OBSERVATIONS ON THE BREEDING ACTIVITY AND LARVAE OF THE BROWN TREE FROG *LITORIA EWINGI* IN THE SOUTH ISLAND, NEW ZEALAND

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ABSTRACT

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Twenty sites on the west coast of the South Island were monitored between 7 February 1989 and 18 January 1990 for the presence of spawn and larvae of the brown tree frog, *Litoria ewingi*. This introduced species spawns throughout the year on the west coast of New Zealand. Breeding habitat includes acidic brown water ponds and depressions. Reproductive activity was highly variable both within and between sites, and was not obviously associated with temperature, rainfall or time of year. Spawn was not found in highly acidic habitats (below pH 5.2) although tadpoles were seen in ponds at pH 4.8. Factors that may account for marked changes in tadpole densities are examined.

KEYWORDS: reproduction - acid water - frogs - tadpoles - *Litoria ewingi*.

INTRODUCTION

The brown tree frog or Australian whistling frog, *Litoria ewingi* (Dumèril and Bibron), is one of three exotic anurans naturalised in New Zealand. There is only one record of importation of *Litoria ewingi* into New Zealand (Thomson 1922): frogs and tadpoles collected from Tasmania were privately liberated at Greymouth, South Island in 1875 for unspecified reasons (Marriner 1907). The species is now abundant on the west coast, and occurs throughout much of the South Island and in parts of the North Island and Stewart Island (Bell 1982).

Litoria ewingi in New Zealand exhibits a similar breeding biology to populations in Australia (McCann 1961, Gill 1973, 1978, Robb 1980, Bell 1982). The species is tolerant of considerable temperature variation (Littlejohn 1971), and adults remain active at ambient temperatures as low as 7°C (Cree 1984). This wide temperature tolerance enables an extended breeding season (Littlejohn & Martin 1974) with spawning throughout the year (Gill 1973, Cree 1984, Alderton 1985). Tadpoles are found in every month in the North and South Islands although development is thought to be suspended over winter because newly emerged frogs have only been observed from November to May (Gill 1973, Cree 1984, Alderton 1985).

Litoria ewingi spawns in naturally acidic brown waters on the west coast of the South Island of New Zealand. High concentrations of fulvic and humic acids derived from decomposing organic matter in the soil result in water pH as low as 4.0 (Winterbourn & Collier 1987). A reduction in the diversity and abundance of amphibian species has been reported for brown water habitats (Gosner & Black 1957, Heatwole & Getz 1960, Janzen 1974, Beebee & Griffin 1977, Strijbosch 1979, Dale *et al.* 1985, Freda & Dunson 1986, Leuven *et al.* 1986). The detrimental effects of low pH on the reproduction and survival of amphibians has been repeatedly documented (Saber & Dunson 1978, Hall & Likens

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1980, Haines 1981, Schlichter 1981, Tome & Pough 1982, Cook 1983, Freda & Dunson 1984, 1985, 1986, McDonald 1984, Clark & Hall 1985, Cummins 1986, Leuven *et al.* 1986, Andren *et al.* 1988).

In this study, the breeding activity of *Litoria ewingi* was investigated in brown water and clear water habitats on the west coast of the South Island of New Zealand. Aspects of the larval phase of the life cycle were also examined.

STUDY SITES AND METHODS

Between 7 February 1989 and 18 January 1990 twenty ponds, wetlands and puddles on the west coast of the the South Island were monitored for spawn and larvae of *Litoria ewingi*. At each site (Table 1) several measurements of pH (Advantec portable pH meter) were recorded, calling was noted, and adults, when caught, were examined for breeding condition and released. Water temperatures were recorded monthly beginning in June 1989. Larval densities were estimated in shallow ponds and puddles every month by counting all tadpoles present in randomly selected 10x10 cm (100 cm^2) areas. Larval densities could not be estimated in deep ponds or in puddles when visibility was obscured by aquatic vegetation or ice. Densities of spawn were estimated by counting all egg clumps present along several randomly selected 1 m lengths of habitat margin. Larval development was staged in the field from live animals, and embryonic development was staged from preserved embryos following the table developed by Gosner (1960).

The gut contents of 50 larvae in various developmental stages collected from Reefton, Hanmer Springs and Goldney Saddle (sites 4-15, 17 and 19) were mounted on slides in lactophenol-PVA, stained with Lignin Pink and dried at 37°C for 2 weeks. The frequency of occurence of algae, fungi, macrophyte and animal fragments, and other materials was recorded.

REEFTON AREA (SITES 1-15)

Sites near Reefton were visited at least once

Table 1. Localities and characteristics of sites used for field observations. a = *Azolla rubra*; b = *Myriophyllum* sp.; c = *Polygonum hydropiper*; d = *Lemna minor*; - = absent.

No.	Map Reference	Locality	Habitat type	Water type	Aquatic Vegetation	Terrestrial Vegetation	Elevation (m)
1	NZMS260, L30 054204	Larry River	deep pond (I)	brown	-	forest	220
2	NZMS260, L30 053206	Larry River	deep pond (I)	brown	-	forest	240
3	NZMS260, L30 095173	Larry River	deep pond (I)	brown	-	forest	140
4	NZMS260, L30 094173	Larry River	wet depression (II)	brown	b,c	pakihi	140
5	NZMS260, L30 079155	Larry River	wet depression (II)	brown	b,c	pakihi	140
6	NZMS260, L30 971159	Observation Pt	deep pond (I)	brown	-	forest	375
7	NZMS260, L30 966164	Observation Pt	deep pond (I)	brown	-	forest	410
8	NZMS260, L30 967168	Observation Pt	deep pond (I)	brown	-	forest	380
9	NZMS260, L30 966164	Observation Pt	puddle (III)	brown	-	forest	380
10	NZMS260, L30 969152	Reefton	puddle (III)	brown	-	paddock	220
11	NZMS260, L30 976152	Reefton	puddle (III)	brown	-	paddock	200
12	NZMS260, L30 969131	Snake gully	wet depression (II)	brown	b,c	pakihi	220
13	NZMS260, L30 010119	Maimai	puddle (III)	brown	-	forest	300
14	NZMS260, L30 010125	Maimai	puddle (III)	brown	-	forest/pakihi	320
15	NZMS260, L30 015127	Maimai	puddle (III)	brown	-	forest	180
16	NZMSI S44 801181	Hanmer Springs	wet depression	clear	-	paddock	424
17	NZMSI S54 789193	Hanmer Springs	wet depression	clear	a,d	wetland	364
18	NZMSI S66 160244	Cass Biol. Stn.	wetland	clear	c	wetland	720
19	NZMSI S66 196220	Goldney Saddle	wet depression	clear	c	tussock	700
20	NZMSI S59 334051	Arthur's Pass	tarn	brown	-	tussock	909

every month. Reefton is located in Westland, 73 km from Lewis Pass at an altitude of 233 m a.s.l. The climate is humid and relatively mild although severe winter frosts sometimes occur (1989 temperature maximum 28°C, minimum 8°C, Department of Conservation, Inangahua District). This region is characterized by high annual rainfall distributed evenly throughout the year (1989 annual rainfall 1764 mm, Department of Conservation, Inangahua District). Breeding habitats of *Litoria ewingi* were placed in three main categories.

Type I habitats (sites 1-3 and 5-8) included permanent ponds greater than 1 m in depth (constructed to hold large supplies of water for fire control). These ponds were on reforested hillsides at altitudes up to 410 m. Forests were mainly mixed beech (*Nothofagus* spp.), beech/podocarp, or introduced conifers (*Pinus* spp.).

Type II habitats (sites 4,5 and 12) were permanent ponds or depressions less than 1 m deep in pakahi induced by burning or logging at elevations greater than 140 m. Pakahi are open wet areas supporting mainly mosses (*Sphagnum* spp.), sedges (*Baumea* spp.) and rushes (*Juncus* spp.).

Type III habitats (sites 9-11 and 13-15) were ephemeral puddles and wet areas with a maximum depth of 23 cm and lengths up to 36 m. Most were located in roadside ditches servicing forested areas such as the Maimai Experimental Area.

Mosses (*Sphagnum* spp.), ferns (*Gleichenia* spp., *Pteridium aquilinum*), sedges (*Baumea* spp.), rushes (*Juncus* spp.), manuka (*Leptospermum scoparium*), and gorse (*Ulex europaeus*) were the dominant plants surrounding all three habitat types. Aquatic macrophytes were limited to waterfern (*Azolla rubra*), water pepper (*Polygonum hydropiper*), duckweed (*Lemna minor*), and water millfoils (*Myriophyllum* spp.), and occurred only in shallow permanent depressions (Type II habitat). The substrates of all habitat types were thick mud and detritus.

HANMER SPRINGS (SITES 16 AND 17)

Two sites were visited monthly beginning in April 1989. Site 16 was a shallow wet depression (2 m diameter) in a sedge meadow (*Carex* spp.) and drainage ditches along the forest edge behind the Automobile Association camp. Site 17 was a large mud-bottomed wetland (30 m x 20 m) in a paddock behind the town shopping mall. It was heavily shaded by willow trees (*Salix* spp.), and supported an almost continuous surface cover of duckweed (*Lemna minor*) and water fern (*Azolla rubra*).

CASS BIOLOGICAL STATION AND ARTHUR'S PASS (SITES 18-20)

Searches were made for frogs and tadpoles on 26 February 1989 and on 1 May 1989 at a wetland created by runoff from Lake Sarah at Cass biological station (Site 18). The wetland supported a lush growth of raupo (*Typha* spp.), sedge (*Carex* spp.), and flax (*Phormium* spp.). A shallow mud-bottomed pond (8 m diameter) surrounded by scrub and tussock grass (*Chionochloa macro*) at an altitude of 700 m at Goldney Saddle (Site 19) was visited monthly from March to July, and in October and December 1989. Several tarns at Arthur's Pass (25 km west of Cass) were also investigated on 26 February 1989.

RESULTS

REEFTON AREA (SITES 1-15)

Field observations on the reproductive activity of *Litoria ewingi* on the west coast of the South Island (sites 1-15) are summarized in Table 2. Males called at night and on overcast afternoons in every month. Infrequent calling was heard on some warm sunny mornings in reforested areas at Larry River and at Observation Point. Several males were caught during brief day searches near breeding sites in all months except July and November. Nuptial pads, indicating breeding condition, were apparent on all males caught.

Spawn was abundant in wet depressions and puddles (habitat types II and III) at water temperatures between 3 and 28°C throughout the observation period but occurred less frequently in deep ponds. Reproductive activity varied within habitat types: spawn sometimes occurred at high densities (15 clumps/m length habitat margin) in some localities but was not found in

Table 2. Monthly field observations on the reproductive activity of the brown tree frog *Litoria ewingi*, from February 1989 to January 1990 on the west coast of the South Island. O = observed; X = looked for but not seen; blank = not looked for. Habitat types: I = deep pond; II = wet depression; III = shallow puddle. * = lowest pH of deep pond containing spawn.

Life stage or Parameter	Habitat type	Month (1989 - 1990)											
		Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan
Adults in breeding condition		O	O	O	O	O		O	O	O		O	O
Emerging tadpoles (stage 40+)		O	O	O	X	X	X	X	X	X	O	O	O
Tadpoles (stages 23-32)	I	O	O	O	O	X	X	X	X	O	O	O	O
	II			O	O	O	O	O	O	O	O	O	O
	III	O	O	O	O	O	O	O	O	O	O	O	O
Spawn	I	O	X	X	X	X	X	X	X	O	O	O	O
	II			O	O	O	O	O	O	O	O	O	O
	III	O	O	O	O	O	O	O	O	O	O	O	O
Water temperature (°C)	I					8.5	8	9	15.5	23	24	16	31
	II					11	7	12	18	21	24	15	28
	III					9.5	3	8	15	17	21	16	28
pH ($\bar{x}$)	I	5.4*	4.8	4.8	4.8	4.4	4.7	4.7	4.8	5.2*	5.4*	5.2*	5.0*
	II			5.4	5.8	6.1	6.2	6.2	6.2	6.0	5.4	5.6	5.5
	III	6.5	5.9	5.4	5.4	6.0	6.1	6.2	6.2	5.2	6.0	5.2	5.2

the same habitat type within 3 km.

The highest density of spawn observed was 15.6 clumps/m in April, while the lowest density was 0.3 clumps/m (type III habitat) in July. Clutches contained between 12 and 60 embryos. Small clutches occurred with large clutches at the same sites. The average clutch size in most months was 25 - 40 embryos/clutch (based on approximately 70 counts per sighting). Clumps of spawn frequently contained dead embryos (6-30%) on the outer edges of the gelatinous matrix. These were easily identified by their white colour and loss of firmness.

Tadpoles were found in puddles throughout the year at water temperatures between 3 and 28°C. Larvae were not observed in deep ponds from June to September although they were presumed to be present because late-stage tadpoles were found in November. Tadpoles in advanced growth stages (stages 31-46, Gosner 1960) were observed in all habitat types between 7 February and 26 April 1989, and between 18 November and 18 January 1990. Mean tadpole densities ranged from 9 per 100 cm^2 in May to 0.2 per 100 cm^2 in November in habitat types II and III.

On 22 July 1989, living tadpoles (stages 23-30) and fresh spawn were observed under ice 4 mm thick at densities of 7 larvae/100 cm^2 and 1.1 clumps/m habitat edge.

HANMER SPRINGS (SITES 16 AND 17)

On 1 April 1989 calling was heard in the early afternoon, and two males were collected from near a small pool behind the Automobile Association camp water supply tank at Hanmer Springs (site 16). No tadpoles or spawn were found at this site in any month. A drainage ditch along the periphery of the AA camp was also searched each month but no tadpoles or spawn were seen. Nevertheless, calling was heard in this vicinity every month.

Tadpoles (stages 20-30) were found in a small wetland located behind the town shopping mall (site 17) every month from April to January 1990. Tadpoles in advanced stages of development were observed only from 19 November 1989 to 18 January 1990. The water pH at this site was 6.8 to 6.9.

CASS BIOLOGICAL STATION (SITES 18-20)

Litoria ewingi does not occur in the species list for Cass published in 1977 (Burrows 1977), but Bell (1982) mentioned its occurrence at Mount Misery (elevation 1760 m), 3 km from the

Cass Biological Station. On 26 February and 1 May 1989 males were heard calling at Cass (site 18) and searches were made for frogs and tadpoles; however none were observed. Tarns at Arthur's Pass (site 19) did not contain any tadpoles on 26 February 1989 and no adults were found.

On 26 March however, many *Litoria ewingi* were observed crossing Highway 58 at Goldney Saddle, 3 km north of Cass, on a rainy night (A Suren, pers. comm.). Eight females were collected. On 2 April, spawn was observed in a shallow pond at Goldney Saddle (site 19). Frogs were heard calling at this site on an overcast afternoon in May, and four males in breeding condition were caught. Tadpoles were observed in this pond on 1 May, 22 July (under thick ice), and 18 October; and late developmental stages on 7 December 1989. The pH of water in this pond ranged from 6.5 to 6.9.

OTHER LOCALITIES

On 11 February 1989 frogs were heard calling from a private residence on Memorial Avenue, Christchurch, and several tadpoles were collected. The owner of the property had introduced tadpoles taken from the west coast into his garden pond (1 m diameter) in 1986.

On 28 October tadpoles (stages 26-30) were observed in a large deep pond at the Blue Skies National Scout Camp at Kaiapoi. A wet depression on the edge of a paddock off Double Day Road on the outskirts of Kaiapoi contained spawn and tadpoles every month from 6 April 1989 to 10 January 1990.

On 23 December calling was heard at night from the Wia-iti Motel at Akaroa, and tadpoles (stages 23-42) were observed in a garden pond. The owner of the property did not know how or when the frogs had been introduced to this site.

GUT CONTENTS

Macrophyte fragments, fungi, fine detritus and silt predominated in guts of larvae (stages 29-40) collected from all habitat types in all months. This indicates that tadpoles were mainly benthic feeders. Diatoms (*Cocconeis* spp. and *Frustulia* spp.) represented less than 10% of the materials ingested in brown water habitats, but occurred more frequently (30%) in guts of larvae collected from clear waters. Animal fragments were rarely observed in larval guts.

DISCUSSION

On the west coast of the South Island the reproductive activity of *Litoria ewingi*, although variable from month to month within and among sites, occurred throughout the year with no apparent seasonal peaks. All males caught had nuptial pads, and calling was heard in every month.

Spawning occurred in puddles (type III habitat) at Reefton in every month but was observed infrequently in deep ponds (Type I) even when they were close to puddles. Occurrence of spawning may be related to differences in water pH between habitat types. The pH of water containing spawn was never less than 5.0 (although tadpoles were found at pH 4.8), and deep ponds became more acidic in winter and after heavy rainfall: pH ranged from 4.4-4.8 between March and September. In contrast, the pH of puddles was always 5.0-6.5. Several amphibian species avoid spawning in acidic habitat (Gosner & Black 1957, Heatwole & Getz 1960, Cooke & Frazer 1976, Saber & Dunson 1978, Strijbosch 1979, Dale *et al.* 1985, Freda & Dunson 1986, Leuven *et al.* 1986). Beebee & Griffin (1977) reported that many anurans characteristic of bog water communities select less acidic microhabitats (mean pH 6.3). However, considerable temporal variation in the acidity of a single site has been reported for humic waters (Freda & Dunson 1985, Pierce *et al.* 1984, Pierce & Harvey 1987), and the pH of waters containing spawn of *L. ewingi* may have been different from that when spawning occurred. Factors such as water depth, plant community structure, substrate and site fidelity may also influence spawning site selection (Cooke 1975, Strijbosch 1979, Cree 1984, Aston *et al.* 1987).

Tadpoles in late developmental stages (stages 40-46) were not observed at any site from 26 April to 18 November, although tadpoles in earlier growth stages (stages 20-30) were present throughout the study. Larval development therefore appeared to be depressed at colder temperatures. Tadpoles reared in the laboratory under 14 hour daylength required at least 50 days at 17°C to complete metamorphosis but 81 days

at 15°C (Cousineau 1990). The high densities at which tadpoles sometimes occurred, and the quality of food available in brown water habitats may further depress growth rates in winter (Brochelman 1969, Wilbur 1976, Collier & Winterbourn 1987).

Estimates of tadpole densities varied considerably from month to month at each site. For example, at site 13 which was dry on 10 February, tadpole densities (stages 20-30) were estimated at 7/100 cm^2 on 1 April, 1.6/100 cm^2 on 26 April, 9/100 cm^2 on 15 May and 1/100 cm^2 on 25 June. Furthermore, spawn was frequently observed at high densities (ie., 15 clumps/m habitat margin) whereas the following month numbers of larvae (stages 20-25) were low. Larval mortality did not result from the drying up of ephemeral habitat at any study site, but shallow puddles (sites 9,10,11 and 13-15) were exposed to torrential currents following heavy rainfall, and some sites (14 and 15) were vulnerable to trampling by cattle. Density changes may therefore have been the result of dispersal to habitat downstream, displacement from puddles or crushing by cattle.

Mortality of anuran larvae, particularly early stages, is typically high (Savage 1961, DeBenedictis 1974) and is often considered to be a consequence of predation (Littlejohn 1971, Licht 1974, Travis 1983, Wilbur 1984, Travis *et al.* 1985). However, few predators of anuran larvae seem to occur in New Zealand. Potential avian predators such as the white-faced heron *Ardea novaehollandiae*, the kingfisher *Halcyon sancta*, and the Australasian harrier *Circus approximans* were never observed at breeding sites, and if present would probably take mainly large tadpoles. In some North American studies, predation by aquatic insect larvae has been shown to regulate larval anuran populations (Calef 1973, Caldwell *et al.* 1980, Wilbur 1980, Smith 1983, Travis *et al.* 1985). Blue damselfly *Austrolestes colensonis* and yellow-spotted dragonfly *Procordulia grayi* larvae were observed in puddles in every month, and may have contributed to mortality of embryonic stages. On one occasion, 3 freshwater crayfish *Paranephrops planifrons* were found in a deep pond approximately 14 m in diameter (site 7). These may account for some predation because they fed on larvae (< stage 38) in the laboratory. Other anuran species were not observed at any of the sites, however, in the laboratory the introduced green frog *Litoria raniformis* fed readily on adults of *L. ewingi*, and may restrict the distribution of the latter (Cousineau 1990).

Although populations of many herbivorous scavengers, such as anuran larvae, are more likely to be limited by predation than resources (Hairston *et al.* 1960, Licht 1974), acidic brown water streams (and presumably other brown waters) on the west coast of the South Island are characterized by relatively low algal biomass (Collier & Winterbourn 1987), low microbial activity, and limited nutrients (Collier 1988), and by implication provide poor food resources. Competition in brown water habitats for high quality foods such as diatomaceous algae (Anderson & Cummins 1979) may play a role in population regulation (Martin 1967, Brochelman 1969, Wilbur 1977, Steinwascher 1978, Haines 1981, Smith 1983).

In summary, the breeding activity of *Litoria ewingi*, although variable from month to month and among sites, occurred throughout the year on the west coast of the South Island including periods when air temperatures fell below 0°C. It was not obviously associated with temperature, rainfall or season. Spawning occurred in both temporary and permanent habitats, although deep ponds in the vicinity of Reefton were avoided in winter, possibly because they were most acidic (pH 4.4) in these months. Tadpoles occurred throughout the year in deep ponds, permanent depressions, and ephemeral puddles, and development appeared to be dependent on temperature: thereby restricting metamorphosis to summer months. Estimates of tadpole densities were highly variable from month to month. Aquatic predators, larval dispersal, habitat disturbance, and food resources may regulate larval population densities. Gut analyses indicated that larvae are mainly benthic grazers.

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