The effects of invasion by alien shrubs and trees on the fuel properties of ecosystems in the Western Cape, South Africa

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1. INTRODUCTION

This report is in the format requested by Working and constitutes an abbreviated report accompanies the final report on the "*fuel properties of four invasive woody alien plants in South Africa*".

2. TERMS OF REFERENCE

The terms of Reference were as follows:

- Assess the physical fuel properties of selected invasive alien plant species, including fuel loads by size class, amounts of dead and live material, and the spatial distribution of fuel;
- Monitor the moisture contents of live fuel over one year;
- Assemble fuel models that simulate the combined impacts of invasion on fuel properties at a stand level;
- Use fire behaviour simulation techniques to assess the effects of changes in fuel properties on fire regimes (including the likely frequency, intensity, behaviour and impacts of wildfires); and
- Where possible, verify the assessments in the field, either by conducting experimental burns or making opportunistic use of prescribed burns or accidental fires.

3. DURATION OF THE PROJECT

The project commenced in September 2002 and was completed in April 15, 2004.

4. oRIGINAL PROJECT PLAN

The original project plan is provided in Table 1. We were not able to conduct experimental burns due to logistical and legal constraints.

Table 1. ***Original Project Plan. This plan is currently running behind schedule.***

Month / Year	**Activities**
2002	
September	Species selection
	Determine variables to measure
	Search literature for similar recent studies
	Procure equipment
	Design field forms
	Select study sites
	1st fuel moisture sampling
October	Background on Behave Programme
November	2nd fuel moisture sampling
2003	
January	3rd fuel moisture sampling
February	Acacia cyclops field sampling
	A. cyclops drying and weighing
	Build A. cyclops fuel model
	Run Behave simulation
March	*Leptospermum laevigatum* field sampling
	L. laevigatum drying and weighing
	Build *A. cyclops* fuel model
	Run Behave simulation
	Acacia mearnsii field sampling
	A. mearnsii drying and weighing
	Build *A.mearnsii* fuel model
	Run Behave simulation
April	*Pinus pinuster* field sampling
	P. pinuster drying and weighing
	Build *P. pinaster* fuel model
	Run Behave simulation
	4th fuel moisture sampling
	Analyse model outputs
May	Visit sites of recent veldfires involving invasive alien vegetation
	Start report writing
	5th fuel moisture sampling
July	6th fuel moisture sampling
	Produce draft scientific paper

5. PROJECT BUDGET

This study forms part of the existing CSIR contract to provide scientific support to the Working for Water Programme. The full contract value was R2.4 million over two years. About 10% of the budget was earmarked to support the fuel properties study and related capacity development activities. The proportion accounted for by these activities is contained in detailed monthly invoices to the working for water programme.

Abstract. Two study sites invaded by *Acacia cyclops* and *Pinus pinaster* were sampled for moisture contents, vegetation height and stratification and biomass. Data were used to compare fuel loads of these sites to those of adjacent uninvaded areas. Also, data were used to construct fuel models of *A. cyclops* and *P. pinaster* for the simulation of fire behaviour through the use of the BehavePlus fire modeling system. This model was used to compare fire bahaviour under similar climatic conditions between invaded and adjacent uninvaded areas of the study sites. Data on vegetation height and stratification demonstrated increases in fuel loads following invasion by *A. cyclops* and *P. pinaster*. BehavePlus simulated rates of spread, flame length, fire line intensity and head per unit area were all higher for *A. cyclops* and *P.pinaste*r fuel models. This was due to the amount of fuel that was available for burning as a result of these shrubs and trees.

Additional keywords: fuel model; alien woody; BehavePlus fire model

Running heading: Effects of alien invasion on fuel properties

INTRODUCTION

Non-indigenous woody plant species, introduced by humans, either intentionally or unintentionally, can spread into native forests, pastures, or cultivated areas. Such species are termed "invasive." In many parts of the world, introduced woody plants have become invasive and have necessitated some form of management. These invasive species affect, to a varying degree, the structure and function of invaded ecosystems. For example, invasions can result in an increase in biomass and changes in nutrient pools and cycling (Versfeld and van Wilgen, 1986; Richardson *et al.*, 1992; Stock and Allsop, 1992). An increase in biomass is generally associated with an increase in evapotranspiration (Le Maitre *et al.*, 1996). Other major disadvantages of invasive plants include: changes in natural community structure, penetrating and replacing indigenous vegetation (Henderson *et al*. 1987; Henderson 2001), reduction of surface water resources (Chapman and Le Maitre 2001, Versfeld *et al*. 1998), siltation of dams and estuaries, intensification of floods, and increase in fire hazard through increased fuel loads.

A perusal of the scientific literature suggests that work has been done in South Africa and elsewhere in trying to quantify the impact of invasive woody alien plant species on fire behaviour. The abundance of invasive woody alien plant species in numerous habitats throughout the world has been well researched and documented (see Vitousek 1997, Groves 1986, Stone *et al*. 1992). However, the bibliographical data suggest that South Africa is the only place in the world where it has been shown that invasive woody alien plant species affect fire behaviour (see van Wilgen and Richardson 1985) by increasing fuel loads. Elsewhere in the world (particularly in Hawaii), most of the evidence of the impact of alien plant species on fire regimes has been in relation to alien grasses. Such studies have shown that invasive alien grass species enhance the spread of fires by providing a more continuous fuel load than pre-invasion vegetation (Smith 1985, Smith and Tunison 1992, D'antonio *et al*. 2000).

van Wilgen and Richardson (1985) found that invasion of fynbos by the Australian shrubs *Acacia saligna* and *Hakea sericea* increased fuel loads by 50 – 60%. The data were used in Rothermel's (1972) fire behaviour simulation model, which predicted that both rates of spread, and fire intensity were reduced by invasion. However, it was recognised that shortcomings in Rothermel's model prevented the accurate simulation of high intensity fires that are known to have occurred in invaded areas under extreme weather conditions. Such fires are known to vigorously consume the increased biomass of shrub crowns, are difficult to control, and are potentially more damaging to ecosystems than fires in natural vegetation. van Wilgen and Richardson (1985) suggested that, under such extreme conditions, invasion would increase fire hazard and fire intensity.

The interaction between fire and invasive woody alien plants in South Africa has been extensively reviewed by Bond & van Wilgen (1995). They describe how invasion by introduced woody plants affects fire behaviour by changing the structure of the fuel bed. Versfeld and van Wilgen (1986) found that invasion of mountain fynbos by pines could increase biomass by up to 300%. In a separate study, Scott *et al*. (2000) report that infestation by alien invasive plants had increased fuel loads over most of the areas that burned on the Cape Peninsula in January 2000. Less than 10% of the area was not invaded by alien plants prior to 1998. Alien plants greatly increased the fuel load and fire risk, by virtue of their faster growth rates and greater age than the native fynbos, and the physical characteristics of the stands of aliens.

While such studies have helped build up our understanding of the interaction between fire and invasive woody alien plants, there are still gaps in our understanding of the interaction between fire and woody alien invasive plants in South Africa. Besides the two species studied by van Wilgen and Richardson (1985) (*Acacia saligna* and *Hakea sericea*), there is no information on the fuel properties of invasive alien tree invasions. There is also no information of the impacts of fires in invaded stands in biomes other than fynbos and montane grassland. Given the potential impacts that such invasions may have, and given the amounts being spent on controlling such invasions, it would be desirable to expand the knowledge base to cover additional species and biomes.

This study examines the fuel properties of two invasive woody alien plants in South Africa to determine how they affect fire behaviour. The two species are *Acacia cyclops* (Rooikrans), *Pinus pinaster* (Pines). It is often claimed that invasions increase fire hazard through changing vegetation structure and increasing fuel loads. However, very few studies have shown this, and then only for a few species. We need more information to be able to fully understand the impact of invasions on fire regimes.

The aims of this study were:

- To assess the physical fuel properties of stands of *P. pinaster* and *A. cyclops*, including fuel loads by size class, amounts of dead and live material, and the spatial distribution of fuel;
- To monitor the moisture contents of live fuel over one year;
- To assemble fuel models that simulate the combined impacts of invasion on fuel properties at a stand level;
- To use fire behaviour simulation techniques to assess the effects of changes in fuel properties on fire regimes (including the likely frequency, temperature, behaviour and impacts of wildfires); and
- Where possible, verify the assessments in the field, either by conducting experimental burns or making opportunistic use of prescribed burns or accidental fires.
- Compare fuel loads of uninvaded and invaded areas of the study sites.
- To document changes in vegetation structure following invasion, with emphasis on those structural properties that affect fire. This could be useful for later studies that attempt to model fire behaviour or potential fire risk.

MATERIALS AND METHODS

Study sites

Data were collected at two different sites, Coetzenburg and Koeberg in the Western Cape Province of South Africa. The sites were selected because the natural fynbos vegetation had been replaced by invading woody alien plants and with the aim of documenting the fuel properties of such invaders. At each study site we selected an uninvaded area and an adjacent area invaded by woody invasive alien plants.

Coetzenburg

Coetzenburg (33º57′S, 18º55′E) forms part of the Jonkershoek Valley and is property of the University of Stellenbosch. The climate of the area is similar to that of Jonkershoek which has been well described by van Wilgen and Richardson (1985). It is characterised by warm summers with regular south-easterly winds, creating a fire hazard. Winters are cold and rainy, the annual rainfall being almost 600 – 700 mm. The vegetation of the Coetzenburg area is mainly mountain fynbos. Distinctive species are *Protea repens, P. neriifolia*, mountain cypress, as well as various ericas and restios. The area has been invaded by Hakea, Black wattle, Pines and other invasive alien plants which threaten the indigenous fynbos.

Koeberg

The study site is situated in the Koeberg Nature Reserve (18° 26’ E, 33° 41’ S), about 30 km north of Cape Town on the west coast. The reserve is situated on land owned by Eskom and is regarded as critical conservation area and a key part of the proposed West Coast Biosphere Reserve (CMC 2000, Heijnis *et al.*, 1999; Maze and Rebelo, 1999). The climate is Mediterranean with most of the rain falling during the winter half-year and temperatures are strongly moderated by the proximity to the Atlantic Ocean. The annual rainfall is almost 414 mm (Colvin *et al*. 2002). Wind direction is due south to south-east, especially during the dry summer months, with winter rainstorms being associated with north-west and south-west winds (Heineken, 1987).

There are two main types of indigenous vegetation on the deep quaternary sand deposits of the West Coast: dune thicket (also known as strandveld) and fynbos (Boucher, 1981a, 1983; Boucher and Le Roux, 1993; Daines and Low, 1993, Heijnis *et al.*, 1999). Dune thicket is found primarily on alkaline (calcareous i.e. lime-rich) sandy soils, and fynbos on the acidic sandy soils derived from sandstones and granites and acidic dune sands. Dune thicket is an open to dense, vegetation, dominated by large evergreen shrubs. The invaded portion of the study area is dominated by *A. cyclops* (Rooikrans) with occasional *A. saligna* (Port Jackson). The impacts of these invasions on groundwater losses are not known but dense invasions result in an increase in biomass and changes in nutrient pools and cycling (Versfeld and van Wilgen, 1986; Richardson *et al.*, 1992; Stock and Allsop, 1992). An increase in biomass is generally associated with an increase in evapotranspiration (Le Maitre *et al.*, 1996) so it is likely that the invaded stands may intercept or transpire more water, reducing recharge.

Field, laboratory and simulation methods

Vegetation height and stratification

Data on vegetation height and stratification were obtained from a transect (1× 50 m) at each of the invaded sites and the adjacent univaded site. The transects were positioned in an area chosen randomly within vegetation judged to be representative of the site. The following data were recorded on each transect: (1) mean depth of the litter layer; (2) the height, crown diameter and height of the lowest leaves of each plant on the transect. Plants were first identified at species level then later recorded as either dominant shrubs (*A. cyclops*, *P. pinaster* or microphyllous shrubs similar to the indigenous genus *Protea*), other microphyllous shrubs, shrubs, picophyllous shrubs similar to the genus *Erica*, evergreen herbaceous plants similar to the indigenous genus *Restio* and standing dead plants. The data were later used to draw profile diagrams and to define fuel bed depths.

Biomass and fuel loads

Both experimental sites consisted of uninvaded and invaded stands. In both uninvaded and invaded stands we established a 50 m straight line transect. Detailed measurements of the vegetation were then undertaken at these transects in order to obtain biomass and fuel load estimates. The biomass data were collected according to the BehavePlus fire modelling system (Andrews and Bevins 1999) fuel load input requirements. Thus we examined the model data requirements before going into the field for data collection.

Biomass was determined by collecting all plant material, except for dominant alien shrubs, from a random sample of ten plots (2.5×2.5 m) within the 50 m transect. Clipped material was divided into the following categories: (1) woody shrubs other than dominant shrubs; (2) herbaceous (non-woody) plants; and (3) litter (all dead material including that still standing). These categories were further subdivided into size classes (BehavePlus fuel input requirements) of less 6 mm (1 hr fuel load), 6 – 25mm (10 hr fuel load), 25 – 76 mm (100 hr fuel load). This division followed the convention used in estimating available fuel in fuel models (Countryman & Philpot 1970; Deeming & Brown 1975; van Wilgen 1982). Estimation of the biomass of dominant alien shrubs was done by regression analysis. Twenty shrubs, selected to cover a representative range of diameters, were harvested outside the sites after measuring their diameters 10 cm above the ground. Each shrub was divided into potential fuel (pieces with diameters <6 mm) and larger pieces, weighed and then sub sampled for moisture content to estimate the dry weight of the original material. Non-linear, power and exponential regressions of stem diameter on dry weight were fitted (see van Wilgen and Richardson 1985).

Moisture contents

Twenty samples of the foliage of *A. cyclops*, *P. pinaster* were taken over a period of one year in order to examine seasonal trends in moisture content and to define moisture scenarios for the simulation of fire behaviour. Samples were sealed in air-tight bottles to prevent moisture loss, weighed and oven dried. The percentage moisture content was calculated on a dry weight basis.

Simulation of fire behaviour

Biomass and other structural data were used to define fuel models for each of the site. Fire behaviour predictions were done using the Windows application BehavePlus fire modelling system (Andrews and Bevins 1999). BehavePlus predicts various fire behaviour characteristics of interest to fire management specialists. It replaces the venerable 1984 DOS version of the *BEHAVE Fire Behaviour Prediction and Fuel Modelling System (*Burgan and Rothermel 1984). BehavePlus uses a minimal amount of site-specific input to predict fire spread rate, area, perimeter, intensity, flame length, scorch height, spotting distance, tree mortality, etc. under stated climatic conditions at a point in time.

RESULTS

Vegetation height and stratification

The increase in height following invasion by *A. cyclops* and *P. pinaster* can clearly be seen in Figs. 1 and 2. Also, there was a marked increase in foliage density after invasions by both invading woody alien plants.

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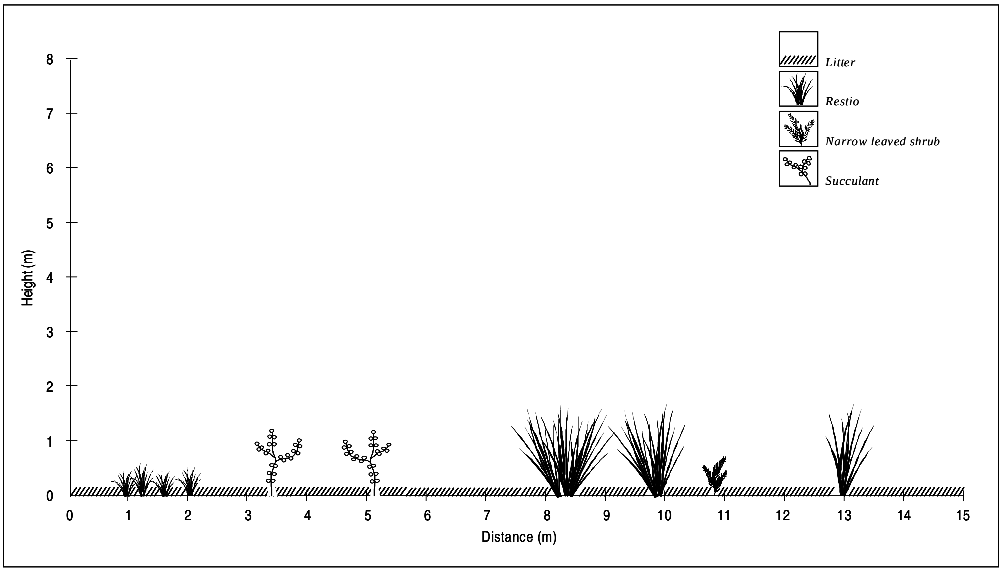

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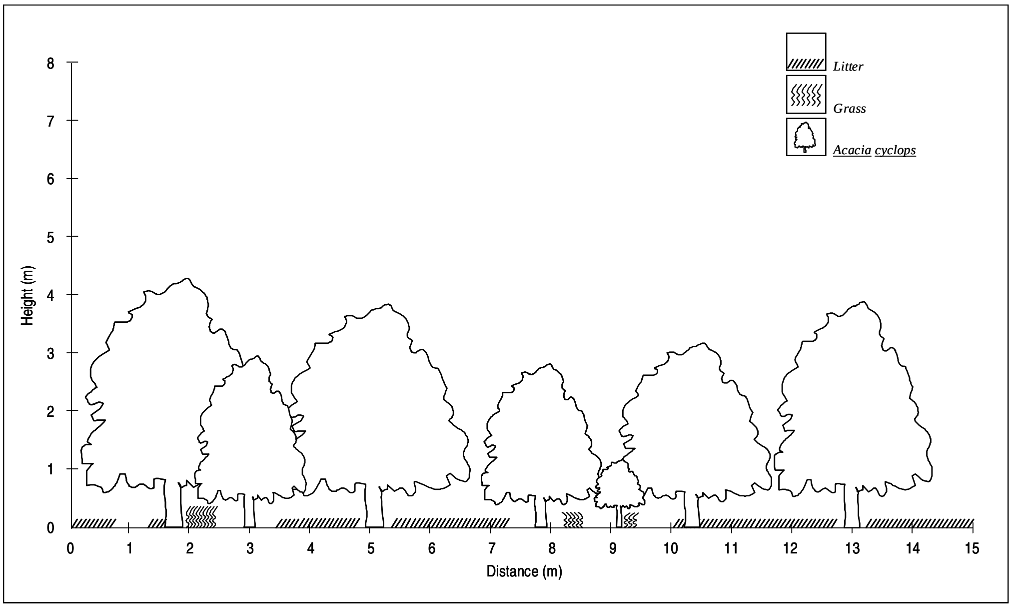

Fig. 1. Profile diagrams from 2.5×2.5 m-wide transects through plant community stands. Diagrams provide visual impression an uninvaded area (a) and the same area (a) invaded by *A. cyclops* at the Koeberg study sites.

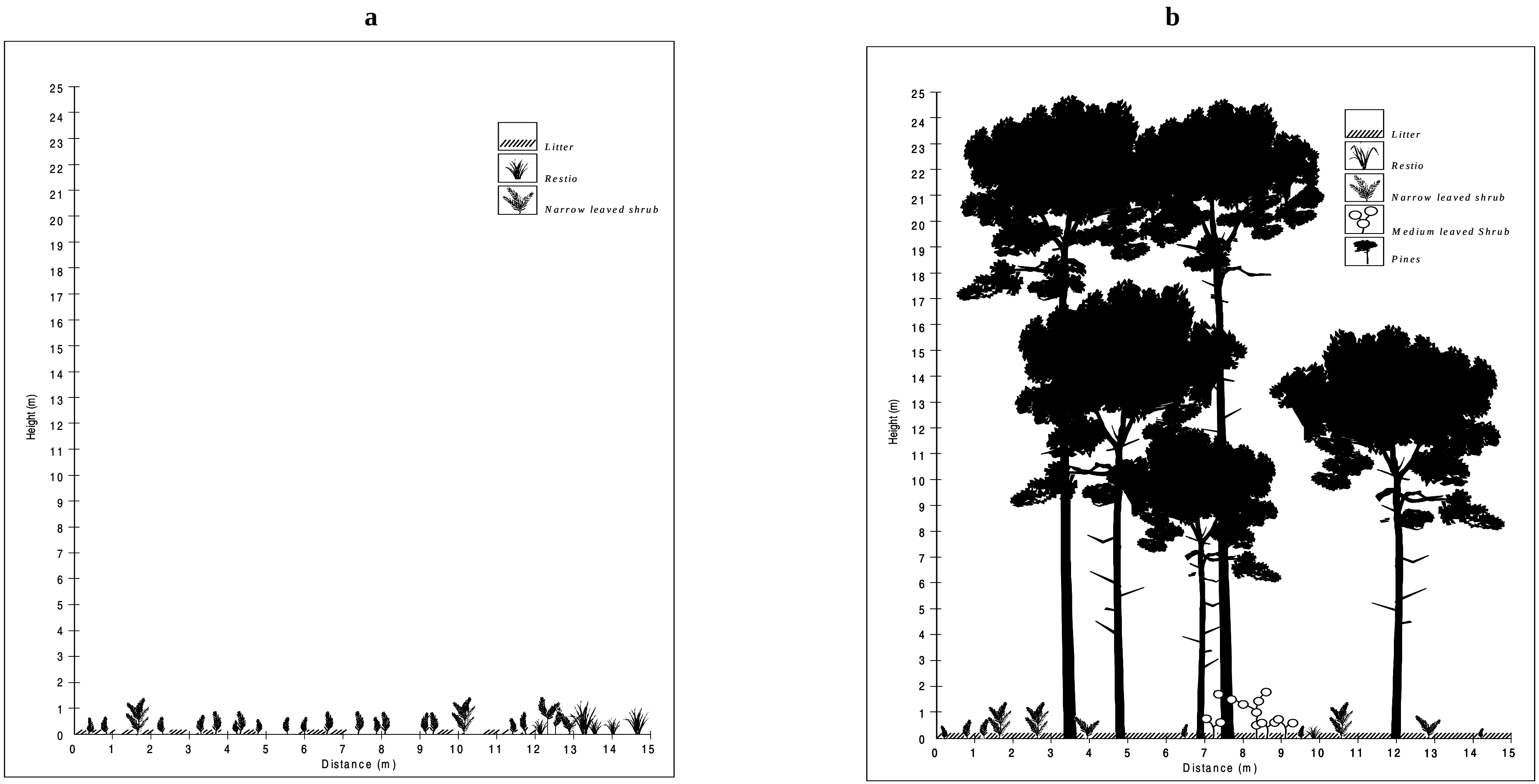

Fig. 2. Profile diagrams from 2.5×2.5 m-wide transects through plant community stands. Diagrams provide visual impression an uninvaded area (a) and the same area invaded by *P. pinaster* at the Koeberg study site

Biomass and fuel loads

Details of the biomass sampled on each study site for uninvaded and invaded areas are presented in Tables 1&2. The total mass of plant parts that can be regarded as fuel during fire behaviour simulations was higher at the invaded areas than at the uninvaded areas for both the Coetzenburg and Koeberg study sites. At the Coetzenburg site the amount live plant material <6 mm in diameter was 7.9 times greater, dead plant particles were 9.9 times greater, and the total fuel load (dead and live) was 8.1 times greater than at the *P. pinaster* invaded area (Table 1). At Koeberg, the total fuel load (dead and live) increased to about 3.1 times following invasion by *A. cyclops*. Similarly, live plant particles (<6 mm) and dead material increased 4.8 and 2.5 times respectively following invasion of strandveld areas by *A. cyclops*. Thus there was a marked increase in the biomass component and fuel loads following invasion by the woody alien plant species and this is similar to previous observations by van Wilgen et al. 1990, van Wilgen and Richardson (1985).

Table. 1. Above-ground biomass of vegetation components (t/ha) in uninvaded and invaded area of the Coetzenburg site

Live Plant Material (t/ha)	Renostebos	*P.pinaster*
< 6 mm	9	68
Herbaceous Plants (< 6 mm)	1	0
Dead Material		
< 6 mm	2	15
6 - 25 mm	1	19
25 - 75 mm	1	2
Total	14	104

Table. 2. Above-ground biomass of vegetation components (t/ha) in pristine and invaded area of the Koeberg site.

Live Plant Material (t/ha)	Strandveld	*A.cyclops*
< 6 mm	5	24
Herbaceous Plants (< 6 mm)	0	0
Dead Material		
< 6 mm	1	25
6 - 25 mm	2	4
25 - 75 mm	9	4
Total	18	57

Moisture contents

Changes in fuel moisture content of the two woody invasives sampled are depicted in Fig 3. These are compared to fynbos moisture content sampled by van Wilgen *et al*. 1990. From the illustration, it can be deduced that the is no marked difference in fuel moisture contents of the tree species. It should however be noted that data are from three different sites.

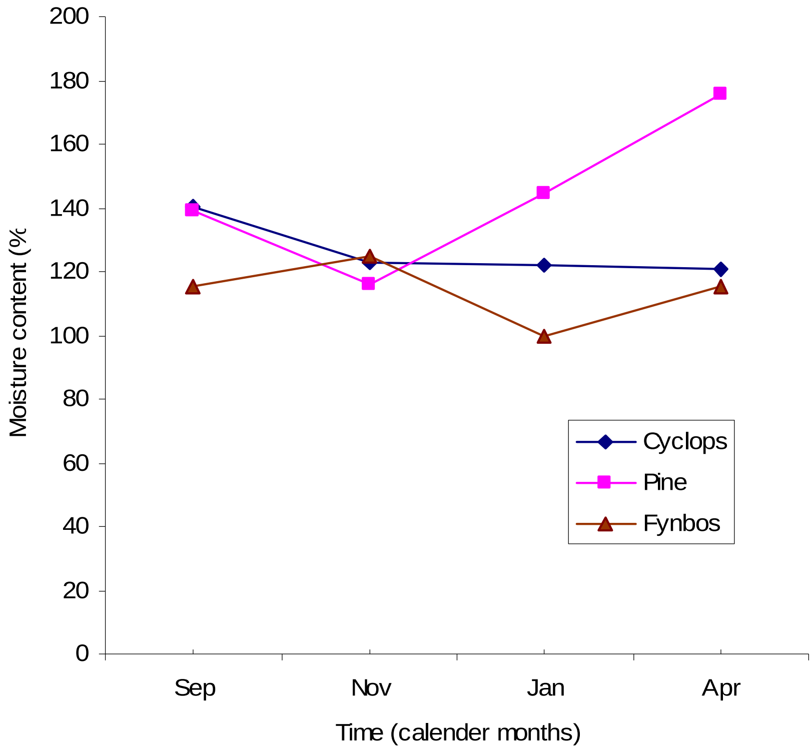

Figure 3. Changes in the moisture content of the foliage of three species growing at three different sites. The species are the species are *A. cyclops*, *P. pinaster* and 6 fynbos species

Simulation of fire behaviour

Fuel model parameters used in the simulation of fire behaviour are given in Tables 3&4. The surface area to volume ratios of the Renosterbos are those used by van Wilgen and Richarson (1985). Also, fuel moisture of extension and fuel heat content is taken from that study. For both Coetzenburg and Koeberg, fuel loads showed an increase following invasion by the woody alien invasive species. At Coetzenburg most of the live fuel is held aloft in stands of *P. pinaster*, and the model is only capable of simulating surface fire spread in the litter layer below the canopy. Another limitation of the BehavePlus fire model is that it has an upper limit (1.8 m) for the fuel bed depth and thus the fuel bed depth of *P.pinaster* is reduced to that limit. Generally all the fuel models in the study support the general observation that (Kruger 1979) that invasion by alien shrub increases fuel load that is available for burning.

Table. 3. Fuel model data assembled for Renosterbos and *P. pinaster* for Coetzenburg site. Fuel models are used as input parameters during simulation of fire behaviour.

Model Parameter	Renosterbos	*P. pinaster*
Fuel load/Vegetation (t/ha)		
1-h	2	15
10-h	1	19
100-h	1	2
Live herbaceous	1	0
Live woody < 6 mm	9	68
Surface area to volume ratios (m^2m^{-3})		
1-h Surface Area/Vol Ratio[A]	7215	9817
Live Herb Surface Area/Vol Ratio	5900	0
Live Woody Surface Area/Vol Ratio[A]	4920	9817
Fuel bed depth (m)	1	2
Dead Fuel Moisture of Extension (%)[A]	34	34
Dead Fuel Heat Content (kJ/kg)[A]	20000	18700
Live Fuel Heat Content (Kj/kg)[A]	20000	18700

[A] after van Wilgen and Richardson (1985).

Table. 4. Fuel model data assembled for Strandveld and *A. cyclops* for the Koeberg site. Fuel models are used as input parameters during simulation of fire behaviour.

Model Parameter	Strandveld	*A. cyclops*
Fuel load/Vegetation (t/ha)		
1-h	1	25
10-h	2	4
100-h	9	4
Live herbaceous	0	0
Live woody < 6 mm	5	24
Surface area to volume ratios (m^2m^{-3})		
1-h Surface Area/Vol Ratio[A]	7215	6400
Live Herb Surface Area/Vol Ratio	0	0
Live Woody Surface Area/Vol Ratio[A]	4920	6400
Fuel bed depth (m)	1	1
Dead Fuel Moisture of Extension (%)[A]	34	30
Dead Fuel Heat Content (kJ/kg)[A]	2000	18500
Live Fuel Heat Content (Kj/kg)[A]	2000	18500

[A] van Wilgen and Richardson (1985).

Fire behaviour simulations by the BehavePlus model were made for four sets of climatic conditions which according to van Wilgen and Richardson (1985) represent typical days with low, moderate, high and extreme fire hazard (Table 5). Estimates of live moisture contents for *P.pinaster* and *A.cyclops* are based on observation from the field.

Table. 5. Weather parameters and fuel moisture contents in simulating fire behaviour.

Degree of fire Hazard	Low	Moderate	High	Extreme
Air Temperature ($^{\circ}$C)	15	20	30	40
Relative Humidity (%)	50	40	25	15
Windspeed (Km/h)	1.8	7.2	18	25.2
Slope (degrees)	0	0	0	0
Dead Fuel moisture content (%)	9	8	6	4
Live fuel Moisture Content (%)				
Uninvaded Renestorbos	180	150	140	130
Uninvaded Strandveld	180	150	140	130
A. cyclops	180	150	140	130
P. pinaster	180	150	140	130

The fuel model parameters (Tables 3&4) together with the weather parameters (Table 5) were used as BehavePlus model input parameters for the simulation of fire line intensity (Tables 6&7), heat per unit area (Tables 6&7), rate of fire spread (Figure 4a&b) and flame length (Figures 5a&b). Model estimates of fire intensity and heat per unit area were higher in invaded areas of the study sites with differences between uninvaded and invaded areas becoming larger with increasing fire hazard. Also, estimates of fire intensity and heat per unit area were higher at the *A. cyclops* invaded stand at Koeberg than at any other stands. Uninvaded Renosterbos show the lowest estimates when compared to any other stands under all the climatic conditions.

Table. 6. Simulated estimates of fire behaviour for the Coetzenburg study site**.** Table shows estimates of fire line intensity and heat per unit area for uninvaded Renosterbos and invaded stands (*P.pinaster)*.

Simulation results	Low	Moderate	High	Extreme
Simulated Fireline Intensity (Kw/m)				
Renosterbos	4	25	104	159
P.pinaster	95	814	5432	13996
Simulated Heat per unit area (KJ/m^2)				
Renosterbos	2594	2681	2916	3248
P.pinaster	12666	13093	14243	15861

Table. 7. Simulated estimates of fire behaviour for the Koeberg study site**.** Table shows estimates of fire line intensity and heat per unit area for uninvaded Strandveld and invaded stands (*A. cyclops*).

Simulation results	Low	Moderate	High	Extreme
Simulated Fireline Intensity (Kw/m)				
Uninvaded Strandveld	7	42	173	359
A. cyclops	1123	7211	31608	63936
Simulated Heat per unit area (KJ/m^2)				
Uninvaded Strandveld	3367	3481	3786	4217
A. cyclops	50796	55084	58314	62651

Simulated rates of fire spread (Figure 4a&b) were highest in the invaded areas of both Coetzenburg and Koeberg study sites under all climatic conditions. Simulated flame lengths (Figure 5a&b) showed a similar pattern. The differences were becoming larger with increasing fire hazard. Also, rate of fire spread was the highest under all the conditions.

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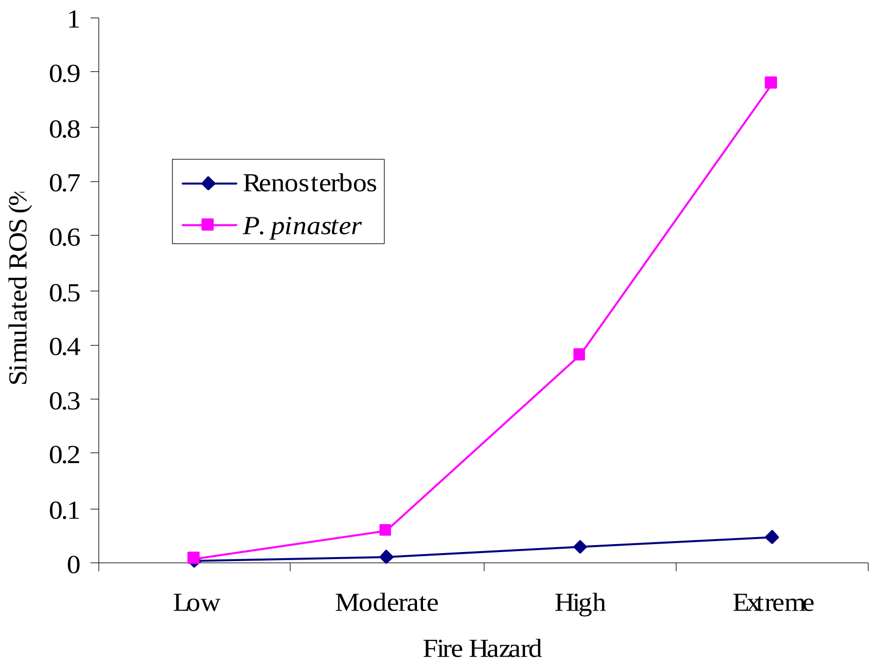

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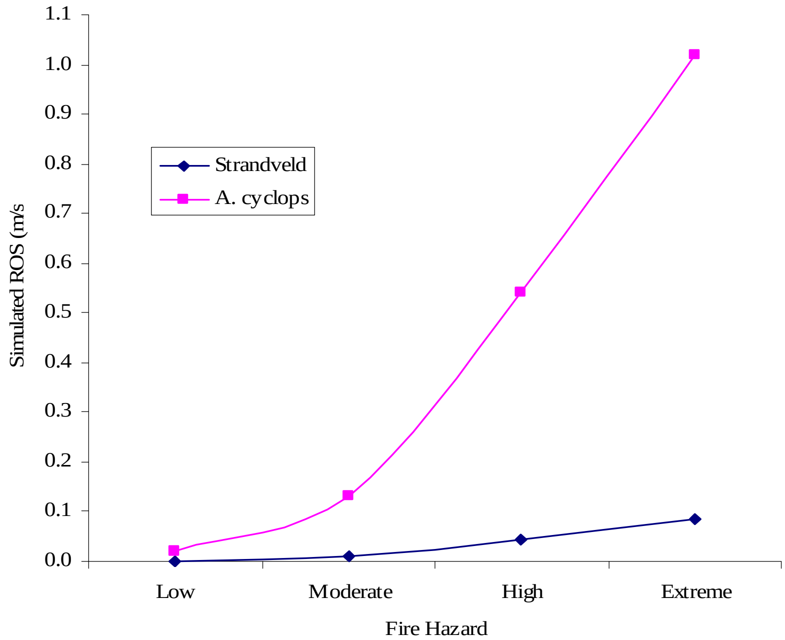

Fig. 4 a&b. Simulated rates of fire spread (ROS ms^{-1}) using the BehavePlus fire model and four different fuel models (Tables 3&4) at four levels of fire hazard (Table 5) at two different study sites. The study sites are Coetzenburg (a) and Koeberg (b) and both sites have uninvaded and invaded areas.

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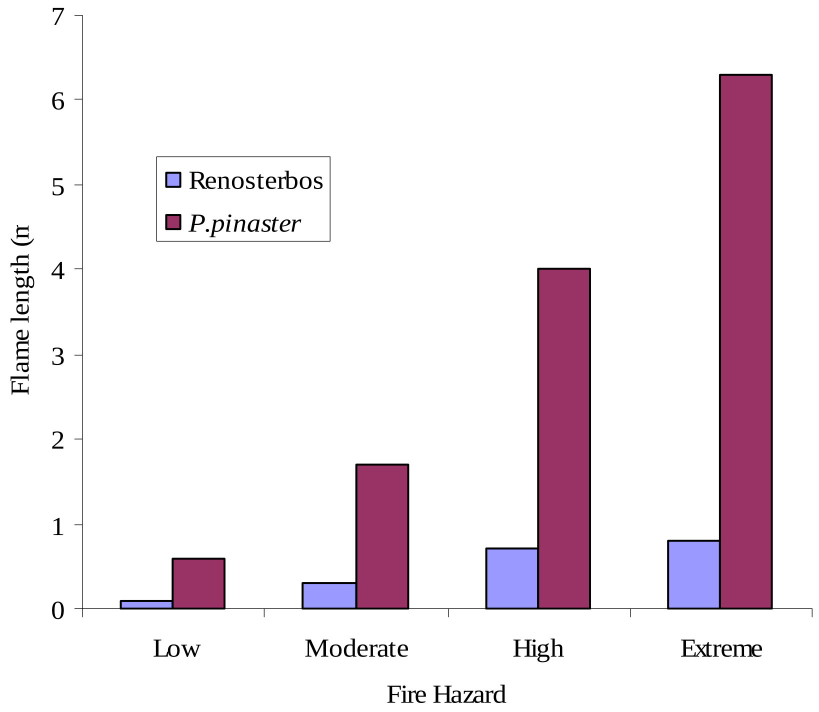

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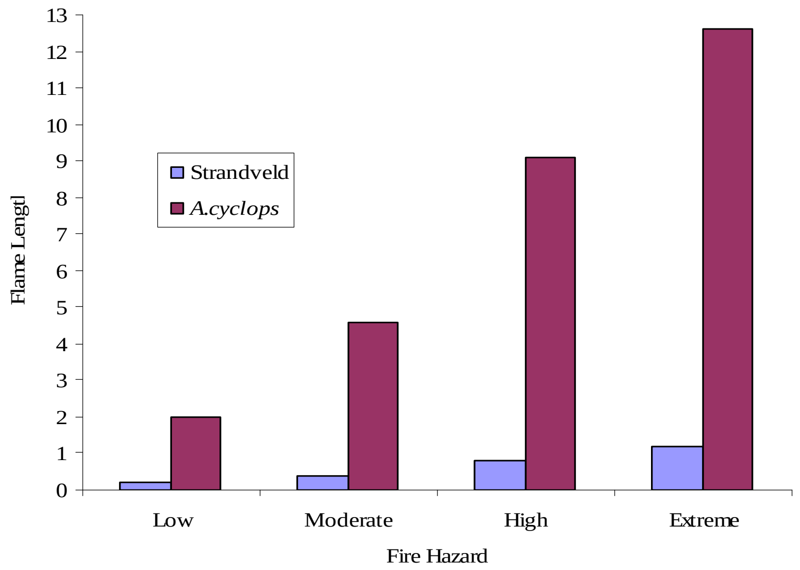

Fig. 5 a&b. Simulated flame lengths (m) using the BehavePlus fire model and four different fuel models (Tables 3&4) at four levels of fire hazard (Table 5) at two different study sites. The study sites are Coetzenburg (a) and Koeberg (b) and both sites have uninvaded and invaded areas.

DISCUSSION AND CONCLUSION

Classification of vegetation types into fuel models is an important component of wildland fire management worldwide (Payne *et al*. 1996; Dimitrakopoul 2002). Field work done during this study collected data on vegetation height and stratification, biomass and fuel loads, moisture contents, and surface area to volume ratios for uninvaded and invaded areas at two different study sites. This data was then used in the formation of three localised site specific distinct fuel models, one for indigenous vegetation (Strandveld) and two for invasive woody alien plants (*P. pinaster* and *A. cyclops*) (Tables 3&4). The fourth fuel model (Renosterbos) is that used by van Wilgen and Richardson (1985). The four different models showed differences in the total amount and distribution of fuel load in size classes and in the vegetation structure and height, all in greater quantities for the invasive woody alien vegetation.

All the fuel models were then used as inputs to the BehavePlus fire behaviour simulation model to predict fire line intensity, heat per unit area, rate of fire spread and flame lengths under different climatic conditions. The invasive woody alien fuel models showed the most severe fire potential due to the heavier fuel loads. Based on the BehavePlus fire behaviour simulations, both the *P. pinaster* and *A. cyclops* fuel models resulted in the most intense and fastest fires. As a result of reduced fuel loads the indigenous vegetation fuel models (Renosterbos and Strandveld) resulted in less fire line intensity, heat per unit area (Tables 5&6 , rate of fire spread and flame lengths (Figures 4&5). Also, the differences in fire behaviour between the indigenous fuel models and the woody invasive alien models increased with increasing fire hazard. It should however be noted that the BehavePlus fire model does not simulates surface fire spread and has an upper limit for fuel bed depth (1.8 m). This might partly explain why the *A. cyclops* fuel model generates more sever fires when compared to the pines which have a higher fuel load.

Results in this study confirm Kruger's (1979) observation that woody invasive alien plants increase fire hazard through increased fuel loads. The implications such results are that (a) fires burning on invaded areas will be most severe, (b) most difficult to control. Further, such fires are likely to be more damaging to the ecosystem than fires in indigenous vegetation (van Wilgen and Richardson 1985). Thus this study supports the idea of controlling and reducing invasions by woody invasive alien plant species.

Acknowledgement

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