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ORIGINAL PAPER

# Identifying critical habitat for freshwater turtles: integrating long-term monitoring tools to enhance conservation and management

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**Abstract** The effective conservation and management of threatened species requires comprehensive knowledge about resource utilisation. Here we integrated tissue stable isotope analysis and biotelemetry to identify the predominant dietary resources of two sympatric species of freshwater turtle, and locate where those items were acquired. We deployed an array of underwater acoustic telemetry receivers to autonomously, simultaneously, and continuously, monitor the movements of the threatened *Elseya albagula* and *Elusor macrurus*, over a 12-month period. Stable isotope (SI) values ($\delta^{13}C$ and $\delta^{15}N$) were measured within the carapace of each species, and compared with SI values within potential food items. The integration of movement information and carapace SI data revealed that whilst these species had overlapping home ranges, there was less than 5% probability of inter-species dietary niche overlap. *E. macrurus* acquired food items consisting of bivalves, gastropods and aquatic insects within rocky riffles whilst *E. albagula* fed on filamentous algae and crustaceans foraged from the muddy and vegetated shallow margins of deep water pools. Our findings differ from stomach content analysis and mark-recapture studies, which reported these species to have similar habitat and resource requirements. We argue that the observed disparity is because our methods provided a weighted measure of an individual's dietary preference and habitat utilisation over a broad time-scale, whilst stomach content analysis and mark-recapture studies offer only a single observation of an individual's dietary preference. The research demonstrates the utility of

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integrating passive acoustic telemetry and carapace stable isotope analysis for identifying critical habitat for freshwater turtles.

**Keywords** Ecological niche · Trophic ecology · Acoustic telemetry · Stable isotope analysis · SIA

## Introduction

The movement and occurrence of species generally reflects spatiotemporal patterns in the quantity and quality of resources (Hutchinson 1957; Tempel and Gutiérrez 2013). The effective conservation of threatened species requires comprehensive information about species distributions, and a large body of research has been focused around identifying the resources utilised by a species and predicting where these occur in the environment. To collect these types of data, tissue stable isotope analysis and biotelemetry devices have become popular research techniques (Dwyer et al. 2015; Campbell et al. 2015) The composition of stable isotopes in animal tissues reflects their diet, and since different tissues turnover at different rates, the isotopic composition of different tissues in the same animal can provide insight into diet over multiple time frames (Jardine et al. 2012; Hanson et al. 2015). Integrating dietary information with individual-based movement data, collected by animal-borne biotelemetry devices, can reveal the relative significance of habitats to an individual, population, or species (Cunjak et al. 2005; Papastamatiou et al. 2010; Matich et al. 2011; Caron-Beaudoin et al. 2013; Rosenblatt et al. 2015).

In marine turtle research, biotelemetry technologies are used extensively to collect high resolution location data upon individuals (Pajuelo et al. 2012). These data are then used to reveal the location of significant areas, critical habitats, and corridors (Stokes et al. 2014, 2015). Similarly, tissue stable isotope analysis is used routinely to assess dietary preferences and identify the location of marine turtle feeding grounds (Godley et al. 1998; Burkholder et al. 2011). The integration of diet and movement information has dramatically enhanced our understanding of marine turtle resource use, and has improved the conservation and management for many populations (Brooks et al. 2009; Bailleul et al. 2010; Ceriani et al. 2012; MacDonald et al. 2012, 2013; Pajuelo et al. 2012; Scales et al. 2011; Thums et al. 2013).

In contrast, automated biotelemetry locating technologies and tissue stable isotope analysis have been seldom used to identify critical habitat and resource use in freshwater turtles (e.g. Seminoff et al. 2007; Bulte and Blouin-Demers 2008; Aresco 2010; Lara et al. 2012; Pearson et al. 2013; Micheli-Campbell et al. 2013; Christensen and Chow-Fraser 2014; Markle and Chow-Fraser 2014). In freshwater turtle research, movement and habitat preference data are typically collected by direct observation, mark-recapture, or active tracking using VHF radio (Georges 1982; Eckler et al. 1990; Buhlmann and Vaughan 1991; Slavenko et al. 2016). These methods provide irregular and infrequent location fixing, and produce data that are not effective for identifying high-utilisation areas at the fine spatial scale (Kie et al. 2010). To assess diet in freshwater turtles' stomach flushing and then analysis of the content remains the most common method (Spencer et al. 2014). This is despite a growing body of literature that asserts that a single measure of the stomach contents does not provide reliable information for understanding the trophic niche requirements of an individual or population (Marques et al. 2011).

It is not immediately apparent why research methods used routinely for assessing diet and habitat preference in marine turtles have not been similarly applied to freshwater turtles. It may simply be that automated biotelemetry devices and tissue stable isotope analysis are more expensive to implement than mark/recapture, VHF telemetry, and stomach flushing; and considered beyond the financial limits of freshwater turtle conservation and management programs. The costs of autonomous biotelemetry devices and tissue stable isotope analysis has however, reduced substantially in recent years, and because freshwater turtle populations are in severe decline (Hoffmann et al. 2010), we considered it important to assess if the application of these research techniques enhanced our understanding of critical habitat in freshwater turtles.

Here we assessed the resources used by two species of sympatric and threatened species of freshwater turtle, *Elusor macrurus* and *Elseya albagula*. We used animal-borne acoustic transmitters with depth-sensors and fixed underwater receivers to ascertain the location of high-use foraging areas at the fine spatial scale. These data were integrated with a broad temporal-scale assessment of dietary preference, by comparing stable isotope values within the turtle carapace with potential food items. The findings were compared with current knowledge about resource for these species, gathered through the traditional sampling techniques of stomach flushing, mark-recapture, and active location fixing using VHF-radio telemetry.

## Materials and methods

### Study area

The study was conducted in the mid-catchment stretch of the Mary River, Queensland, Australia (Fig. 1). This stretch was selected because both *E. macrurus* and *E. albagula*

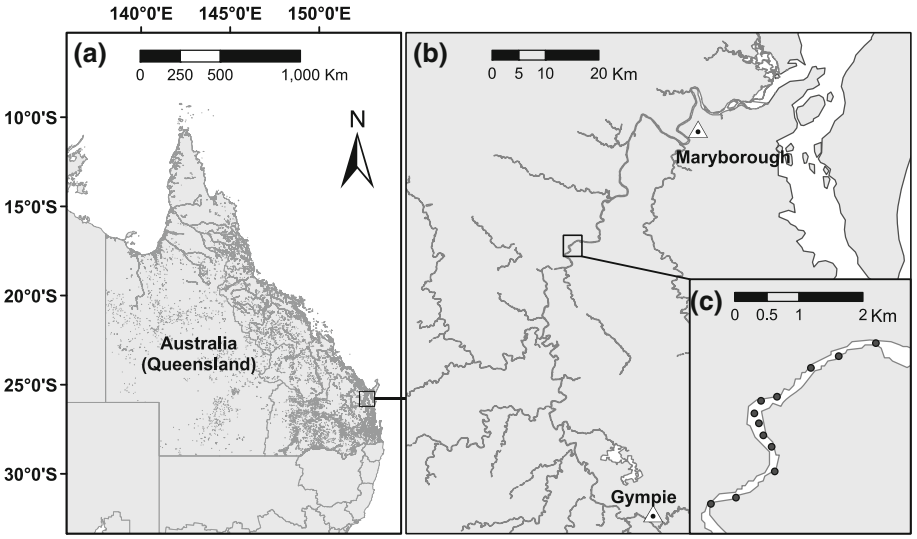


**Fig. 1** **a** The location of the Mary River catchment in south-east Queensland, Australia. **b** The location of the study stretch within the Mary River catchment. **c** The location of the underwater acoustic hydrophones within the study area

have been captured here (Limpus 2008). The river stretch is composed of a sequence of riffle (depth = 0.5–1 m; flow < 1.5 $ms^{-1}$) and pool sections (depth 3–6 m; flow < 0.2 $ms^{-1}$), an arrangement that is characteristic of the Mary River (Pusey et al. 2004; Kennard et al. 2006).

## Turtle capture

Turtles were captured using double-winged set-nets. The nets were deployed at six locations throughout a 4.7 km river stretch, within water of 1–1.5 m depth. The net design resulted in the funnelling of turtles moving along the river into a 4 m length × 1 m diameter cod-end. Once in the cod-end, the turtles could move freely and surface to breathe. A total of 16 adult female *E. macrurus* (body mass 3.4 ± 0.3 kg, carapace length 313 ± 8 mm, mean ± SE) and 15 adult female *E. albagula* (body mass 4.19 ± 0.15 kg, carapace length 327 ± 5 mm, mean ± SE) were captured using this method.

## Biotelemetry

Five female adults of each species had acoustic transmitters (V13TP; VEMCO, Halifax, NS, Canada) attached to their carapaces. The transmitters were 36 L × 13 D mm, weighed 11 g in air (<1% of the turtle's body mass), and had an in-build depth sensor (accurate to 0.1 m). The recorded depth data and a unique ID code for each turtle was emitted as a sonic pulse every 60 s at an output of 147 dB. The transmission frequency and power output was optimised to provide battery longevity of ~12 months. The acoustic transmitters were attached to the posterior marginal scutes of the carapace using a purpose built cap, plastic saddle, and PVC nuts and bolts (1.5 mm). The transmitter was attached to the carapace via two holes (2.5 mm diameter) drilled vertically though the marginal scutes. The bolts were inserted through the holes on the underside of the carapace and fixed with a washer and nut. The nuts were secured with Loctite 243 (Henkel, Victoria, Australia), and the ends of the bolts were covered in a two-part epoxy putty (KneadIt, Selleys, Padstow, Australia) to prevent abrasion with the turtles' skin.

Twelve static underwater hydrophones (VR2-W; VEMCO) were deployed along a 5.5 km stretch of river to detect the acoustic pulses emitted from the transmitters. The receiver array encompassed the trapping area, plus four riffles and three pooled stretches of river (Fig. 1). The hydrophones were spaced every 500 ± 50 m, receiver spacing was dependant on the availability of suitable deployment locations. Each hydrophone was secured to a concrete anchor (15 kg) and moored to the riverbank using 6 mm multi-strand stainless steel cable. The detection range of each hydrophone was between 150 and 350 m, depending on river topography. The detection distance of each hydrophone was determined by towing an activated transmitter behind a boat away from each hydrophone, and comparing the received and missing detections with the geographic location of the boat as determined by GPS (680, Garmin USA). The hydrophones were deployed in October 2012 and retrieved in October 2013.

## Stable isotope analysis

Stable isotope analysis was performed on the carapace of 11 *E. macrurus* and 10 *E. albagula*. The sample area was cleaned of biofilm and algae, and the core extracted using a standard drill (Ryobi, HRD, Japan) fitted with a 3 mm bonded diamond drill bit for

porcelain (DiamondDrillandTool.com). The core was immediately placed on ice and then stored in a laboratory freezer at −20 °C within 24 h.

Tissue samples were also collected from a wide range of potential turtle food sources within the study area using standard methods detailed in Jardine et al. (2012). These included terrestrial vegetation, filamentous algae, epilithic biofilm (representing a mixture of periphyton and detritus), seston (likely including phytoplankton, organic detritus, and inorganic material), molluscs (bivalves and gastropods), aquatic insects (simuliids, corixids, ephemeropterans, trichopterans) and crustaceans (atyids and macrobranchium). Seston samples (n = 4, replicate samples) were filtered using a pre-combusted filter, and a hand pump system. Each sample was filtered from at least 500 ml of water. Filamentous algae samples (n = 7) were collected by hand. Epilithic biofilm samples (n = 6) were scraped from rinsed rocks with a scalpel and stored in 5 ml sterile plastic tubes. The bivalves (n = 6) and gastropods (n = 6) were collected by sieving the substrate. Aquatic insects (n = 18) were collected using a dip net (mesh size 250 μm). Crustaceans (n = 12) were collected by seine net (mesh size 11 mm), and dip net. Samples were immediately placed in individually labelled zip-lock bags, or in 5 ml tubes, and then stored on ice. Samples were subsequently frozen for transportation and storage at −20 °C in a laboratory freezer.

Following standard stable isotope sample preparation and analysis protocols (see Fry 2006; Jardine et al. 2012), all turtle food source and turtle carapace samples were defrosted, rinsed with distilled water, and then dried in an oven (60 °C for at least 24 h). They were then ground to a fine powder in an electric ball-mill grinder (Retsch MM200, Haan, Germany). The resultant mixture was weighed, transferred into small tin capsules and analysed for C and N isotopes. Isotope analyses were performed via combustion and mass spectrometry using a Sercon Europa EA-GSL inlet with a Sercon Hydra 20-22 isotope ratio mass spectrometer, at the Australian Rivers Institute Stable Isotope Laboratory. Stable isotope values of samples were calculated as parts per thousand (‰) relative to international standards (Pee Dee Belemnite carbonate and atmospheric nitrogen). Lipid correction was not performed on $\delta^{13}C$ values, as most samples had C/N ratios <4, which are indicatives of low lipid content (Jardine et al. 2012). Machine measurements were precise, within ± 0.1‰ SD for $\delta^{13}C$, and ± 0.1‰ SD for $\delta^{15}N$, respectively.

## Data analysis

Acoustic detection data were downloaded and converted into durations of time when tagged turtles were within (residence event) and between the detection fields of each hydrophone (movement event). This was performed in the V-Track package (Campbell et al. 2012) in R (R Core Team 2016). These data were used to determine movement and home-range parameters, following methods in Dwyer et al. (2015). The centroid point of each turtle home-range was determined using the Calculate Geometry tool in ESRI ArcGIS 10.2.2.

Generalised linear mixed effects models were used to test for species differences in vertical occurrence and activity. The depth recorded by the transmitter sensor was assigned the dependent variable, time and body mass as co-variables, species as factor, and individual ID as the random effect in the model. Depth data were log-transformed to ensure linearity. Significance of dependent variables were assessed by dropping parameters from the full model and applying a deviance test, where $P < 0.05$ indicated that the variable was a significant predictor of horizontal activity (Zuur et al. 2009).

The stable isotope values ($\delta^{13}C$ and $\delta^{15}N$) for each individual and potential turtle food sources were plotted in two-dimensions. Minimum convex polygons were drawn around isotopic values for each species, and used to visually represent dietary overlap between species and infer potential food sources. Significant differences in isotopic values between species were examined using One-Way ANOVA. To quantify the isotopic niche for each species, and the degree of inter-species overlap, a probabilistic analysis was performed with two-dimensional stable isotope data ($\delta^{13}C$ and$\delta^{15}N$) using the nicheROVER package in R (details in Swanson et al. 2015). This multivariate approach incorporated statistical uncertainty through a Bayesian framework, and did not assume the uniform distribution of individuals within the niche region when calculating the degree of overlap between species. Therefore, the technique is applicable to the small (>10) and unequal sample sizes used in this study. We defined the degree of inter-species niche overlap as the probability that the isotopic niche from an individual *E. macrurus* would be located within the isotopic niche of *E. albagula*, and vice versa.

## Results

### Movement and space-use

The location of each of the tagged turtles was recorded continuously over 12 months. The average number of days tracked per turtle was 342 ± 0.21 days (mean ± SE). A total of 443,942 acoustic detections (263,563 *E. macrurus;* 180,379 *E. albagula*) were collected across the 11 hydrophones within the array (Table 1), with an average of 44,394 ± 9045 acoustic detections per turtle. *E. macrurus* travelled a five-fold greater daily distance along the river when compared to *E. albagula,* with 80% of *E. macrurus* moving >1 km river distance per day. This increased daily movement resulted in *E. macrurus* having a significantly larger linear home-range (Table 1; Fig. 2; $f = 15.8$; df = 1,6; $P < 0.01$) compared to *E. albagula*. The activity centre of the home-range for *E. macrurus* was within the

**Table 1** Metrics and movement information for acoustically tagged *E. macrurus* (Em) and *E. albagula* (Ea)

| Species | Weight (kg) | Number of detections | Number of tracking days | Minimum distance moved (km $d^{-1}$) | Linear HR (km) | Distance from HR centroid to riffle (m) |
|---|---|---|---|---|---|---|
| Em 1 | 3.31 | 97,682 | 346 | 1.75 | 4.03 | 2 |
| Em 2 | 3.43 | 48,872 | 345 | 1.25 | 4.03 | 42 |
| Em 3 | 3.70 | 22,369 | 345 | 0.84 | 2.00 | 8 |
| Em 4 | 3.96 | 82,484 | 345 | 1.10 | 4.98 | 74 |
| Em 5 | 3.39 | 12,210 | 323 | 1.81 | 4.03 | 95 |
| Ea 1 | 4.55 | 12,539 | 345 | 0.22 | 2.22 | 267 |
| Ea 2 | 3.69 | 55,811 | 345 | 0.24 | 1.10 | 476 |
| Ea 3 | 4.08 | 60,601 | 341 | 0.22 | 1.10 | 510 |
| Ea 4 | 4.08 | 36,668 | 340 | 0.23 | 1.16 | 533 |
| Ea 5 | 4.56 | 14,706 | 345 | 0.21 | 1.54 | 626 |

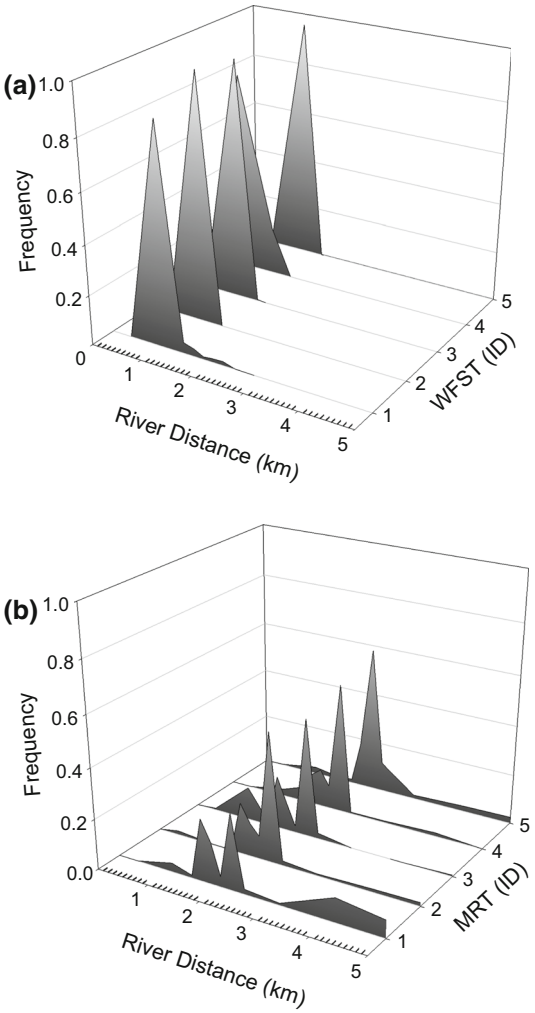


**Fig. 2** Frequency distribution of the time spent within the detection range of individual hydrophones throughout the 12-month study: **a** *E. albagula* (n = 5) and **b** *E. macrurus* (n = 5)

river riffles, whilst that of *E. albagula* was outside the riffles and of a distance placing the home-range centroid in slow moving pooled water sections of the river (Table 1).

Individuals from both species spent the majority of their underwater activity at depths $\geq$ 2 m. All individuals did occasionally dive to depths greater than 6 m (Fig. 3). Over the 24-h period, there were significant inter-species differences in the maximum depth profile attained whilst diving (Table 2). The highest proportion of dives undertaken by *E. albagula* were between depths of 1 and 2 m. *E. macrurus* showed a bimodal distribution, undertaking dives to depths of less than 1 m but also dived frequently to depths between 4 and 6 m. Combining the vertical depth data with the horizontal movement information showed that *E. macrurus* spent the largest proportion of shallow dives within riffles. In contrast, the shallow dives undertaken by *E. albagula* were within the ponded slow-moving sections of river (Table 1; $f = 166$; df = 1,6; $P < 0.01$). Surveys of the river substratum around the home-range activity centres, showed that *E. macrurus* dived in areas with a substratum composed of large boulders (>0.5 m diameter), whilst at the centroid of

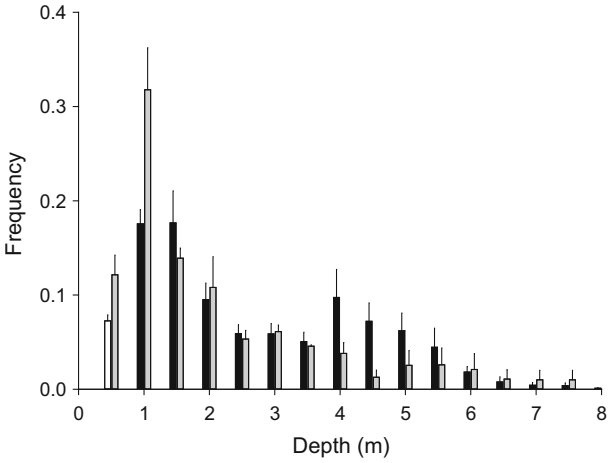


**Fig. 3** Frequency distribution (mean ± SE, n = 5) of the maximum depths achieved during underwater dives for *E. macrurus* (*black bars*) and *E. albagula* (*grey bars*)

**Table 2** Comparison of mixed effects general linear models to test for differences in vertical activity due to species (sensor depth ~ body wt + time + (1|ID) ± species)

| | Df | AIC | $\varkappa^2$ | *P* |
|---|---|---|---|---|
| no factor | 4 | 7583 | | |
| Species as factor | 3 | 7584 | 0.49 | 0.048 |

the home-range for *E. albagula* the substratum was composed of a muddy, sandy, leaf litter, or vegetated substratum.

## Trophic ecology

Stable isotope analysis of the carapace revealed that *E. macurus* had significantly lower $\delta^{13}C$ and higher $\delta^{15}N$ isotopic values than *E. albagula.* This indicated inter-species differences in dietary carbon sources and trophic position between the two species (Table 3). *E. macrurus* had a greater intra-species variation in $\delta^{13}C$ compared to *E. albagula*, but intra-species variation of $\delta^{15}N$ was similar between species. Visual comparison of turtle carapace stable isotopic values with potential food sources (Fig. 4) illustrated that *E.*

**Table 3** Mean (±1SD) and range (in parentheses) of isotopic values ($\delta^{13}C$, $\delta^{15}N$, $\delta^{18}O$, and $\delta^{2}H$) of carapace scutes from *E. macrurus* and *E. albagula.* F values and significance levels for one-way analysis of variance in isotopic values between species are also shown

| | *E. albagula* | *E. macrurus* | F | *P* |
|---|---|---|---|---|
| $\delta^{13}C$ | −23.03 ± 1.01 (−24.62 to −21.62) | −25.93 ± 1.15 (−27.60 to −24.05) | 37.47 | <0.001 |
| $\delta^{15}N$ | 11.05 ± 0.93 (9.70–12.66) | 12.81 ± 0.82 (11.05–14.16) | 21.39 | <0.001 |

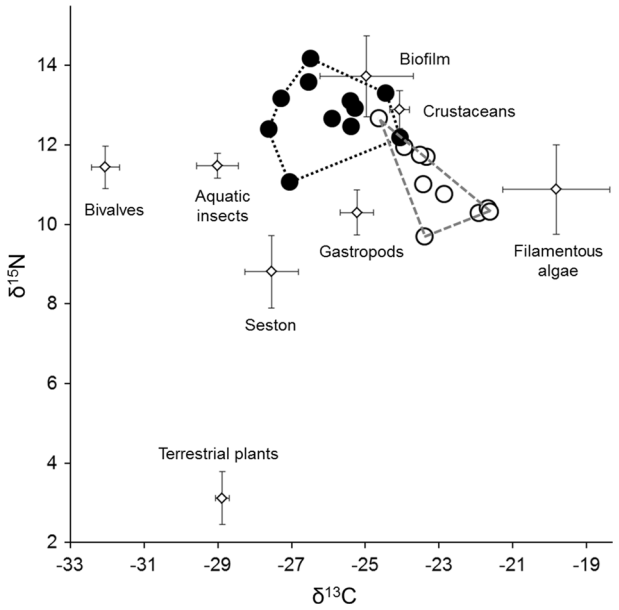


**Fig. 4** Stable isotope ratios of $\delta^{13}C$ and $\delta^{15}N$ of carapace scutes from *E. albagula* (n = 10; *open circles*) and *E. macrurus* (n = 11; *closed circles*). *Dashed lines* show minimum convex polygons encompassing the range of variation in $\delta^{13}C$ and $\delta^{15}N$ for each species. Mean stable isotope ratios ($\delta^{13}C$ and $\delta^{15}N$) of potential turtle food sources (±1SE) are shown

*macurus* had a greater reliance on seston and biofilm carbon sources and likely foraged on bivalves, gastropods, aquatic insects and crustaceans (for some individuals). In contrast, the comparatively higher carbon isotope values for *E. albagula* were more closely matched to those of filamentous algae, crustaceans and gastropods. Assessment of the isotopic niche across the two dimensions of $\delta^{13}C$ and higher $\delta^{15}N$ showed that the probability that *E. macrurus* fed within the dietary niche of the *E. albagula* population was 3%, and the probability that *E. albagula* fed from within the dietary niche of the *E. macrurus* population was 5% (Fig. 5).

## Discussion

The sympatric freshwater turtle species *E. macrurus* and *E. albagula* are reported to have similar dietary and habitat requirements (Cann 1998; Rogers 2000; Tucker 2000; Flakus 2002; Thomson et al. 2006; Limpus 2008; Tucker et al. 2012; Department of the Environment 2016a, b). Contrary to these observations, this study found these species fed predominantly on different resources, located in discrete areas of the river, and characterised by distinct environmental conditions. We argue that the inter-study discrepancies are because the methods used in this study provide a weighted measure of dietary preference and habitat utilisation over a broad timescale, whilst stomach content analysis and mark-recapture provide only a single observation of an individual's diet and occurrence. We discuss the potential impact of these findings for freshwater turtle conservation and management.

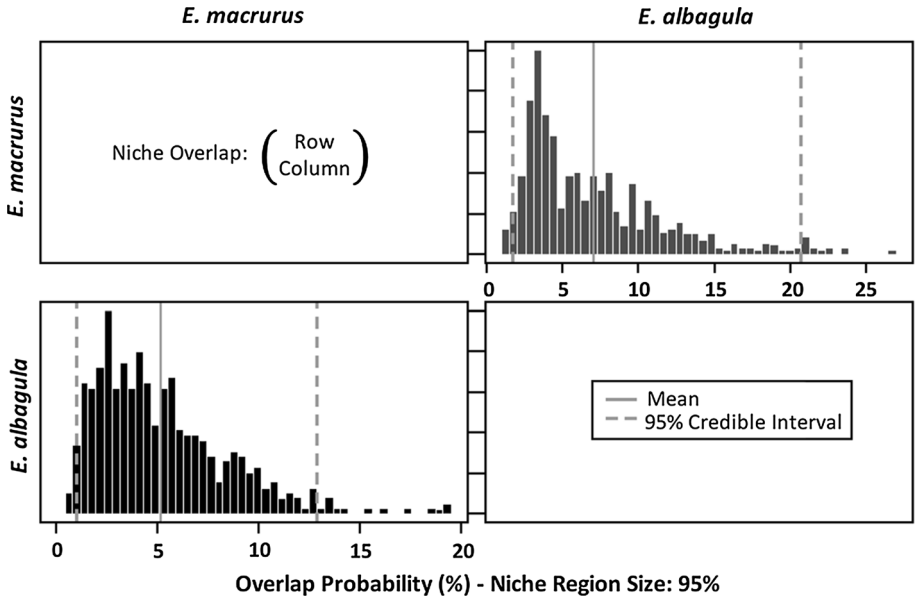


**Fig. 5** Posterior distribution of the probabilistic niche overlap metric (%) between *E. albagula* and *E. macrurus*. The posterior means and 95% credible intervals (probability of species displayed in rows overlapping onto those displayed in columns) are displayed in *grey lines*

The application of passive acoustic telemetry to assess the habitat utilisation of freshwater turtles is not common in the literature. The technology was designed for monitoring fish, and application of this technology in fisheries research and management remains its primary use. Here we demonstrated that this equipment is easily adapted to effectively monitor habitat utilisation and movement in freshwater turtles. The transmitters can be attached externally to the carapace without impediment to the turtle or risk of entanglement. The relatively small home-ranges exhibited by freshwater turtles, and their low rate of daily movement, allows for individual turtles to be detected continuously, and simultaneously, over long periods of time. In this study, the collective detection data across the receiver array were of sufficient frequency, duration, and resolution, to reveal finite inter-species differences in high-usage areas of the river. We argue that this finding may not have been observed with less frequent location sampling because these species do have overlapping home-ranges. The acoustic transmitters also recorded and transmitted the water depth of the tagged turtles, allowing vertical movements to be recorded simultaneously with the horizontal movements. Using these data, it was possible to observe 1/areas where the turtles foraged, 2/areas where they rested, and 3/areas which the turtles merely moved through (Gordos et al. 2007; Campbell et al. 2010).

We discovered that $\delta^{13}C$ levels within the carapace differed significantly between *E. macrurus* and *E. albagula*. In river systems, $\delta^{13}C$ generally varies in a predictable manner with water velocity, with more depleted $\delta^{13}C$ being predominant within slow moving stretches of water and enriched $\delta^{13}C$ within faster flowing stretches (Finlay et al. 2002). The fact that *E. albagula* had more depleted $\delta^{13}C$ within the carapace compared to *E. macrurus* suggests *E. albagula* fed within river stretches with slower moving water than did *E. macrurus*. This also supports the acoustic telemetry data, which showed there was inter-species segregation in foraging locations. Comparison of the carapace stable isotope

values with potential food items revealed *E. macrurus* fed predominantly on bivalves, aquatic insects, and gastropods, and *E. albagula* fed primarily on crustaceans and filamentous algae. These observations are in contrast to stomach content analyses, which reported both species to feed primarily on aquatic plants (79%), with terrestrial plants and aquatic invertebrates only comprising a minor component of the diet (Rogers 2000; Tucker 2000; Flakus 2002; Tucker et al. 2012; Thomson et al. 2006). The contrasting results likely relates to the temporal scale over which the observations were made. Stomach content analysis is a single snap-shot of recently ingested items, whilst the stable isotopic values within the turtle carapace have been laid down over many years (Van der Zanden et al. 2010).

Dietary studies of other sympatric freshwater turtle species have also relied upon the stomach content analysis method (Vogt and Guzman 1988; Allanson and Georges 1999; Rogers 2000; Tucker 2000; Flakus 2002; Thomson et al. 2006; Tucker et al. 2012; Spencer et al. 2014). Interestingly, these studies also reported the sympatric species of study to feed on similar resources. We argue that these observations may be artefacts of the methodology, which may be influenced by seasonal shifts in resources, rates of digestion, and nutrient assimilation (Marques et al. 2011). Moreover, the observation that sympatric species of freshwater turtle feed on the same resources is at odds with the competitive exclusion principal (Hardin 1960). Therefore, we suggest that researchers assessing dietary preferences in freshwater turtles integrate stomach content analysis with assessment of stable isotopes values within the carapace, because this will provide a more complete understanding of dietary preferences over the turtle's long life time.

## Management implications

The methods used in this study were a higher cost to implement than mark-recapture, VHF telemetry and stomach content analysis techniques. To ensure that limited conservation dollars are used effectively it is important to assess if this new information would aid in the formulation of management decisions and improved conservation for the species. Below we have assessed the novel findings from this study with what is currently known for these species.

*E. macrurus* is currently listed as 'endangered' both nationally (Department of the Environment 2016a) and internationally (IUCN 2015). This study does not alter the listing status of *E. macrurus* because the methods did not provide evidence of changes in geographic distribution or population size. Instead the study showed that *E. macrurus* had a high dietary dependence on riffle-dwelling food items and used deep water pools for resting. Therefore, management actions for this species should focus on conserving riffle-pool sequences, and ensuring water conditions are suitable for the riffle dwelling fauna this study identified *E. macrurus* to predominately feed upon.

*E. albagula* is currently listed nationally as 'critically endangered', based upon an observed lack of juvenile recruitment into the population (Department of the Environment 2016b). The species has not yet been evaluated for listing by the IUCN. The findings from this study do not support or oppose the listing but do contrast with some of the current reports about *E. albagula* biology. Impoundments have been proposed as a major contributor to the species decline because they obstruct migration to nesting sites (Limpus 2008; Department of the Environment 2016b). Our data does not support a nesting migration of *E. albagula*, and the adult females tagged in this study either did not nest or nested locally during the 12-month study. Further telemetry work on *E.albagula* on other river stretches is required to reassess the migration theory. It is suggested that *E. albagula*

are dependent on fast flowing well-oxygenated water (Limpus 2008; Department of the Environment 2016b). In contrast, the *E. albagula* tagged in this study foraged in the shallow margins of slow moving pooled water, they rested in deep slow moving water, and rarely moved through or occupied fast-flowing water. Therefore, they did not seem dependant on habitats consisting of fast-flowing well-oxygenated water. The absence of *E. albagula* from standing water bodies (Hamann et al. 2007) requires further investigation because this study does not suggest it to be dietary related.

The evidence from this study highlights the utility of continuous location monitoring via acoustic telemetry and carapace stable isotope analysis for determining resource use in long-lived animals, such as freshwater turtles. Integrating these methods provided a weighted measure of dietary resource acquisition. This was measured over a suitably broad temporal scale to identify threatening processes, whilst at an appropriately fine spatial scale to direct management actions.

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