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Habitat Use and Movements in an Upland Population of Johnstone River Snapping Turtles, *Elseya irwini*

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***Abstract*.—Our objectives were to ascertain the patterns of movement and habitat use in upland populations of the regionally restricted Johnstone River Snapping Turtle, *Elseya irwini*, in tropical Queensland, Australia. Between October 2014 and October 2015, we radio tracked eight (four male and four female) *Elseya irwini* in the headwaters of the Johnstone River in far north Queensland. Over this time, we made 342 radio fixes for males and 353 for the four females, with fixes varying between 78 and 90 per animal. There was not a significant relationship between the distances a turtle moved from its point of release and the number of days since release, suggesting turtles restrict their movements to a home range. While the movement of males was more variable than females, male movement did not differ significantly from females in linear range span or total linear distance. Linear home range of the eight turtles varied between 387 and 1128 m. Daily displacement distances were small (9–31 m) with the four individuals with the largest and smallest displacement distances being male. Other than one male, which disappeared from the area for a period of six weeks, there was no indication of long-range migratory movements. This species appears to be largely sedentary with small home ranges and short daily movements. Long range movements do occur but appear to be extremely rare. A sedentary lifestyle potentially makes this turtle more susceptible to localized negative impacts such as habitat degradation, disease, and feral animal predation of nests.**

Key Words.—conservation; daily movements; home range; linear distance; Queensland; radio tracking

Introduction

Globally, freshwater turtles are a highly threatened group of vertebrates (Buhlmann et al. 2009). Of 331 turtle and tortoise species, 155 (46.8%) are listed as threatened (Critically Endangered, Endangered, or Vulnerable), and of this total, 101 (30.5%) are considered Endangered or Critically Endangered (van Dijk et al. 2012). Recent analysis suggests that 57% of all modern tortoise and turtle species are already extinct or threatened (van Dijk et al. 2012). As a major vertebrate group, turtles are more threatened than birds, mammals, cartilaginous and bony fish, or amphibians (van Dijk et al. 2012). Locally in the state of Queensland, Australia, five of 14 freshwater turtle species (36%) are currently listed as threatened (Endangered and Vulnerable) under state nature conservation legislation (Queensland Nature Conservation Act, 1993). Those species listed as threatened tend to have highly restricted distributions as well as being under threat from water infrastructure development, habitat loss, and/or feral animal predation of nests (Hamann et al. 2007; Limpus et al. 2011; Limpus 2012; Freeman et al. 2014, 2016).

The Johnstone River Snapping Turtle, *Elseya irwini* (Fig. 1), is a medium to large-sized turtle known from the North and South Johnstone rivers in tropical north Queensland, Australia (Turner 2006; O'Malley 2007). *Elseya irwini* was thought to be a unique taxon despite originally being included within the *E. dentata* species complex (Georges and Adams 1996; Cann 1998; Georges and Thomson 2006). Subsequently the Johnstone River *Elseya* was described as a separate species, *E. stirlingi* in 2007 (Wells 2007). However, the method of this description, a non-peer reviewed, electronic newsletter, was controversial (Iverson et al. 2001; Georges and Thomson 2010). In 2010 this description was overturned and the species *E. stirlingi* was synonymized with Irwin's Turtle (*E. irwini*; Georges and Thomson 2010), a species that had previously been thought to be confined to the Burdekin drainage south of the Johnstone River. Despite being synonymized at a species level, the Johnstone River Snapping Turtle was still recognized as distinctive genetic taxa (Georges and Thomson 2010), a view that has subsequently been supported by further genetic research (Todd et al. 2014).

Previous studies on *E. irwini* have focused on lowland populations < 300 m elevation (Turner 2004; Turner 2006; O'Malley 2007). In contrast, our radio tracking work was part of a monitoring and survey project of high altitude populations of *E. irwini* on the Atherton

Figure 1. Female Johnstone River Snapping Turtle (*Elseya irwini*) just before release with transmitter attached. Within a very short time the transmitter became discolored with algae and became largely indistinguishable from the color of the carapace. (Photographed by Alastair Freeman).

Tablelands at an elevation > 700 m. We implemented this study in response to concerns expressed about the conservation status of the turtle in light of its restricted distribution to one highly modified catchment. Our objective was to study the movement and habitat use of upland populations of *E. irwini* and identify potential threats to their conservation status.

Materials and Methods

Study area.—The study site occurred on Atherton Basalts, which is the predominant geology at the top of the Johnstone catchment on the Atherton Tablelands, Queensland, Australia (Lottermoser et al. 2008). The Johnstone River catchment is 1,680 km^2 with approximately 57% of that area highly modified by clearing for human settlement and agricultural development. The other 43% is largely covered in rainforest, most of which is protected within the Wet Tropics World Heritage Area (Turner et al. 2004). The broader study area is typified by pasture, small rainforest fragments, often in the form of narrow riparian strips and low-density rural-residential subdivision. The river in this part of the landscape is a combination of shallow (< 1 m) to deep (> 3 m) pools interspersed with lengths of riffles 10 to approximately 50 m in length (Fig. 2). We radio tracked turtles along two river kilometers in the upper catchment area of the Johnstone River located east of the town of Malanda (Fig. 3).

Capture and transmitter attachment and tracking.—We captured eight turtles (four males and four females) by snorkeling on 23 October 2014 (Table 1). We weighed, measured, and individually marked turtles with a combination of PIT tag, flipper tag, and scute notches. We attached VHF transmitters to the lower outer marginal scales using a combination of plastic cable tie, superglue, and two part marine epoxy (Fig. 1). We released all the turtles at the site of capture on 24 October 2014.

Table 1. Turtle identification number (ID), sex (M = male, F = female), straight-line carapace length (SCL) in cm, number of radio fixes, period tracked, and the number of days (ND) tracked for individual Johnstone River Snapping Turtle (*Elseya irwini*) recorded by radio telemetry in the upper catchment of the North Johnstone River, Atherton Tablelands, Australia. For Period tracked, the dates refer to the first day tracked post release to last day tracked and pre attempt to re-capture.

ID	Sex	SCL	Fixes	Period tracked[1]	ND
1	M	23.88	78	26 October 2014 – 2 October 2015	341
2	M	20.72	85	26 October 2014 – 18 September 2015	327
3	M	21.88	89	26 October 2014 – 7 October 2015	346
4	M	20.14	90	26 October 2014 – 7 October 2015	346
5	F	29.56	84	26 October 2014 – 18 September 2015	327
6	F	29.54	89	26 October 2014 – 2 October 2015	341
7	F	23.67	90	26 October 2014 – 7 October 2015	346
8	F	25.69	90	26 October 2014 – 7 October 2015	346

We tracked turtles using a Communications Specialists Inc. 1000 telemetry receiver (Orange, California, USA) with a Sirtrack™ (Havelock North, New Zealand), folding, three element, directional Yagi antenna. We obtained fixes approximately every 3.8 d from a kayak or from shore using a close approach methodology (Table 1). As the turtles were invariably not observed directly, we used signal strength to calculate distance to animal. Prior to the transmitters being placed on the turtles, they were calibrated out of the water to the specific receiver used in the study, which enabled us to calculate a conservative distance to animal when tracking using signal volume. We estimated all kayak-based fixes to be accurate to within 10–15 m of individual turtles, while we estimated the accuracies of shore-based fixes to vary between 10–30 m. Once a position was fixed, we took a GPS point for that locality using a handheld Etrex 30 GPS (Garmin Ltd., Olathe, Kansas, USA). We often cross checked shoreline fixes using Google Earth when it was not possible to get close to the animal. While all effort was made to keep disturbance of the turtles to a minimum, there is little doubt that on occasions our presence did disturb individual turtles. However, disturbed individuals never moved far from where they were first recorded and, except for one individual on one occasion, always remained within the general area.

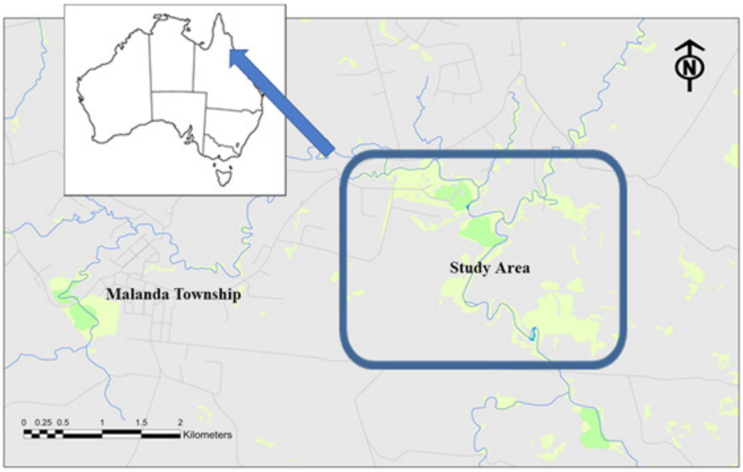

Figure 2. Location of study area in far north Queensland, Australia.

Statistical analysis.—We calculated displacement distances (distance divided by number of days between fixes) by measuring the shortest possible distance of travel by a turtle excluding terrestrial movement. We defined linear home range as the distance between the farthest locations travelled upstream and downstream in the river (the sum of linear segments within stream; Plummer et al. 1997). We calculated total distance as the sum of the displacement distances from October 2014 to October 2015 (sum of straight line segments between the first and final fixes). We also calculated the average daily displacement distance, which is the displacement distance divided by the number of days between the two fixes (m/d). We used Spearman's Rank Correlations between number of telemetry fixes and linear home range size, total distance, and displacement distance to test if animals that moved farther were harder to locate and located less often. Animals that maintain a home range should not wander randomly from their release site (Slip and Shine 1988). We used a simple linear regression to test for an increase in proximity from the release site over a 60-d period after release. Individuals not restricted to a home range have the tendency to be located farther away from its starting points over time.

Table 2. Linear range span (in meters), total distance moved (in meters), number of locations (n), and displacement distance for four male (ID 1–4) and four female (ID 5–8) Johnstone River Snapping Turtle (*Elseya irwini*) radio-tracked from October 2014 to October 2015 in the upper catchment of the North Johnstone River, Atherton Tablelands, Australia. Displacement distance shows means ± standard error and range of daily movement in m/day.

ID	Linear range span	Total distance	n	Displacement distance (m/d)
1-M	1,127.7	7,838.9	78	30.13 ± 5.25 (0–208.1)
2-M	972.4	8,871.8	85	30.97 ± 4.70 (0.8–178.8)
3-M	770.9	2,974.0	89	10.24 ± 2.15 (0–152.4)
4-M	358.7	2,839.0	90	9.14 ± 1.48 (0–83.1)
5-F	885.8	4,581.3	84	16.77 ± 2.87 (0–154.4)
6-F	386.7	3,916.2	89	12.32 ± 1.88 (0–97.7)
7-F	1,057.8	3,578.9	90	12.82 ± 3.09 (0–263.8)
8-F	540.8	6,752.0	90	19.95 ± 3.20 (0–166.6)

The collection of data did not begin until 26 October 2014 providing turtles a 48-h period to settle back into their habitat. We used the historical rainfall data available at the Australian Bureau of Meteorology (www.bom.gov.au) for Malanda (Queensland, 17.38°S, 145.58°E) to plot the average displacement distance between males and females in relation to monthly average rainfall. Differences in movements variance were tested using a Levene's test. We tested for differences in movements between sexes with a standard t-test (Sokal and Rohlf 1981) or Welch two sample t-test when variances were unequal. For statistical analyses, we used R v.3.0 (R Development Core Team 2014) and Microsoft Excel 2013. The alpha level was set at 0.05. We conducted all spatial analyses in ArcGIS 10.3.1™.

Results

The number of fixes was not significantly correlated with linear home range size (rho = -0.540, n = 8, P = 0.167), total distance (rho = -0.589, n = 8, P = 0.124) or displacement distance (rho = -0.528, n = 8, P = 0.179). Neither could a significant relationship be demonstrated between the distance a turtle was located from its point of release and the number of days since release (Table 2). The home ranges of all individuals overlapped with each other (Fig. 4).

Figure 3. Typical habitat for the Johnstone River Snapping Turtle (*Elseya irwini*) in the upper catchment of the North Johnstone River, Atherton Tablelands, Australia. (Photographed by Alastair Freeman).

Females travelled shorter daily distances (< average of 20 m per day) while males could be divided in two groups, one covering shorter (< 11 m) and another longer (> 30 m) average daily distances (Table 2). Variances were homogeneous for linear home range sizes ($F_{1,6}$ = 0.011, P = 0.920); however, there was evidence of heterogeneity of variances using Levine's test for total distance ($F_{1,6}$ = 9.351, P < 0.050). Total distances covered by males were significantly more variable than females. Mean linear home range (linear range span) for all the turtles was 762.6 ± 106.4 m (n = 8). There was no significant difference between mean female and male linear home range size (females: 717.8 ± SE 154.1 m; males: 807.4 ± 166.4 m; t = -0.395, df = 6, P = 0.706) or mean total distance moved (females: 4,707.1 ± 712.7 m; males: 5630.9 ± 1587.3 m; t_{Welch} = -0.531, df = 4.163, P = 0.623). We found males to be more active in months with the highest rainfall (February and March 2015), while movements of females were not related to rainfall (Fig. 5).

Discussion

Elseya irwini appears to be a largely sedentary species compared with other species of Australian turtles, with linear home ranges for seven of the eight turtles spanning less than 1,060 m over the course of a year. The 763 m mean linear home range we found for *E. irwini* in the current study was larger than that recorded for the White-throated Snapping Turtle, *E. albagula*, on the Burnett River, Queensland, which were considered to be generally < 500 m (Hamann et al. 2007), but similar to that recorded for the Fitzroy River Turtle, *Rheodytes leukops*, with a length of 678 m on the Fitzroy River, also in Queensland (Tucker et al. 2001). Flakus (2002) recorded the total linear range of Mary River Turtles (*Elusor macrurus*) at one site as varying from 100 m to 2 km, with females ranging from 250 m to 2 km and males from 100 m to 1.1 km. Female Pig-nose Turtles, *Carettochelys insculpta*, on the Daly River in the Northern Territory, Australia, have a mean linear home range of 8.3 km, which is much larger than the 3.2 km recorded for males (Doody et al. 2002). In contrast we found *E. irwini* males in the present study exhibited a mean linear home range slightly larger than females. Our study did not show a tendency for long-range movements in *E. irwini* over the course of the year, although such movement patterns may occur infrequently.

Recent genetic analysis showed that upland and lowland populations of *E. irwini* share common genetic variants and lacked significant genetic population structure, indicating that rare, long-range movements by *E. irwini* have occurred in their recent evolutionary history (Todd et al. 2014; Erica Todd, unpubl. data for 12 microsatellite markers). This is despite the middle reaches of the Johnstone River crossing a steep escarpment of boulder drop offs, cascades, and waterfalls constituting what we consider largely unsuitable habitat for this turtle. Similar long-range movements by individual *E. albagula* on the Burnett River, Australia, have also been recorded (Hamann et al. 2007). Such movements can be over distances of 4–6 km and are thought to be females moving to aggregate on nesting areas (Hamann et al. 2007). However, long range movements in this species is not exclusively a female phenomenon as males have been documented moving over 10 km at mating time (Limpus et al. 2011). This is in line with a range-wide population genetic study of *E. albagula*, which found that populations were largely well-connected by gene flow within, but not across, three adjacent river catchments (Todd et al. 2013).

We did not record one *E. irwini* male (No. 1) on the study site for seven weeks, between 9 January and 27 February 2015. During this period, he is thought to have departed the area as searches 1.8 km downstream and 4.5 km upstream of the study area failed to locate him. The last record for this individual before this period of absence was one of the most upstream locations we have for him, while the first observation of this

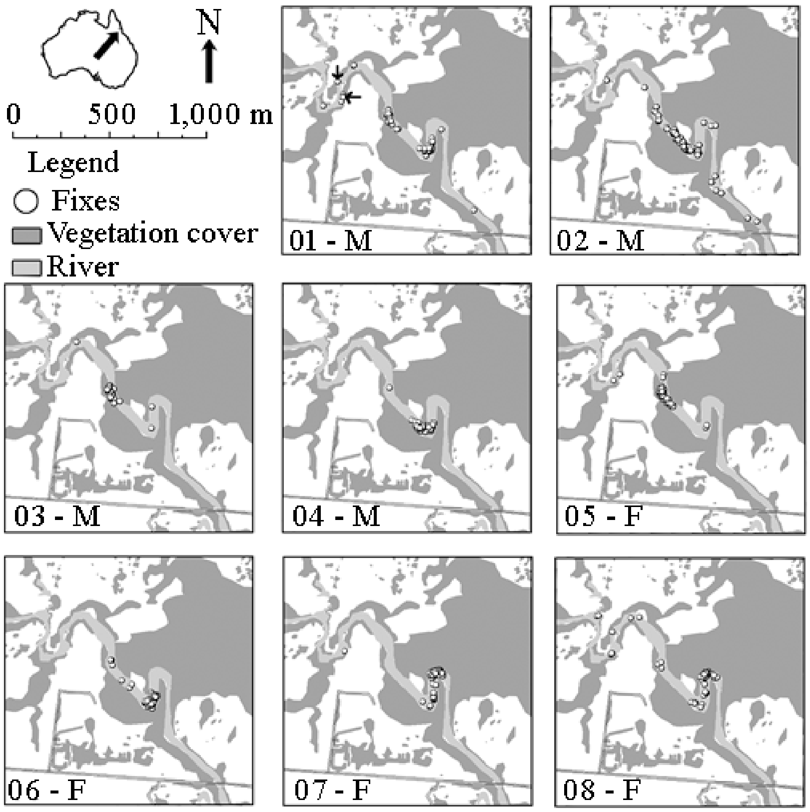

Figure 4. Fixes for four males and four females of Johnstone River Snapping Turtle (*Elseya irwini*) radio-tracked from October 2014 to October 2015 in the upper catchment of the North Johnstone River, Atherton Tablelands, Australia. Periods between fixes were in average 3.9 ± 0.3 (SE) days. Arrows on 01-M indicate last and first fix before and after the seven weeks absence between January and February 2015.

individual back in the study area was also upstream of his usual locality indicating he was probably upstream of the study area during this time. The period he was absent from the study area coincided with the only time when we observed courtship behavior in male turtles in this study. After six weeks this individual reappeared at the study area and remained there for the rest of the fieldwork period. Overall, while *E. irwini* appear to be largely sedentary by nature, occupying relatively small home ranges, these long-lived species may have significant life-time dispersal capacity with population genetics indicating that at least occasional long-range movements do occur.

Males were more active at times of greatest rainfall in February and March. It was also during this period we made the only observation of reproductive behavior among *E. irwini* males. On the 3 and 6 February, we observed non-transmitted turtles nuzzling, the equivalent of approach behavior documented in *Emydura macquarii* and *Myuchelys* (referred to as *Elseya*) *latisternum* (Murphy and Lamoreaux 1978) and follow and cloacal check in *Emydura subglobosa* (Norris 1996). We also observed close approach or curiosity behaviors. The latter behavior has also been recorded in male *Elseya lavarackorum* and is invariably associated with other mating behaviors (Alastair Freeman, unpubl. data). When displaying this behavior, male turtles show a curiosity or fearlessness not seen at any other time of the year, approaching snorkeling humans and objects such as kayaks and boats to within a meter or closer.

Generally, river turtles are assumed to nest annually (Moll and Moll 2006). For example, it has been reported that the majority of *E. albagula* females can be expected to breed every year (Hamann et al. 2007; Limpus et al. 2011), while it was suggested that all mature *E. dentata*, at a study site in the Northern Territory, Australia, laid eggs every year (Kennett 1999). Similarly, 78% of adult female *Myuchelys belli* were found to ovulate in any one season (Fielder et al. 2015). Therefore, it is not unreasonable to assume that of the four females with transmitters, at least some, if not all, would have attempted to nest during the 2015 nesting season. None of the female *E. irwini* in this study made long-range migratory movements, behavior often seen in other species of freshwater turtle species (Moll and Moll 2004). Using camera traps, we recorded nesting taking place in the study area over two nights (16 and 17 May). However, displacement distances for the four radio-

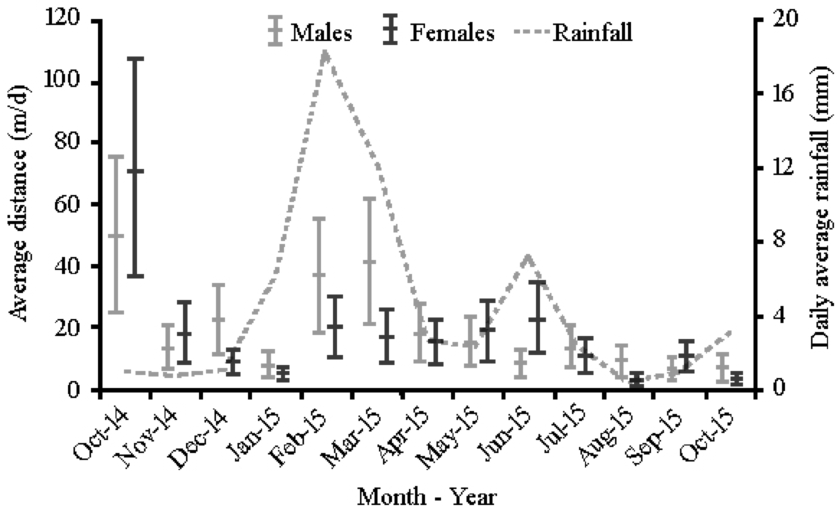

Figure 5. Monthly average rainfall (Malanda, Queensland, Australia) and displacement distance (m/d) for four male and four female *Elseya irwini* radio-tracked from October 2014 to October 2015 in the upper catchment of the North Johnstone River, Atherton Tablelands, Australia. Error bars represent standard errors.

tracked females during the month of May showed no obvious departures from other months, suggesting they were using local nesting sites.

The study area included at least five separate known nesting sites in 2015 (Alastair Freeman, unpubl. data). In contrast, female *Elusor macrurus* have been recorded making short (475–783 m), but distinct, migratory journeys from foraging areas to sandy nesting banks (Flakus 2002; Limpus 2012). These banks are traditional nesting sites, revisited across decades (Cann 1998; Flakus 2002). In contrast, nesting sites used by *E. irwini* appear to be more ephemeral, often areas that have been cleared of vegetation by the preceding wet season floods or new banks that have been created by slumping of fluvial erosion, unlikely to last more than a wet season or two. The most significant nesting site in the general area of the study is a patch of lawn maintained by regular mowing.

After only one year of tracking, longer range migratory movements by *E. irwini* females to nesting areas as seen in other species of river turtles cannot be dismissed. Wet seasons are variable in rainfall intensity and duration. As a result, the extent, number and distribution of nest sites within the area are likely to vary from year to year. Consequently, the extent of movement of female *E. irwini* to suitable nesting sites may also vary.

The displacement distances we documented in the present study for *E. irwini* were small, varying from nine to 31 m, with some pattern of differentiation being evident between females and males. However, this pattern of differentiation is not easily explained as the two individuals with the largest daily movements were males (30.13 m and 30.97 m) while the two smallest (9.14 m and 10.24 m) were also males. Female daily movements fell between these two extremes. Tracking data for *E. albagula* in the Burnett River also revealed no clear pattern of sexual differentiation in individual movement patterns for the majority of turtles that were followed (Hamann et al. 2007). Female linear home ranges in Hamann et al. (2007) were larger than male home ranges; however, this result was confounded somewhat by several long-range movements made by a few individuals (males and females). In contrast, Broad-shell Turtles (*Chelodina expansa*) showed significant differences between male and female displacement distances with the former having a mean range span of 11.18 km (± 4.10) and the latter 1.43 km (± 1.73; Bower et al. 2012). However, *C. expansa* lives in river systems subject to great flood extremes over wide flood plains and extensive wetland areas, while *E. irwini* and *E. albagula* are herbivorous and inhabit relatively stable tropical rivers.

A significant flood event occurred on the upper Johnstone during the month of February resulting in a dramatic rise in the level of the upper Johnstone River where it flowed through the study area. Within 24 h of this rainfall event, we tracked the turtles from the riverbank. Despite the river being in flood conditions, we accounted for all but two turtles within the study area. We recorded one of the missing turtles back in the study area two days later while the other missing individual had departed the area at least 12 d before the flood event. Our tracking data suggested that, during the period of high water levels, the turtles remained stationary in the channel of the river near where flood waters would have been, or at their deepest. For a turtle living in an environment that is subject to regular flooding events as a result of monsoonal wet season rainfall, the strategy of sitting on the bottom of the main river channel during these floods is probably a means of conserving energy while enabling it to maintain its position within its home range. The maximum water velocity is just below the surface of the water, while water velocity is almost zero on the river bed due to frictional resistance (Gordon et al. 2007). The study site itself is largely confined to the main channel with little opportunity for surplus flood waters to flow into side channels or off-river pools and wetlands. Thus, the area does not appear to be well endowed with off-river flood refugia for resident *E. irwini* during flood events. During these flood events, the river bed probably provides a physiologically low maintenance, protected refugia for the turtles. The distribution of records offers no evidence of territorial behavior with all turtles overlapping with the same sex in time and space during tracking. This behavior is not unexpected, as territoriality has seldom been documented in freshwater turtles and is likely to be rare. For example, in the closely related species, *E. lavarackorum*, agnostic behavior between individuals has been observed amongst turtles aggregating under riparian fruiting trees, over fallen fruit a key food source, but there is no suggestion that this constitutes territorial behavior (Freeman 2014).

Conservation considerations.—The original aim of this research was to help inform conservation management of *E. irwini* in upland areas of tropical far North Queensland. Survey data in the upper catchment points to a species that has a patchy distribution concentrated around pool-riffle systems that flow through fertile basalt soils (Alastair Freeman, unpubl. data). Our tracking data collected during the present study indicates that most turtles followed over the year were largely sedentary with only one turtle of the eight tracked potentially making longer journeys outside of the study area. As a result of this sedentary lifestyle, *E. irwini* is potentially more susceptible to localized threats in the form of habitat destruction and modification, disease outbreaks, or nest predation by feral animals. While major water infrastructure development is unlikely for the foreseeable future in the Johnstone catchment, cumulative impacts from rural-urban development are likely to increase. Human population is projected to increase in the greater Malanda area by over 8% by 2036 (http://www.qgso.qld.gov.au/products/tables/proj-pop-medium-series-sa2-sa3-sa4-qld/index.php). Overlaying all future development scenarios will be the impact of climate change. Under climate change modeling, it is predicted that annual temperatures in the Wet Tropics region will increase to well beyond those experienced for the last 50 y. The best estimate of projected rainfall changes shows a decrease under all emissions scenarios while evaporation could increase by 7–15% (Queensland Government 2009). It has already been suggested that a disease outbreak that occurred in late 2014 / early 2015 that lead to mass mortality in *E. irwini* upstream of the current study area could occur more frequently over the coming years due to changes in the interrelationship between temperature, rainfall, water quality and disease, resulting from climate change (Ariel et al. 2017). The vast majority of known high-quality upland habitat for *E. irwini* is not protected. Combined with a very restricted overall distribution, the conservation status of this turtle on the Atherton Tablelands should be considered far from secure.

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