

**AN EXAMPLE OF FRESHWATER TURTLE HABITAT
DESTRUCTION BY FORAGING FERAL PIGS
IN TROPICAL NORTH-EASTERN AUSTRALIA**

ACTFR Report No. 08/21

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A report prepared for the Cape York Peninsula Biodiversity Technical Advisory Group

ACTFR Report No. 08/21

November 2008

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ACKNOWLEDGEMENTS

Financial support for this work was principally provided by the Natural Heritage Trust Program via the Cape York Peninsula Biodiversity Technical Advisory Group, and secondarily by the Federal Department of Environment and Water Resources due to their funding of a concurrent project (083/0607 DEW).

The use of sentient animal subjects was approved by the James Cook University Animal Experimental Ethics Review Committee (No. A1319), and permission to capture and radio-track freshwater turtles was provided by the Queensland Parks and Wildlife Service (No. WITK05229708).

Jim Mitchell and Shane Campbell of the Tropical Weeds Research Centre (Queensland Department of Primary Industries and Fisheries) kindly provided logistical support.

This report should be cited as follows:

Doupé, R.G., Schaffer, J. and Knott, M.J. (2008) An example of freshwater turtle habitat destruction by foraging feral pigs in tropical north-eastern Australia. ACTFR Report No. 08/21. Australian Centre for Tropical Freshwater Research, Townsville.

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1.0 SUMMARY

Foraging by feral pigs can strongly affect vegetation assemblages and so too wider ecological processes, although how this impacts upon freshwater ecosystems and their inhabitants have seldom been studied. Between May and October 2008, we assessed the ecological effects of pig foraging activities in a pair of fenced and unfenced ephemeral floodplain lagoons at Lakefield National Park on Cape York Peninsula, and from July we estimated the comparative effect of pig disturbance on the resident freshwater turtle fauna in each lagoon. Foraging by 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 light penetration and water clarity, and caused prolonged anoxia and pH imbalances in the unfenced treatment. The combined effects of vegetation destruction and the subsequent excretion of pig wastes caused high levels of nutrient enrichment in the unfenced lagoon.

From July 2008, we used radio telemetry to track the movements of eight long-necked turtles (*Chelidae*) in their respective lagoons (i.e. four turtles in each treatment), and found that by September individuals had begun to move among and from the wetlands, and some had disappeared altogether. In September, one individual had migrated from the fenced to the unfenced treatment to join the single turtle remaining in that lagoon, and another had left the unfenced lagoon and taken residence in the adjacent Laura River. Despite the migration of one individual from the fenced to the unfenced treatment, we are unconvinced that the 150 mm wire mesh would not impede the movement of larger turtles through the exclusion fence and recommend the occasional removal of bottom vertical wires along the perimeter. Also in September, we found that only one turtle remained in the fenced treatment and that two turtles in each lagoon could not be located within 1.5 km of the study sites. By October, telemetry indicated that none of the eight turtles were in the wetlands and that two individuals from the unfenced treatment were residing in the Laura River. The finding that no turtles remained to aestivate probably indicates that these particular lagoons are not obligate habitat for them and do not serve as (over) seasonal refugia, being opportunistically colonised after the wet season. Notwithstanding this, we suspect that most if not all missing turtles were predated upon, probably by raptors but perhaps also by wild pigs. Exclusion fencing will clearly protect freshwater turtle habitats from feral pig foraging activities, however the choice of which lagoons to fence should only be made after gaining a better understanding of their seasonal usage by freshwater turtles.

2.0 INTRODUCTION

Freshwater turtles are found throughout the permanent and ephemeral swamps and wetlands of northern Australia (Cogger 2000). They are 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 an important indicator of wetland habitat maintenance due to their markedly different life history pattern (Bodie and Semlitsch 2000). For example, they are semi-aquatic and have a long life cycle that is characterised by late maturity and a low reproductive output (Klemens 2000). This clearly contrasts against other obligate wetland inhabitants such as fish and invertebrates.

Feral pigs (*Sus scrofa*) are an exotic disturbance agent that has invaded most regions and habitat types on all continents except Antarctica (Tierney and Cushman 2006). Pigs can greatly increase disturbance levels in 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). Whilst primarily phytophagous, wild pigs are true omnivores and will vary their diets to suit the seasonal availability of alternative foods including arthropods, birds, reptiles, amphibians and fish (Giménez-Anaya et al. 2008). Foraging for food in the soil profile 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).

In northern Australia, freshwater turtle activity is interrupted by the tropical dry season, when wetland water levels retreat and often completely dry (Fordham et al. 2008). It is in the later phases of wetland drying that turtles move to the shallows to bury themselves in mud and aestivate, and it is during this period immediately before drying that feral pig predation on them is heaviest (Fordham et al. 2006, 2007). Fordham et al. (2008) recently argued 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 pig predators.

Together with the Tropical Weeds Research Centre (Queensland Department of Primary Industries and Fisheries), staff at the Australian Centre for Tropical Freshwater Research (James Cook University) are presently working on several feral pig management projects at Lakefield National Park on Cape York Peninsula. One program (083/0607 DEW) includes testing the efficacy of pig-proof fencing using four pairs of ephemeral floodplain lagoons, and we were aware of individual long-necked turtles (Chelidae) in at least some of these and of an extant population in two adjacent lagoons. The pig exclusion fencing has been in place since mid-2007 and so any test of its protective benefit(s) to freshwater turtles would already have a temporal dimension to it. Conversely, this same data can indicate if pig-proof fencing has had a negative effect on turtles. For example, fencing may preclude turtle habitation and/or dispersal.

The aims of this study were to:

- (1) Quantify the effect of feral pig foraging activities on freshwater turtle habitat
- (2) Quantify the effect of feral pig foraging activities on resident freshwater turtles
- (3) Quantify the efficacy of wetland fencing as a remedial treatment for the effects of feral pig foraging

3.0 MATERIALS AND METHODS

Preamble and explanatory note

In 2007, a current research project “Impact of feral pigs on freshwater ecosystems” (083/0607 DEW) established replicate pig exclusion fencing treatments in two ephemeral floodplain lagoons at each of the Twelve-mile (S 15° 10' E 144° 21'), Anabranh (S 15° 20' E 144° 26'), Laura (S 15° 20' E 144° 27') and Welcome (S 15° 15' E 144° 35') waterhole locations in Lakefield National Park (Figure 1). In early July 2008 we set up to six baited ‘cathedral-style’ turtle traps in different microhabitats within each lagoon between dusk and dawn for up to four successive days. Trapping success was highly variable, recording one northern snake-necked turtle (*Macrochelodina rugosa*) in the unfenced Twelve-mile lagoon and one *M. rugosa* in the fenced Welcome lagoon, but no turtles at the Anabranh lagoons. It was only at the Laura lagoons that we captured a population of freshwater turtles in both lagoons, comprising three male and one female *M. rugosa* in the fenced lagoon, and one male and two female *M. rugosa*, and one female Cann’s long-necked turtle (*Chelodina canni*) in the unfenced lagoon. It was therefore decided to concentrate the study effort at the Laura lagoons for three reasons. First, we could still measure the pig disturbance of comparatively similar turtle habitat at this location, albeit without replication; second, there were sufficient resident turtles in the fenced and unfenced treatments at Laura to potentially measure their response to pig foraging disturbance; and third, the subsequent decision to utilise telemetry might provide more meaningful turtle movement data as pig disturbance increased in the unfenced lagoon.

Site description and experimental design

The Laura lagoons are approximately 200 m apart and adjacent to the Laura River, which is approximately 400 m to the north-west. The lagoons are dish-like in shape and about 0.5 ha in size, and contain similar aquatic macrophyte communities, being predominated by giant water lily (*Nymphaea gigantea*) and spiny mudgrass (*Pseudoraphis spinescens*). One lagoon was enclosed by a pig-proof fence constructed about six metres above the demarcation between the wetland margin and the surrounding savannah woodland. Fencing was 1100 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.

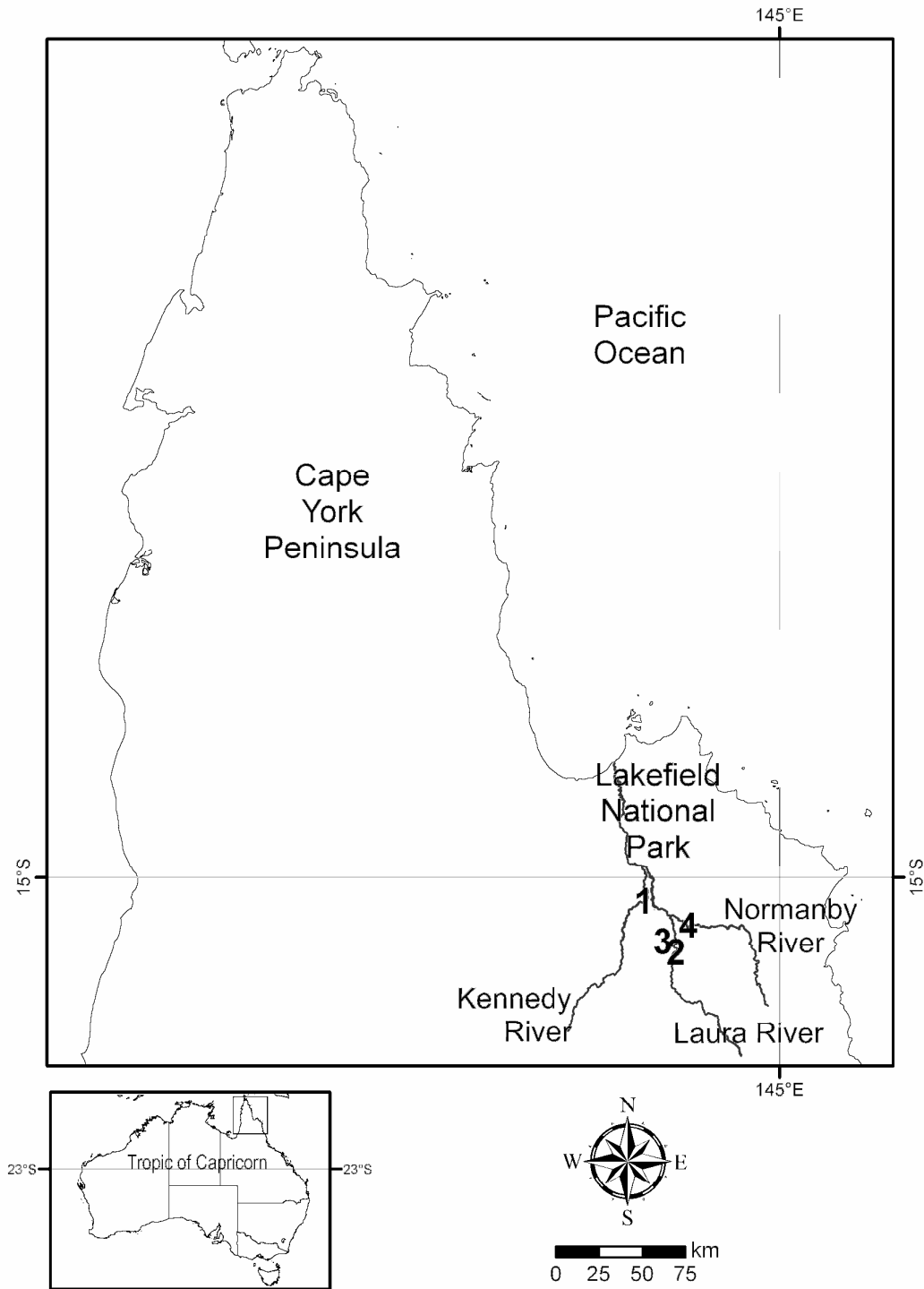


Figure 1 Locality plan showing approximate positions of the Twelve-mile (1), Anabranh (2), Laura (3) and Welcome (4) waterholes at Lakefield National Park, Cape York Peninsula

Lagoon sampling and data collection

In May 2008 and when fully hydrated, we began the first of four successive samplings over the tropical dry season. The deepest point of each lagoon was marked by fixing a permanent stake, and a water quality multi probe (Hydrolab DataSonde USA) was attached 200 mm below the surface in each to concurrently record water pH, temperature (°C), dissolved oxygen (mg L^{-1} and % saturation) and electrical conductivity ($\mu\text{S cm}^{-1}$) at 30-minute intervals for a 24-hour period. Also at this deepest point we measured water and secchi depths (mm), and water was sampled for total and dissolved components of nitrogen, phosphorus and ammonia (all in $\mu\text{g L}^{-1}$), and turbidity (in Nephelometric Turbidity Units or NTU). Water samples were filtered on site where necessary, and then 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. Quadrats of 4 m^2 were located at 10 – 15 m intervals along each transect, providing 28 quadrats at each lagoon. Within each quadrat, emergent (and where possible submersed) macrophytes were identified and percentage cover estimated 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, the extent of bare ground was also estimated to provide an index of pig foraging activity.

The lagoons were sampled 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.

Telemetry of freshwater turtles

Captured turtles were scute-marked for individual identification (Cagle, 1939), and sexed, measured and weighed. For each individual we fixed a Tx – GPI – 17450 customised radio transmitter (Titley Electronics, Ballina, Australia) to the approximate shell centre using an epoxy resin such that the antenna trailed behind the turtle (see Boarman *et al.* 1998; Plate 1). Turtles were then released and radio-tracked during August, September and October 2008.



Plate 1 Freshwater turtles with radio-transmitters attached prior to release in the unfenced Laura lagoon, July 2008. Turtle in the centre is *Chelodina canni* flanked by *Macrochelodina rugosa*

Data analyses

Any differences in hydraulic residence time between the lagoons was estimated 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 by correlation. The optical properties of lagoons were estimated 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 (see 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^{-1} (Kirk 1986).

For lagoon water dissolved oxygen, temperature and pH, we divided their 24-hour 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 toxic (30%) levels (see Sprague 1985; Butler and Burrows 2007) for each 24-hour period.

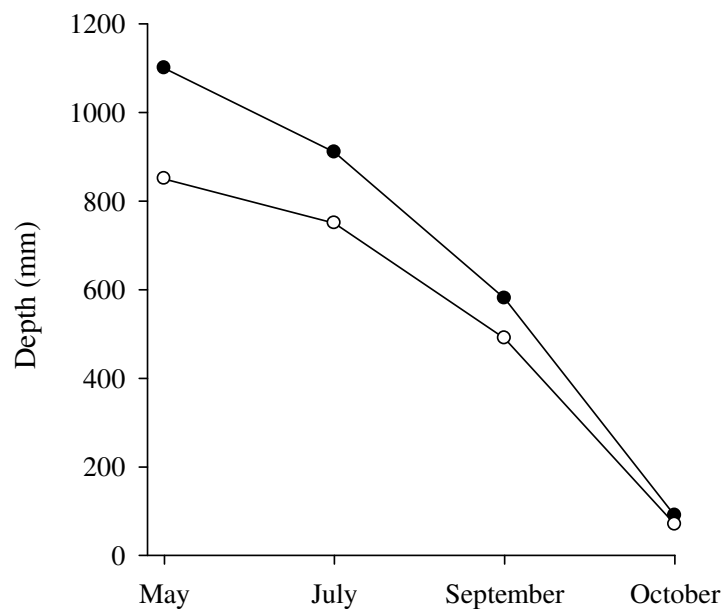
We estimated the particulate fraction of nitrogen and phosphorus by subtracting the dissolved from total components, and since electrical conductivity was not expected to show any diurnal variation due to biological activity we did not differentiate between day and night in the data presentation.

4.0 RESULTS AND DISCUSSION

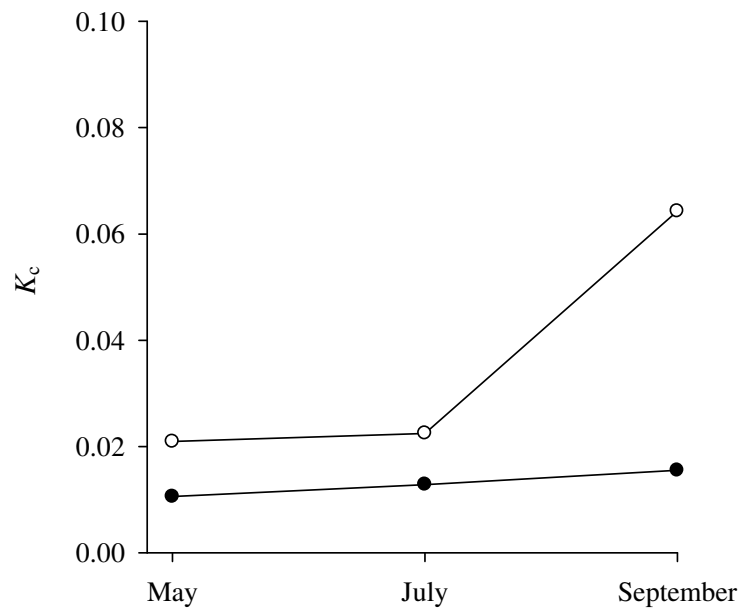
The two lagoons had identical hydraulic residence times (-0.91) and their seasonal dehydration was very highly correlated ($r = 0.997$, $P < 0.00001$; Figure 2a). This confirms that the lagoons have very similar hydrologic regimes and geomorphologies, and has allowed us to make greater inferences for the effects of feral pig foraging in an environment where natural seasonal drying has occurred concurrently.

From July, the unfenced lagoon developed significantly shallower secchi depths and therefore a much higher light attenuation coefficient (Figure 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 the fenced lagoon (Figure 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 (Figure 2d) or night (Figure 2e) temperatures between the lagoons.

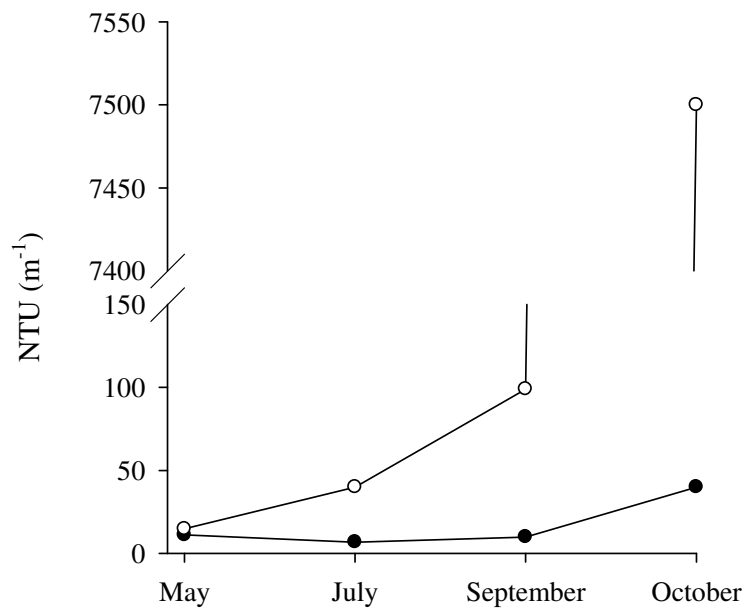
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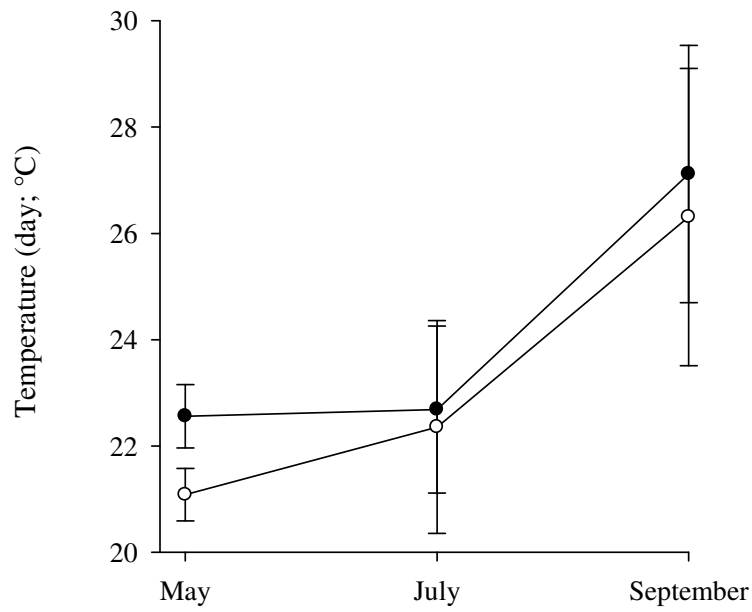
(b)



(c)



(d)



(e)

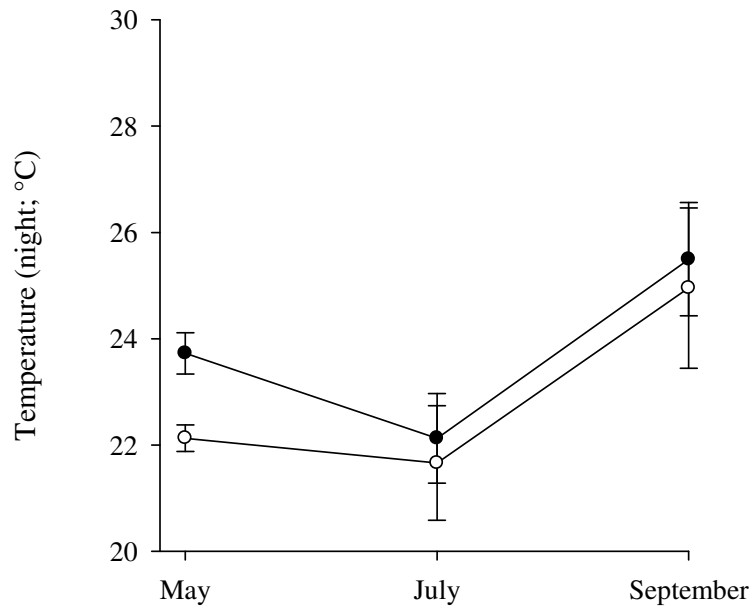
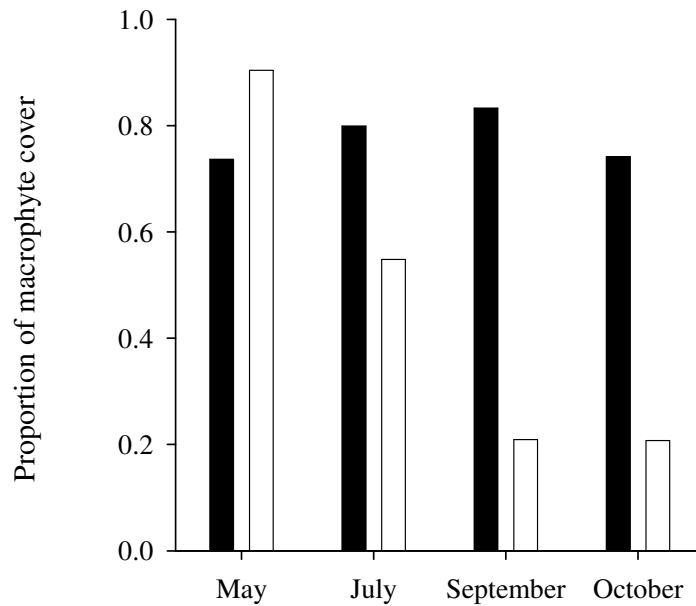


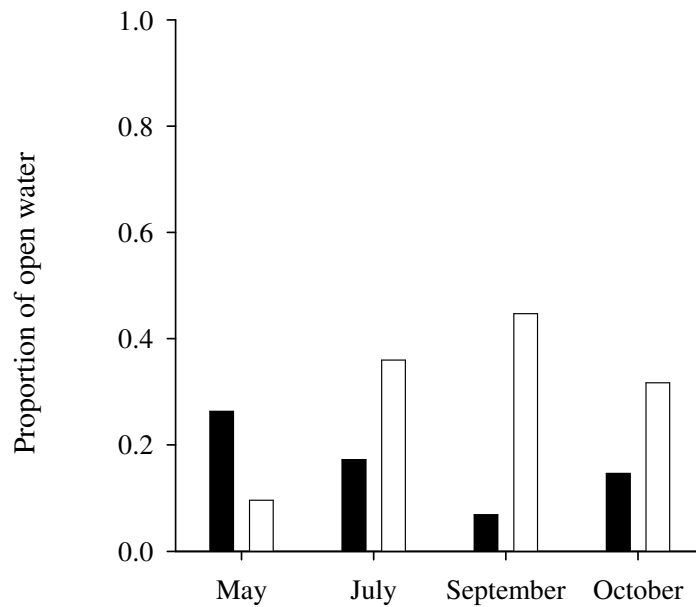
Figure 2 Effects of feral pig disturbance in the unfenced lagoon (○) on (a) water depth, (b) secchi depth, (c) turbidity, (d) day temperature and (e) night temperature. Temperature values are 12-hour means \pm S.E.

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 (Figure 3a), and macrophyte cover was gradually replaced with open water (Figure 3b) and bare ground (Figure 3c); also see the pictorial record in Plates 2 and 3.

(a)



(b)



(c)

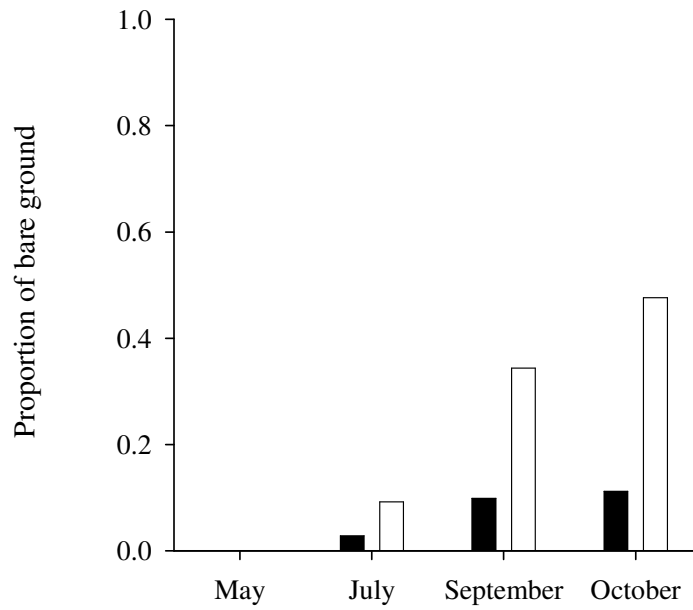


Figure 3 Proportional changes due to pig foraging activities in (a) macrophyte cover, (b) open water and (c) bare ground, in the fenced (■) and unfenced (□) lagoons at Laura

(a)



(b)



(c)



(d)



Plate 2 Fenced lagoon at Laura in (a) late May, (b) early July, (c) early September and (d) mid-October 2008.

(a)



(b)



(c)



(d)

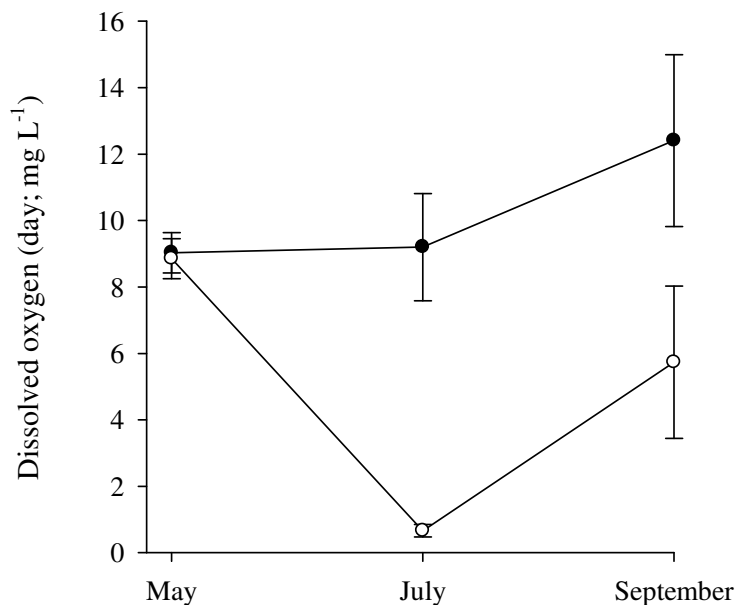


Plate 3 Unfenced lagoon at Laura in (a) late May, (b) early July, (c) early September and (d) mid-October 2008.

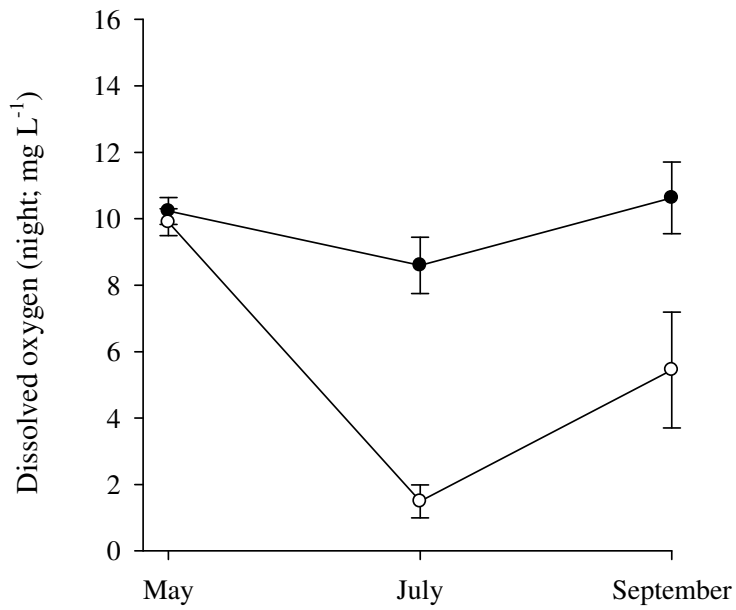
The temporal destruction of wetland vegetation by foraging feral pigs in the unfenced lagoon created sustained respiration and so resulted in a significant biological oxygen demand. In contrast, we measured markedly higher dissolved oxygen levels during the day and night in the fenced lagoon, and this increased over time for day (Figure 4a) and night (Figure 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 below 30% saturation for the full 24-hour measurement period in July (Figure 4c). These anoxic conditions partially recovered in September, but we still recorded dissolved oxygen levels of between 30 and 75% saturation for over 12 hours (Figure 4d), and these can create chronic sub-lethal effects for associated biota (Butler and Burrows 2007).

This same sustained respiration due to the decomposition of organic matter in the unfenced lagoon caused increasingly acidic conditions to develop. We recorded pH levels of close to 5 by October in the unfenced lagoon, whereas the fenced lagoon was close to or above the neutral level of pH 7 (Figure 5). Psenner (1994) nominates pH levels of 6.5 as the trigger value for beginning sub-lethal effects on sensitive species.

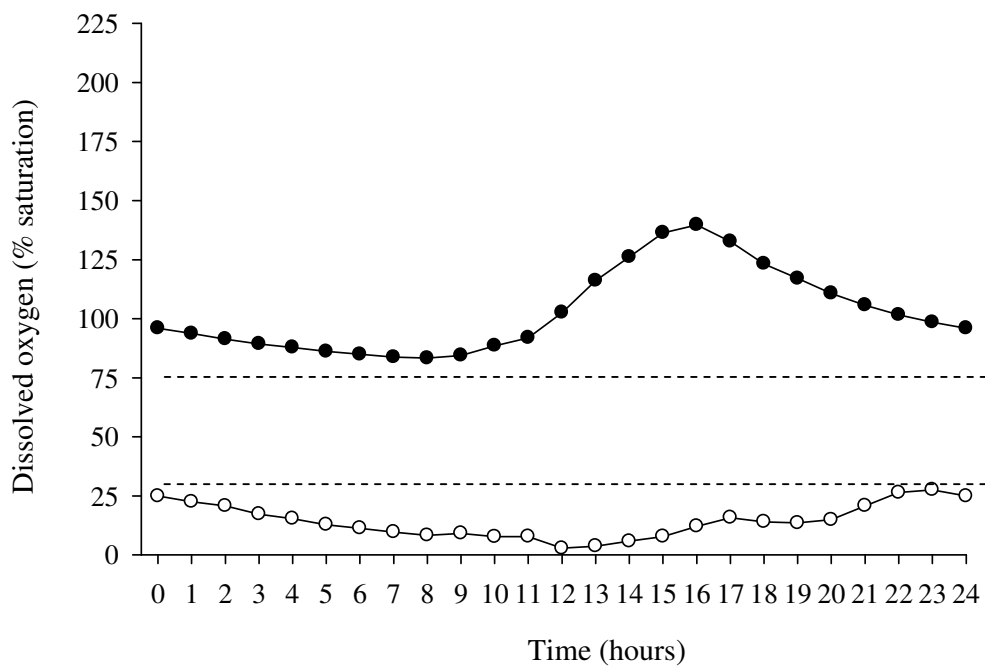
(a)



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(c)



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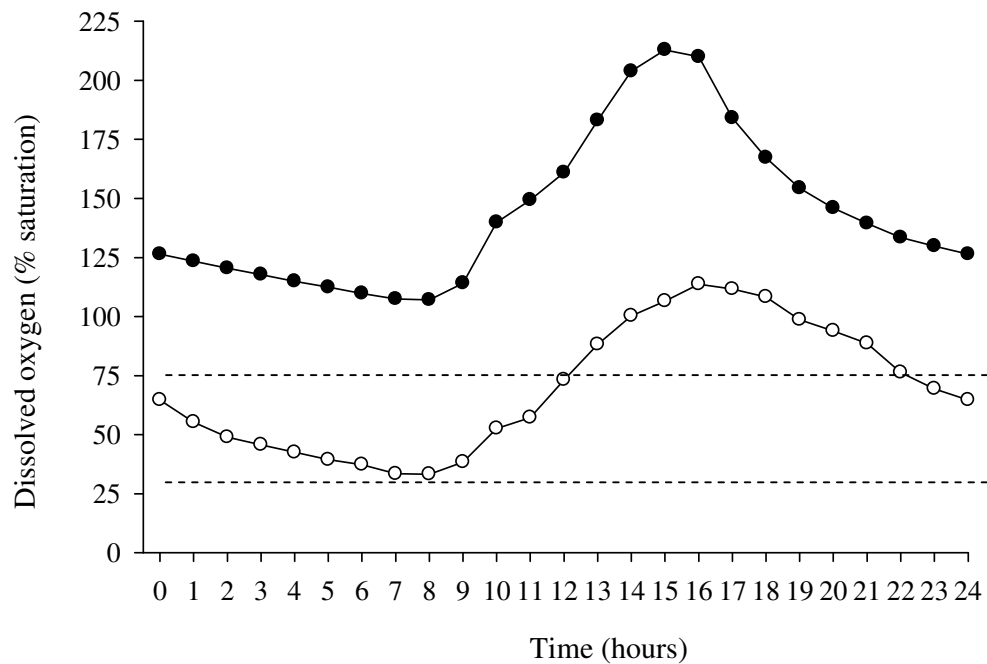


Figure 4 Comparative effects of pig exclusion fencing (●) on (a) day dissolved oxygen, (b) night dissolved oxygen, (c) dissolved oxygen percentage saturation in July and (d) dissolved oxygen percentage saturation in September. Dissolved oxygen levels values in mg L⁻¹ are 12-hour means ± S.E. Note that dissolved oxygen levels were above 75% saturation in both lagoons in May

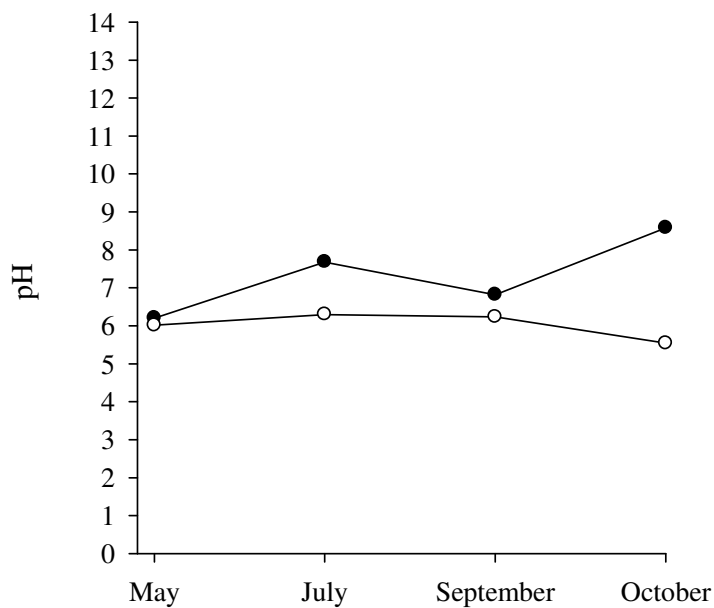
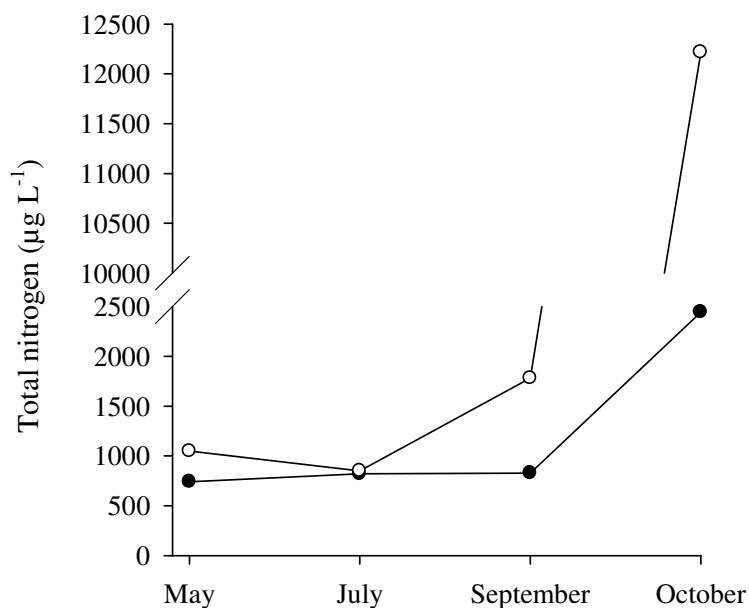


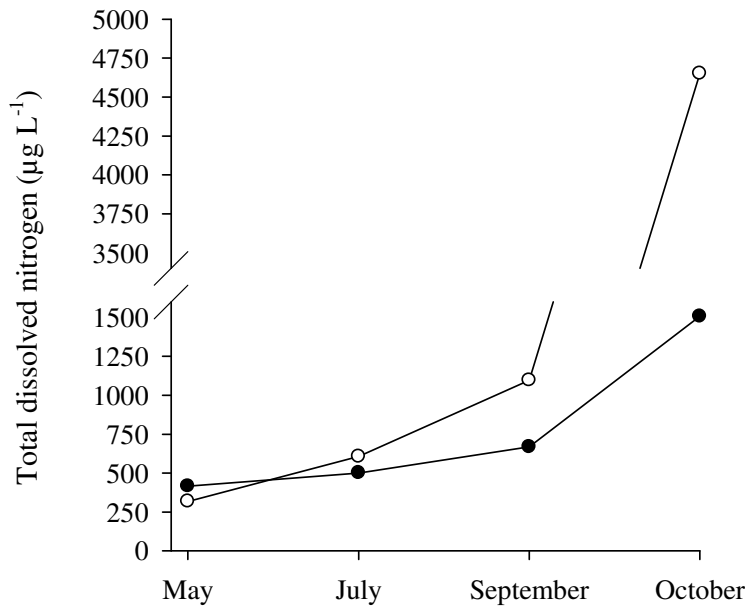
Figure 5 Seasonal pH change in the fenced (●) and unfenced (○) lagoons at Laura

Very large increases in total, dissolved and particulate concentrations of nitrogen and phosphorus in the unfenced lagoon were recorded from July onwards, when the impacts of feral pig foraging became increasingly obvious. These rapid increases in total and dissolved nitrogen (Figure 6a, b) and phosphorus (Figure 6e, f), and later ammonia (Figure 6d), are mostly due to the combined effects of vegetation destruction and the subsequent excretion of pig wastes. The high nutrient levels recorded in the unfenced lagoon are indicative of extreme nutrient enrichment (Ryding and Rast 1989), but there is also, however, parallel evidence in the fenced lagoon for the natural seasonal effects of plant die-off and evapo-concentration. The large seasonal increases in particulate nitrogen (Figure 6c) and phosphorus (Figure 6g) indicate that a corresponding increase in nutrient loading of the unfenced lagoon is also occurring, and low dissolved oxygen levels may also contribute to the release of phosphorus otherwise bound to sediments.

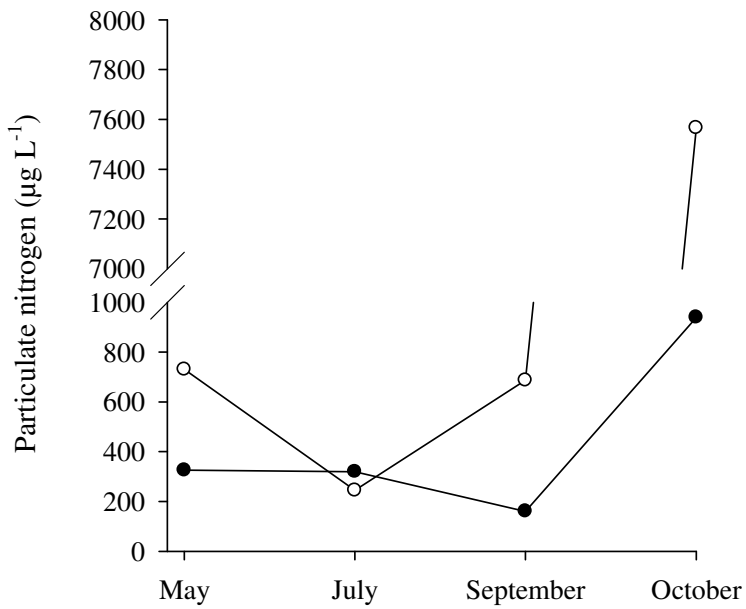
(a)



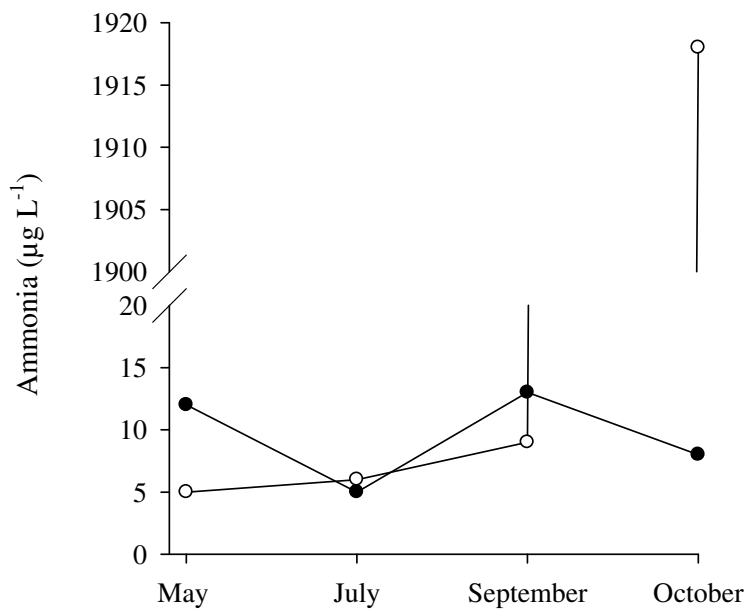
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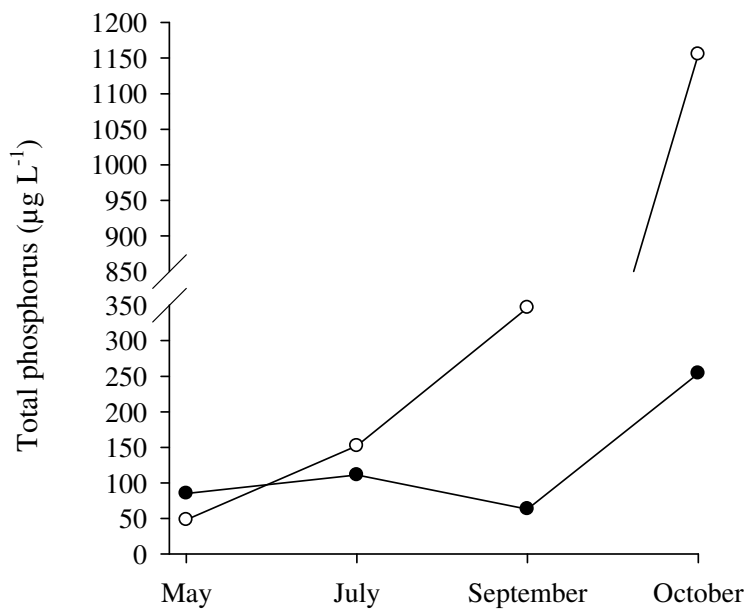
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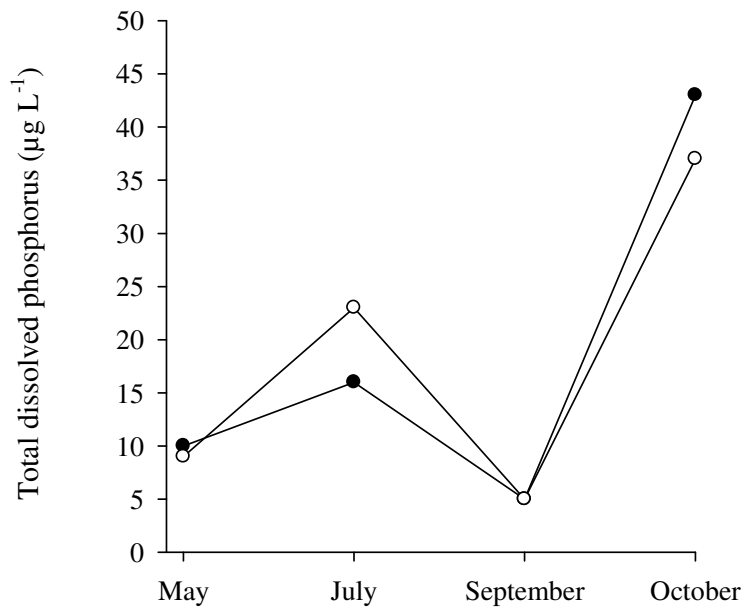
(d)



(e)



(f)



(g)

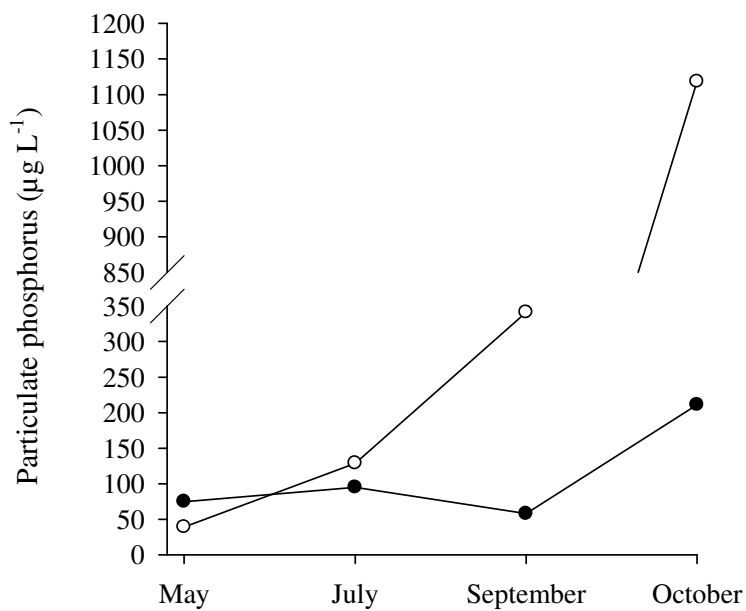


Figure 6 Comparative effects of pig exclusion fencing (●) on (a) total nitrogen, (b) total dissolved nitrogen, (c) particulate nitrogen, (d) ammonia, (e) total phosphorus, (f) total dissolved phosphorus and (g) particulate phosphorus

Electrical conductivity increased in both lagoons as the seasonal effects of lagoon dehydration increased (Figure 7). The observed differences in salinity between the lagoons were low and not biologically meaningful (Hart et al. 1991), and both lagoons remained fresh.

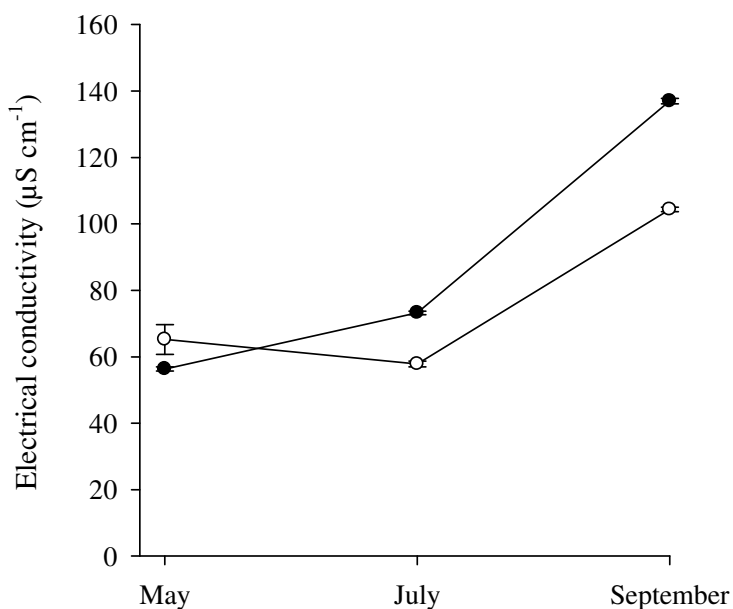


Figure 7 Seasonal changes in electrical conductivity in the fenced (●) and unfenced (○) lagoons at Laura. Values are 24-hour means \pm S.E.

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). Here we have demonstrated a clear effect by foraging feral pigs on a freshwater turtle habitat. Pigs destroy aquatic vegetation, upheave the sediments, create anaerobic and acidic conditions, and enrich the wetland with nutrients. What is less clear, however, is how this disturbance has affected the resident freshwater turtle populations of the Laura lagoons, because turtles began to leave the wetlands between August and September, and were gone from both by October (Table 1).

In September, we recorded only a single turtle remaining resident in each of the fenced and unfenced lagoons, and that another (*C. canni*) had left the unfenced lagoon and migrated to the Laura River, about 400 m away. Telemetry also showed that two individuals in each lagoon could not be located within 1.5 km of the study sites and had seemingly disappeared.

Table 1 Individual descriptions and telemetric movement patterns of freshwater turtles in the fenced and unfenced lagoon treatments adjacent to the Laura River, Lakefield National Park. Note that all turtles were captured, radio-tagged and released during July 2008

Treatment	Species	Sex	Presence (P) or absence (A) at monthly radio-tracking		
			August	September	October
Fenced	<i>Macrochelodina rugosa</i>	Male adult	P	A	A
Fenced	<i>Macrochelodina rugosa</i>	Male adult	P	P ¹	A
Fenced	<i>Macrochelodina rugosa</i>	Male adult	P	P	A
Fenced	<i>Macrochelodina rugosa</i>	Male adult	P	A	A
Unfenced	<i>Macrochelodina rugosa</i>	Female adult	P	A	A
Unfenced	<i>Macrochelodina rugosa</i>	Female adult	P	P	A ³
Unfenced	<i>Macrochelodina rugosa</i>	Male adult	P	A	A
Unfenced	<i>Chelodina canni</i>	Female adult	P	A ²	A ⁴

¹ This turtle migrated from the fenced to the unfenced lagoon² This turtle migrated to an overflow channel of the Laura River³ This turtle migrated to an overflow channel of the Laura River⁴ This turtle remained in the overflow channel of the Laura River

In addition, we found that one individual had migrated from the fenced to the unfenced site (Table 1), regardless that the unfenced lagoon was extremely affected by feral pigs. This migration indicates that seasonal ecological factors were the likely reason for leaving the fenced lagoon, because that habitat remained intact. We also consider that the observed movement through the exclusion fence does not necessarily demonstrate that the wire mesh would not hinder migrations between alternative habitats for larger turtles. For example, this particular turtle was the smallest tagged individual in the fenced treatment with a carapace width of 137.6 mm compared to a mean carapace width of 161.3 ± 4.1 mm for the other three, and so while the gap space may have allowed its passage we suspect it would impede larger animals. Nevertheless, turtle passage through the fence could be readily permitted by the occasional removal of bottom vertical wires along the perimeter.

By October, lagoon water depths were both below 100 mm and the unfenced lagoon habitat was all but destroyed by pigs (Figure 3, Plate 2). *C. canni* remained in the Laura River and was joined by an original resident from the unfenced lagoon (Table 1). The turtle that had migrated from the fenced to the unfenced lagoon had subsequently disappeared from the unfenced lagoon by October, either leaving due to pig-induced disturbance, which is why we believe the remaining resident turtle had migrated to the nearby Laura River (see Table 1), or it was predated upon. The *C. canni* and *M. rugosa* that had taken residence in the Laura River were the only turtles that we could locate by October (Table 1).

We can't discount either transmitter failure or predation in explaining the disappearance of six of the eight animals, although transmitter failure seems less likely to us than does predation. Pigs may have predated upon turtles in the unfenced treatment, but it is also likely that predation by the ubiquitous raptors is the reason; either way, we can only speculate of their fate. If transmitter failure had occurred in at least some individuals then it might also be linked to attempted predation by birds of prey, in that the long blue transmitter aerial trailing the carapace (see Plate 1) may have attracted raptor attention and was bitten off, thereby ceasing transmission. If raptor predation did otherwise occur then we expected to retrieve the transmitter. Similarly, if pig predation is even partially responsible for their disappearance then we would have expected to find transmitters attached to at least some shells, since the carapace lengths of all radio-tagged turtles (mean = 234 ± 12.7 mm) were probably too large for pigs to consume (Fordham et al. 2006). Fordham et al. (2007) argued that the interaction between pig abundance and survival of *C. rugosa* was related to vegetation

structure and the timing of wetland drying. Our data confirms the seasonal relationship between pig foraging activities and wetland vegetation disturbance, but we can't explicitly factor turtle predation into this equation. Notwithstanding even the effects of heavy pig predation, is the finding by Fordham et al. (2006) that the natural survival of adult *M. rugosa* is greatly reduced in years when wetlands dry, although the reasons for this are unclear.

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.). The finding that no turtles remained to aestivate in either lagoon probably indicates that they are not obligate habitat for them and do not serve as (over) seasonal refugia, being opportunistically colonised after the wet season. Our intention to trap the lagoons in the post-wet season of 2009 should confirm this and our scute marking of all individuals in 2008 will assist in identifying re-colonisers.

Feral pigs actively hunt for freshwater turtles in floodplain wetlands, meaning that their foraging activities threaten the persistence of turtle populations both in outright numbers and through habitat disturbance (Fordham et al. 2008). 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 for example 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 turtles in these ephemeral lagoons, needs to be better understood before deciding which lagoons should be chosen for wetland protection.

5.0 REFERENCES

- APHA. (2005) Standard methods for the examination of water and wastewater, 20th ed. American Public Health Association, American Water Works Association, Water Environment Federation, Washington.
- Arrington, D.A., Toth, L.A. and Koebel, J.W. Jr. (1999) Effects of rooting by feral hogs *Sus scrofa* L. on the structure of a floodplain vegetation assemblage. *Wetlands* 19:535-544.
- Baber, D. and Coblenz, B. (1987) Diet, nutrition, and conception in feral pigs on Santa Catalina Island. *Journal of Wildlife Management* 51:306-317.
- Boarman, W., Goodlett, T., Goodlett, G. and Hamilton, P. (1998) Review of radio transmitter attachment techniques for turtle research and recommendations for improvement. *Herpetological Review* 29:26-32.
- Bodie, J.R. and Semlitsch, R.D. (2000) Spatial and temporal use of floodplain habitats by lentic and lotic species of aquatic turtles. *Oecologia* 122:138-146.
- Bowman, D. and Panton, W.J. (1991) Sign and habitat impact of banteng (*Bos javanicus*) and pig (*Sus scrofa*), Cobourg Peninsula, northern Australia. *Australian Journal of Ecology* 16:15-17.
- Browne, C.L. and Hecnar, S.J. (2007) Species loss and shifting population structure of freshwater turtles despite habitat protection. *Biological Conservation* 138:421-429.
- Butler, B. and Burrows, D.W. (2007) Dissolved oxygen guidelines for freshwater habitats of northern Australia. ACTFR Report No. 07/32. Australian Centre for Tropical Freshwater Research, Townsville.
- Cagle, F.R. (1939) A system for marking turtles for future identification. *Copeia* 1939:170-173.
- Covacevich, J., Couper, P., McDonald, K. and Trigger, D. (1990) Walnurra, Bungarra nali, and the Gangalidda at Old Doomadgee. *Memoirs of the Queensland Museum* 29:322.
- Cogger, H.G. (2000) Reptiles and amphibians of Australia, 6th edition. Reed New Holland, Sydney.
- Fordham, D., Georges, A., Corey, B. and Brook, B.W. (2006) Feral pig predation threatens the indigenous harvest and local persistence of snake-necked turtles in northern Australia. *Biological Conservation* 133:379-388.
- Fordham, D.A., Georges, A. and Brook, B.W. (2007) Demographic response of snake-necked turtles correlates with indigenous harvest and feral pig predation in tropical northern Australia. *Journal of Animal Ecology* 76:1231-1243.
- Fordham, D.A., Georges, A. and Brook, B.W. (2008) Indigenous harvest, exotic pig predation and local persistence of a long-lived vertebrate: managing a tropical freshwater turtle for sustainability and conservation. *Journal of Applied Ecology* 45:52-62.

- Giménez-Anaya, A., Herrero, J., Rosell, C., Couto, S. and García-Serrano, A. (2008) Food habits of wild boars (*Sus scrofa*) in a Mediterranean coastal wetland. *Wetlands* 28:197-203.
- Hart, B.T., Bailey, P., Edwards, R., Hortle, K., James, K., McMahon, A., Meredith, C. and Swadling, K. (1991) A review of the salt sensitivity of the Australian freshwater biota. *Hydrobiologia* 210:105-144.
- Heppell, S. (1998) Application of life-history theory and population model analysis to turtle conservation. *Copeia* 1998:367-375.
- Howe, T., Singer, F. and Ackerman, B. (1981) Forage relationships of European wild boar invading northern hardwood forest. *Journal of Wildlife Management* 45:748-754.
- Janzen, D.H. (1983) No park is an island: increase in interference from outside as park size decreases. *Oikos* 41:402-410.
- Kennett, R. and Christian, K. (1994) Metabolic depression in aestivating long-neck turtles (*Chelodina rugosa*). *Physiological Zoology* 67:1087-1102.
- Kirk, J.T.O. (1986) Optical limnology – a manifesto. In: P. De Deckker and W.D. Williams (eds) *Limnology in Australia*, pp33-62. CSIRO/Dr W. Junk, The Netherlands.
- Klemens, M.W. (2000) *Turtle conservation*. Smithsonian Institution Press, Washington.
- Mulrennan, M.E. and Woodroffe, C.D. (1998) Saltwater intrusion into the coastal plains of the lower Mary River, Northern Territory, Australia. *Journal of Environmental Management* 54:169-188.
- Primack, R.B. (1998) *Essentials of conservation biology*. Sinauer Associates, Massachusetts.
- Psenner, R. (1994) Environmental impacts on freshwaters – acidification as a global problem. *Science of the Total Environment* 143:53-61.
- Roe, J.H. and Georges, A. (2007) Heterogeneous wetland complexes, buffer zones, and travel corridors: landscape management for freshwater reptiles. *Biological Conservation* 135:67-76.
- Roe, J.H. and Georges, A. (2008) Maintenance of variable responses for coping with wetland drying in freshwater turtles. *Ecology* 89:485-494.
- Ryding, S-O. and Rast, W. (1989) *The control of eutrophication in lakes and reservoirs*. Parthenon Press, Man in the Biosphere Series Vol. 1. UNESCO, Paris.
- Semlitsch, R.D. and Bodie, J.R. (2003) Biological criteria for buffer zones around wetlands and riparian habitats for amphibians and reptiles. *Conservation Biology* 17:1219-1228.

Sprague, J.B. (1985) Factors that modify toxicity. In: G.M. Rand and S.R. Petrocelli (eds) *Fundamentals of aquatic toxicology*, pp 124-163. Hemisphere Publication Corporation, Washington.

Tierney, T.A. and Cushman, J.H. (2006) Temporal changes in native and exotic vegetation and soil characteristics following disturbances by feral pigs in a California grassland. *Biological Invasions* 8:1073-1089.