TARGETS FOR ECOSYSTEM REPAIR IN RIPARIAN ECOSYSTEMS IN FYNBOS, GRASSLAND AND SAVANNA BIOMES

FINAL REPORT TO THE WORKING FOR WATER PROGRAMME – JULY 2007

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Alien Acacia *regenerating following a Fell & Remove treatment (foreground), Palmiet River, Western Cape*

1. Executive Summary

In May 2004, a three-year research project was started in the Fynbos, Grassland and Savanna Biomes to assess ecosystem repair targets in alien-invaded riparian zones. The aim of the project was to recommend realistic and achievable targets for ecosystem repair following invasion. We tested the hypothesis that alien clearance alone enhances ecological integrity in riparian vegetation and tried to assess in which situations thresholds to recovery (abiotic and biotic) had been passed that require further active interventions to meet the desired ecosystem repair target.

The research used vegetation survey and experimental methodologies and represented novel work in all regions. Research sites covered a wide area in the Boland mountains in the Western Cape, the Featherstone Kloof and Berg River areas in the Eastern Cape, all representing the Fynbos Biome, and a long length of the Sabie River in Mpumulanga that traverses the Grassland and Savanna Biomes.

In all biomes, riparian ecosystems were generally found to have high ecological resilience to invasion by alien plants, except in some situations of closed alien stands (75-100% canopy cover). This means that where alien invasion is the only (or major) disturbance at a site, and invasion intensity is <75%, the recovery of riparian vegetation structure and functioning is a realistic target through alien clearance alone. Careful clearance of the aliens, particularly in denser stands, to avoid damaging persistent indigenous species, whilst ensuring a high kill rate for resprouting alien species, is sufficient action to ensure ecosystem recovery. In catchment areas where patches of good quality riparian scrub or woodland persist, recovery of vegetation composition and diversity may be anticipated to occur over a longer time-frame. However, it is important that alien follow-up control is maintained at a sufficient frequency and that adaptive management is exercised to deal with unplanned events that may stimulate renewed alien recruitment, such as fire or a heavy rainfall year.

In closed alien stands on the other hand, whereas in some situations alien clearance may be sufficient to restore ecosystem structure and functioning, in others it may not. Realistic targets must be set that take into account the planned future use of the riparian zone and the current ecological state of the surrounding catchment area. Where ecological integrity of the catchment is low, and surrounding areas are mainly transformed, in most cases it will not be an appropriate target to restore riparian ecosystem structure or composition. A more realistic target will be to restore ecosystem functioning through providing a vegetation cover that comprises non-invasive species (preferably indigenous) that are resilient to flood events and re-invasion by alien plants.

In the Fynbos Biome, the “Fell & Remove” treatment was found to be the best for facilitating vegetation recovery in closed alien stands. However, where large trees are present it may be more practical to kill these standing in situations where there are no secondary industry markets for the wood. This clearance approach is also appropriate in the Grassland and Savanna Biomes, although decomposition rates are higher in summer rainfall areas, which allows for more flexibility in the handling of slash.

The seed bank studies indicated that some components of riparian vegetation have persistent seeds in the soil, especially wet bank herb and dry bank herb and shrub species. Indigenous seed density and diversity depends on a number of factors, but probably invasion history is the most important, with recovery potential declining with time (or fire-cycles) of closed-stand invasion. In most situations, persisting seed banks are sufficient to initiate vegetation recovery after alien clearance, and thus to restore

some ecosystem functions such as bank stability and hydrological flows. However, vegetation structure will only be restored following the recruitment of riparian scrub and woodland trees and shrubs (whichever is appropriate for the particular biome). Most of these species do not have soil-stored seeds and have to colonize from neighbouring riparian vegetation patches. Thus the condition of the catchment, such as extent of transformation by aliens and other factors (e.g. cultivation, alteration of hydrological patterns) will influence the recovery rate of vegetation structure post-clearance. If the target is to restore ecosystem structure, then in many cases following closed-stand alien clearance it will greatly facilitate recovery to re-introduce the riparian woody species, at least in some focal areas.

We have developed simple management tools, in the form of decision-trees with accompanying information boxes and species lists, to assist in applying appropriate clearance methods, identify sites requiring active restoration and suggest methods for doing this. Because of the complexity of the decision process, it is recommended that specialists assist project managers in drawing up site-specific restoration plans that dovetail with the Management Unit Clearing Plans and Annual Plans of Operation. All restoration projects should be accompanied by a simple monitoring programme that can identify problems quickly so that management can react and adapt its actions.

The “targets for ecosystem repair in alien-invaded riparian vegetation” project has yielded new insights into the ecology of riparian vegetation, especially relating to invasion impacts, seed bank dynamics and resilience, that can relate directly to the improved management of riparian zones. The project has also been successful in training post-graduate students (8) and preparing manuscripts for publication. One PhD thesis (in progress), 4 MSc (2 completed and 2 in progress) and 3 honours projects (completed) have been achieved. Students have been active in presenting their studies to local and international audiences at various fora during the project period (Fynbos Forum, South African Association of Botanists, Thicket Forum and Society for Conservation Biology), as well as at our internal workshops. Two peer-reviewed scientific papers were published during the three-year project period and a further eight are being submitted for a Special Issue of the South African Journal of Botany (to be published in 2008; Annexure 5.10).

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1. Introduction and Background

1.1 Background & rationale

The Working for Water programme (WfW) was initiated in 1995 in response to the massive threat posed by invasive alien plants (IAPs) to ecosystems and natural resources and aims to bring IAPs under control. The goals of the programme are to enhance ecological integrity, water security and social development. In 2003, WfW advertised for tenders from research groups to study “targets for ecosystem repair in alien-invaded riparian vegetation in Savanna, Grassland and Fynbos Biomes”. WfW received two acceptable tenders from teams led by Saskia Fourie (Rhodes University) and Patricia Holmes (Cape Ecological Services), and requested that these be combined into one proposal (Annexure 5.1). Owing to this development, there was a delay in approval from the Department of Water Affairs and Forestry (DWAF), which resulted in the starting date being deferred from January 2004 to May 2004.

The background and rationale to the research project are outlined in Annexure 5.1, but a brief overview is presented here. The impacts of IAPs on natural ecosystems have been well documented and include the replacement of diverse ecosystems with alien (sometimes monoculture) stands; alterations to soil chemistry, fire regimes, geomorphological processes and hydrology. Riparian ecosystems are among the most invaded in South Africa and abroad, owing to the facilitated dispersal of alien propagules, and the natural disturbance cycles that yield regular establishment sites, along river courses.

Implicit in the WfW goal of enhancing ecological integrity is the assumption that control of alien vegetation alone will result in improvements to ecosystem structure and functioning. At regional and catchment scales this undoubtedly will be the case, as strategic planning should prioritize invasive fronts and outliers, thus preventing further degradation of ecosystems and facilitating rapid recovery in recently invaded, alien-cleared sites. However at local scales, in situations where dense to closed alien stands have existed for some time, thresholds may have been passed whereby ecosystems do not recover by alien clearance alone and require either vegetation manipulation, modification of the physical environment, or both.

Our approach in this study was therefore to derive clear and achievable goals for riparian ecosystem repair following alien plant invasion in the different biomes. Although complete ecological restoration to some pre-invasion natural state may be an appropriate goal at sites that are lightly invaded or have only recently become densely invaded, at long-invaded sites such a target may be unattainable in the short to medium term without very expensive interventions. We thus differentiate between “restoration”, defined as a reconstruction of a prior ecosystem including the re-establishment of former functions and characteristic structure, communities and species; and “rehabilitation”, defined as the reintroduction of certain ecosystem functions, such as improving water infiltration or erosion control, to benefit ecosystem functioning at the landscape scale, but not necessarily biodiversity. The term “ecosystem repair” refers to actions that overcome limitations in both the abiotic and biotic components of the ecosystem and thus embraces objectives from both restoration and rehabilitation.

We proposed to base our target setting on the desired characteristics for the ecosystem in the future rather than being restricted to some historical ecosystem of the past for which we may not have adequate understanding. Such a framework allows appropriate targets to be set based on the degree of ecosystem degradation that has occurred and in relation to other environmental variables and the proposed future land-use in an area.

1.2 Terms of reference

The terms of reference (below) outlined four phases to the project over the three year period, i.e.: project set-up, baseline studies, establish impacts of clearing on riparian ecosystem repair & set goals, and project finalization & development of protocols for repair goals and monitoring. The first two phases ran according to plan, although a few projects started later than originally envisaged. Students attempted to answer the questions posed in phase 3, but owing to the complexity and dynamic nature of riparian zones it was difficult to identify clear thresholds of riparian ecosystem degradation or keystone species. More research will be needed in the different biomes before a better understanding emerges on abiotic and biotic thresholds and keystone species. We were able to assess what is achievable in each of the different situations studied, what could be improved, and what are the realistic repair goals.

<u>Phase 1: Project set-up (6 months)</u>

- Advertise for post-graduate students to become involved in the research programme (Previously Disadvantaged Individuals will be given preference where possible).
- Review of SA scientific & grey literature, including recent unpublished studies, on riparian vegetation in Fynbos, Grassland and Savanna ecosystems, especially in relation to invasion by aliens, ecosystem degradation and restoration efforts. Relevant international literature on these subjects also will be reviewed.
- From the literature review identify impacts and factors that may be important in limiting riparian ecosystem recovery.
- In collaboration with WfW GIS staff, analyze available spatial information on Fynbos, Grassland and Savanna riparian areas, classified by stream order, to indicate invaded areas (by density and species) and cleared areas (by clearing methods and dates). Identify which are the major IAP species and clearing methods in each biome.
- Organize and hold workshops with interested managers from WfW and the Provincial Conservation Authorities and WfW technical staff, to discuss the findings from the literature review and the proposed research approach in relation to the managers’ experiences in the field.
- Finalize detailed methodologies in the light of workshop outcomes; identify study sites and finalize work programme with team and client.

Phase 2: Baseline studies (18 months)

- Baseline studies to assess the impacts of alien clearance on vegetation recovery and ecosystem functioning in riparian zones will be conducted.
    - Variables that will be used to stratify the study include: vegetation type, river order (i.e. headwater versus downstream sections), alien species, density and history, clearing method and time since clearance. Use of chronosequences of sites (of different ages since clearance) potentially will allow assessment of vegetation development along trajectories towards vegetation targets.
    - Important co-variables will be physical environmental factors (e.g. soil type and channel characteristics) and surrounding ecosystem condition (i.e. condition of adjacent non-riparian ecosystems and propagule sources).
    - Permanent monitoring plots may be set up in each biome for long-term monitoring of the impacts of alien clearance on vegetation recovery (see ToR 3 & 4).
    - Information from completed studies will be used to define reference or control sites. If no information exists for a particular river order and vegetation type, sampling will be done to provide this information where such sites exist. Ideally, data both on comparable intact sites and invaded, uncleared sites will be compiled for comparative purposes with the cleared sites.
    - It is intended to sample several rivers in each biome where clearing has taken place during the past five years and for which sufficiently detailed management information is available. Collaboration with WfW to clear sites at the start of the study to facilitate a two-year monitoring period is an alternative strategy that may be discussed.
    - The proposed sampling methods will be adapted from those of earlier studies in the fynbos, using either plot sampling or a 10-m wide transect across the river floodplain to sample for perennial vegetation and physical features. The transect approach enables the different riparian zones to be sampled. The transect approach was used in the savanna biome study of one MSc in the Kruger National Park. However, the opportunity to resample the 40, 0.1 ha (50 x 20 m) modified Whittaker plots within the grassland and savanna reaches of the Sabie River, Mpumalanga province was considered as most appropriate for another MSc study in order to obtain a longer term perspective.
    - Indicators to be considered include measures of vegetation recovery (strata, cover, composition, richness – alien and indigenous species), ecosystem functioning (bank stability and sedimentation) and where possible, aquatic ecosystem health (from external studies or student projects). Attention will be given to the sources of indigenous species (seedling versus resprouter).
    - Sampling intensity will depend upon site accessibility, breadth of riparian vegetation and budget. It is estimated that about 100 transects (= plots) could be achieved in the Western Cape, but the larger flood plains in the Grassland/ Savanna regions may result in a smaller number of samples there.
- Seed banks will be sampled to indicate the potential for vegetation recovery and intensity of alien recolonization.
- An example study on post-cutting resprouting will also be included.

- If appropriate, sites where additional interventions have been applied (e.g. post-clearance sowing of grasses or riparian species) will be included in the baseline field studies.

Phase 3: Establish impacts of clearing on riparian ecosystem repair & set goals

Data from the baseline field studies will be analyzed to explore the relationships between the degree of ecosystem degradation and recovery. Potential techniques include logistic regression to investigate relationships between vegetation variables and extent of invasion and/or clearing methods. Multivariate analyses will be employed to explore vegetation development along trajectories towards the benchmark ecosystems. It is intended to answer the key questions (below) relating to ecosystem repair in the three biomes.

- What has been achieved: i.e. what level of ecosystem repair has been achieved in each of the different situations studied?
- Are the thresholds derived from ecological theory applicable in practice?
- In what situations have biotic thresholds been passed?
- In what situations have abiotic thresholds been passed?
- What is achievable in each of the different situations studied?
- What could be improved?
- Have any important ecosystem drivers or keystone species (to facilitate recovery) been identified?
- What are the realistic goals for the different situations, particularly in relation to vegetation type, river order and level of ecosystem degradation?
- Produce research reports and scientific papers.
-

Phase 4: Project finalization & development of protocols for repair goals and monitoring

- Synthesize all information researched into a final report.
- Organize and hold workshops with interested managers and WfW technical staff to discuss the findings & the development of management tools. It is envisaged that one workshop will be required in the Fynbos Biome (Western Cape) and one spanning the Grassland and Savanna Biomes, but alternatively a combined workshop may be held.
- Develop protocols for achieving the realistic goals within a framework of facilitating ecosystem recovery. Different levels of ambition for the target ecosystem should be included in this framework.
- Develop a management tool (e.g. a guidelines booklet incorporating decision trees) to assist managers in implementation.
- Develop simple and useful monitoring criteria and indicators to assess the achievement of goals.

1.3 Project time-line (May 2004 – June 2007)

	PHASE 1	**PHASE 2**	**PHASE 3**	**PHASE 4**
	Start-up	Baseline studies	Data analyses	Finalizing targets
2004 May-Oct	▨			
2004 Nov-Jun		▨		
2005 Jul-Dec		▨		
2006 Jan-Jun		▨	▨	
2006 Jul-Dec		▨	▨	
2007 Jan-Jun			▨	▨

2. Methodology and Approach

The methodology produced from Phase 1 set out the research approaches to be used during the baseline studies in the three biomes (Annexure 5.6). The methodology was developed from the original proposal following collaborations and a workshop with Working for Water staff and other interested parties (held in September 2004) and a detailed review of the literature. A broad overview and a few deviations from the methodology report are outlined below. The literature review also led to two scientific publications (Holmes et al. 2005; Richardson et al. 2007; Annexure 5.10).

2.1 Baseline surveys

In order to address the key questions, baseline vegetation surveys were done to assess the impacts of alien clearance on vegetation recovery in riparian zones. In the Eastern and Western Cape regions, vegetation plots (25m^2 and 50m^2 respectively) were set up in the riparian zones at uninvaded reference sites to compare with plots established at invaded and cleared sites. In the Grassland and Savanna study along the Sabie River, previously established Whittaker plots (1000m^2) were resampled following WfW alien clearing (Garner and Witkowski 1997[1]) and the 2000 large flood event. In a second study, ten-metre wide transects across the river channel were sampled close to and inside the Kruger National Park. Locality coordinates are available for all these survey plots to facilitate long-term monitoring opportunities (Annexure 5.4).

These study approaches were adequate to assess the impact of alien invasion and clearance on riparian vegetation recovery potential, but a lack of good site management history records hampered the interpretation of results, particularly in the Eastern Cape (see 4.2 for more details). Ideally, field experimental studies designed to directly test the impacts of initial treatments (such as burning versus non-burning) and follow-up treatments (such as hand-pull versus spot herbicide application), would complement the survey work and enable higher confidence levels in the interpretation of results.

In all studies, various abiotic and biotic variables were measured, and the management profiles for each site compiled. Multivariate analyses allowed the relative importance of these variables to be assessed in relation to the degree of vegetation recovery. The impact of post-clearance duration was assessed in each region by sampling chronosequences of sites in the Eastern and Western Cape regions, and in Mpumulanga by resampling permanent plots first sampled in 1996.

Soil seed bank studies, using the seedling emergence approach, were done in the Eastern and Western Cape regions to directly test restoration potential at a range of riparian sites, including reference and invaded sites. This provided the first seed bank data sets for riparian zones in the Fynbos Biome. A soil seed bank study had already been completed in the Grassland and Savanna Biomes by Richard Garner from the same Whittaker plots resampled for vegetation recovery in this project. Methods largely followed those outlined in the methodology report (Annexure 5.6).

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[1] Garner R.D. & Witkowski E.T.F. (1997). Changes in plant diversity after clearing of alien plants along riverine corridors in Mpumalanga, South Africa. Report to the Mpumalanga Water Conservation Programme, pp 34.

2.2 *Experimental studies*

The Eastern Cape experimental study was implemented, but in a slightly changed format to that outlined in the methodology report. One initial alien clearing treatment (Fell & Burn) was subdivided into three rehabilitation treatments (grass plugs and seed of *Digitaria eriantha*; indigenous plants and seed; and control), which were further subdivided by follow-up treatments (handpull, herbicide, and control). Preliminary experimental results are available from the Eastern Cape study, but the planned Western Cape study had to be abandoned owing to the initial treatments not being implemented in time (see 4.3 for further details).

2.3 Additional studies

In the Eastern Cape region a botany honours study investigated the impact of slash fires on seed mortality and germination in soil seed banks of alien *Acacia longifolia* and four indigenous species (Behenna et al. submitted, Annexure 5.10). The variables investigated included soil moisture, depth of burial and fuel load. The study indirectly addressed the question of the optimal season for burning alien slash to promote indigenous vegetation recovery in the Grassy Fynbos.

In the Western Cape region a study to investigate the feasibility of re-introducing woody riparian species in highly transformed areas was initiated in early winter 2005. This was set up as a replicated field experiment along a recently cleared riparian dry bank zone of the Berg River in the Asbos Project. The study compared the establishment success of specialist riparian scrub species (*Metrosideros angustifolia*, *Brachylaena neriifolia* and *Brabejum stellatifolium*) from either truncheons (stem cuttings) or seedlings (collected from the wet bank zone prior to winter inundation or from germinated seeds). Unfortunately an early winter flash-flood swept the entire area and many of the translocated plants were lost. These preliminary results will be available in Ryan Blanchard’s MSc thesis.

An additional conservation ecology honours study in the Western Cape re-sampled a riparian restoration trial following a wildfire in December 2005, that had been originally set up in 1998 at Oaklands Farm, near Wellington. An initial “Fell & Burn” treatment in 1998 had been given different restoration sowing treatments in a randomized experiment of 20 plots, and one alien follow-up treatment, prior to being left to grow unattended. Stem diameters and survival of all woody individuals in the 20 plots were measured, and seedling germination was monitored in 1m^2 subplots during the late winter following the fire. The study was able to address the question of how sustainable restoration interventions were to re-invasion and fire. Results are reported in detail in Pretorius et al. submitted (Annexure 5.10).

3. Results and Recommendations

The main findings of the riparian ecorepair project are reported here. It is important to note that in the Eastern and Western Cape regions we focused on mountain stream and foothill sites and did not sample flood plain rivers that occur primarily in the transformed landscapes of the lowlands. In the Mpumulanga studies, a longer river length was sampled, starting in mountain stream segments, through foothill segments to the larger flood plain segments at lower altitude. For more details on individual studies, please refer to the list of theses, scientific papers and other documents in Annexures 5.9 and 5.10.

The key questions asked of this research (from the Terms of Reference Phase 3 outline) are:

a) What has been achieved in terms of ecosystem repair following WfW alien clearance?

b) Have abiotic or biotic thresholds been passed that prevent natural ecosystem repair? Have any important ecosystem drivers or keystone species been identified?

c) What is achievable in terms of ecosystem repair in each of the different situations studied and what could be improved?

d) What are realistic ecosystem repair goals for the different situations?

3.1 Fynbos Biome – Western Cape

a) <u>What has been achieved?</u>

In the W. Cape, the research focus was on the worst-case scenarios: closed-stand invasions (>75% cover), which are most likely to exhibit ecosystem repair failure post-clearance. The dominant invasive alien plant species in most reaches was *Acacia mearnsii*. Observations to date indicate that lower density invasions (up to 75% cover), in which indigenous vegetation persists among the aliens, recover well following careful clearing operations. In this research it is assumed that ecosystem functioning is repaired at sites where vegetation recovery post-clearance is on a trajectory towards an appropriate uninvaded, reference site.

The vegetation study indicated that even for closed-stand invasions, over 40% of the cleared sites regenerated vegetation with a species composition comparable to uninvaded reference sites (Figure 3.1.1; Blanchard & Holmes, submitted, Annexure 5.10). The results were not randomly distributed among clearing treatments, however, and it was found that about 60% of Fell & Remove and Fell Only treatment sites closely approached the reference site composition compared to only 20% in the Fell & Burn treatment. In assessing the other vegetation variables measured, the Fell & Remove treatment outperformed the other two: it had the highest indigenous vegetation cover, species richness and diversity values of all treatments and was only significantly lower than the reference sites for % projected canopy cover (Table 3.1.1). The Fell Only treatment sites had the lowest indigenous cover while their woody alien cover was the highest. This may reflect the difficulty of doing follow-up clearance amongst felled slash. On the other hand, the Fell & Burn treatment promoted herbaceous alien growth.

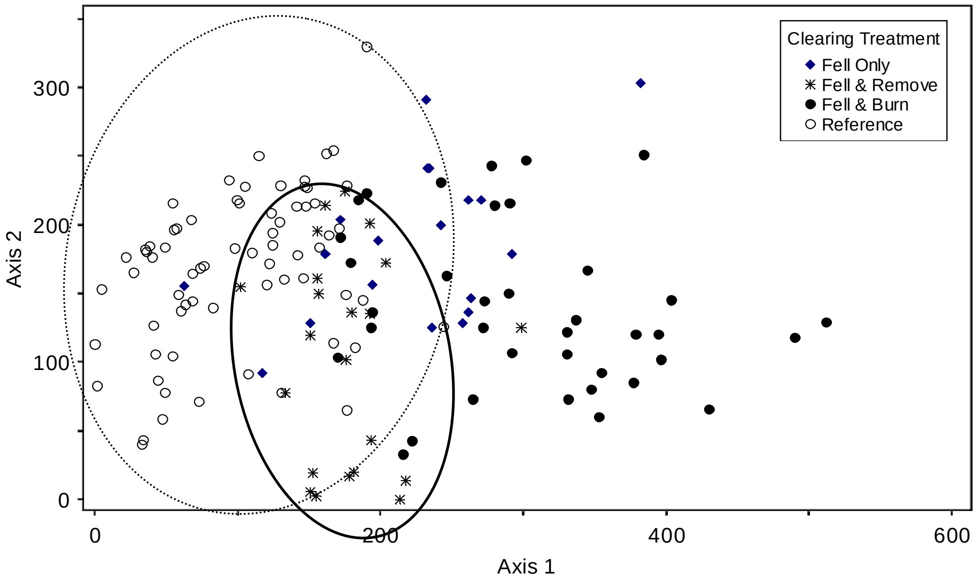

Figure 3.1.1. Detrended Correspondence Analysis ordination of all sample plots based on indigenous perennial species with infrequent species down-weighted. The ellipses represent the reference plots (dotted line) and Fell & Remove (solid line)

In terms of vegetation structure, which is arguably more important for ecosystem functioning than species composition, the Fell & Remove treatment was much more closely aligned to the reference condition than the other two treatments, with 95% of sites overlapping in the ordination compared to only 10% in Fell Only and 30% in Fell & Burn (Figure 3.1.2; Blanchard & Holmes, submitted, Annexure 5.10). In Fell Only sites, forbs were over-represented and most other growth forms under-represented relative to the reference sites. In Fell & Burn sites, graminoids – particularly grasses – were over-represented, and other growth forms except low shrubs under-represented relative to the reference sites.

Table 3.1.1 - Comparison of vegetation variables (mean ± SD) following three alien clearing treatments and reference sites. Within each variable, columns with different letter superscripts are significantly different.

Vegetation Variables	Fell Only	Fell & Remove	Fell & Burn	Reference
N	19	22	37	69
Indigenous Vegetation				
% Cover	41.3 ± 5.96^{a}	66.9 ± 4.39^{b}	54.2 ± 4.23^{ab}	73.1 ± 1.40^{c}
Species Richness (1 m$^{2)}$	1.72 ± 0.21^{a}	3.10 ± 0.31^{bc}	2.16 ± 0.13^{ab}	4.48 ± 1.19^{c}
Species Richness (50 m^{2})	9.11 ± 0.98^{b}	15.5 ± 1.29^{a}	11.2 ± 0.70^{b}	11.0 ± 0.57^{b}
Shannon Diversity (*H'*)	1.30 ± 0.60^{a}	1.90 ± 0.40^{c}	1.50 ± 0.30^{ab}	1.70 ± 0.50^{cb}
Pielou Evenness (*J*)	0.58 ± 0.06^{a}	0.81 ± 0.04^{ab}	0.66 ± 0.02^{a}	0.74 ± 0.03^{b}
Alien Vegetation				
% Cover woody species	21.7 ± 6.18^{a}	17.5 ± 4.14^{a}	5.03 ± 1.25^{b}	1.92 ± 0.50^{b}
% Cover herbac. species	7.87 ± 2.83^{abc}	2.30 ± 1.57^{a}	14.4 ± 3.73^{bc}	0.05 ± 0.03^{a}

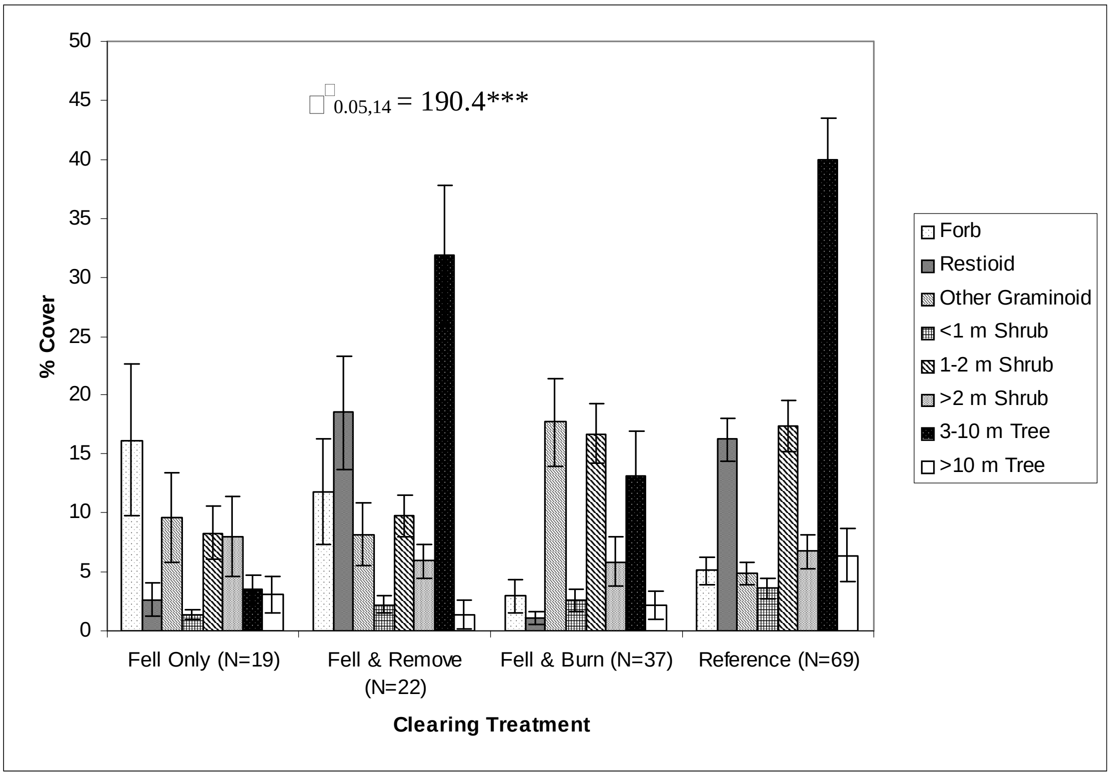

Figure 3.1.2. Projected % canopy cover for eight narrow growth forms (mean ± standard error) in cleared and Reference plots. The X^2 analysis was calculated using contingency tables with Reference as the expected values.

The influence of time since clearance on vegetation recovery was investigated by first dividing the data set into those sites cleared before or after five years ago. Indigenous vegetation cover increased over time, but there was no overall change in species richness. For Fell Only and Fell & Remove sites, older cleared sites more closely aligned to the reference sites in terms of species composition, but for the Fell & Burn treatment this pattern was less evident. This indicates that unburnt sites are on a trajectory towards recovery, but for the burnt treatment sites, recovery tends to be more protracted.

Results from this vegetation study clearly indicate that for closed alien stands in the riparian zone a Fell & Remove treatment optimizes ecosystem repair potential. Aspects of both Fell Only and Fell & Burn treatments compromise indigenous species recovery in the short-medium time frame (of ten years). In the case of the Fell Only treatment, slash on the ground likely inhibits germination and establishment in a range of indigenous species. By contrast in the Fell & Burn treatment, a high severity fire resulting from high levels of slash biomass on the ground may kill indigenous seeds while promoting germination in the hard-coated alien *Acacia* seeds. An alternative explanation for poor recovery in the latter treatment (since riparian fynbos communities are adapted to fire) is that fire stimulates mass recruitment in alien *Acacia*, which triggers the management response of herbicide spraying as a follow-up treatment. During such a treatment, any regenerating indigenous plants, except monocotyledons, are likely to be killed, further setting back the recovery process. Thus the recovering stand has a high cover of grasses, including aliens, with the possibility of this community being persistent and inhibiting development along a trajectory towards the desired state.

In 1998, a restoration field trial was initiated in a catchment near Wellington to determine if fynbos riparian areas cleared of alien vegetation require post clearance restoration actions to accelerate indigenous vegetation recovery (Pretorius et al. submitted; Annexure 5.10). The aim was to assess the relative effectiveness of three sowing treatments for restoring indigenous vegetation cover and reducing soil erosion after the widely used Fell & Burn method of invasive alien tree clearance. Sowing treatments included a general fynbos and riparian species seed mix, combined with non-invasive alien annual grasses in order to determine if they may be used for short-term soil erosion control without having a negative effect on re-establishing indigenous vegetation. A summer fire, eight years after trial initiation, provided the opportunity to determine how resilient restoration treatments are to alien re-invasion and fire.

Table 3.1.2 Mean plant densities (± standard deviations) and % cover in 4 quadrats (1m^2) for Control and sowing treatments (Fynbos, Mix, Terraces) in 1998, 1999 and 2006. Mix combines fynbos and alien annual grass seed; in terraces, grass is sown in rows with fynbos seed broadcast.

Growth form guild	Control			Fynbos treatment		
	1998	1999	2006	1998	1999	2006
Ericoids	42.6±52.47	7.3±1.64	50.95±47.24	75.5±77.48	15.08±6.72	25.05±33.99
Proteoids	0.05±0.23	0.7±1.30	0.00±0.00	7.40±5.84	6.36±3.36	0.00±0.00
Acacia mearnsii	7.65±7.24	-	17.90±18.99	9.11±10.44	-	9.03±4.51
Eucalyptus spp.	4.43±2.23	-	0.10±0.14	1.35±1.63	-	0.70±1.43
Indigenous grasses	2.35±3.20	22.76±24.41	41.95±45.83	5.55±10.66	23±26.20	46.60±67.49
Alien grasses	0.15±0.67	1±2.24	0.40±0.29	0.00±0.00	0.75±1.12	0.25±0.25
Indigenous forbs	2.35±3.13	4.16±7.91	3.55±3.63	2.35±3.34	3.05±2.29	3.05±2.52
Alien forbs	1.00±1.45	2±0.77	21.80±31.35	0.80±1.28	2.15±1.36	7.70±6.76
Broadleaved shrubs	0.00±0.00	0.2±0.33	1.25±3.65	0.05±0.22	0.05±0.11	19.35±36.06
Bracken	29.1±18.63	10.82±9.18	22.3±10.69	37.0±25.17	9.77±4.31	18.70±10.33
Geophytes	0.40±0.75	2±3.93	2.3±2.27	0.70±1.42	0.5±0.87	15.45±17.54
Alien cover	9%	9%	-	8.20%	-	-
Indigenous cover	30%	51%	-	39%	51%	-
Total cover	35%	51%	30%	42%	52%	30%
Growth form guild	**Mix treatment**			**Terraces treatment**		
	1998	1999	2006	1998	1999	2006
Ericoids	54.30±45.45	11.86±4.11	27.05±23.91	46.10±35.96	12.71±4.62	41.60±55.34
Proteoids	4.90±4.00	4±1.49	0.00±0.00	6.46±6.06	4.2±2.31	0.00±0.00
Acacia mearnsii	9.86±8.00	-	11.95±10.69	10.50±13.32	-	10.50±4.57
Eucalyptus spp.	0.95±1.32	-	0.00±0.00	1.20±1.24	-	0.00±0.00
Indigenous grasses	40.50±33.88	5.5±10.95	9.60±8.22	56.00±36.51	9.26±9.06	13.05±11.63
Alien grasses	57.50±61.63	97.9±49.20	0.05±0.11	17.00±45.20	51.52±24.34	0.10±0.22
Indigenous forbs	1.80±2.21	1.25±1.72	4.60±4.79	2.00±3.21	1.15±0.96	9.45±7.98
Alien forbs	3.25±10.69	1.05±0.93	6.05±2.75	0.65±1.42	1.9±1.46	10.40±9.05
Broadleaved shrubs	0.00±0.00	0.00±0.00	0.15±27.64	0.45±1.61	0.05±0.11	0.00±28.6
Bracken	20.20±20.25	8.01±7.24	15.10±12.14	22.10±23.7	8.81±8.54	14.35±8.18
Geophytes	0.20±0.52	0.05±0.11	3.90±5.04	0.30±0.92	0.1±0.22	2.40±3.18
Alien cover	19%	20%	-	11%	17%	-
Indigenous cover	23%	40%	-	24%	41%	-
Total cover	37%	52%	17%	31%	51%	24%

Restoring the site by sowing indigenous seeds after alien clearance did increase the species and structural diversity of the plots (Table 3.1.2). However in 2006, alien *Acacia mearnsii* dominated the restoration site at the time of the subsequent wild fire, as follow-up weeding had not been continued beyond the first follow-up in 1999. The eight-year post-fire results indicated that some of the sown indigenous species survived by resprouting (e.g. *Brabejum*); ericoids, forbs and graminoids survived through seedling recruitment, but serotinous proteoids that are killed by fire (e.g. *Leucadendron*) failed to recruit from seed. The alien *Acacia* survived fire both by resprouting and recruiting from seed. Alien *Acacia* seedling recruitment was lower during 2006 in plots that had received a sowing treatment in 1998, indicating some potential of indigenous species to suppress the aliens. Sown alien grass inhibited the establishment of indigenous species of various guilds (ericoids, proteoids, grasses). However, these annual grasses were found to be non-persistent post-fire. Active restoration of riparian areas after alien plant clearing improves indigenous vegetation recovery potential, and assists in suppressing woody alien recruitment, but must be coupled with regular follow-up removal of invasive aliens.

The early results from the propagation experiment (reported in Ryan Blanchard's MSc thesis) indicated that most of the truncheons died, thus propagated cuttings or seedlings are likely to have higher establishment potential. *Brabejum* showed potential for establishment directly from seed (as confirmed in the Oaklands experiment).

b) Have thresholds to recovery been passed?

None of our baseline studies were able to specifically address abiotic thresholds in relation to ecosystem repair. Earlier work indicated that stable slopes may be required for the establishment of characteristic fynbos riparian scrub species (Galatowitsch & Richardson 2005). Unpublished work by C. Boucher and students (University of Stellenbosch) indicated that alien tree stands in foothill river reaches may accumulate sediments and alter river geomorphology. Such features could inhibit post-clearance recovery if the indigenous seed bank is buried too deep below the sediments for successful germination, or if the sediments are unstable and thus unsuitable for colonization by desirable riparian scrub species.

Our studies did address biotic thresholds, both indirectly through the vegetation study, and directly through the soil seed bank study. However, both these studies need to be interpreted in relation to the surrounding catchment area, as recovery potential and barriers to recovery relate to propagule sources both within the site and from the upstream and neighbouring landscape, as well as to suitable establishment sites.

The soil-seed bank study of uninvaded vegetation confirmed that many of the characteristic closed-scrub fynbos species are not present in the seed bank. Non-soil seed bank species include the dominant riparian scrub trees (e.g. *Brabejum stellatifolium*, *Metrosideros angustifolia*) and serotinous shrubs (e.g. *Leucadendron salicifolium*). Herbaceous and low-shrub growth forms dominated the seed bank (Figure 3.1.3; Vosse et al. submitted, Annexure 5.10).

The most frequently-occurring species in the soil-seed bank comprised herbaceous and small-medium shrub species of fynbos affinity, with families such as Poaceae, Cyperaceae and Asteraceae prominent (Figure 3.1.4; Vosse et al. submitted, Annexure 5.10). Seed bank composition was clearly defined by the moisture regime (wet or dry bank lateral zone), longitudinal position (mountain stream or foothill), and river catchment area, with some rivers showing a greater diversity of species associated with the different riparian zones than other rivers. The wet bank zone was dominated by riparian species, with the families Cyperaceae and Poaceae prominent, whereas the dry bank zone had a higher richness and diversity that comprised of mainly fynbos species (including both terrestrial and wetland-adapted species). The soil seed bank of riparian corridors is thus important in regenerating the wet bank lateral zone vegetation and the understorey of the dry bank lateral zone vegetation following disturbance.

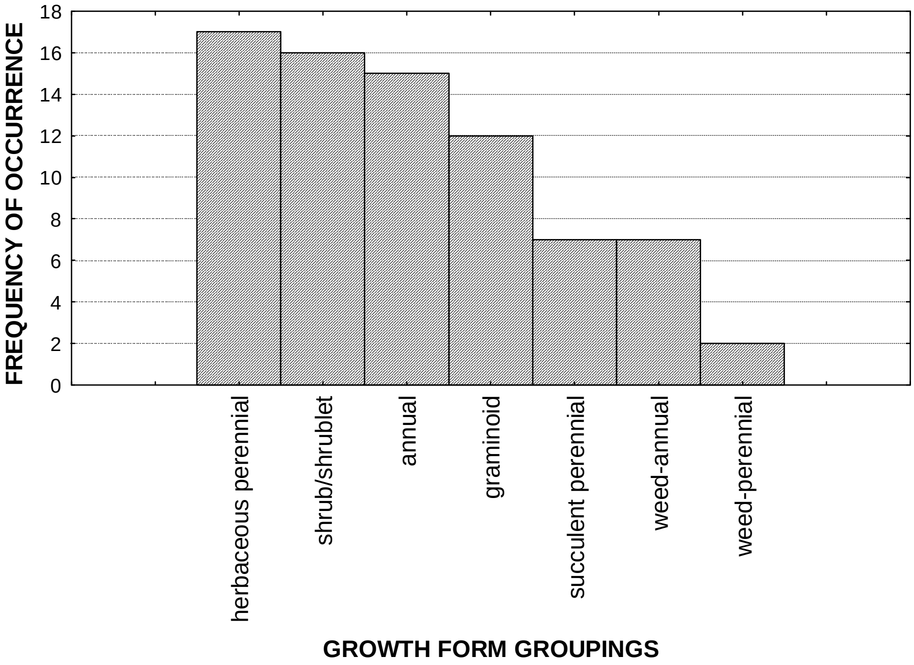

Figure 3.1.3 The distribution of plant growth forms in the riparian seed bank flora of the Western Cape. Data are for all sample plots combined (n = 290).

Table 3.1.3 Seedling abundance for reference (Ref) and invaded (Inv) sections of four rivers divided into growth forms.

RIVER	**Berg**	**Berg**	**Eerste**	**Eerste**	**Mol**	**Mol**	**Wit**	**Wit**
State	**Ref**	**Inv**	**Ref**	**Inv**	**Ref**	**Inv**	**Ref**	**Inv**
tree	0	0	11	0	0	0	0	0
shrub/shrublet	338	13	137	48	174	164	198	100
herbaceous perennial	768	76	370	274	623	150	386	191
succulent	109	9	30	176	57	35	33	107
herbaceous annual	540	206	406	396	218	251	76	443
graminoid	2672	521	1308	788	1578	818	816	519
TOTALS:	**4427**	**825**	**2262**	**1682**	**2650**	**1418**	**1509**	**1360**

The soil-seed bank composition in closed alien stands changed to a less species-rich one dominated by herbaceous species, with alien species more frequent and dominant

(Table 3.1.3; Vosse et al. submitted, Annexure 5.10). Nevertheless, indigenous riparian graminoids and a few shrub seeds persisted at invaded sites, although species composition was much more variable and unpredictable. The results imply that vegetation regenerating from the seed bank post-alien clearance is more likely to comprise herbaceous, short-lived species.

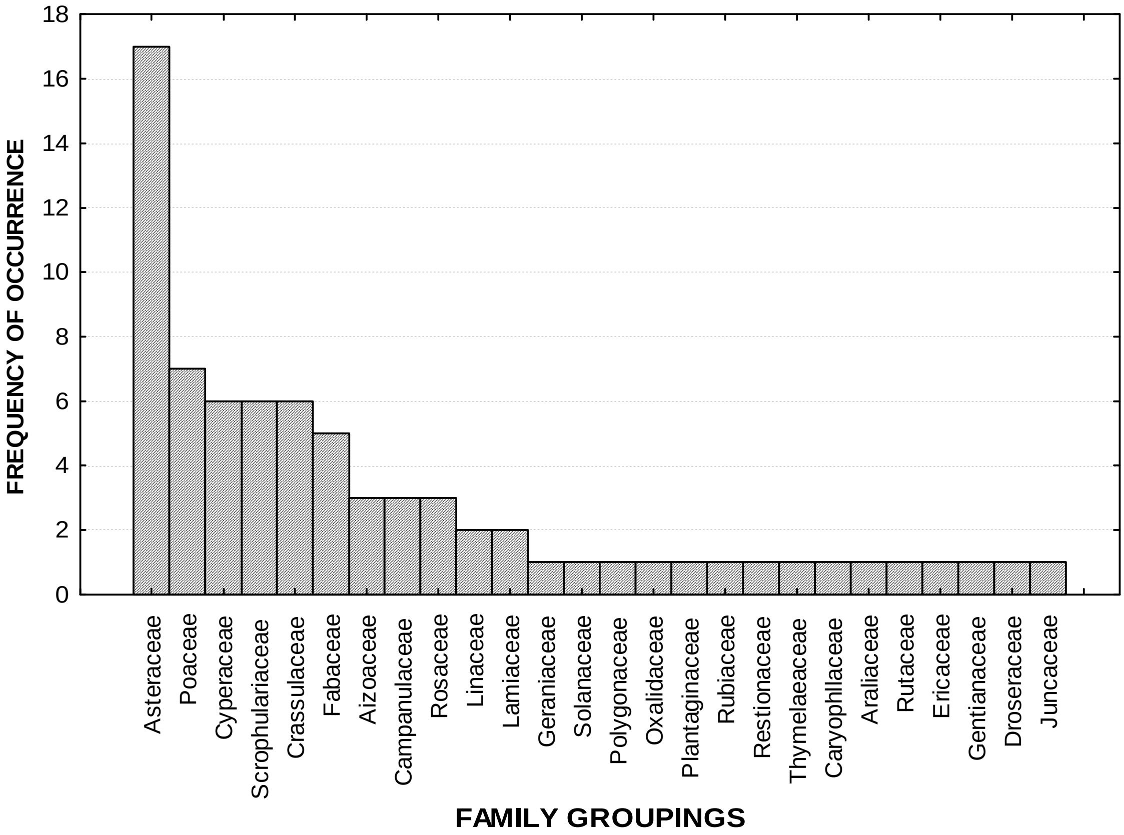

Figure 3.1.4 Frequency of plant families occurring in riparian seed banks of the Western Cape. Data are for all sample plots combined, n = 290 samples.

Whether the seed bank results indicate that a biotic threshold has been passed depends on the condition of the surrounding catchment area. If invasion of riparian vegetation is patchy upstream of the site, or if indigenous vegetation survives upslope of the riparian zone, then the soil seed bank should be sufficient to initiate vegetation recovery and woody, longer-lived species will re-colonize from outside. However, if the catchment is heavily invaded by alien vegetation and/ or transformed to another land-use on the slopes (e.g. agriculture or forestry) then a shortage of non-seed bank woody species typical of riparian vegetation may not be available for re-colonization and a recovery threshold will have been passed. This threshold may be overcome by sowing or planting nodes of the later-seral riparian scrub species following alien clearance.

The vegetation study further indicated that in sites receiving a Fell & Burn treatment, the seed bank is likely to have been depleted further (owing to the combined effects of fire and post-fire herbicide application). A biotic threshold would more likely be passed in this treatment compared to the others, particularly in situations where the surrounding catchment area is degraded and indigenous propagule pressure from outside the site is low.

c) What is achievable and what could be improved?

In the majority of alien-invaded foothill and mountain stream reaches of rivers in the Western Cape, recovery of natural vegetation post alien-clearance is an achievable target. Exceptions are:

i) Where long-standing closed alien stands are cleared in a degraded and transformed catchment and propagule sources are lacking in the surrounding area.

ii) Where a closed alien stand receives a “Fell & Burn” alien clearing treatment.

It is recommended that managers consider using the “Fell & Remove” treatment in all cases of dense to closed alien stand clearing along rivers. Where it is impractical to remove slash, it should be stacked away from the riparian zone in areas where winter season stack burns can be safely carried out. In some areas in foothill or flood plain reaches it may be possible to burn stacks on sandbars in the river bed, before the onset of winter rains, to avoid damage to surrounding vegetation. From observations in the field and the vegetation survey results following a “Fell & Burn” treatment, more care should be exercised when clearing vegetation to avoid damaging any indigenous plants. This applies to indiscriminately felling indigenous species as well as spraying them with herbicide during follow-up treatments. It would thus appear that more effort is required in training and supervising the contract teams who do the work.

Where the goal is to return an indigenous stand of riparian vegetation, there is potential to improve recovery through active restoration. This should be considered in catchments that are degraded and have few remaining propagule sources to drive the recovery of areas, and also where damage may have been done locally through a high severity fire or excessive use of herbicides. A case study by Reinecke et al. (submitted)[2] along the Silvermine River indicated that after alien clearance and fire, riparian shrubs and trees either colonize within the first year or two or else the vegetation remains largely herbaceous. Thus simple post-fire monitoring should indicate areas where active restoration is required.

d) What are realistic goals?

In the majority of mountain stream and foothill river reaches of the Western Cape a realistic goal following alien invasion is to return the riparian zone to a vegetation stand that is structurally representative of riparian scrub and dominated by indigenous species. This goal is appropriate in that riparian scrub vegetation will best ensure that the ecosystem functions of the riparian zones are restored.

For some dense to closed alien stands it may be an unrealistic goal to restore the vegetation to a pre-invasion reference community (in terms of species composition and diversity) within a short-medium time-frame. However, once indigenous vegetation structure is restored and invasive aliens are controlled, diversity and composition are likely to continue to change over time along a trajectory towards a reference community.

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[2] Reinecke MK, Pigot A & King JM (submitted). Unassisted recovery of riparian fynbos: a viable restoration strategy? South African Journal of Botany.

In the lowland flood plain river reaches degradation and invasion in the riparian zones have a long history and it is unrealistic to set a goal of restoring these sites to some pre-invasion reference condition. Instead, the goals should be set according to the required functions of the riparian zone in the particular area, in other words to rehabilitate the riparian zones to serve these ecosystem functions. Wherever possible, indigenous species should be used in the rehabilitation and invasive alien species avoided.

At the 2007 workshop (Annexure 5.8), discussions among managers and researchers indicated we should strive for functional ecosystems with measures other than species richness being employed to guide ecosystem repair: for example, using structural diversity/ indicator species and water discharge rates. Secondly, for aliens with successful biological controls, a more appropriate goal than 100% clearance may be the thinning of aliens to allow gradual recolonization by indigenous riparian species. This approach could prevent the establishment of alternative stable states of secondary invasions developing in response to disturbance by the initial clearance of closed alien stands.

For mountain stream and foothill river segments, a summary of the restoration protocols required to achieve the goal of re-instating indigenous vegetation and riparian scrub structure are outlined in Table 3.1.4.

Table 3.1.4. Restoration protocol for alien-invaded riparian vegetation in the W. Cape

Situation	**Protocol**	**Treatment**
• Alien stand <50% cover	1,3,4,5,7	1. Fell aliens (& stump-treat if resprouters)
• Alien stand ≥50% cover	1,2,3,4,5,7	2. Remove large logs
• Dense alien stand that has burnt:		3. Stack slash outside riparian zone in bare, degraded, or river sand bar, areas
- largely untransformed watershed	4,5,7	4. Avoid damage to indigenous plants
- transformed watershed	6,5,4,7	5. Continue regular follow-up alien control (minimize herbicide spraying)
		6. Plant or sow seed of indigenous fynbos & riparian species
		7. Monitor aliens and vegetation recovery

3.2 Fynbos Biome – Eastern Cape

a) <u>What has been achieved?</u>

The vegetation study was done within the Albany Project in various watersheds near Grahamstown, where the dominant invasive alien species is *Acacia longifolia*. Analysis of the indigenous species community data, using multi-dimensional scaling, indicated a clear separation of reference and cleared sites (Figure 3.2.1). None of the cleared sites overlapped with the Afrotemperate Forest reference, whereas some of the Featherstone Kloof cleared sites (dating from the earliest initial clearance in 1997) overlapped with either the wetland or riparian reference sites, or fell in between the two. Riparian and Forest reference sites were richer (24 and 21 species respectively) than the cleared sites, with Featherstone Kloof East being the most depauperate cleared site with a total of only ten species recorded. Dissimilarity among cleared and reference sites was very high, the lowest being 83% between the Berg River sites and the Riparian Fynbos reference sites.

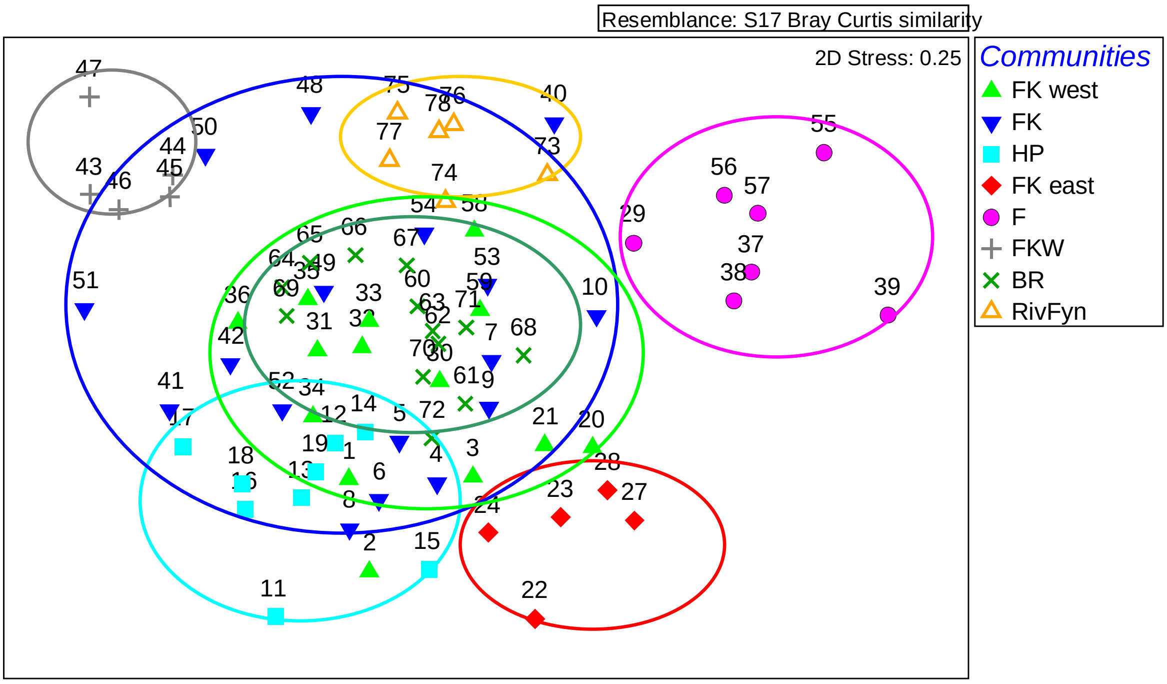

Figure 3.2.1. Multi-dimensional scaling scatter plot of communities in cleared and reference areas, excluding alien and invasive species. Reference communities are RivFyn (riverine fynbos), F (Afrotemperate Forest) and FKW (Featherstone Kloof wetland); the remainder are alien-cleared sites.

The high dissimilarity in species composition between the cleared sites and the riparian reference sites, largely relate to a suite of indicator species (*Eleocharis spp.*, *Anthospermum ciliare*, *Cliffortia graminea*, *Ficinia filiformis*, *Erica brownleea, Carpha spp.*) consistently being missing from the cleared communities. However, there was also a great dissimilarity among cleared sites. This indicates that environmental and/or management factors also play a large role in shaping community structure.

None of the environmental or management factors correlated strongly with community data, and it is therefore difficult to explain the differences among the communities. However, as critical management history data is missing, the most important being the original species composition, alien stand age and density, date of initial clearance, number of follow-ups, and fire history, weak correlations can be expected. If this data were available, it is probable that the patterns could have been explained more clearly.

Fire history is one of the most important missing factors, as the number, frequency and intensity of fires, as well as the time since the last fire event greatly influences plant community structure. Fires are very frequent in grassy fynbos areas, with many areas burning every two or three years owing to the high cover & short maturation period of grasses. However, fires often are patchy, thus it is difficult to reconstruct accurate fire-histories for each site.

It was observed that the age since clearance and fire severity (particularly the extent of residual burning at the soil surface) influences subsequent recovery. Thus a “Burn Standing” treatment is less damaging to indigenous soil seed banks than a “Fell & Burn” treatment. In the latter, recruitment is dominated by *Acacia* seedlings, which are heat-stimulated and can germinate from deeper in the soil owing to their relatively large size and available resources.

In the field experiment at the Berg River watershed (Fourie, unpublished data), felled slash was stacked across the slope with fuel loads ranging from low to high in the stacks. Results from monitoring maximum soil temperatures during the November 2005 fire indicated that soil surface temperatures exceeded 900°C in 90% of high, 62% of medium and 17% of low slash stacks. Temperatures did not exceed 100 °C at 50mm below ground except for 20% of cases under the high slash stacks. These results indicate that seeds in the upper soil layer would be killed in the high slash treatment. The thermocouples indicated that soil temperatures continued to be elevated four hours after the fire front had passed at 50 and 100mm below ground: temperatures measured were 80 and 65 °C respectively. These sustained high temperatures could have implications for seed survival and soil structure. The hydropyrometers indicated that fire intensity was highest close to the river and declined upslope.

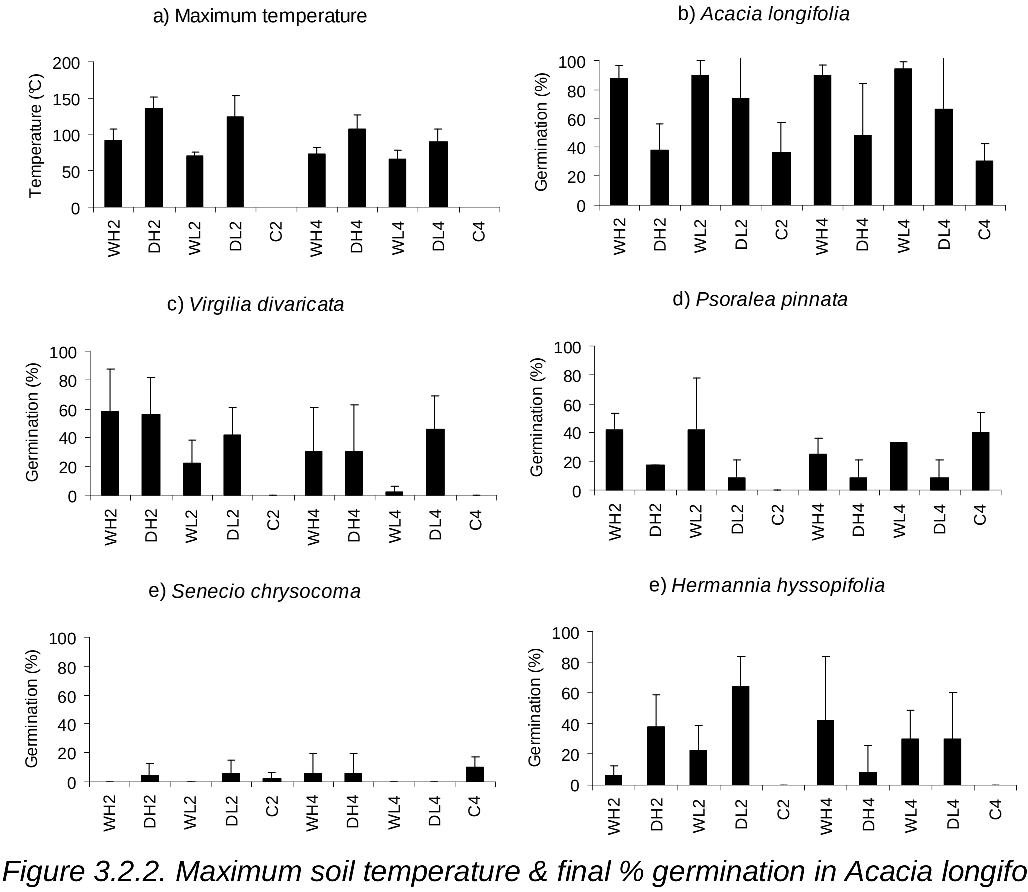

Figure 3.2.2. Maximum soil temperature & final % germination in Acacia longifolia & 4 indigenous species under simulated burns. Treatments codes: soil depth (2 = 20 mm, 4

= 40 mm), soil moisture (W = moist, D = dry) and simulated fuel load (H = high, L = low). C = non-burnt controls. Error bars show one standard deviation.

In a simulated slash fire experiment, the effects of fuel load (low versus high slash stacks), depth of seed burial (20 versus 40 mm below soil surface) and soil moisture (moist versus dry) on soil temperatures and seed viability of *A. longifolia* and four native plant species (*Virgilia divaricata*, *Psoralea pinnata*, *Senecio chrysocoma* and *Hermannia hyssopifolia)* were investigated (Behenna et al. submitted; Annexure 5.10). Soil temperatures were higher in dry soils, at shallower depth and under higher fuel loads, with the effect of moisture being the most pronounced. *Acacia longifolia* had the highest seed germination overall. *Acacia longifolia* and *P. pinnata* had higher germination in moist soils and at lower soil temperatures. *Virgilia divaricata* showed the opposite response. *Senecio chrysocoma* had low germination in all treatments (Figure 3.2.2). All species except *Senecio* showed fire stimulated germination, and all had seeds that could withstand maximum temperatures of up to 160°C and sustained temperatures exceeding 100°C for more than 20 minutes. Soil depth affected germination mainly *via* its effect on soil temperature, as even the smallest seeds could germinate from a depth of 40 mm. These results corroborate earlier work and indicate that damaging soil temperatures from burning high fuel loads can be minimized by burning the slash when the soil is wet. Alien *Acacia* seed will germinate well in response to moist heat and this will significantly reduce its seed bank the soil.

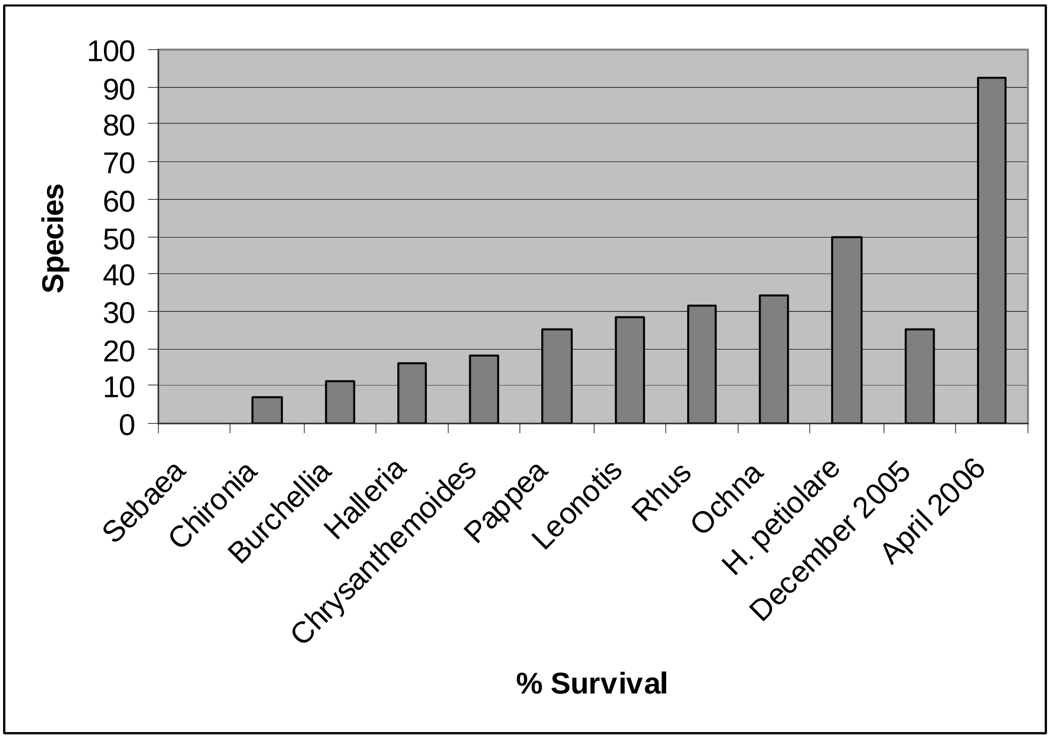

Figure 3.2.3. Survival of species planted in indigenous plots after a Fell & Burn treatment

After fire in December 2005 some of the Berg River plots were actively rehabilitated by planting and sowing indigenous species, while others were planted with the commercial grass *Digitaria eriantha*. Survival of indigenous planted material after one summer averaged less than 30%, with *Helichrysum petiolatum* the most successful (50%) and *Sebaea* species the least successful species (0%) (Figure 3.2.3). However, an autumn planting in April 2006 had higher initial survival by June 2006 (90%).

The grass established well and significantly reduced the *Acacia longifolia* seedling recruitment (and thus follow-up requirement) from about $10/m^2$ in the control and indigenous treatments to less than one seedling per $10\ m^2$. Subsequent seed bank testing indicated that this was due to post-germination competition, as there was no difference in *Acacia* seed banks between the grass and control plots. The potential of indigenous species to suppress the alien may have been significant had they been planted at an equivalent rate to the *Digitaria* (225 plugs instead of 14 plugs per plot) and had their survival rate been higher. Unfortunately the sown indigenous seed was lost to strong winds shortly after sowing. However, on the north-facing dry bank of the river, *Acacia* regrowth was also much less where the indigenous cover was higher, indicating that indigenous vegetation does indeed have the potential to suppress invasive species (Figure 3.2.4).

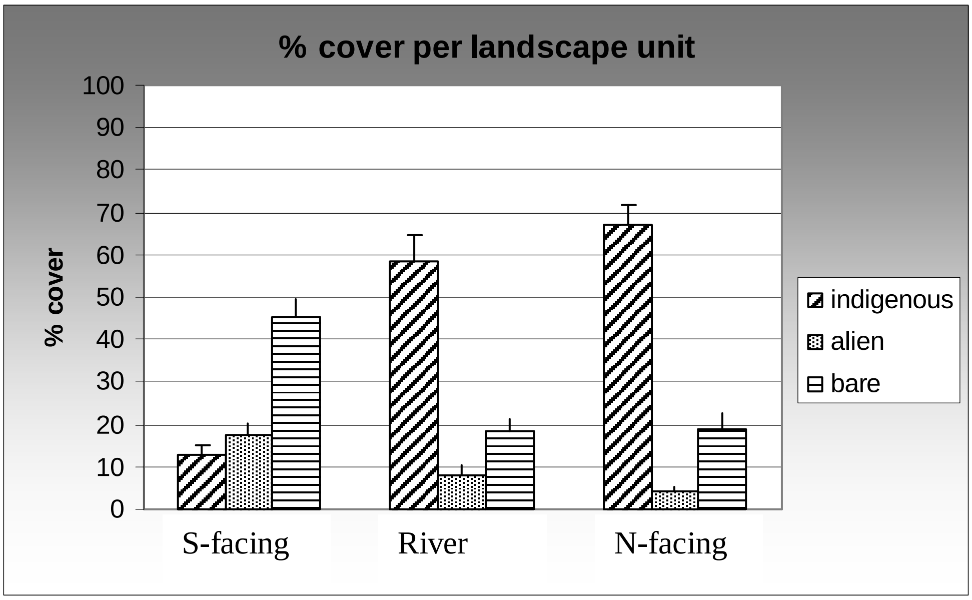

Figure 3.2.4. Percentage cover of indigenous and alien vegetation per landscape unit at the Berg River experimental site

b) Have thresholds to recovery been passed?

Indirect evidence from the vegetation study (above) indicated that the poor recovery at Featherstone Kloof East tributary may be partly due to a post-clearance burning treatment in December 2003, after which very little natural vegetation re-established. Subsequently, *A. longifolia* dominated in patches except where rehabilitation with the commercial grass *Digitaria eriantha* was implemented. It would appear that a threshold of recovery had been passed in this site, as indigenous seed banks had been depleted and no natural recovery will take place without intervention.

The nearby Featherstone Kloof Western tributary exhibited a much higher diversity, with *Pteridium aquilinum* and *Rumohra adiantiformis* recognized as indicator species. This area is most similar to the riparian reference sites after the Berg River sites. The area is very similar in topography and aspect to the east tributary (above), and without a full management history of these two sites it is not possible to give definitive reasons for the one site recovering after alien clearance while the other has fallen below a biotic threshold to natural recovery. However, it is very likely that the reason relates to different invasion and/or management histories at the two sites. The Western tributary was rehabilitated using indigenous species.

A soil seed bank study at the Berg River watershed conducted across different riparian and terrestrial lateral zones (Fourie unpublished data), indicated that, despite dense invasion by invasive alien *Acacia longifolia*, sufficient indigenous seeds remain in the soil to restore ecosystem structure and initiate recovery of vegetation composition (Table 3.2.1). Thus provided that no high severity fire damages the soil and seed banks, the restoration potential is good and a threshold to recovery will not have been passed. However, if the goal is to restore diversity and composition, this did not occur at the majority of cleared sites and plant assemblages generally were more grassy than at the reference sites. Whether the grass component inhibits full ecological recovery, and thus represents a biotic threshold, requires further study.

The deep incision of riparian areas, for example as observed in Featherstone Kloof, could present an abiotic threshold to recovery. Where the channel is deeply eroded, the stream banks are steep and bare owing to lack of plant establishment. Only where the banks have subsided resulting in a less steep gradient, can vegetation re-establish. In such cases, physical structures may be required to halt the head-cut erosion, allow sedimentation and the subsequent stabilization of banks.

Alien *Acacia* seeds were very dense and averaged 4000 seeds/m^2 in the riparian sites, indicating that intensive alien follow-up control would need to be implemented and maintained to ensure long-term indigenous vegetation recovery.

c) <u>What is achievable and what could be improved?</u>

Results from the Eastern Cape studies corroborate many of the findings from the Western Cape. A key difference is that grassy fynbos is more prone to frequent unplanned fires owing to the larger grass component in the vegetation, and if this is not controlled in the restoration phase, the woody riparian species may have difficulty in re-establishing and growing sufficiently to become fire-resistant. Thus, as for the Western Cape, recovery of natural vegetation post alien-clearance is an achievable target. Exceptions are:

i) Where long-standing closed alien stands are cleared in a degraded and transformed catchment and propagule sources are lacking in the surrounding area.

ii) Where a closed alien stand receives a “Fell & Burn” alien clearing treatment under hot summer conditions when soils are dry.

Table 3.2.1. Seed density in the 10 most dominant species for each zone. D = seed density (no/m^2), R = ranking within zone; F = % frequency

It is recommended that managers consider using the “Fell & Remove” treatment in all cases of dense to closed alien stand clearing along rivers. Where it is impractical to remove slash, it should be stacked away from the riparian zone in areas where wet season stack burns can be safely carried out, as heat transfer below ground is much lower when the soils are wet.

Where the goal is to return an indigenous stand of riparian vegetation, there is potential to improve recovery through active restoration. This should be considered in catchments that are degraded and have few remaining propagule sources to drive the recovery of areas, and also where damage may have been done locally through a high severity fire. Good indigenous recovery also has the benefit of suppressing alien seedling regrowth, which could have long-term cost benefits.

Accurate mapping and recording of management actions is critical to the assessment and evaluation of the clearing programme. The lack of reliable early management clearing data hindered the interpretation of current levels of riparian ecosystem repair. It is important that current and future management actions are rigorously recorded.

d) <u>What are realistic goals?</u>

An important goal is to keep good areas clear and to clear light infestations first Preventing degradation and further invasions by aggressive and emergent alien species is a top priority. At the landscape scale, strategic planning should initiate alien clearance from the top of the catchment down and identify abiotic thresholds that may have been passed, e.g incision and head-cut erosion and address these at the same time. Geomorphological changes are very important in changing the physical and biological integrity of riparian ecosystems.

In Eastern Cape grassy fynbos, land-use options may include grazing livestock owing to the prominent grass component in the vegetation. Where stock animals are present in an area, restoring riparian vegetation to some pre-invasion state may be difficult, and it may be more pragmatic to rehabilitate for ecosystem functioning using indigenous perennial species that can withstand grazing pressures and trampling. Observations to date indicate that the commercial grass *Digitaria eriantha* would be a useful species to use as it is palatable and also establishes well and helps to suppress alien *Acacia* re-establishment. However, in conservation areas its use could suppress fynbos and riparian scrub recovery. In areas where livestock can be controlled for a few years, and in conservation areas, restoring riparian scrub to mountain stream and foothill river segments is a more realistic prospect. In such cases, the restoration protocols outlined for the Western Cape riparian fynbos would equally apply to the Eastern Cape situation (Table 3.1.4).

4.3 Savanna and Grassland Biomes

a) <u>What has been achieved?</u>

Vegetation surveys were conducted along the Sabie River in Mpumulanga, where WfW prioritized alien clearing projects from its inception in 1995. Many of the study sites had been cleared (felled) three times between 2000 and 2005, but records of earlier clearance were not available. However, permanent Whittaker plots set up in 1996 at

Grassland and Savanna Biome riparian sites sampled both high (>50% cover) and low (<50%) density alien invasion, half of which had received an initial alien clearing treatment (manual felling). Three plots were all adjacent to *Eucalytpus grandis* plantations, which was as a result the dominant alien at the study sites at the start of the study in 1996. Reference vegetation along this river corridor comprises mainly riparian forest and woodland communities and does not always reflect the composition of the adjacent terrestrial grassland or savanna plant communities. There is considerable overlap in species composition between the higher altitude grassland and lower altitude savanna riparian sites (M. Beater 2006, MSc Thesis).

In the 2005 study that re-sampled the 1996/7 Whittaker plots, a total of 282 species were recorded, 222 (79%) of which were indigenous and 60 (21%) alien (M. Beater 2006, MSc Thesis). Of the 60 alien species that were recorded, 17 (28%) were shrubs and 15 (25%) were trees. *Eucalyptus grandis* was the dominant alien tree and *Rubus cuneifolius*, *Lantana camara* and *Solanum mauritianum* the dominant alien shrubs.

Comparing the datasets between 1996 and 2005, total species richness increased from 163 species in 1996, to 282 in 2005 (a 42% increase). Mean site species richness (at the 1 000 m^2 scale) increased significantly from 24.1 ± 1.0 in 1996 to 44.4 ± 1.5 in 2005 (M. Beater 2006, MSc Thesis). This increase was reflected by all growth forms. However the greatest total increase was for Category 1, 2 and 3 invasive alien species, from 20 in 1996/7 to 51 in 2005 (a 61% increase; Table 3.3.1). Nevertheless, overall invasion intensity (as measured by % aerial cover) was very similar between the years (30.0 ± 4.6% in 1996/7 versus 31.9 ± 3.2% in 2005) indicating that WfW clearing efforts were not succeeding in controlling the aliens (Figure 3.3.1). Closer examination of the data indicated a decrease in the aerial cover of large alien trees and shrubs (> 2 m height), and an increase in the aerial cover of the smaller alien trees and shrubs (1 - 2 m height). The latter comprised both resprouts and young saplings. Therefore, the WfW clearing programme was succeeding in removing the larger individuals, but not in controlling the regenerating plants.

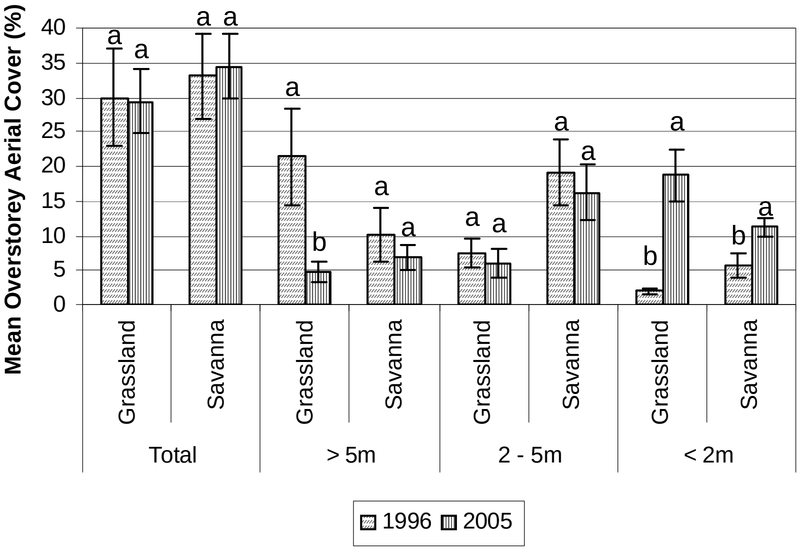

Figure 3.3.1. *Percentage aerial cover of alien vegetation (mean ± S.E.) for plots in the Grassland and Savanna Biomes in 1996 and 2005. Columns with different superscript*

letters within the same height class and biome are significantly different using t-tests (for independent-samples; P < 0.05). N = 20 for each height class and biome; d.f. = 38.

Table 3.3.1. *Total, indigenous, alien, herbaceous, shrub, tree, grass and weed species (counts and percentages) in riparian zones in 1996 and 2005, as well as the percentage increases in these species in the Grassland and Savanna Biomes over time (i.e. from 1996 to 2005*).

Species	**Grassland**		**Savanna**		**Percentage increase from 1996 to 2005**	
	1996	**2005**	**1996**	**2005**	**Grassland**	**Savanna**
TOTAL	140	222	106	171	40%	38%
Indigenous	111(79%)	176(79%)	89 (84%)	132(77%)	37%	32%
Alien	29 (21%)	46 (21%)	17 (16%)	39 (23%)	37%	56%
Herbaceous	64 (46%)	100(45%)	38 (36%)	67 (39%)	36%	43%
Shrub	36 (26%)	64 (29%)	33 (31%)	50 (29%)	44%	34%
Tree	21 (15%)	31 (11%)	21 (20%)	32 (19%)	32%	34%
Grass	19 (13%)	27 (12%)	14 (13%)	22 (13%)	30%	36%
Weed	24 (17%)	37 (17%)	18 (17%)	30 (17%)	35%	40%

However, the above comparison between the 1996/7 and 2005 sampling compares 50% of plots cleared in 1996/7 with 100% plots cleared by 2005. By comparing the pre- and post-clearing alien aerial cover in the cleared plots in 1996/7, the initial effectiveness of the WfW treatments can be determined. Clearing was much more effective in the grassland (high invasion intensity = 71% reduction, low = 94%) than the savanna (high = 55% reduction, low = 52%). Hence, considering the cleared plots, the overall pre-clearing invasion intensity was 62% in the grassland, and WfW clearing in 1996/7 resulted in a reduction to 12%. Similarly, although less successfully, the overall pre-clearing invasion was 44% in the savanna, and WfW clearing reduced it to 20% (Table 3.3.2.). In addition the early clearing had a major impact on vegetation structure, with clearing in high invasion grasslands resulting in the alien aerial cover of trees > 5 m in height being reduced from 67% to only 13% (Table 3.3.2). The comparable result in the savanna was a reduction from 28% to 1%.

In 1996, the low-density invaded sites were significantly more species-rich than the high-density invaded sites, but this difference was not sustained through to the 2005 survey. Nor were any differences from clearing status in 1996 sustained through to 2005. Hence there is progressive homogenisation of alien invasion intensity over time across the 40 plots.

This is one of the few studies that has assessed both the initial effectiveness of WfW clearing in the mid 1990s, as well as the long term effects, on alien plant invasion, vegetation structure and the nature of the ground cover. This long term view has clearly shown that the nature of the alien invasion problem along the Sabie River has changed considerably from the original mid-90's situation of relative few large *E.*

grandis trees needing to be cut down (at least along the selected study sites), to one where a large suite of alien species have become important, and the density of plants that need to be cleared has increased dramatically. This has implications for increasing both WfW staff training and clearing time commitments.

Table 3.3.2. Percentage aerial cover of alien vegetation (mean ± S.E.) for 1996 and 2005. Values with different subscript letters within the same experimental category of the three different experimental treatments and same aerial cover category in 1996 and 2005 are significantly different using t-tests (for independent-samples) ($P < 0.05$). Values with different superscript letters within rows are significantly different using Tukey's honest significant difference (HSD) tests ($P < 0.05$) (probability values are given in Appendix 17).

% Alien Vegetation Aerial Cover	**High Altitude (Grassland)**				**Low Altitude (Savanna)**			
	High Invasion		**Low Invasion**		**High Invasion**		**Low Invasion**	
	Cleared	**Uncleared**	**Cleared**	**Uncleared**	**Cleared**	**Uncleared**	**Cleared**	**Uncleared**
				1996				
Total	$21.1\pm11.8_a^b$	$72.2\pm7.5_a^a$	$3.3\pm1.1_b^b$	$11.0\pm3.8_a^b$	$29.1\pm8.0_a^b$	$69.1\pm11.2_a^a$	$10.9\pm3.7_a^b$	$23.0\pm6.6_a^b$
> 5m	$12.7\pm11.4_a^b$	$67.1\pm8.9_a^a$	$0.8\pm0.8_a^b$	$5.2\pm3.2_a^b$	$0.8\pm0.5_b^b$	$28.0\pm11.9_a^b$	$4.2\pm4.2_a^b$	$7.3\pm3.2_a^b$
2 –5 m	$6.2\pm2.7_a^b$	$18.1\pm6.3_a^b$	$1.3\pm0.8_a^b$	$4.3\pm1.8_a^b$	$14.7\pm3.7_a^b$	$45.5\pm12.4_a^a$	$3.4\pm1.8_a^b$	$12.8\pm3.6_a^b$
< 2 m	$3.0\pm1.7_a^b$	$2.1\pm1.3_a^b$	$1.3\pm0.4_a^b$	$1.5\pm0.4_a^b$	$13.9\pm5.4_a^a$	$4.1\pm1.8_a^{ab}$	$3.4\pm2.1_b^{ab}$	$1.7\pm0.9_b^b$
				2005				
Total	$25.0\pm9.2_a^a$	$40.3\pm9.3_b^a$	$28.5\pm8.5_a^a$	$23.8\pm9.7_a^a$	$38.3\pm7.8_a^a$	$37.0\pm7.2_b^a$	$27.3\pm9.7_a^a$	$35.0\pm13.1_a^a$
> 5m	$3.0\pm1.3_a^a$	$8.8\pm2.7_b^a$	$6.3\pm4.8_a^a$	$1.0\pm1.0_a^a$	$11.5\pm3.3_a^a$	$5.5\pm5.5_a^a$	$4.2\pm1.7_a^a$	$6.2\pm2.5_a^a$
2 –5 m	$0.8\pm0.5_a^a$	$11.8\pm6.1_a^a$	$3.5\pm2.0_a^a$	$7.5\pm4.7_a^a$	$17.3\pm7.5_a^a$	$23.3\pm3.1_a^a$	$11.0\pm8.3_a^a$	$13.5\pm11.9_a^a$
< 2 m	$21.2\pm9.4_a^a$	$19.8\pm8.0_a^a$	$18.8\pm8.5_a^a$	$15.3\pm6.3_a^a$	$9.5\pm3.2_a^a$	$8.2\pm2.5_a^a$	$12.0\pm2.8_a^a$	$15.3\pm1.3_a^a$

The 2000 flood event had an estimated 90-200 year return interval and moved a tremendous amount of sediment (Foxcroft et al. submitted[3]). It is probable that the simultaneous stripping of riparian vegetation and deposition of sediments and propagules by the flood would have reset the vegetation succession to a recolonization phase at many of the permanent study sites, irrespective of prior alien invasion and clearance treatment. Hence many more species, both indigenous and alien, were present in 2005 compared to 1996. This event highlights the dynamic nature of riparian ecosystems and the need to sustain alien clearing operations, and prioritize upper catchment reaches, in order to gain long-term control of invasive species and facilitate riparian ecosystem repair.

Another study compared vegetation structure immediately before and after alien clearance in transects across the Sabie River inside and close to the Kruger National Park (Morris et al. submitted, Annexure 5.10). This study indicated a reduction by 80% post-clearance of alien plants and a concomitant increase in indigenous plant densities both inside and outside the national park (Figure 3.3.2). Indigenous herbs, then shrubs, increased the most in transects that were previously heavily invaded (transects 1-5). Another study inside KNP indicated that alien plant densities establishing after the 2000 flood were relatively low compared to indigenous species, and related to specific patches in the river channel (Foxcroft et al. submitted). Both the former clearing actions by WfW and the high richness and density of native vegetation were invoked to explain low levels of alien plant establishment inside the park.

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[3] Foxcroft LC, Parsons M, McLoughlin CA & Richardson DM (submitted). Patterns of alien plant distribution in a river landscape following an extreme flood. South African Journal of Botany.

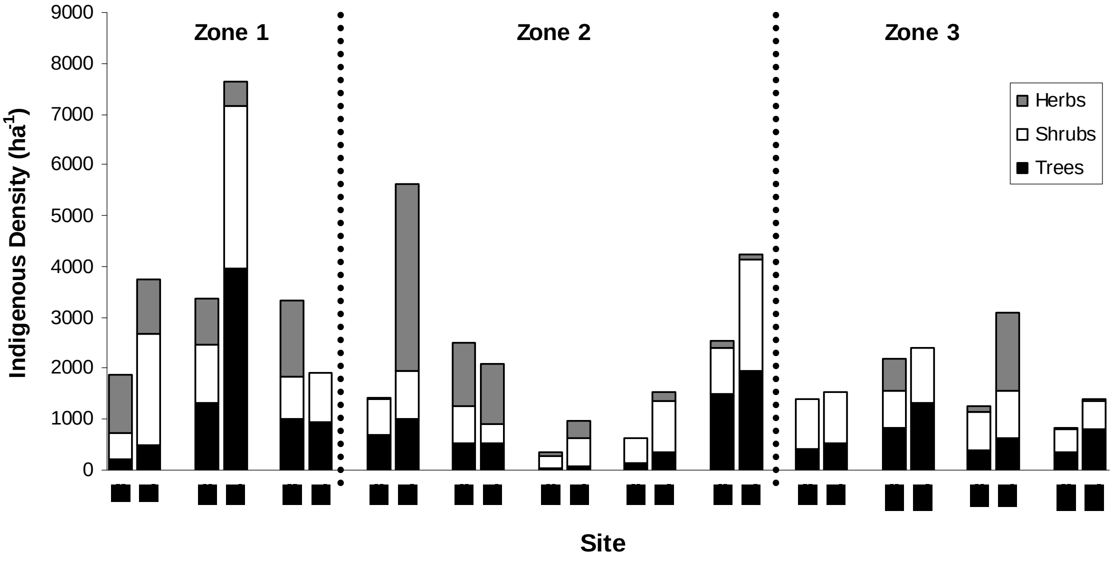

Figure 3.3.2. Density (ha^{-1}) of indigenous plants (herbs, shrubs and trees) before (B) and after (A) the seasonal alien clearing by "Working for Water". Site numbers are in consecutive order from upstream (west) to downstream (east) along the Sabie River. Zone 1 comprises sites upstream of Kruger National Park (KNP), Zone 2 are sites inside the KNP closer to the border that carry higher alien densities and Zone 2 are sites with lower alien densities closer to the Mozambique border.

b) Have thresholds to recovery been passed?

Based on the Sabie River plot re-sampling study no threshold to recovery had been passed, as sites were able to rapidly recover vegetation structure, richness and diversity in the few years following a major flood event, irrespective of earlier invasion intensity. This applied to high altitude Grassland Biome and low altitude Savanna Biome sites. The other study in the vicinity of Kruger National Park corroborated the above findings and indicates resilience to disturbance by alien plants in savanna riparian ecosystems and good natural restoration potential following alien clearance. However, few of the sites studied had closed-stand alien invasion, so it is not possible to say whether a threshold to recovery would be passed in a situation of more severe invasion. The presence of indigenous herb and shrub seed banks and propagule sources is key to initiating ecosystem repair in savanna riparian zones post alien clearance.

Sites with closed canopy invasion by *Eucalyptus grandis* or other invasive alien trees may need some active restoration intervention to re-instate riparian woodland structure and composition post alien-clearance, especially in transformed catchment areas. Plantings of indigenous riparian trees and shrubs should be done at the start of the wet season (November) using forestry plugs or pre-grown transplanted seedlings.

c) What is achievable and what could be improved?

There is good potential for indigenous riparian vegetation recovery following alien clearance alone at sites supporting dense (50-75%) alien invasion, particularly in conservation areas and other areas where disturbance by human activity (e.g. agriculture and livestock grazing) has not been too intense. However, medium-term (5-10 years) reductions in alien plant densities did not result from sustained WfW clearing operations. Aliens that regenerated post-clearance were trees and shrubs, many of which survived by resprouting. These results indicate that aliens with resprouting capability, for example *Solanum mauritianum*, need to be tackled as a priority, with the quality of clearing (correct cutting and herbicide application) improved to prevent survival by resprouting. Cutting *Solanum* below 28 cm in height resulted in 100% success (total kill), while cutting above 50 cm resulted in 100% resprouting recovery (total failure). It further indicates a need to train the clearing teams in the importance of cutting lower on the stem. Assessing stem cutting effectiveness, in conjunction with herbicide applications, on other important species would also be very useful in order to improve techniques.

The considerably better control of IAPs in the Kruger National Park (KNP) section of the Sabie River, which receives more frequent follow-up clearing of new seedlings and recovering resprouters, strongly suggests the need for more frequent follow ups in the upper catchment of the river as well. This would help to prevent the re-establishment of aliens from seed. The KNP study also indicates that greater attention is required after above-average rainfall years, as alien densities tend to increase to a much greater extent than in low rainfall years.

Both studies indicate that considerable flexibility will be needed in planning alien plant control operations in riparian zones of the Savanna and Grassland Biomes. Alien plants respond rapidly to disturbance, for example a major flood event or a high rainfall year, and clearing schedules need to be updated to prevent the aliens from re-establishing, reproducing and dispersing propagules downstream. Owing to the high frequency of natural perturbations in riparian ecosystems it is also recommended as an overall strategy that control operations commence upstream and move downstream, in order to minimize invasion and re-invasion of downstream areas. This requires communication between managers and regular regional progress meetings.

d) What are realistic goals?

In the Grassland and Savanna Biomes, intensive studies along the Sabie River indicate that riparian ecosystems are relatively resilient to the impacts of invasion, and that alien clearance ultimately can lead to the recovery of indigenous vegetation structure and diversity. Owing to the timing of the 2000 large flood event, the studies also highlighted that riparian ecosystems are naturally highly dynamic and that adaptive management will be required to maintain control of invasive alien species in the long-term.

For sites with medium to dense alien invasions, a realistic goal is to restore riparian ecosystem structure and composition, provided that sufficient and appropriate alien follow-up controls are done. For some more densely invaded sites, supporting closed alien trees stands such as tall *Eucalyptus grandis* trees, ecosystem functioning may be restored through alien clearance, but active restoration of riparian tree and shrub components may be required in order to restore vegetation structure and composition within a reasonable time-frame.

4.4 Recommendations & management tools

Synthesis

Implicit in the rationale behind our research into ecosystem repair targets is the assumption that indigenous vegetation recovery is a fundamental requirement of long-term control of invasive species. It is generally assumed that, as a minimum, non-invasive vegetation that can fulfill basic ecological functions must be re-instated. Thus, management of invasive plants and ecosystem repair are inextricably linked. The field studies that were initiated under this research project are not sufficient to answer all the questions relating to ecosystem repair targets. However, they do provide new and valuable insights into the impacts of aliens, alien clearance and other factors on riparian vegetation recovery that enable us to provide some guidance on realistic ecosystem repair targets.

Although the riparian ecosystems studied in the three biomes – Fynbos, Grassland and Savanna – are very different, many of the findings from the specific studies have general applicability. Some examples (with locations of the studies in parentheses) include:

- Where indigenous propagule sources persist (in the soil seed bank or in upstream vegetation pockets), considerable recovery of natural vegetation can be expected, especially when care is taken during operations to clear invasive alien plants, even where alien stands are dense (all three biomes).
- The type of clearing method applied has a strong influence on the degree of natural vegetation recovery (Fynbos Biome).
- Studies spanning the 2000 large flood indicated a huge impact of this episodic event on river geomorphology and riparian vegetation. This serves as a reminder that rivers are non-equilibrium systems. This must be taken into account in setting and monitoring ecosystem repair targets (Savanna & Grassland Biomes).
- Ineffective alien control (enabling coppicing) and/or insufficient follow-up alien control may prevent ecosystem repair targets being met (Grassland & Savanna Biomes).
- Where invasion has caused head-cut erosion and deepened stream channels, vegetation does not readily recover following alien clearance owing to the steepened and unstable banks being unsuitable for plant colonization (Fynbos Biome). In this instance, an abiotic threshold may have been breached. Physical structures to halt the head-cut erosion and to trap sediments will be needed as a first step in ecosystem repair in such situations. The national "Working for Wetlands" project has experience in this type of work and should be contacted for advice and assistance.
- Active restoration – through planting or the sowing of seed – reduces the amount of follow-up control required and has the potential to facilitate natural vegetation recovery (Fynbos Biome).
- Active restoration must be seen in the landscape/ catchment context – this requires coordination and large-scale planning. Small scale attempts to re-establish vegetation are expensive and unlikely to succeed if the bigger picture is not taken into consideration (Fynbos Biome)

Restoration frameworks

World-wide, ecologists and natural resource managers are grappling with the complex challenge of how to best control invasive alien plants while simultaneously promoting ecosystem repair and delivering the required ecosystem services to humankind. Many factors operate to influence decisions on the ground, both ecological and socio-political, and realistic repair targets must take all of these into account. While ecological research can assist in improving our understanding of invasion and restoration processes, these findings need to be incorporated into conceptual and practical frameworks to assist restoration in practice (Hobbs 2007)[4].

a) Conceptual Restoration Framework

In considering frameworks for restoring invaded riparian ecosystems in South Africa, many variables operate to make this a daunting task. It is necessary to provide an over-arching conceptual framework (Figure 3.4.1) within which more specialized practical frameworks may be formulated. This idea was expressed by managers at the final workshop in January 2007 (Annexure 5.8): it was agreed that national goals and targets should be outlined, but from this it is essential to develop more regional and site-specific targets with input from local managers. Variables that influence practical restoration frameworks include: biome and vegetation type, river order, invasion history (species, intensity & time) and surrounding land-use/ extent of transformation.

The appropriate restoration target for a site should be informed by ecological factors, such as extent of degradation by aliens and availability of indigenous propagules, as well as by non-ecological factors such as the desired land-use for the area and availability of resources (human and financial). Essentially there are three broad ecosystem repair targets (goals) for riparian zones, listed in an increasing order of restoring ecological integrity:

- *Restore ecological functioning*: e.g. recovery in stream flow or erosion control. An important research objective (outside the scope of this study) is to establish the ecological flows required to maintain river and riparian functioning. In some catchment areas alien vegetation control alone, or accompanied by appropriate re-vegetation actions, may achieve more natural hydrological and geomorphological functioning of the river. By contrast in other catchments impoundments and water abstraction may mitigate against restoring natural hydrological functioning.
- *Restore natural vegetation structure*: e.g. control aliens at an economically viable, sustainable level of infestation, where sufficient indigenous vegetation is restored to keep the aliens at a manageable level and restore ecological functioning. This requires adaptive (and long-term) management suitable to the particular area and the latter should be guided by the degree of biocontrol for the particular alien species.
- *Restore vegetation structure and diversity*: appropriate goal for conservation areas and catchments where areas of intact natural vegetation persist; requires aliens to be controlled to a maintenance level and processes reinstated that facilitate recolonization by indigenous species.

As mentioned above, alien control and restoration are closely linked, thus it is important to align restoration frameworks with the existing alien clearing strategies and policies of

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[4] Hobbs R J 2007. Setting effective and realistic restoration goals: key directions for research. Restoration Ecology 15:354-357.

WfW. The “Working for Water Programme Strategic Planning Policy”[5] sets out the national policy on strategic planning for control of invasive alien plants. The priorities as outlined in the document align well with optimizing ecosystem repair goals at national and regional scales. The WfW “Self Assessment Standards” provide the framework for project operational planning within the regional and area strategic plans.

b) Practical Restoration Frameworks

Most of the research conducted for this project focussed on mountain stream or foothill segments of rivers traversing landscapes that retain some intact natural vegetation. However, many of South Africa’s main stem rivers traverse transformed agricultural lands in the lowlands, are in poor condition and are highly threatened (Nel et al. 2007)[6]. Discussions among managers and researchers (final workshop Annexure 5.8) suggested that in the case of rivers transformed for some time, it may be more appropriate to re-instate some desirable riparian ecosystem function, such as the temporary stabilization of banks, rather than trying to restore some pre-invasion reference condition (which may be unknown).

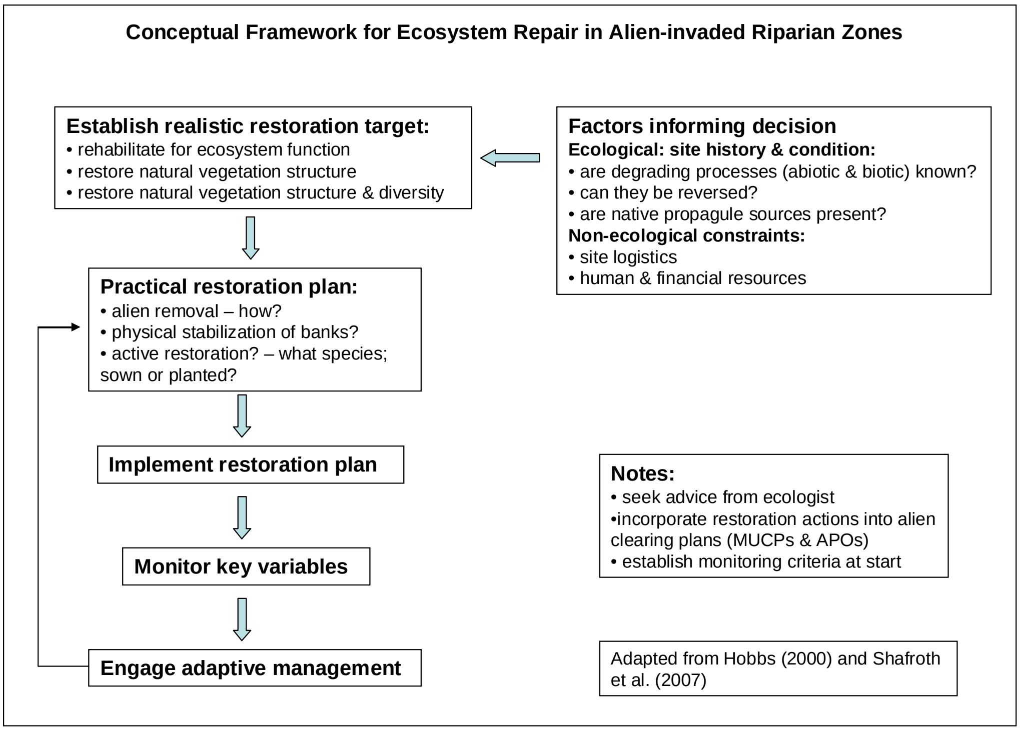

Figure 3.4.1. Conceptual restoration framework[7]

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[5] WfW (2004). Strategic Planning Policy. The *Working for Water* Programme Executive Committee, 6pp.

[6] Nel J L, Roux D J, Kleynhans C J, Moolman J, Reyers B, Rouget M & Cowling R M 2007. Rivers in peril inside and outside protected areas: a systematic approach to conservation assessment of river ecosystems. Diversity & Distributions 13: 341-352.

[7] Hobbs R J 2000. Ecological repair following biotic invasions. Pp. 181-8 In: Preston G, Brown G and van Wyk E (editors) *Best Management Practices for preventing and controlling invasive alien species.* Symposium Proceedings ISBN 0-620-26172-2.
Shafroth P B, Beauchamp V B, Briggs M K, Lair K, Scott M L & Sher A A 2008. Planning riparian

Management Tools

At a practical level, two important WfW documents: “Recommended Clearing Norms and Treatment Methods”, and “The Revised Policy on the use of Herbicides for the Control of Alien Vegetation”, which specify appropriate clearing methods and herbicide use, greatly assist in best practice decision-making for alien control. In practical restoration frameworks the above norms, treatments and herbicide policies will in many cases be appropriate. However, it must be borne in mind that these tools were developed primarily to maximize alien plant reduction and there are some instances where an ecosystem repair target may require a deviation from these approaches. For example, where the target is to restore natural riparian vegetation structure following the clearance of an old, dense alien stand, it will be very important to protect any establishing indigenous plants from herbicide drift, as these plants may be scarce but nevertheless form the basis for the restoration. Therefore the follow-up treatment method could change from foliar herbicide application to hand-pull or cut and stump treatment (depending on alien species, size and density), in order to lower the risk of indigenous plant death. The change in treatment method could have a cost implication, but the benefit in protecting indigenous species could obviate the need for active restoration (e.g. tree and shrub planting) at possibly greater expense.

Where habitat-specific tools have been developed, for example “Clearing Protocols for Mesic Savannas and Sweet Grassveld” (Euston-Brown et al. 2007[8]), these should also be used to guide ecosystem repair.

Our research indicates that in most situations, recovery of fynbos riparian vegetation following alien clearance follows a similar trajectory in the Eastern and Western Cape. Decision trees designed for the Fynbos Biome were found to apply well to Grassland and Savanna Biome riparian areas as well (Figures 3.4.2&3), despite their different hydrological patterns and phytogeographical affinities. It was thus decided to use the same decision trees for all biomes, but to accompany these with different information boxes (Boxes 3.4.1&2) to provide the ecosystem repair details that differ between the biomes.

Within a biome, there will also be differences according to site history, extent of transformation in the catchment and future land-use. Thus the decision trees and restoration notes should be used to draw up site-specific restoration plans. Differences will apply in relation to recommended species to use in active restoration programmes. Tables of suitable species (Tables 3.4.1&2) have been provided for the different biomes as a broad guideline. However, in all cases of indigenous plant re-introduction it is important that local species and gene pools are used in order to prevent possible hybridization or loss of genetic integrity in ecosystems.

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restoration in the context of *Tamarix* control in western North America. Restoration Ecology 16 (in press).

[8] Euston-Brown D, Rathogwa M, Richardson D M 2007. Development of a clearing protocol based on ecological criteria for mesic savannas and sweet grassveld for the Working for Water Programme. Report prepared for the Working for Water Programme.

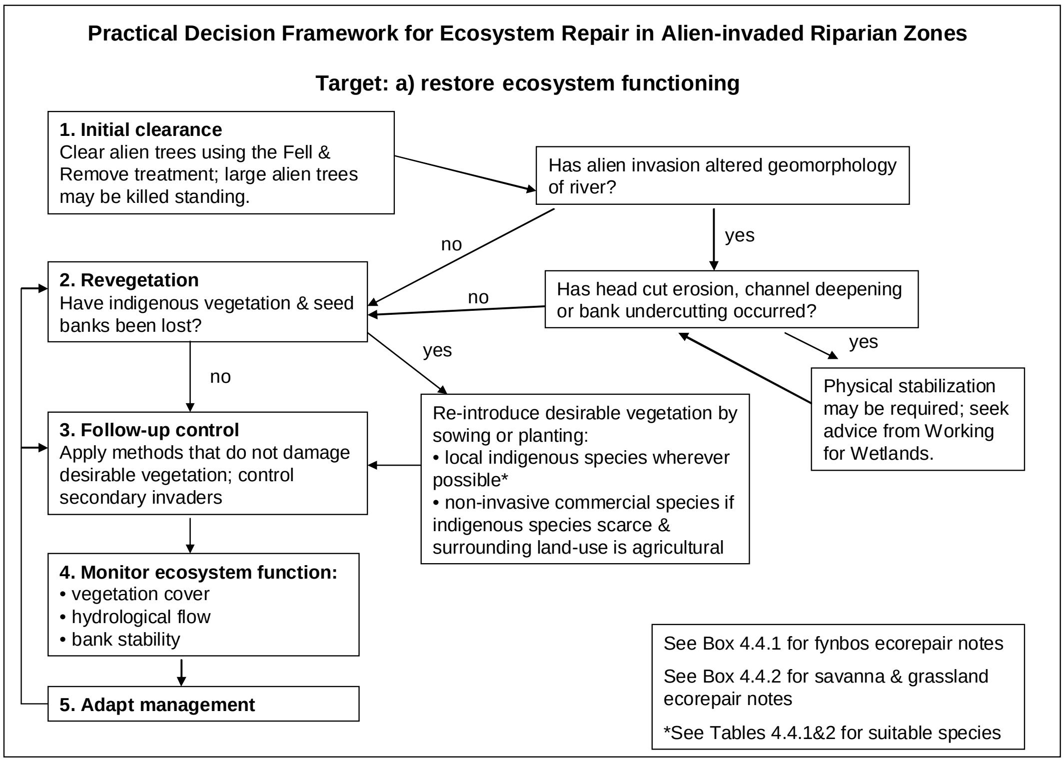

Figure 3.4.2 Practical decision framework to restore ecosystem functioning

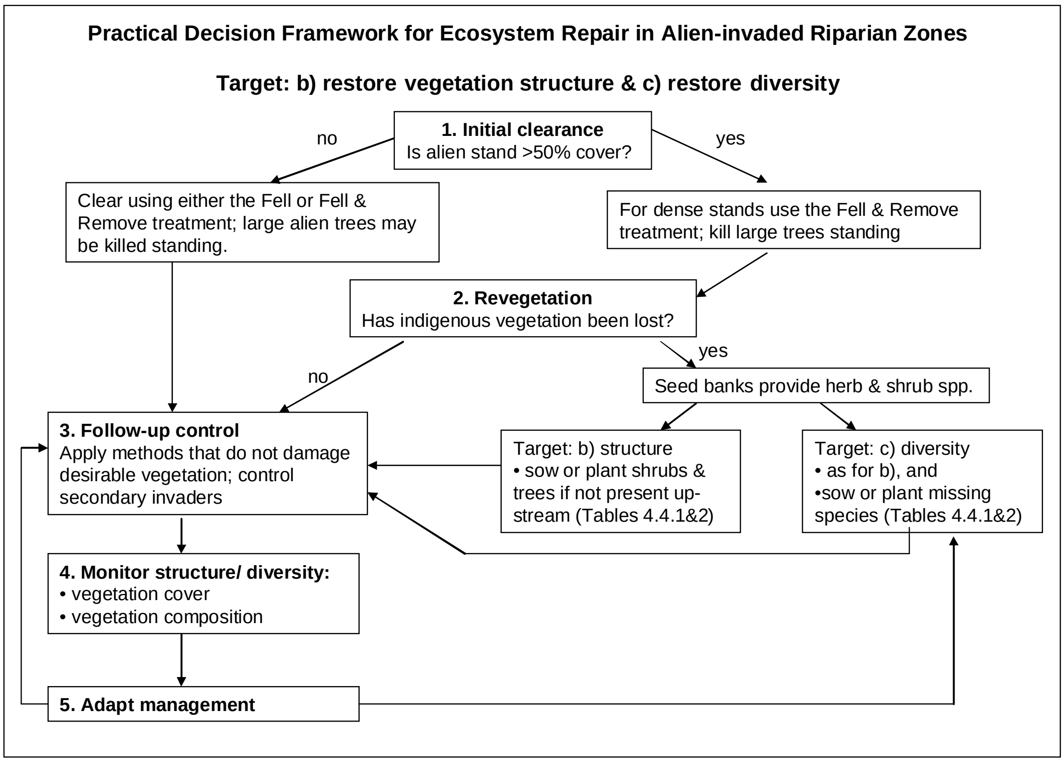

Figure 3.4.3. Practical decision framework to restore vegetation structure and diversity (assumes relatively natural geomorphology)

Box 3.4.1 Fynbos ecosystem repair notes to accompany practical decision frameworks

1. Initial clearance

- For dense to closed woody alien stands it is best to fell & remove large diameter wood (>50mm) from the riparian zone. This wood may be sold to offset some of the clearance costs, or else should be burnt in stacks when the soil is wet to minimize soil and seed bank damage. Where there is no secondary industry market, large-diameter (>250mm) trees should be killed standing (ring-barked or frilled). For aliens under substantive biocontrol, consider phased removal.
- For light to medium density stands, slash may be left to decompose in situ or burn in the next fire without negatively impacting the recovery potential of the site. However large-diameter trees should be killed standing to keep biomass off the soil surface.

2. Revegetation

- If some indigenous vegetation is present prior to alien clearance, soil seed banks supplying indigenous herbaceous and shrub understorey species are likely to be present. If there was little evidence of indigenous vegetation pre-clearance, seed banks may still be present provided that there was no other habitat disturbance (such as ploughing) or long-term dense invasion (exceeding 2 fire-cycles).
- However, if a severe fire has gone through the area (with evidence of burnt soil organic matter or subsequent soil erosion) seed banks will have been severely depleted.
- Where indigenous seed banks have been depleted, the site requires active revegetation. To restore ecosystem functioning, the minimum requirement is bank stability and soil surface erosion control. Thus a mix of local pioneer, understorey (herb and shrub) species should be sown (see Tables 4.4.1&2). Where seed of local indigenous species is not available or insufficient, commercial non-invasive grasses may be used in an area that is primarily agricultural or disturbed. In the Western Cape, potential species are annuals such as sterile Italian Rye Grass (*Lolium perenne*) and commercial oats (*Avena sativa*). In the Eastern Cape *Digitaria eriantha* may be used.
- In terms of restoring structure, if pockets of indigenous scrub persist along the river - within 200m or upstream of the site - then these species will recolonize over time. If there are very few pockets of remaining scrub in the catchment, then active planting of scrub species is recommended, especially if the surrounding terrestrial vegetation is degraded and cannot supply pioneer shrub species.
- Riparian scrub species may be established from rooted cuttings or seedlings transplanted in the field, or for some Western Cape species (e.g. *Brabejum stellatifolium*) directly from fruits placed on site. However, early results suggest that unrooted truncheons have limited success (for species list see Tables 4.4.1).
- Sowing should be done directly onto bare ground, with the seed lightly raked into the soil or covered by light woodchip mulch. If done after initial clearance, the establishing vegetation has potential to partially suppress alien recruitment and reduce follow-up costs. Seed should be sown in autumn in the Western Cape, and either early autumn or early spring in the Eastern Cape.
- Planting is best done under similar conditions to the sowing treatment, although some scrub species may establish better in the presence of sheltering herbaceous species. In the Eastern Cape grasses are better planted in spring.

3. Follow-up control

- Only methods that do not damage recovering indigenous species should be used: e.g. hand-pull, cut & stump treat. If foliar herbicide spraying has to be done, then it must be on a wind-free day with all indigenous species first covered in a protective cone or similar device.
- Special care should be taken to identify aggressive secondary invader species and control these timeously to allow time for indigenous vegetation recovery.

4. Monitor ecosystem recovery

- *Geomorphology*: simple measures such as channel depth and width (using permanently marked locations)
- *Soil erosion*: hammer steel pins into bank & and measure soil loss or gain
- *Vegetation cover*: fixed point photography, permanent plots to measure alien and indigenous cover (herbaceous and woody)
- *Vegetation composition*: permanent plots to monitor species presence and cover.

5. Adapt management

- Assess monitoring results relative to ecosystem repair targets and where necessary revisit methods and adapt management.

Box 3.4.2 Grassland & savanna ecosystem repair notes to accompany practical decision frameworks

1. **Initial clearance** (also see Euston-Brown et al. 2007[6])
   - For dense to closed woody alien stands, fell & remove large diameter wood (>50mm) from the riparian zone. This wood may be sold to offset some of the clearance costs, or else stacked and left to decompose. Where there is no secondary industry market, large-diameter (>250mm) trees should be killed standing (ring-barked or frilled). For aliens under substantive biocontrol, consider phased removal.
   - For light to medium-density stands, slash may be left to decompose in situ. Woody species must be cut low enough to prevent re-sprouting. However large-diameter trees should be killed standing to keep biomass off the soil surface to lower the risk of damaging fires in regenerating riparian woodland.
2. **Revegetation**
   - If some indigenous vegetation is present prior to alien clearance, soil seed banks supplying indigenous herbaceous and shrub species are likely to be present. If there was little evidence of indigenous vegetation pre-clearance, seed banks may still be present provided that there was no other habitat disturbance (such as ploughing) or long-term dense invasion (e.g. wattle or *Eucalyptus grandis*).
   - Where indigenous seed banks have been depleted and the surrounding catchment is transformed, the site requires active revegetation. To restore ecosystem functioning, the minimum requirement is bank stability and soil surface erosion control. Thus grass or understorey (herb and shrub) species should be sown or planted. Campbell (2000)* compiled guidelines for using grass to cover soil after alien plant control (including species and planting guidelines). Although aimed at terrestrial ecosystems, these techniques can apply to highly transformed riparian zones. Grasses broadcast sown or planted help to suppress recruitment of aliens (e.g. wattle) from the seed bank while providing cover to bare soil. Grasses sown in rows or terraces may assist in halting surface erosion on slopes. Where seed of local indigenous grass is not available or insufficient, commercial non-invasive grasses may be used in an area that is primarily agricultural or disturbed.
   - In terms of restoring structure, if pockets of riparian woodland persist along the river - within 200m or upstream of the site - then these species will recolonize over time. If there are very few pockets of remaining indigenous trees in the catchment, then active planting of tree species is recommended, particularly following dense wattle or *Eucalyptus* invasion.
   - Planting of trees and shrubs should be done at the start of the wet season (November), from seeds (scarified or prepared in order to allow rapid germination) or using pre-grown transplanted seedlings (~20 cm tall) in forestry plugs (for species list see Table 4.4.2).
   - Sowing and/ or planting should be done after a thorough initial clearing treatment and the re-introduced plants tended (weeds removed around them) during follow-ups and during the first year until well established.

3. Follow-up control

- Only methods that do not damage recovering indigenous species should be used: e.g. hand-pull, cut & stump treat. If foliar herbicide spraying has to be done, then it must be on a wind-free day with all indigenous species first covered in a protective cone or similar device.
- Special care should be taken to identify aggressive secondary invader species and control these timeously (before seed-set) to allow time for indigenous vegetation recovery.

4. Monitor ecosystem recovery

- *Geomorphology*: simple measures such as channel depth and width (using permanently marked locations)
- *Soil erosion*: hammer steel pins into bank & and measure soil loss or gain
- *Vegetation cover*: fixed point photography, permanent plots or transects to measure alien and indigenous cover (herbaceous and woody)
- *Vegetation composition*: permanent plots or transects to monitor species presence and cover.

5. Adapt management

- Assess monitoring results relative to ecosystem repair targets and where necessary revisit methods and adapt management.

*Campell PL (editor) 2000. Rehabilitation recommendations after alien plant control. Plant Protection Research Institute Handbook No. 11. ARC, Hilton 3245.

Table 3.4.1. Examples of relatively common species to use in restoring riparian vegetation in the Fynbos Biome (SSB = soil seed bank; CSB = canopy seed bank)

a) Winter rainfall fynbos areas

Species	**Growth form**	**Regeneration mode**	**Seed**	**Split**	**Cutting**
Wet bank					
Calopsis paniculata	Herb - restio	Reseeder SSB	√	√	
Elegia capensis	Herb – restio	Resprouter	√	√	
Erica caffra	Shrub	Reseeder SSB	√		
Isolepis prolifer	Herb – sedge	Reseeder SSB		√	
Juncus capensis	Herb – rush	Reseeder SSB		√	
Juncus lomatophyllus	Herb – rush	Reseeder SSB		√	
Pennisetum macrourum	Herb – grass	Reseeder SSB	√	√	
Salix mucronata	Shrub	Resprouter			√
Dry Bank					
*Anthospermum aethiopicum**	Shrub	Reseeder SSB	√		
Berzelia lanuginosa	Shrub	Reseeder CSB	√		√
Brabejum stellatifolium	Shrub-tree	Resprouter	√		√
Brachylaena neriifolia	Shrub-tree	Resprouter	√		√
Diospyros glabra	Shrub	Resprouter	√		√
Leucadendron salicifolium	Shrub	Reseeder CSB	√		
Metrosideros angustifolia	Shrub-tree	Resprouter			√
Morella serrata	Shrub	Resprouter			√
Pentaschistis pallida	Herb - grass	Reseeder SSB	√		
Psoralea pinnata	Shrub	Reseeder SSB	√		
Rhus angustifolia	Shrub	Resprouter	√		√
*Tribolium uniolae**	Herb - grass	Reseeder SSB	√		

* Common local grass and shrub species from surrounding fynbos vegetation may be added to seed mixes in order to boost initial vegetation cover.

b) All-year rainfall areas - Grassy Fynbos

Species	**Growth form**	**Seed**	**Split**	**Cutting**
Wet bank zone:				
Anthospermum herbaceum	Herb – forb			√
Blechnum sp.	Herb – fern	√		
Carpha glomerata	Herb – sedge	√		
Chironia baccifera	Shrub	√		√
Cliffortia graminea	Shrub		√	√
Cliffortia strobilifera	Shrub			√
Conyza ulmifolia	Herb - forb	√		
Cyperaceae spp.	Herb – sedge	√	√	
Cyperus textilis	Herb – sedge		√	
Elegia asperifolia	Herb - restio	√		
Ficinia capillifolia	Herb – sedge	√	√	
Ficinia oligantha	Herb – sedge	√	√	

Fuirena sp.	Herb – sedge	√	√	
Tristachya leucothrix	Herb - grass	√	√	
Helichrysum epapposum	Herb - forb	√		√
Isolepis cernua	Herb – sedge	√	√	
Isolepis prolifer	Herb – sedge	√	√	
Miscanthus capensis	Herb - grass	√		
Rumohra adiantiformis	Herb – fern	√		
Dry bank:				
Alloteropsis semialata	Herb - grass	√	√	
Anthospermum herbaceum	Herb – forb			√
Berzelia commutata	Shrub	√		
Carpha glomerata	Herb – sedge	√		
Chrysanthemoides monilifera	Shrub	√		
Erica brownleeae	Shrub	√		
Halleria lucida	Shrub	√		
Helichrysum cymosum	Shrub	√		√
Helichrysum petiolare	Shrub	√		√
Merxmuellera cincta	Herb - grass	√		
Passerina filiformis	Shrub	√		√
Pelargonium cordifolium	Shrub	√		√
Phylica axillaris	Shrub	√		√
Polygala virgata	Shrub	√		
Psoralea pinnata	Shrub	√		
apanea melanophloeos	Tree*	√		√
Rhus sp.	Shrub/ tree	√		
Senecio chrysocoma	Herb/ shrub	√		
Senecio rigida	Herb/ shrub	√		
Themeda triandra	Herb - grass	√	√	

* Other tree species can be re-introduced in special situations, e.g. area of high conservation value, to speed up natural recovery.

Table 3.4.2. Examples of woody species potentially suitable in restoring heavily impacted riparian sites in the Grassland and Savanna Biomes of Mpumalanga. For heavily degraded sites, the species listed in this table would be the first choice for replanting. Some suggestions on propagation method can be found in Schmidt et al. (2002)[9]*.*

		Frequencies (number / 5 plots)	
	Growth Form	Grassland	Savanna
Euclea crispa	shrub	3	2
Combretum kraussii	tree	1	3
Clutia affinis	shrub	4	1
Keetia gueinzii	liana	1	0
Cliffortia nitidula	shrub	2	0
Buddleja salviifolia	shrub*	2	0
Syzygium cordatum	tree	0	1
Apodytes dimidiata	tree	0	3
Tricalysia capensis	shrub	0	1
Acacia ataxacantha	tree*	0	4
Acacia robusta	tree**	-	-

*, most favoured species, **, for sites closer to the Kruger National Park.

Additional tree species suggested by Mervyn Lotter (Mpumalanga Parks Board):
Ekebergia capensis
Harpephyllum caffrum
Protorhus longifolia
Anthocleista grandiflora
Bridelia micrantha
Breonadia salicina
Pittosporum viridiflorum
Ficus sur
Celtis africana (be careful not to introduce one of the exotic *Celtis* species in nurseries)
Nuxia floribunda (higher altitudes)
Diospyros whyteana (shrub)
Rhamnus prinoides

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[9] Schmidt, E., Lotter, M. and McCleland, W. 2002. Trees and shrubs of Mpumalanga and Kruger National Park. Jacana, Johannesburg.

4. Problems and Constraints

As with any new research project various challenges were met at all levels. In most cases these were successfully overcome to achieve many of the original aims of the research. However, in some cases the problems were not overcome, and did limit the output, and it is worth mentioning these for future reference.

4.1 Project starting date

Owing to the late approval of the project, the original start-up date of January 2004 was postponed until May 2004. This meant that the timing for advertising post-graduate positions was not optimal, as most students complete their honours degrees at the end of the year and look for post-graduate opportunities at that time or early in the New Year. This delayed the start-up of some of the post-graduate studies until various times during 2005. Although the majority of studies yielded results by early 2007, two are not yet completed (June 2007). Nevertheless, through close communications within the research team, most of these results have been incorporated into the final report.

4.2 Site management history

The largest constraint to the research overall has been in accessing information from WfW on the management histories of cleared, alien-invaded sites. This information was required for selecting a suitable range of survey plot localities and later for interpreting the results. The Savanna & Grassland Biome studies re-sampled plots from an earlier study or worked close to the Kruger National Park and although management history information was available from the year 2000 onwards, earlier records were not available except where the researchers directly observed clearing from cut tree stumps and hence this was how the 20 cleared plots (of the 40 in total) were selected/ confirmed at the start of the study in 1996/7 (as well as by word of mouth from WfW staff). In the two Fynbos Biome regions the lack of comprehensive management history information has been a major constraint. Initially, this delayed the initiation of field work, as it was difficult to find suitable study sites with sufficient management information. Subsequently, it has impacted on our ability to confidently interpret the results, particularly where follow-up controls are not adequately described, or exact localities of treatments are not clear. In the Albany Project, data on alien densities, initial clearing and number of follow-ups have been lost for the period prior to 2002. This emphasizes the importance of experimental work (see below) where treatments can be controlled and monitored.

The earlier management data (pre-WIMS) is either held in Excel spreadsheets or in paper reports at Project Management offices, rather than at Regional Offices, and it appears that some of this information has been lost during change-overs in management. For the WIMS data, riparian and non-riparian contracts are not distinguished on the database, so a riparian subset first has to be extracted by intersecting nbals with a river GIS layer. Then the data needs to be interrogated to check that it meets minimum research requirements (i.e. in W. Cape studies, a closed alien stand that has received initial clearing at least two years previously). Often it is not clear what method of follow-up control has been done at each stage.

4.3 Facilitation of field experiments

One of the major recommendations from our 2004 introductory workshop was that comparing different clearing treatments across one relatively homogeneous site overcomes problems encountered in a broad-sweep survey approach, where differences in site characteristics mask certain clearing treatment effects. Thus field experimental studies were planned in both the W Cape & E Cape project areas. However, the success of implementing field experiments relies on the willingness of WfW Project Managers to facilitate the setting up of different clearing treatments within relatively short time-frames, and relies on a good working relationship between researcher and manager. In both regions, this did not happen according to plan: in the W. Cape, the experiment had to be abandoned owing to the treatments not being implemented in time for the MSc study; in the E. Cape, the experiment was initiated later than planned, so that results of the follow-up treatments are still being monitored. Both these experiences indicate that field experiments should be initiated in the first months of a research project, and that it will be necessary for the Working for Water National Office personnel to facilitate this up-front in collaboration with the Project Managers and researchers, particularly in ensuring that the required clearing contracts are upheld timeously.

- *W. Cape experiment*

The planned field experiment was a split plot design combining initial "Fell & Burn" and "Fell & Remove" treatments with various different follow-up methods nested within these. A suitable site was identified at the Asbos project, together with the Project Manager, where closed-stand aliens had already been felled. The fire was planned for late May 2005 and had to be done before the end of June, so that the major germination period could then follow. According to the manager it was "no problem" to do the burn within this window. However, for various reasons the controlled burn was not done by the end of June. It then became too wet and too late to do the burn or switch to an alternative site (although another suitable site was not found). The failure to implement this field experiment means that we have no direct experimental data to compare with our survey results and the predictions we make are thus less certain. It is also a drawback to Ryan Blanchard's MSc as this study was planned as his second research chapter. In retrospect, perhaps the collaboration should have been wider, possibly asking Working on Fire to facilitate the burning treatment. However, we were given no indication from Working for Water's side that it would not happen.

- *E. Cape experiment*

The planned field experiment was a split plot design across a felled alien stand in the Berg River catchment, set up in collaboration with the Albany WfW management team. However, a delay in getting permission to burn the area, as well as implementing the actual burn almost jeopardized the experiment. However, the Albany WfW management team was very helpful in assisting with the creation of firebreaks and collection of slash fuel loads for the research, and due to this assistance, the experimental burn was able to be done at the end of 2005.

Unfortunately very dry post-fire weather (beyond anyone's control) delayed the implementation of follow-up treatments at the experimental site. This in turn delayed the monitoring of these treatments and consequently data analysis for this study, which is now behind schedule. Subsequently, a follow-up control treatment was done by WfW without the researcher being informed, so that data on the impact of rehabilitation treatments on alien growth could not be collected.

4.4 Time & resource constraints

Given the ambitious goals of the project, and some of the constraints discussed above, a longer project period with a greater lead-in time would in retrospect have benefited the project. More time would have enabled us to better overcome the obstacles in setting up field experiments and allowed us to seek expert opinion on related issues, such as impacts of aliens and clearance on geomorphology, that we were unable to address in the three-year time-frame.

Financial resources have been adequate for the research undertaken. Additional external funding (from co-funding by the Centre for Invasion Biology and the Mellon Foundation for Taryn Morris's project) have enabled us to complete the project well within budget and to support an additional study.

4.5 Future research recommendations

a) Fynbos Biome

Given the surprising result that fire has a negative impact on riparian vegetation recovery following alien invasion, it is highly recommended that the planned experimental study, which failed to be implemented in this project, still be done. The purpose of this split plot experiment was to investigate the combined effects of an initial treatment (Fell & Remove and Fell & Burn) with various follow-up treatments on riparian vegetation recovery. The advantage of an experimental approach is that factors such as land-use and invasion history and biophysical features may be standardized.

It was beyond the scope of this project to investigate the impacts of aliens and clearance on geomorphology. Although we did note incidents of geomorphological change, such as localized erosion, channelisation and head-cuts, we were not able to monitor changes over time. It is recommended that some simple measures (e.g. channel depth and width, bank erosion) be monitored as part of the WfW monitoring process, to investigate whether additional research is required on the impacts of aliens and clearance on geomorphology.

Most of the baseline study sites dealt with wattles and thus the impact of *Eucalyptus* species on recovery potential has not been adequately investigated. Many of the old *Eucalyptus* stands are only now beginning to be cleared, as a market has been found for the wood. It is recommended that post-clearance recovery should be monitored for *Eucalyptus* invasions so that appropriate ecosystem repair targets may be set, and where required, active interventions initiated.

Experiments in the Eastern Cape indicate that sowing or planting commercial grass suppresses wattle regeneration and reduces follow-up costs. However, what is not clear is whether this grass sward represents an alternative stable state that will resist riparian fynbos recovery. It is recommended that restoration experiments test whether indigenous riparian herb and shrub species may be used instead of commercial grasses to suppress the aliens while facilitating vegetation recovery. Work in the Western Cape suggests that this will indeed be possible.

b) Grassland and Savanna Biomes

The 40 Whittaker plots on the Sabie River have been very well characterized over the years, and these should be maintained as permanent plots and assessed again in the future. The sites surrounding these plots would also be highly suitable for biocontrol agent releases, and hence excellent sites where integrated control strategies could be explored and monitored. Experiments could also be undertaken in order to improve the efficacy of control strategies against particular important alien invasive species.

As the Grassland and Savanna Biome work focused on one river system – the Sabie River in Mpumalanga – it is recommended that further baseline studies to investigate riparian ecosystem recovery be carried out in different parts of these biomes, especially following the clearance of dense-closed alien stands. It would be particularly interesting to find out whether the findings are applicable to a wider range of grassland and savanna types, from the dry end of the spectrum to the wetter end.

c) General

It would be worthwhile to initiate more hands-on research projects to assess WfW clearing teams' levels of training and effectiveness in applying appropriate clearing methods, including levels of knowledge and ability to identify species (both important aliens and indigenous species). If not already done, confidential questionnaire surveys using a stratified random sample (by "new" versus "old" recruits, gender and age classes) of workers on their perceptions of the value of the work, why it is important, and how they can contribute to solving the invasion problem. These may provide insights into systemic problems and also suggest potential solutions.

Futher field trials to investigate the simplest and most effective way of re-introducing key woody riparian species (riparian scrub trees in fynbos and riparian woodland trees in grassland/ savanna) could reduce the costs of restoring riparian structure at sites where this is considered beneficial (both to improve ecosystem integrity and suppress secondary alien invasions).

Initial restoration experiments indicate some suppression of alien recruitment following successful vegetation establishment, with potential positive economic impacts (through a reduction in follow-up costs) as well as positive ecological impacts. It is recommended that active restoration programmes are initiated at a range of sites supporting closed-stand invasions, where the ecosystem repair target is to restore ecosystem structure and functioning. These sites should be monitored for both ecosystem recovery and costs of restoration (alien clearance and vegetation re-introduction), in comparison to sites that have only been cleared, in order that a more complete cost-benefit analysis of active restoration may be done.