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Resilience and resistance of zooplankton communities to drought-induced salinity in freshwater and saline lakes of Central Asia

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ABSTRACT

Effects of drought-induced salinity changes on aquatic communities are less studied in lentic than in lotic systems. We present changes in zooplankton assemblages from five arid lakes before, during, and after a supra-seasonal drying event in which lake inflow ceased in 2001. We catalogued zooplankton communities in fresh and saline lakes of the Sudochye wetland in Central Asia. During this record low flow period, salinity increased in the lakes. Zooplankton species richness was inversely correlated with salinity. Linear regression using species richness indicated that zooplankton communities in the two least saline lakes were strongly correlated with changes in salinity. Post-drought recovery of species richness suggested resilience to this perturbation. Both saline lakes' zooplankton communities had low correlation with changes in salinity, suggesting greater resistance than the freshwater communities. The fifth lake showed a hybrid response, beginning in the fresh range, but experiencing higher salinities than the other fresh lakes. In the fifth lake species-richness was similarly correlated to changes in salinity as compared to the saline lakes, correlation of % halotolerant species was intermediate between saline and fresh communities, and post-drought species richness was similar to the fresh lakes, which could indicate a "resilient" recovery of species richness.

1. Introduction

The ecological terms 'resilience' and 'resistance' were initially outlined by Harrison (1979), although Westman (1978) defined similar concepts using the terms 'resilience' and 'inertia.' In essence, resistance is the ability of an ecosystem to weather disturbance without loss, whereas resilience is the capacity to recover from losses following the cessation of a disturbance (Lake, 2013). In comparison to studies of lotic freshwater environments, less information exists on the resilience or resistance of lentic invertebrates to drought-induced salinity (Bond et al., 2008), especially in arid environments. Observations of lotic invertebrates in freshwater environments indicate that resilience is more important than resistance (Fritz and Dodds, 2004; Lake, 2003) because these communities often experience predictable seasonal drying. However, aquatic communities show more variable resistance and resilience to unpredictable supra-seasonal drought than to predictable seasonal drought (Fritz and Dodds, 2004; Lake, 2003), although Niemi et al. (1990) found that most aquatic systems are ultimately resilient to temporary disturbances such as drought, returning to pre-disturbance states in under 3 years. Observations from zooplankton communities in lakes recovering from physical or abiotic perturbations such as acidification or metal or chemical contamination suggest a) zooplankton communities are generally resilient and recover to similar species richness and composition as control lakes or pre-disturbance conditions (Angeler and Moreno, 2007; Arnott et al., 2001; Frost et al., 2006; Khan et al., 2012; Yan et al., 1996); b) recovery can take many years following removal or cessation of the stressor (Frost et al., 2006; Knapp et al., 2001); and c) length of recovery can be positively related to length and/or intensity of disturbance (Angeler and Moreno, 2007; Frost et al., 2006; Kozlowsky-Suzuki and Bozelli, 2004; Yan et al., 1996).

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Biomass has been shown to correlate poorly with changes to the abiotic environment, since tolerant species can increase in abundance when more sensitive species disappear from the community (Angeler and Moreno, 2007; Yan et al., 1996). Species richness, however, has consistently been a good indicator of resilience of communities to perturbation (Downing and Leibold, 2010; Khan et al., 2012). Yan et al. (1996) found that richness and diversity were each strong univariate predictors of damage and recovery by acid and metal contamination in lakes, while abundance was the poorest predictor.

Central Asia is located in the zone of prevailing westerlies, but it is far from the ocean, and the Himalaya and Pamir mountain ranges hinder the monsoon from entering the subcontinent (Glantz, 2005). As a consequence, an extreme continental climate with very cold winters influenced by the Siberian High prevails in the inner Aral Sea basin (Khamzina et al., 2008). In this arid region, global warming has caused an increase of air temperature of about 2 °C in the past 40 years (Conrad et al., 2012; Groll et al., 2015), which could influence the incidences of drought and future fluctuation in lake water levels and salinities. Groll et al. (2015) note that glacial retreat due to global warming could reduce discharge of Central Asian rivers by as much as 50% by 2050.

To understand effects of drought-induced salinity on arid-region lake zooplankton communities of the Amu Darya lower reaches in Central Asia, we studied zooplankton composition of the Sudochye wetland in northwest Uzbekistan. The Sudochye wetland is located in the inner Aral Sea basin in the northwest part of the Amu Darya floodplain (Fig. 1). The regional climate is characterized by large annual temperature amplitudes (greater than 40 °C in summer and less than −10 °C in winter; FAO, 2015) and very sparse precipitation (~100 mm annually; FAO, 2015) that mainly occurs as snow between November and March (Conrad et al., 2012).

Zooplankton, especially large cladocerans and copepods, play a key role in freshwater food chains by transferring energy from primary productivity to higher trophic levels (Lampert and Sommer, 1997). Because of their relatively short generation time and body size, zooplankton respond rapidly to changes in water quality. Our initial study objective was to describe zooplankton communities of five lakes of the Sudochye wetland that varied in salinity at the start of the study in 1999 between 2.6 and 21.7 g/L. However, in the second year of our study, water inflow dropped dramatically and then ceased before resuming again in the third and final year of the study. This allowed us to document responses of zooplankton communities from both freshwater and saline lakes to the same severe drought-induced increases in salinity, as well as their resilience when post-perturbation fresh water conditions returned. We examined three groups of zooplankton (rotifer, cladocera and copepod) and traced seasonal composition and abundance changes in these groups with fluctuations of water salinity over 3 years. We hypothesized that halotolerant communities in the more saline lakes would be resistant to the increase in drought-induced salinity, whereas communities adapted to freshwater conditions prior to the drought would be sensitive to a similar degree of salinity increase and experience declines in species richness.

2. Materials and methods

2.1. Study site

Before the 1960s, Bolshoe Sudochye Lake was the largest delta lake of the Amu Darya. However, since that time, the lake has received almost no water from the Amu Darya, and water levels in the lake have decreased greatly, leading to fragmentation of the lake into several smaller, shallow water bodies that we refer to here as Sudochye wetland. Since 1984, two collectors, Kungrad (delivering 75–80% of Sudochye wetland's inflowing water), and Ustyurt (delivering 10–15% of inflow), have been built to feed these lakes with irrigation drainage water (Fig. 1). Additionally, Sudochye canal brings 5–10% of the wetland's inflow as freshwater from the Amu Darya. Annual inflow to these lakes is approximately 660×10^6 km^3 with mean salinity of 3–4 g/L. Typically, water levels rise in the lakes two times per year: during discharge of leach water in April–May, and during discharge of irrigated water from rice fields in August–September (unpublished data from International Fund for Saving the Aral Sea).

We studied zooplankton from five shallow (≤2 m) lakes of the Sudochye wetland from fall 1999 to fall 2002 (Table 1; Fig. 1): Bolshoe Sudochye (hereafter referred to as B. Sudochye), Begdulla-Aydin (B. Aydin), Karateren, Akushpa and Tayli. Although Akushpa and Tayli are hydrologically connected, their water chemistry and zooplankton communities are distinct and we considered these lakes as two separate systems. Dissolved oxygen concentration in the pelagic zones during the study was ≥7 mg/L in Akushpa, ≥8 mg/L in the other 4 lakes, and 2–4 mg/L in all littoral zones due to macrophyte decomposition. Water temperatures ranged from 15.9 to 20.1 °C in the spring, from 24 to 28.2 °C in the summer, and from 8.7 to 17.9 °C in the autumn during the study (Aparin, 2003). During the study period, pH ranged from 7.3 to 8.7, with higher values observed at higher salinity (Aparin, 2003). In winter, the studied lakes were covered by ice from approximately December to March. From January 2001 until May 2002, the Kungrad and Ustyurt collectors received no water input from irrigated land and water inflow to the lakes ceased. Inflow returned to the lakes in June 2002 (Aparin, 2003).

Fall 2000 to summer 2002 was characterized as an extreme low-flow period for the Amu Darya (Fig. 2; Uzhydromet unpublished data), the lowest in recorded history. Mean annual discharge recorded at the regional Samanbai monitoring station was 153.4×10^6 m^3 between 1981 and 1999, compared with 26.4×10^6 m^3 in the 2000–2002 low flow period and 100.3×10^6 m^3 in the 2003–2012 post low-flow period. During the low flow period, water levels declined to a low in 2001, then leveled off or increased for the last three sampling events in 2002 (Fig. 3); the lakes' total surface areas decreased by about one-fourth during this time. Water levels did not recover to original levels in the final year of the study. All lakes were ~1–1.5 m lower at the end of the study compared to the beginning (Fig. 3).

2.2. Sampling methods

Salinity in the lakes, collectors and canal was measured *in situ* using a Horiba U-10 field probe and was calculated as the mean of one measurement taken at the surface and one at a depth of 1 m. The Horiba U-10 uses an alternating 4-electrode, direct-immersion, multi-parameter sensor to calculate salinity from specific conductivity (μS/cm). Simultaneous measurements of pH, specific conductivity, temperature, dissolved oxygen and salinity were typically taken in the afternoon hours. Lake water levels were measured monthly by observing water stage on a ruled pole placed in each lake for the duration of the study.

Zooplankton were sampled three times per year (April, June, and October) from approximately the same points in each lake: for the pelagic zone, samples were taken at the surface 100 ± 25 m from shore and for the littoral zones, samples were taken from littoral macrophyte plants. 100 L of water from each zone was taken using a 10 L bucket at 3–5 points covering approximately 20–25 m^2 around the sampling zone. The 100 L of water were sieved through a small conical plankton net (diameter 18 cm, length 35 cm, mesh size 0.064 mm) and zooplankton were preserved in 4% formalin