention); they often recruit offspring freely, usually close to adult plants, and do not necessarily invade natural, semi-natural or human-made ecosystems."

- **Invasive –** "Naturalized plants that produce reproductive offspring, often in very large numbers, at considerable distances from parent plants (approximate scales: > 100 m; < 50 years for taxa spreading by seeds and other propagules ; > 6 m/3 years for taxa spreading by roots, rhizomes, stolons, or creeping stems), and thus have the potential to spread over a considerable area."

On a time scale IAPs proceed through three phases when progressing from immigrant to invader (Figure 1.3) (Groves, 1999; Mack *et al.*, 2000; Wilson *et al.*, 2013), namely: (1) lag phase, (2) phase of rapid exponential increase which continues until the species eventually reaches the boundaries of its new range after which (3) its invasive range size starts to stabilise due some limiting factor. The relative times of the respective phases may differ significantly, ranging from very brief periods to decades (Mack *et al.*, 2000; Pyšek & Hulme, 2005) and in some cases even more than 100 years from the time of introduction to naturalization (Caley *et al.*, 2008). Only a limited number of species have an exponential increase in population size immediately after they are introduced (Groves, 1999). The difficulty therefore lies in distinguishing during the lag phase between future invaders and populations that pose no threat at all (Mack *et al.*, 2000).

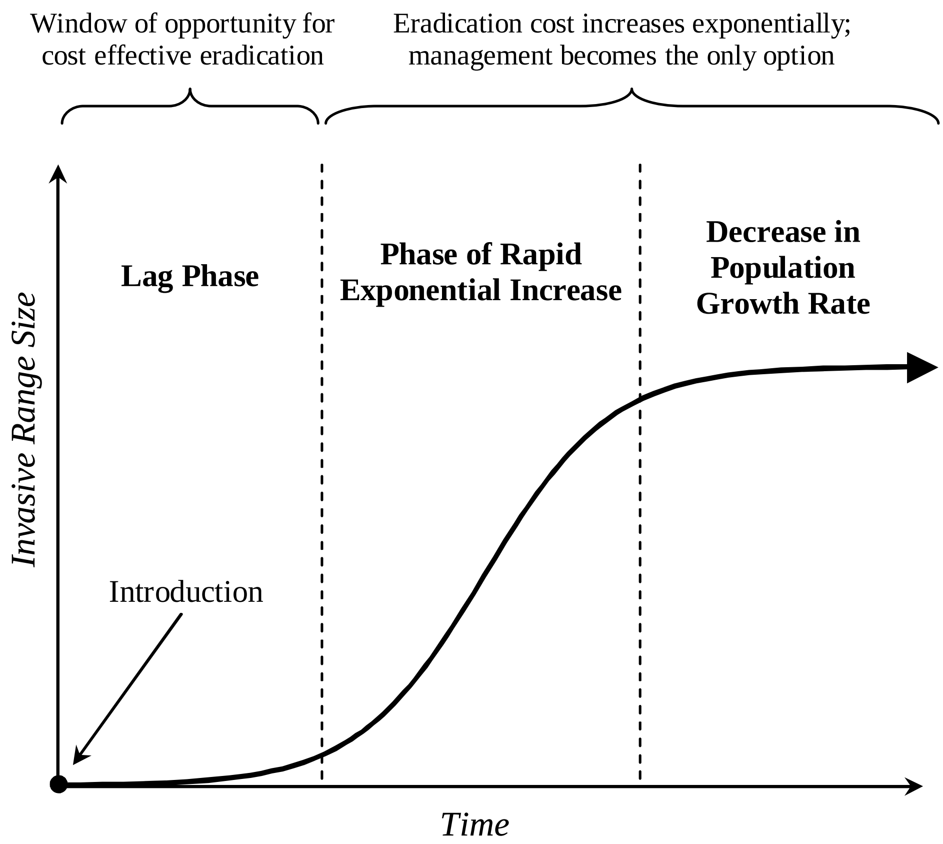


Figure 1.3: Simplified scenario of the three phases that alien invasive species undergo upon arriving in a new environment. See text for details. ***(drawn and interpreted from Mack et al., 2000 and Wilson et al., 2013)***

An exponential relationship exists between the likelihood of success of an eradication program and the size(s) of the target species population(s) (Rejmánek & Pitcairn, 2002; Le Roux *et al.*, 2010). The same is true for eradication effort (work hours), since the effort increases exponentially with increasing population size (Rejmánek & Pitcairn, 2002). Even though invasive populations eventually cease to grow in size when they reach their geographical and environmental limits in their new habitat, they continue to persist if left uncontrolled and are virtually impossible to eradicate (Mack *et al.*, 2000).

The lag phase in which IAPs populations are still small and controllable is the only period in which there is a significant opportunity to cost effectively eradicate the species before its invasive range size becomes too large (Rejmánek & Pitcairn, 2002; Le Roux *et al.*, 2010).

South Africa contains about 9 000 introduced plant species (Glen, 2002) of which about 1 000 are naturalized (Henderson, 2007) and some 200 are already considered invasive (Le Maitre *et al.*, 2011).

The ultimate goal is therefore to identify potential future invaders before or during the lag phase (Mack *et al.*, 2000; Wilson *et al.*, 2013) and eradicate them before they become a problem and have a noticeable impact on the environment (Blackburn *et al.*, 2014) and the economy (De Lange & Van Wilgen, 2010).

In South Africa there has been a recent development towards assessing and planning eradication for emergent invasive species (Wilson *et al.*, 2013), i.e. those species that pose an invasion risk but which have not spread to occupy substantial areas. One such genus of concern is *Berberis*. This genus has numerous species that are popular with the horticultural industry and are cultivated the world over. As a consequence of this, many species have been introduced into new regions and this has resulted in some of them becoming invasive. Currently about seven *Berberis* spp. have been recorded as invasive in other countries (D' Appollonio, 1997; Ehrenfeld, 1997; DeGasperis & Motzkin, 2007; McAlpine & Jesson, 2007; Ward *et al.*, 2010; Randall, 2012; Speith, 2012) and some of these species are known to be cultivated in South Africa (Glen, 2002). Together with this, sightings of naturalized *Berberis* populations have recently been made and this has prompted a cause for concern. However, no study up to date has investigated the cultivation history, potential invasive status or naturalized distribution range of any *Berberis* spp. in South Africa. Therefore, in accordance with the recent shift in focus to include emergent invasive species in management plans together with widespread invasive species, the status of *Berberis* in South Africa in terms of the invasive potential that its members pose is in need of assessment. Thus, the aims of this study are as follows:

1. Determine the extent of existing populations of *Berberis* in South Africa.
2. Predict the future spread of selected species by means of habitat suitability modelling.
3. Determine the invasion risk that *Berberis* spp. pose to South Africa.
    a. Compile a list of nurseries stocking *Berberis* spp.
    b. Elucidate all herbarium records
    c. Establish all species that are and that have been present in the country
4. Determine eradication feasibility.
    a. Conduct trial clearing and establish the most effective herbicides that can be used for control of naturalized populations

Chapter 2: Literature Review

2.1. Introduction

Invasive alien plant species (IAPs) are usually only managed once they become noticed (Wilson *et al.*, 2013), by which time they have already spread to occupy a substantial area and are thus well established (Le Maitre *et al.*, 2000, 2002; Mgidi *et al.*, 2007). Such established populations generally use most of the available management resources (e.g. labour, chemicals etc.) (Rouget *et al.*, 2004) and these species are therefore not feasible targets for eradication. This means that management becomes the only option and the species will in all likelihood persist in its introduced region for good. Invasive alien plant species populations should be managed while they are still small and geographically confined instead of waiting until the population sizes reach unmanageable proportions (Groves, 1999). It is therefore desirable to invest in resources for excluding, detecting and eradicating IAPs from as early as possible as this is the most cost-effective long term solution (Wittenberg & Cock, 2001; Rejmánek & Pitcairn, 2002). Emergent invasive species should receive a very high priority in terms of attempting eradication.

Invasive alien plant species cost South Africa an estimated R6.5 billion every year in ecosystem services (De Lange & Van Wilgen, 2010) and consume *ca.* 9 billion litres of water per day (Chapman & Le Maitre, 2001). Approximately 10 million ha (8.28%) of South Africa and Lesotho are to some degree invaded by a wide range of alien species (Le Maitre *et al.*, 2000). The negative impacts of IAPs on ecosystem services is a serious problem and growing in significance, with the situation deteriorating as new species arrive and become invasive (Van Wilgen *et al.*, 2008).

Several species of *Berberis* have become serious invaders in some parts of the world (D' Appollonio, 1997; Ehrenfeld, 1997; DeGasperis & Motzkin, 2007; McAlpine & Jesson, 2007; Ward *et al.*, 2010; Speith, 2012) due to having been transported extensively (Campbell & Long, 2001). In South Africa there have been reported cases of *Berberis* spp. becoming naturalized (personal communication with Dr. John Wilson, SANBI-ISP, 2012). No formal study has been conducted regarding the history, invasive status or impact of *Berberis* in South Africa. There are only four records of *Berberis* documented in the SAPIA database (South African Plant Invaders Atlas, May 2013). This includes one record that is only indicated as *Berberis* sp., one for *Berberis* cf. *chitria* and two for *Berberis julianae*. About 24 species of Berberidaceae (18 for *Berberis*, 5 for *Mahonia* and 1 for *Nandina*) have been documented to be cultivated in South Africa (Glen, 2002). None of these cultivated species have been listed officially as invasive in SA. However, *B. thunbergii* has been listed as category 3 (sterile cultivars exempted) under the National Environmental Management Biodiversity Act (South African Department of Environmental Affairs and Tourism, 2014), meaning that it is not yet invasive but may longer be traded and/or propagated (see Appendix B). Also, *B. julianae* has recently been placed under the SUSPECT list (Species Under Surveillance — Possible Eradication or Containment Targets) (Wilson *et al.*, 2013). Given the fact that some *Berberis* spp. have shown potential to naturalize in South Africa it makes sense to investigate the potential invasive threat that they pose and to determine which steps to take, if necessary, in order to eradicate them in the early stages.

2.2. Description, impacts and control of *Berberis* spp.

2.2.1. Berberidaceae

The family Berberidaceae Juss. contains between 11 and 16 genera (depending on taxonomic treatment) and includes many ornamental plants (Whetstone *et al.*, 1997; Morris, 2009; Junsheng *et al.* 2011; Kellermann, 2013). This family is comprised of herbs, perennials, shrubs and small trees and are sometimes rhizomatous (*Sinopodophyllum* T.S.Ying, *Plagiorhegma* Maxim.) or tuberous (*Gymnospermium* Spach) (Morris, 2009; Junsheng *et al.*, 2011; Kellermann, 2013). Leaves can be alternate, opposite or basal, and can be simple, pinnately or ternately compound, with stipules present or absent (Junsheng *et al.* 2011). The perianth is usually two- or three-merous and rarely absent (Junsheng *et al.*, 2011). The sepals are distinct, often petaloid, between six and nine and occur in two or three whorls (Junsheng *et al.*, 2011). There are six petals which are also distinct and can be with or without nectaries (Junsheng *et al.*, 2011). Some regard the outer perianth whorl as sepaloid and the inner perianth whorl as petaloid staminodes, thus making no distinction between sepals and petals (Morris, 2009; Takhtajan, 2009). Stamens are six and occur opposite the petals with anthers being two-celled and dehiscing by valves or longitudinal slits (Junsheng *et al.*, 2011). The ovary is superior, one-carpellate and one-locular with one to many ovules, the style is present or absent and sometimes persists in the fruit as a beak (Morris, 2009; Junsheng *et al.*, 2011; Kellermann, 2013). Fruits can be berries, capsules, follicles, or utricles (Junsheng *et al.*, 2011).

Some well-known members of the family are the familiar garden plants *Nandina domestica* Thunb. (Nandina or heavenly bamboo), *Mahonia* Nutt., *Epimedium* L. and more obviously

Berberis L. (Morris, 2009). The genera of the family that have been recognized both in the past and present are given by Table 2.1, together with some of their common names. Takhtajan (2009) has opted for separating the plants of the order Berberidales into four families, namely Nandinaceae, Berberidaceae, Ranzaniaceae and Podophyllaceae, with the latter having the four sub-families Leonticoideae, Epimedioideae and Podophylloideae. In Junsheng *et al.* (2011) these families are all included under the family Berberidaceae.

Table 2.1: Genera of the family Berberidaceae that have been recognized in the past and present. Common names are also given. ***(genera from Kim et al., 2004 Takhtajan, 2009)***

Genus	Common names
Aceranthus C.Morren & Decne.	-
Achlys DC.	Vanilla leaf, deer's foot
Berberis L.	Barberry
Bongardia C.A.Mey.	Golden rod, lady's nightcap
Caulophyllum Michx.	Cohosh
Diphylleia Michx.	Umbrella-leaf
Dysosma Woodson	Chinese mayapple
Epimedium L.	Barren wort, fairy wings
Gymnospermium Spach	-
Jeffersonia Bart.	Twinleaf
Leontice L.	Lion's foot
Mahonia Nutt.	Algerita, Oregon grape, grape-holly
Nandina Thunb.	Heavenly bamboo
Plagiorhegma Maxim.	-
Podophyllum L.	May-apple, wild mandrake
Ranzania T.Ito	-
Sinopodophyllum T.S.Ying	Himalayan mayapple
Vancouveria C.Morr. & Decne.	Inside-out flower

About 56 species of the family Berberidaceae have been recorded as naturalized or invasive in the world and include the genera *Berberis*, *Bongardia*, *Caulophyllum*, *Epimedium*, *Leontice*, *Mahonia*, *Nandina* and *Podophyllum* (Randall, 2012).

2.2.2. The genus *Berberis* L.

The name *Berberis* originates from the word 'berberys', which is the Arabic name used for its fruit (Kellermann, 2013). The genus *Berberis* L., also referred to as barberry, contains between 500 and 600 species (Ulloa, 2011). Specifically, according to The Plant List (http://www.theplantlist.org/1.1/browse/A/Berberidaceae/Berberis/, accessed 20 November 2014) there are 580 (54.8%) accepted species names and 265 (25%) synonyms, while a further 214 (20.2%) names remain unassessed. Because all of these species have simple leaves they are considered true *Berberis* (Ulloa, 2011). However, there are some 200 species that are traditionally placed under the genus *Mahonia* Nutt., all of which have compound leaves, but some of which according to molecular data should not be separate and should instead be placed under the genus *Berberis* (Ulloa, 2009; Ulloa, 2011; Kellermann, 2013). This is partly responsible for the uncertainty in the number of *Berberis* species. Another reason is that the genus has never been revised as a whole.

Berberis spp. usually form dense, multi-stemmed bushes and can be evergreen or deciduous (Junsheng, 2011). They are characterized by spines (Figure 2.1) that can take on various shapes and sizes (e.g. star-shaped, palmate, recurved, straight) and can be numerously branched, although the usual case is three- to five-branched (rarely single, e.g. *B. vulgaris* and *B. thubergii*) (Landrum, 1999; Junsheng, 2011). Some regard the spines of *Berberis* spp. as being modified leaves occurring on elongated primary stems, whereas the true leaves occur on short axillary spur shoots (Whittemore, 1997). Such a view regards the stems as being dimorphic. Flowers are three-merous and usually subtended by two to three bracts (refer to Figure 2.2 and Figure 2.3 for flower characteristics) (Junsheng, 2011; Kellermann, 2013). There are six sepals (outer sepals I and inner sepals II in Figure 2.4), six petals with nectariferous bases (petals often smaller than sepals) (III in Figure 2.4) and six stamens (III in Figure 2.4) that occur opposite the petals (Junsheng, 2011; Kellermann, 2013). The ovary is superior and can contain one to many ovules, with the style being very short or absent, the latter resulting in a sessile stigma (Junsheng, 2011; Kellermann, 2013). See also Figure 2.5 for a back view of the various flower parts. Frugivorous birds are the primary distributors of *Berberis* seeds (Silander & Klepeis, 1999).

Figure 2.1: Species of the genus *Berberis* are characterized by spines that occur below the leaves (although some regard these as modified leaves; see text for details).

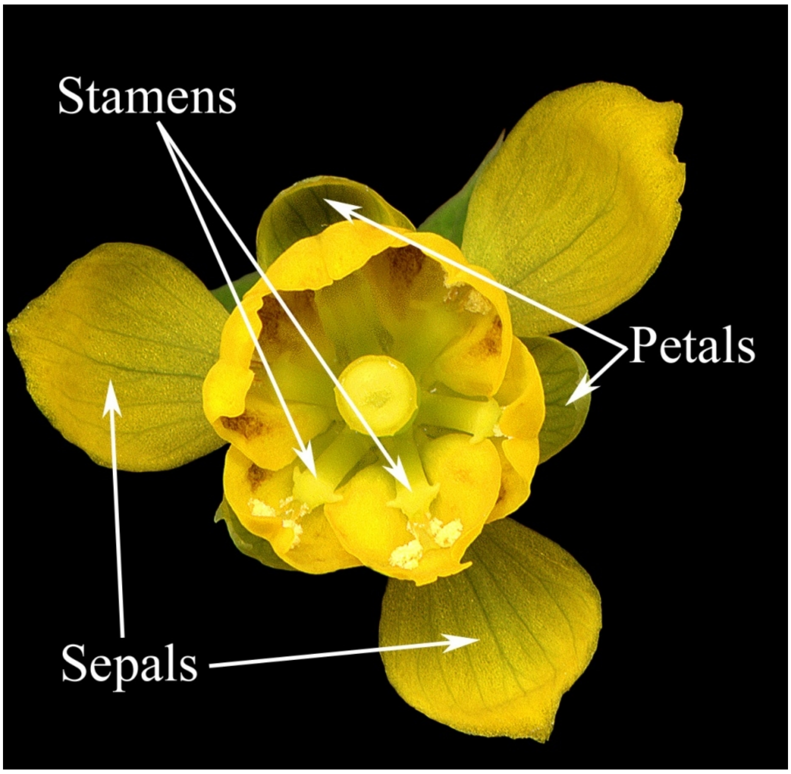


Figure 2.2: Flower of *Berberis swaseyi* showing the petals, sepals and stamens. The petals and sepals are sometimes referred to as inner sepals and median sepals, respectively. *(photo: Bob Harms)*

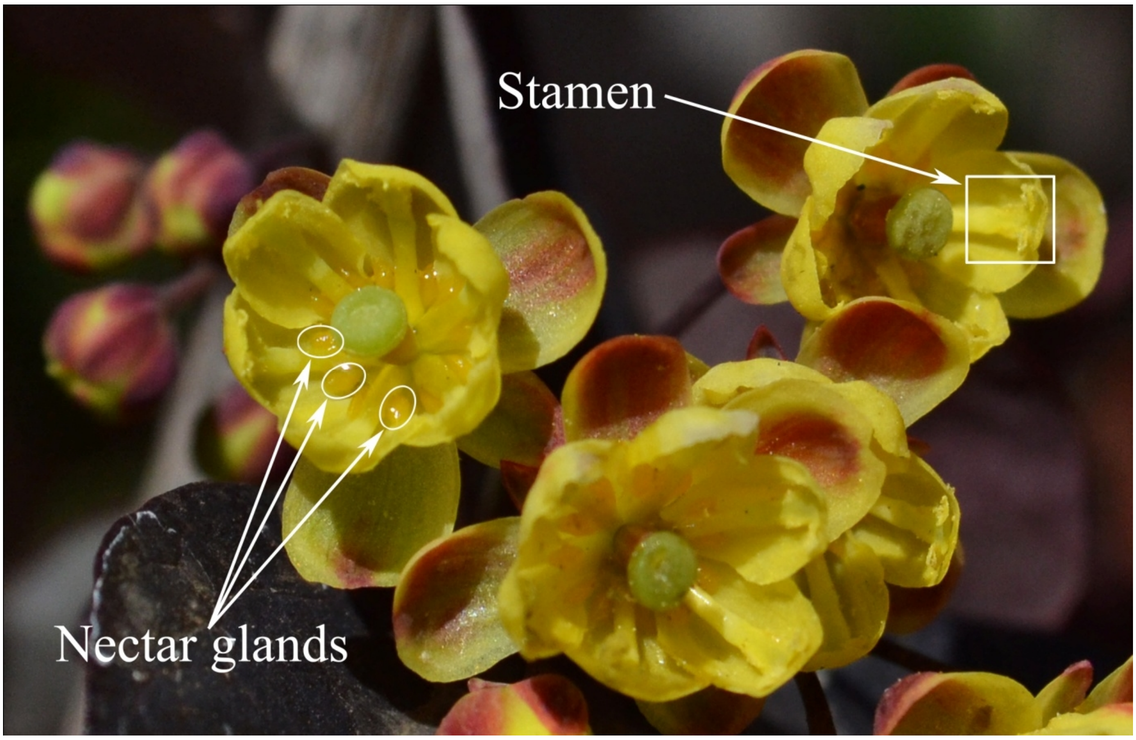


Figure 2.3: Nectar glands and stamens in a flower of *Berberis thunbergii* var. *atropurpurea*.

Figure 2.4: Various perianth segments (I, II and III) of a *Berberis swaseyi* flower. Prophylls (i), ovary (a) and stigma (b) also indicated *(photo: Bob Harms)*

Figure 2.5: Flower of *Berberis swaseyi* as seen from behind (compare Figure 2.4). ***(photo: Bob Harms)***

Berberis spp. are spread over two principal regions of the world (Harber, 2010), namely: (1) the Eurasian land mass stretching from the Sierra Nevada of southern Spain to the Russian Far East and Japan with hotspot areas in the Himalayas and south-western China (e.g. Yunnan), and (2) across Latin America from the Falkland Islands to Nicaragua, being concentrated in the Andean spine. Apart from those two principal regions, there are species of *Berberis* in Madeira, the Philippines, Indonesia, the United States and Juan Fernández Islands.

The African species form a diminutive portion of the total species number. According to Harber (2010) and Maliwichi-Nyirenda *et al.* (2011) three species of *Berberis* occur naturally on the African continent, one of which is endemic. The first species, *Berberis vulgaris* L., occurs in north-west Africa but is also distributed over central and southern Europe and western Asia. The second species, *Berberis holstii* Engl., is endemic to the mountains of eastern and south-eastern Africa and has a distribution range over seven countries, viz. Ethiopia, Somalia, Kenya, Uganda, Tanzania, Zambia and Malawi. The third species, *Berberis hispanica* Boiss. & Reut., occurs in northern Africa. *Berberis* spp. are thus native to North and South America, Europe, Asia, Malesia and northern and eastern Africa (Kellermann, 2013); hence there are no species of *Berberis* or genera of the family Berberidaceae that occur naturally within South Africa.

2.2.3. Species descriptions

Based upon invasive history elsewhere (notably New Zealand, USA, Australia and certain European countries) (D' Appollonio, 1997; Ehrenfeld, 1997; DeGasperis & Motzkin, 2007; McAlpine & Jesson, 2007; Ward *et al.*, 2010; Randall, 2012; Speith, 2012; Kellermann, 2013) and documented occurrence within South Africa (SAPIA, May 2013) five species of *Berberis* are reviewed here. They are *B. julianae, B. thunbergii*, *B. darwinii*, *B. aristata* and *B. vulgaris*.

2.2.3.1. *Berberis julianae*

Berberis julianae C.K. Schneid., also known as the Wintergreen barberry, is a dense, spiny evergreen shrub between 1 and 3 m tall (Junsheng, 2011). The leaves are shiny dark green above, leathery and have a heavily serrated margin with each tooth ending in a short, sharp spine (Figure 2.6 A) (Ulloa, 2009); the leaves develop a red colour in the winter months. The species bears the very characteristic three-branched spines that occur just below the leaf clusters (Figure 2.6 E). The flowers are small and yellow and are numerous, occurring in clusters in the leaf axils (Figure 2.6 A). The fruits are bluish-black berries (Figure 2.6 D and F) that are about 8 mm in length.

Berberis julianae is native to central China. In its natural habitat it occupies slopes, forests, thickets and bamboo groves (Junsheng, 2011). It is a shade-tolerant species which is fast-growing and which also possesses the ability to alter soil chemistry (Speith, 2012). In a foreign environment this can be to the detriment of the native vegetation. It can form dense thickets which exclude all other plants and is reportedly the most cold tolerant of the invasive *Berberis* spp. (Speith, 2012). There is little documentation on its invasiveness, being only recently listed as an invasive plant by the Center for Urban Ecology, Washington DC (USA) (Speith, 2012). It has also been listed as naturalized in the United Kingdom and as a casual alien in Austria (Randall, 2012).

Berberis julianae as it is known in South Africa is thought to be a hybrid (Harber, 2010). However, the genus has never been revised as a whole and it is difficult to verify exactly whether it is indeed a hybrid or not, and if so, to what extent it has hybridized. This species has been included on the SUSPECT list (Species Under Surveillance – Possible Eradication or Containment Targets) as of May 2013 (Wilson *et al.*, 2013).

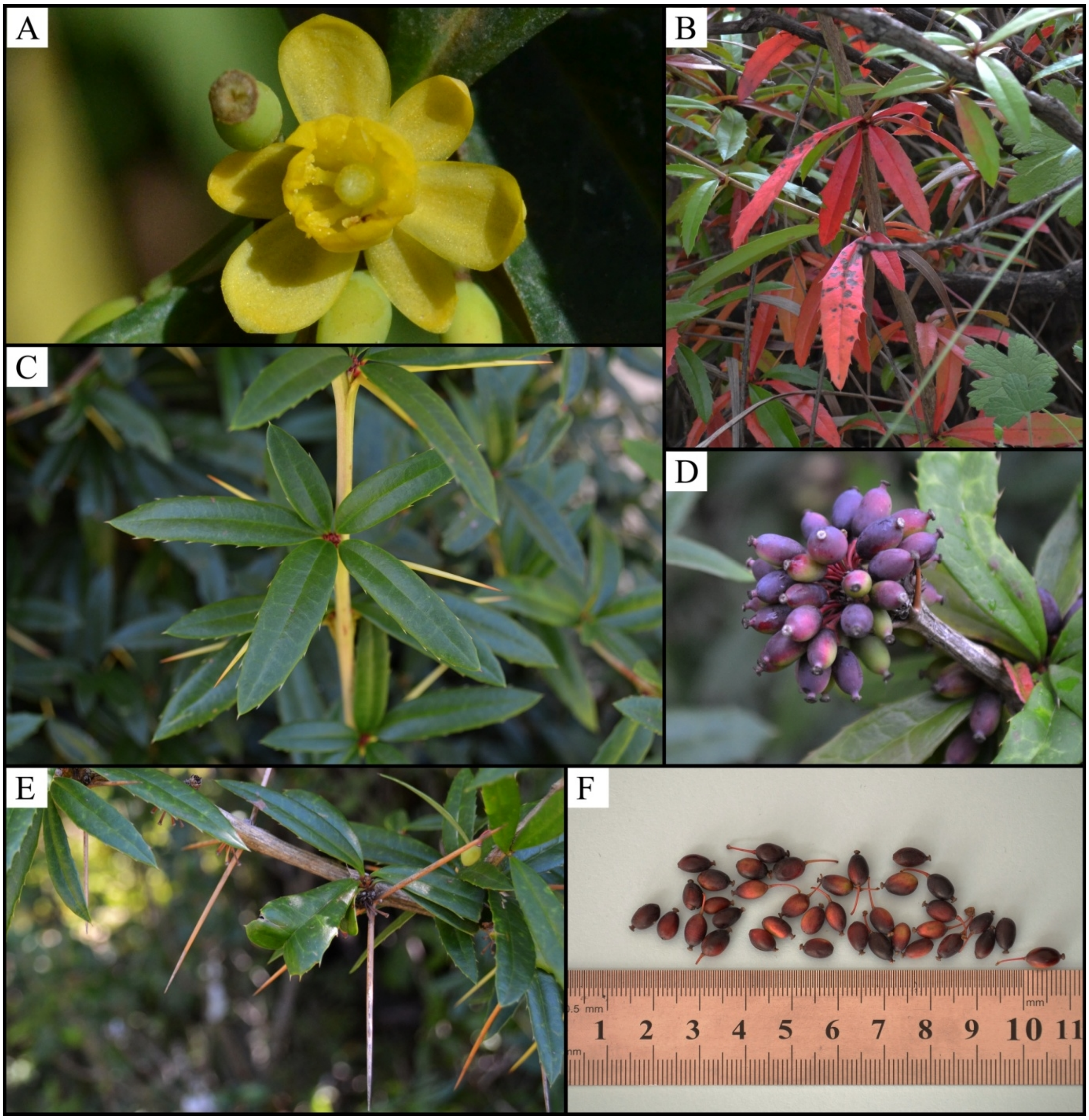


Figure 2.6: Characteristic features of *Berberis julianae* C. K. Schneid.: A) Yellow flowers, B) wine-red autumn colouration of the leaves, C) alternately arranged leaves with a whorled appearance due to clustering at the nodes, D) bluish-black fruit that occur in clusters, E) three-branched spines occurring at each node, and F) fruits according to scale (ruler marked in centimeters).

2.2.3.2. *Berberis thunbergii*

Berberis thunbergii DC., also known as the Japanese barberry, is a compact deciduous shrub about 1 m tall and is native to Japan (Junsheng, 2011). The leaves are greyish-green above and green below, being of a thin, papery texture and having a smooth margin (Figure 2.7) (Junsheng, 2011). The flowers are yellow in colour (the outer sepals being red) and are characteristically borne in umbels (Figure 2.7 A and B). The fruits are reddish berries which eventually dry out as they mature (Figure 2.7 C). This is one of the most widely cultivated species of *Berberis* (Junsheng, 2011) and numerous cultivars and hybrids exist (over 40) (Brand *et al.*, 2012). The attractive foliage and berries of *B. thunbergii* is the main reason why it is so widely cultivated (Harrington *et al.*, 2003). Seeds of *B. thunbergii* var. *atropurpurea* (see Figure 2.7 D for general appearance) have been shown to have high a germination success and seedling vigour (Lehrer *et al.*, 2006).

Berberis thunbergii is a species that is causing great concern the North-eastern United States where it is already classified as invasive in 20 states, as well as four provinces in Canada (Ward *et al.*, 2010); however they continue to be widely planted and marketed to the public by nurseries (Harrington *et al.*, 2003). Also, it has been documented as naturalized in China, Sweden, Netherlands, UK, Germany, Denmark and New South Wales (Australia) as well as being regarded as a casual alien in Hungary, Belgium, Ireland, Austria and Finland (Randall, 2012).

According to DeGasperis & Motzkin (2007), *Berberis thunbergii* is principally an invader of agricultural fields that have been abandoned and post-introduction land use is the single strongest predictor of *B. thunbergii* occurrence. It possesses the ability to alter soil chemistry in that it can increase the rate of net nitrification, which it uses to support the creation of a larger biomass to the detriment of the native shrubs (Ehrenfeld *et al.*, 2001). Native plants have a poor capacity of regenerating under a *B. thunbergii* canopy and there is little short-term recovery after they are released from the barberry overstory (D' Appollonio, 1997). This in itself has management implications, since even if *B. thunbergii* is controlled as an invasive shrub, plantings of native trees will still be required in order to regenerate the canopy on site (D' Appollonio, 1997). It has unpalatable foliage which contributes to the lowering of the productive capacity of the native region (Ehrenfeld, 1997). *Berberis thunbergii* shrubs also possess the ability to resprout from the root collar and may spread vegetatively, thus making pulling out by hand a very ineffective method since stem fragments invariably remain in the ground (Silander & Klepeis, 1999; D' Appollonio, 1997). Some cultivars of *B. thunbergii* (e.g. ‘Aurea’ and ‘Crimson Pygmy’) are claimed by horticultural outlets not to have invasion potential (Knight *et al.*, 2011), despite the fact that a high germination success and seedling vigour has been recorded by some workers (Lehrer *et al.*, 2006). Cultivars of invasive species are often marketed as being non-invasive but usually without significant evidence to back these claims. These claims are made based upon the cultivars themselves (which are propagated vegetatively) and not on their offspring, which more often than not do not breed true and thus regain the ability to invade (Knight *et al.*, 2011). Caution should therefore be used when considering the reported “non-invasiveness” of cultivars, including *B. thunbergii*.

Figure 2.7: Characteristic features of *Berberis thunbergii*: A) Yellow flowers, B) umbel type inflorescences (also note the singular spines), C) bright red fruits and D) leaves and flowers of var. *atropurpurea*. ***(all photos Peter Hot’ka)***

2.2.3.3. *Berberis aristata*

Berberis aristata DC., also known as the Indian barberry or tree turmeric, is a deciduous shrub that can grow up to 5 m in height and is native to the Himalayas in Nepal (being one of the most common *Berberis* spp.) (Adhikari *et al.*, 2012). Like most other *Berberis* spp., it has three-branched thorns that are about 1.5 cm long (Figure 2.8 C). The leaves are light green above, dark green below, leathery and have a toothed margin (Figure 2.8 E). The inflorescence has 10 to 20 yellow flowers (Figure 2.8 A and D). The fruits are round to ovoid (sometimes asymmetric) and purple in colour (Figure 2.8 F).

This is the first species of *Berberis* that was collected in Nepal (Adhikari *et al.*, 2012). In its natural habitat it is commonly found at an altitude of 1 300 – 3 400 m, frequenting forest clearings and disturbed vegetation along forest edges and roadsides (Adhikari *et al.*, 2012). This species is commonly treated by some as *B. chitria*, but this is in fact a synonym of *B. aristata* (Adhikari *et al.*, 2012). In its native region it is known as "Daruhaldi" (Ali *et al.*, 2008).

Berberis aristata has been recorded as naturalized in New South Wales, Australia (Randall, 2001; Randall, 2012). Ironically, *B. aristata* is a critically endangered shrub in its native Himalayan range due to its extensive collection for medicinal and other uses (Ali *et al.*, 2008). These medicinal uses include the use of the root extract, called "rasount" in India, to treat skin and eye diseases, malaria and piles (Sharma *et al.*, 2005). The fruits are ingested to serve as laxatives and anti-scorbutics (Sharma *et al.*, 2005). The roots and stems are also used to dye woollen garments and fibres yellow (Sharma *et al.*, 2005).

In the SAPIA database *Berberis aristata* has been recorded in the Woodbush State Forest (Tzaneen area, Limpopo Province), but it is recorded under the name of *Berberis* cf. *chitria* which is a synonym of *B. aristata* as mentioned.

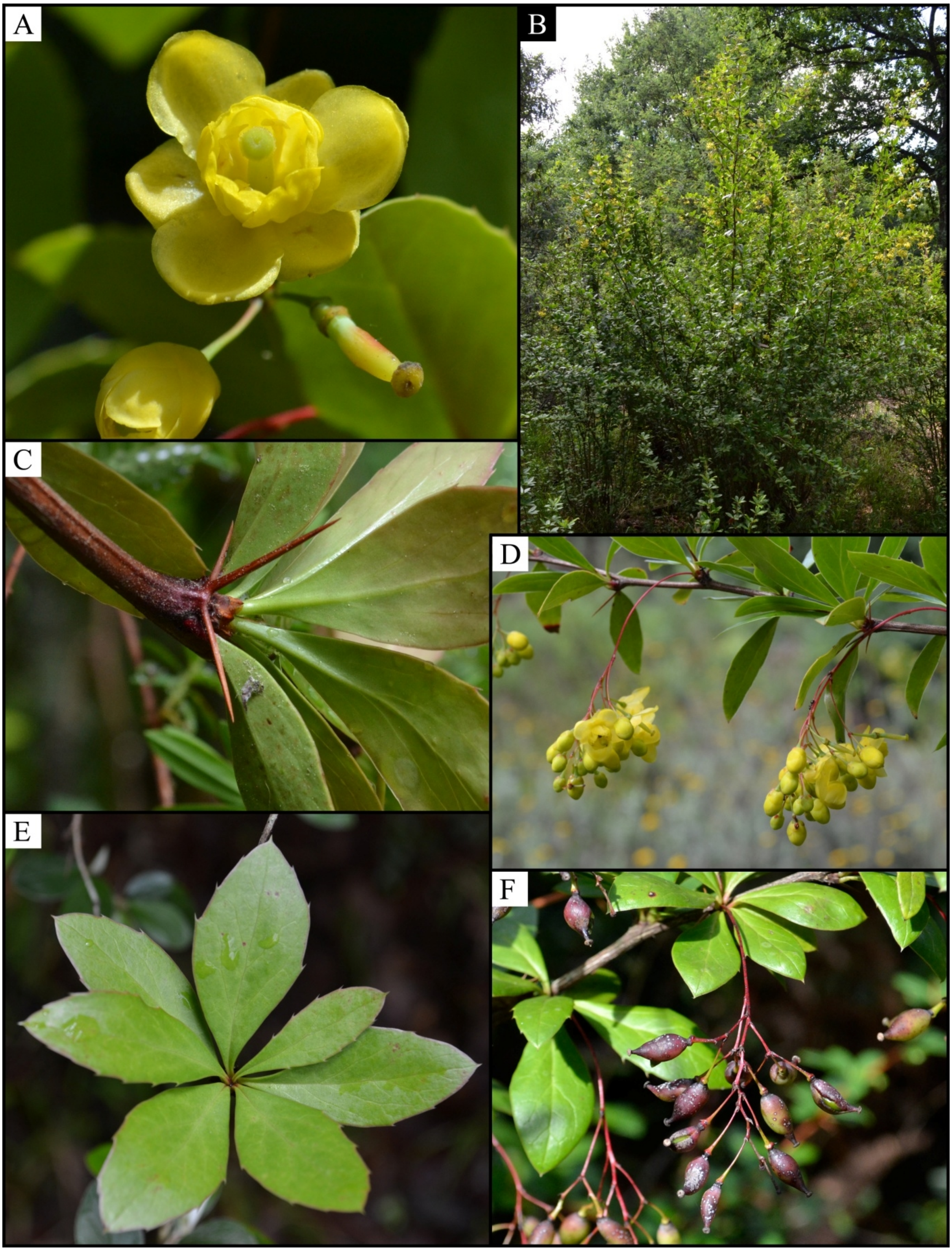


Figure 2.8: Characteristic features of *Berberis aristata*: A) Yellow flowers, B) multi-stemmed habit, growing up to 3 m tall, C) three-branched reddish spines, D) raceme inflorescences, E) pale green leaves, and F) purplish fruits.

2.2.3.4. *Berberis darwinii*

Berberis darwinii Hook., also known as Darwin's barberry, is a shrub that can grow up to about 1.5 m tall and is native to Chile and southern Argentina (Landrum, 1999). The spines differ somewhat from the previous three species (*B. julianae*, *B. thunbergii* and *B. aristata*) in that they are five- to seven-branched and small (Landrum, 1999). The leaves are shiny green above, dull beneath, and have one to four pairs of spines on the margin together with a terminal one (Figure 2.9) (Landrum, 1999). The inflorescence is a raceme which bears approximately 10 flowers that are orange in colour (Figure 2.9 B) (Landrum, 1999). The fruits are round, dark blue in colour and have waxy covering (Figure 2.9 A). In its natural habitat it frequents disturbed forest habitats (Landrum, 1999).

Berberis darwinii was introduced in New Zealand in 1946 (Sykes, 1982) and has invaded a number of vegetation types (remnant forest stands, scrub and roadside vegetation) (McAlpine & Jesson, 2007; McAlpine & Jesson, 2008) thereby threatening New Zealand's native ecosystems. It has also been recorded as naturalised in New South Wales (Australia), Iceland, United Kingdom, Ireland, Tasmania and USA as well as being invasive in Canada (Randall, 2012).

Berberis darwinii does not have a persistent seed bank, with only a small quantity surviving for more than a year and with most of the seed germinating during the first spring following seed production (McAlpine & Jesson, 2008). A key trait in the success of *B. darwinii* is widespread seedling dispersal (McAlpine & Jesson, 2008). The advantage of producing large amounts of short-lived seeds that germinate *en masse* in spring is reduced exposure to pathogens and seed predators (Alvarez-Buylla & Martinez-Ramos, 1990), which if coupled to effective seed dispersal, as is the case with *B. darwinii*, produces numerous, widespread seedlings at a time of year which is most conductive to seedling survival (McAlpine & Jesson, 2008).

Berberis darwinii is shade-intolerant and thrives in full sun (McAlpine & Jesson, 2007). Since invasions into open (grasslands) habitats are more prominent than in closed-canopy forest ecosystems (Ehrenfeld, 1997; Kourtev *et al.*, 1998) the potential exists for this species to become a serious problem in South Africa due to suitable vegetation regimes (Mucina & Rutherford, 2011).

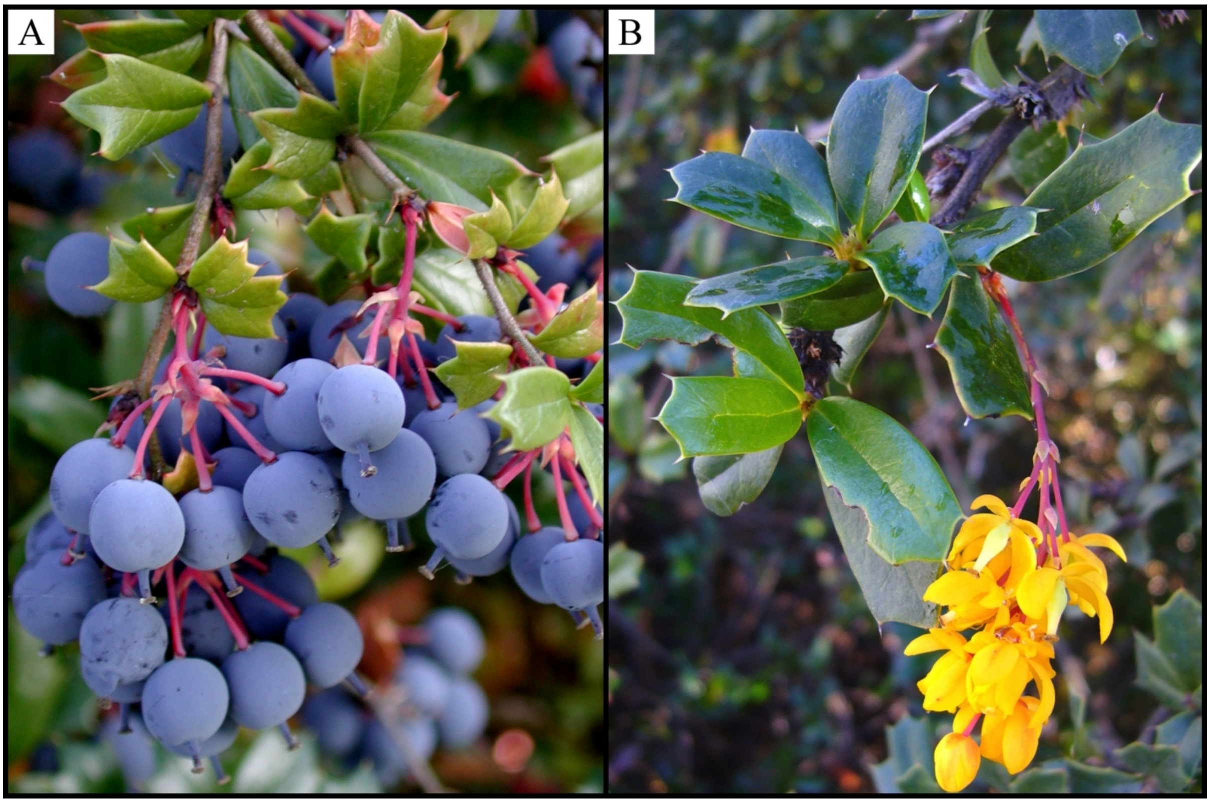


Figure 2.9: Features of *Berberis darwinii*: A) Round, dark blue fruits, and B) yellow flowers arranged in a raceme. Both photos show the leaves having only a few marginal spines (three to five can be seen here). *(photos: A – John Hayden; B – Zoya Akulova)*

2.2.3.5. *Berberis vulgaris*

Berberis vulgaris L., also known as the common barberry or European barberry, is a deciduous shrub growing up to 3 m tall (Whetstone *et al.*, 1997). Spines occurring on *B. vulgaris* can be simple or three-branched. The leaves are usually obovate in shape, have a dull colouring both underneath and above and have a very characteristic finely serrated margin (Figure 2.10) (Whetstone *et al.*, 1997). Flowers are yellow in colour and occur in raceme inflorescences of 10 to 20 flowers (Figure 2.10 D) with the fruits being fleshy and of a red to purple colouring (Figure 2.10 A) (Whetstone *et al.*, 1997).

Berberis vulgaris is an invasive species in the USA and Canada and is also recorded as naturalized in Norway, New South Wales (Australia), Sweden, Norway, Iceland, New Zealand, Ireland, Denmark and Ukraine (Randall, 2012). Some consider that *B. vulgaris* is not as invasive today than in the past with regards to the USA (Silander & Klepeis, 1999), the grounds for this being that it is no longer as frequent and is even regionally eradicated in some places. This is fallacious thinking since the current infrequent distribution of the common barberry in some parts of the USA might purely be an artefact of the intensive eradication campaign against it that took place during the early twentieth century and it continues to proliferate over vast areas of North America (and Europe).

One of the biggest threats that *Berberis vulgaris* pose is that is serves as an alternate host for the destructive black stem rust fungi of wheat (*Puccinia graminis* Pers. f. sp. *tritici*) (Jin, 2011). This pathogen uses certain barberry species to complete the sexual stage of its life cycle. The decimation of wheat crops due to this pathogen led to an extensive barberry eradication program in the USA to prevent the development of new virulent rust races (Stakman, 1919). It is of considerable interest to note that, despite this intensive eradication attempt, *B. vulgaris* is still regarded as invasive in the USA. This in itself demonstrates how important it is to stop invasive species from becoming widespread, since eradication becomes an unattainable target after a species has spread to occupy vast areas of land.

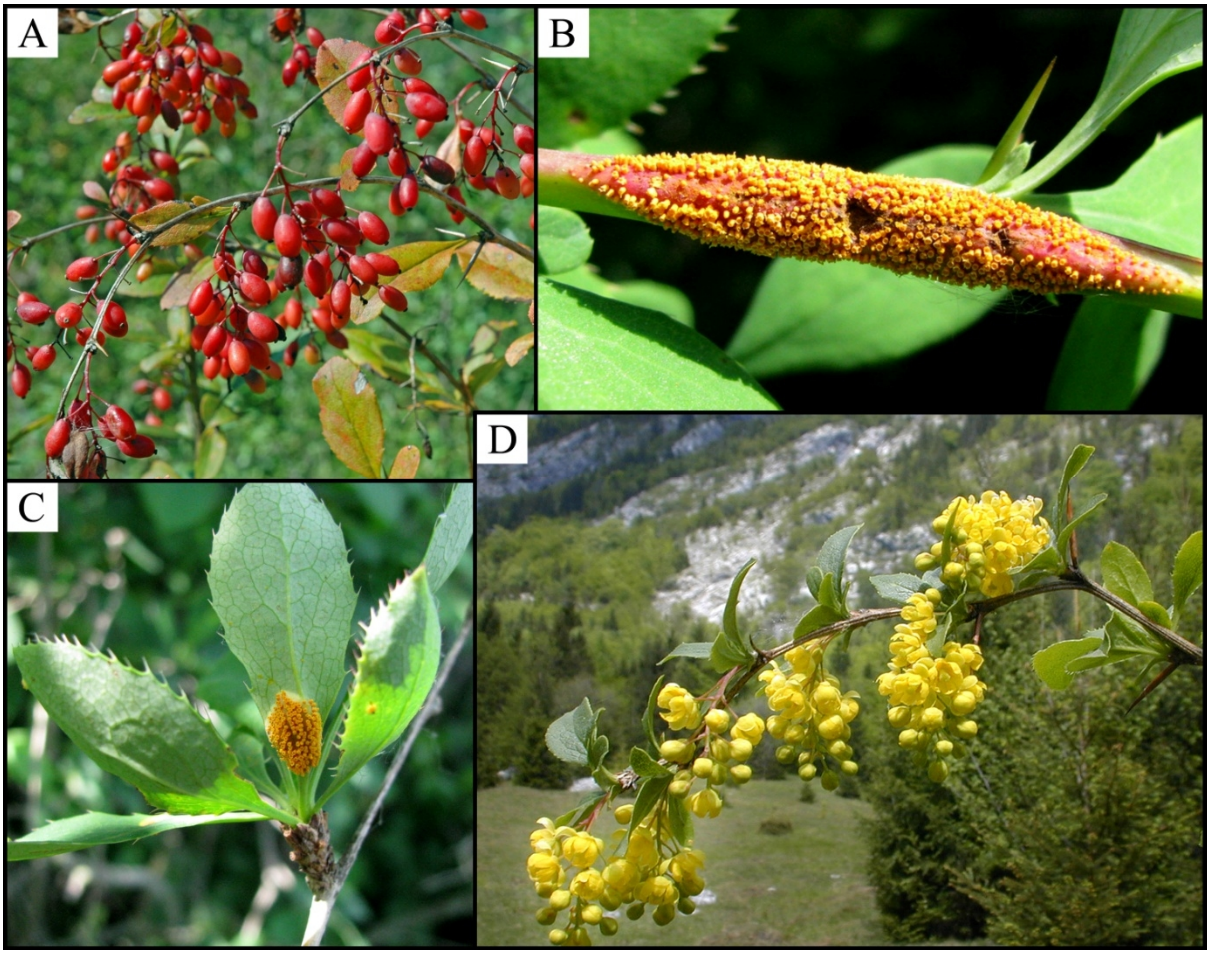


Figure 2.10: Features of *Berberis vulgaris*: A) Bright red fleshy fruits, B) aecia of black stem rust on a branch, C) leaves with a finely serrated margin (also with aecia of black stem rust), and D) yellow flowers arranged in racemes. ***(photos: A and D, Amadej Trnkoczy; B and C, Zakkie Pretorius)***

2.2.4. Uses and impacts of *Berberis*

Berberis spp. have been transported all over the world (Campbell & Long, 2001), mostly for landscaping purposes (MNFI, 2012). They have a variety of uses, probably the most popular of which are to form impenetrable hedges and barriers due to their spiny nature (Gilman, 2011). Certain species are used as fuel wood and fodder for goats (Ali *et al.*, 2008), while the fruits are enjoyed by native tribes (e.g. the *Malani* of India) (Sharma *et al.*, 2005) and are also harvested on a commercial scale (e.g. *B. vulgaris* var. *asperma*) (Tehranifar, 2003). The berries of some species are used as flavour enhancers of food (e.g. rice) and for making fruit juice, jam, marmalade and syrup (Tehranifar, 2003). They are widely used in indigenous medicinal practices, such as treating coughs, skin and eye diseases, pneumonia, infertility, epilepsy, jaundice, piles, malaria and even sexually transmitted diseases (Sharma *et al.*, 2005 Rajasekaran & Kumar, 2009; Maliwichi-Nyirenda *et al.*, 2011). Some species are the subjects of intense medical research, e.g. the potential of *B. aristata* extracts as anticancer drugs (specifically colon cancer) (Das *et al.*, 2009). It is even reported that the ancient Egyptians as early as 500 BC used certain species to prevent plagues (Mazumder *et al.*, 2011).

Berberis spp. can have considerable negative environmental and economic impacts. These include altering soil chemistry, lowering veld carrying capacity, serving as alternate hosts for stem rust of wheat and preventing access to watercourses when occurring in dense thickets (D' Appollonio, 1997; Ehrenfeld, 1997; DeGasperis & Motzkin, 2007; Jin, 2011; Speith, 2012). They can also replace indigenous vegetation, to the detriment of native fauna and the ecosystem as a whole (Speith, 2012). Some *Berberis* spp. are known to be able to fix atmospheric nitrogen in the soil (Ehrenfeld *et al.*, 2001; Speith, 2012), thus adding a new function to the invaded ecosystem (Le Maitre *et al.*, 2011). Invaders that have this ability have caused some of the most striking impacts in South African systems, most notably that of Australian *Acacia* spp. in lowland fynbos (Le Maitre *et al.*, 2011). They are therefore able to have a significant impact on their introduced region.

Stem rust, or black rust, is a disease caused by the fungal pathogen *Puccinia graminis* Pers. f. sp. *tritici* Eriks. & E. Henn. and destroys wheat crops (Singh *et al.*, 2008); it has been a serious problem since ancient times (Peterson, 2001). Several *Berberis* spp. serve as alternate hosts for stem rust where sexual recombination takes place to give rise to new virulent strains (Jin, 2011). The steam rust epidemic of 1916 which caused major losses of wheat in North

America launched one of the biggest and most successful eradication campaigns in history, namely against *B. vulgaris* (Campbell & Long, 2001).

Of the 18 barberry species previously recorded as cultivated in South Africa (Glen, 2002), *Berberis holstii* and *B. vulgaris* are known to be susceptible to these rusts. Although there are currently only a few *Berberis* species that are known to be susceptible to stem rust, it is thought that there are many more susceptible species still to be found (Jin, 2011). The presence of such naturalised invasive stands of barberry could thus threaten wheat production in South Africa and should be treated with vigilance.

2.2.5. Control of *Berberis*

Public support for the eradication of IAPs, or the lack thereof, can mean the difference between the success and failure of such projects (both in natural and urban areas) (Bremner & Park, 2007). The methods that are used to control an alien species as well as the species itself can influence the level of public support, particularly when the species involved are pleasing to the public (e.g. popular horticultural species) (Manchester & Bullock, 2000; Fraser, 2006). Concerns over the use of certain control methods, especially regarding the use of herbicides, is generally characterized by uncertainty (Fraser, 2006). Thus, managing invasive alien species is equally a social issue as it is a scientific one (Reaser, 2001; Bremner & Park, 2007) and any eradication/control program should have public support to be successful. This should be of utmost importance if eradication campaigns were to be launched against selected *Berberis* species in South Africa, since some of them are popular in the horticultural industry.

Species of *Berberis* can only be controlled either mechanically or chemically, since there are currently no known biological control agents (Rhoads & Block, 2011), although some are currently under investigation (e.g. in New Zealand; Norambuena *et al.*, 2011). Mechanical control involves the hand pulling of small plants, but heavy gloves should be worn due to the sharp thorns (TN-EPPC, 2009; Rhoads & Block, 2011). Another mechanical control method involves mowing/cutting and is appropriate for small populations or environmentally sensitive areas where herbicides cannot be used (TN-EPPC, 2009); in this method it is recommended that stems be cut at least once per growing season as close to ground level as possible and will control the spread of *Berberis* but will not, however, eradicate it (TN-EPPC, 2009). This method (cutting/mowing) is not encouraged, unless the entire root system can be removed, as some species of *Berberis* possess the ability to sprout from the root collar (D' Appollonio *et al.*, 1997). It should be noted however that all mechanical control methods, specifically in the case of *Berberis* but also with invasive species in general, are largely a waste of time and resources if herbicides are not included in the treatment since the plants will almost certainly resprout. This only exacerbates the original problem.

A crucial consideration for any herbicide treatment is the proximity of the target species to any water sources (e.g. rivers and wetlands) (MNFI, 2012). The current most effective method of control for *Berberis* spp. seems to be the application of herbicides (D' Appollonio, 1997; Ehrenfeld, 1999; Silander & Klepeis, 1999). It is suggested that herbicides should be applied early in the growing season immediately after the leaves of *Berberis* have sprouted (and also just before the leaves of other native trees and shrubs have sprouted) in order to minimize non-target impacts (D' Appollonio, 1997). Applying glyphosate to *Berberis* populations through spraying in early spring when other plants are not yet in leaf can be 100% successful in eradication (Silander & Klepeis, 1999). Focus should be on small, marginal populations or so-called "nascent foci" and can possibly provide the most effective control during the course of time (Moody & Mack, 1988; Silander & Klepeis, 1999). Others suggest that spring is in fact not the best time to apply herbicide because sap is flowing upward while leaves are emerging (MNFI, 2012).

If herbicide application during spring is not possible, then *Berberis* plants can be sprayed before the maturation of their fruits and seeds and subsequent fall in autumn (D' Appollonio, 1997).

The methods of chemical control are as follows: In areas where desirable grasses occur it is suggested that a foliar spray of 2% Triclopyr with 0.5% non-ionic surfactant be used, otherwise the same concentrations of glyphosate (Glyphosate Roundup) and surfactant can be used and applied before indigenous species have started to leaf out (D' Appollonio, 1997; Silander & Klepeis, 1999; TN-EPPC, 2009; Rhoads & Block, 2011; Speith, 2012). In the case of foliar spray application, the air temperature should be above 18.3˚C and a coarse spray pattern with low pressure should be used to reduce spray drift (TN-EPPC, 2009). When applying herbicide where the target species occurs in or close to a wetland, then the amine formulation of Triclopyr (for e.g. Garlon 3A®) can be used (MNFI, 2012).

The advantages of using glyphosate is that it quickly degrades to non-toxic materials in the span of a few days and it can be 100% successful if applied in early spring when *Berberis* is one of the few plants that have started to leaf out (Silander & Klepeis, 1999). Pilot tests showed that glyphosate treatment had no observable negative effects on other species that were present and also demonstrated its efficacy both in terms of spot- and broadcast treatments (Silander & Klepeis, 1999). However, glyphosate should be used with care since it is a non-selective herbicide that kills any plant that is green and actively growing and can thus pose a major threat to native plants if not applied properly (Silander & Klepeis, 1999)

In addition to abovementioned methods a cut-stump treatment can be used if foliar application is not possible or populations are still small, where a 25% solution of either glyphosate or Triclopyr is applied to cut stumps at any time except when the ground is frozen (D' Appollonio, 1997; TN-EPPC, 2009; Rhoads & Block, 2011; Speith, 2012). In the cut-stump method barberry stems should be horizontally cut at or near the ground level with herbicide immediately applied afterwards, covering the outer 20% of the stump (TN-EPPC, 2009). It is important to note that these recommendations are based on cold Northern Hemisphere climates. The case with regards to the climate of South Africa is not known since no study has been conducted up to date regarding chemical methods of control on *Berberis* in South Africa and it can only be assumed that such treatments as described above will also be effective.

In the end it is essential that the entire root system of a *Berberis* plant be killed, otherwise it will only resprout and continue to spread vegetatively (D' Appollonio, 1997).

2.3. Assessing the risk of introduced species

The economic losses/costs incurred due to IAPs (Pimentel *et al.*, 2000, 2001; De Lange & Van Wilgen, 2010) have prompted methods to be developed that assess the risk that potential new IAPs pose to introduced regions (Tucker & Richardson, 1995; Pheloung *et al.*, 1999).

The goal of risk assessment is to calculate the likelihood of a specific consequence or hazard and as such requires a clear definition of the hazard (Hulme, 2012). The three broad approaches used in weed risk assessment are quantitative statistical models (Richardson & Rejmánek *et al.*, 2004), semi-quantitative scoring (Pheloung *et al.*, 1999; Williams & Newfield, 2002) and qualitative expert assessment (Hulme, 2012). The assessment itself can be conducted as pre- or post-border screening, i.e. on proposed new plant introductions or on existing naturalized species, respectively (Hulme, 2012). Some argue that weed risk assessments are little more than considering prior invasion history and degree of climate match (Hulme, 2012), but if used in conjunction with other techniques they can provide a valuable basis for decision making (Keller *et al.*, 2007). Environmental suitability and history of invasion are well tested criteria for predicting the invasiveness of species (Faulkner *et al.*, 2014).

The Australian Weed Risk Assessment (WRA) is a protocol that was developed for the screening of potential new invaders in Australia, and if found to be a threat, preventing their importation (Pheloung *et al.*, 1999). It can be classified as a semi-quantitative scoring model (Hulme, 2012). The WRA was developed by having experts assess 370 taxa in Australia for weediness, representing both weeds and useful taxa from agriculture, the environment and other sectors (Pheloung *et al.*, 1999). The basis for the WRA is the answers to 49 questions concerning various attributes and impacts of weeds, and the assigning of weighted scores to these answers and their summation to obtain a final score. This final score is then used to determine whether the taxon in question should be accepted or rejected for importation or whether it needs further evaluation (Pheloung *et al.*, 1999).

The use of this screening system can have significant benefits. For example, Keller *et al.* (2007) determined that its implementation could save Australia up to $1.8 billion (Australian) over 50 years. The method has also been shown to perform consistently well (high accuracy) over a range of geographies (Gordon *et al.*, 2008; Gordon *et al.*, 2010). This method has already found application in terms of a South African context (Zenni *et al.*, 2009; Kaplan *et al.*, 2012; Geerts *et al.*, 2013; Jacobs *et al.*, 2014). The aim of its use in this study is to give a semi-quantitative assessment on the selected *Berberis* spp. as to the potential risk that they pose. This is based on the final assessment score. If this score indicates rejection, meaning that the species in question would have failed a pre-border screening and would thus not have been accepted to enter the country if was not already present, then it would serve as basis for justifying that the species is a potential hazard for agriculture and/or the environment.

2.4. Predicting potential spread of emergent invasive species

Various environmental factors play a role in determining the geographical distribution of a plant species. These include, but are not limited to, temperature, precipitation, soil type and altitude, and their relative contributions differ for different species. The environmental requirements of a species can be reasonably deduced from the observed distribution of such a species (Pearson, 2007). Although species are likely to respond to multiple environmental factors, climatic suitability (which is based on temperature and precipitation) forms a key part of a species' native distribution range and can therefore also be used to determine in part where a species will be able to invade once introduced into a new region (Wiens & Graham, 2005).

Climatic envelope models (CEMs), also known as "bioclimatic envelope models", "ecological niche models", "habitat suitability models" or "species distribution models", make use of associations between climatic characteristics and known species distributions to produce sets of conditions under which viable populations are likely to be maintained (Rouget *et al.*, 2004; Thuiller *et al.*, 2005; Pearson, 2007; Araújo & Peterson, 2012). These sets of conditions are then used to generate potential species distribution maps, i.e. the full possible range which a species can occupy (Rouget *et al.*, 2004). CEMs constitute a subset of species distribution models (Watling *et al.*, 2012) since they only make use of climate data.

In this thesis I have opted for the name of Habitat Suitability Models (HSMs) for the actual products of the modelling process, whereas bioclimatic modelling refers to the process itself. The reasoning for this has the following logic: since the species under consideration (i.e. *Berberis* spp.) are not part of the natural South African landscape and are not currently known to be widely naturalized within South Africa it would not be sensible to refer to 'possible species distributions'; it would make more sense to use the latter term for the case where a species is known to occupy a large area and the model aims to extend the known distribution range (to 'fill in the gaps'). Rather, the possible habitable ranges (via suitable environmental factors) are being modelled (Pearson, 2007) and therefore it makes more sense to refer to the end products as habitat suitability models. In other words, the end product is not intended to represent a possible species distribution (at least in terms of present day status), but to represent a range that could be inhabitable by the species and thus potentially open to invasion.

Uses of HSMs include identifying species diversity hotspots (Platts *et al.*, 2010), estimating potential current ranges of invasive species (Rouget *et al.*, 2004), identifying sites for species reintroductions (Peterson, 2006), conservation planning and reserve design (Peterson, 2006) and forecasting the effects of climate change on biodiversity (Hijmans & Graham, 2006; La Sorte & Jetz, 2012). For predicting future potential ranges models are first calibrated according to contemporary climate conditions and then projected for future climates, with the assumption that present relationships hold for future conditions (Watling *et al.*, 2012).

Specifically, the use of HSMs is particularly useful for predicting future distribution ranges of IAPs (Duursma *et al.*, 2013). For example, Rouget *et al.* (2004) demonstrated through HSMs that invasive species with the greatest potential to increase in distribution range were not those previously identified by experts as important invaders (Robertson *et al.*, 2004). Such HSMs can therefore greatly aid in determining which species should receive high priority for monitoring and/or control. This can also be linked to the potential costs that would be associated with eradicating or managing the species should it start invading. With regards to emergent invasive species HSMs are an invaluable tool for justifying early control of the species.

A distinction is made between potential and realized distributions: potential distributions represent areas where a species can potentially exist while realized distributions represent areas where a species actually exist (Pearson, 2007; Jiménez-Valverde *et al.*, 2008). Species can be excluded from suitable habitats due to various abiotic (e.g. limited dispersal) and biotic (e.g. predation, competition, parasitism etc.) factors (Pearson, 2007; Broennimann & Guisan, 2008). Potential and realized distributions vary with time and should refer to a discrete period (usually present time) (Jiménez-Valverde *et al.*, 2008).

The modelling process works by establishing a species' distribution range in environmental space and then projecting it back into geographical space (Figure 2.11) (Elith *et al.*, 2006; Pearson *et al.*, 2007). This is based on the concepts of a species' fundamental niche (the full set of environmental factors that enable the existence and persistence of a species) and occupied niche (the portion of the fundamental niche that a species actually occupies due to various constraints) (Pearson *et al.*, 2007). The modelling algorithm uses environmental conditions at observed localities to determine suitable conditions under which the species can exist. Using such conditions the model then predicts all the potential localities where the species can exist. This includes areas where a species occurs but where it has not yet been detected (Figure 2.11 area 2) and areas where the species does not occur but where it can potentially exist (Figure 2.11 area 3).

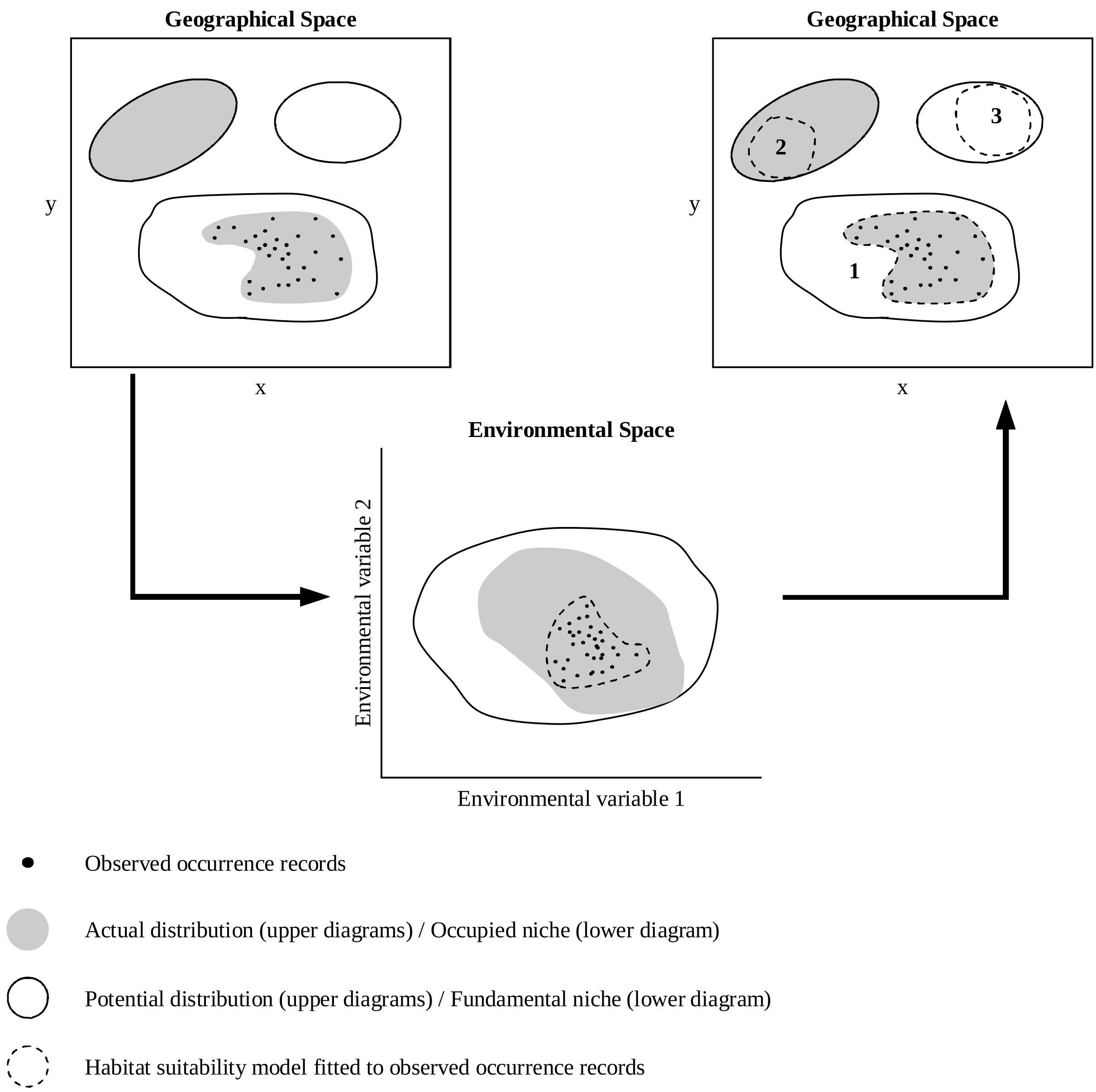


Figure 2.11: The process of habitat suitability modelling. The modelling algorithm uses observed occurrence records in geographical space together with environmental variables to establish a species' niche in environmental space (for simplicity only two environmental variables are shown). Once the model has been trained it is projected back into geographical space where it then predicts (1) the observed distribution range, (2) part of the actual distribution range that has not yet been sampled and (3) part of the potential distribution range. ***(redrawn and adapted from Pearson et al., 2007)***

Based on the modelling process itself one of the major limitations of HSMs is the assumption that a species is at equilibrium with the environment, i.e. it occurs in all suitable environments (Rouget *et al.*, 2004; Pearson, 2007; Watling *et al.*, 2012). This is rarely, if ever, the case. The current distribution of a species does not always provide a good indication of its potential range, but unfortunately HSMs assume that it does and this can affect the accuracy of the model (Rouget *et al.*, 2004). Another factor influencing modelling results concerns environmental space and the degree to which occurrence records provide a representative sample of this (Pearson, 2007). If few occurrence records are available they are unlikely to represent the full range of environmental conditions occupied by the species under consideration (Pearson, 2007). These limited occurrences might result from limited survey effort (Martínez-Meyer *et al.*, 2004) or low probability of detection (Pearson *et al.*, 2007). Biased sampling (e.g. sampling only in easily accessible places) can also affect the degree to which occurrence records represent the environmental space of a species. Different modelling algorithms can influence the outcomes of the modelling process depending on sample size (Stockwell & Peterson, 2002) and thus consideration should be given as to which algorithm is used. In this regard the modelling algorithm MaxEnt (Phillips & Dudík, 2008) has been shown to have a consistently high performance when compared to others (Elith *et al.*, 2006; Hijmans & Graham, 2006; VanDerWal *et al.*, 2009; Duursma *et al.*, 2013).

Once HSMs have been developed it is necessary to test or evaluate them in order to determine the relative accuracy at which they are predicting (Watling *et al.*, 2012). Evaluation metrics for these models fall into one of two categories, namely threshold dependent and threshold independent (Watling *et al.*, 2012). The outputs of HSMs can be considered as estimates of climate suitability (or probabilities of presence if potential distribution is being modelled) and range from 0 to 1 on a continuous scale (0 being highly unsuitable/improbable and 1 being highly suitable/probable) (Pearson *et al.*, 2007; Freeman & Moisen, 2008; Watling *et al.*, 2012). Thus, threshold independent metrics evaluate performance/accuracy exclusively on the output probabilities, whereas threshold dependent metrics require the user to first convert probabilities into a binary outcome (i.e. suitable/present or unsuitable/not present) and then evaluates the model according to the binary predictions (Freeman & Moisen, 2008; Watling *et al.*, 2012).

One of the most widely used evaluation metrics is the Area Under the Receiver Operating Characteristic Curve, or AUC in short (Elith *et al.*, 2006; Pearson, 2007; Lobo *et al.*, 2008; Watling *et al.*, 2012). This evaluation metric is threshold-independent (Lobo *et al.*, 2008) and assesses the rate of correct classification of presence points by the model (Duursma *et al.*, 2013). Receiver operating curves (ROC) plot the true positive rate against the false positive rate as the threshold varies from 0 to 1 (Freeman & Moisen, 2008). Thus, in a good model the true positive rate will be high while the false positive rate is still small (Freeman & Moisen, 2008), thereby accurately discriminating between locations where the species is present or absent (Pearson *et al.*, 2007). As such, the area under the ROC (i.e. the AUC) in a perfectly predicting model will be 1. When background points are used, instead of true absences (as is the case with MaxEnt [Phillips & Dudík, 2008]), the AUC can approach but not reach a value of 1 (Duursma *et al.*, 2013). An AUC value of more than 0.75 is thought to indicate that the model has a useful level of discrimination (Elith *et al.*, 2006), while a value of 0.5 means that the model is no better than random chance prediction (Pearson *et al.*, 2007). ROC plots allow the comparison of models' discriminatory abilities across species and localities (Freeman & Moisen, 2008).

The AUC statistic has however come under scrutiny for several reasons (Lobo *et al.*, 2008), of which two are important here. Firstly, it is sensitive to the spatial extent from which background data is obtained (VanDerWal *et al.*, 2009), thus the AUC value can increase simply by expanding the geographical extent of the region being modelled. Also, predictive models will have a poor ability of establishing the fine scale conditions that are actually responsible for limiting species distributions if pseudo-absences are geographically disparate from presence localities (VanDerWal *et al.*, 2009). Instead, model parameters will only discriminate between regional conditions (VanDerWal *et al.*, 2009). One way to address the first problem is to use Köppen-Geiger climate zones to objectively define the region from which background data is to be drawn (Moodley *et al.*, 2014). Secondly, the AUC weights commission and omission errors equally (false-presences and false-absences, respectively) and is of special concern when background data is used for pseudo-absences because it inflates the number of false absences.

Despite some of its drawbacks the AUC still continues to find widespread use (Zenni *et al.*, 2009; Kaplan *et al.*, 2012; Duursma *et al.*, 2013; Geerts *et al.*, 2013; Jacobs *et al.*, 2014; Moodley *et al.*, 2014) and still remains a useful evaluation metric when its limitations are taken into consideration and amended appropriately. In fact, some workers believe that ROC plots with their associated AUC values are "one of the most powerful techniques for evaluating the discriminatory ability" of models (Freeman & Moisen, 2008). Others that have realized the drawbacks of AUC (Duursma *et al.*, 2013) have started to report the AUC in conjunction with other evaluation metrics, e.g. the threshold-dependent binomial test of omission.

Chapter 3: Study Areas

There were two main areas of study in this project, one of which was located in the Golden Gate Highlands National Park (Free State Province) and the other in the Woodbush State Forest (Limpopo Province).

3.1. Golden Gate Highlands National Park

3.1.1. Location

The Golden Gate Highlands National Park (GGHNP) is situated in the eastern Free State Province close to the northern border of Lesotho and the north-western border of the KwaZulu-Natal Province (Figure 3.1). This national park was proclaimed on 13 September 1963 (SANParks, 2013) and constitutes the upper catchment of the little Caledon River (Roberts, 1969). The current extent of the park is approximately 32 750 ha and includes the old QwaQwa National Park, with the highest point in the park being 2 829 m at Ribbokkop (SANParks, 2013). The largest plant family in the park is the Poaceae (grasses) (SANParks, 2013) and as such it is the only South African national park that officially conserves grassland as the major vegetation type.

The park forms part of the Maloti Drakensberg Transfrontier Conservation Area which constitutes a 700 km long alpine and montane region of international significance (SANParks, 2013). The park also forms part of the most important water catchment in South Africa, namely the Maloti Drakensberg Catchment Complex (SANParks, 2013).

The first area of interest, in terms of *Berberis* invasion, is the Glen Reenen Rest Camp which is situated on the western side of the park close to the Golden Gate hotel. It consists of a few admin offices, a curio shop and 31 accommodation units (SANParks, 2013) together with a camping site. The Little Caledon River flows past the north-eastern side of the rest camp and also marks the north-eastern border of the camping area. The second area of interest is the Alma Ranger Station. It is situated more to the eastern side of the park and consists of a house where the senior section ranger lives together with a few offices. A small seasonal stream flows down from the mountain to the north-east of the ranger station. Both sites are indicated by Figure 3.1.

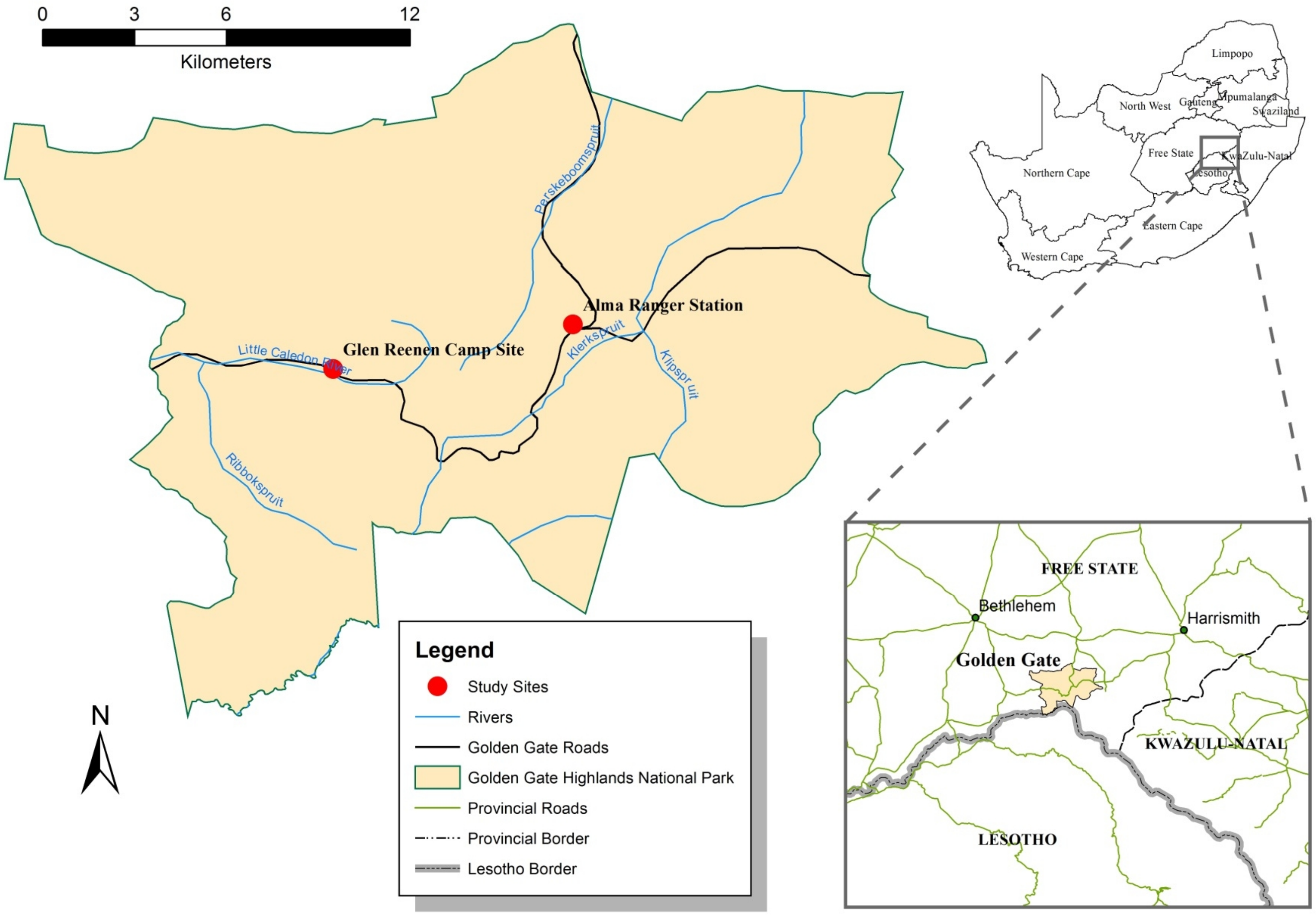


Figure 3.1: The Glen Reenen and Alma study sites are located within the Golden Gate Highlands National Park. The park is situated in the eastern Free State close to the borders of KwaZulu-Natal and Lesotho. (Note: the scale bar is to be used with the main map)

3.1.2. Vegetation

The GGHNP occurs in the Drakensberg Grassland Bioregion and is comprised of the following vegetation types (together with their vegetation codes) according to Mucina & Rutherford (2011):

Drakensberg Wetlands (AZf 4)

This is an azonal vegetation type. Tall herb and shrubby vegetation of medium height occur along fringes of mountain streams with the frequent occurrence of terrestrial orchids and characteristic *Kniphofia* spp. and *Geranium* spp. Some of the fast-flowing streams in this vegetation type can suffer from extensive erosion and the soils have a high clay content, often with a high humus content as well. Maximum precipitation occurs in December to February. Stream flow can be highly affected by sudden melting of snow cover on the surrounding grasslands, causing erosion of river channels. The geology consists of Jurassic basalts and dolerites of the Drakensberg Group and also sandstones and mudstones of the Clarens and Elliot Formations (Karoo Supergroup).

Northern Drakensberg Highland Grassland (Gd5)

A mountainous region that is characterised by steep slopes of broad valleys which predominantly supports short, sour grasslands that are rich in forbs. Widely scattered trees of *Protea roupelliae* and *P. caffra*, constituting so-called “Protea savannas”, are present in this unit. Numerous special plant communities thrive in a large number of habitats created by sandstone cliffs, a major characteristic feature of the landscape which often provides protection from fire. The geology consists of mudstone and sandstone of the Elliot Formation and sandstone from the Clarens Formation (Stormberg Group, Karoo Supergroup). Soils are typically of the Fc landtype (dominant) as well as Ac and Bb. The climate constitutes a summer-rainfall region with occasional snowfalls that can last for several days. Summer mists are frequent, together with hot dry winds that occur from July to October. Summers are warm and winters very cold with severe frost events occurring regularly.

Drakensberg-Amathole Afromontane Fynbos (Gd6)

The landscape consists of steep valleys and escarpment slopes at the starting point of rivers with associated stream gullies and depressions. The vegetation consists mainly of evergreen shrublands that are 1 – 3 m tall, with numerous shrubs having ericoid leaves. The most prominent parts of this shrubland include genera such as *Passerina*, *Cliffortia*, *Erica*, *Euryops*, *Helichrysum*, *Macowania*, *Protea*, *Widdringtonia* and *Ischyrolepis*. The geology consists of Jurassic basalts (Drakensberg Group) and an array of Karoo Supergroup sedimentary rocks (mainly of the Clarens Formation of the Stormberg Group). Soils have varying depth and nutrient status with the dominant land type being Ac, followed by Fa and Ad. The climate is that of a summer-rainfall region with occasional snowfalls and frequent summer mist. Even though the overall regional mean annual temperature (MAT) is only 12.2 °C, summer days can be relatively hot and the occurrence of frost in winter is frequent (more than 40 days). Hot and dry winds are a common incidence from July to October.

Lesotho Highland Basalt Grassland (Gd8)

A terrain consisting of numerous plateaus and high ridges of mountains that are often separated by very deep valleys. The vegetation is comprised of closed, short grassland communities with many areas being dominated by *Passerina montana*. Smaller shrubs such as *Chrysocoma ciliata* and *Pentzia cooperi* are often very common in disturbed areas. The unit spans a broad altitude range where a number of species extend to various altitudinal levels or belts. *Themeda triandra* has a tendency for being more important in terms of dominance at lower and middle elevations, with *Festuca caprina* being more important at higher altitudes. The medium tall grass *Merxmuellera macowanii* is found alongside water courses and drainage lines. The area covered by the unit is more or less entirely underlain by basaltic lava flows of the Drakensberg Group. The soils that are derived from the basalt have relatively even proportions of coarse sand, fine sand, silt, clay and organic matter. Organic matter content can range from about 20% on slopes to about 26% in valleys. A high water-retention capacity of the soil results from the high organic content (which is an acidic, slowly decomposing humus that is formed mainly by decaying grass roots). The main land type is Ea. Climate here comprises a summer-rainfall region with very little rain in the winter. The occurrence of frost lasts throughout the winter and even occurs on occasion in summer at higher altitudes. Hail is common in summer together with a high occurrence of lightning.

3.1.3. Rainfall and temperature

Rainfall and temperature data for the respective vegetation units, in the form of mean annual precipitation (MAP), mean frost days (MFD; days when screen temperature was below 0 °C), mean annual temperature (MAP) and minimum and maximum temperatures, are given by Table 3.1.

Table 3.1: Rainfall and temperature data for the respective vegetation units covered in the Golden Gate Highlands National Park study area. Refer to text for details on abbreviations. *(from Mucina & Rutherford, 2011)*

Vegetation Type	MAP (mm)	MFD (days)	MAT (°C)	Temperature (°C)	
				Min.	Max.
AZf 4	739	103	9.7	-3	20
Gd 5	1017	41	13.4	0	24
Gd 6	1167	41	12.2	0	23
Gd 8	707	96	9.6	-4	20

3.2. Woodbush State Forest

3.2.1. Location

The Woodbush State Forest (WSF) is situated approximately 15 km west of Tzaneen in the Limpopo Province (Figure 3.2; the figure indicates only the section that occurs north of the R71 road). It is one of 18 plantations managed by Komatiland Forests (KlF), their main silvicultural focus being on growing mostly *Pinus* spp., *Eucalyptus* spp. and *Acacia* spp. for the sawing industry (KlF, 2008). The plantations of KlF are spread across Mpumalanga, KwaZulu-Natal and Limpopo provinces. WSF itself consists of a mixture of plantation and protected natural forests. It offers various hiking trails and backpacker cottages to the public together with picnic and camping areas.

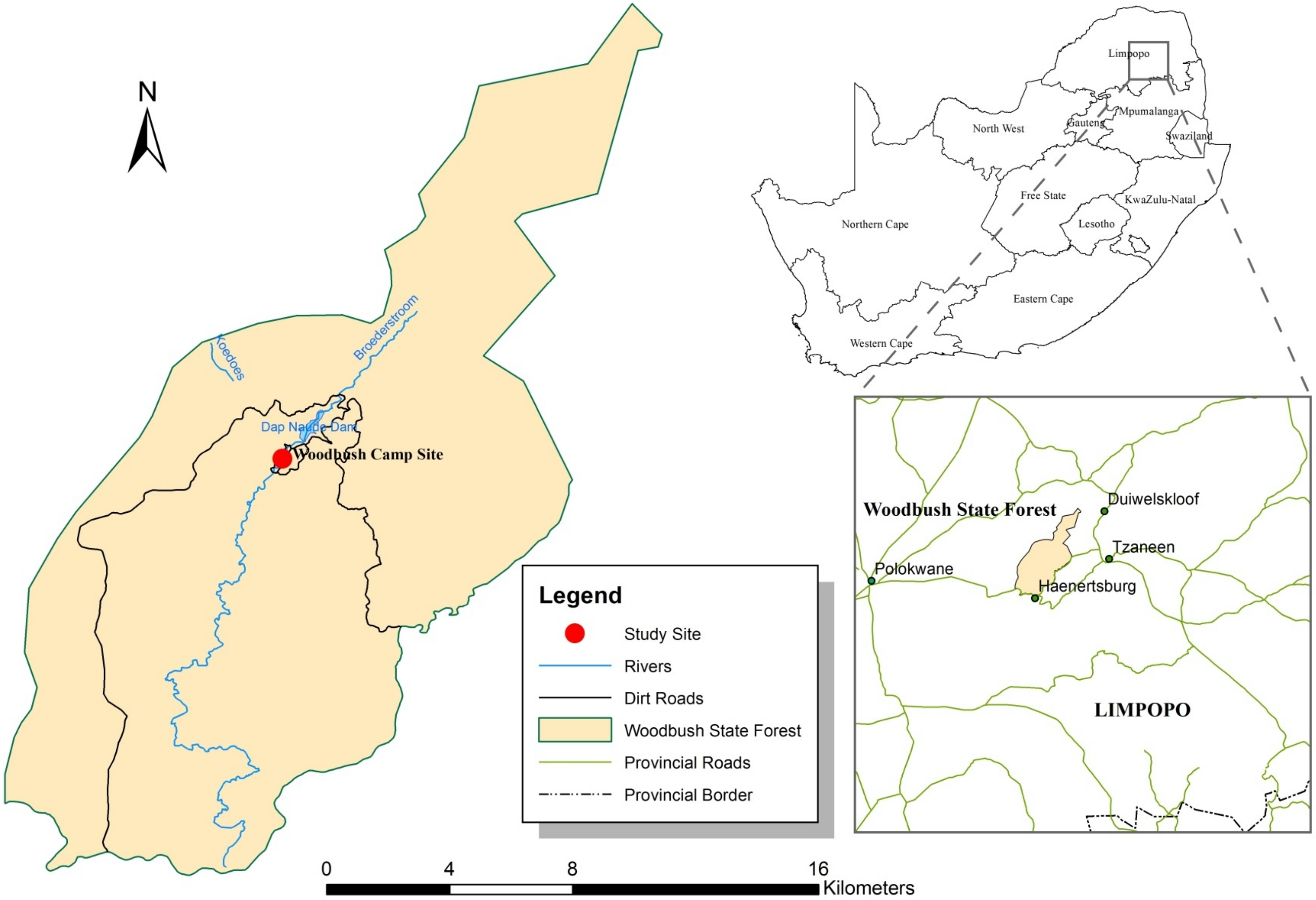


Figure 3.2: The Woodbush camp site study area is situated in the Woodbush State Forest, approximately 15 km west of Tzaneen, Limpopo Province. The map indicates only the section that occurs north of the R71 road. (Note: the scale bar is to be used with the main map)

3.2.2. Vegetation

The Woodbush State Forest occurs in a mixture of two bioregions, namely Mesic Highveld Grassland and Lowveld, and the Northern Mistbelt Forest vegetation type. The study area is comprised of the following vegetation types (and vegetation codes) according to Mucina & Rutherford (2011):

Northern Mistbelt Forest (FOz 4)

Vegetation type occurring mostly in east-facing fire refugia (e.g. sheltered kloofs) and consisting of tall, evergreen afrotemperate mistbelt forests. This vegetation type characteristically forms fragmented patches. The main soil forms are of Avalon and Hutton and are highly weathered and clayey, derived from shales, quartzite, dolomite, granite and diabase from the Pretoria Group, Black Reef Formation, Chuniespoort Group, Nelspruit Basement and Mokolian intrusives, respectively. The majority of the vegetation type occurs between an altitude of 1 050 – 1 650 m and has a high incidence of rain (mean annual precipitation of 1 084 mm) and no frost. These forests usually have a high species richness owing to the fact that they contain a mixture of afromontane and subtropical elements. A few alien species of local concern include *Solanum mauritianum*, *Caesalpinia decapetala*, *Acacia mearnsii* and *Lantana camara*.

Woodbush Granite Grassland (Gm 25)

A grassland vegetation type that occurs on mountainous plateaus and having an increased low-shrub density on steep south- and east-facing slopes; occurring at an altitudinal range of 1 080 – 1 800 mm. The dominant land type is Ab with Hutton soils and the geology consists of Archaean granite, gneiss and greenstone basement with sporadic dolerite dykes and quartz veins. Some rainfall may occur in winter, but the unit receives summer rain with a MAP ranging from 700 mm in the east to 1 500 mm in the west. Due to an orographic effect on the escarpment, mist is a common feature. Frost is an infrequent feature of this vegetation type. This is a critically endangered unit and there are currently no conservation areas protecting any patches of it. The biggest threat to this unit is silviculture and to a lesser extent cultivation and urban development. Bush encroachment can become problematic and is exacerbated by the exclusion of fire. The unit is also threatened by alien taxa such as *Acacia mearnsii*, *A. dealbata*, *Prunus serotina*, *Lilium formosanum*, *Agrimonia procera*, *Solanum mauritianum* and *Acanthospermum australe*.

Mamabolo Mountain Bushveld (SVcb 24)

Landscape consisting of low mountains and rocky hills with moderate to steep slopes, covered by small trees and shrubs and occurring at an altitude of 1 200 – 1 600 m. Xerophytic and succulent species occur on sparsely vegetated rock slabs or domes. The geology consists mostly of basement granite and gneiss, clastic sediments of the Pretoria Group (Vaalian) and ultramafic and mafic metavolcanics of the Pietersburg Group (Swazian). The dominant land types are Ib and Fa with shallow and skeletal soils, including Mispah and Glenrosa soil forms. Frost occurs somewhat infrequently and the MAP is about 450 – 750 mm. Erosion is high in some areas. This unit has the coolest mean annual temperature of all the savanna units, excluding the three mountain bushveld units of the Highveld.

Tzaneen Sour Bushveld (SVl 8)

A vegetation type occurring at an altitude of 600 – 1 000 m and consisting of deciduous, tall open bushveld with a well-developed, tall grass layer. The unit occurs on low to high mountains and undulating plains on the lower to middle slopes and base of the north-eastern escarpment. The geology consists of potassium-poor gneisses of the Goudplaats gneiss (Swazian Erathem) with an Archaean granite dyke underlying most of the area and occasional presence of shales and quartzite of the Wolkberg Group. The land types include Fa, Ab, Ae and Ia with soils of the Mispah, Glenrosa and Hutton forms ranging from shallow to deep and sandy to gravelly. Winters are dry and summer rainfall occurs with a MAP ranging from 550 mm on the footslopes of the escarpment in the east to 1 000 mm to the west where it borders on grassland at higher altitudes. Occasional frost occurs at higher altitudes. This unit is endangered with only about 1% statutorily and 2% privately conserved. Afforestation plays a major role in the higher-lying parts of this unit while the lower-lying parts are under agricultural and horticultural crops. The spread of alien species such as *Chromolaena odorata*, *Lantana camara* and *Psidium guajava* is encouraged by the subtropical climate of this unit.

3.2.3. Rainfall and temperature

Rainfall and temperature data for the respective vegetation units, in the form of mean annual precipitation (MAP), mean frost days (MFD; days when screen temperature was below 0 °C), mean annual temperature (MAP) and minimum and maximum temperatures, are given by

Table 3.2. The WSF itself has received a total rainfall in mm of between 1 568 and 2 522 per year for the past five years (figures courtesy of Paul Mostert, Plantation Manager).

Table 3.2: Rainfall and temperature data for the respective vegetation units covered in the Woodbush State Forest study area. Refer to text for details on abbreviations. ***(from Mucina & Rutherford, 2011)***

Vegetation Type	MAP (mm)	MFD (days)	MAT (°C)	Temperature (°C)	
				Min.	Max.
FOz 4	863	-	16.7	5	29
Gm 25	1166	7	16.6	5	25
SVcb 24	655	8	16.7	4	27
SVl 8	781	1	19.7	7	29

Chapter 4: Materials and Methods

The aim of this chapter is to give details about the methodology that was used during this study. All methods and equipment that were used are indicated here.

4.1. Population surveys

Three types of surveys can be conducted for the early detection of new invasive species, namely general/random surveys, site-specific surveys and species- or genus-specific surveys (Wittenberg & Cock, 2001). The surveys conducted in this study were genus-specific, since the target species were any *Berberis* spp. and thus generic. In other words, the surveys were directed at finding only *Berberis* spp. irrespective of site.

Localities were collated from the SAPIA database (South African Plant Invaders Atlas) (May 2013), SANBI personnel and by the physical (in the form of pamphlets) and electronic distribution of awareness material (see Appendix C). Due to the relatively small sizes of the populations at GGHNP it was not necessary to conduct a systematic survey, as described by Cacho *et al.* (2006). Instead areas were surveyed using a random survey technique extending beyond 50 to 100 m of the most isolated plant (as per Geerts *et al.*, 2013). The geographic position of each plant was marked using a hand-held Global Positioning System (GPS Garmin® GPSmap 62, maximum resolution of 5 m). Area calculations were done in ArcMAP 10.2 with mimum convex hulls.

4.2. Population characteristics and reproductive size

Measurements for *Berberis* populations were made in the form of plant height, perpendicular canopy diameters and presence/absence of flowers and/or fruits. The latter measurement was used as a proxy for reproductive maturity (Geerts *et al.*, 2013). Unlike other studies (Geerts *et al.*, 2013), basal stem circumference was not measured due to the multi-stemmed nature of the species that were found during this study (i.e. *B. julianae* and *B. aristata*). Homogenous and representative subsamples of the populations were chosen for the measurements.

Frequency distribution curves of height and canopy size were drawn to visualize the physical structure of the populations. All the above mentioned measurements were used to determine size of species at reproductive maturity. The significance of plant measurements in predicting the reproductive maturity was assessed using a generalised linear model, with a binomial error distribution, with signs of reproduction (0/1) as the response variable and height and mean canopy diameter as predictor variables as per Geerts *et al.* (2013). Log regressions were also tested for both measurements. Analysis was conducted in R (R Development Core Team, 2012) with the package boot (for frequency distribution curves) and package bbmle (for reproductive size regression curves).

4.3. Nursery and herbarium Survey

In order to establish which *Berberis* spp. are currently cultivated in South Africa, a national survey (excluding the Northern Cape) was conducted by contacting nurseries via phone/email or personal visit to find out which species/cultivars they stock. These included both regional stockists and wholesale growers. Together with this a herbarium survey was conducted to establish which species have been recorded as present in the country.

The data from the nursery and herbarium surveys was used to generate a comprehensive list of all the possible *Berberis* spp. that are and were at some or the other time present in South Africa. Analysis of the results was conducted in R (R Development Core Team, 2012) with the package ggplot2.

4.4. Seed viability tests

Ripe fruits of *Berberis julianae* were collected during the period of 21 to 24 March 2013. Fruits of *B. aristata* were collected during the period of 6 to 11 April 2014. Seeds of *Berberis* are reported to require alternating temperatures in order to germinate (Morinaga, 1926; Davis, 1927). Seeds were removed from the fruits and cleaned by washing in running water after which they were dried on towel paper. The seed were left to dry out for a period of approximately four weeks. According to Davis (1927) seeds that are protected from frost but still exposed to the fluctuating temperatures of spring can reach a germination success of between 60% and 70%. Thus, an alternating temperature scheme was used whereby seeds were exposed to 22˚C for 6 hours and 10˚C for 18 hours (Morinaga, 1926) in Labcon germination cabinets with no scarification. A control treatment consisted of a constant temperature of 22˚C. Both experimental and control treatment seeds were treated with a topical fungicide (copper oxychloride, 0.6 g per 500 mL water). Seed viability itself was quantified as the percentage of seeds that germinated (when the emerging seed radicle was visible) per sample. The treatments for both species were the same.

4.5. Weed risk assessment

Weed risk assessment systems are a valuable aid for decision making and assessing potential invasiveness (Keller *et al.*, 2007). The Australian Weed Risks Assessment method (AWRA) (Pheloung *et al.*, 1999) was used in this study, which consists of a series of questions (agricultural, environmental and combined) with yes/no answers (with a few exceptions). The invasiveness of a species is evaluated based on 49 questions that concern the species' biogeographical, biological and ecological characteristics together with invasive traits and history (Pheloung *et al.*, 1999). Scores are given for each answer and all values are summed to yield an overall score. The overall score is assessed as follows: higher than six results in rejection, less than one results in acceptance and anything in between requires that the species be evaluated further. The AWRA was originally designed as a pre-border screening system but has consequently been extensively used to assess the invasion risk of introduced species (Zenni *et al.*, 2009; Kaplan *et al.*, 2012; Geerts *et al.*, 2013; Jacobs *et al.*, 2014).

An assessment was conducted for *Berberis aristata* and *B. julianae*. The minimum required number of questions were answered for each section and a score allocated accordingly. Predictions of the habitat suitability models were used in answering section 2.01 of the assessment (i.e. "is the species suited to South African climates?"). Guidelines for answering the questions for regions of the world outside Australia were applied (Gordon *et al.*, 2010).

4.6. Bioclimatic modelling

4.6.1. Software

The MaxEnt software package (version 3.3.3k) was used for habitat suitability modelling (obtained from Princeton University; http://www.cs.princeton.edu/~schapire/maxent/) (Phillips *et al.*, 2006). MaxEnt predicts potentially suitable areas for species based upon presence-only data (in the form of occurrence records) and environmental variables (Elith *et al.*, 2011). The algorithm itself is based on the concept of maximum entropy (Phillips *et al.*, 2006): it finds the most spread out or uniform probability distribution (i.e. maximum entropy) subject to a set of constraints. Since MaxEnt uses presence-only data it creates pseudo-absences where species have not been recorded (but could be present) from a defined background area (Elith *et al.*, 2011; Merow *et al.*, 2013). This algorithm was chosen because it has been found to consistently perform well compared to other methods and has a high predictive accuracy (Elith *et al.*, 2006; Hijmans & Graham, 2006; Phillips & Dudík, 2008; VanDerWal *et al.*, 2009; Elith *et al.*, 2011; Duursma *et al.*, 2013).

4.6.2. Distribution records

Occurrence data for species was obtained from the Global Information Biodiversity Facility (GBIF), South African Plant Invaders Atlas (SAPIA) and survey data. Localities were also obtained from the Chinese Virtual Herbarium (for *Berberis julianae*) and from Dr. Bhaskar Adhikari (for *B. aristata*). Duplicates and false localities (for example points occurring in the sea or in cities) were removed from the datasets.

Failing to take into account the fact that alien species can occupy different climatic niches when moving into novel environments can lead to an underestimation of potential invasive ranges (Broennimann *et al.*, 2007; Beaumont *et al.*, 2009). For example, biotic constraints in a species' native range (e.g. competitors) can cause it to be excluded from climatically suitable areas which it might potentially occupy if the constraints were to be removed (Broennimann & Guisan, 2008). Specifically, invasive species can occupy new niches that cannot be predicted from its native range alone (Broennimann *et al.*, 2007). Thus it is recommended that occurrence data from the plants' native and introduced range be using modelling habitat suitability (Mau-Crimmins *et al.*, 2006; Broennimann & Guisan, 2008). In fact, models that utilize occurrence data from both native and invasive ranges improve in performance over models based exclusively on native ranges (Broennimann & Guisan, 2008). Therefore, in this study occurrence data was used from species' native ranges together with localities present in South Africa. A total of 22 records were used for *B. julianae* and 59 for *B. aristata*. Based on current data, both species do not have wide distribution ranges in South Africa.

4.6.3. Environmental variables

Environmental data consisted of 2.5 arc-minute resolution grids for current and future conditions (2020), and was obtained from WorldClim (current conditions; http://www.worldclim.org/) (Hijmans *et al.*, 2005) and GCM Data Portal (future conditions; http://www.ccafs-climate.org/). Data sets for future conditions are based on the CSIRO Mk3 Climate System Model (Gordon *et al.*, 2002). Only climatic data was included in the analyses, which consisted of 19 bioclimatic variables that are derived from monthly minimum and maximum temperatures, and monthly precipitation (see Appendix D).

4.6.4. Background selection

MaxEnt requires a defined background region from which to create pseudo-absences (Elith *et al.*, 2011). The extent of the background region relative to the occurrence points can significantly influence the models ability to accurately predict habitat suitability (VanDerWal *et al.*, 2009). Also, evaluation metrics such as the AUC is sensitive to the spatial extent from which background data is obtained (Lobo *et al.*, 2008); careful definition of the background is thus needed. To delineate the boundaries of the background sampling space, the Köppen-Geiger climate classification was used (http://koeppen-geiger.vu-wien.ac.at/). Based on recommendations from Elith *et al.* (2011) the background was restricted to Köppen-Geiger polygons that contained one or more records of the species being modelled. From this a mask variable was created to be used in the modelling process, effectively limiting the region from which background samples can be chosen. A total of 10 000 background points were created by sampling random points within the defined environmental mask.

4.6.5. Modelling technique

The model was run using default parameters of ‘logistic output’, ‘jackknife measures of variable importance’, ‘clamping’ and a regularization value of 1 to reduce over-fitting. A k-fold cross-validation data splitting procedure was used and replicated 5 times. This method partitions all records into a training (calibration) and testing (evaluation) subset in each model (Phillips *et al.*, 2006). The cross-validation technique was used because it makes better use of small sample sizes (Freeman & Moisen, 2008). The ‘random seed’ option was enabled so that different training and testing samples were generated with each replicate. To allow for smoother response curves only ‘hinge features’ were used (Elith *et al.*, 2010; Moodley *et al.*, 2014).

The minimum training presence logistic threshold was used to convert continuous output maps to binary predictions of suitable and unsuitable (Moodley *et al.*, 2014). This threshold describes the lowest probability that is associated with the presence of a species (Pearson *et al.*, 2007). The continuous probability output maps were retained however, since it is recommended that these maps be presented together with binary maps so that the end users can choose their own threshold value depending in the intended map use (Freeman & Moisen, 2008).

4.7. Clearing Trials

No herbicides are currently registered for any species of *Berberis* in South Africa. The Glen Reenen population at GGHNP, namely *B. julianae*, was chosen as the site for performing trail clearing operations in order to establish potential herbicides that can be registered for the control of this species and potentially for others as well. The treatments were conducted in the spring so as to take advantage of the fact that *B. julianae* was in leaf before the majority of other native vegetation. This was to minimize non-target impacts.

The experimental plot layout for the trials is indicated by Figure 4.1. A total of four plots were delineated for use in the trails. Each plot was treated with a different active ingredient or mixture of different active ingredients. Each plot was also divided in half to test two different concentrations of the specific active ingredient(s) designated for the plot, i.e. each plot was subdivided into ‘a’ and ‘b’ rates of the specific chemical. Due to varying width of the area in between the river and the steep riverbank slopes not all plots were of equal area. Plots were delineated so as to include a representative amount of plants in each plot, but some plots were a little overrepresented. The area of each plot was calculated in ArcMAP 10.2.

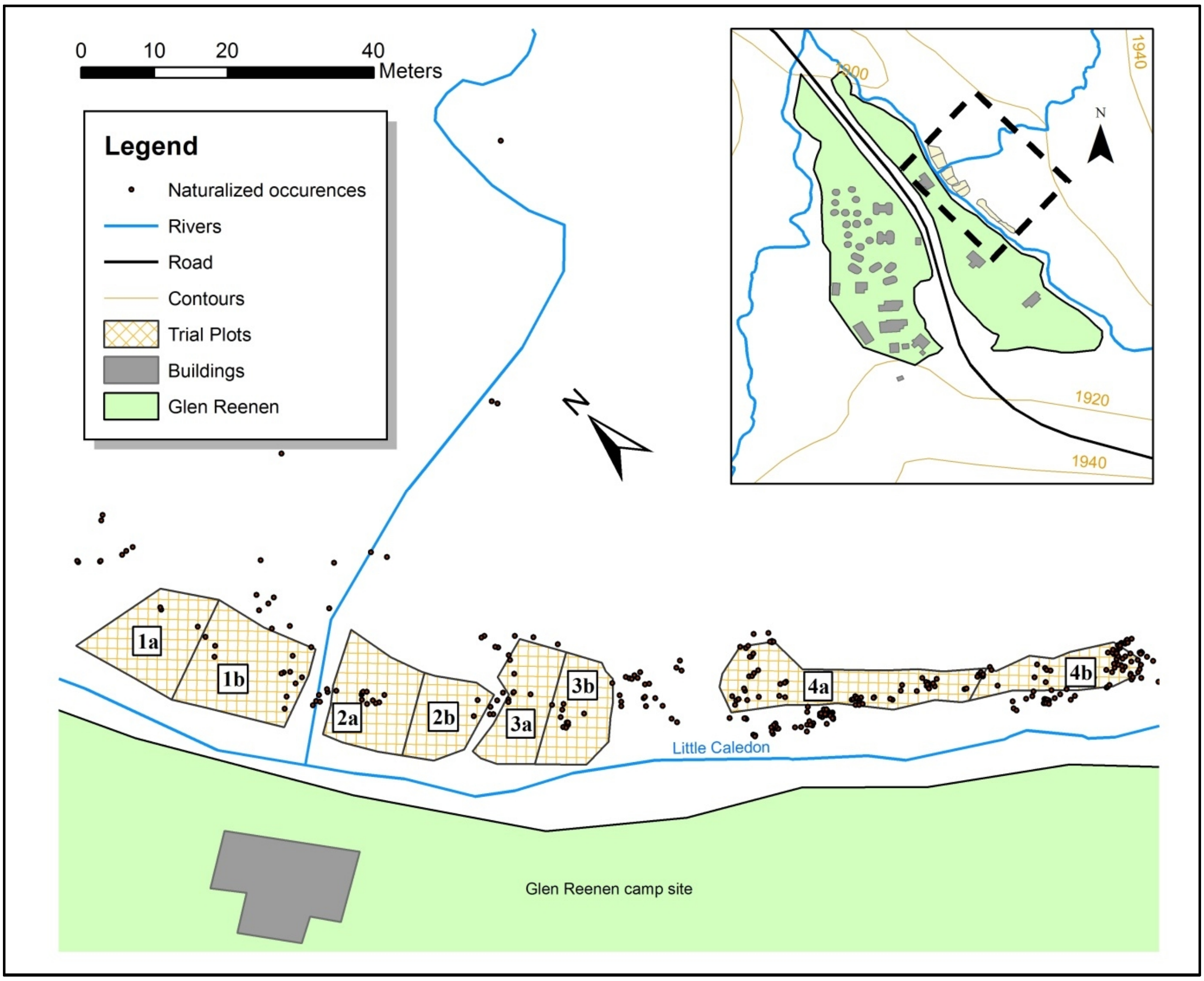


Figure 4.1: The experimental plot layout used during herbicide testing of *Berberis julianae* at GGHNP. Steep slopes and dense vegetation prevented plots from being square. Some occurrences are shown. The inset indicates the position of the trial clearing area in relation to Glen Reenen (compare Figure 5.2 in the results chapter).

The chemicals and concentrations that were used for testing purposes are given by Table 4.1. All herbicides were supplied by Arysta LifeScience. Plot treatments are indicated by Table 4.2.

Table 4.1: Chemicals used during trial clearing of *Berberis julianae* at Golden Gate Highlands National Park.

Product Trade Name	Foliar Treatment Rates	Cut Stump/Treatment Rates
Kaput® 100 Gel	None	1mm layer to freshly cut stump
Forester® 600 WP	25 – 50g/100L water plus 0,5% H&R crop oil or similar	Apply to point of run-off
Astra® 360 SL	350ml – 700ml plus 0,5% H&R crop oil or similar	Apply to point of run-off
Volcano Triclon® 480 EC	500ml – 700ml plus 0,5% H&R crop oil or similar	Apply to point of run-off
AH0914	250ml – 700ml plus 0,5% H&R crop oil or similar	Apply to point of run-off

Table 4.2: Plot treatments of the clearing trials at Golden Gate Highlands National Park.

Plot Number	Product	Active Ingredient	Stock	Concentration used	Plot Size (m^2)
1a	Forester® 600 WP	Metsulfuron-methyl	600g/kg	25g/100L	173
1b	Forester® 600 WP	Metsulfuron-methyl	600g/kg	50g/100L	228
2a	Astra® 360 SL	Triclopyr & Clopyralid	270g/L 90g/L	350mL/100L	171
2b	Astra® 360 SL	Triclopyr & Clopyralid	270g/L 90g/L	700mL/100L	110
3a	Volcano Triclon® 480 EC	Triclopyr	480g/L	500mL/100L	137
3b	Volcano Triclon® 480 EC	Triclopyr	480g/L	700mL/100L	130
4a	AH0914	Under Development	50g/kg	250mL/100L	223
4b	AH0914	Under Development	50g/kg	700mL/100L	114

In addition to foliar spraying, a few plants that were large enough at Glen Reenen were selected for cut-stump treatments. The active ingredient used for the cut-stumping was glyphosate (Kaput® 100 Gel). Plants were cut down to approximately knee height and an even layer of gel was applied to the entire surface of the stumps (Figure 4.2). The application of the gel was done within 10 minutes of cutting down each stump and the stump cleaned of saw dust prior to application. The advantage of the cut-stump technique is that it minimizes non-target damage because it is applied accurately and in a controlled fashion to individual stumps. Together with the plants at Glen Reenen all planted individuals at the Alma Ranger Station were cut down and treated with glyphosate as described above.

Figure 4.2: An example of the cut-stump technique where a *Berberis julianae* shrub was cut down and treated with glyphosate gel.

Chapter 5: Results

5.1. Population Statistics

5.1.1. Locality surveys

A total of five localities were surveyed during this study as indicated by Figure 5.1. Also indicated on the map are the records of *Berberis* in the SAPIA database.

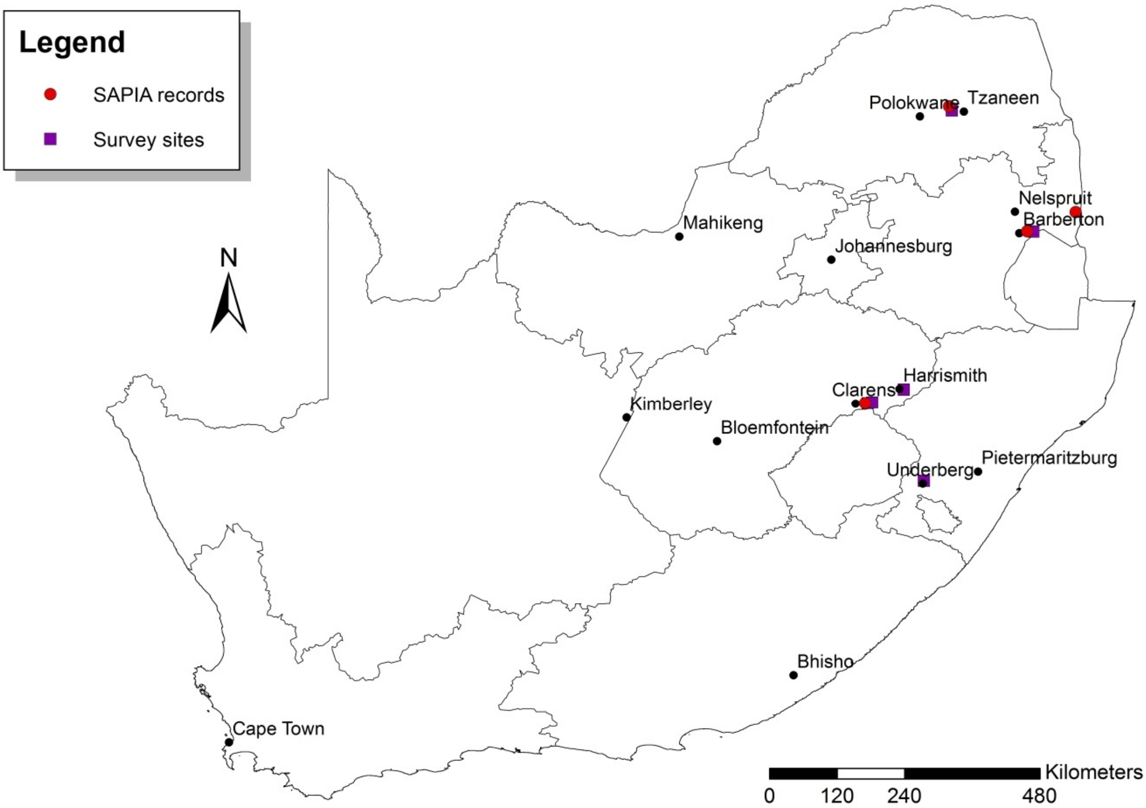


Figure 5.1: Localities that were surveyed during this study.

5.1.1.1. Golden Gate Highlands National Park

A population survey was conducted in the Golden Gate Highlands National Park (eastern Free State) between the 24th and 27th of March 2013. The survey focused on two regions, namely the Glen Reenen rest camp [28.505494°S 28.618410°E] (Figure 5.2) and Alma Ranger Station [28.492569°S 28.689427°E] (Figure 5.3). Refer to Figure 3.1 for the localities of the two sites within the GGHNP as well as the locality of GGHNP within South Africa.

The only species that was found in GGHNP was *Berberis julianae.* At the Glen Reenen site a total of 443 individuals were counted and at the Alma Ranger Station site a total of 30 individuals were counted. The two sites thus yielded a combined total of 473 individuals occupying a total area of 0.42 ha (0.02 condensed canopy ha). There seems to have been a clearing effort in the past at the Glen Reenen rest camp, as evidenced by the presence of some cut down individuals of *B. julianae* next to the Little Caledon River. Many of these have resprouted and there are still numerous specimens, some of which are already reasonably big. Three large specimens were found in between the offices and chalets (Figure 5.2 purple squares) and are suspected to be the original source plants responsible for providing the propagules which led to the naturalized population at Glen Reenen. The furthest occurrence point that was found from a source plant was approximately 300 m. Also, considering that Glen Reenen was only established after 1963 (SANParks, 2013) the population is less than 51 years old.

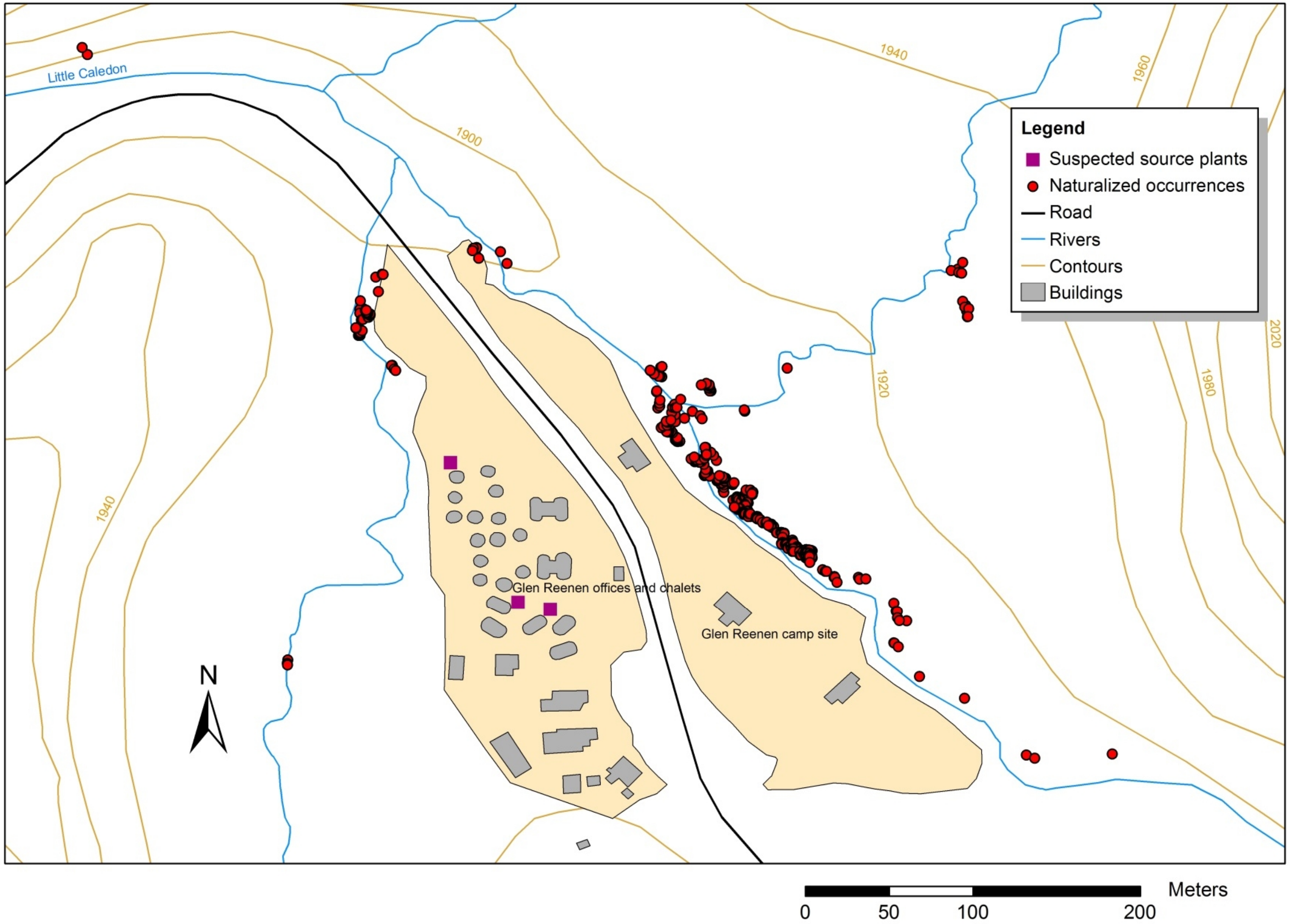


Figure 5.2: Topographical map showing all recorded occurrences of *Berberis julianae* near the Glen Reenen rest camp.

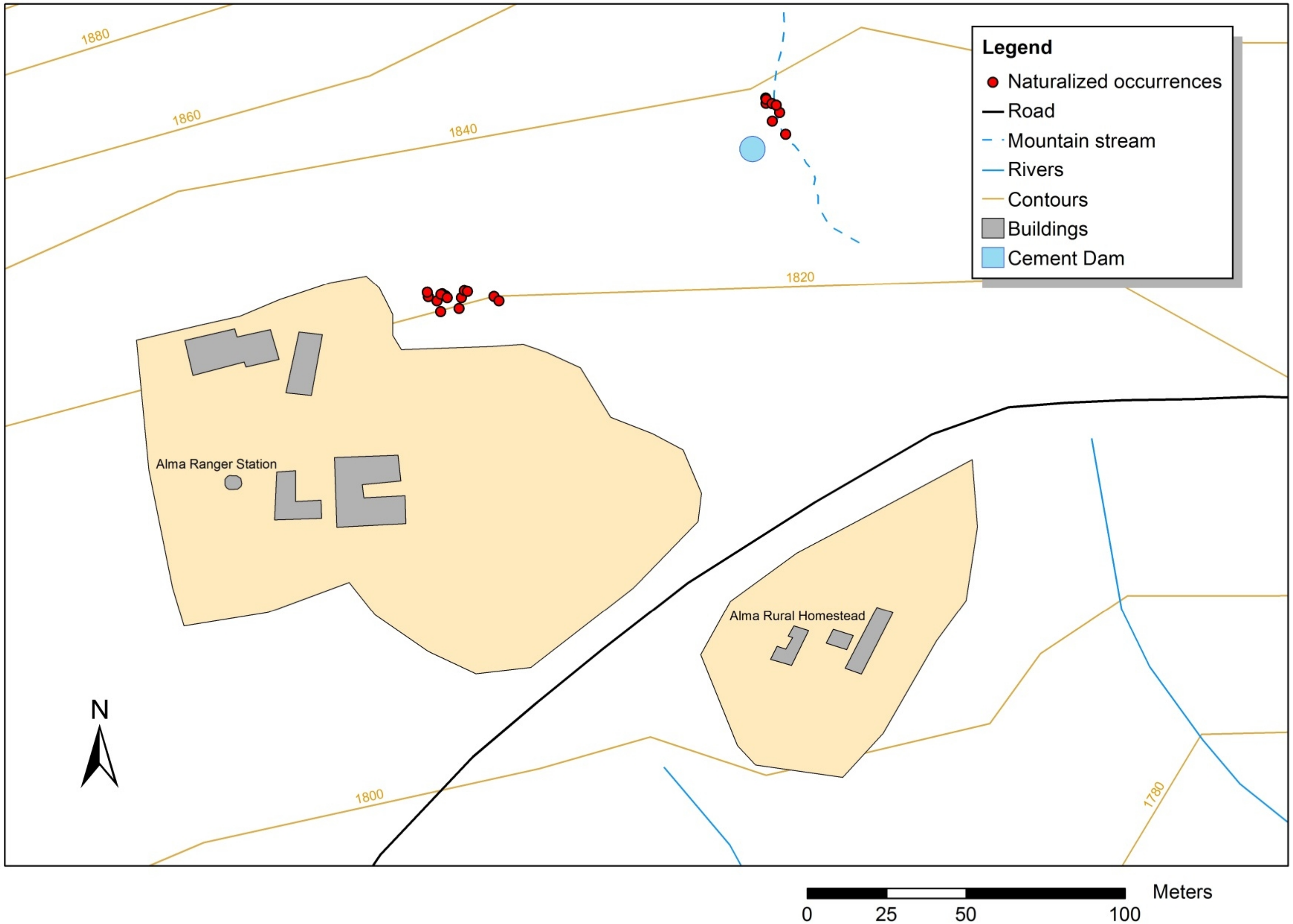


Figure 5.3: Topographical map showing all recorded occurrences of *Berberis julianae* near the Alma ranger station.

5.1.1.2. Woodbush State Forest

A survey was conducted between the 18th and 22nd of November 2013 in the Woodbush State Forest north-east of Tzaneen, Limpopo Province [approximate GPS coordinates: 23.818180°S 29.961520°E] (see Figure 3.2 for the locality within South Africa). The survey was based on a reported locality in the SAPIA database (which had the wrong GPS information). The only species that was found in WSF was *Berberis aristata*. This survey yielded the presence of 4 602 individuals, which accounts for the main part of the population (Figure 5.5).

The population at the WSF has never been delineated in any way. The first survey thus revealed that the population was much larger than originally anticipated. The main part of the population was not fully surveyed with the first attempt due to time constraints; this was rectified upon a second survey.

A second survey of the WSF population was conducted between 6th and 12th April 2014. With this second attempt the main population was surveyed to completion. To make better use of the remaining time, the search effort was redirected towards the surrounding area in order to establish the extent of occurrence (Wilson *et al.*, 2014). More specimens were discovered occurring far away from the main portion of the population. The second survey added an additional 1 123 individuals, thus bringing the total specimen count to 5 725 individuals (Figure 5.4).

The entire population is spread over an area of 115 ha and equates to 1.58 condensed canopy ha. That is, it has an extent of occurrence of 115 ha and an area of occupancy of 1.58 ha (*sensu* Wilson *et al.*, 2014).

The Broederstroom River runs through the site and the banks of the river are heavily infested with *Berberis aristata*. The river is joined downstream by a smaller tributary which is equally badly infested, at least in the portion immediately upstream of where the two meet. Furthermore, the plants have started spreading into the plantation.

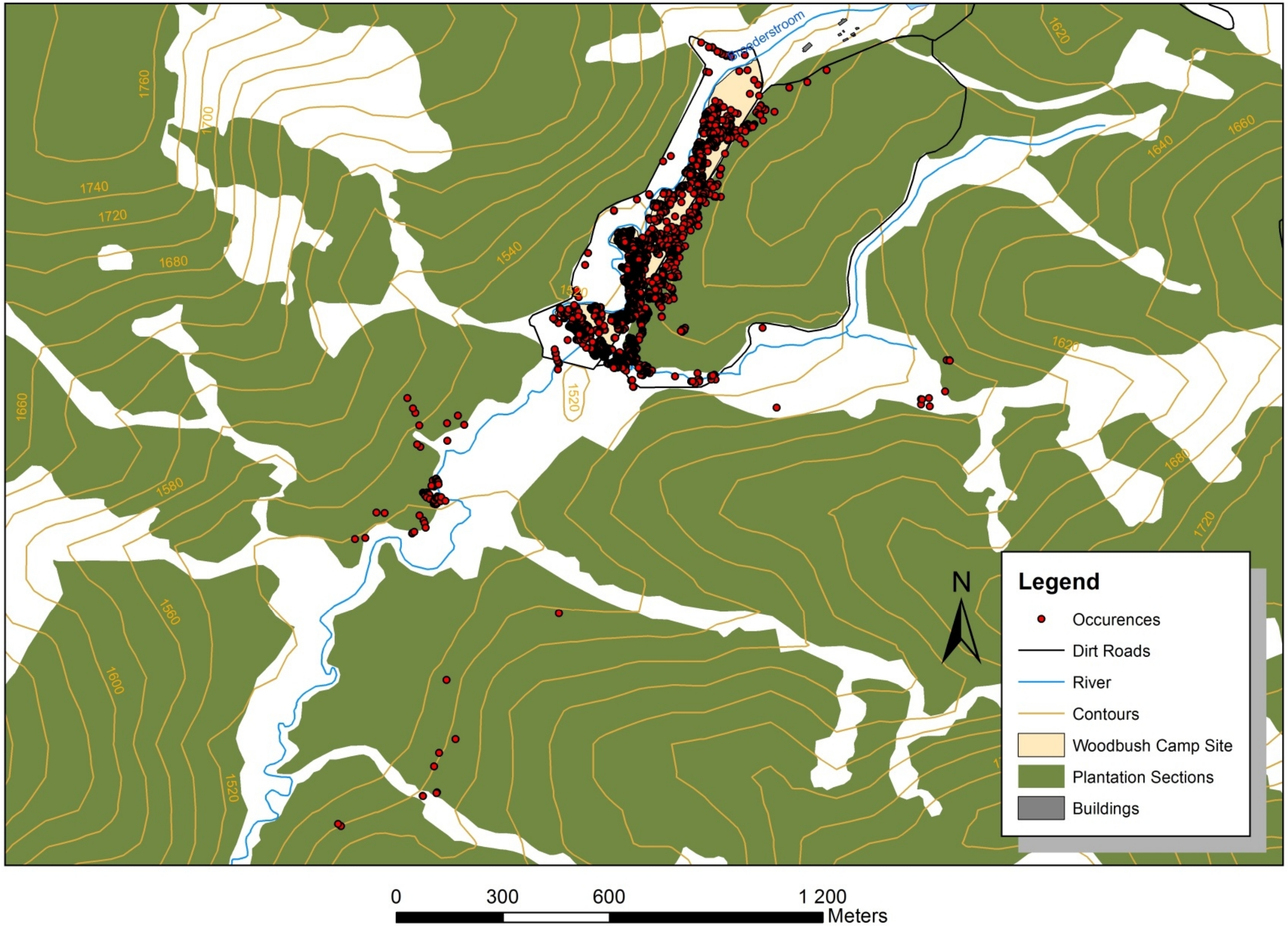


Figure 5.4: Topographical map showing all recorded occurrences of *Berberis aristata* in the Woodbush State Forest.

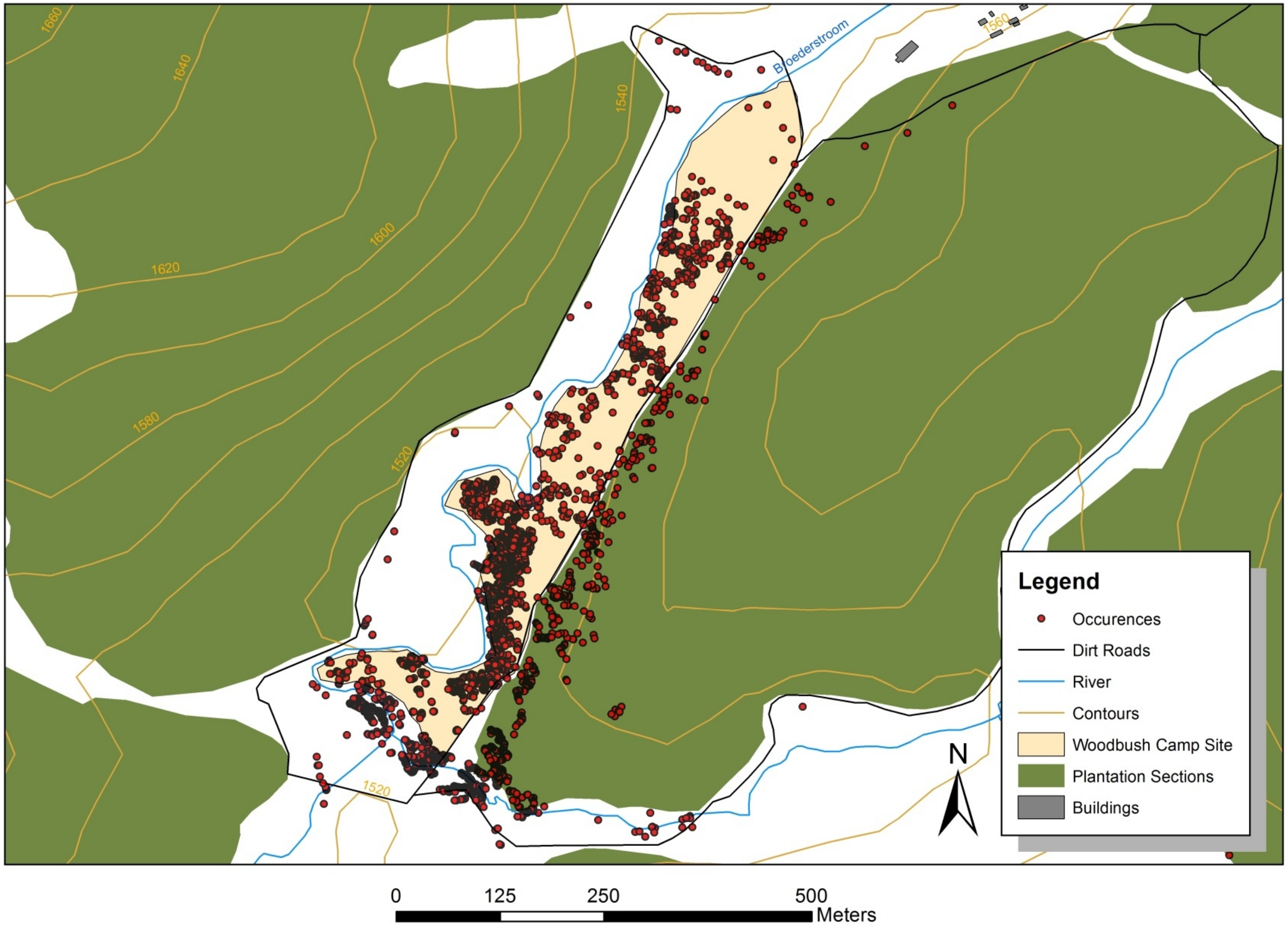


Figure 5.5: Topographical map showing the main portion of the *Berberis aristata* population in the Woodbush State Forest.

A proportion of the area surveyed comprises a camping/picnic site. Many of the individuals occurring there have been cut down to ground level by management (Figure 5.6 A). There seems to be no indication of herbicide being applied in these instances since all of the cut down individuals are resprouting and are thus still actively growing (Figure 5.6 C). All these individuals were therefore included in the surveys. Furthermore, numerous oak trees grow in the site and these trees seem to be facilitating the dispersal and establishment of seedlings due to acting as perching sites for birds that are dispersing the seeds and providing protective cover for the young seedlings (Figure 5.6 B).

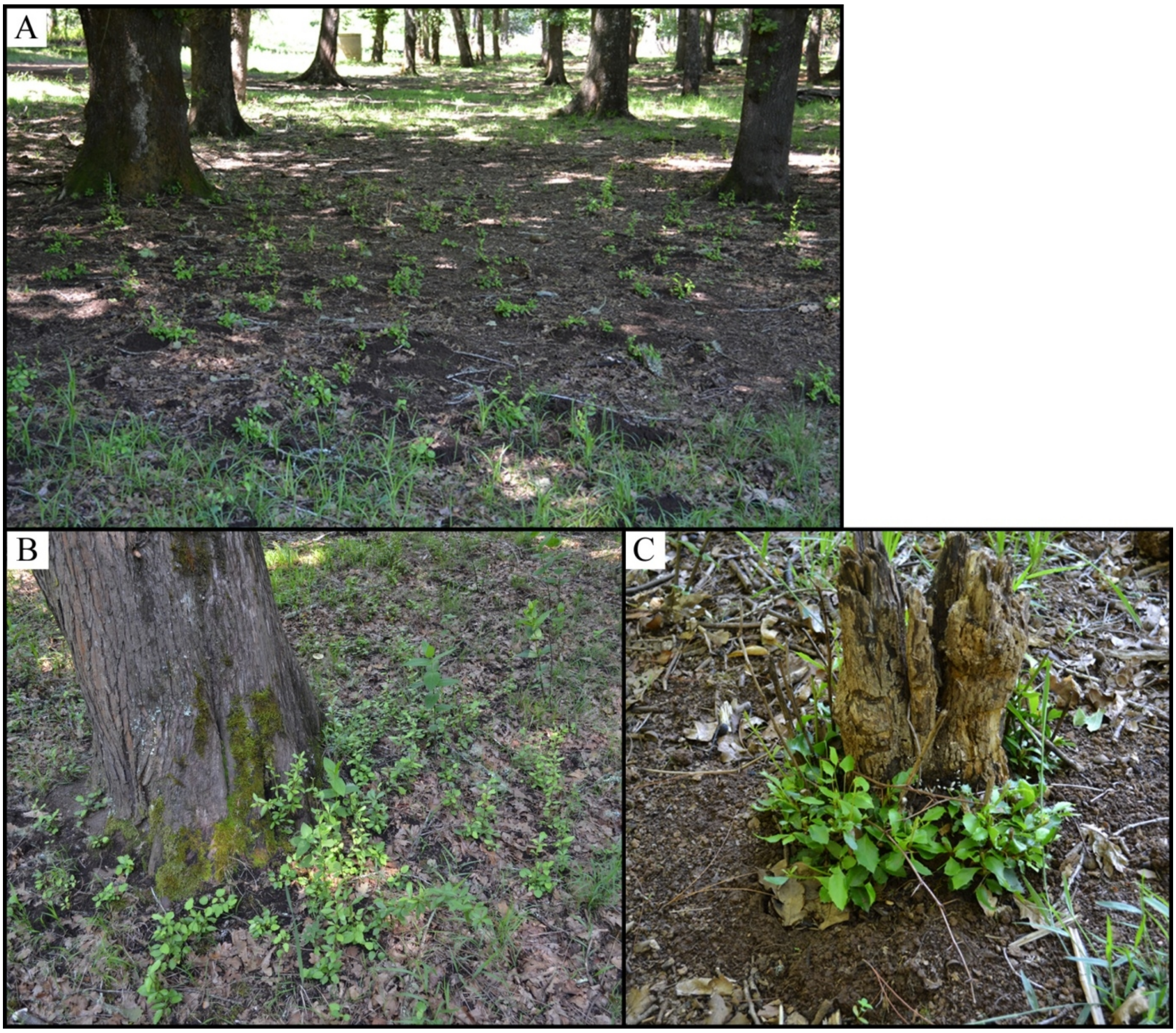


Figure 5.6: A) Part of the area where *Berberis aristata* occurs comprises a camping/picnic site where management has cut down numerous individuals without treating them with herbicides. B) Oak trees occurring in the camping site provide cover for seedlings of *Berberis aristata*. C) An example of one of the larger cut-down specimens that is resprouting at the base.

5.1.1.3. Underberg region

A survey was conducted between the 6th and 10th of May 2014 in the Underberg region of KwaZulu-Natal. The survey failed to confirm the presence of an established *Berberis* population. The survey was conducted by travelling along selected roads and also included visits to Cobham Nature Reserve, Coleford Nature Reserve, Himeville Nature Reserve, Garden Castle Nature Reserve and The Swamp Nature Reserve. Although no large population of *Berberis* was found, a group of four *B. julianae* specimens was found growing underneath a row of oak trees that line the drive-way of the Hazeldene farm [29.69184°S 29.520003°E], about 5 km north of Himeville.

Several species/cultivars of *Berberis* were found to be cultivated on the property of Heritage Plants Nursery just outside of Underberg [29.763716°S 29.454841°E].

5.1.1.4. Barberton region

A survey of the Barberton area and the Shyialongubudam was conducted between the 16th to 19th October 2013 [approximate GPS coordinates: 25.755720°S 31.262130°E]. This was based on a locality in the SAPIA database. The survey failed to yield the presence of an existing *Berberis* population.

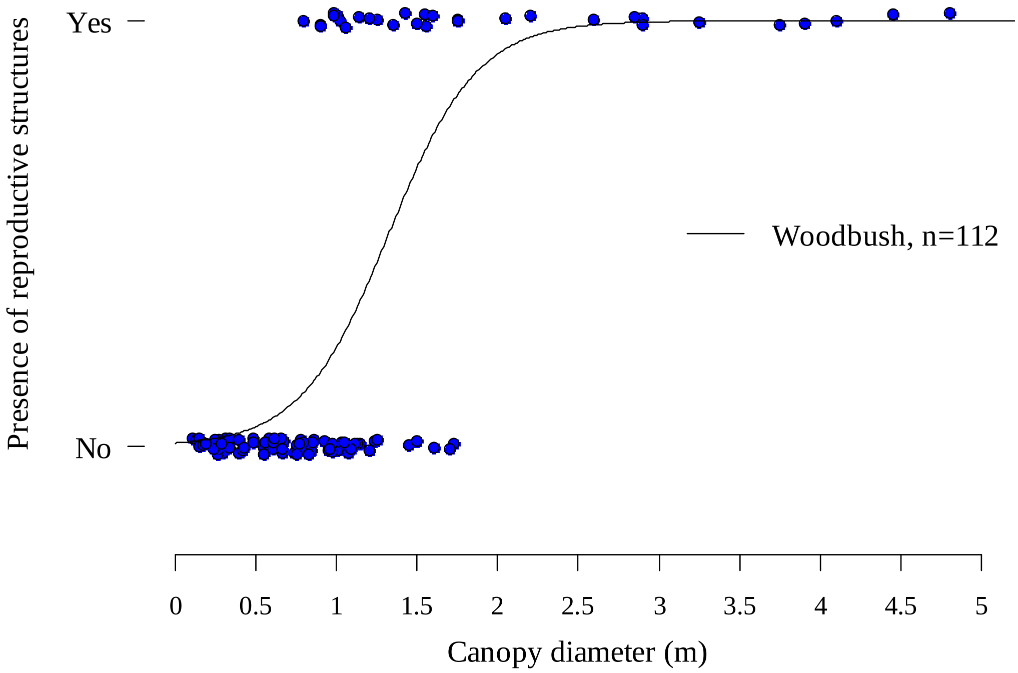
5.1.1.5. Platberg Nature Reserve

A reported locality near Harrismith in the Platberg Nature Reserve [approximate GPS coordinates: 28.286474°S 29.193264°E] was briefly visited in February 2013 but failed to yield a confirmation of an existing *Berberis* population due the extent of the forested habitat and time constraints. This locality was revisited for a second time in October 2013 and again failed to yield a confirmation of an existing *Berberis* population.

5.2. Population characteristics and reproductive size

Due to the size and extent of the *Berberis aristata* population in WSF a homogenous subsample which was representative of the population was chosen for growth measurements and reproductive characters. The sample size was 112 individuals. The population of *B. aristata* showed an unequal height distribution and appears to comprise multiple generations (due to the multi-modal nature of the population curve) (Figure 5.7). The situation is the same when considering a relative canopy diameter frequency curve (Figure 5.8), although there is a much sharper peak at around 1 m, indicating that the majority of the sample had average perpendicular canopy diameters of equal length.

A)



B)

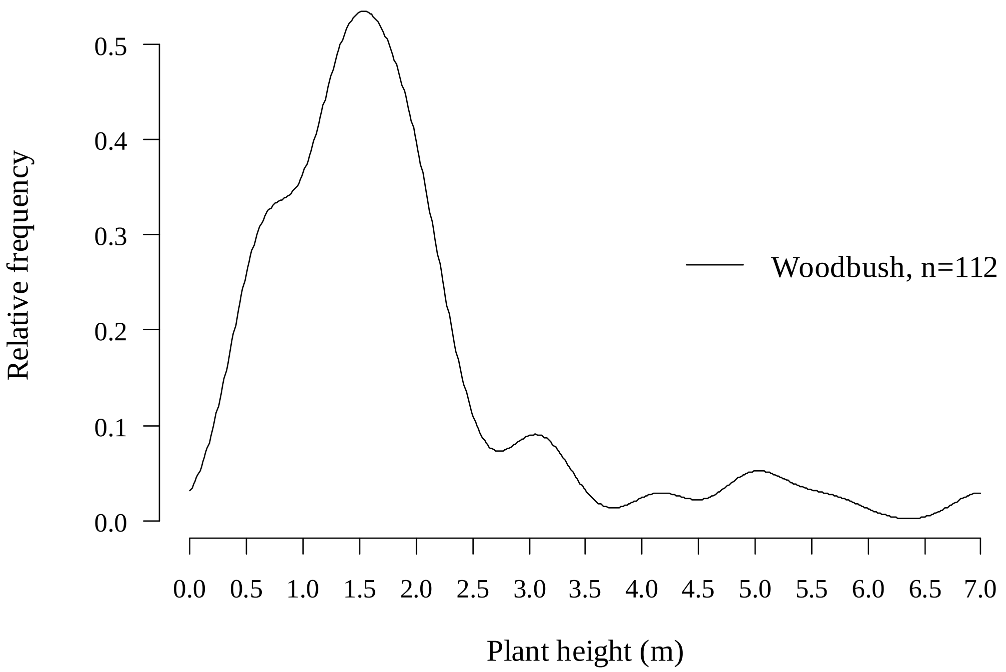


Figure 5.7: A) Reproductive maturity vs. canopy diameter regression curve and B) relative height frequency distribution curve for a homogenous subsample of the *Berberis aristata* population in the Woodbush State Forest.

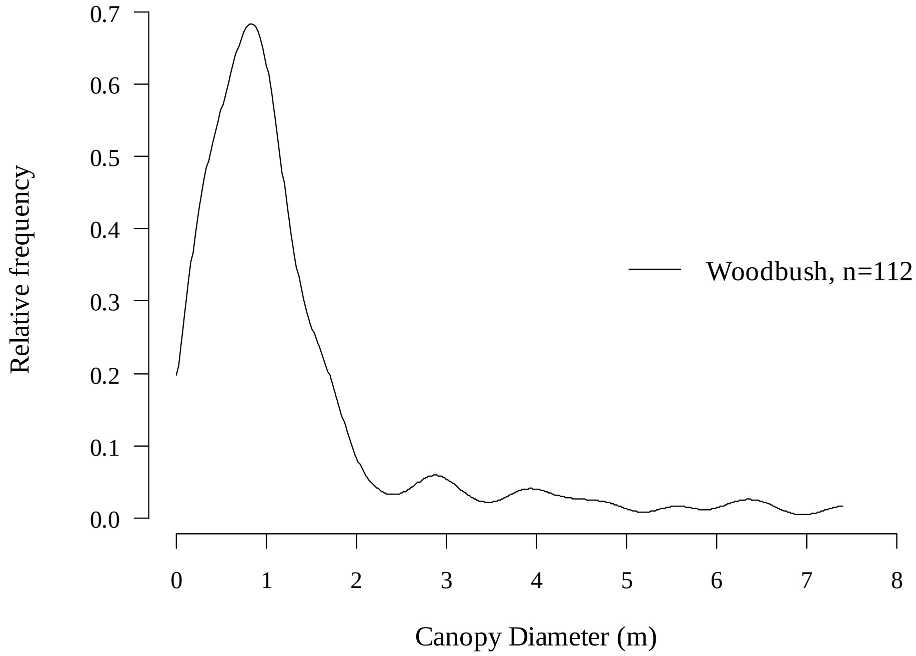
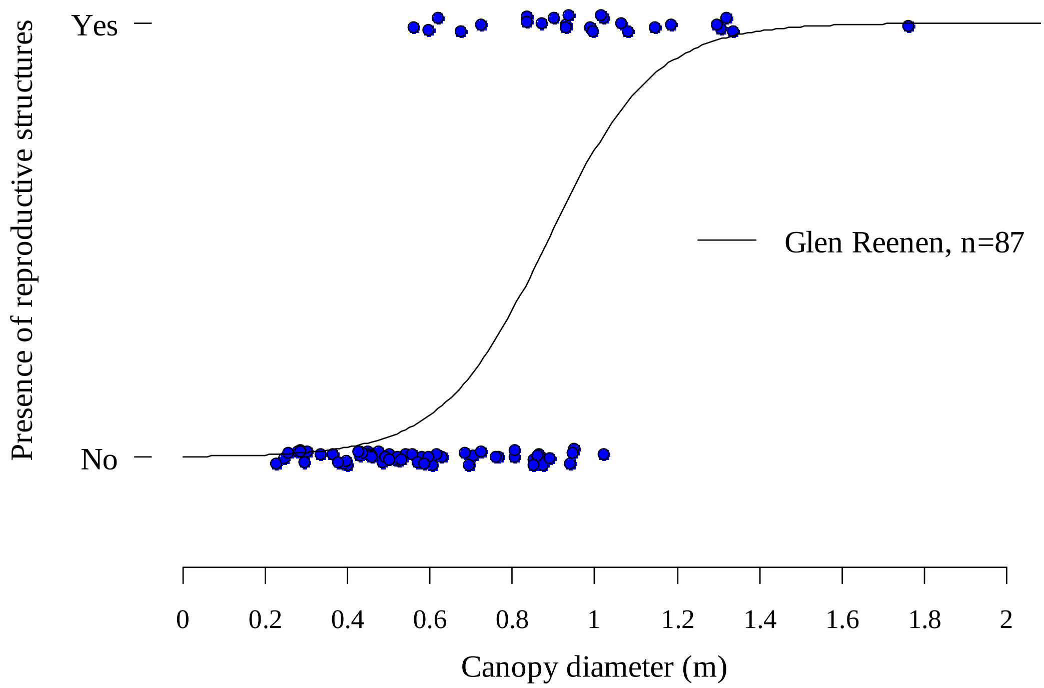


Figure 5.8: Relative canopy diameter frequency distribution curve of the *B. aristata* population subsample at WSF.

The best-fit additive model to explain reproductive onset incorporated log (canopy diameter) and log (plant height) in terms of Akaike Information Criterion (AIC) (weight of 0.42 out of 1 using the R function AICtab [package bbmle]), explaining 52.4% of the variance. However, a model incorporating only canopy diameter explained 48.6% of the variance and was therefore chosen as the most practical predictor of reproductive maturity. Therefore it is recommended that, if plants are to be measured to determine reproductive capability, recording canopy diameter is sufficient. The reproductive size curve (Figure 5.7 A) indicates that plants are predicted to be reproductively active when their average canopy diameters are between 1 and 1.5 m. A small amount of jitter was added to the graph to prevent over fitting.

A subsample of the *Berberis julianae* population growing on the banks of the Little Caledon River at the Glen Reenen rest camp (GGHNP) was chosen for growth measurements and reproductive characters and included a total of 87 individuals. Unlike the sample for *B. aristata* at WSF, the relative height frequency curve showed a more unimodal distribution, albeit skewed to the right (Figure 5.9). However, when considering canopy diameter over height, a multimodal nature can be seen (Figure 5.10).

A)



B)

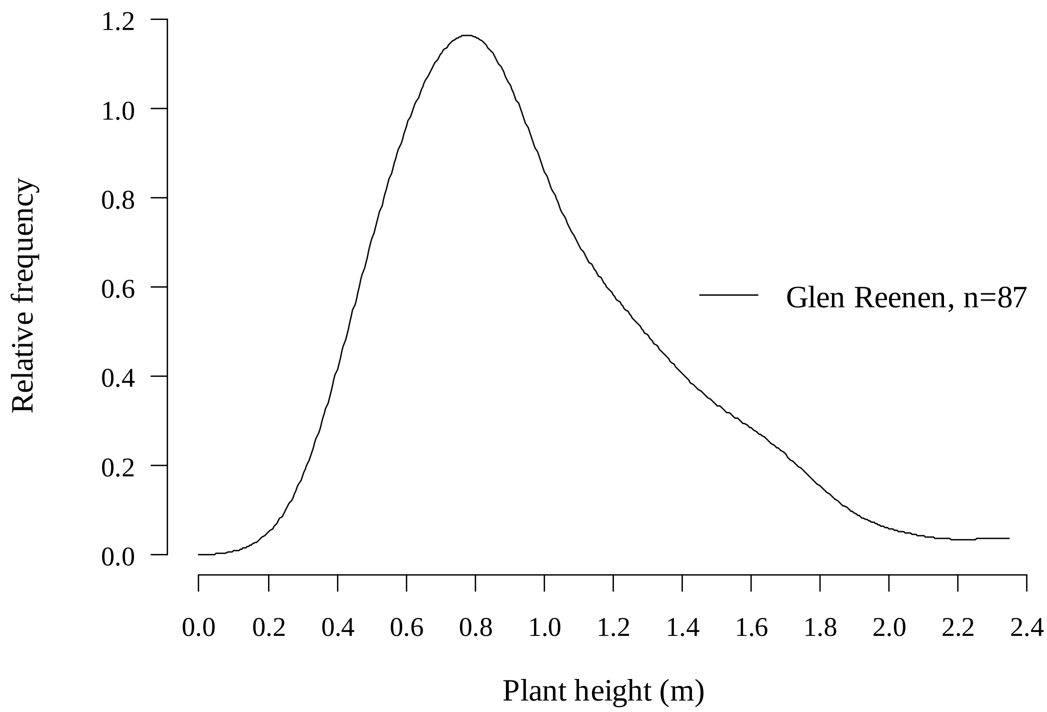


Figure 5.9: A) Reproductive maturity vs. canopy diameter regression curve and B) relative height frequency distribution curve for a homogenous subsample of the *B. julianae* population at Glen Reenen in the Golden Gate Highlands National Park.

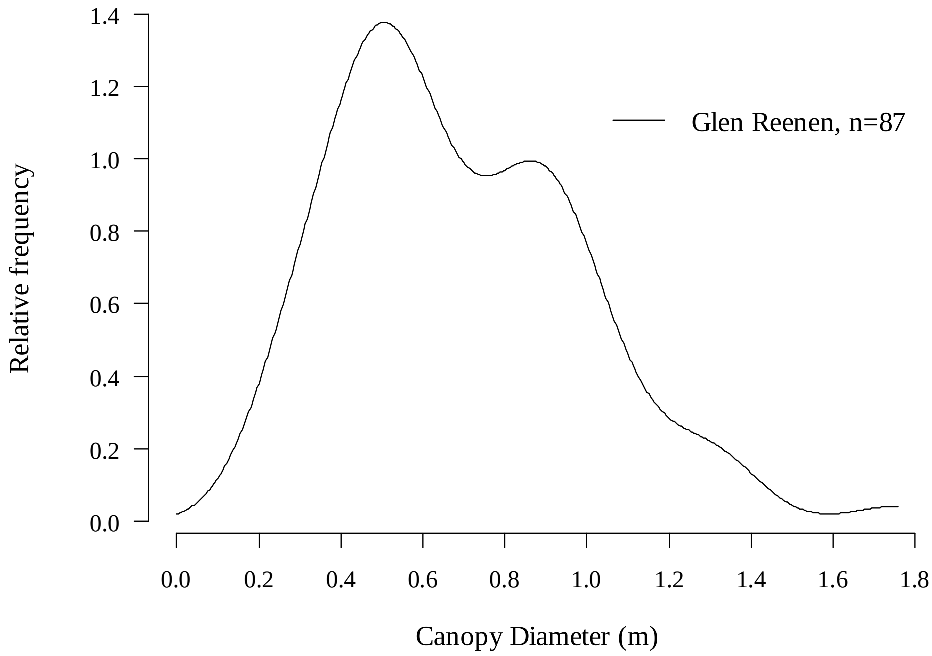


Figure 5.10: Relative canopy diameter frequency distribution curve of the *B. julianae* population subsample at Glen Reenen rest camp, GGHNP.

In terms of the best-fit additive model to explain reproductive onset, normal canopy diameter had the greatest weight in terms of AIC (weight of 0.51 out of 1 using the R function AICtab [package bbmle]). This model explained 42.2% of the total variance and was thus chosen for regression against reproductive maturity. As is the case with *B. aristata*, it is recommended that if plants are to be measured to determine reproductive capability, recording canopy diameter is sufficient. Specifically, plants are predicted to be reproductively active when their average canopy diameters are between 0.8 and 1.2 m (Figure 5.9 A). A small amount of jitter was added to the graph to prevent over fitting.

When considering cumulative relative canopy diameter frequency curves, it is evident that a large part of both species' populations are already reproductively mature (Figure 5.11) as predicted by the regression curves of reproductive maturity against canopy diameter (Figure 5.7 A and Figure 5.9 A). Specifically, for *Berberis aristata* 42% of the individuals in the population subsample already have an average canopy diameter of 1 m and more, while for the *B. julianae* population subsample at Glen Reenen 38% have an average canopy diameter of 0.8 m and more. Thus, for both species a significant amount of plants are already capable of flowering and setting seed in order to recruit next generations.

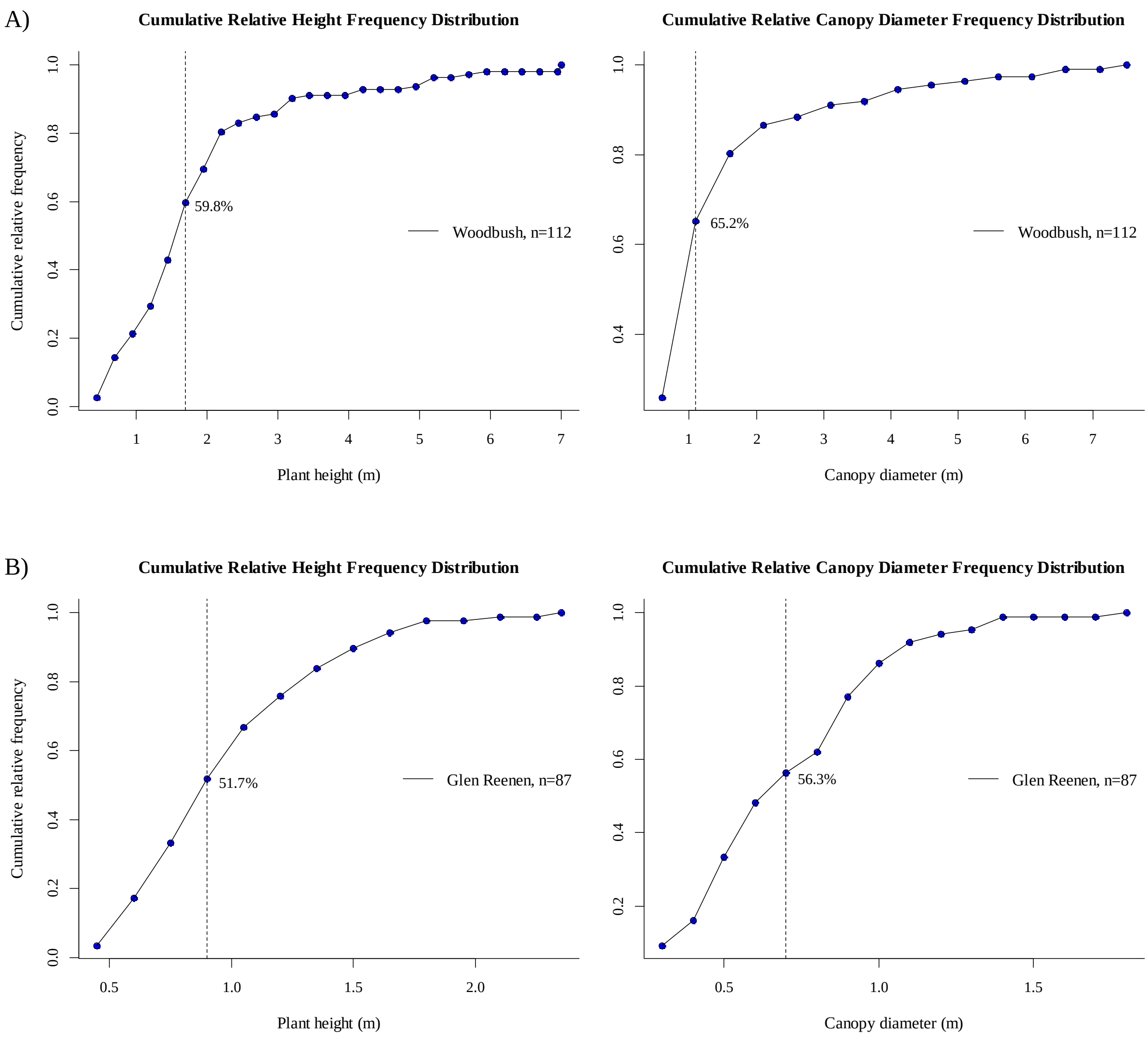


Figure 5.11: Cumulative relative height and canopy diameter frequencies for the A) *B. aristata* population subsample in the Woodbush Forest Reserve and B) the *B. julianae* population subsample in Golden Gate Highlands National Park. Percentage values indicate the proportion of each population that is less than or equal to the value on the x-axis.

5.3. Nursery and herbarium surveys

The extent of cultivation of *Berberis* in South Africa was established by means of a nursery survey. These included regional stockists, wholesale growers and private growers (Table 5.1). The number of stockists per species/cultivar of *Berberis* that were found in the nursery survey is indicated by Figure 5.12. The most widely cultivated species in South Africa is *Berberis thunbergii* “Golden Ring”. Also, the Gauteng province has the most recorded stockists of this species.

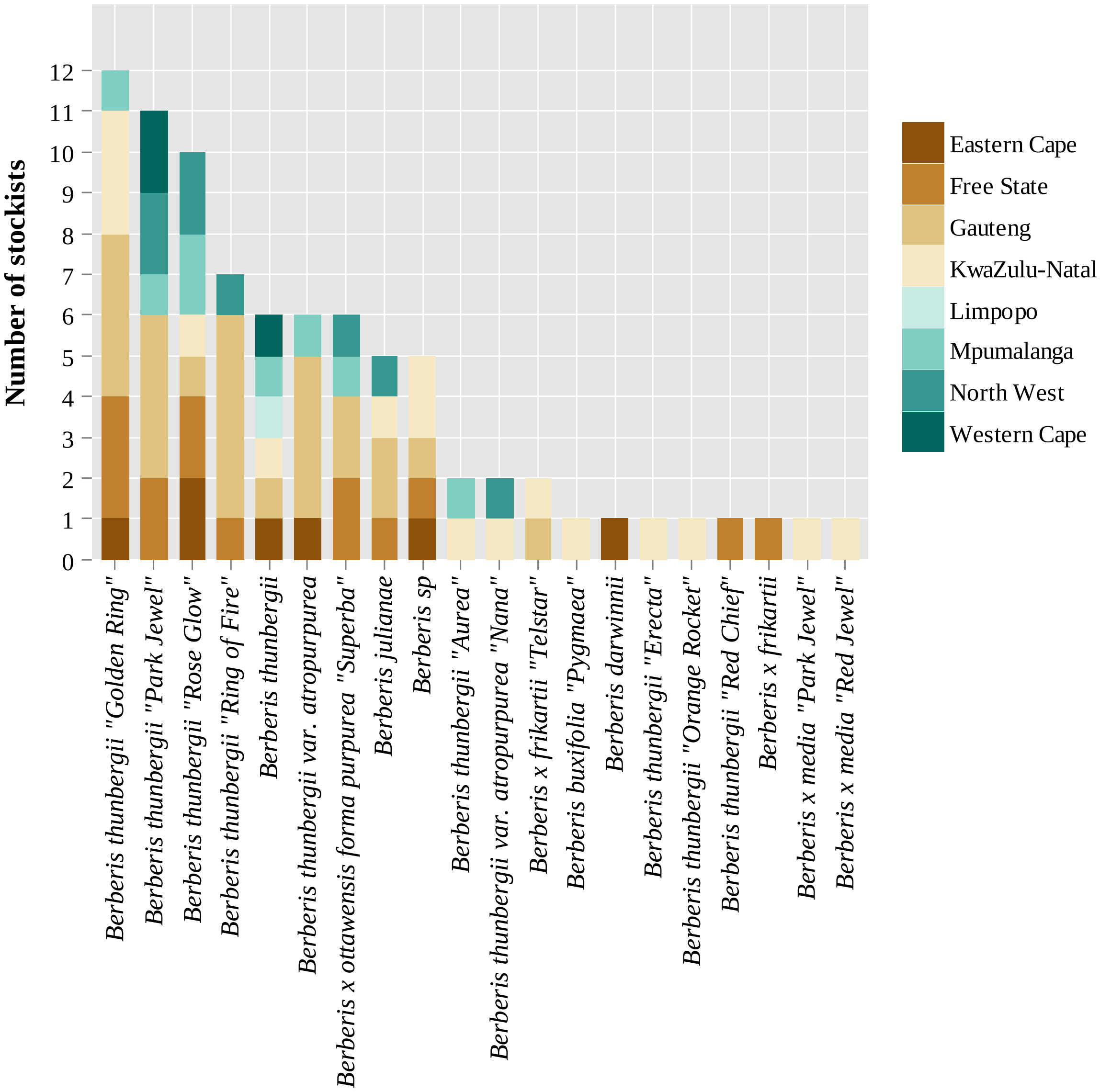


Figure 5.12: Various *Berberis* species and cultivars that were found to be stocked by selected nurseries/growers. In the case of "*Berberis* sp.", the species/cultivar name given could not be confirmed when compared to currently known names.

Table 5.1: Total number of nurseries contacted per province during the nursery survey (contact via email/phone or personal visit).

Province	No. of nurseries contacted	No. of responses
Eastern Cape	11	8
Free State	13	7
Gauteng	55	23
KwaZulu-Natal	25	10
Limpopo	25	9
Mpumalanga	12	8
North West	4	3
Western Cape	12	8
Total	**156**	**76**

Thirty seven herbaria in SA were contacted to find out whether or not they had any specimens of *Berberis,* of which twenty seven responded. These herbaria are indicated by Table 5.2.

Table 5.2: Herbaria in South Africa that were contacted during the survey and which responded.

Acronym	Herbarium Name	Herbarium City/Town
BLFU	Geo-Potts Herbarium	Bloemfontein
BNRH	Buffelskloof Herbarium	Lydenburg
BOL	Bolus Herbarium	Cape Town
FFS	Williams Herbarium	Stellenbosch
GADI	Grootfontein Agricultural Development Institute	Middelburg (Eastern Cape)
GHPG	Harold Porter National Botanical Garden Herbarium	Betty's Bay
GKAR	Karoo National Botanical Garden Herbarium	Worcester
GRA	Selmar Schonland Herbarium	Grahamstown
HSMC	Hortus Siccus McMurtrianus	Karino
J	Charles E. Moss Herbarium	Johannesburg
JRAU	Department of Botany Herbarium (Univ. of Johannesburg)	Johannesburg
KEI	Botany Department Herbarium (Walter Sisulu University)	Mthatha
LYD	Mpumalanga Parks Board Herbarium	Lydenburg
NBG	Compton Herbarium	Cape Town
NH	KwaZulu-Natal Herbarium	Durban
NMB	Botany Department Herbarium (National Museum)	Bloemfontein
NU	Bews Herbarium	Pietermaritzburg
HNTA	Hugh Nicholson and Tony Abbott Herbarium	Durban
PEU	Ria Olivier Herbarium	Port-Elizabeth
PRE	National Herbarium	Pretoria
PRU	H.G.W.J. Schweickerdt Herbarium	Pretoria
PUC	Goossens Herbarium	Potchefstroom
SAAS	School of Natural Resource Management Herbarium (Nelson Mandela Metropolitan University, George Campus)	George
SCHG	Southern Cape Herbarium	George
UDW	Ward Herbarium	Durban
UNIN	Larry Leach Herbarium	Mankweng-E
ZBP	Herbarium Soutpansbergensis	Farm Little Leigh (Soutpansberg)

Apart from the nursery and herbarium surveys, it was confirmed that the species *Berberis holstii* is cultivated on the property of the owners of Buffelskloof Nature Reserve (pers. comm. John Burrows, April 2014) and that *B. thunbergii* is cultivated in the Johannesburg Botanical Gardens (pers. comm. Sandra Viljoen [curator], September 2014).

From the herbarium records, *Berberis julianae* was the most prevalent and a total of 14 records were found (Figure 5.13), all of which was cultivated specimense. This agrees with *B. julianae* being the third most widely stocked species in South Africa after cultivars of *B. thunbergii* and *B. x ottawensis* (Figure 5.12). All records with GPS coordinates or QDS grid references are shown by Figure 5.14. Cultivars and hybrids are not included in this map.

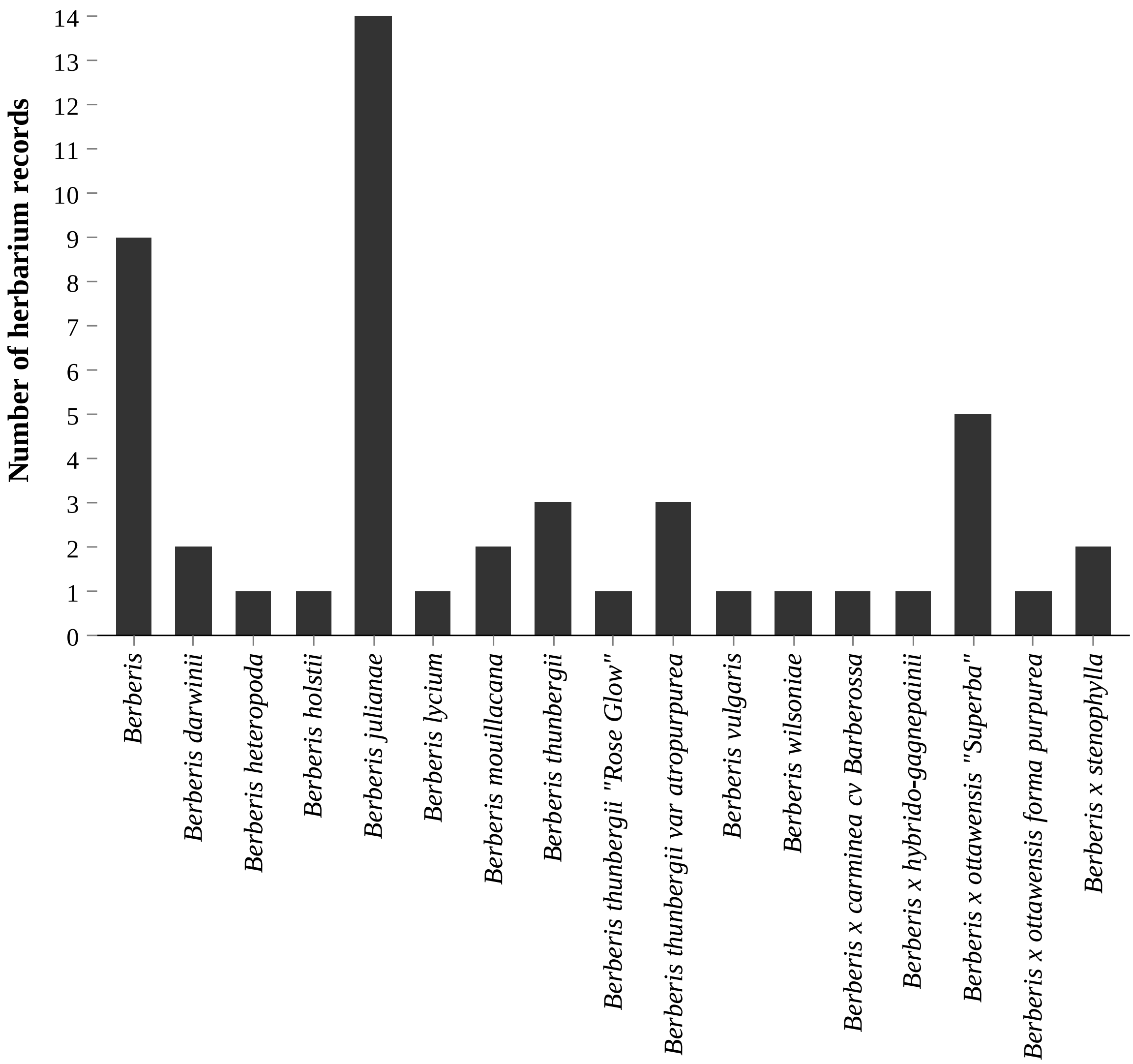


Figure 5.13: Number of records of *Berberis* that were found in the herbarium survey. The specimens labelled as "*Berberis*" did not have a species indicated on them.

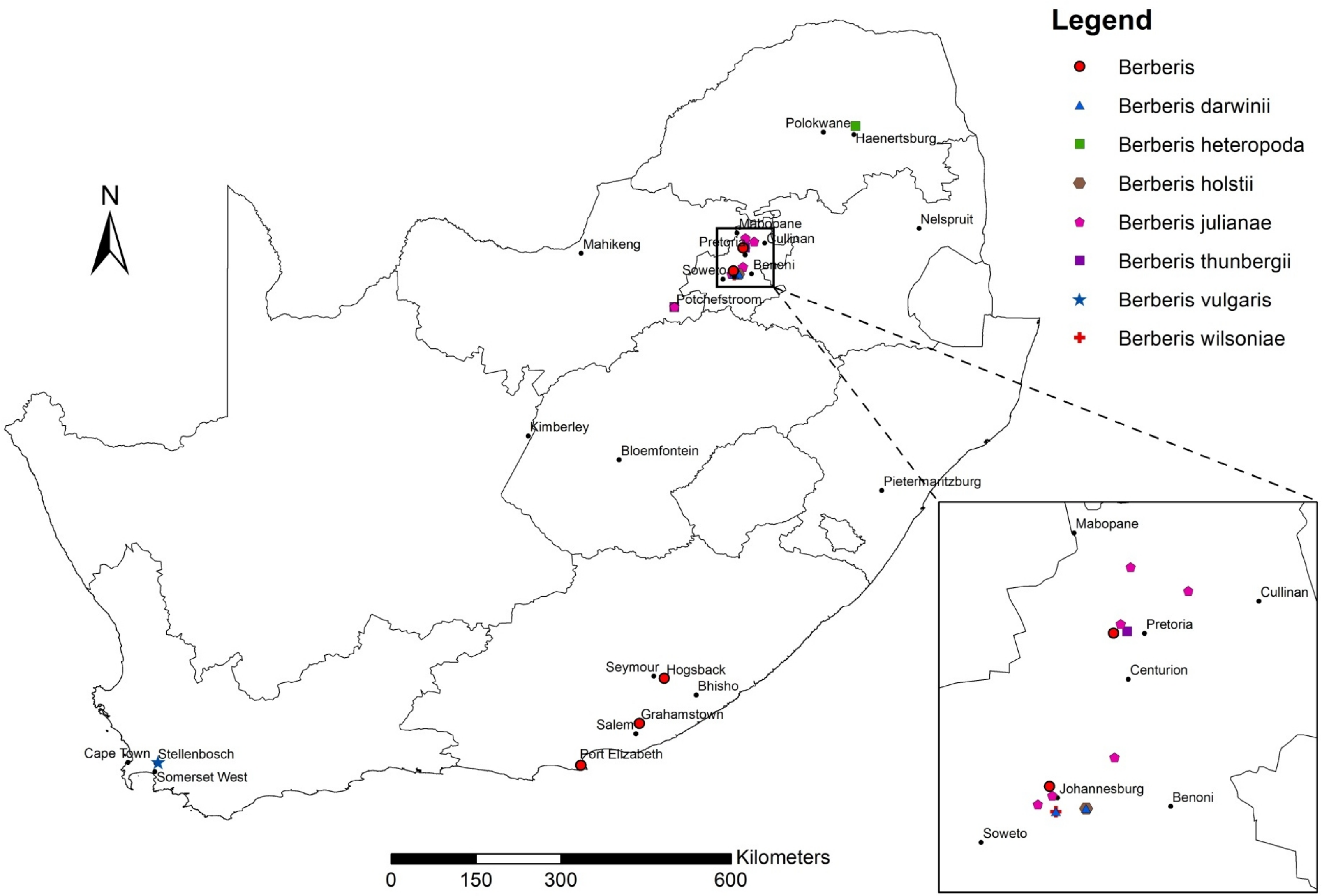


Figure 5.14: Georeferenced herbarium records of *Berberis* spp. in South Africa. Records of cultivars and hybrids are not shown.

The specimen results of the nursery and herbarium surveys, together with other confirmed presences of *Berberis* are summarized by Table 5.3 and accounts for all species of *Berberis* that have been cultivated in South Africa in some or other stage and is comprehensive. This list includes 30 different species/cultivars/hybrids.

Table 5.3: All species of *Berberis* that have been and are cultivated in South Africa

Berberis aristata	*Berberis thunbergii* "Ring of Fire"
Berberis buxifolia "Pygmaea"	*Berberis thunbergii* "Rose Glow"
Berberis darwinii	*Berberis thunbergii* var. *atropurpurea*
Berberis heteropoda	*Berberis thunbergii* var. *atropurpurea* "Nana"
Berberis holstii	*Berberis vulgaris*
Berberis julianae	*Berberis wilsoniae*
Berberis lycium	*Berberis* x *frikartii*
Berberis mouillacana	*Berberis* x *frikartii* "Telstar"
Berberis thunbergii	*Berberis* x *hybrido-gagnepainii*
Berberis thunbergii "Atropurpurea"	*Berberis* x *media* "Park Jewel"
Berberis thunbergii "Aurea"	*Berberis* x *media* "Red Jewel"
Berberis thunbergii "Erecta"	*Berberis* x *ottawensis* forma *purpurea*
Berberis thunbergii "Golden Ring"	*Berberis* x *ottawensis* "Superba"
Berberis thunbergii "Orange Rocket"	*Berberis* x *stenophylla*
Berberis thunbergii "Park Jewel"	
Berberis thunbergii "Red Chief"	

A *Berberis* specimen was observed to be stocked by a nursery in Gauteng which was believed to potentially be *B. glaucocarpa*, but unfortunately this record could not be confirmed due to the owner not responding to further enquiries, potentially due to the fact that this is a prohibited species according to NEMBA.

The earliest herbarium records found of *Berberis* in South Africa were dated 1942. These included *B. heteropoda* (J37979, J) found in the Tzaneen district and two records for *B. mouillacana* (90002386, 90006673, PRE) from Grasskop and Middelburg (EC), respectively. The great majority of the records found were cultivated specimens.

No record was found of cultivation of *Berberis aristata*. However, the specimen labelled as *B. heteropoda* (J37979, J) is believed to potentially be *B. aristata*. No other locality data is given except for "Woodbush". As such it is not exactly clear whether or not this is the same species, but since no other *Berberis* spp. have been found in this area except for *B. aristata*, the author believes that this specimen is indeed the latter. As a consequence, the population in the WSF started to establish from 1942 onwards.

Concerning *Berberis julianae* a total of 14 herbarium records were found that were labelled as such (Figure 5.13 and Figure 5.15); however a further four records were found that is believed to also be *B. julianae* but which were only labelled as "*Berberis*". The earliest record that exists for this species is 1944 (90002374, PRE). The major recorded areas of cultivation were Pretoria (5 records), Johannesburg (4 records) and Potchefstroom (3). There was also one record for each of Midrand and Vrede.

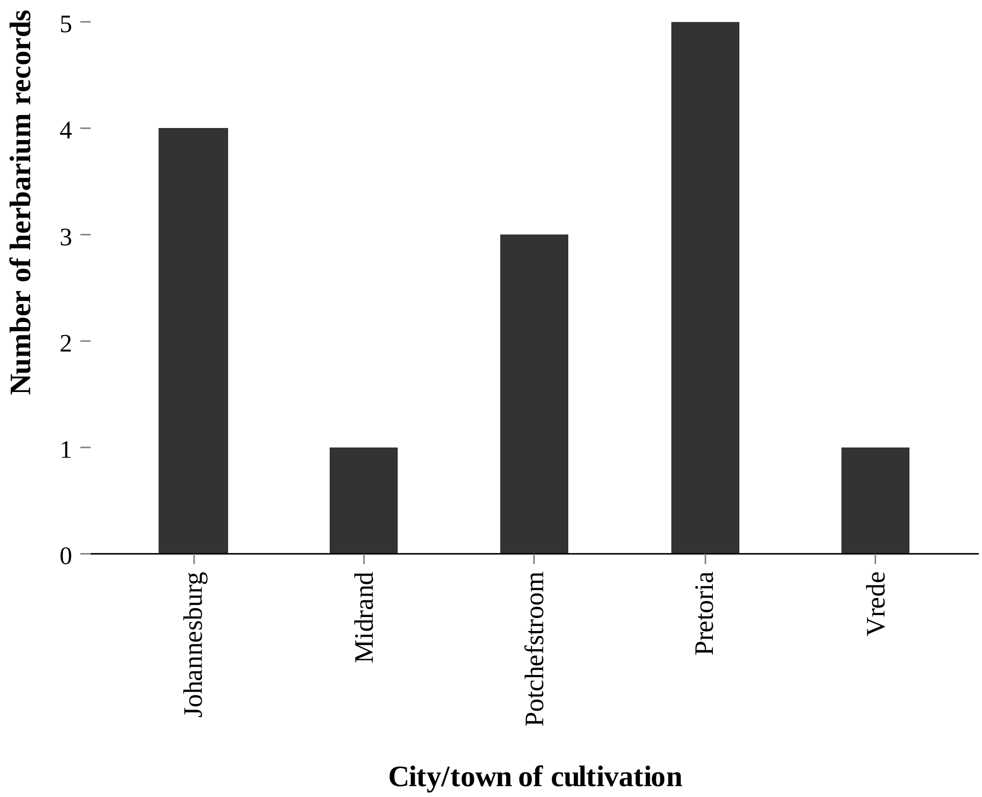


Figure 5.15: Herbarium records of *Berberis julianae* that were found during the herbarium survey. All records were indicated to be from cultivated origin.

One of the shortcomings of the nursery survey is the fact that nurseries sell/stock different plant species during different times of the year. Thus a species of *Berberis* that is normally stocked might have been absent at the time of contacting with the nurseries and present later on in the year. However, nurseries were specifically asked to indicate as best as they could which species of *Berberis* they normally stock, irrespective of the time of year or availability from wholesale/private growers. It is assumed that 1) nurseries provided the correct information and 2) that *Berberis* spp. were identified as accurately as possible. Unfortunately there is little than can be done to test the accuracy of the nursery information.

Interestingly, the KwaZulu-Natal province had the highest number of different *Berberis* species/cultivars stocked by nurseries and growers (Figure 5.16). Although the Gauteng province has many more nurseries and growers, it did not have as high a diversity of species/cultivars than KwaZulu-Natal, while the Limpopo province showed the lowest diversity. What is also noteworthy is that the Free State province had the third highest diversity of species/cultivars. This should be noted in management considerations since the Free State was the only province, apart from Limpopo, that was found to have an invasive *Berberis* population. In contrast to this it seems that there can be a potentially low concern for Limpopo in terms of different species of *Berberis* becoming invasive.

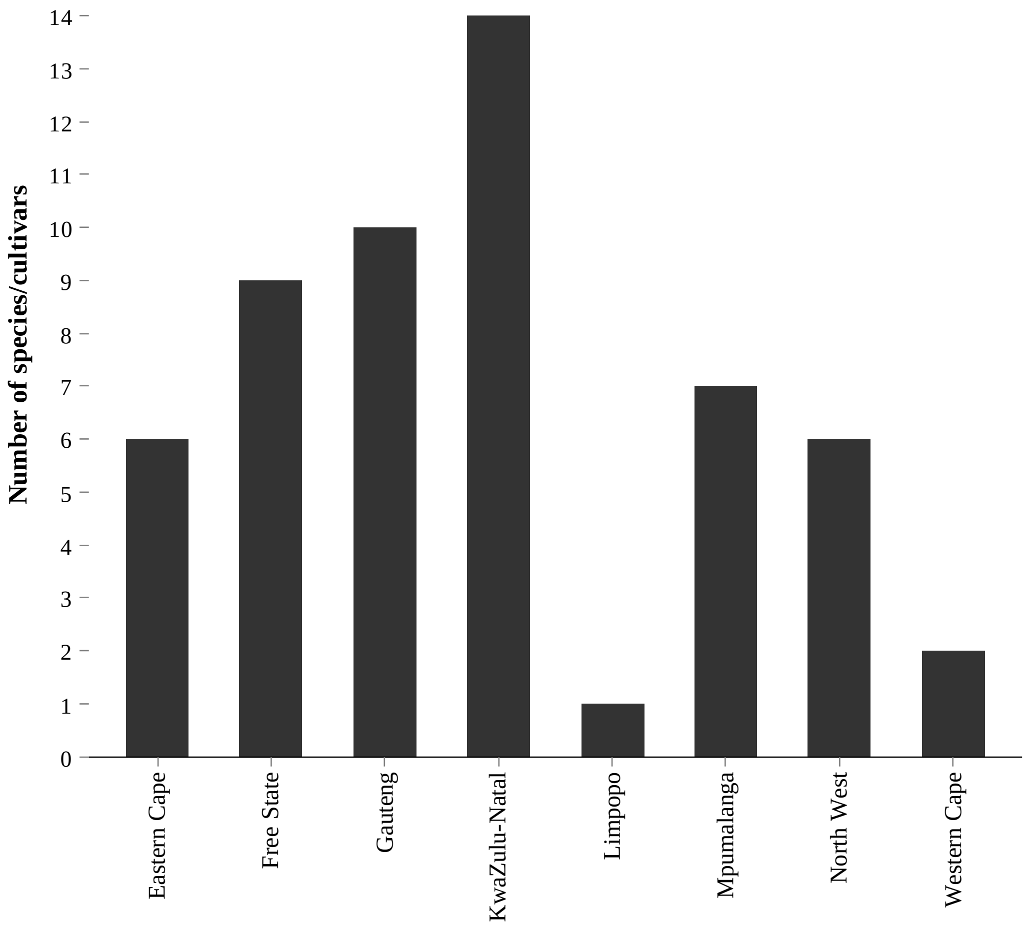


Figure 5.16: Bar chart indicating the combined number of species and cultivars of *Berberis* that were found to be cultivated per province in the nursery survey (Northern Cape excluded).

5.4. Seed viability tests

Seeds of *Berberis julianae* that were collected from GGHNP and that were subjected to an alternating temperature cycle took a minimum of 26 days until germination (Figure 5.17). An average of 95% germination was obtained in 63 days, indicating a very high seed viability. The control seeds (constant temperature of 22˚C) started to germinate much earlier than the seeds subjected to the cycle, but did not reach such a high germination percentage, only 47% in 63 days. However, this is still a substantial amount of viable seeds.

The maximum germination percentage that was obtained for *Berberis aristata* between both the control and cycle treatments was only 14% (Figure 5.17). Both control and cycle treatment conditions were the same as for *B. julianae.* Furthermore, seeds from the control treatment took a minimum of six days until germination while those of the cycle treatment took 75 days until germination. As with *B. julianae* the control seeds of *B. aristata* started germinating much earlier than the seeds of the cycle treatment, but they did not nearly germinate as well as *B. julianae*. Thus, the seeds of *B. aristata* appear to have a lower seed viability.

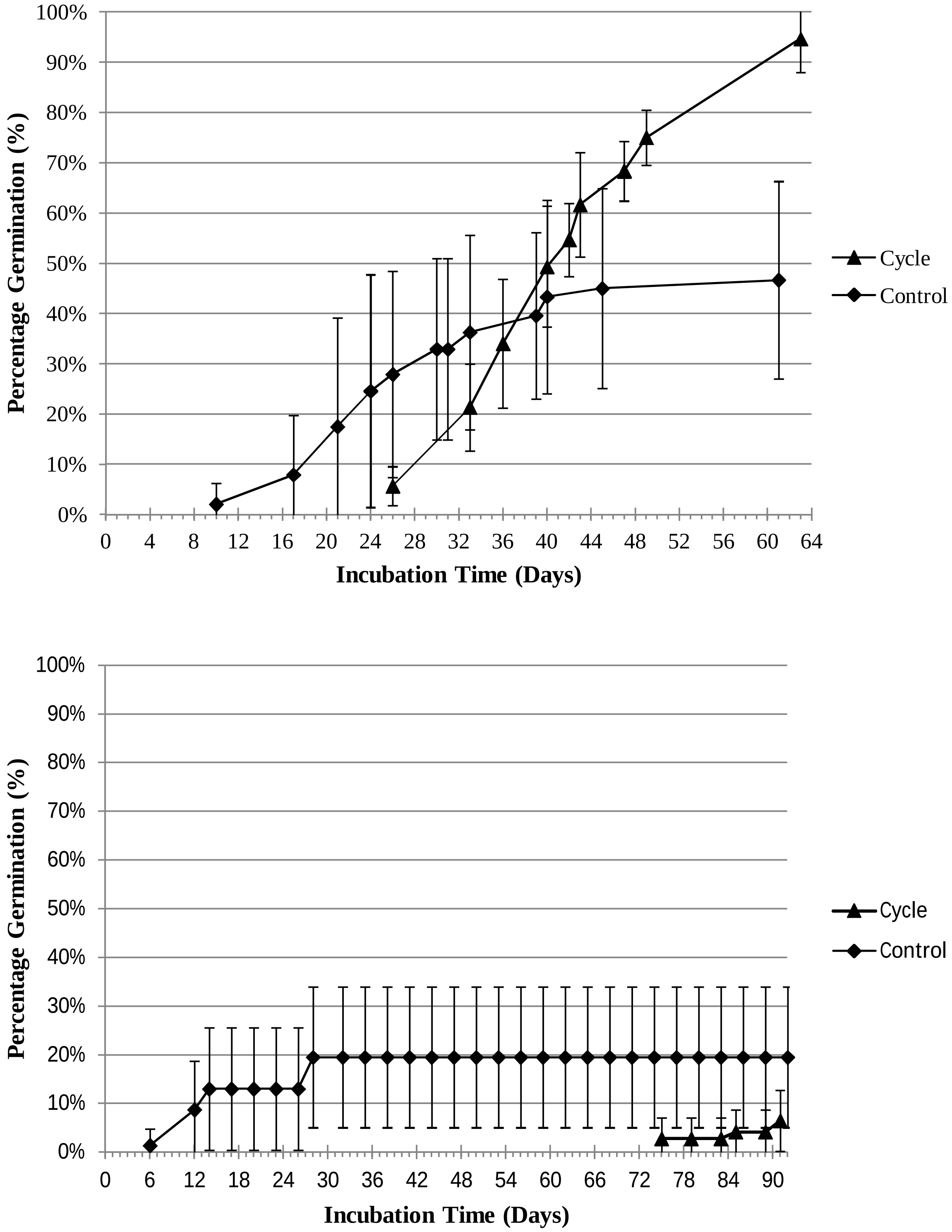


Figure 5.17: Average germination success of *Berberis julianae* seeds that were collected in Golden Gate Highlands National Park (top) and *B. aristata* seeds that were collected in Woodbush State Forest (bottom). Error bars indicate standard deviation for triplicate studies.

5.5. Weed risk assessment

The Australian Weed Risk Assessment (AWRA) (Pheloung *et al.*, 1999) was conducted for *Berberis aristata* (Appendix F) and *B. julianae* (Appendix G). For both species the minimum number of questions was answered in each section of the assessment, thereby fulfilling the requirements of the assessment. Questions 2.01 and 2.02 were answered within a South African climate context and based on the habitat suitability models (as in Jacobs *et al.*, 2014). Based on the availibilty of data and literature a total of 36 questions were answered for *B. aristata* and 34 for *B. julianae.* Scores of 27 and 22 were obtained for *B. aristata* and *B. julianae*, respectively. A score higher than six indicates rejection and therefore both species would have been rejected in a pre-border evaluation. For a species to be accepted by the assessment a score lower than one is required. Any value in between one and six requires the researcher to conduct further evaluations on the species to determine whether or not it should be accepted or rejected.

One of the premises of the assessment is that the invasion history of species can be used as an accurate predictor of invasion potential in a new region with similar climatic conditions (Gordon *et al.*, 2008). Thus, if a species is found to have a history of invasiveness outside of its native region and a habitat suitability model is created that predicts a reasonable climate match, then the species under consideration poses an invasion risk. The assessment also considers undesirable attributes which can negatively impact the environment or other plants/mammals/humans, for example having a climbing or smothering habit, being unpalatable, having the ability to survive in dense shade or possessing toxic fruits and/or spines. Finally, the biology and ecology of the species is also taken into consideration in calculating the final score; attributes that enable a species to reproduce, spread and persist fall under this final section of the AWRA (Pheloung *et al.*, 1999).

5.6. Bioclimatic modelling

Freeman & Moisen (2008) suggest that continuous probability maps should be produced so that end users can decide for themselves which threshold cut-off values are appropriate depending on the intended use of the map. This is because the reclassification of a probability surface into a binary output reduces the information available to the map user (Freeman & Moisen, 2008). Therefore both situations are represented here.

In terms assessing the predictive performance of models, AUC values can be considered as follows (Swets 1988): excellent AUC > 0.90, good 0.90 > AUC > 0.80, fair 0.80 > AUC > 0.70, poor 0.70 > AUC > 0.60 and fail 0.60 > AUC > 0.50.

The model for *Berberis aristata* performed excellent with a mean AUC value of 0.984 for five replicate runs (Appendix E). The minimum training presence logistic (MTPL) threshold value that was used to separate suitable from unsuitable areas was 0.071. The bioclimatic variables that contributed most to the results were temperature annual range (52.2%) and annual mean temperature (28%). Using the MTPL threshold a total area of predicted suitability calculated with ArcGIS 10.2 for current climate conditions was 54 million ha (Figure 5.18). Future predicted suitability (2020) calculated similarly than for current conditions gave an area of 36 million ha that is potentially suitable (Figure 5.19). This indicates an approximate range size decrease of 33%.

The model for *Berberis julianae* had a mean AUC value of 0.763 for five replicate runs, which can be regarded as fair model performance (Swets, 1988) (Appendix E). The MTPL threshold value that was used to separate suitable from unsuitable areas was 0.3824. The bioclimatic variables that contributed most to the results were Mean Temperature of Wettest Quarter (53.9%) and Temperature Seasonality (27.2%). Using the MTPL threshold a total area of predicted suitability for current climate conditions calculated with ArcGIS 10.2 was 69 million ha (Figure 5.20). Calculating future predicted suitability (2020) similarly than for current conditions gave an area of 42 million ha that is potentially suitable (Figure 5.21). This indicates an approximate range size decrease of 40%. The low AUC value might be attributed to the small dataset that was used to train and test the model (only 22 records) (Pearson, 2007).

From the models, *Berberis julianae* is predicted to have a higher suitability both in current and future climates compared to *B. aristata*. However, *B. julianae* is also predicted to have higher decrease in range size than *B. aristata* (40% versus 33%). Nevertheless, both species were predicted to have substantial areas of climatic suitability within South Africa both currently and in 2020.

According to the bioclim datasets both species are able to grow in areas that have less than 25 mm precipitation in the driest quarter. This is an important consideration for the AWRA (Pheloung *et al.*, 1999) since such species potentially have the ability to invade arid regions (Gordon *et al.*, 2010).

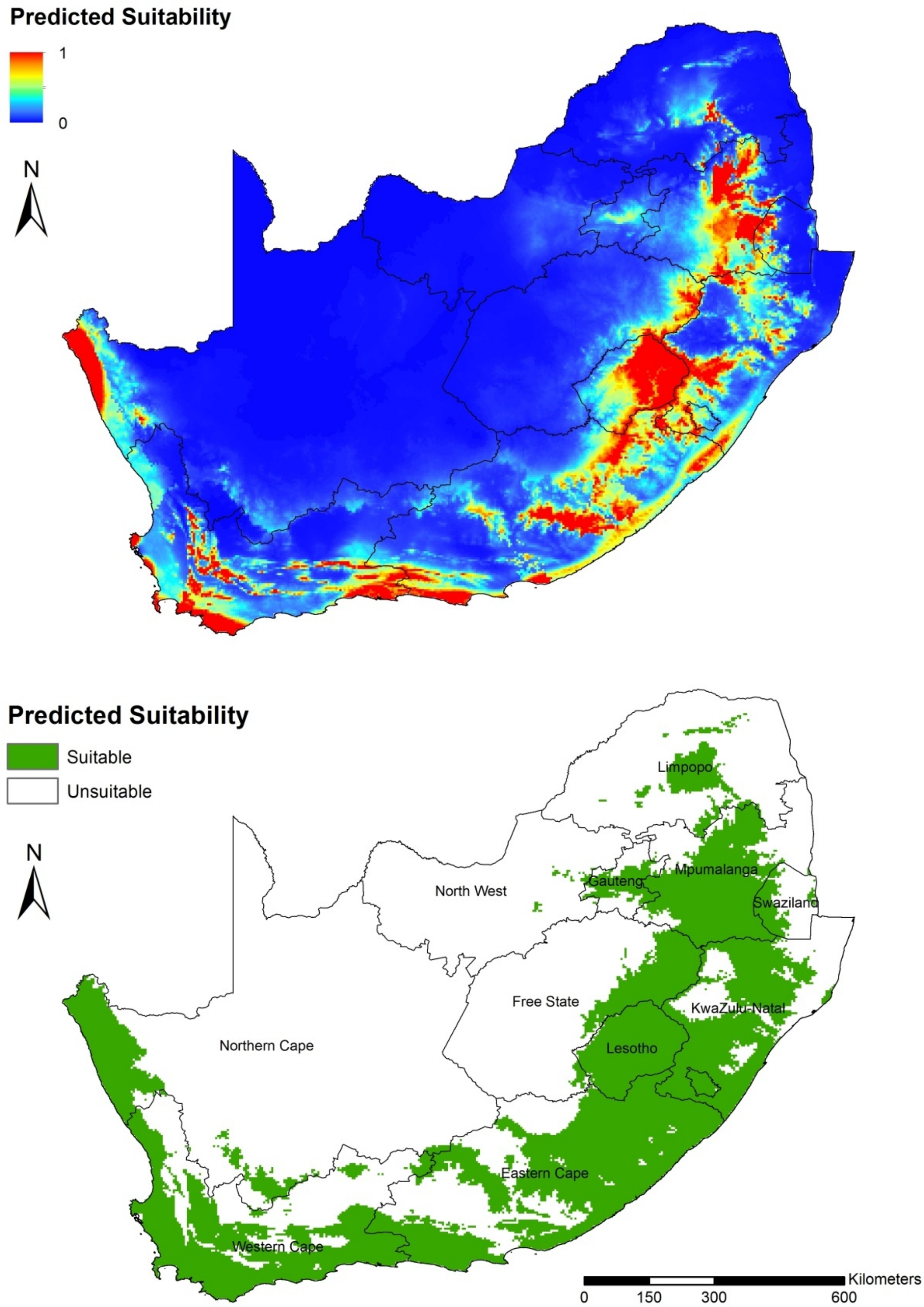


Figure 5.18: Habitat suitability of *Berberis aristata* for current climate conditions. The top figure represents a continuous probability distribution while the bottom figure incorporates the minimum training presence logistic threshold value to separate suitable and unsuitable habitats.

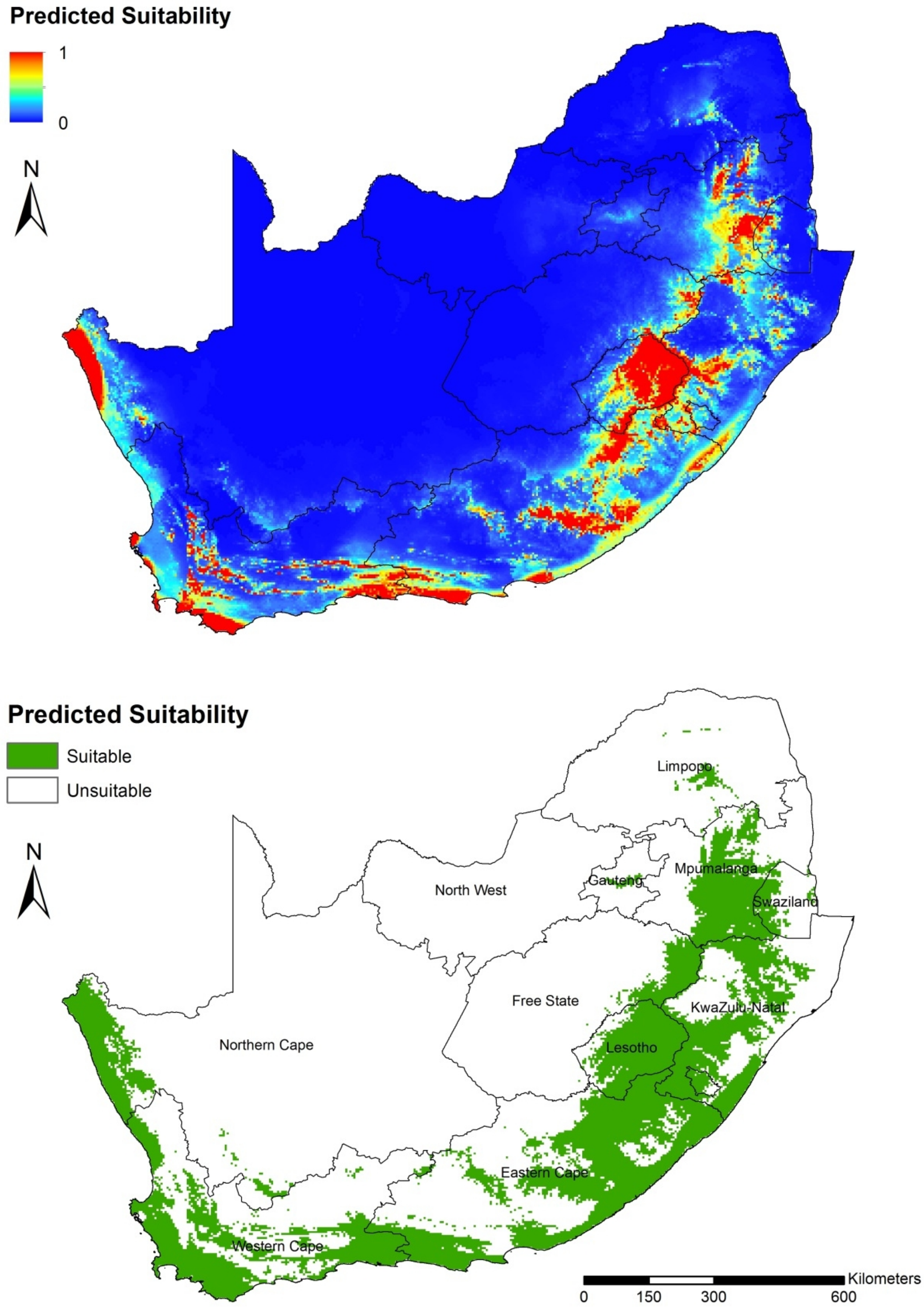


Figure 5.19: Habitat suitability of *Berberis aristata* for 2020 climate conditions. The top figure represents a continuous probability distribution while the bottom figure incorporates the minimum training presence logistic threshold value to separate suitable and unsuitable habitats

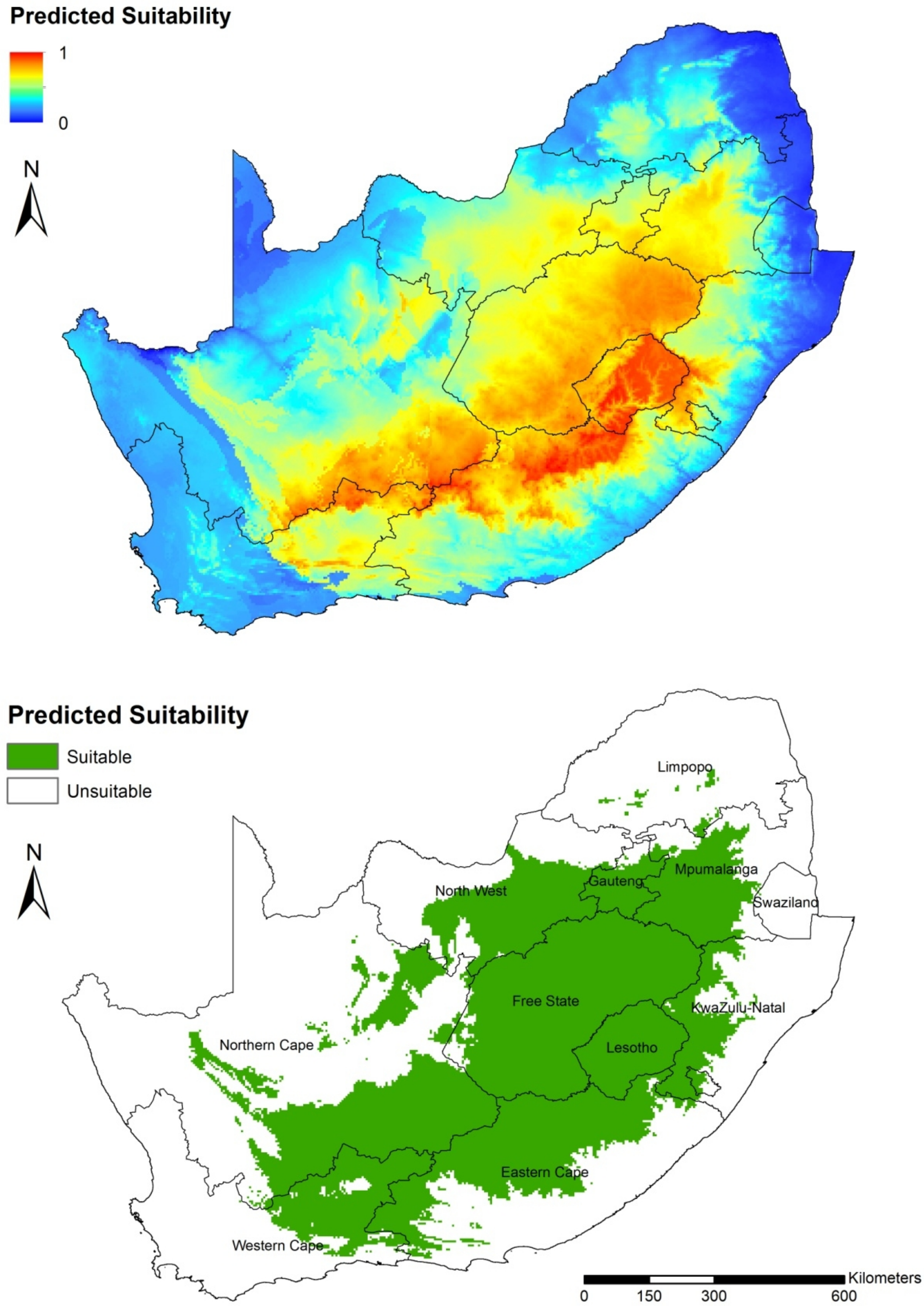


Figure 5.20: Habitat suitability of *Berberis julianae* for current climate conditions. The top figure represents a continuous probability distribution while the bottom figure incorporates the minimum training presence logistic threshold value to separate suitable and unsuitable habitats

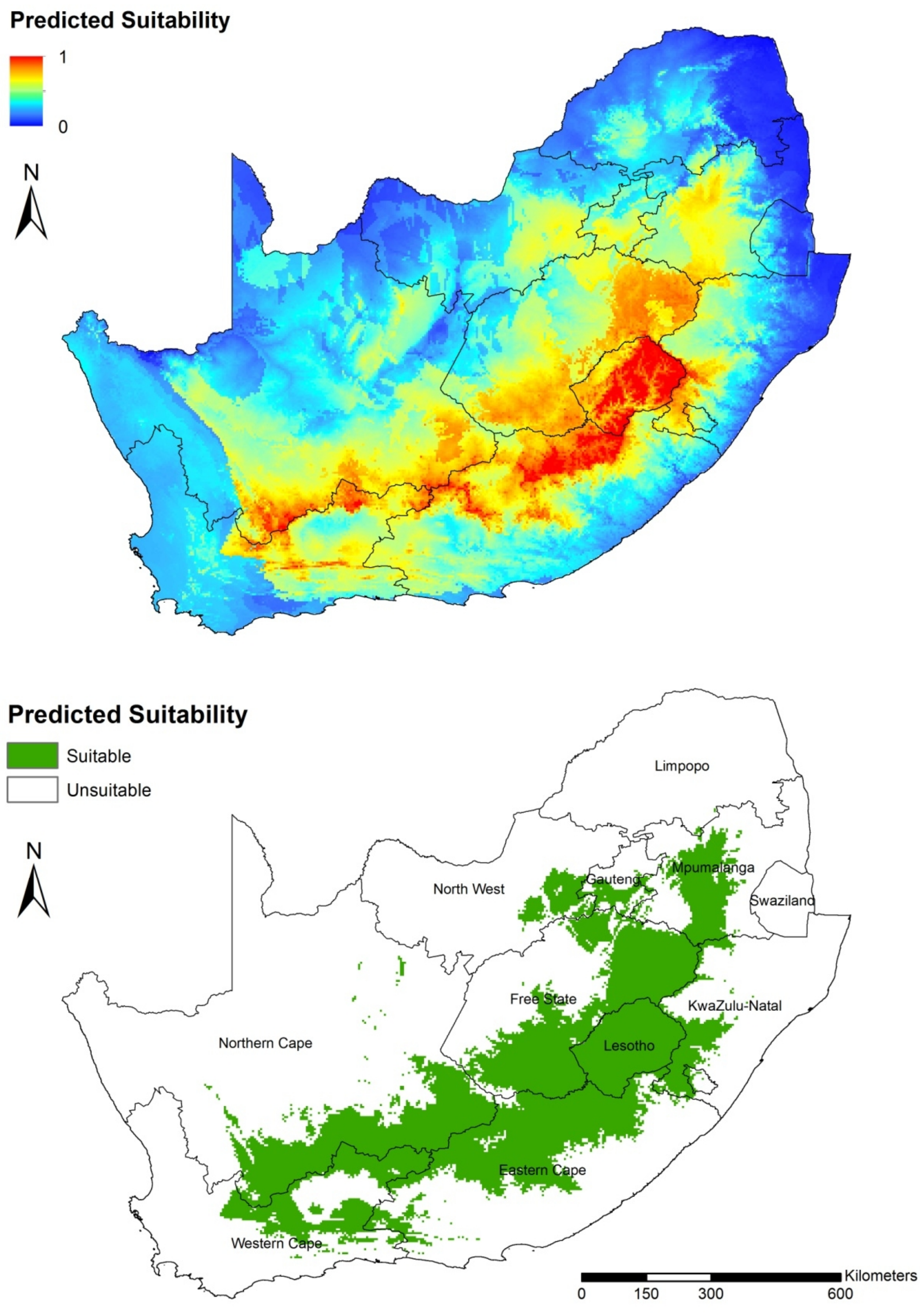


Figure 5.21: Habitat suitability of *Berberis julianae* for 2020 climate conditions. The top figure represents a continuous probability distribution while the bottom figure incorporates the minimum training presence logistic threshold value to separate suitable and unsuitable habitats

5.7. Clearing trials

Due to steep slopes along the river and a varying riverbank width not all plots had an equal area. Also, owing to the scattered nature of the plants not all the plots had an equal amount of plants and thus some plots were overrepresented while others were underrepresented.

A follow-up recount to determine chemical efficacy was conducted thirty days after the initial treatment of the plants. Percentage regrowth was determined by re-counting all sprayed plants that showed any signs of new growth.

A combined total of 511 plants were treated by foliar-spraying in the four plots. This included many seedlings that were not GPS tagged during the original survey of the population. A further 28 plants that were big enough were cut down and treated with glyphosate gel (Kaput® 100 Gel) as per cut-stump treatment recommendations. These included the three suspected source plants that were planted in between the offices and chalets.

From the follow-up inspection it was clear that the Forrester B treatment (Metsulfuron-methyl at a concentration of 50g/100L) proved to be the most effective among all foliar-spray treatments (Figure 5.22). The use of this herbicide resulted in only 9% regrowth. Another treatment, namely Triclon B (Triclopyr at a concentration of 700 mL/100L), also proved to be effective as only 43% regrowth was observed.

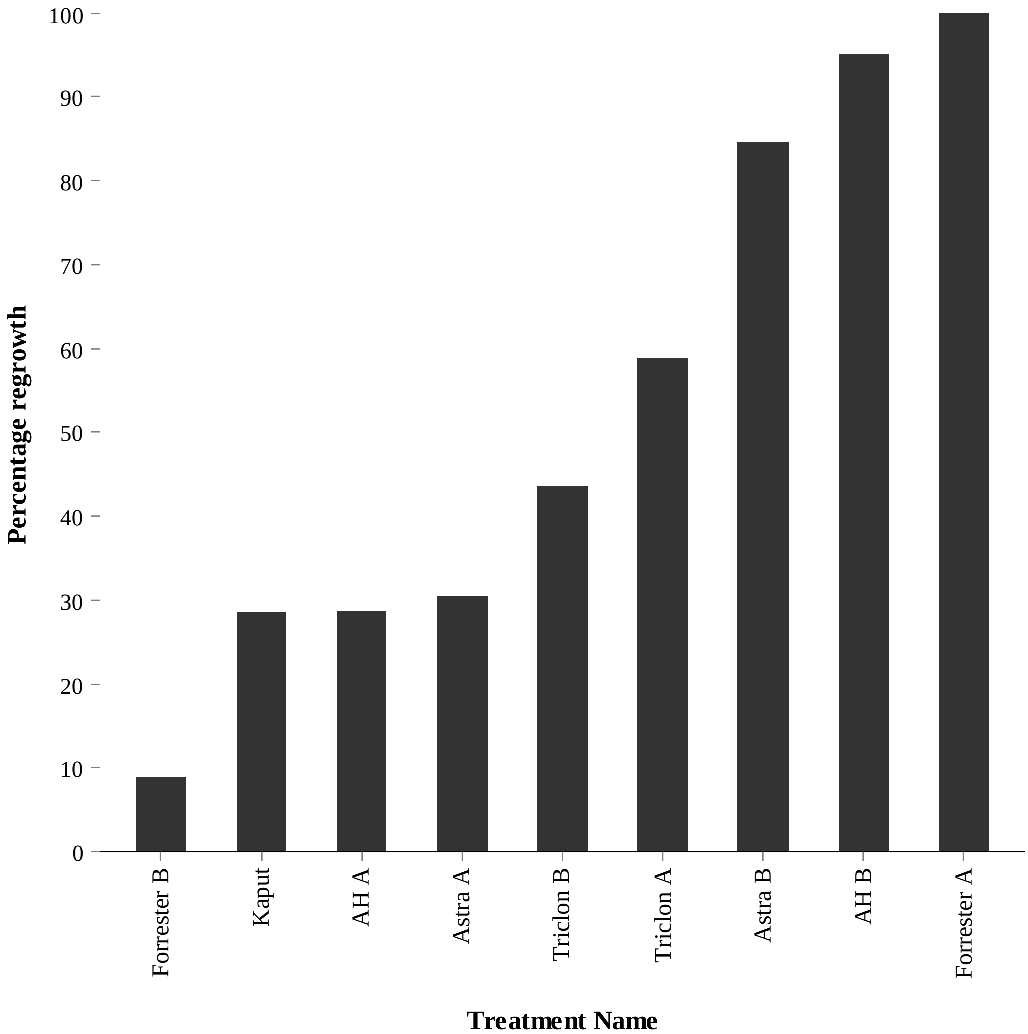


Figure 5.22: Percentage regrowth of herbicide trials. Trade names are indicated together with the plot treatment number, except for the case of Kaput. For treatments see Table 4.2.

Similar results were obtained from the cut-stump treatment (Kaput® 100 Gel) where only 29% regrowth was observed. In these cases it was easy to see any regrowth that had taken place after treatment (Figure 5.23). Thus, it would appear that there are at least threeeffective herbicides with which to control *Berberis julianae* and which, when combining both foliar-spray and cut-stump treatments, could be used to effectively manage the spread of this species.

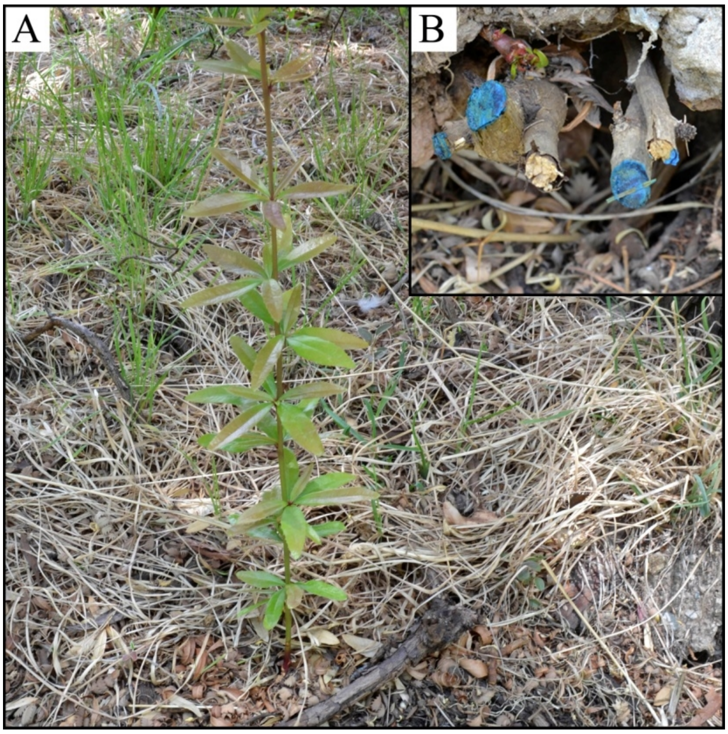


Figure 5.23: Visible regrowth from a specimen that was cut down and treated with glyphosate gel. A) A shoot emerging from the root stock of the plant after it was treated and B) a few of the cut stumps that were treated with the herbicide (blue colouring).

Chapter 6: Discussion

6.1. Existing populations

6.1.1. *Berberis aristata*

The first known record of *Berberis* for the WSF study area was collected in 1942 (J37979, J). The original identification for the species was given as *Berberis heteropoda*. Also, no locality data is given on the sample except for "Woodbush TVL" (with TVL being an acronym for Transvaal, the old province in which the now provinces of Gauteng, Limpopo, North West and Mpumalanga were combined). Since *B. aristata* is the only known naturalized *Berberis* species currently in this area it is suspected that the mentioned herbarium record might actually be the latter species instead of *B. heteropoda* and would potentially have been the original source and start of the WSF population.

If the species indicated in the herbarium record was indeed *Berberis aristata* it means that the WSF population has been expanding for 84 years, seemingly too long to regard it as an invasive threat. This is not uncommon however, since estimates have placed the time from introduction to naturalization of woody perennials to be over a 100 years (Caley, 2008). The more important consideration should be that the population is expanding, albeit slowly, and should it be left to continue it can still enter the phase of rapid exponential increase (Groves, 1999; Mack *et al.*, 2000; Wilson *et al.*, 2013) where after it will take considerable time, effort and money to control it (Rejmánek & Pitcairn, 2002; Le Roux *et al.*, 2010). It should be noted however, that since the herbarium record cannot be linked directly with the WSF population with certainty, the aforementioned conclusion regarding the potential age of the population remains speculative at best.

In the picnic sections there are four large specimens. These plants might have served as sources of introduction for the population together with the aforementioned herbarium record. As mentioned, since this cannot be proven with certainty, this statement remains speculative. However, the fact remains that individuals are surviving and reproducing considerable distances from the main population (Figure 5.4). According to Richardson *et al.* (2000) this population can therefore be classified as invasive (category D2 *sensu* Blackburn *et al.* [2011], "self-sustaining population in the wild, with individuals surviving and reproducing a significant distance from the original point of introduction", where it is assumed that the point[s] of introduction is [are] located within the main population).

Some parts of the site are highly invaded with the species (Figure 6.1), including the picnic area and part of the plantation. Thus, the species already impacts on leisure activities and economic aspects of the plantation, since in both cases the specimens need to be cleared before the commencement of such activities (e.g. fishing and camping for the picnic site and commercial timber/log harvesting for the plantation sections).

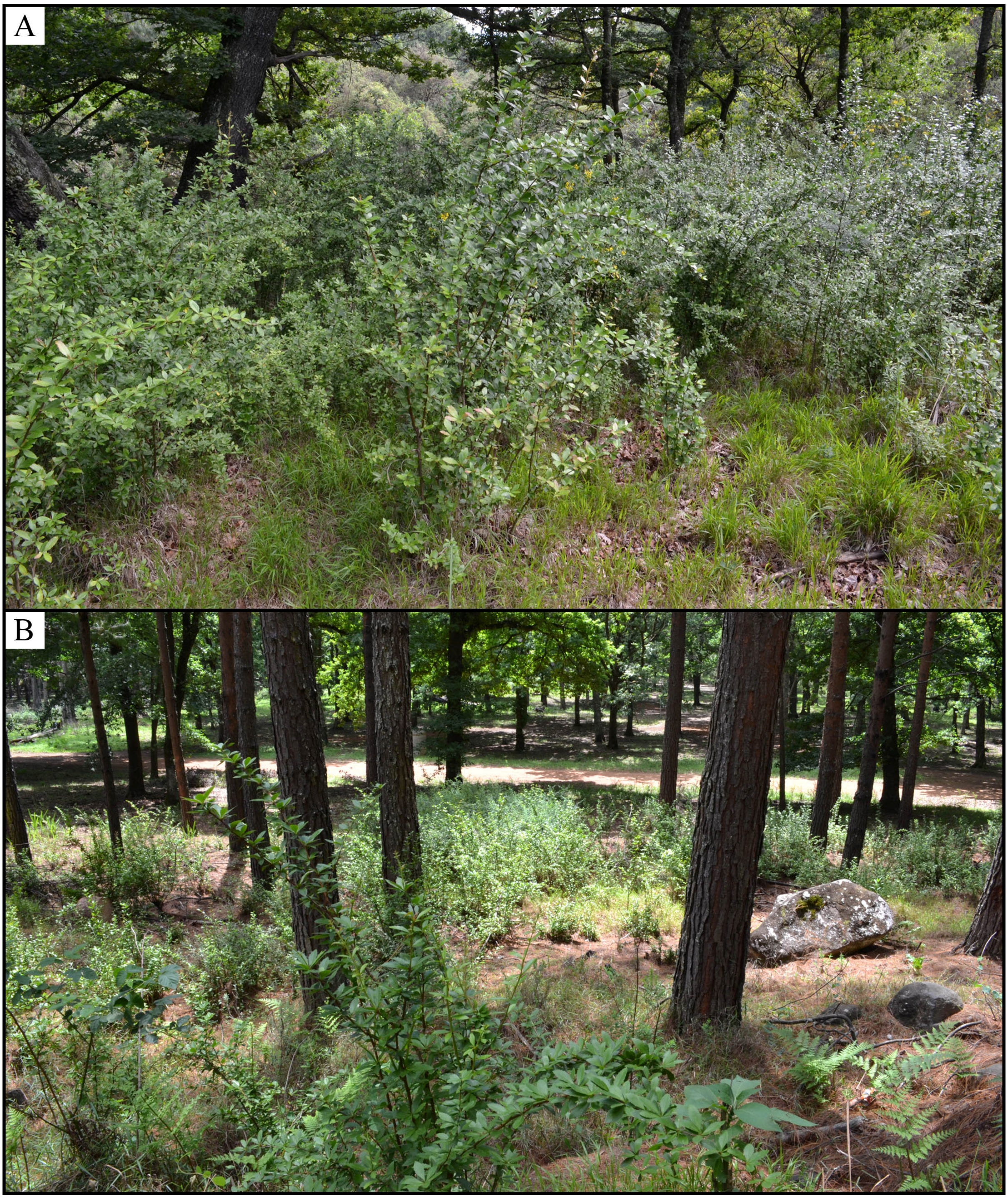


Figure 6.1: The invasive population of *Berberis aristata* in the Woodbush Forest Reserve showing A) a particularly dense stand in a piece of semi-natural vegetation next to the Broederstroom River and picnic site and B) a stand that is invading part of the plantation.

Species that are known to be invasive elsewhere should receive higher prioritisation for early detection and eradication planning (Wittenberg & Cock, 2001) since the "weed elsewhere" question serves as an accurate predictor of invasion in a new habitat (Gordon *et al.*, 2008). Since *Berberis aristata* has been classified as invasive in Australia (Randall, 2001; Randall,

2012) it should receive a high prioritization here in South Africa seeing that it is documented to have the potential to become a problematic species.

As a general rule IAPs that occupy an area greater than 1 000 ha are thought to no longer be feasible targets for eradication (Rejmánek & Pitcairn, 2002) and therefore biological control remains the only effective long-term solution for management. However, populations that have a large extent of occurrence may still have a relatively small area of occupancy (Rejmánek & Pitcairn, 2002; Wilson *et al.*, 2014), meaning that control should be related to condensed area instead of total area. Eradication of populations that occur over less than 1 ha is usually possible and those that range from 1 to 100 ha are still highly likely (Rejmánek & Pitcairn, 2002). Considering that the population at WSF occupies an area of approximately 115 ha it marginally falls outside the range given by Rejmánek & Pitcairn (2002). Furthermore, since the population only occupies 1.58 condensed canopy ha it has a high potential for eradication.

6.1.2. *Berberis julianae*

Horticultural species/cultivars are often claimed to be sterile (Lehrer *et al.*, 2006). Such cultivars are more often than not created and propagated vegetatively instead of by seed, since it takes much longer to do the latter (Knight *et al.*, 2011). As a consequence their offspring do not breed "true" and thus the cultivars *per se* do not necessarily invade, but their offspring might (Knight *et al.*, 2011). These cultivars with "reduced fertility" are often marketed to the public as less invasive but without scientific evidence (Knight *et al.*, 2011). Several cultivars of *Berberis julianae* exist and the current study questions the 'non-invasive' nature of them. The earliest record of *B. julianae* in cultivation in South Africa is 1944 (90002374, PRE). Numerous other herbarium and nursery records exist for this species (Figure 5.12 and Figure 5.13) and are indicative of the fact that it is a popular landscaping and garden specimen, having been cultivated in South Africa for at least 70 years. Despite its long residence time, the distribution of *B. julianae* remains limited compared to other invasive species (for example Australian *Acacia* spp.).

In the case of the *Berberis julianae* population at GGHNP three potential source plants were identified (Figure 5.2), having been planted among the chalets and offices. Since *B. julianae* is a very popular horticultural and landscaping specimen, it is believed that the planted species might have been of reduced fertility. However, as some viable seeds were spread towards the site of invasion (banks of the Little Caledon River, Figure 6.2), most likely by birds (Silander & Klepeis, 1999), these offspring established and started to recruit the next generation of plants.

Taking into account the fact that the population has spread significant distances from the point of introduction it can be classified as category D1 *sensu* Blackburn *et al.* (2011) ("self-sustaining population in the wild, with individuals surviving a significant distance from the original point of introduction"), considering that there are known source plants and that it is not yet possible to determine whether or not their removal will cause a decline in the population or not. This also means that it can be regarded as invasive *sensu* Richardson *et al.* (2000) since it has spread more than 100 m from the original point of introduction in less than 50 years.

Figure 6.2: *Berberis julianae* occurring at the Glen Reenen rest camp. A) Emerging seedlings, B) an individual growing through the crown of an indigenous tree (namely *Leucosidea sericea*) and C) dense riparian vegetation next to the Little Caledon River where the species occurs.

From an ecological viewpoint it is recommended that all specimens of *Berberis julianae* be removed from GGHNP. Reasons for this are firstly that the species has shown potential to interfere with and replace indigenous vegetation. At Glen Reenen it was noted that *B. julianae* has a tendency to start off its life cycle underneath taller vegetation. As it matures it then starts growing through the canopy of its nurse plant(s) and eventually robs the native species of sunlight (Figure 6.2 B), in conjunction with competing for nutrients. Secondly, the species possesses the ability to alter soil chemistry (Speith, 2012). This will have an effect on the native plant community dynamics since below ground soil conditions and interactions play a significant role in determining above ground community structure and composition (Stinson *et al.*, 2006). Thus it has a direct effect on the ecosystem as a whole given that it has the ability to add a new function to the system (Le Maitre *et al.*, 2011). Thirdly, by virtue of its spiny and impenetrable nature it can restrict access when occurring in dense thickets (Speith, 2012). This is of particular importance considering that it is invading the banks of the Little Caledon River. This is an essential water source in the park (see Figure 3.1) and restricted access to this river would negatively impact the fauna of the park. Precautionary measures should be implemented so that *B. julianae* does not spread to the other major river within the park, namely the Klerkspruit River. Currently, the removal of this species from the park should not be difficult since it only occupies an area of 0.42 ha (less than 0.02 condensed canopy ha). This area is well below the 1 ha bottom-line threshold given by Rejmánek & Pitcairn (2002) and local eradication is therefore highly plausible.

One of the vegetation units where IAPs do not yet play an important role is the Drakensberg Wetlands unit (AZf 4) (Mucina & Rutherford, 2011) of which parts occur within GGHNP. A large portion of this unit (~50%) is conserved in statutory protected areas and in principle should not be severely threatened by invasive *Berberis julianae*, since these protected areas are required to control alien species. However, the unit itself is not extensive and it contains a number of biogeographically important and endemic taxa and as such the presence of a new invasive species can threaten the biodiversity levels of the unit. Considering the extraordinary biodiversity within South Africa, the presence of such an invasive species should not be taken lightly.

6.2. Other *Berberis* species in South Africa

Nurseries are prime vectors in terms of increasing plant naturalizations and invasions (Mack, 2000), with factors such as a longer length of time that species are sold, higher number of nurseries selling the species and lower price of their seeds increasing the invasion success of introduced species (Dehnen-Schmutz *et al.*, 2007). The majority of alien species of several regions are therefore a result of horticultural introductions (Mack & Erneberg, 2002;

Pyšek *et al.*, 2002) and local market outlets as repeat introducers of species are often overlooked (Mack, 2000; Kowarik, 2003).

Of notable interest is that the species *Berberis darwinii*, *B. thunbergii* and *B. vulgaris* are represented by herbarium records (i.e. previously cultivated) (Figure 5.13) and are stocked by certain nurseries/private growers (i.e. currently cultivated) (Figure 5.12). Herbarium records showed that these species have all been cultivated for a long time in South Africa, with *B. darwinii* having been cultivated for over 45 years (90020441, PRE, 1966), *B. thunbergii* for at least 60 years (90002397, PRE, 1954) and *B. vulgaris* for over 50 years (H95, NBG, 1961). All three of these species have been documented as being invasive in other countries (DeGasperis & Motzkin, 2007; McAlpine & Jesson, 2008; Randall, 2012). As already mentioned, higher prioritization should be given to species that are known to be invasive elsewhere in terms of early detection and eradication planning (Wittenberg & Cock, 2001). Since no invasive populations have yet been found of any of the three mentioned species, they are prime targets for inclusion in watch lists (Faulkner *et al.*, 2014) and their whereabouts should ideally be investigated further.

Owing to its association with black stem rust *Berberis vulgaris* has the potential to wreak havoc on wheat production if it should become an invasive (or even just naturalized) species in the country (Jin, 2011). *Berberis darwinii* and *B. thunbergii* have already had significant negative impacts on native ecosystems abroad and pose a serious threat for biodiversity in South Africa. Numerous cultivars also exist of *B. thunbergii* and as noted these cultivars are not always as sterile as they are claimed to be (Knight *et al.*, 2011). In fact, two cultivars of *B. thunbergii* have been shown to exhibit a significant germination capacity, namely *B. thunbergii* var. *atropurpurea* and *B. thunbergii* "Rose Glow" (Lehrer *et al.*, 2006). The latter species was found to be the third most widely stocked cultivar in the country (Figure 5.12), while the former is also a popular garden plant. The potential for the mentioned cultivars (and possibly others) of also becoming invasive in the future should not be overlooked.

All three of the aforementioned species, including the cultivars, should be included in early detection programmes so that their potential naturalization can be detected timeously.

Another species that has occasionally been found to escape cultivation is that of *Berberis wilsoniae* (Sykes, 1982; Randall, 2012), for example in New Zealand. This species was found to still be cultivated in private nurseries (pers. obs. at Heritage Plants Nursery and in front of Helshoogte men's residence, Stellenbosch University) and is represented by a single herbarium record (90002405, PRE, no date given) (potentially a second record that was only labelled as "*Berberis*" [25460, J, 1951]). This species has not yet been found to be invasive elsewhere and as such should not be a cause for concern. However, it would be good practice to at least include this species on a watch list (Faulkner *et al.*, 2014).

It is unfortunate that the query regarding a potential *Berberis glaucocarpa* was never resolved with the respective stockist. This is a prohibited species according to NEMBA and as such is illegal to be imported into South Africa. It is a widespread invasive species in New Zealand (Wotherspoon & Wotherspoon, 2002; Waipara *et al.*, 2005) and of greater concern is that the rust fungus *Puccinia graminis* has been found occurring on it (Waipara *et al.*, 2005), meaning that it is susceptible to infection by this pathogen. Its seeds are also known to be well dispersed by rodents (Williams *et al.*, 2000). Thus, when considering its invasion history elsewhere it can be reasonably concluded that it has the potential to invade in South Africa (Gordon *et al.*, 2008) and this coupled to its susceptibility to stem rust can make it a threat not only to native ecosystems but to the agricultural industry as well. It is highly recommended that the potential presence of this species within the South African nursery industry should be investigated further.

6.3. Habitat suitability in a climatic context

Numerous workers have, in the process of modelling the habitat suitability of invasive species, opted to train their models only on the native range of the species and then project them onto the introduced range (Zenni *et al.*, 2009; Geerts *et al.*, 2013; Jacobs *et al.*, 2014; Moodley *et al.*, 2014). While this is sensible, valuable information regarding a species' fundamental niche might be excluded. Failing to take into account the fact that alien species can occupy different climatic niches, when moving into novel environments, can lead to an underestimation of potential invasive ranges (Beaumont *et al.*, 2009). Barriers such as dispersal and competition can restrict a species from realizing its fundamental niche more fully in its native range than in an invaded range (Kriticos & Randall, 2001; Mau-Crimmins *et al.*, 2006). Thus it is best to use occurrence data from an IAPs' native and introduced range when modelling potential habitat/climatic suitability (Mau-Crimmins *et al.*, 2006). The models presented here were developed with data from both native and introduced ranges (as in Kaplan *et al.*, 2012) and therefore includes the possibility of potential niche shifts.

With regards to *Berberis aristata*, the habitat suitability model indicated large areas of South Africa are climatically suitable for its establishment (Figure 5.18). Specifically, it seems that the species has its highest potential suitability in the more mountainous areas in South Africa, which makes sense since the species occurs naturally in the Nepalese mountains (i.e. the Himalayas). The model also had a high predictive performance, more so than for *Berberis julianae*.

The situation regarding *Berberis julianae* is similar to that of *B. aristata* in that a relatively large part of South Africa is climatically suitable for the species (Figure 5.20). A difference between the models is that *B. julianae* seems to be more suited to the interior parts of the country. The model for *B. julianae* did not have such a high predictive performance as *B. aristata* and only had a fair AUC value (Swets, 1988). Nevertheless the indication of potentially suitable areas is an invaluable tool for investigating the potential presence of more invasive populations.

For both species the future models predicted a decrease in potentially suitable areas (Figure 5.19 and Figure 5.21). While from a management perspective it might seem relieving that the potential areas open for invasion will decrease in future, the suitable areas still occupy a significant portion of the country.

Although both species do not yet occupy a substantial geographical range in South Africa, the climatic suitability of many areas in the country indicates that both species pose a high invasion risk.

6.4. Management considerations and invasion potential

Seeds of *Berberis julianae* collected from GGHNP showed a very high germination success. It has been reported that *Berberis* seeds can lie for several years in the soil before germinating (Campbell & Long, 2001). Thus, even if the population at Glen Reenen were to be cleared, follow up inspections would be of the utmost importance to prevent the recruitment of a new generation and subsequent re-establishment of the population. Further investigation is also needed in terms of the sterile nature of all cultivars of this species as claimed by nursery stockists. An interesting opportunity exists to study the effects of the clearance at the Glen Reenen rest camp since the three suspected source plants were cut down and treated with herbicides during the trial clearings. Thus, in theory there is no longer a large source of propagules that can aid the spread and sustainability of the invasive population. If the population continuous to expand and persist, then it has become self-replaceable and would therefore have to be upgraded from category D1 to D2 *sensu* Blackburn *et al.* (2011). At this point it should be given a high priority for control.

A few factors would strongly suggest that other invasive *Berberis julianae* populations exist in South Africa. Firstly, a total of 14 herbarium records exist for *B. julianae* in cultivation (Figure 5.15) and are spread across three provinces, viz. Free State, Gauteng and North West. Together with this the nursery survey revealed that the species is also currently stocked in the KwaZulu-Natal and Western Cape provinces (besides being stocked in Gauteng and Free State), thereby bringing the total number of provinces in which the species is currently or has been cultivated in to five. As a consequence numerous nascent foci exist that serve as sources of propagules that can contribute to the establishment of invasive populations (Moody & Mack, 1988; Wilson *et al.*, 2014).

Secondly, although surveys conducted in the Underberg region (KwaZulu-Natal) failed to yield the presence of an existing invasive *Berberis julianae* population, four naturalized individuals were found. This is in support of the high seed viability that was found to be exhibited by *B. julianae* at the Glen Reenen rest camp. Thus, the high germination success of *B. julianae* seeds coupled with bird dispersal (Silander & Klepeis, 1999) constitutes a combination that is conducive for the establishment of new populations.

Thirdly, *Berberis julianae* has been cultivated in South Africa for at least 70 years (possibly even longer). This combined with its high germination capacity and widespread cultivation allows ample time for more populations to have been established in South Africa. Together with this, bioclimatic modelling indicated that substantial parts of the country are climatically suitable for the establishment of the species.

In light of the aforementioned this species is not proposed to be a target for a national eradication attempt since the possibility exists that more invasive populations will be found. Before enough time has been allowed to confidently ascertain whether or not more populations exist, the population at Glen Reenen cannot be considered the only existing invasive stand (excluding the minor occurrences at Alma). Also, being a widely cultivated garden species it contributes to the country’s economy via the horticultural industry. In any case, even if all naturalized/invasive populations were to be eradicated there are simply too many specimens that exist in towns and cities (in gardens, parks etc.) for the species to be declared eradicated nationally. Instead, eradication will have to be localized, for example the elimination of all specimens and propagules from GGHNP. The species was rejected with a high score in the AWRA and consequently poses an invasion risk to the country is. It is therefore proposed that *Berberis julianae* be classified as category 1b in the National Environmental Management Biodiversity Act in non-urban areas, while not being listed in urban areas (see Appendix B for NEMBA categories).

Concerning *Berberis aristata*, there are a couple of factors suggesting its eradication from South Africa is a realistic goal. Firstly, only a single population is currently known to exist within South Africa, namely in WSF. This population does have a considerable extent of occurrence (115 ha), thereby warranting significant effort should an attempt be made. The challenging nature of the terrain (steep slopes and a thick layer of pine needles) would also contribute to the challenge of eliminating the species. However, the majority of the population is localized (Figure 5.4 and Figure 5.5) and thus a concentrated effort on a small area will have a considerable impact on the greater part of the population. Considering that the current population of *B. aristata* covers only about 115 ha, an attempted eradication would seem to potentially have promising results seeing as the eradication of IAPs populations ranging from 1 to 100 ha is highly probable (Rejmánek & Pitcairn, 2002).

Secondly, not one of the nurseries contacted during the nursery survey was found to stock/sell the species (Figure 5.12). Taking into account the fact that many nurseries remain that were not contacted during the survey and also that there are numerous private growers and collectors, the possibility that this species might be under cultivation somewhere in the country cannot be excluded. However, if the species had been cultivated for many years then there would have been a higher probability of at least a few herbarium records documenting its cultivation. Yet only one probable record of this species was found to be housed in a South African herbarium (J37979, J, 1942). And since this particular specimen has its locality recorded as “Woodbush”, it gives all the more credibility to the assumption that the WSF population is the only one of *Berberis aristata* in South Africa. Awareness material in the form of electronic and printed pamphlets regarding various *Berberis* spp. that were distributed did not yield information as to potential new sites of this particular species.

Thirdly, based on the clearing trials conducted for *B. julianae* it seems that there are very effective herbicides available that can be used for the control of *Berberis* spp.

Finally, the seed viability for *Berberis aristata* was very low and as such there is not a big chance that the population will be able to re-establish quickly from the seed bank once it has been cleared.

The predicted habitat suitability of *Berberis aristata* justifies an eradication attempt, since large areas are predicted to be potentially suitable for this species, both currently and in the future (Figure 5.18 and Figure 5.19). Why it has not spread to such an extent given the amount of time that it has possibly been in existence in WSF (approximately 72 years with current date as reference) remains unexplained. The population occurs in the very mountainous region of Magoebaskloof, which may present a form of dispersal barrier. However, this might seem a bit unlikely when considering that *Berberis* seeds are bird dispersed (Silander & Klepeis, 1999) and as such propagule dispersal would not necessarily be restricted by mountains. Considering the high score at which the species was rejected by the AWRA, the risk that this species poses is obvious and further justifies an eradication campaign.

If an eradication attempt on *Berberis aristata* was to be successful it would reduce the country's national invasion debt as one of the benefits (Wilson *et al.*, 2013) together with the conservation of native biodiversity. Such eradication would however also be a major milestone for plant invasion biology in South Africa, since there has not yet been any known successful plant eradication up to date in the country despite several attempts (Wilson *et al.*, 2013). In fact, only two known successful eradication attempts of any invasive species have been made by South Africa, namely that of domestic cats from the sub-Antarctic Marion Island (Bester *et al.*, 2002) and the Mediterranean snail (*Otala punctata*) from Cape Town (Herbert & Sirgel, 2001). Considering the spatial limitation of *B. aristata* and the fact that it is not stocked by the nursery industry in South Africa, this is definitely an achievable goal. Also, when taking into account its invasion history elsewhere (Randall, 2012) together with the high score with which it was rejected by the AWRA, it can be concluded that this species poses a significant invasion risk in the country.

In light of this and the results found in this study, it is therefore strongly recommended that *Berberis aristata* be classified as a category 1a invasive species in the National Environmental Management Biodiversity Act, thereby effectively prohibiting any further breeding, growing, moving and selling of the species and requiring compulsory control of any existing specimens/populations.

The resprouting nature of both *Berberis aristata* and *Berberis julianae* can potentially add a level of difficulty to their control and as such any population treated with herbicides should receive regular follow-ups to detect any regrowth that has taken place since initial treatment.

Further investigations on invasive *Berberis* spp. populations should have a strong focus on the KwaZulu-Natal province since it has the highest diversity of *Berberis* species/cultivars stocked by nurseries/wholesale-/private growers (Figure 5.16).

Chapter 7: Conclusion

Until the current study, the status of *Berberis* in South Africa as potential emergent invasive species was not known. The only data that was available were a few reported localities. Some of these localities were outdated and supplied with wrong geospatial information. This study found existing populations of *B. aristata* and *B. julianae* and also established the presence of three other *Berberis* spp. in South Africa (i.e. *B. darwinii*, *B. thunbergii* and *B. vulgaris*) that have become widespread invasive species elsewhere in the world. In total 30 different *Berberis* species/cultivars/hybrids were found to have been under historic or current cultivation in South Africa. None of these have been listed officially under the Conservation of Agricultural Resources Act (1983/2001), while only *B. thunbergii* has been listed as category 3 in the National Environmental Management Biodiversity Act (10/2004).

Invasive species should be controlled from as early as possible in order to use available resources as effectively as possible. Both *Berberis aristata* and *B. julianae* can be considered to be in the lag phase of the invasion process, meaning that they have not yet started to exponentially increase in their invasive range size. Thus, both of these species are prime targets for invasive species management programs.

Both species are also good candidates for eradication, since both can be considered to have been detected early enough *sensu* Simberloff (2003), i.e. before they have started to spread. However, due to the economic importance of *Berberis julianae* (i.e. being a popular garden specimen) only *B. aristata* should receive a high priority for eradication. Furthermore, it is highly recommended that *B. aristata* be listed as category 1a under NEMBA while *B. julianae* be listed as category 1b in non-urban areas and not listed in urban areas.

Since South Africa has not yet had a single successful plant eradication up to date, the potential successful eradication of *Berberis aristata* from the country can be a first for invasion biology in South Africa. It will also be of international significance since many eradication attempts on invasive species have been made but few have been successful. This study has highlighted the need to conduct in depth investigations into potential emergent invasive species so as to yield a proper assessment on invasion risk.

As mentioned, at least three other potential invasive *Berberis* species are currently cultivated in the country and these species should be assessed further for the potential invasion risk that they pose. Their existence in the horticultural industry should be investigated and is of great economic importance, especially considering the fact that one of them, namely *B. vulgaris*, is an alternate host for the destructive black stem rust of wheat (*Puccinia graminis* Pers. f. sp.

tritici). These species should not be allowed to spread to the same extent in South Africa as they have done in other countries and their continuous monitoring, as with all potential invasive species, should be of the utmost importance. The opportunity exists now to prevent any species in the genus *Berberis* from becoming widespread invasives within South Africa.

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Appendix A Definitions

[Abbreviations: cf. = compare; syn. = synonym]

Alien Applied to taxa that owe their presence to the direct or indirect, intentional or accidental, activities of humans (Rejmánek *et al.*, 2006; Richardson *et al.*, 2000); syn. *exotic, non-native*.

Casual A term used for alien species when they are only able to persist temporarily in a new environment without a human-assisted input of diaspores and which are unable to form self-replacing populations, even though they might flourish and reproduce occasionally (Rejmánek *et al.*, 2006; Richardson *et al.*, 2000); cf. *naturalized* and *invasive*.

Diaspore A term pertaining to the dispersal units of plants (seeds, fruits, spores, rhizomes, bulbils etc.). Can be either of a vegetative or non-vegetative (i.e. sexual) nature (Rejmánek *et al.*, 2006); syn. *propagule*.

Eradication The elimination of every single individual of a species (including all diaspores) from a geographical region such that a reinvasion/re-colonisation is highly improbable (Wilson *et al.*, 2013; Myers *et al.*, 1998).

Exotic See alien.

Indigenous See native.

Invasive Applied to naturalized taxa that produce reproductive offspring at substantial distances from parent plants and thus have the potential to spread over considerable areas without the aid of humans (Rejmánek *et al.*, 2006; Richardson *et al.*, 2000); cf. *casual* and *naturalized*.

Native Applied to taxa that were not introduced into a region via direct or indirect activities of humans (Rejmánek *et al.*, 2006); syn. *indigenous*.

Naturalized Pertaining to taxa that form stable populations and reproduce consistently over many life cycles without the aid of humans, but which do not necessarily spread and invade natural, semi-natural or human-made ecosystems (Rejmánek *et al.*, 2006; Richardson *et al.*, 2000); cf. *casual* and *invasive*.

Non-native See alien.

Noxious Applied to a subset of particularly harmful weeds whose control and/or eradication is mandatory (the term is often used in the USA, Australia and New Zealand) (Pyšek *et al.*, 2004).

Propagule See diaspore.

Transformer(s) A subset of *invasive plants* which change the character, condition, form or nature of ecosystems over a substantial area relative to the extent of that ecosystem (Richardson *et al.*, 2000). They have clear ecosystem impacts and several categories may be distinguished:

a. Excessive users of resources
b. Donors of limiting resources
c. Fire promoters / suppressors
d. Sand stabilizers
e. Erosion promoters
f. Colonizers of intertidal mudflats / sediment stabilizers
g. Litter accumulators
h. Salt accumulators / redistributors

Weed(s) Plants (not necessarily *alien*) that grow in sites where they are not wanted and which usually have detectable economic and/or environmental effects (Richardson *et al.*, 2000); also referred to as *plant pests*, *harmful plants* and *problem plants*.

Appendix B CARA and NEM:BA Categories

Three categories are recognised within the Conservation of Agricultural Resources Act, 1983/2001 (**CARA**):

Category	Description
1	Species that are prohibited and which must be controlled or eradicated, except in biocontrol reserves which serve as sources for the breeding of their biocontrol agents.
2	Invader species with certain useful qualities that may be planted under permit in demarcated areas under controlled conditions, except within 30 m of a one-in-fifty year flood line.
3	Alien plants that are proven invaders and from which further plantings and trade in propagative material is prohibited, but existing specimens are allowed to remain.

Four categories are recognised within the National Environmental Management: Biodiversity Act, 10/2004 (**NEM:BA**):

Category	Description
1a	Emerging invasive species that are high priority and require compulsory control. Breeding, growing, moving and selling of these species are banned.
1b	Invasive species that are already widespread and are required to be controlled by an invasive species management programme. Breeding, growing, moving and selling of these species are banned.
2	Species which require a permit to carry out a restricted activity within an area specified by the permit (e.g. plantations). No person may carry out such an activity without a permit. All spread of such species outside the specified area must be controlled. Species listed under this category that occur outside the specified areas of the permit are considered to be under category 1b.
3	Species that are allowed to remain where they are planted except when they occur in riparian areas, whereby they are then considered to be under category 1b. If a Species Management Programme has been developed for such species then they must be controlled in accordance with such a programme. Any further plantings and trade in propagative material is prohibited.

References: Bromilow (2010), South African Department of Environmental Affairs and Tourism (2014).

Appendix C Awareness Material

HAVE YOU SEEN THIS PLANT?

Berberis

Berberis thunbergii

environmental affairs
Department: Environmental Affairs
REPUBLIC OF SOUTH AFRICA

SANBI
Biodiversity for Life

EXPANDED PUBLIC WORKS PROGRAMME
CONTRIBUTING TO A NATION AT WORK

WORKING FOR WATER

What you can do to help

If you've seen a naturally occurring population of *Berberis* (i.e. not planted in a garden), please let us know. To assist with the management of *Berberis* please provide us with the following information where possible:

- **The locality** — preferably supply GPS information (coordinates) of the population, otherwise give directions to the population in relation to the nearest farm, district or town and supply any landmarks that will help us locate the plants
- **A photograph** of the population and/or individual plants
- **The population size** — give a rough estimate of the surface area of invasion/number of plants in the population (for example: less than 50, more than 500, between 100 and 200 etc.)

Contact details

The Invasive Species Programme: Early Detection and Rapid Response relies on the awareness and sharp eyes of you and others to achieve its success. If you see this invasive plant, please get in touch with us so that the infestation can be included in the overall management plan. For help in identifying species, visit www.ispot.org.za

Gauteng & Free State Regional Coordinator:
Ms Dan'sile Cindi
Tel: 012 843 5152
Cell: 083 235 6787
E-mail: d.cindi@sanbi.org.za

Research Scientist
Mr Jan-Hendrik Keet
Tel: 071 451 4853
E-mail: jhkeet@hotmail.com
Alternatively for more information please email us at invasivespecies@sanbi.org.za

The South African National Biodiversity Institute (SANBI) is mandated to conserve South Africa's rich biodiversity. Its Invasive Species Programme: EDRR, funded by the Department of Environmental Affairs, aims to reduce the threat of biological invasions through detection, identification assessment and management of invasive species that may be contained or eradicated.

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About *Berberis*

Several species of *Berberis* are popular garden shrubs with ornamental features including: attractive leaves, yellow flowers and red or blue-black berries. Low-growing *Berberis* plants are also commonly planted as pedestrian barriers. Taller-growing species are used as hedges to provide security to properties as these very dense, viciously spiny shrubs make very effective barriers impenetrable to intruders. Invasive *Berberis* species can have negative environmental impacts such as altering soil chemistry, lowering veld carrying capacity, serving as alternate hosts for stem rust of wheat and preventing access to watercourses when occurring in dense thickets. There are approximately 450 – 500 species of *Berberis*. Featured below are *B. julianae*, *B. thunbergii*, *B. darwinii*, *B. vulgaris* and *B. aristata*.

Berberis julianae

Wintergreen barberry

The wintergreen barberry is native to central China and was introduced into South Africa for use in borders and hedges due to its spiny nature. Naturalized populations have recently been found in Golden Gate Highlands National Park in the Eastern Free State where it is starting to invade forested habitats that occur in ravines and along watercourses.

What does it look like?

The leaves are clustered at the nodes, have a spiny margin and are dark green in appearance with a leathery texture.

The flowers are yellow and occur in dense clusters.

Photo credits: Jan-Hendrik Keet

Berberis thunbergii

Japanese barberry

The Japanese barberry is a widespread invasive species in the USA, particularly in the forests of the North East, and there is a concern that it might also become a problem in South Africa.

Red fruits of *Berberis thunbergii* 'Atropurpurea'

What does it look like?

The cultivated *Berberis thunbergii* *'Atropurpurea'* has characteristic reddish-purple leaves.

The flowers can be solitary or can occur in clusters (umbels).
Photo credits: Louis–M Landry

Berberis darwinii

Darwin's barberry

Darwin's barberry is native to southern Chile and Argentina. It has invaded a wide range of environments in New Zealand and is a serious threat to indigenous ecosystems and biodiversity conservation. In South Africa, the invasive potential of Darwin's barberry and the threat it poses needs to be assessed and there are concerns that it may be as damaging here as in New Zealand.

What does it look like?

Darwin's barberry has a drooping inflorescence of yellow flowers.

(Photo credits: Dr Zoya Akulova)

The fruits of are bluish-black, round and fleshy.

Photo credits: Dr John Hayden

Berberis vulgaris

Common / European barberry

The common barberry occurs naturally in Europe, North-west Africa and Western Asia. In the USA the common barberry has been linked to failing wheat crops because it serves as alternative host for stem rust (*Puccinia graminis f. sp. tritici*). It is able to invade grasslands, savannas, thickets and dense woodlands or forests. Therefore, the possibility exists for the common barberry to invade indigenous ecosystems of South Africa.

What does it look like?

Yellow flowers of the common barberry.

Photo credits: Dr. Amadej Trnkoczy

Characteristic raceme infructescences showing the bright red, fleshy fruits that appear after flowering.

Photo credits: Dr. Amadej Trnkoczy

Berberis aristata

Indian barberry; Tree turmeric

The Indian barberry is native to the Himalayas and Nepal and has been recorded in the Woodbush Forest Reserve near Tzaneen in the Limpopo province. It has invaded some of the riverbanks and is starting to form dense stands in certain parts.

What does it look like?

Berberis aristata has a drooping, raceme-like inflorescence with yellow flowers.

Photo credits: Jan-Hendrik Keet

Appendix D Bioclimatic Variables

The following table gives a description of the bioclimatic variables that were used during species distribution modelling:

Bio-variable	Description
BIO1	Annual Mean Temperature
BIO2	Mean Diurnal Range (mean monthly max temp - mean monthly min temp)
BIO3	Isothermality (BIO2/BIO7)*(100)
BIO4	Temperature Seasonality (standard deviation*100)
BIO5	Max Temperature of Warmest Month
BIO6	Min Temperature of Coldest Month
BIO7	Temperature Annual Range (BIO5-BIO6)
BIO8	Mean Temperature of Wettest Quarter
BIO9	Mean Temperature of Driest Quarter
BIO10	Mean Temperature of Warmest Quarter
BIO11	Mean Temperature of Coldest Quarter
BIO12	Annual Precipitation
BIO13	Precipitation of Wettest Month
BIO14	Precipitation of Driest Month
BIO15	Precipitation Seasonality (Coefficient of Variation)
BIO16	Precipitation of Wettest Quarter
BIO17	Precipitation of Driest Quarter
BIO18	Precipitation of Warmest Quarter
BIO19	Precipitation of Coldest Quarter

From: WorldClim — Global Climate Data (accessed 06 November 2013 from http://www.worldclim.org/bioclim)

Appendix E Bioclimatic Modelling

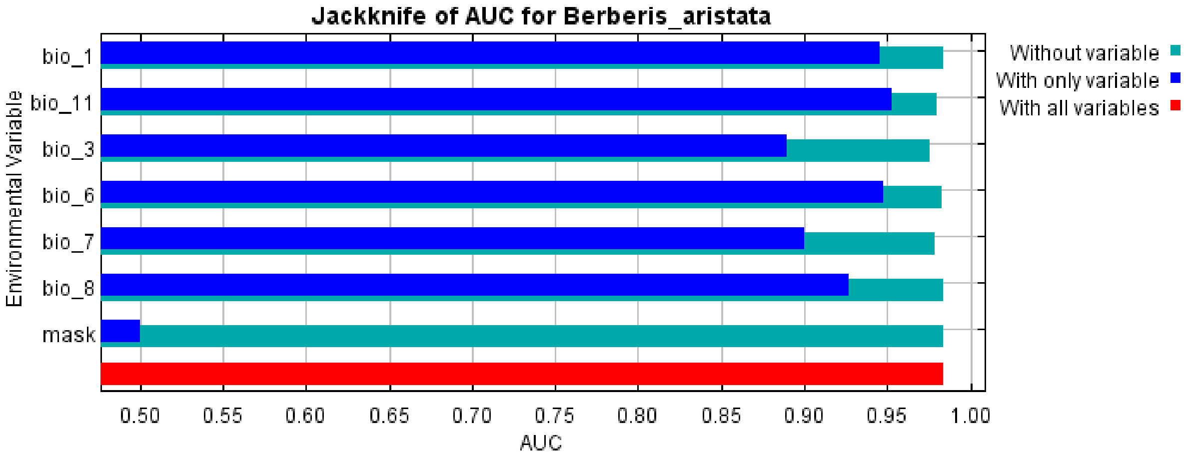

Figure S1: Jackknife evaluations of the relative importance of the predictor variables that were used to develop the MaxEnt habitat suitability model for *Berberis aristata*. Note that the mask predictor was not used in the actual development of the model; rather it served only to restrict the training region from which background samples (i.e. pseudo-absences) were drawn.

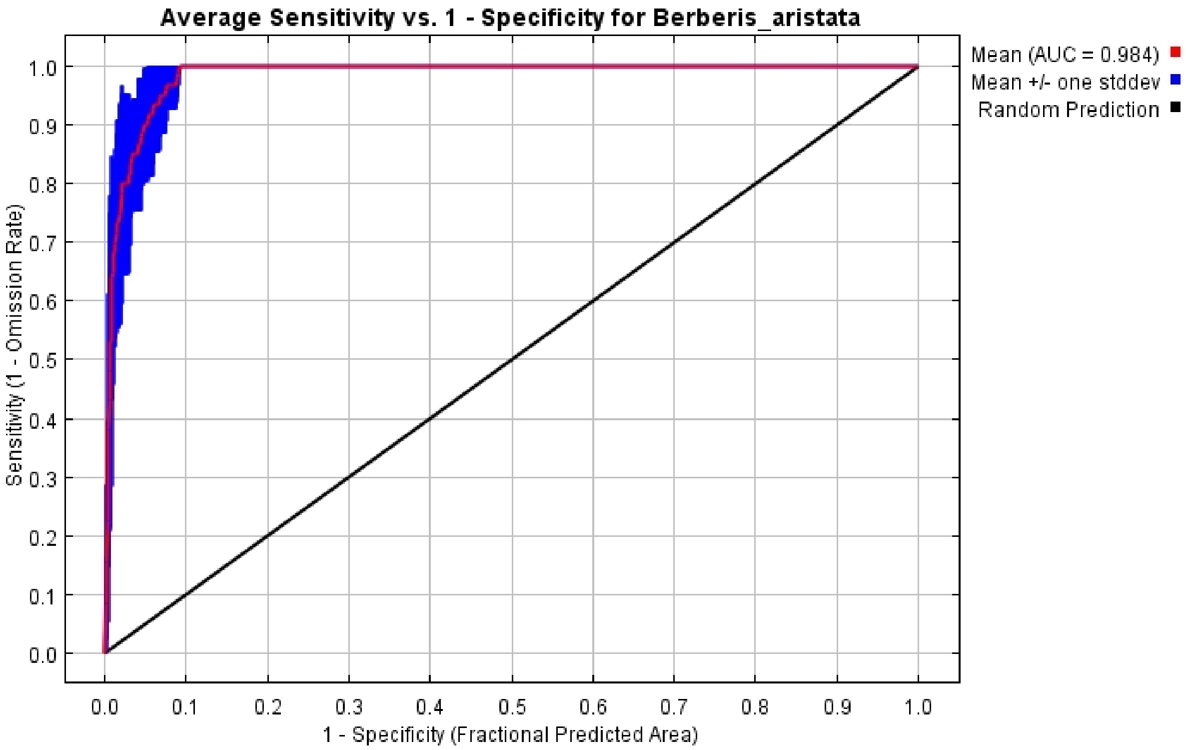

Figure S2: Receiver operating characteristic (ROC) curve for the MaxEnt habitat suitability model of *Berberis aristata*. The curve depicts the mean (red) and unit standard deviation (blue) for a total of 5 replicate runs.

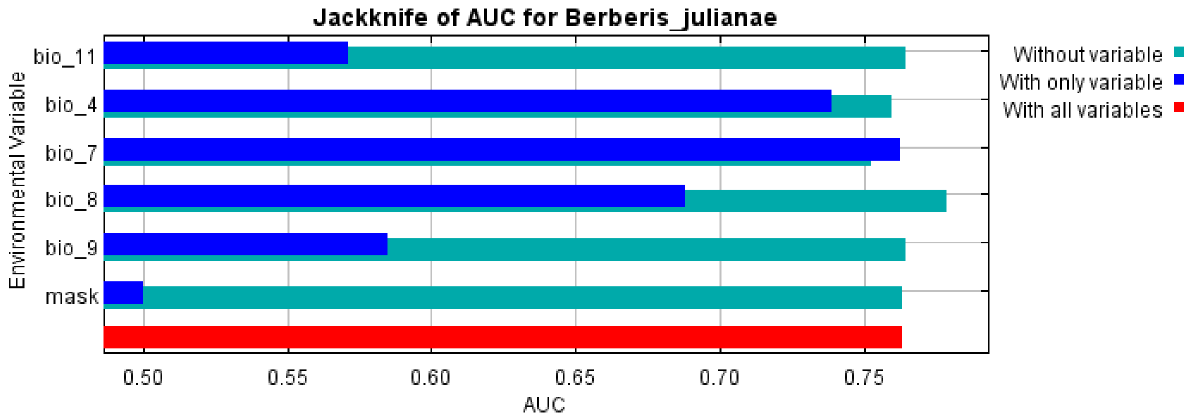

Figure S3: Jackknife evaluations of the relative importance of the predictor variables that were used to develop the MaxEnt habitat suitability model for *Berberis julianae*. Note that the mask predictor was not used in the actual development of the model; rather it served only to restrict the training region from which background samples (i.e. pseudo-absences) were drawn.

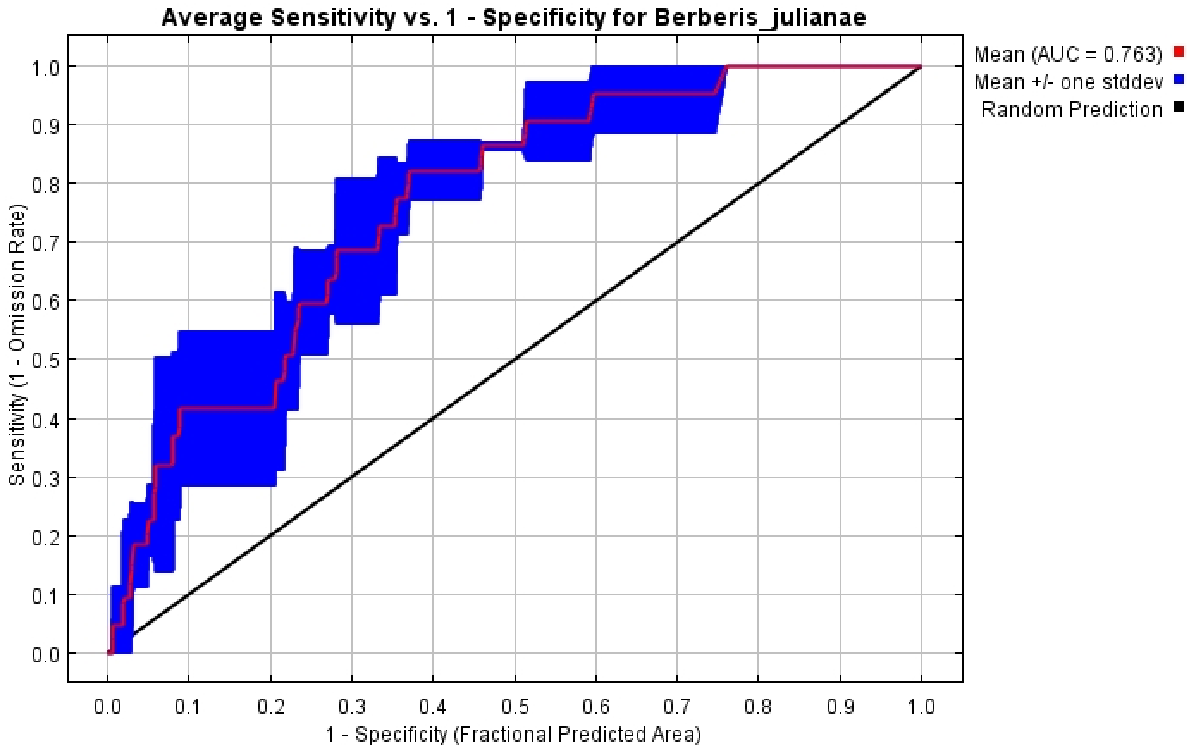

Figure S4: Receiver operating characteristic (ROC) curve for the MaxEnt habitat suitability model of *Berberis julianae*. The curve depicts the mean (red) and unit standard deviation (blue) for a total of 5 replicate runs.

Appendix F Weed Risk Assessment: *Berberis aristata*

Botanical Name	***Berberis aristata***	Outcome	**Reject**
Common Name	**Indian barberry**	Score	**27**
Family Name	**Berberidaceae**	Your Name	**Jan-Hendrik Keet**

		History / Biogeography		Y/N	Ref.	Score
1	Domestication / Cultivation	1.01	Is the species highly domesticated? If 'no' go to 2.01	Y	1,9	-3
		1.02	Has the species become naturalized where grown?	Y	2,9,10,11,12, Results	1
		1.03	Does the species have weedy races?	-	-	
2	Climate and Distribution	2.01	Species suited to South African climates (0-low, 1-intermediate, 2-high)	High	Results	2
		2.02	Quality of climate match data (0-low, 1-intermediate, 2-high)	Intermediate	Results	1
		2.03	Broad climate suitability (versatility)	Y	7 (Köppen Geiger zones)	1
		2.04	Native or naturalized in regions with extended dry periods	Y	Bioclim Data	1
		2.05	Does the species have a history of introductions outside its natural range?	Y	2	2
3	Weed Elsewhere	3.01	Naturalized beyond native range	Y	2,3, results	2
		3.02	Garden/amenity/disturbance weed	Y	9,14,15	2
		3.03	Weed of agriculture/horticulture/forestry	Y	9,10,Results	4
		3.04	Environmental weed	Y	3,9,13,16	4
		3.05	Congeneric weed	Y	4,5,6	2
		Biology / Ecology				
4	Undesirable Traits	4.01	Produces spines, thorns or burrs	Y	results	1
		4.02	Allelopathic	N		0
		4.03	Parasitic	N		0

		4.04	Unpalatable to grazing animals	-	-	
		4.05	Toxic to animals	-	-	
		4.06	Host for recognized pests and pathogens	-	-	
		4.07	Causes allergies or is otherwise toxic to humans	Y	8,9	1
		4.08	Creates a fire hazard in natural ecosystems	N		0
		4.09	Is a shade tolerant plant at some stage of its life cycle	Y	Results	1
		4.10	Grows on infertile soils	Y	17	1
		4.11	Climbing or smothering growth habit	N	Results	0
		4.12	Forms dense thickets	Y	16,Results	1
5	Plant Type	5.01	Aquatic	N		0
		5.02	Grass	N		0
		5.03	Nitrogen fixing woody plant			0
		5.04	Geophyte	N		0
6	Reproduction	6.01	Evidence of substantial reproductive failure in native habitat	-	-	
		6.02	Produces viable seed	Y	Results	1
		6.03	Hybridizes naturally	Y	17	1
		6.04	Self-fertilization	Y	17	1
		6.05	Requires specialist pollinators	N	Bees and sunbirds	0
		6.06	Reproduction by vegetative propagation	Y	19	1
		6.07	Minimum generative time (years)	-	-	
7	Dispersal Mechanisms	7.01	Propagules likely to be dispersed unintentionally	-	-	
		7.02	Propagules dispersed intentionally by people	N	Nursery results	-1
		7.03	Propagules likely to disperse as a produce contaminant	-	-	
		7.04	Propagules adapted to wind dispersal	N	Results	-1
		7.05	Propagules buoyant	-	-	
		7.06	Propagules bird dispersed	Y	18	1
		7.07	Propagules dispersed by other animals (externally)	N	results	-1
		7.08	Propagules dispersed by other animals (internally)	-	-	

8	Persistence Attributes	8.01	Prolific seed production	Y	results	1
		8.02	Evidence that a persistent propagule bank is formed (>1 yr)	-	-	
		8.03	Well controlled by herbicides	Y	16	-1
		8.04	Tolerates or benefits from mutilation, cultivation or fire	Y	17	1
		8.05	Effective natural enemies present in South Africa	-	-	
Number of questions answered: 36 out of 49					**Total**	**27**

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Appendix G Weed Risk Assessment: *Berberis julianae*

Botanical Name	***Berberis julianae***	Outcome	**Reject**
Common Name	**Wintergreen barberry**	Score	**20**
Family Name	**Berberidaceae**	Your Name	**Jan-Hendrik Keet**

History / Biogeography				Y/N	Ref.	Score
1	Domestication / Cultivation	1.01	Is the species highly domesticated? If 'no' go to 2.01	Y	1, 2, 3, results	-3
		1.02	Has the species become naturalized where grown?	Y	Results	1
		1.03	Does the species have weedy races?	-	-	
2	Climate and Distribution	2.01	Species suited to South African climates (0-low, 1-intermediate, 2-high)	1	Results	1
		2.02	Quality of climate match data (0-low, 1-intermediate, 2-high)	1	Results	1
		2.03	Broad climate suitability (versatility)	Y	16 (Köppen Geiger zones)	1
		2.04	Native or naturalized in regions with extended dry periods	Y	Bioclim data	1
		2.05	Does the species have a history of introductions outside its natural range?	Y	1, 2, 3, 4, 5	2
3	Weed Elsewhere	3.01	Naturalized beyond native range	Y	2, Results	2
		3.02	Garden/amenity/disturbance weed	Y	6	2
		3.03	Weed of agriculture/horticulture/forestry	-	-	
		3.04	Environmental weed	Y	5 ,Results	3
		3.05	Congeneric weed	Y	7, 8, 9, 10	2
Biology / Ecology						
4	Undesirable Traits	4.01	Produces spines, thorns or burrs	Y	3, 11, results	1
		4.02	Allelopathic	-	-	
		4.03	Parasitic	N		0

		4.04	Unpalatable to grazing animals	Y	5, results	1
		4.05	Toxic to animals	-	-	
		4.06	Host for recognized pests and pathogens	-	-	
		4.07	Causes allergies or is otherwise toxic to humans	-	-	
		4.08	Creates a fire hazard in natural ecosystems	-	-	
		4.09	Is a shade tolerant plant at some stage of its life cycle	Y	5, 11, results	1
		4.10	Grows on infertile soils	Y	5, 11	1
		4.11	Climbing or smothering growth habit	N	Results	0
		4.12	Forms dense thickets	Y	5, 11	1
5	Plant Type	5.01	Aquatic	N	Results	0
		5.02	Grass	N	Results	0
		5.03	Nitrogen fixing woody plant	Y	5	1
		5.04	Geophyte	N	Results	0
6	Reproduction	6.01	Evidence of substantial reproductive failure in native habitat	-	-	
		6.02	Produces viable seed	Y	Results	1
		6.03	Hybridizes naturally	Y	12	1
		6.04	Self-fertilization	-	-	
		6.05	Requires specialist pollinators	N	Bee pollination	0
		6.06	Reproduction by vegetative propagation	Y	5, 15	1
		6.07	Minimum generative time (years)	-	-	
7	Dispersal Mechanisms	7.01	Propagules likely to be dispersed unintentionally	-	-	
		7.02	Propagules dispersed intentionally by people	Y	5, 11, 12, nursery results	1
		7.03	Propagules likely to disperse as a produce contaminant	-	-	
		7.04	Propagules adapted to wind dispersal	N	Results	-1
		7.05	Propagules buoyant	-	-	
		7.06	Propagules bird dispersed	Y	5,13	1
		7.07	Propagules dispersed by other animals (externally)	N	Results	-1
		7.08	Propagules dispersed by other animals (internally)	-	-	

8	Persistence Attributes	8.01	Prolific seed production	Y	Results	1
		8.02	Evidence that a persistent propagule bank is formed (>1 yr)	-	-	
		8.03	Well controlled by herbicides	Y	5	-1
		8.04	Tolerates or benefits from mutilation, cultivation or fire	Y	14	
		8.05	Effective natural enemies present in South Africa	-	-	
Number of questions answered: 34 out of 49					**Total**	22

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