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Original Investigation

Effect of water quality on species richness and activity of desert-dwelling bats

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ABSTRACT

Natural bodies of open water in desert landscapes are important resources for survival of desert-dwelling animals and in recent years artificial bodies of water may have become equally important. In the present study we are testing if species richness and activity of bats are related to the water chemistry both in natural and artificial bodies of water, and if these measures can indicate water quality in desert habitats where water is scarce. We combined acoustic monitoring of bat activity and species richness in artificial and natural bodies of water in the Negev desert, Israel and measured 27 variables of water chemistry and quality at each site. Significant differences in water chemistry and quality were found between natural and artificial bodies of water. Species richness and activity of bats did not differ between artificial and natural bodies of water, indicating that desert-dwelling bats may benefit from artificial bodies of water, however activity within species differed between natural and artificial bodies of water. Some species of bats were only recorded at natural bodies of water, suggesting that these species are not tolerant to lower quality of water and emphasizes the importance of natural bodies of water in desert ecosystems. Our results demonstrate that community measures, such as total bat activity and species richness of bats in desert habitats, may not be sufficient to indicate changes in water chemistry and quality. Rather it is recommended and applicable to use the activity of specific species as indicators of water quality in desert habitats.

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Introduction

Bats can use open water as a source of drinking water and many species use water sources to forage over because there tends to be higher insect abundance (Vaughan et al., 1996; Grindal et al., 1999; Ciechanowski, 2002; Korine and Pinshow, 2004). Calm surface water provides a less cluttered acoustic signal return from echolocation pulses (Mackey and Barclay, 1989; Siemers et al., 2001), making bodies of open water, such as springs, ephemeral pools, waste-water treatment pools and water reservoirs, key foraging habitat for many insectivorous bats worldwide (Racey, 1998).

Many factors affect bat activity around bodies of water leading to the idea that bats can be used as bioindicators of water quality in Britain (Vaughan et al., 1996). Water surface availability is probably the most important factor; however the size of the body of water or even its depth may affect the decision of a bat to fly over the source or to drink from it (Ciechanowski, 2002; Tuttle et al., 2006). Bat activity at open bodies of water can be influenced by the quality of habitats occurring in the surrounding landscape, for example native broad-leaved forests are preferred in summer, unlike sites surrounded by intensively managed farmland (Rainho, 2007).

Water quality may affect the bats (Racey et al., 1988; Russ and Montgomery, 2002; Jones et al., 2009) directly when the bats drink from a polluted source, the extreme case being death from ingesting water containing toxic chemicals (Clark, 1981; Clark and Hothem, 1991), and indirectly through their insect prey (Cain et al., 1992). Aquatic-emergent insects are key exporters of contaminants to terrestrial ecosystems (Menzie, 1980; Runck, 2007) and data show significant lateral transfers of PCBs to terrestrial riparian predators such as Coleoptera, Diptera and species of fishes (Walters et al.,

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2008). Vaughan et al. (1996) compared the differences in bat activity upstream and downstream from sewage outputs and showed that there is a species specific effect, where downstream activity of *Pipistrellus* species decreased whereas that of *Myotis daubentonii* increased relative to upstream sites. Biscardi et al. (2007) also showed that *Myotis capaccinii* preferred bodies of water with low pollution levels. However, Naidoo et al. (2013) reported that foraging of *Neoromicia nana* was higher at polluted sites than at the unpolluted sites upstream.

The use of bodies of water might be based on availability of certain minerals, such as calcium, which is an essential limiting factor in the diet of some insectivorous bats (Kwiecinski et al., 1987; Barclay, 1994). It has been reported that reproductive females, which are known to require high levels of calcium during the breeding season, and juveniles are captured at higher frequency at sites having the "hardest" water that correlates strongly with dissolved calcium content (Adams et al., 2003).

Bats are an important component of the mammalian fauna and are the most successful desert mammals (Carpenter, 1969). In the deserts of Israel, insectivorous bats are the most diverse group of mammals (Mendelssohn and Yom-Tov, 1999), with 12 bat species recorded in the Negev Desert (Korine and Pinshow, 2004) and 17 species in the Dead Sea area (Yom-Tov, 1993; Feldman et al., 2000). The importance of bodies of open water for desert-dwelling bats is enhanced because water is scarce, particularly during summer when the perennial sources of water are dry. Thus, water may well be a key resource influencing the survival, activity, resource use and the distribution of insectivorous bats (Razgour et al. 2010). Razgour et al. (2010) found that both within and between ponds bat species richness and activity significantly increased with increasing pond size. Furthermore, manipulation of the pond size led to a significant reduction in bat species richness and activity and affected the bat community composition. Pilosof et al. (2014) showed that sewage pollution in the Negev desert affected the immune response of Kuhl's pipistrelle and those females and young bats are more susceptible to ectoparasites when foraging over polluted water.

Korine and Pinshow (2004) found that levels of bat activity in the Negev Desert were very high over wastewater treatment pools, however species richness was low. Our objective was to test if natural and artificial bodies of water are different quality resources for bats and if species richness, general activity levels of the bats and level of activity within species could indicate the quality of the water either for drinking or foraging in desert habitats. We hypothesized that artificial bodies of water have lower water quality and bats will prefer the natural bodies of water. We predicted that indices of water quality such as electrical conductivity, total suspended solids, chemical oxygen demand, total nitrogen, and heavy metal concentrations will be higher at artificial bodies of water (i.e. lower water quality) and that species richness and bat activity would be lower at these sites.

Material and methods

Study sites

The study was done in the Negev Desert, Israel between May and June 2005. We selected 33 permanent bodies of open water, including artificial bodies ($n = 17$), such as water reservoirs and wastewater treatment pools, and in natural bodies of water ($n = 16$), such as natural springs and ephemeral pools (Supplementary Appendix). We measured the average and minimum night ambient temperature using iButtons®, tied to the vegetation near each pond at approximately 0.5 m above the ground. We measured the maximum length, width and depth of the pools, and multiplied these variables to calculate an index of maximum pond volume following Razgour et al. (2010). We estimated percent of woody or herbaceous vegetation cover immediately adjacent to each pond based on Korine and Pinshow (2004).

Water chemistry

We collected water samples once for each site. We collected the water at two locations around the edge of the water (distanced ca. 3 m from each other), where bats were observed foraging and drinking. Samples were cooled and brought to the laboratory for further analysis within a few hours.

We estimated the general differences in water quality between the two types of bodies of water by measuring indices of water quality. These indices included pH and Electrical Conductivity (EC) that were measured onsite and in the laboratory by hand held multi-parameter water analyzer (model 340i WTW, Germany), Total Suspended Solids (TSS) by the gravimetric method, chemical Oxygen Demand (COD) by the standard dichromate method and total nitrogen (TN) by the persulfate digestion followed by the 2nd derivative method for nitrate (Gross et al., 1999; APHA, 2005).

In addition, subsamples were analyzed for concentrations of major and trace elements: Aluminum (Al), Barium (Ba), Boron (B), Cadmium (Cd), Calcium (Ca), Chromium (Cr), Cobalt (Co), Cupper (Cu), Iron (Fe), Lead (Bp), Lithium (Li), Magnesium (Mg), Manganese (Mn), Nickel (Ni), Phosphorous (P), Potassium (K), Silicon (Si), Silver (Ag), Sodium (Na), Strontium (Sr), Sulfur (S) and Zink (Zn) by inductively coupled plasma (ICP-AES, Varian, 720-ES, Australia). These are commonly used indices for water analysis, with well-established and standard methodology (Nollet, 2007). High values of these indices indicate generally low water quality. If not mentioned otherwise, water analyses followed standard procedures (APHA, 2005). All water analyses were done at the Zuckerberg Institute for Water Research, Ben-Gurion University of the Negev.

Bat Recording

We recorded bat activity with an AnaBat II detector (Titley Electronics, Australia) at each one of the sites from dusk to dawn for one night on the same night as water sampling. We placed the detector up to 2 m away from the edge, pointing upwards at a 45° angle. We analyzed the output of the detector using the 'Analook' software. Since the call characteristics of bats found in the area do not overlap (Hackett et al., 2013), we were able to distinguish individual calls to the species level. Bat activity was defined as the number of passes per night of recording at each site, whereby a pass is a sequence of bat calls (Fenton, 1970). Overall activity was the total number of bat passes per night, regardless of species. Species richness was determined based on the number of bat species recorded over each site, during the entire night. We did not record bat activity on windy nights, and on full moon nights, in case these factors affect bat activity levels.

Data analysis

We tested if there were differences between artificial and natural bodies of water using principal components analysis (PCA) and discriminant function analysis (DFA). We used PCA with *PCA* in package FactoMineR (Husson et al., 2013) including the entire elements present in the water chemistry analysis (see above). We used linear DFA (*lda* in package MASS, Venables and Ripley, 2002) with the first two principal component (PC) scores to classify sites by type. We tested for normality of variables using Shapiro–Wilk normality test (*shapiro.test* in R) and transformed, using natural log or square root, non-normal water chemistry variables and overall activity. We used multivariate analysis of variance (MANOVA) to compare all water chemistry and, separately, overall activity

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