Science of the Total Environment 631–632 (2018) 733–744

Contents lists available at ScienceDirect

Science of the Total Environment

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

A semi-arid river in distress: Contributing factors and recovery solutions for three imperiled freshwater mussels (Family Unionidae) endemic to the Rio Grande basin in North America

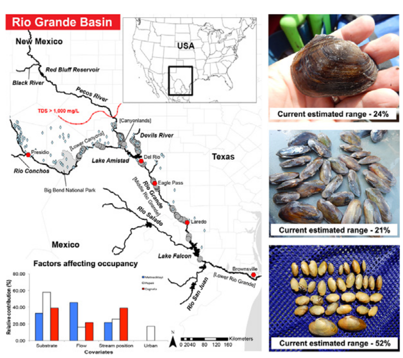
Charles R. Randklev [a,*], Tom Miller [b], Michael Hart [a], Jennifer Morton [a], Nathan A. Johnson [c], Kevin Skow [a], Kentaro Inoue [a], Eric T. Tsakiris [a], Susan Oetker [d], Ryan Smith [e], Clint Robertson [f], Roel Lopez [a]

[a] Texas A&M Natural Resources Institute and AgriLife Research Center at Dallas, Dallas, TX, United States
[b] Environmental Science Center, Laredo Community College, Laredo, TX, United States
[c] U.S. Geological Survey, Wetland and Aquatic Research Center, Gainesville, FL, United States
[d] U.S. Fish and Wildlife Service, Southwest Region, Albuquerque, NM, United States
[e] The Nature Conservancy of Texas, San Antonio, TX, United States
[f] Texas Parks and Wildlife Department, River Studies Program, San Marcos, TX, United States

HIGHLIGHTS

- We assessed the conservation status of three rare mussel species in the Rio Grande basin.
- Actual and modeled occupancy of focal species was low indicating high level of imperilment.
- Modeled range reductions suggestive of human mediated water quantity and quality issues.
- Recommendations for water management and high value conservation reache to improve prognosis of focal species.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 29 November 2017
Received in revised form 2 March 2018
Accepted 3 March 2018
Available online xxxx

Editor: Jay Gan

Keywords:
Occupancy modeling
Monitoring program
Landscape ecology
Southwestern United States
Biodiversity
Imperiled species

ABSTRACT

Freshwater resources in arid and semi-arid regions are in extreme demand, which creates conflicts between needs of humans and aquatic ecosystems. The Rio Grande basin in the southwestern United States and northern Mexico exemplifies this issue, as much of its aquatic biodiversity is in peril as a result of human activities. Unionid mussels have been disproportionately impacted, though the specific factors responsible for their decline remain largely unknown. This is problematic because the Rio Grande basin harbors one federally endangered unionid mussel (*Popenaias popeii*, Texas Hornshell) plus two other mussel species (*Potamilus metnecktayi*, Salina Mucket; and *Truncilla cognata*, Mexican Fawnsfoot), which are also being considered for listing under the U.S. Endangered Species Act. To date, surveys for these species have not corrected for variability in detection so current range estimates may be inaccurate. Using single occupancy-modeling to estimate detection and occupancy at 115 sites along ~800 river kilometers of the Rio Grande in Texas, we found that detection probabilities were relatively high, indicating that our survey design was efficient. In contrast, the estimated occupancy was low, indicating that our focal species were likely rare within the Rio Grande drainage. In general, the predicted occupancy of our focal species was low throughout their respective ranges, indicating possible range declines. A comparison of currently occupied ranges to presumptive ranges underscores this point. The best-approximating models

* Corresponding author.
E-mail address: crandklev@ag.tamu.edu (C.R. Randklev).

https://doi.org/10.1016/j.scitotenv.2018.03.032

indicated that occupancy was influenced by habitat, water quantity and quality, and proximity to large-scale human activities, such as dams and major urban centers. We also discuss a series of conservation options that may not only improve the long-term prognosis of our focal species but also other aquatic taxa.

1. Introduction

Arid and semi-arid regions occupy ~40% of the world's surface area (Kingsford et al., 1998; Reynolds et al., 2007; Thomas, 2011) and rivers in these regions are under intense demand because they are the only exploitable surface water resource (Sheldon et al., 2002; Kibaroğlu and Schmandt, 2016). Perennial river systems that flow through arid zones are often sourced from snowmelt and rainfall, but depending on stream position, tributaries, groundwater resurgence and springs, may also contribute (Tooth and Nanson, 2011). These inputs, which vary in their duration and magnitude, combined with regional climate phenomena, result in a high degree of spatiotemporal habitat heterogeneity that over time leads to tightly coupled biotic and abiotic interactions. Human mediated impacts, which operate over both short and long temporal- and spatial-scales, disrupt these linkages and undermine the ecological integrity of these systems (Walker et al., 1995; Sheldon et al., 2002).

The Rio Grande is the 4th largest river in North America, draining a total of 870,236 km^2 within Colorado, New Mexico, and Texas in the southwestern United States and the states of Chihuahua, Coahuila, Nuevo Leon, and Tamaulipas in northern Mexico (Kammerer, 1990; Kibaroğlu and Schmandt, 2016). Throughout its length, the river flows through arid and semi-arid desert scrubland and grassland habitats (Dahm et al., 2005). The mainstem and its tributaries serve as a major water supply for communities that exist throughout the basin (Kibaroğlu and Schmandt, 2016); this demand for water has had negative consequences for aquatic biodiversity and ecosystem functioning within these systems (Contreras-Balderas et al., 2002; Hoagstrom et al., 2010; Karatayev et al., 2012). For example, 50% of the imperiled fishes in Texas are endemic to the Rio Grande drainage basin (Hubbs et al., 1991, 2008). Similarly, 25% of the freshwater mussel fauna in the Rio Grande drainage basin have either gone extinct or are in decline (Howells, 2001; Karatayev et al., 2012, 2015). Such losses have led conservationists to label the Rio Grande as one of the most imperiled rivers in North America (Wong et al., 2007).

Freshwater mussels (Bivalvia: Unionidae) are among the most imperiled faunas due to human impacts on water quantity and quality (Williams et al. 1993; Haag, 2012). The influence of stream flow, and presumably water quality, on mussels is pervasive because of the role stream flow plays in shaping mussel habitat and governing population endpoints, such as growth, survivorship and reproduction (Allen et al., 2013). Moreover, mussels provide important ecosystem services, such as biofiltration, nutrient cycling, and physical habitat modification, which are also influenced by water quantity and quality (Vaughn and Hakenkamp, 2001; Vaughn et al., 2008; Vaughn, 2018).

For many rivers, baseline data used to assess the status and distribution of species are missing or biased (NNMCC, 1998; Haag and Williams, 2014; FMCS, 2016; Holcomb et al., 2018). Biased survey data are often the result of survey designs that do not account for factors that can influence detection, which can include observer effects such as effort, life histories, and environmental conditions (Yoccoz et al., 2001; Martin et al., 2006). To date in the Rio Grande, monitoring programs for mussels have relied on haphazard sampling designs and survey methods that do not account for incomplete detection (Howells, 2001; Karatayev et al., 2012; Karatayev et al., 2015). As a result, inferences regarding a species status and long-term viability may be incorrect, which is problematic given that several mussel species (*Potamilus metnecktayi*, *Popenaias popeii*, *Truncilla cognata*) among others known to occur in this drainage basin have been petitioned for protection under the U.S. Endangered Species Act (ESA, 1973; USFWS, 2009; 2016). Thus, information on status and threats to mussels, in turn, could be used to support their management and protection (e.g., identifying stronghold populations and defining critical habitat), as well as provide additional information on the current condition of the aquatic biodiversity in the Rio Grande.

In this paper, we provide a case study on the threats to freshwater mussels in semi-arid rivers within the southwestern United States. We assessed the conservation status of three mussel species that are endemic to the Rio Grande basin. First, we use single-occupancy modeling to estimate the influence of survey and site-specific factors on occupancy and detection probabilities of *Popenaias popeii* (Texas Hornshell), *Potamilus metnecktayi* (Salina Mucket), and *Truncilla cognata* (Mexican Fawnsfoot). Second, we map the resulting predicted probabilities to evaluate range curtailment for these species within the Rio Grande. Third, we discuss factors that contribute to the decline of these species along with management implications and potential solutions.

2. Methods

2.1. Study area

The present study occurred across 4 sub-watersheds in the Rio Grande basin (Fig. 1). The uppermost sites were in the Lower Canyons of the Rio Grande Wild and Scenic River (upstream of Lake Amistad; hereafter, Lower Canyons), located in the Low Mountains and Bajada province of the Chihuahuan Desert ecoregion (Griffith et al., 2007). Flow within this portion of the Rio Grande is derived primarily from the Rio Conchos, spring inflows from the Edward-Trinity Plateau Aquifer, and historically spring snowmelt from Colorado and New Mexico (URGBBEST, 2012). Water infrastructure projects in the Rio Conchos and upper Rio Grande and introduction of the Giant Reed (*Arundo donax*), have reduced flow, leading to declines in mean and peak stream discharge.

The lowermost sites were in the middle Rio Grande between Lake Amistad and Falcon Reservoir (Fig. 1); these sites were located within the Rio Grande Floodplain and Terraces of the Southern Texas Plains ecoregion (Griffith et al., 2007). Flow in this portion of the Rio Grande is influenced by two large reservoirs (e.g., Lake Amistad in Del Rio, TX, and Falcon Reservoir, downstream of Laredo, TX), a number of small low-head dams, and the Maverick Canal, which is located downstream of Del Rio, TX. These projects have contributed to substantial daily variation in stream discharge and water depth. The middle Rio Grande is also urbanized relative to the other study reaches, and this land use along with agricultural and industrial activities have degraded water quality (Griffith et al., 2007; TCRP, 2013).

The remaining two sub-watersheds that were sampled in this study were located in the Devils River and the Canyonlands of the Pecos River (Fig. 1). The Devils River is a pristine tributary of the Rio Grande and lies within the Semi-arid Edwards Plateau province of the Edwards Plateau ecoregion (Griffith et al., 2007), which is a transition zone between central and western Texas. Flow in the Devils River is unregulated and is derived from groundwater seepage and springs (URGBBEST, 2012). The Pecos River is the largest northern tributary of the Rio Grande, and is located in the Chihuahuan Basins and Playas province of the Chihuahuan Deserts ecoregion and the Semi-arid Edwards Plateau province of the Edwards Plateau Region (Griffith et al., 2007); survey sites were located in the Canyonlands of the lower Pecos River. The flow in the Pecos River has been reduced from historical levels due to irrigation, flow-regulation, canal diversions and groundwater extraction, all of which have