ECOLOGICAL ASSESSMENT OF THE GROEN ESTUARY

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The lower reaches of the Groen Estuary in February 2015

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1 SUMMARY

This study assessed the present ecological state of the Groen Estuary based on macrophytes, invertebrates and birds. In February 2015 the estuary could be divided into a lower hypersaline lagoonal area with abiotic characteristics very different to the narrow and shallow (<50 cm deep) channel in the middle and upper reaches. We recorded salinity of 223 ppt in the lower reaches which dropped to 70 ppt at approximately 0.7 km upstream from the mouth of the estuary. Reeds were abundant in the upper reaches indicating brackish conditions as they grow best at salinity less than 20 ppt. Freshwater springs at the head of the estuary are an important source of water to the estuary and at the time of the visit in February 2015, spring water recorded a salinity of around 10 ppt.

Mapping of habitat changes over time showed that surface water is always present in the estuary. However, the total water surface area has decreased (13 ha in 1943, 11 ha in 1985, 8 ha in 2011 and 2014). Vegetation mapping showed that the estuarine habitats have been stable with no major fluctuations. Supratidal salt marsh covered the largest area (8 ha). Intertidal salt marsh covered 4 ha while reeds and sedges occupied 1 ha. Plants were distributed along an elevation gradient showing typical zonation with the succulents *Salicornia meyeriana* and *Sarcocornia natalensis* closer to the water edge and supratidal salt marsh higher up. The dominant supratidal plant was the highly salt tolerant *Sarcocornia pillansii*.

Dense floating mats of filamentous macroalgae (*Rhizoclonium riparium*) and cyanobacteria (*Lyngbya* sp.) were abundant particularly in the upper reaches where they covered the water column. Windblown mats of algae were found in the surrounding salt marsh vegetation transporting salt to this environment and causing dieback.

This study has provided new information on the lateral boundary of the estuary that will be used in the next National Biodiversity Assessment. The estuarine functional zone delineated by the 5 m contour line has been redrawn. The new estuarine functional zone excludes dune vegetation that occurs on the north bank at the mouth of the estuary as well as the terrestrial vegetation on the south bank in the middle-upper reaches. These elevated habitats are not suitable for estuarine vegetation.

Sediment and groundwater characteristics were measured in the different vegetation zones. Sediment salinity decreased from the intertidal zone towards the terrestrial vegetation.

Sediment organic matter content and redox potential increased with distance away from the open water. Sediment samples were also taken at three reed sites in the upper reaches of the estuary to establish the salinity and depth to groundwater which was lower than all other sites in the estuary. The reeds are abundant at this site because of the freshwater spring.

The only zooplankton found were insect larvae collected in the upper reaches at a salinity of 26 ppt. These larvae were associated with the floating algal mats. Extremely high salinity and anoxic sediment in the lower estuary excluded macroinvertebrates and mesozooplankton, while anoxic sediment in the channel area of the estuary (where salinity was lower) became the main limiting factor impacting the biota. Overall conditions were too stressful for invertebrates to thrive.

Most birds feeding in the estuary were either on the expansive sandflat in the lagoonal area of the lower reaches or present on or around the algal carpets floating on the water surface in the upper estuary. There were 15 different bird species and the total number of individuals was 109. Approximately one-third of the bird numbers were utilizing the estuary as a roosting area and not for feeding purposes. Long-billed benthic feeders and piscivores were not recorded on the estuary.

The absence of benthic macroinvertebrates, mesozooplankton, fish and low bird counts (mainly short-billed waders) support the conclusion that the Groen Estuary was a stressed ecosystem in February 2015. Main stressors were extreme hypersalinity, relatively low water volume, anoxic sediments and a mouth that had remained closed for a relatively long period of time (years).

Previous reports in Bickerton (1981) suggest that biota are likely to colonize the estuary after mouth breaching, with individual species becoming locally extinct as increasing salinity and anoxic sediments reach threshold levels. This conclusion is also supported by comments in 2015 made by local inhabitants. General comments suggest that the Groen Estuary has become increasingly drier and now opens less frequently compared to the past when fish, for example, were harvested from the estuary. Mapping of the open water area from aerial photographs reflects the same general trend of a drier system (less open water) in more recent years.

The Hydrological and Geochemical Report undertaken in 2015 (SWS, 2015) supports the conclusion that perennial sub-surface flow along the riverbed of the Groen River is negligible or non-existent. Consequently, the likelihood of contamination of springwater by the

Kamieberg Project is highly unlikely. The spring at the head of the estuary (flux approximately 1l/sec) is likely fed from groundwater discharge, but the exact origin of the spring remains unclear. Salinity of the spring water is ca 10 ppt and therefore too high to support an oligohaline invertebrate community, even under current conditions (threshold 5-6 ppt). However reeds and sedges that grow best at salinity less than 20 ppt are abundant. Post-mining groundwater TDS levels will peak at approximately 24 ppt at the mining site (ca 10 km from the spring and head of the estuary). While there is no evidence of any hydrological connection between the mining site and spring, any potential passage of contaminated water across the 10 km distance will exceed hundreds of years on a temporal scale, as well as being subject to long-term dilution effects over this distance (SWS, 2015). Consequently, any potential increase in salinity at the head of the estuary is unlikely, but in the event of any flux of such water, salinity will increase in the upper estuary, but probably not beyond threshold levels of estuarine organisms that could potentially occur there. For these reasons the water input to the estuary from the spring must be monitored and protected.

The Groen Estuary is a unique estuary nationally and worthy of conservation as it provides a perennial water habitat along the dry Namaqualand coast which would be particularly important for birds. However, hypersalinity (particularly extreme levels) will deter from the conservation importance of the estuary. Mapping of habitats suggests that the area of open water appears to have decreased over past decades (supported by anecdotal statements made by local residents) and this in part, may be related to increased borehole extraction of water by farming practises and other purposes (see Bickerton, 1981 and van Niekerk & Turpie, 2012), leading to a reducing spring water discharge. According to the National Biodiversity Assessment the Present Ecological Status of the Groen Estuary is a 'B' as it has few impacts. The estuary is fully contained in the Namaqualand National Park and for this reason it should be managed towards an 'A' or best attainable status. An immediate and important management objective would be to protect the freshwater spring in the upper reaches (quality and quantity) and to ensure that salinity in this area remains less than 10 ppt. Although reeds tolerate higher salinity values (up to ca 20 ppt), current levels of 10 ppt provide a buffer protection zone. Of added concern is the prediction that rainfall will decease along the west coast of South Africa (see CES, 2015) and that the Groen Estuary will become progressively drier and therefore more inhospitable to biota in the future. Thus, future changes of the Groen Estuary are potentially linked to both natural and anthropogenic influences

As stated in the EIA report it is essential to conduct a pre-mining baseline assessment of salinity levels and the general biological state of the estuary, and to monitor these variables on a regular basis. The previous assessment of the Groen Estuary (Bickerton, 1981) was conducted over 35 years ago and the present study was undertaken during an extreme hypersaline event. Different scenarios between a major flood (open mouth and freshwater dominated) and the present state (closed mouth and extreme hypersalinity) are lacking, primarily with respect to biotic response along the salinity continuum. It is suggested that Sanparks undertake the following monitoring: permanent probes should be deployed to continuously measure salinity in the upper reaches of the estuary; quarterly measurements of salinity and other physico-chemical characteristics should be conducted along the length of the estuary; vegetation mapping and biological surveys are needed to check for health of brackish wetlands and salt marshes; and quarterly bird counts of the estuary should continue. It is also suggested that Zirco undertake monitoring of the proposed mining operations by deploying permanent salinity probes between the mining site and the head of the estuary to monitor any potential future change in groundwater salinity.

2 INTRODUCTION

1.1 STUDY OBJECTIVES

The following terms of reference were followed:

1. Assess the present ecological state of the Groen Estuary based on macrophyes, larger invertebrates and birds.

    a. Measure water column physico-chemical characteristics along the length of the estuary.

    b. Map the present vegetation cover and assess changes over time, measure the distribution of the plants along transects representing a specific elevation gradient and measure sediment and groundwater characteristics in the different vegetation zones.

    c. Complete an analysis of the macrobenthic and mesoplanktonic invertebrates.

    d. Estimate the numbers of birds present on the estuary and identify different feeding guilds.

2. Comment on the responses to salinity changes at the head of the estuary.

3. Suggest future monitoring requirements.

1.2 ASSUMPTIONS AND LIMITATIONS

Study specific assumptions and limitations include:

1. The Groen Estuary is one of the most variable estuaries in South Africa in terms of its physico-chemical attributes. Consequently, a once-off field survey would only reflect prevailing conditions and would not capture seasonal or longer term shifts (between years) along a physico-chemical continuum. Extreme states are represented by an open mouth following a flood (low salinity) and extreme hypersaline conditions following a long period (years) of mouth closure. Field surveys in February 2015 were undertaken in summer when extreme hypersaline conditions prevailed in the lower reaches.

2. The study only focussed on the macrophytes, invertebrates and birds as indicators of the health and functioning of the estuary.

2.1 AVAILABLE INFORMATION ON THE GROEN ESTUARY

The Groen Estuary is a coastal inlet situated along the cool temperate, arid west coast of South Africa, Fig. 1. (30°50'48"S; 17°34'35"E) (Whitfield & Baliwe, 2013). The estuary flows infrequently and remains closed for long periods, with reports from farmers in the 1980s indicating that flow only occurs during heavy flooding roughly every 5 years. The occurrence of perennial water, however makes the estuary an important habitat along the dry Namaqualand Coast. Little is known about the estuary because of its small size and remote location. It is said to have a catchment area of 4500 km^2 (Heydorn & Tinley, 1980, cited by Bickerton, 1981). The total estuarine area up to 2.5 km from the mouth was approximately 28 ha whereas the total open water area was 13 ha (Bickerton, 1981).

Mean Annual Rainfall in the catchment varies from 100-200 mm. During low or no flow conditions the estuary becomes highly saline with salinity readings of 125 ppt recorded. Springs at the head of the estuary maintain a lower salinity in the upper reaches. Detailed spring and seep surveys by CSIR (1981) and SWS (2013 to 2015) found only one discrete point of perennial discharge into the estuary. This spring is located in the wetland area ca 1 km upstream of the estuarine lagoon. SWS (2015) recorded a downstream flow rate of ca 1l/s in February 2014. Table 1 summarizes salinity, oxygen and temperature conditions reported in Bickerton (1981). The high oxygen concentrations recorded during the Estuarine and Coastal Research Unit (ECRU) study were ascribed to the dense algal mats present in the estuary at the time. Bickerton (1981), described the substrate in the lower estuary as sandy, with anoxic conditions prevailing a short distance away from the water’s edge. The sediment in the upper estuary was described as fine anoxic silt. Bickerton (1981) reported that surface water is probably always present in the estuary, maintained by the springs feeding into the upper estuary. Occasional freshwater inflow dilutes the highly saline surface water and transient tidal conditions may occur when the mouth opens.

The National Biodiversity Assessment (NBA, van Niekerk & Turpie, 2012) described the health status of the Groen Estuary as a ‘B’ as it has few impacts. There have been some changes in flow, pollution, habitat loss, mining, artificial breaching and fishing effort. The estuary is described as largely natural with few modifications where the ecosystem functions are essentially unchanged. The NBA considers the estuary to have good hydrology, water quality, physical habitat, microalgal and invertebrate health. Birds and macrophytes were described to be in excellent condition due to little disturbance. This information was based on a desktop assessment and this report represents the first recent study on the ecology of the estuary.

The Groen Estuary is fully contained, with medium legal protection according to van Niekerk and Turpie (2012) in the Namaqualand National Park. The estuary should therefore be maintained in an ‘A’ or Best Attainable State. In the past the Groen Estuary fell within the prospecting zones of De Beers Consolidated Diamond Mines, but the mouth was open to the public (Bickerton, 1981). Bickerton (1981) identified the following impacts occurring in the floodplain of the estuary: bridges, low level road crossings, fences, agricultural land and development (informal settlements, helicopter pad and camp sites).

Table 1 Available salinity, temperature and oxygen readings reported in Bickerton (1981).

Physico-chemical variables		VALUES REPORTED			
Date		January 1979 Collected by Grindley		October 1980 Collected by Bickerton	
Zone		Lower	Upper	Lower	Upper
Salinity (ppt)	Near surface	118.0	12.0	66.0	7-10
	Near bottom	no data	no data	70.0	7-10
Oxygen concentration (mg/l)	Near surface	5.0	7.0	9.1	no data
	Near bottom	2.9	10.4	6.7	no data
Water temperature (°C)	Near surface	27.0	29.5	21.3	24.6-27.6
	Near bottom	no data	no data	21.3	24.6-27.6

Figure 1 **The Groen Estuary on the west coast of South Africa. The red line indicates the Estuarine Functional Zone according to the 2012 NBA (Image date: 2011)**

According to the NBA (2012) the estuary supports 6 ha of salt marsh. The ECRU studies in the 1980s described *Sarcocornia natalense* on the northern bank of the estuary near the mouth. *Sarcocornia pillansii* and *Juncus acutus* fringed the banks of the upper reaches of the estuary (Bickerton, 1981). Bickerton (1981) described siltation evident from sediment deposition on the shoreline vegetation. Dense concentrations of algae and phytoplankton, indicative of eutrophic conditions, were present during the surveys. Filamentous algae and *Stuckenia pectinata* (previously *Potamogeton pectinatus*) was present in the estuary, approximately 2.5 km from the mouth. *Stuckenia pectinata* is intolerant of high salinity. Bickerton (1981) described its presence in the estuary to be due to moderating influences of the springs at the head of the estuary. Terrestrial vegetation recorded in the vicinity of the estuary included *Drosanthemum* sp., *Eragrostis cyperoides*, *Limonium equisternium, Othonna* sp., *Rushia* sp. and *Zygophyllum morgsana.* A few Eucalyptus trees occur around farm buildings in the upper reaches of the estuary. These trees are still present around the Namaqua National Park reception buildings and housing units. Extensive sand dunes occur on the northern side of the mouth. Bickerton's (1981) generalised vegetation map of the Groen Estuary is provided in Figure 2.

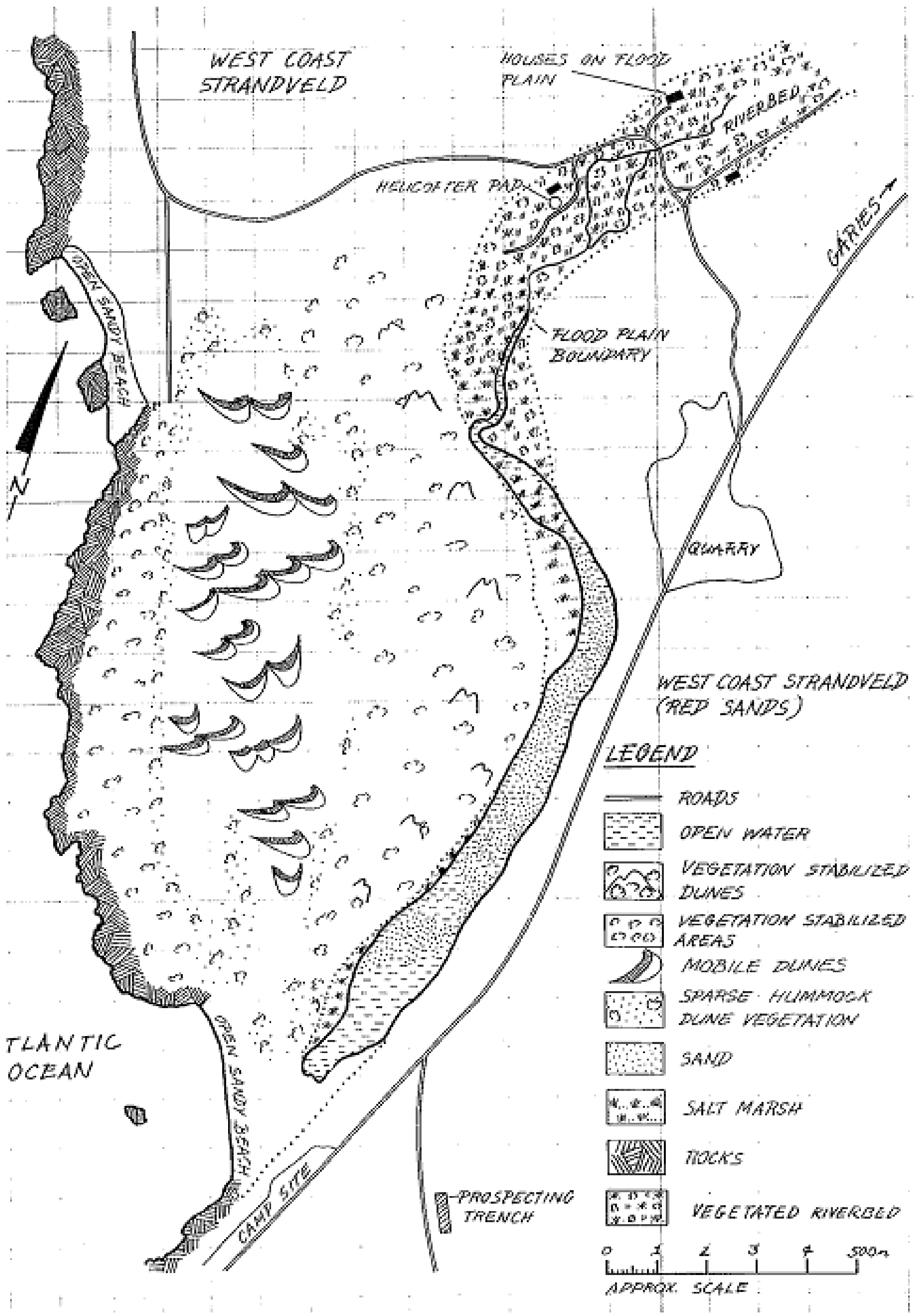

Figure 2 **Vegetation map of the Groen Estuary (from Bickerton, 1981).**

Bickerton (1981) reported that no invertebrates were present in the water column of the lower estuary (using a D-net towed for four minutes over 200 m), and no burrowing prawns (the sandprawn *Callichirus kraussi* or the mudprawn *Upogebia africana*) were found. Nine mullets representing two species (*Mugil cephalus* and *Liza richardsoni*) were collected in gill nets set over 23 h.

Previous bird counts done by Grindley (January 1979), Cooper (January 1980) and the ECRU study (October 1980) reported a combined total of 37 species of birds. Numbers of the five numerically dominant species varied between the three visits (Table 2), with Greater Flamingo (maximum 282), Cape Teal (maximum 38), Red-knobbed Coot (maximum 72), Curlew Sandpiper (maximum 106) and Little Stint (maximum 61) heading the list (Bickerton 1981). Only 16 species were present on the estuary at the time of Grindley's visit (salinity 118 in the lagoon area). Although there was overlap of the five numerically dominant species, numbers varied between the three visits, especially for Greater Flamingo, Red-knobbed Coot and Curlew Sandpiper. Greenshank and Avocet were only present in the 1979 study (Table 2).

Table 2 The five numerically dominant bird species recorded by Grindley (January 1979), Cooper (January 1980) and the ECRU study (October 1980) on the Groen Estuary. Extracted from Bickerton (1981).

SPECIES	REPORTED ABUNDANCE		
	Grindley 1979	Cooper 1980	ECRU Study 1980
Greater Flamingo	-	49	282
Cape Teal	30	34	58
Red-knobbed Coot	-	72	50
Curlew Sandpiper	108	73	-
Little Stint	25	61	32
Sanderling	-	-	10
Greenshank	12	-	-
Avocet	19	-	-

3 METHODS

3.1 ABIOTIC CHARACTERISTICS

The physico-chemical characteristics of the estuary were measured using a YSI hand-held multiprobe at 17 locations along the length of the estuary (Figure 3). Sediment samples were taken at three reed sites in the upper reaches of the estuary to establish the salinity and depth to groundwater (Figure 3). Variability in the estuary conditions was also assessed from questionnaires answered by local residents. In total, eight questionnaires were completed mostly by residents that have resided in the area for decades (Appendix table).

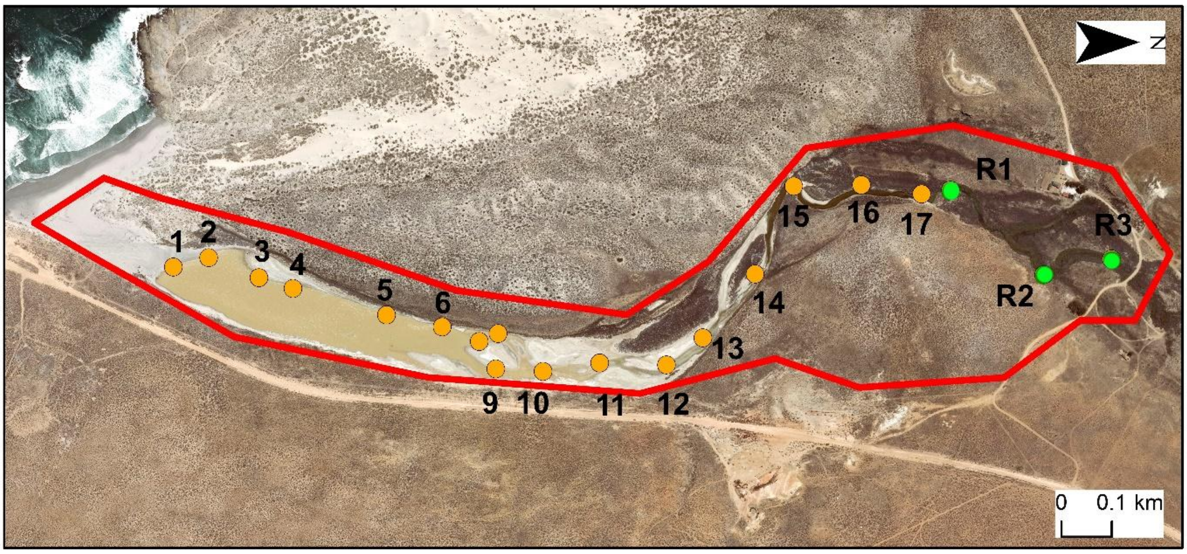

Figure 3 **Location of 17 sites where physico-chemical readings were taken along the length of the Groen Estuary as well as the location of the three reed sites (R1 – R3) investigated. Benthic and zooplankton samples were collected at seven and three of the sites respectively (see below).**

3.2 HABITAT MAPPING

The estuarine functional zone (estuarine habitat area) was digitized using the most recent (2011 and 2014) aerial photographs obtained from the National Geo-spatial Information (previous Chief Directorate: Surveys and Mapping) as well as Google Earth images. Earliest aerial photographs (1943, 1985) were also digitised and estuarine open water areas mapped. Macrophyte habitats (inter- and suptratidal salt marsh, reeds and sedges) were mapped and the boundaries ground-truthed during the field visit. Changes over time were determined by visual comparison of the past aerial photographs (1943, 1985, 1967, 1979, 1980, 1985, 2011 and 2014). All maps were digitised in ESRI ArcGIS™ Version 10.2.

3.3 DISTRIBUTION OF VEGETATION ALONG TRANSECTS, GROUNDWATER AND SEDIMENT ANALYSIS

Vegetation distribution was analysed along three transects as indicated in Figure 4. Vegetation cover was measured as average percentage cover in duplicate quadrats (1 m^2) placed at intervals along each transect. Transect 1 was 36 m long and vegetation cover was measured every m along the length of the transect. Transect 2 was 130 m long and vegetation cover was measured every 5 m whereas for Transect 3 (85 m long) vegetation cover was measured every 1 m for the first 10 m and then at 5 m intervals on the floodplain terrace. Taxon names follow Germishuizen and Meyer (2003), and Mucina and Rutherford (2006). Voucher specimens were housed in the Ria Oliver Herbarium (PEU) of the Nelson Mandela Metropolitan University.

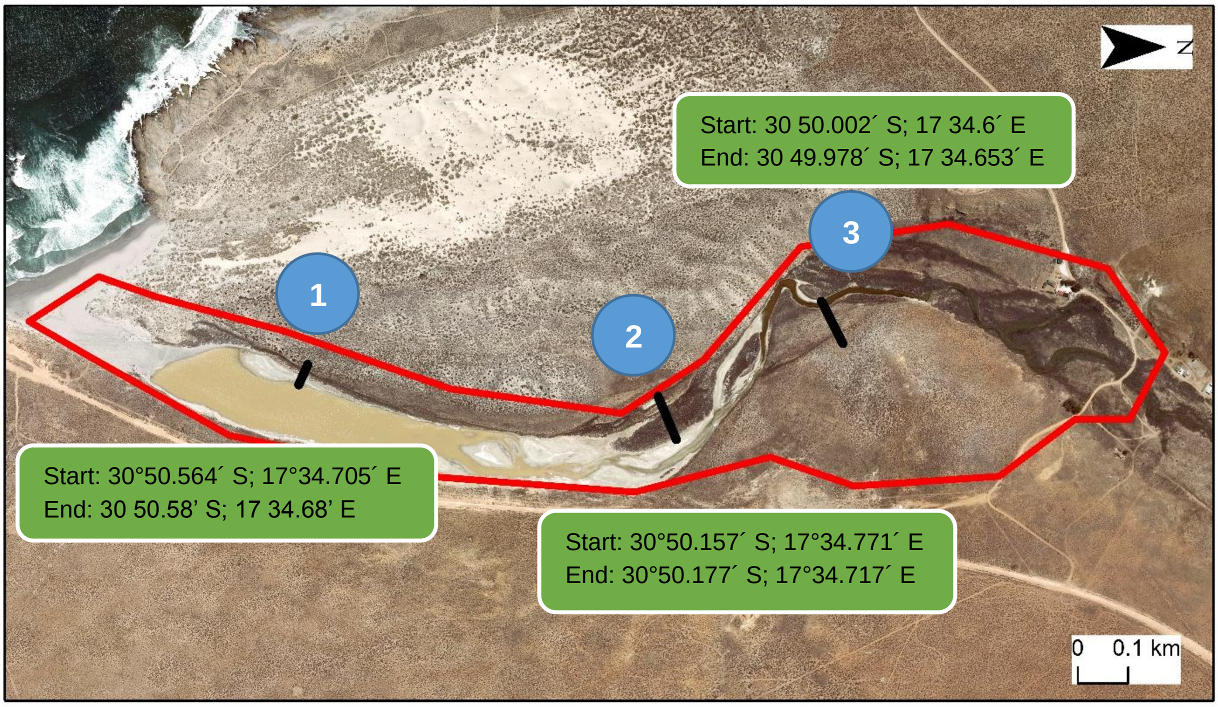

Figure 4 Location of vegetation transects along the length of the Groen Estuary.

Three vegetation zones were identified for each transect where sediment and groundwater characteristics were measured. Depth to groundwater was determined by manually auguring down to the water table. Duplicate sediment samples were taken at the surface and bottom of the augured hole for analyses in the laboratory. Analyses included sediment moisture and organic content as well as sediment electrical conductivity, following the methods of Black (1965 – sediment moisture content), Briggs (1977 – sediment organic matter) and The Non-

Affiliated Sediment analyses Working Committee (Barnard 1990 – sediment electrical conductivity). In situ measurements of the groundwater salinity and electrical conductivity were made using an YSI handheld multiprobe.

3.4 BENTHIC AND PLANKTONIC INVERTEBRATES

Subtidal benthic samples were collected by wading from the shoreline (maximum water depth <0.5 m) and using a Van Veen type grab at Sites 1, 4, 6, 11, 14, 15 and 17 (Figure 3). Contents were then sieved through a 500 μm mesh screen bag to recover any invertebrates present. The grab has a 200 cm^2 bite that penetrated the sediment down to about 10 cm depth. Three replicates were collected over an area of approximately 5 m^2. Animals retained by the sieve were stored in 500 ml plastic bottles and preserved with 10% formaldehyde solution. Additional surveys were undertaken along the shoreline to establish the presence of any burrowing prawns (*Callichirus kraussi* and *Upogebia africana*).

Zooplankton samples were collected at Sites 1, 15 and 17 using a rectangular net (40 x 25 frame with 200 um micron mesh). Samples were collected by wading and where water depth permitted submersion of the net. In the upper estuary particular emphasis was placed on sampling close to, or under the filamentous algal mat that carpeted the deeper pools. Open water sites were also sampled.

Analysis of samples and identification of species was completed in the laboratory. Final abundance was expressed as the average number of each species per m^2 of substrate (in the case of the benthos) or numbers of individuals m^3 (in the case of the zooplankton) at each site. A surface sediment scrape was also collected at Sites 1 and 17 and diluted to 50% and 25% sea water concentration respectively in order to determine whether resting eggs of organisms were present. These samples were transported to the B & B facility at Groenvlei and observed regularly over the following three days.

3.5 BIRDS

Time spent on the estuary was also used to observe birds present below the vegetation line around the fringes of the estuary. Birds were identified to species level and an estimate made of numbers present using 8 x 42 Swarowsky binoculars. Where necessary, phographs were taken using a Canon 5D camera and a 100 – 400 image stabilizer zoom lens to aid identification.

4 RESULTS

4.1 ABIOTIC CHARACTERISTICS

In February 2015 the estuary could be divided into a lower saline lagoonal area characterized by abiotic characteristics very different by comparison to the narrow and shallow (<50 cm deep) channel in the middle and upper reaches (Figure 5). There was a sharp drop in salinity between Sites 7 and 8 (approximately 0.7 km upstream from the mouth of the estuary) from a maximum of 223 to 70 ppt (Figure 5a). From Site 11 upstream the salinity decreased from 31 to 9 ppt clearly indicating a longitudinal salinity gradient along the length of the estuary. Oxygen concentrations (% saturation) were also variable (Figure 5b), usually <60% saturation below Site 11. Upstream of this site, concentrations increased but did not exceed 80% saturation level. Lowest values were recorded at the middle sites. Water depth increased upstream (Figure 5d), but did not exceed 50 cm at any of the 17 sites. By contrast, pH decreased (Figure 5c) in an upstream direction. Maximum water clarity persisted throughout the estuary and the sediment surface was always clearly visible. Water temperatures (Figure 5c) ranged between 16.2^{o}C (Site 7) and 20.6^{o}C at Site 11. Generally, the upper reaches of the estuary were marginally warmer compared to the lower estuary.

4.2 HABITAT MAPPING AND CHANGES OVER TIME

The areal extent of the estuary was reported in Bickerton (1981) to be around 28 ha, and at the time of the survey, in October 1980, the approximate area of open water in the lagoon was 13 ha. The area contained within the estuarine functional zone of the Groen Estuary is 52.4 ha and open water area covered an area of 8 ha in 2011 and 2014. The change in area of the open water surface area mapped from available past imagery is shown in Figure 6. In 1943 the approximate area of open water was 13 ha. In 1985 open water occupied an area of roughly 11 ha. The lagoonal water surface area in the lower reaches of the estuary has decreased over time. The quality of the past aerial photographs prevents mapping of vegetation changes over time. However, little change is expected due to limited anthropogenic disturbance.

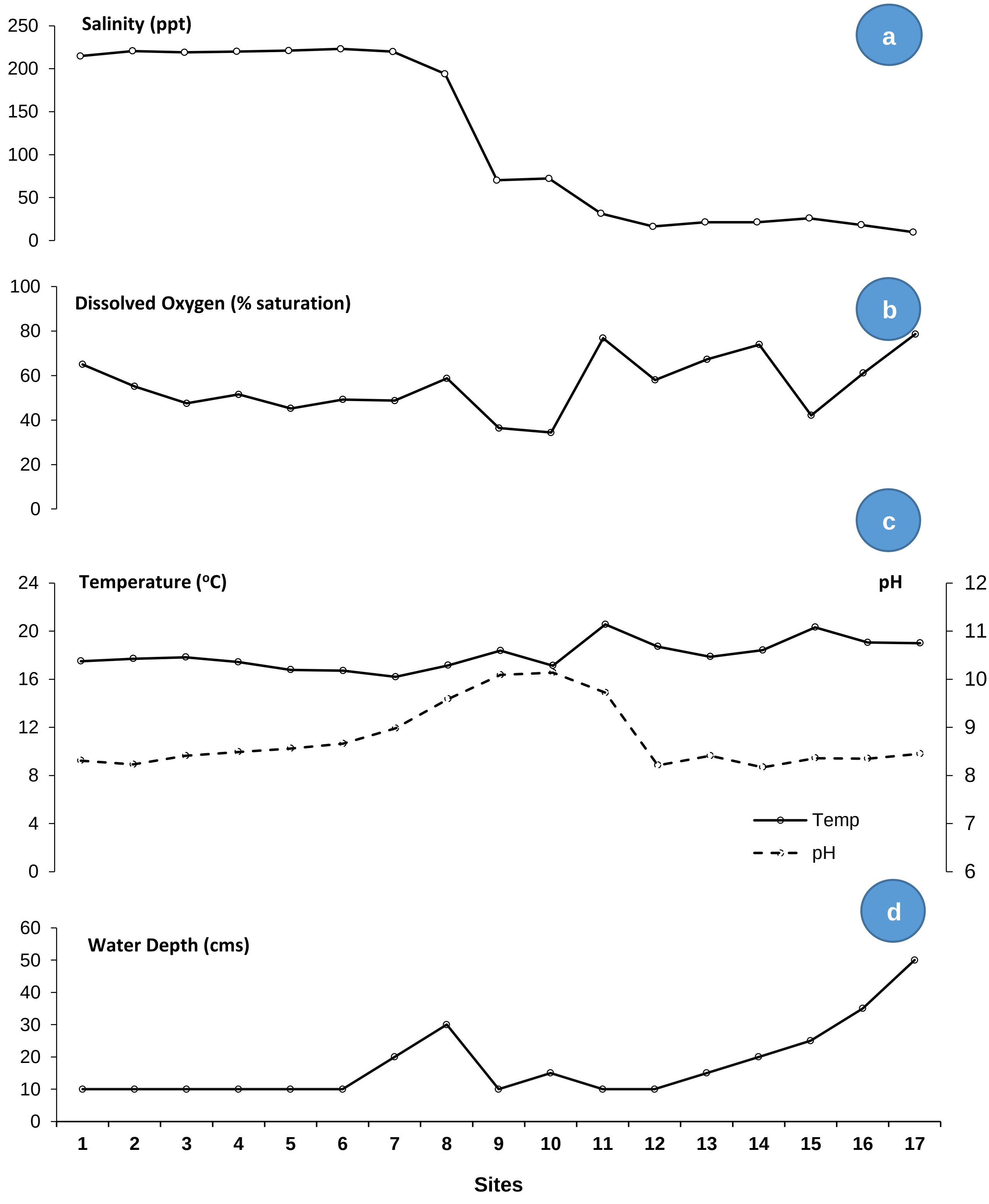

Figure 5 **Physico-chemical characteristics at 17 sites along the length of the Groen Estuary (a) salinity; (b) dissolved oxygen; (c) temperature and pH; and (d) water depth.**

The estuarine functional zone was remapped after the site visit. Figure 7 indicates the original 5 m contour line and the new proposed boundary. The new estuarine functional zone excludes dune vegetation that occurs on the north bank at the mouth of the estuary as well as the terrestrial vegetation on the south bank in the middle-upper reaches. The elevation of this habitat is not suitable for estuarine vegetation. The revised area of the estuarine functional zone of the Groen Estuary is 39 ha.

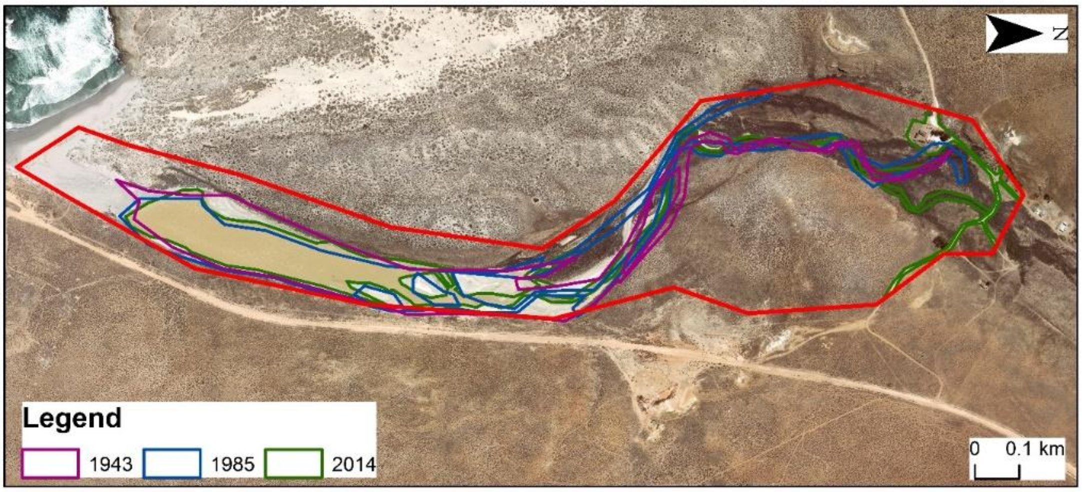

Figure 6 **Open water surface area of the Groen Estuary mapped for different years. The red line indicates the incorrect EFZ mapped for the NBA (2012).**

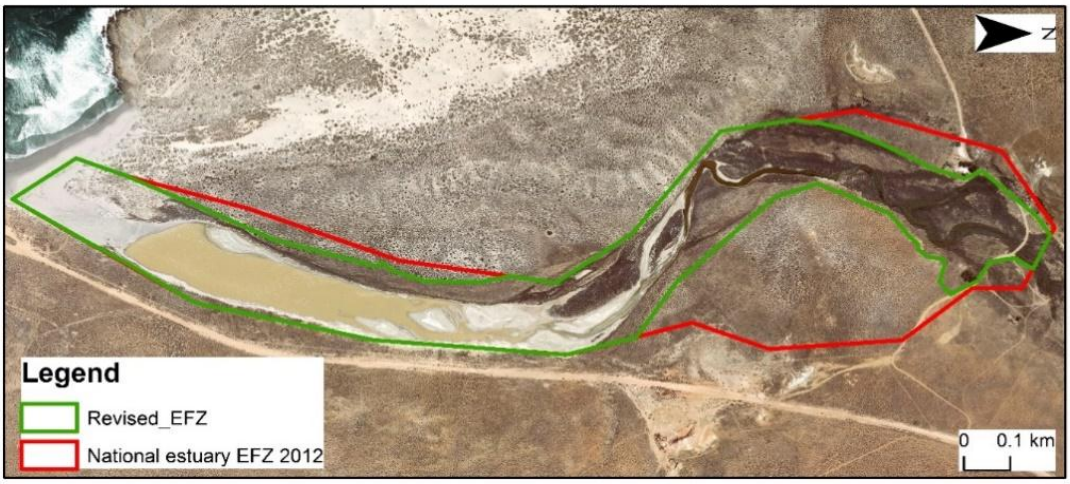

Figure 7 **Revision of the estuarine functional zone (EFZ) for the Groen Estuary to exclude higher elevations.**

The dominant habitat at the Groen Estuary was supratidal salt marsh with the dominant species *Sarcocornia pillansii* that covered 8 ha (Figure 8, Table 3, Plate 1d). Intertidal salt marsh represented by *Sarcocornia natalensis* and *Salicornia meyeriana* occurred along the banks of the estuary mostly along the lower reaches of the northern bank. Terrestrial species including *Lampranthus* sp., *Lycium strandveldense* and *Mesembryanthemum guerichianum* were present in the ecotone between the suptratidal zone and terrestrial habitat. The reed and sedge habitat, represented by common reed (*Phragmites australis*), fringed the steeper channel in the upper reaches of the estuary (Plate 2d). This habitat is important as it indicates freshwater seepage in the upper reaches of the estuary. Figure 8 provides a vegetation map of the revised estuarine functional zone of the Groen Estuary based on 2011 and 2014 aerial photographs and field surveys in February 2015.

Filamentous macroalgae with the dominant species *Rhizoclonium riparium* (Cladophoraceae, Chlorophyta) are an important feature of the estuary. The filamentous cyanobacteria *Lyngbya* sp. was abundant in the estuary forming dense floating mats (see Plate 2c). Windblown algal mats (Plate 2f) were observed on the surrounding vegetation. This can increase salt load causing die-back but it is also a source of organic material to the surrounding supratidal salt marsh area. Microalgae (*Chlorella* sp.) and diatoms (*Gyrosigma*, *Navicula* and *Nitzchia* spp.) were present in the water samples collected at Sites 1-3. Photographs are shown in the appendices.

Salt pans were present in the middle and upper reaches of the estuary. These waterlogged areas were devoid of vegetation (Plate 2d). Much of the vegetation surrounding the estuary was dead at the time of sampling in February 2015 (Plate 1f). Although not included as estuarine habitat the following species were identified in the dune vegetation at the mouth of the estuary: *Aloe arenicola, Asparagus* spp.*, Ballota africana, Calobota spinescens, Chrysanthemoides incana, Cotyledon orbiculata, Mesembryanthemum guerichianum, Salvia africana-lutea* and *Tapinanthus oleifolius.* The elevation of the north bank in the lower reaches is unsuitable for establishment of estuarine vegetation.

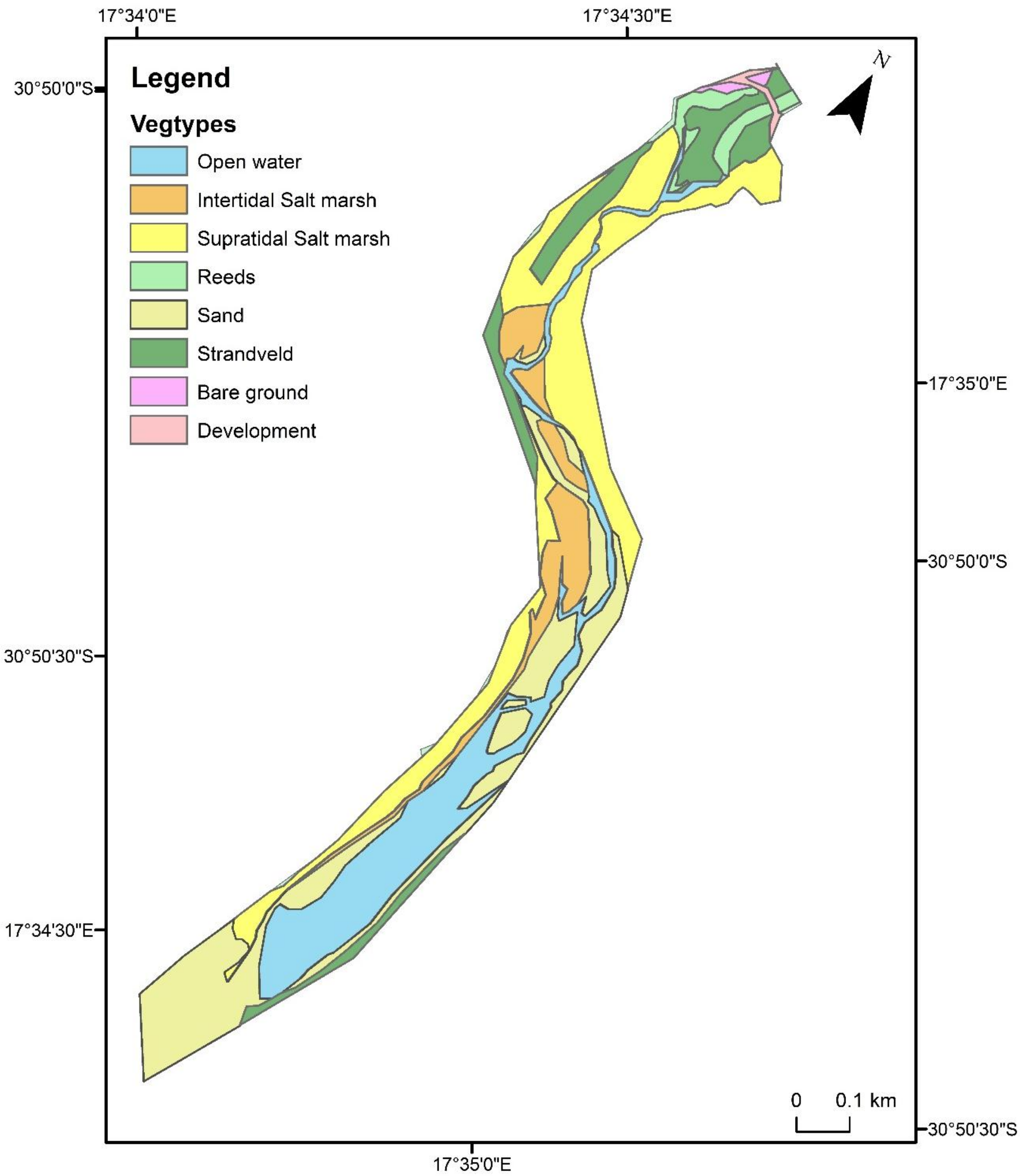

Figure 8 **Macrophyte habitats in the Groen Estuary based on 2014 aerial photographs and the field survey in 2015.**

Table 3 Macrophyte habitats in the Groen Estuary based on 2014 aerial photographs and the field survey in 2015.

HABITAT TYPE	DEFINING FEATURES, TYPICAL/DOMINANT SPECIES	AREA (HA)
Open surface water area	Serves as a possible habitat for phytoplankton	8
Sand and mud banks	Habitat for microphytobenthos	10
Macroalgae	Algae occurred throughout the estuary and were collected at Transects 1 to 3. The macroalgae *Rhizoclonium riparium* (Cladophoraceae, Chlorophyta) and the filamentous cyanobacteria *Lyngbya* sp. were abundant in the water column. These species formed free floating mats and are also attached to the substrate.	Not mapped
Submerged macrophytes	Bickerton (1981) reported pondweed *Potamogeton pectinatus* (*Stuckenia pectinata*) in the upper reaches of the estuary. These plants were absent in 2015. They grow best at salinity less than 10 ppt.	0
Reeds and sedges	*Phragmites australis* occurred in the upper reaches of the estuary and indicated brackish conditions. Other species found here were *Juncus acutus* and *Isolepsis* sp.	1
Salt marsh	Intertidal species included *Sarcocornia natalensis, Salicornia meyeriana* and *Sporobolus virginicus. Sarcocornia pillansii* was the dominant supratidal species.	12
Floodplain	Namaqua Strandveld occupied 7 ha mainly in the middle reaches on the south bank. This vegetation consisted of sparse *S. pillansii* interspersed with terrestrial species. The Namaqua National Park reception and ranger accommodation occupies 1 ha within the upper reaches of the estuarine functional zone.	8

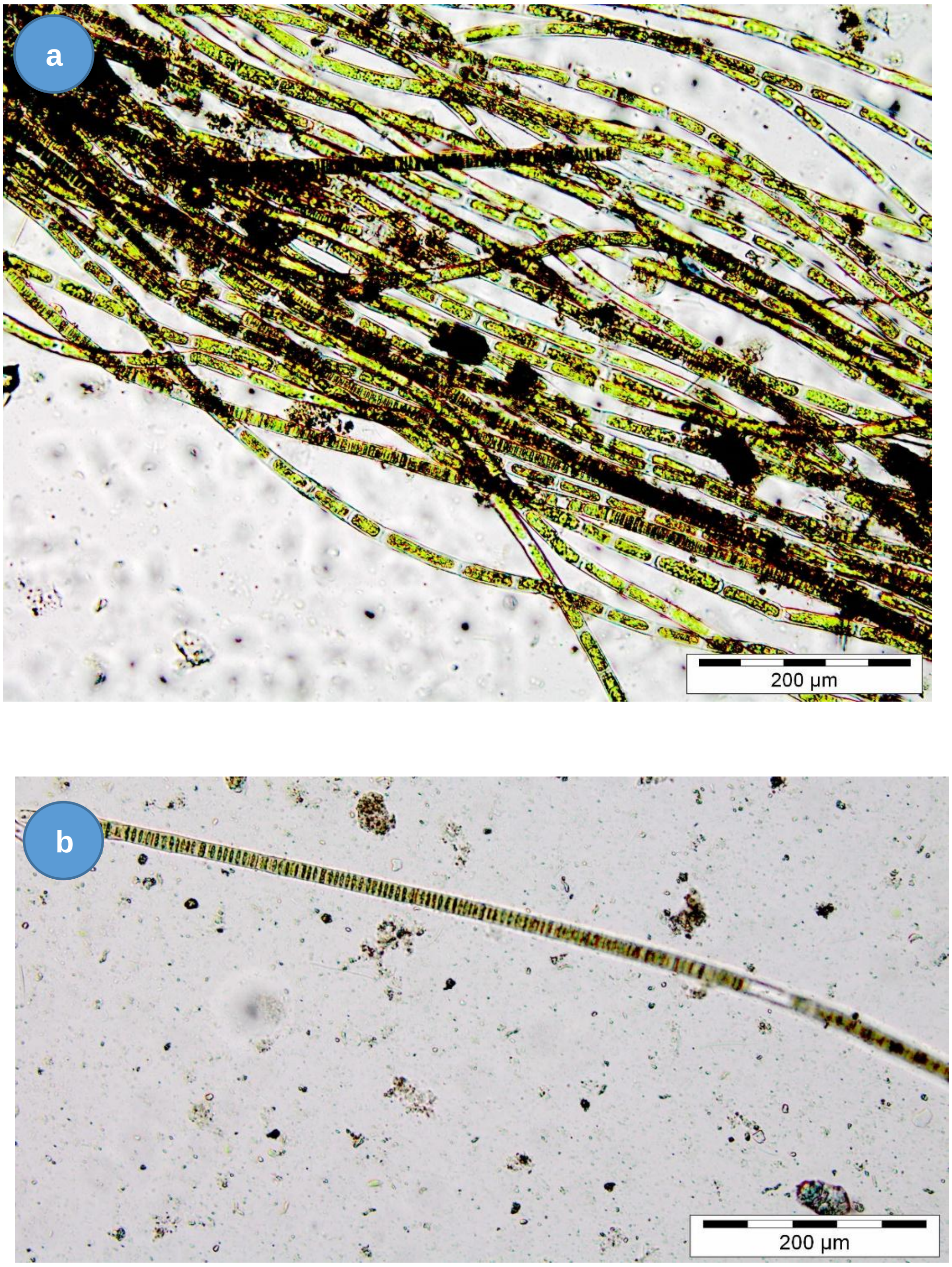

Figure 9 a). Filamentous macroalgae ***Rhizoclonium riparium,*** and
b). filamentous cyanobacteria, ***Lyngbya*** sp. formed algal mats in the water column of the Groen Estuary.

Plate 1 a) Dry kelp present on the sand berm indicating overwash from the sea, b) the mouth of the Groen Estuary indicating the width of the sandberm closing the estuary to the sea, c) the transition from intertidal salt marsh (***Sporobolus virginicus*** grass and ***Sarcocornia pillansii***) to terrestrial dune vegetation in the background, d) intertidal salt marsh habitat present on the north bank at the mouth of the Groen Estuary, e) the wide sand/mud banks present at the Groen Estuary. This photograph was taken from the water's edge at the mouth facing towards the north bank, f) Dead salt marsh vegetation likely due to windblown salt accumulation (Photographs taken by J. Adams, February 2015).

Plate 2 a) Windblown cyanobacteria and salt foam accumulated on salt marsh vegetation, b) cyanobacteria has discoloured the thick salt crust present on the sand surrounding the open water, c) thick floating mats of ***Lyngbya*** sp. present in the water column throughout the Groen Estuary, d) a dry arm of the estuary situated on the north bank in the middle reaches, e) reeds habitat can be clearly distinguished from the homogenous floodplain in the upper reaches, f) ***Phragmites australis*** and ***Juncus acutus*** present in the less saline upper reaches (Photographs taken by J. Adams, February 2015).

4.3 DISTRIBUTION OF VEGETATION ALONG TRANSECTS, GROUNDWATER AND SEDIMENT ANALYSIS

Salt marsh is typically distributed along an elevation gradient from lower intertidal to upper intertidal to supratidal salt marsh and then terrestrial vegetation. There was a gradual elevation change along Transect 1 and 2 with a more abrupt increase from lower intetidal to supratidal / floodplain area in Transect 3 (Figure 10). Transect 1 showed clear zonation with a large area of bare gound along the first 18 m, this was followed by a zone of the annual succulent *Salicornia meyeriana*. Thereafter the upper intertidal species *Sarcocornia natalensis* occurred but it was mostly dead. There was also a small zone of brakgras, *Sporobolus virginicus*. The supratidal zone was represented by *Sarcocornia pillansii* which was also mostly dead (16.3 % alive, 57.1 % dead). From 31 m bare ground increased with distance away from the main water channel. This represented a side channel that has dried up over time. *Sarcocornia pillansii* was the dominant plant along Transect 2 as this represented a supratidal salt marsh area. Most (22.7 % alive, 51.2 % dead) of the plants were also dead. There was greater species richness along Transect 3 as it consisted of a small intertidal marsh followed by a much larger supratidal area.

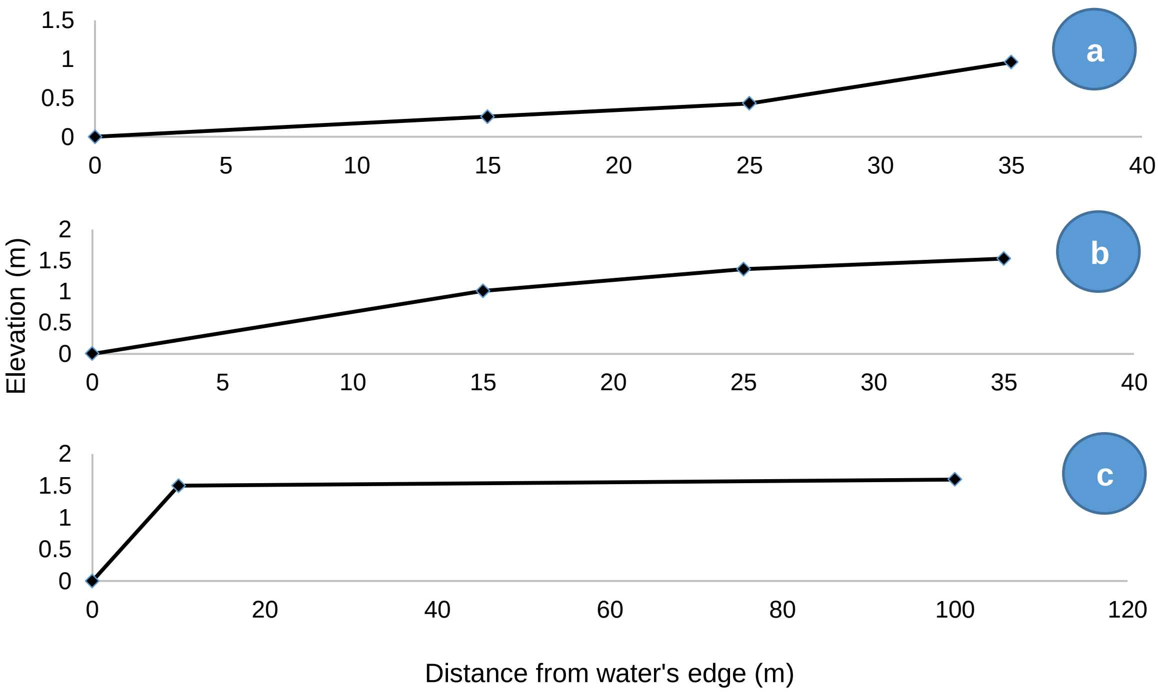

Figure 10 Elevation profiles of the three transects placed in the (a) lower, Transect 1 and (b & c) middle reaches of the Groen Estuary (Transects 2 and 3).

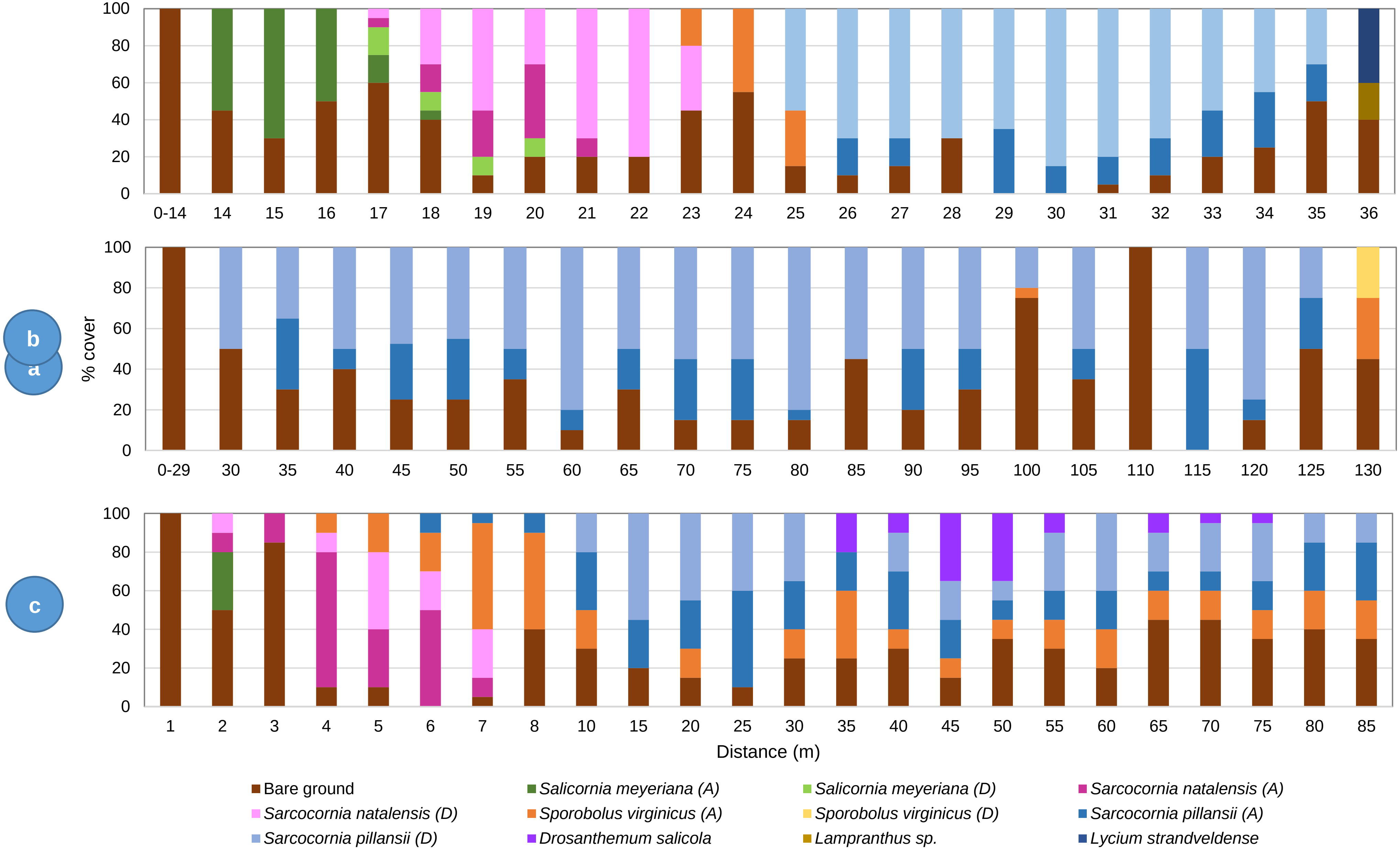

Figure 11 Vegetation along transects in the (a) lower and (b & c) middle reaches of the Groen Estuary. (D = dead, A= alive).

Sediment salinity decreased in an upstream direction along the estuary as well as from the intertidal zone towards the terrestrial vegetation. Surface sediments were more saline than bottom sediments (average surface salinity 19.2 ppt vs average bottom salinity 7.3 ppt, Figure 12). The maximum salinity recorded was 68.8 ppt recorded in the salt pan in the supratidal zone of Transect 2. Lowest sediment salinity was recorded in the upper reaches in the reed beds at the freshwater spring site (Site 1 - 3 ppt, Site 2 - 7.3 ppt and Site 3 - 2 ppt, Figure 12). In addition a hole was augured allowed to fill with water and thereafter the salinity was measured as 18 ppt at Reed Site 1 and 9 ppt at Reed Sites 2 and 3.

Sediment organic matter content and redox potential increased with distance away from the open water. Organic matter content declined with depth (average surface organic matter content 8.3 % vs average bottom organic matter content 2.8 %), the reverse was evident for soil redox potential which increased towards the water table. Organic matter content was highest in the upper intertidal zone of Transect 3 which had a maximum organic content of 16.3 %. Sediment pH was variable but averaged 8.3 indicating alkaline soils (Figure 12). The reed sites were waterlogged (average 70.5 %) and had higher sediment organic matter content (average 21.1 %) than the estuary sites. The lower reed sites (1 and 2) were acidic whereas the reed site situated at the head of the estuary was slightly alkaline indicating the presence of low brackish conditions (freshwater input).

On average the soil texture of Transect 1 and 3 were a silt loam, Transect 2 was loam and the reed sites were a clay loam. Soil texture was similar along transects with the sand faction decreasing away from the water channel. In general surface sediments had a higher sand faction than bottom sediments. Soil texture of the reed sites varied greatly with Site 1 classified as clay, Site 2 as silt loam and Site 3 as loam (Figures 13 and 14).

The depth to groundwater increased away from the water channel. Groundwater salinity could only be recorded at some of the zones as the water table was too deep and could not always be reached. The results were thus inconclusive. Groundwater salinity decreased away from the water channel for Transect 1, the reverse was however evident for Transects 2 and 3 (Figure 15).

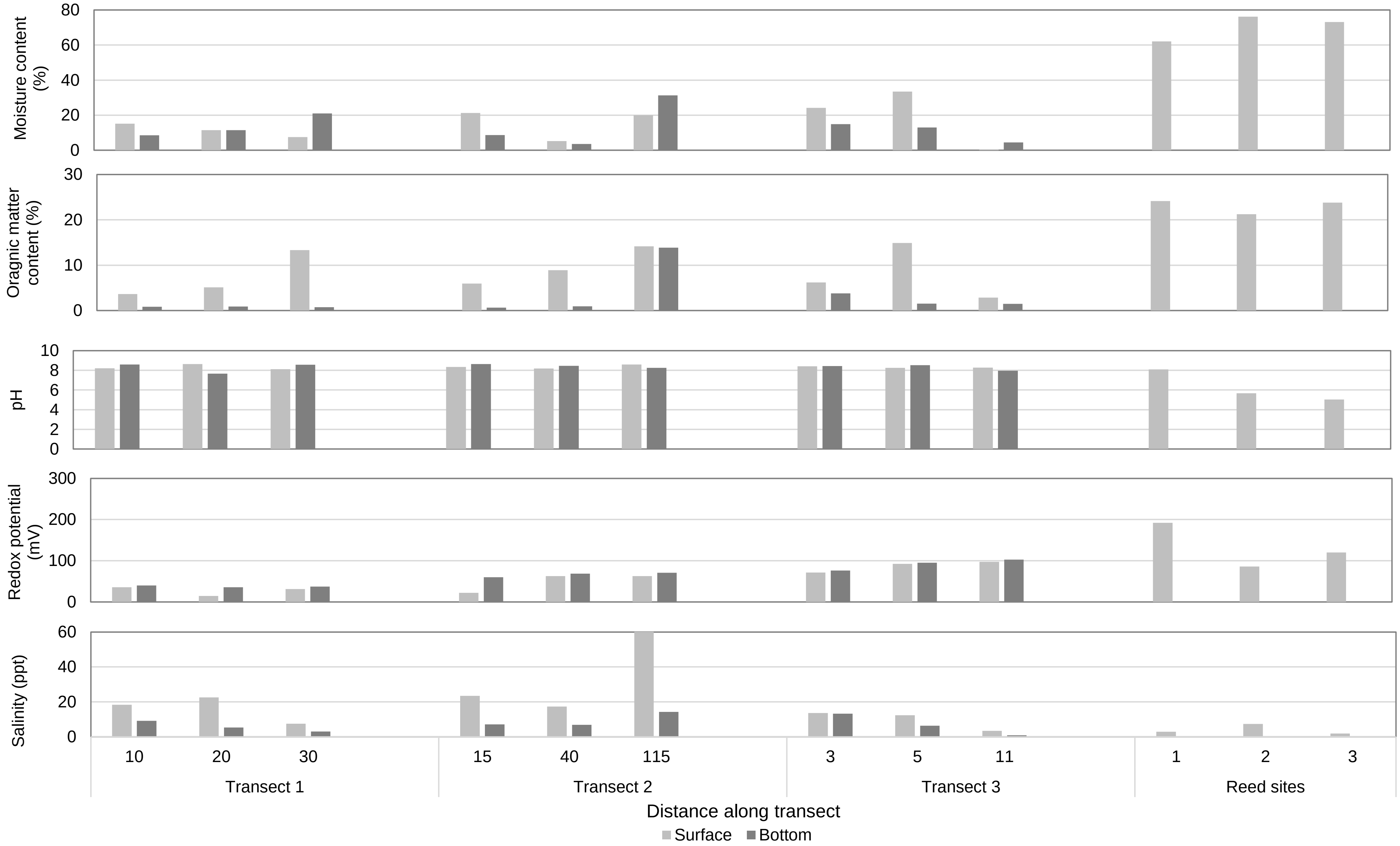

Figure 12 **Sediment characteristics (moisture content, organic matter content, pH, redox potential and salinity) of surface and water table samples measured along transects in the Groen Estuary.**

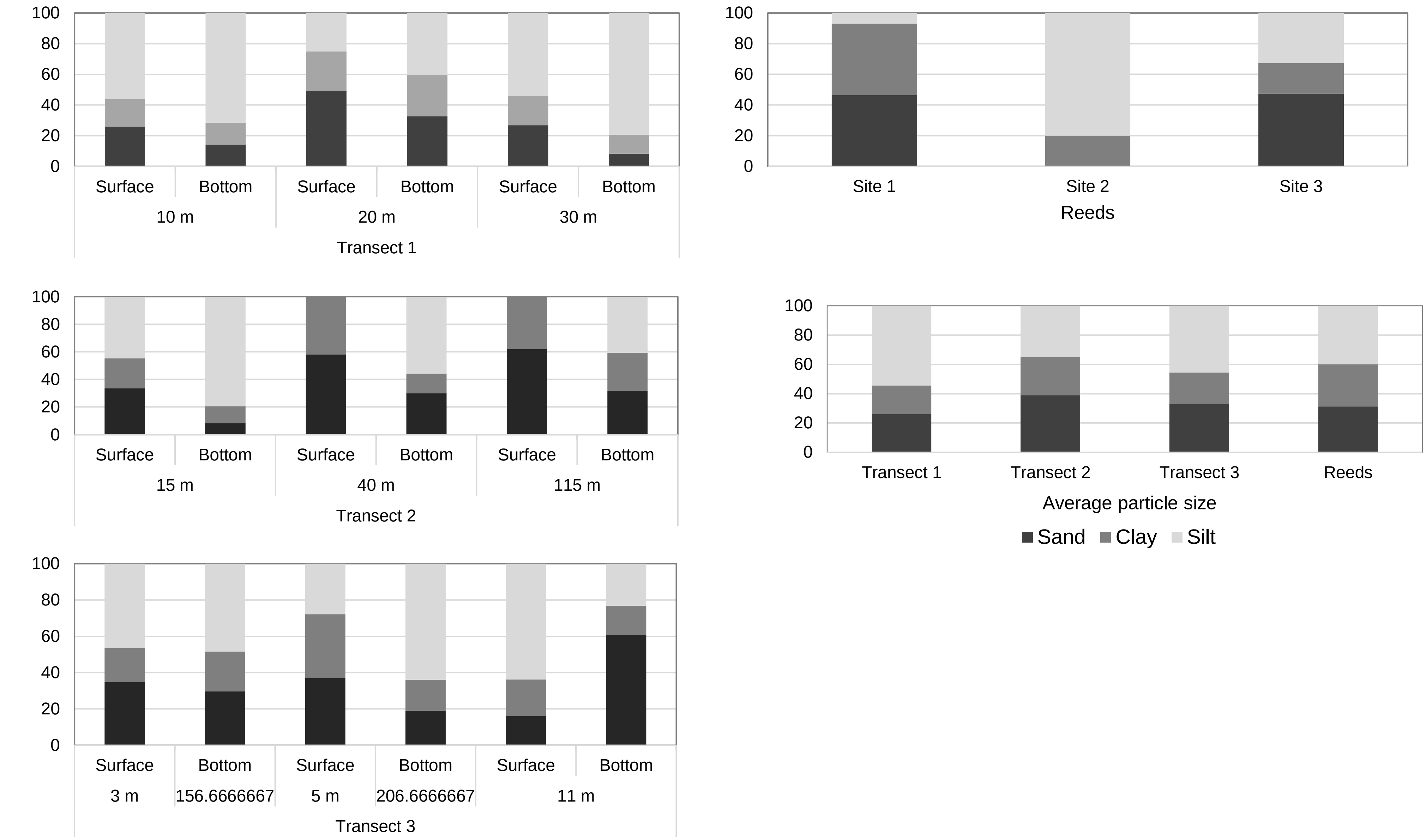

Figure 13 **Sediment particle size analysis of surface and water table samples measured along transects at the Groen Estuary.**

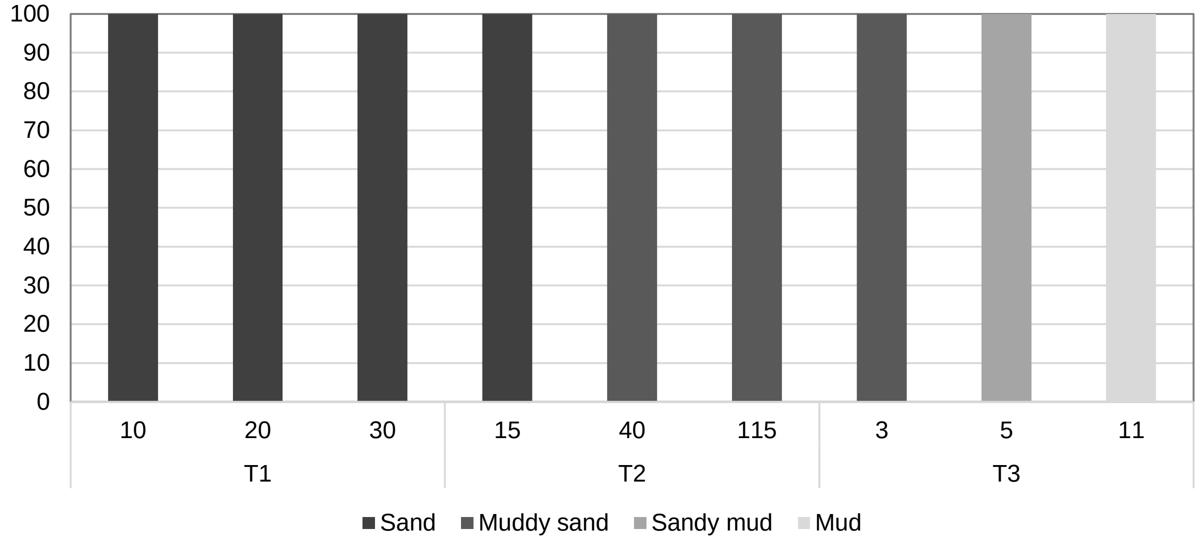

Figure 14 Sediment classes based on mud content of sediment collected in the three zones (lower intertidal, intertidal and suptratidal) along transects at the Groen Estuary.

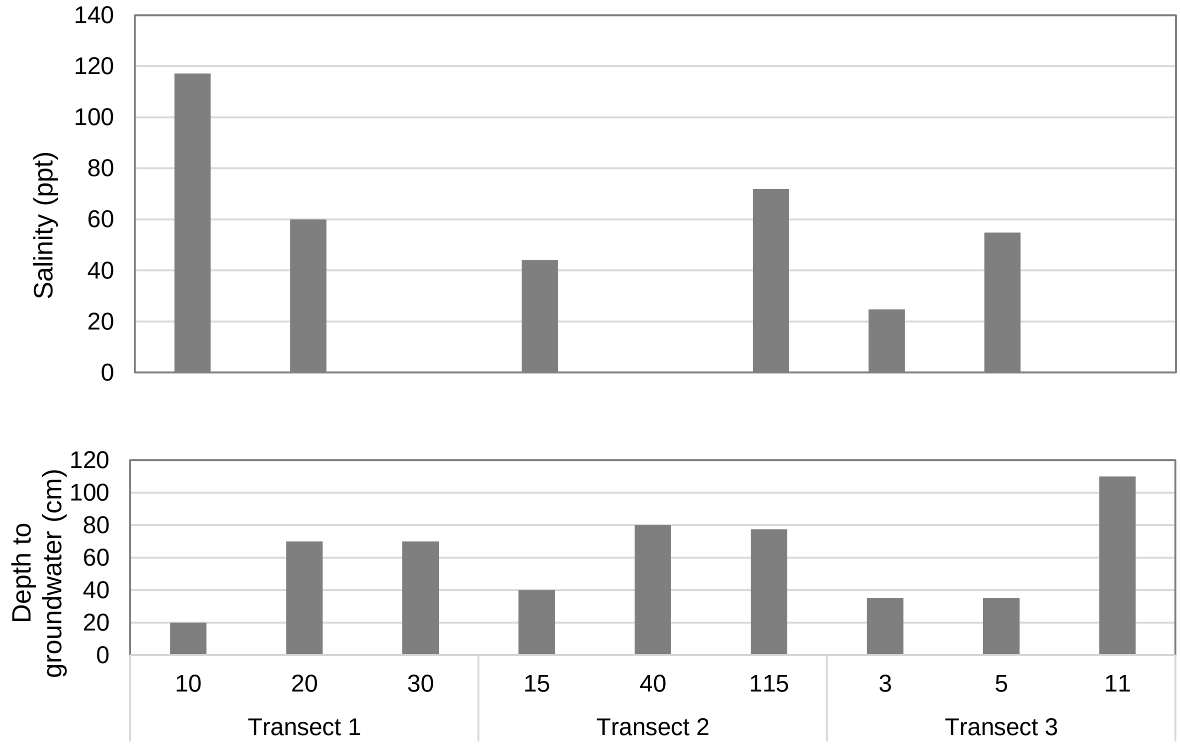

Figure 15 Groundwater characteristics (salinity and depth to groundwater) measured in the intertidal, suptratidal and terrestrial fringe of transects at the Groen Estuary.

4.4 BENTHIC AND PLANKTONIC INVERTEBRATES

No macro-invertebrates were present in benthic samples collected at any of the seven sites. An anoxic black layer was present immediately below the surface of the sediment and extended down to a depth of at least 0.5 m. Any disturbance of the sediment (even superficial) resulted in a strong smell of Hydrogen sulphide (H_2S). Zooplankton samples showed the same pattern – reflecting an absence of zooplankton in the water column. However, 26 insect larvae (ca 20 ind/m^3) were collected at Site 15 where a salinity of 26 ppt was recorded. These insects were associated with the underside of the carpet of algae floating at the water surface (Plate 3).

4.5 BIRDS

Avifauna species associated with the water body are listed in Table 4. Roosting birds were transient, present for a few hours only. Although Ostrich are not usually associated with estuaries, four were found trapped in the anoxic mud in the middle and upper estuary. Only one was alive and it was eventually dragged from the mud. Most birds feeding in the estuary were either on the expansive sandflat in the lagoonal area of the lower reaches or present on or around the algal carpets floating on the water surface in the upper estuary (Plate 3). Approximately 109 birds representing 15 different species were recorded (Table 4).

Table 4 Bird species associated with the Groen Estuary and recorded during the 2015 field visit. Roosting birds were transient and not recorded feeding at any time during the field survey. Diet information from Hockey & Turpie (1999).

SPECIES	TOTAL NUMBERS	ACTIVITY	DIET
Greater Flamingo	13	Feeding	Aquatic plants, invertebrates
White-breasted Cormorant	24	Roosting	-
Spur-winged Goose	7	Roosting	-
Egyptian Goose	2	Roosting	-
Red-billed Teal	1	Near death	-
Cape Teal	9	Feeding	Aquatic plants, invertebrates
Ostrich	4	Trapped in mud	-
Black-winged Stilt	2	Feeding	Aquatic plants, invertebrates
Kittlitz's Plover	8	Feeding	Invertebrates, mainly aquatic
White-fronted Plover	4	Feeding	Invertebrates, mainly aquatic
Chestnut-banded Plover	2	Feeding	Invertebrates, mainly terrestrial
Three-banded Plover	5	Feeding	Invertebrates, mainly aquatic
Sanderling	4	Feeding	Invertebrates, mainly aquatic
Little Stint	15	Feeding	Invertebrates, mainly aquatic
Kelp Gull	9	Roosting	-

Plate 3 a) The lower reaches of the Groen Estuary, also showing a roosting flock of White-breasted Cormorants; and b) A Cape teal with its ducklings present at the Groen Estuary at the time of sampling.

The upper photograph in Plate 3a illustrates the lagoon near the mouth of the Groen Estuary. Also shown in the photo is the expansive sandflat adjacent to the water body and a roosting colony of White-breasted Cormorants. These birds were present for a few hours only. Most of the plover species were feeding on the open sandflat where insects were present. In the lower photograph (Plate 3b) a Cape Teal with accompanying ducklings swims past the clearly visible floating algal carpet at Site 15. The water was very clear at this site.

5 DISCUSSION

5.1 FIELD SURVEY FINDINGS

This study has provided new information on the estuary such as the delineation of the lateral boundary which will be used in the next National Biodiversity Assessment. Habitat mapping from past aerial photographs showed that the open water surface area has decreased over time but the vegetated areas have remained stable. Supratidal salt marsh is dominant and covered an area of 8 ha. Intertidal salt marsh covered 4 ha while reeds and sedges occurred over 1 ha. The reeds extended from the upper reaches of the estuary into the river section. Common reed (*Phragmites australis*) is abundant in the fresh to brackish upper reaches of South African estuaries. Studies have shown that when the plants are exposed to 20 ppt they are stressed after two weeks and will die if exposed to 20 ppt for greater than three months. However if the roots are in fresher water they can survive. In some estuaries *P. australis* is tidally inundated with seawater but survives as the roots occur in freshwater at seepage sites. (Adams and Bate, 2002). The persistence of the reeds in the upper reaches of the Groen Estuary is maintained by the spring input.

Floating mats of macroalgae and cyanobacteria were also abundant in the upper reaches of the estuary. *Rhizoclonium riparium* is a cosmopolitan filamentous alga that is abundant in South African estuaries. *Rhizoclonium riparium* can survive under fresh to hypersaline conditions (Nienhuis, 1974). Chao *et al.* (2004) found that *Rhizoclonium riparium* prefers brackish standing water to full marine conditions and grows best at a salinity of 20 ppt. Prinsloo (2012) in a study on macroalgae in Eastern Cape estuaries found that *Rhizoclonium riparium* and *Rhizoclonium lubricum* occurred as floating mats in the middle to upper reaches of estuaries where abundances varied between 5% and 20% on the water's surface. The cyanobacteria, *Lyngbya* sp., can inhabit fresh, brackish or marine environments and prefers nutrient rich environments. *Lyngbya* can be solitary or form large leathery mats that can be attached or free floating (Janse van Vuuren *et al.* 2006). The mats have a characteristic, raw sewage-like smell. The species is known to release toxins that may cause major contact irritations.

The dominant supratidal plant *Sarcocornia pillansii* is specialized to grow at high salinity. Bornman *et al.* (2002, 2004) showed at the Olifants Estuary that the survival of this plant was dependent on the utilization of saline groundwater, particularly during the dry period (8 months) of the year. The cover abundance of *Sarcocornia pillansii* was visibly reduced where the water table was deeper than 1.5 m and/or where the electrical conductivity of the groundwater had a high ion concentration (> 80 mS cm^{-1}). The greatest water table depth recorded along transects at the Groen Estuary was 1.1 m. However at some sites the water was too deep to auger to. At the Groen Estuary the majority of the salt marsh vegetation was dead. This reflected the end of the dry summer season. Also windblown algae coated with salt were deposited on the vegetation causing some dieback.

According to O'Callaghan (1992) *Sarcocornia natalensis* can survive salinity fluctuating between 15-140 ppt. *Sporobolus virginicus* has been observed growing at salinity of 34 ppt in the field, however growth of the grass is reduced at 15 ppt and inhibited at 20 ppt (Breen *et al.*, 1977; Marcum & Murdoch, 1992; Naidoo & Naidoo, 1992; 1998; Muir, 2000). *Sporobolus virginicus* was particularly abundant at the mouth of the Groen Estuary and thus may be more tolerate of higher salinities than previously described. The grass may be accessing fresh groundwater that infiltrates down the steep, sandy north slope.

Transects were used to plot the distribution of vegetation along an elevation gradient and relate the dominant species to sediment and groundwater characteristics. Sediment organic content was high while sediment redox potential increased away from the water's edge indicating less reduced conditions. The alkaline soil water is due to the underlying geology of the area. Namaqualand strandveld communities prefer alkaline soils for growth, whereas sand fynbos prefers leached acidic soils. The ecotone between these vegetation types is primarily driven by differences in pH (Mucina & Rutherford, 2006).

Sediment characteristics showed similar trends to unpublished data from Veldkornet (2015) regarding average characteristics for the different estuary zones (Table 5). In most cases the sediment and groundwater characteristics of the dominant plants in the Groen Estuary occurred within the range recorded for other estuaries. Notably the groundwater electrical conductivity was higher in the Groen Estuary. Also the sediment electrical conductivity for the intertidal species *Salicornia meyeriana* was higher than that recorded in other estuaries. This reflects the nearby hypersaline lagoon conditions. Interestingly in the Groen Estuary *Sarcocornia pillansii* occurred in a salinity range of 13.4 + 3.2 mS cm^{-1} whereas Veldkornet (2015) has a higher average value of 34.4. mS cm^{-1}. Higher electrical conductivity readings of surface sediment and groundwater have been recorded in the back reaches of the cool temperate Orange and Olifants estuaries. Bornman *et al.* (2004) recorded surface and groundwater electrical conductivity readings as high as 109.02 ± 17.8 mS cm^{-1} and 117.7 ± 10.4 mS cm^{-1}, respectively, at the Olifants Estuary. Surface sediment and groundwater in the desertified salt marsh at the Orange had electrical conductivity readings of 120.9 ± 4.7 mS cm^{-1} and 105 ± 6.7 mS cm^{-1}, respectively, when sampled by Shaw *et al.* (2008). Following a flood in 2006 at the Orange Estuary the sediment electrical conductivity readings were in a similar range to that recorded at the Groen Estuary (surface sediment= 50.5 ± 4.9 mS cm^{-1} and groundwater= 52 ± 4.8 mS cm^{-1}). This is within the range for the growth of the dominant supratidal plant *Sarcocornia pillansii.*

Approximately 300 ha of salt marsh, mainly *Sarcocornia pillansii*, have been lost from the Orange Estuary since the 1980s due to anthropogenic pressures (Bornman & Adams, 2010; Bornman *et al.* 2010; Shaw *et al.* 2008). The backwaters of the Orange Estuary have become a hypersaline desertified salt marsh. The high electrical conductivity recorded in the standing surface water, sediment and groundwater is unsuitable for the growth of *Sarcocornia pillansii* (> 80 mS.cm^{-1}) and development of a hard salt crust prevents the germination of seeds. Rehabilitation efforts have been implemented at the Orange Estuary to improve backflooding to the desertified salt marsh. Aerial photographs from 2010 have showed an increase in salt marsh suggesting that the flushing of the backwaters has reduced the salinity of the sediment and groundwater (Bornman *et al.*, 2010). These are extreme conditions which should be prevented from occurring at the Groen Estuary. Hypersaline conditions could cause dieback of salt marsh habitat which will increase erosion causing desertification. Occasional floods are important as they flush out salts and reduce groundwater salinity.

From an invertebrate perspective prevailing conditions in the Groen Estuary were too stressful for benthic invertebrates to survive. Salinity was high and anoxic conditions extended to at least 50 centimetres depth. Thus, anoxia extends well below the burrowing depth of most estuarine benthic species. In addition to salinity and sediment characteristics, a closed mouth state that persists for long periods of time leads to a poor macrofauna diversity (de Villiers & Hodgson, 1999).

In the lower Groen Estuary, salinity values were around 220 ppt (salt concentration around 6x the concentration of seawater). Saturation point is around 300 ppt when crystallizing brine characterizes the water body (refer to Carrasco & Perissinotto, 2012). Typical estuarine macroinvertebrates tolerate salinity values up to ca 60 - 65 ppt (<2 x seawater concentration), after which the medium becomes lethal (de Villiers & Hodgson, 1999). Although these values represent maximum tolerance limits, breeding ceases well below these levels. Consequently, it is not surprising that benthic invertebrates (excluding insects) were not recorded in the Groen Estuary.

Table 5 **Sediment and groundwater physico-chemical characteristics dominant in each zone for the Groen Estuary compared to unpublished data by Veldkornet (2015) (values are arithmetic means with standard errors, n=6 unless otherwise stated).**

	Lower intertidal		**Upper intertidal**		**Supratidal/terrestrial fringe**	
	Salicornia meyeriana		*Sarcocornia natalensis*		*Sarcocornia pillansii*	
Physico-chemical characteristic	**Groen**	**Veldkornet**	**Groen**	**Veldkornet**	**Groen**	**Veldkornet**
Sediment Moisture Content (%)	15.5 ± 2.1	22.1 ±1.1	13.1 ± 3.1	23.8 ± 1.4	14.1 ± 3.7	19 ± 0.9
Sediment Organic Content (%)	3.5 ± 0.9	3.5 ± 0.2	5.4 ± 1.6	3.8 ± 0.3	7.7 ± 2	3.8 ± 0.2
Sediment Electrical Conductivity ($mS.cm^{-1}$)	54.2 ± 23.2	41.3 ± 1.5	21.1 ± 4.3	33.7 ± 1.8	13.4 ± 3.2	34.4 ± 1.5
Sediment pH	8.4 ± 0.1	7.5 ± 0.1	8.3 ± 0.2	7.2 ± 0.1	8.3 ± 0.1	7.2 ± 0.1
Sediment Redox Potential (mV)	50.8 ± 6.2	4.6 ± 10	61.4 ± 8.9	13.27 ± 8.8	67 ± 8.2	56.2 ± 6.6
Groundwater Electrical Conductivity ($mS.cm^{-1}$)	62 ± 17.8	32.1 ± 7	56.6 ± 4.9	28.8 ± 1.9	71.93	39.6 ± 3
Groundwater depth (cm)	31.7 ± 3.8	38.4 ± 4.2	60 ± 8.9	54.4 ± 5.8	90.8 ± 6.6	122.7 ± 4.8

The St Lucia Estuary in South Africa has been well studied with respect to salinity tolerance of the estuarine fauna. At St Lucia, salinity values approaching 300 ppt have been recorded in the northern limits of the system (Carrasco & Perissinotto, 2012). In a recent study, Carrasco and Perissinotto (2012) recorded the presence of a flatworm, two copepod species and a ciliate in salinities >100 ppt. These four species only disappeared from the northern parts of St Lucia when salinity values reached about 130 ppt. However, another ciliate is known to survive in salinity values up to 300 ppt (Carrasco & Perissinotto, 2012). In this study on the Groen Estuary, the sampling method (mesh size of the zooplankton net used was 200 microns) would not retain ciliates if present in the water column.

The presence of insects (and therefore their larvae) in the upper reaches of the Groen Estuary is by contrast, not surprising. Here, salinity values were below the concentration of seawater. Numbers were relatively low, but this may be a reflection of high predation pressure by foraging birds on the algal mat. Despite disturbance to the surface algae during sampling for mesozooplankton (retained by a 200 micron mesh net), no other invertebrates were collected.

Relationships between estuarine bird predators and their prey are relatively well known in South Africa (Hockey & Turpie, 1999). The relatively low numbers of species as well as the number of birds on the Groen Estuary is probably a consequence of food limitation at the time of the visit in February 2015 (when compared to previous counts - refer to Bickerton, 1981 and Table 2, this report). The majority of invertebrate feeders on the Groen Estuary in February 2015 were small, short-billed waders and were observed foraging on the sandflats in the lower reaches and on or adjacent to algal mats in the middle-upper estuary. Given the absence of burrowing invertebrates in the estuary at that time, foraging waders were presumably feeding on insects and their larvae. Longer-billed waders (e.g. Curlew Sandpipers that were relatively common in previous visits – Table 2) also probe the sub-surface sediment for their prey and their absence further supports the conclusion that burrowing invertebrates were not present in the estuary at the time (February 2015). Fish were also not observed during the field visit. Their apparent absence is supported by the absence of avian predators that also forage on fish (e.g. Herons, Egrets, Kingfishers).

The absence of benthic macroinvertebrates, mesozooplankton, fish and low avian species counts and abundance support the conclusion that the Groen Estuary was a stressed ecosystem in February 2015. Main stressors were extreme hypersalinity, relatively low water volume, anoxic sediments and a mouth that had remained closed for a number of years.

5.2 ESTUARY DYNAMICS AND RESPONSES TO FUTURE SALINITY CHANGES

The Groen does not function as a typical temporarily open/closed estuary for much of the time. Salinity in the system fluctuates between extreme values, ranging from near freshwater to hypersaline, depending on duration of the closed mouth phase. For example, a salinity of 223 ppt recorded in February 2015 is the highest yet recorded in the lagoonal area. Following a major flood, the mouth opens and exchange with the sea is temporarily restored. This provides opportunity for biota to enter the estuary that subsequently becomes trapped after the mouth closes again. Biological functioning of the estuary is temporarily restored and typical of temporarily open/closed estuaries under the prevailing conditions (refer to Bickerton, 1981). On a temporal scale, abiotic conditions become progressively more intense and limiting for the biota after mouth closure. Water inflow from the springs at the head of the estuary is relatively low and is less than the water (per unit time) lost through evaporation from the estuary. As water volume in the estuary decreases and salinity values increase, mass mortality of the biota begins according to the tolerance level of species present. Increasing deposition of organic material on the substrate contributes to the development of extreme anoxia, and macrobenthic and mesozooplanktonic organisms are no longer able to survive in the system.

Figure 16 depicts a generalized hydrological cycle for the Groen Estuary adapted from Bickerton (1981). The time periods for the completion of one cycle would depend on the frequency and degree of episodic flooding. The changes in the estuary after episodic flooding have not been measured and monitored. For this reason the next flooding event should be followed by a detailed monitoring programme so that the functional importance of the estuary can be measured and understood.

The 17th Conference of the Parties (COP17 2011) predicted a 1-2°C increase in temperature in coastal regions by about 2050 (CES, 2015). The western side of South Africa is likely to experience significant reductions in the flow of streams in the region. Long-term climate change predictions for this area are a future decrease in rainfall. Change in wind patterns and increased sea storms could increase sediment input to the mouth area causing closure. Decreased rainfall coupled with increasing temperatures will result in increased evapotranspiration, increased salinity and the lowering of the water table. The Groen Estuary will become drier and more saline.

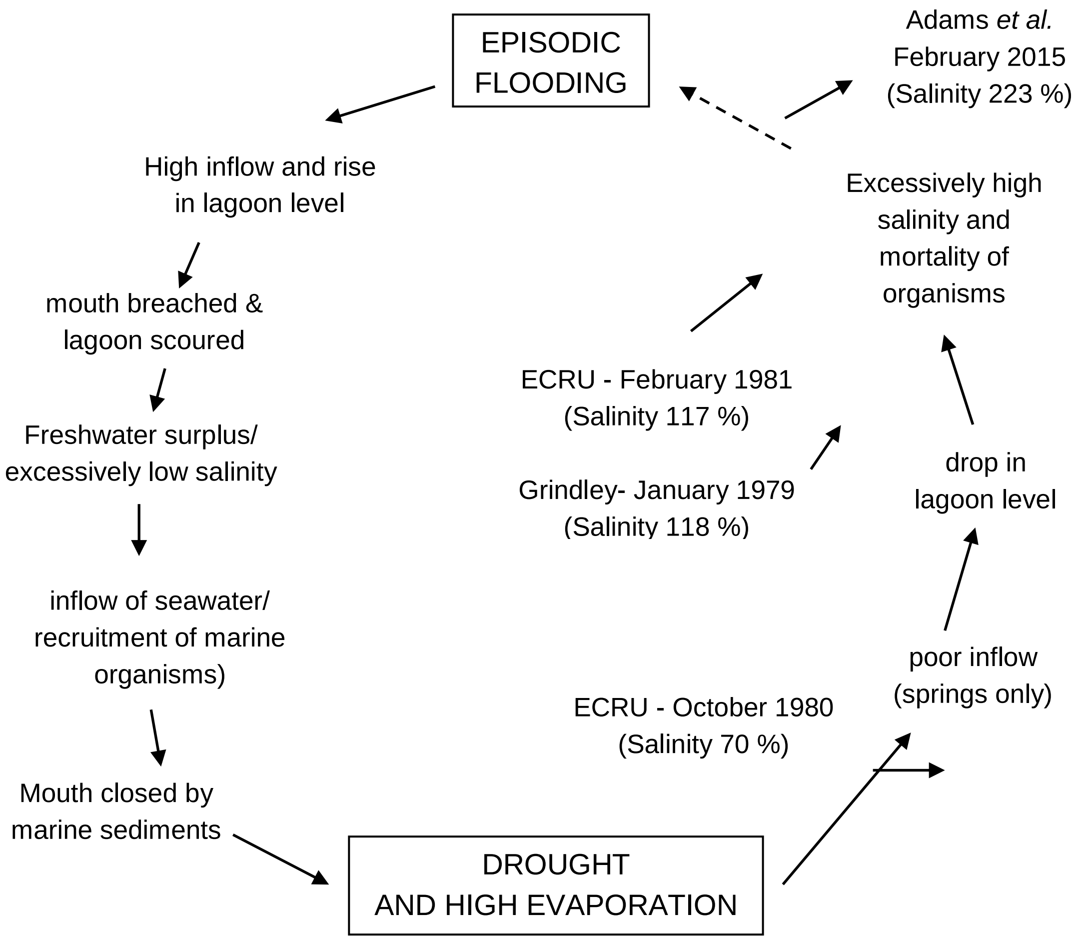

Figure 126 Generalized hydrological cycle for the Groen Estuary. The time periods for the completion of one cycle would depend on the frequency and degree of episodic flooding. Dashed line reflects highest salinity values – this state may persist from months to years (Adapted from Bickerton, 1981).

The Groen Estuary mouth is situated 10.5 km south-west of the south-western corner of the Roode Heuvel proposed mining block. An objective of this study was to assess the response of the estuary to future salinity changes as a result of mining inputs. The Hydrological and Geochemical study in February 2015 (SWS, 2015) along the riverbed of the Groen River confirmed the conclusion that perennial sub-surface flow is negligible or non-existent. No evidence exists from the various studies undertaken to support the conclusion that a hydrological connection is present between the Kamiesberg Site and the estuary; although connectivity caused by surface flooding is unknown.

Rainfall at the coast is approximately 95 mm per annum (129 mm was recorded in 2014), this is insufficient to maintain a surface river inflow to the estuary (CES, 2014; SWS, 2015). The spring at the head of the estuary (flux approximately 1l/sec) is likely fed from groundwater discharge, but the exact origin of the spring remains unclear. This appears to be the sole source of perennial inflow to the estuary, but the evaporation rate from the estuary far exceeds the inflow rate from the spring. Consequently salinity values in the estuary rapidly increase, particularly in the lagoonal area. Data are available to show that there has been consistently lower rainfall in the area than decades ago. The lower reaches of the estuary are expected to remain in a saline state, however the response of the estuary to a future large flood is unknown and should be studied.

Salinity of the spring water is ca 10 ppt and therefore too high to support an oligohaline invertebrate community, even under current conditions (oligohaline communities have an upper threshold of ca 5-6 ppt). Post-mining groundwater TDS levels will peak at approximately 24 ppt and any flux of such water to the head of the estuary (considered highly unlikely) will raise the salinity in the upper estuary, beyond threshold levels of estuarine organisms that could potentially occur there. For example reeds and sedges grow best at salinity less than 20 ppt. The survival of benthic invertebrates in this area is currently limited by the anoxic sediment. Available information suggests that the estuary becomes a biologically functional system following river floods, but the duration of this phase will essentially depend on the rate of evaporation from the estuary, salinity tolerance levels of species and the development of anoxic conditions in the sediment.

The Groen River flows approximately once in every five years, however surface water is always present in the estuary. Much of the water flowing from the Kamiesberg mountains is absorbed by the dry river bed. Only during large floods would water reach the estuary downstream. Extreme floods can occur and it is reported that the flood in 1961 covered the floodplain to 3 m above the river bed. Underground flow in the river bed does not occur (SWS 2015) and input to the estuary is via the spring during inter-flood periods. However the low flow from the spring does not compensate for the evaporative losses, resulting in a decrease in water level and increase in salinity during the dry months and years.

Comments from local residents in response to a questionnaire (Table 7 in the Appendices) suggest that, in the past, the river flowed more frequently and aquatic life in the estuary was observed. For example, fish and crabs were present. Bickerton (1981) also refers to local inhabitants and holiday makers netting fish in the lagoon. This possibly indicates fresher conditions in the lower lagoon area in the past. Over time trees along the shoreline have also disappeared (presumably due to water quality issues such as high salinity values). After floods, trees again establish themselves, but do not grow to any size before disappearing again. One respondent suggested that the mouth opened more frequently in the past and that the sand spit between the lagoon and nearshore has become more substantial and broad. At least one quote says that local rainfall can fill up the estuary. This supports the conclusion that the lagoon connected to the sea more frequently in the past. Overall the impression is of a drier system that now opens less frequently to the sea compared to past conditions. For these reasons the freshwater input to the estuary from the spring must be maintained and protected.

6 RECOMMENDATIONS

The low-level road crossing, fences, agriculture and development in the floodplain has decreased the health of the Groen Estuary. The present ecological status is a 'B', however the estuary is in a protected area (Namaqua National Park) and should therefore be restored and maintained in the best possible state of health. The estuary should therefore be maintained in an 'A' or Best Attainable State (description of states provided in Table 8 in the Appendices). In order to maintain the estuary in its present state Thresholds of Potential Concern need to be set. Should these thresholds not be met the health of the estuary due to hypersalinity will decline and the ecosystem services it provides to this harsh region will be impacted. There are three main issues of concern:

1. The proposed mining activities upstream of the estuary could potentially lead to an increase in groundwater salinity. However, there is no evidence of any hydrological connection between the mining site and spring. In addition, any potential passage of contaminated water across the 10 km distance will exceed hundreds of years on a temporal scale, as well as being subject to long-term dilution effects over this distance (SWS, 2015). Consequently, any potential increase in salinity at the head of the estuary is unlikely, but in the event of any flux of such water, salinity will increase in the upper estuary, but probably not beyond threshold levels of estuarine organisms that could potentially occur there.

2. Mapping of habitats suggests that the area of estuarine open water appears to have decreased over past decades (supported by anecdotal statements made by local residents). This may be related to borehole extraction of water, at least in part, by farming practises and for other purposes (see Bickerton, 1981 and van Niekerk & Turpie, 2012), potentially leading to reducing spring water discharge. An immediate and important management objective would be to protect the freshwater spring in the upper reaches (quality and quantity) and to ensure that salinity in this area remains around 10 ppt or less. Although reeds tolerate higher salinity values (up to ca 20 ppt), current levels provide a buffer protection zone. Of added concern is the prediction that rainfall will decease along the west coast of South Africa (see CES, 2015) and that the Groen Estuary will become progressively drier and therefore more inhospitable to biota in the future.

3. Thus, future changes of the Groen Estuary are potentially linked to both natural and anthropogenic influences.

As stated in the EIA report it is essential to conduct a pre-mining baseline assessment of salinity levels and the general biological state of the estuary, and to monitor these variables on a regular basis. The previous study (Bickerton, 1981) was conducted over 35 years ago and the present study was undertaken during an extreme hypersaline event. Different scenarios between a major flood (open mouth and freshwater dominated) and the present state (closed mouth and extreme hypersalinity) are lacking, primarily with respect to biotic response along the salinity continuum.

It is suggested that:

1. Permanent probes be deployed to continuously measure salinity in the upper reaches of the estuary.
2. Regular measurements of salinity and other physico-chemical characteristics be conducted along the length of the estuary (quarterly).
3. Vegetation mapping and biological surveys are needed to check for health of brackish wetlands and salt marshes (variable – linked to the rate of salinity change in the lower estuary).
4. Bird counts of the estuary should continue (quarterly).
5. With respect to the proposed mining operation, permanent salinity probes need to be deployed between the mining site and the head of the estuary to monitor any potential future change in groundwater salinity.

Points 1 to 4 should be the responsibility of Sanparks, while Point 5 should be addressed by Zirco. To better understand the dynamic nature of the estuary and determine biotic response to salinity changes, it is essential that monitoring of the estuary be operational following the next flood. This will also establish the degree of estuary flushing and duration of various salinity conditions following mouth closure.

7 CONCLUSION

The Groen Estuary is a unique system nationally. It is a hypersaline in the lower reaches with a salinity gradient in the middle-upper reaches. This part of the estuary maintains a functional role that persists for longer during the dry phase relative to the expansive lagoonal part because of freshwater seepage from the spring at the head. Although open water surface area fluctuates it remains a perennial water body on an arid coast where the next estuary is the Orange, 267 km north.

The Groen Estuary is one of the most variable estuaries in South Africa in terms of its physico-chemical attributes. Consequently, a once-off field survey would only reflect prevailing conditions and would not capture seasonal or longer term shifts (between years) along a physico-chemical continuum. Extreme states are represented by an open mouth following a flood (low salinity) and extreme hypersaline conditions following a long period (years) of mouth closure. Field surveys in February 2015 were undertaken at the end of summer when extreme hypersaline conditions prevailed in the lower reaches.

The conservation value of the salt marsh vegetation at the Groen Estuary lies in the fact that halophytes are the only plants adapted to grow in these harsh environments and the loss of this vegetation would lead to the formation of bare, dry salt pans that are more easily eroded by wind and water. Conservation of the Groen Estuary is essential to maintain connectivity for water birds and other coastal biota. It is recommended that SANParks develop an estuary management plan for the Groen Estuary. This is a requirement of the Integrated Coastal Management Act (Act 24 of 2008). Monitoring of the estuary should be initiated as soon as possible. The management plan should also incorporate ways of enhancing spring water supply should this supply be reducing because of direct anthropogenic activities.

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9 APPENDICES

Table 5 Plant species recorded at the Groen Estuary in 2015.

Species name	Family	Red List Status	Intertidal	Supratidal	Terrestrial fringe
Aloe arenicola Reynolds	Asphodelaceae	NT			
Amphibolia laevis (Aiton) H.E.K.Hartmann	Mesembryanthemaceae				
Asparagus lignosus Burm.f.	Asparagaceae				
Asparagus rubicundus P.J.Bergius	Asparagaceae				
Ballota africana (L.) Benth.	Lamiaceae				
Calobota spinescens (Harv.) Boatwr. & B.-E.van Wyk	Fabaceae				
Chrysanthemoides incana (Burm.f.) Norl.	Asteraceae				
Cotyledon orbiculata L. var. *orbiculata*	Crassulaceae				
Drosanthemum salicola L.Bolus	Mesembryanthemaceae				
Jordaaniella cuprea (L.Bolus) H.E.K.Hartmann	Mesembryanthemaceae				
Lampranthus stipulaceus (L.) N.E.Br.	Mesembryanthemaceae				
Lycium strandveldense A.M.Venter	Solanaceae				
Mesembryanthemum guerichianum Pax	Mesembryanthemaceae				
Othonna cylindrica (Lam.) DC.	Asteraceae				
Salicornia meyeriana Moss	Chenopodiaceae				
Salvia africana-lutea L.	Lamiaceae				
Sarcocornia natalensis (Bunge ex Ung.-Sternb.) A.J.Scott var. *affinis* (Moss) O'Callaghan	Chenopodiaceae				
Sarcocornia pillansii (Moss) A.J.Scott var. pillansii	Chenopodiaceae				
Sporobolus virginicus (L.) Kunth	Poaceae				
Stipagrostis ciliata (Desf.) De Winter var. *capensis* (Trin. & Rupr.) De Winter	Poaceae				
Tapinanthus oleifolius (J.C.Wendl.) Danser	Loranthaceae				

Table 6 **Plant species previously recorded by Bickerton (1981) and Helme *et al.* (2014) at the Groen Estuary.**

Species	ECRU studies (Bickerton, 1981)	Helme *et al.* (2014) coastal fringe species
Arcotheca populifolia		
Amphibolia laevis		
Arctotis decurrens		
Aspragus capensis		
Aridaria noctiflora		
Atriplex bolusii		
Babiana hirsuta		
Berkheya fruticosa		
Carpobrotus edulis		
Cephalophyllum sp.		
Cephalophyllum spongiosum		
Cladoraphis cyperoides		
Chrysanthemoides monilifera		
Conicosis sp. (*pugioniformis)*		
Cotula sp.		
Crassula muscosa		
Crassula nudicaulis		
Dicrocaulon sp.		
Didelta carnosa		
Drosanthemum salicola		
Eragrostic sabulosa		
Eragrostis cyperoides		
Euclea sp.		
Euphorbia brachiata		
Frankenia pulverulenta		
Galenia fruticosa		
Grielum grandiflorum		
Hebenstreitia cordata		
Helichrysum sp.		
Helichrysum dunense		
Helichrysum tricostatum		
Hypertelis angrae pequenae		
Isolepsis sp.		
Jacobsenia sp.		
Jordaaniella cuprea		
Jordaaniella spongiosa		
Juncus acutus		
Lampranthus sp. (*stipulaceus)*		
Lebeckia cinera		
Lycium sp. (*strandveldense)*		
Manochlamys albicans		
Mesembryanthemum crystallinum		
Oncosiphon schlechteri		
Oncosiphon suffruticosus		
Osteospermum incanum		
Osteospermum oppositifolium		
Othonna sp. (*cylindrical)*		
Othonna floribunda		
Pelargonium fulgidum		
Pernia		
Pharnaceum microphyllum		
Psilocaulon sp.		
Pteronia spp. (*onobromoides)*		
Rhynchopsidium pumilum		
Ruschia spp.		
Ruschia verdifolia		
Salvia sp.		
Sarcocornia natalensis		
Sarcocornia pillansii		
Senecio bulbinifolia		
Senecio sarcoides		
Sporobolus virginicus		
Stipagrostis ciliata		
Tetragonia decumbens		
Thamnochortus bachmanii		
Thesium strictum		
Tripteris sp.		
Trachyandra divaricata		
Vanzijlia sp.		
Zygophyllum cordifolium		
Zygophyllum cuneifolium		
Zygophyllum divaricatum		
Zygophyllum morgsana		
Zygophyllum spinosa		

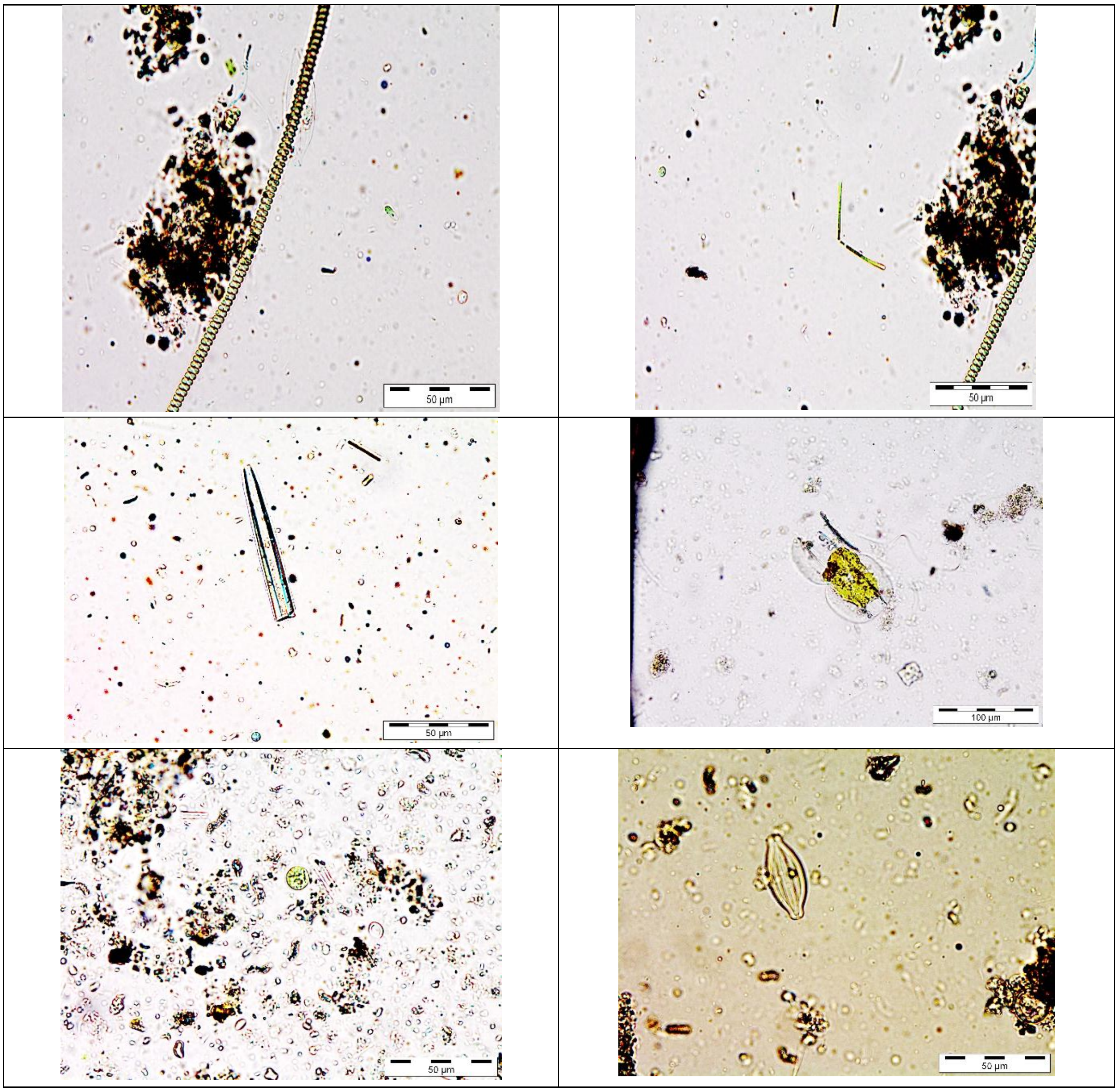

Figure 13 **Microalgae and diatoms from water samples taken at Sites 1-3 of the Groen Estuary.**

Table 7 **Questionnaire posed to farmers in the area regarding the dynamics of the Groen Estuary. Responses are listed from 1 to 8 following each question.**

Sinmaak en verstaan van die Groen riviermond dinamika	
Die Groen riviermond is 'n seewatermonding geleë langs die koel, matige en droë weskus van Suid-Afrika, fig. 1. (30 ° 50'48 "S; 17 ° 34'35 " E) (Whitfield & Baliwe , 2013). Die monding vloei selde aktief en is meestal permanent gesluit. Boere in die 1980's het berig dat vloei slegs tydens swaar oorstromings plaasvind; ongeveer elke 5 jaar. Die teenwoordigheig van standhoudende water maak egter die monding 'n belangrike habitat langs die droë Namakwaland kuslyn. As gevolg van sy klein grootte en afgeleë ligging is die Groen monding redelik onbekend. Ten einde die voorgestelde mynbedrywighede (Zirco projek) naby die Groenrivier monding se potensiële impakte beter te verstaan, word 'n evaluering van geselekteerde organismes (veral ongewerweldes en plante) en geohidrologie (die verhouding tussen grondwater en die fisiese omgewing) beoog. Die inligting verkry vanaf hierdie vraelyste sal dus in samewerking met wetenskaplike data gebruik word om die interaksies van die Groen monding en omliggende gebiede beter te verstaan. Die inligting verkry uit hierdie studie sal nie gebruik word vir enige advertensie doeleindes nie. Geen van die vrae is verpligtend nie.	
Kontak besonderhede	
Naam:	
Kontak nommer:	
Adress:	
Hoe lank bly u al in die area?	
Vrae met betrekking tot die Groen monding en die omliggende gebiede	
Beskryf asb. die reënval patrone van die area? Byvoorbeeld, in watter seisoen het die hoogste reënval plaas gevind?	
1. Dit vissel van jaar tot jaar seisoen in die winter maande	5. Winter reenval
2. Die winterreenval streek	6. Winter reenval
3.	7. Winter reenval
4. Winter	8. Winter
Kommentaar vanaf die 1980's, van boere in die Groen riviermond area, dui daarop dat die rivier selde vloei. Is die mond self (dit wil sê, waar die rivier die see ontmoet), gewoonlik droog of gevul met staande, sout water?	
1. Van 1971 of weet ek van 10 jaar wat die rivier nie gevloei het nie.	5. Ja is gevoel met water.
2. Daar is so hier en daar sout(lieule) wat hul jaar bly.	6. Rivier vloei selde. Kleinsee gevul met soutwater.
3. Staande sout water	7. Gewoonlike gevul met sout water
4. Gewoonlike droog of gevul met staande, sout water.	8. Ja tot n entjie van die hoogwatermerk. M.A.W water in die lagune.
Vloei die Groenrivier ooit tydens oorstromings en vloede uit na die see toe? Wanneer het u dit al gesien gebeur?	
1. Wanneer dit in die Kamiesberge baie gereenhet en die water in vloed van kgs afkom loop die water in die see in.	5. ja hy spoel daar, so 7 jaar gelede 6. Ja. 7. Hy spoel wel deur. Onseker van datum. 8. 1961, 1967, 1974, 1996, 1997, 2006, 2007.
2. Jas oms. Partykere raak die water te min en	

hou dit op voor dit see kry.	
3. Oorstromming en vloede is nie nodig om die see te haal nie, net volddende reen in die opvangs gedied.	
4. 1961, 1962, 1974, 7983, 1996, 1197, 2001, 2007.	
Het die staande water by die mond (na-aan die see) ‘n slegte of kenmerkende reuk? Groei daar normaalweg plantmateriaal in die water? Het dit ‘n vreemde/snaakse kleur of lywigheid?	
1. Ja die mond van die rivier reuk baie sleg wanner die water oudword en lank staan.	5. Ja hy stink as hy lank staan.
2. Dit stink as dit te lank laas gevloei het. Daar is algae in lagune.	6. Wster ruik nie lekker nie. Water het n donker kleur.
3.	7. Het slegte reuk en kry soms n rooi pienk kleur.
4. Slegte reuk, word soms groen en some lelik vaal.	8. ja n slegte kenmerkende reuk. Soms groei daar plantmateriaal in die water en ja daar is a vreemde kleur.
Is die sand banke by die mond al ooit meganies verwyder of geskuif om toe te laat dat die stagneerende, staande water dreineer?	
1. nee nie wat ek van weet nie.	5. Nooit meganies verwyder nie.
2. Nee	6. Nee
3. Nee	7. Nie meganies nie, net met die hand.
4. Nee	8. Nee
Watter omstandighede verander na 'n vloed gebeurtenis, byvoorbeeld, word sediment (sand) uit die rivier en riviermondkanaal gewas na 'n vloed?	
1.	5.
2.	6. Drade spoel. Sand work ook gespoel.
3.	7. plantegrooi verbeter langs rivier.
4.	8. By die monding word die sand in die see gespoel. Klippe op bedding is stigbaar sand later weer toe.
Word die Groen rivermond gebruik vir enige ontspanningsdoeleindes, bv. visvang, bootry, swem, ens…?	
1. Ja, visvang.	5. Swem.
2. Het baie mense gebruik, maar vandat Park oovergeneem het bly ons tuis.	6. Nee.
3. Huidelike nee. Vroeer jare is daar geswem en Harders gevang.	7. Geen sodert die park.
4. Ja.	8. Ja.
Hoe het die natuurlike omgewing verander in die tydperk wat u daar gewoon het, spesifiek met betrekking tot die rivier en die riviermond. Byvoorbeeld, was daar enige veranderinge in reënvalpatrone, staande water vlak in die monding (d.w.s. die einde van die rivier naby aan die see), of hoe dikwels die rivier en riviermond in vloed is?	
1.	5. As rivier lanklaas geloop het sak die staande watervlak.
2.	6. Staande watervlok in mond wissel van reenval en of die rivier loop tot by die see.
3. Watervlak in rivier is laer, miskien omdat rivier minder loop wat seker n oorsaak is van die keerwalle in die rivier. Wat die mond betref is die ‘dppie see’ nou verder van die see af as	7. Op kinder dae was rivier gevul met lewe en daar was kuile. Sodart rivier minder loop is daar geen lewe in die rivier en daar is geen of min kuile.

vroeer jare. Die algemene toestand van die rivier het in my leeftyd versleg. Waar ek bly ongevver 80 km vanaf die see was kuile water met vs en krappe. Dit her verdywn. Hier is nog kuile maar dit is pekelsout. Baie bome het ook verdywn. Nadat die rivier geloop het, kom baie bome op, maar min raak groot.	
4. Volgens oorlewing was die Groenrivier tot by Kliphoek standhouderd. Die rivier het baie meer in die see geloop met standhoudended kuiles warm water. Na 1900 gebuer dit sleg elke 10 to 20 jaar.	8. Reenval patrone 100-150 mm per jaar gemiddeld. Hoer as gemiddleld- rivier in die see: 1996- 185 mm, 1997- 191 mm, 2006- 131 mm, 2007- 217 mm. Monding is baie toegewaai en vol sand see spoel seld oor die sandbank na die lagune rivier vloei sledded tot by die lagne laast jare tot by klipkraal.
Is daar plantegroei aan die oewer van die rivier of riviermond of is dit kaal grond? As daar wel plantegroei is, kan u enige van hulle beskryf of benoem? Wissel die spesie samestelling oor die gang van die verskillende seisoene?	
1. Ja daar is planted en bossies langs die rivier stroom.	5. Doringbome en Brak Ganna langs rivier.
2. Daar groei see-riet	6. In/langs die rivier is plante byvoorbeeld doringbome, riet maar by mond self nie veel.
3. In di rivier is daar doringbomes, brakbos en party plekke fluitjies riet en biessies.	7. Doringbome langs rivier en bosse. Langs mond self is net ganna bos en riet.
4. Riete en biessies	8. Tipiese vleiland plantegroei: riet, biessies, brakbosse. Tydens reentyd: blomme. Sandveldplantgroei.
Dankie vir u deelname in hierdie vraelys. U insette verskaf waardevolle inligting oor die bogenoemde studie area. Indien u enige navrae het, kontak gerus Meredith Cowie op meredith.cowie@nmmu.ac.za	

Table 8 Description of Present Ecological Status categories for estuaries

PES	GENERAL DESCRIPTION
A	Unmodified, or approximates natural condition; the natural abiotic template should not be modified. The characteristics of the resource should be determined by unmodifed natural disturbance regimes. There should be no human induced risks to the abiotic and biotic maintenance of the resource. The supply capacity of the resource will not be used
B	Largely natural with few modifications. A small change in natural habitats and biota may have taken place, but the ecosystem functions are essentially unchanged. Only a small risk of modifyng the natural abiotic template and exceeding the resource base should not be allowed. Although the risk to the well-being and survival of especially intolerant biota (depending on the nature of the disturbance) at a very limited number of localities may be slightly higher than expected under natural conditions, the resilience and adaptability of biota must not be compromised. The impact of acute disturbances must be totally mitigated by the presence of sufficient refuge areas.
C	Moderately modified. A loss and change of natural habitat and biota have occurred, but the basic ecosystem functions are still predominantly unchanged. A moderate risk of modifying the abiotic template and exceeding the resource base may be allowed. Risks to the wellbeing and survival of intolerant biota (depending on the nature of the disturbance) may generally be increased with some reduction of resilience and adaptability at a small number of localities. However, the impact of local and acute disturbances must at least partly be mitigated by the presence of sufficient refuge areas.
D	Largely modified. A large loss of natural habitat, biota and basic ecosystem functions has occurred. Large risk of modifying the abiotic template and exceeding the resource base may be allowed. Risk to the well-being and survival of intolerant biota depending on (the nature of the disturbance) may be allowed to generally increase substantially with resulting low abundances and frequency of occurrence, and a reduction of resilience and adaptability at a large number of localities. However, the associated increase in the abundance of tolerant species must not be allowed to assume pest proportions. The impact of local and acute disturbances must at least to some extent be mitigated by refuge areas.
E	Seriously modified. The loss of natural habitat, biota and basic ecosystem functions is extensive
F	Critically modified. Modifications have reached a critical level and the lotic system has been modified completely with an almost complete loss of natural habitat and biota. In the worst instances the basic ecosystem functions have been destroyed and the changes are irreversible

Table 9 Guidelines to assign Recommended Ecological Category based on protection status and importance, as well as Present Ecological Status of estuary (DWA, 2008)

PROTECTION STATUS AND IMPORTANCE	REC	POLICY BASIS
Protected area	A or BAS*	Protected and desired protected areas should be restored to and maintained in the best possible state of health
Desired Protected Area (based on complementarity)		
Highly important	PES + 1, min B	Highly important estuaries should be in an A or B category
Important	PES + 1, min C	Important estuaries should be in an A, B or C category
Of low to average importance	PES, min D	The remaining estuaries can be allowed to remain in a D category

* BAS = Best Attainable State