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Factors driving the distribution of an endangered amphibian toward an industrial landscape in Australia

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ABSTRACT

Although human-modified habitats often result in a loss of biodiversity, some have been found to serve as habitat refuges for threatened species. Given the globally declining status of amphibians, understanding why some species are found in heavily modified environments is of considerable interest. We used the endangered green and golden bell frog (*Litoria aurea*) as a model to investigate the factors influencing their distribution toward industrial areas within a landscape. The number of permanent waterbodies within a kilometer of surveyed sites was the best predictor of *L. aurea* occupancy, abundance and reproduction. It appears that industrial activities, such as dredging and waste disposal inadvertently created refuge habitat for *L. aurea* to fortuitously persist in a heavily modified landscape. Future conservation plans should mimic the positive effects of industrialization, such as increasing the number of permanent waterbodies, especially in areas containing ephemeral or isolated waterbodies and threatened with drought. Our findings also suggest that despite amphibians being relatively small animals, some species may require a larger landscape than anticipated. Recognizing life history traits, in combination with a landscape-based approach toward species with perceived limited motility, may result in more successful conservation outcomes. Identifying why threatened species persist in heavily disturbed landscapes, such as industrial sites, can provide direction toward future conservation efforts to prevent and reverse their decline.

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1. Introduction

Habitat modification from anthropogenic activities such as urbanization, agriculture, and industrialization is one of the primary causal agents in the global decline of biodiversity (Bar-Massada et al., 2014; Pekin and Pijanowski, 2012; Pereira et al., 2012; Vié et al., 2009). Changes to natural landscapes can directly affect species by reducing survival and reproductive output, or indirectly by disrupting ecological processes (Dodd et al., 2003; Sanderson et al., 2002). For example, habitats may become unsuitable for species due to changes in hydrological regimes (Paul and Meyer, 2008; Poff et al., 2006), disruptions to community structure (Pereira et al., 2012), alterations in nutrient cycles (Pereira et al., 2012; Vitousek et al., 1997), the accumulation of pollutants (Gallagher et al., 2014; Laurance et al., 2009; Paul and Meyer, 2008), and the fragmentation or complete loss of habitat (Bar-Massada et al., 2014; Hamer and McDonnell, 2008; McKinney, 2002). Anthropogenic activity can also lead to the introduction of invasive predators, competitors and diseases, which can further reduce species richness (Bar-Massada et al., 2014; Bradley and Altizer, 2007; Laurance et al., 2009; Leprieur et al., 2008; Pereira et al., 2012).

Although anthropogenic disturbances often result in a loss of biodiversity, it can also benefit a select few species which are better able to adapt to these environmental conditions, such as crows (*Corvus* spp.), foxes (*Vulpes vulpes*), skunks (*Mephitis mephitis*), and possums (*Trichosurus vulpecula*) (Bar-Massada et al., 2014; McKinney, 2002). Similarly, heavily disturbed landscapes, like industrialized areas, have been found to serve as habitat refuges for a small number of threatened species such as limestone quarries for arthropods and plants (Beneš et al., 2003; Krauss et al., 2009; Tropek et al., 2010; Tropek and Konvicka, 2008); gravel pits for butterflies (Lenda et al., 2012) and waterbirds (Santoul et al., 2004); rock quarries (Moore et al., 1997) and sandpits (Heneberg et al., 2013) for peregrine falcons; and fly ash deposits from coal combustion for bees and wasps (Tropek et al., 2013). Military training sites have also been found to create a mosaic of habitats that mimic natural conditions. As a result, they can contain unusually high rates of biodiversity and provide habitat for a variety of threatened plant, mammal, bird, and amphibian species (Rivers et al., 2010; Warren and Büttner, 2006; Warren et al., 2007).

Given the current globally declining status of amphibians (Bishop et al., 2012; Vié et al., 2009), their significance as indicator species, and importance in ecological communities (Blaustein and Wake, 1995; Blaustein et al., 1994), the question of why some species are

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currently found in heavily modified environments is of considerable interest. Although disease has been a key contributor to their global decline (Bishop et al., 2012), amphibians are also sensitive to many other human derived environmental perturbations due to their high skin permeability, limited mobility, small ranges and biphasic life history (Blaustein and Wake, 1995; Pope et al., 2000; Semlitsch, 2002; Vos and Chardon, 1998; Wilbur, 1980; Wyman, 1990). As a result, amphibians are more likely to be found in areas with decreased human disturbance, and it is this reason that land usage is often a better predictor of their distribution even when compared to climate (Brum et al., 2013).

Despite most amphibian species responding negatively to human induced changes within their environment, some continue to persist in these disturbed habitats (Hamer and McDonnell, 2008; Hamer and Parris, 2011; Price et al., 2011; Scheffers and Paszkowski, 2012; Smallbone et al., 2011). These species are usually broadly adapted, generalist or colonizing species with r-selected traits and large distributions that range across disturbed areas as well as their undisturbed source habitats (Hamer and Mahony, 2007). There are, nevertheless, species that do not fit this paradigm, including those that paradoxically persist in highly disturbed environments while being absent or declining in their "natural" ones. Examples include the threatened natterjack toad (*Bufo calamita*) (Denton et al., 1997; Warren and Büttner, 2008), yellow-bellied toad (*Bombina variegata*) (Canessa et al., 2013; Warren and Büttner, 2008), growling grass frog (*Litoria raniformis*) (Heard et al., 2008) and the green and golden bell frog (*Litoria aurea*) (Darcovich and O'Meara, 2008; Hamer et al., 2002; Mahony et al., 2013; White and Pyke, 1996).

To better understand this phenomenon, we used the endangered Australian green and golden bell frog as a model. This species once occurred as regional metapopulations throughout coastal natural wetlands and agricultural flood plains of eastern New South Wales but has since undergone a directional range contraction toward the coastline with more than 90% of historical sites now extinct (Hamer and Mahony, 2007; Mahony et al., 2013; White and Pyke, 2008). The species now persist in a series of isolated populations, often in highly disturbed landscapes and freshwater impoundments, such as brick pits, quarries, and various other industrial and mining sites (Hamer et al., 2002; Mahony et al., 2013; Pickett et al., 2014; Pyke and White, 2001). For this study, we investigated the factors influencing the distribution of an *L. aurea* population in a heavily modified landscape where the decline pattern highlights a contraction away from a national park and persistence in industrial areas echoing that of other populations and the species as a whole. Our aim was to investigate the landscape attributes that drive occupancy, abundance and reproduction; and identify differences in habitat features between the industrialized habitat and a national park. Recognizing the landscape characteristics which promote persistence in industrialized environments will aid conservation efforts by allowing similar habitat features to be incorporated into created or existing habitats.

2. Methods

2.1. Study area

The study was conducted on the reclaimed Ash and Kooragang Island complex situated in the Hunter River estuary, New South Wales, Australia (32° 51′ 49S, 151° 44′ 29E). This landscape was originally made up of deltaic islands and mudflats used for agriculture from the early 1800s (NCIG, 2013). Land reclamation occurred after the 1950s by joining the islands from dredged river sediment, slag, and industrial pollutants (Albrecht, 2000; Irwin, 1968; NCIG, 2013). Kooragang Island was then used for industrial activities and disposal of hazardous waste (Albrecht, 2000; NCIG, 2013). These activities mainly occurred in the southeastern half of the island which still remains heavily industrialized and is currently a major coal export port, containing industrial waste emplacement sites, railways, and coal loading facilities for the Port of Newcastle (Albrecht, 2000; NCIG, 2013). The formerly agricultural northwestern half of Kooragang is currently in the process of being rehabilitated and belongs to the Hunter Wetlands National Park system. This area is dominated by mangroves, kikuyu pasture, wetlands, and salt marsh. Kooragang Island supports one of the last remaining and the largest *L. aurea* populations in the region, with the nearest extant population located 60 km away on Broughton Island in Myall Lakes National Park (Stockwell et al., 2015). Although *L. aurea* occurs throughout Kooragang, the species exist as a patchy population which disproportionally occupies the industrialized area (Hamer and Mahony, 2010; Hamer et al., 2002).

2.2. Amphibian surveys

We surveyed 58 waterbodies across Kooragang Island over 3 breeding seasons (between October and March) from 2011 to 2014. All waterbodies were sampled 4 times within a breeding season, with 32 located in the Hunter Wetlands National Park and 26 within the industrial area. We recorded the relative abundance of calling *L. aurea* and other frog species through standardized auditory surveys (Scott and Woodward, 1994). Auditory surveys were conducted in the evening and consisted of listening for calling males for 3 min at each waterbody, followed by imitating *L. aurea* calls for 1 min and another 3 min of listening. We then conducted standardized visual-encounter surveys (VES) at each waterbody, covering the entire perimeter of the pond once (Crump and Scott, 1994). These surveys consisted of searching the emergent and fringing vegetation within the waterbody and terrestrial habitat with 1 m of the water's edge. The VES were conducted in a manner so searchers did not overlap with each other and completed when all the areas were thoroughly searched. Every *L. aurea* encountered was captured in a thin disposable plastic bag which was inverted and tied to contain the individual. At the end of the survey, we recorded the total number of *L. aurea* detected at each waterbody.

The age class and gender of captured individuals were determined by their size and secondary sexual characteristics. Those with snout to vent length (SVL) less than 45 mm were recorded as juveniles (Hamer, 1998). Individuals with an SVL greater than 45 mm were recorded as males if nuptial pads were present and as females if nuptial pads were absent. All newly-captured individuals larger than 35 mm were implanted with passive integrated transponder (PIT) tags injected subcutaneously into the dorsal lymph space. We scanned all captured animals with a Trovan LID-560ISO PIT-tag reader to identify previously tagged individuals. All animals were subsequently released back at their point of capture.

We also conducted 4 tadpole trapping surveys per season across all 3 breeding seasons to determine the presence of tadpoles, relative abundance of fish, and aquatic invertebrate family at all waterbodies following the methods of Shaffer et al. (1994). Mesh fish funnel traps (dimensions: 23 × 23 × 43 cm) were used with a 13 cm fluorescent yellow glow-stick and 10 fish food pellets as bait to attract tadpoles and aquatic vertebrates (Grayson and Roe, 2007). Traps were set during the late afternoon in the edge of waterbodies and tied to emergent vegetation with a third of the trap sitting above water to provide air to captured individuals. Traps were left overnight and inspected the following morning with the species of tadpoles and invertebrate taxa recorded. Since trapping effort may not be sufficient to detect tadpoles, we also included the presence of metamorphic individuals during trapping and VES surveys to identify a breeding event at a waterbody.

2.3. Survey and site covariates

Water quality parameters (pH and salinity levels) at each waterbody were measured prior to VES surveys using an YSI Professional Plus water meter. Measurements were taken from 1 to 4 areas at each site, by placing the probe near the middle of the waterbody so that it was completely covered with water and not stuck in sediment. We defined

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