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The ecological response of insectivorous bats to coastal lagoon degradation

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ABSTRACT

Coastal lagoons provide key habitat for a wide range of biota but are often degraded by intense urbanization pressures. Insectivorous bats use these highly productive ecosystems and are likely to be impacted by their decline in quality. We compared bat activity and richness and invertebrate biomass and richness across a gradient of lagoon quality (9 lagoons) in the Greater Sydney region, Australia to determine the extent to which bats and their prey were impacted by lagoon degradation. Bats were more diverse and 19 times more active at higher quality lagoons. The trawling bat, *Myotis macropus*, was absent from all low quality lagoons, but these lagoons were used by other species such as *Miniopterus schreibersii oceanensis*. Invertebrate richness and biomass did not differ significantly across lagoon quality. We examined potential mechanisms of insectivorous bat decline at degraded lagoons by measuring toxic metal concentrations in bat fur, invertebrates and sediment. Lead and zinc were detected at environmentally significant levels in the sediments of lower quality lagoons. Furthermore, lead concentrations were 6 times the lowest observable adverse effects level for small mammals in the hair of one individual *M. macropus*. The present study demonstrates that coastal lagoons support a rich bat community, but ongoing development and pollution of these habitats is likely to negatively impact on insectivorous bat species, especially trawling species.

1. Introduction

In 2012, the world's population reached 7 billion with the United Nations projecting an increase to 8 billion by the end of the decade (Department of Economic and Social Affairs/UN, 2014). Currently, 60% of the global population lives on the coast, which accounts for only 4% of the Earth's total landmass (UNEP/UN, 2006; Bellio and Kingsford, 2013). This proportion is much higher in Australia, where 85% of people live within the coastal zone, exposing adjacent ecosystems to high levels of disturbance (Creighton et al., 2015; McGuirk and Argent, 2011). Despite this, there are no formal, global estimates for the amount of degradation coastal systems have experienced (Koutsodendris et al., 2015; Lotze et al., 2006) and regional baseline data is often lacking (Pérez-Domínguez et al., 2012). It is well established, however that when coastal ecosystems are urbanized, habitat quality degrades as native vegetation is cleared (Gedan et al., 2010), waterways are eutrophied (Lapointe et al., 2015) and water quality declines (Newton et al., 2014). This degradation in habitat quality alters the community dynamics of a wide range of biota (Grimm et al., 2008).

Insectivorous bats are sensitive to urbanization at the species and community level, and are therefore considered indicators of wider ecosystem health (Jones et al., 2009). When mature trees are cleared for urban developments, bat species lose potential roosting habitat and communities shift towards disturbance-tolerant species (Basham et al., 2011; Threlfall et al., 2012). Contamination of coastal waterways is likely to be a key issue for many insectivorous bat species as aquatic invertebrates provide a vector for sediment-based contaminants to reach higher trophic positions (Walters et al., 2008; Mendoza-Carranza et al., 2016). The risk of bats consuming contaminated prey is relatively high in coastal lagoons where high population density, industrial activity and decreased water exchange with the ocean ("flushing") can result in high contaminant concentrations (Birch et al., 2015).

Prior to urbanization, coastal lagoons likely supported diverse and abundant food webs, including bat communities, due to the productivity of these systems (Lee et al., 2006). Urban coastal lagoons, however are commonly dredged, which activates otherwise dormant contaminants allowing them to interfere with biological systems (Mertens et al., 2001, 2004). Contamination at low trophic levels can have a profound ecological impact (Oberholster et al., 2008, 2012), where

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contaminants restructure prey communities by creating conditions that exclude disturbance-sensitive species (Naidoo et al., 2013; Greig et al., 2012). Insectivorous bats are exposed to direct contamination from lower trophic levels as a result of their high metabolic and food consumption rate (Sánchez-Chardi and Nadal, 2007). These shifts in prey communities may also reduce foraging opportunities for urban- or pollution-sensitive bat species while increasing them for the urban-tolerant (Abbott et al., 2009; Vaughan et al., 1996). Despite these threats, coastal lagoons remain highly productive compared to the surrounding urban landscape, providing rich foraging grounds that may buffer insectivorous bat communities against effects of urbanization. Coastal lagoons are important habitats, yet the impacts of urbanization on their bat communities are poorly known.

It is likely that the impacts of lagoon degradation on insectivorous bats will be greatest on trawling bat species as they are adapted to prey upon surface-dwelling aquatic invertebrates and small fish of waterways (Brigham et al., 1992; Frick et al., 2007). They are particularly reliant on their associated riparian zones for roosting and terrestrial foraging (Campbell, 2009, 2011). Pesticide contamination, for example, significantly lowered survivorship of juvenile *Myotis yumanensis* (Frick et al., 2007), which forage on emerging aquatic invertebrates (Brigham et al., 1992; Frick et al., 2007). Sub-lethal symptoms, such as immune system suppression have been found in *M. daubentonii* populations, contaminated with higher concentrations of organic tin compounds (used in antifouling paints for marine vessels; Lilley et al., 2013). As a result, trawling species are intrinsically linked to the state of coastal lagoons, potentially acting as indicators of both lagoon degradation and restoration.

We investigated the relationship between coastal lagoon degradation and insectivorous bats and their prey by measuring bat species richness and activity and prey richness and biomass across a degradation gradient at nine coastal lagoons in the Greater Sydney region, Australia. We further investigated contamination of bat and prey tissues, and lagoon sediments by measuring concentrations of ten metallic contaminants. We hypothesised that insectivorous bat richness and activity would be greater at higher quality lagoons than at their degraded counterparts. Similarly, prey species richness would decline with lagoon quality, though biomass may increase due to eutrophic conditions, which has been shown to stimulate invertebrate biomass in aquatic ecosystems (Dunck et al., 2015). We expected that sediments sourced from degraded lagoons would have higher concentrations of metallic contaminants than those from high quality sites, and these metallic contaminants would be present in the insectivorous bats and invertebrates at these lagoons. Finally, we hypothesised that the activity of the trawling specialist, *M. macropus* (Campbell, 2011) would decrease with lagoon degradation and that the tissues of this species would have higher concentrations of metallic contaminants than the generalist species, *Miniopterus schreibersii oceanensis*.

2. Materials and method

2.1. Study area

The study was conducted along the Australian south-east coast surrounding Sydney (Fig. 1; For Sydney during sampling period: Max. air temperature (°C) = 21.7 ± 4.7, min. air temperature (°C) = 13.8 ± 4.4, annual rain fall (mm) = 1198 ± 350; Bureau of Meteorology, 2014). Four lagoons of low-moderate quality were located within metropolitan Sydney (16–23 km from Sydney's CBD, Supp. Table 1) and included those at Curl Curl, Dee Why, Manly and Narrabeen. Much of the native vegetation surrounding these moderate and low quality lagoons was cleared for suburban development (Pressey, 1996; Roper et al., 2010). For instance, Curl Curl Lagoon is located near a former landfill site where metal-loaded ground water enters the lagoon (Supp. Table 2; Healthy Rivers Commission/NSW, 2002). The two remaining moderate lagoons, Smiths Lake and Kioloa, were the most northerly and southerly sites in the study, respectively. The vegetation at these sites was identified as sensitive to human intervention due to population growth and local economies (Benson and Picone, 2009; Healthy Rivers Commission/NSW, 2002; Roper et al., 2010). Finally, high quality sites (Marley, Meroo and Termeil lagoons) experienced high levels of environmental protection within national parks (Royal and Meroo National Parks) and have few anthropogenic pressures (Supp. Tables 1, 2).

2.2. Study design

The nine coastal lagoons were selected with reference to a ‘pressure index’ based on indicators such as water quality, proportion of cleared land and human population densities associated with the lagoon (Roper et al., 2010; Supp. Table 1; Fig. 1). Lagoons were classified as either ‘High’, ‘Moderate’ or ‘Low’ quality, with three lagoons of each quality. Coastal lagoons are defined by a salinity gradient ranging from a non-permanent channel open to the ocean (the saltwater inlet) to the freshwater tributaries (the freshwater outlet; Tagliapietra et al., 2009). We sampled bats (acoustically) and terrestrial and aquatic invertebrates at three different localities across each lagoon: the saltwater inlet (within 150 m of the inlet; mean electrical conductivity (EC) = 29.72 ± 1.62), an intermediate position on the lagoon (within 75 m of the lateral midpoint; mean EC = 22.41 ± 0.83) and freshwater outlet (on the tributary within 150 m of lagoon; mean EC = 16.75 ± 2.25).

2.3. Bat and invertebrate surveys

We surveyed insectivorous bats and invertebrates in February (late-Summer) to March (early-Autumn) 2013. One ultrasonic bat detector (Anabat, Titley Electronics) was paired with one light trap (for sampling nocturnal invertebrates) and deployed at each lagoon's saltwater inlet, freshwater outlet and intermediate locality, both sampling for an entire night. Anabats and microphones were positioned 1 m above the ground on the lagoon shore, parallel to the water's surface. Light traps were positioned at least 100 m from the Anabat to avoid influencing bat activity (Adams et al., 2005). Aquatic invertebrates were sampled at the water's edge adjacent to each lagoon locality within five separate quadrants (1 × 1 m), by agitating the lagoon bed and skimming the surface using a sweep-net. Samples from these five quadrants were then pooled. Invertebrates captured in the light traps and sweep-nets were frozen as soon as possible after collection. Invertebrates were identified to order or family, and then assigned a ‘morphospecies’ classification. Anabats were deployed for three consecutive nights, while light traps were deployed for two. Within each lagoon, each locality was sampled concurrently to reduce variability of weather on bat and insect activity.

Bat calls were identified using an automated key specific to the Sydney region (B. Law unpubl. data), within the bat call identification software program ‘Anascheme’ (Adams et al., 2010). Calls with fewer than 3 valid pulses (pulse = minimum of 6 data points and model quality of ≥0.8) were not analysed by Anascheme. Since multiple bat species may call simultaneously, calls were only assigned to a species if >50% of pulses within the sequence were attributed to that species and only calls with a minimum of three pulses classified to the same species were identified. The key grouped all steep linear calls of *M. macropus* and *Nyctophilus* spp. together and these calls were checked manually to confirm identifications. Species that have been infrequently recorded in the study area (e.g. *Chalinolobus dwyeri*) were also confirmed manually.

2.4. Sample collection and preparation for toxic metal analysis

We collected sediment, invertebrate and bat hair samples to investigate the concentration of metals within lagoon food webs. One benthic sediment sample (0 to 3 cm depth) was collected from the freshwater outlet of each lagoon. Only the freshwater outlet was sampled as