A skink out of water: impacts of anthropogenic disturbance on an Endangered reptile in Australian highland swamps

Sarsha Gorissen, Matthew Greenlees and Richard Shine

Abstract The Blue Mountains water skink Eulamprus leuraensis is an Endangered swamp specialist known from < 60 sites and restricted to the rare, threatened and fragmented habitat of Temperate Highland Peat Swamps on Sandstone. Understanding the species’ ecology, notably its vulnerability to threatening processes such as hydrological disturbance, is essential if we are to retain viable populations of this Endangered reptile. We examined the impact of anthropogenic disturbance (longwall mining practices, development (industrial, urban, infrastructural) and damage by recreational vehicles) on this species, other herpetofauna and the swamp by surveying six paired undisturbed and disturbed sites in south-eastern Australia. The abundance of E. leuraensis was severely affected by disturbance. The species was absent from disturbed swamps, where it was replaced by its congener E. heatwolei and other woodland reptile species. Disturbance was associated with a halving of soil moisture content and a loss of surface water; the dense, live understory was replaced by a sparser, drier habitat with dead vegetation, logs, rocks and bare ground. In effect, disturbance eliminated the distinctive features of the swamp habitat, transforming it into an area that resembled the surrounding habitat in terms of fauna, flora and physical characteristics. Our surveys suggest that hydrological disturbance (groundwater loss or alterations in surface water chemistry) extirpates E. leuraensis. This species’ dependence on groundwater renders it sensitive to habitat degradation through hydrological disturbance. The conservation message for management authorities is clear: to protect the skink, protect the habitat.

Keywords Conservation, groundwater, hydrology, mining, mire, threatened ecosystem, threatened species, water pollution

Introduction

An essential first step in understanding the level of threat to a species is to determine its response to disturbance (Shine et al., 1998; Pike et al., 2010; Böhm et al., 2013). Habitat loss and degradation are key causes of extinction of threatened wildlife worldwide (Gibbons et al., 2000; Hibbitts et al., 2013). Research into the impacts of disturbance on herpetofauna has focused on the global amphibian decline (e.g. Collins & Storfer, 2003). A similar global decline may also be underway in reptiles but has attracted less research (Gibbons et al., 2000; Böhm et al., 2013), although localized declines and extinctions have been well documented (Cogger et al., 1993; Hecnar & M’Closkey, 1998; Shine et al., 1998; Reading et al., 2010; Sinervo et al., 2010). Specialist, fragile or low-mobility species may be at greatest risk when environments change (Steffen et al., 2009). One such imperilled species is the Endangered Blue Mountains water skink Eulamprus leuraensis (ARASG, 1996).

This iconic reptile is known only from < 60 isolated sites within the montane regions of south-eastern Australia (Blue Mountains and Newnes Plateau; Gorissen, 2016). It is endemic to a unique peat-swamp habitat, Temperate Highland Peat Swamps on Sandstone, which is also rare (c. 4,000 ha in extent; Hensen & Mahony, 2010) and federally listed as Endangered (TSSC, 2005). Genetic studies show low rates of lizard dispersal, and thus gene flow, between these swamps (Dubey & Shine, 2010), and even less genetic connectivity between the two main regions where such swamps occur (i.e. Blue Mountains water skinks on the Newnes Plateau are genetically distinct from those in the Blue Mountains; Dubey & Shine, 2010). Climate change is expected to cause hotter and drier weather conditions in the area, reducing water availability (CSIRO & BOM, 2007; IPCC, 2013). Longwall mining is an immediate and landscape-scale threat, given its detrimental and often severe impacts on swamps in this region (Aurecon, 2009; Goldney et al., 2010; Enforceable Undertaking, 2011) via groundwater loss through subsidence (and chemical pollution from mine-water discharge), and is listed as a Key Threatening Process in protective legislation (NSW Scientific Committee, 2005). Development (industrial, urban) and damage by vehicles are other threatening processes affecting swamps of the region (Hensen & Mahony, 2010; Fryirs et al., 2012; Belmer et al., 2015) and may potentially degrade habitat quality for this Endangered reptile. We surveyed swamps exhibiting habitat degradation (and thus altered hydrological regimes), to clarify the impact of hydrological disturbance on E. leuraensis and its swamp habitat.
Study area

The Newnes Plateau and Blue Mountains areas of south-eastern Australia, c. 100 km north-west of Sydney (Fig. 1), have a temperate climate, with mean monthly temperature of 6.3–23.1°C (BOM, 2015), mean annual rainfall of 464–1,450 mm (Keith & Benson, 1988; Whinam & Chilcott, 2002; DEC, 2006), and an underlying sandstone geology (Keith & Benson, 1988).

Methods

Study sites

The swamps sampled included Blue Mountains sedge swamps and Newnes Plateau shrub swamps (Keith & Benson, 1988; Benson & Baird, 2012). Islands within a matrix of sclerophyll woodland and open forest, these swamps are dominated by sedge, shrub and grass vegetation growing on peaty soils (Keith & Benson, 1988; TSSC, 2005; Benson & Baird, 2012). The swamps contain one or more drainage lines, and many are elongate in shape (Benson & Baird, 2012). Nine such swamps were selected for surveys (Fig. 1, Table 1), c. 3,500–120,000 m² in extent, with mean elevations of 680–1,170 m. Three swamps were pristine at one end but disturbed at the other (BS, MS, XFC1; Plate 1a), providing both control and treatment sites. We therefore sampled 12 sites in total (selected based on their level of disturbance), comprising six pairs of undisturbed and disturbed sites, paired by proximity and availability. All disturbed sites exhibited hydrological degradation, in terms of ground- and/or surface-water quantity (loss through subsidence from longwall mining practices at EWS, (Plate 1b) and JS (Plate 1c,d)), damage by recreational vehicles (XFC1 (Disturbed); Hensen, 2010) or development of infrastructure (MS (Disturbed); Fryirs et al., 2012). Surface-water quality was also affected (physical and/or chemical properties) by pollution and/or sedimentation as a result of industrial (BS (Disturbed); N. Belmer et al., unpubl. data) or urban development (BRS; Belmer et al., 2015). Eight of the study sites were on the Newnes Plateau, mainly within State Forests, at c. 1,100 m elevation, and four were in the Blue Mountains, on land managed by the Blue Mountains City Council, at c. 850 m elevation.

These 12 swamp sites span the entire known distributional range of the Blue Mountains water skink, which is the sole
endemic vertebrate of the region (Fig. 1). Prior to surveying, pilot trapping established presence of the lizard in all undis-
turbed swamps. Of the three disturbed sites, the species was
recorded prior to disturbance at JS and BRS (Fig. 1; NSW OEH,
2015) but not at EWS (Fig. 1). Although we lack a definite record of the species at the latter site, the
area has remnant vegetation and some residual peat, typical
of natural swamps, and shares common tributaries with
neighbouring swamps that contain the species (SS, Fig.
1) or that have records of it (JS, Fig. 1). We inferred the histor-
ical presence of E. leuraensis in the disturbed sections of the
remaining three swamps (BS, MS, XFC1), each of which
contain both a pristine and a disturbed area, based on pres-
ence of the lizards in the pristine area of each swamp.

Focal species

Known from < 60 populations, E. leuraensis is restricted in
distribution (Gorissen, 2016) and listed as Endangered under
both state and federal legislation (NPWS, 2001). Surveys sug-
gest that the species is a swamp specialist (> 95% of occur-
rence records from swamps, and none from an equivalent
trapping effort in surrounding woodland < 20 m from the
swamp boundary; Gorissen et al., 2015). These scincid lizards
are medium-sized (total length to 21.6 cm, c. 14.8 g), vivip-
arious, and active on warm sunny days and during the hotter
months (September to April/May). To escape predation
E. leuraensis takes shelter in dense sedgeland tussocks or
in holes in the peat substrate (Shea & Peterson, 1985).

Quantifying faunal abundance

We quantified herpetofaunal and invertebrate abundances
at paired swamp sites (disturbed and undisturbed) by
mark–recapture over 3-day sessions during November
2014–March 2015. We divided the swamp ecosystem into
three survey zones: swamp, transition (swamp margin)
and woodland (Gorissen et al., 2015; Gorissen, 2016).
Trapping was conducted only on days with a maximum
temperature of 20–35°C and no rainfall (BOM, 2015). At
each zone in each swamp we set 10 traps c. 10 m apart.
Pitfall traps (10 L, 27 × 28 cm; without drift fences; 1 per
zone) and unbaited funnel traps (18 × 18 × 75 cm; 9 per
zone) were used. Traps were checked in the late afternoon.

<table>
<thead>
<tr>
<th>Swamp site (Type)</th>
<th>Swamp name</th>
<th>Disturbance</th>
<th>Hydrological impact</th>
<th>Year disturbed</th>
<th>Elevation (m)</th>
<th>Area (m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pair 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PNP4 (Undisturbed)</td>
<td>Upper Dinner Gully</td>
<td>Longwall mining; subsidence</td>
<td>Water loss</td>
<td>2003–2004</td>
<td>973</td>
<td>42,400</td>
</tr>
<tr>
<td>JS (Disturbed)</td>
<td>Junction</td>
<td></td>
<td></td>
<td>1,170</td>
<td>4,111</td>
<td></td>
</tr>
<tr>
<td>Pair 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SS (Undisturbed)</td>
<td>Sunnyside</td>
<td></td>
<td></td>
<td>1,135</td>
<td>83,000</td>
<td></td>
</tr>
<tr>
<td>EWS (Disturbed)</td>
<td>East Wolgan</td>
<td></td>
<td></td>
<td>1,120</td>
<td>40,400</td>
<td></td>
</tr>
<tr>
<td>Pair 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>XFC1 (Undisturbed)</td>
<td>Happy Valley</td>
<td></td>
<td></td>
<td>1,075</td>
<td>119,018</td>
<td></td>
</tr>
<tr>
<td>XFC1 (Disturbed)</td>
<td>Happy Valley</td>
<td></td>
<td></td>
<td>1,085</td>
<td>2,922</td>
<td></td>
</tr>
<tr>
<td>Pair 4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BS (Undisturbed)</td>
<td>Browns</td>
<td></td>
<td></td>
<td>1,100</td>
<td>108,200</td>
<td></td>
</tr>
<tr>
<td>BS (Disturbed)</td>
<td>Browns</td>
<td></td>
<td>Development (industrial); sedimentation</td>
<td>Prior to 2008</td>
<td>1,120</td>
<td>9,057</td>
</tr>
<tr>
<td>Pair 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MS (Undisturbed)</td>
<td>Marmion Road</td>
<td></td>
<td></td>
<td>945</td>
<td>22,413</td>
<td></td>
</tr>
<tr>
<td>MS (Disturbed)</td>
<td>Marmion Road</td>
<td></td>
<td>Development (infrastructure)</td>
<td>2003–2004</td>
<td>960</td>
<td>1,925</td>
</tr>
<tr>
<td>Pair 6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SL (Undisturbed)</td>
<td>South Lawson</td>
<td></td>
<td></td>
<td>685</td>
<td>21,749</td>
<td></td>
</tr>
<tr>
<td>BRS (Disturbed)</td>
<td>Boronia Road</td>
<td></td>
<td>Development (urban); concrete contamination</td>
<td>2011–2012</td>
<td>755</td>
<td>3,790</td>
</tr>
</tbody>
</table>
Herpetofauna were identified to species, and invertebrates to order. Lizards were marked individually for later identification. Our index for population size was the number of individuals captured, excluding same-survey recaptures of individuals. Only live invertebrates were included, and we scored presence rather than abundance \( (n = 1) \) if the trap also contained material (usually scats) that served as an attractant to insects. In addition to records from ground traps we made some opportunistic sightings.

Quantifying habitat characteristics

SG recorded a suite of habitat characteristics around each trap for all three zones and all 12 swamp sites. Each quadrat was a circular area of 1 m radius, centred on the trap. Volumetric soil moisture content was calculated as the mean of three spatially randomized measurements from an MP406 Soil Moisture Instant Reading Kit (ICT International, Armidale, Australia). We also recorded the distance from surface water (drainage line or permanent pool \( \geq 0.5 \) m diameter); the proportion of substrate covered by live vegetation, dead vegetation, log, surface water, rock, and bare ground (dirt or mud); the proportion of cover/sunlight penetration at the canopy \( (> 5 \) m high) and understorey \( (0.5–5 \) m high) levels; and the proportion of substrate exposed to direct sunlight at the sun’s zenith. Distance measurements were made using a global positioning system, and canopy cover was approximated using a canopy cover estimation chart (Hnatiuk et al., 2009).

Statistical analysis

In all tests we compared disturbed vs undisturbed sites (i.e. a paired design) to control for locally variable factors. We evaluated normality and used paired statistical tests accordingly (a two-tailed \( t \)-test or Wilcoxon paired-sample test) to investigate the effects of swamp type (undisturbed vs disturbed; independent variable) on faunal abundances and habitat characteristics (dependent variables; see Table 2 for statistical tests). When differences in distributions were non-normal a standard \( \log_{10}(x + 1) \) transformation was applied (Zar, 1999). We used total abundance per swamp site as the unit for analyses (Table 2). Non-swamp lizards are taxa that (based on extensive surveys; Gorissen, 2016) usually inhabit the drier surrounding habitats (woodland and transitional zones) rather than the swamp itself (Gorissen, 2016). Our analyses of invertebrates included only species that are likely to be the prey of \( E. \ leuraensis \) (Veron, 1969; Brown, 1991; LeBreton, 1992, 1996).

Results

Impacts on threatened and other fauna

\( Eulamprus \ leuraensis \) occurred in all six undisturbed swamps but we did not record any in the six disturbed sites during our surveys (Fig. 2a, Table 2). Consistently, \( E. \ leuraensis \) was found in swamp habitat \( (> 95\% \) of records) and was the most abundant herpetofaunal species in this
Table 2 Descriptive statistics for paired test results (two-tailed t-test; Wilcoxon paired-sample test) comparing undisturbed (U) vs disturbed (D) swamp types (for swamp habitat only, unless otherwise stated) in terms of faunal and habitat characteristics.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Undisturbed (mean ± SE)</th>
<th>Disturbed (mean ± SE)</th>
<th>Test</th>
<th>df/n</th>
<th>t/S</th>
<th>P</th>
<th>Trend</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abundance, <em>E. leuraensis</em></td>
<td>6.83 ± 2.55</td>
<td>0</td>
<td>t-test</td>
<td>5</td>
<td>6.82</td>
<td>0.0010*</td>
<td>U &gt; D</td>
</tr>
<tr>
<td>Abundance, non-swamp lizards</td>
<td>0.17 ± 0.17</td>
<td>2.50 ± 0.72</td>
<td>t-test</td>
<td>5</td>
<td>-3.50</td>
<td>0.0173*</td>
<td>U &lt; D</td>
</tr>
<tr>
<td>Abundance, total herpetofauna</td>
<td>7.50 ± 2.68</td>
<td>2.83 ± 0.79</td>
<td>t-test</td>
<td>5</td>
<td>2.15</td>
<td>0.08</td>
<td></td>
</tr>
<tr>
<td>Abundance, invertebrates (prey)</td>
<td>1.12 ± 0.38</td>
<td>1.32 ± 0.21</td>
<td>t-test</td>
<td>59</td>
<td>-1.66</td>
<td>0.10</td>
<td></td>
</tr>
<tr>
<td>Soil moisture content (%)</td>
<td>86.86 ± 1.98</td>
<td>45.13 ± 4.49</td>
<td>Wilcoxon</td>
<td>60</td>
<td>833.00</td>
<td>&lt; 0.0001*</td>
<td>U &gt; D</td>
</tr>
<tr>
<td>Distance from water (m; all zones)</td>
<td>38.59 ± 2.58</td>
<td>135.37 ± 11.85</td>
<td>Wilcoxon</td>
<td>180</td>
<td>-2,856.00</td>
<td>&lt; 0.0001*</td>
<td>U &lt; D</td>
</tr>
<tr>
<td>Substrate %, live vegetation</td>
<td>66.75 ± 1.49</td>
<td>46.00 ± 3.63</td>
<td>Wilcoxon</td>
<td>60</td>
<td>573.50</td>
<td>&lt; 0.0001*</td>
<td>U &gt; D</td>
</tr>
<tr>
<td>Substrate %, dead vegetation</td>
<td>26.75 ± 1.36</td>
<td>32.83 ± 2.80</td>
<td>t-test</td>
<td>59</td>
<td>-0.39</td>
<td>0.69</td>
<td></td>
</tr>
<tr>
<td>Substrate %, water</td>
<td>0.33 ± 0.26</td>
<td>1.50 ± 0.54</td>
<td>Wilcoxon</td>
<td>60</td>
<td>116.00</td>
<td>0.0001*</td>
<td>U &gt; D</td>
</tr>
<tr>
<td>Substrate %, rock</td>
<td>4.33 ± 0.81</td>
<td>1.58 ± 0.45</td>
<td>Wilcoxon</td>
<td>60</td>
<td>-19.00</td>
<td>0.06</td>
<td></td>
</tr>
<tr>
<td>Substrate %, bare ground</td>
<td>0</td>
<td>1.42 ± 0.46</td>
<td>Wilcoxon</td>
<td>60</td>
<td>-27.50</td>
<td>0.0020*</td>
<td>U &lt; D</td>
</tr>
<tr>
<td>Cover %, canopy</td>
<td>1.83 ± 0.53</td>
<td>15.92 ± 3.37</td>
<td>Wilcoxon</td>
<td>60</td>
<td>-267.00</td>
<td>&lt; 0.0001*</td>
<td>U &lt; D</td>
</tr>
<tr>
<td>Cover %, understory</td>
<td>0.41 ± 0.30</td>
<td>2.41 ± 1.14</td>
<td>Wilcoxon</td>
<td>60</td>
<td>-15.00</td>
<td>0.13</td>
<td></td>
</tr>
<tr>
<td>Cover %, sunlight penetration</td>
<td>35.42 ± 1.90</td>
<td>48.67 ± 3.34</td>
<td>t-test</td>
<td>59</td>
<td>-4.01</td>
<td>0.0002*</td>
<td>U &lt; D</td>
</tr>
</tbody>
</table>

*Statistically significant at P < 0.05

habitats within undisturbed swamps (*E. leuraensis*, n = 41; other herpetofauna, n = 4). We trapped more non-swamp lizards in the swamp habitat in disturbed sites than in undisturbed sites (Table 2), notably the skinks Acrotiscincus platynota (n = 4), *Eulamprus heatwolei* (n = 3) and *Lampropholis guichenoti* (n = 4). In undisturbed swamps, in contrast, *E. heatwolei* was trapped only in the swamp margins. The numbers of original vs regrown tails were similar in lizards from disturbed swamps, and nine in disturbed swamps, with an equal species richness in swamp habitat in both disturbed and undisturbed sites (five species). The total abundance of herpetofauna was similar for both swamp types ($\chi^2 = 0.34, P = 0.56$).

Overall, 12 species of herpetofauna were captured in undisturbed swamps, and nine in disturbed swamps, with an equal species richness in swamp habitat in both disturbed and undisturbed sites (five species). The total abundance of herpetofauna was similar for both swamp types (Table 2).

Within the swamp habitat, invertebrates were equally abundant in disturbed and undisturbed sites (Table 2). Arthropods were the most common invertebrates. Notable species in the swamp included the burrow-forming Sydney crayfish *Euastacus australasiensis* and the burrow-forming and Endangered giant dragonfly *Petalura gigantea*, both of which were found in undisturbed but not disturbed swamp habitat.

Habitat degradation

Predictably, soil moisture declined with distance from water (n = 358, $r^2 = 0.16, P < 0.0001$). Disturbed swamps were further from water and had drier soil, with volumetric soil moisture content approximately half that of undisturbed swamps (Table 2). Substrate composition also changed with degradation, from a swamp habitat with abundant live vegetation and surface water (with almost no rocks, logs or bare ground) to one with more bare ground, rocks and dead vegetation (including logs; Fig. 2b, Table 2). Disturbance was also associated with a reduced understory density and increased sunlight penetration to ground level within the swamp habitat (Fig. 2c, Table 2). Transition and woodland habitat characteristics were relatively unaffected by disturbance to the swamp (S. Gorissen et al., unpubl. data). Although the direction of these trends is predictable, the shift in habitat characteristics (especially water availability) following disturbance is striking.

Discussion

Our surveys reveal a stark impact of anthropogenic disturbance on the distribution and abundance of the Endangered Blue Mountains water skink. Although found in all of the undisturbed swamps that we surveyed, these lizards were not caught in any of the disturbed swamps. Earlier surveys and records suggest that *E. leuraensis* occurred previously in at least five of the six disturbed swamps, and probably in all six. The loss of this iconic taxon is consistent with the species’ restriction to densely vegetated and wet swamp habitat (Gorissen et al., 2015; this study), its lower abundance in urban than in bush swamps (Gorissen et al., 2015), and the changes to its habitat that follow anthropogenic disturbance (this study). Most obviously, the disturbed swamps were drier than pristine swamps, resembling habitats that previously surrounded the swamp itself (Gorissen, 2016). In keeping with that change, disturbed swamps contained lizard species typical of these transitional and woodland habitats, rather than the swamp-specialist *E. leuraensis* (Gorissen, 2016).

Our sample size was limited by the small geographical range of the focal species, the limited availability of...
and therefore the simultaneous loss of a water skink is unsurprising. Nonetheless, the congeneric water skink *E. heatwolei*, whose distribution is less closely tied to waterlogged habitats (Gorissen, 2016), not only persisted around these swamps but moved into the swamps vacated by *E. leuraensis*. Manipulative experiments would be needed to explore whether that habitat expansion was facilitated simply by the habitat shift, or by release from interspecific agonistic interactions (Done & Heatwole, 1977).

The absence of *E. leuraensis* from disturbed swamps may reflect a physiological dependence on moist conditions (e.g. because of high rates of evaporative water loss; Heatwole & Veron, 1977; Greer, 1989; Neilson, 2002) or an ecological dependence on specific habitat attributes that persist only where soil moisture levels are high. Again, manipulations could decipher these possibilities. The loss of *E. leuraensis* from two swamps where water quantity was unaffected but water quality was compromised suggests that habitat features other than simply moisture levels may be important for this Endangered species. In keeping with this interpretation, many aspects of vegetation cover shifted significantly in our disturbed sites (especially when water was removed from the system). However, patches of relatively dense cover remained in some disturbed sites, and the frequency of caudal autotomy—often used as an index of predation risk (Smith & Ballinger, 2001) and/or of the frequency of failed predation attempts (Schwarzkopf & Shine, 1992)—did not differ between lizards in disturbed vs undisturbed swamps. Similarly, the abundance of invertebrate prey was not modified substantially by habitat disturbance. The vulnerability of *E. leuraensis* populations in the disturbed swamps may have been exacerbated by the relatively small spatial extent of most of these sites (Table 1).

The relative similarity in total herpetofaunal abundance between disturbed and undisturbed sites suggests that some species (such as *E. leuraensis*) are negatively affected by anthropogenic disturbance, whereas others (such as *E. heatwolei*) benefit. The taxa that thrive tend to be generalist woodland species, none of which are categorized as threatened (possibly reflecting the broad availability of this habitat type). The victims of anthropogenic degradation of swamps are the habitat specialists, at least one of which (*E. leuraensis*) is of major conservation concern (NPWS, 2001). In essence, swamp degradation reduces the availability of a scarce habitat type, replacing it with an already widespread habitat type. The consequences for faunal conservation are unlikely to be positive.

Translocation is a potential but unexplored management response to disturbance, and may assist in the conservation of *E. leuraensis*. Some of the swamps in this region are at risk of hydrological disturbance as a result of longwall mining on the Newnes Plateau, a stronghold for this Endangered reptile. We could capture lizards from imminently threatened sites and translocate them to novel (currently lizard-free) swamps to maintain genetic diversity within the species.
(Dubey & Shine, 2010). Biological aspects of the species that could be capitalised upon for this process include its low dispersal rate, high habitat specificity and high reproductive rate (compared to congeneric skinks in this montane environment). Analogously, Templeton et al. (2011) translocated populations of the eastern collared lizard *Crotaphytus collaris collaris* to combat local extinction without recolonization within a patchy habitat.

In summary, the Blue Mountains water skink is a habitat specialist that is restricted to < 60 groundwater-dependent swamps within an area subject to major anthropogenic pressure (e.g. Wright, 2011; Benson & Baird, 2012; Fryirs et al., 2012; Belmer et al., 2014, 2015). Habitat loss or degradation of any of these sites would further threaten this already Endangered species. Especially given its low vagility, *E. leuraensis* may be vulnerable to habitat change brought by climate change, urban pollution and longwall mining activity (Dubey & Shine, 2010). To conserve *E. leuraensis* in the wild, its rare, fragile and distinctive swamp habitat must be shielded from hydrological disturbance such as groundwater loss and surface water contamination. To conserve the genetic diversity of the species and hence maximize its resilience to any localized adverse impacts we must conserve populations from across its current range (and ideally from as many isolated swamps as is practical). To protect this species we must protect its habitat.

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**Author contributions**

SG conceived the study and conducted the research. SG, MG and RS designed the study. SG and RS analysed the data and wrote the article.

**References**


A skink out of water 617


Biographical sketches

Sarsha Gorissen primarily researches the conservation of wildlife, in particular, the conservation biology and ecology of threatened species to develop better management guidelines. Matthew Greenlees researches the ecology and evolution of Australian herpetofauna and has a broad interest in natural history, with a particular focus on the impacts of anthropogenic activities and invasive species. Richard Shine’s research concerns the interface between evolution and ecology, particularly in reptiles, with recent work focusing on major issues in conservation, especially the biology, impact and control of invasive species such as the cane toad.