Prioritizing sites for conservation based on similarity to historical baselines and feasibility of protection

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Running head: Zooarchaeological Baseline

Keywords: conservation feasibility, shifting baselines, freshwater mussels, applied zooarchaeology, river conservation

Article Impact Statement

Zooarchaeological data can be used to establish conservation baselines and are not incongruent with conservation feasibility.

Abstract

The shifting baseline syndrome concept advocates for the use of historical knowledge to inform conservation baselines, but does not address the feasibility of restoring sites to those baselines.

This article has been accepted for publication and undergone full peer review but has not been through the copyediting, typesetting, pagination and proofreading process, which may lead to differences between this version and the Version of Record. Please cite this article as doi: 10.1111/cobi.13128.

In many regions, conservation feasibility varies among sites due to differences in resource availability, statutory power, and land-owner participation. We use zooarchaeological records to identify a historical baseline of the freshwater mussel community's composition before Euro-American influence at a river-reach scale. We evaluate how the community reference position and the feasibility of conservation might enable identification of sites where conservation actions would preserve historically representative communities and be likely to succeed. We first present a conceptual model that incorporates community information and landscape factors to link the best conservation areas to potential cost and conservation benefits. Using fuzzy ordination, we identify modern mussel beds that are most like the historical baseline. We then quantify the housing density and land use near each reach to estimate feasibility of habitat restoration. Using our conceptual framework, we identify reaches that have high conservation value (i.e., reaches that contain the best mussel beds) and where restoration actions would be most likely to succeed. Reaches above Lake Belton in central Texas, U.S.A. were most similar in species composition and relative abundance to zooarchaeological sites. A subset of these mussel beds occurred in locations where conservation actions appear to be most feasible. This study demonstrates how to use zooarchaeological data (biodiversity data often readily available) and estimates of conservation feasibility to inform conservation priorities at a local spatial scale.

Introduction

Conservation of ecological communities is impaired when our collective idea of the 'natural' baseline shifts due to cultural perceptions (shifting baseline syndrome; Humphries & Winemiller 2009; Papworth et al. 2009, Radeloff et al. 2015). Thus, incorporating historical knowledge, including zooarchaeological data, in ecological baselines is important (Lyman 2012; Scharf 2014). Baseline accuracy can improve knowledge of native animal communities, but knowledge doesn't always mean improved conservation tactics. The use of zooarchaeological data at landscape scales to conserve animal communities requires three items: zooarchaeological remains that preserve well and represents localized animal communities, knowledge of current animal communities, and an understanding of the costs, benefits, and feasibility of potential conservation actions. This study explores this approach for managing freshwater mussels in a southcentral U.S. river, with methods applicable to other taxa that meet these requirements.

While the inclusion of zooarchaeological data typically improves historical baselines, this doesn't always translate into improved management because conservation feasibility varies widely among sites. We define conservation feasibility as the cumulative effect of factors that increase the likelihood that management options will be undertaken and will be successful. These factors are related to social/government structure (Hobbs 2007; McBride et al. 2007; Mills et al. 2013), faunal biodiversity (Nel et al. 2009), site vulnerability and condition (Linke et al. 2007), and the presence of co-occurring stressors (Evans et al. 2011, Brown et al. 2013, Neeson et al. 2016). For freshwater systems, conservation feasibility varies widely because of the co-reliance of humans and riverine organisms on freshwater. Freshwater reserves can be difficult to establish because humans need stores of water (reservoirs) while riverine animals require stretches of flowing water without impediments (Strayer and Dudgeon 2010). For example, connectivity between headwater streams and the mouths of rivers is essential for some migrating fish and reducing the number of impoundments reduces habitat alteration for stream organisms. Riverine communities also shift species composition based on their location within a watershed because upstream and downstream habitats can be quite different and harbor different species assemblages. River restoration often requires the participation of multiple conservation groups to restore natural stream habitat (Allan et al. 1997, Milt et al. 2017, Moody et al. 2017). Since feasibility aspects and reference uncertainty have been used to argue against the reliance on historical baselines for conservation prioritization (Dufour & Piégay 2009), we propose a method to compare the two simultaneously.

Zooarchaeological assemblages, faunal remains found in archaeological settings, provide a representation of past environments for paleoecologists, wildlife managers and conservation biologists (Lyman 2012). For freshwater mussels (Bivalvia: Unionidae; hereafter mussels), zooarchaeological research has focused on prehistoric extinctions (Williams & Fradkin 1999), extirpations (Ortmann 1909; Bogan 1990; Mitchell and Peacock 2014), and range shifts (Randklev et al. 2010; Peacock et al.

2016; Wolverton & Randklev 2016). Mussels have unique traits that make them excellent sources of zooarchaeological information. They have large, calcium carbonate shells that often preserve well (Parmalee & Klippel 1974). Native mussels are largely sedentary as adults and are constrained to particular habitats, thus archaeological shells reflect the past river environment (Matteson 1960; Peck et al. 2014). Finally, because mussels usually occur in multispecies aggregations (mussel beds), with densities 10 to 100 times higher than outside of beds (Strayer et al. 2004), they were likely collected indiscriminately within these beds by past human foragers (Peacock et al. 2012). Zooarchaeological records of freshwater mussels should be deposited close to their collection site as their shell represent heavy, perishable packets of low caloric value (Peacock et al. 2012). To our knowledge, zooarchaeological data have not been used to prioritize specific reaches for conservation within a river system, making it a novel technique for identifying areas for habitat protection.

Freshwater mussels are a globally imperiled fauna (Lydeard et al. 2004). In North America, anthropogenic impacts have led to substantial declines with 70% of the mussel fauna currently considered threatened (Haag 2012; Haag & Williams 2014). As long-lived, burrowing filter feeders, mussels provide ecosystem services by contributing to biofiltration, nutrient recycling and storage, providing and modifying habitat, and supporting food webs (Vaughn & Spooner 2007; Allen et al. 2012; Atkinson et al. 2013; Vaughn et al. 2015; Vaughn 2018). Because mussels require conservation action, improve riverine ecosystems, and leave local archaeological signal, their archaeological shell potentially provides a tool to inform conservation actions.

Zooarchaeological data can improve the two main approaches to freshwater mussel conservation, habitat and population restoration (Neves 1995; Freshwater Mollusk Conservation Society 2016), by allowing identification of river areas known to support diverse, healthy mussel beds. Population restoration is best performed after habitat restoration has insured a good place for the propagated or translocated to live (McMurray & Roe 2017), thus here we focus on habitat quality and potential restoration. Mussel beds are long-term features of a river that can remain in the same location for hundreds of years (Strayer 1999; Vaughn & Spooner 2004), thus, the location of zooarchaeological mussel remains should be located close to the mussel beds from which they were collected. In addition, the species composition of these mussel beds remains relatively unchanged over long time periods. Such persistence of mussel communities likely means that habitat conditions are good for these communities, and shifts in community structure may reflect large-scale habitat change (White 1977, Vaughn et al. 1996).

Landscape ecology can be used to delineate appropriate mussel habitat. Mussels require stream channels that are stable, continually wetted, and that are not subject to heavy sedimentation or eutrophication (Morales et al. 2006; Allen & Vaughn 2010; Osterling et al. 2010). Riparian forest restoration and reduction in nutrient loading can help to achieve these habitat conditions (Haag 2012). Riparian restoration through cattle fencing and tree augmentation can prevent bank collapse, reduce sedimentation, and prevent cattle from adding excessive nutrients to streams (Dosskey et al. 2010). These local and landscape management actions can improve habitat for both resident and future propagated mussels, as well as other aquatic fauna.

Here, we used zooarchaeological data and a landscape ecology approach to identify river reaches for habitat preservation based on their mussel community and feasibility of conservation actions (Peacock et al. 2016). We obtained data on present day and pre-EuroAmerican mussel communities from a moderately impacted river in the southcentral U.S. We used fuzzy ordination to identify reaches that should be conservation sites based on the similarity of their present-day community to the historical baseline. To establish feasibility of riparian restoration and nutrient loading reduction, we quantified housing density and local land use. We used these analyses to explore which sites would be appropriate for conservation actions and if restoring them to their pre-EuroAmerican baseline would be achievable.

Methods

Study Area

The Leon River is a 5th order tributary of the Brazos River in central Texas, U.S. The area experiences hot, dry summers and wet winters (Rose & Echelle 1981) and the surrounding landscape is dominated by agricultural land. This river is moderately anthropogenically impacted with two small urban centers (Belton and Hamilton) and three impoundments (Fig. 1). A recent quantitative survey documented 11 mussel species, with declines over time in both species richness and abundance (Randklev et al. 2013). Historically, the river harbored three mussel species of conservation concern: false spike (*Fusconaia mitchelli),* Texas fawnsfoot *(Truncilla macrodon),* and smooth pimpleback (*Cyclonaias houstonensis;* Randklev et al. 2013; Popejoy et al. 2018; Williams et al. 2017). Only *C. houstonensis* persists in the river today, though all three are present in other Brazos tributaries.

Conservation conceptual model

To evaluate which river reaches represent the best conservation areas, we created a conceptual model that relates habitat quality and resident mussel communities to potential restoration costs and ecosystem services provided by mussels (Fig. 2). In the model, the y-axis represents the current community's similarity to historical communities. This is important because communities that are more similar to past communities likely contain remnant, endemic populations that are of high conservation concern. The x-axis represents conservation feasibility, defined broadly to include all economic, social and political aspects that determine the likelihood of successfully implementing conservation. For example, high conservation feasibility could represent less cost (in both effort and money) to conservation biologists and managers. Tier 1 sites represent mussel beds that should be easiest to preserve and likely have intact mussel-derived ecosystem services such as biofiltration and nutrient cycling. Tier 2 sites have higher costs, requiring either more work to restore the mussel community or to restore habitat, but still have good ecological function. Tier 3 sites represent high-cost conservation situations: both the mussel community and habitat would need to be restored. For our conceptual model, tier 1 beds will have a high similarity index (>0.5) with also an above average conservation feasibility. Tier 2 beds have either a high similarity index or low conservation feasibility or vis versa. Tier 3 has a similarity index <0.5 and has a below average conservation feasibility.

Locating 'pristine' mussel beds

We used data on present day mussel communities from a 2011 systematic survey of the river by Randklev et al. (2013), which located 52 mussel beds from just below Lake Leon to the confluence of the Leon River with the Little River (Fig. 1). We used two pre-EuroAmerican zooarchaeological datasets to represent the late Holocene mussel community: the 41HM61 assemblage and the Belton Lake assemblages (Popejoy et al. 2018). The 41HM61 assemblage represents an upstream portion of the Leon River near Hamilton. The Belton Lake assemblages comprise remains from 18 separate cave sites that surround Belton Lake. These assemblages represent mussels collected and discarded by native peoples during the late Holocene (approximately 2000 years ago; Weinstein 2015). We identified shell remains that contained a non-repetitive element (umbo) to the lowest taxonomic category possible (Giovas 2009; Driver 2011; Harris et al. 2015). Based on freshwater mussel ecology and their low caloric value, species exclusion within mussel beds by human predation is unlikely (Parmalee & Klippel 1974). But differential preservation between mussel species can alter the composition of the archaeological remains (Wolverton et al. 2010).

Archaeological shell have been subjected to multiple filters by the time the shell are identified (Lyman 2010); differential remain preservation and sampling adequacy are two pertinent filters to consider when doing applied zooarchaeology. Like bones, sphericity and density impact mussel shell preservation (Wolverton et al. 2010). Since threeridge (*Amblema plicata)* has a robust and easily identifiable shell, it tends to dominate in zooarchaeological assemblages. The assemblages from Belton Lake have high preservation, with 7.1% unidentifiable shells, but represent small samples. The 41HM61 assemblage has moderate preservation, with 21.3% unidentifiable shells, and has a larger sample size (Popejoy et al. 2017). Because both assemblages include species that are unlikely to preserve (Louisianna fatmucket, *Lampsilis hydiana*, and rock pocketbook, *Arcidens confragosus*), we accept that they represent the late Holocene mussel community. Zooarchaeological samples are the amalgamation of multiple sampling events through time and sample adequacy is important in any community focused research (Woo et al. 2015). To ensure complete sampling of the late Holocene community, we use a rarefaction curve to eliminate samples that do not adequately represent community richness using the R package *vegan* (R Core Team 2014; Oksasnen et al. 2017). Based on our rarefaction curve (Supporting Information), we eliminated archaeological samples that did not contain 5 mussel species. Thus, we used six zooarchaeological sites to represent the late Holocene freshwater mussel community and to establish a pre-EuroAmerican baseline.

Using species abundance data and mussel bed spatial location, we used fuzzy ordination to determine which contemporary sites are most like the pre-EuroAmerican baseline in terms of mussel species richness and relative abundance. Mussel bed location is the number of river km upstream from the confluence of the Little and Leon Rivers. Fuzzy ordination employs fuzzy set logic by comparing the community composition of each site and assigning them a fuzzy classification (Roberts 2009). Fuzzy set logic works well for archaeological data because the data contain inherent uncertainties, such as preservation bias (Hermon et al. 2004; Baxter 2009). The sites are assigned to two sets (A and B) based on location with values from 0 to 1. A third set (C) is constructed by finding the set anticommutative difference (sites that are similar to set A but are not similar to B) of the other sets. This third set essentially represents the predicted membership of sets A and B of the sites based on other variables. In this case, sets A and B are based on the spatial location of the sites. Set C is the predicted river km location of each sample based on mussel relative abundance. The correlation between actual location and predicted locations evaluates if the environmental gradient is appropriate for predicting community composition. Set C represents the similarity index of each bed between modern and prehistoric communities. We completed fuzzy ordination of the prehistoric and the modern mussel sites using R Core Software and the *fso* package (Roberts 2013; R Core Team 2014).

To ensure that the similarity index represents current conservation goals, we ran a Spearman's rho correlation to correlate the similarity index (*mu*) values to *C. houstonensis* abundance and to mussel density. Nonparametric statistics are most appropriate for zooarchaeological data due to uncertainty related to preservation, hence why we used fuzzy-set ordination and spearman's rho correlation (Driver 2011; Wolverton 2013).

Conservation feasibility analysis

To evaluate how feasible it would be to conserve the mussel beds that are most similar to the pre-EuroAmerican baseline, we assessed two common conservation actions: riparian forest preservation and improving land management in the area. To complete this spatial analysis, all 52 mussel beds were snapped to a shapefile of the mainstem of the Leon River, from the USGS National Hydrologic Database, using the *maptools* package in R (Bivand & Lewin-Koh 2016). This shapefile is composed of line segments that represent hydrologically unique reaches of the river (National Hydrography Dataset 2016). We then reduced the length of these segments to areas of the river within a 300 m radius of the mussel bed. Reaches dissected from the river had a mean length of 0.68 km (SD 0.31 km). We considered different approximations of anthropogenic factors that influence river ecosystems to evaluate conservation feasibility. Ideally, reaches that have communities similar to the pre-EuroAmerican baseline will be located in areas with low housing density and low developed and crop land use areas. Where mussel beds are in areas with less houses and more forest/wetland, it might be easier to convince property owners to put up cattle fences and reduce fertilizer use.

Evaluating protection of riparian forests

Protecting riparian forests, through augmenting vegetation or constructing cattle fences, relies on landowner cooperation. While trust between landowners and water managers increases the likelihood of conservation success, stakeholder involvement does not (Young et al. 2013). To minimize the number of stakeholders affected by riparian restoration, we identified reaches with a low number of property owners. To do this, we estimated the density of property owners based on the number of houses within U.S. census blocks that abutted each mussel reach (US Census Bureau, 2010). We collected blocks that were within 100 m of the river and divided the number of houses within each block by the land area to determine housing density for that block. Housing density for all blocks surrounding the reach was then averaged to get a single value for each reach. The resulting value approximates the number of property owners near a mussel reach and provides an indirect measure of other anthropogenic impacts.

Evaluating land use

Improving land management across river basins can reduce nutrient loading, sedimentation, and anthropogenic chemical input (i.e. herbicides and pesticides) in rivers (Allan et al. 1997). Local improvement of land management directly influences habitat quality in stream reaches. As such, we evaluated the proportion of land area under different uses within one km area of each mussel bed using land use raster data from the USDA (Atkinson et al. 2012; Homer et al. 2012). The relative abundance of forest and wetland within the area surrounding the river is used to predict the feasibility of protecting/supplementing existing forest near river reaches.

Results

The ordination using mussel community composition and river kilometer was significant ($r = 0.64$, $p < 0.01$), indicating that river kilometer predicted community composition. This ordination ordered the sites based on their species composition and returns their set C (*mu*) value that indicates the probability of belonging to either ends of the river continuum spectrum (Fig. 3). The *mu* values, indicating similarity between modern and prehistoric communities, ranged from 0.376 - 0.627. This ordination showed a shift from sites dominated by *A. plicata* (late Holocene) to sites dominated by lentic species (yellow sandshell (*Lampsilis teres)* and fragile papershell (*Leptodea fragilis*)).

The mussel community at the AW site was most similar to the prehistoric community because it was dominated by *A. plicata* (Fig. 3). The AW site had a low catch-per-unit-effort (CPUE) and abundance of mussels: eight *A. plicata* and four *C. houstonensis* were found. Thus, it isn't the ideal bed for conservation actions. The next site with a community with the highest *mu* of 0.58 is AE: this bed had both high mussel CPUE and abundance of *C. houstonensis*.

The similarity index was correlated with *C. houstonensis* abundance ($rho = 0.71$, $p < 0.001$) and mussel density ($rho = 0.66$, $p < 0.001$). Since the similarity index matches past community structure and modern conservation goals, we used this value to identify beds that contain a resident mussel community suitable for conservation.

Generally, mussel beds with species composition similar to the late Holocene mussel assemblages were located in reaches that had a low density of houses in adjacent census blocks (Fig. 4a). The average number of houses at each reach ranged from 1 to 55 while average census block area ranged from 0.19 to 18.29 km^2 (Supplementary Information). This resulted in housing density ranging from 0.045 to 19.7 houses per km^2 with a mean of 3.16 houses per km^2 (4.88 SD). Mussel beds that were most similar to the pre-European baseline were also in areas with low housing density: sites AG, AH and AD had 0.48 houses per km^2 and site AE had 0.67 houses per km^2 (Fig. 4a).

Reaches with more forest and wetlands had mussel beds more similar to historical communities (Fig. 4b). Pasture was the highest land use surrounding the reaches, followed by shrubland and grain crops (Supplementary Information). Mussel beds that were most similar to the late Holocene baseline were often surrounded by forest: site AD had 49.9% forest cover, and site AO and AE had 48.3% forest cover (Fig. 4b).

Based on our conceptual model, we found multiple options for conserving mussel beds in the Leon River. Eight of the 52 known mussel beds contained similar mussel communities to the past, had a low housing density and high relative abundance of forest, making them tier 1 in our conceptual model. This conceptual model allows managers to evaluate the benefits of preserving and restoring different resident communities based on goals and available resources.

Discussion

This paper demonstrates that zooarchaeological and landscape data can be combined to identify mussel beds that have high conservation priority and where it may be most feasible to implement conservation activities. Our study also provides potential solutions for protecting high quality reaches and rehabilitating habitat based on land use change and similarity of current beds with the past mussel community. This study is a good example of how using unconventional datasets can further conservation of aquatic species. It also highlights the role zooarchaeological data can play in mussel conservation, beyond just measuring temporal changes in faunal assemblages.

Freshwater mussels and aquatic systems are under multiple threats in the Leon River. Climate change and anthropogenic water use often exacerbate harsh water conditions in southern rivers (Vaughn et al. 2015). By ensuring enough water during critical biologic times, water managers can mitigate harm caused through needed anthropogenic water use (Gates et al. 2015). Zebra mussels (*Dreissena polymorpha*), a new invasive species in the river system (Olson 2016), adversely affect native mussels through food and space competition (Strayer & Malcom 2007). The beds that represent the best conservation opportunities are upstream of current zebra mussel locations (Lake Belton) and thus are potentially protected since zebra mussel larvae are poor dispersers against flow (Stoeckel et al. 1997). By considering the multiple threats aquatic systems face, conservation biologists can better concentrate resources to improve return of investment.

By restoring mussel beds, both humans and aquatic organisms benefit. Freshwater mussels can aid water quality efforts as their filtering removes bacteria from the water column (Faust et al. 2009, Othman et al. 2015). This filter-feeding improves stream clarity and increases macroinvertebrate resources in the river (Vaughn 2018), which could potentially increase the recreational value of the river. By working with successful management groups to enact species conservation efforts, conservationists can improve the river for recreation purposes. The Leon River Watershed Protection Program, a local management group, successfully engaged stakeholders through outreach to improve the river's water quality to state and federal standards (Koch & Cawthon 2014). By working with this stakeholder-engagement program, it might be possible to implement more species-centric conservation actions.

Considering our conceptual model, managers should focus their efforts on tier 1 beds as they represent the best opportunities for conservation. Tier 1 beds contain irreplaceable mussel communities that are likely providing important ecosystem services. They also represent cost-effective opportunities for conservation: less money would need to be spent restoring the habitat or the mussel population. Beds in tier 2 also represent viable conservation options, depending on available resources and stakeholder receptiveness. By working with current stream management structures and considering two looming threats to the river, the Leon River and its stakeholders would benefit from conserving freshwater mussels.

The Leon River case study presented demonstrates the real-world utility of zooarchaeological data, which is rarely used by mussel conservationists, in management and recovery planning. While this paper focused on a threatened mussel fauna within a small tributary in Texas, this approach could be extended to other faunas, as long as both conservation and zooarchaeological constraints are considered. Faunas must produce archaeological signatures, most often through hard-part preservation in middens. Zooarchaeological data must be local (long-distance transport would eliminate any local spatial data) and be a good representation of the local faunal community. Lastly, a good understanding of zooarchaeological data quality is essential for applying the data to conservation applications. Since zooarchaeological data is often collected during archaeological excavations, it represents a potentially inexpensive and irreplaceable source of historical ecological data. While there are some obstacles to applying this methodology to all fauna found within archaeological deposits, we have shown that it is a useful approach that can improve conservation actions.

Acknowledgments

We would like to acknowledge the Nʉmʉnʉʉ nation on whose traditional land this research took place. We thank M. Patten, T. Parr and B. Tweedy for conversations that improved this manuscript. We appreciate two reviewers whose comments improved this manuscript. Original data collection was funded by Texas Department of Transportation, Coastal Environments, Inc. and AMEC Earth & Environmental Inc.

Supporting Information

Data sources are available online. The authors are solely responsible for the content and functionality of these materials. Queries (other than absence of the material) should be directed to the corresponding author.

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Figure Captions

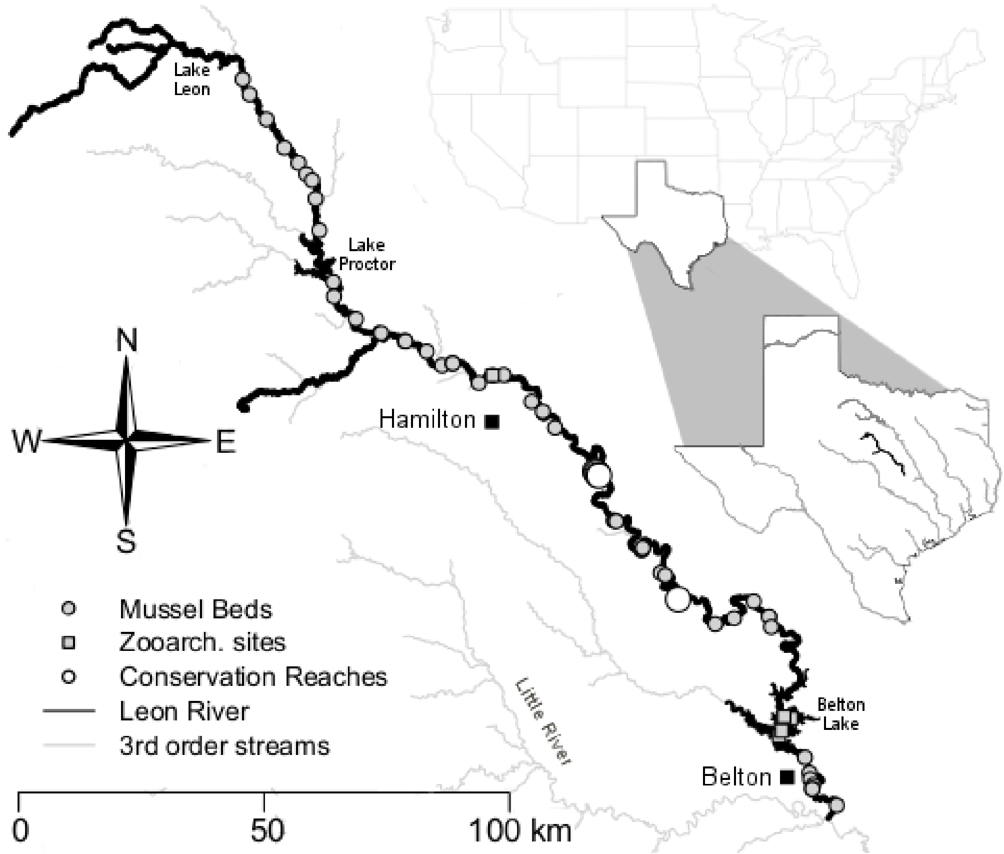

Fig. 1 Map of the Leon River and mussel site locations. Inset shows the state of Texas and all sixth-order streams within the state. The black line represents the Leon River. Map generated with code from the *hydroMap* R package (DeCicco & Blodgett 2017).

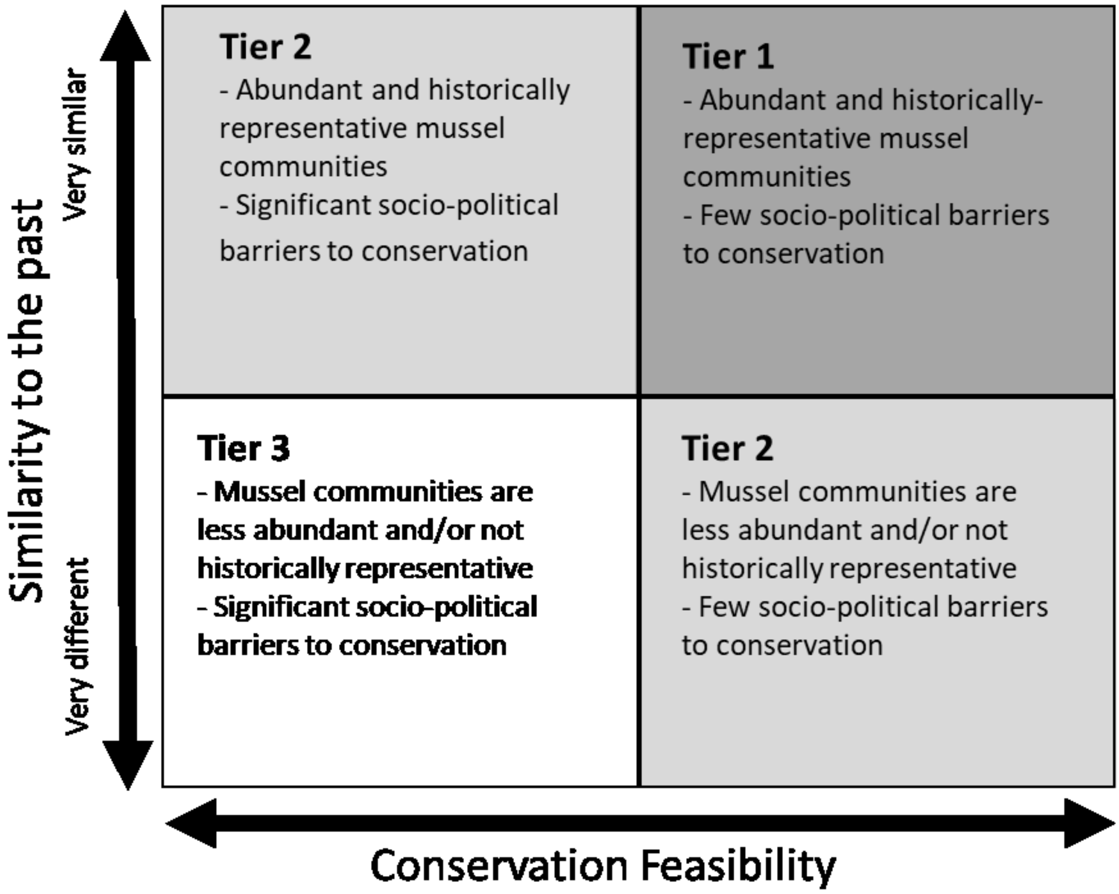

Fig. 2 Conceptual model relating community similarity and conservation feasibility to mussel-provided ecosystem services. The intensity of the gray represents the best conservation options in terms of community similarity and cost.

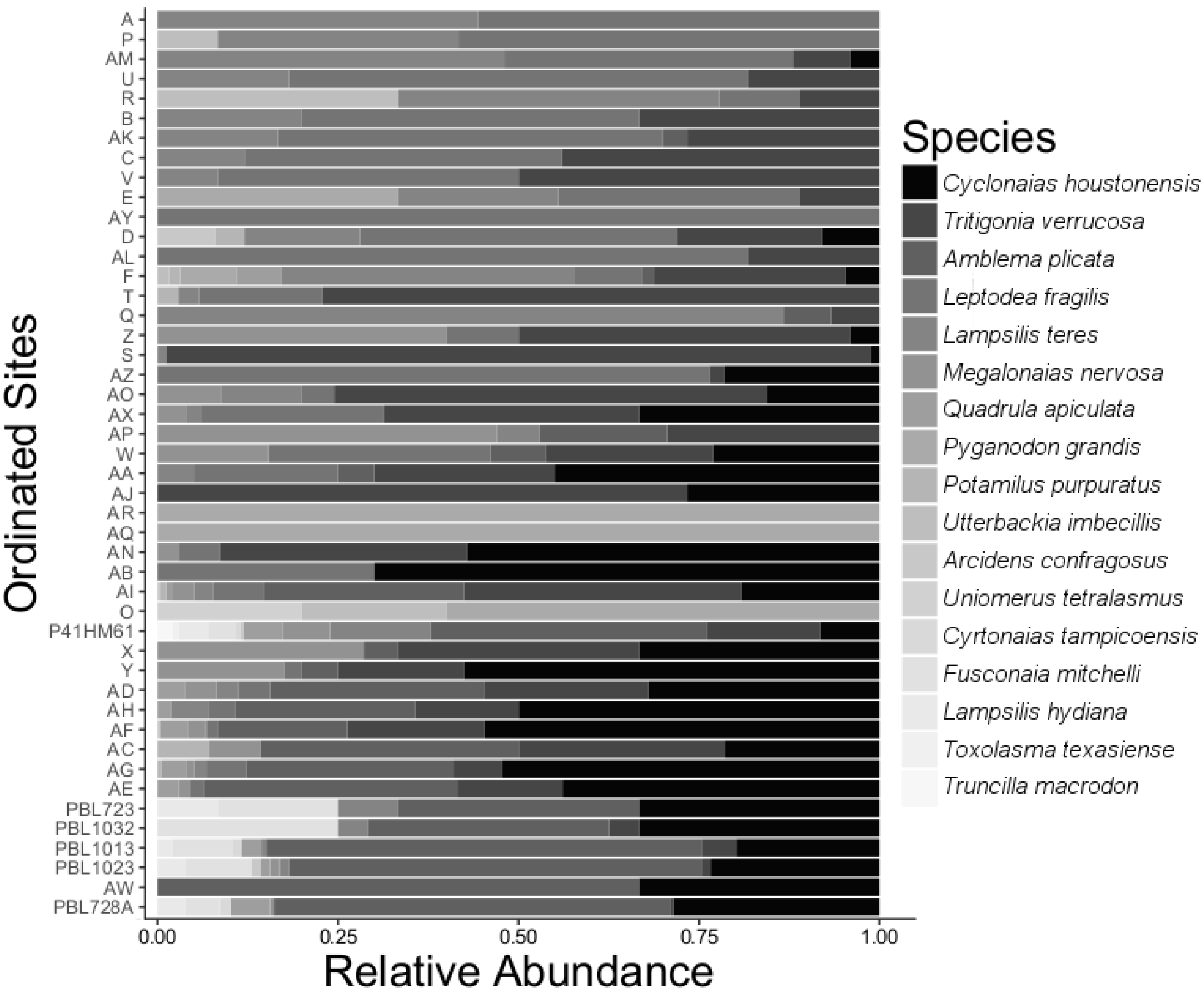

Fig. 3 Species composition of ordinated mussel sites. Mussel beds are ordered by past similarity index on the y axis; zooarchaeological sites are generally at the bottom and start with a P[site name], while modern sites consist of only one or two letters. Species ordered in legend by modern abundance.

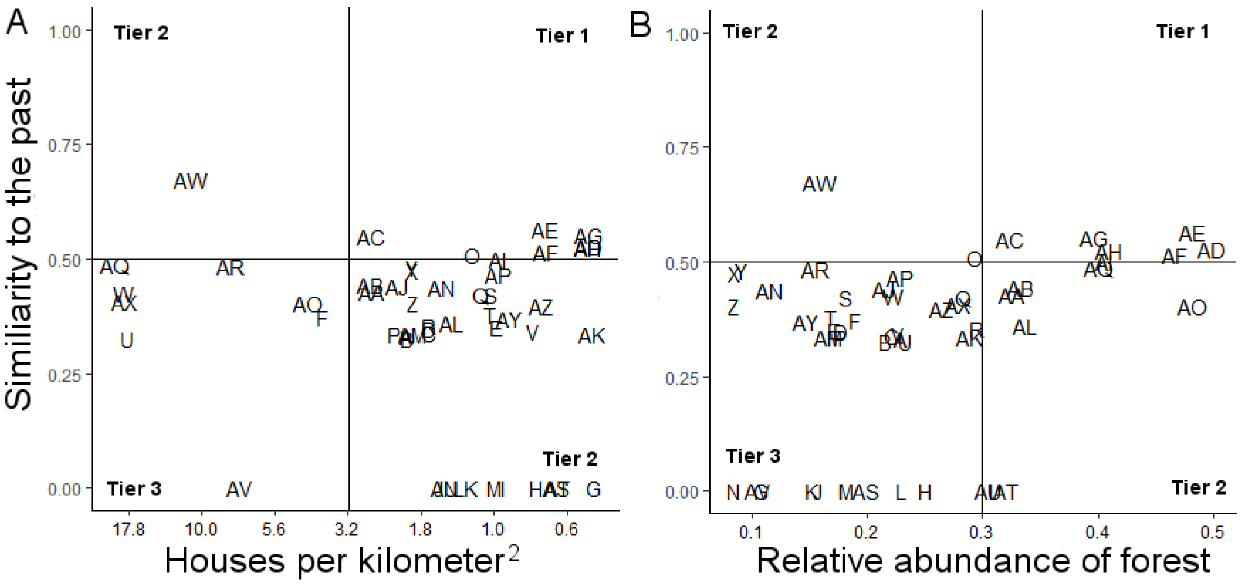

Fig. 4 Similarity to the past and feasibility relationship. The y axis is the probability the mussel bed would be grouped with the zooarchaeological-dominated set. The x axis are variables that represent feasibility of conservation: less houses should be less property owners and more trees represent healthier riparian forests. Fig 4A identifies AE and AG as beds in low housing density areas with good mussel communities. Fig 4B identifies AE and AD as beds in forested reaches with good mussel communities