Kelp forests are found in temperate and polar coastal regions around the world (Mann 1973). Kelp is classified as a keystone species making kelp forests one of the most productive ecosystems in the world (Mann, 1973; Fredriksen, 2003; Rysgaard and Nielsen, 2006; Merzouk, 2011), with the most productive kelp forests found in areas of frequent upwelling (Druehl 1981). The underwater forests provide shelter, food and nursery grounds for various marine species (Merzouk, 2011). Kelp is considered an ecosystem engineer and provides many ecosystem services, which include purifying and removing waste products produced by organisms living within the forest.

Many environmental factors influence 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, grazing (McQuaid and Branch 1984; Kalvas and Kautsky, 1993), nutrient levels, photoperiod (Luning 1980, 1990), tides, topography of substrata and depth among other ecological factors. Depth is directly related to light attenuation (Luning 1990), which makes it a major controlling factor of the vertical distribution of kelps. Staehr and Wernberg (2009) discovered an inverse relationship between temperature and depth, where depth decreases by 10% with a 5° C increase in temperature, for species in cold, temperate waters. In more turbid environments, depth limits decrease by 50%.

Ecklonia maxima is a species of large brown kelp from the order Laminariales, and is characterised by a long hollow stipe, spear-shaped primary blade, with secondary blades grow bilaterally. It is the dominant of four kelp species found along the coasts of Southern Africa, along with Laminaria pallida, Macrocystis pyrifera and Ecklonia radiata. The former three species inhabit the cold nutrient rich waters of the Benguela Marine Province, and E. radiata inhabits the warmer east coast of South Africa. E. maxima and L. pallida form extensive kelp beds along the South African west coast, in the southern portion of the Benguela region and parts of the Benguela – Agulhas transition zone (Bolton 2012). E. maxima forms the floating canopy up to depths of 19m and L. pallida forms the sub-canopy at depths of 20m or greater.

South Africa like many other countries is bordered by two large intense currents, the warm tropical Agulhas current on the east coast, and the cold nutrient rich Benguela on the west coast, thus interaction of these two currents have profound effects. But South Africa is unique in that the interaction of these currents occurs over a relatively short spatial scale, between Cape point and Cape Agulhas, resulting in a large temperature gradient along the shore (Smit et al 2013, 2017).

E. maxima occur in areas of warm to cold temperate waters in the sub- and intertidal rocky substrate (Stenek and Johnson 2013, Rothman 2015), and its biogeographical range extends from north of Luderitz, Namibia to west of Cape Agulhas in South Africa. This biogeographical range is largely determined by kelp species’ tolerance of high summer maxima and low winter minima temperatures (Luning, 1984; van den Hoek and Luning, 1988; van den Hoek et al., 1990; Adey and Steneck, 2001). Previously described as a cold water species by Griffths and Mead (2011), it is more fittingly described as a warm, temperate water species; as E. Maxima is found in False Bay where monthly mean temperatures in summer exceed 18 °C (Bolton 2012). However E. Maxima does not grow in areas where the monthly mean winter temperature falls below 10°C (Bolton 2012). False Bay`s high summer temperatures are a result of solar heating of entrained water (Anderson et al. 1997).

Gerard and Mann, 1979; Cousens, 1982; Cheshire and Hallam, 1988; Molloy and Bolton, 1996; Ralph et al., 1998; Hurd, 2000; Blanchette et al., 2002; Roberson and Coyer, 2004 state that wave exposure is the most identified cause of morphological variation in kelp. It has been demonstrated by Koehl 1986, Wheeler 1988 and Hurd 2000, that wave exposure affects many morphological characteristics in kelp (Wernberg and Thomsen 2005). Because of the many parameters within wave exposure it is probable that different morphological variables would respond differently to each parameter. Generally kelp growing in exposed areas is tougher, sturdier, and more strongly attached than those in sheltered areas. Frond characteristics of kelp in exposed areas are narrow, thick, flat and smooth, whereas in sheltered areas, blades are wide and thin with ruffled margins.

Wernberg and Thomsen (2005) observed that Ecklonia radiata responded to intense wave exposure by having small narrow blades (Gerard 1987) with minimal spinosity to reduce drag, as well as larger holdfasts (Sjøtun and Fredriksen, 1995), thicker stipes (Cheshire and Hallam, 1988; Klinger and DeWreede, 1988) and thicker lamina (Cheshire and Hallam, 1988; Molloy and Bolton, 1996; Kawamata, 2001) for increased strength. Morphological adaptations are beneficial for mortality (Friedland and Denny, 1995; Blanchette et al., 2002, Wernberg and Thomsen, 2005) but are consequential in that it reduces rates of photosynthesis, productivity and growth (Gerard and Mann, 1979; Jackelman and Bolton, 1990; Blanchette et al., 2002, Wernberg and Thomsen, 2005).

Kelps need to be flexible, to resist hydrostatic bending forces (Norton et al. 1982). It is suggested that kelp flexibility in the stipes might be related to wave exposure especially in shallow water, implying kelps strategy for survival in high water motion environments is flexibility rather than strength and resistance (Rothman, 2015).

Global temperature change is known to have had effects on kelp ecosystems. The Agulhas Current system has warmed significantly by 1.5°C in 20 years. Decreases in sea surface temperature (up to 0.5°C per decade) have been observed along the West Coast and near Port Alfred and Nelson Mandela Bay (Port Elizabeth) (Rouault et al. 2009, Rouault et al. 2010, Rouault et al. 2011). Bolton (2012) suggests that there is a high probability that kelp abundance was increasing (1986-2007) along the west coast of South Africa, where water temperatures are said to be getting cooler, due to climate change altering wind and rainfall patterns which in turn changes the intensity of the Benguela upwelling system (Rouault et. al 2010).

Due to climate change and elevated sea temperatures, the environment for kelp to successfully grow in is at risk. This poses a huge threat to biodiversity within the ocean. Kelps are an important indicator of change as they are highly responsive to environmental conditions, and are highly exposed to human activities (harvesting, pollution, fishing recreation and sedimentation) that impact the coastal zone (Krumhansl et al. 2016). Increased sea surface temperatures could result in a loss of abundance and range of this keystone species (Merzouk 2011). There are three ways in which a species can respond to a change in their environment: firstly by migrating to a more favourable area, secondly by adapting to the new conditions of the environment and finally by becoming extinct (Merzouk 2011).

The aim of this study is to determine how environmental factors such as temperature and wave exposure influence or affect the morphology of shallow water Ecklonia maxima. This will be achieved by understanding how the various aspects of kelp morphology and environmental parameters differ at sites along the Cape Peninsula. Also to be investigated is which parameters of temperature and wave exposure best explain the morphological variation in the different kelp communities, this will be achieved using statistical analyses. It is predicted that populations with similar temperature and wave exposure regimes will be similar in morphology. Temperature will influence morphological variables related to nutrient uptake, whereas wave exposure will influence morphology of the fronds.

**Methods**

* Study area

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 spring 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.

* 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 performed. 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 – (to be completed)

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

Fig 1: Morphological variables of E.maxima collected at 1m depth.

Frond length showed no specific pattern in geographic location among the sites. Both west coast and False Bay sites had variable frond lengths. Kalk Bay and Soetwater both had significantly shorter frond lengths than the other sites displayed. Olifantsbos, St James North, Yzerfontein and Oudekraal showed the largest variability in frond lengths when comparing the descriptive statistical boxplots. Frond mass however, displayed large variability at Oudekraal, St James and Yzerfontein and Kommetjie, with the former three sites having lager masses than that of Kommetjie. All other sites had relatively low variability and lighter frond mass. Sites located fairly close together such as Miller’s Point (including Miller’s A, B and C), St. James north and St. James South, and Black Rocks and Buffels, showed no significant difference in frond mass compared to each other.

Stipe length displayed the most variability among sites, irrespective of the proximity of their locations. False Bay sites generally have longer stipes than sites along the west coast. Stipe mass is fairly similar across all sites. Stipe circumference is rather similar for all sites except Bakoven on the west coast and Kalk Bay in False Bay.The primary blades of E. maxima have high variability in their lengths, with longer primary blades found along the west coast, especially at olifantsbos, Oudekraal and Slangkop.

Fig 2: A comparison of E. Maxima morphological variables collected at different depths. (deep/adult collected at 1m depth, shallow/adult and shallow/juvenile collected at the shoreline)

Both deep and shallow adult kelp show morphological variation between St James North and St James South for all variables, however the differences are not significant. However, all morphological variables of shallow kelp collected at Kalk Bay is significantly larger than that of adult kelp collected at 1m. Juvenile kelp at all sites is significantly different in primary width, stipe circumference, stipe length, stipe mass and total length.

Question: at what length does adult kelp become different in appearance between sites? other sampling methods required.

Fig 3: morphological variables of E. Maxima collected at different depths ( deep/adult collected at 1m , deepest/adult collected at 7m)

The general pattern observed from this figure, shows that kelp collected at 7m deep is larger for all variables than those collected at 1m deep. Kommetjie and Soetwater display significantly different values between depths for all variables. Buffels bay specimens are only significant in stipe length, stipe mass, frond mass and number of tufts. Oudekraal differs significantly only in stipe length and stipe mass.

Fig4: morphological variables of E. Maxima collected at Kalk Bay at different depths ( deep/adult collected at 1m , deepest/adult collected at 7m, shallow/adult and shallow/juvenile collected along the shoreline).

Kelp at 7m depth have a larger variability, but are not really significantly different from adult kelp in shallow water, except for stipe length, stipe mass, total length and number of tufts. Adult kelp collected in 1m deep water is more similar in morphology to juvenile kelp collected at the shoreline.

Question: why are adult individuals growing in shallow water larger than adult individuals growing in 1m deep water?

Fig5: morphological variables of E. Maxima collected at Miller’s Point at different depths (deep/adult collected at 1m, deepest/adult collected at 7m).

Adult E,maxima growing at depths of 7m at Miller’s Point, differs only from 1m adults in frond length, stipe length, stipe mass, total length and number of tufts, with all these variables being larger than that of kelp collected at 1m. Sites A, B and C show no significant differences in any of the morphological variables.

Sum.stats: The descriptive statistics of temperature

Monthly descriptive statistics: the monthly descriptive statistics of temperature for seven sites around the cape peninsula, and Yzerfontein.

From May to September, there is no significant difference in temperatures for all sites, despite their geographic location. Summer months, December to March, shows more variation among sites. Sea surface temperature at west coast sites, remain fairly consistent throughout the year (due to upwelling during summer months = same as winter lows). However, False Bay sites especially Bordjies, Kalk Bay and Muizenberg tend to reach temperatures of 18oC or more in summer. Although, the means, displayed by the black triangles remain relatively constant around 16oC throughout the year at all sites.