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**Morphometric properties of shallow water kelp, *Ecklonia maxima*, along thermal and wave exposure gradients.**

Kelp have a maximum temperature at which they survive. Although some species thrive in cold Antarctic waters (eg). These kelp usually grow slower and are more shrubby looking .

Wave action causes kelp to develop strong holdfasts and stipes or risk breaking off . wave action also encourages mixing within the water column, which brings nutrients to the surface, especially in nutrient limited water.

Kelp in deep water have to put all their energy into vertical growth so that they can get enough light ..

Kelp are a very diverse range of organisms, with abilities to adapt to various different marine environments. They are mostly found in cool to temperate oceans. Kelp are ecologically important as the kelp beds they create provide food, shelter, habitat and protection for many benthic marine organisms. They play a key role in the marine food chain .. (boltons slides), and are ecosystem engineers.

Kelp forests serve as coastal protection from intense wave action, therefore kelp have to be adapted to various intensities..

However, environmental conditions and hydrographic properties do influence the morphology of kelp.. (expand on temperature and wave action)

**Background info:**

* Kelp ecology

~~Kelp beds are among the most productive ecosystems in the world (Mann, 1973; Fredriksen, 2003; Rysgaard and Nielsen, 2006) and provide food, shelter and nursery grounds for a variety of organisms (merzouk)~~

* Kelp in SA

1937, thought that the discontinuous distribution around False Bay of E.maxima was due to high temperatures, especially in summer ([[1]](#footnote-2)).

~~three of the four kelp species found in S.A inhabit the colder west coast waters, with E.maxima being the only on to extend eastward beyond the CApe of Good Hope([[2]](#footnote-3)). E. radiata is an exception in that it inhabits warmer waters along the east coast of S.A~~

~~Inshore conditions along this coastline range from cool through warm temperate to fringe tropical (Bolton and Anderson, 2004; Bolton et al., 2004), and are influenced by two major ocean currents in two oceans that set up a strong thermal gradient along the shore (Smit et al., 2013). (Smit et al 2017)~~

The coastline is broadly influenced by two major ocean currents, the Benguela Current and the Agulhas Current. One is an eastern boundary upwelling system and defines a cool temperate environment, and the other a western boundary current driving meridional transport of sub-tropical water toward the tip of Africa (smit et al 2017)

~~Ecklonia maxima is a large brown kelp from the order Laminariales, one of four kelp species found along the south-west coast of Southern Africa, along with Laminaria pallida, Macrocystispyriferaand Ecklonia radiata~~.

~~E.maxima and L.pallida are the only two species that are both ecological and economically beneficial.~~

~~E.maxima occurs in areas of warm to cold temperate waters in the sub- and intertidal rocky substrate (Stenek and Johnson 2013, Rothman 2015). E.maxima and L.pallida form extensive kelp beds along the South African west coast. With E.maxima forming the floating canopy up to depths of 10m and L.pallida forming the sub-canopy at depths of 20m or greater.~~

* Kelp and depth

Depth is directly related to light attenuation (Luning 1990), which makes it a major controlling factor of the vertical distribution of kelps.

* Kelp and temperature

~~Sites in False Bay lie in the Transition zone but where summer temperatures are higher because of solar heating of entrained water (Anderson et al. 1997)~~

~~Benguela marine province (west coast sites) and Benguela- Agulhas transition zone(false bay sites)~~

Kelp may be particularly vulnerable to climate change due to their cold-water affinities and limited dispersal ability ([[3]](#footnote-4))

T~~emperature is one of the most important factors controlling the geographic distribution of seaweeds, and their tolerances to high (summer maxima) and low (winter minima) temperatures generally define their biogeographical boundaries (Luning, 1984; van den Hoek and Luning, 1988; van den Hoek et al., 1990; Adey and Steneck, 2001~~). Moreover, the low dispersal ability ofmany kelps (Norton, 1992) may limit their ability to “track” large-scale environmental changes. (merzouk)

increased water temperature will not only have direct physiological effects, but will also induce indirect effects that can modify the biogeographic range of seaweeds;

~~Many environmental factors influence the kelp bed communities, where temperature generally controls the geographical distribution of marine organisms (Lüning 1990, Rothman 2015) kelp beds are controlled by factors such as wave action, nutrient levels, photoperiod, tides, topography of substrata and depth among others. Previous studies show that …~~

~~Bolton and Anderson (date) have shown a strong relationship between seawater temperature and the geographical distribution of kelp species. Because of South Africa`s unique location and it being bordered by two large intense currents, the warm tropical Agulhas Current on the east coast, and 1the cold nutrient rich Benguela on the west coast, the interaction of these two currents have profound effects.~~

In the Benguela Marine Province, seawater temperature serves as a proxy for nutrients, with an inverse relationship (Diekmann 1980).

Temperature and irradiance are the two most important factors influencing early stage of development (Luning 1990). Heteromorphic life histories are beneficial in that organisms can survive in different environmental conditions seeing that the different stages have different environmental requirements. E.maxima gametophytes have a broader temperature range for growth and survival than sporophytes (Bolton and Levitt 1985). Rothman 2006, generalise that once sporophytes are established and reach a certain size (stipe > 25mm), they have a good chance (75%) of maturing and forming part of the canopy

E.maxima historically never occurred further than Cape Agulhas, increasing in abundance within False Bay between 1966-2007, possibly due to the lower temperatures in that region.

* Kelp and wave parameters

~~trends suggested that E. radiata responds to exposure by having drag-reducing (small size, narrow laterals and blades, low spinosity) and strength-increasing (relatively large holdfast, thick stipe and thick blades and lamina) morphological traits~~, as observed for several other kelps in small-scale studies.We conclude that while wave exposure does have an effect on kelp morphology, the effect is not independent of other location-specific processes ([[4]](#footnote-5)).

~~the effect of wave exposure (hereafter referred to as ‘exposure’) on the morphology of macroalgae, and it has been demonstrated that exposure may affect a wide range of morphological characters (Koehl, 1986; Wheeler, 1988; Hurd, 2000) ([[5]](#footnote-6))~~

T~~hese adaptations to exposed environments may include thallus streamlining (Gerard, 1987), increased stipe (Cheshire and Hallam, 1988; Klinger and DeWreede, 1988) and thallus thickness (Cheshire and Hallam, 1988; Molloy and Bolton, 1996; Kawamata, 2001) or increased holdfast biomass (Sjøtun and Fredriksen, 1995). Although morphological adaptation to the hydrodynamic environment may reduce mortality (Friedland and Denny, 1995; Blanchette et al., 2002)it may also have physiological consequences such as reduced capacity for photosynthesis, productivity and growth (Gerard and Mann, 1979; Jackelman and Bolton, 1990; Blanchette et al., 2002) ([[6]](#footnote-7))~~

A recent study of E. radiata demonstrated that there was considerable morphological variation among Australasian populations of this species, but that the magnitude of this variation was unrelated to spatial separation of populations as it would have been expected from a genotypic or environmental cline (Wernberg et al., 2003b). Because the morphology of kelp populations separated by only 10’s of kilometers was just as different as populations separated by 100’s or 1000’s of kilometers these results suggest a strong non-clinal phenotypic component in the origin of this morphological variation.(wernberg 2005)

~~Wave exposure is probably the most commonly identified cause of morphological variation in macroalgae (e.g. Gerard and Mann, 1979; Cousens, 1982; Cheshire and Hallam, 1988; Molloy and Bolton, 1996; Ralph et al., 1998; Blanchette et al., 2002; Roberson and Coyer, 2004; see also review by Hurd, 2000). (wernberg 2005)~~

the prevailing paradigm that hydrodynamic gradients exert a unidirectional influence on macroalgal morphology, with drag-increasing morphologies at low exposure levels (to break down boundary layers) and drag-decreasing and strength-increasing morphologies at high exposure levels (to decrease dislodgement)

~~wave exposure is a very complex factor with many attributes (e.g. speed, acceleration, lift, period, duration and direction) and it seems likely that different morphological characters respond differently to each of these attributes of the hydrodynamic environment.~~

location-specific processes such as depth (Molloy and Bolton, 1996), grazing pressure (Kalvas and Kautsky, 1993) or nutrient levels (Blanchette et al., 2002) have an overriding effect on E. radiata morphology, influencing various morphological characters differently.

~~Studies show that morphological factors of seaweed can be a function of environmental factors, especially wave action. Kelps need to be flexible, to resist hydrostatic bending forces, and have strong thalli (Norton et al 1982). Generally kelp growing in exposed areas is tougher, sturdier, and more strongly attached than those in sheltered areas. The bigger the organism the bigger the drag force.~~

~~Adult E.maxima is characterised by a long hollow stipe, spear-shaped primary blade, with secondary blades grow bilaterally.~~

Morphological plasticity in kelps induced by environmental conditions, Hurd and Pilditch 2011, blade width and thickness varies with wave exposure, but adaptations help reduce drag and maximise nutrient uptake.

* Sheltered: thin blades with ruffled margins,
* Exposed: flat and smooth blades

Climate change

When facing an environmental challenge outside the normal range of phenotypic variability, populations may respond in one of three ways: (i) Migration: dispersal shifts the distribution towards a more favorable area; (ii) Adaptation: selection shifts the phenotypic reaction norm of individuals to match the new environment; and (iii) Extinction: neither migration nor adaption occurs, and the species becomes extinct (Clarke, 1996). (merzouk 2011)

. Increasing sea surface temperatures and other indirect climate-related effects will likely decrease the resilience of kelp beds, potentially leading to loss in abundance and range of this key component of coastal ecosystems (merzouk)

Kelp beds occur in the cold nutrient-rich waters of temperate to polar habitats where seasonality is important (@Dayton1985; @Steneck2002). Kelp beds affect the community structure of their surrounding area [@Steneck2002] and therefore any impacts on kelp due to global warming would have ripple effects on other marine ecosystems (Wernberg et al., 2010). If kelp species are not able to withstand the additional turbulence and hydrodynamic forces associated with the changing wave and temperature climate, their distribution will be limited to deep waters (Harley et al., 2006), or excluded from an area completely (Wernberg et al. 2011).

* Rationale and aim

Aims:

To determine if environmental factors such as temperature, wave intensity and depth have an effect on the morphology of shallow water sporophytes of Ecklonia maxima.

To quantify the effects of temperature, wave action and depth on kelp morphology.

Objectives:

* To determine whether kelp morphology is different between sites.
* To determine whether temperature differs between sites.
* To determine the differences in wave action between sites.
* To quantify the influence of depth on kelp morphology.

**Proposed methods:**

Three sets of data were used for this study. The first dataset is the morphometric measurements of the kelp collected. Thirteen individuals were haphazardly collected collected at 16 sites around the Cape of Good Hope.

The second comprised of coastal temperature data, provided by the South African Coastal Temperature Network. This dataset was used as the first set of explanatory variables (Smit et al 2017)

The third dataset included wave parameters simulated by the SWAN model at a 200 meter resolution, at 5 meter and 7 meter contours. The wave data was used as the second set of explanatory variables.

* Site

Sites were selected according to the geographic distribution of *E. Maxima*, under varying levels of wave exposure and temperature regimes, along the south west coast of South Africa. The chosen sites were also a combination of exposed and sheltered sites, along the West Coast and False Bay regions, ranging from St. James in False Bay to Yzerfontein on the West Coast.

* Morphometric data collection

Sampling took place between March and October 2018 during low tide. The thirteen largest *Ecklonia maxima* individuals were collected by snorkel in an area of kelp bed ~1m deep and shallow water (along the shoreline). Juvenile kelp (juvenile sporophytes) about 30cm in length were collected from shallow water on the shore. After the collection of kelp was completed, various morphological and biomass measurements were recorded. A measuring tape was used to measure the various morphological features, and biomass was measured by cutting the kelp into two sections and placing the material in a net bag, which was weighed using scientific scales.

The morphological factors that were measured are: primary blade length, primary blade width, frond length, stipe length, stipe circumference, number of tufts and epiphyte length. The biomass was divided into frond mass and stipe mass, were the sections were separated with a cut below the primary blade. These measurements allowed for comparisons in length, weight and thickness between sites and varying depths.

Abiotic Factors:

* Temperature data

The monthly shallow water temperature data was obtained from the South African Coastal Temperature Network (SACTN). The temperature dataset was a compilation of contributions made by several sources, using in situ data and digital underwater temperature recorders (UTRs).

* Wave parameters

All wave data, taken at three hour resolutions, was obtained by the South African Weather Service (SAWS). Short-crested waves, generated by wind into the coastal environment (), were then modelled from the data using the Simulating Waves in the Nearshore (SWAN) model. SWAN enables the removal of wave parameters from particular gridded locations in the nearshore (). For this study, a 200 meter resolution was used, at both 5 meter and 7 meter contours.

Statistical methods:

Tests for normality were performed, and due to the morphological and temperature data not being normally distributed, Non-parametric analyses were executed. The data was then standardised to a mean of 0 and a standard deviation of 1, in order to easily compare variables measured on different scales.

In order to visualise and compare the differences in morphology of kelp among sites, boxplots were constructed using the descriptive statistics of the morphometric data collected. The descriptive statistics include; minimum, maximum, 1st quartile(25th percentile), 3rd quartile (75th percentile), median and the interquartile range, which is the distance between the 1st and 3rd quartiles.

A descriptive summary of temperature was also conducted, including statistics such as minimum, maximum, mean, median, range and standard deviation. This too was displayed as boxplots showing the descriptive statistics of the temperature at each site.

Wave data --

A redundancy analysis (RDA) was performed to determine which parameters of temperature and wave exposure would best explain how kelp morphology is influenced by environmental factors. Explain rda----

Separate RDAs were conducted on temperature and wave parameters to fully identify the most influencing variables.

All statistical analyses were conducted through The R-Project for Statistical Computing.

Results

Descriptive stats of the Morphometric variables per site

Temperature descriptive stats per site

Comparisons of depth

* Deep vs shallow(all sites)
* Miller`s point
* Kalk bay

1. Papenfuss, “Studies of South African Phaeophyceae . I . Ecklonia Maxima , Laminaria Pallida , Macrocystis Pyrifera Author ( s ): George F . Papenfuss Source : American Journal of Botany , Vol . 29 , No . 1 ( Jan ., 1942 ), Pp . 15-24 Published by : Botanical Society.” [↑](#footnote-ref-2)
2. Papenfuss. [↑](#footnote-ref-3)
3. Merzouk and Johnson, “Kelp Distribution in the Northwest Atlantic Ocean under a Changing Climate.” [↑](#footnote-ref-4)
4. Wernberg and Thomsen, “The Effect of Wave Exposure on the Morphology of Ecklonia Radiata.” [↑](#footnote-ref-5)
5. Wernberg and Thomsen. [↑](#footnote-ref-6)
6. Wernberg and Thomsen. [↑](#footnote-ref-7)