Final Report

Department of Water Affairs and Forestry: Working for Water

For

Christo Marais

Fynbos Work for Water Programme

The influence of vegetation type and fire severity on catchment stability after fire: a case study from the Cape Peninsula, South Africa.

Emerging Candelabra flower, *Brunsvigia orientalis*

By

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1. SUMMARY

Soil erosion and vegetation recovery was monitored after the Fish Hoek fires of March 1999 and the Peninsula fires of January 2000. At the Fish Hoek sites a storm one-month after the fire caused severe soil erosion. Nine months after the fire, in December 1999, a monitoring experiment was set up across a range of soil types, vegetation types and fire severities present in the area. We were interested in determining the influence these factors may have on post-fire soil erosion and vegetation recovery. In January 2000, fires burnt large areas of fynbos and alien vegetation on the Cape Peninsula. The opportunity of setting up a soil erosion monitoring experiment before the first post-fire storm was seized.

After the first winter rainfalls following the Peninsula fires, no net change in soil surface level was found in fynbos, while a little over of 100 m^3/ha was lost from alien infested areas. Over double this amount was lost from areas cleared of alien vegetation. A less damaging alien clearing method is required.

There was considerable variance in soil erosion, so predicting erosion risk and erosion events is difficult. However, substrate type was most important in determining levels of soil loss, being more on deeper sandy soils than on rocky TMS soils. Vegetation induced differences in soil erosion were most significant on TMS soils. A combination of sandy soil, alien vegetation and a severe fire at the soil surface are most likely to present soil erosion problems. Vegetation type and fuel load predicts fire severity potential. Measures of fire severity in this study, however, did not correlate closely with soil erosion. The fire severity index may not be a good predictor of how fire affects soil properties. Furthermore, factors such as soil moisture at the time of the fire may be more important.

Fire severity (degree of heating of the surface soils) was greater in alien and cleared vegetation (especially where cleared aliens were stacked) than in fynbos. In terms of measurable effects, fires in alien infested areas were on average, about 65% more severe (more damaging) than fynbos fires. The most severe fire in aliens can cause two thirds of species and plant cover to be destroyed in fynbos.

The soil erosion process could be explained by soil type, vegetation type and fire severity's influence on soil physical and water repellency properties. The passage of a fire can enhance the water repellent layer lower down in the soil profile. More severe fires at the soil surface can destroy hydrophobic substances thereby generating a thicker wettable surface layer. The water repellent layer beneath this surface soil resists the percolation of water, resulting in overland flow through a highly erodible soil during heavy rainfall. The repellent layer tends to be thicker and more persistent on deeper sand soils than on TMS. The rockiness of TMS soils also provides sites where water can percolate through the repellent layer. Vegetation recovery after a fire may also provide protective cover to the soil surface, mitigating the impact of rain splash.

2. INTRODUCTION

The occurrence of increased sediment run-off after fires is well known and documented for fire prone vegetation around the world (Scott and Van Wyk, 1990; Scott and Schulze, 1992; Walsh *et al.* 1995; Wells *et al.* 1979). The aim of this study was to test if the kind of vegetation cover on a slope, the severity of the fire, and the link between these two factors, had a significant influence on catchment stability and sediment runoff. If soil movement and loss is greater on slopes covered with alien vegetation rather than on slopes with fynbos vegetation, then this implies that alien clearing operations are an appropriate means of minimizing the potential for soil erosion. Such a finding would increase the impetus and value of alien clearing operations. Alien clearing operations are typically done in order to preserve the indigenous fynbos vegetation that it replaces, to increase water runoff from water catchment areas and to protect property by making wild fires more manageable (by reducing high fuel loads associated with alien vegetation).

The mechanism whereby alien vegetation may increase post fire soil erosion is generally related to the severe fires and high fuel loads associated with alien vegetation. Severe fires at the soil surface can consume the leaf litter, humus and organic roots in the soil, leaving surface soils loose and more exposed to erosive forces. Indigenous fynbos vegetation typically has a much lower fuel load, and the flammable leaf litter on the surface is, relative to that of alien vegetation, very small. A more severe fire has also been shown to induce a water-repellent layer beneath the wettable surface soil (Wells *et al.* 1978; Wells, 1981). This water repellent layer can impede the percolation of water, and this increases the risk of the surface layer becoming saturated during heavy rainfall events. This in turn leads to surface wash or overland flow, which drives the erosion of the surface soils. On burned areas, surface flow and soil erosion may tend to be higher in storms following long dry periods, when hydrophobicity is enhanced (Walsh *et al.* 1995). Soil erosion decreases rapidly in the years following the fire as the vegetation recovers and the repellent layer becomes less prevalent (Wells *et al.* 1979; Walsh *et al.* 1995).

A severe fire in the Brakkloofrant Mountains near Fish Hoek on the Cape Peninsula in March 1999 was followed by a storm on 21 April, resulting in unusually high sediment runoff from the mountain, including sediment dumping in residential areas. About thirty residential properties were damaged by the flooding event, and over R1 million was spent on clean up operations by the municipality (Taylor, 1999). An erosion monitoring experiment was set up on the destabilized slopes above Fish Hoek in December 1999.

In January 2000, large areas of natural and alien vegetation were burnt in wild fires on the Cape Peninsula. In response to this event, soil erosion monitoring experiments were set up across a range of sites in March 2000, before the onset of winter rains. The permanent sample plots for both studies were re-sampled in June 2000, after the first winter rainfall event.

We tested whether soil erosion and fire severity was related to vegetation types. We were particularly interested in whether sediment run-off differed between catchments covered with alien vegetation and those covered with indigenous fynbos vegetation.

3. METHODS

3.1 Fish Hoek Study

3.1.1 Description of study area

The Brakkloofrant mountains are on the Cape Peninsula, in the southwestern Cape region of South Africa (34°08′S, 18°15′E). The hot dry summers and cool wet winters are typical of the Mediterranean type climate that prevails here. The geology of most of the area comprises Peninsula Formation Sandstone of the Cape Supergroup. The high gravel and rock content, low bulk density (1150 fg m^{-3}) and high pore volume (55%) of this substrate allows rainfall to infiltrate readily (Versveld 1981). Dune sand, a recent deposit of the Witzand Formation, originating from wind blown beach sand, overtops this geology in places. These dunes have mostly been covered by alien vegetation, as have parts of the indigenous fynbos vegetation that occurs on the sandstone geology. *Acacia cyclops* and *Hakea suaveolens* were the most abundant aliens in the study area, and had formed dense closed stands over 5 m tall in places, all of which were burnt in the fire of March 1999.

3.1.2 Sample design, data collection and analyses

Three main vegetation types were present on the mountain before the fire: alien vegetation, fynbos cleared of alien vegetation and pristine fynbos. These three vegetation types were categorized into two fire severity classes based on post fire skeletal remains. In a severe fire most of the flammable material is consumed in the fire, while in a less severe fire, flammable material is not all consumed. In fynbos cleared of alien vegetation, cut branches were piled in rows, and the location of these could be seen on aerial photographs taken before the fire. Areas where dead fuel was piled were regarded as having a more severe fire, than where this was not the case. Fire severity was however measured objectively within each of the post fire states. Thus, six post-fire vegetation/fire severity categories were found occurring on the north facing slopes above Fish Hoek residential area, where sediment dumping damaged houses during the storm of 21 April 1999.

It was possible to sample these vegetation/fire severity categories across three major substrate types: rocky, Peninsula Formation sandstone (TMS), wind blown sand deposits (Sand), and on a mixture of these two geological substrates (Mix).

Sample sites were subjectively chosen in the landscape. Watercourses that had delivered sediment were avoided because the various vegetation states were not found there and because of human intervention and disturbance before and after the fire. We also attempted to choose sites that had similar slope, aspect and rock cover, soil depth and soil properties within the three geological types.

Table 1 illustrates the sampling design. At each site a 20m transect was subjectively laid down to ensure that it remained within the chosen geology/vegetation/fire severity category. Wooden pegs, approximately 80 cm long and with a diameter of 3-5 cm were hammered into the earth at 5 m intervals along the transect to permanently mark the center point of the circular sample plots. The circular sample monitoring plots had a radius of 60 cm and area of 1.13 m^2. A total of 18 transects with 5 plot replicates each (n=90) were sampled for a wide range of variables. The method of measuring these variables is described below.

Table 1 Experimental design for sampling fire severity and soil erosion. This constituted the 18 sites that were sampled.

Geology/soil type	Vegetation type	Fire severity	Fire severity
TMS	Fynbos	High	Low
TMS	Alien	High	Low
TMS	Cleared	High	Low
Sand	Fynbos	High	Low
Sand	Alien	High	Low
Sand	Cleared	High	Low
Mix (TMS & sand)	Fynbos	High	Low
Mix (TMS & sand)	Alien	High	Low
Mix (TMS & sand)	Cleared	High	Low

3.1.3 Pre fire vegetation and Fire Severity Index (hereafter FSI).

By measuring plant skeletal remains, fire severity indices, based on work by Moreno and Oechel (1989) and Keely (1998), can be produced. In simple terms, the index is based on the assumption that thinner branches remaining on burnt vegetation indicates less severe fires. This index is useful in that it is area specific. Various additional tools were measured, and assigned values, so as to devise a Fire Severity Index (hereafter FSI). The method of devising the FSI is based on assigning numerical values to indices of fire severity and summing them. Table 2 defines the method.

Fuel loads at the different sites was estimated by observing patches of un-burnt vegetation in the area, and by studying aerial photographs taken of the area prior to the fire. The minimum twig diameter of remaining burnt vegetation was recorded within 0.5 m, between 0.5 and 1m, 1 and 2 m and over 2m above the soil surface. The following fire severity indicators were also recorded, but they were not used in calculating the FSI: shattered rocks, blackened rocks, ash, blackened soil and charcoal on the soil surface. These indicators were assigned the value “0” if absent and “1” if present.

Table 2. The derivation of the Fire Severity Index.

Fire severity variable	Method of measure(within 60cm radius of point; n=90)	Low severity	Score	Medium severity	Score	High severity	Score
Fuel load	Height and type of pre-fire vegetation	1	1	2	2	3	3
Charred stumps	Number of charred stumps	0	1	1<3	2	≥3	3
Charred stump diameter	Maximum diameter (cm) of charred stumps	0	1	1-3	2	≥4	3
Minimum twig diameter	Minimum remaining twig diameter (cm), within 0.5 cm of the soil surface	<0.20	1	0.21-0.99	2	≥1	3
Fire Severity Index (FSI)	Sum of the above		**4**		**8**		**12**

The percentage cover estimate of the aerial cover of skeletal remains from pre-fire vegetation and of un-burnt organic litter on the soil surface was measured. The species, basal diameter (cm) and distance (cm) to the nearest pre-fire bush from the peg marking the center of the sample plot was also recorded.

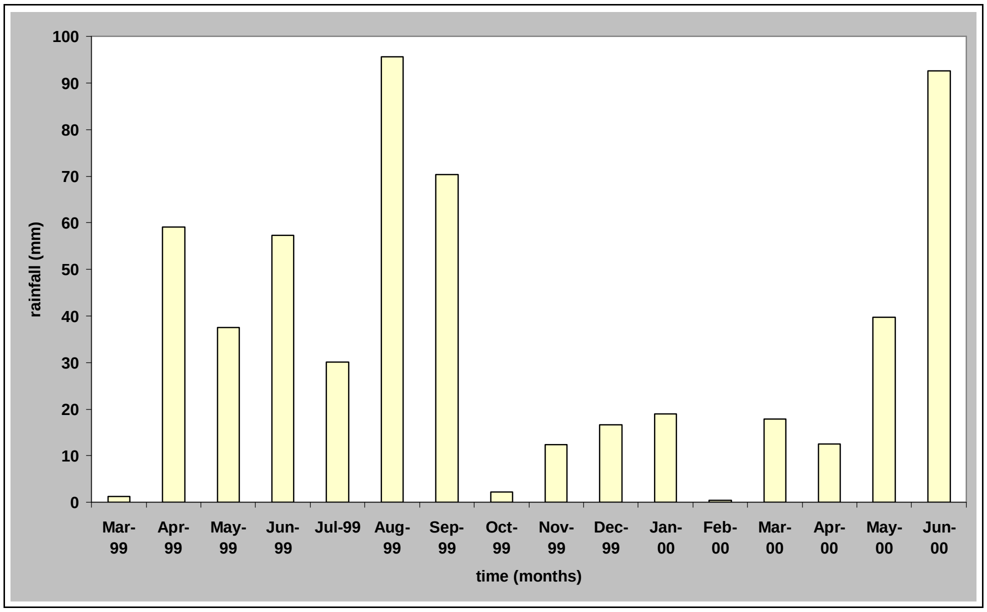

Figure 1. Monthly rainfall figures from March 1999 to June 2000. SAWB rainfall data from Cape Point and DF Malan Airport weather stations was averaged.

3.1.4 Soil erosion indicators and vegetation recovery

We measured the following variables in November/December 1999, nine months after the fire, and certain of these variables (indicated below) were recorded again in June 2000, after the first winter rains (see Figure 1).

3.1.4.1 Overburden depth

Overburden depth (cm) was recorded as the average of three depths of the overburden soil (loose sand that is deposited on top of the true soil surface by wind or water after the fire). This was measured with a ruler at three points that represented the variation in overburden depth within the 1.13 m^2 sampling area.

3.1.4.2 Sand to aggregate ratio

The sand to aggregate ratio is a measure of the cohesion of the soil. Fires burn organic matter and this can reduce soil aggregation. The sand to aggregate ratio was measured in November/December by sieving a soil sample and measuring the volume (ml) of loose sand passing through the sieve and the volume (ml) of the aggregated soil and roots remaining in the sieve. Care was taken to shake the sieve so as not to loosen the aggregated material. The soil was carefully dug out with a small hand shovel (11×6cm spoon). Overburden soil was not included in the sample.

3.1.4.3 Sediment run-off

Sediment run-off was measured by collecting sand below the sites in a vertical screen laid parallel to the contour line on the soil surface (Scott & Van Wyk, 1990, Foden, 1997). The polytex screens allow water to pass through while trapping sand. The screens were approximately 110cm wide and 60 cm tall and attached to wooden poles approximately 100 cm long. These were hammered into the earth so that the screen was flush with the soil surface. Rocks and sand were placed on the screen at the soil surface to ensure that no sand could spill under the screen. Rocks and logs were placed on the edge of the screens to prevent soil from spilling around the edges of the screens. The screens were put in place on 22 December, nine months after the burn. The collected sand was measured with three sticks that were placed 10-15 cm above the screen and marked at the soil surface. The screens were measured on 6 January, 8 March, 8 May and 1 June. The total rainfall (measured at DF Malan airport) during the interval between measuring was 22mm, 37mm, 3mm and 60mm respectively. The sand caught in the screens was removed and the sticks replaced after each measurement.

3.1.4.4 Soil water repellency

Soil water repellency tests were done to measure soil resistance to water infiltration (Scott & Van Wyk, 1992). Measures of water drop penetration time (hereafter WDPT) and critical surface tension or the percentage molarity of an ethanol drop (hereafter MED) was done (DeBano, 1981 in Scott & Van Wyk 1990). These were recorded at the beginning of the project in November/December 1999. The tests were done on four different surfaces: the undisturbed surface, the disturbed surface (by brushing ones fingers lightly over the surface), the surface with the overburden removed and the surface approximately 10-15 cm below the previous surface. The time taken for a water drop to completely infiltrate the soil surface was recorded. If the water drop had not infiltrated within 20 seconds then the WDPT was assigned a value of 30 seconds.

The MED test was done by waiting for two seconds for water drops of increasing ethanol concentrations (0,1,3,5,7,10,20 and 30 per cent by volume) to penetrate the soil surface. Increasing ethanol concentrations reduce the surface tension of the water drop, thereby increasing its affinity to penetrate the soil. The tests were replicated three times (i.e. three separate drops) and the average was used for the analysis.

At the end of the project in June 2000, sampling was done between 13 and 16 June, after 77.8 mm had rained between 1 and 16 June (recorded at DF Malan airport). After this rainfall, it was possible to record the depth to which the soil had been saturated. Repellency tests were limited to determining the existence of a repellent layer, and measuring the depth of the repellent layer, to a maximum depth of 25 cm. This was done by doing WDPT tests at three different points within 50 cm of the permanent sample points. The soil was recorded as repellent if the water drop had not penetrated within 10 seconds.

3.1.4.5 Ground cover

The percentage cover of rocks and organic litter and the occurrence of roots of pre-fire vegetation on the surface (as a result of topsoil erosion) were recorded in November/December 1999. The occurrence of charcoal on the soil surface was also recorded.

3.1.4.6 Plant regeneration after the fire

The following measures of vegetation recovery after the fire were recorded in November/December 1999 and again in June 2000:

- Percentage cover indigenous plants
- Percentage cover indigenous resprouters
- Percentage cover alien vegetation
- Total number of indigenous species

Measures of seedling mortality were planned for the study. However, in April 2000 an alien clearing team was sent through the study area and removed alien seedlings from some of the sites. This disturbance interfered with vegetation recovery monitoring results, and seedling mortality component of the study was precluded.

3.2 Cape Peninsula Study

The large Peninsula fires that occurred between 16 and 20 January 2000 presented the opportunity to measure soil loss before a heavy rainfall event had occurred. Table 3 indicates the 19 sites that were set up to monitor soil loss and vegetation recovery. Two sites were excluded from the analysis due to insufficient data.

At each site 5 points were permanently marked with a wooden peg at 10m intervals along the contour line. A photograph was taken of each peg in February/March 2000 and again in June 2000 in order to visually display changes in the soil surface and vegetation recovery across all the sites (see Appendix 1).

Table 3. The study sites that were set up in March 2000 to monitor soil erosion, one and a half months after the Peninsula fires of January 2000. The location, pre-fire vegetation, geology, treatment (cleared or not cleared), slope and aspect of the sites are shown.

No.	Site name	Vegetation	Geology	Treatment	Slope	Aspect.
1	Scarborough	Fynbos	TMS	Fynbos	27	S
2	Scarborough	Fynbos	TMS	Fynbos	25	W
4	Chapmans Peak	Alien	Mixed	Cleared	25	S
5	Chapmans Peak	Alien	Mixed	Alien	23	S
6	Soetwater	Alien	TMS	Cleared	16	W
7	Tierboskloof	Alien	TMS	Alien	25	N
8	Hout Bay	Alien	Granite	Alien	29	W
9	Hout Bay	Alien	Granite	Cleared	23	W
10	Constantia neck	Alien	Granite	Alien	20	E
11	Hout Bay	Fynbos	Granite	Fynbos	26	N
12	Dagama Park	Alien	TMS	Cleared	20	E
13	Dagama Park	Alien	TMS	Alien	15	E
15	Dido valley	Alien	TMS	Alien	24	S
16	Simonstown	Alien	Dune	Alien	32	E
17	Simonstown	Alien	TMS	Alien	25	E
18	Misty Cliffs	Alien	TMS	Cleared	24	N
19	Misty Cliffs	Fynbos	TMS	Fynbos	25	W
20	Misty Cliffs	Alien	TMS	Alien	26	W
21	Misty Cliffs	Alien	TMS	Alien	32	W

Between 28 February and 8 March 2000 the following variables were recorded within a 60 cm radius of each peg (n=95; 19 sites with 5 pegs each):

- A photograph, taken approximately 2 m from the peg facing up the slope.
- The height (m) of the peg from its tip to the soil surface, measured on the lower side of the peg.
- The height (mm), at 50 cm intervals, from a string (drawn between the first two pegs) to the soil surface.
- The height (m) of the stand of pre-fire vegetation.
- The minimum diameter of twigs/stumps (mm) on skeletal remains within 30 cm of the soil surface.
- The minimum diameter of twigs/stumps on skeletal remains above 30cm of the soil surface.
- The occurrence, pre-fire of stacks of slashed aliens associated with alien clearing.
- The occurrence of charred stumps.
- An estimate of the percent aerial cover of standing skeletal remains.
- The percentage cover of un-burnt soil leaf litter.
- The percentage cover of leaf litter derived from skeletal remains.
- The basal diameter of the nearest bush species.

- The occurrence and colour of ash on the surface.
- Whether or not the soil was incinerated.
- The percentage rock cover.
- Whether or not a water drop penetrated the undisturbed soil surface within 10 seconds.
- Whether or not a water drop penetrated the disturbed soil surface (by brushing over with fingers) within 10 seconds.
- The depth below the surface at which a water drop penetrated within 10 seconds (i.e. the depth of the water-repellent layer).
- The occurrence of re-sprouting plants.

On 30 and 31 May, after 54mm of rainfall recorded at DF Malan Airport between 25 and 30 May, all the sites were re-visited and the depth of the wettable surface soil was recorded. This aimed to provide direct evidence for the existence/non-existence of a repellent soil surface after the first heavy rainfalls of winter.

The sites were re-sampled between 18 and 21 June and the following variables were recorded within a 60cm radius of each peg:

- A photograph, taken approximately 2 m from the peg facing up the slope.
- The height (m) of the peg from its tip to the soil surface, measured on the down slope side of the peg.
- The height (mm), at 50 cm intervals, from a string (drawn between the first two pegs) to the soil surface.
- The number of indigenous bulb species
- The number of indigenous re-sprouting species
- The total number of indigenous species
- The percentage cover indigenous resprouters
- The total percentage cover indigenous species
- The percentage cover of alien vegetation

Table 4. Summary table showing the distribution over time of the fires and sampling events for both projects.

Date	Fish Hoek Project	Cape Peninsula Project
6 – 12 Mar 1999	Fires on Brakkloofrant mountain	
21 Apr 1999	Storm and massive erosion	
26 Nov – 10 Dec 1999	First sampling of permanent plots	
22 Dec 1999	Silt screens in place	
6 Jan 2000	First measurement of screens	
16 – 20 Jan 2000		Cape Peninsula fires
28 Feb – 4 Mar 2000		First sampling of permanent plots
8 March 2000	Second measurement of screens	
8 May 2000	Third measurement of screens	
30/31 May		Sampling of wettable surface layer
1 Jun 2000	Fourth measurement of screens	
13 – 16 Jun 2000	Second sampling of permanent plots	
19-21 Jun 2000		Second sampling of permanent plots

Table 4 summarizes the sequence of sampling events for the two projects.

4. RESULTS

4.1 Fire Severity Index

Table 5. The correlation matrix, displaying R^2 values for indicators of fire severity. N=90. It is incorrect to do regression analyses on the presence/absence factors (e.g. shattered rocks), but this table serves only as an indication of the relatedness of factors. Key to abbreviated indicators: fl load=fuel load; shtrks=shattered rocks; blkrks=blackened rocks;ash=ash on surface; blksl=blackened soil; coal=charcoal on surface; chstmp=number of charred stumps; stmpdi=maximum charred stump diameter; sklt 0.5=minimum remaining twig diameter below 0.5 m; skl0.5-1=minimum remaining twig diameter between 0.5 and 1 m; sklt 1-2= minimum remaining twig diameter between 1 and 2 m; sklt 2= minimum remaining twig diameter above 2 m; FSI=Fire Severity Index; basldi=basal diameter of nearest bush.

	fl load	Shtrks	Blkrks	Ash	blksl	Coal	Chstmp	Stmpdi	Sklt 0.5	sklt 0.5-1	Sklt 1-2	sklt 2	FSI	basdia
Fl load	1.00													
Shtrks	0.27	1.00												
Blkrks	0.37	0.60	1.00											
Ash	0.46	0.07	0.06	1.00										
Blksl	0.32	0.20	0.28	0.65	1.00									
Coal	-0.01	0.08	0.02	0.12	0.15	1.00								
Chstmp	0.30	0.19	0.22	0.14	0.25	0.19	1.00							
Stmpdi	0.36	0.15	0.21	0.08	0.31	0.19	0.44	1.00						
Sklt 0.5	0.49	0.21	0.19	0.12	0.34	0.13	0.29	0.67	1.00					
Sklt 0.5-1	0.55	0.08	0.20	0.52	0.50	0.11	0.23	0.47	0.85	1.00				
sklt 1-2	0.41	-0.02	-0.07	0.40	0.36	0.09	0.36	0.48	0.66	0.84	1.00			
Sklt 2	0.20	-0.04	-0.10	0.19	0.17	0.05	0.74	0.23	0.14	0.33	0.54	1.00		
FSI	0.68	0.25	0.32	0.29	0.31	0.23	0.67	0.66	0.52	0.47	0.51	0.38	1.00	
Basdia	0.37	0.12	0.15	0.20	0.33	-0.09	-0.02	0.48	0.51	0.53	0.52	-0.11	0.24	1.00

The fire severity index (FSI) correlated well with some indicators, and not with others (Table 5). Less reliable indicators that were influenced by the flooding event such as ash and coal on the surface were not good fire severity indicators. The use of indicators of fire severity that reflected differences over small (30 cm) spatial scales was important. The FSI correlated best with fuel load, the occurrence of charred stumps and the basal diameter of charred stumps. It also correlated well with the minimum diameter of skeletal remains.

4.2 Does alien and cleared vegetation burn more severely than fynbos?

The fire severity index correlated well with the subjectively chosen vegetation-fire severity categories (Table 6). Alien and cleared vegetation burned more severely than fynbos. High severity fynbos fires were not as severe as those in alien vegetation. Low severity alien fires were more severe than high severity fynbos fires. Higher severity fynbos fires tended to occur on sand dunes and mixed soils, and lower severity fynbos fires occurred on TMS soils. Based on this fire severity index, alien and cleared fires were, on average, 65% more severe than fynbos fires.

Table 6. The average and standard deviation of the Fire Severity Index for each of the vegetation/soil type/fire severity sites sampled at Fish Hoek in November/December 2000. The average and standard deviation for all sites in each vegetation category (avg. all) is shown at the bottom of the table. Sample number is 5 for each category and 30 for each vegetation type.

Veg. Type	**Alien**						**Cleared**						**Fynbos**					
Soil type	Dune		Mix		TMS		Dune		Mix		TMS		Dune		Mix		TMS	
Fire sev.	H	L	H	L	H	L	H	L	H	L	H	L	H	L	H	L	H	L
Avg.	10.80	9.80	11.00	10.40	11.60	7.60	11.20	9.00	11.20	10.60	11.00	7.00	8.60	6.00	7.20	8.40	5.40	5.00
Std.	1.64	1.64	1.73	0.55	0.55	1.52	1.79	1.00	0.45	1.52	1.22	1.22	1.82	1.73	1.10	1.52	2.07	1.22
Avg. all	**10.20 ± 1.81**						**10.00 ± 1.95**						**6.77 ± 2.05**					

The minimum diameter of skeletal remains indicates fire severity by measuring the smallest width of twigs that were not burnt in the fire. This variable was sampled at 19 sites two months after the Peninsula fires in January 2000. Figure 2 shows how fire severity, based on skeletal remains, is much higher in alien and cleared vegetation than in fynbos.

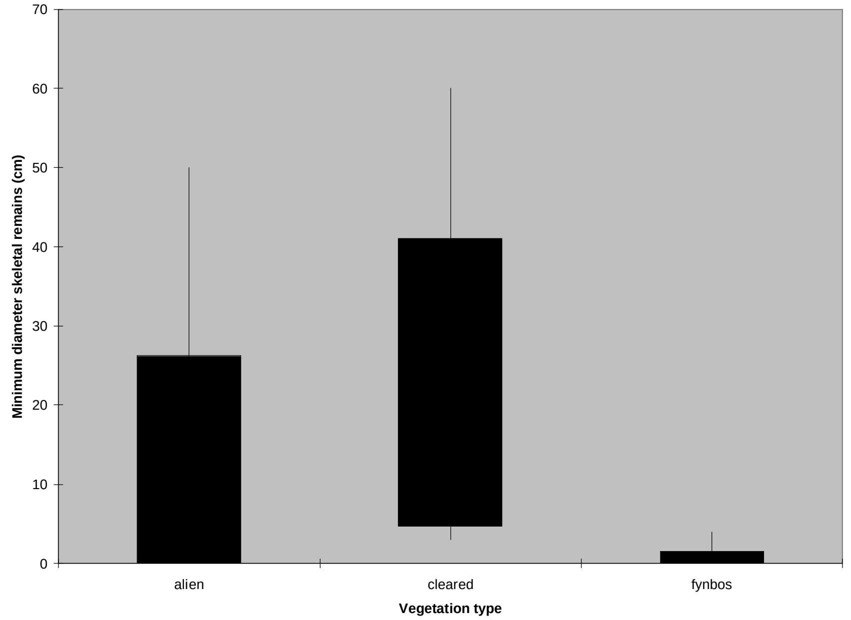

Figure 2. The standard deviation around the mean (black bars) and maximum and minimum values (lines) for the minimum diameter (cm) of skeletal remains after the fire for three different vegetation types. Alien vegetation: 10 sites, sample number = 50; Cleared vegetation: 5 sites, sample number = 25; Fynbos vegetation: 4 sites, sample number = 20. Sampled in March 2000, two months after the Peninsula fires in January 2000.

Figure 2 also indicates that, in some cases, alien vegetation burnt without consuming all the fuel, while in cleared vegetation the fuel was more thoroughly consumed, and there were no fine twigs remaining after the fire. The fine structure of fynbos vegetation, and the absence of tall trees in fynbos, precludes the occurrence of the very high severity fires that can occur in old stands of alien or cleared vegetation.

4.3 Does vegetation type and/or fire severity influence catchment stability?

The Fire Severity Index did not correlate significantly with the total sand caught in the silt traps between 22 December 1999 and 1 June 2000 (Figure 3a&b). However, Figure 3a clearly shows how soil type influenced sand runoff, being consistently higher on the mixed soils. This indicated that soil type was more important than vegetation type in explaining the variation in sand runoff between sites.

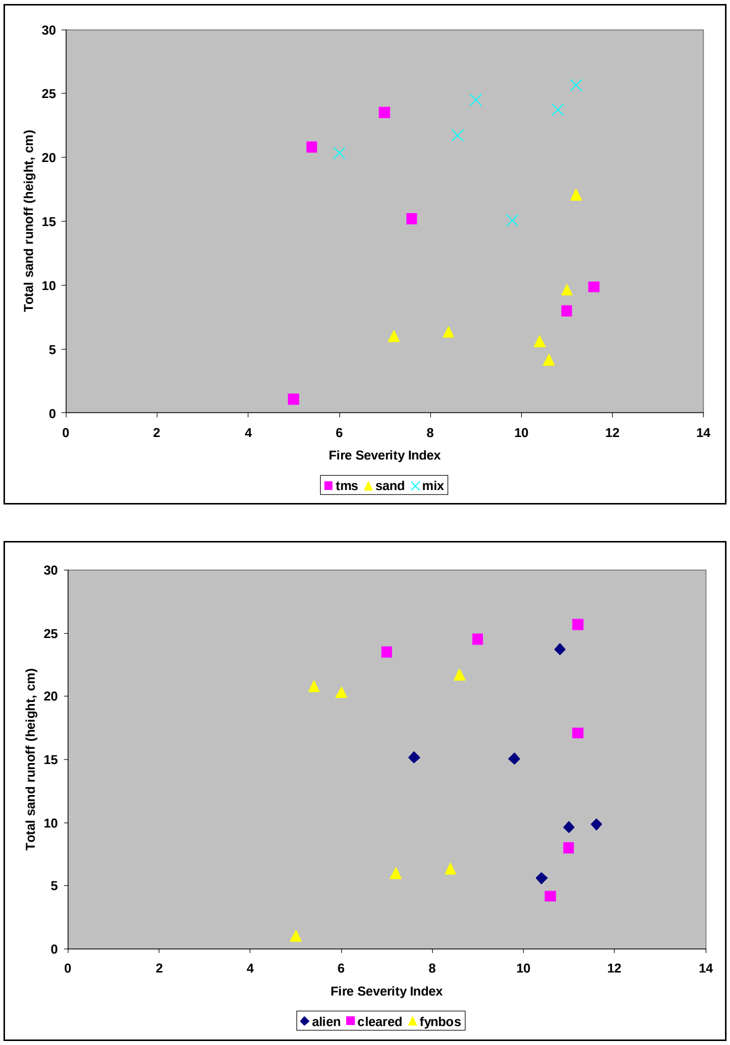

Figure 3a&b. The correlation between the fire severity index and the total sand caught in the silt screens between 22 December 1999 and 1 June 2000, with soil type as series (top figure) and vegetation type as series (bottom figure).

The amount of sand caught in silt screens varied between the sites and between the four intervals when sand trapped in the screens was measured (Figures 4a,b,c&d). The silt screens recorded most sand movement after the rainfall events on 1 January 2000 (16 mm) and on 29 May 2000 (20 mm)(Figures 4a&d). The total rainfall during these two intervals was 22mm and 60 mm. The screens recorded relatively low sand runoff between 6 January and 8 March, during which 37 mm of rainfall was recorded, with 20.5 mm on 2 March. A negligible amount of sand was caught in the screens between 8 March and 8 May, when only 3 mm of rain was recorded. The January record (Figure 4a) showed that vegetation type only influenced the amount of sand run-off on TMS soils, where alien sites had greater sand runoff than cleared sites, and fynbos had the least run-off. Vegetation appeared to have a very slight influence on sand runoff on the mixed and sand soil types. Sand runoff was highest on the mixed soil type.

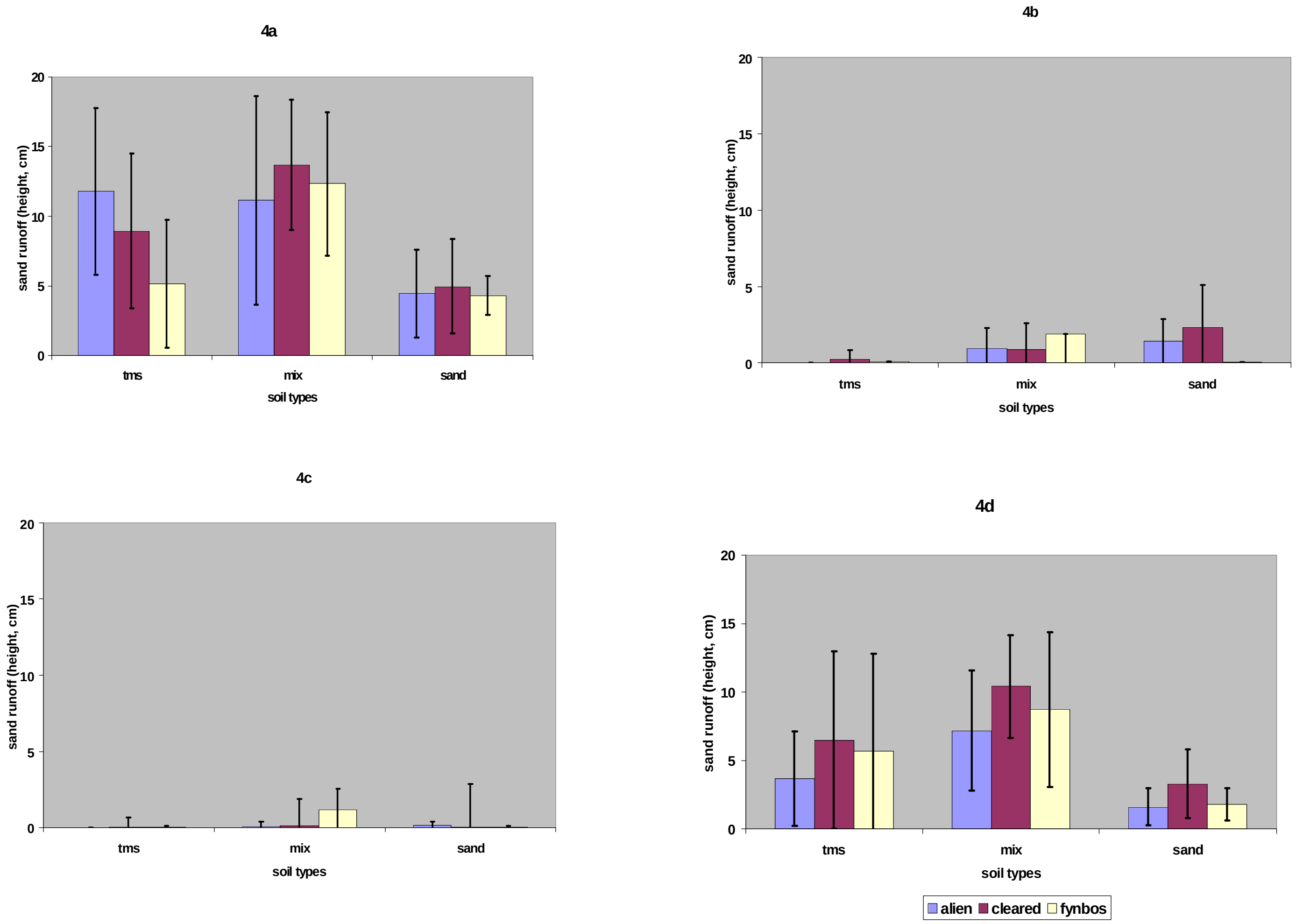

Figure 4a,b,c &d. The average (bars) and standard deviation (lines) for the depth of sand caught in the silt traps across the different vegetation and soil type categories, over the following four time periods: a) 22 December to 6 January, b) 6 January to 8 March, c) 8 March to 8 May, d) 8 May to 1 June.

During the periods when sand runoff was relatively low (Figures 4b&c) it was noticeable that the TMS sites were more stable than the mixed and sand sites. The highest runoff during this period was recorded on the cleared sites on sand.

After the first winter rains at the end of May, sand runoff was marginally greater on cleared sites across all soil types (Figure 4d). The highest runoff was once again recorded on the mixed soils, and the lowest on the sand soils. Contrary to the January records, sand runoff was lower at alien sites than cleared or fynbos sites.

The Peninsula study, however, found a significant increase in soil erosion with increasing fire severity (Figure 5) in cleared vegetation. Minimum remaining skeletal diameter (cm) was used to indicate fire severity. In alien vegetation, soil erosion occurred but this did not increase with increasing fire severity, and there were cases of soil deposition. In fynbos vegetation, the minimum remaining skeletal diameter (cm) never exceeded 5cm, indicating much lower severity fires than fires in alien or cleared vegetation. Furthermore, soil erosion at fynbos sites never exceeded 1.5cm and averaged as a net increase in soil surface level (Fynbos, average: 0.36±1.87cm) in contrast to the average loss in alien and cleared vegetation (Alien, average: –1.13±1.92; Cleared, average: -2.44±2.31).

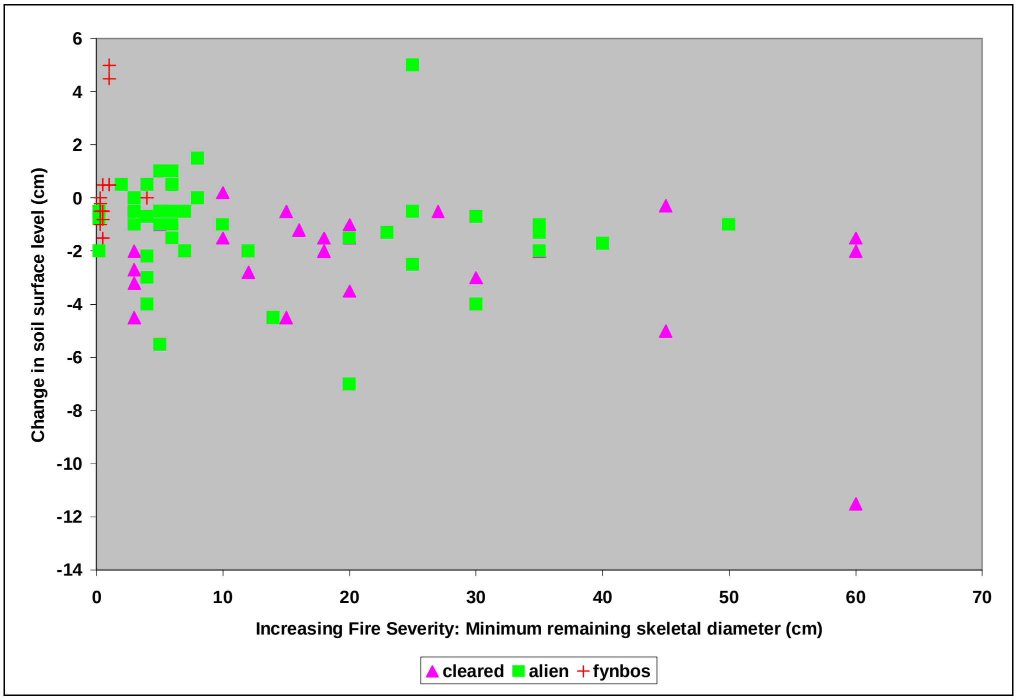

Figure 5. The relationship between fire severity and the change in the soil surface level that occurred during the first six months after the Peninsula fires of January 2000, between 8 March and 21 June.

The most extreme erosion event occurred in a cleared area that had burnt most severely.

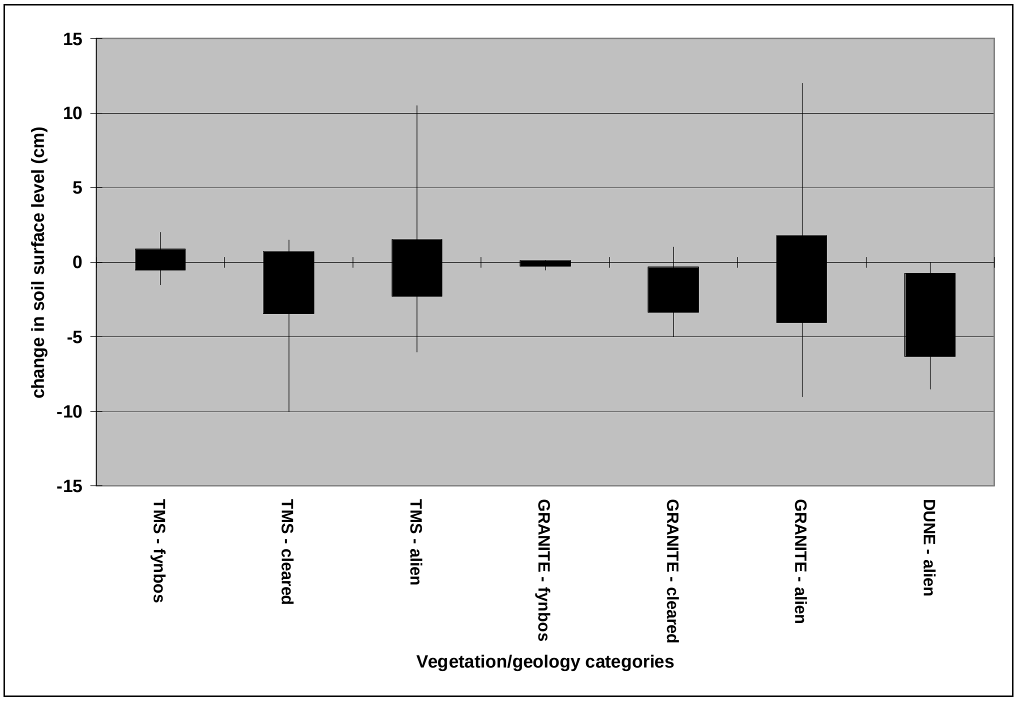

Figure 6. The change in soil surface level between 8 March and 21 June for the various vegetation geology categories that were sampled on the Peninsula. The box indicates the standard deviation around the mean and the whisker the maximum and minimum values. The number of sites followed by the sample number for each category was as follows: TMS-fynbos – 2,34; TMS-cleared – 3,54; TMS-alien – 5,100; GRANITE-fynbos - 1,17; GRANITE–cleared - 1,18; GRANITE-alien – 2,43 DUNE-alien – 1,17.

A separate measure of change in soil surface level by means of a string drawn across a slope also recorded greater soil loss occurring in alien and cleared vegetation than in fynbos vegetation (Figure 6). Furthermore, this result also found that soil erosion was more consistent at cleared sites, while at alien sites, there were cases of sand deposition. This result also indicated the influence of soil type on soil erosion, and found that soil loss was highest on sand dunes. However, it is not clear from these results weather or not fire severity influences soil erosion. Rather, there was a large variation in soil surface changes, which were best explained by geology and vegetation type.

4.4 How does vegetation type influence soil erosion?

Water repellency tests done in December 1999 (nine months post fire) at the Fish Hoek sites found subsurface soils to be highly repellent across all the sites, irrespective of fire severity and/or vegetation type (Table 7). The topsoil or overburden soil had a much lower repellency than the subsurface soils, and in some cases was non-repellent. Topsoil under alien vegetation showed the least repellency, and topsoil repellency was greatest in cleared vegetation. Topsoil also showed the greatest variation in water repellency (Table 7).

Table 7 The average and standard deviations of the % molarity of an ethanol drop (med) on the soil surface (topsoil), on the surface with the topsoil removed (less topsoil) and on the surface approximately 15 cm below the former surface (subsurface). Low med values = low water repellency. The data was grouped into low and high severity fires and into the three vegetation types: alien, cleared and fynbos.

Fish Hoek, 9 months post fire, March 2000 Water Repellency (% med)												
	Low severity fire(≤8)						High severity fire (≥9)					
	Alien		Cleared		Fynbos		Alien		Cleared		Fynbos	
	Avg	Std	Avg	Std	Avg	Std	Avg	Std	Avg	Std	Avg	Std
	N=17		n=9		n=12		N=13		n=21		n=18	
Topsoil	3	7	14	12	11	13	6	9	10	12	8	8
Less topsoil	28	7	31	4	27	8	26	8	25	7	25	7
Subsurface	29	8	31	3	29	5	29	6	28	5	26	5

There were no significant differences in water repellency between the surface with the topsoil removed and fifteen centimeters below this surface (Table 7). However, the deeper surface tended to be more repellent. In the subsurface soils, low severity fires had a slightly higher repellency than high severity fires, especially in cleared vegetation.

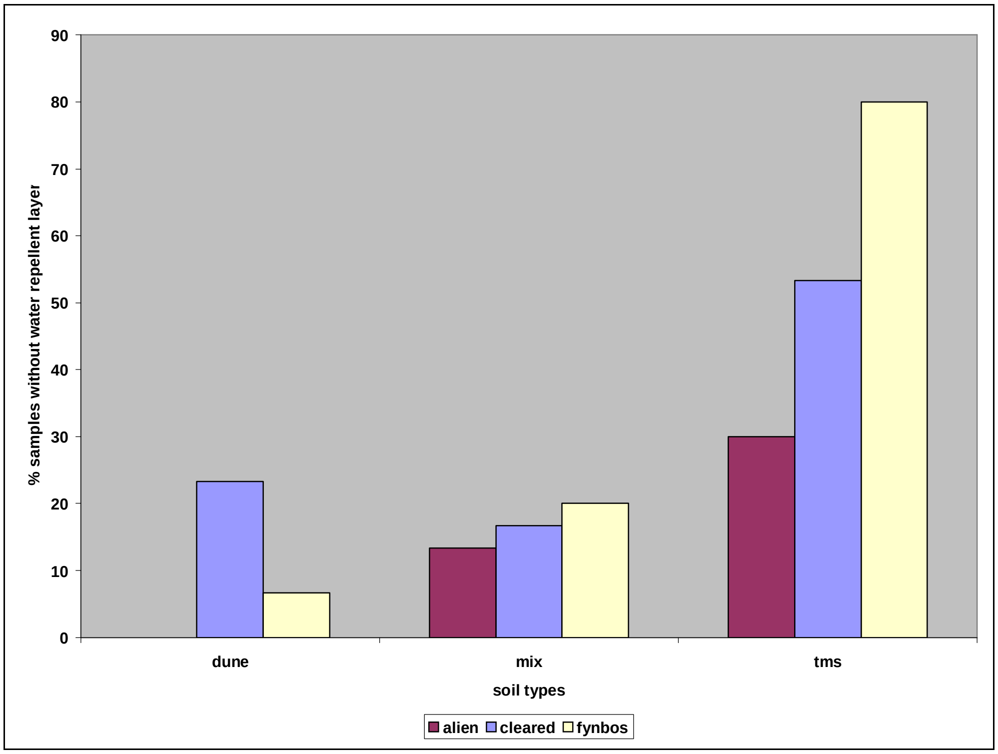

Figure 7 The percentage of the samples in each vegetation/soil type category (n=30) that had no repellent layer. Recorded on 13-16 June 2000, fifteen months after the fire in Fish Hoek.

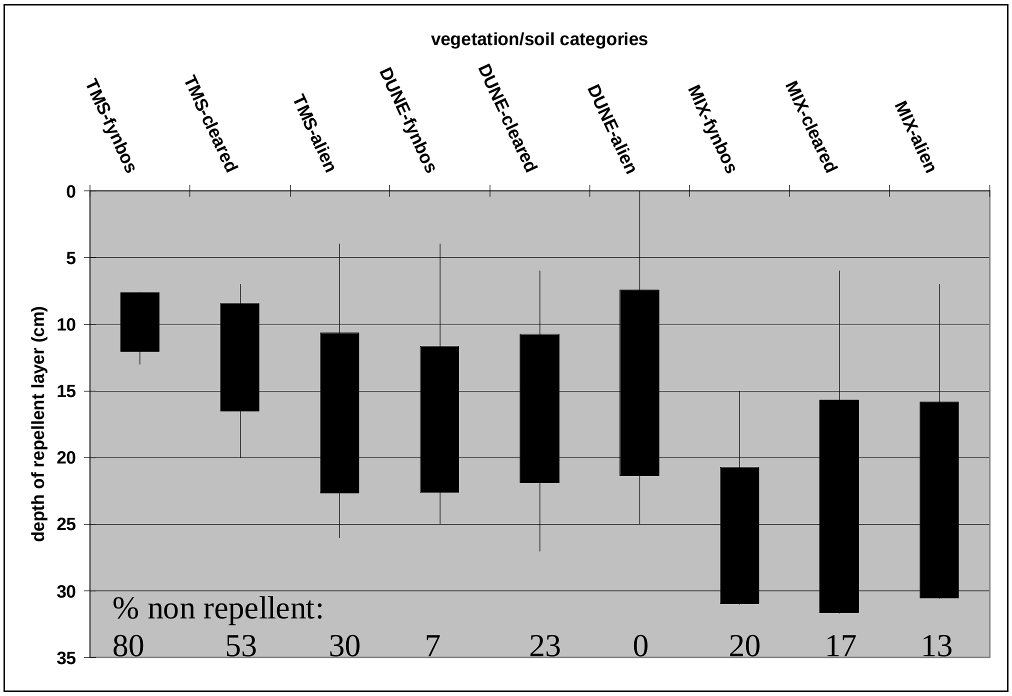

Figure 8. The standard deviation around the mean (box) and maximum and minimum values (whiskers) for the depth of the repellent layer for the nine different vegetation/soil type categories. Data collected at Fish Hoek on 13-16 June 2000, fifteen months after the fire. The percentage of samples where no repellent layer was recorded were excluded from this analysis, and are shown at the bottom of the figure and in Figure 7.

In June 2000, fifteen months after the fire and after the start of the second season of winter rainfall (see Figure 1) the permanent sample plots (18×5) were re-sampled. The percentage of these samples that recorded the absence of a repellent layer (i.e. the soil was continuously damp, and water drops penetrated readily) are shown in Figure 7. Fynbos sites on TMS recorded the highest occurrence of non-repellent soil, while soil was more hydrophobic on mixed or sand dune sites. Alien vegetation on sand dunes recorded complete water repellency.

The depth of the repellent layer was found to be deeper on mixed geology (wind blown sand overtopping TMS) and sand dunes and shallowest on TMS with fynbos (Figure 8). However, cleared and alien vegetation on TMS recorded increasing repellent layer depths. Aliens on TMS recorded a similar depth of the repellent layer to that of aliens on dunes.

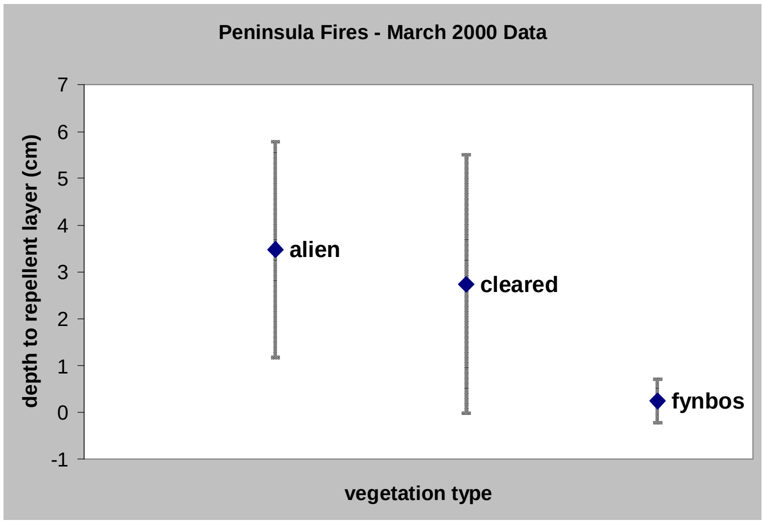

Figure 9. The average and standard deviation (line) of the depth to a water-repellent layer for three different vegetation types. 19×5 sample sites. Alien:n=45;Cleared n=30;Fynbos n=20.

Within two months of the January fires, and before any heavy rainfall, the depth to the repellent layer was recorded at 19×5 sample sites around the Peninsula (Figure 9). Fynbos recorded a shallower wettable surface layer than alien and cleared vegetation.

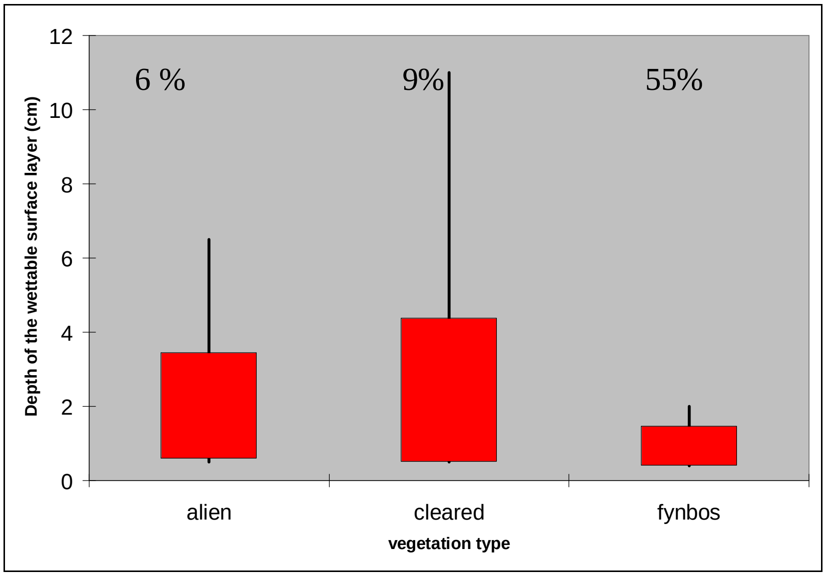

Figure 10. The standard deviation around the mean (box) and the maximum and minimum values (whiskers) for the depth of the wettable surface soils across three pre-fire vegetation types on TMS soils. Sampled on 30/31 May after approx. 54mm rainfall between 25 and 30 May. The percentage of the plots that had no repellent layer is shown for each vegetation type.

After the first large winter rainfall event of the season, the permanent sample plots were sampled for the depth of the wettable surface soil (i.e. the depth to the repellent layer) within two days of the end of the rainfall event (Figure 10). This recorded a similar trend to that in Figure 9, that alien and cleared vegetation had deeper wettable surface soils on top of the water repellent layer (Figure10). Fynbos soils on TMS had the highest incidents of “holes” in the repellent layer (55 % of the samples), that can allow the penetration of water, thereby reducing overland flow and soil erosion.

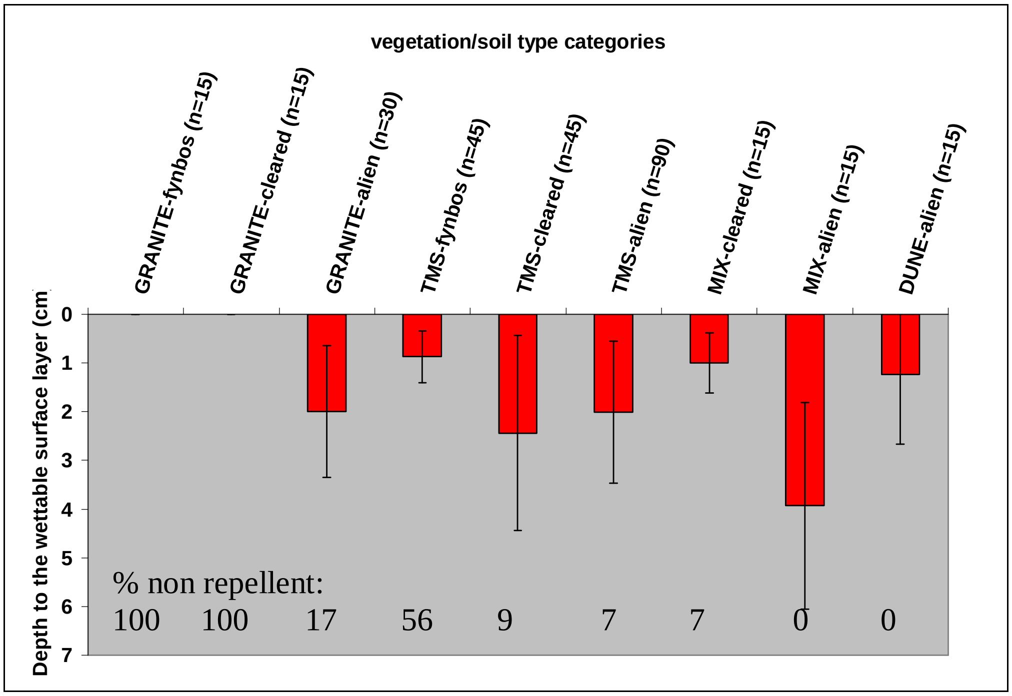

Figure 11. The average (bars) and standard deviation (lines) of the depth of the wettable surface layer for different vegetation/soil type categories. The number of samples (n) is indicated, there were fifteen samples per site. Sampled on 30&31 May 2000. Where there was no repellent layer, the wettable surface layer was recorded as absent. The percentage of samples where no repellent layer was found (i.e. wettable throughout) is shown at the bottom of the figure.

The deepest wettable surface layer was found in alien and cleared vegetation on mixed and TMS soil types (Figure 11), and this was also where the repellent layer was most consistent. Under fynbos and cleared vegetation on granite soils, the complete absence of a repellent layer was recorded. The repellent layer was present in 83 percent of the samples in alien infested areas on granite soils. Under fynbos on TMS soils, the repellent layer was present in less than half the samples. Soil erosion tended to be greater where the repellent layer was most prevalent and where the depth of the wettable surface layer was greater.

Figure 12 illustrates how a greater soil loss was associated with a greater depth to the repellent layer. This trend was most significant in cleared vegetation. However, in alien vegetation, the depth to the repellent layer was only slightly less where soil loss was less than the median value.

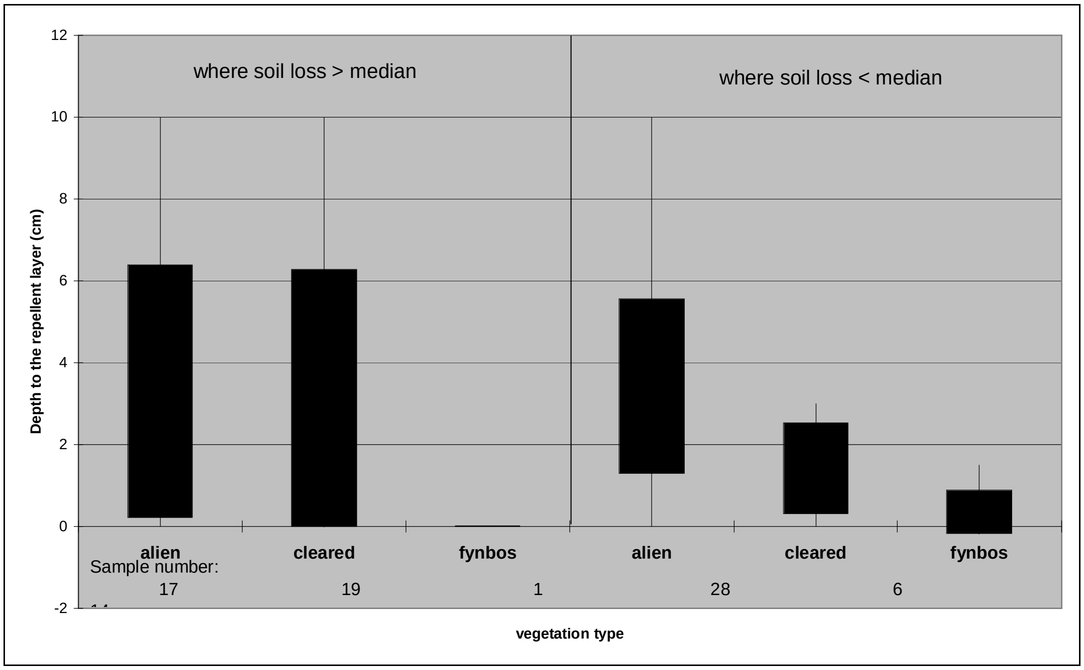

Figure 12. The data was split into that where the change in the soil surface level (from March to June 2000) was more than the median value of –1 cm, and where it was less than or equal to –1 cm. The standard deviation around the mean (box) and maximum and minimum values (whiskers) of the depth to the repellent layer is shown for the vegetation types in each soil loss grouping. The sample numbers are shown at the bottom of the figure.

The number of samples in the two soil loss categories also indicates how fynbos consistently had a low level of soil loss. In alien vegetation, 62 % of the samples had soil losses of less than the median value. However, in cleared vegetation only 24 % of the samples had soil losses of less than the median value.

4.5 Does vegetation type/fire severity influence vegetation recovery and plant diversity?

Sites exposed to higher severity fires had fewer plant species regenerating, nine months after the fire at Fish Hoek (Figure 13). This trend was most significant in fynbos vegetation. Cleared vegetation had slightly more diverse vegetation recovery than alien vegetation in lower severity fires. Indigenous resprouting species were absent in alien vegetation and did not exceed five percent cover in cleared vegetation (Figure 14). In fynbos vegetation, the percentage cover of resprouters showed a significant correlation with fire severity, and was greatest in lower severity fires.

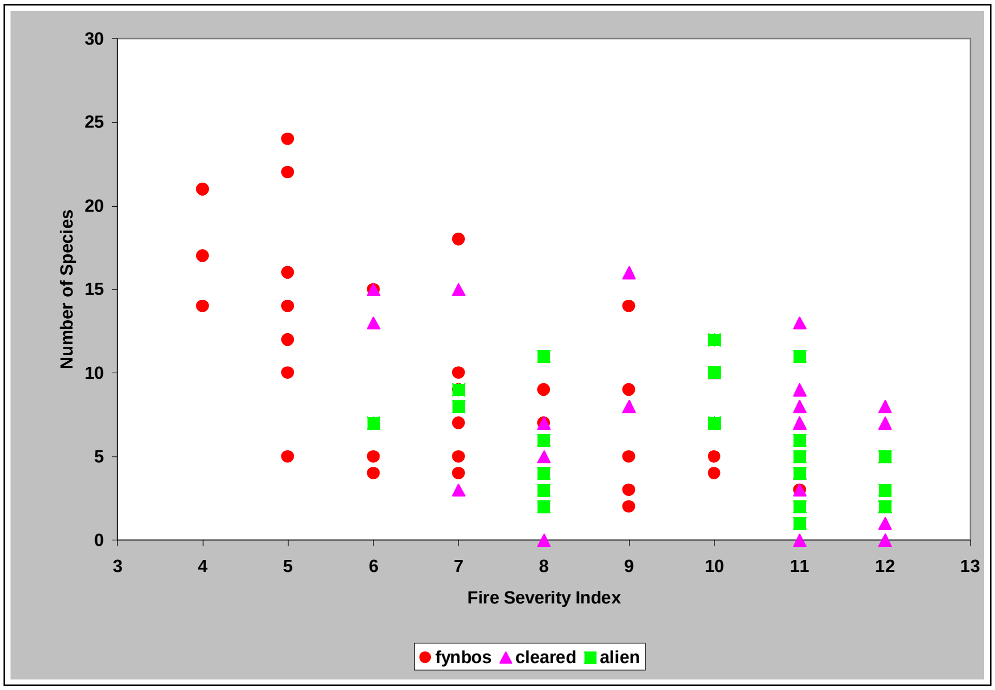

Figure 13. The relationship between the fire severity index and the number of species regenerating after the fire. Recorded in December 1999, nine months after the Fish Hoek fire.

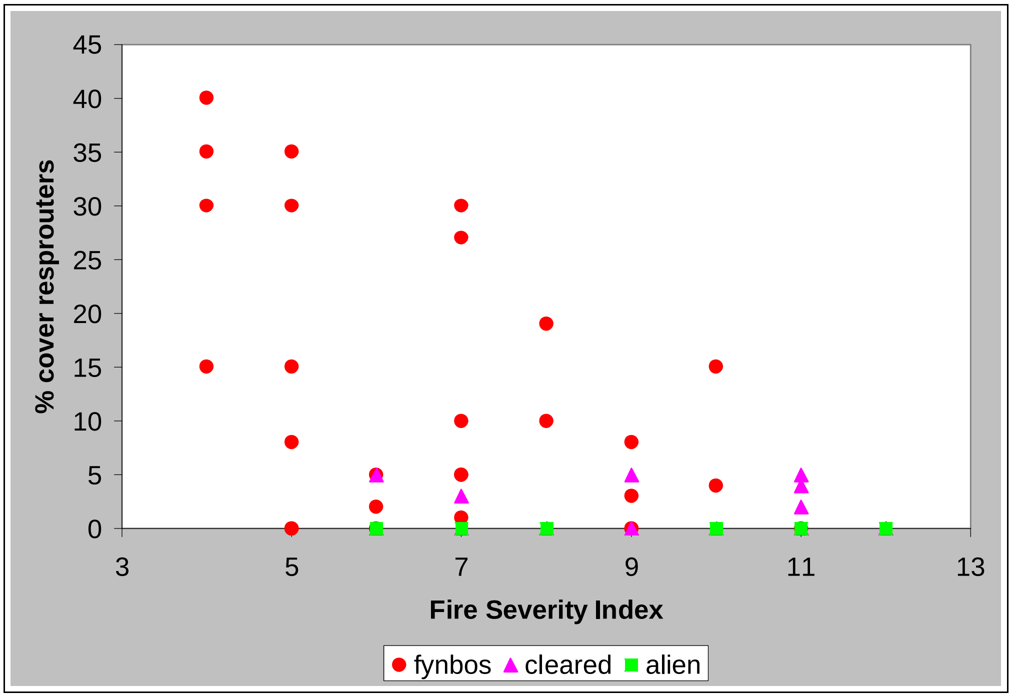

Figure 14. The relationship between the % cover of indigenous resprouters and the fire severity index for fynbos, cleared and alien vegetation. Recorded at Fish Hoek in December 1999, nine months after the fire.

Table 8. The mean (avg) and standard deviation (std) of various measures of post fire vegetation recovery sample in three pre-fire vegetation states: alien, cleared and fynbos. Sampled on 30/31 May, at nineteen sites around the Peninsula, four months after the fire.

	Alien (n=50)		Cleared (n=25)		Fynbos (n=20)	
	Avg	Std	Avg	Std	Avg	Std
Number of species	1.44	1.54	2.80	2.31	21.30	4.81
Number of resprouting species	0.74	0.85	1.40	1.22	8.60	2.84
Number of geophyte species	0.62	0.78	0.96	0.93	4.10	1.33
% cover indigenous plants	0.85	1.47	3.44	3.23	30.55	21.09
% cover indigenous resprouters	0.51	1.01	2.34	2.97	19.95	16.64
% cover alien plants	3.03	5.65	4.79	8.85	0.00	0.00

Approximately four months after the Peninsula fires, vegetation recovery showed dramatic differences between the three vegetation types (Table 8). Fynbos had healthy post fire recovery, but this was negligible in alien and cleared vegetation. Cleared vegetation had better recovery than alien vegetation.

5. DISCUSSION

This study supports the contention that fuel load is of primary importance in influencing fire severity (Keely, 1998). Pre-fire stand age should be a reliable predictor of fire severity potential. Geology and soil type can influence the rate and amount of biomass accumulation that occurs between fires. Higher severity fynbos fires on mixed and sand dune soils may be related to the taller and possibly denser structure of the *Leucadendron coniferum* plant community associated with these sites. Fynbos on rocky TMS geology's tended to have a sparse proteoid canopy. The age of the stand, and fire history, may also influence the structural and species composition of a site, which would also influence fire severity potential.

Stands of alien vegetation tend to attain greater heights and densities on deeper sandy soils than on shallow, rocky TMS soils. Furthermore, the distribution of dense stands of aliens is generally associated with deeper sandy soils. This may be partly due to the reason for their introduction to the area over sixty years ago, to stabilize shifting sand dunes. Thus, it was difficult to separate the influence of vegetation type and soil type on erosion levels, as the two are closely related. For example, one might argue that soil erosion is greatest on sand dunes because fire severity was greatest there, but a sand slope may simply have more material for erosive forces to work on than a rocky slope. Furthermore, the sandy areas have probably been covered with alien vegetation for longer, and this may have changed the soil properties.

Most of the energy released by the combustion of standing plant biomass is lost upward (Wells *et al.* 1978). De Bano (1974) estimated that only about 8 percent of the energy released by a burning chaparral canopy was absorbed at the soil surface and transmitted downward in the soil. From this it follows that a severe fire in the canopy may not influence fire severity at the soil surface. However, if burning branches or stumps fall to the ground and continue to burn on the soil surface (which is more likely to occur in severe burns), or if wood piles from cleared vegetation burn on the soil surface, then changes in soil properties will be more dramatic. One of the changes that occurs to the surface soils exposed to higher temperatures and longer heating times during fires is the loss of water repellency, so the surface soils of burned catchments is extremely wettable (Scott & Van Wyk, 1990). This wettable layer, however, is usually underlain by a layer of soil that is virtually waterproof (Wells, 1981) and this may also be more repellent as a result of fire severity and soil heating (Scott & Van Wyk, 1990). This aspect of post fire soil erosion is discussed below.

The most obvious effect of fire is its removal of the protective cover of vegetation and litter from the soil surface (Wells, 1981). This increases the effective source area for sediment production, since surfaces become exposed to all eroding forces, especially precipitation and wind. Fire severity can influence this because in a lower severity fire the skeletal remains left standing, and any leaf litter remaining (either from unburnt organic litter, or unburnt leaves & twigs on the canopy that drop down) can protect the soil from erosive forces. The cases of sand deposition that occurred in alien and fynbos vegetation, and soil erosion in cleared vegetation and high severity alien fires, can be partly explained by fire severity’s influence on protective cover.

The minimum remaining skeletal diameter was a good post-fire indicator of fire severity, and this has also been demonstrated in other studies (Keely, 1998; Foden, 1997; Moreno & Oechel, 1989). The amount of fuel available in cleared and alien vegetation resulted in fires of much greater severity than in fynbos. Furthermore, in alien vegetation, the thick layer of dry leaf litter was important for initiating and supporting high severity fires on the soil surface. In cleared vegetation, this organic layer is usually lost within a few years after clear felling, and the fuel is concentrated into stacks of dead and decomposing (depending on how long after felling) woodpiles. The greatest fire severity can be associated with the location of these woodpiles, but the occurrence of places in between the piles where the fuel load should be low is important. The consistency of a severe burn through alien vegetation may average out (on a catchment scale) as a more severe burn than the patchy distribution of severe burns in cleared vegetation.

A water repellent layer on or near the soil surface prevents water from penetrating, resulting in surface flow (Scott, 1991). Scott (1991) and Scott & Van Wyk (1990) found that a wildfire through a plantation caused water repellency to be burned off the surface soil but intensified it in lower soil layers. In chaparral it has been shown that fires can cause the intensification and translocation of water repellent substances (De Bano, 1969). Further, a more severe fire at the soil surface can destroy or move the water repellent substances downward during the fire, leaving an extremely wettable surface on top of the water repellent layer (Wells, 1981). Rainfall on top of an already saturated wettable surface causes it to “slide off” the repellent layer, resulting in a debris flow. This may have been the process that occurred during the Fish Hoek erosion event. Since the

Peninsula fires, there has not been a big enough rainfall event to cause major sliding, but there has already been a considerable amount of soil loss. Rilling and some sheet erosion, caused by overland flow on the soil surface have probably dominated the erosion process on the Peninsula up till June 2000.

There are usually places where and times when repellency is poorly developed and absent, where infiltration and percolation of water can occur. This was generally the case for fynbos vegetation on TMS, while in alien and cleared vegetation the repellent layer was more consistent (Figure 12). The sites of "holes" in the repellent layer may be next to rocks, root channels, disturbed soil or other macropores. Gradual wetting during soft soaking rain allows a reduction of repellency to develop. However, a sudden downpour that exceeds the available storage in the soil mantle, is more likely to result in erosion of the surface soils. A weakly developed and inconsistent repellent layer was prevalent on rocky TMS soils, but infrequent on sand dunes, or where sand overtops TMS soils. The latter two substrates were where the most soil erosion occurred, especially at sites with alien or cleared vegetation.

This study found little difference in the degree of water repellency in the subsurface soils. However there were marked differences in the depth of the repellent layer, and the depth to the repellent layer (or the depth of the wettable surface layer) and also the consistency of the repellent layer. Soil loss correlated with the depth of the wettable surface layer in cleared vegetation, but not in alien or fynbos vegetation. The depth of the wettable surface layer was associated with greater severity fires and deeper sandy soils, and also with where the depth of the repellent layer was greatest. Coarse textured soils, such as is found in fynbos, may be more susceptible to becoming highly water repellent than finer textured clay soils, such as on granite (Figure 11). However, since the water repellent layer and aggregated soil surface correlate (i.e. the repellent layer is where aggregated soil (intact root system & organic matter) begins in the post fire soil profile). It is not clear which factor (soil physical or chemical/biological properties) is more important for predicting soil erosion of the overburden & underlying soil. In California, when slash was piled and burned over coarse textured soils it presented wettability problems, particularly when the soil was dry (Wells *et al.* 1978). The thickness of the water repellent layer depends on the intensity of the fire, the soil water content at the time of the burn, and the soil physical properties (Wells *et al*. 1978).

The erodibility (the inherent resistance of the soil to erosion) of the soil tends to decrease in proportion to fire severity (soil heating). The process is through combustion of incorporated organic matter in the soil. The organic matter acts to hold soil particles into larger aggregates. Thus, the surface layers that are heated most, become both fully wettable and highly erodible (soil is all individual grains). Since January 2000, erosivity (energy available to drive erosion) has limited the process more than erodibility. However, winds did cause much movement prior to the rains, and some erosion was driven by surface runoff during rains. However, there have not yet been any large and intense rainstorms as experienced in Fish Hoek in April 1999.

Massive sediment deposition on Chapmans Peak drive above Noordhoek, 31 May 2000, four months after the fire. Alien and cleared vegetation occurred above this site.

Soil profile showing the wettable surface layer (darker wet soil) above the water repellent layer (dry soil), 31 May 2000, four months after the fire. Alien vegetation occurred on the site. The yellow ruler is 20 cm long.

Dense Rooikrans occurred on these sandy slopes in Dido vealley. The polytex screens aimed to trap sediment runoff from the slope. Taken on 31 May 2000, four months after the fire.

Soil profile showing how water does not infiltrate the water repellent layer (light brown, dry soil) resulting in overland flow. Alien vegetation occurred on the site, 31 May 2000, four months after the fire.

Cleared vegetation on sand dunes at Fish Hoek one year after the fire in March 1999. The barren strips were where cut alien wood was stacked.

Fynbos recovery on 30 May 2000, four months after the Peninsula fires in January 2000 at Scarborough. The resprouting bush is *Leucopermum conocarpodendron.*

The accumulation of leaf litter, and the increasing height and density of alien vegetation over time, may influence the depth of the water repellent layer (Teramura, 1980). Water repellency is derived from soil organic matter, and in chaparral they seem to occur during the normal breakdown of plant litter and are leached from the litter into the mineral soil. From this it follows that alien clearing might be associated with a break down or reduction in water repellency, and some evidence for this was found in this study (Figure 7). However, the persistency of the water repellent layer, and how it may be changed, is poorly understood.

Figure 15 illustrates the hypothetical process that may explain the variation in soil loss that was recorded. Severe fires in alien and cleared vegetation (under woodpiles) can generate a greater volume of soil (the wettable surface layer) that is prone to erosion, than lower severity fires in fynbos. To exacerbate this situation under heavy rainfall events, the repellent layer is deeper and more persistent with alien vegetation.

In cleared vegetation, the absence of organic matter or skeletal remains that may have trapped moving soil during overland flow adds to the likelihood that soil erosion will occur. Protection of the soil surface by recovering vegetation (which may also help to establish “holes” in the repellent layer) is also minimal in severe fires, so the process of slope stabilization and recovery may also take much longer in cleared and alien vegetation than in fynbos. The process of transition from cleared vegetation to restored fynbos may take several fire cycles, during which one would expect an overall decrease in soil erosion. With persistence of aliens, one may find a similar pattern to that in fynbos although soil erosion may be more, depending on fire frequency and severity.

The persistence of the repellent layer after fire is not well studied locally. In Lodgepole pine forest in Oregon the water repellent layer persisted for 5 years after the fire (Dryness, 1976 in Wells *et al.* 1978). *Ad hoc* tests done for this study in about 20-year-old vegetation indicated the existence of a repellent layer in both alien, cleared and fynbos vegetation. Through a single winter rainy season, repellency diminishes as a function of soil wetness, and increases again with drying out in summer (Scott, pers comm). The ecological function of soil water repellency is also not well studied, although Scott (1991) has suggested that it may serve to prevent colonization of parent plant soils, thereby reducing competition (in the same way as allelopathy).

The negative impact of increasing fire severity on plant species richness and the cover of resprouters was also found in southern California (Keely, 1998). The poor regeneration of indigenous species in high severity fires is most likely due to the seed bank being incinerated by the fire (Foden, 1997). However, the seed bank may also have been destroyed by alien vegetation present on the site before the fire, or be derived from less diverse plant communities (e.g. *Leucadendron coniferum* fynbos versus TMS rocky fynbos). Furthermore, adequate spatial measures of plant diversity were lacking in this study (Vlok & Yeaton, 1999). The slightly improved vegetation recovery found in cleared sites over alien sites was encouraging. This recovery tended to be associated with the gaps between the piles of cut aliens, where fynbos vegetation may have recovered before the fire. There is an urgent need to understand plant species responses to alien infested areas, alien clearing methods and fire severity. Which species are prone to local extinction as a result of abnormally severe fires on the Cape Peninsula and in the Cape?

6. CONCLUSION

The results showed considerable variance in soil erosion, so there is a high measure of uncertainty in predicting erosion. The main causes of soil loss were primarily substrate type, and secondly vegetation type. Dune sand and lower rock cover had more soil loss, irrespective of vegetation type. However, soil erosion was greater at sites with alien or cleared vegetation, and less in fynbos. TMS soils were most susceptible to vegetation induced changes in soil erosion. This study found no clear relationship between fire severity and soil losses, although vegetation type and post-fire age does indicate fire severity potential.

In terms of measurable effects, fires in alien infested areas are, on average, about 65 % more severe (more damaging) than fynbos fires. Fire severity differences, alone, can reduce species to one third of the average fynbos fire (Figure 13) and the potential percent plant cover by the same amount. In other words, the most severe fire in aliens could cause two thirds of the species and vegetation cover to be lost in fynbos.

The worst erosion was in areas cleared of aliens. Ways of removing aliens with less destruction of soil and biodiversity must be sought. The change in soil surface level recorded no net change in fynbos, 113 m^3/ha or 147 tons/ha in alien infested areas, and over double this amount in areas cleared of alien vegetation.

Why is more soil lost from cleared and alien infested sites? The evidence suggests it was linked to water repellency and the depth of the non-repellent layer on the soil surface. The non repellent and repellent layers were deeper and more consistent after alien invasions, while in fynbos they were shallower and also more patchy. However, these factors were not strongly linked to fire severity, at least as measured in this study.

Heavy rainfall can trigger soil movement only once the wettable surface layer has been saturated. If this occurs, then overland flow occurs over a highly erodible surface. Once the wettable surface layer, the depth of which can be determined by veld age and fire severity, has been washed off and the repellent layer is exposed, the surface remains erodible for as long as overland flow persists. This depends on the break down of the water repellent layer, which is not well studied. Fire frequency may control soil erosion by minimizing fuel loads and fire severity.

Vegetation recovery may be critical in allowing protection from raindrops and also in providing locations where water infiltration can occur, thereby reducing overland flow. Alien vegetation may need to be part of the fynbos restoration process for it to achieve more rapid slope stabilization, in the first two years after a fire. However, biodiversity loss that can occur in the years following this does not permit the persistence of alien vegetation where indigenous plant diversity still exists. It is important that all alien and cleared vegetation is cleared while the indigenous seedlings are still alive. Alien vegetation can out-compete most species to the point of local extinction. Fynbos recovery without costly human intervention is dependent on the survival of the seed bank after the passage of a fire.

7. MANAGEMENT IMPLICATIONS & RECOMMENDATIONS

This study showed that post fire soil erosion was greater in cleared and alien vegetation than in fynbos. Furthermore, cleared vegetation tended to have more soil loss than alien vegetation. The impetus for eradicating alien vegetation and restoring indigenous vegetation is not only for preventing biodiversity loss and for controlling fire, but also for minimising soil erosion.

It may be possible to minimise soil loss during the period of transition from alien to fynbos vegetation. The current method of alien clearing may be inappropriate if fires cannot be controlled. The January 2000 fires on the Cape Peninsula demonstrated our inability to control runaway wild fires under extreme conditions. Large areas of alien and cleared vegetation on the Peninsula remain vulnerable to burning. Planning without expecting runaway fires may be unacceptable because of the hazards associated with severe fires in cleared and alien vegetation. Some management options that may curtail the damage caused in fire-storm-erosion events are described below.

In cleared vegetation, the most effective way of avoiding severe fires on the soil surface under woodpiles is by removing the heavier wood. This will also enhance fynbos vegetation recovery. Alternatively, woodpiles should be burnt in damp conditions and extinguished before excessive soil heating occurs. This can serve as a fuel reduction process and also speed up wood decomposition. The wood should be stacked so that most of the heat energy is lost upward. If there are slopes steeper than 20°, and with human infrastructure below, then alien clearing should remove all cut material off the slope. However, slope destabilization caused by the wood extraction process, must be weighed up against that caused by using controlled fires to minimize fuel loads in cleared areas.

In some places on the Peninsula (e.g. on the slopes between Misty Cliffs and Scarborough) the standing Rooikrans skeletons have been cut down and stacked in piles parallel to the slope. This was done primarily as an anti-erosion measure. However, by cutting the standing skeletons one is removing protective cover from the soil, which may increase surface flow. Furthermore, if these woodpiles are not removed before the passage of the next fire, they may cause more damage by soil heating. It may be argued that the woodpiles may have decomposed by the time the next fire passes. However, Rooikrans is a hard heavy wood that will take longer than the average fire cycle to decompose. It is recommended that skeletal remains are left standing and only after the vegetation has recovered (alien and indigenous) after about one and a half to two years, should the skeletons be removed, together with the regenerating alien seedlings and saplings.

This study has shown the biodiversity loss and soil erosion that can be caused by severe fires in alien and cleared vegetation. However, promoting the concept of lower severity fires in alien vegetation may also have negative implications, if one considers the ultimate goal of transition from alien to fynbos vegetation. If there is no infrastructure lower down the slope, or if the area has a flat or gentle slope (i.e. if soil erosion is not a threat) then a severe fire may be more appropriate because it can destroy much of the alien seed bank. This can reduce the workload of follow up clearing operations. Such an option should only be considered if there is no indigenous biodiversity remaining in the alien stand, which is seldom the case. A lower severity fire is more appropriate if follow up clearing of regenerating aliens is guaranteed within the first two to three years of a fire, and there after. Although burning aliens standing may reduce erosion risk compared to cleared stands with high fuel loads, the latter can enhance post fire fynbos recovery. This is especially the case if cut fuel is burnt in localized woodpile fires, before the entire area becomes prone to fire again. This is currently being done on the Peninsula by clearing operations

Another potential disadvantage of a lower severity fire in alien vegetation may be the persistence of the organic leaf litter, from which water repellent substances are derived and also where the alien seed bank is located. Successful, post fire fynbos recovery may be dependent on the absence of an organic litter layer. However, the organic litter layer can also protect the mineral soil from heating in a low severity fire, which may reduce the depth of the repellent layer. In the context of the alien to fynbos transition, it is not known whether fire severity can influence the rate of slope stabilization and fynbos recovery.

The fire-storm-erosion events associated with fynbos can be minimised by keeping fire frequencies short (less than 15 years). The fuel loads in fynbos vegetation older than 15 years increases the risk of high severity fires. It is important to maintain the natural fire season in fynbos, over and above the risks associated with severe fynbos fires. Severe fires in fynbos may also impair the diversity of post fire regeneration.

This study also showed that sand dunes and where sand overtops TMS are more susceptible to soil erosion after fire, irrespective of vegetation type. These soil types may be inherently erodible, and anti erosion measures and alien eradication could be prioritized on slopes with these soils. However, situations where aliens occur on TMS are also vulnerable. Since sand dunes were originally un-vegetated, their restoration to an unnatural state (the option of reinstating sand dunes should be re-evaluated) should not be a priority in terms of biodiversity conservation. Rather, areas where indigenous plant diversity was previously prevalent should be prioritized.

The role of wind, and the historical origin, erosion and deposition of sand needs to be investigated. Much of the sand washing off the mountain in fire-flood-erosion events may have been deposited by wind. Alien vegetation has effectively eliminated this process. If this sand is not replenished, as it would have happened historically, it may cause dramatic changes to the soil (a gradual loss in topsoil, and decrease in soil depth) which may cause changes in the composition and structure of the vegetation community that occurred there. In this context, fynbos communities that are associated with wind blown sand overtopping TMS soils are severely threatened on the Cape Peninsula.

8. RESEARCH PRIORITIES

There are several aspects of this subject that require further study if we are to understand the implications of our management actions. It is recommended that a coordinated and integrated multi-disciplinary approach to various research topics be adopted. Research should be based on long term monitoring plots, the design and layout of which should incorporate the aims of the various research topics. The following topics should be monitored across the full range of vegetation habitats and environmental gradients on the Cape Peninsula.

- The repellent layer: the nature, origin and change in the repellent layer and the influence of vegetation and soil changes on the repellent layer.
- Soil deposition and erosion: the changes in soil composition and erosion, including that caused by wind.
- Vegetation recovery and alien clearing methods: the role of vegetation, and the influence of different vegetation treatments or clearing methods.

There is also a requirement to generate post fire soil erosion figures that can be extrapolated to other areas. These can be used in a resource economic study that can evaluate soil loss under alien vegetation and relate this to the productive potential of the land. These results provide indications of the worst case scenario, but additional soil loss data is required to establish more generalized values that can be applied to other situations. Table 9 illustrates the kind of soil erosion values that could be applied.

Table 9. Calculations of surface soil changes in m^3 ha^{-1} after the Peninsula fires in January 2000 and after the first winter rainfalls on 21 June 2000.

			Wettable surface layer (m^3 ha^{-1}) after the fire (8 March 2000)			Change in surface soils (m^{3}ha^{-1}) after first winter rains (21 June 2000)		
Vegetation type	Geology	Sample number	Average	Maximum	Minimum	Average soil loss	Maximum soil loss	Minimum soil loss or maximum deposition
Alien	Granite	10	420	600	200	-130	-550	200
Alien	Mixed	5	660	1000	400	-215	-450	-50
Alien	Sand	5	200	1000	0	-340	-700	-150
Alien	Tms	30	300	600	0	-50	-400	150
Cleared	Granite	5	300	300	300	-305	-450	-200
Cleared	Mixed	10	110	500	0	-215	-450	-50
Cleared	Sand	No data						
Cleared	Tms	10	425	1000	50	-245	-1150	20
Fynbos	Granite	5	0	0	0	-45	-100	0
Fynbos	Mixed	No data						
Fynbos	Sand	No data						
Fynbos	Tms	15	35	150	0	80	-150	500

Estimates soil changes in terms of m^3ha^{-1} are shown in Table 9. The application of this data to other areas in the Cape may be possible, although the sample numbers are inadequate for some of the vegetation/geology categories. Furthermore, additional soil loss that occurs after this needs to be incorporated. It is recommended that data from other studies is assessed and generalised values are used for extrapolation to other areas and post fire erosion events.

The role of aliens versus fynbos for sequestering carbon also needs to be addressed in the context of current global warming. Although aliens may sequester more carbon because of greater biomass accumulation than in fynbos, severe fires in aliens probably release more carbon. Over several fire cycles fynbos is probably a more effective carbon sink, but this still needs to be proven and evaluated. The alien clearing process may initially release more carbon (because fire is an alien clearing tool), but this may be justified if the ultimate goal of transition to fynbos results in a more dependable carbon sink for the Cape.

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11. APPENDICES

11.1 Appendix 1. Photographic depiction of 95 Peninsula permanent sites in March 2000 and again in June 2000, after the first winter rainfalls. Supplied as attachment on CD.

11.2 Appendix 2. Photographic depiction of the Fish Hoek sampling sites in March 2000.

11.3 Appendix 3. Additional photographs.