Micro-scale zonation patterns of a salt flat in the Port Curtis Region

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Kasey Welch and Kandace Walton

Centre for Environmental Management
Central Queensland University
Gladstone Q 4680

Central Queensland
UNIVERSITY

Abstract

Salt flats are an understudied feature of a mangrove estuary system, and the relationship between the mangroves and adjacent salt flats is not known. In the Port Curtis region of Queensland, Australia, salt flats are frequently destroyed, typically for commercial practices. The Port Curtis region of Gladstone is a highly industrial area, which is often characterised by effluent discharge. The influence of salt flats on the movement of chemicals and nutrients is also unknown. The goal of this study was to determine if the physical and chemical characteristics of a salt flat could be determined from aerial photographs, and if zones with different types of vegetation had different physical and chemical characteristics. The authors hypothesised that the zones without vegetation would have elevated conductivity, and that there would be a significant difference for all the physical and chemical characteristics between the three types of zones: Mixed vegetation, Algae, and Zones without vegetation. Grain size, porosity, conductivity, and organic carbon appear to be the abiotic factors that are the most differential between the three types of zones. The aerial photographs obtained of the study site were of low resolution, so it is unknown if the physical/chemical characteristics of an area can be determined by looking at such photographs.

Introduction

Salt flats are a prominent feature of any estuarine environment encompassing mangroves, but they are seldom studied (Teasdale et al. 2005). Areas adjacent to the salt flats, such as mangrove stands, are important habitat in estuarine systems, but not much is known about their relationship with salt flats, and what salt flats potentially contribute to this environment (Connolly & Guest 2004). It is thought that the outwelling of nutrients, particularly phosphates and silicates, during the spring tides may contribute to the nutrient budget of mangroves and estuaries (Ridd et al.1997).

Salt flats in the Gladstone region have decreased in total acreage, it has been estimated that 650 hectares of mangroves and 950 hectares of salt flat have disappeared from the region, about 17% and 24%, respectively (Duke et al. 2003). Mangroves are important habitat for many animals, such as birds and fish, including those of commercial and recreational importance, and the affect or contribution of salt flats is not known. Salt flats are characterised by increased salinity and minimal, salt tolerant vegetation that exist in a notable depression, on the landward side of a mangrove stand (Teasdale et al. 2005).

The Port Curtis region is a major industrial centre and an international harbour, and there has been effluent discharge and reclamation of many types of habitat throughout the region, including salt flats, particularly since the 1960s (Duke et al. 2003). It is not clear what role salt flats play in the movement of chemicals and nutrients into the environment, but sediment and soil conditions such as organics, salinity, and the amount of fine textured sediment can relate to mangrove zonation (Teasdale et al. 2005).

South Trees Inlet is located in the Port Curtis Region of Central Queensland. This was selected as the location of the study site because it was easily accessible and the zonation patterns are readily visible. There is also a channel that runs through the centre, creating further zones in the salt flat.

The goal of this study was to map out the zonation patterns of the salt flat and study associated physical and chemical features to determine if aerial photographs could be used to decipher the characteristics of salt flat zones. This study also aimed to increase the understanding of salt flats, and their importance to estuarine systems. The authors hypothesized that salinity would be elevated in zones without vegetation, and that moisture content and porosity would be lower. They also expected that there would be a marked difference between the types of zones for all elements of the analysis, and that moisture content would be higher in vegetated zones.

Methods

Sediment Analysis

Sediment cores were taken from each zone at the study site using a 60 mL syringe with the tip removed, following the Syringe Technique outlined in Mudrock et al. (1997). A total of three 30-50 cubic centimetres cores of sediment were extracted per repetition. The cores were taken adjacent to each other in 5 randomly selected places in each zone, a total of 15 cores per zone to ensure enough sediment was collected for analysis. A $0.25m^2$ quadrant was used in each zone to look at percent cover and species present for each repetition. A scraping of the sediment, about 2 cm deep was also taken adjacent to the cores and used for sediment grain size analysis. All samples were stored in a freezer until further analysis.

The surface scraping was put through a series of graded sieves, ranging from 63μm, 125μm, 250μm, 500μm, and 1.0mm, with sediment <63 μm being collected in a pan (Hendry et al. 2005). The sample collected in each sieve was placed in the oven at 100°C for a minimum of 24 hours. Samples were then weighed, and the percent particle fraction for each sieve was determined for each zone. A one-way ANOVA and Tukey's post hoc tests were used to test the proportional difference of sediment <63μm in each zone.

Moisture content was measured immediately upon returning to the lab. One core from each repetition was weighed, and then placed in a drying oven for 24 hours at 100°C, and each sample was again weighed. The amount of moisture in the sample is the difference between the two weights, expressed as the percent moisture by weight (Douglas 2005; Port Curtis Seagrass Monitoring Programme 2005). A one-way ANOVA was used to examine the differences in moisture content between each zone, as well as between each type of zone (mixed vegetation, bare sediment, and algae covered).

Porosity was calculated using cores of a known volume (30 cubic centimetres) and measuring the wet-bulk density. The equation described in Mudrock et al. (1997) was used for this calculation. The cores for zones J-V were used for moisture content, the porosity calculation, and organic carbon, and the cores for zones A-J were used for moisture content and organic carbon content only.

The loss on ignition technique (Heiri et al. 2001) was used to measure organic carbon. After the moisture content was measured, the dried sample was ground using a mortar and pestle, and then placed in a muffle furnace at 550°C for one hour. The weight loss measured represented the amount of organic carbon in the sample. A one-way ANOVA was used in the statistical analysis.

Air-dried core samples were crushed with a mortar and pestle. Approximately 10 g of the first three repetitions from each zone was placed in a beaker, and 50mL of RO water was added. The mixture was stirred until all sediment was suspended in the water, and then left overnight to allow the sediment to settle. The water was then poured off, and the pH and conductivity was measured using a TPS 90FL-T. Conductivity values were multiplied by 7.5 to convert from the electrical conductivity of the 1:5 soil/water mixture to the electrical conductivity of the sediment (Slavich & Petterson 1993).

Zonal Mapping

Zones on the salt flats were mapped in the field using a handheld Garmin GPSMap 76, set for taking a track point at one second intervals. Markers were placed around the perimeter of the study area to use as a geo-reference each day in the field. The perimeter of each visually distinct zone was mapped with GPS unit, as well as features such as channels running through the study site. Zones were visually assessed based on sediment colour and texture, and vegetation. Observational data for each zone was collected, such as flora and fauna present, and a general description of the landscape.

After the GPS data was downloaded into ArcMap, the spatial adjustment tool using the affine transformation technique was used to help minimize inaccuracies caused by collecting the GPS data on different days. Day 1 was used at the basis for the corrections, and the four markers placed at the corner of the study site were used to create the links between the different days.

Results

Zonation

The zones mapped out appear to be visible from aerial photographs (Figure 2). However, this has not been analysed in detail, and the photograph is of poor resolution. The Mixed Vegetation zones are much darker in colour than surrounding zones (Figure 2a), but it is difficult to distinguish between zones without vegetation, and zones with algae (Figure 2b-c). One zone that is particularly distinguishable is Zone F (Figure 2c).

Grain size analysis

For all samples collected, >45% was less than 63 μm, and the average for all samples was 76.35% (Figure 3). All zones were significantly different ($p<0.001$, $F=5.249$) with respect to the amount of sediment <63 μm. The mixed vegetation zones were not significantly different ($p=0.110$, $F=2.134$), and formed one homogenous subset after a Tukey's test ($\alpha = 0.05$). However, the algae and zones without flora present, when compared with other zones of the same type, were significantly different, and did not form one homogeneous subset ($p < 0.001$, $F = 11.916$; $p = 0.012$, $F = 0.4234$, respectively). The vegetated zones, both the mixed vegetation and the algal zones, had a larger percentage of sediment <63 μm than the zones that were not vegetated (Figure 4; $p = 0.003$, $F = 6.507$).

Moisture content

The overall range in moisture content was 8.4% to 19.2%. Zones were significantly different from each other ($p < 0.001$, $F = 11.685$) and formed 8 subsets, with many zones that were placed in multiple groups. None of these patterns followed the type of zone, or the day that the sample was taken on. When zones were separated into groups by type of zone, zones were still significantly different from other zones in the same group (Mixed vegetation: $p < 0.001$, $F = 15.810$; Algae: $p = 0.006$, $F = 3.903$; Zones without flora: $p < 0.001$, $F = 24.443$). When the moisture content was averaged for each type of zone, the groups were not significantly different ($p = 0.569$, $F = 0.566$), and formed one homogeneous subset (Figure 5). Zones that were sampled for the second time (Zones A, B, E, and H) did not show a significant change in moisture content ($p = 0.971$, correlation = 0.009). The average moisture content of the four zones did increase from 14.4 to 16.7, as well as a large increase in the standard deviation, from 3.2 to 11.5 (Figure 6).

Porosity

Zones were significantly different from each other ($p < 0.001$, $F = 4.757$; Figure 7). Zone A was dropped from the evaluation, due to a high variability, a standard deviation of 91.3, and the average porosity for that zone was 102.8. Looking at the field notes, there was nothing based on the percent and type of cover from which the samples were collected to explain this variability. Once Zone A was excluded from the evaluation, when the porosity average for the type of zone were put through Tukey's test, the vegetated zones (both mixed vegetation and algae) formed one group, and the non-vegetated zone formed the other ($\alpha = 0.05$; Figure 8).

Organic carbon

All Zones were significantly different from each other ($p < 0.001$, $F = 6.295$; Figure 9). When zones were separated by type of zone and averaged together, they were found to be significantly different ($p < 0.001$, $F = 7.299$), and Algae was found to form its own subset (Figure 10). Zones that were sampled for the second time did not differ significantly in the percent organic carbon ($p = 0.147$, correlation = 0.336; Figure 11).

pH

Zones were significantly different from each other ($p < 0.001$, $F = 6.220$), but the types of zones were not separated into different subsets (Figures 12 and 13). Zones that were sampled for the second time did differ significantly between the two time periods ($p = 0.013$, correlation -0.693; Figure 14).

Conductivity

All zones were significantly different from each other ($p < 0.001$, $F = 9.247$; Figure 15). Each type of zone formed its own subset, and the three types were significantly different from each other ($p <0.001$, $F = 25.741$; Figure 16). The four zones sampled for the second time were significantly different from each other ($p = 0.019$, correlation = 0.661; Figure 17).

Flora and Fauna

Flora and fauna were not identified, but it is likely that those described in Douglas (2005) are the same species that were seen at this study site. The flora and fauna observed at the present site, but not identified taxonomically were: mangroves, fiddler crabs, mudskippers, a pink succulent plant, and a green herbaceous plant, as well as algal mats (Figure 18).

Discussion

The abiotic factors which appear to affect zonation most are grain size, porosity, conductivity (salinity), and organic carbon. Those abiotic factors that do not appear to affect zonation at all are water content and pH. Teasdale et al. (2005) concluded that porewater salinity was the most important factor in the zonation of the vegetation in the wetland habitat of Gladstone. However, there was a lot of variability associated with porosity, and when zones were separated into one of three categories, zones within the same category were usually significantly different from each other.

Some of the results are comparable to those already found for other salt flats. Douglas (2005), showed a rough increasing proportion of sediment <63 μm towards the mangroves, and the majority of the grain size for most samples being also <63 μm. This suggests the vegetation may prefer an overall smaller grain size, or that the presence of vegetation may trap the smaller grain sizes. However, Teasdale et al. (2005) found that the proportion of sediment <63 μm increased with distance from the mangrove, whereas this study found that the zones containing mixed vegetation, which included mangroves, had a higher proportion of the smaller grain size sediment.

There was no significant difference in the moisture content between the three types of zones, but this may be because most of the days on which sample collection occurred were during a period when the high tide did not cover the salt flat, and there had been little rainfall. However, the porosity of the vegetated zones, both the mixed vegetation and the algae, was greater than that of the non-vegetated zones, so it is likely that vegetation prefers zones that have the ability to hold more moisture. Teasdale et al.

(2005) found that porosity was lower in the salt pan than the mangroves, supporting this idea. Because samples were collected during periods when the salt flat was relatively dry, the plants and algae may have utilized the excess moisture that the soil has the ability to hold, so the moisture content did not significantly differ between zone types.

The carbon content found in the samples is within range of those found by Douglas (2005) in salt flats that were also in the Port Curtis region. Some algal material may have been mixed in with the sediment samples for the zones that contained algae, which could have caused the elevated organic carbon content, because the algae was not removed when cores were collected. It was thought that the algae might actually contain some of the salts and may affect the pH, but carbon content was not taken into consideration. The cores used for each physical/chemical analysis were randomly selected. The mixed vegetation zone and the zone without vegetation contained minimal plant material. When collecting cores amongst the low growing shrubs, the plants were carefully excluded from the core.

The type of zones did not differ in pH, and the pH ranged from 6.72 to 7.98. It is therefore unlikely that pH is contributing to zonation in the saltflat.

Each type of zone had a significantly different conductance, and each group formed its own subset. The mixed vegetation zone had that lowest conductance, which may be explained by plants taking up nutrients, such as salts, from the sediment. Douglas (2005), showed that salinity showed a slight decreasing pattern as the transect approached the mangrove fringe. Many of the mixed vegetation zones also contained some mangroves, and the vegetation was similar to that observed at the mangrove fringe.

Teasdale et al. (2005) also found that pore water salinity increased with distance from the mangroves.

Whether or not you can actually look at an aerial photograph and determine what physical and chemical characteristics a particular area will show is unknown. This is largely due to the difficulty in obtaining a good and recent aerial photograph of the study area. Once you get past the classification of mixed vegetation, it is difficult to separate out the zones, but this may be due to the poor resolution of the aerial photograph (Figures 1 and 2). If a better aerial photograph is obtained, it would be beneficial to complete an accuracy matrix of the zones to see how accurately you can see them in the aerial photograph.

In addition, a more in depth analysis needs to be completed, separating out the types of flora and fauna, and looking at those zonation patterns. It was also difficult to categorize the zones into one of the three categories, because many of the zones lumped into the same category were quite different, particularly with the non-vegetated zones. The colour and texture of the non-vegetated zones often differed dramatically, and this is represented in the variability of this category.

Zones that were sampled for a second time, after a series of tides that covered the salt flat, and a period of rainfall, only differed significantly in conductivity, and did not show a change in the moisture content, organic carbon content, and pH. The difference in moisture content may not have been significant because it was a few days after these events that the samples were actually collected. There was an average overall increase in the moisture content of the zones, and a large increase in the variability of the mixed vegetation zones. The mixed vegetation zones are so variable within themselves, and the percent cover changes greatly with replicate location, and from zone to zone. One particular mixed vegetation zone may be densely covered in low-growing shrubs, and another may not be as dense, or the randomly selected site may occur where there is no vegetation, even though it is in that zone. It would be expected that the two replicates would not be the same, and is likely that this contributes to this variability observed.

It is surprising that the conductance increased in Zones B and E. The elevated salinity in salt flats is largely attributed to the high evaporation rate, and the low precipitation rate and tidal inundation. Therefore, after a period of rainfall and tidal inundation, it would be expected that the salinity would decrease because many of the salts would be washed away. This increase in conductance does support the idea that tidal inundation does replenish the salts.

For future study, it would be nice to note which fauna is associated with which type of zone, and whether or not this is related to tidal inundation and precipitation. While in the field, the authors only observed fauna close to the channel and the drainage pipe at the head of the channel, as well as at the fringe of the mangroves, and amongst the vegetation. This relationship was not examined quantitatively, and the species that were observed are unknown. Also, many insects, mostly ants, and spiders were observed in all zones, particularly in the zones devoid of vegetation. Some ants and spiders were collected in pitfall traps, but these collections were not identified or analysed once brought back to the laboratory.

The relationship between zonation patterns and proximity to such features as the channel, estuary, and the road are also things that could be looked at in the future. Another potentially important factor would be the height of the tide at which the zone is covered, and the length of time for which a given zone is covered, as the deposition of sediment is often determined by tides and currents (Teasdale et al. 2005). Many plants and animals typically have a minimum and maximum that they can tolerate with respect to environmental factors, such as exposure to something such as air, or the infrequent exposure to something such as the tide. This will often impact on where flora and fauna are located.

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Appendix
Detailed description of zones

A – Mixed vegetation zone, mostly red shrubs and algae, some green shrubs.

B – Algae; little or no vegetation except algae, white appearance, algae covers a large percentage of the total area.

C - Similar to zone B, but less algae and much more patchy, all reps <20% algae cover, some ants at site

D - Sediment is not as white as other zones, grain size appears to increase as you get closer to the road in this zone (more gravel and rocks)

E - Sandy zone

F – mostly bare, few algae patches

G - Algae (80-95% cover), part of zone is muddy, recent high tide

H - No vegetation, close to channel, very muddy, still wet from tide, crab holes present closer to the channel, frog/fish things present

I - Vegetation: mostly red bush, some green, closer to the channel was absent of vegetation, crab holes present close to channel

J - 4 samples were taken in algae patches (20-80% cover), one in crab pellets (10%)

K - Power on, may not be reliable; Mixed vegetation zone, green and red shrubs, few mangroves, some bare sediment and algae, 50-60% overall ground cover

L - drier, little vegetation, some green and red plants, surface sediment is more coarse, likely due to spray from the road

M - Mixed vegetation zone of red and green shrubs, adjacent to channel, and road

N - mostly algae, interspersed with 2 green plants, all reps taken from patches of algae (20-75% cover)

O - looks like zone drains into channel, sort of a side channel but there is currently no water present, adjacent to Zone N, sediment looks drier relative to adjacent zones, little vegetation, few algae patches, reps from bare sediment

P - no vegetation, furthest zone from channel, large zone, up to site boundary, zone seems to get wetter with increasing distance from road

Q - zone is mostly covered in algae, about 90%, with 2 patches of red shrubs in the middle of the zone, reps taken from 30-90% cover

R - next to channel; zone is mostly red shrubs, but some green and small mangroves, adjacent to channel; rep 1 taken in bare sediment, other 4 reps were 25-55% cover red

S - next to channel; Mixed vegetation zone, mostly small patchy red plants with mangroves closer to creek, mangroves increase in size as you get closer to the mangrove patch; reps range from 5% red to 2-7% algae

T - Really small red patches, mangroves next to creek (about 5 total), red patches are ~10cm-25cm in diameter; some coarse sediment, very little algae

U - Mangroves and some shrubs, increase in size to site boundary, some red shrub, a lot of crab holes especially around the mangroves

V - bare sediment and dead mangroves

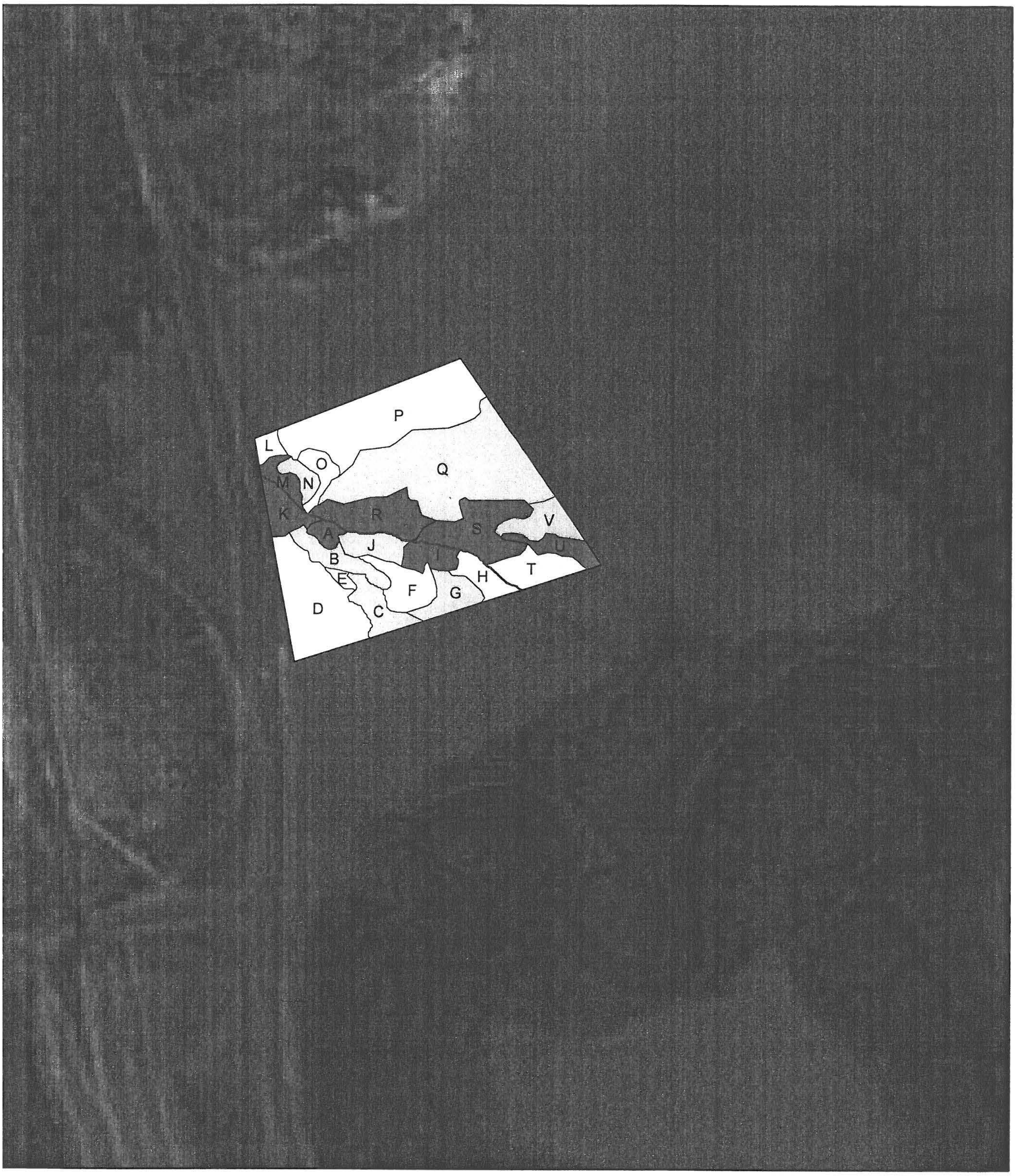
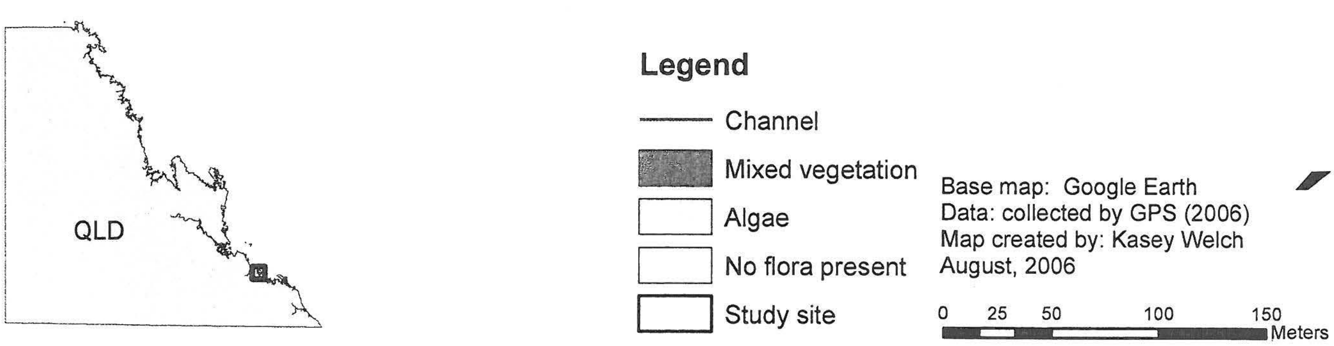
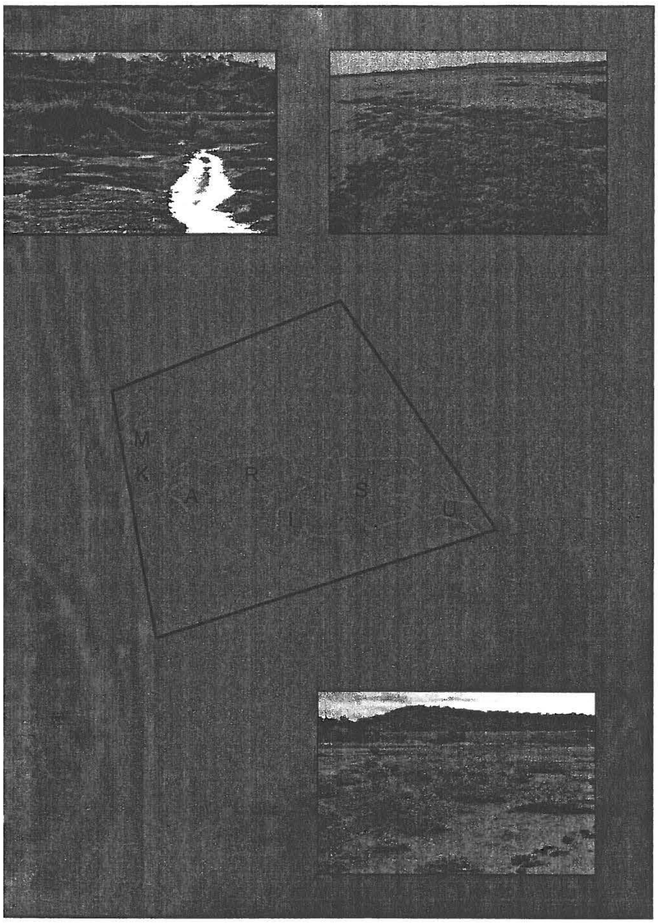
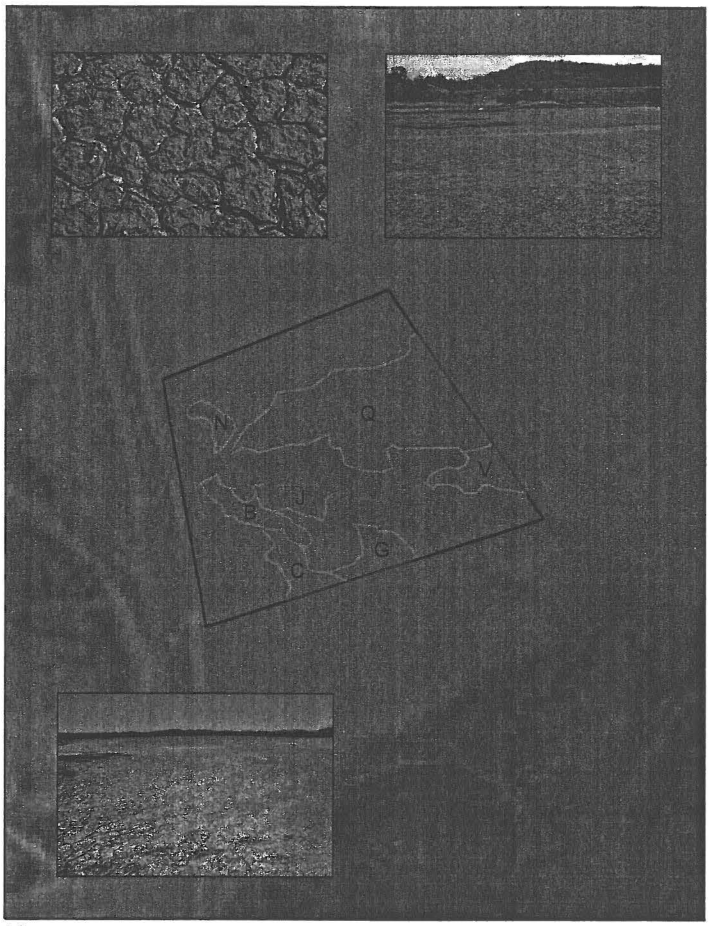


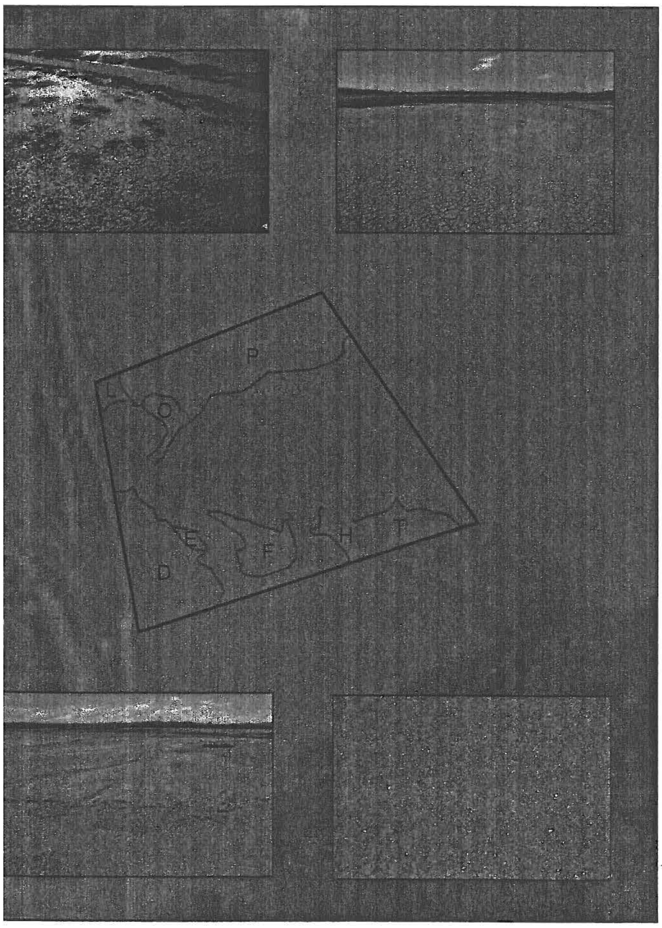
Figure 1. Location of salt flat study site, South Trees Inlet.







b)



Legend

- Mixed vegetation
- Study_site
- Channel
- Algae
- Zones without vegetation

0 40 80 160 240 Meters

Base map: Google Earth
Data: collected by GPS (2006)
Map created by: Kasey Welch
August, 2006

Figure 2. The zonation patterns of the salt flat. The zones were placed into three categories: a) Mixed vegetation, b) Algae covered, and c) those zones without vegetation. Inset photographs are from zones in that category. Notice the visual difference in the color and texture of the zones without vegetation.

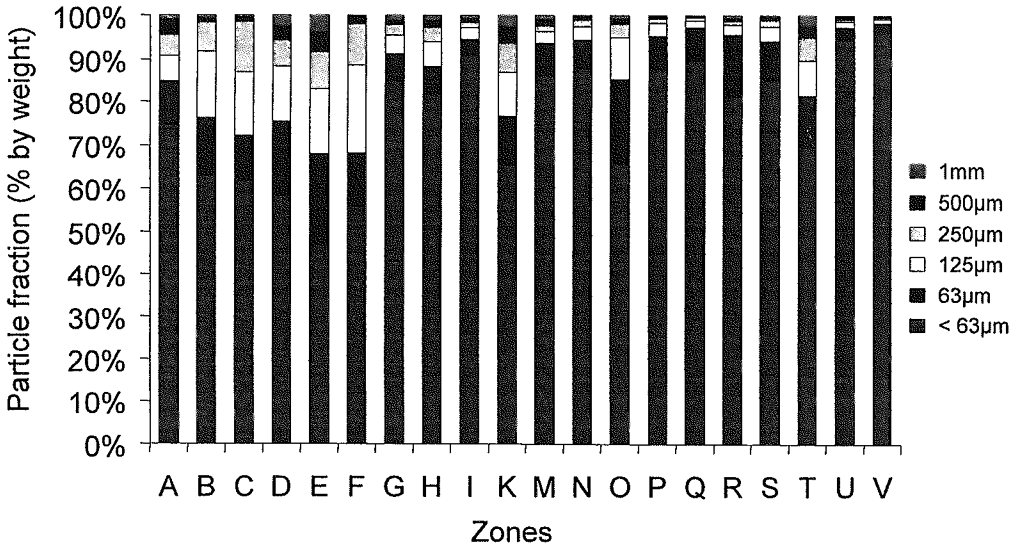


Figure 3. The particle size distribution for each zone, as determined by the percent of total weight.

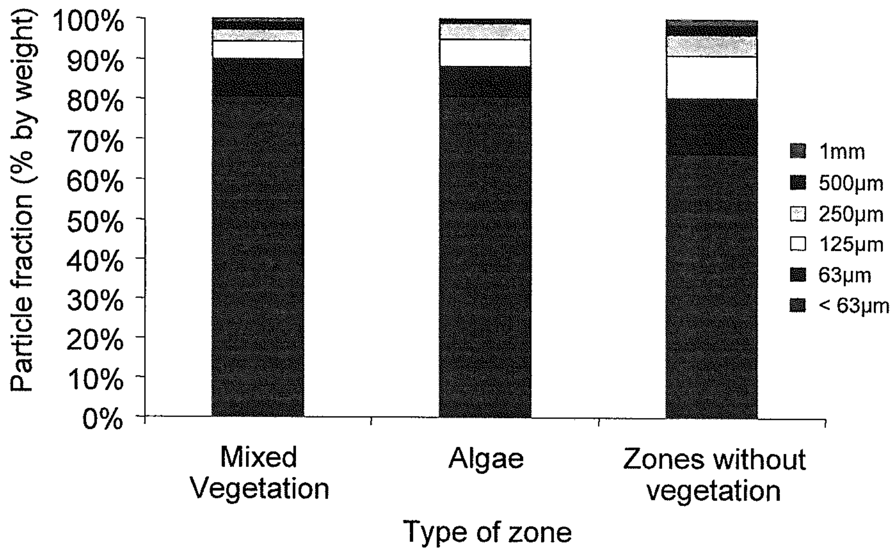


Figure 4. Each of the 22 zones was separated into one of three categories. The particle fractions of each category were averaged together.

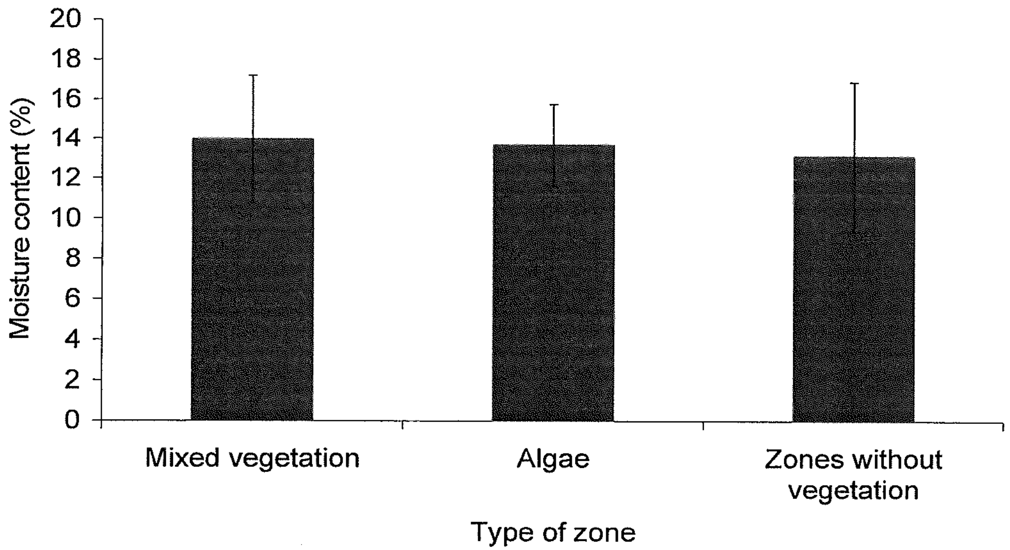


Figure 5. Each of the 22 zones was separated into one of three categories. The moisture content each category was averaged together, and the difference between the type of zone was not significant ($p = 0.569$, $F = 0.566$). Error bars represent standard deviation.

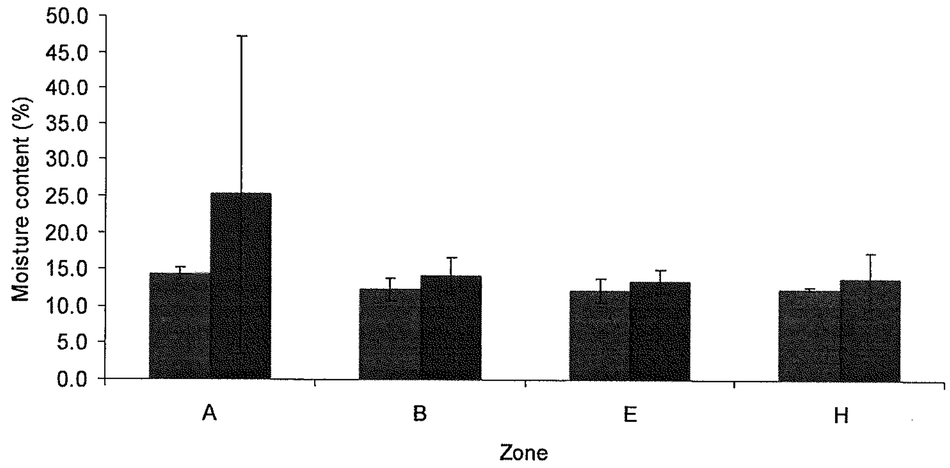


Figure 6. These four zones were resampled after a series of high tides that covered the study site, as well as some unseasonal rainfall. The moisture content did not change significantly between the two sampling times. Error bars represent standard deviation.

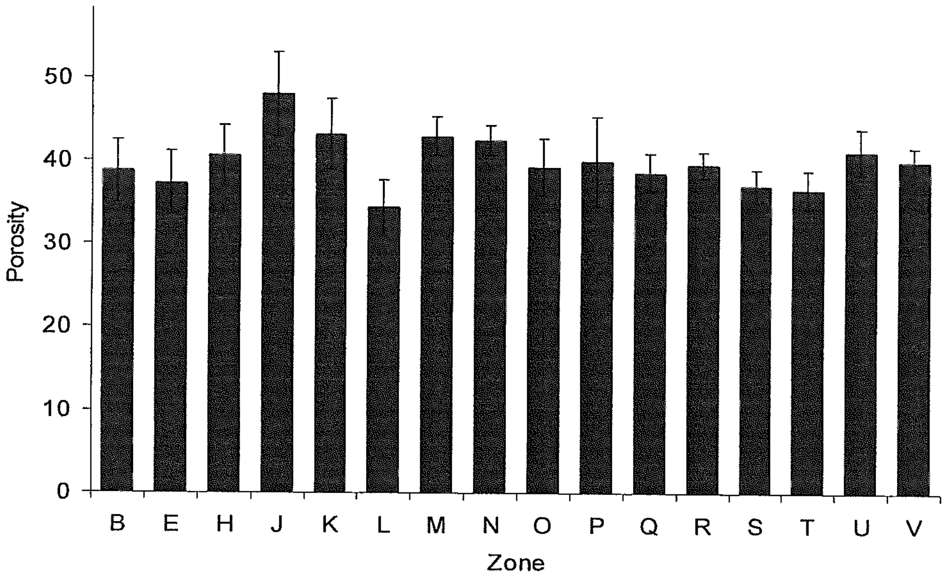


Figure 7. Porosity was calculated from the moisture content and bulk density for the above zones. The zones were significantly different. Error bars represent standard deviation.

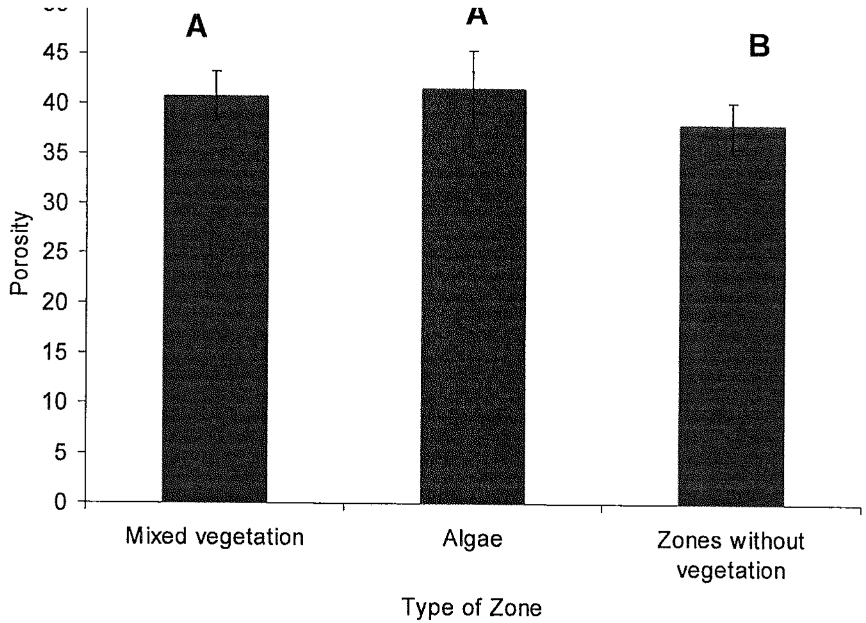


Figure 8. Each of the 22 zones was separated into one of three categories. The porosity of each category were averaged together. Subsets were determined using Tukey's test ($\alpha = 0.05$). Error bars represent standard deviation.

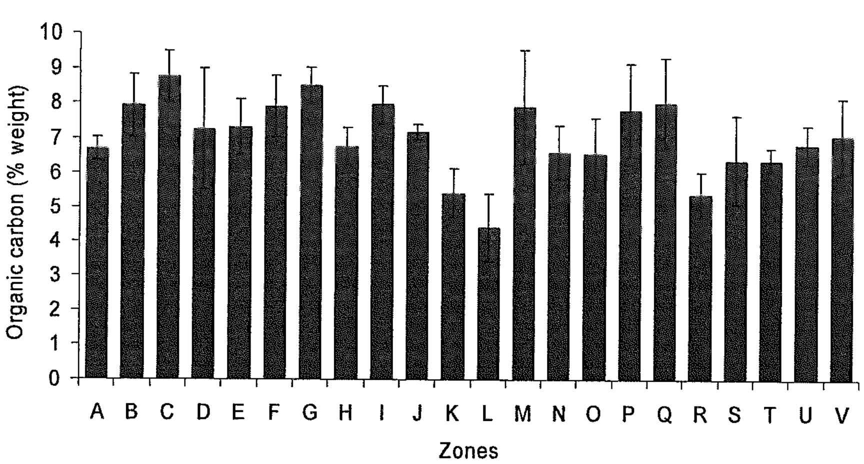


Figure 9. Percent of organic Carbon was calculated using the Loss on Ignition technique all zones. The zones were significantly different. Error bars represent standard deviation.

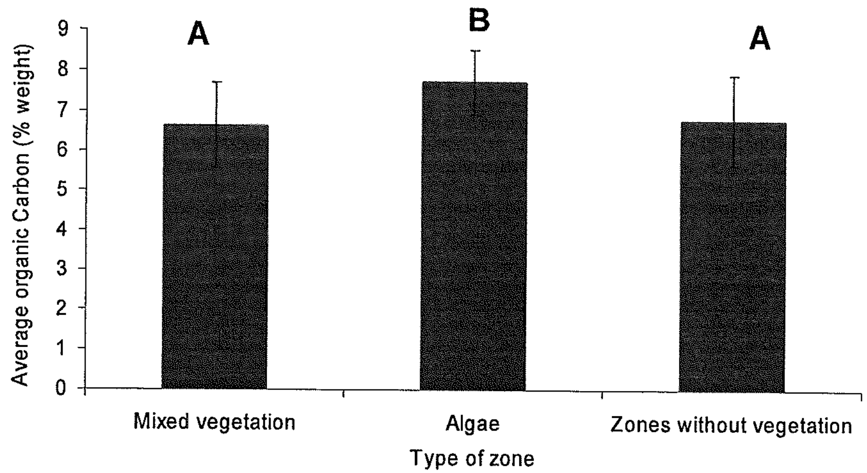


Figure 10. Each of the 22 zones was separated into one of three categories. The percent organic Carbon of each category was averaged together. Subsets were determined using Tukey's test ($\alpha = 0.05$). Error bars represent standard deviation.

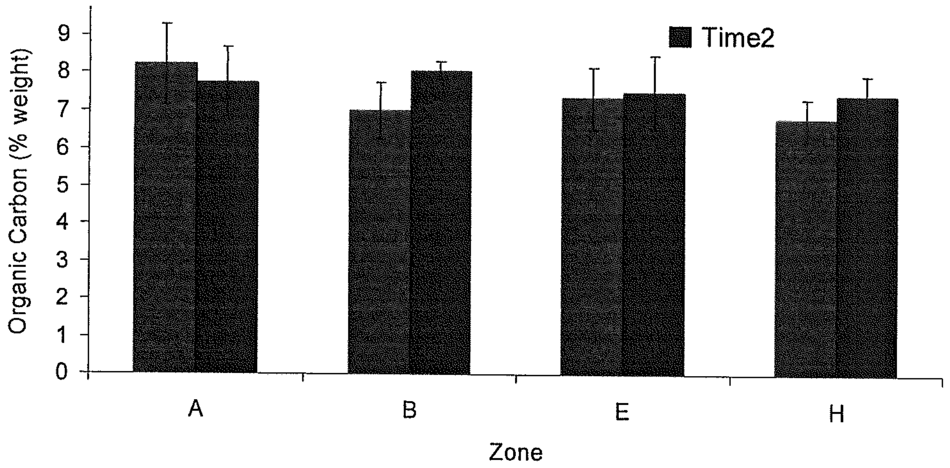


Figure 11. These four zones were resampled after a series of high tides that covered the study site, as well as some unseasonal rainfall. The organic carbon did not change significantly between the two sampling times. Error bars represent standard deviation.

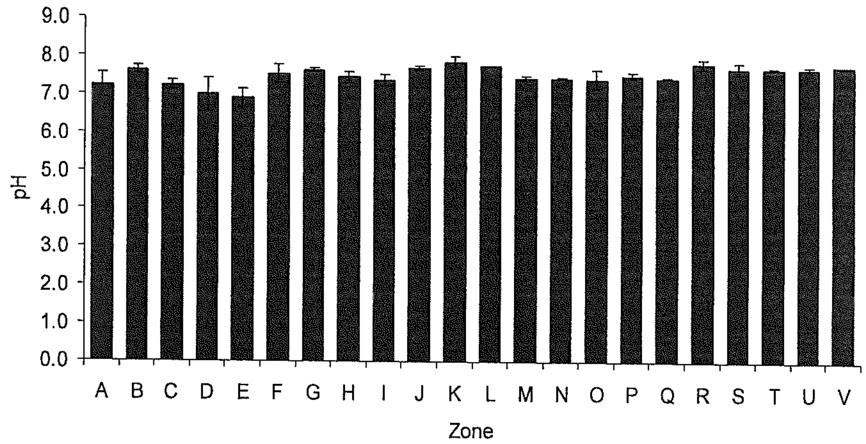


Figure 12. pH was calculated using a probe for the above zones. The zones were significantly different. Error bars represent standard deviation.

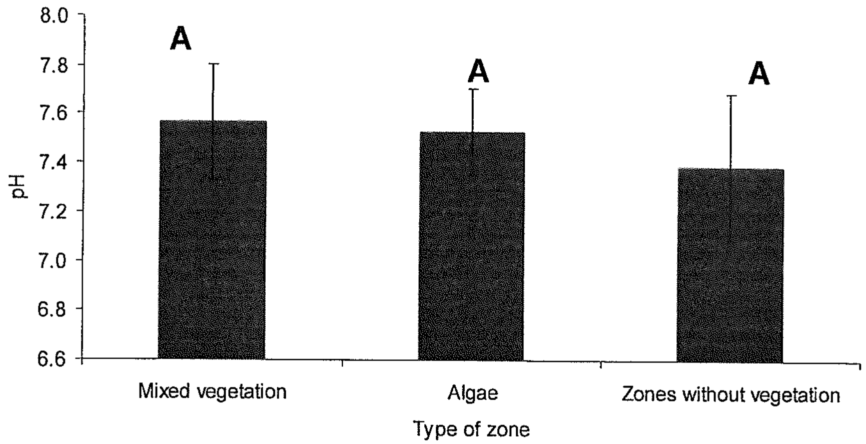


Figure 13. Each of the 22 zones was separated into one of three categories. The pH of each category was averaged together, and subsets were determined using Tukey's test ($\alpha = 0.05$). Error bars represent standard deviation.

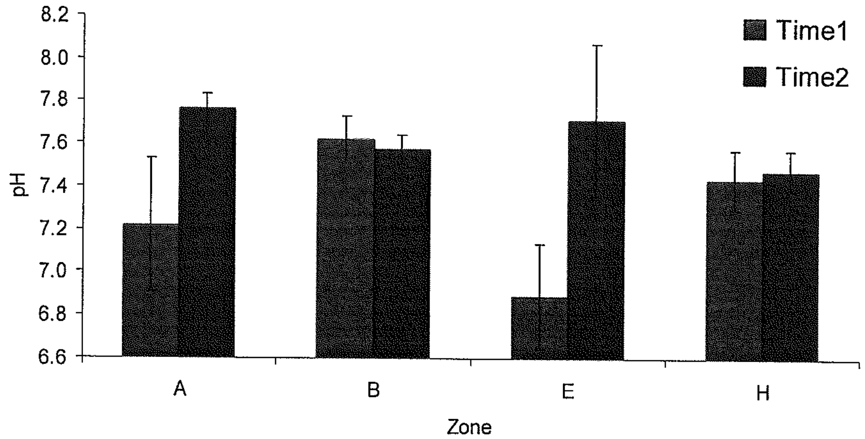


Figure 14. These four zones were resampled after a series of high tides that covered the study site, as well as some unseasonal rainfall. The pH did significantly change between the two sampling times. Error bars represent standard deviation.

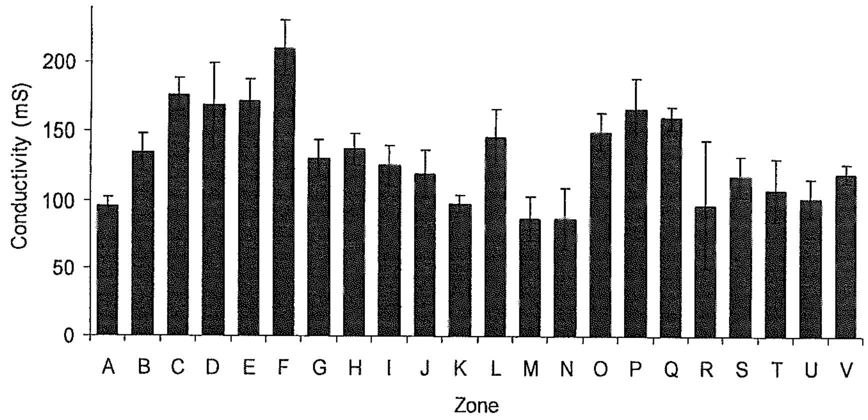


Figure 15. Conductivity was calculated using a probe for the above zones. The zones were significantly different. Error bars represent standard deviation.

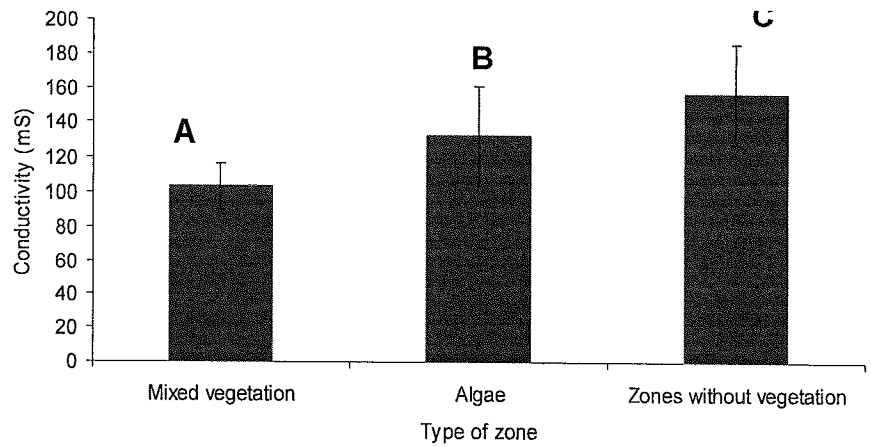


Figure 16. Each of the 22 zones was separated into one of three categories. The conductivity of each category was averaged together, and subsets were determined using Tukey's test ($\alpha = 0.05$). Error bars represent standard deviation.

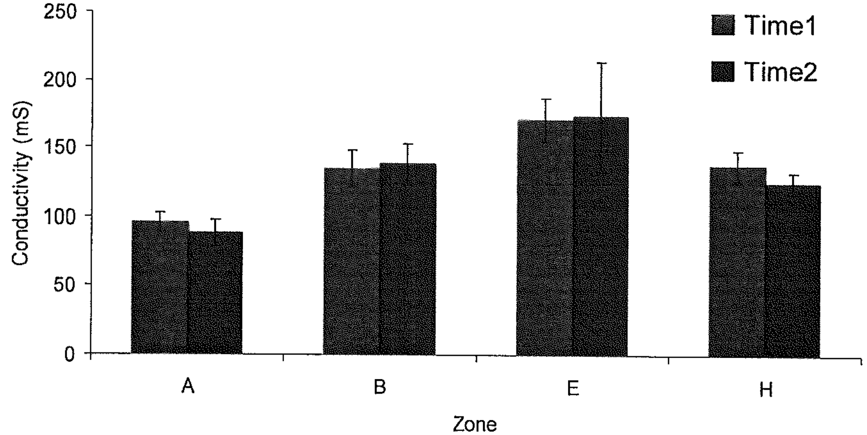


Figure 17. These four zones were resampled after a series of high tides that covered the study site, as well as some unseasonal rainfall. The conductivity differed significantly between the two sampling times. Error bars represent standard deviation.

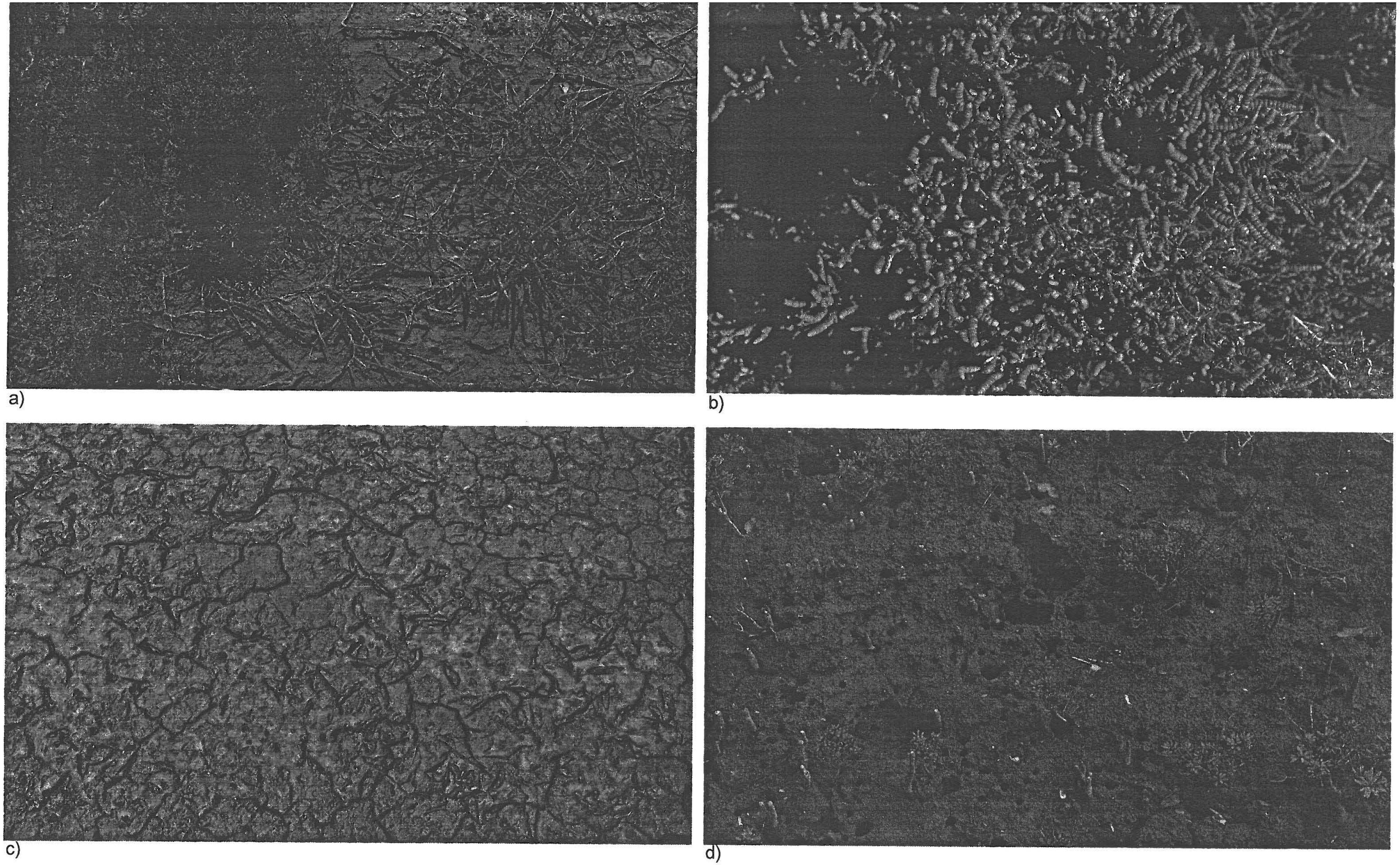


Figure 18. A selection of pictures of the flora and fauna at the study site. a) low growing shrubs and the pink succulent plant observed in the mixed vegetation zone, b) a green low growing shrub observed in the mixed vegetation zone, c) the algae that formed mats in the Algae zones, d) faunal holes that were usually located in the Mixed Vegetation zones, and near the channel.