Radio-tracking Interval Effects on the Accuracy of Diel Scale Crayfish Movement Variables

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Abstract.—The effect of increasing the interval between radio-tracking fixes above 1 h was examined for estimates of the diel activity, diel mobility, and diel range of the Murray River crayfish, Euastacus armatus. Estimates of these diel variables were determined by radio-tracking six individuals at intervals of 1 h for three diel periods. These data were then sub-sampled to simulate radio-tracking at intervals of 2 h, 3 h, 4 h and 6 h. Our perception of diel activity was altered as a consequence of different sub-sampling intervals, and variation in activity over the diel period was lost as tracking interval was increased. Both mean diel mobility and mean diel range decreased linearly with less frequent radio-tracking. A shift from 1 h to 6 h tracking corresponded to 49% and 55% reduction in estimated diel mobility and diel range, respectively. However, we suggest that these trade-offs between information gain and radio-tracking effort be viewed in the context of a comprehensive understanding of home-range across multiple seasons with a view to conserving this species. [Keywords.—diel activity; diel mobility; diel range; Euastacus; Radio-telemetry; temporal resolution].

INTRODUCTION

Radio-telemetry is an established method for studying the movement of terrestrial animals and freshwater vertebrates, and hence is valuable in providing information required for managing threatened and endangered species. In aquatic environments, where animals are generally difficult to observe, radio-telemetry provides an effective means of studying animals whilst causing minimal disturbance. Despite the common practice of radio-tracking river fauna, the appropriate interval at which to manually radio-track remains an important issue. Uncertainty about tradeoffs between accuracy, cost and practicality has led to a lack of standardisation in radio-telemetry methods (Horton et al. 2004), which reduces comparability between studies.

The effect of radio-tracking interval on records of fish movement has been the subject of several studies (Baras 1998; Ovidio et al. 2000; Horton et al. 2004; Natsumeda 2007). Radio-tracking of the Barbel, Barbus barbus (Linnaeus), less often than daily has been reported to bias interpretations of home-range and mobility (Baras 1998). That study showed radio-tracking at an interval of weekly or greater produced unacceptable losses of accuracy, on average 19% and 35.3% for 14 and 28-day intervals, respectively (Baras 1998). A similar study of brown trout, Salmo trutta Linnaeus (Ovidio et al. 2000) found that a reduction in the frequency of radio-tracking from two to 14 days resulted in a loss of accuracy in estimates of mobility by 28.7% and 82.9%, respectively. Furthermore, estimates of home-range decreased in accuracy by 13.3% and 48.7% from two to 14 days, respectively. Ovidio et al. (2000) concluded that radio-tracking interval should be considered carefully in relation to the objectives of future studies.

Similar findings have arisen from studying spotted bass, Micropterus punctulatus (Rafinesque) (Horton et al. 2004). That study also demonstrated the importance of radio-tracking the target species while it is most active. Similarly, the nocturnal Japanese fluvial sculpin, Cottus pollux Günther was tracked intensively at night and it was observed that home-range estimates decreased as the radio-tracking interval was increased from 1 h to 2 h, 3 h, 4 h and 6 h (Natsumeda 2007). Focusing effort at times when animals are most active may be an effective way to conduct a radio-telemetry study, however, it requires that the basic activity pattern of a species is already known.

Unlike in the study of fish, appropriate radio-tracking intervals have not been examined for crayfish. Previous radio-tracking studies of crayfish have been conducted at intervals ranging from 3 h (Webb and Richardson 2004) to every one or two days (Robinson et al. 2000; Bubb et al. 2004, 2006). Other research on the movement of crayfish has used mark-recapture techniques (e.g., Gherardi et al. 2000; Byron and Wilson 2001) and direct observation (Barbaresi and Gherardi 2001). There is limited comparability of these studies as a consequence of the disparity in methods used in each case.

The Murray River crayfish, Euastacus armatus (Clark), is the second largest freshwater crayfish in the world yet its ecology remains poorly understood (as with most Australian crayfish species). It is increasingly important to understand ecological aspects of this vulnerable species (Crandall 1996) to ensure its...
survival. To this end it would be of benefit to understand the long-term home-range requirements of this species. Whilst this is beyond the scope of the current study, we were interested in developing an initial understanding of the home-range and diel activity of the species based on investigation at a fine temporal and spatial scale. Specifically, we aimed to determine the effect of radio-tracking interval on estimates of the diel activity, diel mobility, and diel range of *E. armatus*.

**METHODS**

**Radio-tracking**

Radio-tracking was used to investigate the movement of *E. armatus* in the Murrumbidgee River, Australian Capital Territory (ACT), in autumn 2005. *Euastacus armatus* are known to be most active in the cooler months (March – August) during their breeding and brooding season (Geddes 1990). Crayfish were caught in a single pool (235 m long and 20 – 50 m wide) using baited hoop nets following Lintermans and Rutzou (1991) and Asmus (1999). Only males were captured which is likely to be a result of them being more active at the beginning of the breeding season. A radio-tag (Advanced Telemetry Systems, Isanti, USA) less than 10% of body weight, following Robinson et al. (2000), was attached to each of the six individuals. To reduce the possibility of radio-tags becoming snagged and detached or inhibiting crayfish movement, radio-tag aerials were tightly coiled around the body of the radio-tag and set in place with 5 minute epoxy adhesive (Araldite®, Switzerland). Radio-tags were then attached to the dorsal surface of the carapace using the same adhesive. After ten minutes a second application of resin was applied to the top of the radio-tag and was smoothed to fill gaps between the radio-tag and the carapace. After a drying time of around 2 h, individuals were released at the same location from where they were collected.

The locations of crayfish were determined using the Primary Marker System developed by ACT Parks, Conservation and Lands (Broadhurst et al. 2005, unpublished data). An arrangement of physical markers was established at the study site as a basis.

![Figure 1. Diel activity of *E. armatus* when sampled at intervals of a) 1 h, b) 2 h, c) 3 h, d) 4 h and e) 6 h. Points represent the mean activity of 5 crayfish (+/- SE). Shading denotes hours of darkness.](image)
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for recording the spatial position of individual crayfish based on radio-tracking over several diel periods. Reference markers were positioned so that they could be viewed at approximately eye level from a canoe. The spatial location of each reference marker was determined from 60 records on a differential GPS (Trimble Pro XR, Sunnyvale, USA), obtained over 10 min. The average of these 60 records was used to plot the true location of the reference markers in a Geographical Information System (GIS) (Acris; Arcview GIS 3.2, Redlands, USA).

Crayfish were radio-tracked at 1 h intervals for three diel (24 h) periods (10th May 2005; 18th May 2005; 1st June 2006). The order in which crayfish were radio-tracked throughout a diel period remained constant to ensure intervals of 1 h were maintained. Radio-tracking was primarily conducted from a canoe and the amount of disturbance caused by paddling was minimised when in close proximity to radio-tagged crayfish. Individuals were located with a 150 – 152 MHz receiver unit (Australis 26k; Titley Electronics, Ballina, Australia) and a yagi antenna (Titley Electronics, Ballina, Australia) until within a few metres of radio-tagged crayfish and then the exact position (assumed to be ± 20 cm: Ebner 2005, unpublished data) was obtained from a gap loop antenna (Titley Electronics, Ballina, Australia). The position was then recorded by measuring the distance to three of the reference markers with a laser range finder (Yardage Pro Trophy; Bushnell, Heatherton, Australia) at distances > 5 m and with a measuring pole (marked with 10 cm increments) at distances < 5 m.

### Data Analysis

The locations of crayfish were plotted using GIS (ArcGIS) using the distances recorded from reference markers to create the point of best fit. Distances between these locations were measured and used as a basis for estimates of diel activity (distance moved between intervals) and diel mobility (sum of distances moved over 24 h). Diel range (area inhabited over 24 h) estimates were calculated as minimum convex polygons in the Arcview extension, Animal Movement Program (version 2.04) (Hooge and Eichenlaub 1997).

To determine the effects of less frequent radio-tracking, hourly data were sub-sampled to simulate radio-tracking at intervals of 2 h, 3 h, 4 h and 6 h. These intervals were selected because of their divisibility into 24 h. Distance moved per time interval was plotted and used to assess the relationship between sampling resolution and estimates of diel activity. Similarly, we tabulated the percentage reduction in accuracy of diel mobility and diel range estimates in relation to temporal sampling resolution. Comparisons were based on sample means and individual-specific data. Regression analysis was conducted to determine the relationship between tracking interval and mean diel mobility and mean diel range.

### RESULTS

Radio-tagged crayfish remained within the pool in which they were originally collected, however two individuals remained inactive throughout all three diel periods.

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**Table 1. Reduction in accuracy of diel mobility of *E. armatus* when data from radio-tracking at intervals of 1 h were sub-sampled at intervals of 2 h, 3 h, 4 h and 6 h.**

<table>
<thead>
<tr>
<th>Individual</th>
<th>OCL (mm)</th>
<th>Sex</th>
<th>Mean diel mobility (m) at 1 h intervals</th>
<th>Reduction in accuracy (%) if fixes obtained at intervals of</th>
</tr>
</thead>
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<tr>
<td></td>
<td></td>
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<td>2 h</td>
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<tr>
<td>B</td>
<td>99</td>
<td>Male</td>
<td>45</td>
<td>15</td>
</tr>
<tr>
<td>C</td>
<td>92</td>
<td>Male</td>
<td>92</td>
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<td>Male</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>E</td>
<td>92</td>
<td>Male</td>
<td>190</td>
<td>23</td>
</tr>
<tr>
<td>F</td>
<td>95</td>
<td>Male</td>
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</tr>
<tr>
<td>Mean</td>
<td>98</td>
<td></td>
<td>93</td>
<td>18</td>
</tr>
</tbody>
</table>

**Table 2. Reduction in accuracy of diel range of *E. armatus* when data from radio-tracking at intervals of 1 h were sub-sampled at intervals of 2 h, 3 h, 4 h and 6 h.**

<table>
<thead>
<tr>
<th>Individual</th>
<th>OCL (mm)</th>
<th>Sex</th>
<th>Mean diel range (m²) at 1 h intervals</th>
<th>Reduction in accuracy (%) if fixes obtained at intervals of</th>
</tr>
</thead>
<tbody>
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<td>2 h</td>
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<td>B</td>
<td>99</td>
<td>Male</td>
<td>40</td>
<td>19</td>
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<tr>
<td>C</td>
<td>92</td>
<td>Male</td>
<td>211</td>
<td>21</td>
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<tr>
<td>Mean</td>
<td>98</td>
<td></td>
<td>275</td>
<td>16</td>
</tr>
</tbody>
</table>
tracking following the current study found one of these crayfish (Individual D) to be active; however, no movements were recorded for the other crayfish (Individual A) (Ryan 2005, unpublished data) and hence its data are not reported in the current study.

Crayfish activity occurred during both day and night, with a maximum movement of 49 m recorded in 1 h. The average hourly activity for all crayfish over the three diel periods showed a highly variable pattern with some peaks in activity around sunrise, midnight, and nightfall (Figure 1a). At less frequent radio-tracking intervals, diel activity patterns become progressively concealed (Figure 1). The main peaks in activity observed from fixes at intervals of 1 h were still evident to some extent when data are sub-sampled at intervals of 2 h, 3 h, 4 h and 6 h. Points represent mean diel mobility and diel range of five crayfish (± SE).

Diel range areas varied from 0 – 939 m² (mean = 275 m², sd = 296) and often overlapped in the case of: a) each individual among diel periods; and b) among individuals (Ryan 2005, unpublished data). Diel mobility ranged from 0 – 220 m (mean = 94 m, sd = 75). Sub-sampling of data collected at intervals of 1 h resulted in a significant and linear decrease in mean diel mobility (P < 0.05) and mean diel range (P < 0.05) (Figure 2). Regression analysis found that the change in tracking interval explained 85% of variability in diel mobility and 93% of the variability in diel range (Figure 2). The mean reduction in accuracy was up to 45% for diel mobility (Table 1) and 55% for diel range (Table 2).

The reduction in accuracy of diel mobility and diel range varied between individuals. With the exception of the crayfish that was not active for the entire three diel periods (Individual D) the reduction in accuracy from 1 h to 2 h intervals ranged from 15 – 48% for diel mobility (Table 1) and 18 – 45% for diel range (Table 2). At 6 h intervals the reduction in accuracy ranged from 52 – 70% for diel mobility (Table 1) and 57 – 75% for diel range (Table 2).

**DISCUSSION**

Although the mode of crayfish movement is different from that used by fishes (i.e., walking versus swimming), the impact of radio-tracking interval on estimates of diel movement, remain similar for both taxa (in that the accuracy of estimates reduces as intervals increase) (Baras 1998; Ovido et al. 2000; Horton et al. 2004; Natsumeda 2007; the current study – Figures 1 and 2). The dormancy of Individual D, provided an exception in the current study. Stationary phases have been reported for other crayfish, including the white-clawed crayfish, *Astropotamobius pallipes* (Lereboullet) (Robinson et al. 2000) and the giant Tasmanian crayfish, *Astacopsis gouldi* (Clark) (Webb and Richardson 2004), and may have an important biological basis (i.e., reproductive state, molting, loss of appetite or response to environmental conditions) (Webb and Richardson 2004). In contrast, extended periods of immobility are uncommon for many fishes and have been used as an indication of mortality or radio-tag rejection in some studies (e.g., Ebner et al. 2007). Visual confirmation of the fate of dormant aquatic animals is clearly desirable as an independent check in radio-tracking studies. Innovative solutions to confirming the fate of dormant crayfish may be required where radio-tags are located in inaccessible microhabitats and/or in low visibility waters.

Our finding of reduced diel mobility estimates with less frequent radio-tracking of *E. armatus* (Table 1 and Figure 2a) are comparable with similar studies of fish. Radio-tracking at intervals of 14 days produced 56.8% and 82.9% reduction in estimates of mobility from daily data for barbel, *B. barbus* (Baras 1998) and brown trout, *S. trutta* (Ovido et al. 2000), respectively. On a finer temporal scale Horton et al. (2004) found up to 64% reduction in accuracy of mobility estimates for spotted bass, *M. punctulatus*, when reducing the frequency of radio-tracking intervals from 15 min to 2 h. Thus, accurate mobility estimates are based on intensive manual radio-tracking or remote telemetry (Hanson et al. 2007) since this variable is a continuous measure of movement (rather than a summary of total area occupied, as is the case with home-range estimates).

Diel activity of *E. armatus* showed peak periods and high variation throughout diel periods in the current study (Figure 1).
While studies in the Northern hemisphere have found freshwater crayfish to be primarily nocturnal (e.g., Procambarus clarkii (Girard); Gherardi et al. 2000; A. pallipes: Barbarese and Gherardi 2001), Webb and Richardson (2004) found the giant Tasmanian crayfish, A. gouldi to be neither predominantly nocturnal nor diurnal. However, diel activity patterns of E. armatus appear diurnal as tracking intervals increase to 4 h and 6 h (Figure 1). Therefore, we caution against making comparisons of diel activity between species where different sampling intervals have been used.

The diel activity patterns shown by E. armatus when radio-tracked at intervals of 1 h (Figure 1) suggest that primary periods of activity are variable for this species. Previous studies of species with a predictable diel activity pattern have been monitored with manual radio-tracking effort concentrated on periods of high activity. For instance, Natsumeda (2007) demonstrated the importance of tracking the Japanese fluvial sculpin, C. pollux at times when it is most active to ensure accuracy in estimates of home-range. For animals with an unpredictable diel activity pattern, such a study design is not effective and randomised or uniform temporal sampling rather than stratified sampling is necessary. The use of continuous remote-telemetry loggers would be ideal under these circumstances since it can yield information at a resolution of minutes (cf., David and Closs 2001; Hanson et al. 2007).

Our finding of reduction in diel range estimates of E. armatus in relation to less frequent radio-tracking (Table 2 and Figure 2b) is a function of underestimating both lateral and longitudinal in-stream movement. Accuracy of range estimates has been found to be less dependent on the frequency of radio-tracking intervals for fish that make movements along a linear axis (Baras 1998; Ovidio et al. 2000). The giant Tasmanian crayfish A. gouldi is known to have a large linear range in small (narrow) streams (Webb and Richardson 2004) and therefore less intensive radio-tracking may suffice to determine its diel range compared with that of E. armatus in a large, wide river (e.g., the Murrumbidgee River) where both substantial longitudinal and lateral movement is possible. The current study has identified the need for intensive radio-tracking of E. armatus to accurately estimate diel range. For conservation purposes, including designating closed areas, where E. armatus are protected outside of the ACT, we recommend a next step of obtaining home-range estimates and understanding habitat use of this species over an annual cycle. In the absence of remote telemetry capability (cf., Hanson et al. 2007) we recommend that the home-range and habitat use of E. armatus be based on weekly tracking across all four seasons in a subset of upland and lowland rivers. Radio-tracking E. armatus at night appears to be unnecessary based on the findings of the current study.

Understanding the relationship between radio-tracking interval and estimates of diel mobility, diel activity, and diel range provides a basis for designing future studies of E. armatus behaviour and habitat use. Estimates of diel mobility and diel range of E. armatus are dependent on how frequently radio-tracking is conducted. These two variables are likely to be useful for measuring short-term changes in behaviour in response to short-term disturbances including environmental flows, to achieve ecological outcomes. However, the conservation of E. armatus may be best served in the immediate future by collecting spatial information on the species at coarse time intervals over multiple seasons with a view to understanding its habitat requirements.

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LITERATURE CITED


