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MULTISCALE HABITAT ASSESSMENT FOR THE ENDANGERED BOOROOLONG FROG (*LITORIA BOOROOLONGENSIS*): IMPLICATIONS FOR THREATENED SPECIES MANAGEMENT IN THE RURAL LANDSCAPE OF SOUTHEASTERN AUSTRALIA

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***Abstract*.—Effective management of threatened species typically requires an adequate knowledge of key habitat requirements, particularly for species occurring in highly modified landscapes that are intensively managed by humans. With a view to informing habitat management and restoration along rivers in rural landscapes occupied by the endangered Booroolong Frog (*Litoria booroolongensis*) in southeastern Australia, we examined patterns of habitat use at both the stream-reach and breeding-habitat scales to identify factors that explain variation in occupancy. To achieve this, we undertook repeated spotlight surveys, and subsequently compared habitat features between occupied and unoccupied sections of stream. Detectability of *L. booroolongensis* at the stream-reach scale was 1.00 (SE = 0.001), and 0.92 (SE = 0.026) at the breeding-habitat scale. At the stream-reach scale we identified a positive relationship between the occurrence of *L. booroolongensis* with total length of rocky habitat and average water depth, and a negative relationship with increasing canopy closure. At the breeding-habitat scale, we observed a positive relationship with rocky habitat length and abundance of aquatic rock crevices, and a negative relationship with water depth and presence of exotic willows (*Salix* sp.). These results demonstrate the important components of rocky stream habitats to the persistence of *L. booroolongensis* and will assist in the development of management prescriptions that should reduce impacts of several disturbance processes, particularly those that increase sedimentation and weed invasion.**

Key Words.—amphibian conservation; detectability; habitat analysis; habitat management

INTRODUCTION

Continuing declines and extinctions are an ongoing conservation concern for many amphibian taxa across the globe (Stuart et al. 2004; Wake and Vredenburg 2008). To date, there have been few positive conservation outcomes for amphibians, and in many cases, options appear to be limited (Beebee and Griffiths 2005; McCallum 2005). One of the major threats contributing to recent amphibian declines, and biodiversity in general, is degradation and loss of suitable habitat (Alford and Richards 1999; Stuart et al. 2004). It logically follows that developing management prescriptions to ensure the persistence of suitable habitat for threatened species is best achieved through an understanding of the species' critical habitat requirements. This can be particularly important for species occurring in an agricultural landscape where management practices can alter habitat composition, and there is often scope for modifying current practices so that they are more conducive to maintaining biodiversity (Hazell 2003; Lindenmayer and Fischer 2006).

Included in the list of threatened Australian frog species is the Booroolong Frog, (*Litoria booroolongensis* Moore 1961), a medium sized riverine species that was historically known to occupy permanent rocky streams along the Great Dividing Range of southeastern Australia (Anstis 2002). The altitudinal range of *L. booroolongensis* is 200–1300 m above sea level (New South Wales Wildlife Atlas. Available from http://www.bionet.nsw.gov.au/ [Accessed 20 June 2012]), and prior to 1990, *L. booroolongensis* was considered both common and secure (Tyler 1992). By the mid 1990s, however, the majority of known populations for this species appeared to be locally extinct (Heatwole et al. 1995; Gillespie and Hines 1999), which formed the basis for the listing of *L. booroolongensis* as endangered under both state and federal legislation in Australia, and critically endangered under the International Union for Conservation of Nature Red List (Hero et al. 2004). Subsequent surveys confirmed that *L. booroolongensis* had contracted from greater than half of its former known range, and that the South West Slopes region of New South Wales contained a high proportion of extant populations (Graeme Gillespie, unpubl. report). Additionally, *L. booroolongensis* may fill an important ecological niche, as it is typically the only obligate river breeding frog species in many of the montane and foothill streams in this region (Anstis 2002).

Currently, there is limited information on the habitat requirements of *L. booroolongensis*, except for a general association with extensive rocky stream habitat (Anstis 2002). Identifying habitat features associated with the persistence of *L. booroolongensis* is important for assessing hypotheses as to why the species has declined from much of its range in recent years. More importantly for the immediate management of *L. booroolongensis*, identifying key elements that need to be maintained for the persistence of the species would provide guidance for riparian restoration and conservation. *Litoria booroolongensis* commonly occurs in degraded habitats in rural landscapes (Hunter 2007; Graeme Gillespie, unpubl. report), and as a consequence, habitat modification may be an important threat to populations. The specific objective of our study was to identify habitat variables that explain variation in the occupancy of *L. boorolongensis* at multiple scales in the South West Slopes region of New South Wales, Australia, with a view to informing riparian habitat management and restoration.

MATERIALS AND METHODS

Study species.—*Litoria booroolongensis* is restricted to New South Wales and northeastern Victoria, predominantly along western-flowing streams of the Great Dividing Range, Australia (Heatwole et al. 1995; Anstis et al. 1998). This species is generally associated with permanent streams in wet and dry forest, woodland, and cleared grazing land (Anstis et al. 1998; Hunter 2007). Adults tend to occur on or near cobble banks or bedrock within stream margins or near slow-flowing, connected, or isolated pools that contain suitable rock habitats (Anstis et al. 1998). Breeding is known to occur in spring and early summer, from October through early January (Hunter 2007). Egg deposition sites are typically in shallow, slow-flowing sections of stream or isolated rock pools along the stream margins (Anstis et al. 1998). The egg clutch is a rigid gelatinous clump, adhered to rock in crevices (Anstis et al. 1998). Clutch sizes, based upon egg complements in museum specimens and field observations, range from 688 to 1784, with a mean of 1331 (Anstis et al. 1998; Anstis 2002). Tadpoles take two to four months to develop, metamorphosing in late summer to early autumn (Anstis 2002).

Presence/absence surveys.—We undertook surveys in the South West Slopes region (hereafter referred to as SWS) of New South Wales, Australia (Fig. 1). We surveyed 123 sites across 31 streams, which provided coverage across all but one stream with potential habitat for *L. booroolongensis* in this region (permanent streams with exposed rocky habitat; Hunter 2007). The streams we surveyed are all within the Murray and Murrumbidgee catchments, and varied in size from relatively small third-order streams that are 1–4 m wide during summer basal flow to fifth-order streams that are 5–15 m wide. We chose initial survey locations on an *ad hoc* basis, which was typically determined by accessibility (landholder permission and proximity to vehicle access).

We undertook surveys within one breeding season (November-December 2006) by walking upstream at night and spotlighting for frogs along all emergent areas to within 4 m of the water's edge. We undertook surveys when air temperature was greater than 10 °C and not during rain events. Each site at the stream-reach scale was a 500-m section of stream, with all sites being separated from each other by a minimum of 2 km. We considered the species present at a site if at least one individual was located.

At the breeding-habitat scale, we defined a site as a section of stream bank greater than 1 m in length with a continuous cover of loose or solid rock, with all sites used in the analyses separated by at least 15 m. At this scale, we considered *L. booroolongensis* present if at least one adult male in breeding condition (engaging in calling activity and having pigmented nuptial pads) was located. We considered the presence of adult males in reproductive condition as an indication that the occupied habitat was potentially suitable for breeding, as egg deposition occurs within the stream adjacent to areas occupied by calling males (David Hunter, pers. obs.). To account for imperfect detection, we undertook three surveys spaced a minimum of seven days apart for the majority of sites at the stream-reach scale and for all sites at the breeding-habitat scale.

The final analysis at the stream-reach scale included all sites where *L. booroolongensis* was located (41 sites from 25 streams), which we compared to an equivalent number of randomly chosen sites from the 82 sites where we did not find the species. All sites included in the breeding-habitat scale analyses came from 15 sections of stream from six different streams. The final analysis at the breeding-habitat scale included all sites where breeding male *L. booroolongensis* were located (39 sites), which we compared to an equivalent number of randomly chosen sites. We located random sites at the breeding-habitat scale by choosing a random point along the 500-m section of stream and then locating the nearest unoccupied site that was > 15 m from the nearest occupied site. We measured habitat variables across the frog survey period.

Stream-reach scale.—We measured and compared three habitat variables at the stream-reach scale: water depth, percentage canopy closure, and length of rocky habitat. Based upon our current knowledge of *L. booroolongensis*, we believed that these variables were likely to have some biological relevance as previous surveys identified open stretches of permanent rocky

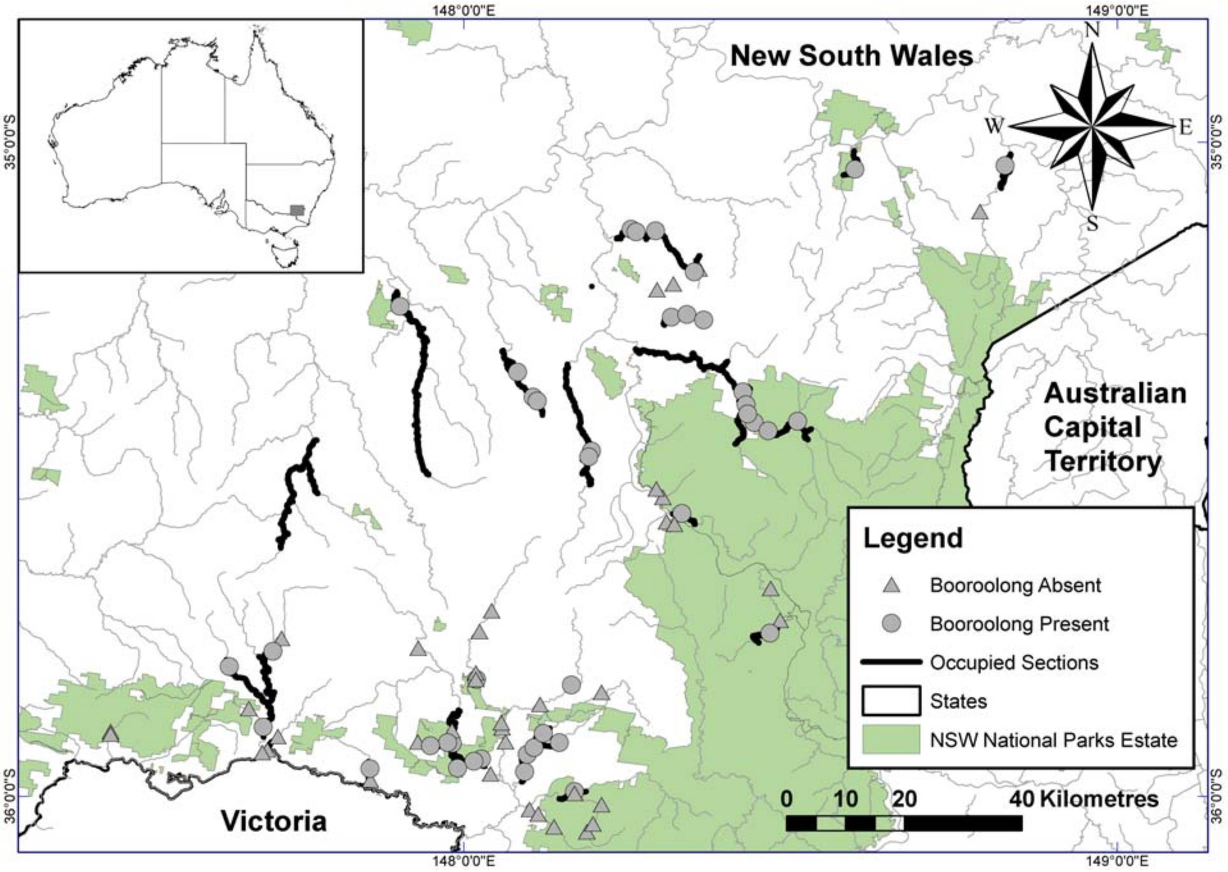

FIGURE 1. The South West Slopes region of New South Wales showing survey localities and sections of stream known to support extant populations of *Lithobates booroolongensis*. The extent of stream estimated to be occupied is from Hunter (2007). The inset shows the location of the study area on a map of Australia.

streams as important to this species (Graeme Gillespie, unpubl. report).

We measured total length of rocky habitat as the total length of cobble and bedrock surfaces along the 500-m section of stream. Clear sections of rocky habitat can be identified and are interspersed among sections of stream that are lacking rocky structures (e.g., sand bars and soil banks). We defined a cobble bank as a section of stream bank > 1 m with a continuous cover of loose rock, and bedrock as a section of stream bank > 1 m with a continuous cover of solid embedded rock.

We defined percentage canopy closure as the average percent canopy for measurements taken every 100 m along the 500-m section of stream. We estimated the percentage canopy closure for each point by taking a vertical digital image, using a Nikon Coolpix 995 (Nikon Group, Sendai, Japan), with the angle of the longest axis of the image being 30 degrees from the vertical. We determined the percentage canopy closure by overlaying a grid of 100 evenly spaced points on the image, and then counting the number of points falling on vegetation. For streams < 2 m across, we took only one image from the center of the stream, whereas for streams > 2 m, we took an image from either side.

We measured average water depth as the average of 10 measurements taken every 50 m along the 500-m section of stream. Each water depth measurement was the maximum depth determined along a straight line from one side of the bank to the other for that point on the stream.

Breeding-habitat scale.—To examine attributes of rocky patches that may be important for *L. booroolongensis* breeding habitat, we compared differences in several environmental variables between occupied and unoccupied sites (see above for the definition of a site at the breeding-habitat scale). We specifically investigated the importance of four habitat variables: length of rock habitat, average water depth, presence of exotic willows (*Salix* spp.), and number of aquatic crevices. We measured average water depth along the rock bank as the average of four evenly spaced measurements at 1 m into the stream from the water's edge. Using the above definition of rock habitat, we measured the length of rock habitat to the nearest meter. We included the influence of willow because these introduced tree species can greatly modify the riparian environment (Jayawardana et al. 2006), and we considered willow present if a mature willow (trunk diameter > 30 cm) was growing from within or was on the edge of the rock bank. While there are three willow species predominating in this region (*S. babylonica*, *S. nigra*, *S. fragilis*), we did not distinguish among them because of their consistent growth form (dense canopy and surface roots).

We included a measure of the number of aquatic crevices, as these habitat features are used by *L. booroolongensis* as oviposition sites (Fig. 2; Anstis et al. 1998) and are therefore biologically important. We defined an aquatic crevice as a space under or between rock where a 2.5 cm wide, 1 cm tall, and 3 cm long piece of metal could be freely inserted, but which was no higher than 3 cm. We considered these dimensions representative of the crevices typically used by *L. booroolongensis* for egg deposition as this was about the size of crevices frequently observed with eggs (David Hunter, pers. obs.). Regardless of crevice length, we considered continuous crevices in bedrock or under individual rocks as one crevice. The number of crevices was measured within a 50-cm by 50-cm quadrat. We randomly placed these quadrats in the aquatic environment within 1 m of the water's edge, with a quadrat position allocated to every 1-m section of stream bank. We determined the position of the quadrat within the 1-m section using a random number table to select X and Y coordinates. The number of crevices we included in the analyses was the mean number of crevices across the quadrats for that particular bank.

Data analyses.—We used logistic regression analyses to explore the relationships between the presence/absence of *L. boorolongensis* and the habitat predictor variables at both the stream-reach and breeding-habitat scales. We examined correlation between variables by visually inspecting scatter plots for all paired combinations of the variables in each analysis. Because we could not assume that *L. booroolongensis* would be detected on each visit to an occupied site, we used the approach for estimation of occupancy rates under imperfect detection devised by MacKenzie et al. (2002). This approach treats the set of sites under consideration as being drawn from two discrete categories: occupied sites, where on each visit the species will be detected with an unknown probability, *p*, and unoccupied sites where the species will never be detected. By carrying out repeated surveys, it is possible to make statistical inferences regarding the actual rate of occupancy and the probability of detecting the species during a single census.

We used the unmarked package (Fiske and Chandler 2011) run within R statistical software (R Development Core Team 2012) to fit the models to the data. Models with all possible combinations of the independent variables as predictors of occupancy (total number of models, stream-reach scale = 8, breeding-habitat scale = 16) were compared via Akaike's Information Criterion (AIC; Burnham and Anderson 2002) using the model selection features of the AICcmodavg R package (Mazerolle 2012). We did not include any interaction terms in the models. Final inferences were derived from all models with AIC cumulative weight > 0.95. Model-averaged estimates were calculated with the AICcmodavg R package (Mazerolle 2012). We graphed the relationship between occupancy and the environmental variables identified as significant across the range of values observed in the field, which involved holding the other variables in the model at their means.

FIGURE 2. Male and female Booroolong Frog (*Litoria booroolongensis*) in amplexus depositing eggs in an aquatic rock crevice. (Photographed by David Hunter).

RESULTS

Stream-reach scale.—The number of frogs found at a site (i.e., 500-m section of stream) varied from eight to 54. The top two models examining occupancy at the stream-reach scale accounted for 99% of the cumulative AIC weight. Comparison of the fitted models revealed that *L. booroolongensis* occupancy related strongly and positively to total length of rocky habitat and negatively to percentage canopy closure (Table 1). There was also a relatively weak relationship between occupancy and average water depth. Examination of the AIC values suggested that the model incorporating length of rocky habitat and percentage canopy closure provided the best fit (Table 1). Based on the probability plots, there was a high probability of *L. booroolongensis* occupying a 500-m section of stream that contained > 200 m of rocky habitat along its banks, while streams with an average canopy closure > 50% had a greatly reduced probability of being occupied (Fig. 3). While the relationship with water depth was relatively weak,

TABLE 1. Parameter and model-averaged estimates from the models with a combined Akaike's Information Criterion (AIC) cumulative weight (Cum. wt) greater than 0.95 for the (a) stream-reach scale analysis, and the (b) breeding-habitat scale analysis. The stream-reach scale analysis included the habitat variables of length of rock bank (Rlength), canopy closure (Canopy), and water depth (Depth). The breeding-habitat scale analysis included length of rock bank, water depth, presence or absence of willow (Willow), and abundance of aquatic rock crevices (Crevice).

						Occupancy					
Model	AIC	Delta AIC	AICwt	Cum. wt	Detection Intercept	Intercept	Rlength	Canopy	Willow	Crevice	Depth
(a) Stream											
1	90.12	0	0.6	0.6	10.76	0.03	1.3	-1.09			
2	90.95	0.83	0.4	0.99	11.51	0.03	1.19	-1.14			0.35
Model-averaged estimate				Mean	11.06	0.03	1.25	-1.11			0.35
				upper 95 CI	90.7	0.58	2.03	-0.4			1.01
				lower 95 CI	-68.58	-0.52	0.48	-1.83			-0.3
(b) Breeding											
1	137.78	0	0.52	0.52	2.39	-0.24	0.8		-0.68	1.16	-1.72
2	138.68	0.9	0.33	0.85	2.39	-0.14	0.81		--	1.37	-2.13
3	141.48	3.7	0.08	0.93	2.39	-0.2	--		-0.67	1.11	-1.54
4	142.82	5.03	0.04	0.98	2.38	-0.13	--		--	1.34	-1.95
Model-averaged estimate				Mean	2.39	-0.2	0.8		-0.68	1.23	-1.85
				upper 95 CI	3.04	0.52	1.52		0.1	2	-0.47
				lower 95 CI	1.73	-0.92	0.08		-1.47	0.47	-3.22

occupancy did increase as the average water depth became > 60 cm (Fig. 3). At the stream-reach scale, the detectability of *L. booroolongensis* was 1.00 (SE = 0.001) as the species was located during every survey for sites identified as occupied.

Breeding-habitat scale.—The number of breeding males detected along sections of rocky habitat during any one survey varied from one to 13. The top four models examining occupancy at the breeding-habitat scale accounted for 98% of the cumulative AIC weight. Comparison of the fitted models indicated that occupancy was related strongly and positively to length of the rocky habitat and number of aquatic crevices, and negatively to water depth and presence of willows (Table 1). A comparison of models incorporating different combinations of the descriptor variables suggested that the full model provided the best fit (Table 1). The importance of the four descriptor variables to the presence of breeding male *L. booroolongensis* was further demonstrated by the probability plots as they all displayed relatively strong relationships (Fig. 4). The detectability of *L. booroolongensis* at the breeding-habitat scale was 0.92 (SE = 0.026).

DISCUSSION

In general, our results are consistent with current knowledge of the habitat requirements of *L. booroolongensis* and provide additional information on the ecology of the species that will assist in the protection and enhancement of its habitat. The life cycle of the species appears to be particularly centered on rocky riparian and aquatic structures, around which males congregate to form breeding choruses and females deposit eggs in aquatic crevices (Anstis et al. 1998). Furthermore, the tadpole of this species appears to use aquatic rock crevices for shelter, and all frog stages can be found sheltering under rocks along the stream, both within and outside of the breeding season (Anstis et al. 1998; Anstis 2002). Accordingly, there is reasonable biological support for the notion that the species depends on sections of rocky habitats with aquatic crevices. More specifically, our results suggest that the management of *L. booroolongensis* should focus on maintaining and or enhancing riparian rocky habitat in relatively shallow water that contains ample rock crevices in the aquatic environment.

An important finding in our study was the negative association between exotic willow trees and the presence of *L. booroolongensis*. This is likely to be due to

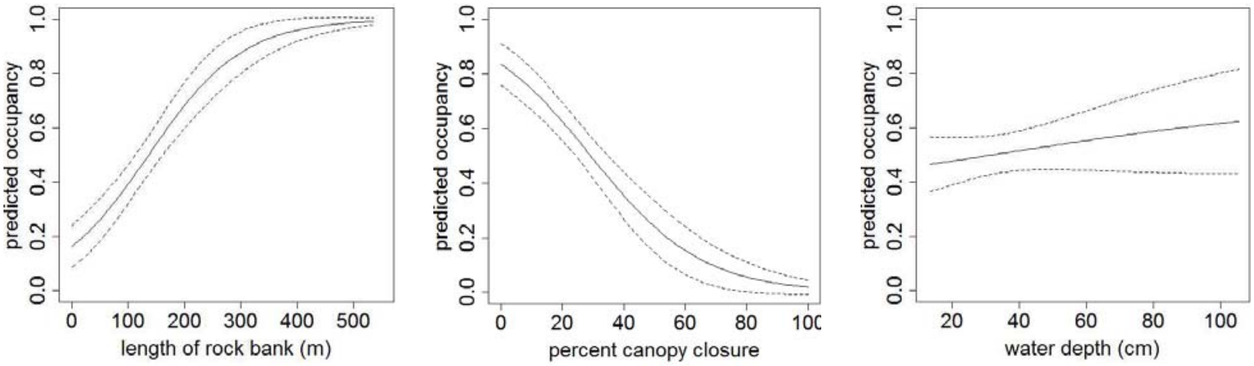

FIGURE 3. Fitted curve (solid) and standard errors (dashed lines) for model averaged probability of occupancy versus predictor variables at the stream-reach habitat scale.

willows disrupting the life-cycle of *L. booroolongensis* through altering the thermal properties of the riparian zone and reducing available oviposition sites. Compared with native trees, willows typically form a denser canopy (Jayawardana et al. 2006), which would reduce sun exposure and hence the temperature of microhabitats occupied by *L. booroolongensis*. This has the potential to reduce growth rates of frogs and tadpoles (Skelly et al. 2002), and may also increase susceptibility to pathogens such as the amphibian chytrid fungus, *Batrachochytrium dendrobatidis* (Richards-Zawacki 2010; Gantz and Sheafor 2012). The surface root mats created by willows (Jayawardana et al. 2006) would also reduce the quality of rocky patches as breeding habitat as they smother the rock crevices required by *L. booroolongensis* as oviposition sites (Anstis et al. 1998). The potential impact of willow infestation may also account for the negative association between *L. booroolongensis* and increasing canopy cover at the stream-reach scale, because many of the streams we surveyed in the rural landscape had a high abundance of this invasive plant. Because there are relatively few studies examining mechanisms by which invasive plants impact amphibians as compared to studies of impacts of invasive animals (see Cotton et al. 2012), further research should be undertaken into the physical mechanisms by which willows may be impacting *L. booroolongensis*.

The different relationship between water depth and *L. booroolongensis* occupancy at the stream-reach and breeding-habitat scales is likely a reflection of the different water depth requirements at these two scales. One advantage of breeding in shallower sections of stream is that there is likely to be greater food resources for tadpoles as a result of the greater productivity within the euphotic zone (Moss 2005). In addition, *L. booroolongensis* tadpoles are susceptible to predation by a range of co-occurring fish species (Hunter et al. 2011), and shallower water may afford some protection to eggs and tadpoles by limiting predator access. The importance of deeper water at the stream-reach scale is likely to reflect a greater propensity for occupied sections of steam to maintain free standing water during drought conditions, as *L. booroolongensis* was observed to contract from sections of stream that completely dried during recent drought events (David Hunter, unpubl. data).

A notable feature of our results was the very high detection of *L. booroolongensis*, particularly the perfect detection at the stream-reach scale. This result is due to male *L. booroolongensis* sitting in exposed positions throughout the breeding season where they can be easily detected by spotlighting, whereas surveys for most other amphibian species rely on behavior, such as calling, that may be more sporadic (Blankenhorn 1972). It should be noted that our surveys were undertaken during conditions considered optimal for detecting *L. booroolongensis*, and detection likely have been considerably lower if surveys were undertaken outside the breeding season, during less suitable climatic conditions (e.g., Weir et al. 2005), or if the species was in extremely low abundance (e.g., Tanadini and Schmidt 2011). Since high detectability increases the cost efficiency and capacity to interpret the results of survey and monitoring programs (Kéry and Schmidt 2008), our results bode well for designing a cost effective and informative monitoring program to inform future management of *L. booroolongensis* populations.

An important feature of the distribution of *L. booroolongensis* on the SWS is that the majority of occupied streams flow through privately owned and managed land in the rural landscape, which is due to the limited coverage of conservation reserves in the area where this species occurs. Thus, adequately conserving *L. booroolongensis* on the SWS will rely on ensuring the persistence of this species along streams that are subject to a variety of agricultural practices, in particular removal of riparian vegetation and constant grazing by cattle and sheep within the riparian zone. We suspect that the persistence of *L. booroolongensis* in areas with high levels of habitat disturbance may be due to its association with rocky patches along the stream,

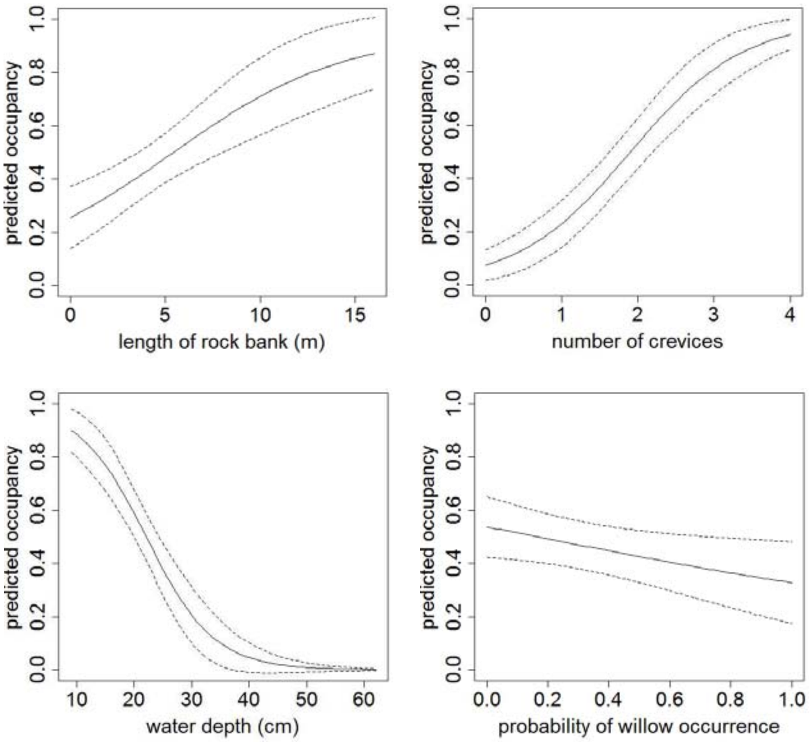

FIGURE 4. Fitted curve (solid) and standard errors (dashed lines) for model averaged probability of occupancy versus predictor variables at the breeding-habitat scale.

because removing this habitat type has not been the direct focus of agricultural practices. Nonetheless, it should not be assumed that the suitability of these rocky patches for *L. booroolongensis* will continue with current land management practices. One important component of these rocky patches and crevices in the aquatic environment appears to be highly susceptible to a range of ongoing disturbance processes, including smothering from weeds and sedimentation.

From a management perspective, the occurrence of *L. booroolongensis* in rural landscapes provides considerable opportunity for habitat management and restoration (Hazell 2003). For example, given the extensive willow infestations throughout the SWS region, and capacity for this weed to reduce the quality of *L. booroolongensis* breeding habitat, replacing willows with native vegetation is likely to be a very effective conservation strategy for this endangered species. Moreover, high sediment loads entering the stream can also fill rock crevices. Hence, the range of factors causing increased erosion and sedimentation, such as a reduction in vegetation cover, excessive livestock grazing, and use of heavy machinery near streams, are all practices that can be modified to reduce impacts on *L. booroolongensis*. In general, promoting regeneration of native riparian vegetation should provide a valuable buffer against stream erosion and sediment inflow (Prosser et al. 2001).

While removing willows, restricting stock access, and increasing riparian vegetation are desirable for a range of environmental reasons (Naiman and Decamps 1997; Pusey and Arthington 2003), it should not be assumed that populations of *L. booroolongensis* would respond positively. For example, the Natterjack Toad (*Bufo calamita*) recovery program found that this species preferred ponds with vegetation at an early successional stage, and the complete exclusion of cattle was ultimately to the detriment of this threatened toads' persistence (Denton et al. 1997). Similarly, cattle grazing has been shown to maintain a more desirable hydroperiod in vernal ponds for the California Tiger Salamander (*Ambystoma californiense*; Pyke and Marty 2005). For the management of *L. booroolongensis*, controlled grazing within the riparian zone is likely to be important to maintain suitable breeding habitat, at least until a sufficient cover of native vegetation has been restored; otherwise excessive weed growth will counteract any benefit of livestock removal.

Identifying relationships between environmental characteristics and species occupancy provides a model of existing knowledge that can be used within an adaptive management framework with a goal of creating, maintaining, and/or restoring viable habitat for the ongoing persistence of species (Lindenmayer et al. 2000). Such an adaptive management approach relies upon the modeling of alternate management options and successful monitoring and evaluation (cf., Schreiber et al. 2004) and accordingly, these aspects of a conservation program for *L. booroolongensis* must be addressed. Even though the conservation of amphibians can involve complex interactions, and must often consider a range of factors that can operate in synergy (Beebee and Griffiths 2005), we believe that the provision of viable riparian habitat is a necessary and achievable prerequisite for the conservation of *L. booroolongensis*. Finally, riparian zones are an important component of woodland environments for other fauna groups, such as birds (MacNally et al. 2000), and therefore the riparian protection and restoration approach we recommend for the conservation of *L. booroolongensis* will have broader biodiversity benefits.

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LITERATURE CITED

Alford , R.A., and S.J. Richards. 1999. Global amphibian declines: a problem in applied ecology. Annual Review of Ecology and Systematics 30:133–165.

Anstis, M. 2002. Tadpoles of South-eastern Australia: a Guide with Keys. Reed New Holland, Sydney, Australia.

Anstis, M., R.A. Alford, and G.R. Gillespie. 1998. Breeding biology of *Litoria booroolongensis* Moore and *L. lesueuri* Dumeril and Bibron (Anura: Hylidae). Transactions of the Royal Society of South Australia 122:33–43.

Beebee, T.J.C., and R.A. Griffiths. 2005. The amphibian decline crisis: a watershed for conservation biology? Biological Conservation 125:271–285.

Blankenhorn, H.J. 1972. Meteorological variables affecting onset and duration of calling in *Hyla arborea* and *Bufo calamita*. Oecologia 9:223–234.

Burnham, K.P., and D.R. Anderson. 2002. Model Selection and Multimodel Inference: a Practical Information Theoretic Approach. 2nd Edition. Springer, New York, USA.

Cotton, T.B., M.A. Kwiatkowski, D. Saenz, and M. Collyer. 2012. Effects of an invasive plant, Chinese Tallow (*Triadica sebifera*), on development and survival of anuran larvae. Journal of Herpetology 46:186–193.

Denton, J.S., S.P. Hitchings, T.J.C. Beebee, and A. Gent. 1997. A recovery program for the Natterjack Toad (*Bufo calamita*) in Britain. Conservation Biology 11:1329–1338.

Fiske, I., and R.B. Chandler. 2011. Unmarked: an R package for fitting hierarchical models of wildlife occurrence and abundance. Journal of Statistical Software 43:1–23.

Gantz, J.D., and B.A. Sheafor. 2012. Behavioral thermoregulation and its role in decreasing morbidity and mortality associated with chytridiomycosis. Integrative and Comparative Biology 52:E249–E249.

Gillespie, G.R., and H.B. Hines. 1999. Status of temperate riverine frogs in south-eastern Australia. Pp. 109–130 *In* Declines and Disappearances of Australian Frogs. Campbell, A. (Ed.) Environment Australia, Canberra, Australia.

Hazell, D. 2003. Frog ecology in modified Australian landscapes: a review. Wildlife Research 30:193–205.

Heatwole, H., J. De Bavay, P. Webber, and G. Webb. 1995. Faunal survey of New England. IV. The frogs. Memoirs of the Queensland Museum 38:229–249.

Hero, J-M., G. Gillespie, F. Lemckert, P. Robertson, and M. Littlejohn. 2004. *Litoria booroolongensis*. *In* IUCN 2012. The IUCN Red List of Threatened Species. Version 2012.1. Available from: http://www.iucnredlist.org/apps/redlist/details/23179/0. Accessed 20 July 2012.

Hunter, D. 2007. Conservation management of two threatened frog species in south-eastern New South Wales, Australia. Ph.D. Dissertation, University of Canberra, Canberra, Australia. 176 p.

Hunter, D.A., M.J. Smith, M.P. Scroggie, and D. Gilligan. 2011. Experimental examination of the potential for three introduced fish species to prey on tadpoles of the endangered Booroolong Frog, *Litoria booroolongensis*. Journal of Herpetology 45:181–185.

Jayawardana, J.M.C.K., M. Westbrooke, M. Wilson, and C. Hurst. 2006. Macroinvertebrate communities in willow (*Salix* spp.) and reed beds (*Phragmites australis*) in central Victorian streams in Australia. Marine and Freshwater Research 57:429–439.

Kéry M., and B.R. Schmidt. 2008. Imperfect detection and its consequences for monitoring for conservation. Community Ecology 9:207–216.

Lindenmayer, D., and J. Fischer. 2006. Habitat Fragmentation and Landscape Change: an Ecological and Conservation Synthesis. Island Press, London, UK.

Lindenmayer, D.B., C.R. Margules, and D.B. Botkin. 2000. Indicators of forest sustainability biodiversity: the selection of forest indicator species. Conservation Biology 14:941–950.

MacKenzie, D.I., J.D. Nichols, G.B. Lachman, S.

Droege, J.A. Royle, and C.A. Langtimm. 2002. Estimating site occupancy rates when detection probabilities are less than one. Ecology 83:2248–2255.

MacNally, R., T.R. Soderquist, and C. Tzaros. 2000. The conservation value of mesic gullies in dry forest landscapes: avian assemblages in the box-ironbark ecosystem of southern Australia. Biological Conservation 93:293–302.

Mazerolle, M.J. 2012. Model selection and multimodel inference based on (Q)AIC(c). R Foundation for Statistical Computing, Vienna, Austria.

McCallum, H. 2005. Inconclusiveness of chytridiomycosis as the agent in widespread frog declines. Conservation Biology 19:1421–1430.

Moore, J.A. 1961. The frogs of eastern New South Wales. Bulletin of the American Museum of Natural History 121:149–386.

Moss, B. 2005. Ecology of Fresh Waters. Blackwell Publishing, Oxford, UK.

Naiman, R.J., and H. Decamps. 1997. The ecology of the interfaces: riparian zones. Annual Review of Ecology and Systematics 28:621–658.

Prosser, I.P., I.D. Rutherfurd, J.M. Olley, W.J. Young, P.J. Wallbrink, and C.J. Moran. 2001. Large-scale patterns of erosion and sediment transport in river networks, with examples from Australia. Marine and Freshwater Research 52:81–99.

Pusey, B.J., and A.H. Arthington. 2003. Importance of the riparian zone to the conservation and management of freshwater fish: a review. Marine and Freshwater Research 54:1–16.

Pyke, C.R., and J. Marty. 2005. Cattle grazing mediates climate change impacts on ephemeral wetlands. Conservation Biology 19:1619–1625.

R Development Core Team. 2012. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Richards-Zawacki, C.L. 2010. Thermoregulatory behaviour affects prevalence of chytrid fungal infection in a wild population of Panamanian Golden Frogs. Proceedings of the Royal Society B: Biological Sciences 277:519–528.

Schreiber, E.S.G., A.R. Bearlin, S.J. Nicol, and C.R. Todd. 2004. Adaptive management: a synthesis of current understanding and effective application. Ecological Management and Restoration 5:177–182.

Skelly, D.K., L.K. Freidenburg, and J.M. Kiesecker. 2002. Forest canopy and the performance of larval amphibians. Ecology 83:983–992.

Stuart, S.N., J.S. Chanson, N.A. Cox, B.E. Young, A.S.L. Rodrigues, D.L. Fischman, and R.W. Waller. 2004. Status and trends of amphibian declines and extinctions worldwide. Science 306:1783–1786.

Tanadini, L.G., and Schmidt, B.R. 2011. Population size influences amphibian detection probability: Implications for biodiversity monitoring programs. PLoS ONE 6(12): e28244.doi:10.1371/journal.pone. 0028244

Tyler, M.J. 1992. Encyclopedia of Australian Animals–Frogs, The National Photographic Index of Australian. Angus and Robertson, Sydney, Australia.

Wake, D.B., and V.T. Vredenburg. 2008. Are we in the midst of the sixth mass extinction? A view from the world of amphibians. Proceedings of the National Academy of Sciences of the United States of America 105:11466–11473.

Weir, L.A., J.A. Royle, P. Nanjappa, and R.E. Jung. 2005. Modelling anuran detection and site occupancy on North American Amphibian Monitoring Program (NAAMP) routes in Maryland. Journal of Herpetology 39:627–639.

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