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Seasonal variation in pans in relation to limno-chemistry, size, hydroperiod, and river connectivity in a semi-arid subtropical region

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Seasonal pans are hydrologically dynamic, with significant changes in water volume and depth in response to high evaporation, infiltration rates and inundation events. Intra-seasonal and inter-seasonal changes in endorheic and floodplain pans in relation to limnology, size, hydroperiod, and river connectivity were studied over two rainfall seasons across 36 pans at the Save Valley Conservancy. In the study region, floodplain pans were identified as pans that had connectivity with the Save River, while the endorheic pans (large and small) were hydrologically isolated basins. Seasonal trends for physico-chemical variables were initial low and gradual increased for both rainfall seasons. Significant inter-seasonal differences for several physico-chemical variables were observed. No significant differences in physico-chemical variables were observed between large and small endorheic pans, with the except for vegetation cover, which was higher in large pans. Floodplain pans differed from the endorheic systems in pH, conductivity, nutrients and suspended solids. Connectivity was found to be insignificant, as connections between these systems were probably too infrequent. Seasonal pans were uniquely distinguished by their morphometric, physico-chemical and hydrological characteristics. Inevitably, they are vulnerable to climate change with the extent of their resilience currently unknown.

1. Introduction

Temporary pools also known as ephemeral pools, are vulnerable aquatic habitats which are difficult to protect due to their dynamic nature and sensitivity to degradation (Blaustein and Schwartz, 2001; Ferreira et al., 2012; Polačik et al., 2014; Dalu et al., 2016a,b). They are the dominant aquatic habitats in semi-arid and arid areas and are therefore an important category of wetland type (Jones and Day, 2003; De Meester et al., 2005; Wasserman et al., 2016a,b). Because of the paucity of permanent systems in arid regions, the ecological significance and service function of temporary aquatic systems is much larger than was previously realized, resulting in greater need to understand them better (Williams, 2006; Dalu et al., 2016b). These temporal pools are an essential habitat for a variety of amphibians, invertebrates, fish and birds, hence are of scientific and conservation value because they house a variety of species with often different life strategies (Brendonck and Williams, 2000; Blaustein and Schwartz, 2001; Dalu et al., 2016a; Reynolds and Cumming, 2016).

On average, temporary pools are small and this makes them highly susceptible to climate change (Olmo et al., 2016). Several studies report on the wide fluctuations in limnological conditions in these systems ranging from diurnal to inter-seasonal time scales (e.g. Arle, 2002; Angélibert et al., 2004; Batzer et al., 2004; Olmo et al., 2016). Depending on the type of pool, nature of its substrate and nutrient loading, the trophic state can potentially vary from oligotrophic to hypertrophic over time. Evidence of this has been highlighted, where seasonal succession of phytoplankton was closely linked to the gradual change from mesotrophic to hypertrophic conditions in rain-fed pools (Al-Homaidan and Arif, 1998). Although nutrients and other abiotic factors vary over time, not many studies have determined whether these changes also affect the overall trophic status of temporary pools.

Physico-chemical properties play a central role in shaping temporary habitats and their communities (e.g. Wellborn et al.,

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1996; Angélibert et al., 2004; Olmo et al., 2016), and it is important to understand factors that influence their temporal and spatial development.

Studies highlight that community-regulating mechanisms also change along gradients of habitat duration. In these ephemeral habitats, physico-chemical properties tend to be more important while in more permanent systems, biotic interactions have a stronger regulatory effect (Wellborn et al., 1996). Factors that determine the physico-chemical environment in temporary pools include pool structural characteristics (e.g. morphometry, substrate nature), biotic factors (vegetation cover, species interaction), hydroperiod and temporal variability (seasonal or inter-seasonal; Williams, 2006; Wasserman et al., 2016a,b). The stochastic variability in the input of external materials from surface runoff and sediment-bound organic matter also affects nutrient cycling dynamics.

In southern Africa semi-arid and arid areas, flat and sediment-filled depressions that hold water periodically are locally known as 'pans' (Vanschoenwinkel et al., 2011). Two broad categories of pans can be classified. Endorheic pans have an autonomous hydrology consisting of an inward drainage system largely dependent on local precipitation and run-off, while floodplain pans are depressions along riverbanks inundated when the river is in flood, often on a seasonal basis (Davies and Day, 1998). Hydrological connectivity of the river and floodplain pools consists of several stages of variable duration, which include filling, connection, isolation and finally, desiccation (Lampert and Sommer, 2007; Larned et al., 2010; Olmo et al., 2016). The interaction between rivers and floodplains is essential for maintaining various biological processes within these systems as contained in the flood pulse concept (Tockner et al., 2000; Amoros and Bornette, 2002; Thorp and Delong, 2002; Lampert and Sommer, 2007; Larned et al., 2010; Olmo et al., 2016).

Research carried out on temporary pans in Zimbabwe has largely been exploratory and a few studies have dealt with ecological processes (Weir, 1968, 1969; Nhiwatiwa et al., 2009, 2011; Vanschoenwinkel et al., 2011). Other limnological studies in the southern Africa region on freshwater and salt pans have been more detailed focusing on the internal dynamics (e.g. Hamer and Appleton, 1991a,b; Meintjes et al., 1994; Meintjes, 1996; De Klerk and Wepener, 2011; Riato et al., 2014). There is limited knowledge on the variability of pans especially in periods of climatic extremes. Therefore, the limnological (abiotic and biotic) characteristics of temporary pans with variable size and different levels of connectivity with the main river were studied in the Save River floodplain system with the primary aim to determine: (1) are there significant limnological differences between different types of pans with hydroperiod, size and different water sources; and (2) are there seasonal differences in the limnological characteristics of the pans between a drought and normal rainfall season. The study was carried out over two subsequent years, i.e. drought (below average rainfall) and normal rainfall season. This presented us with a unique opportunity to investigate the effects of extreme climatic variation and inter-seasonal variability, where there is a gap in knowledge.

2. Material and methods

2.1. Study area

Thirty-six study pans are located within the Save Valley Conservancy area in the southeast lowveld of Zimbabwe (20°08′22.94″S, 32°05′21.03″E), with the Save River forming the eastern boundary of the conservancy (Fig. 1). The Save River flows in a south eastern direction towards the Indian Ocean, with a total catchment area of 48925 km^2. The river has a total mean annual run-off volume of 20.3 × 10^9 m^3 (mean annual runoff (MAR) – 109 mm; Carmo Vaz, 1999). The climate of the region is characterised by a hot-wet season from December to April, followed by a cool-dry season (May to August) and lastly hot-dry period (September to November). The mean regional rainfall is 582 mm, with the total rainfall for the drought season being 285 mm and the normal season (590 mm; see Fig. 2a).

Connectivity with the main river led to the clear distinction between floodplain and endorheic pans. Due to accessibility problems during the flood season, we could not quantify pan-river exchanges accurately. By observing river peak flows and direct observations relating it to the presence of fish in the pans (*Oreochromis* spp. which are unique for permanent waters), connectivity was estimated, which lasted for less than two weeks and was limited to one main event each season (high rainfall or flood event). The specific hydroperiod (time that pan basin was inundated) of each pan was determined fortnightly.

2.2. Field sampling

Thirty-six pans were sampled in an unbalanced design (owing to the inaccessibility of some pans at particular moments): fifteen small endorheic pans (SP; surface area range 50–600 m^2; depth = 0.10–0.65 m), fifteen large endorheic pans (LP; surface area range 2000–4000 m^2; depth = 0.50–2.0 m) and six floodplain pans (FP; surface area range 2000–10,000 m^2; depth = 1.35–4.0 m). Sampling for all the pans was done bi-weekly between December and June for the two consecutive seasons. Three sites on the Save River were sampled once every month for the same period as the pans. Sampling was carried out before midday to minimise diurnal variability. The maximum length and width of each pan was measured using a tape measure. Average depth was measured along the longest axis, at 1 m intervals for small pans and 2 m intervals for large pans with a graduated stick. Similar measurements were done on the orthogonal axis. Surface area was estimated as the surface area of an ellipse and multiple ellipses were used for more complex pools. An assessment of total macrophyte vegetation cover was visually done and scored using an arbitrary scale where: 0 (absent), 1 (<25%), 2 (26–50%), 3 (51–75%), and 4 (76–100%) based on Killick (1978), with the dominant macrophyte taxa being recorded.

Temperature, dissolved oxygen (DO) and pH were measured *in situ* at the middle of the pan using a multi-parameter meter (Model HQ 20, HACH LDO, Germany). Conductivity was measured with a conductivity meter (WTW LF330, Sigma Aldrich). Water quality samples for laboratory analysis were collected using a 10-L Ruttner water sampler (KC Denmark) at each of the eight sampling points (i.e. 4 shallow and 4 deep areas) in each pan to form an integrated sample. The chlorophyll-*a* concentration was determined using the ethanol extraction method (Brönmark and Hansson, 2005), whereas, total suspended solids were measured according to Gibbs (1967). Turbidity was measured using a spectrophotometer (HACH DR/2010, Colorado). Analysis of nutrients (i.e. ammonia, total nitrogen, total phosphorus, nitrates, and reactive phosphate) was done using a spectrophotometer (HACH DR/2010, Colorado) following standards methods (HACH, 2007).

2.3. Data analysis

Limnological differences between pan categories (i.e. floodplain, large and small endorheic pans) were tested using a redundancy analysis (RDA) (Monte Carlo permutations (9999)). The pan categories were the explanatory variables while surface area, depth and hydroperiod were incorporated as covariables. The statistical