Physico-chemical factors influencing the spatial and temporal distribution of the seagrass, *Zostera capensis*, in Langebaan Lagoon

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Abstract

Seagrass meadows have important ecological roles in coastal ecosystems and provide high-value ecosystems services compared to other marine and terrestrial habitats. Despite this, there is growing evidence that this key ecosystems is declining on a global scale. Much of these declines have been attributed to the effects of human alterations of marine habitats. Continued destructive activities, in both South Africa and elsewhere, if not managed properly will result in the demise of seagrass beds from coastal areas. With this in mind, the aim of the project is to determine the main physico-chemical factors influencing *Zostera capensis* biomass and distribution in Langebaan Lagoon. Five sites within the Langebaan Lagoon were selected and within these sites a minimum of three and maximum of ten *Z. capensis* beds were sampled, depending on the availability of the beds. Five 10 cm core samples were collected from each bed, from which seagrass biomass, density, leaf length, leaf width and epiphytic algal biomass were estimated. Physico-chemical data were collected with a CTD to test for the differences in: temperature, turbidity, pH, salinity, dissolved oxygen and dissolved chlorophyll levels. The results indicated that temperature and salinity are the main factors driving biomass and distribution along Langebaan Lagoon. Increasing temperature appears to have a negative effect on both leaf length and leaf width, while increasing salinity has a positive effect on seagrass biomass. Although, the ancestral seagrass populations thrived in conditions of higher temperatures, today the rates of change along the coast is so rapid that seagrass populations cannot keep up with this change. In addition, sites near the open ocean experienced a higher seagrass biomass than the sites further away, indicating that salinity is an important factor driving growth and distribution. However, temperature and salinity are not the sole factor responsible for the distribution of Z. capensis at Langebaan lagoon. Turbidity and dissolved chlorophyll also appear to impact certain sites more than others. It is thus clear that at least a few other factors must be considered: the interaction between nutrients, epiphytes and macrograzers and the plants tolerance to the sediment quality. These different aspects need to be studied in concert in order to perceive the full range of impacts on the *Z. capensis* beds and to better manage these ever-declining key ecosystems.

Introduction

Seagrass ecosystems are key ecosystems with important functions in the marine environment (Duarte, 2002). Globally, seagrasses support diverse and productive communities of marine invertebrates, fish (Hughes *et al.* 2002) as well as megaherbivores like dugongs and sea turtles (Duarte, 2002). According to Hughes *et al.* (2002), seagrass habitats offer protection and enhance feeding opportunities to a variety of fishes and invertebrates, allowing for greater diversity, abundance and biomass than in non-vegetated, shallow water habitats.

Seagrass ecosystems provide important ecological and economic functions, which include high-value ecosystem services such as ocean nutrient cycling, sediment stabilisation and sequestration of carbon and usually support commercial and subsistence fisheries that can sustain whole communities (Orth *et al,* 2006). There is however growing evidence that seagrass meadows are currently experiencing worldwide declines in cover (Duarte, 2002). These coastal ecosystems along with salt marshes, coral reefs and mangroves are being lost, raising several ecological and economic concerns (Waycott, 2009).

Although natural factors such as 'wasting disease' have played a role in seagrass declines, the main threat to seagrass ecosystems and marine biodiversity are human activities (Fletcher and Fletcher, 1995; Waycott, 2009) which are responsible for the destruction of structurally complex habitats in oceans round the globe (Pillay *et al.* 2010). Increased coastal development, destructive harvesting and fishing techniques as well as poor water quality are the major causes of seagrass loss and will eventually lead to environmental homogeneity (Pillay *et al.* 2010). Pillay *et al.* (2010) also argued that coastal development such as harbour construction and dredging can change the sediment dynamics and this too can be fatal to seagrasses as it may impede the flow of light that reaches the plant, or cause smothering.

According to Pillay *et al.* (2010), eutrophication has a direct effect on seagrass decline, as increased nutrient levels enhance the microalgal growth on the seagrass blades, which hampers availability of light for photosynthesis. The removal of predatory fish by over-exploitation during fishing can also intensify the effects of eutrophication. This is because in the absence of top predators the intermediate predators drastically reduce the abundance of grazers, thus allowing algal growth to increase severely and smother the seagrasses (Baden *et al.* 2010).

The global trend of losses of seagrass ecosystems is also evident in Langebaan Lagoon, South Africa, where roughly 40% of seagrass beds have been lost over the last 50 years (Pillay *et al.* 2010). Langebaan Lagoon and Knysna Estuary are the last two systems supporting large stands of seagrasses in South Africa and the last remaining system with populations of the critically engendered seagrass limpet *Siphonaria compressa*. In both the global and South African contexts, continued destructive activities, if not reversed or well managed, can lead to permanent eradication of seagrass ecosystems from coastal environments, with inevitable knock-on implications for communities and ecosystems (Pillay *et al.* 2010). With these concepts in mind, the aim of this project is to determine the major physico-chemical factors influencing seagrass biomass and distribution in Langebaan Lagoon. This information is crucial for management agencies to determine the mitigatory actions necessary to conserve the existing seagrass meadows in the lagoon.

Methods

- **Study Sites**

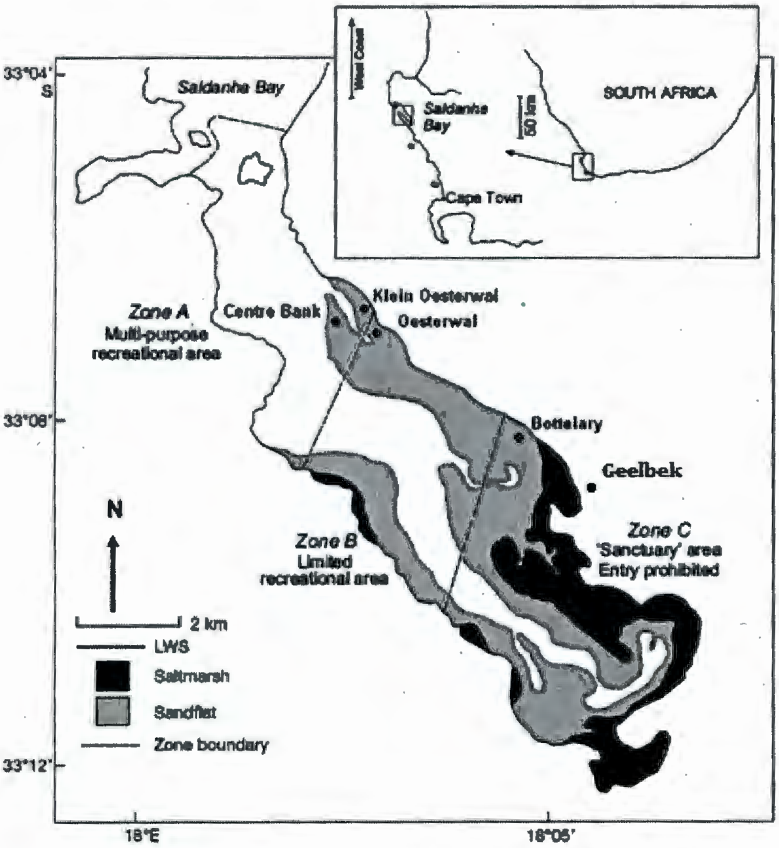

Figure1: Geographical position of Langebaan Lagoon on the South African Coastline, as well as sampling sites and park zones. Geelbek is part of the sanctuary, where entry without a permit is prohibited.

Sampling took place in both summer (April) and winter (July) seasons at five sites in Langebaan Lagoon viz. Klein Oesterval, Oesterval, Centre bank, Bottelary and Geelbek. A maximum of ten beds were sampled within each of the five sampling sites, depending on the availability of beds at each site. Data on seagrass biomass, microalgal growth and water quality were collected as outlined below.

A: Seagrass bed size, biomass and microalgal growth

Five core samples (10 cm diameter) were collected from each bed, from which seagrass density and biomass were estimated. These were collected at low tides. Density was determined by counting numbers of shoots per core sample, while biomass was determined by drying seagrasses samples at 60 °C for at least 11 hours and then weighing. Microalgal growth on seagrasses was estimated from ten seagrass blades per core by lightly scraping algae off with a blade. Total biomass of microalgal scrapings were determined per core by drying at 60 °C and then weighing.

B: Water Quality

Three water quality measurement were taken with a CTD (YSI 550MP) at each site. These measurements include: temperature, salinity, dissolved oxygen levels, pH, chlorophyll-a concentrations and turbidity.

Statistical Analyses

The data collected were analysed using Statistica10. Tests for homogeneity and normality were performed on the data, after which, Two-Way (or Factorial) ANOVA were run comparing both the seasonal and site effect of the data. When significant differences were detected the data were further analysed with Tukey tests to determine where exactly the differences occurred. Physico-chemical parameters and seagrass variable were correlated, using the Spearman Rank Correlations test, to determine the degree of influence the former had over the latter.

Results

Seagrass variables

Letters were used to show the significant differences between seagrass variables for each site. Different letters indicate a significant difference between the seagrass variables. Seagrass biomass (Figure **1a**) was significantly influenced by season ($F_{1,4}$=7.1; p= 0.008) and site ($F_{1,4}$=20.1; p< 0.001) as well as by their interaction ($F_{1,4}$= 19.0; p< 0.001). In summer, seagrass biomass had a decreasing trend moving from Centre Bank to Geelbek. However, in winter, biomass was slightly lower at Centre Bank and Klein Oesterval than at Oesterval after which it again followed a decreasing trend as one moves to Geelbek. Oesterval and Centre Bank were the only two sites that had significant temporal difference in seagrass biomass (p< 0.001). Blade density (Figure **1b**) differed significantly between sites ($F_{1,4}$= 122.7; p < 0.001) but was not affected by the season ($F_{1,4}$= 0.62; p= 0.43), however, the interaction between season and site appeared to have a significantly influence on the density of blades ($F_{1,4}$= 14.2; p < 0.001). Blade density appears to be increasing from Centre Bank, in the north, to Geelbek in the south for both summer and winter. Oesterval (p< 0.001) and Geelbek (p=0.003).had significant temporal differences in the density of blades

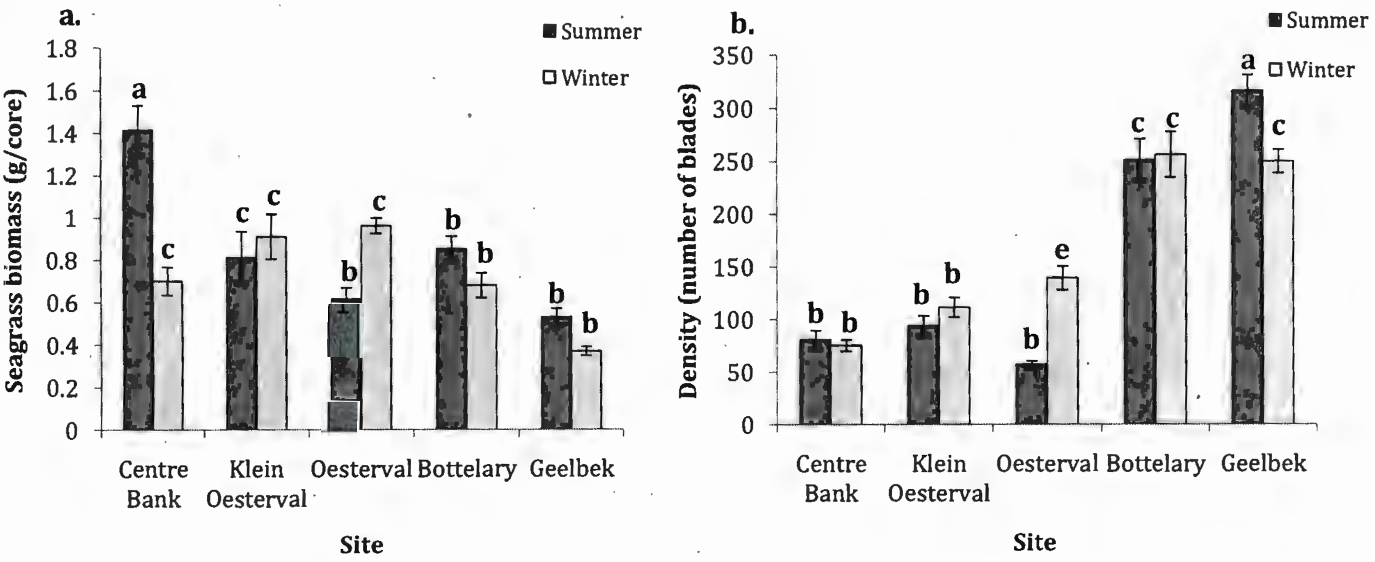

Figure1: Differences in **(a)** mean (±SE) seagrass biomass and **(b)** mean (±SE) blade density, between each of the five sites for both summer and winter months.

Leaf length was significantly influenced by season ($F_{1,4}$= 9.1; p= 0.003), site ($F_{1,4}$= 59.9; p< 0.001) and also by the interaction ($F_{1,4}$=5.5; p < 0.001) between the two. Mean leaf length was highest at Centre Bank (343.45 mm ± 11.25 SE), during summer and showed a drastic decrease (226.39 mm ± 7.22 SE) during winter. On average, Geelbek had the shortest leaves in both summer (81.61mm ± 3.20 SE) and winter (87.92mm ± 3.13 SE). Overall, there was a decreasing trend of leaf length in summer and winter, from Centre Bank to Geelbek. Centre Bank had a significantly different (p< 0.001) temporal distribution, with higher leaf length in summer than winter. Leaf width was also significantly influenced by season ($F_{1,4}$= 9.5; p= 0.002), site ($F_{1,4}$= 101.9 ; p< 0.001) and their interactions ($F_{1,4}$= 3.3; p= 0.013). An overall decrease in leaf width was apparent as one moves from Centre Bank southwards to Geelbek. Oesterval (p= 0.004) and Centre Bank (p= 0.015) were temporally significantly different in leaf width.

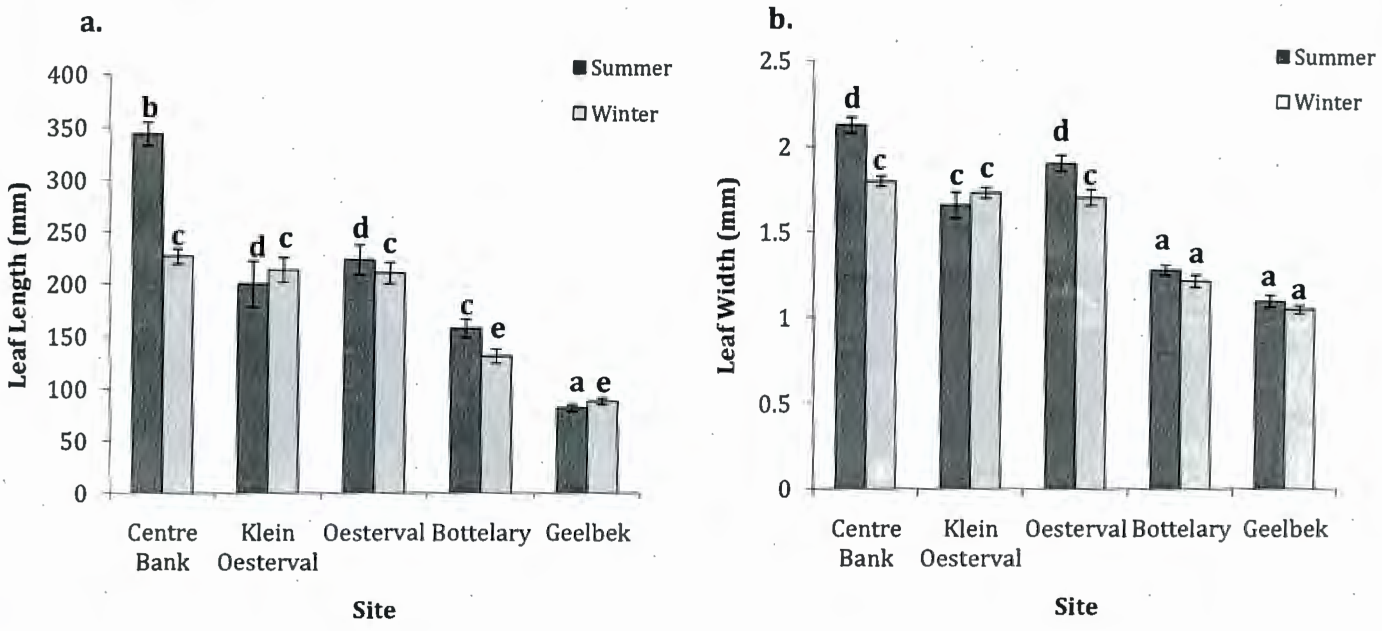

Figure 2: Differences in **(a)** mean (±SE) seagrass leaf length and **(b)** mean (±SE) seagrass leaf width (mm), between each of the five sites for both summer and winter months.

Epiphytic algal biomass was significantly influenced by season ($F_{1,4}$= 6.4; p=0.012), site ($F_{1,4}$= 3.3; p=0.011) and their interaction ($F_{1,4}$= 3.1; p=0.016). During summer the epiphytic algae were more prevalent, occurring at Centre bank, Klein Oesterval and Oesterval, as opposed to winter when they occurred only in the seagrass beds of Klein Oesterval. During summer, epiphytic algal biomass in Oesterval was significantly different to Bottelary and Geelbek. Oesterval also showed significant temporal differences in epiphytic algal biomass.

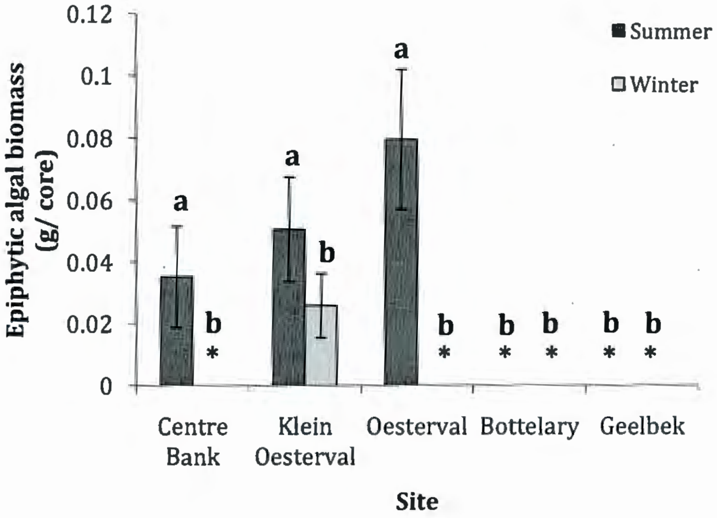

Figure 3: Differences in mean (±SE) epiphytic algal biomass between each of the five sites for both summer and winter months. * denotes sites with no epiphytic algal biomass.

Physico-chemical Parameters

Due to malfunctioning of the CTD, complete summer sampling of the physico-chemical data in Geelbek was not possible, consequently, the seasonal effect on the data could only be tested when Geelbek was excluded from the analyses. According to Underwood, (1997), if there is no season-site interaction when excluding Geelbek from the analysis, the data should be included in the Two-Way ANOVA analysis. Conversely, if there is a season-site interaction when excluding the missing Geelbek data, the data should be excluded from the analysis. When excluding Geelbek from analysis, season-site interactions were seen for all physico-chemical parameters except turbidity.

Temperature was significantly influenced by site ($F_{1,3}$= 45.23; $p< 0.001$), season ($F_{1,3}$= 571.07; $p< 0.001$) and by the interaction between season and site ($F_{1,3}$= 18.76; $p< 0.001$). Temperature levels increased from Centre Bank to Geelbek, in winter. This overall increase in temperature was also seen in summer but it was slightly less pronounced. As expected water temperature was much lower during the winter month than summer, with Centre Bank (12.7 °C) and Oesterval (13.3 °C) experiencing the lowest temperatures. During summer, Oesterval is also the site showing the highest increase (7.73 °C) in water temperature, from 13.3 °C to 21.0 °C. All sites, save Geelbek, have significant temporal differences in temperature. Turbidity had no significant difference ($p> 0.05$) between sites, seasons or the interaction between season and site. In winter, turbidity is constant from Centre Bank to Bottelary with a drastic increase occurring at Geelbek. No temporal differences in turbidity were found for the remaining four sites.

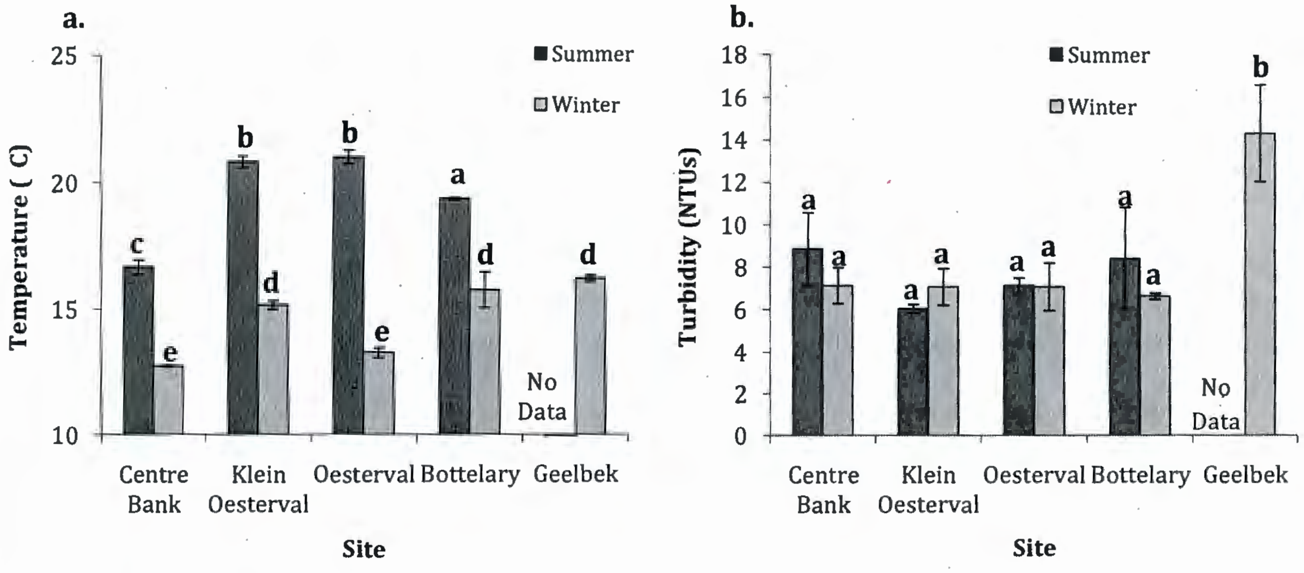

Figure 4: Differences in measured environmental factors, **(a)** mean (±SE) temperature and **(b)** mean (±SE) turbidity, between each of the five sites for both the summer, and winter months.

The pH was significantly influenced by season ($F_{1,3}$= 412.8; p< 0.001), site ($F_{1,3}$=31.4 ; p< 0.001) and also the interaction ($F_{1,3}$= 6.1; p=0.006) between site and season. In summer, Klein Oesterval, Oesterval and Bottelary had similar pH levels with that of Centre Bank being slightly lower. Overall, pH showed an increasing trend from Centre Bank southwards to Geelbek during the winter months. All sites were significantly different, temporally, in terms of the water pH level. During summer, salinity ranged from $35.3^{0}/_{00}$ to $37.1^{0}/_{00}$ but during winter this range was much lower ($32.8^{0}/_{00}$ to $34.4^{0}/_{00}$). Salinity was significantly influenced by season ($F_{1,3}$= 358.0; p<0.001), site ($F_{1,3}$= 6.3; p= 0.005) and its interaction between season and site ($F_{1,3}$= 25.8; p< 0.001). In summer, salinity showed an increasing pattern as one moves from Centre Bank to Bottelary, while in winter, the overall pattern is decreasing. Salinity was temporally significantly different across all the sites, except at Geelbek.

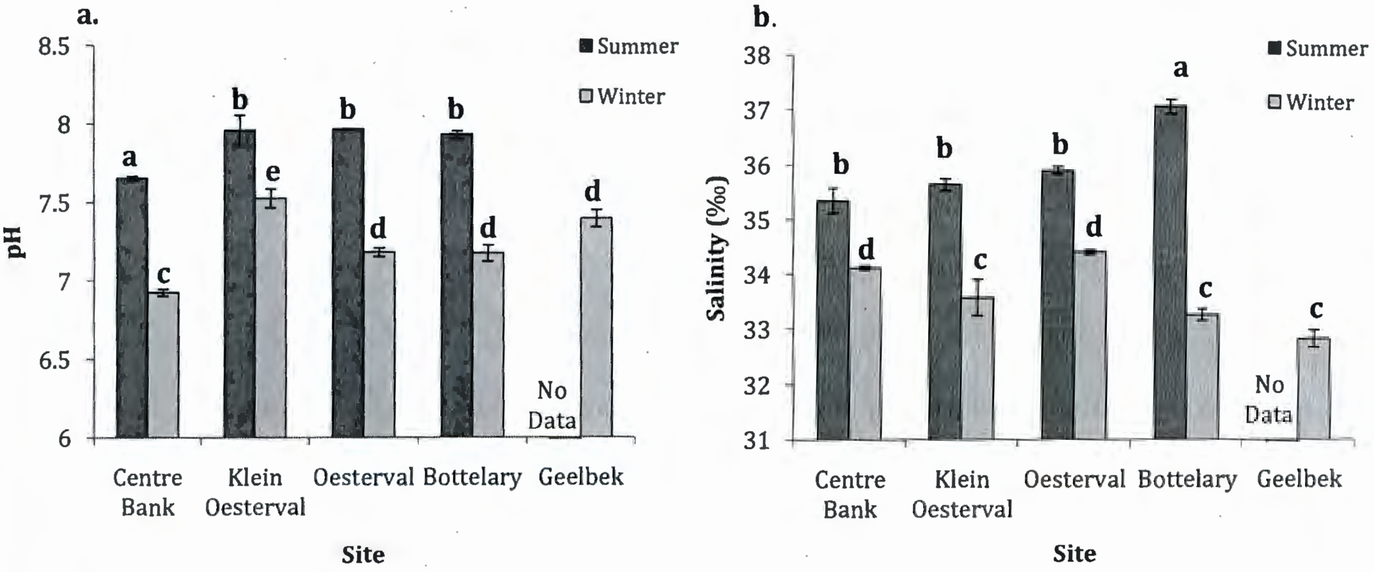

Figure 5: Differences in measured environmental factors, **(a)** mean (±SE) pH and **(b)** mean (±SE) salinity, between each of the five sites for both the summer and winter months.

Dissolved oxygen was significantly influenced by season ($F_{1,3}$=24.8, p< 0.001), site ($F_{1,3}$=26.3; p< 0.001) as well as the interaction ($F_{1,3}$= 7.6; p= 0.002) between site and season but season alone did not show any result due to missing data. Dissolved oxygen level was highest at Klein

Oesterval (14.6 mg/l) in winter and appears to be significantly different to all other sites. Temporal differences in dissolved oxygen were evident only at Klein Oesterval. Dissolved Chlorophyll (mg/l) was significantly influenced by site ($F_{1,3}$=8.7; p= 0.001) and the interaction between season and site ($F_{1,3}$= 4.5; p= 0.018). There was no significant difference between sites during summer but during winter, the dissolved chlorophyll levels were significantly higher at Geelbek compared to all other sites (p< 0.001). No temporal differences within sites were evident when examining the dissolved chlorophyll data.

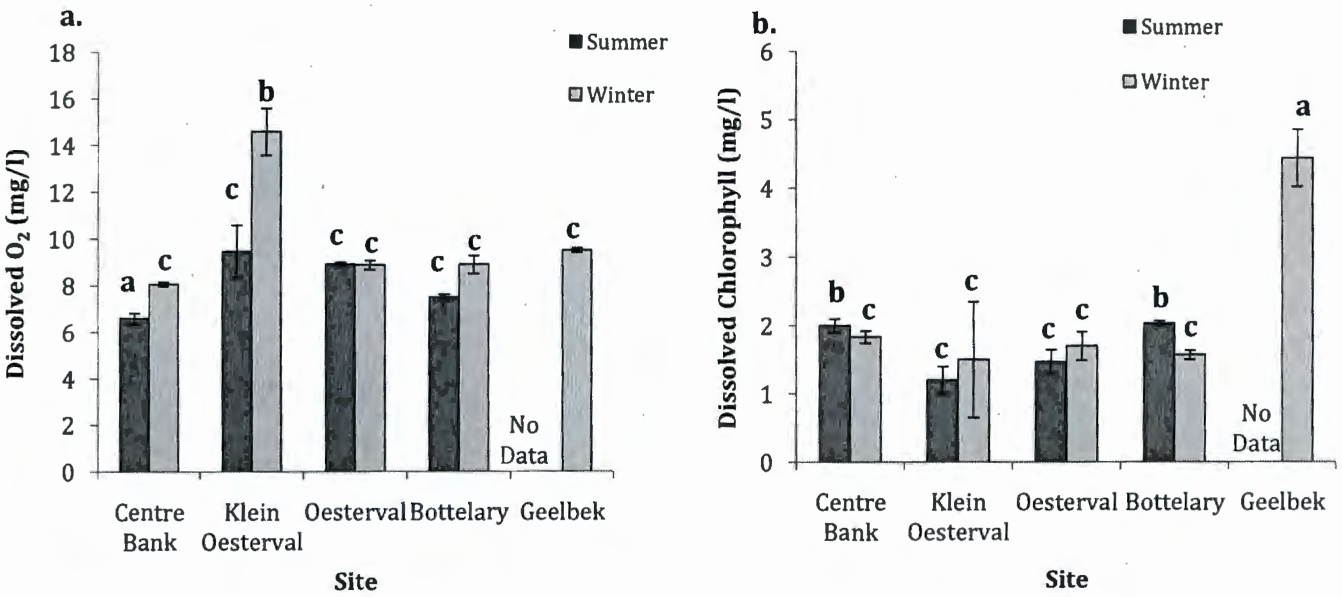

Figure 6: Differences in measured environmental factors, **(a)** mean (±SE) dissolved O_2 (mg/l) and **(b)** mean (±SE) dissolved chlorophyll (mg/l), between each of the five sites for both the summer and winter months.

Correlations

The Spearman Rank Order Correlations comparing the physico-chemical parameters with the seagrass variables, indicated that temperature negatively influenced leaf length (r= -0.90, p=0.037) and leaf width (r= -0.90, p=0.037), during winter. Moreover, it was also evident that salinity positively influenced seagrass biomass (r= 0.90, p=0.037), during the winter months.

During summer, the physico-chemical parameters appeared to have no significant influence on any of the seagrass variables.

Discussion

Although many factors are responsible for the decline in seagrass distribution, the relationship between seagrass habitat and water quality is of particular interest because of the history of seagrass losses caused by water quality degradation (Fourqurean *et al.* 2003). According to Burrell and Schubel (1977), the tolerance of individual species to their physical environment is comparatively very wide. However, in many cases the responses of species to variables such as salinity, temperature and turbidity are not well known.

The correlation analyses indicated that the trends in seagrass biomass could be explained by the salinity levels of the surrounding water column. Seagrass biomass was highest at Centre Bank and followed a decreasing trend to Geelbek (Figure 1a). This pattern indicates that *Z. capensis* has a higher biomass in marine environments and decreases as salinities become less marine.

The low biomass occurring at Geelbek can also be explained in terms of the turbidity levels at this site (Figure 1a and 4b). High turbidity can possibly cause a high level of light attenuation in the water column, limiting the amount of light that reaches the seagrass leaves and, consequently, impeding photosynthesis and inevitably also the growth at this site. The high turbidity at Geelbek cannot be attributed to anthropogenic disturbance as this site is within the sanctuary and inaccessible without a permit. It is possible that the turbidity at this site is due to the muddy substrate, which easily becomes suspended upon wave-induced disturbance. The high level of dissolved chlorophyll (Figure 6b) at Geelbek suggests a large amount of phytoplankton to be present in the water column and this may add to the increased turbidity.

For both biomass and density of *Z. capensis* blades, Oesterval appears to experience considerable dieback during summer. This could possibly be due to the increased epiphytic algae found at this site during the summer months (Figure 1a and 1b). When epiphytic algae occur in dense mats on the leaf surface, it hinders the flow of light and consequently the ability of the plant to photosynthesise (Adam and Talbot, 1992). Epiphytes may also hasten the loss of seagrass leaves by imparting a much higher drag on the leaf during wave surges so that leaves may be torn off (Borowitzka and Lethbridge, 1989), consequently, decreasing the biomass. In the case of Centre Bank, it can be possible that the smothering effect of high epiphytic covering stimulates the production of new leaves and subsequent abscission of old leaves (Talbot and Bate, 1987) but the exact driver of growth and distribution is unclear for this site.

Evidently, leaf length and leaf width was highest at sites with more marine environments (Figure 2a and b). These more marine sites were also extremely disturbed sites and may be inhabited by less macro-grazers than the sanctuaries, which were further away from the open ocean. It is thus possible that grazers may explain the lack of epiphytic algae and the shorter, thicker seagrass blades found at sites further from the open ocean (Figure 2 and 3). If grazers were the cause, this could explain the lower seagrass biomass at the sanctuary sites as the grazers would presumably also reduce the photosynthetic surface of the plants when feeding on the epiphytes. Accordingly, to meet the carbon requirements, *Z. capensis* beds at these sites have more shoots per site explaining the high density observed (Figure 1b).

The correlation analysis demonstrated that, in winter, temperature has a negative relationship with *Z. capensis* leaf dimensions. This indicates that climate change may significantly influence seagrass distribution and growth. Today, seagrasses live in a marine environment with a lower mean temperature and lower available CO_2 than were experienced in the past (Orth, 2006). Due to this it would be expected that the recent trends of increasing temperature and CO_2 concentrations would result in environments that are more conducive to them. However, increased anthropogenic pressures to the coastal zones hasten the rates of change experienced in the coastal waters, and these rates far exceed the speed at which seagrass species can adapt to such changes (Orth, 2006). Furthermore, the direct effects of increased temperatures are dependent on the individual species' thermal tolerance and their optimum temperature for photosynthesis, respiration and growth and may thus differ greatly between species (Sort an Neckles, 1999).

Several suggestions can be made to explain the causes of the fragmented distribution of seagrass beds in Langebaan Lagoon. Some maintain that the primary cause of these losses are connected to reduction in water clarity (Erftemeijer and Lewis, 2006), which can be a result of either anthropogenic activities (e.g. dredging and disposal operations) or natural phenomena (e.g. storms, wind-induced wave action and other perturbations). As for most plants, light is one of the key environmental resources imperative for the growth and survival of seagrasses (Erftemeijer and Lewis, 2006). Furthermore, the reduction in light due to turbidity (Longstaff and Dennison, 1999) has been identified as a major global cause of decline in seagrasses. However, turbidity does not appear to be a major determining factor for seagrass distribution and growth at Langebaan Lagoon, with more emphasis being placed on temperature and salinity. It is thus clear that, while turbidity may play an important role in the persistence of the seagrasses in other regions, it is only one of a number of environmental factors that set the bounds for seagrass habitat requirements (Fourqurean *et al.* 2003) in Langebaan Lagoon.

Temperature, salinity, nutrient availability, grazing and phytoplankton can also determine the suitability of a site for the growth and distribution of seagrasses and should invoke further study.

Due to the rapid change in the environment, the future for seagrasses does not look optimistic (Orth, 2006). Major recommendations to alleviate this decline, include extensive conservation efforts involving nutrient management schemes, sanctuaries or protected areas as well as educating the public on the importance of seagrass ecosystems and the services they provide. However, before these actions can be undertaken we must first broaden our knowledge on the species' habitat preferences and tolerance levels as these may differ significantly from one species to another. Such conservation efforts have proven to be valuable in other areas around the world as in Tampa Bay, Florida (Tomasko *et al.,* 2005) where nutrient inputs were reaching harmful levels. This demonstrates that with good conservation effort and the appropriate management plans areas such as Langebaan Lagoon, South Africa, too can revert to its pristine seagrass conditions. Such conservation efforts will not only benefit the populations of *Z. capensis* found at Langebaan but will allow for the preservation of their associated organisms as well as the entire coastal ecosystem.

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