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Frog ecology in modified Australian landscapes: a review

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Abstract. Frog decline in Australia has often occurred where habitat is relatively intact. Habitat alteration and loss do, however, threaten many species. Widespread degradation of aquatic and terrestrial systems has occurred since European settlement, with only 6.4% of Australia's landmass reserved for conservation. But what do we know about how frogs use modified Australian landscapes? Do wildlife managers have the information required to ensure that frog habitat is considered in the management and revegetation of these areas? This review examines published Australian research on frogs to determine knowledge on processes of habitat loss and degradation. Literature that informs landscape restoration and revegetation is also examined to determine whether the habitat needs of frogs are considered. While many threats associated with frog habitat loss and change have been identified there is little quantitative information on frog–habitat relationships in modified landscapes, habitat fragmentation or knowledge of the connectivity required between terrestrial and aquatic frog habitat. Without this information frogs have largely been ignored in efforts to revegetate and manage for the conservation of Australian biota outside reserves. Ecological frog research in modified landscapes is required to avoid land-management decisions and conservation strategies based on inappropriate assumptions of how biota respond to landscape change.

Introduction

Frogs exhibit the highest level of endemism amongst major animal groups in Australia (State of the Environment Advisory Council 1996) with 208 species listed in the Action Plan for Australian Frogs (Tyler 1997). Thirty-one Australian frog species are listed as extinct, endangered or vulnerable by the new *Commonwealth Environment Protection and Biodiversity Conservation Act* (1999). Recent recommendations to the IUCN increase this number to 40 (J.-M. Hero, personal communication). Since 1985 eleven frog species have declined or disappeared in northern Queensland from relatively undisturbed habitat in World Heritage Areas, secure National Parks and State Forests. These include several species of *Taudactylus*, *Rheobatrachus*, *Mixophyes* and *Litoria* (McDonald and Alford 1999). While there are several hypotheses postulating the reasons for these declines, causal factors have yet to be confirmed (Hero 1996; McDonald and Alford 1999).

Unexplained frog declines have received considerable attention (e.g. Czechura 1991; Tyler 1991*a*, 1991*b*, 1991*c*; Couper 1993; Ingram and McDonald 1993; Trenerry *et al.* 1994; Hero 1996; White 1996). Such attention is essential, as these species may become extinct if the threatening processes at work are not identified and halted. In response to this situation, further research is needed in systematic population monitoring and investigation of potential agents of decline, such as disease, pollutants, climate change, UV-B radiation and altitudinal influences as well as synergistic effects (Goldingay *et al.* 1999; Hines *et al.* 1999; Osborne *et al.* 1999). Potential impacts of climate change (Osborne *et al.* 1999; Broomhall *et al.* 2000) and pathogens (Trenerry *et al.* 1994; Laurance *et al.* 1996; Berger *et al.* 1998, 1999) have received particular attention (but see Laurance 1996; Hero and Gillespie 1997).

Habitat alteration and loss have not been major foci for research on frog decline as major losses have often occurred where habitat is relatively intact. These processes have, however, been emphasised as important considerations for frog conservation. Rawlinson (1981) noted that past research on Australian frogs had focussed on taxonomy, evolution and ecology and that little attention has been paid to the effects of human impacts, in spite of their ecological significance. He stressed the need for researchers and wildlife authorities to direct their attention to the impact of humans on the Australian frog fauna. This situation has not altered greatly. Tyler (1997) recognised that while European land uses have greatly altered the Australian landscape, the effects of these activities on frog conservation and habitat availability has remained largely unknown.

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Since 1788 forest cover across Australia has been reduced by an estimated 38% (National Forest Inventory Australia 1998). Australia's streams and their associated wetlands and billabongs have suffered widespread degradation through land clearing and engineered modifications, harvesting for water and the introduction of pollutants and exotic taxa (see Lake and Marchant 1990; Barmuta *et al.* 1992; State of the Environment Advisory Council 1996). In Victoria approximately 27% of all streams are considered to be in 'poor to very poor' condition (Mitchell 1990).

Land reserved for conservation covers only 6.4% of Australia's total land area (Australian Bureau of Statistics 2001). Several ecosystems are poorly represented within these areas, including arid and semi-arid environments, native grassland and wetlands (Department of the Environment, Sport and Territories 1996*b*). Ehmann and Cogger (1985) noted that a small percentage of Australia was reserved for nature conservation and stressed the need for the conservation of herpetofauna (reptiles and frogs) outside reserves. But what is known about how frogs use modified Australian landscapes? What is known about the impacts of habitat loss and changes on population dynamics, habitat connectivity and processes of dispersal and immigration? Do wildlife managers have the information required to ensure that frog habitat is considered in the management and revegetation of modified Australian landscapes?

The aim of this paper is to review published Australian research on frogs and determine current knowledge regarding processes and associated impacts of habitat loss, degradation and landscape change. Australian research literature that supports and informs landscape restoration and revegetation is also examined to determine the extent to which the characteristics and habitat needs of frogs have been considered. Frog conservation outside reserves is also discussed. This review draws primarily from published sources and is not a comprehensive account of the grey (unpublished) literature. International literature is discussed where relevant.

Habitat loss, modification and frog decline

The magnitude of landscape change across Australia is reflected by the considerable number of frog species for which habitat loss and/or change is recognised as a threatening process. Of 41 species recently recommended for IUCN listing as near threatened, vulnerable, endangered or critically endangered, 20 (49%) have declined as a result of habitat loss or degradation, or are threatened by such processes (see Table 1). Ehmann (1997) listed 25 species as threatened in New South Wales, with habitat loss and fragmentation considered as a threat to every species listed. Seventeen of these species are considered under acute, or particularly acute, threat from habitat fragmentation and loss (Ehmann 1997).

There are also species currently without status that are considered threatened by habitat loss and fragmentation. Populations of *Notaden melanoscaphus* in coastal areas near Townsville are disappearing as a result of urbanisation (McDonald and Alford 1999), although this species also occurs in many areas where habitat loss is not occurring. *Litoria cirtropa*, *L. phyllochroa*, *L. nudidigitus* and *L. barringtonensis* are considered susceptible to habitat fragmentation and change (Gillespie and Hines 1999), as are *Assa darlingtoni* (Lemckert 1999) and *Philoria sphagnicola* (Knowles and Mahony 1997). With increasing salinity problems in areas that have been extensively cleared, Roberts *et al.* (1999) warned that Western Australian frog species face an uncertain future.

Species that lack protection through threatened status may still be exposed to habitat loss and modification and thus warrant attention. Mahony (1996) listed several species that have shown no evidence of decline but argued that it should not be assumed they are common or secure. Changes in frog numbers may go unnoticed unless they are of a considerable magnitude (Tyler 1991*a*). In the absence of monitoring, gradual species decline may be overlooked. Mahony (1996) advocated regular monitoring of common species. The presence of common species may be recorded during surveys for threatened species and warrants publication for future comparison (e.g. Gillespie and Hollis 1996; Lemckert and Morse 1999).

The impacts of habitat loss and change on widespread species may go unnoticed because of their extensive distribution. Declines at a local level caused through deterministic processes, such as habitat destruction or pollution, may contribute to a gradual breakdown in the connectivity of extant populations. In the case of the relatively abundant species *Bufo bufo* in the United Kingdom, it has been demonstrated that habitat fragmentation resulting from urban development is associated with lower levels of genetic diversity and fitness (Hitchings and Beebee 1998). In addition, there is a positive correlation between genetic diversity and developmental stability of tadpoles (i.e. growth abnormalities), as well as tadpole survival. The study concluded that the long-term viability of urban populations appeared to be in doubt. Evidence suggested that population isolation occurred approximately 60 years prior to the study (Hitchings and Beebee 1998). This is a substantial time lag between habitat isolation and the resulting population effects.

Undetected decline also may occur through impacts on immigration and dispersal. These impacts may become apparent only when populations are exposed to random stochastic events that cause localised extinctions. For example, Bradford (1991) showed that *Rana muscosa* has disappeared from many higher-elevation sites in the Sierra Nevada of California. Introduced fish species that eat the larvae of *R. muscosa* occur in the streams that connect extant

Table 1. Australian frog species recommended for IUCN listing that are considered threatened by some form of habitat loss or degradation

IUCN rec. = recommended listing. NT = near threatened, V = vulnerable, E = endangered, CE = critically endangered. Recommended IUCN listings were determined by a joint IUCN/Australian Herpetology Society workshop in February 2001 (see also www.gu.edu.au/school/asc/ppages/academic/jmhero/ash/news.html)

Species	Habitat threats	IUCN rec.	Reference
Adelotus brevis	Altered hydrological regimes; increased nutrient and sediment loads	NT	Hines *et al.* (1999)
Crinia tinnula	Land clearing; altered hydrological regimes; increased nutrient and sediment loads		Hines *et al.* (1999)
Geocrinia alba	Wetland destruction/degradation; streamflow disturbance; land clearing	CE	Tyler (1997); Roberts *et al.* (1999)
G. vitellina	Fire; feral pigs	V	Wardell-Johnson and Roberts (1991); Roberts *et al.* (1999)
Heleioporus australiacus	Timber harvesting; high-intensity or -frequency fire; road maintenance / urban runnoff; housing and other development	V	Gillespie (1990); Recsei (1997)
Litoria aurea	Urban development; wetland destruction / degradation	V	Tyler (1997)
L. booroolongensis	Flow modification; willow invasion of riparian areas; land clearing	CE	Anstis *et al.* (1998); Hunter and Gillespie (1999); Gillespie and Hines (1999)
L. cooloolensis	Land clearing; altered hydrological regimes; increased nutrient and sediment loads	NT	Hines *et al.* (1999)
L. freycineti	Land clearing; altered hydrological regimes; increased nutrient and sediment loads	V	Hines *et al.* (1999)
L. olongburensis	Land clearing / urban development; wetland destruction or degradation; streamflow disturbances; inappropriate fire regimes	V	Tyler (1997); Hines *et al.* (1999)
L. piperata	Pastoral practices / forestry practices	CE	Mahony *et al.* (1997*b*)
L. raniformis	Wetland destruction/degradation; seepage change; water /soil pollution; cattle damage	E	Tyler (1997)
L. spenceri	Streamflow disturbance / native forest logging; recreational damage; cattle damage	CE	Tyler (1997)
L. subglandulosa	Cattle grazing; aerial spraying; timber harvesting	NT	Anstis (1997)
Mixophyes balbus	Grazing/clearing of upper catchments; logging	V	Mahony *et al.* (1997*c*)
M. iteratus	Logging / clearing of upper catchments; water pollution	E	Mahony *et al.* (1997*a*)
Philoria frosti	Seepage change; native forest logging; water /soil pollution; alpine development; recreational damage	CE	Tyler (1997)
Pseudophryne australis	Urban growth	V	Thumm and Mahony (1999)
P. corroboree	Stream flow disturbance; seepage change; water/soil pollution; alpine development / recreational development; cattle damage	CE	Tyler (1997)
Spicospena flammocaerulea	Fire	V	Roberts *et al.* (1999)

populations of the species (Bradford 1991), thus hampering the movement of individuals that might otherwise recolonise areas where the species has been extirpated (Bradford *et al.* 1993). Blaustein *et al.* (1994) and Sjögren (1991) suggested that unsuitable habitat between extant groups and those that have disappeared may explain the sudden disappearance of amphibians from relatively pristine areas in several different countries. There is currently no evidence to support this hypothesis within the Australian context.

Local population maintenance and regional population connectivity are processes that warrant consideration when widespread species suffer declines. Within Australia there are several common, widespread frog species that have experienced declines. The green and golden bell frog (*Litoria aurea*) was once common and widespread (Courtice and Grigg 1975; Humphries 1979; Osborne *et al.* 1996*a*) and many populations experienced decline after 1977 (Osborne *et al.* 1996*a*). The tusked frog (*Adelotus brevis*) has historically been considered as a secure, widespread species with a distribution from Nowra, on the south coast of New South Wales to mid-eastern Queensland (Hines *et al.* 1999). The species is thought to have suffered decline on the Northern Tablelands of New South Wales (Gillespie and Hines 1999). In the past, Bibron's toadlet (*Pseudophryne bibronii*) was considered common, with an extensive distribution across south-eastern Australia (Barker *et al.* 1995). However, the species is now listed on the Australian Capital Territory (ACT) endangered fauna list and has disappeared from the Northern Tablelands of New South Wales (Thumm and Mahony 1997).

Research on frog habitat loss, habitat change and landscape change

Ecological research on Australian frogs covers aspects such as biogeography, and the influence of natural processes and the environment on frog diversity, speciation and endemism (e.g. Cogger 1981; Caughley and Gall 1985; Woinarski and Gambold 1992; Wardell-Johnson and Roberts 1993; Williams and Pearson 1997; McGuigan *et al.* 1998; Oliver *et al.* 1998; Woinarski *et al.* 1999*a*, 1999*b*; Williams and Hero 2001). Spatial variation in frog–habitat relationships has also received some attention (e.g. Pyke and White 1996; Parris and McCarthy 1999; Parris 2001). There is also a range of studies that have examined the genetic structure of populations, effective population size, processes of population divergence, and phylogeography (e.g. Osborne and Norman 1991; Osborne *et al.* 1996*b*; Driscoll 1998*a*; Donnellan *et al.* 1999; Driscoll 1999; James and Moritz 2000).

There is a substantial body of literature that has identified specific forms of habitat loss and alteration that threaten frogs (e.g. Gillespie 1990; Wardell-Johnson and Roberts 1991; Webb 1991; Hollis 1995; Daly 1996; Lemckert 1998; see also references in Table 1). In many cases, this literature does not, however, provide an understanding of how frogs are affected by these processes, either by identifying the relevant spatial scale of organisation (i.e. if the threat acts at the individual, local population or regional scale) or stage of the life cycle (i.e. at the egg, tadpole, metamorph or adult stage).

Australian publications with data on processes of frog habitat loss, alteration or the use of modified landscapes are listed in Table 2. Seven studies have examined the characteristics of disturbed or constructed breeding habitat, such as farm dams. One of these studies (Tyler and Watson 1998) presented a qualitative description of frog habitats created by humans. Four of the remaining six studies were limited to a small number of waterbodies (see Table 2.). Only one study (Driscoll 1998*b*) covered the genetic implications of landscape change and habitat loss.

Post-European land clearing is considered a serious threat to biodiversity (Glaznig 1995; State of the Environment Advisory Council 1996), and is thought to be a major influence on the distribution of many frog species in south-eastern Australia (Gillespie and Hines 1999). However, only two studies have examined how frogs respond to this process and its associated impacts (Margules *et al.* 1995; Hadden and Westbrooke 1996). Both of these studies were limited in their ability to provide insight into the impacts of land clearing. Hadden and Westbrooke (1996) examined frog–habitat relationships in woodland remnants on the Wimmera Plains of Victoria. The study examined terrestrial habitat characteristics but did not consider proximity of the remnants to aquatic breeding environments. In addition, limited inference can be drawn from this study due to the small sample size (12 remnant patches) and the large number of explanatory variables analysed (eight).

Margules *et al.* (1995) examined the response of the common eastern froglet (*Crinia signifera*) to habitat fragmentation. They used pitfall traps to compare frog numbers at forest sites both before and after the sites were reduced to isolated patches. They did not record breeding activity or outline the availability of breeding habitat within, or adjacent to, the study sites. Study results may therefore be interpreted in several different ways. Individuals captured in pitfall traps may have been resident at the forest site, or may have been moving to or from surrounding breeding habitat. The lack of captures after surrounding forest was cleared was interpreted as an extinction event within the isolated patches. However, lack of captures may have been more of a response to the destruction of breeding habitat within the created matrix (habitat loss) than a response to the creation of forest patches. Return of frog captures within the fragments four years after clearing was interpreted as recolonisation of the fragments, but may have merely reflected the return of the species to the cleared 'matrix'.

Efforts to determine the impacts of forestry practices on frogs have also been limited in success. Goldingay *et al.* (1996) examined the effects of timber harvesting on frogs but was unable to collect sufficient data to allow analysis. They noted that no study had been able to adequately assess the response of frogs to forest disturbance resulting from logging. Despite considerable survey effort, Kavanagh and Webb (1998) also were unable to collect sufficient data to assess the effects of logging on most of the frog species they recorded. In addition, they were unable to find any adequate assessments of logging impacts in south-eastern Australia with which to compare their results. While there have been some recent contributions (e.g. Lemckert 1999; Gillespie 2002), the impacts of forestry on frogs remain virtually unknown (Gillespie 2002).

Habitat use and effects of landscape change on frogs in agricultural areas have received even less attention. Knowledge of how frogs use such landscapes is limited to several papers regarding land clearing and farm dams (as mentioned previously) and salinity (see below and Table 2). While the creation of wetlands in agricultural areas (i.e. farm dams) has been considered advantageous for frogs (e.g. Bennett *et al.* 1998; Tyler and Watson 1998), changes in the availability and nature of wetlands within agricultural landscapes are thought likely to have had deleterious effects (e.g. Brock and Jarman 2000). Neither position is currently supported by any substantial published data (but see Hazell 2001).

Issues such as salinisation are recognised as major threats to frogs (Ferarro and Burgin 1993; Bennett *et al.* 1998). However, in a review of information available on impacts of

Table 2. Australian quantitative frog research covering aspects of habitat loss and change
Studies are listed in subcategories of research

Topic	Details	Reference
Habitat loss/change	Sand mining	Letnic and Fox (1997)
	River impoundment	Hunter and Gillespie (1999)
	Urbanisation	Thumm and Mahony (1999)
	Sedimentation	Gillespie (2002)
	Logging/forestry	Goldingay *et al.* (1996); Kavanagh and Webb (1998); Lemckert (1999)
	Fire	Bamford (1992); Driscoll and Roberts (1997)
	Salinity	Tyler (1972); Main (1990); Baumgarten (1991); Quincy (1991); Ferraro (1992)
	Loss of course woody debris	MacNally *et al.* (2001)
	Forest disturbance	Parris (2001)
	Stream disturbance	Gillespie and Hollis (1996)
	Introduced predators/competitors	Harris (1995); Reynolds (1995); Pyke and White (1996); Morgan and Buttemer (1996); Webb and Joss (1997); Crossland and Azevedo-Ramos (1999); Crossland (2000); Gillespie (2001)
Habitat loss/change	Introduced chemicals	Beck (1956); Johnson (1976); Brooks (1981); McIlroy *et al.* (1985); Birks and Olsen (1987); Read and Tyler (1990); Baker and Waights (1994); Read and Tyler (1994); Bidwell and Gorrie (1995); Millen (1995); Read (1997); Mann and Bidwell (1998)
Landscape fragmentation and landscape patchiness	Naturally patchy rainforest	Gambold and Woinarski (1993)
	Forest clearing / patch isolation	Margules *et al.* (1995)
	Remnant woodland patches	Hadden and Westbrooke (1996)
Genetics	Maintenance of evolutionary processes	Driscoll (1998*b*)
Use of disturbed or created breeding habitat	6 wetlands	Ferraro and Burgin (1993)
	4 road construction ponds	Watson *et al.* (1995)
	75 waterbodies of all types	Pyke and White (1996)
	4 urban/agricultural billabongs	Healey *et al.* (1997)
	3 created ponds	Pyke and White (1999)
	70 farm dams and 5 wetlands	Hazell *et al.* (2001)
Movement and mobility	Mark–recapture dispersal study	Driscoll (1997)
	Use of riparian stream habitat	Lemckert and Brassil (2000)
	Genetic examination of dispersal	Berry (2001)

salinity on Australian wetland and river biodiversity, Bailey and James (1999) identified a complete lack of data on the salinity tolerances of adult Australian frogs and the effects of salinity on tadpoles or eggs. The only published research found by this review was based on historical evidence of decline in the giant burrowing frog from saline areas in Western Australia (Main 1990), and the impacts of exposure of several species to salt water (Tyler 1972). There are also several unpublished studies that examined salt tolerances of Australian frog species (see Table 2).

Twelve studies have examined the impacts of chemical pollutants on Australian frogs (Table 2). However, the effects on frogs of many chemicals applied to the Australian environment remain largely unknown (Mann and Bidwell 1999). For example, only one study has examined the effects of chemicals used in fertiliser (nitrate) (Baker and Waights 1994). This study was limited to one species (*Litoria caerulea*) and examined effects on tadpoles only. In addition, all tests were undertaken in the laboratory, and may not reflect the risk posed by fertiliser use in the natural environment.

No studies have examined the use of modified or created breeding habitat with consideration of surrounding landscape attributes (such as topographic placement or terrestrial vegetation cover). In addition, no published work has examined the spatial relationship between aquatic and terrestrial needs of Australian frogs and how this has been affected by landscape change.

Conservation of biota outside reserves

Many Australian publications collate or review research on conservation of biodiversity outside reserves and the impacts of landscape management and landscape change (e.g. Saunders *et al.* 1987, 1990, 1993; Saunders and Hobbs 1991;

Hobbs 1992; Hobbs and Saunders 1993; Moritz and Kikkawa 1993; Lunney *et al.* 1994; Bennett *et al.* 1995; Bradstock *et al.* 1995; Glaznig 1995; Department of the Environment, Sport and Territories 1996*a*). Several animal groups are represented within such literature, primarily birds (Kitchener *et al.* 1982; Saunders 1989; Arnold and Weeldenburg 1990; Ford and Barrett 1995) and mammals (Kitchener *et al.* 1980*a*; Arnold *et al.* 1993; Humphries and Seebeck 1995; Lumsden *et al.* 1995; Laurance 1997) with some literature on reptiles (Kitchener *et al.* 1980*b*; Smith *et al.* 1996) and invertebrates (Majer and Brown 1986; Greenslade 1992; Margules *et al.* 1994; Horne *et al.* 1995; Bromham *et al.* 1999).

Frogs have received considerably less research attention on habitat fragmentation and landscape change than mammals and birds. Major publications referred to in the previous paragraph included only two research papers covering aspects of frog conservation. Main (1990) examined museum specimens to piece together the impacts of salinity on *Heleioporus albopunctatus*, while Wardell-Johnson and Roberts (1991) used species distribution, population density, land tenure and historical decline to develop conservation measures for the *Geocrinia rosea* complex.

In summarising a 400-page synthesis of herpetology in Australia, Lunney and Ayers (1993) stated that herpetologists had contributed little to the general debate on conserving biodiversity. They argued that, as a result, frogs would not receive adequate attention in decisions about new national parks, the impacts of development, or the allocation of conservation-orientated research funds. Less than a decade later, there are further implications relating to landscape restoration and conservation outside reserves. This is a growing field of endeavour within Australia (e.g. see Thackway and Stevenson 1989; Saunders *et al.* 1990, 1993; Campbell 1991; Recher *et al.* 1993; Greening Australia 1995; Saunders and Hobbs 1995; Davie and Hynes 1997). Such approaches draw their foundations from literature on the biotic impacts of landscape change, to which frog research has contributed little (see Table 2). As a result, current efforts in landscape planning to conserve biodiversity do not incorporate the habitat needs of frogs (e.g. Hobbs 1993; Freudenberger 1999; Lambeck 1999).

Animal groups, such as frogs, that lack research attention are readily overlooked. This is reflected in the literature that examines the conservation of ‘biodiversity’, ‘fauna’ or ‘biota’. Such literature often lacks any reference to frogs (e.g. Burbidge and McKenzie 1989; Bennett 1993; Gill and Williams 1996; Landsberg *et al.* 1997*a*; Ludwig *et al.* 2000). However, several studies have noted the almost complete absence of information on frogs before proceeding to examine impacts from land-use or land-management practices on the Australian biota (Saunders and Hobbs 1992; Hobbs *et al.* 1993; Metzeling *et al.* 1995; Wilson 1996; Tolhurst 1999). In their comprehensive manual for the restoration of Australian streams, Rutherfurd *et al.* (2000) included frogs as a ‘flagship’ animal group. While they covered impacts of stream turbidity, fine sediment and salinity on frogs, and provided stream-restoration recommendations for frogs, the information was broad and descriptive and lacked referenced examples. This reflects the paucity of Australian research in these areas.

Bennett *et al.* (1998) examined wildlife in the Victorian Riverina, presenting principles for wildlife conservation in this predominantly agricultural region. They included a section on frog species of the region and discussed threats from human activities. However, only three references were cited. Sections covering other animal groups included detailed discussion on habitat clearance and fragmentation, structure of habitat, impacts of water regulation and use, impacts of changing landscape pattern and microhabitat. Such discussion was absent from the frog section.

In a review of extinction, conservation and management of Australia’s terrestrial vertebrate fauna, Recher and Lim (1990) noted that there is less evidence of change in the distribution and abundance of frogs and reptiles than birds and mammals. They contended that small size, low energy requirements and the use of torpor to avoid adverse conditions has allowed frogs and reptiles to persist in regions where other vertebrates have been excluded by European modifications to the environment. There is little empirical data to support such generalisations. Evidence of distributional change requires thorough systematic surveys. Very few such surveys have been undertaken for Australian frog species across their geographic or environmental range (Hines *et al.* 1999; Parris 2001). Sadlier and Pressey (1994), for example, sought information on frogs for the development of a herpetofauna conservation strategy in the western division of New South Wales but found very little long-term monitoring, and a lack of detailed information on the habitat requirements of most species. In assessing the need for conservation efforts they had to rely upon data associated with museum specimens. The notion that frogs are less sensitive to European modification of the environment than birds or mammals (Recher and Lim 1990) is not supported by empirical data. This reinforces the need for more research on frog response to landscape modification.

Reasons for the lack of frog research

One of the main reasons for the lack of ecological frog research may be the slow development of frog taxonomy within Australia. By 1773, there were 22 identified mammal species, 93 bird species, 14 reptiles and 63 fish from Australia, but no frogs (Whitley 1970). In 1961 Moore recognised only 92 species of Australian frogs, whereas in 1997 208 species were recognised (Tyler 1997). Taxonomy provides an essential foundation for examining ecological relationships. Tyler (1979) conceded that frog taxonomy was slowed by the need for frog specimens to be preserved in alcohol.

The lack of research on frog response to landscape modification may also reflect the difficult nature of surveying frogs. Frogs differ from other terrestrial vertebrate groups in the environmental conditions that influence daily and seasonal activity patterns (e.g. rainfall, humidity and temperature) in combination with the landscape characteristics that influence habitat use (e.g. the availability of moisture in both aquatic and terrestrial environments – see Hazell 2001 and Hazell *et al.* 2001). In many cases frogs are seasonal residents of aquatic systems and cryptic or dormant residents of terrestrial systems. Despite differences in activity patterns and habitat needs between frogs and other major vertebrate groups, there are several examples of Australian studies that have attempted to include frogs within surveys for other animal groups (e.g. Margules *et al.* 1994; Kavanagh and Webb 1998; Oliver *et al.* 1998; Mac Nally *et al.* 2001). In these cases, the experimental design has generally been a compromise between animal groups. This limits the ability of such studies to capture the complexity of frog habitat requirements or daily, seasonal and climatic activity patterns. For example, Goldingay *et al.* (1996) designed a survey to examine the impacts of timber harvesting on reptiles and frogs. Using visual searches and hand searches they surveyed 20 forest plots (each 15 × 500 m). Each plot was surveyed twice. This effort yielded only two frog species and a total of 17 individuals. However, a qualitative survey of potential frog breeding habitat within the study area found 15 frog species (Goldingay *et al.* 1996). This demonstrates the limitations of the study design for collecting frog data.

The lack of Australian frog research on the use of modified landscapes is not reflected in the international literature, which addresses a comprehensive set of issues using quantitative methods and systematic surveys. These issues include planning for conservation in modified landscapes (Harris and Harris 1997), genetic effects of habitat fragmentation (Edenhamn *et al.* 2000), application of metapopulation dynamics (Sjögren 1991, 1994; Pope *et al.* 2000), fragmentation effects of roads (Vos and Chardon 1998; deMaynadier and Hunter 2000), spatial analysis of aquatic and terrestrial habitat use in modified landscapes (Knutson *et al.* 1999), habitat fragmentation associated with farmland (Vos and Stumpel 1995; Kolozsvary and Swihart 1999), forest fragmentation (Marsh and Pearman 1997; Gascon and Lovejoy 1998; Gibbs 1998; Gascon *et al.* 1999), use of linear forest remnants (de Lima and Gascon 1999), breeding pond isolation (Marsh *et al.* 1999), landscape connectivity (Lehtinen *et al.* 1999), mobility and movement (Oldham 1985; Dodd and Cade 1998; de Lima and Gascon 1999; deMaynadier and Hunter 1999), use of terrestrial habitat (Dodd 1996; Lamoureux and Madison 1999) and the use of created or modified pond environments (Stumpel and van der Voet 1998; Baker and Halliday 1999; Kupfer and Kneitz 1999). Most of these issues are yet to be examined for any Australian frog species. These studies provide a useful foundation for understanding how Australian frogs are likely to use modified landscapes. However, Australian research on these issues is required, given the unique adaptations and high level of endemism displayed by Australian frogs.

Discussion

The importance of maintaining frog diversity in modified landscapes was recognised nearly two decades ago by Ehmann and Cogger (1985). However, little attention has been given to this issue through published Australian frog research. While many threats associated with habitat loss and change have been identified, there is little understanding of the underlying processes associated with frog response that is based on systematic survey or quantitative methods. There is little quantitative information on frog–habitat relationships in modified environments, information on the impacts of habitat fragmentation, or knowledge of the connectivity required between terrestrial and aquatic habitat. Our limited understanding of how landscape change has influenced natural processes of population dynamics is reflected by the fact that a natural stochastic event (drought) has been listed as a threatening process for some species of Australian frogs (Tyler 1997).

Guidelines for revegetation are being developed across Australia (e.g. Lefroy *et al.* 1991; Holmgren 1994; Howell *et al.* 1994; Stelling 1994; Williams 1995). Revegetation provides a foundation for the conservation of biodiversity, sustainability of agriculture and restoration of functional processes in agricultural landscapes (Saunders and Hobbs 1995). Saunders and Hobbs (1995) considered support for revegetation as an opportunity for ecologists and conservation biologists to design strategies that meet agricultural needs and the need for habitat reconstruction. But restoration requires information on the ecological characteristics of species (Fry and Main 1993). No such database exists for frogs in modified environments. As a result, frogs are largely being ignored in current efforts to conserve the native biota outside reserves, particularly in agricultural areas. When management recommendations are made for frogs in modified landscapes they are not underpinned by published research (e.g. Gaskett 1999; Rutherfurd *et al.* 2000). Such efforts make a valuable contribution towards frog conservation but are unable to provide detail, through the absence of supporting ecological research.

While there is an urgent need to continue research on unexplained Australian frog declines, there is also a substantial argument for landscape-scale frog research, particularly in modified landscapes. This is needed to avoid land-management and conservation strategies that are based on inappropriate assumptions of how biota respond to landscape change. Frogs are unlikely to receive adequate attention in landscape-scale conservation strategies and restoration efforts until there is a better understanding of what influences habitat use in modified environments.

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