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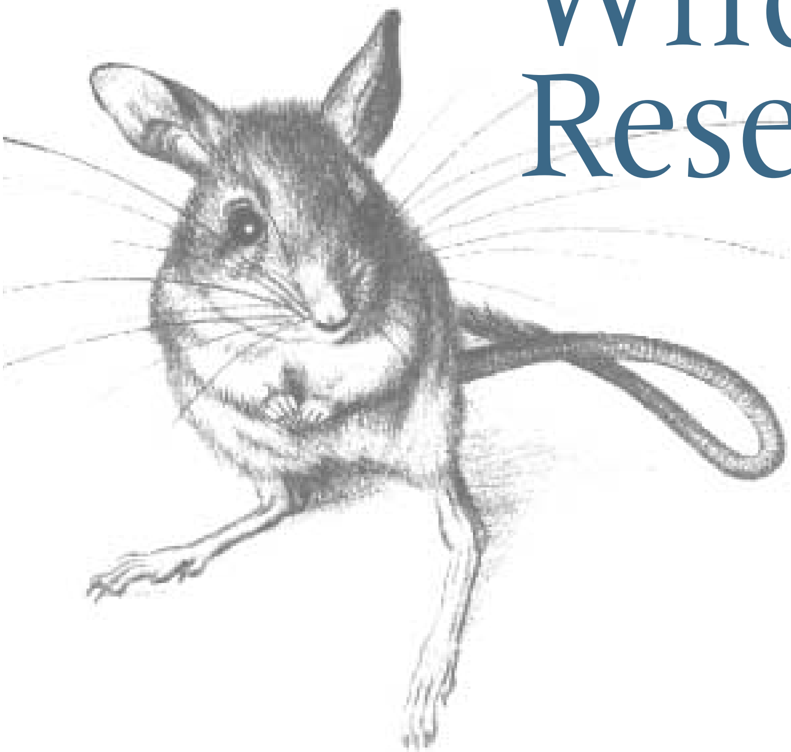

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Aggressive interactions between freshwater turtle, *Chelodina oblonga*, hatchlings and freshwater crayfish, *Cherax* spp.: implications for the conservation of the critically endangered western swamp turtle, *Pseudemydura umbrina*

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Abstract. Interactions between turtle hatchlings of *Chelodina oblonga* and the marron, *Cherax tenuimanus*, the gilgie, *C. quinquecarinatus*, the koonac, *C. preissii* (freshwater crayfish native to Western Australia) and the introduced yabby, *Cherax*. sp., were observed in laboratory-based trials in uncluttered aquaria. Marron, koonacs and yabbies, but not gilgies, showed aggressive and predatory behaviour towards the hatchlings. In total, 59 attacks were observed in 26 of the 80 trials. On 12 occasions, crayfish captured hatchlings in their chelae. On two occasions, the attack of the crayfish was so quick that the hatchling was killed instantly. Compared with movement when alone, movement of hatchlings was significantly greater in the presence of koonacs and yabbies, but significantly less in the presence of marron and gilgies.

The range of non-native yabbies currently is expanding into Ellen Brook Nature Reserve which harbours the last naturally persisting population of the critically endangered western swamp turtle, *Pseudemydura umbrina*. No native crayfish occur in the habitat of *P. umbrina* in this reserve. The possible invasion by the ecological generalist yabby poses a new threat to the survival of *P. umbrina*.

Introduction

The geographical ranges of three species of freshwater turtles and of freshwater crayfish of the genus *Cherax* (Decapoda: Parastacidae) overlap in south-western Australia. The distribution of the western swamp turtle (locally known as western swamp tortoise), *Pseudemydura umbrina* Siebenrock (Testudines: Pleurodira: Chelidae), a critically endangered species, is restricted to scattered localities with seasonal clay swamps within a 3–5-km-wide strip of the upper Swan River and Ellen Brook catchments at the foot of the Darling Scarp between Pearce Airbase and Perth Airport (Burbidge 1981; Burbidge and Kuchling 1994), north-east of Perth, Western Australia (Fig. 1). Two nature reserves, Ellen Brook (65 ha) and Twin Swamps (155 ha), were proclaimed in 1962 to protect most of the remaining natural habitat of this turtle. Seasonal clay swamps in the southern part of Ellen Brook Nature Reserve harbour the last, naturally persisting *P. umbrina* population of 30–40 turtles. *P. umbrina* nearly disappeared from Twin Swamps Nature Reserve during the 1980s; the species persists there only due to the reintroduction of captive-bred juveniles during the 1990s (Burbidge and Kuchling 1994; Kuchling, 1997). Three species of native crayfish occur within the area of the two reserves in the Ellen Brook catchment: gilgies, *Cherax quinquecarinatus* (Gray), and marron, *Cherax tenuimanus* (Smith), in Ellen Brook; and koonacs, *Cherax preissii* (Erichson), mainly in lakes and swamps. Koonacs are rare inhabitants of one swamp in the south-west corner of Twin Swamps Nature Reserve. Koonacs have not been recorded in the clay swamps at Ellen Brook Nature Reserve, although they occur in side arms of Ellen Brook inside the reserve (G. Kuchling, unpublished data) and in clay swamps elsewhere in Western Australia (Austin 1986).

The oblong turtle, *Chelodina oblonga* Gray, and plate-shelled turtle, *Chelodina steindachneri* Siebenrock, have widespread distributions (Kuchling 1988; Cann, 1998) that basically are congruent with the ranges of the native crayfish (Fig. 2). However, where *C. oblonga* and *C. preissii* co-occur, the abundance of turtles and crayfish show opposite trends: turtles are rare where there are large populations of koonacs and *vice versa* (G. Kuchling, unpublished data). This suggests some form of negative interaction between the turtles and crayfish.

In 1932, crayfish, commonly referred to as yabbies, were translocated from western Victoria into a farm dam in the

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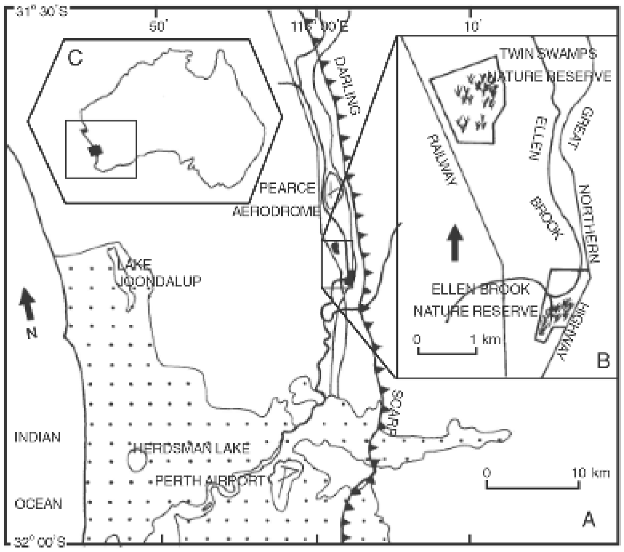

Fig. 1. Map A: location of Ellen Brook and Twin Swamps nature reserves proclaimed for the conservation of the western swamp turtle, *Pseudemydura umbrina*, in the Ellen Brook catchment; enlarged in B. Stippled area in A is the urban area of Perth. Area of the map is shown by the solid rectangle in Insert C.

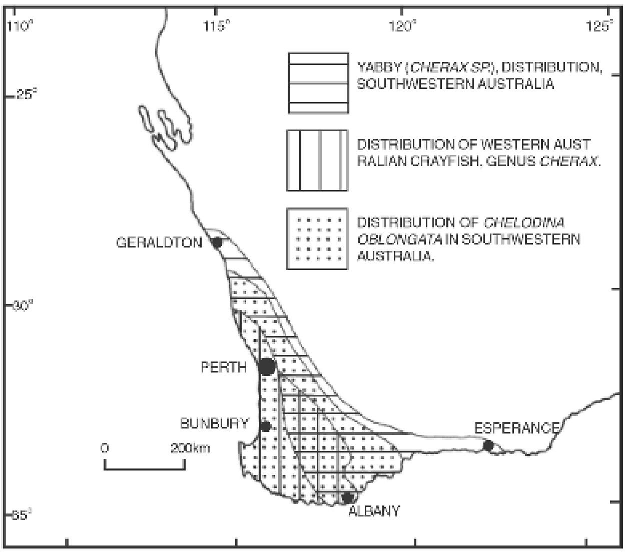

Fig. 2. Distributions of *Chelodina oblonga* and freshwater crayfish, *Cherax* spp., in south-western Australia. Area of the map is shown by the open rectangle in Insert C in Fig. 1.

wheatbelt of Western Australia (Morrissy and Cassells 1992). Two specific epithets have been used for this introduced crayfish, *destructor* and *albidus*, genus *Cherax*, and formal resolution of this nomenclatural issue involves a synonymy that has yet to be formally published, with *destructor* taking precedence by reason of page priority (Austin and Knott 1996). Subsequently, the range of the yabby in Western Australia has increased (Fig. 2), now extending from Geraldton to Esperance (Austin 1985; Horwitz and Knott 1995). By the mid-1980s, yabbies had invaded headwater streams of the Swan River catchment east of Perth, probably through natural dispersal processes of the crayfish. In 1995/96, the species was recorded from within the range of *P. umbrina*, from sites both near Perth Airport and close to the Ellen Brook and Twin Swamps nature reserves, including from a farm dam only 500 m distant from Ellen Brook Nature Reserve (G. Kuchling, unpublished data). Given the wide range of habitats occupied by yabbies (Austin 1986), this crayfish could colonise either of the two remaining major habitats of *P. umbrina*.

Any species is vulnerable to changing ecological conditions, but particularly a species such as *P. umbrina*, which is already critically endangered due to habitat loss and fragmentation and introduced predators (foxes, cats: Burbidge and Kuchling 1994). When changes could be deleterious, it is essential to anticipate them. Freshwater crayfish generally, but particularly those introduced into a new area, have been noted to cause deleterious changes to the native freshwater communities *via* competition, habitat alteration and predation (Holditch 1987). In south-western Australia, the spread of the introduced yabby (Morrissy and Cassells 1992) poses a major, possibly deleterious (Jasinska *et al.* 1993), threat to aquatic ecosystems. Rather than wait until the range of the yabby expands into the nature reserves, this preliminary study was conducted to evaluate the nature of the interaction between yabbies and turtle hatchlings under laboratory conditions, looking particularly for evidence of aggressive or predatory interactions between the two species. All species of crayfish in the Ellen Brook catchment were tested for aggressive/predatory propensity towards turtle hatchlings. In view of the scarcity of specimens and the critically endangered status of the western swamp turtle, oblong turtle hatchlings of approximately the same size were used instead.

Materials and Methods

Between mid-August and September 1998, 10 hatchlings of *Chelodina oblonga* (carapace length 30–35 mm, biomass 4.6–6.5 g) were captured in pit-traps set around the edge of Herdsman Lake, Perth. The hatchlings were housed in two 30-L aquaria with 20 cm of Herdsman Lake water. Water was changed three times per week to ensure sufficient food was available for the hatchlings. Leaf litter scattered across the bottom of each aquarium provided shelter.

Yabbies and marron from commercial sources were used; gilgies and koonacs were captured from Ellen Brook at night using baited drop nets and hand-held scoop nets. The crayfish were housed in plastic circular pools (173 cm diameter) with water 20 cm deep; shelter was provided by rocks, bricks and ice-cream containers. Sizes of crayfish used are given in Table 1.

Crayfish and hatchlings were housed in the same room; under a 10-h white light, 14-h red light photoperiod. Hatchling and crayfish behaviour were observed in plastic, circular aquaria (diameter = 173 cm, tap water 20 cm deep) under low-intensity red light, simulating light conditions shortly after dusk, the time of day when crayfish are most active and feeding. Night-vision binoculars were used during the experiments.

Table 1. Sizes of crayfish used in the 10 treatments investigating interactions between turtle hatchlings and crayfish, with number of trials in which those crayfish showed aggressive behaviour towards the hatchling
n = 8 for each treatment

Treatments	Carapace length (mm)	Biomass (g)	No. of trials with aggressive behaviour shown by crayfish	No. of trials with >1 instance of aggressive behaviour
Large starved yabby			2	1
Large fed yabby	130–155	75–120	2	1
Medium starved yabby			3	3
Medium fed yabby	95–105	28–35	4	3
Large starved marron			3	3
Large fed marron	170–185	125–155	3	2
Medium starved marron			3	3
Medium fed marron	120–140	50–65	1	0
Large fed gilgie	100–125	40–60	0	0
Medium fed koonac	75–85	18–25	5	3
Totals			26	19

Table 2. Types of aggressive behaviour displayed by crayfish towards turtle hatchlings

Category	Behaviour
Direct advances	Crayfish abruptly changes direction and moves directly towards hatchling
Stalking	Slow, interrupted movement towards hatchling
Chasing	Crayfish continuously pursues hatchling
Pouncing	Crayfish pounces on the hatchling or moves over the top of the hatchling
Clawing	Crayfish attempts to grab hold of the hatchling using its chelae.

Eighty trials were conducted using eight hatchlings and 10 crayfish treatments, as indicated in Table 1. Although the same eight hatchlings were used repeatedly as replicates for the ten treatments, each replicate of each treatment involved a different individual crayfish. Yabbies and marron were either left unfed for 3 weeks ('starved') or were given crayfish pellets daily for the week prior to their trial ('fed'). Neither group was fed for the 24 h preceding the experiment. Koonacs and gilgies were not starved because they were captured just prior to the trials.

Each turtle hatchling experienced each crayfish treatment once. Each treatment consisted of two sets of observations: one without, and one with, the crayfish present. Trials without crayfish involved placing an individual hatchling in an aquarium divided into two equal segments by a movable wooden board. They were left for 20 min, after which the board was removed and observations commenced. Every 30 s for 20 min, the turtle was recorded as being either stationary or moving, a total of 40 observations. In trials involving crayfish, a single crayfish was placed on the opposite side of the board at the same time as the turtle. Both animals were left for 20 min before the board was removed. In addition to turtle movement, aggressive behaviour by the crayfish was recorded and classified, as detailed in Table 2. Trials were stopped if crayfish captured hatchlings and restarted once the animals had been physically separated.

The incidence of the different types of aggressive behaviours shown by crayfish was compared among species, size classes and feeding regimes by Monte Carlo simulation using Monte Carlo 2 × N Contingency Table Test V1–01 (software by Bill Engels, University of Wisconsin, Madison, WI 53706, USA). Changes in hatchling behaviour, in response to different species of different sizes and feeding status, or with and without crayfish present, were analysed by repeated-measures analysis of variance using the statistical package SuperAnova (Abacus Concepts 1989).

This study was conducted under UWA Animal Ethics Approval No. 98/008/E13, issued under the Australian Code of Practice for the Care and Use of Animals for Scientific Purposes, and required separation of animals should contact be made.

Results

The yabbies, marron and koonacs, but not the gilgies, all showed aggressive and predatory behaviour towards the hatchlings (Table 1). Among the three species that did attack, there was no significant difference in the attack rate (P = 0.311). A total of 59 attacks occurred in 26 of the 80 trials (Table 1), with multiple attacks in 19 of them. Attacks involving a crayfish moving towards the hatchling followed by a predatory movement occurred on 52 occasions (Table 3). In the remaining seven attacks, a stationary crayfish clawed at or pounced on a hatchling moving towards it. There were no significant differences in the incidence of aggressive behaviour among yabbies and marron of different sizes and starvation status.

Despite the care taken to prevent such happenings, two large yabbies, one fed, one unfed, each succeeded in killing a hatchling, using on both occasions their large chelae to crush the neck of the hatchling. The crayfish responses to the hatchling carcasses were observed over a further 12 h, and in both instances the head, neck and lower fore-limbs of the hatchlings were consumed, leaving the upper fore-limbs, hind-limbs and viscera intact. Since the attack by the fed

Table 3. Incidence of different types of aggressive behaviours

Movement	Followed by successful clawing (= strike)	Followed by unsuccessful clawing	Followed by pouncing	Followed by no strike	Total
Stalking	4	10	1	5	20
Direct advance	2	13	2	3	20
Chasing	2	5	0	5	12
Stationary	4	2	1	–[A]	7
Total	12	30	4	13	59

[A]This combination of behaviours did not qualify as an aggressive behaviour

Table 4. Repeated-measures analysis of the effect of species, size and feeding regime on movement by hatchlings

The analysis includes only those trials in which marron or yabbies, fed or unfed, large or medium, were present. All interactions between these factors were non-significant and are not reported here. Movement was measured as the proportion of time spent moving. The means and standard errors are reported for the two groups in each comparison (n = 32 in each case). Variances were homogeneous as judged by Cochrans' test (C = 0.2259, $P > 0.05$)

Source	d.f.	m.s.	F	P		
Species	1	1.349	31.503	0.0008	Yabby	Marron
Species × subject	7	0.043			0.534 ± 0.047	0.244 ± 0.032
Size	1	0.017	1.262	0.2983	Large	Medium
Size × subject	7	0.014			0.373 ± 0.042	0.403 ± 0.053
Feeding	1	0.119	4.257	0.0780	Fed	Unfed
Feeding × subject	7	0.028			0.432 ± 0.047	0.346 ± 0.047

Table 5. Repeated-measures analysis of the effect of the presence of crayfish on movement by hatchlings

The analysis compared movement by the hatchlings when alone to movement when with each of the four crayfish species. To control for size and feeding regimes, the only trials included in the analysis were those involving fed medium-sized yabbies, marron and koonacs and large fed gilgies. Movement was measured as the proportion of time spent moving. Variances were homogeneous as judged by Cochran's test (C = 0.2158, $P > 0.05$). Treatment means are shown in Fig. 3

Source	d.f.	m.s.	F	P
Species	3	0.418	13.791	0.0001
Species × subject	21	0.030		
Presence of crayfish	1	0.001	0.054	0.8229
Presence × subject	7	0.021		
Species × presence	3	0.366	10.652	0.0012
Species × presence × subject	21	0.034		

yabby (climbing out of the water and over the separating board) occurred before the commencement of the scoring period, this case is not included in the analysis of aggressive behaviours.

Within the trials, in 12 instances involving 11 crayfish, hatchlings were captured in the chelae of the crayfish. This includes the attack by the unfed yabby, resulting in the death of the hatchling. In the other 11 instances it was possible to rescue the hatchling and separate the two animals and let the trial continue. Crayfish differed in their capture rate, with 4 of the 8 koonacs tested capturing hatchlings compared with 4 of 32 yabbies and 3 of 32 marron ($P = 0.044$).

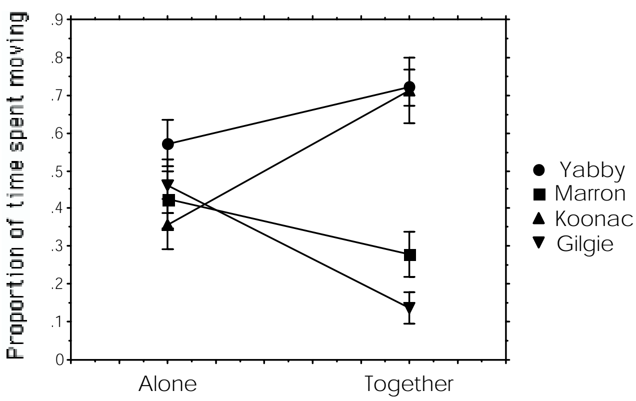

Fig. 3. The amount of movement shown by hatchlings when alone compared with when in contact with each of the four crayfish species. Each point represents the mean proportion of movement for the eight turtle hatchlings, shown with standard errors. The analysis of variance of these data is in Table 5.

Movement by the hatchlings was greater in the presence of yabbies compared with marron (Table 4), but was not affected by crayfish size or feeding regime. There was no overall effect of the presence of crayfish on hatchling movement, but there was a significant interaction between the presence of crayfish and crayfish species (Table 5). Hatchlings moved less in the presence of marron and gilgie, and more in the presence of yabbies and koonacs, than they did in the absence of crayfish (Fig. 3). However, turtle hatchlings did not appear to avoid crayfish actively: they were observed on many occasions to swim near to, even directly above, the crayfish. Nor did the hatchlings show defensive responses: none were observed to withdraw their head beneath the carapace when attacked. Indeed, the only hatchling avoidance response to an aggressive action by a crayfish was to move away, either on the surface of the water or at the bottom. Moving and stationary hatchlings were both attacked by crayfish.

Discussion

Although the experimental conditions used in trials in this study lacked opportunities for hatchlings to hide, as might occur in a complex environment, those used nevertheless probably reflect accurately the conditions where interactions might occur in the two nature reserves between crayfish and *P. umbrina* hatchlings. Hatchlings emerge from the nests in late autumn or early winter when heavy rains fill the previously dry swamps. Submerged vegetation and, therefore, aquatic habitat complexity is largely lacking at that time. Water depth in swamps of the two nature reserves generally ranges between 5 and 20 cm, with maximum depths of 40–50 cm. The 20-cm-deep water of the experimental tanks simulated this natural situation.

Little is known about the interactions between freshwater turtles and crayfish. Adult *P. umbrina* co-inhabited ponds (2 × 6 m, depth 10–40 cm) with small and medium-sized marron for many months at Perth Zoo without any obvious interactions between the species. When crayfish and adult *C. oblonga* enter the same aquatic traps, the crayfish typically are dismantled and eaten by the turtles (G. Kuchling, unpublished data). However, freshwater crayfish rarely have been implicated as predators of Australian freshwater turtles. In his review of predators of Australian turtles, including of their eggs and hatchlings, Cann (1998) did not include freshwater crayfish as known predators of turtle hatchlings. He did speculate that crayfish (*Euastacus* sp.) may have been the cause of mutilated or missing legs on hibernating, dormant *Chelodina longicollis* but he also attributed the damage to water rats. Fernandez and Rosen (1996) suggested that predation on Sonoran mud turtle, *Kinosternon sonoriense* Le Conte (Testudines: Cryptodira: Kinosternidae), hatchlings by the North American crayfish introduced into the area, *Orconectes virilis* (Hagen), as causing the decline in populatiom numbers of this turtle in streams in Arizona. Also in Arizona, Schwendiman (2001) observed predatory actions by this crayfish on Sonoran mud turtle hatchlings in stream habitats; in laboratory studies, *O. virilis* killed *K. sonoriense* hatchlings.

In the present study, yabbies, koonacs and marron showed, in the simple environment of an uncluttered aquarium, aggressive behaviour towards turtle hatchlings, involving active pursuit and the attempt to capture them. This pursuit was successful on 13 occasions, with crayfish catching hatchlings in their chelae. On two occasions the attack by yabbies was too quick for the observer to intercede and both hatchlings were killed instantly. On only a few occasions was an ambush attack observed.

The only avoidance behaviour by turtle hatchlings observed was that of swimming away from the assailant, although there was some indication of short-term learning. Several hatchlings that had experienced a successful strike swam away from the crayfish before a strike action could follow initial aggressive movements during a subsequent encounter. When threatened, juvenile and adult oblong and western swamp turtles (like many other species of most turtle families) exude a yellow, malodorous, pungent liquid from inframarginal musk (Rathke's) glands at the axillary and inguinal upper edges of the shell bridge between the carapace and plastron. This liquid of the eastern snake-necked turtle, *Chelodina longicollis*, contains mainly proteins and carboxylic acids, but no well resolved major volatile components (Eisner *et al.* 1978). The secretion is often thought to deter predators, although various mammals, birds and reptiles that were offered musk of *C. longicollis* in their food did not show adverse reactions (Kool 1981). When a small piece of meat injected with 0.5 mL concentrated *C. longicollis* musk was dropped into the tank of one adult yabby, *Cherax* sp., the crayfish started feeding immediately on the meat; when more musk was directly introduced into the tank with a syringe, no change of behaviour was noted and feeding continued (Kool 1981). However, the predatory fishes *Anguilla reinhardtii*, *A. australis*, *Tandanus tandanus* and *Macullochella peeli* do not swallow live hatchlings of *C. longicollis* and, when taken into the mouth, eject them (Cann 1998). Although the chemical defence of hatchlings of *C. longicollis* may operate against predatory fishes, it seems not to deter crayfish. The results presented here provide four lines of evidence indicating that *C. oblonga* hatchlings do not mount a chemical defence or, if one is released, it is not active against crayfish: (1) no secretions were seen; (2) crayfish repeated attempts to capture hatchlings; (3) crayfish did not let go of hatchlings by themselves; and (4) two hatchlings were consumed.

Orconectes virilis is known to prey on and kill turtle (*K. sonoriense*) hatchlings (Fernandez and Rosen 1996; Schwendiman 2001). The results presented here indicate that Australian turtle hatchlings (Chelidae: Pleurodira) are also susceptible to predation from Australian crayfish, particularly from yabbies but also possibly from koonacs, in habitats lacking structural complexity. *P. umbrina* has a much shorter neck than our model species, *C. oblonga*, and a better ability to retract and protect its head and neck under the shell margins. It may be easier for a crayfish to grasp a *C. oblonga* hatchling than a *P. umbrina* hatchling by the neck. Pleurodire turtles protect their head and neck by folding their neck horizontally under the shell margin, an action generally considered to offer less protection than is provided by the vertical head and neck retraction mechanism of cryptodire turtles (Pritchard 1979). In addition, turtles of the genus *Kinosternon* also have a plastral hinge that allows closure of the anterior shell opening by elevating the anterior plastral lobe. However, despite their cryptodire head- and neck-retraction movement, *K. sonoriense* hatchlings are still susceptible to crayfish predation (Fernandez and Rosen 1996; Schwendiman 2001). This suggests that *P. umbrina* hatchlings, despite having shorter necks than those of our model species, *C. oblonga*, may also be susceptible to crayfish predation. Further, population stability of *P. umbrina* may be more sensitive to increased predation pressure on hatchlings than is the case in *C. oblonga* populations, since females produce only 2–5 eggs per year (Kuchling and Bradshaw 1993). This is a very low annual reproductive output compared with *C. oblonga*, females of which may lay two or three clutches of up to 16 eggs per year (Kuchling 1988).

Is the risk real that one of the group of crayfish shown to be aggressive towards hatchlings (marron, koonacs, yabbies) might invade the swamps of the two nature reserves gazetted for the protection of the western swamp turtle? Marron are typically found in permanent waters and consequently are unlikely to move into the temporary swamps of the nature reserves. Both koonacs and yabbies occur naturally in temporary water-bodies (Austin 1986; Lake and Sokal 1986), but koonacs seem to avoid pure (as opposed to sandy) clay soils. Koonacs are rare in Twin Swamps Nature Reserve, where they seem to be restricted to a relatively small part of the reserve with partly dark and peaty soil (G. Kuchling, unpublished data). Koonacs have not been found in the clay swamps at Ellen Brook Nature Reserve. Yabbies, however, have both high vagility and inhabit clay substrates (Austin 1986). Since Ellen Brook is only 30 m distant at its closest point from the *P. umbrina* swamp habitat at Ellen Brook Nature Reserve, with a semi-permanent stream flowing from the swamps into the Brook, and during the course of the present study, large yabbies were recorded from Ellen Brook at the confluence with this short outflow stream, it is highly likely that the swamps will be invaded by yabbies in the future.

The spread of the yabby, a non-native, potentially efficient predator of turtle hatchlings, into the geographical range of *P. umbrina* therefore represents a threat to survival of the critically endangered western swamp turtle. The impact of yabbies on the survival of western swamp turtle hatchlings and their recruitment into the population needs to be considered in future management programmes for the conservation of *P. umbrina*.

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