Ecological Indicators 95 (2018) 741–750

Contents lists available at ScienceDirect

Ecological Indicators

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

Original Articles

Testing the performance of bats as indicators of riverine ecosystem quality

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ARTICLE INFO

Keywords:
Bioindication
Chiroptera
Macroinvertebrates
Pollution
Riparian habitat

ABSTRACT

Rivers host a wealth of biodiversity and play critical ecological functions, so monitoring their environmental status and tracking its changes has paramount importance for appropriate management. Although some biological groups, and especially benthic macroinvertebrates, are employed routinely to achieve this goal, the quest for bioindicators of river quality is far from over, because finding further suitable organisms may improve indication performances and inform habitat management. Using organisms that are at risk for bioindication also fulfills the goal of providing important information for the conservation of the taxon (or taxa) used for bioindication. Bats are a diverse, threatened mammal group whose characteristics make them potentially suitable bioindicators in many ecosystem types, but research in this field is still limited. In this study, set in Central and Southern Italy, we hypothesize that assemblages of foraging bats will respond to environmental status and quality of riverine ecosystems and that therefore bats may serve as effective bioindicators. We established the environmental status of 50 sampling sites selected along 10 rivers using two indices officially adopted in the country, i.e. the STAR_ICMi (evaluating water quality from macrobenthic invertebrate assemblages) and the fluvial functionality index (*Indice di Funzionalità Fluviale*, IFF), which incorporates several biotic and abiotic components and represents a functional indicator of river ecosystem health. At the sampling sites, we also recorded bat activity with operator-independent real-time bat recorders and classified bat passes to species or phonic groups. We examined 167,371 macroinvertebrates and 55,157 bat passes, corresponding to 15 species or phonic groups. The activity of *Miniopterus schreibersii/Pipistrellus pygmaeus* and *Myotis daubentonii/capaccinii* declined with increasing values of STAR_ICMi and IFF, while the activity of *Nyctalus/Eptesicus serotinus* increased with both indices. The activity of *P. kuhlii* also declined as IFF values increased, while we observed the opposite for *Pipistrellus pipistrellus, Myotis emarginatus*, *Myotis nattereri* and *Barbastella barbastellus*. Pooling together species whose activity respectively increased or decreased as the values of quality indices increased improved indication performances by strengthening statistical significance. Our work constitutes a significant step towards the use of bats as bioindicators in river ecosystems as we show that differences in bat activity may reveal changes in environmental conditions and may thus demonstrate the effects of habitat alteration on the river biota. We highlight that locally adapted bat populations may show differences in foraging behaviour and food preferences; hence our findings warrant confirmation from other regions. Further constraints are given by the variable degree of taxonomic resolution achieved in bat sound analysis, which may represent an issue especially in species-rich bat assemblages such as those of southern Europe.

1. Introduction

Freshwater ecosystems cover less than 1% of world surface, but they contain 6–10% of all species and one-third of all vertebrate species worldwide, demonstrating that they are important hotspots of biodiversity (Dudgeon et al., 2006; Balian et al., 2008; Strayer and Dudgeon,

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https://doi.org/10.1016/j.ecolind.2018.08.018
Received 24 January 2018; Received in revised form 7 August 2018; Accepted 12 August 2018

2010). Freshwater ecosystems also provide several services, fundamental for human settlements and productive activities (both agriculture and industrial). On the other hand, human activities apply high pressure on the natural balance of such ecosystems. Rivers and lakes are losing biodiversity faster than any other terrestrial or marine ecosystem (Jenkins, 2003; Strayer and Dudgeon, 2010). The awareness of the ecological and economic importance of these habitats implicated large efforts around the conservation and restoration of river environments, especially in the last few decades (e.g. Darby and Sear, 2008).

Typically, bioindication methods study the differences between the composition of an expected community and the current community of a particular site or combine the relative abundance of some taxonomic groups with their sensitivity/tolerance to pollution (Armitage et al., 1983; Buffagni and Erba, 2014; Sansoni, 1988). Bioindication is now a necessary supplement to traditional monitoring techniques for riparian ecosystems and is required by legislation such as the Water Framework Directive of the European Union (European Parliament, 2000).

Aquatic macrobenthic organisms have been analyzed for this purpose since the 1960s and are now considered the most suitable as an indicator of water quality (Furse et al., 2006). They are widespread, easy to sample and identify, cover a broad range of trophic levels and pollution tolerances, exhibit fast, taxon-specific reactions to pollutants, and have low mobility: thus, their responses are representative of site-specific conditions (Barbour et al., 1999; Sansoni, 1988). Most biotic indices, developed on species-specific sensitivities and tolerances, are used for monitoring eutrophication, acidification and organic pollution (Delgado et al., 2012). Macrobenthic communities react in predictable ways to environmental changes, mostly showing diversity reduction, the disappearance of sensitive taxa and dominance of opportunistic ones, and the decrease of individual size (Gray, 1989). Several bioindication indices have been developed in various countries, e.g.: the Trent Biotic Index (Woodiwiss, 1964), later modified in the Extended Biotic Index (EBI) (Woodiwiss, 1980); the Saproby Index (SI) (DIN38 410-2, 1990); the Biological Monitoring Working Party Score System (BMWP) (Chesters, 1980); the Average Score per Taxon (ASPT) (Armitage et al., 1983); and the multimetric STAR_ICMi index (Buffagni et al., 2007; Buffagni and Erba, 2014).

The quest for bioindicators of river quality is, however, far from being over, because finding further suitable organisms may speed up or refine monitoring and help improve habitat management. Using organisms whose conservation status also needs to be monitored as a bioindicator is fulfilling two needs with one deed. From this perspective, bats would prove ideal candidates because in many cases they are at risk (e.g. O'Shea et al., 2016; Conenna et al., 2017; Welch and Leppanen, 2017) and thus are in need of systematic monitoring: in Europe, monitoring bat conservation status is an obligation arising from Article 11 of 92/43/EEC "Habitats" Directive. Moreover, bats meet all the criteria for a suitable bioindicator (Jones et al., 2009; Russo and Jones, 2015). Bats are on every continent, except Antarctica, so they are geographically widespread and are among the mammal orders with higher diversity, with > 1300 species (Fenton and Simmons, 2014). Thanks to this worldwide distribution, bats are adapted to different habitats and consequently, they have different trophic needs (Altringham, 2011). Because of their position high in trophic webs, bats could react to pollution faster than other taxa, such as invertebrates (Jones et al., 2009; McGeoch, 1998). Slow reproductive rates make bats ideal indicators for long-term monitoring and for past disturbance, because their populations decline rapidly, but require suitable environmental conditions and a long time to increase again in number (Jones et al., 2009; Russo et al., 2017). On the other hand, foraging activity is likely to react promptly to fluctuations in insect prey availability driven by habitat changes – in fact, insectivorous bats have been found to track changes in insect availability (Fukui et al., 2006; Hagen and Sabo, 2012).

For better understanding food web dynamics in riverine ecosystems, it is important to characterize trophic interactions between terrestrial and aquatic systems (Polis et al., 1997). Aquatic-emergent insects are key exporters of contaminants to terrestrial ecosystems (Runck, 2007), thus insectivorous bats are a promising link between these systems. Moreover, bats depend strongly on water habitats. Their foraging activity is typically higher over rivers and lakes than in other habitats and some species forage exclusively over water or close to riparian vegetation (Adams and Hayes, 2008; Almenar et al., 2009; Biscardi et al., 2007; Hagen and Sabo, 2011; Russo and Jones, 2003; Vaughan et al., 1997). Several bat species follow rivers as preferential pathways for movement and migration (e.g. Fenton and Thomas, 1985; Serra-Cobo et al., 2000; Furmankiewicz and Kucharska, 2009) and many use rivers and streams as a source of drinking water (Korine et al., 2016).

Bats are therefore in most cases likely to show clear responses to the quality of riverine habitats, as shown by several studies whose primary aim was to inform bat conservation (Vaughan et al., 1996; Biscardi et al., 2007; Kalcounis-Rueppell et al., 2007; Naidoo et al., 2013; Salvarina, 2016). Fewer studies considered the potential implications of such responses for bioindication in rivers. Two studies (Langton et al., 2010; López-Baucells et al., 2017) adopted a single species approach focused on the vespertilionid bat *Myotis daubentonii* to explore responses to river quality. In England and Wales, this species was more active on larger waterways with more surrounding woodland, with a broad variation possibly caused by site-specific factors (Langton et al., 2010). The study also showed a positive association of *M. daubentonii* activity with good water quality as expressed by macroinvertebrate diversity. However, López-Baucells et al. (2017) concluded that, for the Iberian Peninsula, *M. daubentonii* might complement other bioindicators, but cannot be used alone for evaluating riparian ecosystem conditions. Noticeably, in a study conducted in North Carolina (Li and Kalcounis-Rueppell 2017) the activity of different bat species showed different responses to water quality at a landscape scale, i.e. water quality could be used to predict which bat species occur in a given landscape when local studies are lacking. Assessing community-scale responses might, in fact, provide better performances (Li and Kalcounis-Rueppell, 2017) and open new avenues for practical applications.

In this study, set in Central and Southern Italy, we tested the responses of bat assemblages to the quality of riverine habitat and explored the potential role of bats as bioindicators in river ecosystems. We hypothesized that bat activity will differ according to riverine habitat quality and that given the different degree of ecological flexibility expressed by the various bat species, responses will be species-specific. We also aimed to establish sets of species that best characterize river health, grouping them together in order to increase their indication performances regardless of their taxonomic or ecological relatedness.

Instead of relying on published maps of river quality, we evaluated it at the same sites where we surveyed bat activity. To assess the ecological quality of rivers, we adopted a dual approach. First, we analysed the macrobenthic community, using the STAR_ICMi (Buffagni et al., 2007; Buffagni and Erba, 2014), the multimetric index now in use in Italy, based on a quantitative multi-microhabitat sampling method. We also calculated the Fluvial Functionality Index (*Indice di Funzionalità Fluviale*, hereafter IFF), which considers biotic and abiotic factors for a comprehensive survey of the river and riparian ecosystem functionality (Siligardi et al., 2007; Siligardi and Cappelletti, 2008). We then assessed bat presence and activity through acoustic surveys done at the same sampling points and tested whether species activity of riverine bat assemblages is associated to changes in the values of STAR_ICMi and IFF, whose bioindication performances are well known and reliable.

2. Materials and methods

2.1. Study area and sampling schedule

Fieldwork took place in May to October 2015 and 2016 on ten rivers in Central and Southern Italy: the Aventino, Sangro, and Sagittario Rivers in the Abruzzo Region, the Calore Irpino, Calore Salernitano,