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## A DESCRIPTION OF FRESHWATER TURTLE HABITAT DESTRUCTION BY FERAL PIGS IN TROPICAL NORTH-EASTERN AUSTRALIA

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**Abstract.**—Feral pigs cause major disturbance to wetland habitats that are frequented by freshwater turtles, although the effects have not been quantified. We assessed how feral pig (*Sus scrofa*) foraging activities affect turtle (Chelidae) habitat in a pair of fenced and unfenced ephemeral floodplain lagoons at Lakefield National Park on Cape York Peninsula, Australia. Feral pigs caused major changes to aquatic macrophyte communities and as a consequence, to the proportional amounts of open water and bare ground. The destruction of macrophyte communities and upheaved wetland sediments significantly affected wetland water clarity and caused prolonged anoxia and pH imbalances in the unfenced lagoon. The combined effects of vegetation destruction and the subsequent excretion of pig wastes also resulted in high nutrient enrichment. Clearly, exclusion fencing will protect freshwater turtle habitats from feral pig foraging activities, however, the choice of which lagoons to fence should only be made with an understanding of their seasonal usage by freshwater turtles.

**Key Words.**—invasive species; *Chelodina*; *Sus scrofa*

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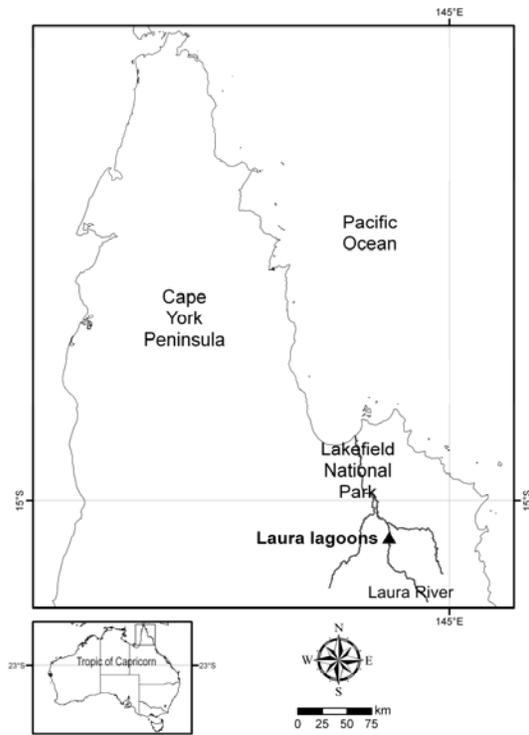
### INTRODUCTION

Freshwater turtles occur throughout the permanent and ephemeral wetlands of northern Australia (Cogger 2000). Long-necked turtles of the genus *Chelodina* (Chelidae) are particularly well adapted to the seasonal drawdown in ephemeral wetlands, because their physiological capacity for low metabolic rates and ability to store water allows them to aestivate until re-flooding occurs (Kennett and Christian 1994; Roe and Georges 2008). Freshwater turtles are also increasingly regarded as important inhabitants of wetlands (Moll 1990; Bodie and Semlitsch 2000). For example, they are semi-aquatic and have a long life cycle and low reproductive output (Klemens 2000), which clearly contrasts against the life-history patterns of other obligate wetland inhabitants such as fish and invertebrates that are the usual focus of wetland research (Bodie 2001).

Feral pigs (*Sus scrofa*) are an exotic pest that have invaded most regions throughout the world with the exception of Antarctica (Tierney and Cushman 2006). Feral pigs are known to greatly disturb areas they invade, by overturning extensive amounts of soil and associated vegetation as they forage for roots, bulbs, and other below-ground material (Howe et al. 1981; Baber and Coblenz 1987). This foraging is the most pervasive habitat disturbance caused by feral pigs in floodplain wetlands (Arrington et al. 1999) because they exacerbate effects of the natural seasonal dehydration as they exploit both the receding littoral zone and wider water body (Bowman and Panton 1991; Mulrennan and Woodroffe 1998). While primarily phytophagous, feral pigs are omnivorous and will vary their diets to suit the seasonal availability of a wide variety of different foods (Giménez-Anaya et al. 2008).

In northern Australia, the tropical dry season interrupts long-necked turtle activity when wetland water levels retreat and often completely dry (Fordham et al. 2008). During this period of dehydration, turtles often move into the shallows to bury themselves in mud and aestivate, and it is about the time immediately before drying that feral pig predation on them is heaviest (Fordham et al. 2006). Recently, Fordham et al. (2008) stated that if turtle predation by pigs is left unmanaged, then extirpation of many populations is all but assured, making conservation strategies an urgent priority. Among a multi-pronged management approach, they advocated fencing of wetlands to preclude predators.

Neither the effects of feral pig foraging on freshwater turtle habitat nor the benefit of pig exclusion fencing have been quantified. We are currently working on several feral pig management projects at Lakefield National Park on Cape York Peninsula, Australia, and one program includes testing the efficacy of pig-proof fencing using several pairs of ephemeral floodplain lagoons (i.e., fenced or unfenced, see Doupé et al. in press). While some of the study lagoons were known to contain one or two freshwater turtles, only one pair of adjacent lagoons contained small populations ( $n \approx 4$ ) of long-necked turtles in each, and it was in them that we estimated the seasonal effects of feral pig foraging activities on turtle habitat and how wetland fencing might serve as a protective measure. We predicted that in the unfenced treatment there would be a progressive replacement of consumed or destroyed vegetation with increasing amounts of bare ground and open water due to feral pig foraging, and that the physical and chemical properties of the wetland would also become increasingly disturbed and polluted.



**FIGURE 1.** Map showing approximate position of the Laura Lagoons on the Laura River floodplain in Lakefield National Park, Cape York Peninsula, Australia.

## MATERIALS AND METHODS

**Site description and experimental design.**—Lakefield National Park is situated on Cape York Peninsula in north-eastern Australia (Fig. 1). The region experiences a wet-dry monsoonal climate with a mean annual rainfall of about 1,200 mm falling predominantly during December to April. The ‘Laura lagoons’ are adjacent to the Laura River (S 15° 20’ E 144° 27’) and approximately 200 m apart within the tropical savannah. They are about 0.5 ha in size, saucer-like in shape, and contain similar aquatic macrophyte communities, being predominated by Giant Water Lily (*Nymphaea gigantea*) and Spiny Mudgrass (*Pseudoraphis spinescens*). In mid-2007, one lagoon was enclosed by a pig-proof fence constructed about 6 m above the demarcation between the wetland margin and the surrounding savannah woodland. Fencing was 1,100 mm in height consisting of a plain top wire 200 mm above 900 mm of 150 mm × 150 mm netted wire mesh and reinforced steel post corners. Bottom wires were barbed and secured into the earth to deter pig burrowing.

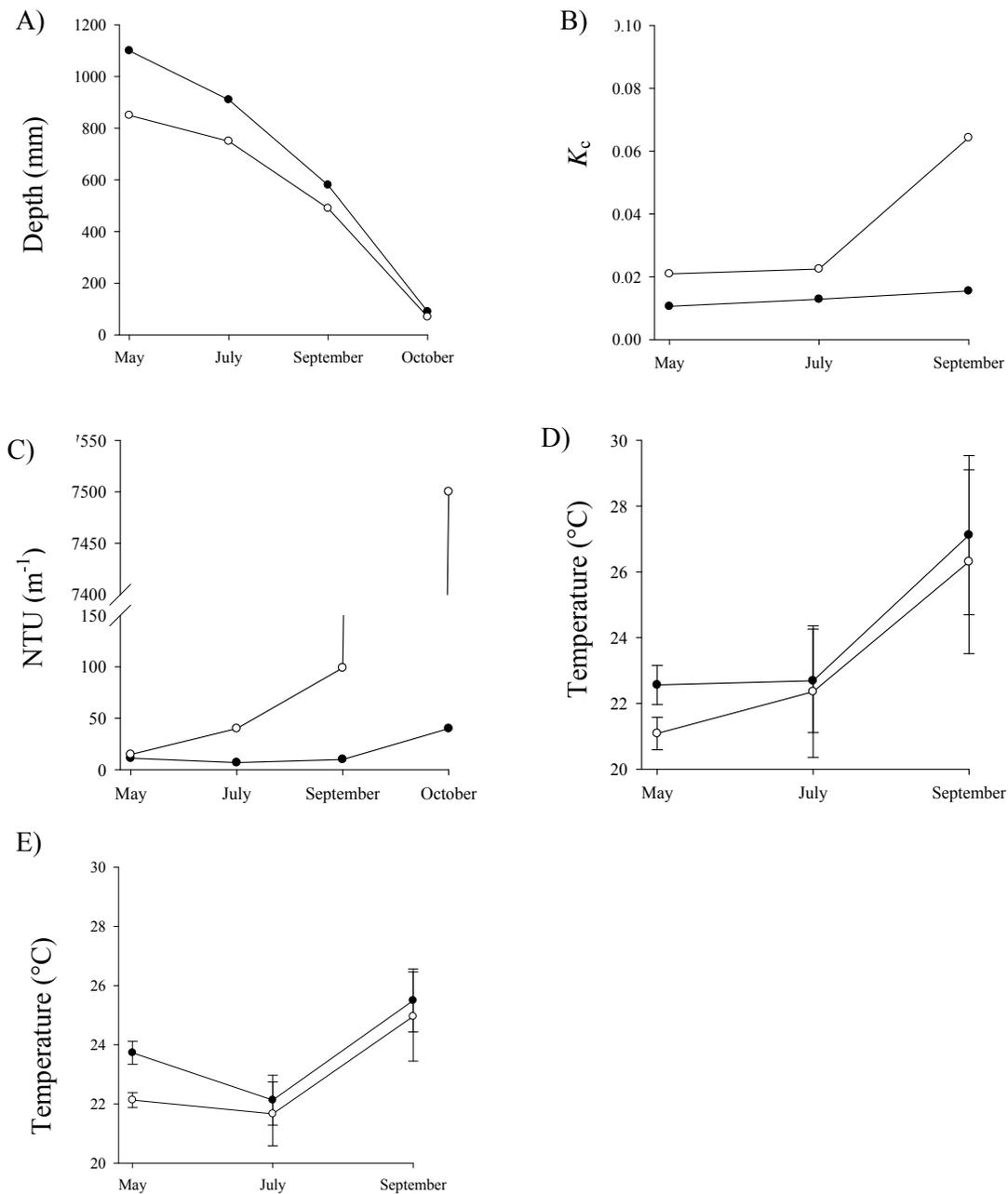
**Lagoon sampling and data collection.**—In May 2008, we began the first of four successive samplings over the tropical dry season. We marked the deepest point of each lagoon by fixing a permanent stake, and we attached a water quality multi probe (Hydrolab

DataSonde, Loveland, Colorado, USA) 200 mm below the surface in each lagoon to concurrently record water pH, temperature (°C), dissolved oxygen (mg L<sup>-1</sup> and % saturation), and electrical conductivity (μS cm<sup>-1</sup>) at 30-min intervals for a 24-h period. Also, at this deepest point, we measured water and secchi depths (mm), and we sampled water for total and dissolved components of nitrogen, phosphorus and ammonia (all in μg L<sup>-1</sup>), and turbidity (in Nephelometric Turbidity Units or NTU). We filtered water samples on site where necessary, and all were frozen and returned to the laboratory for assay using standard methods (APHA 2005).

We also established six permanent transects at 15–20 m intervals in each lagoon, beginning at the wetland margin and traversing the basin to finish at a similar point opposite. We located quadrats of 4 m<sup>2</sup> at 10–15 m intervals along each transect, providing 28 quadrats at each lagoon. Within each quadrat, we identified emergent (and where possible submersed) macrophytes and we estimated percentage cover by eye. Plant coverage as a percentage of lagoon surface area also allowed us to estimate the comparative extent of open water we expected to see increasing in the unfenced lagoon over time due to pig disturbance of aquatic vegetation. Similarly, we also estimated the extent of bare ground to provide an index of pig foraging activity. We sampled the lagoons for all parameters in late May, early July, and early September 2008, and again in mid-October 2008, except that in October neither the Hydrolab or secchi disk was used due to lagoon water levels being less than 100 mm deep.

**Data analyses.**—We estimated lagoon hydraulic residence time as the proportional loss of water between May and October [(end depth–start depth) / start depth], and the comparative change in lagoon water depths was tested using Spearman’s Rho with an alpha level of 0.01. We analysed water clarity using secchi depth and turbidity estimates. Secchi depths compared the visual clarity of different lagoons using the vertical contrast attenuation coefficient ( $K_c$ ) from the relationship  $K_c = 9/Z_{SD}$ , where  $Z_{SD}$  is the depth at which the secchi disc disappears from view and gives a higher  $K_c$  value with decreasing secchi depth (Kirk 1986). Turbidity measured as NTU compared the distance that light is scattered due to water body reflectance, considered to be equivalent to scattering coefficient values in m<sup>-1</sup> (Kirk 1986).

For lagoon water dissolved oxygen, temperature, and pH, we divided their 24-h measurements between day (0600–1800 h) and night (1800–0600 h) periods to estimate the respective biological effects of lagoon production and respiration. We used lagoon water dissolved oxygen percentage saturation levels to compare the amount of oxygen available for respiration in the fenced and unfenced lagoons, and counted the number of hours in which percentage saturation values were below either chronic sub-lethal (75%) or acute

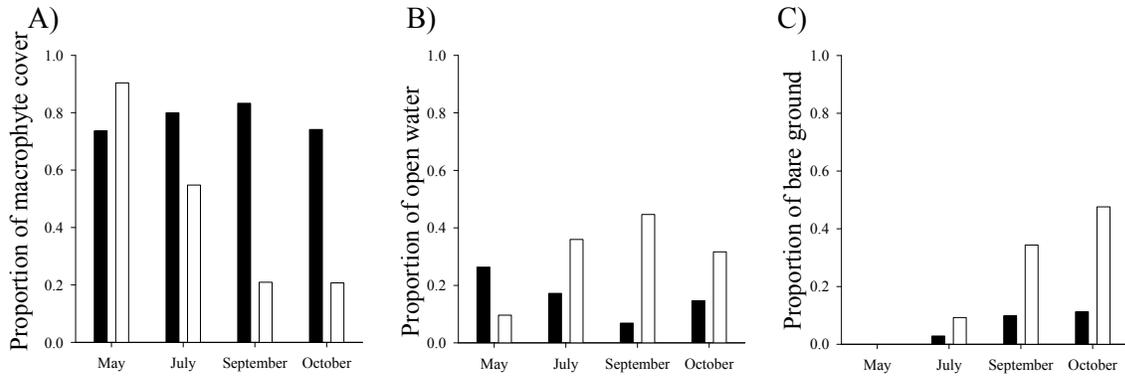


**FIGURE 2.** Effects of feral pig (*Sus scrofa*) disturbance in a fenced (●) and unfenced lagoon (○) in Australia on (A) water depth, (B) secchi depth, (C) turbidity, (D) day temperature, and (E) night temperature. Temperature values are 12-hour means  $\pm$  S.E.

toxic (30%) levels (see Sprague 1985) for each 24-h period. We estimated the particulate fraction of nitrogen and phosphorus by subtracting the dissolved from total components, and because electrical conductivity was not expected to show any diurnal variation due to biological activity, we did not differentiate between day and night.

## RESULTS

The two lagoons had identical hydraulic residence times (-0.91) and their seasonal dehydration was highly correlated ( $R = 0.997$ ,  $P < 0.001$ ; Fig. 2a). This confirmed that both lagoons had very similar hydrologic regimes and geomorphologies. From July, the unfenced lagoon developed significantly shallower

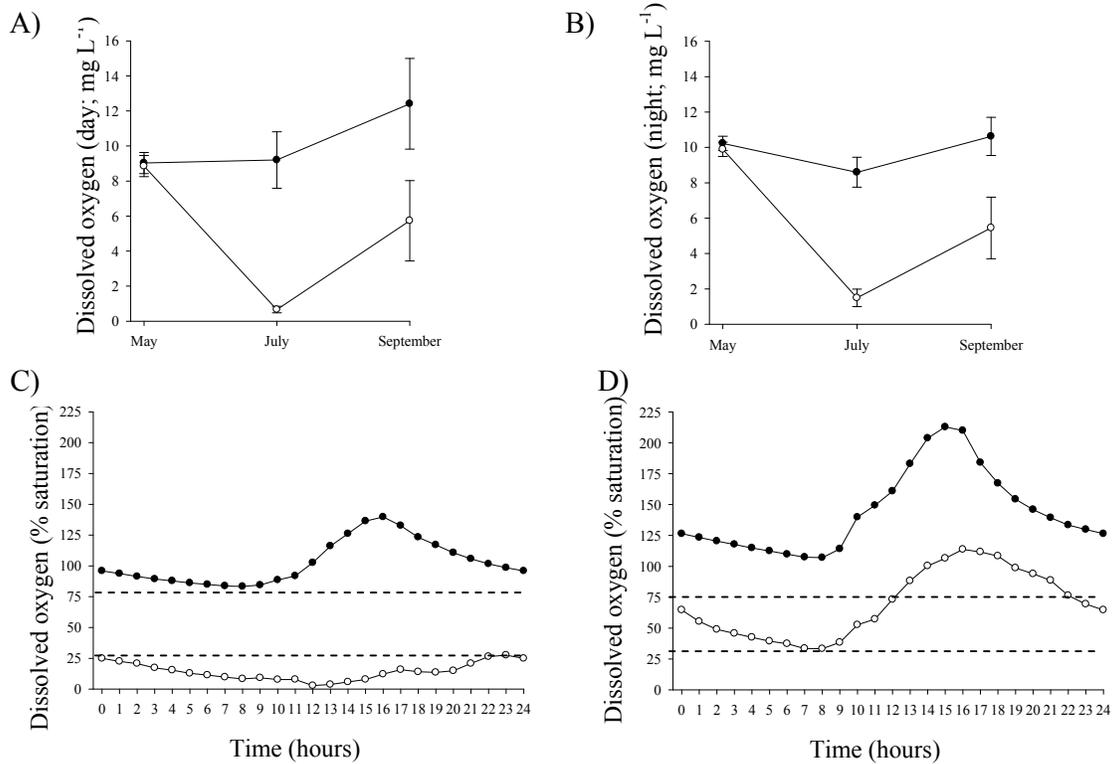


**FIGURE 3.** Proportional changes due to pig (*Sus scrofa*) foraging activities in (A) macrophyte cover, (B) open water and (C) bare ground, in the fenced (■) and unfenced (□) lagoons at Laura, Australia.

secchi depths and therefore a much higher light attenuation coefficient (Fig. 2b). Water clarity became strongly affected by pig activity in the unfenced lagoon and turbidity increased markedly until October to be several orders of magnitude higher than in the fenced lagoon (Fig. 2c). Despite the higher potential for light scattering and heat reflection in the more turbid unfenced lagoon, there were no clear differences in either day (Fig. 2d) or night (Fig. 2e) temperatures between the lagoons.

We recorded a significant change in the proportional cover of aquatic macrophytes in the unfenced lagoon as feral pig foraging activities progressively destroyed the lagoon habitat (Fig. 3a),

and macrophyte cover was gradually replaced with open water (Fig. 3b) and bare ground (Fig. 3c). The temporal destruction of wetland vegetation by foraging feral pigs in the unfenced lagoon created sustained respiration and so resulted in a significant biological oxygen demand. In contrast, we measured markedly higher dissolved oxygen levels during the day and night in the fenced lagoon, and this increased over time for day (Fig. 4a) and night (Fig. 4b) readings. Lagoon percentage dissolved oxygen saturation clearly shows how this biological oxygen demand created a potentially toxic environment in the unfenced lagoon. For example, the consumption-driven conditions in the unfenced lagoon resulted in dissolved oxygen levels of



**FIGURE 4.** Comparative effects of pig (*Sus scrofa*) exclusion fencing around fenced (●) and unfenced lagoon (○) on (A) day dissolved oxygen, (B) night dissolved oxygen, dissolved oxygen percentage saturation in (C) July and (D) September. Values for dissolved oxygen levels in mg L<sup>-1</sup> are 12-hour means ± S.E. Note that dissolved oxygen levels exceeded 75 % saturation in both lagoons in May (data not shown). The horizontal dashed lines represent 25% and 75% dissolved oxygen saturation thresholds.

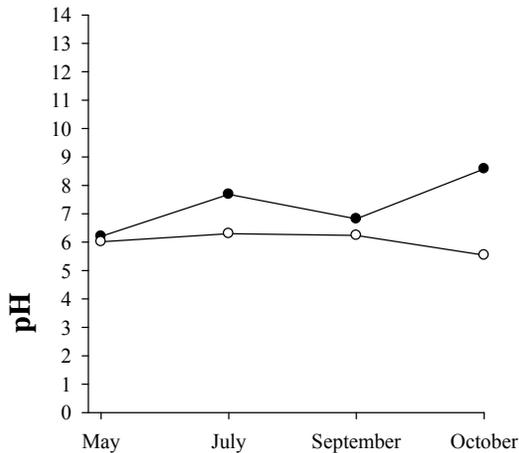


FIGURE 5. Seasonal pH change in the fenced (●) and unfenced (○) lagoons at Laura lagoons.

below 30% saturation for the full 24-h measurement period in July (Fig. 4c). These anoxic conditions partially disappeared in September, but we still recorded dissolved oxygen levels of between 30 and 75% saturation for over 12 h (Fig. 4d). This sustained respiration due to the decomposition of organic matter caused increasingly acidic conditions to develop in the unfenced lagoon and pH levels of close to 5.0 were recorded by October. In contrast, the fenced lagoon was close to or above the neutral level of pH 7.0 (Fig. 5).

We recorded very large increases in total, dissolved, and particulate concentrations of nitrogen and phosphorus in the unfenced lagoon from July onwards. These rapid increases in total and dissolved nitrogen (Fig. 6a, b) and phosphorus (Fig. 6e, f), and later ammonia (Fig. 6d), are mostly due to the combined effects of aquatic macrophyte destruction and consumption by foraging pigs, and the subsequent excretion of their wastes. The large seasonal increases in particulate nitrogen (Fig. 6c) and phosphorus (Fig. 6g) indicate that a corresponding increase in nutrient loading is also occurring in the unfenced lagoon, and low dissolved oxygen levels there might also contribute to the release of phosphorus otherwise bound to sediments. Electrical conductivity increased in both lagoons as the seasonal effects of lagoon dehydration increased (Fig. 7). The observed differences in salinities between the lagoons were low and levels not biologically meaningful (Hart et al. 1991), with both lagoons remaining fresh (i.e., below  $300 \mu\text{S cm}^{-1}$ ) over the season.

#### DISCUSSION

The very similar hydrologic regimes and geomorphologies of the study lagoons provided us with two sites that would allow us to make greater inferences for the effects of feral pig foraging on a

tropical freshwater turtle habitat, albeit without replication. Despite our limited experimental design, we have clearly demonstrated that pigs upheave the sediments, destroy aquatic vegetation, create anaerobic and acidic conditions, and enrich an unprotected wetland with nutrients. The results parallel those of Doupé et al. (in press) who describe the effects of pig disturbance on several pairs of adjacent ephemeral floodplain lagoons at Lakefield. What we have not been able to illustrate, however, is how these changes might directly affect the resident freshwater turtle fauna. This, and the general lack of a literature describing how Chelids respond to the sorts of changed physical, chemical, and biological conditions depicted here, provides obvious avenues for further work. Nevertheless, we can make some qualified interpretations of our data.

The upheaval of wetland sediments and the parallel destruction of wetland vegetation progressively destroyed the unfenced wetland habitat, decreasing water clarity and increasing bare ground and open water. These could have multiple effects on the resident turtles. For example, turbid conditions would limit visibility and so compromise hunting opportunities. Moreover, several studies (e.g., Ernst et al. 1989; Reese and Welsh 1998) have found an inverse relationship between increasing habitat siltation and smaller turtle populations. The gradual disintegration of macrophyte coverage would be expected to enhance turtle predation pressures by the many feral pigs, raptors, and native dogs (*Canis familiaris dingo*) of the area. The removal of vast amounts of wetland vegetation by foraging pigs significantly altered production and respiration regimes in the unfenced lagoon, causing anoxic conditions and subsequent pH imbalances. The unfenced lagoon frequently experienced dissolved oxygen levels between 30–70% saturation or below, and these conditions create chronic sub-lethal effects for the associated biota (Sprague 1985). How prolonged exposure to aquatic anoxia or hypoxia affects air-breathing Chelid turtles is unknown, however, such conditions disrupt swimming behaviour in fishes (McNeil and Closs 2007) and low aquatic oxygen levels decrease dive times in cloacally respiring turtles as the animal is forced to surface more often (e.g., Dejours 1994; Clark et al. 2009). We also found that macrophyte destruction raised lagoon acidity due to sustained respiration in the unfenced wetland, which via increased biological oxygen demand, became a consumption-driven environment. There, pH levels decreased to almost 5.0. Psenner (1994) nominates pH levels of 6.5 as the trigger value for beginning sub-lethal effects on sensitive species, although what these levels mean for the turtles is again uncertain. The high nutrient levels recorded in the unfenced lagoon are indicative of extreme nutrient enrichment (Ryding and Rast 1989), but there is also parallel evidence in the fenced lagoon for a seasonal build-up of nutrients

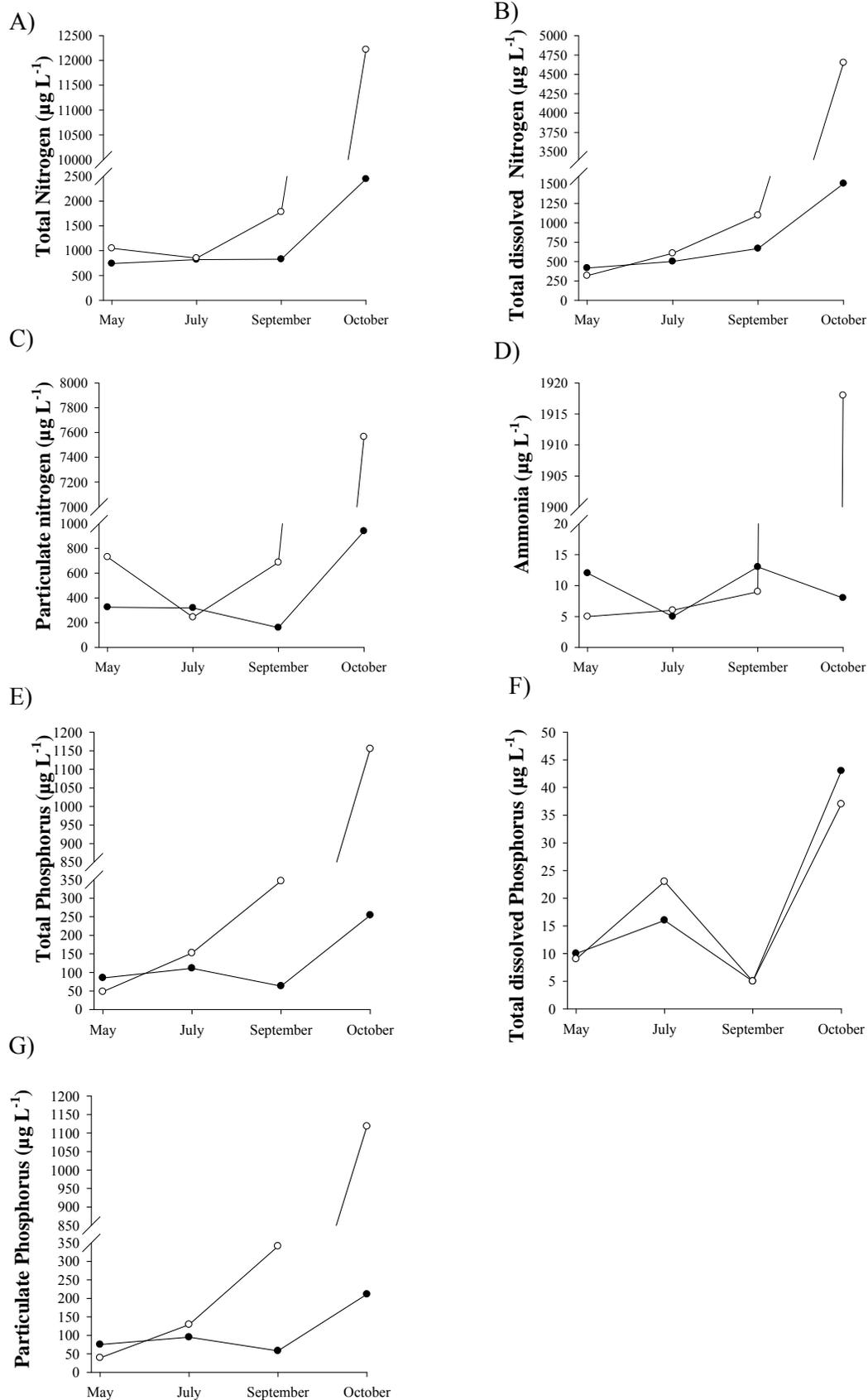


FIGURE 6. Comparative effects of pig (*Sus scrofa*) exclusion fencing around fenced (●) and unfenced lagoon (○) in Laura, Australia on (A) total nitrogen, (B) total dissolved nitrogen, (C) particulate nitrogen, (D) ammonia, (E) total phosphorus, (F) total dissolved phosphorus, and (G) particulate phosphorus.

caused by natural plant die-off and evapo-concentration. This suggests that the turtles will persist under seasonally eutrophic conditions.

We have been trapping and radio-tracking long-necked turtles in these and several other lagoons at Lakefield for the past couple of years. Our unpublished field data describes two species of long-necked turtle from the area: *Macrochelodina rugosa* and *Chelodina canni*. The range of *C. canni* overlaps with several freshwater turtle species, but it has only been collected syntopically (i.e., sharing the same habitat) with *M. rugosa* (Covacevich et al. 1990) and we assume that these two species are likely to be more ecologically equivalent than any other freshwater turtles of the region (e.g., *Emydura* spp.). Notwithstanding, our preliminary data at Lakefield shows that (1) *C. canni* may travel many kilometres overland between wetlands, whereas *M. rugosa* tends to move only between proximate water bodies; (2) both turtle species will readily leave lagoons during periods of seasonal wetland dehydration with or without pig disturbance, suggesting that seasonal ecological factors influence migration more so than pigs; (3) turtles will move into an adjacent wetland even during a major pig disturbance event; and (4) in 2009 juvenile *M. rugosa* recruits were captured in unfenced wetlands being impacted by feral pigs and the same lagoons were severely affected by pigs during the previous dry season, indicating that turtles will persist in those wetland habitats.

Doupe et al. (in press) proposed that the annual disturbance regime of seasonal flooding may exert a far greater influence on the ecological communities of the Lakefield floodplains than does the feral pigs because seasonal inundation will essentially reset lagoon conditions following the pig-mediated disruption. This work continues. The decline and loss of wetlands have important implications for not only the conservation of aquatic biota, but for the wider ecological community that directly and indirectly depends on them (Semlitsch and Bodie 2003; Roe and Georges 2007). Habitat protection is the cornerstone of biological conservation (Browne and Hecnar 2007) and together with high adult survivorship, are seen as crucial for achieving long-term population stability in turtles (Heppell 1998). Here, we show that exclusion fencing will clearly protect ephemeral freshwater lagoon habitats from the foraging activities of feral pigs. However, a piecemeal approach to managing relatively small fragments of natural areas as preserves, in this case by individual wetland fencing, may provide only initial support to the protected species and later threaten their persistence simply through the residual effects of isolation (Janzen 1983; Primack 1998). This consideration and the uncertainty for what are the ecological requirements of the turtles that use these ephemeral lagoons needs to be better understood before deciding which lagoons should be chosen for wetland protection.

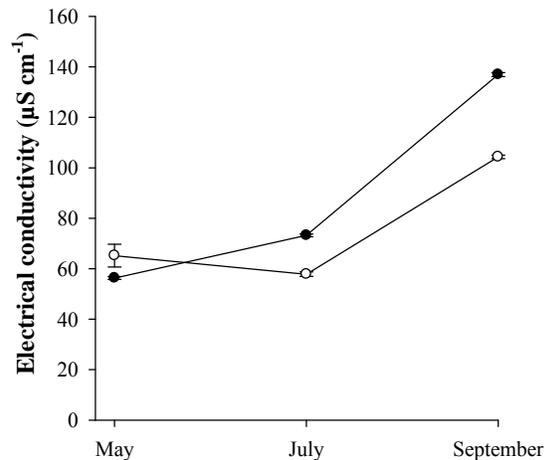


FIGURE 7. Seasonal changes in electrical conductivity in the fenced (●) and unfenced (○) lagoons at Laura, Australia. Values are 24-hour means  $\pm$  S.E.

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## Herpetological Conservation and Biology

The authors form part of the Freshwater Ecology team at the Australian Centre for Tropical Freshwater Research, James Cook University. In the past two years, Rob Doupé has lead research projects concerning the effects of habitat change on freshwater turtles in north-eastern Australia. These projects include the conservation status of the highly restricted Jardine River Painted Turtle, *Emydura subglobosa*, the effects of altered hydrological conditions on the diving physiology of the cloacally respiring Irwin's Turtle, *Elseya irwini*, and studies on feral pig management strategies for conserving native aquatic biota, which includes the work presented here. The authors did not submit photographs of themselves.