Dowsing fynbos fires with sea water

An investigation into the effects of utilising sea water dropped by helicopter to extinguish fires in Cape Mountain Fynbos.

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Abstract

The Cape Floristic Region is a highly distinctive phytogeographical unit comprising over 8550 species, of which more than 68% are endemic to the region (Cowling *et al.*, 1989). Based on it's unique species richness and high level of endemism therefore this region is regarded as a high priority conservation area. As such it is subject to intense management, the aims of which are the conservation of the biotic diversity within the fynbos ecosystem and the maintenance of ecosystem functioning. Fires, which occur frequently in the fynbos ecosystem are intensively managed and unplanned fires rapidly extinguished. One of the most effective methods of extinguishing uncontrolled fires is to dowse them with water collected from the nearest source. This is often the sea and as a result fynbos fires are dowsed with salt water. Concern has been expressed regarding the effects of the salt water on the fynbos ecosystem. Two sites were studied, both recently burnt, the fires having been extinguished with sea water dropped by helicopter. The physical and chemical impacts of this extinguishing method on the vegetation of these two sites was investigated. It was found that the physical effects of the impact of the sea water were only significant where the soil type was sandy. The chemical effects of the sea water, in terms of soil salinisation, were however more pronounced revealing species compositional changes in the field and reduced germination and growth in the greenhouse experiments. The rapid leaching of the salts from the soil in the field reduced the impacts of the salt on vegetation regrowth. If however leaching in the field were to be reduced, the chemical effects of the salt water on the vegetation would approach the results obtained in the greenhouse experiments. This could lead to erosion through reduced vegetation cover and species compositional changes, both of which contradict management aims.

Introduction

The Cape Floristic Region is a highly distinctive phytogeographical unit which is recognised as a floristic kingdom of its own (Goldblatt, 1978; Takhatajan, 1986). According to Cowling *et al.* (1989), for equivalent-sized areas, the Cape Floristic Region has the highest recorded species density for any temperate or tropical region in the world. In addition to this remarkable species richness, the region shows an unusually high degree of endemism, with 68% of the more than 8550 species being endemic to the region (Cowling and Holmes, 1992). Based on it's unique species richness and endemism therefore, the Cape Floristic Region is regarded as a high priority conservation area (Rebelo, 1992). As a result, extensive areas of the Cape Floristic Region are subjected to intense management by local authorities such as Cape Nature Conservation (CNC) and the Cape City Council (CCC). The aims of such management generally involves the conservation of biotic diversity within the region and the maintenance of ecosystem function (Van Wilgen *et al.*, 1994).

Fire is the principle driving force behind the ecosystem dynamics of the Cape Floristic Region, and in particular behind the dynamics of the fynbos vegetation of the region (Kruger and Bigalke, 1984; Van Wilgen *et al.*, 1992; Van Wilgen *et al.*, 1994). According to Van Wilgen *et al.* (1994), resilience in the fynbos at the level of species, communities and ecosystems is to a large extent dependent on the fire regime, and managing fynbos therefore equates to managing fire. As a result fire control is the major tool used in the management of the fynbos biome. Prescribed burning regimes are based on a knowledge of the effects of fire frequency, intensity and season on the vegetation, largely focusing on the well-documented Proteaceae family. The rule of thumb of Kruger and Lamb (1978) is used to determine the minimum fire frequency for the fynbos vegetation. They suggest that prescribed burns should take place once 50% of the population of the slowest maturing species in a given area has flowered for at least three successive seasons. This rule is usually applied to the shrubs of the

Proteaceae, since these are generally the slowest to mature in fynbos. At the other end of the scale, maximum fire intervals are determined by senescence in the Proteaceae. Senescence leads to a fuel build up (in the form of leaf litter) and when a fire does occur, it is of unusually high intensity. This adversely affects the vegetation (particularly resprouters) leading to a decline in species richness (Van Wilgen *et al.*, 1992). These considerations have lead to a recommended fire frequency of between 10 and 25 years (Van Wilgen *et al.*, 1990). In terms of fire season, the current management regime allows for late summer-early autumn burns only. This is based on the knowledge that serotinous Proteaceae killed by fire during this period show maximum seedling recruitment (Van Wilgen *et al.*, 1992). The response of other species in the fynbos to variations in the fire season support the late summer-early autumn burning period. Most resprouters, for example, are dormant during late summer-early autumn and therefore survive fires best at this time of year. If such resprouters are subjected to fire during seasons of active growth, their survival and regrowth is reduced as the depleted reserves are further drained by the resprouting event (Kruger and Bigalke, 1984).

It follows that wild fires occurring outside of the prescribed fire regime (10-25 year frequency, late summer-early autumn season) may have effects on the fynbos ecosystem that contradict the management aims. These include local extinctions, a decline in species diversity and an alteration of ecosystem function. In addition, uncontrolled fires can be hazardous to life and property (for example the Betty's Bay fire of 1970 destroyed 21 houses; Kruger and Bigalke, 1984). It is essential therefore that such fires are rapidly extinguished. One of the most effective methods of extinguishing uncontrolled fires is to dowse them with water collected by helicopter from the nearest source. In the Cape region, the nearest source of water is often the sea and as a result fynbos fires are dowsed with salt water. The public, Cape Nature Conservation and the

Cape City Council have recently expressed concern about the negative effects of salt water on the unique fynbos ecosystem.

The aim of this study is to investigate whether such concerns are justified. If they are, managers will need to investigate alternative methods of extinguishing uncontrolled coastal fires in the fynbos. These may include the use of fire hoses, manual sacking of the fireline or the use freshwater dropped by helicopter; all of which have their disadvantages. Manual sacking of the fireline and the use of fire hoses is often ineffective in the control of large fynbos fires and the use of freshwater dropped by helicopter proves ineffective if the freshwater reserves are not in close proximity to the fire (as flying times are increased and so therefore both the time of uncontrolled fire spread and the costs of the fire control operation). If on the other hand salt water is shown to have little or no effect on the fynbos ecosystem, fires occurring along the coastline can continue to be extinguished by helicopter, using the sea as an accessible and plentiful water source.

Materials and Methods

Study sites

Two study sites were chosen for this investigation, both of Cape Mountain Fynbos (Acock's (1975) Veld Types 69 and 70) that was recently burnt, the fire having been extinguished using sea water dropped by the Russian helicopter RA 27 129. The first study site is situated along Chapman's Peak Drive, on the western slopes of the Constantiaberge (34°03'50"S, 18°22'30"E) (figure 1). This site was burnt on the 8th of January 1995, the fire covering an area of approximately 70 hectares. The second site is situated on the north-western slope of Lion's Head (33°57'50"S, 18°23'40"E) (figure 2). This site was burnt on the 23rd of March 1995, again covering an area of approximately 70 hectares. At both sites the fires were outside of the planned burning regime. The

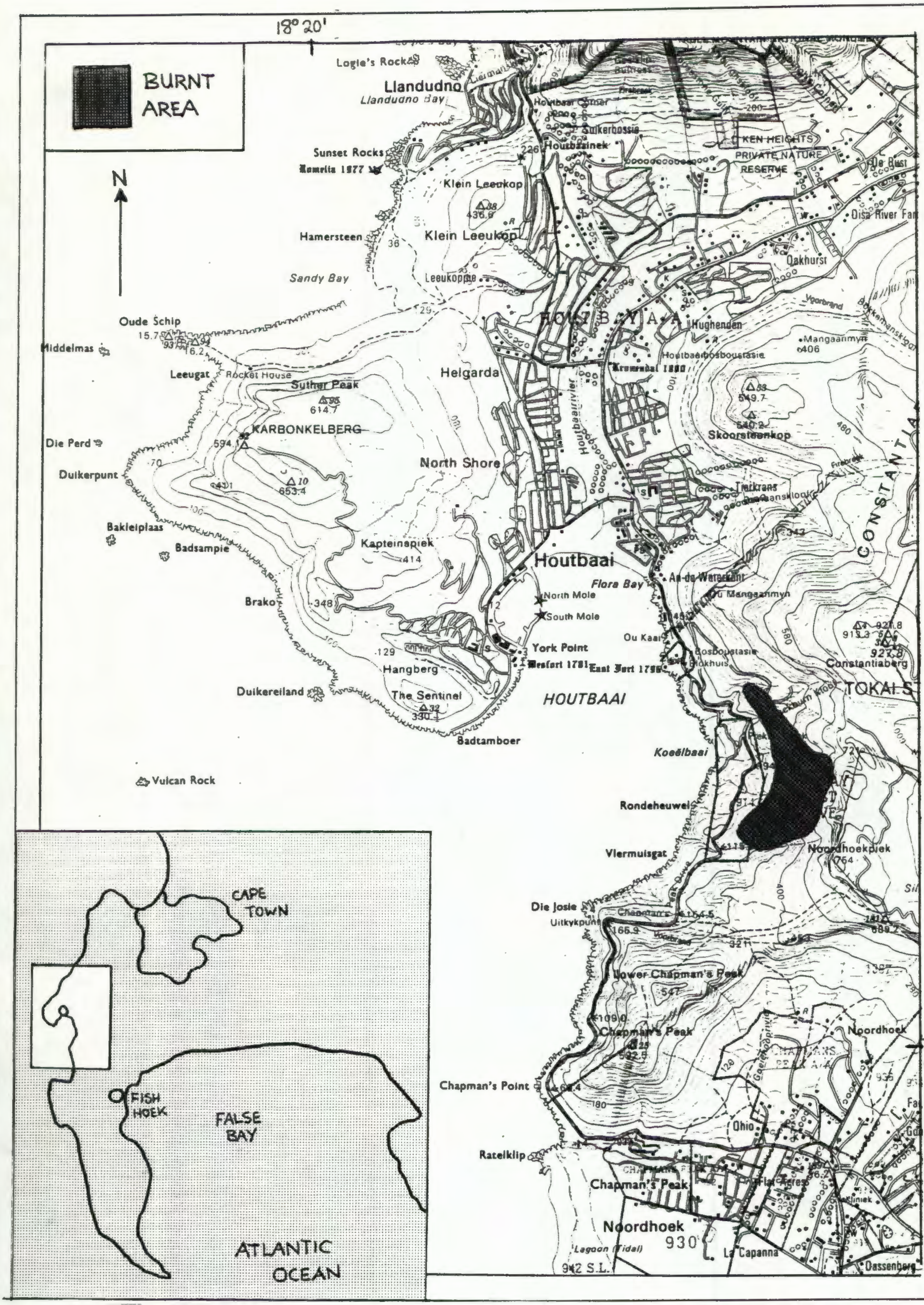

Figure 1. Map of Chapman's Peak study site (1:50 000) showing the burnt area on the western slopes of the Constantiaberge.

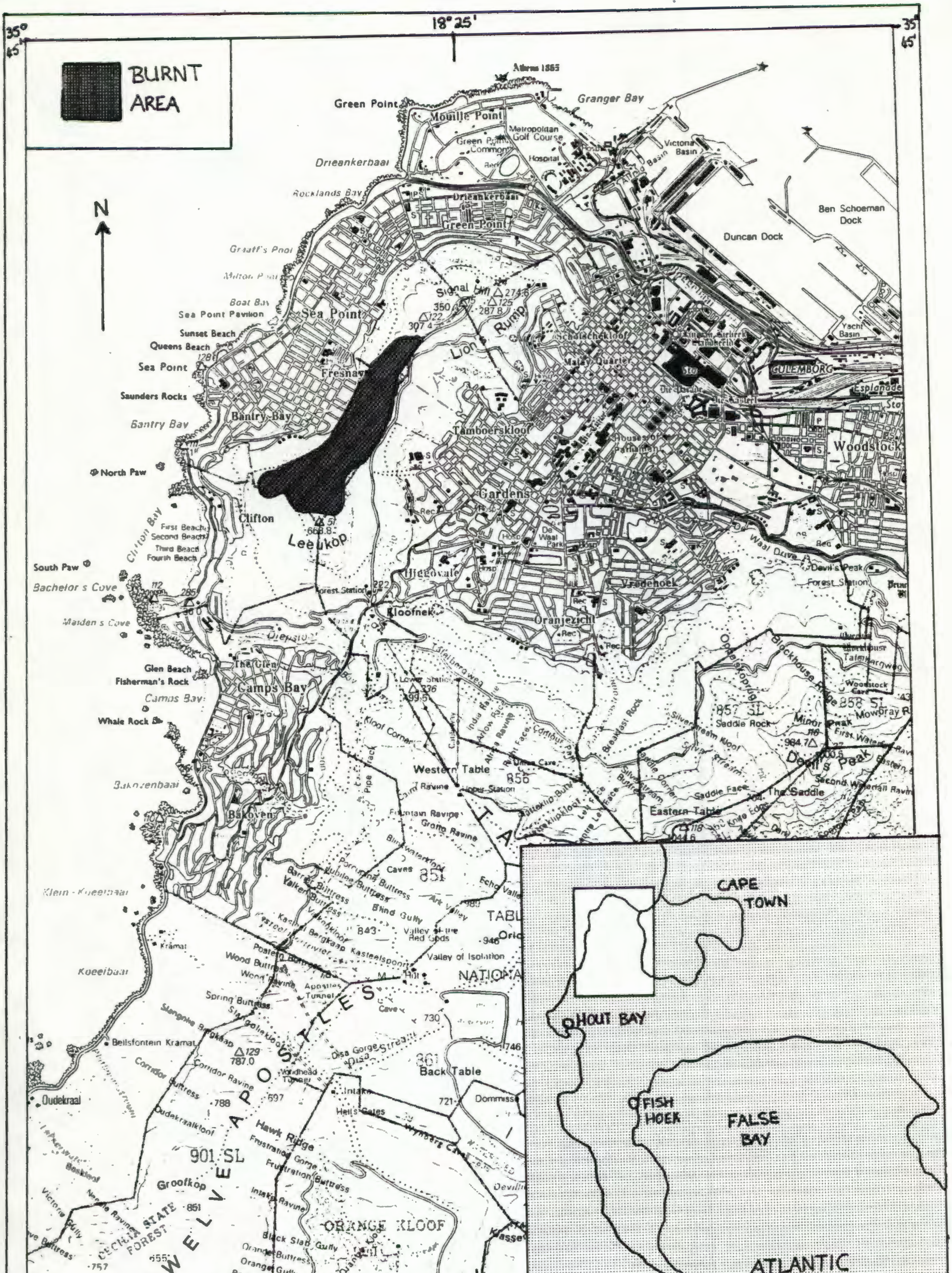

Figure 2. Map of Lion's Head study site (1: 50 000) showing the burnt area on the north-western slopes of Lion's Head.

Chapman's Peak fire was started by Picnic makers and the Lion's Head fire by the equipment of workers in the area. The Chapman's Peak site had been burnt four years previously and the fire was therefore a threat to the young vegetation and could lead to the local extinction of slowly maturing species that had not yet acquired a seed bank. The Lion's Head site is situated above the residential areas of Seapoint, Fresnaye, Bantry Bay and Clifton and the fire therefore posed an economic as well as an ecological threat to the area. Both fires were rapidly extinguished with the aid of the Russian helicopter RA 27 129. The closest water source was used to extinguish the fire. For both sites this was the sea and the sites were therefore inundated with salt water.

Research approach

The application of salt water to the firelines of both study sites may have resulted in both physical and chemical impacts on the ecosystem at each site. The helicopter used in the salt water application at both study sites was equipped with a "bambi bucket" which drops water from a height of approximately 50 foot (figure 3). The design of this bucket allows no control over the water flow and a continuous, strong stream of water bombards the fireline. This characteristic of the "bambi bucket" makes it useful for forest fires or when the wind is strong (Z. Erasmus, CNC, pers. comm.). For both the Chapman's Peak and the Lion's Head fires, the wind was a strong south-easter and a decision was made to use the "bambi bucket" to ensure that the water hit the fireline and was not easily carried away by the wind. The alternative to the "bambi bucket" is the "monsoon bucket" which is equipped with a footplate allowing some degree of control over the water flow. The extended footplate disperses the water, preventing a strong stream of water from hitting the ground. This bucket type produces less of a physical effect on the area but is only effective on calm days when the wind does not carry the water spray away from the fireline. Due to the strong south-easters, the "bambi bucket" was used at both study sites and there may therefore be physical impacts present along the

Figure 3. The Russian helicopter RA 27 129 dowsing the Chapman's Peak fire with sea water collected from Hout Bay. Note the "bambi bucket" used to carry the water. This bucket allows no control of the water flow and a continuous stream of water bombards the fireline.

firelines of each study site. It was noted in the initial examination of the study sites that there was a conspicuous buildup of coarse-textured sand along the fireline at the Chapman's Peak site. The physical impact of the salt water on the fireline areas of both study sites was investigated in terms of this soil overburden. The high salt content of the water used to extinguish the fires (aproximate concentration of sea water = 33 p.p.t.) will have chemically altered the abiotic environment by increasing the soil salt concentration of the fireline areas at each site. These physical and chemical alterations of the abiotic environment may in turn affect the biotic component of the ecosystems at each study site. In terms of vegetation, these impacts would be revealed in the amount of regrowth after the fire and perhaps in compositional differences between the species present along the fireline and those present upslope of the fireline.

The soil overburden may inhibit vegetation regrowth through physical suppression of resprouting vegetation and seedlings. Species tolerant of sandy conditions would be favored under these conditions, leading to possible changes in species composition along the fireline. The soil salinisation along the fireline may also affect vegetation regrowth. Increased salinity increases the osmotic pressure of the soil water thereby slowing plant water uptake, hindering seed germination and active growth (McBride, 1994). Again this may lead to compositional changes as species tolerant of saline soils are favored along the fireline. Retarded vegetation regrowth along the fireline (due to physical and chemical suppression) would be problematic in that such fireline scars often lead to erosion gullies, removing top-soil and degrading the ecosystem. Species compositional changes along the fireline may be important if a population of a rare and localised species is situated the area. Compositional changes along the fireline may lead to the decline of a large proportion of such a population, or even to the local extinction of the species. This would lead to a decline in species diversity, contradicting the aims of the fynbos management program.

To investigate the impact of the salt water inundation on the fynbos ecosystem soil overburden, soil salinity, regrowth of vegetation and species compositional changes were therefore investigated. The fireline was regarded as the treatment as the salt water was applied to the fireline only. Upslope of the fireline (a distance of 30m or more) was regarded as the control for all investigations as no salt water was applied to these sites. In addition, greenhouse experiments were carried out to investigate the direct effects of soil salinisation on plant germination and growth and also to determine the concentrations of salt required to produce these effects.

Soil overburden

Line transects 30m long were run perpendicular to the fireline. The depth of the sand overburden was estimated every 1m along the transect. Twelve of these transects were taken along the Chapman's peak fireline and five along that of Lion's head. The distances between the transects were randomly chosen between one and five meters.

Soil salinity

For each study site soil was collected from ten random points along the fireline and from eleven random points upslope of the fireline. At each point soil was removed from depths of 2cm, 4cm, 6cm, 8cm and 10cm. The soil was oven dried for two days at 80°C.

The conductivity of the ten fireline samples and of ten of the upslope samples was measured (Black, 1965).

- 100 grams of oven dried soil was weighed and placed into a beaker containing 100 milliliters of distilled water.
- The mixture was briefly stirred and allowed to stand for 1 hour. During this period the mixture separates into a soil layer at the bottom and a liquid layer on top.

- The liquid layer was poured off onto filter paper in a filter funnel and filtered by suction.
- The filtered liquid was transferred to a small beaker where it's conductivity was measured using a field conductivity meter (4070 conductivity meter).

One upslope sample from each study site was used to create standard curves. For each site a standard curve was drawn up for soil at a depth of 2cm, 4cm, 6cm, 8cm and 10cm (see figures 4-13). Each standard curve was calculated by adding 0g, 0.02g, 0.05g, 0.10g and 0.15g of sea salt to 100 grams of soil each and measuring the conductivity of each soil treatment as above. The standard curve is a plot of the conductivity measures (microSiemens) against grams of sea salt per 100 grams of soil.

Vegetation regrowth

A line transect method was used to monitor vegetation regrowth after the fire. Vegetation presence or absence was noted every 10cm along a line 300cm long. For each analysis 25 lines were randomly taken along the fireline and 25 upslope of the fireline. The Chapman's peak site was analysed on days 112, 146, 194 and 240 after the fire and the Lion's head site was monitored on days 45, 91 and 157 after the fire.

Species composition

For each site, three 5m^2 plots were demarcated randomly along the fireline and three were demarcated upslope of the fireline along a contour parallel to that of the fireline. The upslope contour was situated approximately 30 meters above that of the fireline. The species present in each plot were recorded and their percentage cover within the plot estimated.

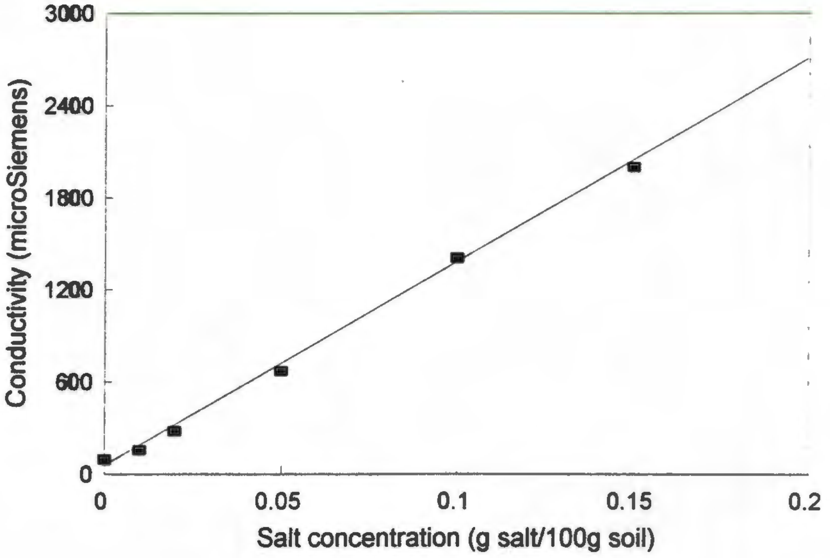

Fig. 4. Chapman's Peak, 2cm soil depth

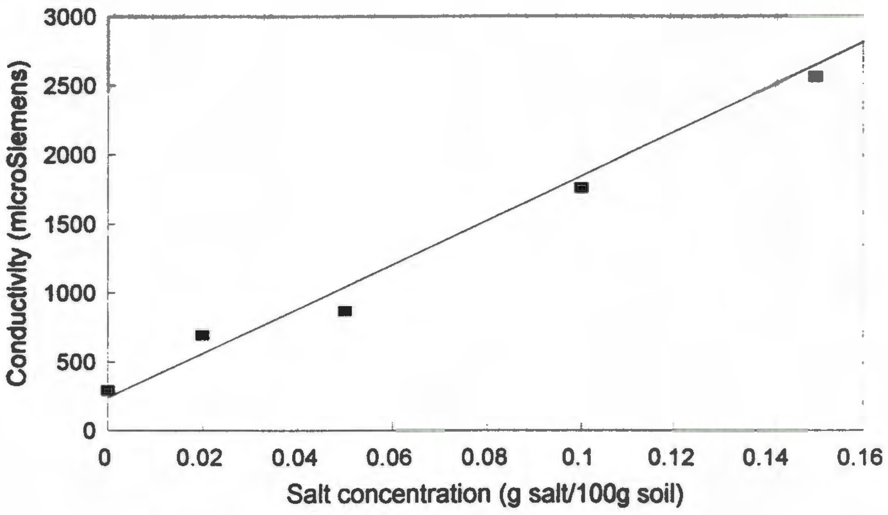

Fig. 5. Chapman's Peak, 4cm soil depth

Figures 4-8. Standard curves drawn up for soil salinity of the Chapman's Peak the soil. Standard curves were drawn up for soil depths of 2cm, 4cm , 6cm , 8cm and 10cm.

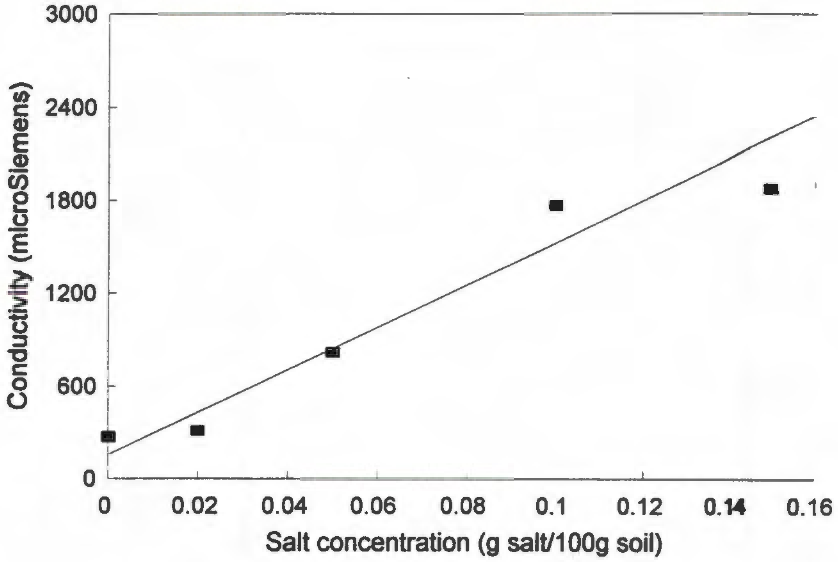

Fig. 6. Chapman's Peak, 6cm soil depth

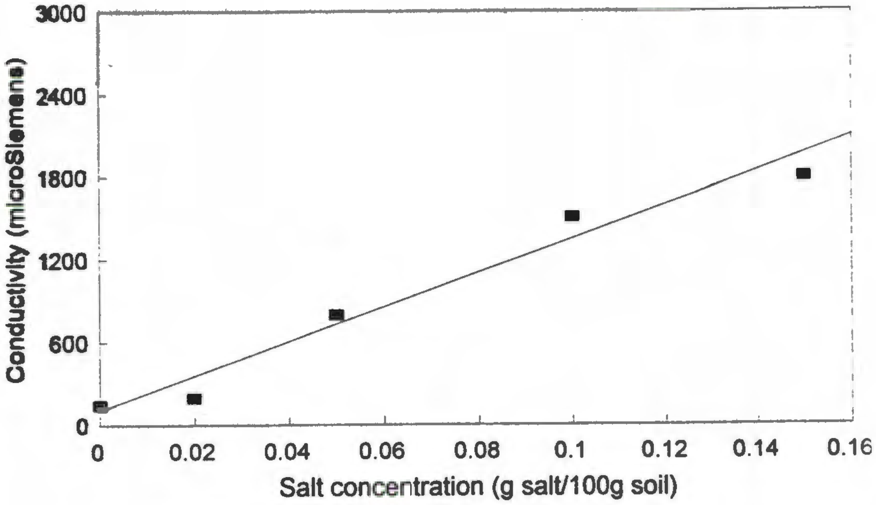

Fig. 7. Chapman's Peak, 8cm soil depth

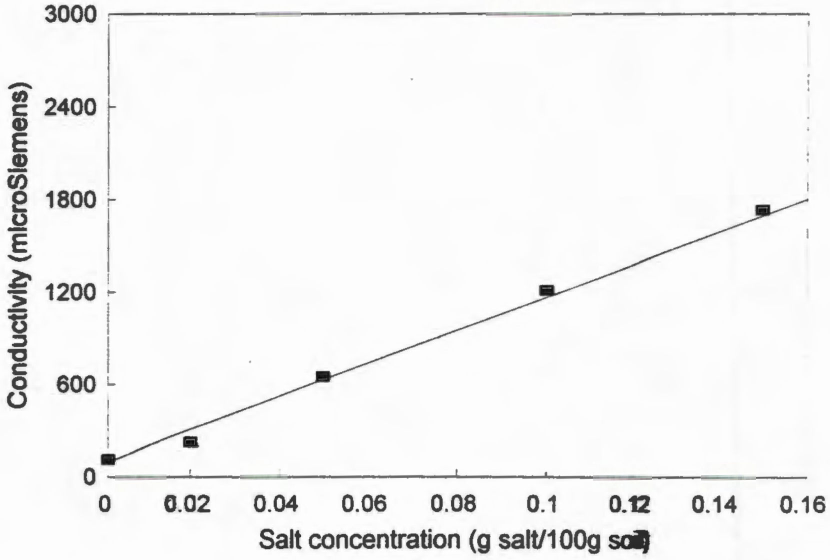

Fig 8. Chapman's Peak, 10cm soil depth

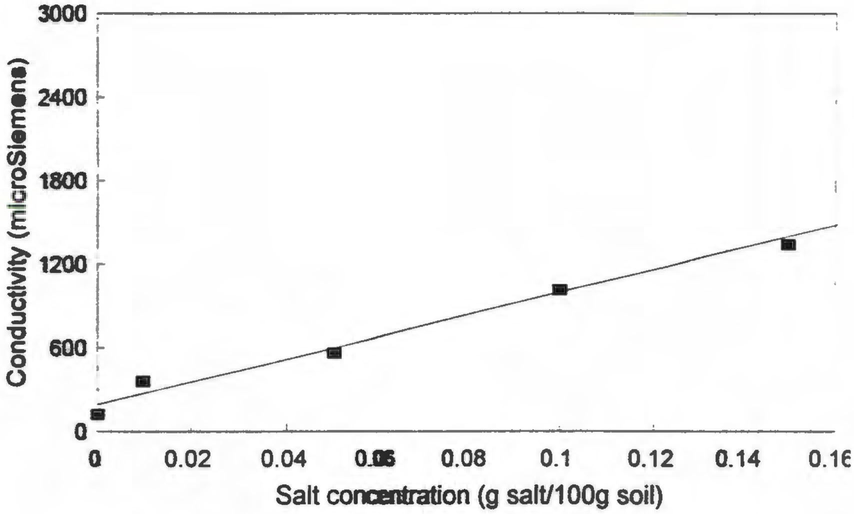

Fig. 9. Lion's Head, 2cm soil depth

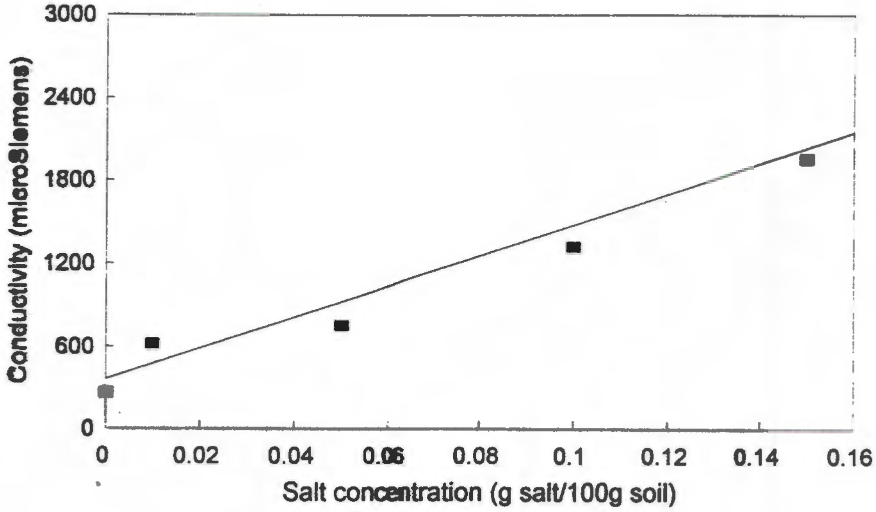

Fig. 10. Lion's Head, 4cm soil depth

Figures 9-13. Standard curves drawn up for the soil salinity of the Lion's Head study site. Curves were drawn up for soil at depths of 2cm, 4cm, 6cm, 8cm and 10cm.

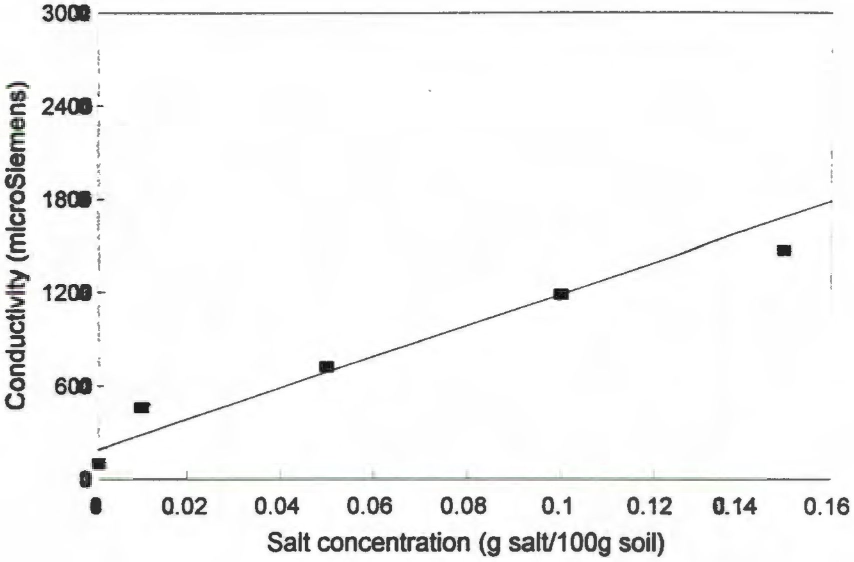

Fig. 11. Lion's Head, 6cm soil depth

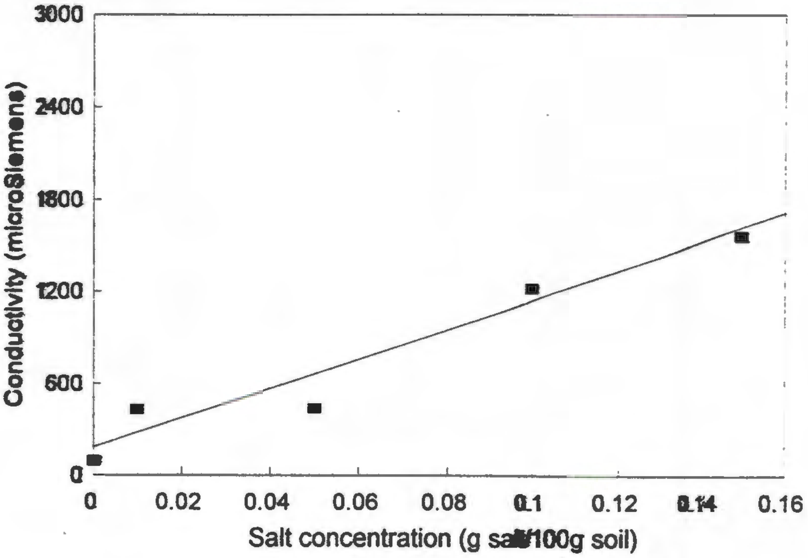

Fig. 12. Lion's Head, 8cm soil depth

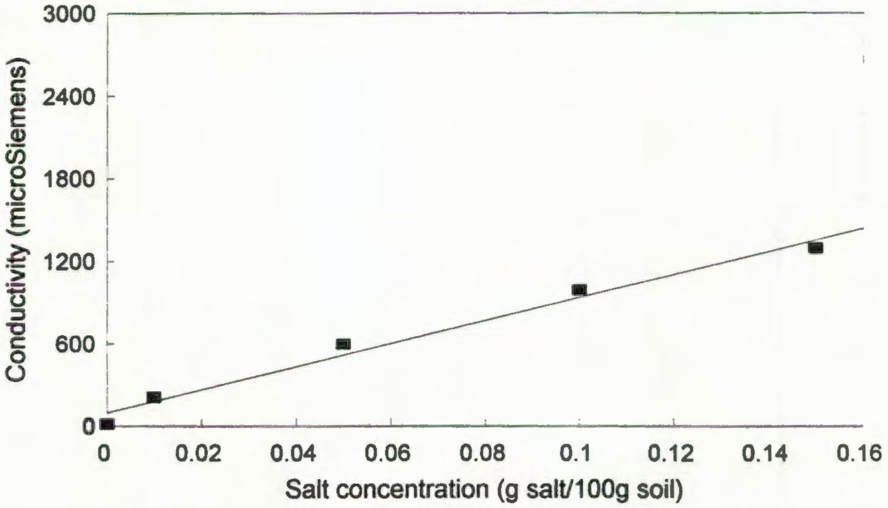

Fig. 13. Lion's Head, 10cm soil depth

Greenhouse experiments

Six fynbos species, covering a wide range of seed weights, were chosen for experiment - *Erica mammosa* L., *Watsonia tabularis* J. W. Mathews & L. Bol., *Wachendorfia thyrsiflora* Burm., *Phylica pubescens* L., *Podalyria sericea* (Andr.) R. Br. ex Ait. and *Leucospermum glabrum* Phill. In a large pot of acid-washed sand ten seeds of each species were planted in rows. The planting depths used were those recommended by K. Maze (Hons. thesis, 1994) (table 1). Twenty-five pots were planted in this way. Smoke water was prepared using dried plants of the *Passerina* genus. The dried plant matter was set alight and the smoke produced bubbled through distilled water for two hours. One liter of smoke water was applied to each pot. The pots were then randomly arranged in the greenhouse.

Table 1. Planting depths recommended for a number of fynbos species (After K. Maze, Hons. thesis, 1994).

Species	**Planting depth**	**Seed weight**
Erica mammosa	1cm	0.09g
Watsonia tabularis	2cm	10g
Wachendorfia thyrsiflora	2cm	14g
Phylica pubescens	2cm	22g
Podalyria sericea	2cm	23g
Leucospermum glabrum	3cm	105g

Two days later, salt treatments were applied to the pots. Five treatments were applied (fresh water, 33%, 66%, 100% and 200%), allowing five replicates per treatment. For treatment 1, five liters of tap water was applied to five pots as a fine spray (one liter per pot). The pots were then watered once a day for one month and then once every two days for the following two months. For treatment 2, five liters of "33% sea water" was prepared using 1667ml sea water (unfiltered, collected in Hout Bay) and 3333ml tap water. The "33% sea water" was applied to five pots as a fine spray, again using one liter per pot. These five pots were similarly watered with fresh water daily for one month and then every second day for the consecutive two months. Treatments 3, 4 and 5 were carried out in the same way but 66%, 100% and 200% sea water were applied as a fine spray in the initial watering. The 200% sea water was made up by adding 165 grams of sea salt to five liters of sea water (calculated from the concentration of sea water, approximately 33 p.p.t.).

Results

Soil overburden

The results of the examination of soil overburden presence at Chapman's Peak and at Lion's Head are presented as three dimensional graphs of soil overburden cover (figures 14 and 15 respectively). It is clear from figure 15 that there was very little physical impact on the soil at Lion's head, with no soil movement resulting from the impact of the sea water on the fireline. This can be attributed to the soil type at Lion's Head, namely Table Mountain Series Shale Band (Theron *et al.*, 1992). The clayey nature of this soil has an overall binding effect on the soil making it less prone to soil shifting (McBride, 1994). The Chapman's Peak site on the other hand showed marked soil movement with a soil overburden accumulation along the fireline (up to 20cm deep). Again this effect can be attributed to soil type as the soil at Chapman's Peak is Table Mountain Series Sandstone (Theron *et al.*, 1992). This loose, sandy soil is easily shifted, creating the effects observed in figure 14 (McBride, 1994).

Soil salinity

The conductivity readings obtained from the salinity analysis of the soil at Chapman's Peak and Lion's Head are shown in tables 2 and 3 respectively. The readings obtained for the soil collected from the firelines are significantly higher than those of the upslope soil samples for both study sites (Parametric analysis: *Two-way analysis of variance*; Chapman's Peak: d.f. = 1, F-ratio = 24.5, $p<0.0001$; Lion's Head: d.f. = 1, F-ratio = 39.4, $p<0.0001$; Non Parametric analysis: *Kruskal-Wallis analysis*; Chapman's Peak: d.f. = 1, test statsitic =

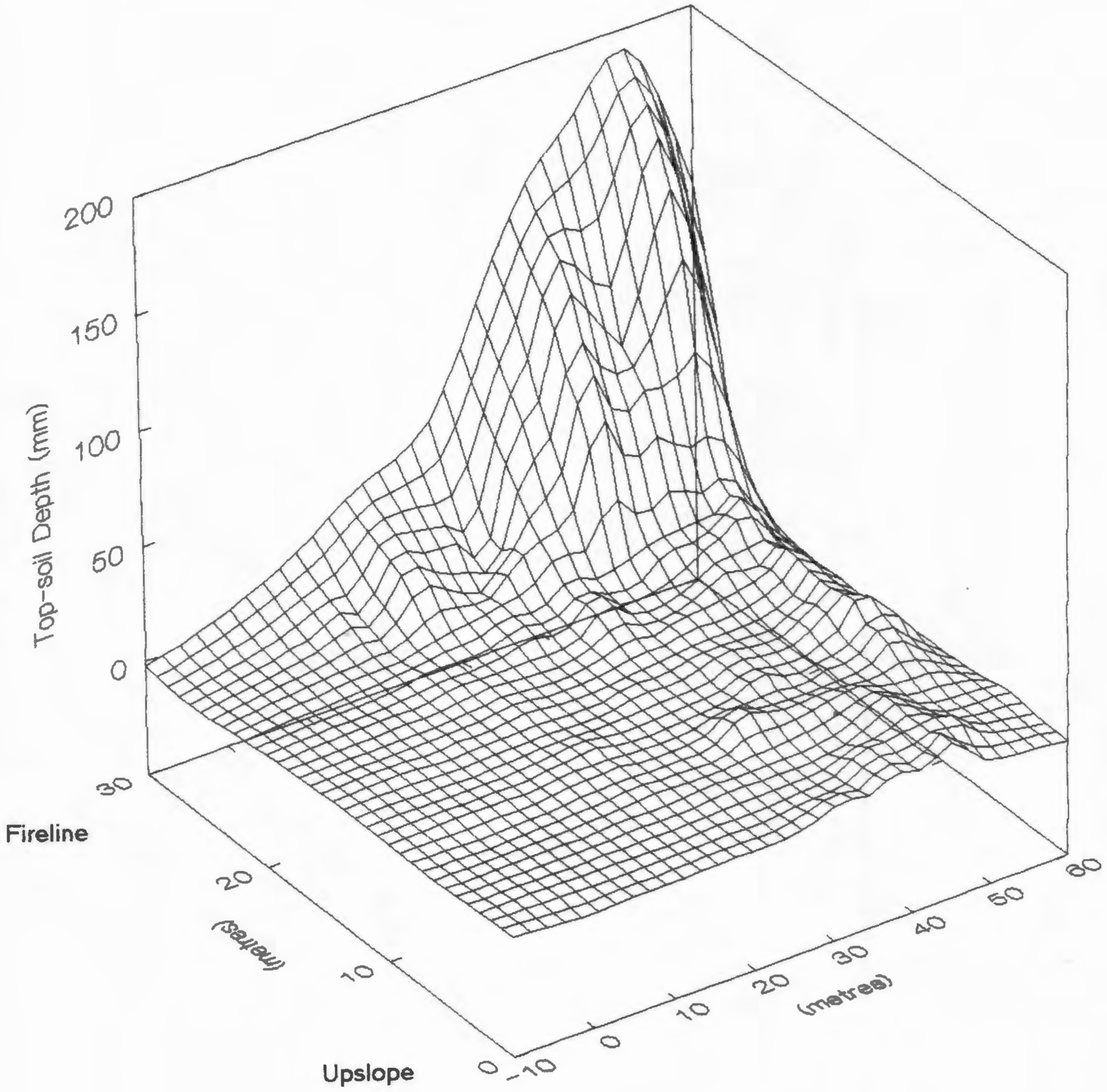

Figure 14. Soil overburden at the Chapman's Peak study site showing accumulation of sand along the fireline.

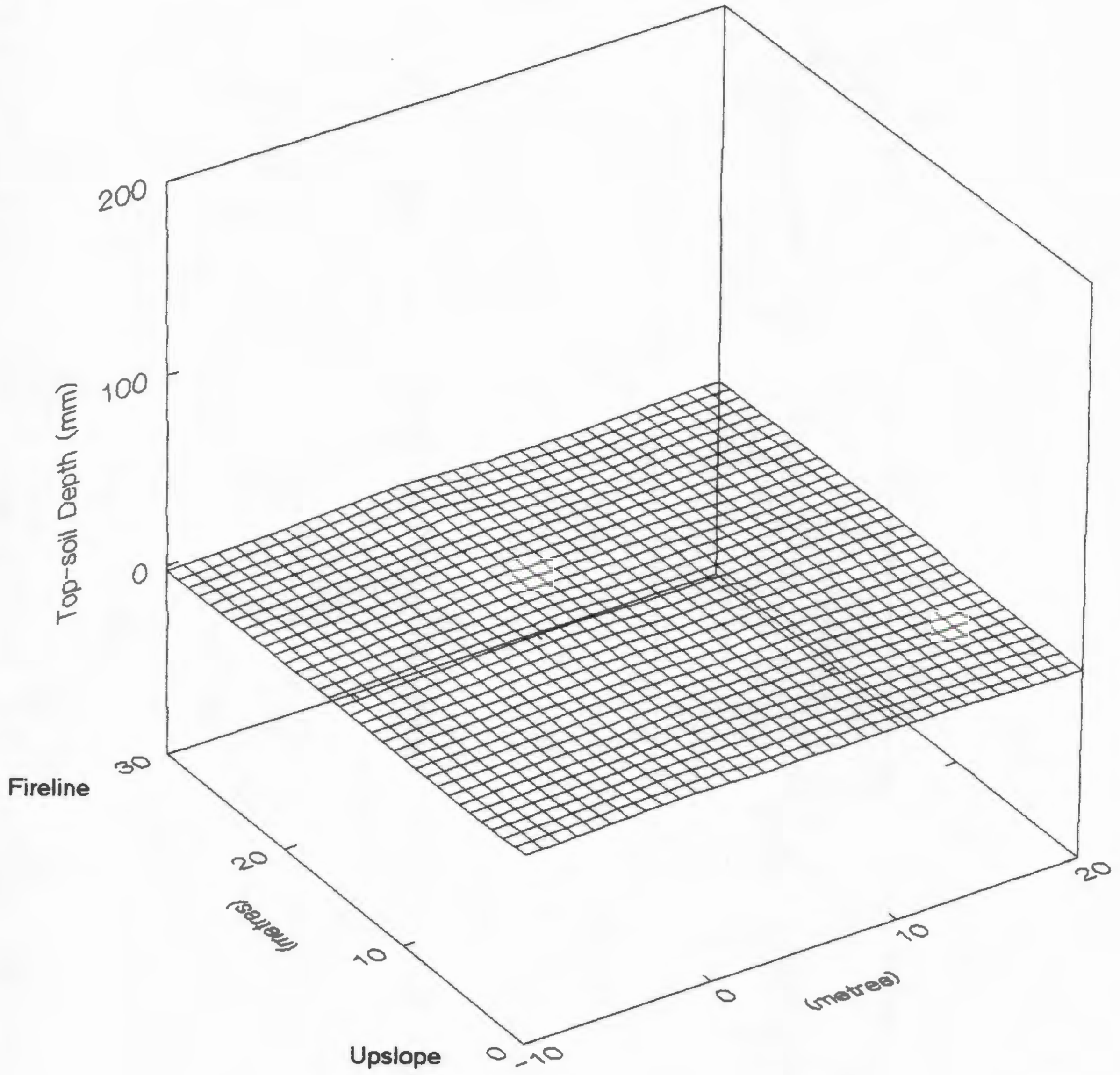

Figure 15. Soil overburden at the lion's Head study site showing no soil accumulation.

27.6, $p<0.0001$; Lion's Head: d.f. = 1, test ststistic = 32.9, $p<0.0001$). This is expected since the fireline was inundated with salt water. Nonetheless this data is important in confirming the width of the area inundated by the salt water, ensuring that investigations carried out upslope of the fireline are on areas not subjected to salt water.

It is interesting to note the high variability of the fireline data compared to the data obtained from the upslope areas of both study sites (Chapman's Peak standard errors: fireline = 147.3 μS, upslope = 24.6 μS; Lion's Head standard errors: fireline = 132.9 μS, upslope = 34.2 μS). This can be explained by the method of salt water application. The helicopter bombards the fireline many times and may make more than one drop along a single section of fireline if previous drops were unsuccessful in extinguishing the fire. Other areas of the fireline may however only receive salt spray carried by the wind.

Table 2. Conductivity measurements of soil samples collected at different depths from the upslope area (control) and along the fireline (treatment, salt water inundation) at the Chapman's Peak study site. Measurements represent salinisation of the soil and are measured in microSiemens (µS).

Depth	***Sample***										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**mean-depth**
Upslope:											
2cm	98	61	198	68	221	62	28	53	53	204	**104.6**
4cm	425	190	242	124	452	102	38	129	143	235	**208.0**
6cm	333	168	117	491	180	109	98	289	302	82	**216.9**
8cm	69	135	69	285	48	61	157	306	207	90	**142.7**
10cm	184	128	61	208	310	57	130	158	108	65	**140.9**
										S.E. (depth) =	21.5
mean - sample	**221.8**	**136.4**	**137.4**	**235.2**	**242.2**	**78.2**	**90.2**	**187.0**	**162.6**	**135.2**	
								S.E. (sample) =	24.6		
Fireline:											
2cm	720	982	262	158	42	72	298	158	191	831	**371.4**
4cm	1268	1271	245	340	59	139	348	425	990	855	**594.0**
6cm	1380	762	216	368	56	302	685	625	3580	1198	**917.2**
8cm	1143	658	200	403	92	316	225	685	1916	919	**665.7**
10cm	840	402	125	287	112	168	153	378	1078	465	**400.8**
										S.E. (depth) =	99.2
mean - sample	**1070.2**	**815.0**	**209.6**	**311.2**	**72.2**	**199.4**	**341.8**	**454.2**	**1551.0**	**853.6**	
								S.E. (sample) =	147.3		

Table 3. Conductivity measurements of soil samples collected at different depths from the upslope area (control) and along the fireline (treatment, salt water inundation) at the Lion's Head study site. Measurements represent salinisation of the soil and are measured in microSiemens (µS).

Depth	***Sample***										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**mean-depth**
Upslope:											
2cm	453	101	372	408	56	122	66	204	352	217	**235.1**
4cm	416	197	410	418	130	264	251	235	368	335	**302.4**
6cm	310	96	390	280	308	99	182	186	211	202	**226.4**
8cm	256	58	286	381	158	95	134	91	98	61	**161.8**
10cm	184	51	114	146	109	16	57	62	72	55	**86.6**
									S.E. (depth) =		36.6
mean-sample	**323.8**	**100.6**	**314.4**	**326.6**	**152.2**	**119.2**	**138.0**	**155.6**	**220.2**	**174.0**	
						S.E. (sample) =			34.2		
Fireline:											
2cm	279	235	986	1672	58	220	635	1215	550	339	**618.9**
4cm	1500	689	1490	725	146	310	721	2260	1123	520	**948.4**
6cm	1632	572	1132	668	159	354	540	1634	832	503	**802.6**
8cm	1541	225	786	542	96	159	491	724	845	287	**569.6**
10cm	1450	150	542	465	72	96	303	631	498	254	**446.1**
									S.E. (depth) =		102.6
mean-sample	**1280.4**	**374.2**	**987.2**	**814.4**	**106.2**	**227.8**	**538.0**	**1292.8**	**749.6**	**380.6**	
						S.E. (sample) =			132.9		

The values shown in tables 2 and 3 for the firelines of each study site represent the salinity of the soil 145 days after salt water inundation for Chapman's Peak and 70 days after salt water inundation for Lion's head. To be able to comment on maximum salinisation effects the soil salinity immediately after the salt water inundation needs to be calculated. Below is a rough calculation of the soil salinity of each study site immediately after inundation with salt water.

"Bambi bucket" capacity - **3500 liters sea water**

Approximate width of area inundated with one bucket - 10m
Approximate length of area inundated with one bucket - 35m
Approximate area inundated with one bucket - **350m^2**

3500 liters sea water / 350m^2
10 liters sea water / m^2

1 liter sea water = 33 grams of salt (salt concentration of sea water)
10 liters sea water = 330 grams of salt
therefore: **330 grams of salt covers 1m^2 of fireline**

1 liter of sea water was added to a pot with a radius of 15cm (area = 0,07m^2):
1 liter sea water = 33 grams of salt
therefore there was 33grams of salt covering the pot (0.07m^2)

33 grams salt / 0.07m2
471 grams of salt / 1m^2

Conductivity reading for pot = 4220 µS
Using standard curve (figure 4) this equates to 0.29g salt / 100g soil

471g salt / m^2 = 0.29 g salt / 100g soil
330g salt / m^2 = ?
ans: **0.20 grams salt / 100 grams soil in field.**

Chapman's Peak: 400m fireline estimated to have been inundated.
31 buckets at 35m fireline length per bucket
= 3 buckets per site.
0.20g salt / 100g soil * 3 = **0.60g salt / 100g soil**

Lion's Head: 350m fireline estimated to have been inundated.
55 buckets at 35m fireline length per bucket
= 5.5 buckets per site.
0.20g salt / 100g soil * 5.5 = **1.10g salt / 100g soil.**

It should be noted that these calculated values (Chapman's peak = 0.60g salt / 100g soil and Lion's Head = 1.10g salt / 100g soil) are average values for the post-fire salt concentration at any position along the fireline. The variability in salt concentration along the fireline is high (as shown by the standard errors in tables 2 and 3) and the actual salt concentration at any point along the fireline could therefore be less or very much greater than this average value.

The average salt concentrations for the Chapman's Peak fireline 145 days after the fire and for the Lion's head fireline 70 days after the fire are calculated from tables 2 and 3 respectively. The standard curves (figures 4-13) are used to translate the conductivity data presented in tables 2 and 3 into grams of salt per 100 grams soil (table 5). This allows for direct comparison with the immediate post-fire value of 0.60g salt / 100g soil for Chapman's Peak and 1.10g salt / 100g soil for Lions Head calculated above.

Table 5. Average conductivity measurements for the soil collected from the firelines (salt application) of both study sites converted into units of grams salt / 100 grams soil using the standard curves shown in figures 4 to 13.

	Chapmans Peak fireline		**Lion's Head fireline**	
Depth	Average conductivity (μS)	Salt concentration (g salt / 100g soil)	Average conductivity (μS)	Salt concentration (g salt / 100g soil)
2cm	371.1	0.03g	618.9	0.06g
4cm	594.0	0.03g	948.4	0.08g
6cm	917.2	0.05g	802.6	0.09g
8cm	655.7	0.04g	569.6	0.05g
10cm	400.8	0.04g	446.1	0.04g
Mean		**0.04g**		**0.06g**

It is clear that the salt from the sea water inundation has been leached from the soil at both study sites. The average salinity of the Chapman's Peak fireline decreased from 0.60g salt / 100g soil to 0.04g salt / 100g soil. Similarly, the Lion's Head fireline salinity decreased from 1.10g salt / 100g soil to 0.06g salt / 100g soil. This leaching process occured more rapidly at the Lion's Head site (over 70 days as opposed to 145 days at Chapman's Peak). This may be an effect of the steeper slope at Lions head, allowing greater drainage and runoff of dissolved salt after rains. The pattern shown by the conductivity readings plotted against soil depth may support the contention that slope affects leaching (see figures 16 and 17). There is a significant difference in the conductivity readings over depth for the firelines of both study sites (Analysis of variance on logged data; Chapman's Peak: n = 4, F-ratio = 2.80, $p<0.05$; Multiple range test shows 6cm depth to differ significantly from 2cm and 10cm; Lion's Head: n = 4, F-ratio = 4.06, $p<0.01$; Multiple range test shows 4cm depth to differ significantly from 10cm). Conductivity increases at a depth of 6cm for Chapman's Peak and at 4cm for Lion's Head. This may indicate that the salt at the Lion's head site was rapidly shifted downslope, preventing its penetration into the deeper soil layers. The shallower slope at Chapman's Peak on the other hand may have reduced the leaching process, allowing the salt to penetrate to deeper soil layers. These patterns could however simply be an effect of the soil types of the study sites. The Table Mountain Series Sandstone of Chapman's Peak is highly permeable, allowing easy penetration of the salt water dropped by the helicopter and of the salt following rains. The Table Mountain Series Lower Shale Band of Lion's Head on the other hand is less permeable, preventing penetration of the salt water and of the salt following rain. It is likely that the patterns observed in figures 16 and 17 are a result of the different leaching processes at each site (effect of slope) emphasised by the soil type at the site.

Vegetation regrowth

Figures 18 and 19 show vegetation cover over time for Chapman's peak and Lion's head respectively. There is no significant difference between the final vegetation cover values (measured on the 7th of September) of the fireline and upslope areas for either study site (t-test: Chapman's Peak: n = 25, $p>0.05$; Lion's Head: n = 25, $p>0.05$). Inundation by sea water has not therefore affected the overall vegetation regrowth of either study site. It interesting to note however that there is a significant decrease in vegetation cover for areas of

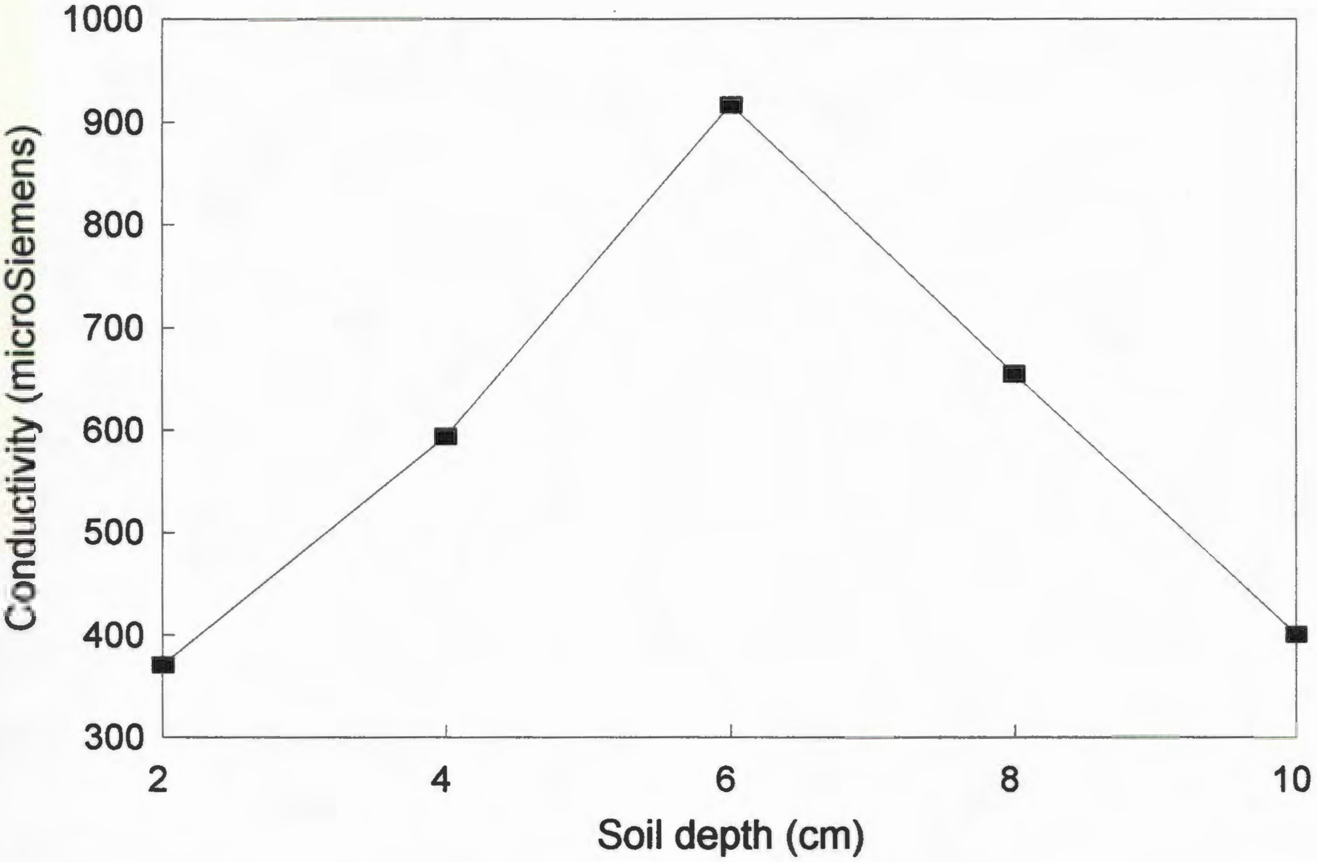

Figure 16. Chapman's Peak: Conductivity of the soil as a function of soil depth. The conductivity and therefore the salinity of the soil is highest at a soil depth of 6cm.

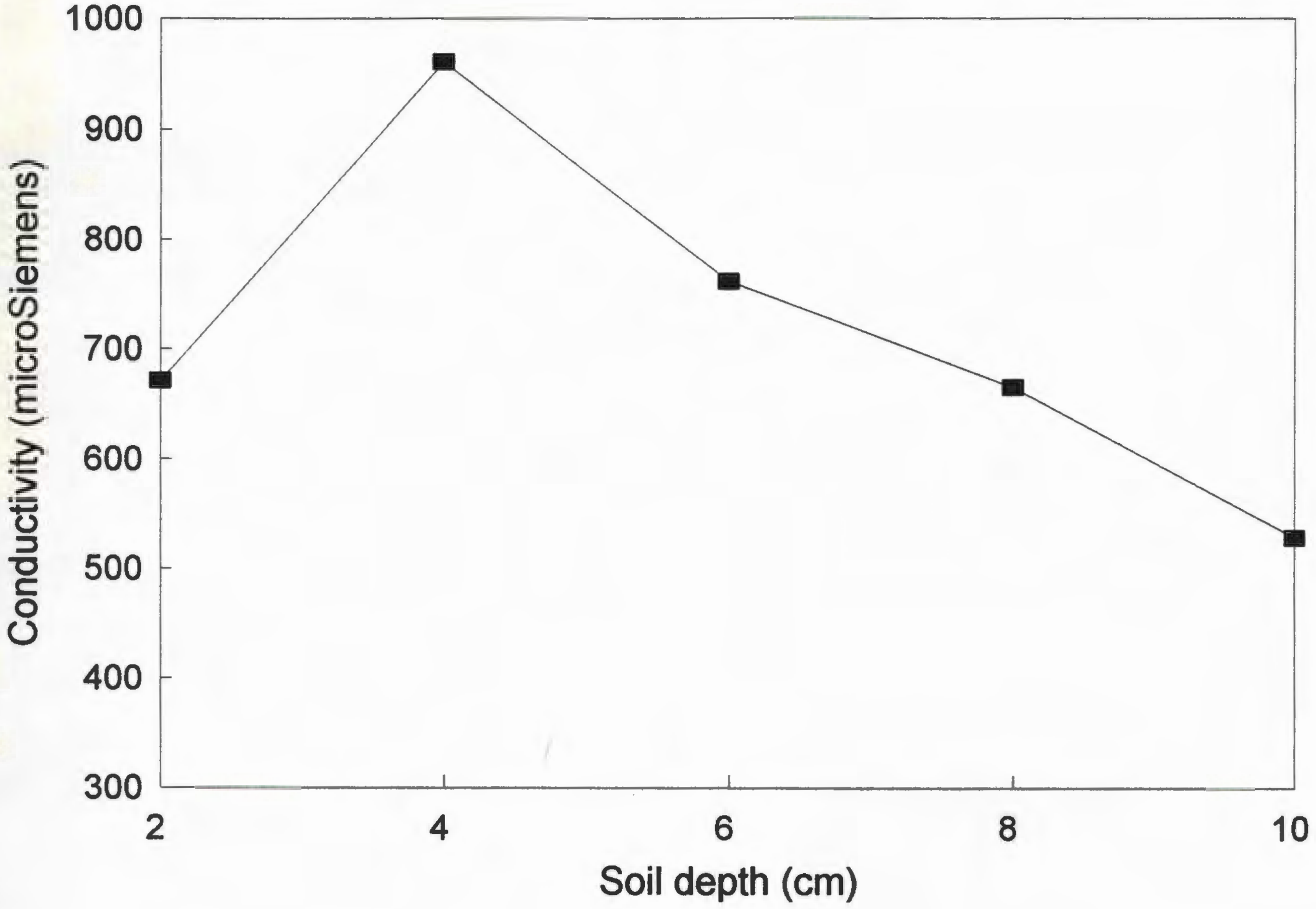

Figure 17. Lion's Head: Conductivity of soil plotted against the depth of the soil. The salinity of the soil is highest at 4cm depth.

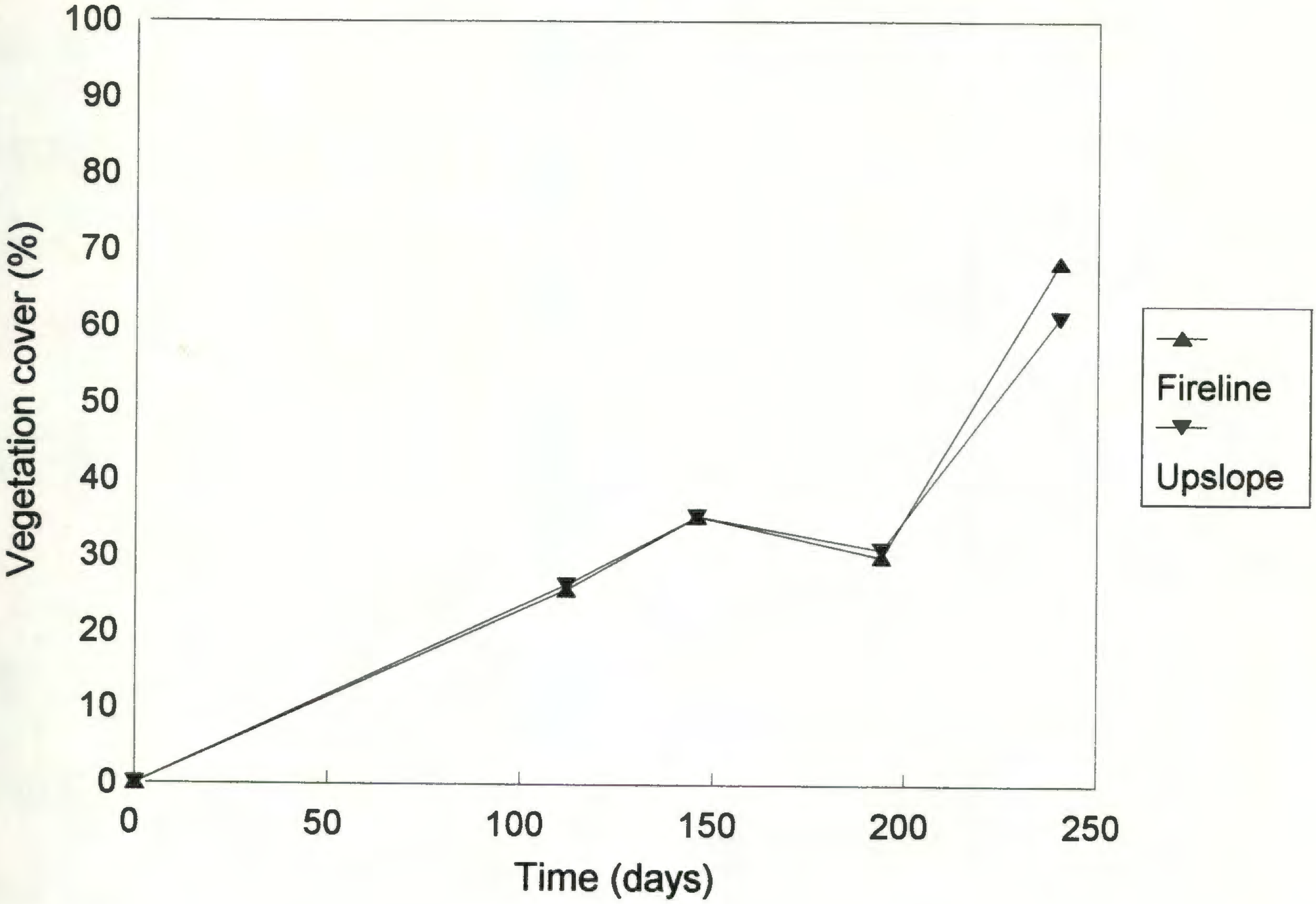

Figure 18. The vegetation cover of the fireline and upslope from the fireline of the Chapman's Peak study site. There is no significant difference between the final vegetation cover measurements made on the 7th of September (t-test, n = 25, p>0.05). Time zero represents the 8th of January 1995 when the area was burnt.

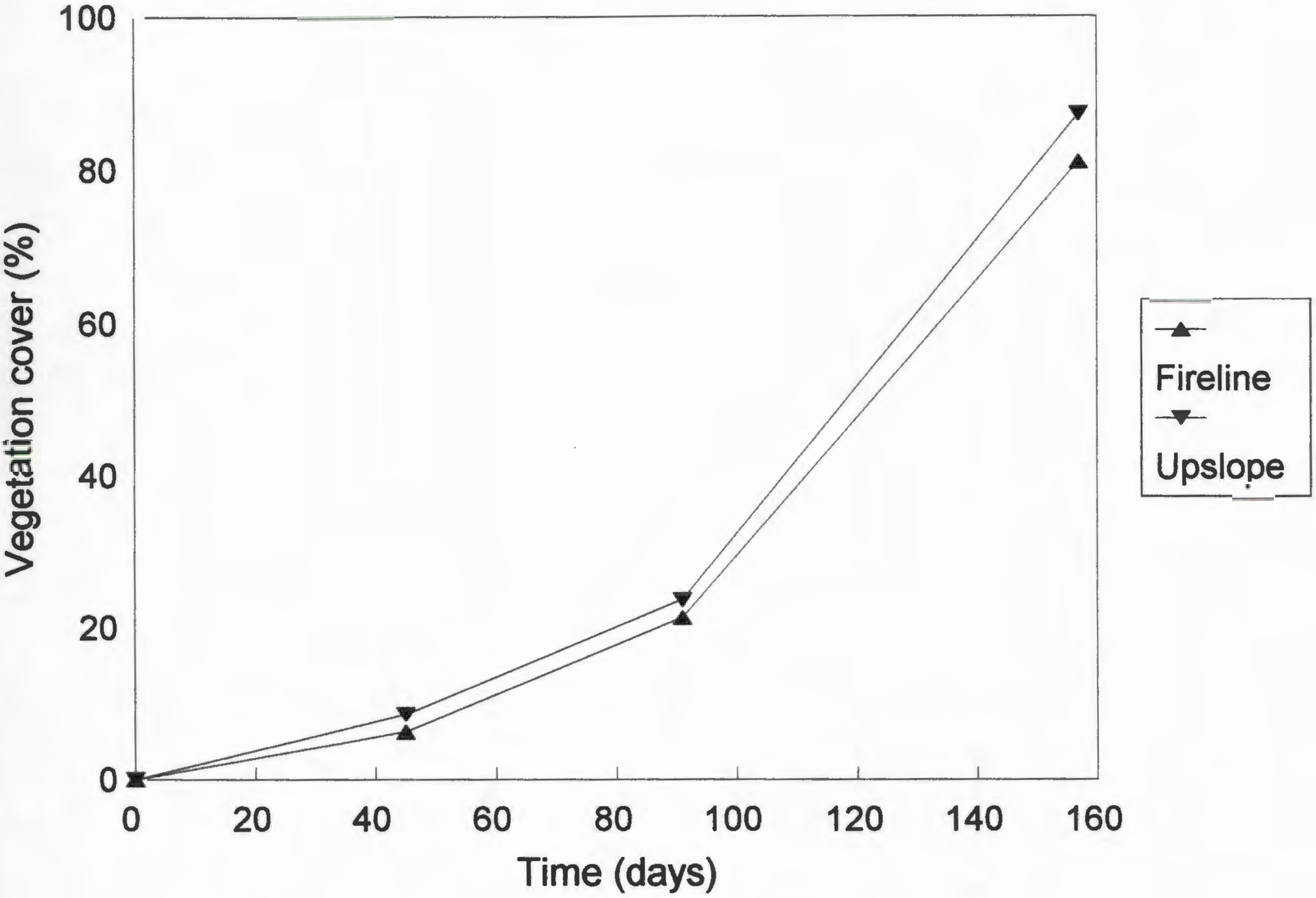

Figure 19. The vegetation cover of the fireline and upslope of the fireline at the Lion's Head study site. There is again no significant difference between the final vegetation cover readings (7th September, t-test, n = 25, $p>0.05$). Time zero represents the date of the Lion's Head fire, 23rd March 1995.

Chapman's Peak where the soil overburden depth is greater than 20cm (t-test: n = 15, p<0.01). The overburden appears to have suppressed vegetation regrowth, explaining the slower overall revegetation of the Chapman's Peak site. The sandy, nutrient deficient soil of Chapman's Peak may also however have contributed to the slower recovery of this site compared to that of Lion's Head.

Species composition

The results of the species composition analyses for the Chapman's Peak site and the Lion's Head site are shown in tables 6 and 7 respectively. The species recorded at each site have been divided into two classes, high cover and low cover. The high cover species are those that were recorded in a minimum of four of the six quadrats sampled at the study site. The low cover species were recorded in less than four of the quadrats for the study site. Only high cover species were analysed for differences in their percentage cover on the fireline and upslope from the fireline. For the Chapman's Peak site *Anthericum muricatum* and *Oxalis dentata* showed significant differences in percentage cover between the fireline and upslope areas (Lord's Range Test (for small sample sizes): *A. muricatum*; k = 2, n = 3, L = 1.00, p<0.05; *O. dentata*; k = 2, n = 3, L = 2.33, p<0.01). *O. dentata* showed increased cover along the fireline whereas *A. muricatum* was predominant upslope of the fireline. For Lion's Head an *Aspalathus* species showed significant presence upslope of the fireline and *Oxalis luteola* was predominant along the fireline (Lord's Range Test: *Aspalathus* sp.; k = 2, n = 3, L = 0.90, p<0.05; *O. luteola*; k = 2, n = 3, L = 0.64, p<0.05).

The predominance of *O. dentata* and *O. luteola* along the fireline may be a result of their resprouting geophytic nature which con~~in~~fers an advantage on these species under the conditions of salinity stress imposed by the fireline. The stored reserves of these geophytes makes them less dependent on the surrounding soil during the initial stages of growth (resprouting after the fire). It follows that these geophytes would be less affected by increased soil salinity than a seedling (for example an *Aspalathus* seedling) that is more dependent on the soil environment for both germination and growth.

Table 6. Estimated percentage covers (within a 5m^2 quadrat) of the species present along the fireline (salt treatment) and upslope of the fireline (control) at the Chapman's Peak study site.

	Upslope cover (%)				**Fireline cover (%)**			
Species		Sample				Sample		
	1	2	3	**mean**	1	2	3	**mean**
High cover species								
**Anthericum muricatum* L.f.	4	2	2	**2.6**	0	0.5	0	**0.2**
Aspalathus sp.	10	3	2	**5**	1	0.5	0	**0.5**
Fabaceae sp.	2	0.5	0	**0.8**	0.5	0	1.5	**0.7**
Ficinia nigrescens (Schrad) Raymal	7	1	10	**6**	0	1	20	**7**
Gnidia squarrosa (L.) Druce	0	1	4	**1.7**	5	1	0	**2**
Lobostemon glaucophyllus (Jacq.) Buek.	0	0.5	4	**1.5**	0	10	15	**8.3**
**Oxalis dentata* Jacq.	1.5	5	4	**3.5**	20	25	25	**23.3**
Ruchia sp.	0.5	0.5	1	**0.7**	0.5	0	0	**0.2**
Thamnochortus lucens (poir.) Linder	20	5	10	**11.7**	4	1	0	**1.7**
Low cover species								
Apiaceae sp.	0	0	2	**0.7**	0	0	0	**0**
Arctopus echinatus L.	0	0	4	**1.3**	0	0	0	**0**
Asteraceae sp.	0.5	0	0	**0.2**	0	0	0	**0**
Babiana sp.	4	0	8	**4**	0	0.5	0.5	**0.3**
Corymbium glabrum L.	0	0	0	**0**	0	0	0.5	**0.2**
Cullumia sp.	1	1	0	**.7**	0	0	3	**1**
Dischisma sp.	0	0	0.5	**0.2**	1	0	0	**0.3**
Euphorbia tuberosa L.	0	5	0	**1.7**	0	0	0	**0**
Euryops sp.	3	0.5	0	**1.2**	0	0.5	0	**0.2**
Ficinia filiformis (Lam.) Schrad.	3	0	0	**1**	0	2	0	**0.7**
Lachenalaia sp.	0	0	0	**0**	0.5	0	0	**0.2**
Lobelia coronopifolia L.	0	1	0	**0.3**	0	5	0	**1.7**
Manulea cheiranthus (L.) L.	0.5	0	0	**0.2**	0	0	0	**0**
Merxmuellera decora (Nees) Conert	0	0	3	**1**	0	0	3	**1**
Montinia caryophyllacea Thunb.	0.5	0	0	**0.2**	0	0	0	**0**
Penaea mucronata L.	1	0	0	**0.3**	0	0	0	**0**
Phylica stipularis L.	0	0	0	**0**	0	1	0	**0.3**
Pseudognaphalium sp.	0	0	0	**0**	0	1	1.5	**0.8**
Rumex sp.	0	0	0	**0**	0	0.5	0	**0.2**
Tetaria bromoides (Lam.) Pfeiffer	0	0	0	**0**	3	0	0	**1**
Watsonia sp.	0	0	0	**0**	0.5	0	0	**0.2**

* denotes a statistically significant difference

Table 7. Estimated percentage covers (within a 5m^2 quadrat) of the species present along the fireline (salt treatment) and upslope of the fireline (control) at the Lion's Head study site.

Species	**Upslope cover (%)**				**Fireline cover (%)**			
		Sample				Sample		
	1	2	3	mean	1	2	3	mean
High cover species								
**Aspalathus* sp.	8	10	8	**8.7**	5	0.5	3	**2.8**
Dischisma ciliatum (Berg.) Choisy	7	15	1	**7.7**	8	0	3	**3.7**
Eragrostis curvula (Sch.) Nees.	0	10	25	**11.7**	3	25	8	**12.0**
Erodium malachoides Willd.	35	15	10	**20.0**	20	5	6	**10.3**
Euryops abrotanifolius (L.) D.C.	3	2	2	**2.3**	2	1	1	**1.3**
Ficinia sp.	6	2	7	**5.0**	8	1	3	**4.0**
Homeria ochroleuca Salisb.	0.5	0	1	**0.5**	2	1	0.5	**1.2**
Hyparrhenia hirta (L.) Stadf.	2	0	2	**1.3**	8	0	4	**4.0**
Lichtensteinia lacera Cham.& Sch.	0.5	1	0.5	**0.7**	0.5	0	0.5	**0.3**
**Oxalis luteola* (Jacq.)	1	0	0	**0.3**	2	4	8	**4.7**
Trachyandra muricata L.f.	2	1	2	**1.7**	1	0.5	2	**1.2**
Zaluzianskya villosa (Thunb.) F.W. Schmidt	0	0	1	**0.3**	1.5	0.5	2	**1.3**
Low cover species								
Androcymbium eucomoides (Jacq.)	0	0	0	**0**	7	0	0	**2.3**
Babiana stricta (Ait) Ker-Gawl.	0	0	0	**0**	2	0	0	**0.7**
Bromus sp.	0	0	0	**0**	1	0	0	**0.3**
Chasmanthe floribunda (Salisb.) N.E. Br.	0	5	5	**3.3**	0	0	1	**0.3**
Dorotheanthus bellidiformis (Burm. f.) N.E. Br.	1	0	0	**0.3**	0	0	0	**0**
Euphorbia peplus L	1	0	0	**0.3**	0	0.5	0	**0.2**
Gnidia squarrosa (L.) Druce	5	0	1	**2**	0	0	3	**1**
Helichrysum sp.	0	0	0	**0**	0.5	0.5	0	**0.3**
Montinia caryophllacea Thunb.	0	0	0	**0**	0.5	0	0	**0.2**
Nemesia barbata (Thunb.) Benth.	0	2	1	**1**	0	0	0.5	**0.2**
Oxalis dentata Jacq.	0	0	0	**0**	0	0	15	**5**
Oxalis obtusa Jacq.	0	0	0	**0**	0	3	5	**2.7**
Pelargonium sp.	0	0	0	**0**	0	0	2	**0.7**
Ruschia sp.	0	0	0.5	**0.2**	1	1	0	**0.7**

* denotes a statistically significant difference

Greenhouse experiments

The number of plants per species that germinated under each treatment is shown in table 8. The data represents germination over a three month period. There is a general trend of decreasing germination with increasing salt concentration of the treatment, however only *Wachendorfia thyrsiflora* and *Watsonia tabularis* showed significant total germination for statistical analyses to be performed on the results obtained. Both *Wachendorfia thyrsiflora* and *Watsonia tabularis* showed a significant difference in germination with treatment (Parametric: One-way analysis of variance; *W. thyrsiflora*, d.f. = 4, 20, F-ratio = 29.4, $p<0.001$; *W. tabularis*, d.f. = 4, 20, F-ratio = 11.6, $p<0.001$; Non parametric (germination data is discrete): Kruskal-Wallis analysis; *W. thyrsiflora*, t-statistic = 16.7, $p<0.01$; *W. tabularis*, t-statistic = 15.4, $p<0.01$). For both species, germination under fresh water is significantly higher than germination under any of the salt treatments (Multiple Range Analysis, see table 9.). It is clear therefore that increased soil salinity retards germination. The mechanism behind this is the hinderance of the seed's water uptake through increased osmotic pressure of the soil water (McBride, 1994).

Table 8. Maximum number of seedlings germinated per species under each of the five salinity treatments (FW, 33%, 66%, 100% and 200%). Data represents germination over 3 months.

Treatment	**Species**					
	P.pubescens	*P.sericea*	*L.glabrum*	*E.mammosa*	*W.thyrsiflora*	*W.tabularis*
FW	16	5	2	10	38	46
33%	3	3	0	0	2	25
66%	2	2	0	0	15	34
100%	0	2	0	0	0	5
200%	0	0	0	0	2	2

Table 9. Germinatation data for *W. thyrsiflora* and *W. tabularis* under each of the five salinity treatments. Multiple Range analysis shows where significant differences in germination between salinity treatments were obtained.

Treatment (% sea water)		**Replicate pots**						**Multiple Range Analysis:**
	1	**2**	**3**	**4**	**5**	mean	std. error	* Lines represent no significant difference.
W. thyrsiflora								
FW	4	5	9	7	6	6.2	0.86	FW
33%	2	0	2	0	0	0.8	0.49	33% │
66%	0	1	0	0	0	0.2	0.20	66% │
100%	0	0	0	0	0	0.0	0.00	100% │
200%	0	2	0	0	0	0.4	0.4	200% │
W. tabularis								
FW	9	10	10	13	10	10.4	0.68	FW
33%	7	8	10	3	0	5.6	1.80	33% │
66%	0	7	10	9	5	6.6	1.77	66% │
100%	0	0	1	3	1	1.0	0.55	100% │
200%	2	0	0	0	0	0.4	0.40	200% │

Of the seedlings that germinated, many began to die after about one month. This was characterised by browning of the leaves, whole plant wilting and then decay. Table 10 shows the percentage of germinated seedlings of each species that died under each treatment. A death index is calculated for each species by dividing the percentage death under the fresh water treatment by the sum of the percentage deaths for the salt treatments. It follows that the lower the death index, the more sensitive the species is to high soil salinity. *Erica mammosa* and *Leucospermum glabrum* are not included in the death analysis as no germination occurred in the treatment pots for these species. From table 10 it is clear that *Podalyria sericea* is the most salt tolerant species (with a death index of 1.2). The rooting depths of the seedlings are included in table 10. It is possible that a greater rooting depth allows increased survival under saline conditions. Seedlings with deep roots are able to obtain water from deeper soil layers (with less salt and therefore a lower osmotic pressure). The plant is therefore less hindered in it's water uptake than those with shallow rooting systems.

Table 10. Percentage death of seedlings of four species during active growth under the five salinity treatments. A death index is also calculated for each species as follows: Death Index = percentage death under fresh water treatment / sum of the percentage deaths under the salt treatments.

Treatment	**Percentage death**			
	P.pubescens	*P.sericea*	*W.thyrsiflora*	*W.tabularis*
FW	0	40	5	2
33%	0	33	100	44
66%	50	0	6	94
100%	*	0	*	100
200%	*	0	100	100
FW/sum (33%..200%)	0	1.2	0.02	0.01
Mean rooting depth (mm)	28.6	65.7	59.1	54.8

* indicates that no seedlings have germinated for this species under the particular treatment.

Do the greenhouse experiments reflect field conditions?

The salt concentration values (in grams salt / 100 grams soil) of the soil under the varying salinity treatments in the greenhouse are shown in table 11. Salt concentration immediately after salt water treatment and 75 days after treatment are both shown. These analyses were made in terms of conductivity (microSiemens) and converted to salt concentration using the standard curve in figure 4. In addition the salt concentration estimates made for the fireline soil directly after salt water inundation are shown together with the salt concentration values measured for the firelines after 145 days for Chapman's Peak and 70 days for Lion's Head.

Table 11. Comparison of salt concentrations (g salt / 100g soil) used in the greenhouse experiments with those in the field.

	Days after treatment	
Greenhouse		
	0 days	**74 days**
FW	0.02	0.02
33%	0.12	0.10
66%	0.22	0.20
100%	0.29	0.28
200%	0.40	0.39
Field		
Chapman's Peak		
	0 days	**145 days**
	0.60	0.04
Lion's Head	**0 days**	**70 days**
	1.10	0.06

The pots in the greenhouse were watered every day for the first 30 days and then every second day for the following 2 months. The pots were watered with a fine spray until the soil became completely saturated and water drained out of the base of the pot into the base container. Despite this intense watering little leaching is observed. This is possibly due to the base container of each pot which prevents the salt from being removed.

The soil salinity of both Chapman's Peak and Lion's Head following inundation of the firelines with salt water is higher than the salinity represented by the 200% treatment pots in the greenhouse. These pots showed little or no germination, the salt at this concentration causing a major negative effect on germination. The salinity at the field sites however rapidly decreased with time and after 145 days for Chapman's Peak and 70 days for Lion's Head the soil salinity correlates with a salinity less than that in the 33% treatment pots. At this soil salinity effects on germination may be negliable. Leaching is therefore an essential component of these study sites relieving the salinity stress, allowing the vegetation to recover from the fire.

Discussion

The use of sea water dropped by helicopter to extinguish fires in Cape Mountain Fynbos can adversely affect the fynbos ecosystem in two ways, physically and chemically. The effect of the physical impact of the water bombarding the fireline appears to be negligible, unless the soil is sandy (for example Table Mountain Series Sandstone). Sandy soil is prone to movement on impact and an overburden of coarse-grained soil accumulates along the fireline. This soil overburden does not however seem to have a large effect on vegetation regrowth and as such is of little concern in terms of erosion. Where feasible however, when extinguishing fires with water dropped by helicopter, the "monsoon bucket" should be favored over the "bambi bucket" to reduce possible physical effects on the fynbos ecosystem.

The chemical effects on the fynbos ecosystem are more pronounced than the physical impacts. The major chemical change resulting from the use of sea water is the salinisation of the inundated soil. Immediatly after dowsing, the soil environment along the inundated fireline exceeds that of the 200% treatment in the greenhouse experiment, which was found to adversely affect seed germination and growth. The soil salinisation resulting from inundation of the fireline with salt water should therefore adversely affect vegetation regrowth in the field and possibly lead to erosion of the area. The results obtained from the field suggest however that the effects of soil salinisation on the vegetation were not significant in terms of vegetation regrowth. This can be attributed to the rapid leaching that occurred at each site, reducing the salinities of the soil to below that represented by the 33% greenhouse treatment. If however, leaching does not occur to the extent that it has at the two sites studied, salinity stress will not be relieved and the vegetation may be adversely impacted by the salt water inundation. A reduction in vegetation may act as an erosion trigger leading to the loss of top-soil and to the degradation of the ecosystem,. Such high risk sites can be defined in terms of their topography and soil type, since sites with a low slope increment and fine clay soil types will be the most prone to reduced leaching, leading to erosion through the suppression of vegetation regrowth.

In addition, the use of salt water to extinguish fires may have adverse effects on rare and localised species within the fynbos. If these are very sensitive to salt stress or if their habitat is a high risk (low leaching) site, the application of salt water may eliminate a large proportion of the population in the area. This may lead to local extinction, which would be detrimental to the species if very few populations existed. The risk of species extinction of would oppose the management aim of maintaining biodiversity in the fynbos ecosystem.

Conclusions

High risk areas within the fynbos can be defined where the use of sea water to extinguish the fires may lead to effects on the fynbos ecosystem that contradict the management aims. These are areas that have one or more of the following characteristics: flat topography with a fine clay soil type; the presence of rare and localised species; or the presence of exceptionally sandy soil. If the site in question is not characterised by any of the above features the impacts of using sea water to dowse fire should be low. The impacts may include slight changes in species composition, and slight accumulation of soil overburden, along the fireline. The importance of these effects is negligible and outweighed by the economic and larger-scale economic risks of a fire, such as the loss of life and property and the ecological risks associated with burning immature fynbos.

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