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Biotic responses to extreme hypersalinity in an arid zone estuary, South Africa

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ABSTRACT

The Groen Estuary does not function as a typical temporarily open/closed estuary for much of the time, due primarily to the high variability of its physico-chemical attributes. Extreme states are represented by an open mouth following a flood (low salinity) and extreme hypersaline conditions that develop after a prolonged period (years) of mouth closure and a high rate of evaporation from the water body. Available information suggests that biotic recruitment from the marine environment follows mouth breaching, but species disappear progressively as salinity increases and threshold salinity values are reached. A field survey in February 2015 indicated that at the time, salinity ranged from 223 in the lower reaches and <10 upstream over a distance of <1 km. The study provided new information on the estuary that includes the revised delineation of the lateral boundary. Habitat mapping from past aerial photographs showed that the open water surface area has decreased over time but the vegetated areas have remained stable. No benthic macroinvertebrates, mesozooplankton or fish were present. Together with low avian species counts and abundance it was concluded that the Groen Estuary represented a small, naturally 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).

1. Introduction

Estuaries that display hypersaline conditions (salinity of the estuary is greater than that of the adjacent ocean water) are widespread in hot arid climates. Hypersalinity develops in a number of regions in the world including central America (e.g. Winant and de Velasco, 2011), South America (e.g. Alexander and Dunton, 2002; Dussaillanta et al., 2009; Price et al., 2012), Australia (e.g. Nunes Vaz et al., 1990; Price et al., 2012; Kämpf and Ellis, 2015), Africa (e.g. Savenije and Pagès, 1992; Kantoussan et al., 2012), the Great Barrier Reef (e.g Andutta et al., 2011) and even temperate regions such as North America (e.g Largier, 2010; Schlenk and Lavado, 2011) and the Mediterranean (e.g. Largier et al., 1997). Common to many hypersaline estuaries is low freshwater supply that persists for varying lengths of time, a relatively long residence time of the water body, high evaporative loss from the estuary basin, a temporary loss of connectivity to the sea and often, a small river catchment area (Largier et al., 1997). Hypersaline estuaries are also referred to as negative, inverse or low flow estuaries as evaporation exceeds freshwater inflow. Negative estuaries experience higher salinity in the upper reaches compared to the lower reaches (Potter et al., 2010). Largier (2010) gives a comprehensive overview of the general dynamics that govern such low-inflow estuaries.

Many of the estuaries that experience hypersaline conditions close to the ocean during dry periods. During heavy riverine discharge these estuaries can progressively change from hypersaline conditions to fresh conditions and then natural seawater following breaching (Whitfield, 2005; Hoeksema et al., 2006; Chuwen et al., 2009; Potter et al., 2010). In most estuaries hypersalinity is a seasonal phenomenon occurring in the dry season; however in some systems such as the Baja California Estuary in Mexico hypersalinity persists throughout the year (Andutta et al., 2011). Cooper (2001) noted that some southern Africa estuaries become markedly hypersaline and may even dry out for periods of time thus becoming inhospitable to life forms.

The St Lucia system on the east coast is probably the best described example of a South African estuary experiencing hypersaline conditions (Day, 1981; Whitfield et al., 2006; Cyrus et al., 2011, among others). Other South African examples are also documented, including the Seekoei Estuary on the south coast (Whitfield and Bruton, 1989; James and Harrison, 2010) and Milnerton Lagoon on the west coast (Day, 1981). All three of these estuaries close off from the sea for varying lengths of time. In the Milnerton system, the development of hypersalinity is associated with hot dry summers, typical of Mediterranean climates in general (Largier et al., 1997).

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The Groen Estuary further north along the west coast also receives a winter rainfall, but this small estuary is located in one of the most arid regions in South Africa where rainfall in the catchment varies from 100 to 200 mm per annum. At the coast, rainfall is <100 mm per annum on average (Schumann et al., 1999). The river flows infrequently and remains closed for long periods, with reports from farmers in the 1980s indicating that surface flow only occurs during heavy flooding roughly every five years (Bickerton, 1981). 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. Stock-farming is practised in the catchment, and scattered boreholes provide water for animals, but the volume of water used is not known. The estuary is said to have a catchment area of 4500 km^2 (Heydorn and Tinley, 1980). 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). Springs at the head of the estuary maintain a salinity of <35, in the upper reaches, but salinity values in the lower reaches may exceed 100. Detailed spring and seep surveys by the CSIR (reported in Bickerton, 1981) and a survey undertaken by Schlumberger Water Services (unpublished hydrological and geochemical investigation on the interaction of the Kamiesberg project with the Groen Estuary, 2015 for Zirco Roode Heuwel (Pty) Ltd., Johannesburg) 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. Schlumberger Water Services (2015) recorded a downstream flow rate of ca 1 l/s in February 2015. Bickerton (1981) reported that surface water is probably always present in the estuary, maintained by the springs feeding into the upper estuary. This persistence of a permanent water body was also confirmed by the National Biodiversity Assessment 2011 (Van Niekerk and Turpie, 2012) which could find no satellite imagery showing evidence of drying out of the water body. Occasional freshwater inflow dilutes the highly saline surface water and transient tidal conditions may occur when the mouth opens.

This study investigated the present ecological state of the Groen Estuary, based on a once-off survey. Specific parameters addressed were the physico-chemical water column characteristics along the length of the estuary, the present vegetation cover and assessment of changes over time, the distribution of the plants along transects representing a specific elevation gradient, sediment and groundwater characteristics in the different vegetation zones, an analysis of the macrobenthic and mesoplanktonic invertebrates in the estuary and an estimate of the numbers of birds present on the estuary as well as the identification of different feeding guilds. Van Niekerk and Turpie (2012) indicated that the estuarine functional zone of the Groen Estuary was based on vegetation as no 5 m MSL contour existed for this system from the Survey General. The mapping under taken as part of this paper therefore represents a refinement of the boundaries informed by field observations.

2. Methods

2.1. 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 in February 2015 (Fig. 1). Sediment samples were taken at three reed sites in the upper reaches of the estuary to establish the salinity and depth to groundwater (Fig. 1). 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.

2.2. 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.

2.3. Distribution of vegetation along transects, groundwater and sediment analysis

Vegetation distribution was analysed along three transects, one in each zone of the estuary. Vegetation cover was measured as average percentage cover in duplicate quadrats (1 m^2) placed at intervals along each transect. Transect 1 (start at 30°50.564′ S; 17°34.705′ E) was 36 m long and vegetation cover was measured every m along the length of the transect. Transect 2 (start at 30°50.157′ S; 17°34.771′ E) was 130 m long and vegetation cover was measured every 5 m whereas for Transect 3 (start at 30 50.002′ S; 17 34.6′ E and 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 (2006), and Mucina and Rutherford (2006). Voucher specimens

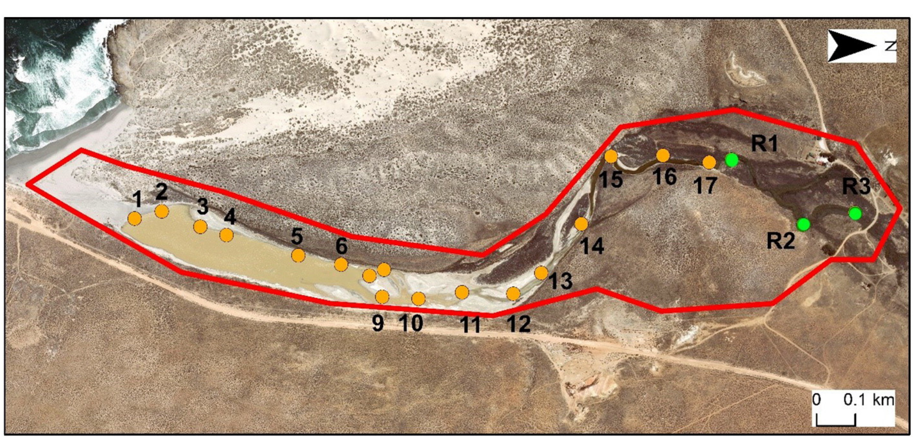

Fig. 1. Location of 17 sites where physico-chemical readings were taken along the length of the Groen Estuary as well as the location of the three reed sites (R1 – R3) investigated. Benthic and zooplankton samples were collected at seven and three of the sites respectively (see below). The red line indicates the estuarine functional zone or estuarine habitat area. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

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