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# Range extension of a euryhaline crab, *Varuna litterata* (Fabricius, 1798) (Brachyura: Varunidae), in a climate change hot-spot

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# ABSTRACT

We present the first recorded range extension of a euryhaline invertebrate in the climate change hot-spot along Australia's southeastern coast. The river swimming Crab, *Varuna litterata* (Fabricius, 1798) (Varunidae) was found in the Coffs Harbour-Bellinger and Nambucca river basins of New South Wales, Australia in 2013, 2014 and 2016. The crabs were found during winter in shallow freshwater habitats, and may be using these habitats to avoid predators or minimise exposure to colder temperatures in deeper water. At locations where the crabs were found, water temperatures during winter (July 2016) were up to 4.5 °C warmer in shallow-water habitats (< 0.2 m depth) compared to adjacent deep-water habitats (> 1.0 m). The new southernmost locations of *V. litterata* reported here represent a ~290 km poleward range extension. The likelihood that climate change and a strengthening East Australian Current have contributed to this range extension is discussed, as well as the potential impacts of these crabs on existing biological communities in newly colonised locations.

**Key words**: dispersal, distribution, East Australian Current

# INTRODUCTION

Brachyuran crabs play important roles in the ecosystems they inhabit. Changes in the distribution of these crabs can therefore have important consequences for the size, complexity, and functioning of ecosystems. For example, anthropogenic translocations of crabs have led to ecological shifts in marine systems, decreasing the abundances of native species (e.g. Dittel & Epifanio, 2009; Falk-Petersen *et al.*, 2011). One factor likely to drive changes in the distribution of crabs is climate change, with species generally expected to track isotherms poleward (Root *et al*., 2003). Documenting changes in the distributions of crab species over time is fundamental to understanding their responses to changing environmental conditions and predicting the effects of their colonisation in areas where they have previously been absent.

The river swimming crab, *Varuna litterata* (Fabricius, 1798) (Varunidae H. Milne Edwards, 1853), is a euryhaline crab found throughout the tropical Indo-West Pacific, including South Africa, India, Vietnam, Taiwan, Indonesia, Papua New Guinea, New Caledonia, and Australia (Davie, 2002; Waltham *et al*., 2014). We report a major poleward range extension of *V. litterata* along the southeastern coast of Australia (Fig. 1).

## METHODS

Specimens of *Varuna litterata* were caught using hand-held scoop nets or box traps during biodiversity surveys of northeastern New South Wales (NSW), Australia in 2013, 2014 and 2016 (Table 1). At each site, 2–4 traps were deployed (6–10 m apart) for the same amount of time in shallow-water (< 0.6 m depth) and deep-water (> 0.6 m depth) habitats respectively, and scoop nets were used to haphazardly sample complex structures within both habitat types. Voucher specimens were fixed in 75–100% ethanol for formal taxonomic identification, and subsequently held in the Australian Crayfish Project collection (Karuah, NSW, Australia) or lodged with the Queensland Museum or Australian Museum; all other crabs were examined, photographed and released (Table 1). All collections were authorized by the NSW Department of Primary Industries (Scientific Collection Permits P05/0077-4.1 and P14/0014-1.0) and the National Parks and Wildlife Service (Scientific Licence SL100138). Location coordinates, landforms, aquatic vegetation, stream conditions, and water quality information were recorded at each survey site (see Supplemenatary material "Site Descriptions and Ecological Observations"; also see McCormack, 2014).

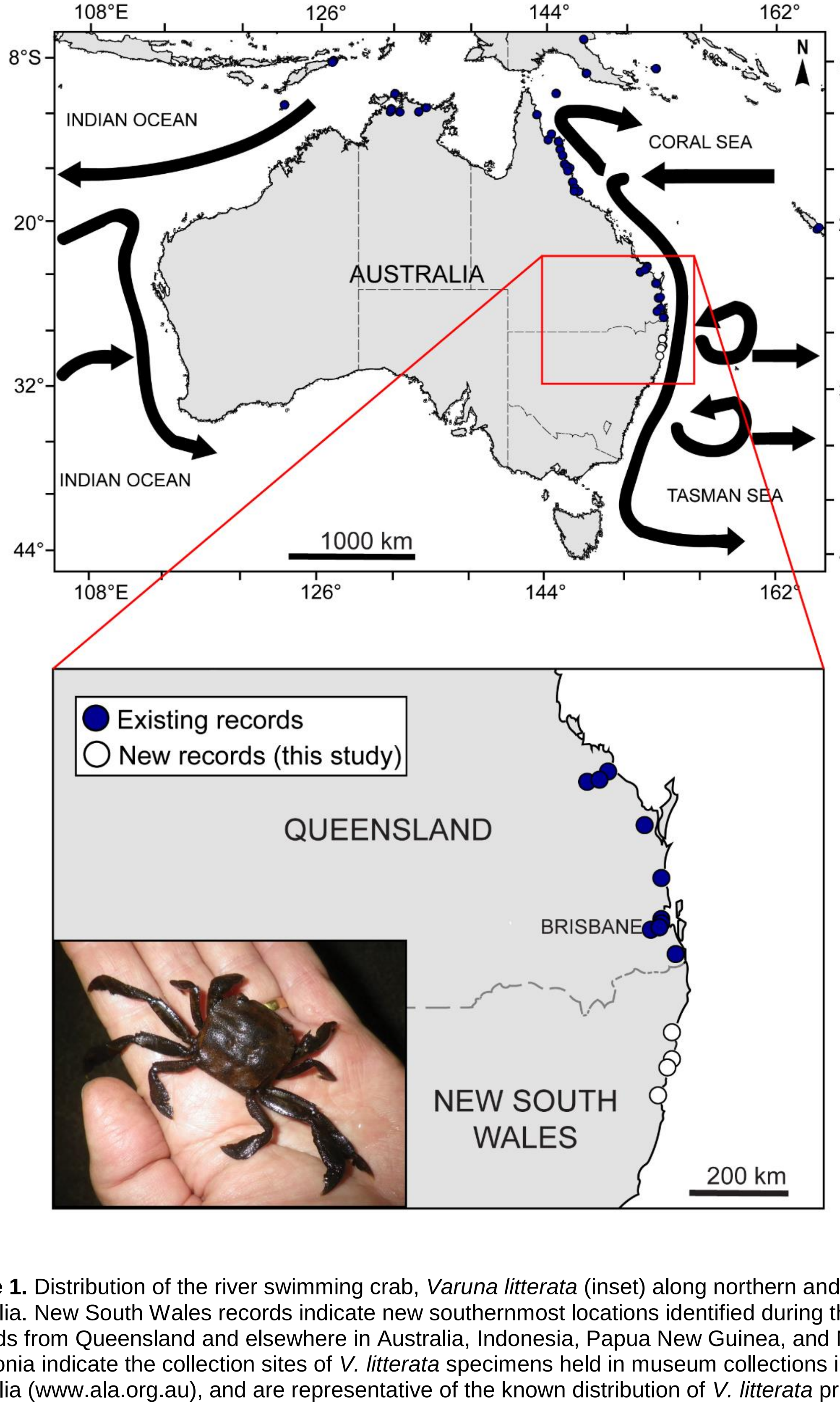


**Figure 1.** Distribution of the river swimming crab, *Varuna litterata* (inset) along northern and eastern Australia. New South Wales records indicate new southernmost locations identified during this study. Records from Queensland and elsewhere in Australia, Indonesia, Papua New Guinea, and New Caledonia indicate the collection sites of *V. litterata* specimens held in museum collections in Australia (www.ala.org.au), and are representative of the known distribution of *V. litterata* prior to this study. Arrows indicate dominate ocean currents; East Australian Current (east coast of Australia) and the Leeuwin Current (west coast of Australia).

High resolution temperature-data loggers (iBCod 22L, Thermodata, Melbourne, Australia) were used to examine variation in the temperature of shallow-water and deep-water habitats at locations where the crabs were captured. Loggers were deployed during winter at the Bowraville (11 July 2016) and Boambee (26 July 2016) sites for a period of seven days each, but could not be deployed at Yuraygir National Park due to low water levels. The flow regimes and the structure of the water courses at the Bowraville and Boambee sites were similar to when the crabs were captured. Two loggers were used at each site, with one placed in a shallow backwater (< 0.2 m depth) and the other in an adjacent deep pool (> 1.0 m depth). Each logger took measurements every 15 mins, within 60 sec of the other logger deployed at the same site. Temperature data was calibrated to account for differences between loggers when held at the same temperature, which were always < 0.2 °C.

## RESULTS

The southern limits of the distribution of *V. litterata* in the Pacific Ocean have previously been recorded as New Caledonia and northern Australia south to the Nerang River in southern Queensland (Davie, 2002; www.ala.org.au) (Fig. 1). We found *V. litterata* in three new locations, approximately 190–290 km south of their previously recorded distribution (Fig. 1, Table 1). One specimen was found in a tributary of Newports Creek at the crossing of North Boambee Road, Boambee, New South Wales (NSW) in May 2013. Three *V. litterata* were found in a 50 m stretch of a freshwater creek beside Pebbly Beach access road, Yuraygir National Park, NSW in May 2014. An additional three specimens were caught in the same stretch of creek in a follow-up survey in August 2014. Another specimen was found in the Nambucca River at Bowraville, NSW in May 2016. All specimens were caught in shallow water (< 0.3 m) and most were caught in box traps, except for the two specimens from Boambee and Bowraville, which were caught in scoop nets. Finally, we uncovered a specimen held at the Australian Museum which was collected from a freshwater dam near Woolgoolga, NSW (30°06’55”S, 153°09’04”E) in summer, January 1982 (Table 1).

During winter 2016, temperatures recorded in shallow backwaters were often greater than temperatures in adjacent deep pools (Supplementary material S1 Table). Temperatures in the shallow-water habitat at Bowraville were 1.3–4.5 °C higher than temperatures in the adjacent deep-water habitat at all times (Supplementary material S2a Figure). Temperatures in the shallow-water habitat at Boambee were 0–2.8 °C warmer than the deep-water habitat during the day, but 0–2.0 °C cooler at night.

In the shallow-water habitat at Boambee and both habitats at Bowraville, temperatures generally increased during the day and decreased through the night (Supplementary material S2 Figure). Temperatures in the deep-water habitat at Boambee displayed the opposite trend, however, generally cooling during the day and warming at night (Supplementary material S2b Figure). This may have been associated with the high canopy cover at the Boambee site and the inflow of warmer water from upstream where there is little canopy cover.

**Table 1.** Location, sex, size and collection data for individuals of *Varuna litterata* from New South Wales, Australia. ACP, Australian Crayfish Project collection; AM, Australian Museum collection; QM, Queensland Museum collection. The individual without a sample number was released. CW, carapace width at widest point; RBM, Robert B. McCormack; CNB, Craig N. Burnes.

| | Date | Location | | | | Sex and size | | | Collector |
|---|---|---|---|---|---|---|---|---|---|
| **Sample no.** | | | **Latitude** | **Longitude** | **Elevation (m)** | **Sex** | **Weight (g)** | **CW (mm)** | |
| QM W29212 | 10 May 2013 | Boambee | 30°18’27” S | 153°05’02” E | 13 | m | - | 29.0 | RBM |
| AM P.97364 | 31 May 2014 | Yuraygir | 29°57’54” S | 153°14’28” E | 17 | m | 33.2 | 48.4 | RBM & CNB |
| ACP 5207 | 31 May 2014 | Yuraygir | 29°57’56” S | 153°14’28” E | 16 | f | 10.0 | 30.9 | RBM & CNB |
| AM P.97363 | 31 May 2014 | Yuraygir | 29°57’56” S | 153°14’28” E | 16 | m | 3.39 | 19.9 | RBM & CNB |
| QM W29210 | 22 August 2014 | Yuraygir | 29°57’58” S | 153°14’33” E | 6 | m | 18.04 | 37.3 | RBM & CNB |
| ACP 5252 | 22 August 2014 | Yuraygir | 29°57’53” S | 153°14’29” E | 7 | f | 3.6 | 21.1 | RBM & CNB |
| QM W29211 | 22 August 2014 | Yuraygir | 29°57’55” S | 153°14’30” E | 7 | m | 8.42 | 27.8 | RBM & CNB |
| | 24 May 2016 | Bowraville | 30°38’26” S | 152°51’21” E | 13 | m | - | 33.1 | B Mos |
| AM P.76171 | 22 January 1982 | Woolgoolga | 30°06’55” S | 153°09’04” E | - | m | - | 50.6 | PP Clark |

# DISCUSSION

The river swimming crab, *Varuna litterata* is here recorded for the first time from New South Wales (NSW), Australia, representing a southerly range extension of approximately 290 km. The southeastern coast of Australia, including NSW, has been identified as a global warming hot-spot, a region experiencing greater increases in temperature than the global average (Hobday & Lough, 2011). To our knowledge, this study is the first recorded range extension of any euryhaline invertebrate in this climate change hot-spot, and one of the few examples globally of a range extension by any euryhaline invertebrate in a climate change hot-spot (also see Whitfield *et al*., 2016). We do not regard our results as artefacts of limited past sampling as considerable field sampling has been conducted along the NSW coast since the 1950s by the Australian Museum and others (e.g. Austin, 1996; Morgan, 1997; Coughran, 2005).

We found adult *V. litterata* in shallow backwaters in pure freshwater creeks. We hypothesise two reasons why these crabs may prefer to occupy these habitats. Firstly, the crabs may be avoiding predators. Avoidance of predatory eels, such as the long-finned eel *Anguilla reinhardtii* Steindachner, 1867, drives the distribution of other freshwater macroinvertebrates (e.g. McCormack, 2005), and this may also be the case for *V. litterata*. Large individuals of *A. reinhardtii* capable of preying on adult *V. litterata* were only observed in deep-water habitats. Secondly, the tropical *V. litterata* may be responding to thermal gradients. Shallow habitats were often warmer by up to 4.5 °C and could be acting as thermal refuges, enabling the tropical *V. litterata* to over-winter in the sub-tropics. If so, *V. litterata* from these southern localities may be living at the present limits of their thermal tolerance. Our results should be interpreted with caution, however, as they were taken from a small number of sites over short periods of time, and further studies testing our hypotheses are required.

The planktonic larval phase of *V. litterata* is one mechanism by which this species could have extended its range from southern Queensland into northern NSW (see review of biogeographic patterns and mechanisms of dispersal of Australian littoral crabs by Davie, 1985). The larval phase of *V. litterata* lasts 36 days in the laboratory (Tu, 1992), but may be longer under natural conditions (Anger *et al*., 2015). Because dispersal distance can increase with the amount of time larvae spend in the water column (Shanks *et al*., 2003), larval *V. litterata* have the potential to be dispersed hundreds of kilometres by ocean currents. Alternatively, it is possible juvenile or adult *V. litterata* dispersed southwards by rafting on floating debris associated with flood events. A large flood event in southeastern Queensland in 2011, for example, resulted in an extensive plume that was driven southwards along the coast of northern NSW by wind and ocean currents (http://eatlas.org.au/rrmmp/qld-flood-plumes-2011).

The primary ocean current along eastern Australia is the southward-flowing East Australian Current (EAC) (Fig. 1). The EAC has strengthened and extended further south over the past 60 years (Ridgway & Hill, 2009) and is predicted to strengthen by a further 20% by 2070 (Cai *et al*., 2005). The strengthening of the EAC is facilitating southwards range extensions of marine invertebrates through enhanced larval dispersal (e.g. Pitt *et al*., 2010). Climate-driven strengthening of the EAC could also be driving the southwards range extension of *V. litterata* into NSW, similar to the range expansion of the sandy beach ghost crab (*Ocypode cordimana* Latreille, 1818) in southeastern Australia (Schoeman *et al*., 2015). It is noteworthy that *V. litterata* and other euryhaline crabs are also undergoing a poleward range extension along the east coast of South Africa, another climate change hot-spot with a strengthening ocean current (Whitfield *et al*., 2016).

It is unclear if the populations of *V. litterata* in NSW are self-sustaining or maintained by intermittent supply of larvae or juveniles from populations to the north. Larvae and juveniles may recruit to southerly locations under benign seasonal conditions and survive and persist as adults, even though it may be seasonally too cold for them to reproduce. For example, adult mud crabs (*Scylla serrata* (Forskål, 1775)) are occasionally found in the far north of New Zealand, but they appear to be unable to form a self-sustaining population (McLay, 1988). The few *V. litterata* caught during this study may be indicative of a small population in their new range, which could also impede reproduction, for example, by preventing pre-spawning mass migration and spawning behaviours that occur elsewhere (e.g. Bickerton & Sapsford, 1981). Intermittent recruitment from northern populations may also explain the ~2 degrees of latitude gap between the locations where we found *V. litterata* and previous records north of the Queensland border (Fig. 1).

The ecological consequences of the advance of *V. litterata* into freshwater habitats in sub-tropical eastern Australia are unknown. *Varuna litterata* is omnivorous and highly fecund (Devi *et al*., 2013; Tu, 1992), and crabs with these characteristics are often problematic when invading new areas due to their ability to outcompete native organisms for food and living space (e.g. Dittel & Epifanio, 2009; Falk-Petersen *et al*., 2011). This is concerning given that the range extension of *V. litterata* reported here overlaps with an area supporting a high diversity of freshwater organisms, such as freshwater crayfishes (*Euastacus* spp.). Most of these endemic crayfishes have small distributions and are already threatened by habitat modification, climate change and competition with introduced tropical crayfish (Coughran *et al*., 2009; Richman *et al*., 2015). It is also possible that *V. litterata* could carry tropical parasites and pathogens into temperate waters. As predicted changes in climate over the next century are likely to boost the recruitment of tropical species to populations at the poleward edge of their current ranges (Root *et al*., 2003), additional studies are urgently required to fill knowledge gaps about how increasing abundances of *V. litterata* and possibly other euryhaline organisms may affect subtropical freshwater ecosystems.

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# SUPPLEMENTARY MATERIAL

## SITE DESCRIPTIONS AND ECOLOGICAL OBSERVATIONS

The site at Boambee, New South Wales (NSW), Australia comprised sandy pools and rocky riffle sections flowing through a forested riparian area, approximately 2.5 km upstream of the tidal limit. The individual of *Varuna litterata* was collected by turning over rocks in a shallow section (0.1 m deep) between deeper pools. Long finned eels (*Anguilla reinhardtii*), spiny crayfish (*Euastacus dangadi*), plague minnows (*Gambusia holbrooki*), empire gudgeons (*Hypseleotris compressa*), riffle shrimps (*Australatya striolata*), glass shrimp (*Paratya* sp. **‘***australiensis*’ species-complex), eastern river prawns (*Macrobrachium tolmerum*), and dobsonfly larvae (*Stenosialis australiensis*) were also common.

The site at Yuraygir National Park, NSW, Australia comprised a shallow stream, approximately 400 m upstream of the tidal limit. Surveys of a large lake further upstream did not produce any crabs and surveys of the stream further downstream towards the tidal limit were also unproductive. Long finned eels, striped gudgeons (*Gobiomorphus australis*), empire gudgeons, firetail gudgeons (*Hypseleotris galii*), Pacific blue-eyes (*Pseudomugil signifer*) and eastern river prawns were also caught.

The site at Bowraville, NSW, Australia comprised deep pools (> 1 m depth) with shallow backwaters linked by shallow riffle sections, approximately 3 km upstream of the tidal limit. The substrate was a mix of rock, gravel and sand. The *V. litterata* specimen was caught amongst aquatic vegetation (*Vallisneria* sp.) alongside shrimp (*Paratya* sp. '*australiensis*' species-complex and *Caridina* sp. '*indistincta*' species-complex), Pacific blue-eyes and gudgeons (*Hypseleotris* spp.) in a shallow backwater (< 0.2 m deep). Long finned eels and multiple species of fish (unidentified) were sighted in deeper pools.

**Table S1**. Water physico-chemical parameters during collection of *Varuna litterata* at three sites in New South Wales, Australia.

| | **Newport Creek, Boambee** (30°18'27"S 153°05'02"E) | **Yuraygir National Park** (29°57'56"S 153°14'28"E) | **Nambucca River, Bowraville** (30°38'26"S 152°51'21"E) |
|---|---|---|---|
| **Temperature (°C)** | 15.5 | 17.5 | 19.0 |
| **Salinity (ppt)** | 0.07 | 0.10 | 0.06 |
| **Dissolved Oxygen (ppm, %)** | 6.5, 68 | 9.2, 97 | - |
| **pH** | 6.95 | 7.40 | 6.91 |
| **Conductivity (µS.cm$^{-1}$)** | 154 | 202 | 118 |
| **Total Dissolved Solids (ppm)** | 109 | 135 | - |
| **Visibility (m)** | > 0.8 | > 1.0 | > 3.0 |

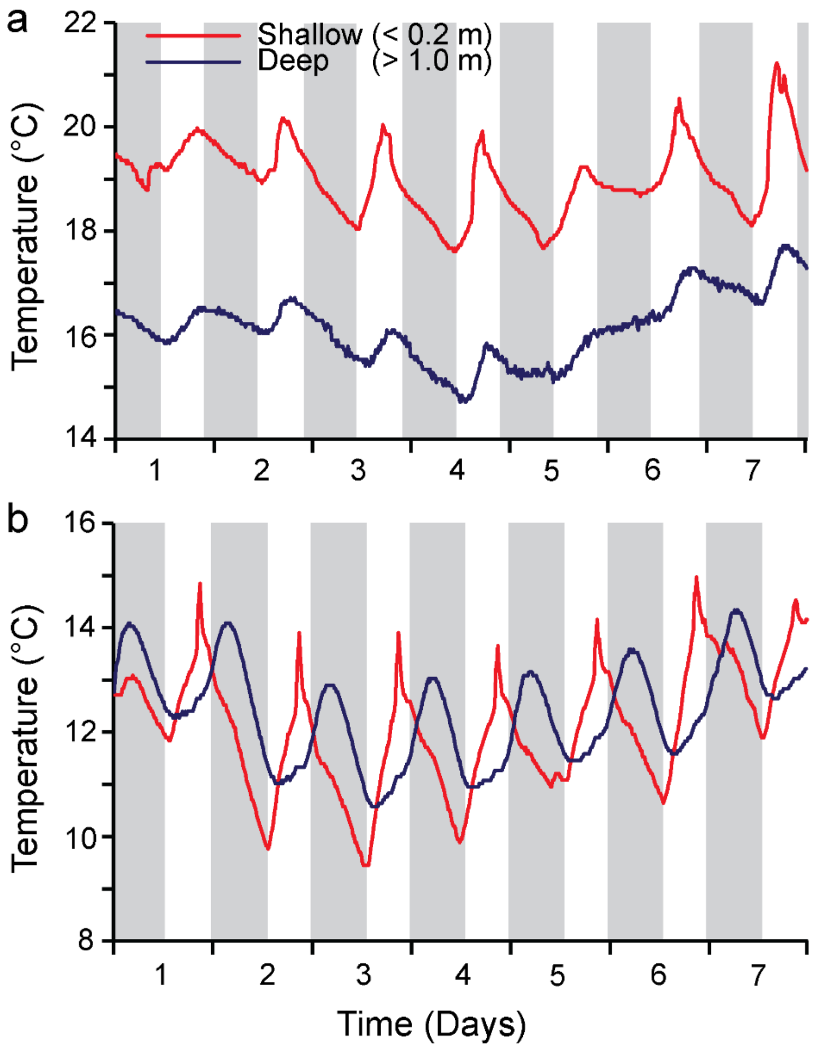


**Figure S2**. Temperature data recorded in freshwater habitats over seven days during winter at two sites in northern New South Wales, Australia. (a) Bowraville, 11–18 July 2016. (b) Boambee, 26 July to 2 August 2016. See Methods for site details. Red lines represent temperatures from shallow habitats (< 0.2 m deep), and dark blue lines represent temperatures from deep water habitats (> 1.0 m deep). Grey and white backgrounds represent night and day respectively.