CSIRO PUBLISHING
www.publish.csiro.au/journals/ajz Australian Journal of Zoology, 2008, 56, 173–178

Body sizes, activity times, food habits and reproduction of brown tree snakes (*Boiga irregularis*) (Serpentes : Colubridae) from tropical north Queensland, Australia

D. F. Trembath[A,C] *and S. Fearn*[B]

[A]Museum and Art Gallery of the Northern Territory, GPO Box 4646, Darwin, NT 0801, Australia.
[B]Department of Primary Industries and Water, Level 1, 167 Westbury Road, Prospect, Tas. 7250, Australia.
[C]Corresponding author. Email: dane.trembath@nt.gov.au

Abstract. Brown tree snakes (*Boiga irregularis*) are medium to large colubrid snakes that are relatively common within the eastern and northern parts of tropical Australia. An invasive population on Guam in the western Pacific has resulted in *B. irregularis* being one of the most studied snakes on earth. However, no field studies have ever been conducted on Australian populations. During a seven-year period we collected data on 265 field-caught specimens in north Queensland. These snakes were from three populations and provided data on body sizes, activity times, food habits and reproduction. *B. irregularis* were found to attain larger body sizes in the Wet Tropics populations than in the Townsville and Magnetic Island populations. More snakes were encountered during the wet and warm season than during the dry and cool season. Sexual size dimorphism was not detected in any population. The diet included a wide range of vertebrates. Reproductive data were scant from the populations examined.

Introduction

The brown tree snake (*Boiga irregularis*) occurs throughout subtropical and tropical eastern and northern Australia as well as Melanesia, Papua New Guinea and Indonesia (Rodda *et al.* 1999). Within Australia, *B. irregularis* occurs in a wide range of habitats from eucalypt and savanna woodland to closed rainforest (Cogger 2000).

Previous studies of Australian *B. irregularis* have examined pooled samples of museum specimens from across the taxon's range to examine general ecology (Shine 1991), reproduction (Whittier and Limpus 1996; Bull *et al.* 1997), activity patterns (Bull and Whittier 1996) and morphology (Whittier *et al.* 2000). Specimens of north Queensland *B. irregularis* are poorly represented in all these previous studies. In a broader context, the establishment of an invasive population of *B. irregularis* on the island of Guam in the western Pacific and the subsequent damage to the island's endemic reptile and avian fauna has resulted in *B. irregularis* being one of the most studied reptiles on earth. Rodda *et al.* (1999) report more than 100 studies on *B. irregularis* that were initiated to understand its ecology and to identify effective control measures on Guam. In this work we present data on body size, trophic ecology and activity patterns from a large sample of field-caught *B. irregularis* from three contrasting habitat types in Townsville, Magnetic Island and the Wet Tropics (rainforest) in the vicinity of Tully and Cairns, Queensland.

Methods

Between 1997 and 2006 living and road-killed specimens of *B. irregularis* were examined at four localities, representing three contrasting habitat types in tropical coastal Queensland.

(1) Townsville (TSV). Within a 30-km radius of James Cook University, Townsville (19°19′53″S, 146°45′6″E), in the strongly seasonal wet–dry tropics. Vegetation in the Townsville area is dominated by eucalypt savanna woodland with a grassy understorey.
(2) Magnetic Island (MI). Situated 4.5 km off the coast from Townsville (19°10′00″S, 146°50′00″E). Magnetic Island is a high continental island with elevations to 540 m and an area of 5184 ha. Vegetation consists mainly of open eucalypt woodland with small patches of closed vine forest in sheltered gullies and creek lines. Climatic regimes are very similar to nearby Townsville (Fig. 1), with markedly seasonal rainfall and a wet season (October–March) that varies between years.
(3) Wet Tropics (WT). From the vicinity of Tully (17°45′30″S, 145°38′02″E) and the Lamb Range on the outskirts of Cairns (16°58′55″S, 145°41′11″E). Both these sites have higher year-round rainfall than the Townsville district (Fig. 2) and vegetation consists primarily of closed rainforest (simple notophyll vine forest) with adjoining anthropogenic habitats (formerly rainforest) of grazing land as well as banana and sugarcane plantations.

Snakes were primarily obtained by nocturnal road driving (60 km h^{-1}) at all three localities throughout the year. Specimens from metropolitan Townsville that were removed from urban and periurban residences as 'nuisance' snakes by staff of the Queensland Parks and Wildlife Service were also included. Road-killed specimens collected while travelling roads between Townsville, Tully and Lamb Range were included in the dataset and assigned to either the TSV or WT categories on the basis of the roadside vegetation at their capture site. For each snake we

 10.1071/ZO08008 0004-959X/08/030173

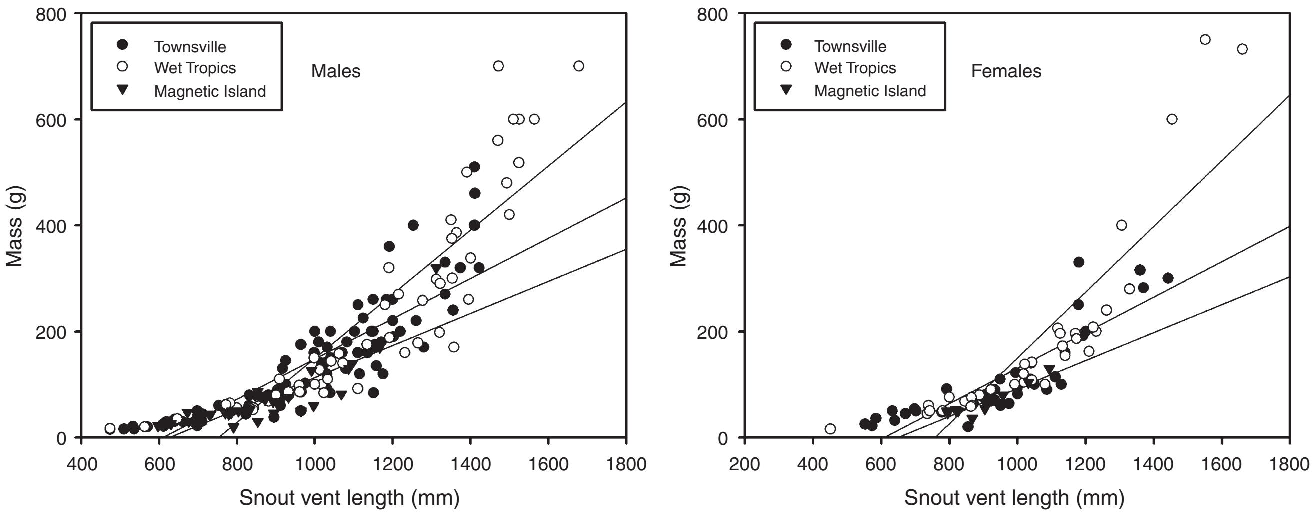

Fig. 1. Body mass relative to snout–vent length of male and female *Boiga irregularis* from the Townsville, Wet Tropics, and Magnetic Island study sites.

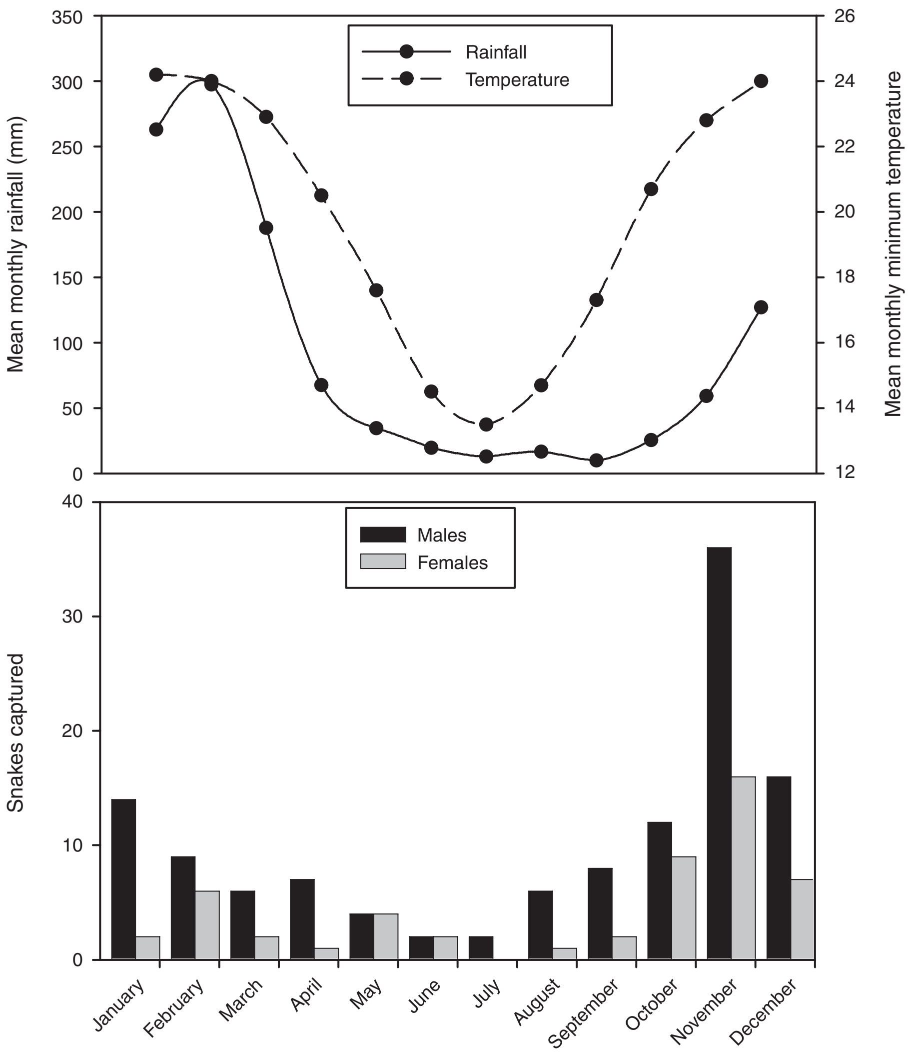

Fig. 2. Climatic data and activity patterns of *Boiga irregularis* from the Townsville and Magnetic Island area based on specimens sampled. Climatic data downloaded from Anon (2006).

recorded the date and location of capture as well as location. Immediately after capture, sex was determined by eversion (or not) of hemipenes, snout–vent length (SVL) and tail length (TL) were measured by stretching the animal along a tape measure, and its mass was determined with spring-balance scales. Living snakes were palpated along the stomach to induce regurgitation of ingested prey items and palpated for faecal samples and the presence of eggs in females. Road-killed specimens were dissected for trophic and reproductive data. Males were not assessed for maturity but females were assessed for shelled eggs, enlarged oviducts, or ovarian follicles >5 mm in diameter.

All variables were log-transformed to improve normality and homogeneity of variance. All snakes showing partial tail loss were excluded from tail length analysis. All comparisons were made between the TSV, WT, and MI sites except for the seasonal activity analysis, which was a combination of the MI and TSV sites in comparison with the WT sites. Statistical analysis of data was conducted using SigmaStat and SPSS.

Results

In total, 265 *B. irregularis* were examined for this study (Table 1); of these, 239 were collected in the field while driving at night, and 26 were obtained as 'nuisance' snake callouts.

Body sizes

The largest specimens of *both* sexes came from the Wet Tropics and the smallest came from Magnetic Island (Table 1). Mean SVL and mass of male *B. irregularis* was significantly different among the TSV, WT, and MI sites (SVL: one-way ANOVA; $F_{2,176} = 11.38$, $P \leq 0.001$; mass: Kruskal–Wallis one-way ANOVA; $H_{2,175} = 26.638$, $P \leq 0.001$). Mean SVL of female *B. irregularis* did not differ significantly among the TSV, WT, and MI sites (Kruskal–Wallis one-way ANOVA; $H_{2,130} = 3.241$, $P = 0.19$); however, mass was significantly different among sites (one-way ANOVA; $F_{2,82} = 4.82$, $P = 0.010$).

Body condition

Male and female *B. irregularis* differed significantly in mass relative to SVL between TSV, WT and MI (Fig. 1) (ANCOVA with site as factor, ln(SVL) as covariate, ln(mass) as dependent variable: (male interaction, $F_{3,174} = 586.07$, $P \leq 0.001$; intercepts, $F_{1,177} = 918.83$, $P \leq 0.00$) (female interaction, $F_{3,81} = 170.70$, $P \leq 0.001$; intercepts, $F_{1,84} = 267.68$, $P \leq 0.00$).

Sexual size dimorphism

Male and female *B. irregularis* from the same locations attained similar sizes (Table 1). No significant differences were found between the mean SVL and relative tail length of male and female *B. irregularis* at TSV (Mann–Whitney *U*-Test: males: $Z = -5.27$, $P = 0.59$; females: $Z = -8,14$, $P = 0.41$), WT (*t*-test: males: $t_{2,88} = 1.432$, $P = 0.15$; females: $t_{2,81} = -0.74$, $P = 0.45$) and MI (T-test: males: $t_{2,39} = -0.75$, $P = 0.45$; females: $t_{2,88} = 0.52$, $P = 0.60$).

Seasonal activity

Both sexes were encountered throughout the year except for July when no females were found during the study period (Figs 2, 3). *B. irregularis* in north Queensland is encountered more often during the hotter and wetter times of the year (Figs 1, 2). Multiple linear regression analysis found that minimum monthly temperature interacting with rainfall predicted the numbers of *B. irregularis* encountered in TSV and MI (one-way ANOVA, $F_{2,9} = 7.358$, $P = 0.013$) and WT (one-way ANOVA, $F_{2,9} = 6.245$, $P = 0.020$) and accounted for 58–62% of the variation seen in this study (Table 2).

Table 1. Sample sizes, body sizes, and mass of *Boiga irregularis* from north Queensland

	SVL (mm)	TL (mm)	Mass (g)	TL/SVL
Males				
Townsville				
Mean ± s.e.	966.59 ± 25.38	216.51 ± 6.53	135.49 ± 11.07	0.22 ± 0.003
Range	474–1422 (*n* = 93)	70–321 (*n* = 90)	15–510 (*n* = 93)	0.07–0.26 (*n* = 90)
Wet Tropics				
Mean ± s.e.	1135.73 ± 36.81	263.74 ± 8.69	233.25 ± 25.56	0.23 ± 0.003
Range	474–1678 (*n* = 56)	115–410 (*n* = 50)	17–700 (*n* = 55)	0.18–0.34 (*n* = 50)
Magnetic Island				
Mean ± s.e.	866.16 ± 30.06	205.65 ± 6.11	72.53 ± 10.79	0.24 ± 0.002
Range	597–1312 (*n* = 30)	135–275 (*n* = 29)	20–330 (*n* = 30)	0.21–0.26 (*n* = 29)
Females				
Townsville				
Mean ± s.e.	945.05 ± 36.87	220.00 ± 9.18	116.15 ± 14.47	0.23 ± 0.002
Range	553–1442 (*n* = 40)	115–341 (*n* = 38)	20–330 (*n* = 39)	0.20–0.26 (*n* = 38)
Wet Tropics				
Mean ± s.e.	1052.00 ± 43.22	250.45 ± 10.64	183.00 ± 30.98	0.23 ± 0.003
Range	451–1660 (*n* = 34)	104–382 (*n* = 33)	16–750 (*n* = 34)	0.19–0.27 (*n* = 33)
Magnetic Island				
Mean ± s.e.	904.58 ± 26.99	216.72 ± 5.36	67.33 ± 7.75	0.24 ± 0.003
Range	792–1093 (*n* = 12)	195–263 (*n* = 12)	36–130 (*n* = 12)	0.22–0.26 (*n* = 12)

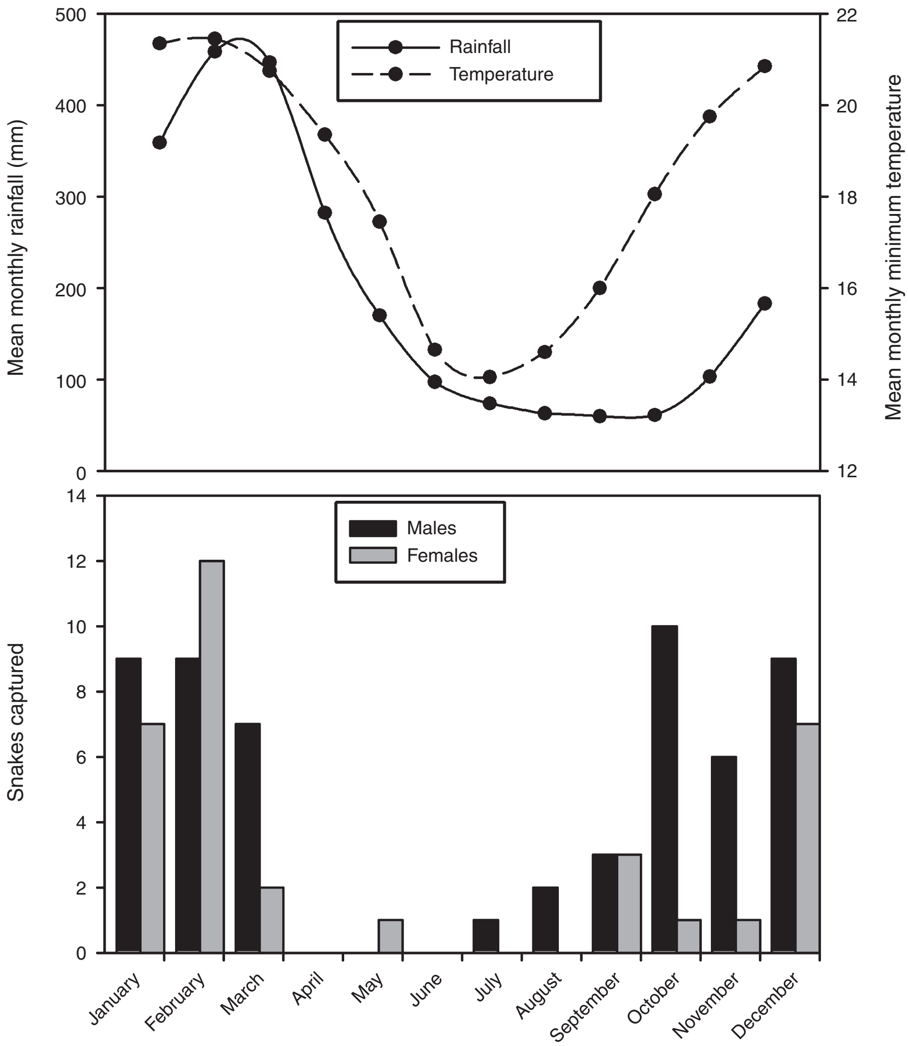

Fig. 3. Climatic data and activity patterns of *Boiga irregularis* from the Wet Tropics area based on specimens sampled. Climatic data downloaded from Anon. (2006).

Table 2. Multiple regression analysis for the effect of average monthly temperature and rainfall on *Boiga irregularis* encountered in the Townsville and Wet Tropics areas

*, significant at $P < 0.05$

Site and variable	F	d.f.	P	Model R^2
Townsville				
Temperature and rainfall	7.358	2, 9	0.013*	0.62
Temperature (°C)	14.260	1	0.004*	
Rainfall (mm)	6.059	1	0.036*	
Wet Tropics				
Temperature and rainfall	6.245	2, 9	0.020*	0.58
Temperature (°C)	13.786	1	0.004*	
Rainfall (mm)	0.0348	1	0.856	

Food habits

B. irregularis consume a large variety of vertebrate prey items (Table 3). Mammalian prey was not observed in any MI specimens and amphibians were recorded as prey items only in MI specimens. *B. irregularis* from TSV and WT ingested similar prey items (Table 3).

Reproduction

Females ($n = 86$) were examined for signs of reproduction but only two were confirmed to be gravid. Enlarged ovarian follicles were observed in June ($n = 1$, SVL = 855 mm) in the TSV area, and in September ($n = 1$, SVL = 1021 mm) in the WT. Both females observed had six enlarged ovarian follicles (5 mm diameter).

Discussion

Boiga irregularis from the Wet Tropics were larger than those from the Townsville area. Though only males were significantly larger, in terms of SVL and mass, there was a significant difference in relative mass to SLV length between all populations. Whittier *et al*. (2000) and Savidge *et al*. (2007) found that

Table 3. Prey items identified from the stomachs of *Boiga irregularis* from north Queensland

Prey items identified with an asterisk were collected from Magnetic Island ($n = 4$)

Prey type	Townsville ($n = 18$)	Wet Tropics ($n = 8$)
Amphibia		
Hylidae		
Litoria rubella	1*	
Aves		
sp. indet.	2, 1*	3
Eggs	2	
Estrildidae		
Taeniopygia guttata	2	
Passeridae		
Passer domesticus	2	
Oriolidae		
Oriolus sagittatus	1*	
Mammalia		
Muridae		1
Mus musculus	3	1
Rattus sp.	1	2
Reptilia		
Agamidae		
Diporiphora australis	2	
Gekkonidae	1*	
Gehyra dubia	1	
Diplodactylus williamsi	1	
Scincidae		1
Totals	20	8

B. irregularis from Guam were larger than snakes from Australian and Papua New Guinean populations. Whittier *et al*. (2000) also examined a small sample from Babinda, north Queensland (in the Wet Tropics) that appeared to have higher mid-body and ventral scale numbers when compared with *B. irregularis* from south-eastern Queensland. We did not take scale count data but Whittier *et al*. (2000) has shown that larger numbers of mid-body, ventral, and subcaudal scales are found in larger snakes and this may be a determining factor explaining the larger snakes from the Wet Tropics in our sample. In our study, larger snakes were present in wetter (and forested) areas. In contrast, on Guam, larger snakes were absent from wetter forested areas (probably because of reduced diversity and abundance of prey), with the largest individuals occurring in urban areas where they are exposed to a wider range of prey and human-derived carrion (Savidge 1991). Savidge (1991) did not differentiate between forest and savannah habitats in his analysis. In the WT, where rainfall is very high, there are also high densities of rodents and other prey. When these roads are sampled for reptiles, small mammals are encountered more frequently than in tropical savannah areas of the TSV (Van Dyck and Longmore 1991; authors' pers. obs.).

Sexual size dimorphism of SVL was not found in any population, supporting the results of Shine (1991), who analysed a large sample of Australian *B. irregularis*. Relative tail length data were not presented by Shine (1991) but no differences have been demonstrated in any populations, including the intensively studied population on Guam (Rodda *et al.* 1999). Sexual size dimorphism is most common in snakes in which males combat for access to females during the mating season (Shine 1978, 1994). Male combat has been reported for captive specimens from Guam populations of *B. irregularis* but has not been observed in any Australian population (Greene and Mason 2000). This may be because the Australian population either does not combat or combat takes place nocturnally or in cryptic locations such as diurnal retreat sites.

Activity in *B. irregularis* appears strongly seasonal, as reported in other studies, with north Queensland *B. irregularis* being far more common during wetter times of the year. Bull and Whittier (1996) found that activity of *B. irregularis* increased with the onset of rains in October for the south-eastern population. On Guam mean air temperature does not vary more than 1°C annually (Rodda *et al*. 1999), thus providing a suitable control sample for any study with which to compare activity times of *B. irregularis*. Studies from Guam have found *B. irregularis* to be more commonly encountered during the rainy season (Rodda *et al*. 1999; McCoid and Hensley 2000). Our study agrees with these findings as *B. irregularis* in the WT, MI and TSV were more commonly encountered during the wetter hotter times of the year.

B. irregularis in North Queensland were found to eat a variety of vertebrate prey, including road-killed items. One *B. irregularis* found during this study had recently consumed a maggot-infested road-killed *Rattus* sp., a finding that supports the observations of Torr and Richards (1996) and agrees with the many records of dead prey items recorded for the Guam population (Rodda *et al*. 1999). A willingness to consume carrion indicates a flexible trophic ecology, allowing rapid exploitation of any available food resources. This study found that snakes from TSV and WT did not appear to eat amphibians, which supports the findings of Shine (1991), who found that amphibians made up only 11% of the diet of *B. irregularis* from Queensland. Considering the high species diversity and abundance of amphibians throughout north Queensland (Ingram and Longmore 1991), amphibians would be expected to constitute a greater component of the diet; however, they may be misrepresented in dietary studies because they are rapidly digested and indistinguishable in the faeces of recently fed snakes. Shine (1991) also found significant dietary differences between sizes classes of *B. irregularis*, with larger specimens consuming more endotherms than ectotherms, with the opposite being true for juveniles. The MI snakes did not appear to prey on mammals, but our sample sizes were small ($n = 4$). These snakes also had the smallest mean body size of the three populations studied. Magnetic Island has, in particular, an impoverished small mammal fauna, with no endemic taxa under 500 g in weight and very low densities of introduced black rats (*Rattus rattus*) that appear to be confined to urban areas. This situation appears to have resulted in smaller body size and lack of sexual dimorphism in sympatric death adders (*Acanthophis antarcticus*) (Fearn 2001) and low recruitment of sympatric juvenile carpet pythons (*Morelia spilota*) into the adult population (Fearn 2005).

Little data were recorded on reproduction in females because few gravid females were observed in the field. In south-eastern Queensland, 80% of mature females may not breed every year, thus making gravid females relatively scarce (Whittier and Limpus 1996). This is also the case on Guam where, even though densities are high, researchers still fail to find gravid females (Rodda *et al*. 1999; Savidge *et al*. 2007). Shine (1991) presented clutch sizes based on all available museum specimens and found a mean clutch size of 5.5, which is similar to the clutch size of 6.0 observed in the present study. Although only one female with enlarged follicles (5 mm) was found in the Townsville area in June, this is in keeping with the fact that, in *B. irregularis* in south-eastern Queensland, vitellogenic follicles are produced during June, with oviposition occurring from October through November (Whittier and Limpus 1996). We caught only one other reproductive female, from the WT during September; this timing agrees with the anecdotal reports of mating, suggesting that *B. irregularis* breed in November in north Queensland (Whittier and Limpus 1996). However, because sample sizes in our study were low and because mature females may not breed every year (Whittier and Limpus 1996), we cannot confirm the exact timing of reproduction in this region.

While our study indicates some interesting trends in geographic variation in body size and activity patterns, we were unable to collect sufficient data to properly discuss these issues because of a lack of dietary and reproductive data. *B. irregularis* is a large-headed, slender-bodied snake and it would be anticipated that the bodies of most endothermic prey would have larger diameters than the snake. Movement is probably substantially impeded for snakes containing a large prey bolus, and they may be exposed to greater risk of predation. This may, in part, explain the very low frequency of snakes in our study with recently ingested prey. Opportunistic, field-based studies are unlikely to resolve this problem. The available literature also clearly demonstrates that gravid females are unlikely to be encountered in the field, because they may restrict their movements and possibly stay close to suitable oviposition sites. Apart from labour-intensive and expensive radio-tracking studies involving large numbers of snakes, we can suggest no methods to improve the chances of obtaining quantitative data on the reproductive and trophic ecology of *B. irregularis* under field conditions, particularly in structurally complex ecosystems such as rainforests.

Acknowledgements

Sincere thanks to the following people for their assistance in the field: John Blackburn, Dr David Blair, Alex Castle, Andre Fagerlid, David Freier, Kathy and Gavin Huddleston, Ray Lloyd, Steve Patane, David Poppi, Damien King, Josh Hawes, Jodi Rowley, Joe Sambono, Jason Schaffer and Dr Lin Schwarzkopf. Thanks also to Jason Elliott, who provided help with statistical analysis. Dr Diane Barton and Dr Paul Horner provided helpful comments on the manuscript. Thanks must also be extended to the Bureau of Meterology for permitting the download of climatic data. This work was conducted under the following permits from the Queensland Parks & Wildlife Service (NO/001446/98/SAB and F1/000330/00/SAA) and Environmental Protection Agency (#WITK02196804, #WISP02196704, and #WISP01039503).

References

Anon. (2006). Bureau of Meteorology. www.bom.gov.au. [Accesed July 2006.]

Bull, K. H., and Whittier, J. (1996). Annual patterns of activity of the brown tree snake (*Boiga irregularis*) in southeastern Queensland. *Memoirs of the Queensland Museum* **39**, 483–486.

Bull, K. H., Mason, R. T., and Whittier, J. (1997). Seasonal testicular development and sperm storage in tropical and subtropical populations of the brown tree snake (*Boiga irregularis*). *Australian Journal of Zoology* **45**, 479–488. doi: 10.1071/ZO97027

Cogger, H. G. (2000). 'Reptiles and Amphibians of Australia.' 6th edn. (New Holland Publishers: Sydney.)

Fearn, S. (2001). Aspects of the morphology and ecology of the death adder *Acanthophis antarcticus* (Serpentes: Elapidae) from Magnetic Island, north Queensland: does prey size determine degree of sexual dimorphism? *Herpetofauna* **31**, 19–25.

Fearn, S. (2005). Evidence of a juvenile skewed population of carpet pythons *Morelia spilota* (Serpentes: Pythonidae) from Magnetic Island, north Queensland. *Herpetofauna* **35**, 87–92.

Greene, M. J., and Mason, R. T. (2000). Courtship, mating, and male combat of the brown tree snake, *Boiga irregularis*. *Herpetologica* **56**, 166–175.

Ingram, G. J., and Longmore, N. W. (1991). The frog records. In 'An Atlas of Queensland's Frogs, Reptiles, Birds, & Mammals'. (Eds G. J. Ingram and R. J. Raven.) pp. 16–44. (Board of Trustees of the Queensland Museum: Queensland.)

McCoid, M. J., and Hensley, R. A. (2000). *Boiga irregularis* (brown tree snake). Seasonal activity. *Herpetological Review* **31**, 44–45.

Rodda, G. H., Fritts, T. H., McCoid, M. J., and Campbell, E. W. (1999). An overview of the biology of the brown tree snake, *Boiga irregularis*, a costly introduced pest on Pacific islands. In 'Problem Snake Management: The Habu and the Brown Tree Snake'. (Eds G. H. Rodda, Y. Sawai, D. Chiszar and H. Tanaka.) pp. 44–80. (Comstock Publishing Associates: New York.)

Savidge, J. A. (1991). Population characteristics of the introduced brown tree snake (*Boiga irregularis*) on Guam. *Biotropica* **23**, 294–300. doi: 10.2307/2388207

Savidge, J. A., Qualls, F. J., and Rodda, G. H. (2007). Reproductive biology of the brown tree snake, *Boiga irregularis* (Reptilia: Colubridae), during colonizaion of Guam and comparison with that in their native range. *Pacific Science* **61**, 191–199. doi: 10.2984/1534-6188(2007)61[191:RBOTBT]2.0.CO;2

Shine, R. (1978). Sexual size dimorphism and male combat in snakes. *Oecologia* **33**, 269–278. doi: 10.1007/BF00348113

Shine, R. (1991). Strangers in a strange land: ecology of the Australian colubrid snakes. *Copeia* **1991**, 120–131. doi: 10.2307/1446254

Shine, R. (1994). Sexual size dimorphism in snakes revisited. *Copeia* **1994**, 326–346. doi: 10.2307/1446982

Torr, G. A., and Richards, S. J. (1996). *Boiga irregularis* (brown tree snake) diet. *Herpetological Review* **27**(1), 22.

Van Dyck, S. M., and Longmore, N. W. (1991). The mammal records. In 'An Atlas of Queensland's Frogs, Reptiles, Birds, & Mammals'. (Eds G. J. Ingram and R. J. Raven.) pp. 284–336. (Board of Trustees of the Queensland Museum: Queensland.)

Whittier, J. M., and Limpus, D. (1996). Reproductive patterns of a biologically invasive species: the brown tree snake (*Boiga irregularis*) in eastern Australia. *Journal of Zoology* **238**, 591–597.

Whittier, J., Macrokanis, C., and Mason, R. T. (2000). Morphology of the brown tree snake, *Boiga irregularis*, with a comparison of native and extralimital populations. *Australian Journal of Zoology* **48**, 357–367. doi: 10.1071/ZO99025

Manuscript received 21 January 2008, accepted 18 September 2008