VOLUME 2
GUIDELINES REPORT

Rehabilitation of Alien Invaded Riparian Zones and Catchments Using Indigenous Trees: An Assessment of Indigenous Tree Water-use

Project Leader: CS Everson

Contributors: Scott-Shaw B.C, Everson C.S, Geldenhuys C.J, Starke, A, Atsame-Edda A, Schutte S

August 2016

WATER RESEARCH COMMISSION

TT 677/16

REHABILITATION OF ALIEN INVADED RIPARIAN ZONE AND CATCHMENTS USING INDIGENOUS TREES: AN ASSESSMENT OF INDIGENOUS TREE WATER-USE

VOLUME 2: The Potential for Natural Forest Regeneration within Stands of Invasive Alien Trees: Forest Rehabilitation Guidelines

Report to the

WATER RESEARCH COMMISSION

and

DEPARTMENT OF ENVIRONMENTAL AFFAIRS

Compiled by

C.S. Everson[a,b,c] (Editor)

With Contributions by:

Starke, A, Geldenhuys C.J, Atsame-Edda A, Everson C.S, Scott-Shaw B.C

[a]Department of Plant Production and Soil Science, University of Pretoria

[b]School of Agriculture, Earth & Environmental Sciences, CWRR, University of Kwa-Zulu Natal

[c]SAEON, Grasslands-Forests, Wetlands Node, Pietermaritzburg

WRC Report No. TT 677/16

August 2016

Obtainable from
Water Research Commission
Private Bag X03
Gezina, 0031

orders@wrc.org.za or download from www.wrc.org.za

The publication of this report emanates from a project entitled *Rehabilitation of alien invaded riparian zones and catchments using indigenous trees*(WRC Project No. K5/2081)

ISBN 978-1-4312-0829-6
Printed in the republic of South Africa

ACKNOWLEDGEMENTS

The research reported in this document forms part of a project funded and managed by the Water Research Commission of South Africa in the Key Strategic Area on Water Utilisation in Agriculture, with co-funding from the Department of Environmental Affairs in the Natural Resource Programme of Working for Water (WfW).

The project team would like to thank the reference group members who provided valuable information and guidance throughout the research period.

Dr GR Backeberg	*Water Research Commission (Chairman)*
Dr PJ Dye	*Wits University*
Dr JSB Scotcher	*ForestLore Consulting*
Prof JG Annandale	*University of Pretoria*
Dr RN Heath	*Forestry SA*
Mr DB Versfeld	*Dirk Versfeld CC*
Dr AJ Sanewe	*Water Research Commission*
Dr MB Gush	*CSIR*
Dr C Marais	*Department of Environmental Affairs*
Mr S McKean	*Ezemvelo KZN Wildlife*
Mr R Brudvig	*Department of Environmental Affairs*
Ms S J. van Rensburg	*SAEON GFW (Minutes)*
Mrs S Clulow	*Secretariat*

The following people provided valuable technical assistance to the experiments:
Alistair Clulow, Siphiwe Mfeka, Caren Jarmain, Terry Everson, Piet-Louis Grundling and Sihle Bukusini.

The following students provided assistance to the various field trips and experiments:
Matthew Becker and Hayden Jacobs.

Various land owners are acknowledged for allowing field work to be conducted on their property. We are very grateful for this and the assistance they provided during the monitoring period. The land owners are as follows:

- Brian and Janet Kilpen (Frog Mountain, Buffeljagsrivier)
- Alfie Messenger, (New Forest Farm, Fort Nottingham) Duncan Macfayden (Wakefield Farm), Laurence Stuart-Hill (Umgeni Poort Farm).
- Manzengwenya Plantation (DAFF, Vasi Pan)

Working for Water and specifically Mr Wessel Wentzel for the construction of security cages at Buffeljagsrivier. The South African Sugarcane Research Institute (SASRI) and specifically Alana Eksteen for temporary loan of two Dynamax systems.

The University of Pretoria Plant Production and Soil Science and the University of KwaZulu-Natal Centre for Water Resources Research is acknowledged for the use of facilities and equipment.

This page was left blank intentionally

CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

There are many different views on how invasive alien plant (IAP) stands should be managed, but the general perception is that IAP's impact negatively on biodiversity and should be cleared. In recent years there were several studies and papers that indicated the opposite trend in terms of natural forest species (for example, Parrotta et al., 1997; Geldenhuys 1997, 1998, 2013), i.e. that planted and naturalising stands of introduced tree species can facilitate the regeneration and establishment of indigenous tree species on a disturbed site. This would therefore require a different approach to the rehabilitation of areas of IAPs towards natural forest. In South Africa, in particular, some guidelines had been developed based on the general concept that light-demanding IAP tree species facilitate the regeneration and establishment of shade-tolerant natural forest species under their canopies, and that this facilitation process can be managed. By contrast, in the grassland and fynbos areas, the IAP stands compete directly with the light-demanding grassland or shrubland species under their closing canopies, and the IAP stands need to be removed in totality to maintain healthy and diverse grassland or fynbos (Geldenhuys, 2008. 2013; Geldenhuys & Bezuidenhout, 2011).

The Water Research Commission (WRC) Project (K5/2081) on 'The rehabilitation of alien invaded riparian zones and catchments using indigenous trees: An assessment of indigenous tree water use', had two main components: a hydrological component to compare the water use of indigenous tree species versus introduced tree species; and an ecological component to determine how natural forest species become established within invader plant stands. The general concept of the ecological study was that natural forest species have the potential to regenerate within IAP stands. This challenged the perception that invasive plants nullify the capacity of native species to regenerate in IAP vegetation systems. The aim of the study was to understand the dynamics of the spread of native regeneration within IAP stands and how adjacent natural forest influences such regeneration. Several hypotheses on the regeneration processes were tested to provide a sound scientific rationale into the ecology of indigenous tree species establishing in IAP stands, particularly the development and expansion of clusters of native forest species, and the influence of distance to native seed sources. The purpose of this report is to give a brief overview of the results from the different ecological and hydrological studies within this project, as a basis for improving the forest rehabilitation guidelines for practical conversion of IAP stands towards recovery of mixed indigenous forest.

2 LITERATURE REVIEW ON THE CONCEPT

Traditional methodology employed by most of South Africa's IAP control implementation agents, including Working for Water (WfW), is to use either cut stump or ring barking as a treatment for IAP species stands (Holmes et al., 2008; Witkowski and Garner, 2008). The first treatment is often termed 'initial control' and the project may need to budget for a further five to seven follow-up treatments usually at a six month to one year intervals, depending on the nature of invasion (Marais et al., 2004).

Follow-up treatments are less labour intensive and involve the removal of regenerating IAPs, however if left for over six months, dense regrowth of IAP species occurs and greater resources are required. Once follow-up treatments are completed, the invasion area theoretically enters a perpetual 'maintenance' phase in which eradication of low density IAP recruits is the objective (Campbell et al., 2000).

Studies and experience over the last 20 years in IAP control have demonstrated that total kill (specifically with post treatment burning) might not necessary be the best method for re-habilitating areas invaded by IAPs (Holmes et al., 2008). The primary reason is that disturbance from cutting and killing IAP species, provides the ideal ecological conditions for regeneration and fast growth of most shade-intolerant (sun-loving) IAP (pioneer) species. Therefore removal of pioneer vegetation nullifies the natural ecological processes, resulting in an arduous cycle of disturbance and recovery that requires large expense.

Forests in South Africa have the potential to develop in areas with rainfall as low as 525 mm/year in winter rainfall areas and 750 mm/year in areas which receive summer and winter rainfall (Rutherford and Westfall, 1986; Geldenhuys and Bezuidenhout, 2008). However, the fire pattern in the landscape confines forests to fire refuge areas which are related to the prevailing winds during the fire season (Figure 2.1; Geldenhuys, 1994). Since the last century, the introduction of agriculture, protection of timber plantations by fire breaks, road infrastructure and urban development, resulted in landscape fragmentation. This has altered the fire patterns that were once dictated purely by prevailing winds. The use of firebreaks and modern fire-fighting technology has resulted in less frequent fires and cooler fires. This resulted in better conditions for tree growth, and mainly pioneer-like introduced species and some native forest species became established (naturalising) within the traditional fire dependent ecosystems such as grassland or fynbos (Geldenhuys, 1997, 2013).

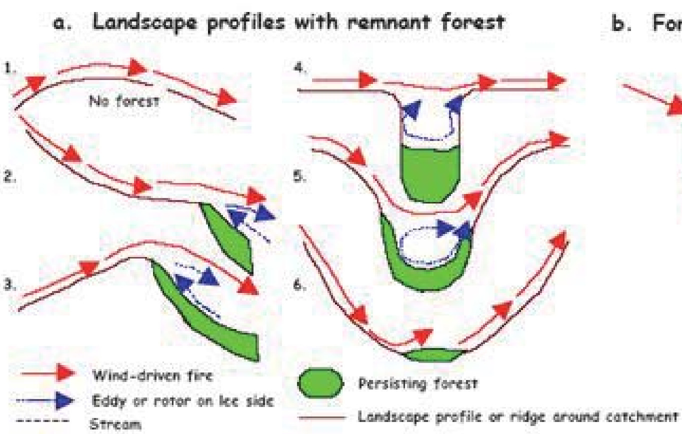

Figure 2.1: A schematic model of the wind flow patterns around or across hills or barriers determining the location pattern of natural forests on slopes and within valleys in relation to prevailing winds during the fire (dry) season. Eddies or rotors are winds flowing in a direction opposite to the general air flow (Geldenhuys, 1994, 2008).

The change in fire pattern has increased the area that natural forests can grow in two ways: Firstly, invasive stands on forest boundaries act as 'nurse stands' in which shade-tolerant forest species can become established. Natural forest clusters develop within these invasive stands and, over time, are able to replace the short lived invasive species (Geldenhuys, 1997; Geldenhuys and Delvaux, 2007; Geldenhuys and Bezuidenhout, 2008; Atsame-Edda, 2014). Secondly, the general reduction of fire within the forest and grassland ecotone permits the change from grassland to woody vegetation and allows the forest edge to expand through the colonisation of native pioneer and invasive species (Geldenhuys and Venter, 2002).

The initial ecological consequence of removing invasive plants is that it alters the abiotic environment by increasing light, heat and reducing competition for water and nutrients. Young invasive species simply re-colonise the site, form dense stands and may smother any natural forest seedlings or saplings during this process (Geldenhuys, 2013). In some circumstances natural forest species within IAP stands have a better chance of survival, if invasive stands remain intact. Invasive stands mature relatively quickly, with reduced density, and during this process provide the ecological conditions for shade-tolerant forest species to grow (Geldenhuys, 2013).

When traditional control methods are employed to eradicate invasive stands, young native forest plants get damaged by foot traffic, killed by foliar spray drift or out-competed by dense sun-loving pioneer IAP species in early successional stages. An alternative to this "total kill" treatment method is to keep the core of the invasive stand structure intact. Manipulation of stands to benefit native species was employed in the current study. The aim was to rehabilitate IAP stands with some native forest species present (forest clusters) by facilitating their development along a successional pathway towards mixed regrowth (Geldenhuys and Bezuidenhout, 2011; Geldenhuys, 2013). Stand manipulation aims to use the natural self-thinning process of the IAP stand to positively alter the microhabitat, which in turn increases the regeneration potential of native species.

The following four general stand development stages (Figure 2.2) have been defined (Geldenhuys and Bezuidenhout, 2011; Geldenhuys, 2013):

- ***Stage 1***: Very dense stand of IAPs, with mostly none to very few shade tolerant native species present
- ***Stage 2***: Stems of the IAP stand start to self-thin and native species begin to colonise in low densities
- ***Stage 3***: The IAP stand develops further with noticeably more invasive stems dying, permitting establishment and development of more native colonising species
- ***Stage 4***: The IAP stand is in an advance development stage towards mixed regrowth forest with most of the stems of IAPs dead or stems removed and native species are developing towards a continuous closed canopy.

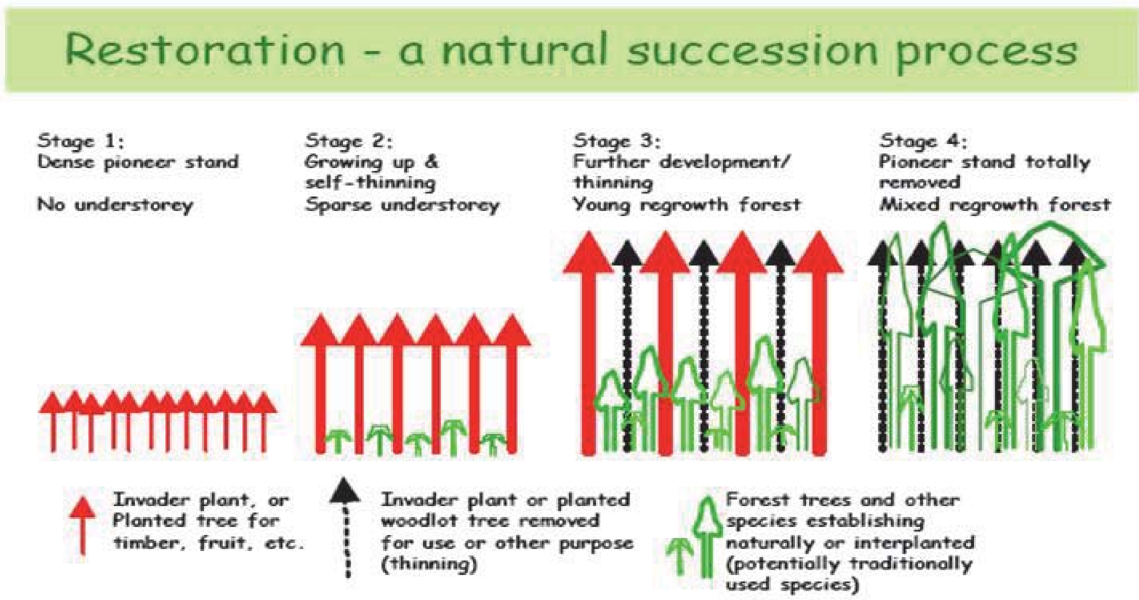

Figure 2.2: A graphical representation of forest recovery as a natural succession process through stand development stages (Geldenhuys, 2008)

3 INSIGHTS FROM THE ECOLOGICAL STUDIES OF THIS PROJECT

3.1 Study sites

Two in-depth ecological studies were conducted within alien plant stands in the vicinity of natural forest. In both study sites the IAP stands contained regenerating native forest species.

The Buffeljagsrivier site near Swellendam had a 90 ha wattle stand (*Acacia mearnsii*) stretching for 3.1 km along the river above the Buffeljagsriver dam. At the upper end of the wattle stand there were several small patches of moist (south facing slopes), dry (north facing slopes) and riparian forest belonging to Western Cape Afrotemperate Forest, covering in total area of about 3 ha. The surrounding natural vegetation on the mountain slopes and foothills is a fire-adapted sclerophyll shrubland (Cape Fynbos) with very high plant species diversity. The wattle stand was of uniform height, density and age (at least 10 years old) and developed after the wattle had been cleared before, and was in an advanced stage of development with natural forest species starting to become established.

The New Forest study site included planted and naturalising (establishing naturally) IAP stands of different species, age and densities. New Forest forms part of the eastern Mistbelt Forest type and the surrounding natural vegetation is Drakensberg Foothill Moist Grassland.

The two studies in general addressed three important questions:

(i) Do natural forest species establish within stands of IAP species?
(ii) What are the underlying processes of natural forest species spreading into the IAP stands?
(iii) Can such invasion of invader plant stands by natural forest species be managed to facilitate natural forest recovery?

A forest patch was defined as a natural forest stand adjacent to an IAP stand. A forest cluster was defined as a group of one to several natural forest trees growing on a limited area within the IAP stand. A cluster had to include at least one reproductively mature tree that could attract dispersal agents.

3.2 Ecological processes

<u>Buffeljagsrivier</u>

The Buffeljagsrivier study showed the successful establishment of natural forest species within the extensive stand of the vigorous introduced invasive wattle, contrary to the general perception that IAP stands have a negative impact on the biodiversity. The results showed how this light-demanding IAP stand nursed the establishment of natural forest species. The forest clusters contained 22 tree (78.6%) and six shrub (21.4%) species, belonging to 20 families. The majority of species were present as both regeneration and mature plants. Six species were common in the clusters.

The wattle stand was divided into three zones in relation to proximity to the indigenous forest patches: Proximal zone (<0.5 km), Intermediate zone (ca. 1 km) and Distant zone (>2 km)(Figure 3.1). Three cluster size classes were defined: Small cluster, with 1 to 3 reproductively mature trees of natural forest species; Medium cluster, with 4 to 9 trees; and Large cluster, with 10 and more trees. The total 90 ha wattle stand was traversed to map the clusters. The recorded 329 forest clusters were distributed across the total wattle stand and the number and size of clusters differed significantly across the zones. The majority of large clusters (59.2%; 0.53/ha) occurred in the Proximal zone and the majority of small clusters (53.0%; 3.52/ha) in the Distant zone. Medium-sized clusters were present in similar proportions in the Proximal (44.4%; 0.53/ha) and Intermediate zones (33.3%; 0.6.ha). This indicated a definite step-wise invasion process. Even if species differed in their composition across the stand zones and cluster sizes, there was no distinct pattern in terms of trees or shrubs. Some species were dominant in one zone and completely absent in other zones, indicating differences in dispersal and establishing processes.

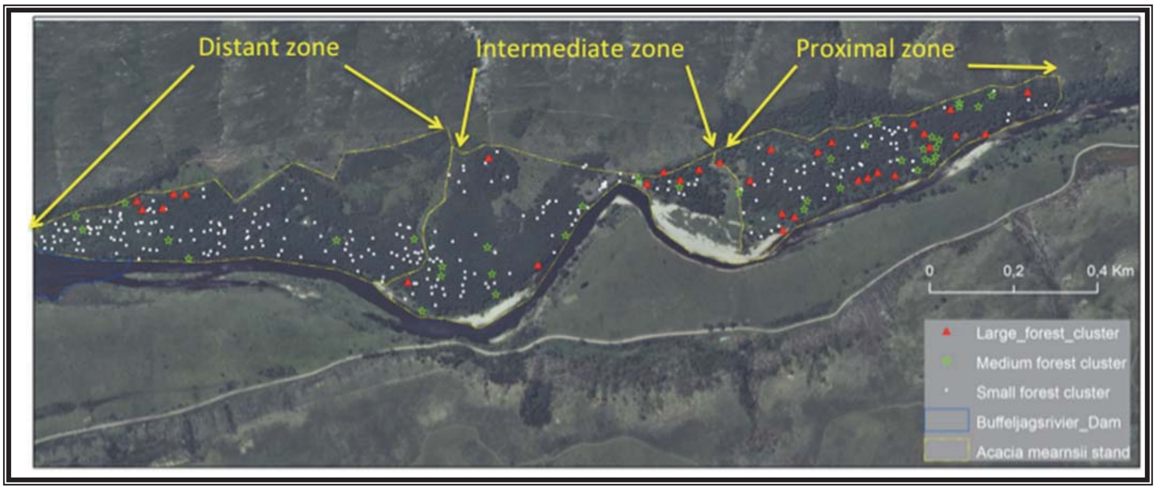

Figure 3.1: Map of the distribution of small, medium and large forest clusters in the proximal, intermediate and distant zones within the wattle stand at Buffeljagsrivier, in relation to the small forest patches at the eastern end of the wattle stand.

The unequal distribution of forest clusters across the wattle stand suggested a directional process in the establishment of natural forest clusters within the IAP stand. The nearest (proximal) zone to the natural forest patches has the highest number of large natural forest clusters, followed by the intermediate distant zones. In contrast, the distant zone had the highest number of small, newly establishing clusters. In terms of the forest succession process, most of the trees first established near to potential seed sources, formed clusters and as they expanded, they facilitated the progressive establishment of new small clusters to the distant zone, via the intermediate zone. The existence of adjacent natural forest patches seems necessary for such succession to take place. However, the arrival of forest species at points far away from the seed source areas may relate to the characteristics of the dispersal agents. For example, some species that were absent from the proximal and/or intermediate zones, such as *Ocotea bullata*, *Apodytes dimidiata* and *Olinia ventosa,* arrived in the distant zone because the baboons may have taken them there.

Adjacent moist, dry and riparian forest patches contributed to a greater or lesser degree to the development of forest clusters within the wattle stand. Forest cluster species composition was more similar to riparian forest patches, most likely because they shared the longest and closest borders with the wattle stand. However, species from both the moist and dry forest patches also contributed to forest cluster development, particularly of small and medium clusters, despite the distance and river as physical barriers for the dry forest patches. Seed characteristics and mode of seed dispersal of species may therefore also be a determinant factor in cluster development, and may be more important than site conditions and distance from seed source. This emphasizes the importance of understanding the type of interactions that may prevail between the rehabilitation area (the wattle stand) and the adjacent natural forest patches.

In general, clusters differed in shape, density and orientation. Some clusters had very low stem density, with mostly large size trees and few small trees, and few wattle stems. Other clusters were much denser with many small trees of both native species and wattle. Some clusters showed multiple globular to linear shapes, indicating expansion and joining of adjacent clusters. Structural analysis of cluster shape provided information on the history, direction and dynamics of cluster establishment and expansion. For example, a double-globular shape cluster was viewed as two initial clusters that over time have fused to form one bigger cluster, i.e. two clusters in close proximity would eventually merge and form a larger cluster. Multi-lobe clusters could indicate that several individual forest clusters (small to large) merged over time to form such larger clusters. The shape of a cluster can also be viewed as a consequence of different dispersal modes. Clusters of linear shape occurred along the river, suggesting running water as the main dispersal mode. Mixed or more regular shapes could be attributed to clusters that occurred in the flat zone of the stand, with fewer irregularities in dispersal mode.

Clusters of natural forest species, once established, became the main seed source for their gradual expansion within the wattle stand. Most dominant regenerating species in the area outside of identified forest clusters had an adult tree within the clusters. However, dominant species in some clusters were not found dominant in or were absent from the surrounding regeneration. Some species in the regeneration outside the clusters were nowhere present within the clusters.

The 40 species recorded from the forest patches and forest clusters included a wide range of fruit and seed characteristics that are important for understanding the movement of the tree and shrub species between the forest patches and the wattle stand, and within the wattle stand away from the establishing forest clusters. The size of the fruit and seed was defined as small or large in relation to potential easy and effective dispersal by smaller birds: small = <5 mm width or diameter; large = ≥5 mm width or diameter. Most species had large fleshy fruit (85%), followed by large dry fruit (7.5%), small fleshy fruit (5%) and small dry fruit (2.5%). Most species had small soft seeds (55%), followed by large soft seeds (32.5%), large hard seeds (10%) and small hard seeds (2.5%). Most of the recorded species are bird and/or mammal dispersed, with one each dispersed by wind, ballistic seed pod opening and water.

Four distinct species groups were identified in relation to their presence/absence in the forest patches and forest clusters and their fruit/ seed characteristics:

- Group 1: Common in forest patches / present in the clusters (8 species): Fruit: Large fleshy drupe (37.5%}, berry (37.5%) or capsule (25%); Seed: Large soft (62.5%) or small soft (37.5%)
- Group 2: Specific to forest patches / present in forest clusters (16 species): Fruit: berry (43.7%), drupe (18.8%), capsule (12.5%), pod (12.5%) or nut (12.5%); Large fleshy (81.3%), large dry (12.5%) or small dry (6.2%); Seed texture/size: Soft-Small 43.8%, Soft-Large 31.2%, Hard-Large 25%
- Group 3: Present in forest patches / absent in clusters (10 species): Fruit: Berry (40%), drupe (30%) or capsule (30%); Large fleshy (80%), small fleshy (10%) or large dry (10%); Seed: Small soft (50%), large soft (40%) or small hard (10%)
- Group 4: Absent in forest patches / present in forest clusters (6 species): Fruit: Large fleshy berry (66.6%), drupe (16.7%) or capsule 16.7%; Seed: Small soft (83.3%) or large soft (16.7%).

Within young clusters, seed characteristics and dispersal mechanisms explained the distribution of scattered small clusters. Species absent from the forest clusters but present in the nearby forest patches (Group 3) had predominantly large-sized fruit, making them inadequate for effective dispersal by most birds and mammals. The shade caused by canopy closure of the wattle stand prevented the regeneration and replacement of this light demanding invasive alien species under its own canopy. The wattle stand, therefore, facilitates germination and establishment of more shade-tolerant natural forest species and contributes to forest succession.

Traditional forest rehabilitation practices tend to rely on nurseries for seedlings to be established on the site to be rehabilitated. However, the associated costs are always a limiting factor to the success of such management actions. This study confirmed the role of adjacent remnant forest patches as potential seed sources in forest succession and recovery. This should be considered as perhaps a better approach to forest rehabilitation than planting.

New Forest

The New Forest study investigated the initial development stages (Stage 1-very dense and 2-thinnining of IAPs) of eastern Mistbelt forest within alien plant stands in the KwaZulu-Natal midlands. The study showed different communities of indigenous tree species growing in sub-canopy conditions of mixed IAP stands (i.e. Pine, Eucalypt and Black Wattle).

Undisturbed mature forest and regeneration plots in IAP stands were compared. Plots were laid out in transects in increasing distance from natural forest patches (into invasive stands) and also linearly parallel to the natural forest edge along an invaded river bank. The stem diameter and species were recorded for canopy trees (within 400 m^2) and for understory species (100 m^2) in each plot. The mature forest patches contained 67 trees species and the IAP stands contained 42 species. There were few (<5 %) large (≥5 cm DBH) native trees growing within the alien plant stands. However almost 50% of sub-canopy species (stems <5 cm DBH) were native species. This showed that most of the regeneration at New Forest was in either stage 1 or 2 of the forest development process.

The study looked at three basic factors (Figure 3.2) which could influence the regeneration process of native species within alien plant stands: (1) the species composition of natural forest patches; (2) the effect of distance from natural forest patches; and (3) the effect of IAP stand structure on natural forest regeneration.

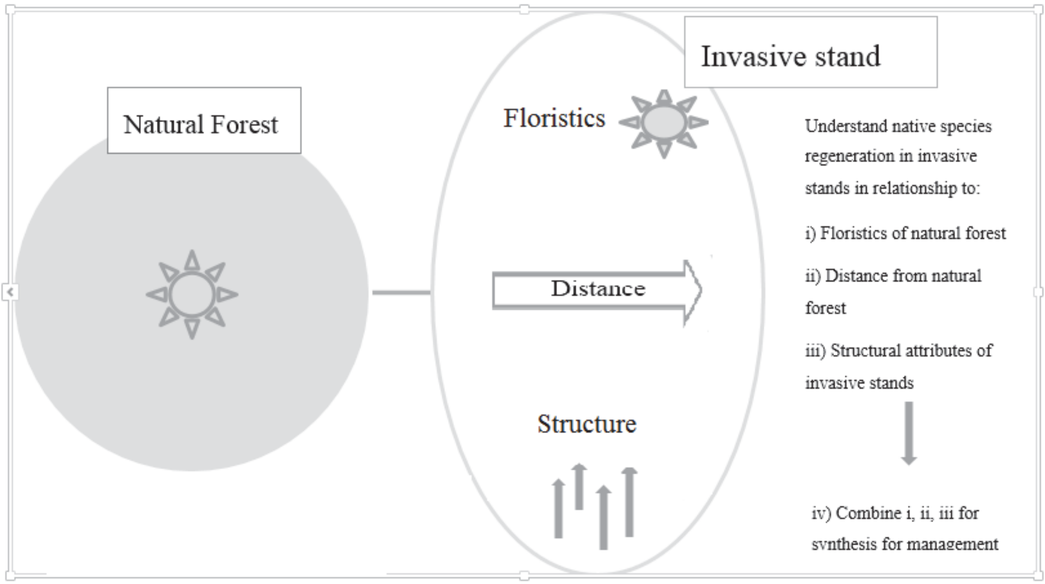

Figure 3.2: A conceptual framework of the factors that were studied at New Forest, which influence native forest development in alien plant stands.

An ordination of native regeneration communities (which included both natural forest and IAP stands) showed that there was a pattern which grouped plots along a development pathway from pioneer through to mature forest. Four regeneration communities were identified along this axis: pioneer, primary-regrowth, secondary-regrowth, and mature. This substantiated the hypothesis that natural forest regeneration communities represented development stages along a successional gradient from pioneer to mature forest. Importance Values (IVs) of native species were calculated from canopy and sub-canopy regeneration communities which showed the relationships between mature forest communities and regeneration communities within invasive stands. Tree species such as *Celtis africana, Scolopia mundii* and *Podocarpus falcatus* were dominant both as canopy trees in mature forest and in the sub-canopy regeneration layer within invasive stands. This demonstrated the multi-faceted nature of regrowth forest communities and their long term potential to develop into mixed secondary-regrowth and/or core forest.

Indicators for these regeneration communities were also in line with the functional aspects of pioneer and mature forest species. It was determined that *Halleria lucida* was an indicator for pioneer regeneration, *Searsia pyroides, Canthium ciliatum* and *Euclea natalensis* were indictors for the primary regrowth communities, whereas *Scolopia zeyheri, Carissa bispinosa, Buddleja auriculata, Scolopia mundii, Grewia occidentalis and Lauridia tetragona* were indicators for slightly older secondary regrowth forest communities.

The effect that distance to native seed source (DNNS) had on the regeneration of native forest species within IAP stands was established though canonical correspondence analysis and linear regression (Figure 3.3). Greater forest development (density and species richness) was noted closer to the seed source (i.e. forest patches) than further away and most species colonised within 40 m of the forest edge. Species composition was the main response variable and inferences regarding the pattern of compositional change along DNSS showed tendencies of a forest development process. Species which colonised close to the native forest patches (i.e. 40 m) were mostly representative of mature forest species. This was thought to be indicative of a gradual expansion of the forest into the IAP stands. Species which were recorded at intermediate (200 m) and far (600 m) distances were pioneer species. This was thought to be indicative of initial cluster development within the IAP stands, which would after time develop into larger forest clusters initiating self-perpetual forest expansion. Figure 2.1

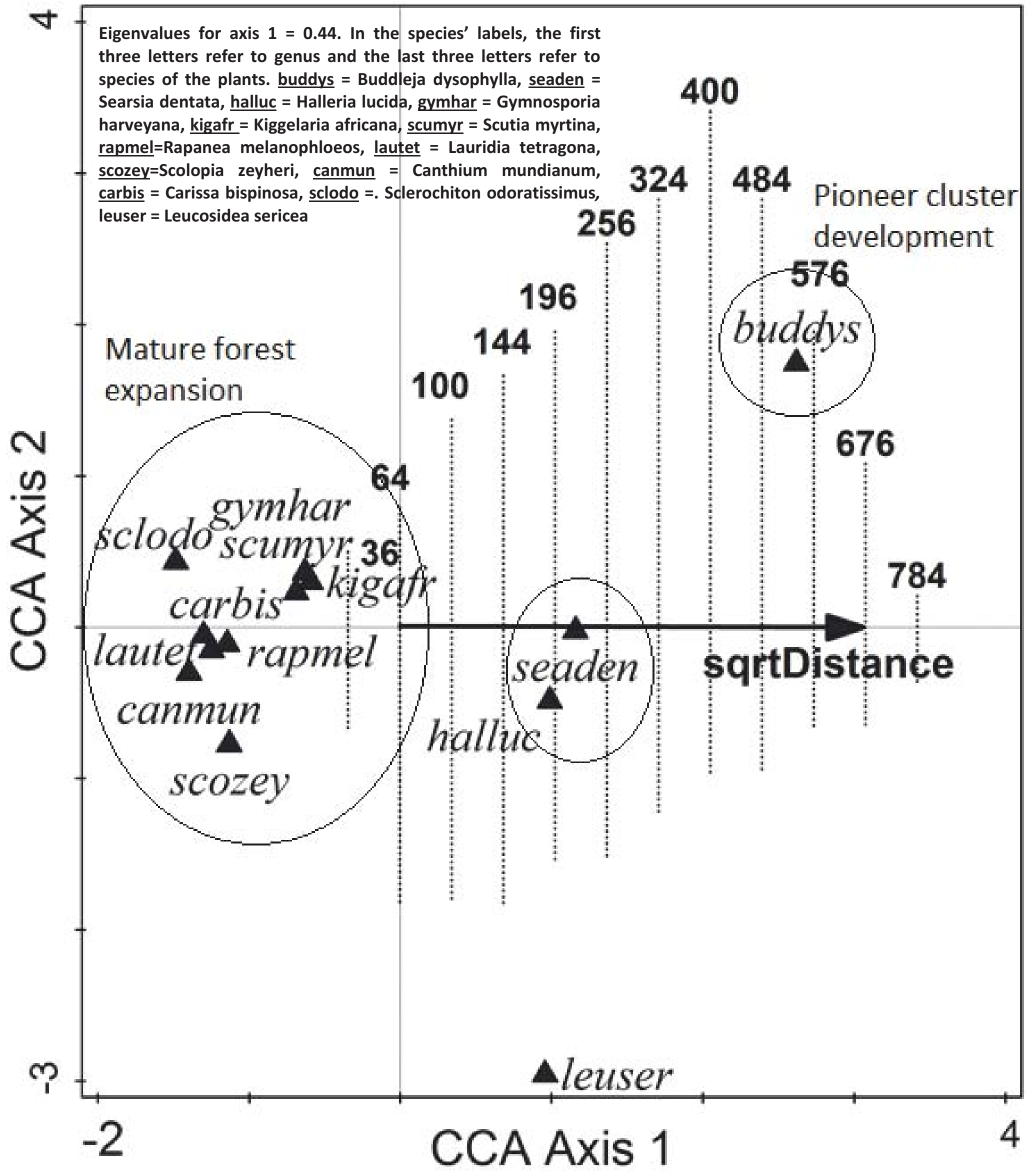

Figure 3.3: Centroids of species along the first two axes of a canonical correspondence analysis (CCA) of the species composition of regenerating forest in relation to square-root transformed distance-to-native-seed-source (sqrtDistance).

Analysis of the fruiting characteristics of native tree species determined that species with smaller seeds and prolific seed production were more likely to colonise further from the seed source than species with larger seeds and less prolific seeding. Although distance to seed source had a weak but significant effect on the species composition and abundance of natural forest species, other unmeasured factors also played a large role in determining the pattern of forest expansion.

The New Forest study showed two forest processes (similar to the expansion of forest clusters at Buffeljagsrivier): (1) A general expansion of the natural forest ecotone into the adjacent IAP stands; and (2) Evidence of the initiation of forest clusters at distances between 200 and 600 m from the forest edge. Edge expansion happened over small distances (40 m) and cluster development over longer distances (200-600 m). Understanding the difference between edge and cluster expansion helped to improve the methodology for manipulating alien plant stands towards forest development.

Natural mortality of IAP stands can be simulated by selective thinning of IAP trees (if within a suitable distance to natural forest) around established and developing forest clusters. Selective stand manipulation (thinning) will manipulate the light/soil/moisture conditions and do two things:

- If clusters are young and contain a few small plants which are not of reproductive age, thinning will accelerate the ability of the species to produce seed, while also provide a more attractive habitat for potential seed dispersal agents such as birds and mammals.
- If the cluster is old enough it will allow the lateral expansion of the cluster though a self-perpetual process of seed producing individual trees within the cluster. This is a very similar process to the gradual ecotone or forest edge expansion recorded at New Forest. The expansion process is assisted by natural seed dispersal agents within the forest such as mammals and birds, i.e. the lager the clusters the more these clusters will attract these ecological agents.

The rehabilitation plan for IAP stands in the natural forest environment needs to incorporate these findings with information from existing published literature, to successfully manipulate the succession process in IAP stand development to facilitate forest recovery.

4 TREE WATER USE

The results from the hydrological and ecological components of the Buffeljagsrivier site were used to compare actual annual water-use per unit area between the invaded and pristine sites. The findings are summarised as follows:

- The stem density of *Acacia mearnsii* was 650 stems.ha^{-1} for the small size class, 200 stems.ha^{-1} for the medium size class and 50 stems.ha^{-1} for the large size class.
- The annual water-use of *Acacia mearnsii* was 5879 L for the small size class, 7639 L for the medium size class and 9981 L for the large size class.
- Therefore the *Acacia mearnsii* stand used approximately 5.85 ML.ha^{-1}.year^{-1}.
- The stem density of combinations of *Vepris lanceolata*, *Rothmannia capensis, Celtis africana* and *Rapanea melanophloeos* was 120 stems.ha^{-1} for the small size class, 65 stems.ha^{-1} for the medium size class and 24 stems.ha^{-1} for the large size class.
- The annual water-use of the indigenous clusters was 1209 L for the small size class, 6321 L for the medium size class and 18900 L for the large size class.
- Therefore the indigenous stand uses approximately 1.01 ML.ha^{-1}.year^{-1}.
- From the above we concluded that, annually, the alien stand uses nearly six times more water per unit area than the indigenous stand.

*Note – Divide ML by 10 000 in order to get values in mm

The annual tree water-use (Figure 4.1) showed the high variability both within and between species. For example, the annual water-use of *A. mearnsii* ranged between a low of 5879 L.year^{-1} and a high of 9981 L.year^{-1}. These data highlight the importance of good replication of a representative sample of size classes. Despite the fact that an individual *Celtis africana* tree can use 24000 L of water per year (14 000 more than the largest *A. mearnsii*) it is the high density of the invaded species which becomes important in the scaling up of the canopy water-use.

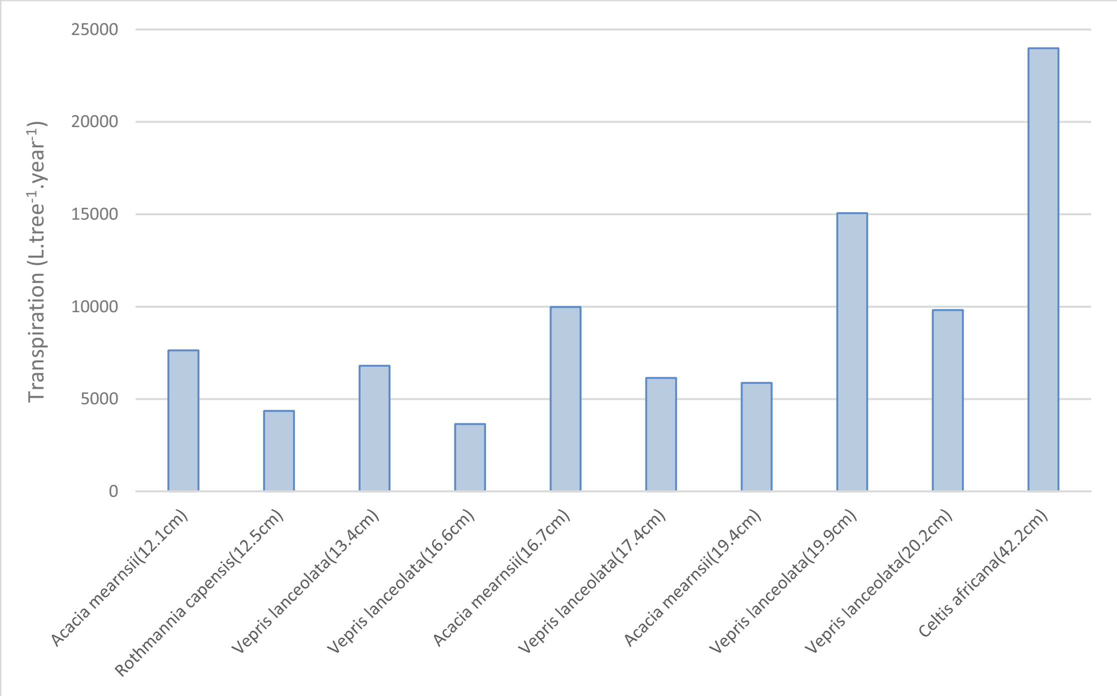

Figure 4.1: Annual water use of the species measured at Buffeljagsrivier categorized according to size

Both transpiration and streamflow were modelled for Buffeljagsrivier and New Forest for three scenarios (current, invaded and pristine) using the ACRU hydrological model. Daily modelled transpiration was on average 20% higher in the invaded (~5 mm) when compared with the pristine condition (~4 mm). This resulted in an accumulated streamflow reduction of 610 mm over the 50 year simulation period.

A summary of the baseline scenario (current state) of the *SWAT* water balance showed for the riparian Hydrological Response Unit (HRU) that 56 % (975 mm) of the precipitation was returned to the atmosphere through total evaporation (Figure 4.2) and 40% (394 mm) of the remaining precipitation contributed to the catchment streamflow in the form of surface runoff, lateral flow and return flow.

On a daily basis ACRU predicted daily evaporation values for the invaded scenario which were almost double the pristine scenario. The differences in water use between indigenous and invaded riparian zones were also reflected in the runoff where the streamflow reduction in the entire catchment was approximately 1 478 m^3 over the 50-year simulation period. Directly scaling up the actual tree water use data using SWAT showed similar findings with the impact of clearing the *Acacia mearnsii* showing clear water balance benefits.

The *SWAT* model showed clear differences between an HRU that was invaded and a pristine state. The total evaporation was approximately 35% less under the pristine state where the streamflow differed by 100 mm over the three year period. Directly scaling up the actual tree water-use data using SWAT showed similar findings with the impact of clearing the *Acacia mearnsii* showing clear water balance benefits (Figure 4.3).

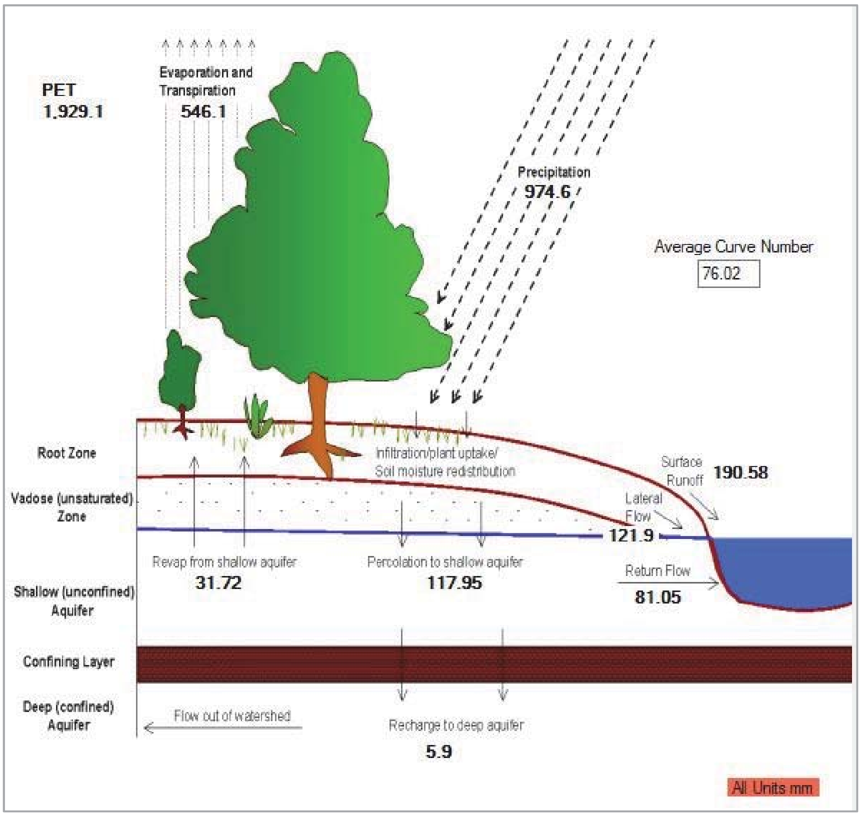

Figure 4.2: Modelled water balance for the current state of Quaternary Catchment H70E (Buffeljagsrivier)using the SWAT model

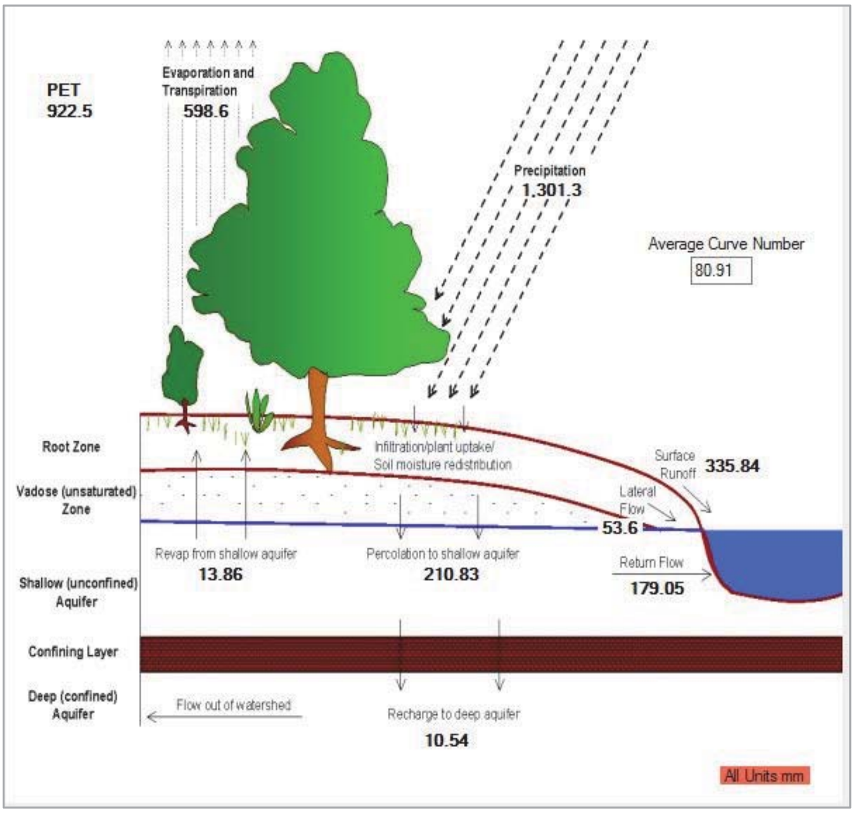

Figure 4.3: Modelled water balance for Quaternary Catchment U20A (New Forest) using the SWAT model

5 GUIDELINES FOR FOREST REHABILITATION THROUGH INVASIVE ALIEN PLANTS AS NURSE STANDS

5.1 Goals of a rehabilitation plan

Forest ecosystems change over geological time (Behrensmeyer et al., 1992) and more recently due to human activity (Lugo and Helmer, 2004). Restoration involves defining a realistic ecological endpoint, such as aiming for some historical condition, but this is often inappropriate and futile, because in most cases riparian vegetation has a long history of human alteration making the original species composition very difficult to replicate (Richardson et al., 2007). The end product is thus termed a novel ecosystem and is bought upon by the presence of humans (Mascaro et al., 2008). In this report, forest rehabilitation refers to the facilitation of the process towards forest recovery.

In South Africa, the fire-sensitive, fragmented natural forest patches persist within a matrix of fire-adapted and tolerant grassland or fynbos. This means that rehabilitation sites a short distance away from the fire-tolerant and fire-sensitive sites will require totally different treatment methods for the same species of invasion. Therefore a clear understanding of what areas are suitable for forest versus grassland/fynbos rehabilitation should be determined and for each type of area the most appropriate rehabilitation approach needs to be implemented. A decision tree is provided in Figure 5.1.

A rehabilitation plan should address the following components in the rehabilitation process (Geldenhuys and Bezuidenhout, 2011; Geldenhuys, 2013):

i) Initial planning
ii) Mapping the vegetation by potential land use management categories
iii) Developing specific management guidelines by vegetation zones
iv) Finding agreement between relevant stakeholders on a plan of action
v) Implementation of relevant rehabilitation actions
vi) Monitoring

Each of these components are dealt with in more detail below for forest rehabilitation in the landscape with IAPs.

5.2 Initial planning

Initial planning should bring all the stakeholders of the area together, such as the project manager, different landowners, scientists, rehabilitation contractors (Working for Water), timber contractors, farm managers, conservancies and local community members. Ideally a project manager should be appointed whom can coordinate the responsibility and activities between the different stakeholders; for example between the rehabilitation contractor and the timber harvesters. The most important stakeholder from a rehabilitation perspective is the rehabilitation contractor. Attention should be given to the following in developing the rehabilitation contract team:

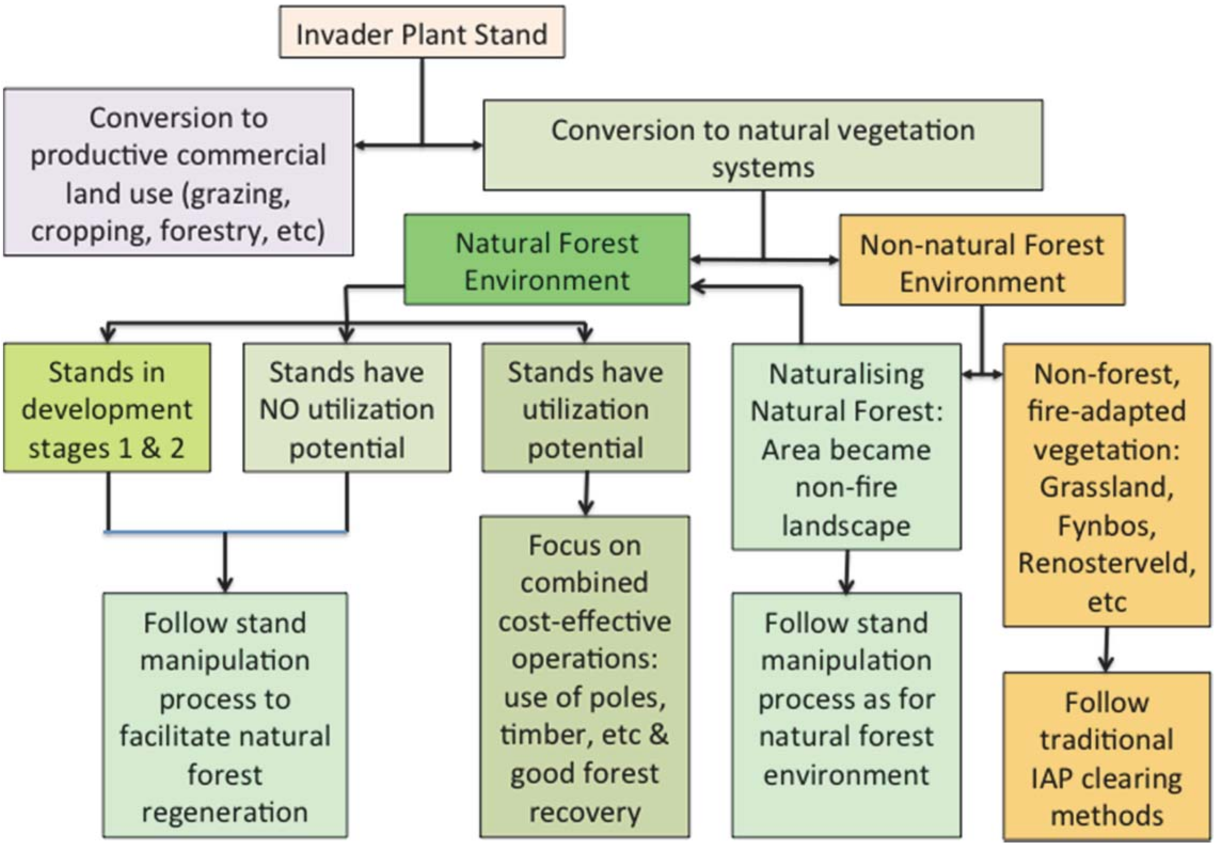

Figure 5.1: A decision tree for the rehabilitation of IAP stands in an area of different natural vegetation and land uses.

.

- Small specialist teams are better suited to this type of work than larger teams. Each team should be between 5-7 people. They should be comprised of people from the local community and be able to work on their own. The team should have at least one experienced team leader who will be able to pass on his experience to other team members. They should all express interest in the natural environment and preferably have knowledge of local plant species.

- All team members should receive the following basic field training: Herbicide application, chainsaw operation, basic first aid and health and safety.

- Specialised training of the infield team should focus on (Geldenhuys and Bezuidenhout, 2008):

    - Plant identification of indigenous and invasive species which are expected to occur on these sites. For example, at Buffeljagsrivier it is particularly important that team members are able to clearly distinguish between Keurboom (*Virgilia oroboides*), Black Wattle and Sesbania

    - Identification of different stages of recovery or stand types (e.g. the difference between mixed regrowth forest and homogenous invasive stands)

    - Identification of native forest clusters and understanding how much thinning needs to be conducted

- Rehabilitation techniques for clearing in different invasion stand types
- Invasive species which need to be removed entirely from the site e.g. Crack Willow (*Salix fragilis*) and *Cotoneaster pannosus*
- Proper use of clearing equipment
- Monitoring techniques after treatment

5.3 Zonation and planning of the rehabilitation area

A broad understanding of the rehabilitation area needs to be established. This should include using an aerial image of the area (such as Google Earth) to assist in determining the natural vegetation zones in relation to the fire pattern of the broader area (Figure 2.1 & Figure 5.2) and visits on foot to evaluate the vegetation in the different zones. This process would identify which areas could naturally be rehabilitated to forest and which should be converted back to grassland/fynbos, or other land uses such as agriculture or forestry. Secondly, the extent and species composition of the zoned invaded areas should be defined within management blocks and indicated on the map. The boundaries of management blocks could be determined by utilising natural landscape features such as valley lines, servitudes or roads. This process should be done in three steps:

- ***Step 1***: Zoning the rehabilitation landscape into specific blocks in terms of the specific rehabilitation endpoints, for example: productive farmland, grassland, continued forestry, regrowth natural forest, etc. This will aid decisions on the type of treatments that are to be used within the specific areas e.g. Clear-felling, burning, ring-barking or gradual stand manipulation (thinning).
- ***Step 2***: For the areas identified to be converted to regrowth natural forest, the zoning should be further refined in terms of stand development stages (Figure 2.2). Parameters such as stand age, size of clusters, dominant natural forest species and their general abundance, stem density and proximity to the natural forest seed source can be used to decide on which development stage the stand is in.
- ***Step 3:*** Work schedules need to be carefully designed for the short, medium and long term of the site which ties in with the perceived natural regeneration processes and objectives of the specific areas identified in step 1.

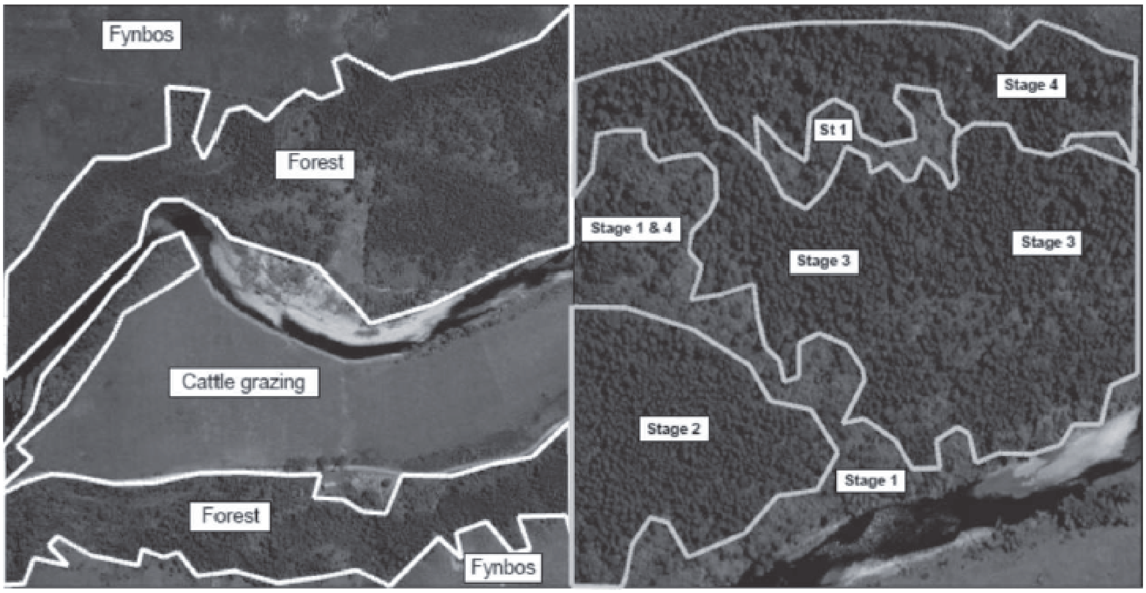

Figure 5.2: Zoning of the rehabilitation area, using the wattle stands along Buffeljagsrivier as example. (a) Left: Zone the area into broad land use zones of natural vegetation (forest, fynbos, etc.) and production systems such as grazing, crop production, forestry, etc.; (b) Right: Zone the areas to be rehabilitated to natural forest by stand development stages 1 to 4.

The next step is to assess and describe each identified zone or compartment of the area to be rehabilitated towards regrowth forest, and to summarize this information in Table 5.1. This assessment should contain the following:

- Identify separate areas within each management block based on their stand type. The stand types should be defined by the dominant canopy within a given area e.g. mixed regrowth forest, Black wattle, mixture of Black Wattle and Pine, etc. Determine and record the general age and history of each stand. Also record the non-dominant invasive plants growing on the site e.g. Bugweed, Castor oil
- Determine whether clusters of natural forest species are present, and the density and height of the species present in those clusters to evaluate their reproductive capacity. Use different size categories, such as seedlings (<1 m height), saplings (1 m height to 1 cm stem diameter at 1.3 m height, poles 1-5 cm, and established trees (>5 cm stem diameter).
- Note the presence of natural forest patches in the area in relation to the IAP stands (distance, size, dominant species, etc.)
- The combination of the overhead stand and status of the natural forest regeneration in the understory should guide the stand development stage (Figure 2) and what actions should be pursued during the rehabilitation.
- Finalize the zonation of the rehabilitation area into management blocks of different stand types (perceived successional stages). Provide for each management block clear management objectives and guidelines on rehabilitation actions such as what species to remove, and how (utilising stems to be removed, ringbarking, hand-pulling, etc.).

The information from the survey will fulfil two objectives: (1) assist in planning; (2) provide information to the field team of what to expect within the different areas on the site.

Table 5.1: Example of the description of each identified zone (block or compartment) to be converted towards forest recovery

Management Block	1	2	3
Location *GPS polygon or description*			
Stand type Dominant IAP species	*Black wattle*	*Mixed regrowth with Eucalypts*	*Black wattle*
Age of stand (young = many stems <5cm DBH, adult = many stems >10cm DBH, mature = many stems > 40cm DBH)	*Young*	*Mature*	*Mature*
Distance to seed source	*60 m*	*30 m*	*100 m*
Clusters (Density/Age)	*Many young clusters*		
Development stage (based on Figure 2.2)	*1*	4	2
Prominent indigenous species (top 5) and general size	Only scattered small plants	*Stinkwood & Ouhout – adult*	*Buddleja spp. – mostly saplings*
Non-dominant IAPs	*Bugweed*	*Bugweed*	
Level of timber harvesting in the stand	*Non*	*Moderate*	

5.4 Project management of relevant stakeholders

Different sites in this project had different stakeholders, and showed how such potential differences in approach towards stakeholder participation should be considered. The sites at Buffeljagsrivier and New Forest were situated in commercial farming areas, but a third smaller site in rural Maputaland was located adjacent to a rural local community. These two types of stakeholders require a different approach to the rehabilitation of the site. In the commercial context, rehabilitation contractors such as Working for Water could be trained to conduct thinning activities and a commercial timber harvester could be used to remove any usable timber from the stands as long as it is in line with the rehabilitation objectives. However, in a rural scenario which involves many community members, the approach should be to identify local user groups or co-operatives which could be trained to conduct the rehabilitation (with perhaps the mentorship from an environmental NGO such as Wildlands Trust). In rural areas the timber extraction would most likely be split between fuelwood, building material for rural homesteads and possibly sold to a commercial enterprise such as a SAPPI out-grower scheme. Coordination between the stakeholders in each example would also be different. In commercial farming areas there are less landowners and decisions could be made on a singular basis rather than for example a rural scenario, where there are many landowners and stakeholder participation would rely strongly on community participation.

5.5 General implementation guidelines for manipulation of IAP stands towards forest recovery

The focus of stand manipulation is to provide more growing space for developing clusters. The first step is therefore to identify developing forest clusters and to remove IAP stems around these clusters. This would facilitate the rapid development of the native species within the cluster, i.e. from an initial non-seed producing cluster to a mature cluster that can contribute to the self-perpetuating process of broader forest development. IAP stems can be cut for use as poles of different size or as firewood, depending on access to the site, or can be ring-barked to die standing. The important point to consider is to keep the canopy of the IAP stand close enough together to prevent suitable light conditions for the regeneration of the IAP species. The reduction in stems will reduce competition and allow the smaller native species ecological opportunity to develop.

The goal of stand manipulation is to facilitate the natural self-thinning processes of overhead invasive stands. This reduces competition for understory resources and increases the ability for native species recruits to develop. This is a long term solution to IAP invasion and suits rehabilitation efforts with small budgets. This method has the potential to be a sustainable management option as the IAP species removed during thinning can be used as a pole or fuel wood resource (Geldenhuys, 2013).

Ring barking keeps larger trees standing and is an economical treatment method (Campbell et al., 2000). It can also be used in stand manipulation towards gradual canopy release. By keeping trees standing it prevents the disturbance of surrounding vegetation from the impact of felling large quantities of trees. Smaller stems should be treated by cut stump when they are in low densities; this method is not labour intensive and does not create large areas of disturbance. The goal of this low impact type of clearing in low density invasion areas is for the natural forest in the immediate area to close gaps created by the removal of IAPs more quickly.

Selective IAP stem thinning further away from mature forest clusters will allow the forest regeneration to establish and grow laterally in the same way that a mature forest edge will develop into an adjacent plantation environment. One would expect that the more characteristic mature forest species would develop closer to the cluster border and that pioneer species with smaller seeds would colonise further into the plantation forming new young forest clusters. As the cluster grows laterally and develops a good canopy, all IAP stems inside and close to the cluster could be removed, and the cluster then developed towards stage 4 (Figure 2.2) i.e. regrowth forest. This is a gradual process of conversion of IAP stands to natural forest and provides the opportunity of more sustainable and longer-term employment of a rehabilitation team.

The level of manipulation of an IAP stand depends on its development stage, and most cost-effective action will be in stages 2 and 3:

<u>Development stage 1:</u> *Young invader stands.*
These stands are generally dense, with many small IAP stems, and none to a few small stems of natural forest species. These stands will self-thin naturally into a more advanced successional stage, and no manipulation is required. The best approach is to leave such stands until they develop towards stand stage 2. Where there are small groups of natural forest species developing, their development could be facilitated by removing trees (hand pulled, cut or ringbarked) of not more than a 1 m in distance from the indigenous tree or cluster of indigenous plants.

<u>Development stage 2:</u> *Sites are still dense but much taller.*
More indigenous seedlings are present and some are in the sapling stage. Clusters are starting to become evident and can be identified easily; they may contain poles or a few small-tree individuals. The focus should be to remove the invader plants around such groups to create an opening in the canopy not more than 5 m in diameter, or equal to the height of the canopy of the stand, while young IAP plants in the understory should be removed (Figure 5.3).

Figure 5.3: An example of development stage 2

Development Stage 3: *More advanced stand development, with good development of forest regeneration*
This stand type is termed mixed-regrowth forest and there are some native forest trees growing into the canopy of the nurse stand. The forest self-perpetuating process is now vigorous and there are many indigenous tree clusters starting to develop. When removing stems the aim should be to continue to open gaps within the nurse stand so the forest cluster can develop through horizontal expansion of the cluster core (large clusters may now join together) and for new clusters to develop away from the cluster core (Figure 5.4)

Figure 5.4: An example of development stage 3

Development Stage 4: *Advanced stage of forest recovery*
The stand is dominated by regrowth forest species, and there are still some scattered IAP nurse plants present. At this stage the shade-intolerant invasive stands cannot become established even if they are present within the understorey. The focus should be to regularly inspect and remove the invader plants left in the stand. If there are still homogenous pockets of invasive plants within the stand they can be thinned to facilitate the succession process, but this should not be a key activity (Figure 5.5).

Figure 5.5: An example of development stage 4

5.6 Monitoring

The aim of manipulating invader plant stands is to encourage the successional development of natural forest species. In development stage 2 and 3 follow-ups need to be more frequent than in the initial stage (stage 1 – not much thinning is required because there are very few natural forest species) and in stage 4 (most of the nurse stand species have been removed and shade-intolerant invasive species cannot develop within a closed canopy).

Key points for the management of development stages:

Understand ecological factors

- The gap in the canopy should be large enough to provide enough light for developing forest seedlings and reduce resource competition to assist the natural forest tree seedlings or saplings to develop into this resource vacuum. The balance has to be correct, because if the gap is too large and too much disturbance is created this will trigger regeneration of light-demanding invasive species and the natural forest tree species will get smothered.
- Facilitating the development of forest clusters is the key to initiating a self-perpetuating forest rehabilitation process. This will not only increase the size of the forest area of each cluster, but will also attract ecological seed dispersal agents and allow the pioneer development on young clusters further into sterile areas of the invasive stands.
- Keeping some of the canopy intact will also provide the added advantage of river bank stabilisation (if in riparian areas) over the longer term. This is because the total kill and removal of large IAP stands could dramatically reduce the river bank stabilisation functions they are performing (Richardson et al., 2007).
- Create as little disturbance as possible – any type of disturbance promotes pioneer regeneration of invasive plants. Thus in areas where ground cover exists e.g. grass, sedges, understory shrubs it should not be removed. This might also include light-demanding low growing species such as *Rubus* spp. as they will eventually die out once the canopy develops and they are shaded out.

- Distance to native forest patch and distance to established clusters – Invasive stands which are located closer to forest patches and clusters are likely to have more native trees growing within them. They will be most likely to be the first areas to be completely converted to forest. The process of conversion is a self-perpetuating process which should aim for the clusters to merge together and eventually cover the entire IAP stand. The manager needs to keep this in mind when zoning and planning work activities on the site.
- Even once the site has been zoned, there are likely to be multiple areas within the zoned areas which are in different stages of development (e.g. an area which is zoned stage 1 might have a developing stage 2 cluster, which requires a gap to be created around it). Because this is a dynamic system, paying attention to this detail will accelerate the forest expansion process and managers should be aware of this.

6 REFERENCES

Atsame-Edda, A., 2014. Regeneration dynamics of natural forest species within a stand of the invasive alien Acacia mearnsii along the Buffeljagsrivier, Swellendam, South Africa. Stellenbosch University.

Behrensmeyer, A.K., Damuth, J.D., Di, M.W.A., Potts, R., Sues, H.D., Wing, S.L., 1992. Terrestrial ecosystems through time. University of Chicago Press, Chicago.

Campbell, K., Kellner, K., Mappledoram, B., Findlay J, B, R., Henderson, L., Kluge, R., 2000. Rehabilitation recommendations after alien plant control. Plant Protection Reseach Institute, Pretoria.

Geldenhuys, C.J., 1994. Bergwind Fires determin the location pattern of forest patches in the Southern Cape landscape, South Africa. South African J. Biogeogr. 21, 49-62.

Geldenhuys, C.J., 1997. Native forest regeneration in Pine and Eucalypt plantations in Northern Province , South Africa. For. Ecol. Manage. 99, 101-115.

Geldenhuys, C.J. & Venter, S. 2002. Plant communities and biodiversity of the Limpopo Province forests: relevance and management options. In: Seydack, A.H.W., Vorster, T., Vermeulen, W.J. & Van der Merwe, I.J. (eds). Multiple use management of natural forests and savanna woodlands: Policy refinements and scientific progress. Proceedings of Natural Forests & Savanna Woodlands Symposium III, 6-9 May 2002, Berg-en-Dal, Kruger National Park. P.23-37.

Geldenhuys, C.J., 2004. Meeting the demand for Ocotea bullata bark : implications for the conservation of high-value and medicinal tree species ., in: Lawes, M.J., Eeley, H.A.C., Shackleton, C.M., Geach, G.B. (Eds.), Indigenous Forests and Woodlands in South Africa: Policy, People and Practice. University of KwaZulu-Natal Press, Pietermaritzburg, pp. 1-30.

Geldenhuys, C.J., 2008. Can I Manipulate alien plant stands to rehabilitate natural forest? Dendron 40, 38-44.

Geldenhuys, C.J., 2013. Converting invasive alien plant stands to natural forest nature's way. Overview, Theory and Practice., in: Jose, S., Singh, H.P., Babish, R.D., Kohli, R.K. (Eds.), Invasive Plant Ecology. Taylor & Francis Group, Boca Raton, pp. 217-237.

Geldenhuys, C.J., Bezuidenhout, L., 2008. Practical guidelines for the rehabilitation of forest-related streambank vegetation with removal of invader plant stands along the Berg River, Western Cape. Forestwood cc, Pretoria.

Geldenhuys, C.J., Bezuidenhout, L., 2011. Rehabilitation of natural forests using nurse stands of plantation or invasive introduced species as allies, in: Bredenkamp B, Upfold S, J. (Eds.), South African Forestry Handbook. pp. 579 -598.

Geldenhuys, C.J. & Delvaux, C. 2007. The *Pinus patula* plantation … A nursery for natural forest seedlings. In: Bester, J.J., Seydack, A.H.W., Vorster, T., Van der Merwe, I.J. & Dzivhani, S. (eds). Multiple use management of natural forests and woodlands: Policy refinement and scientific progress. Natural Forests and Savanna Woodland Symposium IV, Port Elizabeth, South Africa, 15-18 May 2006. Pp 94-107

Holmes, P.M., Esler, K.J., Richardson, D.M., Witkowski, E.T.F., 2008. Guidelines for improved management of riparian zones invaded by alien plants in South Africa. South African J. Bot. 74, 538-552.

Kilawe, E., Habimana, D., Pasiecznik, N., Choge, S., 2015. Integrated management of invasive prosopis for improving food security in the Horn of Africa 7-11.

Lugo, A.E., Helmer, E., 2004. Emerging forests on abandoned land: Puerto Rico's new forests. For. Ecol. Manage. 190, 145-161.

Marais, C., Wilgen, B.W. Van, Stevens, D., 2004. The clearing of invasive alien plants in South Africa : a preliminary assessment of costs and progress. S. Afr. J. Sci. 97-103.

Mascaro, J., Becklund, K.K., Hughes, R.F., Schnitzer, S. a., 2008. Limited native plant regeneration in novel, exotic-dominated forests on Hawai'i. For. Ecol. Manage. 256, 593-606.

Richardson, D.M., Holmes, P.M., Esler, K.J., Galatowitsch, S.M., Stromberg, J.C., Kirkman, S.P., Pysek, P., Hobbs, R.J., 2007. Riparian vegetation : degradation , alien plant invasions , and restoration prospects. Divers. Distrib. 13, 126-139.

Rutherford, M.C. and Westfall, R.H. 1986. Bopmes of southern Africa – an objective categorization. Memoirs of the botanical survey of South Africa 54:1-98

Witkowski, E.T.F., Garner, R.D., 2008. Seed production, seed bank dynamics, resprouting and long-term response to clearing of the alien invasive Solanum mauritianum in a temperate to subtropical riparian ecosystem. South African J. Bot. 74, 476-484.

9781431208296