

Life-history studies and the impact of recent forest harvesting on two frog species, *Crinia signifera* and *Litoria ewingii*

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Abstract

*Most studies measuring the impact of forest harvesting on amphibians have compared population abundance and/or species richness between harvested and control plots. However, large variations in population size are typical of amphibian populations, making it difficult to separate natural variation from trends due to human impacts without impractically high levels of replication. A series of six related investigations were conducted in order to evaluate the utility of life-history studies as an alternative approach for monitoring ecological change associated with clearfell logging. Two amphibian species, *Crinia signifera* and *Litoria ewingii*, were studied. The results indicated that recent clearfell logging influenced life-history parameters in all three stages of the amphibian life cycle, providing information about the way in which the environment produced by recent logging is ecologically distinct from unharvested forest. Life-history studies are able to demonstrate how frogs relate to the commercial forest landscape in Tasmania's southern forests and can inform land management decisions.*

Introduction

Research investigating the impact on amphibians of anthropogenic environmental change is limited in Australia (Hazell 2003). Amphibians have been widely recognised as being particularly sensitive to

environmental change (but see critique by Pechmann and Wilbur 1994). This is because they have permeable eggs, gills and skin, and their different life stages expose them to different parts of ecosystems, thus enabling study of the effects of different environments on the one species. Amphibians also have a limited ability to disperse relative to other tetrapods (Blaustein *et al.* 1994) and are physiologically restricted to moist habitats (Blaustein *et al.* 1994; Tyler 1994; deMaynadier and Hunter 1995).

Our understanding of how logging affects amphibians is based predominantly on literature from North America (deMaynadier and Hunter 1995). In general, these studies have shown a higher abundance of amphibians in control plots than in recently harvested clearfell plots but have detected no significant difference in species richness. Responses tended to be species-specific, with the median abundance for salamanders 4.3 times greater in control than clearfell coupes, but only 1.7 times greater for frogs and toads (deMaynadier and Hunter 1995). Long-term responses to forest age and regeneration are more variable than those resulting from recent logging, making generalisations difficult. It has been suggested that the response of species to forest regeneration may rely on the development of specific microhabitats associated with forest succession (such as

coarse woody debris, deep litter, closed canopy and higher moisture) rather than forest age *per se*.

In Australia, Lemckert (1999) studied the effect of disturbance from selective logging on amphibians at streams and ponds in northern New South Wales. Total species richness at streams increased with logging disturbance but remained unaffected by disturbance around ponds. The response in amphibian abundance at both streams and ponds was species-specific, with some species favoured by logging and others negatively affected.

Most studies measuring the impact of forest harvesting on amphibians have compared population abundance and/or species richness between harvested and control plots. However, amphibians are known for their very high diurnal, seasonal and annual variability in abundance (e.g. annual population fluctuations may vary 10- to 100-fold (Berven 1990; Berven and Grudzien 1990; Blaustein *et al.* 1994; deMaynadier and Hunter 1995). Consequently, such studies require significant resource investment in replication because large variation in population size lowers the power of statistical tests to separate trends due to human impacts from those due to natural variation (Pechmann and Wilbur 1994).

These sampling difficulties are exacerbated by a number of common challenges relating specifically to the experimental design of forestry-related studies. These include difficulty in obtaining true replicates, high spatial and temporal environmental variability (forest type, elevation, weather during migratory period, age discrepancies between control stands and treatments), long time-scales for forest change that typically exceed the duration of project funding, and difficulties with integrating sampling times with logging schedules in order to collect pre-treatment data. The difficulties of addressing all these issues are so great that the results of many

amphibian/logging studies have been compromised in their ability to distinguish trends relating to the logging treatment (deMaynadier and Hunter 1995).

Rather than measuring the abundance and species richness of amphibians as an indicator of environmental health, life-history studies investigate the life-time pattern of growth, development and reproduction. deMaynadier and Hunter (1995) highlighted the response of amphibian life-history traits to logging as a topic having received little attention. Life-history traits (such as the size at birth, growth pattern, age at maturity, size at maturity and number of offspring) can change in response to different environmental conditions. In this way, an organism can maximise fitness (i.e. maximise the number of successful offspring produced within its life time) in a given habitat.

Life-history studies have been extensively used to investigate the consequences of distinct environments resulting from differences in elevation and/or latitude (Berven 1982; Berven and Gill 1983; Gollmann and Gollmann 1996; Merila *et al.* 2000; Laugen *et al.* 2002). However, few studies have investigated the response of life-history traits to anthropogenic land disturbance. The distinct environments produced by habitat modification have the potential to alter factors such as the number and size of eggs produced by females, offspring survival, body condition and the age and size at first reproduction. Such life-history changes can have implications for population health, fitness and abundance, and may be easier to measure and analyse than population abundance.

There are two potential advantages of life-history studies when studying modified environments. Firstly, they may be a useful complement to traditional monitoring as they may provide ecological explanations for differences in abundance and species richness. For example, life-history studies may explain why the effects of logging



Photo 1. An adult *Litoria ewingii*.



Photo 3. An adult *Crinia signifera*. This species is about two-thirds the size of *Litoria ewingii*.



Photo 2. The small size of *Litoria ewingii* metamorphs is apparent from a 5c coin.

are species-specific, which particular life stages are affected, and why effects vary with forest type and silvicultural practices. Secondly, life-history studies may provide alternative and more powerful approaches in their own right for measuring the impact of logging on amphibian populations.

To explore the potential of this novel application of life-history studies, a review was undertaken to examine how the life history of pond-breeding frogs could potentially be altered by clearfell logging (Lauck 2005a). A number of the hypotheses raised in this review were then tested in a series of six related experimental studies (Lauck 2004) to investigate if habitat changes resulting from clearfell logging in the native forests of southern Tasmania affect the life history of two anuran species, *Crinia signifera* and *Litoria ewingii* (Photos 1–3).

This paper provides an integrated synopsis of the findings of these discrete, published investigations (Lauck 2005a, b, c; Lauck *et al.* 2005a) to allow forest managers to assess their value for decision-making, and to highlight investigative avenues for researchers who wish to advance the exploratory nature of life-history studies.

Choice of frog species

The common brown froglet (*Crinia signifera*) and the brown tree frog (*Litoria ewingii*) were chosen as model species with which to investigate the life-history responses of amphibians to logging in cool temperate forests in Tasmania. Both species are abundant in south-eastern Australia and throughout Tasmania, and are habitat generalists that are not excluded by logging. These characteristics make them ideal species for exploratory life-history studies because a number of research difficulties are minimised.

- Abundance is sufficient to avoid compromising sample sizes and statistical power.
- Logistical difficulties resulting from monitoring rare or cryptic species are avoided.
- Unlike data from species with limited distributions, extrapolation to similar forests elsewhere in the same bioregion may be possible.
- The practical problems involved in working with species that are not resilient and have a high risk of mortality within the experimental context are reduced.

In southern Tasmania, both species breed in permanent and ephemeral standing water (Martin and Littlejohn 1982). Breeding occurs predominantly during early spring and summer, with autumnal breeding less common. *Litoria ewingii* lays eggs in non-foamy jelly masses attached to submerged vegetation, with clutch sizes of 300–500 eggs (Lauck 2004). Eggs from the same clutch may be laid in a number of separated clumps. In contrast, the eggs of *C. signifera* are laid singly, attached to substrate and vegetation at the bottom of the pond. Clutch sizes of 150–500 eggs have been noted in Tasmania (Lauck 2004). *Litoria ewingii* has a typical larval period of approximately 1.5–7 months (Sokol 1984; Tyler 1994), although over-wintering of tadpoles also occurs in Tasmania (Lauck 2004). *Crinia signifera* generally has a much shorter larval period of 1.5–3 months (Littlejohn and Martin 1974; Williamson and Bull 1992; Lemckert 2001). Metamorphosis occurs predominantly in summer; however, *L. ewingii* metamorphs have been seen in early spring after larval overwintering (Lauck 2004). At metamorphosis, *L. ewingii* froglets have a snout-to-vent length (SVL) of 14.3 ± 2.4 mm; *C. signifera* metamorphs are much smaller, with a SVL of 9.1 ± 1.0 mm (Lauck 2004).

The study area

The field site was centred on the Warra Long-Term Ecological Research (LTER) Site, located within the southern forests of Tasmania, approximately 60 km south of Hobart (43°3'S; 146°39'E) with an elevation range of 37 to 1260 m a.s.l. (Brown *et al.* 2001). Vegetation at the site consists predominantly of temperate broad-leaf forest (mainly *Eucalyptus obliqua* wet forest), and its logging and fire history has resulted in a full range of successional stages of this forest type. More site details can be found on the website www.warra.com.

Part of the aim of the Warra LTER Site is to develop an understanding of ecological

processes in Tasmania's wet *Eucalyptus obliqua* forests, and the development and demonstration of sustainable forest management practices. Standard logging practices in wet sclerophyll forest and mixed forest consist of clearfell, burn and aerial sowing with eucalypt seed on a planned rotation of 90 years (Hickey and Neyland 2000). Investigations were limited mostly to unlogged forests and forests that had been clearfelled within the last five years, in order to maximise the chance of discerning differences in life history.

Outline of experimental studies

Effects of shading

Lauck *et al.* (2005b) investigated the consequences of decreased shading associated with vegetation removal around permanent and ephemeral ponds for the growth, development and survival of *Litoria ewingii* tadpoles. Within-pond enclosures were used to house tadpoles in four permanent ponds (two shaded and two unshaded). Twenty-eight artificial ponds were constructed (14 shaded and 14 unshaded) to investigate shading effects in ephemeral ponds.

Larval growth and development in shaded and unshaded ponds were not found to be statistically different in permanent ponds, but were significantly affected by pond elevation (altitude). Survival was lower in shaded than in unshaded permanent ponds. In ephemeral ponds, increased shading resulted in a significantly slower developmental rate. The outcomes of the study provided guidelines for vegetation management around breeding sites. The findings suggest that the larval success of *L. ewingii* is not likely to be enhanced by vegetative buffer zones around permanent pond margins but may be enhanced by ensuring heterogeneity of shading conditions around ephemeral ponds.

Reproductive investment

Lauck (2004, Chapter 7) examined whether logging alters maternal reproductive investment and offspring life history for both *Crinia signifera* and *Litoria ewingii*. Eggs were collected from four ponds located in logged forest and five ponds located in unlogged forest, and raised to hatching under common laboratory conditions. Egg size was significantly greater at unlogged than at logged sites for both species. For *L. ewingii*, size at hatching was also significantly greater at unlogged sites but, for *C. signifera*, size at hatching was independent of logging treatment. There was a significantly greater survival at hatching in *C. signifera* eggs from logged sites. The findings indicate that the post-logging environment produces conditions that are ecologically distinct from those in unlogged forest. However, increased maternal investment in egg size did not necessarily confer increased fitness for subsequent life stages in the particular experimental larval environment tested.

Pond isolation

Lauck (2005b) investigated the impact of logging and pond isolation on pond colonisation by *C. signifera* in order to determine the fraction of the forest used as habitat, the effect of logging upon movement through the forest, and the consequences for reproductive output.

Replicated artificial ponds were placed at increasing distances (20, 100, 250 and 500 m) from nine permanent breeding sites (four surrounded by logged coupes and five surrounded by unlogged forest). The experiment was based on the premise that, other factors being equal, the time to colonise new ponds will increase, firstly, with the resistance of the landscape and, secondly, with increasing migration distance. For example, if frogs tended to inhabit the immediate locality around a permanent breeding site, it would take longer for more distant artificial ponds to be colonised than those closer to the permanent pond.

The rate of colonisation, the frequency of colonisation, male size and female size (inferred from clutch size) were monitored over two breeding seasons. There was no significant statistical difference in the mean number of clutches, clutch size, the rate of colonisation and male size with distance from a permanent pond. This indicates that frogs are evenly distributed throughout the forest for up to 500 m from a permanent breeding site. The frequency of colonisation and female size did not differ significantly with logging treatment. Body size of males from unlogged sites was significantly greater than that of males from logged sites (26.0 ± 0.36 mm and 24.1 ± 0.27 mm, respectively). Ponds surrounded by unlogged forest were colonised twice as fast as those surrounded by logged forest (115 ± 45.8 days compared to 331 ± 37.4 days, respectively). There was almost twice the abundance of natural standing water in logged forest as in unlogged forest (4.2 m and 2.4 m per 60 m, respectively); however, the amount of standing water suitable for breeding did not differ significantly with logging treatment. Therefore, the presence of natural standing water did not confound the colonisation experiment. These data indicate that logging increased the resistance of the landscape and slowed movement to breeding sites. As a result, total reproductive output (total clutches laid) at ponds surrounded by unlogged forests was double that of ponds surrounded by recently logged forest over the two seasons sampled. After two seasons, however, the number of ponds colonised did not differ.

Life-history studies

Lauck (2005a) reviewed the potential of life-history studies as a novel approach for investigating the impact of logging on pond-breeding frogs, and provided detailed background information and references.

The life-history characteristics for *C. signifera* at the Warra LTER Site have been reported by Lauck (2005c). A pitfall-trap study was used to investigate the importance

of body size (snout-to-vent length), age, body condition (males only), season, and growth history on male and female life-history traits. Body size (but not age) was a significant determinant of clutch size, total reproductive output (clutch mass) and oviduct mass for females. Season was the predominant influence on egg size, with eggs significantly smaller in summer than in other seasons. Age and body size were both significant determinants of direct investment in male gonads (testes size). Differences in male and female body size and life-history responses show that selective pressures are sex-specific for this species.

Breeding site

Lauck *et al.* (2005a) assessed breeding-site suitability for *L. ewingii* by correlating habitat components (pond proportions, shading, elevation and shape) with life-history traits at 28 small to medium-sized ponds (all of which had active breeding populations of *L. ewingii*). By identifying the types of ponds that maximise life-history traits which increase fitness (such as early metamorphosis, larger size at metamorphosis and greater abundance), it was possible to determine the habitats that are optimal for the species. *Litoria ewingii* laid eggs and metamorphosed significantly earlier in smaller ponds, which may reduce larval mortality due to pond desiccation. Snout-to-vent length at metamorphosis increased significantly with elevation (altitude), and metamorphosis was significantly earlier in less shaded ponds. Elevation and pond shape and/or pond isolation were significant determinants of the maximum number of tadpoles in a pond. The study showed that breeding ponds that maximised the fitness of *L. ewingii* were higher elevation ponds with reduced shading, steeper bank slopes and/or reduced pond isolation. The outcomes of the study provided specific species management recommendations for the anthropogenic construction of appropriate breeding sites.

Discussion

Population structure

Commercial management of the southern forests of Tasmania has increased the abundance of standing water in the landscape (Martin and Littlejohn 1982). All medium to large water bodies sampled in the study area were artificial; that is, they were constructed adjacent to roads as water supplies for fire management by Forestry Tasmania. These ponds provided permanent breeding sites for amphibians at the study area.

Commercial forest management can also increase the abundance of small, ephemeral standing water in two ways. Firstly, the activities of harvest machinery during the process of logging often produces compacted soil ruts from which water is unable to drain into the underlying soil (Wronski 1984). Such water puddling was twice as common in logged coupes as in unlogged forest at Warra (Lauck 2005b). However, the amount of this type of standing water suitable for breeding did not differ significantly between logged and unlogged forest (presumably because water volumes were too small to sustain successful tadpole development). Secondly, the construction of roads provides long-term increases in standing water along road gutters. This significant increase in standing water resulting from commercial forest management has potentially increased the abundance of amphibians in commercially managed forests (Littlejohn and Martin 1974; Taylor 1991).

The increase in pond density is likely to alter the population structure of amphibians. Pond-breeding frogs commonly exist as metapopulations (Skelly 2001). A metapopulation follows a cyclic pattern over time, where local extinction of a population at one site is followed by recolonisation of the site by dispersing individuals from other populations. When the presence of a species is examined over all sites in the

landscape at one time, only a fraction of all suitable sites will be found to contain breeding populations. Over time, the presence or absence of breeding populations at individual sites will be highly dynamic. For frogs, studies have found that the rate of pond colonisation decreases (Marsh *et al.* 1999) and the likelihood of population extinction increases (Skelly *et al.* 1999) with increasing distance between ponds.

Because commercial forest management at Warra has increased pond density and decreased distances between ponds, extinctions of populations are less likely and colonisation from surrounding ponds more likely. Thus, amphibian populations at Warra are less likely to conform to such typical population structures. *Crinia signifera* colonises experimentally constructed artificial ponds located up to 500 m from a permanent breeding site within two breeding seasons (Lauck 2005b). Considering that the average and maximum distance between permanent breeding ponds in the study area is 0.8 and 2.4 km, respectively, movement between ponds is likely to be frequent for this species. Furthermore, population extinctions seem uncommon because *C. signifera* and *L. ewingii* were present at all permanent ponds in all study years (Lauck *et al.* 2005a), again suggesting that the population structures of the study species do not conform to that typical of a metapopulation.

Utilisation of the forest landscape

Because the rate and intensity of colonisation of artificial ponds located at increasing distances from a permanent pond did not differ statistically, it was evident that *C. signifera* disperses evenly throughout the forest landscape for a distance of at least 500 m around permanent breeding sites (Lauck 2005b). The species is likely to be capable of greater dispersion than this but high permanent pond density prohibited testing of this possibility. It is clear, however, that a significant fraction, if not all, of the commercial forest landscape

is utilised as habitat by *C. signifera*, and that the management of forests for species with similar landscape-use habits should consider the broader forest landscape rather than just the immediate vicinity of breeding sites.

The rate of movement of *C. signifera* through unlogged forest was almost twice that through logged forest, as artificial ponds in unlogged forests were colonised twice as quickly as those located in logged forest (Lauck 2005b). Habitat differences such as more consistently humid conditions or greater cover from predators may explain why unlogged forests provide less resistance to amphibian movement than the post-logging environment. The rate of colonisation may also have been influenced by the significantly larger male size recorded in unlogged forest (Lauck 2005b) because larger frogs may actually be able to hop further. Also, because amphibians can lose large amounts of moisture through their skin, they are physiologically restricted to moist habitats. However, larger frogs have a smaller relative surface area that reduces the risk of dehydration. In consequence, they are likely to exhibit greater mobility during drier times (Bellis 1962). Therefore, larger frogs may be able to forage and disperse for longer periods and over longer distances than smaller frogs.

Reproductive investment

For *C. signifera*, male body condition was greater in unlogged than in logged sites (Lauck 2004). Body condition may contribute to male mating success as the species is an extended breeder, and the longer that individuals spend calling at the breeding site the greater their chance of attracting a mate. Because significant amounts of energy are devoted to calling, increased stored energy will allow males to maximise calling endurance, especially at optimal times of breeding success, before lost body mass must be restored through foraging.

Clutches laid in artificial ponds did not differ significantly in size (number of eggs) with logging treatment (Lauck 2004). From this it can be inferred that, unlike males, female body size did not differ in response to logging (because female size is positively correlated with clutch size for *C. signifera* at Warra: Lauck 2005c). However, different rates of movement through logged and unlogged forest did affect the total reproductive output in artificial ponds. Because artificial ponds were colonised faster, the total reproductive expenditure (the total number of clutches laid over the two breeding seasons) of ponds in unlogged forest was double that of ponds surrounded by logged coupes (Lauck 2005b). However, after two seasons, the total number of ponds colonised did not differ and, as a result, any difference in total reproductive expenditure is likely to be less significant. Therefore, differences in the rate of movement through the forest are not likely to be catastrophic for species such as *C. signifera* that are able to rapidly exploit breeding sites. However, for species such as *L. ewingii* that only colonised a quarter as many ponds as *C. signifera* in the same two breeding seasons (unpublished data), logging treatment may have a significant impact on total reproductive expenditure, especially if the location of suitable breeding sites varies appreciably over time or the availability of breeding sites is limited.

Eggs laid at unlogged sites were larger than those from logged sites for both *C. signifera* and *L. ewingii* (Lauck 2004). Differences in temperature and food abundance associated with logging may be responsible for differences in female reproductive investment, as lower temperatures and better nutrition during egg development have both been shown to increase egg size (Berven 1982; Jorgensen 1982; Kaplan 1987; Williamson and Bull 1995; Girish and Saidapur 2000). Invertebrates commonly consumed by *C. signifera* were twice as abundant in unlogged as in recently logged forests (unpublished data). Likewise, the removal

of the overstorey by timber harvesting has been shown to result in increased insolation and higher temperatures on the forest floor (O'Connell 1987; Raymond and Hardy 1991; Vanderwoude and Lobry de Bryun 2000).

Reproductive success

The environmental differences resulting from logging treatment that affect egg size (see above) were sufficient to significantly affect subsequent development of offspring. Larger eggs hatched into larger tadpoles for *L. ewingii* but, for *C. signifera*, any differences in size at the egg stage were not reflected in size at hatching. For *C. signifera*, a greater proportion of smaller eggs from logged sites survived to hatching than larger eggs from unlogged sites. Research has shown that the relationship between egg size, hatch size and offspring fitness is variable and can be complicated by environmental factors during development. For example, Parichy and Kaplan (1992) found that tadpoles from larger eggs were less susceptible to predation than those from smaller eggs when raised in cold water, but that the reverse was true when the animals were reared in warm water. Further investigation is needed in order to determine the actual consequences of differences in *C. signifera* and *L. ewingii* egg size for offspring fitness in the forest environment (as compared to common laboratory conditions used in this study).

Reproductive success can also be affected by the type of pond environment into which eggs are laid. Because breeding sites at Warra are predominantly man-made, the types of ponds constructed may influence breeding-site suitability and therefore the value of the pond as a breeding site for a particular species. Traditionally, the method used to assess the suitability of a breeding site is to correlate the presence or absence of species in ponds with different habitat characteristics. However, because *L. ewingii* is ubiquitous, it provided an ideal opportunity to investigate how habitat characteristics altered tadpole and metamorph life history (Lauck *et al.*

2005a). To do so, a number of assumptions were made: that greater size at metamorphosis and earlier metamorphosis increase individual fitness, and that a greater recruitment of metamorphs increases population fitness through an increase in the adult population size (Berven and Gill 1983; Semlitsch *et al.* 1988; Berven 1990; Amezcuita and Luddecke 1999).

Less shaded ponds gave rise to earlier metamorphosis and this may be an advantage because metamorphs emerge from the pond earlier in the summer, before drier, hotter conditions occur in the terrestrial environment. Larger metamorphs emerged from higher elevation ponds, presumably because of the colder water temperatures in these ponds and the fact that size at metamorphosis is known to be inversely related to the temperature at which development occurs (Berven *et al.* 1979; Smith-Gill and Berven 1979). The maximum number of tadpoles emerged from higher elevation ponds with reduced pond isolation and/or steep pond banks, but the effects of pond bank slope and pond isolation could not be separated.

Removing vegetation around the pond margins affected the life history of *L. ewingii* tadpoles differently in small and large ponds (Lauck *et al.* 2005b). By raising tadpoles in enclosures installed within shaded and unshaded permanent ponds, it was found that, although larval growth and development did not respond significantly to shading treatment, survival was lower in shaded ponds. These findings suggest that, when the pond is of sufficient size to ensure that it does not dry out completely, the larval success of *L. ewingii* is not enhanced by vegetative buffer zones around permanent pond margins.

In comparison, increased shading in ephemeral ponds resulted in a decreased developmental rate of *L. ewingii* tadpoles (Lauck *et al.* 2005b). Because of their small water volumes, less shaded ephemeral ponds tend to dry out faster than shaded ponds due

to higher evaporation rates. This may be of importance as some species (especially those adapted to development in ephemeral ponds) are able to accelerate their rate of development as a response to decreasing pond volume, thus maximising survival by reducing the duration of the tadpole stage (Newman 1988; Crump 1989; Rowe and Dunson 1995; Blaustein *et al.* 1999). Because of this, heterogeneity of shading conditions around ephemeral ponds may ensure a compromise between accelerated developmental rates in unshaded ponds and the risk of complete, premature pond desiccation in dry years (that may be delayed by increased pond shading).

Conclusions

Crinia signifera and *Litoria ewingii* were ideal model species for assessing an experimental approach measuring the impact of logging on amphibians because they are not excluded by logging and are not of any present conservation concern. Such research is timely since forest management invokes considerable public debate, and current research relating to amphibians has large knowledge gaps (particularly outside North America).

Logging can significantly influence the life history of frogs at all three stages of their life cycle. The data from life-history studies summarised in this paper can be used to define species-specific management areas (i.e. the forest area used as habitat by amphibian species) (Lauck 2005b), and to demonstrate how forest harvesting alters movement of amphibians in the environment (Lauck 2005b). The data can also be used to make recommendations about vegetation management around pond margins (Lauck *et al.* 2005b), make species-specific recommendations for the construction of optimal pond habitat (Lauck *et al.* 2005a), and demonstrate that the distinct environments created by logging can alter reproductive output, which has consequences for offspring life history (Lauck 2004).

Life-history studies have provided a fresh and sensitive approach to investigating how frogs relate to the forest landscape in Tasmania's southern forests, and how they are affected by logging. Although the studies summarised within this paper specifically investigate the utility of the life-history methodology in relation to commercial forest management, the approach has broader application to other types of habitat modification (e.g. fire, pollution, sedimentation), other land uses (e.g. agricultural and urban areas), other amphibian species of greater conservation concern, and other biota (both fauna and flora). Further use and development of this approach would increase the understanding of how and why species respond to habitat disturbance. Such information is critical and lacking for the

comprehensive management of modified landscapes in Australia (Hazell 2003).

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