Aquatic Botany 110 (2013) 1–5

Contents lists available at ScienceDirect

Aquatic Botany

journal homepage: www.elsevier.com/locate/aquabot

The phenology of *Ruppia cirrhosa* (Petagna) Grande and *Chara* sp. in a small temporarily open/closed estuary, South Africa☆

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ARTICLE INFO

Article history:
Received 16 March 2012
Received in revised form 7 January 2013
Accepted 8 January 2013
Available online 7 February 2013

Keywords:
Biomass
Chara
Estuary
Phenology
Flowers
Fruit
Ruppia
TOCE

ABSTRACT

The study investigated the phenology of *Ruppia cirrhosa* (Petagna) Grande and *Chara* sp. in the East Kleinemonde Estuary, a warm temperate temporarily open/closed estuary (TOCE) along the south-eastern coastline of South Africa. Monthly growth and sexual reproduction were monitored over a 17 month period, including environmental conditions. The estuary was closed to the sea for the duration of the study and inundation of the submerged habitat ranged from 6 to 86 cm. Both species began to germinate in Autumn 2009 (April and May) once the submerged habitat had been flooded for one month. *R. cirrhosa* began to produce viable seed after five months and production occurred over a four month Spring–Summer period. Maximum seed production occurred in late Spring (26,242 ± 3401 seeds m^{-2}). It took *C.* sp. three months to start producing viable oogonia with production taking place over seven months, from late winter late Summer with a maximum of 196,998 ± 48,004 oogonia m^{-2} produced. Peak biomass was attained during Spring to mid-Summer when *R. cirrhosa* reached 2248 ± 388 g DW m^{-2} and *C.* sp. 142 ± 34 g DW m^{-2}, eight and six months after germination, respectively. Multivariate analysis showed that both biomass and reproductive output increased as water level and pH did. In conclusion, the high biomass and reproductive output of both submerged species under continued water permanence maintains large seed banks for habitat persistence during open mouth states when submerged beds are lost through exposure. This is an important survival strategy in small estuaries where water level fluctuates in response to unpredictable mouth breaching and mouth closure events.

1. Introduction

Submerged macrophytes in temperate temporarily open/closed estuaries (TOCEs) are exposed to a wide range of environmental fluctuations due to the dynamic and often unpredictable connection with the sea (Whitfield et al., 2008). Physico-chemical conditions can range from marine during open mouth states, to either freshwater or hypersaline during closed states (Riddin and Adams, 2012). Submerged macrophytes are often exposed to salinity and water level extremes well above their tolerance range leading to their mass mortality along with their associated biota (Adams and Bate, 1994; Froneman and Henninger, 2009). Whereas mouth status is predictable in some estuaries where rainfall patterns are seasonal, in others, like the temperate East Kleinemonde Estuary, breaching frequency and duration is unpredictable (Whitfield et al., 2008). Submerged macrophytes therefore need to exhibit plasticity regarding length of their life cycle and reproductive output in order to ensure the persistence of submerged macrophyte communities (Brock and Casanova, 1991; Casanova, 1994; Santamaria et al., 1995; Murphy et al., 2003; Cho and Poirrier, 2005; Gesti et al., 2005; Shili et al., 2007; Obrador and Pretus, 2010). It is known that *Ruppia cirrhosa* (Petagna) Grande for example is highly plastic in its reproductive potential, from exhibiting a perennial nature in permanently flooded areas to an annual nature in temporarily flooded areas (Gesti et al., 2005). These changes are usually in response to water level, light and nutrients. However it is not known what the reproductive output of this species would be in an estuary such as the East Kleinemonde where the duration of water permanence is unpredictable. No phenological studies have been done on either *R. cirrhosa* or *Chara* sp. in South African estuaries. This information is crucial to understanding the dynamics of trophic structures of these small estuaries since many systems have had altered freshwater inflow due to anthropogenic influences such as dam construction. This has lead to altered mouth breaching frequency and duration periods. Some estuaries in South Africa do have mouth management policies, such as the Bot and Great Brak estuaries. In these estuaries, the mouths are artificially breached when a predetermined water level is reached. However if breaching events occur too often then submerged macrophytes could fail to germinate, flower and replenish sediment seed reserves. This would result in a complete habitat loss

☆ The final identification of the *Chara* sp. in this paper is still pending.

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http://dx.doi.org/10.1016/j.aquabot.2013.01.008

over time resulting in ecological degradation of the estuary. The aim of this study was therefore to monitor the growth and reproductive potential of these two species over time and determine if and when there were peak phenological periods. It was also the aim to determine which environmental conditions influenced germination, growth, biomass and reproductive output under these conditions. The hypothesis was that germination, growth, biomass and propagule output would be high and continue for as long as habitat was available, *i.e.* permanently inundated and high water level.

2. Materials and methods

2.1. Site description

The East Kleinemonde (33°32′S, 27°03′E) is a temporarily open/closed estuary situated along the south-eastern Cape coastline of South Africa. It is classified as a warm-temperate system (Whitfield, 2000). Rainfall is approximately 500 mm per year with a slight bimodal rainfall pattern occurring in autumn and spring (Heydorn and Tinley, 1980). The area is known to experience cyclical 1:30 year floods (Whitfield and Bate, 2007). During the 17 month sampling period (February 2009–June 2010) the mouth remained closed due to drought conditions. The maximum mean daily summer temperature is 22 °C and the minimum mean daily winter temperature is 14 °C.

The estuary is navigable for 3 km and has an area of 35.7 ha with a catchment area of approximately 43.5 km^2 (Badenhorst, 1988). The mouth usually breaches subsequent to high river inflow or high water levels (>2 m above mean sea level) caused by overwash or high rainfall events (>100 mm) (Cowley and Whitfield, 2001; van Niekerk et al., 2008). The mouth usually stays open only for a few days before closing again. The estuary is predominantly closed and on average opens 2.6 times per year (van Niekerk et al., 2008). Overwash events occur on average 16.4% of a year (Cowley, 1998).

Vegetation of the East Kleinemonde Estuary is represented by supratidal and intertidal salt marsh which grows along the west and east bank in the middle to upper reaches of the estuary (Fig. 1). Stands of reeds and sedges grow intermittently along the banks in the lower and middle reaches of the estuary. Submerged macrophytes grow in a continuous band along both banks above the road bridge. The dominant submerged macrophyte under closed mouth conditions is *R. cirrhosa* while *C.* sp. has a fragmented and scattered distribution. The submerged macrophytes *Halophila ovalis*, *Potamogeton pectinatus* and *Lamprothamnium papulosum* can also known to occur in the estuary (Riddin and Adams, 2008). During the open mouth phase, submerged macrophytes are not present due to substrate instability, high water velocity and high turbidity.

2.2. Abiotic conditions

Daily air temperature data were obtained from the South African Weather Bureau from the closest town Port Alfred, 15 km south of the study site. Water and sediment physico-chemical data were collected from within the submerged macrophyte habitats on a monthly basis ($n = 10$). For the water column, electrical conductivity (mS cm^{-1}), pH and redox potential (mV) were measured using a YSI 650 MDS Multiprobe. Water level within each sampling site was measured using a calibrated pole (cm). A Secchi disc (m) was used to measure the water turbidity. For the sediment sample three replicate samples were collected for the measurement of sediment organic matter content (5 g) and sediment moisture content (5 g). The methodology used was that of Black (1965) and Briggs (1977).

2.3. Macrophyte growth and reproduction

Measurements were taken at monthly intervals near three permanent transects (Fig. 1) located within the lower to middle reaches of the estuary. Samples of *R. cirrhosa* were randomly collected at the start of Transects 1 and 3 and *C.* sp. was randomly collected at the start of Transect 1. Transects 1 and 3 were *circa* 1 km apart. A corer with a 10.5 cm diameter was used to collect plant biomass and a total of 10 samples per species were collected every month. Samples were collected approximately 5 m apart at each site. The plant material was transferred to a re-sealable bag and transported to the laboratory in a cooler box. The plants were cleaned of debris and sediment using a 1 mm (*R. cirrhosa*) and 250 μm (*C.* sp.) mesh filter and allowed to air dry. They were then oven dried for two days at 60 °C and weighed to calculate biomass (g DW m^{-2}). Plant length was determined by measuring 20 individual plant stems and leaves per sample of biomass collected. Any flowers and fruit/seeds present, including flowering and fruiting inflorescences, were counted to determine the average number of flowers, inflorescences, seeds or oogonia and antheridia per m^{-2}. Due to the massive number of sexual organs produced by *C.* sp., three replicate sub-samples were analyzed per each core taken and extrapolated to m^{-2}.

2.4. Data analysis

In order to determine if there were any periods of peak biomass and reproductive output, data were first tested for normality following which the nonparametric Friedman's repeated measures test on multiple dependant groups was applied. Analyses were done using Statistica Version 7 (StatSoft, 2004). Principal Components Analysis (PCA) was then used to obtain a linear ordination of the macrophyte data constrained by environmental variables ($\alpha = 0.05$). This was done to explore any possible interactions between the measured physico-chemical and species parameters (biomass, height, flowering and fruiting outputs). PCA was used since there were too many environmental variables which would make multiple regression analysis modeling too complicated. Multivariate analysis was done using CANOCO for Windows (Version 4.5) (Ter Braak and Šmilauer, 2002).

3. Results

3.1. Abiotic conditions

The mouth of the estuary was closed for the entire sampling period. Water level in the submerged habitat ranged from 1.3 to 85.7 cm (Table 1). Water column electrical conductivity ranged from 37.6 to 63.3 mS cm^{-1}. Redox potential ranged from −295.5 to +246.9 mV but was mostly positive throughout the study period and pH ranged from 7.2 to 8.5. Secchi depth ranged from 0.8 to 1.7 m while the water temperature was between 14.6 and 28.7 °C. For the sediment analysis moisture content and organic matter content ranged from 8.1 to 22.5% and 1.1 to 3.8% respectively (Table 1).

3.2. Macrophyte growth and reproductive output

R. cirrhosa first began to germinate in April 2009 after the habitat had been flooded for one month. Biomass ranged from 2 ± 0 to 2248 ± 388 g DW m^{-2} with significant increases occurring from September 2009 to March 2010 at which time complete die back occurred ($X^2 = 155$, $p < 0.05$) (Table 2). Similarly *C.* sp. reached peak biomass between August 2009 and February 2010, peaking in November 2009 (142 ± 34 g DW m^{-2}; $X^2 = 151$, $p < 0.05$). Biomass also decreased as water level dropped (Tables 2 and 3). Germination began in May 2009 when water level was 1 cm deep