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Desertification, salinization, and biotic homogenization in a dryland river ecosystem

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HIGHLIGHTS

• Hydrologic/biotic trends and their association were examined in a desert river.
• Decreased tributary flow led to decreased flow and increased salinity downstream.
• This spatially uneven hydrologic change caused region-wide habitat homogenization.
• Habitat homogenization led to biotic homogenization via changes in native fishes.
• Salinization as habitat driver of biotic homogenization is novel finding.

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ABSTRACT

This study determined long-term changes in fish assemblages, river discharge, salinity, and local precipitation, and examined hydrological drivers of biotic homogenization in a dryland river ecosystem, the Trans-Pecos region of the Rio Grande/Rio Bravo del Norte (USA/Mexico). Historical (1977–1989) and current (2010–2011) fish assemblages were analyzed by rarefaction analysis (species richness), nonmetric multidimensional scaling (composition/variability), multiresponse permutation procedures (composition), and paired *t*-test (variability). Trends in hydrological conditions (1970s–2010s) were examined by Kendall tau and quantile regression, and associations between streamflow and specific conductance (salinity) by generalized linear models. Since the 1970s, species richness and variability of fish assemblages decreased in the Rio Grande below the confluence with the Rio Conchos (Mexico), a major tributary, but not above it. There was increased representation of lower-flow/higher-salinity tolerant species, thus making fish communities below the confluence taxonomically and functionally more homogeneous to those above it. Unlike findings elsewhere, this biotic homogenization was due primarily to changes in the relative abundances of native species. While Rio Conchos discharge was > 2-fold higher than Rio Grande discharge above their confluence, Rio Conchos discharge decreased during the study period causing Rio Grande discharge below the confluence to also decrease. Rio Conchos salinity is lower than Rio Grande salinity above their confluence and, as Rio Conchos discharge decreased, it caused Rio Grande salinity below the confluence to increase (reduced dilution). Trends in discharge did not correspond to trends in precipitation except at extreme-high (90th quantile) levels. In conclusion, decreasing discharge from the Rio Conchos has led to decreasing flow and increasing salinity in the Rio Grande below the confluence. This spatially uneven desertification and salinization of the Rio Grande has in turn led to a region-wide homogenization of hydrological conditions and of taxonomic and functional attributes of fish assemblages.

1. Introduction

Changes in hydrological conditions and other habitat alterations caused by anthropogenic activities and the effects of these changes on native aquatic biotas are primary concerns in river ecosystems worldwide (Bailey et al., 2006; Kingsford et al., 2006; Pool and Olden, 2012). The effects could be direct, by impacting the ability of resident species to survive, migrate or reproduce in their native ranges (Kingsford et al., 2006; Cañedo-Argüelles et al., 2013) or indirect, by facilitating the establishment of non-native species (Kingsford et al., 2006; Olden, 2006; Lee et al., 2013) including harmful algae (Paerl and Paul, 2012; Patiño et al., 2014). Environmental drivers of biotic change (e.g., biotic homogenization), however, are not well understood

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(Olden, 2006; Pool and Olden, 2012). In particular, while secondary (anthropogenic) salinization is considered to be among the largest threats to river ecosystems worldwide, its impacts and management remain relatively understudied (Bailey et al., 2006).

Biotic homogenization is the process whereby the introduction of cosmopolitan (generalist) species coupled with extirpation of endemic species increases the genetic, taxonomic, or functional similarities of regional biotas (McKinney and Lockwood, 1999; Olden and Rooney, 2006; Rahel, 2010). Because individual species within a community typically vary in their tolerance limits to environmental variables (Linam and Kleinsasser, 1998), changes in hydrological conditions, such as flow and salinity, can directly affect change in fish assemblages. While flow (Rahel, 2010; Taylor, 2010) and broader watershed drivers of biotic change (Olden, 2006; Olden et al., 2008, 2010; Winter et al., 2008; Rahel, 2010) have been previously addressed, the influence of salinization has been largely – if not completely – ignored in studies of biotic homogenization.

The Trans-Pecos region of the Rio Grande/Rio Bravo del Norte (USA-Mexico international border) offers a unique opportunity to explore and improve our understanding of long-term changes and associations between hydrologic and biotic variables, especially in dryland river ecosystems. This region has historical information available for retrospective analyses of fish assemblages and of relevant hydrological variables such as water quality (salinity), river discharge, and precipitation. In addition, a comprehensive characterization of fish faunas of the region was conducted in the 1970s (Hubbs et al., 1977), which provides a valuable reference point for assessments of later biotic change caused by continuing anthropogenic pressures to the ecosystem. The study of fish faunas found that regional variation in salinity was a prominent factor associated with the distribution of fish assemblages. Namely, in the 1970s, fish assemblages were classified into three groups: a saline Rio Grande fauna above the confluence with the Rio Conchos (major tributary), a Rio Conchos–Rio Grande fauna below the confluence, and a tributary creek fauna, also downstream of the confluence (Hubbs et al., 1977).

Several post-1970s studies provided general information about fish faunas of the Trans-Pecos region (Bestgen and Platania, 1988; Edwards et al., 2002; Calamusso et al., 2005; Garrett and Edwards, 2014), and some also qualitatively described changes (declines) in river discharge below the confluence with the Rio Conchos (Garrett and Edwards, 2014). These studies, however, did not subject their data to quantitative analysis and did not address the role that changes in stream salinity (e.g., due to changes in flow below confluence) may play in affecting fish assemblages. The specific objectives of the present study thus were to quantitatively determine post-1970s change in fish assemblages, river discharge, salinity, and local precipitation, and to examine associations between hydrologic and biotic changes. The working hypothesis was that spatially uneven changes (below/above the Rio Conchos confluence) in hydrological conditions would lead to spatially uneven changes in fish faunas, and to region-wide habitat and biotic homogenizations. To our knowledge, this study is the first to address the interaction of salinity and flow regime, and its influence on the process of homogenization of freshwater habitats and biota.

2. Materials and methods

2.1. Study area

The Trans-Pecos region of the Rio Grande/Rio Bravo del Norte (Rio Grande) is situated in the northern part of the Chihuahuan Desert and defines a >1000-km segment of border between Mexico and the USA (Fig. 1). From El Paso (Texas, USA) to the confluence with the Rio Conchos (Chihuahua, Mexico), its main tributary in the region, anthropogenic degradation of the river and its watersheds over the last century transformed the river into a channelized, shallow, heavily silted stream with relatively slow and saline flow that is often dry during periods of drought (Hubbs et al., 1977; Everitt, 1993; Edwards et al., 2002; Schmidt et al., 2003; Calamusso et al., 2005). Discharge from the Rio Conchos markedly changes the habitat characteristics of the Rio Grande. From the Rio Conchos confluence to Amistad Reservoir ("Big Bend area"), the Rio Grande has relatively deeper runs and larger substrate, is of lower salinity (Bestgen and Platania, 1988), and provides refugia to native fish faunas (Platania, 1990). The Rio Grande in the Big Bend area also receives discharge from a series of intermittent tributaries, which serve as important spawning and nursery grounds for several native fishes (Hubbs and Wauer, 1973; Miyazono and Taylor, 2013a).

According to Hubbs et al. (1977), the saline Rio Grande fish fauna upstream of the confluence with the Rio Conchos is represented by native as well as non-native, salt-tolerant fishes (e.g., *Dorosoma cepedianum*, *Cyprinus carpio*, and *Cyprinella lutrensis*), the Rio Conchos–Rio Grande fauna by south Texas and Mexican species (e.g., *Notropis jemezanus*, *Notropis braytoni*, and *Rhinichthys cataractae*), and the tributary creek fauna by Chihuahuan fish species (e.g., *Notropis chihuahua*). The importance of the Big Bend area to the conservation of native faunas and floras of the Rio Grande Basin is highlighted by the presence of multiple national and state parks and protected areas on both sides of the international border (Raines et al., 2012; Garrett and Edwards, 2014). However, anthropogenic stressors on the hydrology of the area remain important concerns (Schmidt et al., 2003; Calamusso et al., 2005).

2.2. Data sources

Fish information for this study was grouped into current (2010–2011) and historical (1977–1989) data. Current data were obtained from various sources including Miyazono and Taylor (2013a) (sites 7–9 and 11, total 9 samples), Edwards (2013) (sites 10 and 12–20, total 10 samples) (Fig. 1; Table 1), and by new sampling of the mainstem (sites 1–6, total 6 samplings) (Fig. 1; Table 1). New sampling was conducted from 16 March to 2 April in 2011. Samples were collected with a seine (4.2 m × 1.7 m, 5 mm mesh) for 35–45 min per site. All available habitat types (i.e., riffles, pools, and runs) were sampled within a stream reach. Fish > 25-cm total length were identified, counted, and returned to the water. Smaller individuals were fixed in 10% formalin and brought to the laboratory for identification, and preserved in 50% ethanol. All fish collections were deposited into the Texas Natural History Collection. Historical fish assemblage data were gathered from Hubbs et al. (1977) (sites 1–7, 10, and 12–20, total 17 samples), Bestgen and Platania (1988) (sites 1–3 and 5–10, total 9 samples), and Linam et al. (2002) (sites 8 and 11, total 2 samples) (Fig. 1; Table 1).

Water quality monitoring sites, flow gages, and weather stations within the Trans-Pecos region with a similar period of record to the fish assemblage data were selected for analyses (Fig. 1; Table 2). Specific conductance data (1970s–2011) were obtained from 6 monitoring sites in the area (Texas Commission on Environmental Quality; http://www80.tceq.texas.gov/SwqmisPublic/public/default.htm), river discharge data (1977–2011) from 10 selected gage stations (International Boundary and Water Commission, http://www.ibwc.state.gov/), and precipitation data (1977–2011) from 10 selected weather stations (National Climatic Data Center; http://www.ncdc.noaa.gov/).

2.3. Statistical analyses

Multiresponse permutation procedures (MRPPs) with the Sorensen distance measure were used to examine differences between the historical fish assemblage data in 1977 and 1988–1989; MRPP is a nonparametric procedure that examines group differences (McCune and Grace, 2002). This preliminary analysis was done to determine whether the two historical datasets, collected 10 years apart, could be combined for comparisons against current data.

Fish sampling sites were classified into five geographic groups according to the following criteria: all sites (region-wide), mainstem