The effect of air pollution on lichen distribution, diversity and abundance in Hell's Gate National Park

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Abstract

The affect of airborne pollution from the geo-thermal power plant in Hell's Gate National Park on lichen cover, diversity and height was investigated in this study. Sampling of lichens focused on two tree species, *Acacia drepanolobium* and *Tarchonanthus camphoratus,* and was carried out in three areas of the park, one heavily impacted by the power plant and two control sites. As lichens are well-documented indicators of air pollution, it was expected that lichen distribution and abundance would be negatively affected by air pollution. The results showed a gradient of increasing lichen cover and diversity with increasing distance from pollution discharge points. Transects upwind of these points also showed greater cover, diversity and height than those downwind of the pollution points. Comparisons between the three sites revealed significantly higher cover, diversity and height at one control site. In the other control site only cover was significantly higher than that of the polluted area. The results suggest that pollution is affecting lichen at a small scale in the vicinity of the power plant. The picture for the whole park is less clear with other environmental factors possibly affecting lichen distribution and abundance.

INTRODUCTION

Lichens are a symbiosis between a fungus, known as the mycobiont, and a photosynthetic organism, either a green alga or cyanobacteria species, the photobiont. They have a wide variety of growth forms, the main morpho-types being crustose (the lichen thalli form a crust over the substrate), foliose (the thalli are 'leafy' with distinct upper and lower sides) and fruticose (the thallus has a shrub-like appearance or is branched) (Swinscow & Krog 1988). Lichen-dominated vegetation comprises 8% of the terrestrial surface of the Earth and they are found in a diverse range of habitats. They are found from the artic tundra (where lichens are the dominant species), throughout temperate and tropical regions, to hot, dry deserts.

Lichens grow on a wide range of substrates, both natural and man-made, and obtain their required nutrients and water directly from the atmosphere. This uptake of nutrients from the atmosphere means lichens are good indicators of environmental disturbance as they bio-accumulate airborne pollutants. Excessive levels of pollutants in the atmosphere, in particular sulphur dioxide ($S0_2$), can alter the physiology and morphology of sensitive species, ultimately killing them and thus changing lichen community structure (Haffner *et al.* 2001, Purvis 2000). The use of lichens as indicators of air pollution has been well studied in Europe and northern America (Loppi & Frati 2006, Thormann

2006, Pinho *et al.* 2004), however, little is known about air pollution and its effects on lichen in Africa.

This study examined lichen distribution and diversity in Hell's Gate National Park and the possible effect, if any, of air pollution on the various lichen species. Hells Gate National Park is an excellent site for studying this phenomenon as it contains a geo-thermal power plant, which releases $S0_2$ into the atmosphere, and an abundance of lichen species. In preliminary observations, it was noted that, within the park, lichens were growing on various tree species, in particular *Acacia drepanolobium* and *Tarchonanthus camphoratus.* The diversity, density and growth-forms of lichens appeared to vary in different areas of the park with lichens in some areas being both larger in size and more abundant, and the variety of species seemed to differ also. The aim of this study was to find out if there is a relationship between the presence of the power plant (and its associated air pollutants), and the distribution and diversity of lichens.

Hypotheses

The overall objective of this study was to determine whether lichen cover, diversity and growth vigour with increasing distance from the geothermal power plant in Hell's Gate National Park. This was studied both on a small scale (by inspecting possible gradients running 100 metres from steam discharge points) and on the larger park scale (by comparing the power plant site with two control sites elsewhere in the park).

The following predictions were tested in order to address the main hypotheses:

(i) There is a gradient of increasing percentage cover, diversity and height of lichens with increasing distance along a 100 metre transect from steam discharge points.

(ii) Lichen cover, diversity and height are higher on trees south of steam discharge points compared to trees growing north; trees on the northern side are expected to be more subjected to air pollution since the prevailing wind direction is north.

(iii) There are no differences between trees in similarly oriented transects in the control sites with respect to percentage cover, diversity and height of lichens.

(iv) Percentage cover, diversity and height of lichens is lower on trees growing in the power plant site compared to trees growing in the control sites.

METHODS

Sampling sites

The study was conducted in Hell's Gate National Park, which is located in the rift valley region of central Kenya, 100km northwest of Nairobi and close to lake Naivasha. The park is a topographically diverse savannah ecosystem, with large open grassland areas and shrub-land dominated by *Acacia drepanolobium* and *Tarchonanthus camphoratus.* Three sites of similar altitude were selected within the park: Ol-karia power plant (S 00 53 217/ E 036 18 527, 1946 m asl), Ol Dubai picnic site (S 00 51 900/ E 036 20 929, 1984m asl) and lake viewpoint (S 00 50 632/ E 036 19 113, 2260 m asl). The sampling period was from the 19^{th}-23^{rd} of September 2006. The prevailing wind direction was to the north.

Sampling method

Six paired transects totalling 100 metres per pair (50 metres north and 50 metres south of a defined point) were conducted in each sampling site. Within the power plant site, 50 metre transects were run north and south of steam discharge points (Fig. 1). The same method was applied in the other sampling sites with randomly generated starting points substituting for the steam discharge points. At the power plant site it was not possible to have starting points at equal distances for all the transects due to the presence of roads, fences and other obstructions. This discrepancy was adjusted for each of the steam discharge points by adding the distance from the vent to the starting points of both north and south transects to the total measured distance along the transect lines. These distances were 50, 30 and 15 metres respectively, resulting in a gradient with a total length of 100 metres for both transect directions.

Along each 50 metre transect, 10 *Tarchonanthus camphoratus* and 10 *Acacia drepanolobium* trees were sampled within 3 metres of each side of the transect. Lichen diversity, (i.e. total number of species found per tree), maximum lichen height (mm) and percentage cover of the main trunk were recorded. Percentage cover was estimated using a presence/absence method along the first metre of the main trunk. Starting from the base, a mathematical compass, calibrated at 3 cm, was 'walked' up the tree along the centre of the main trunk. Lichen presence or absence was noted for 30 points where the point of the compass fell, resulting in an estimated percentage cover. Other variables noted for each tree were the distance from the transect start point (m); the diameter at waist height (dwh, cm); species of ant on acacias (if present); and the tree status (alive, damaged, dead). For each sampling site, the GPS location, altitude, relative humidity, temperature and wind direction were recorded.

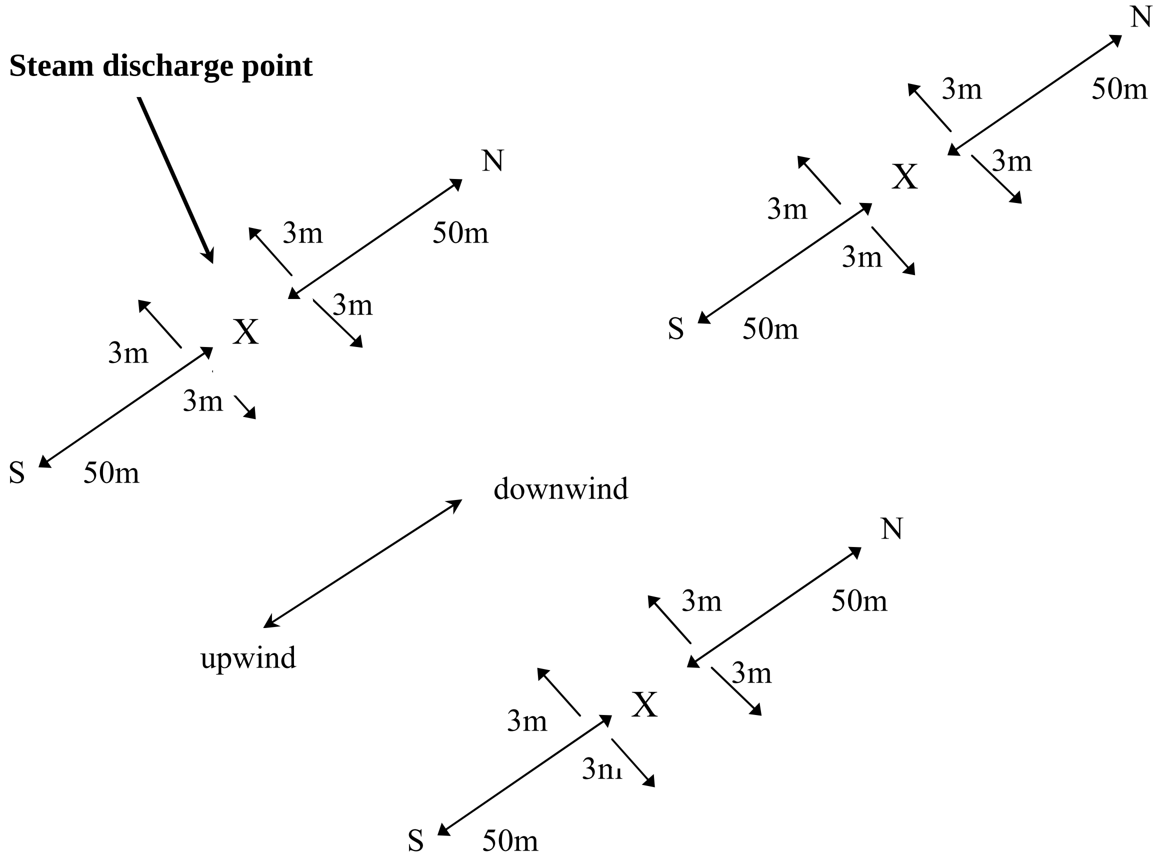

Fig. 1 Schematic of transect sampling method for the power plant site.

Lichen collection

Samples of lichen species found in each site were collected for later identification (if possible) and in order to create a reference 'Lichenarium' for Hell's Gate National Park.

Statistical analysis

Data were analysed using Statistical Package for Social Science (SPSS). All the collected data was analysed for normality using Kolmogorov-Smirnov tests, the data were not normally distributed and therefore non-parametric tests were used. Correlations were carried out for the variables lichen cover, diversity, height and distance in order to detect a gradient from the steam discharge points in the power plant site. The data for the three transects of the same direction were pooled and the analyses were carried out separately for both transect directions. Spearman's rank correlation test was used to assess any gradient present along the transects in the power plant site for each direction. A Mann-Whitney test was used to compare percentage cover; diversity and height between the two transect directions. The north and south transects were also compared for the other sample sites in order to detect any patterns that may have occurred.

On the scale of the park we pooled all the data for each area and compared the three areas for differences in percentage cover, diversity and height using Kruskal-Wallis tests. Tukey HSD post-hoc tests were used in order to determine between which of the sites significant differences occurred. Results are presented in scatter-plots and bar graphs, with bars showing means and error bars showing standard errors. Letters above bars denote significant differences.

RESULTS

Lichen cover, diversity and height around the power plant

Within the power plant site a total of 120 trees were sampled. Percentage lichen cover on the main trunk of both tree species showed a relationship to the distance from the pollution discharge point (Fig. 2). For both wind directions, there was a positive correlation between distance from the discharge point and percentage cover (Spearman's rank correlation: north transects: $r = 0.292$, $n = 60$, $p = 0.024$; and south transects: $r = 0.281$, $n = 60$, $p = 0.030$).

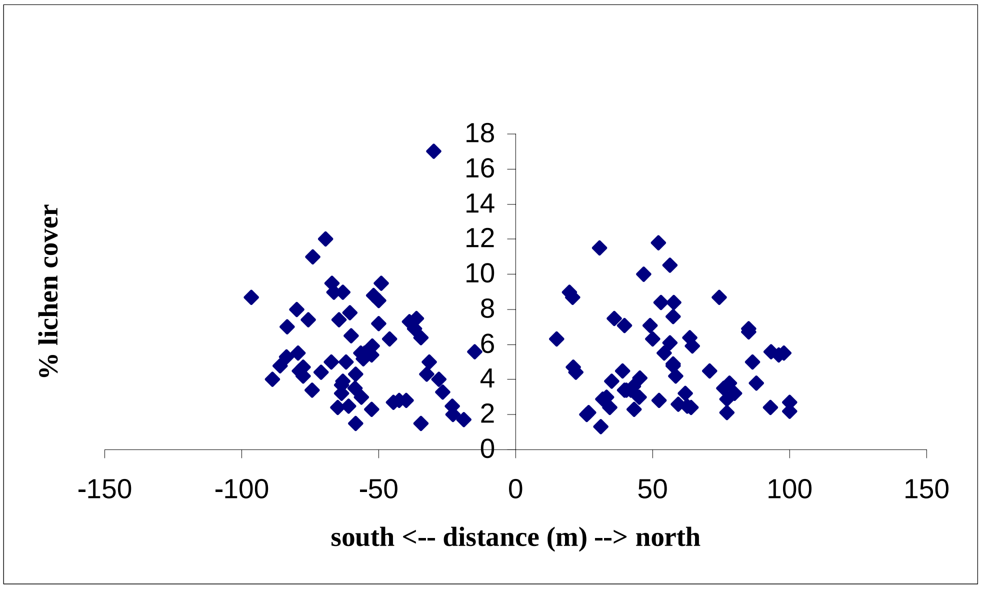

Fig. 2 Percentage lichen cover versus distance in the power plant site.

The number of lichen species found on trees north of steam discharge points increased with increasing distance from the pollution source (Spearman's rank correlation: $r = 0.461$, $n = 60$, $p < 0.001$) (Fig. 3). There was no relationship between distance from the discharge point and the number of lichen species on the southern transects (Spearman's rank correlation: $r = 0.67$, $n = 60$, $p = 0.611$). Lichen height is not affected by increasing distance from the discharge points in both the north (Spearman's rank correlation: $r = 0.004$, $n = 60$, $p = 0.975$) and south transects (Spearman's rank correlation: $r = -0.144$, $n = 60$, $p = 0.273$).

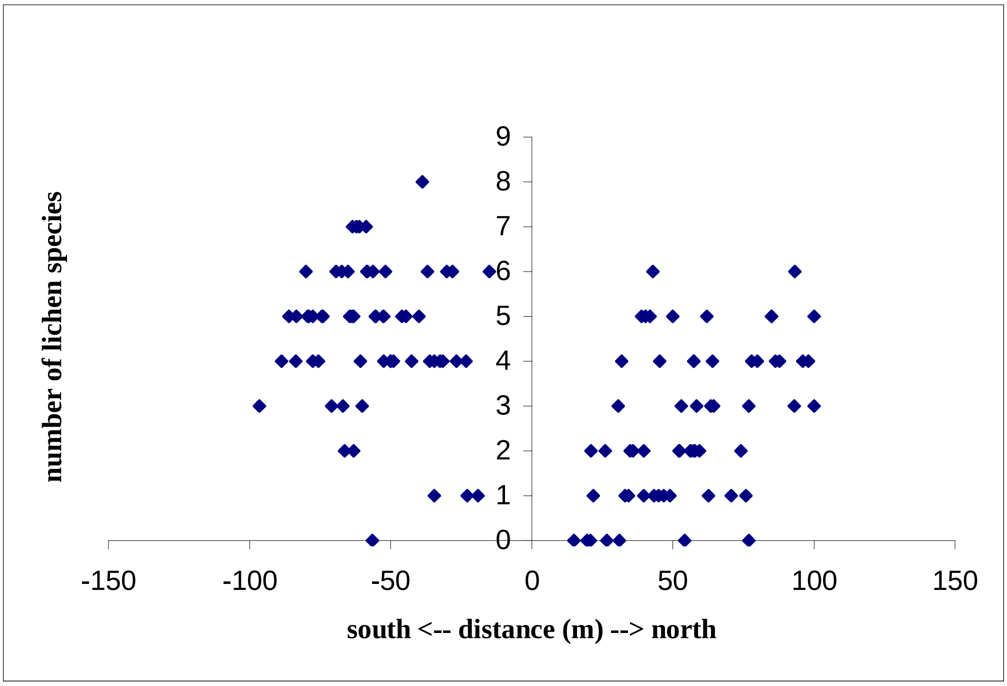

Fig. 3 Number of lichen species versus distance in the power plant site.

Lichen cover was compared between the transects north and south of steam discharge points (Fig. 4). Median percentage cover was higher on trees south of steam discharge points compared to trees north of these points (Mann-Whitney test: $n = 120$, $Z = -2.028$, $p = 0.043$). Both the median number of lichen species and the lichen height were higher on trees found on transects south of the steam discharge points (Mann-Whitney test: $n = 120$, $Z = -5.682$, $p < 0.001$ and $n = 120$, $Z = -3.442$, $p = 0.001$; respectively) (Fig. 5 and 6).

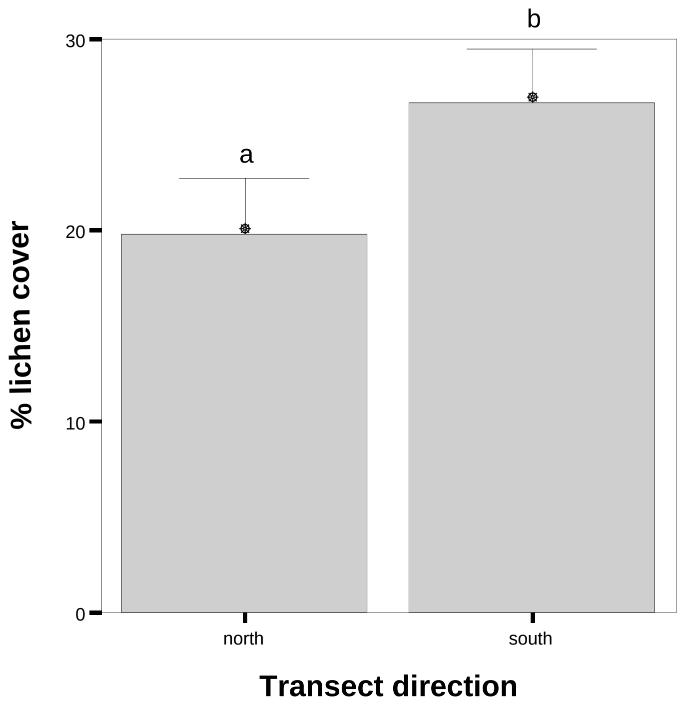

Fig. 4 Percentage lichen cover in the power plant site.

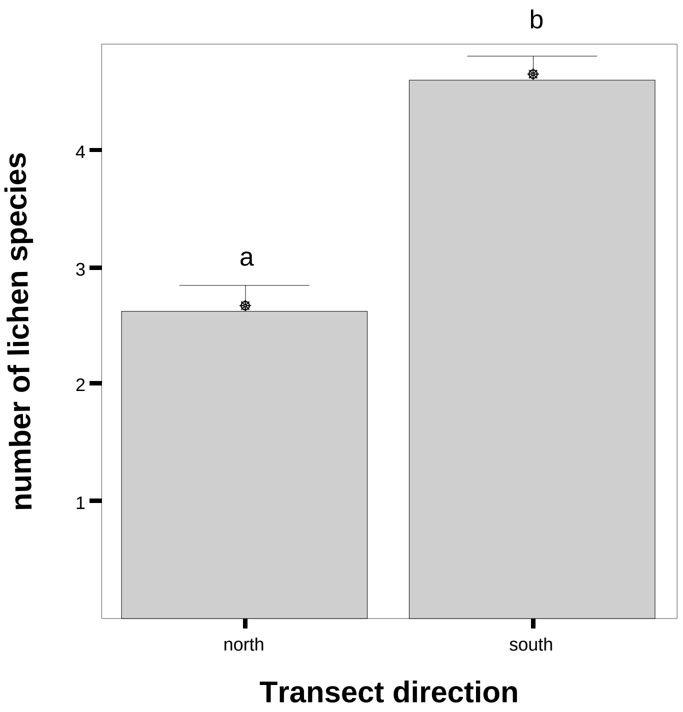

Fig. 5 Number of lichen species in the power plant site.

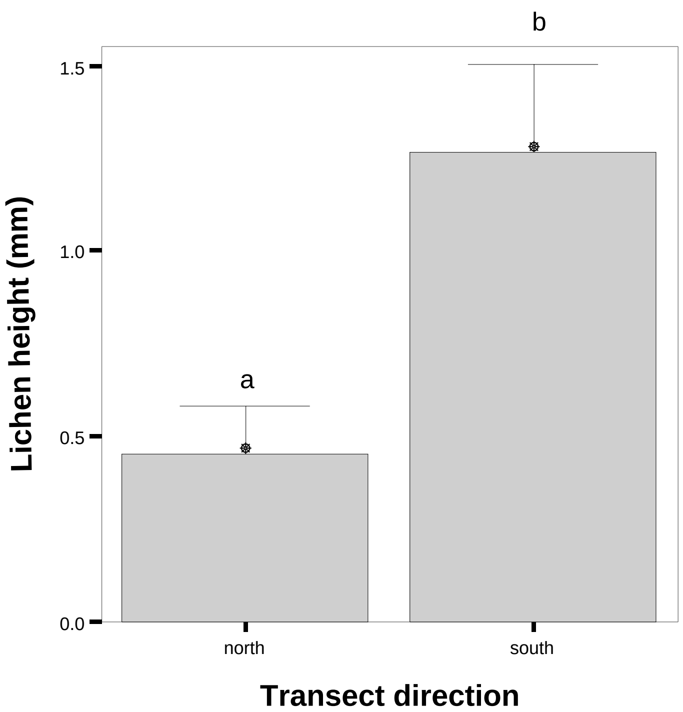

Fig. 6 Lichen height in the power plant site.

Additionally, the data for percentage cover; number of lichen species and lichen height for transects north and south within the viewpoint and picnic sites were compared using Mann-Whitney tests (Table 1).

Table 1 Overview of p-values of comparisons between north and south transects

	% lichen cover	Number of lichen spp	Lichen height
Power plant site	p = 0.043 *	p < 0.001 ***	p = 0.001 ***
Picnic site	p = 0.754	p = 0.001 ***	p = 0.222
Lake view point	p < 0.001***	p = 0.062	p = 0.084

* Denotes levels of significance: * ≤ 0.05, ** ≤ 0.01, *** ≤ 0.001

Lichen cover, diversity and height in the three sites

Data for both tree species and wind directions were pooled for each sampling site and compared for percentage lichen cover for the three sites (Fig. 7). Percentage cover was lowest on trees in the power plant site, whereas the lake viewpoint site had the highest lichen cover (Kruskal-Wallis test: $\chi^2 = 68.089$, df = 2, n = 360, p < 0.001).

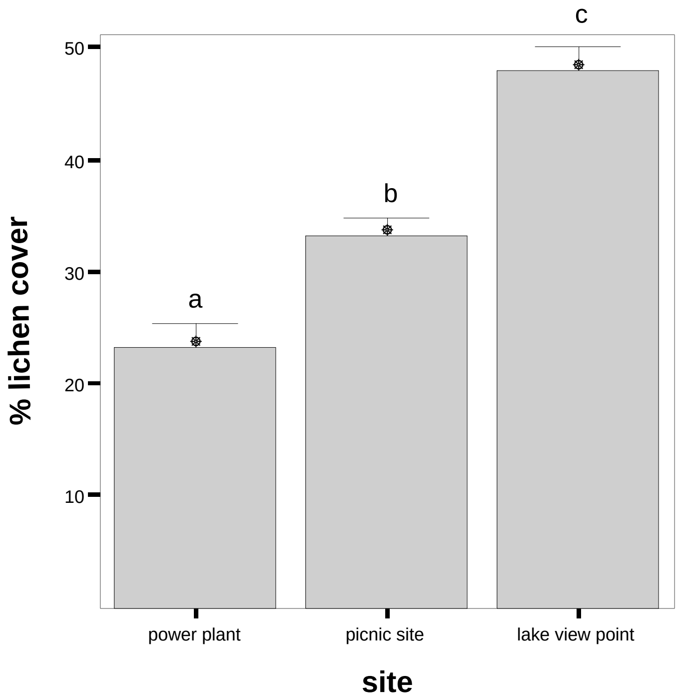

Fig. 7 Percentage lichen cover for the three sites.

The median number of lichen species did not differ between the power plant site and the picnic site, but was significantly higher in the lake viewpoint site (Kruskal-Wallis test: $\chi^2 = 187.652$, df = 2, n = 360, p < 0.001) (Fig. 8). A similar pattern was found for lichen height (Fig. 9), lichens have the highest median vertical height in the lake viewpoint site but did not differ between the power plant site and the picnic site (Kruskal-Wallis test: $\chi^2 = 248.702$, df = 2, n = 360, p < 0.001).

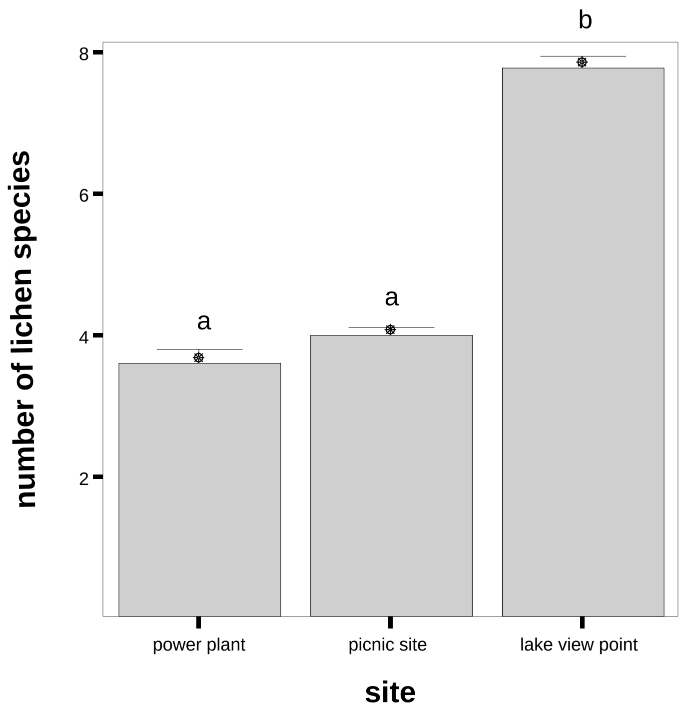

Fig. 8 Number of lichen species for the three sites.

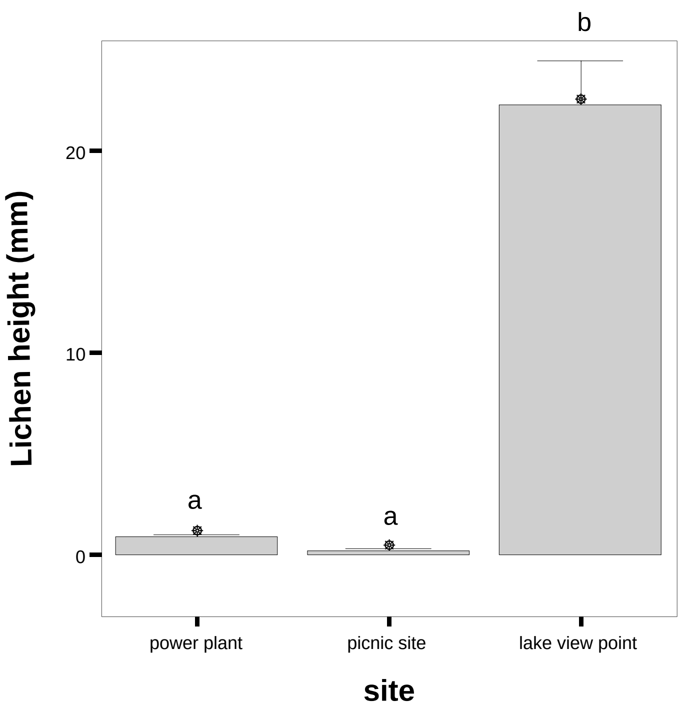

Fig. 9 Lichen height for the three sites.

DISCUSSION

Lichen cover, diversity and height around the power plant

Our results indicate a clear gradient of increasing percentage cover of lichen in both directions from the putative pollution discharge points, with lichen cover being higher in the southern transects (Fig. 2 & 4). This suggests that pollution is having an increasingly negative effect on lichen cover closer to the source of pollution. For diversity of species a gradient is only seen in the north transects and total species number is lower in the northern transects than the southern (Fig. 3 & 5). This could be an indicator of pollution-sensitive species only being able to grow upwind of the pollution source. Furthermore, it is interesting to note, that while diversity in the northern transects increases with distance from the pollution source, the diversity is still lower at one hundred metres than that of the southern transects. This suggests that, even at a distance of one hundred metres from the source, the effect of pollution appears to exclude some species. For maximum lichen height, no gradient was found for either side of the pollution source but the mean maximum height was higher in the southern transects (Fig. 6). This result for height may be attributed to two possible reasons; either pollution does negatively affect lichen height, or it may be that lichen height was greater in the southern transects because of a taller growing species present in the southern transects and possibly absent from the northern transects. In either case lichen height still seems to be affected by air pollution and may be a reliable indicator of polluted air.

When the same analysis was applied to transects in the other sites a significant difference for percentage lichen cover was found at the lake viewpoint and for lichen diversity at the picnic site (Table 1). This was unexpected since there was no direct source of pollution in these sites and the starting points consisted of randomly chosen points within these sites. Therefore, we believe that these results are due to natural variation in lichen cover and diversity. This raises the question as to whether the differences between the northern and southern transects within the power plant site are a result of natural variation or the effect of air pollution. It could be argued that any gradients observed along transects in the power plant site may be incidental. Nevertheless, the fact that differences were found for all three variables at the power plant site suggests that these differences are due to air pollution effects and cannot be accounted for by natural variation.

Lichen cover, diversity and height in the three sites

We found that percentage cover was lowest in the power plant site, again possibly indicating an effect of air pollution on lichen cover (Fig. 7). However, lichen diversity and lichen height were not significantly different between the power plant site and the picnic site, whereas the lake viewpoint had higher cover, diversity and height compared to the other two sites (Fig. 7, 8 & 9). This could suggest that another environmental variable is affecting lichens in both sites and air pollution is not impacting lichens. An alternative explanation is that air pollution is responsible for the lower cover, diversity and height in the power plant site and that the picnic site is affected by another unknown factor. We propose that the similar results for the power plant and picnic sites are not due to the effect of pollution from the power plant acting on the picnic site. This is because the picnic site is approximately five kilometres from the plant and the prevailing wind does not blow in the direction of the picnic site.

The lake viewpoint has higher cover, diversity and height than the other two sites (Fig. 7, 8 & 9). We believe this could be due to an absence of air pollution or differing environmental conditions in this area. The lake viewpoint is a more exposed site and is situated at a slightly higher altitude than the other sites, though it is closer to the power plant than the picnic site. These topographic differences could explain the higher values observed there as the site may be sufficiently far from the power plant to avoid any possible effects of pollution. Moreover, the site may also be exposed to greater levels moisture in the air, which would enhance lichen growth and possibly permit a wider range of species to occur there.

Conclusion and further research (to natural variation)

At the scale of the park, we are unsure of what exactly drives the differences in lichen growth between the sites. Results on the small scale comparisons between the northern and southern transects at the power plant site suggest that air pollution negatively affects cover, diversity and height of lichen. In order to better elucidate the exact causes of variation in lichen distribution and growth forms in Hell's Gate National Park, a greater number of sample sites should be used. This would give a better representation of lichen abundance and distribution across the entire park. It may also give a clearer picture of the effects, if any, of air pollution from the Ol-karia power plant in the park. Furthermore, measuring SO_2 levels at each site would have allowed an accurate determination of possible air pollution present at the studied sites, which was not possible for this study. Solid phase micro extraction (SPME) techniques, which can measure airborne pollution, would provide useful information relevant to this study area (C. Nuttman; pers. comm.).

Possible sources of error in this study were observer bias in estimating species diversity, as it was not always easy to distinguish between different lichen species. Also in estimating percentage cover it was sometimes difficult to tell if lichen was present or absent for smaller lichens and lichens with a similar colour to the tree bark. Additionally, the sampling area on each tree only considered the first one metre of the main stem. This method, while practical for the time frame of this study, may not be fully representative of the levels of lichen cover, diversity and height for the whole tree. Lichens were sometimes seen to be more abundant on the branches of trees rather then the main stem and so were missed by our sampling method. Future research should also include a broader range of environmental sampling taking in rainfall, humidity and light levels and a detailed breakdown of the various pollutants present in the air. It would also be instructive to chemically analyse lichen for the presence of pollutant compounds bio-accumulated in the lichen tissues. Previous studies have shown that the presence of metals can act as signature elements for other pollutants, and high sulphur levels in the lichen are reflective of atmospheric sulphur pollution (Wiseman & Wadleigh 2002, Purvis 2000). This would further clarify any doubt as to whether air pollutants are present in Hell's Gate National Park and, if so, whether they are affecting lichen distribution, diversity and abundance.

ACKNOWLEDGEMENTS

Thanks to Clive, Anthony, Shem and Nick for their advice and guidance and for getting some much needed lichen literature to us, and to Daniel and Clive (again!) for their chauffeuring services back and forth to Hell's Gate. Special thanks must go to the resident Colobus monkey at Elsamere for providing relief during tea and hot chocolate breaks, and also to the staff of Elsamere for the packed lunches, we've never tasted better boiled eggs and frankfurter sandwiches.

REFERENCES

Haffner, E., Lomsky, B., Hynek, V., Hallgren, J.E., Batic, F. and Pfanz, H. (2001) Air pollution and lichen physiology. Physiological responses of different lichens in a transplant experiment following an SO_2-gradient. *Water air and soil pollution* 131 (1-4): 185-201.

Loppi, S. and Frati L. (2006) Lichen diversity and lichen transplants as monitors of air pollution in a rural area of central Italy. *Environmental Monitoring and Assessment* 114: 361-375.

Pinho, P., Augusto, S., Branquinho, C., Bio, A., Pereira, M.J., Soares, A. and Catarino, F. (2004) Mapping lichen diversity as a first step for air quality assessment. *Journal of Atmospheric Chemistry* 49: 377-389.

Purvis, W. (2000) *Lichens.* The Natural History Museum, London.

Swinscow, T.D.V. and Krog, H. (1988) *Macrolichens of East Africa.* British Museum (Natural History), London.

Thormann, M.N. (2006) Lichens as indicators of forest health in Canada. *The Forestry Chronicle* 82 (3): 335-343.

Wiseman, R.D. and Wadleigh, M.A. (2002) Lichen response to changes in atmospheric sulphur: isotopic evidence. *Environmental Pollution* 116 (2): 235-241.