The bald truth about *Ecklonia Maxima*

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Ecklonia maxima (Photograph: Rob Anderson)

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Submitted in partial fulfilment of the requirements for Botany honours (Phycology)

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October
2005

Abstract

In many kelp populations along the South African coastline, certain kelp sporophytes are losing their fronds, resulting in 'Bald' individuals. 'Bald' kelp is caused by exposure to sunlight and herbivory by snails. This study focuses on the factors that determine the level of exposure to sunlight of *Ecklonia maxima* sporophytes, namely wave action and density. We hypothesise that the density 'bald' kelp is higher within the inner part of a kelp bed, at a sheltered site and where there is a higher density of kelp. The prevalence of 'bald' kelp at a number of sites was quantified. Surface sampling was conducted at five sites in the Cape Peninsula and at each site subjectively chosen areas of 'sheltered' and 'exposed' were sampled. A floating 1 x 1m quadrat was used to record the number of 'bald' individuals and the number of individuals with fronds that reached the surface within each quadrat. In order to refine the exposure index of a previous study wind speed and direction were factored into the analysis. This calculated exposure index was used as a measure of wave action throughout this study. The inner parts of kelp beds, which are more protected from swell, have higher densities of bald kelp. Also the density of 'bald' plants increases with an increase in total density of kelp. A higher exposure to wave action decreases the density of 'bald' kelp. A wash up sample analysis of kelp revealed that less 'bald' kelp are broken off by storms than kelp with fronds, because they have lower drag. The causes that produce bald kelp can be used to design harvesting regimes for the Abalone and seaweed industries of South Africa.

Introduction

Kelp beds of *Ecklonia maxima* (Obsbeck) Papenfuss (Alariceae, Phaeophyta) occur from Cape Agulhas north-westwards into Namibia (Anderson *et al.* 2001). Populations of this dominant shallow-water kelp (Anderson *et al.* 2001) are experiencing a partial loss in frond biomass throughout their distribution (R. J. Anderson, 2005 pers. comm. 20 July). Selected populations were studied along a coastal distance of 15km on the False Bay side of the Cape peninsula (Fig. 2). False Bay is one of few sheltered bays along the South African coastline and is in the extreme southwest of the South African coastline (Mathieson and Nienhuis, 1991). This area is situated in an overlap region between two marine provinces and characterized by a considerable temperature gradient. The Agulhas Marine Province, between just north of East London and Cape Agulhas, is warm temperate, with a mean annual water temperature of 17-18°C. The Benguela Marine Province, which extends from Cape Agulhas to the north of Namibia, is characterised by upwelling of cold water and an annual mean temperature of 13-14°C, and is described as 'cool temperate' (Bolton & Anderson, 1997). In study area, the mean monthly sea surface temperature values range from 11.4 in the coldest month to 17.7°C in the warmest month.

The study region is subjected to a simple semi-diurnal tidal regime, with a spring-tide amplitude of 2 to 2.5m and a neap-tidal range of about 1m. Low water of spring tides occurs in the mornings between 08.00 and 10.00 and at night between 20.00 and 22.00 hours, resulting in relatively little heat stress and desiccation. *Ecklonia maxima* form extensive beds to depths of around 8m (Field *et al.*, 1980). This giant brown kelp floats at the surface of the water by means of a swollen gas-filled stipe, forming a dense canopy of fronds at the surface (Field and Griffiths, 2003).

There has been one previous study of 'bald' kelp in relation to environmental factors. Peters (1914) adopted the phrase "bald" kelp to describe a phenomenon occurring within a *Nereocystis luetkeana* population in Puget Sound, Washington USA, where the kelp was losing its fronds. Peters believed the loss of fronds was due to a combination of three factors; (1) exposure to sunlight from being held up by other plants (i.e. density); (2) grazing and weakening of fronds by snails and (3) abrasion against rocky reefs. Peters (1914) stated that “balding is primarily due to sunburn resulting from a few hours drying when held out of the water by neighbouring plants”, i.e. from desiccation. When the plants he observed were relieved of the pull of their fronds the floats stood upright several centimetres out of the water, which was in sharp contrast to their healthy neighbours. This was also noticed in our study sites. Fig. 3 illustrates the initial stages of a ‘balding’ sporophyte and Fig. 4 shows a completely ‘bald’ plant. Peters also found that kelp in the strong currents had relatively few individuals without fronds and that where they did occur they were in clustered groups.

The likelihood of kelp plants being exposed to the sun is also related to their position on the shore. Mork (1996) states that the damping (reduction of amplitude) of surface waves is enhanced by bottom vegetation in shallow waters. From a study site in Hustadvika (Norway), which is strongly exposed to waves from the open ocean, Mork found that the reduction of wave energy from the outer to inner part of the kelp belt, over a distance of 258m, was 70-85% with the highest value at low tide. This study contradicts earlier assumptions and findings’ concerning the sheltering effect of kelp, i.e. that kelp has no effect on wave action (Eckman *et al.* 1989). Thus, kelp within the inner part of a kelp bed, at low tide, will receive significantly less water motion than the outer edge. According to the findings by Peters (1914), ‘bald’ kelp is more likely to appear within the inner part of a kelp bed, at a sheltered site and during a warm time of year.

Peters (1914) demonstrated that ‘balding’ is related to many environmental factors, particularly snails and sun exposure. Sun exposure might be expected to be inversely related to how much wave action an individual plant receives. An individual that receives more wave action will be exposed to the sun for a shorter time compared to others, which do not receive much wave exposure. Wave exposure can be measured according to a method called the Baardseth Index (Baardseth 1970; Ruuskanen *et al.* 1999). The Baardseth Index uses compass bearings to calculate the degree of exposure to the open sea (Fig. 1). It is done by dividing 360 degrees of a compass into nine degree segments, so that 40 segments exist. A compass is placed at the study site (X) and the bearing to the point of obstruction (headland or offshore island) from either side of X is recorded. The Index is calculated by summing the number of segments the compass bearing falls into. The values obtained by the Index range from zero to forty according to their degree of exposure, with zero being extremely sheltered and forty being very exposed. This method does not take wind speed and direction into account. False Bay receives strong consistently directional winds throughout the year and therefore I tried to develop an index that incorporated wind speed and direction.

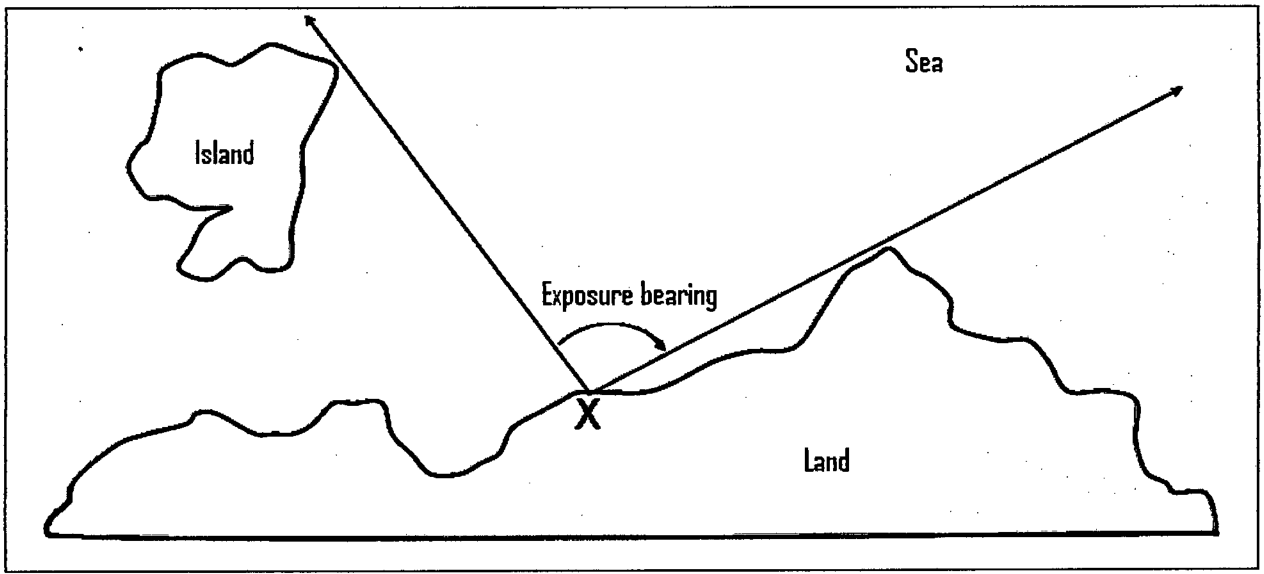


Fig. 1: A compass bearing of the exposure to the open sea at point X (Exposure bearing), according to the Baardseth Index.

"Disturbance is defined as the total or partial loss of biomass from an area by causes other than senescence" (Chapman and Johnson, 1990). The loss of fronds, over a short time, is therefore a form of disturbance that may alter the structure and dynamics of kelp beds, with potentially large ecological and commercial effects (Levitt *et al.* 2002).

In South Africa, the commercial effects are experienced by the seaweed harvesting and abalone farming industries. The seaweed industry harvests *Ecklonia maxima* for the production of a plant-growth stimulant and increasingly, to feed cultured abalone. There has been a steady increase in the demand for South African abalone *Haliotis midae* in both foreign and domestic markets and is creating an increasing demand for freshly-harvested kelp (Levitt *et al.* 2002; Anderson *et al.* 2001). Beach-cast kelp, of various species, has been collected since at least 1953, in quantities that fluctuated with market demands but reached a maximum of about 5000 t d wt in 1977 (Anderson *et al.* 2001). Beach-cast kelp is sun-dried, milled and exported, mainly for the extraction of alginate. Fresh kelp has been harvested since 1979 in relatively small quantities for the production of liquid plant-growth stimulant (Kelpak). Abalone is fed mainly on fresh kelp because it improves flesh taste, and harvests have increased greatly in the last eight years. The harvesting of kelp for abalone feed occurs east of False Bay. Localised demands for fresh kelp will greatly increase when abalone farms reach full production, particularly in areas where farms are concentrated. Abalone farmers harvest kelp by cutting off fronds from sporophyte individuals that reach the surface. The increased demand for seaweed has led to an interest in the causes of 'balding' *Ecklonia* individuals, by abalone farms around the Western Cape, as this can reduce the harvestable biomass of kelp fronds (R. J. Anderson, pers. comm. 2005).

The ecological affect of frond loss is related to the productivity of the kelp bed and the survival of young sporophytes. Kelp fronds behave as moving belts of tissue, growing at the bases and eroding at the tips under the influence of strong wave action. The eroded particles form detritus (particulate organic matter and dissolved organic matter), which sustains bacteria and other microbes, which feed on it. Detritus may be kept in suspension by wave action and consumed by suspension-feeders such as mussels, barnacles and holothurians, totalling 72% of animal biomass. The wave action also breaks free whole plants and large pieces of drift weed, which are fed on by herbivores such as the sea urchins and abalone (Newell *et al.*1982; Probyn and McQuaid 1985).

This study is the first of its kind done in South Africa. The study sites were chosen in False Bay for their accessibility in winter and because the swell is too large during winter on the West Coast. These sites also represent a range of exposures to swell. This paper incorporates six main aims. In estimating exposure to wave action, I tried to improve on Baardseth's Index by incorporating data for wind speed and direction because wave height is related to our hypotheses. The prevalence of 'bald' *Ecklonia maxima* individuals at a number of sites is quantified and the following hypotheses tested: The inner parts of kelp beds (i.e. more protected from swell) will have higher densities of 'bald' sporophytes than the outer parts of the beds (Rob comment). Prevalence of 'balding' is directly related to the density of kelp. 'Balding' is inversely related to the exposure index of sites. Finally we tested if fewer 'bald' kelp would be broken loose by storms because they have less drag.

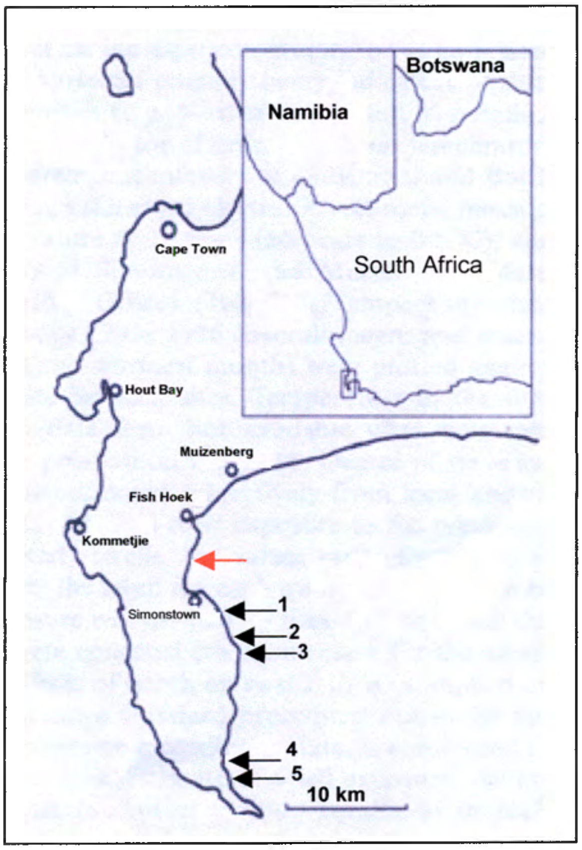


Fig. 2: Study area. Location of the five surface sample sites (black arrows) and the wash up sample site (red arrow) around the Cape Peninsula (South Africa). 1: Windmill Beach, 2: A-Frame, 3: Millers Point, 4: Bordjiesrif, 5: Buffels Bay and Glencairn.

Fig. 3: An *Ecklonia maxima* individual showing the primary blade (black arrow) and the area where initial frond loss occurs (red arrow) (photograph: Rob Anderson, False Bay, South Africa. 2004.)

Fig. 4: An *Ecklonia maxima* population in Gansbaai illustrating the effects of 'balding' (black arrow) (photograph: Rob Anderson, Gansbaai, South Africa. 2000)

Material and methods

Study site and sampling

Sampling was carried out in the winter months July to September 2005, at 10 sites in False Bay: A-Frame "sheltered" (59 quadrats), A-frame "exposed" (60 quadrats), Millers Point "sheltered" (61 quadrats) and Millers Point "exposed" (62 quadrats), Windmill Beach "sheltered" (46 quadrats), Windmill Beach "exposed" (37 quadrats), Buffels Bay "sheltered" (58 quadrats), Buffels Bay "exposed" (58 quadrats), Bordjiesrif "sheltered" (56 quadrats) and Bordjiesrif "exposed" (45 quadrats).

Sampling was undertaken over three low spring tides. We were only able to sample when the sea conditions were calm enough to enter the water, and only an hour before and after low tide, when the densities of surface kelp were highest. Kelp beds were visible from the surface and each one had a reasonable depth range (from 0 m to at least 6m). Kelp beds were selected according to their distribution along the shore, i.e. accessibility and then on their apparent degree of exposure to wind and or waves. The degree of wave exposure, i.e. "sheltered" or "exposed" was classified subjectively from local knowledge of the sites and their exposure to the prevailing winds. These classifications are placed in inverted commas because these estimates of wave exposure were at first not quantatively measured. At each site two divers collected data along a surface transect, one near the shore and the other at the outer edge of the kelp bed. The transects were parallel to the shore. Surface sampling was done with a floating 1 x 1m quadrat, which was flipped along the surface. The density of *Ecklonia* individuals that reached the surface was counted in every second quadrat and recorded on a waterproof slate. Two categories of kelp-heads were distinguished: those with secondary fronds, and those without ("bald"). The quadrats were located between 0.3 and 6 metre depth. Approximately 30 quadrats were sampled in each inshore and outer edge transect, each containing at least one sporophyte. The total number of quadrats at each site varied according to the extent of the kelp bed.

Exposure index

To measure degree of wave/wind exposure as quantitatively as possible, a new method was developed for the purpose of this study called the Wind Speed and Direction (WSD) Index. The Baardseth Index was used in a comparative capacity to interpret the viability of our WSD Index. The bearing, in terms of degree of exposure, was obtained for each of the ten sites using the method illustrated in Fig. 1. Data for the WSD Index were provided by the Cape Town Weather Office. Data for Cape Point were graphically presented in the form of a wind rose (Appendix 1) displaying wind speed, as a bar, and its direction. Ten photocopies of this wind rose were made and the bearings from each site were marked onto the wind rose on each consecutive piece of paper. In order to determine the extent of exposure, the area within the boundaries of these bearing markers and below the bars was cut out and weighed, using a digital scale accurate to 0.1mg As the degree of exposure was higher on larger pieces of paper, each individual piece of paper was weighed and divided by the weight of the smallest piece of paper. These values indicated the WSD Index at each site. The density of 'bald' kelp per quadrat was plotted against both exposure indices to determine if our calculated index was a viable measure.

Data analysis

To assess whether the variables affecting density; (1) between each site, (2) between in-shore and outer-edge (zone) of each kelp bed, (3) total number of plants per quadrat (total) and (4) between 'sheltered' and 'exposed' areas (exposure index) are significant predictors of 'baldness', the number of 'bald' plants in each quadrat ('bald' density) was used as a measure of "baldness" (dependent/response variable). A multiple regression analysis was done on the data. A General Linear Model (GLM), using STATISTICA version 7 (StatSoft), was accepted as the most appropriate analytical method since a plot of the residuals was normally distributed. The term "general" refers to the fact that both continuous and categorical predictors are used in the model (Quinn and Keough 2002). A GLM is classified as a parametric model and a probability distribution is specified for the response variable. The data for the number of 'bald' plants in each $1m^2$ quadrant was not normally distributed and therefore a plot of the residuals was created. This graph showed a relatively normal distribution and therefore a GLM could be performed on the original data (Fig. 5). In multivariate analyses, the equation, which relates the set of variables is composed of a series of, weighted terms added together. To determine which variable is the best determinant of 'baldness' the GLM incorporates the response/dependent variable Y (density), the four predictor/independent variables; site, zone, total and exposure index, an error (residual) and intercept term into the following equation:

$$Y \text{ (density)} = \text{Intercept} + \alpha_1\text{site} + \alpha_2\text{zone} + \alpha_3\text{total density plants} + \alpha_4\text{exposure index} + E$$

The predictor variables will provide the biological explanation for the pattern seen in the density of 'bald' plants (response variable) and the error component represents the part of the response variable not explained by the model, i.e. uncertainty in the response variable (Quinn and Keough, 2003). The parameters (regression slopes, intercept = $\alpha_{1,2,3,4}$) of each variable are predicted relative to the intercept, the whole model estimates are given, the statistical significance of the predictors on kelp 'baldness' are reported and plots of the categorical variables are shown.

Wash-up

To compare the prevalence of 'bald' kelp lost by storm action with those present in kelp beds, a wash-up sample was collected at Glencairn beach, False Bay, in early September 2005. The density of 'bald' kelp in the wash-up was recorded, and used as a comparative measure to the 'bald' density from the surface sampling. These findings were used to infer the effect that a change in kelp wash-up would have on beach ecosystems. Random samples of kelp stands were selected for investigation. The following data were recorded: number of kelp individuals with fronds and the number of 'bald' kelp. A total of 428 individuals were examined.

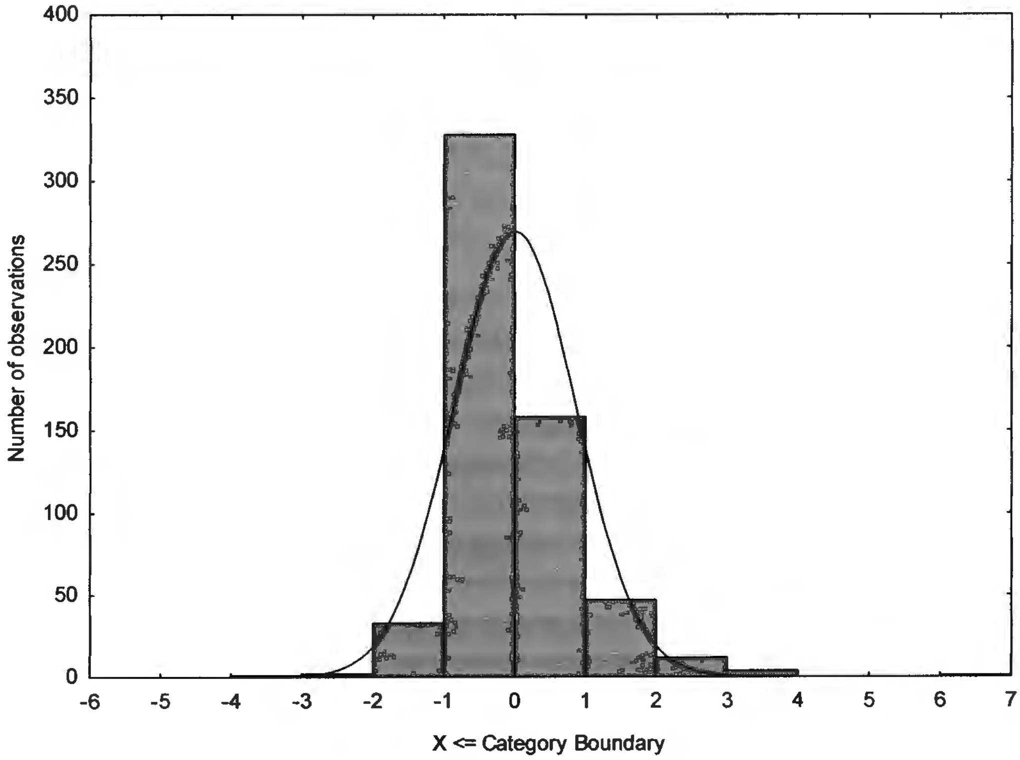
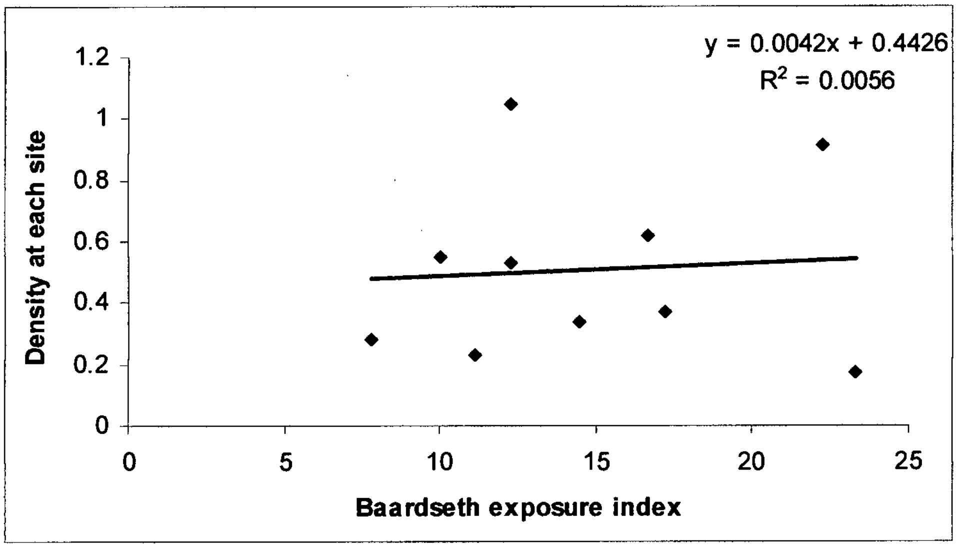


Fig. 5: Histogram showing raw residuals of the number of 'bald' plants per quadrat (dependent variable)

Results

Wave exposure

A



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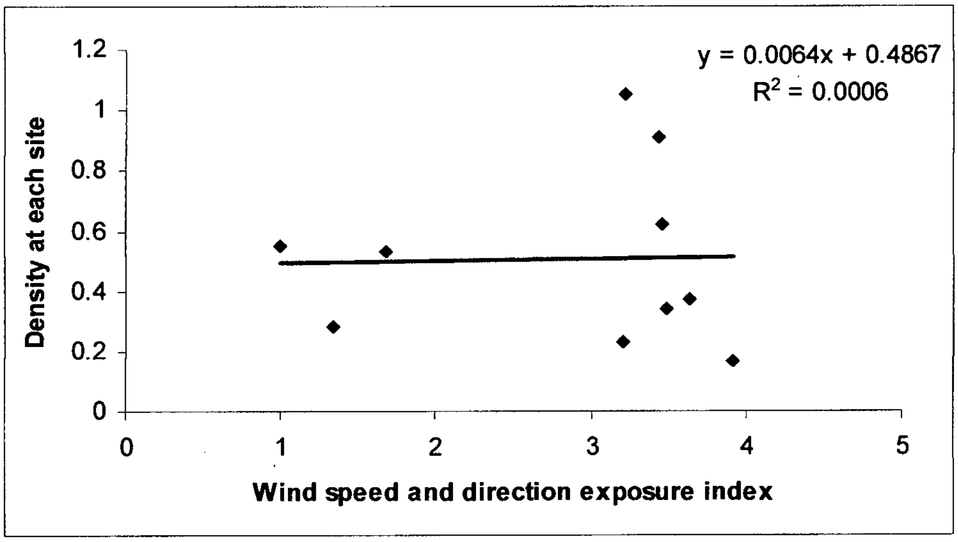

Fig. 6: A. Density at each site versus the Baardseth exposure index. B. Density at each site versus the wind speed and direction exposure index.

The densities of bald kelp at the 10 sites showed a similar relationship to both the Baardseth and WSD indices. I consider the WSD Index to provide a better index of real wave exposure, and it is therefore used in all further analyses.

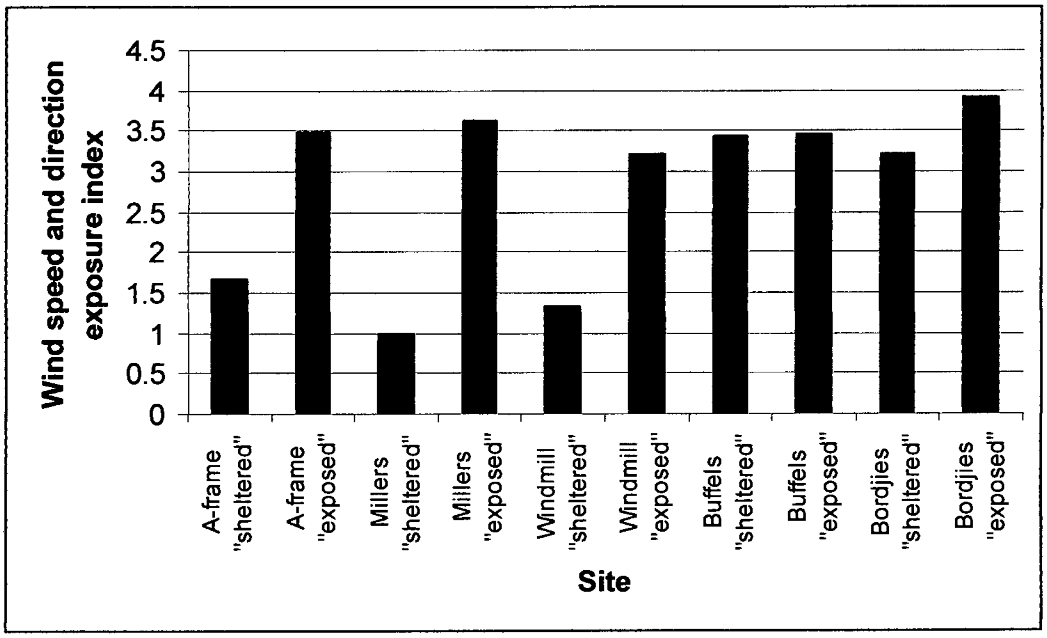

Fig. 7: Wind speed and direction exposure index at each of the ten sampled sites

The subjective classification of sites as 'sheltered' or 'exposed' was related to the calculated exposure index at each location, i.e. every site named 'exposed' had a higher WSD exposure index than the sites named 'sheltered' at a specific coastal location.

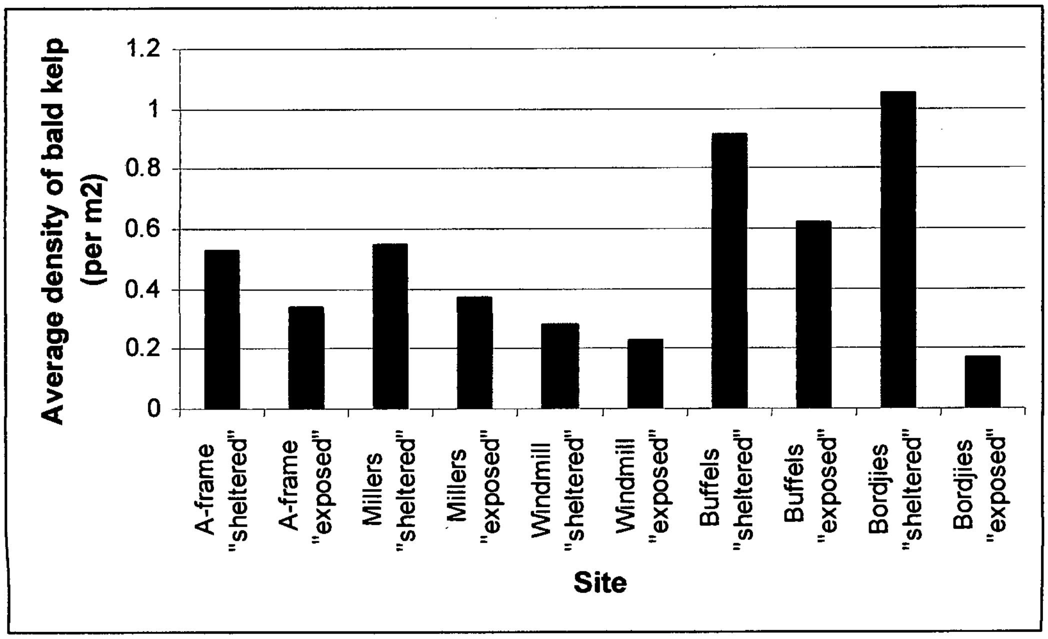

Fig. 8: Average density of 'bald' kelp (m^{-2}) at each of the ten sites

The average density of 'bald' kelp (m^{-2}) found at each site was higher in the "sheltered" sites than the "exposed" sites.

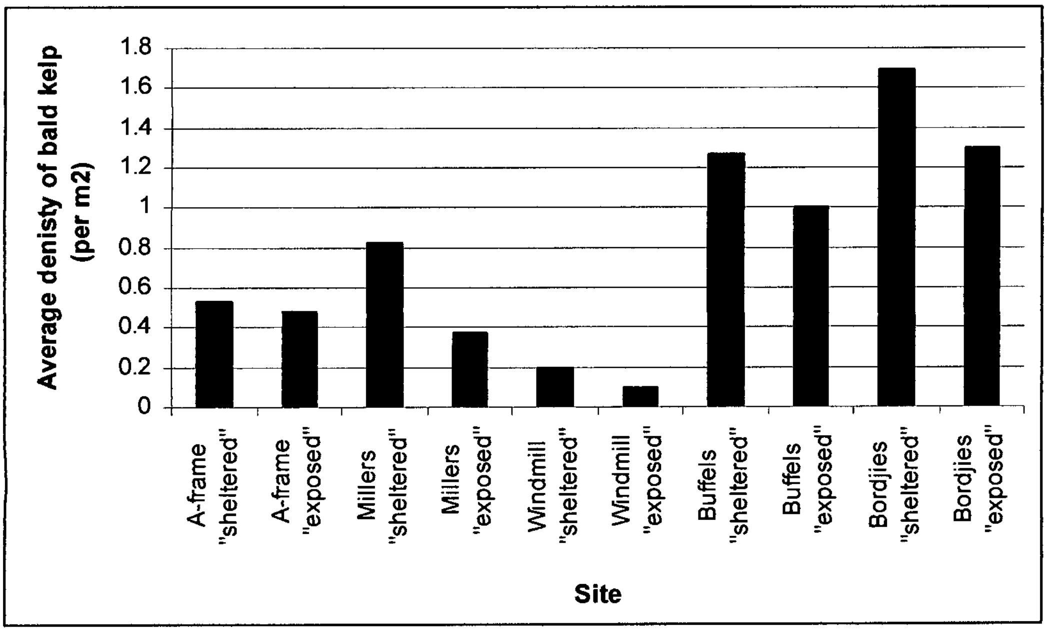

Fig. 9: Average density of 'bald' kelp (m^{-2}) at each site for the inner part of each kelp bed

Within the inner part of the kelp beds, the average density of 'bald' kelp was higher in the "sheltered" sites than the "exposed" for all ten locations.

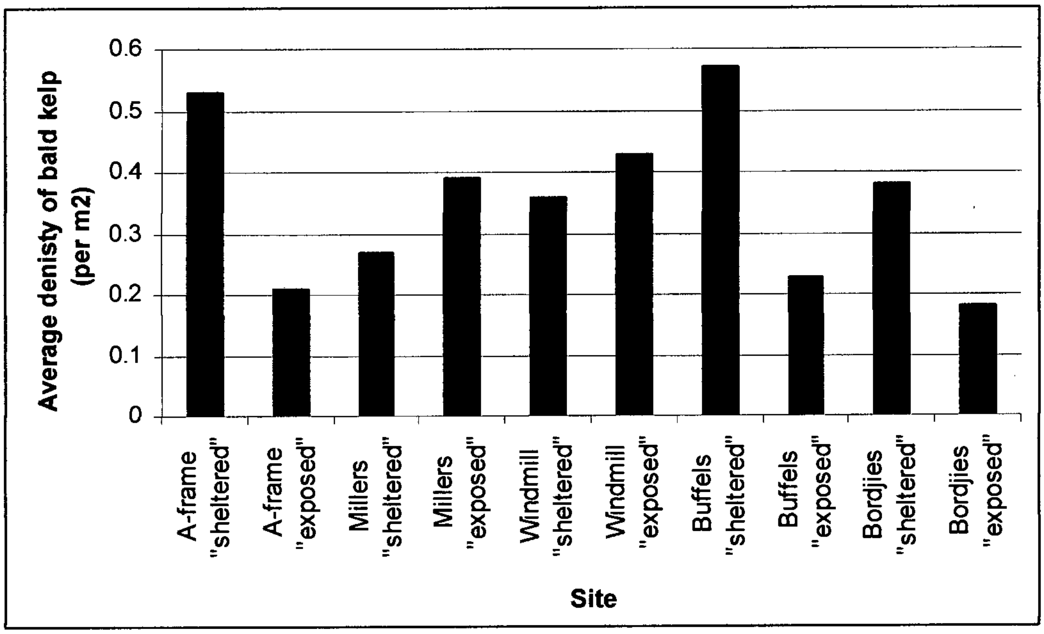

Fig. 10: Average density of 'bald' kelp (m^{-2}) at each site for the outer edge of each kelp bed

Within the outer edge of the kelp beds, the density of 'bald' kelp was higher in the "sheltered" sites than the "exposed" for A-frame, Buffels Bay and Bordjiesrif. Millers Point and Windmill Beach had a slightly higher density in the "exposed" site than the "sheltered".

General Linear Model

The output of the whole model GLM showed that the variables had a significant effect on the density of 'bald' kelp (F = 29.86910, df = 7, p-value = 0.00). The adjusted R^2 value was 0.256751. The R^2 value indicates that 25,68% of the variability in the data was explained by the model. Although the model indicates that all the variables are significant predictors of baldness (Table 1), it did not explain 74.32% of the variability. In order to obtain a value for Y (refer to equation for a GLM in materials and methods) the continuous variables in the equation needed to equal zero: the model randomly selected the site Bordjiesrif (categorical variable) as the intercept, with it occurring offshore (categorical variable) and the exposure index and density as zero (continuous variables). The parameter values are set relative to the intercept (Table 2).

The density at each site was plotted (Fig. 11) with the vertical bars denoting the 0.95 confidence intervals. A-frame was not significantly different from the intercept (p=0.054) (Table 2) and it had fewer 'bald' plants than Bordjiesrif. Millers Point was significantly different from Bordjiesrif with a lower mean density of 'bald' plants (p=0.009) (Table 2). Windmill Beach had a lower mean number of 'bald' plants than Bordjiesrif and was significantly different from the intercept (p=0.0003) (Table 3). Buffels Bay was significantly different from the intercept (p= 0.002) (Table 2) and had fewer 'bald' plants per quadrat than Bordjiesrif.

Zone (inner or outer edge of kelp bed) was a significant predictor of 'baldness', i.e. it contributed to the 'balding' of kelp (p=0.000) (Table 1). Zone had a positive parameter value of 0.1479 (Table 2) relative to the intercept. The inshore sites had a significantly higher density of 'bald' kelp (p=0.0007 Table 3) than the offshore sites (Fig. 12), which supports the first hypothesis that wave exposure plays a role in causing 'bald' kelp.

The total density of kelp was a significant predictor of 'baldness' (p=0.000) (Table 1). The parameter value, for the total kelp in each quadrat, was 0.1919 (Table 2). This value indicated a significantly positive relationship (p=0.000 Table 2) between the density of 'bald' plants and the total density of plants in a quadrat. 'Baldness' increases by 20% as density increases, which supports the second hypothesis of this study that total density is directly related to the prevalence of balding.

The exposure index was a significant predictor of 'baldness' (p=0.000) (Table 1). The exposure index created has a parameter value of -0.1513. The parameter indicates a significantly (p=0.000 Table 2) negative regression slope between the number of 'bald' plants per quadrat and the exposure index. According to the parameter value, as the exposure index increases the number of 'bald' plants will decrease by 15%, supporting the third hypothesis.

Table 1: Univariate test of significance for density of 'bald' kelp ($p<0.05$)

Effect	Degrees freedom	F-value	p-value
Intercept	1	5.9236	0.015241
Site	4	9.8640	0.000000
Zone	1	15.8096	0.000079
Total	1	121.8045	0.000000
Exposure Index	1	11.8116	0.000631

Table 2: Parameter estimates, t-value, p-value and upper and lower 95% confidence limits for the GLM

Effect	Level of effect	Density parameter	Density – t value	Density – p-value	-95% Cnf. Lmt	+95% Cnf. Lmt
Intercept		0.329319	2.43385	0.015241	0.06356	0.59507
Site	A-frame	-0.137220	-1.92308	0.054961	-0.27736	0.00292
Site	Millers Point	-0.193947	-2.59523	0.009693	-0.34072	-0.04716
Site	Windmill Beach	-0.315790	-3.58233	0.000369	-0.48892	-0.14265
Site	Buffels Bay	0.234171	3.05312	0.002369	0.08352	0.38481
Zone	In shore	0.147944	3.97613	0.000079	0.07486	0.22102
Total		0.191979	11.03651	0.000000	0.15781	0.22614
Exposure index		-0.151254	-3.43680	0.000631	-0.23769	-0.0648

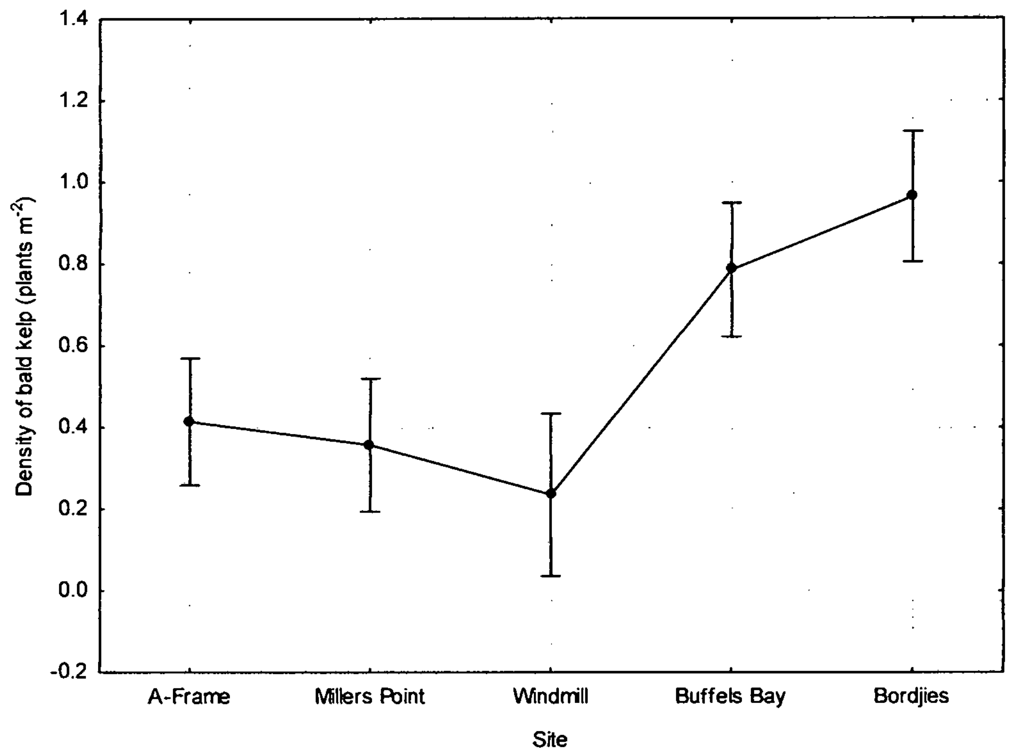

Fig. 11: The Least Squared (LS) mean density of 'bald' kelp per quadrat at each of the five sites. The vertical bars denote the 0.95 confidence intervals.

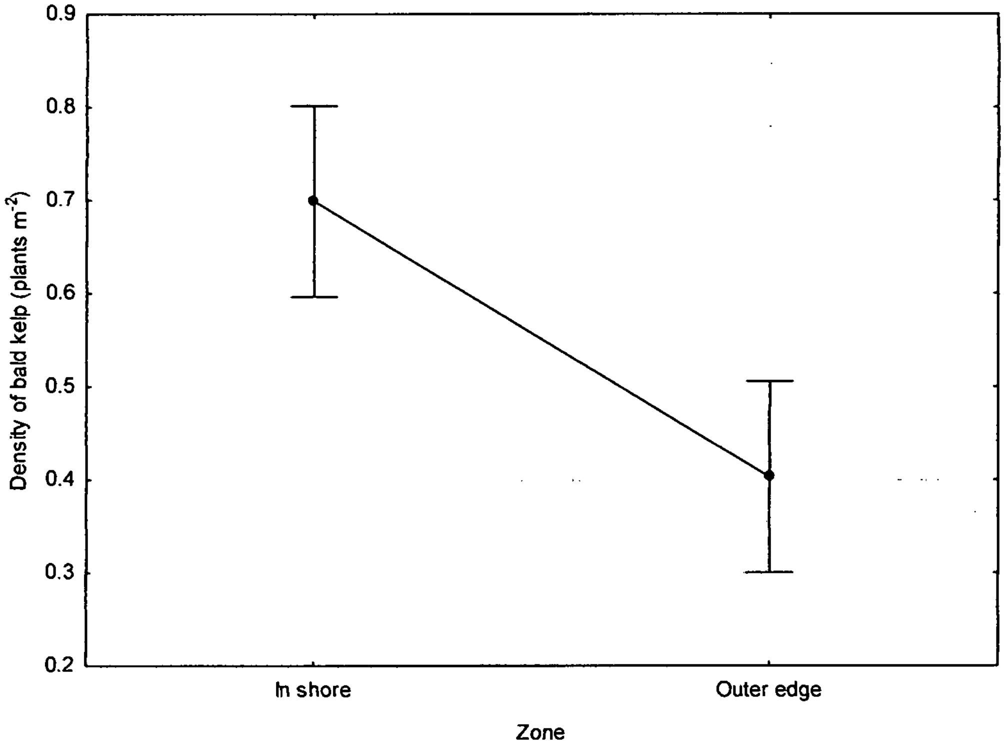

Fig. 12: The mean density of 'bald' plants per quadrat in inshore and outer edge zones. The vertical bars denote the 0.95 confidence intervals.

Wash-up

Table 3: The proportion of 'bald' plants in the total surface sample compared to the wash-up sample.

Sampled area	**Total number of plants**	**Number of 'bald' plants**	**Proportion 'bald' of total**
Sea surface sampling	2004	340	0.1697
Wash-up	425	14	0.0329

The proportion of 'bald' kelp in the wash-up is approximately 1/5 of the proportion found in the surface sampling (3,3% of the washed up kelp is 'bald' and 16.9% in the sea).

Discussion

The calculated Wind Speed and Direction (WSD) exposure index has shown to be a viable method in calculating wave exposure. All the factors, hypothesized to cause 'balding', were found to be true; the inner parts of kelp beds have higher densities of 'bald' sporophytes than the outer parts of the beds, the prevalence of 'balding' is directly correlated with the density of kelp and 'balding' is inversely related to the exposure index of sites. Fewer bald plants are broken off during storms because they have less drag. A few possible effects of 'balding' have been listed and future studies have been suggested.

Wave exposure is extremely difficult to measure as there are many variables that need to be incorporated. The Baardseth Index is calculated using only a map of a study site but the WSD index was calculated from on-site compass reading combined with wind speed and direction data. When the two indices were compared, using average density of 'bald' plants as a comparison, they gave a similar correlation (Fig. 6). This correlation and Fig. 7 show that the index is an accurate measure of wave exposure. Fig. 7 shows that according to the WSD Index the 'sheltered' sites showed a lower exposure index than the 'exposed'. These sites were named from previous knowledge of the area and from a visual estimation. Therefore the naming of the sites and the Index are related and can both be used as a descriptive measure of wave exposure.

Figures 8, 9 and 10 are each graphic representations of two sets of variables, using the original data, i.e. not the modelled data. Fig. 8 shows very distinctly that the density of bald plants per 1m^2 is higher in 'sheltered' than 'exposed' sites for all of the five study sites. Both figures 9 and 10 show that the majority of sites have a higher density of 'bald' kelp in the 'sheltered' sites than the 'exposed'. Within the outer part Millers Point and Windmill Beach show an opposite pattern. These graphs only plot two variables against each other and the fact that these two sites do not follow the hypothesised cause of 'balding' could be due to other factors such as exposure or density. The variation from the expected values at these two sites is explained by the GLM.

The GLM results support the hypothesis that density and decreased wave exposure cause plants to lose their fronds. The results from the overall model indicate that all the variables combined: site, zone, density and exposure, have a significant effect on the density of 'bald' kelp. The fact that the R^2 value is 25,68% is a positive result because this value is relatively high compared to other biological studies (C. Moloney, 2005, pers. comm., 10 October). It can therefore be accepted that the results the model produces are a good explanation of the causes that produce 'bald' kelp.

Significance tests between each of the study sites were carried out as part of the GLM (Table 2). The actual densities of 'bald' kelp at each site show these differences visually (Fig. 11). Four of the sites showed a significant difference from the intercept and A-frame was only slightly insignificant (Table 2). The fact that site is a significant predictor of baldness indicates that geographical location is an important factor in the causes of 'bald' kelp. Bordjiesrif and Buffels Bay have the two highest densities of 'bald' kelp, which is surprising because they also have high exposure indices at both the 'sheltered' and 'exposed' sites (Fig. 7). A possible explanation for this could be that these two sites are closest to Cape Point and thus closer to the entrance to False Bay and consequent incoming currents. Warm currents pass Cape Point occasionally and remnants of the increased sea surface temperatures could move into False Bay, slightly. Therefore during hot summer months, when 'bald' kelp are formed, if there are warm currents entering the bay, SS temperatures could be an important factor in producing 'bald' kelp. The densities found at the other sites vary according to either exposure or density. Low spring tides are only in the mornings and evenings therefore it could be expected that 'bald' kelp would not be found along the False Bay coast. So why does this phenomenon occur here? In the summer months the sun rises before 5am and sets after 6pm, which allows for reasonably high temperatures by early morning.

Where kelp plants grow relative to the shore, has shown to be an important determinant of 'balding'. The GLM indicates that zone is a significant predictor of 'baldness' (Table 1). The parameter value of zone (inshore and outer edge) is positive (Table 2) which relates to the relationship between these two variables (Fig. 12). There is a significant difference in the density of 'bald' kelp between the inner part of the kelp bed and the outer edge. Undoubtedly zone is important when determining the causes of 'bald' kelp.

Density was found to be a significant predictor of kelp baldness (Peters 1914). This study supports Peters findings (1914) (Table 1). The positive parameter between the density of 'bald' plants and the total density of plants supports the hypothesis that the density of 'bald' plants increases as total density increase (Table 2). 'Bald' plants are consequently more likely to occur in a population where the density of kelp is high.

The final factor in predicting 'baldness' is wave exposure at each site. Exposure was found to be a significant predictor of 'baldness' (Table 1). The negative parameter value (Table 2) supports the hypothesis that the density of 'bald' plants decreases with an increase in exposure. The parameter value for exposure is important because it incorporates the other three variables. When the affect of each of the four factors is taken into account the model shows very clearly that all four of them play a role in producing 'bald' kelp.

The wash up data has shown a large difference between the proportion of 'bald' plants growing in the ocean and those reaching the shore. The proportion of 'bald' plants found in the sea is 16.9% and only 3.3% in the wash-up sample (Table 3). From these figures we can conclude that proportionately less bald kelp are removed by storms than kelp with secondary fronds. Consequently a relatively high proportion of bald kelp remain attached after storms.

The loss of fronds causes no immediate threat to the plants survival, i.e. it remains alive in the water column after 'balding'. The problem, however, is that the individuals that remain alive do not produce fronds and they take up space that new plants could have otherwise colonised. Therefore the remaining plants, because they are no longer producing frond material, reduce colonisation of new individuals and reduce the amount of organic matter that should constantly be supporting the surrounding ecosystem. Newell *et al.* (1982) found that the production of primary producers was equal to the estimated energy requirements of consumers. Therefore a loss of 17% of biomass per year could shift this balanced ecosystem to a grazer-dominated environment.

The reduced number of 'bald' plants washed up onto the beach will alter the biomass of the total kelp washed up onto beaches, which will have consequent effects on beach communities. The fauna on southern African beaches are dependent upon imported food resources. The quantities and proportions of food materials will vary with the geographic location and topography of the beach, as well as the proximity and productivity of adjacent rocky areas. The nature of the available food in turn determines the biomass, composition and distribution pattern of fauna. A study done by Griffiths *et al.* (1983) on Kommetjie Beach, showed a rapid decline of biomass and species diversity of macrofauna, in areas where the kelp beds had a low productivity. The herbivores amongst the macrofauna, mainly amphipods of the genus *Talorchestia* and kelp fly (*Fucellia capensis*) larvae, were estimated to consume 71% of the kelp deposited on the beach. They in turn were fed upon by several species of birds, isopods and carnivorous Coleoptera (Griffiths *et al.* 1983). Much of the kelp eaten by herbivores was returned to the beach in the form of faeces and entered the sand column, together with the decomposed remains of uneaten kelp. This material supports a dense meiofauna. This study by Griffiths *et al.* has illustrated how the possible change in community structure and reduced productivity of a kelp bed through 'balding' plants can impact upon energy processes on beach systems. Therefore the 'balding' of approximately 17% of the False Bay population could have discernable effects on the meiofauna on nearby beaches. The fact that the biomass will distribute differently would mean that certain areas will be greater affected. The reduction in new healthy individuals could result in a reduction in total beach wash-up and consequently a decline in beach meiofaunal species.

There are some positive aspects, however, to these individuals remaining in the water column without fronds. A study by Anderson *et al.* (1997) showed that mature holdfasts of *Ecklonia maxima* are an important refuge for recruitment of *E. maxima* sporophytes, in areas where benthic grazers were numerous. Therefore the resulting presence of 'bald'-kelp could possibly increase the chances of sporophyte survival. When the *Ecklonia* fronds are lost there is an increase in light reaching the substrata. This increase in light could possibly promote algal diversity, by increasing algal colonization and succession, but have little effect on the benthic fauna, which is unlikely to respond to light (Levitt *et al.* 2002). The loss of fronds could therefore increase species diversity and promote sporophyte survival.

The obvious affects of 'balding' kelp on the South African seaweed industry and abalone industry is a reduction in harvestable biomass. M. Rothman (2005) found that frond biomass is on average 8.99kg per m^2 around the Cape Peninsula. According to this study 'bald' plants account for 17% the population (Table 3), which equates to 1.52 kg of fronds being lost per m^2? The loss of fronds in kelp harvesting areas could be significant and have detrimental affects on these industries.

In addition to exposure to sunlight, Peters found that the loss of fronds was due to their being eaten and consequently weakened by snails, as well as to abrasion against the rocky reefs. A future study could look at modelling grazing and abrasion. Peters (1914) found that on thick kelp beds where snails were abundant, they ate holes into the fronds, weakening them so that they broke off in large pieces. The snails were observed retreating before the impending loss and continued eating toward the base until the whole frond was removed. The snails in Peters study were found on kelp where the current was weak. Snail species such as *Oxystele sinensis* (Gmelin, 1791) and *Turbo cidaris* (Gmelin, 1791) were observed, at our study sites, feeding out of the water on certain *Ecklonia maxima* kelp heads (R. J. Anderson, 2005 pers. comm. 20 July). These sub-surface animals were also observed being eaten by birds, which indicates a complete change in ecological dynamic between these snail species and birds. According to Chapman and Johnson (cited Levitt *et al.* 2002), control of herbivores is essential for the maintenance of kelp populations, and where herbivores dominate, kelp populations are restricted. Kelp populations need to be controlled but in the case of 'bald' kelp, the combination of herbivores and sunlight may contribute to 'balding' *E. maxima*.

Zimmerman and Robertson (1985) explored the affect of El Nino on kelp communities. Their results showed that a change in temperature and consequently nutrient availability altered the growth of the studied kelp, *Macrocystis pyrifera*. Therefore another variable, which could be factored into the causes of 'bald' kelp, is Global Climate Change and a resultant change in sea surface temperatures (as mentioned above) and nutrient levels. Future observations should tag individual plants in order to calculate the time period over which 'balding' occurs and their longevity with respect to healthy individuals. Questions to still be answered include: Are the numbers of 'bald' kelp increasing? Are wave exposure, density and snails the only causes of 'bald' kelp? And how long does a plant take to go 'bald'? We may not have chosen all the relevant predictors nor considered combinations of predictors, such as interactions between 'balding' and SS temperatures, which might affect the response variable (density of 'bald' kelp). A longer period of observation, i.e. through a whole season, as well as covering a larger area, would be necessary to verify all possible causes of 'bald' kelp. The new measure of wave exposure is an important index that could be used in future studies. This study has shown that 'bald' kelp is more likely to occur in sheltered areas and within the inner part of the kelp bed and kelp frond harvesters could apply this knowledge to developing a harvesting regime that yields the most from their harvesting efforts.

Acknowledgements

I would like to thank my supervisor Rob Anderson for all his time, support and patience throughout this project. Thank you Enrico for proof reading my project and for you excellent suggestions. Thank you to all the people from the Seaweed Unit MCM, and others for your invaluable assistance with diving work and for your contribution to the overall objectives of this study: namely Rob, Chris, Derek, Mark, Katherine, Enrico, Sarah, Dillon and others. The Cape Town weather office for its efficient service. A special thank you to Coleen Moloney, for all her advice and expertise with the statistical analyses. Thank you to my family, friends and Trevor for all your endless support and encouragement. A final thank you to my honours class for all your support and guidance.

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Appendix 1

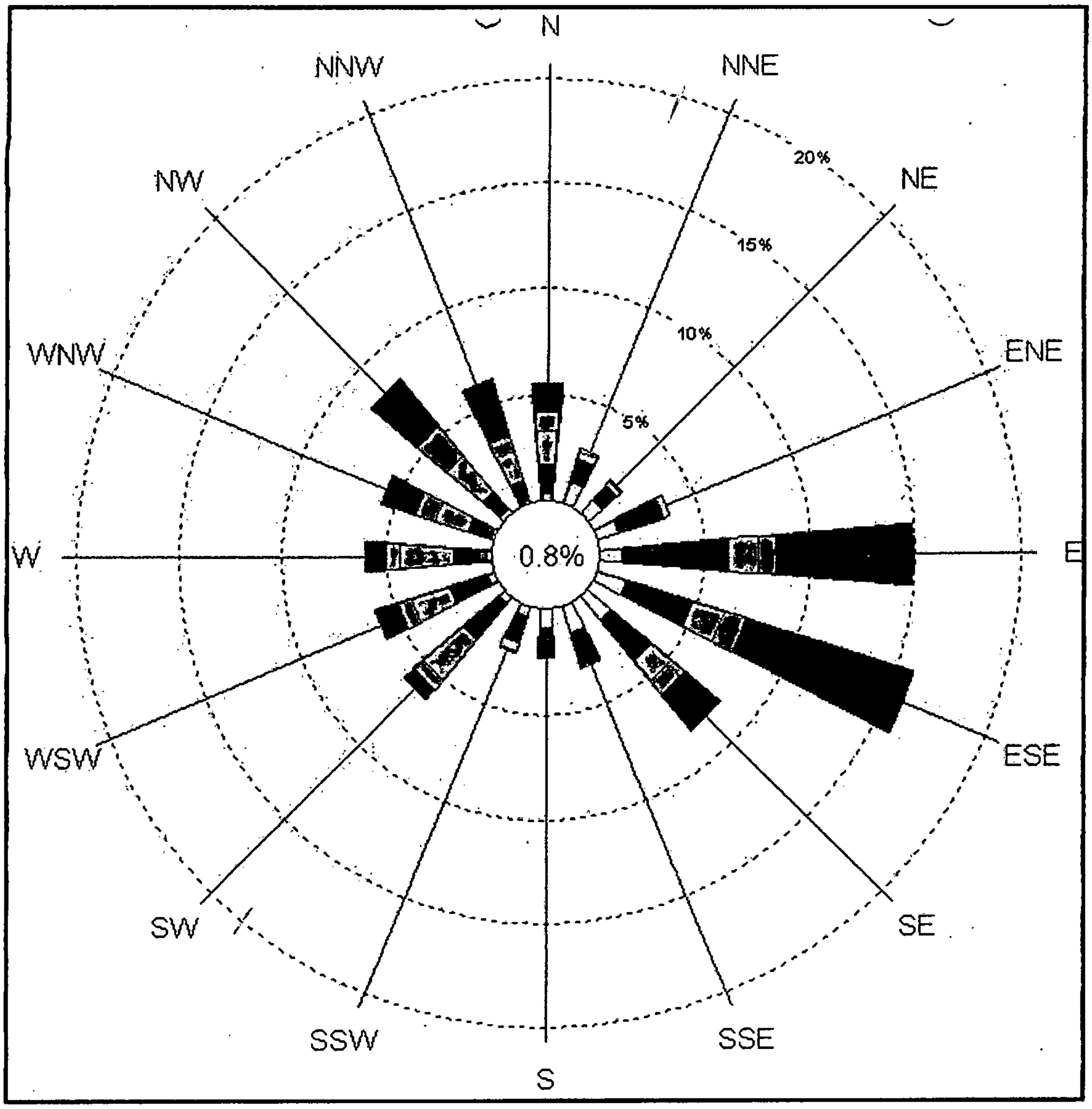

Figure 1: Wind rose showing annual averages of wind speed and direction for 2005 at Cape Point (Cape Town Weather Office).