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THE EFFECTS OF DRYING AND RE-FLOODING ON NUTRIENT AVAILABILITY IN EPHEMERAL DEFLATION BASIN LAKES IN WESTERN NEW SOUTH WALES, AUSTRALIA

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ABSTRACT

We examined the response of nutrient concentrations to the drying and re-flooding of ephemeral deflation basin lakes (EDBL) in western New South Wales, Australia. As lakes dried total nitrogen (TN) and total phosphorus (TP) concentrations increased. TN concentrations increased more quickly and TP concentrations increased more slowly than could be attributed to evaporation alone. This suggested that additional nitrogen was being sequestered from the atmosphere or sediments and that some phosphorus loss to the sediments was occurring. Concentrations of nitrogen oxides (NOx) and filterable reactive phosphorus (FRP), however, declined as lakes dried, suggesting a tighter coupling of nutrient release and uptake mechanisms. Inorganic nutrient concentrations rose sharply in response to re-flooding in all lakes. Evidence is provided to suggest that post-flood nutrient pulses are the net result of both riverine inputs and sediment releases and that the relative significance of either may be influenced by regulation. Copyright © 2002 John Wiley & Sons, Ltd.

KEY WORDS: Menindee Lakes; ephemeral wetlands; drying; re-wetting; flood pulse; sediment nutrient release; nitrogen; phosphorus

INTRODUCTION

Ephemeral deflation basin lakes (EDBL) are widespread throughout the arid and semi-arid regions of the Murray–Darling Basin in Australia. EDBL are naturally dynamic lowland river floodplain environments fluctuating between terrestrial and aquatic states. These changes strongly influence biotic and abiotic processes. Our understanding of the mechanisms by which hydrologic regimes influence ecosystem form and function is fragmented and derived largely from non-arid zone wetlands and from laboratory or mesocosm studies. What has emerged, however, is consensus regarding the importance of both wet and dry periods in maintaining ecosystem integrity (Boulton and Lloyd, 1992; Bunn *et al*., 1997; Boulton and Jenkins, 1998).

Seddon and Briggs (1998) identified 567 EDBL larger than 100 ha within western New South Wales, half having some form of local control of their water regimes (Seddon *et al*., 1997). Management for storage and flood mitigation has increased the permanency of water in many lakes which would otherwise dry out (Walker, 1985; Seddon and Thornton, 1997). Such regulatory strategies risk a reduction in net system productivity (Wetzel, 1983; Briggs and Maher, 1985; Boulton and Lloyd, 1992) and the replacement or loss of species adapted to ephemeral habitats (Williams, 1985; Baird *et al*., 1987), and provide opportunities for invasion by exotic or nuisance species (Leach, 1995).

Reductions in the frequency of drying are considered pivotal in determining net wetland productivity because of the loss of nutrient pulses associated with re-flooding (Wetzel, 1983; Boulton and Lloyd, 1992). Two processes, namely the influx of nutrients with the floodwaters and the release of nutrients from previously dried lakebed sediments into the water column, are thought to increase productivity by initiating a ‘bottom-up’ cascade of energy transfer commencing with the autotrophic (bacterial and photosynthetic) utilization of freely available nutrients.

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Floods maintain the ecological integrity of river–floodplain systems by facilitating the lateral exchange of nutrients, organic matter and organisms (Junk *et al*., 1989; Ward, 1989; Heiler *et al*., 1995; Walker *et al*., 1995; Ward and Stanford, 1995; Puckridge *et al*., 1998). The ecological significance of exchanges between rivers and their floodplains is encapsulated by the flood pulse concept (Junk *et al*., 1989). Although developed for river systems in humid regions where flood pulses are regular, Puckridge *et al*. (1998) suggest that it may also apply to dryland rivers such as the Murray–Darling River system in Australia, where the pulse is more variable. For example, total nitrogen (TN) and total phosphorus (TP) concentrations in the Darling River above Lake Wetherell tend to be positively correlated with flow volume. Elevated TN and TP concentrations at times of higher flow are attributable to increased levels of particle-bound nitrogen and phosphorus entrained in the water column (Oliver *et al*., in press; Novic and Bowling, 2000). Lakes receiving inflows directly from such mainstream flood pulses are, therefore, likely to receive substantial nutrient inputs.

Ample evidence also exists to suggest that sediment drying promotes the release of potentially significant amounts of bio-available N and P on re-wetting; this is the so-called Birch effect (Birch, 1960; reviewed by McComb and Qiu, 1998; Baldwin and Mitchell, 2000). This occurs as a result of: (i) enhanced aerobic microbial mineralization of organic matter and the reduction of nitrate, leading to an accumulation of ammonium N in the sediment; (ii) a decreased capacity of the sediments to adsorb nutrients such as P (Baldwin, 1996); and (iii) the release of cell-bound nitrogen (ammonia) and filterable reactive phosphorus from sediment bacteria as they are killed during drying (Qiu and McComb, 1995). Although both N and P may be liberated by these processes, the reduced capacity of re-wetted sediments to release P under anoxic conditions suggests that more N than P is actually released into the water column on lake filling (Mitchell and Baldwin, 1998).

At present, evidence supporting either external flood pulse loading or sediment release mechanisms for EDBL within the Murray–Darling Basin remains scarce. Generalizations regarding the effect of wet/dry regime alone on nutrient availability are difficult to make because of uncontrolled-for differences between sites, such as (i) type of drawdown (gravity or evaporative), (ii) the severity of drying (proportion of lakebed dried, rate of drawdown), (iii) sediment characteristics and (iv) conditions of refilling (quality of inflowing water and extent of sediment disturbance) (McComb and Qiu, 1998). Evidence taken from mass balance models and laboratory-based studies indicates that sediments have the potential to modify water quality and system productivity substantially by acting as either a net nutrient sink or source (Wetzel, 1983; Baldwin, 1996; Mitchell and Baldwin, 1998; Boon and Bailey, 1998). Recognizing the circumstances under which either of these conditions occurs in the field is a necessary precursor to the effective management of EDBL.

If drying phases are indeed an integral component of deflation basin function because they stimulate system productivity, understanding the relative significance of nutrient releases from dried lakebed sediments and nutrient inflows with river flood pulses is an important first step towards the development of predictive management protocols. We examined responses of a series of lakes that had different flow regimes to a 1-in-70 year flood. We hypothesized that evaporative concentration during lake drying would lead to an increase in suspended nutrient concentrations. We also wished to verify the occurrence of post-flood nutrient increases in EDBL and to examine the contribution of sediment and river nutrient sources to EDBL of the Murray–Darling Basin during a flood event.

METHODS

For this investigation we selected six EDBL within the Menindee Lakes system, in western New South Wales (Figure 1). Lake attributes are summarized in Table I. Lakes Malta, Balaka, Bijiji, Tandure, Menindee and Cawndilla were sampled over a nine month period prior to and for six months after their re-flooding during August 1998. Depth-integrated samples were collected from three littoral sites per lake at water depths of 1–1.5 m (Figure 1). Similarly, floodwater samples were collected during August from Lake Wetherell adjacent to the inflows of lakes Malta and Balaka and near the Main Weir, close to the inflow into Lake Tandure.

Electrical conductivity, standardized to 25 °C, was measured using a U-10 multi-probe (HORIBA Ltd, Australia). A 200 ml sample of unfiltered water was stored frozen for total nitrogen (TN) and total phosphorus

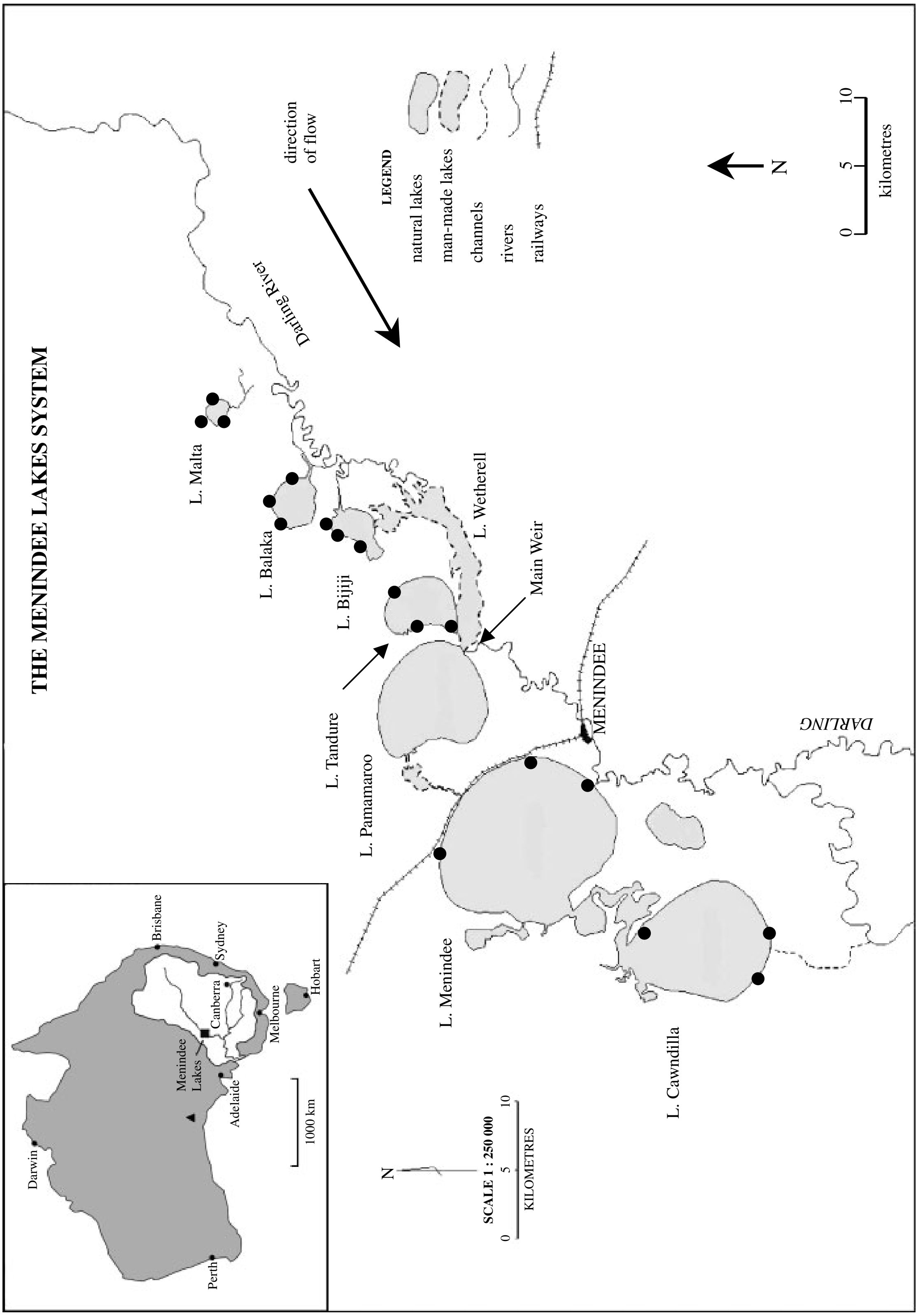

Figure 1. Menindee Lakes system showing lake sampling locations

Table I. Physical and hydrological characteristics of the Menindee Lakes. Maximum lake depths 1988 survey (1959 survey). Losses of submerged habitat (hectares) determined prior to lake re-flooding during August 1998. Drying frequencies determined over the past 30 years since the imposition of flow regulation

Lake	Maximum depth (m)[a]	Full capacity (ha)[b]	Submerged area lost (ha)[a]	Submerged area lost (%)	Water lost to evaporation (%)[a]	Time required to dry (months)[c]	Frequency of complete lake drying (years)[c]	% Organic content of soils (mean ± s.e., $n = 12$)[d]
Malta	1 (2.3)	314	314	100	100	10	3–4	3.4 ± 1.03
Balaka	nd (3.0)	1302	1302	100	100	14	3–4	5.3 ± 2.7
Bijiji	2.5 (3.7)	1018	700	70	>90	16	3–4	1.3 ± 0.32
Menindee	4.6	16 392	6630	40	43	24–36	10	1.1 ± 0.31
Cawndilla	6.8	9359	1083	12	43	>36	15	0.60 ± 0.11
Tandure	nd	2310	100	4	<43	—	Never	1.3 ± 0.36

Sources: [a]Unpublished Department of Land and Water Conservation NSW data; [b]Seddon *et al.* (1997); [c]Green (1997); [d]Scholz *et al.* (1999).
nd, Not determined.

(TP) determinations. A 10 ml sample of 0.45 μm filtered water was stored frozen for later determinations of oxides of nitrogen (NOx), ammonia (NH_3) and filterable reactive phosphorus (FRP). NOx was determined colorimetrically after its reduction to nitrite using a cadmium column (APHA, 1995). Total nitrogen and ammonia were determined as for NOx after pre-digestion in NaOH-$K_2S_2O_8$ and oxidation to nitrate. FRP was determined colorimetrically using ascorbic acid (APHA, 1995). TP samples were determined as for FRP after pre-digestion in NaOH-$K_2S_2O_8$ and oxidation to orthophosphate.

Differences in nutrient characteristics between sites were examined using fixed-factor one-way ANOVAs. Analyses were done on square-root-transformed data where variances were not homogeneous using SYSTAT®9 (SPSS Inc. Chicago, USA). Data are presented as means ± standard errors ($n = 3$) or as individual replicate values where ranges are quoted.

RESULTS

Drying

The severity of drying varied between lakes, ranging from 100% exposure of lakebed sediments in lakes Malta and Balaka to only 4% in Lake Tandure (Table I). Evaporation accounted for most of the water losses in the shallower lakes Malta, Balaka and Bijiji. In contrast, evaporation accounted for only 43% of total water losses from lakes Menindee and Cawndilla where regulated discharges had occurred. Lakebed exposure was lowest in Lake Tandure which has a steeper littoral and is permanently connected to Lake Wetherell. The extent of groundwater interactions on lake water budgets is currently poorly understood (DLWC, 1998a,b).

Electrical conductivity (EC) increased in all lakes as they dried (Figure 2). This was most marked in lakes Malta, Balaka and Bijiji where increases were primarily due to evaporative concentration. For example, by May in Lake Malta EC exceeded 9000 $\mu S\ cm^{-1}$ in the last of the remaining surface water, which covered an area of only *c*. 50 m^2. This represented a 45–50 fold increase above post-inundation EC values. Maximum EC values of 580 ± 2.9 and 628 ± 1.8 were also recorded immediately prior to re-flooding in lakes Menindee and Cawndilla, respectively. EC changed least in these relatively deeper lakes where percentage losses of water to evaporation were lower. Increases in EC noted in Lake Tandure prior to August 1998 were attributed primarily to sharp increases in EC to above 1000 $\mu S\ cm^{-1}$ after November 1997 in Lake Wetherell (Bowling, 1998). EC was used as a marker for evaporative concentration in lakes Malta, Balaka and Bijiji against which changes in suspended nutrient loads were compared.

Total nitrogen (TN) and total phosphorus (TP) concentrations increased as lakes Malta, Balaka and Bijiji dried (Figures 3a and 4a). Maximum TN and TP concentrations (12 $mgN\ l^{-1}$ and 2.0 $mgP\ l^{-1}$, respectively) were recorded in Lake Malta. From November 1997 to February 1998 suspended TN increased 2.3, 3.0 and 1.5 times more rapidly than did EC in lakes Malta, Balaka and Bijiji, respectively. Rates of increases in TN were, therefore, larger than could be attributable to evaporative concentration alone. In contrast, TP increases were only 0.67–0.83 times as fast as EC in these lakes suggesting a net loss from the water column. Less consistent trends were apparent for TN and TP concentrations in lakes Menindee and Cawndilla where evaporative concentration was less severe. TN and TP concentrations were generally lowest in Lake Tandure and did not exceed 0.9 $mgN\ l^{-1}$ and 0.40 $mgP\ l^{-1}$, respectively. This was presumably due to diluting inflows from Lake Wetherell (Bowling, 1998).

Dissolved inorganic nitrogen ($DIN = NOx + NH_3$) and phosphorus (FRP) concentrations generally decreased in all lakes as drying progressed. DIN concentrations remained mostly below 0.05 $mgN\ l^{-1}$ throughout this period and constituted less than 5% of the TN pool (Figure 3a,b). DIN concentration peaks recorded during November 1997 in lakes Tandure (0.12 ± 0.06 $mgN\ l^{-1}$), Menindee (0.32 ± 0.16 $mgN\ l^{-1}$) and Cawndilla (0.44 ± 0.09 $mgN\ l^{-1}$) were attributable to the breakdown of algal blooms reported by Bowling (1998). FRP concentrations showed greater variation between lakes than DIN, ranging from 0.01 to 0.64 $mgP\ l^{-1}$ (Figure 4a). FRP concentrations declined and constituted an increasingly small proportion of the TP pool in lakes Malta, Balaka, Bijiji and Tandure as drying progressed (Figure 4b). Even though FRP concentrations did not vary significantly in lakes Menindee or Cawndilla prior to their re-flooding (one-way ANOVA: $F = 0.237$, $p = 0.796$ and $F = 1.819$, $p = 0.255$, respectively), FRP : TP ratios also declined in these lakes.

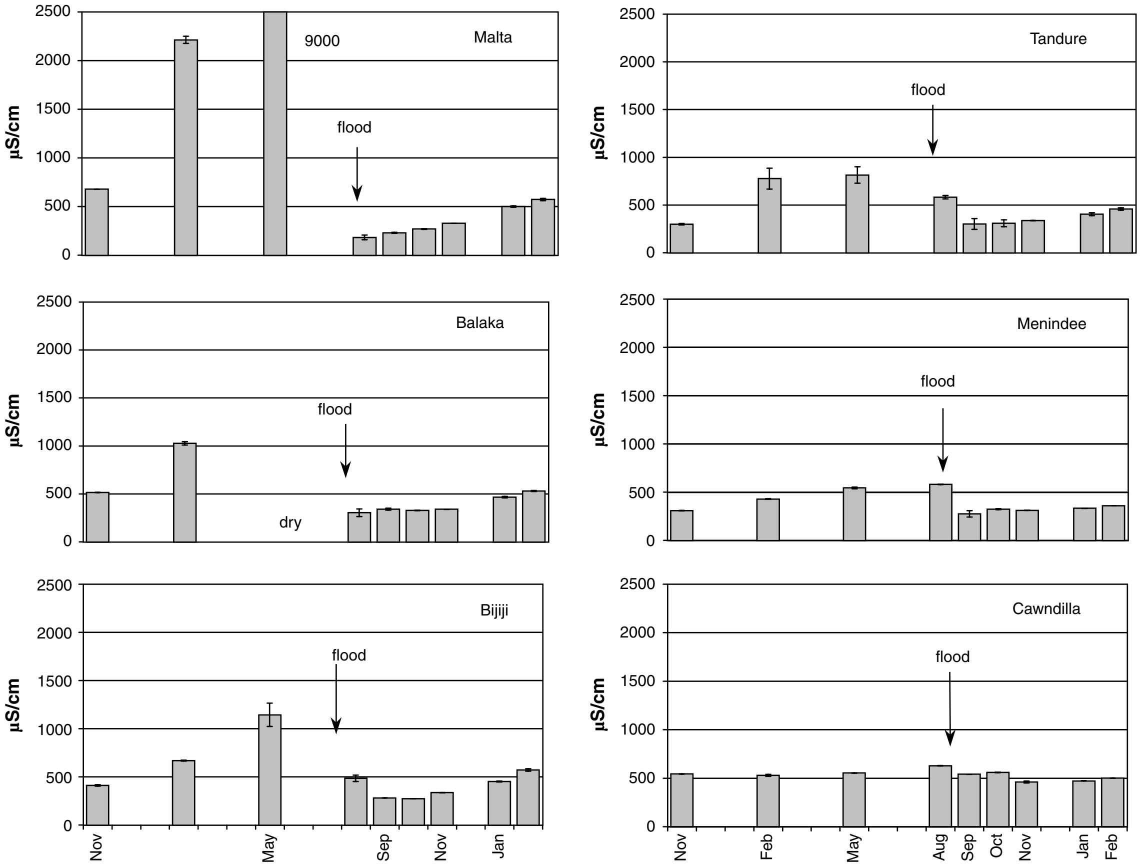

Figure 2. Electrical conductivity (mean ± s.e., $n = 3$) for each of the lakes from November 1997 to February 1999. The onset of flooding is indicated by an arrow

Flooding

Flooding inflows into lakes Malta, Balaka, Bijiji and Tandure from Lake Wetherell, upstream of the Main Weir, commenced within a week prior to sampling in August 1998. Inflows into lakes Malta, Balaka and Bijiji lasted approximately one month. Lake Tandure remained connected to Lake Wetherell throughout the period of investigation. Lake Menindee received two controlled releases from Lake Pamamaroo: the first lasted three weeks between August and September sampling events, and the second commenced two weeks prior to sampling in October and continued until early December 1998. Lake Cawndilla receives all of its inflows from Lake Menindee.

TN concentrations recorded in lakes Malta, Balaka and Bijiji initially after flooding ranged from 0.70 to 2.6 mgN l^{-1} (Figure 3a). TN concentrations did not differ significantly between these lakes or from those recorded over the same period in Lake Wetherell (0.78–2.8 mgN l^{-1}) (one-way ANOVA: $F = 0.530$, $p = 0.674$). TN concentrations in Lake Tandure also reflected those of the inflows near the Main Weir (1.65 ± 0.05 mgN l^{-1}), rising from 0.54 ± 0.02 mgN l^{-1} to 1.48 ± 0.25 mgN l^{-1}between August and September. Similarly, post-flooding TP concentrations in lakes Malta, Balaka and Bijiji, which ranged from 0.17 to 0.41 mgP l^{-1}, did not differ significantly from each other or from those recorded around the same time in Lake Wetherell (one-way ANOVA: $F = 1.003$, $p = 0.440$) (Figure 4a). As with TN, post-flood TP concentrations in Lake Tandure (0.39 ± 0.05 mgP l^{-1}) rose between August and September in response to the relatively richer inflows from the Main Weir (0.41 mgP l^{-1}).

In contrast, flows carrying TN concentrations of 1 mgN l^{-1} into Lake Menindee from Lake Pamamaroo stimulated an increase in TN concentrations from 1.13 ± 0.12 mgN l^{-1} to 1.76 ± 0.11 mgN l^{-1} within two

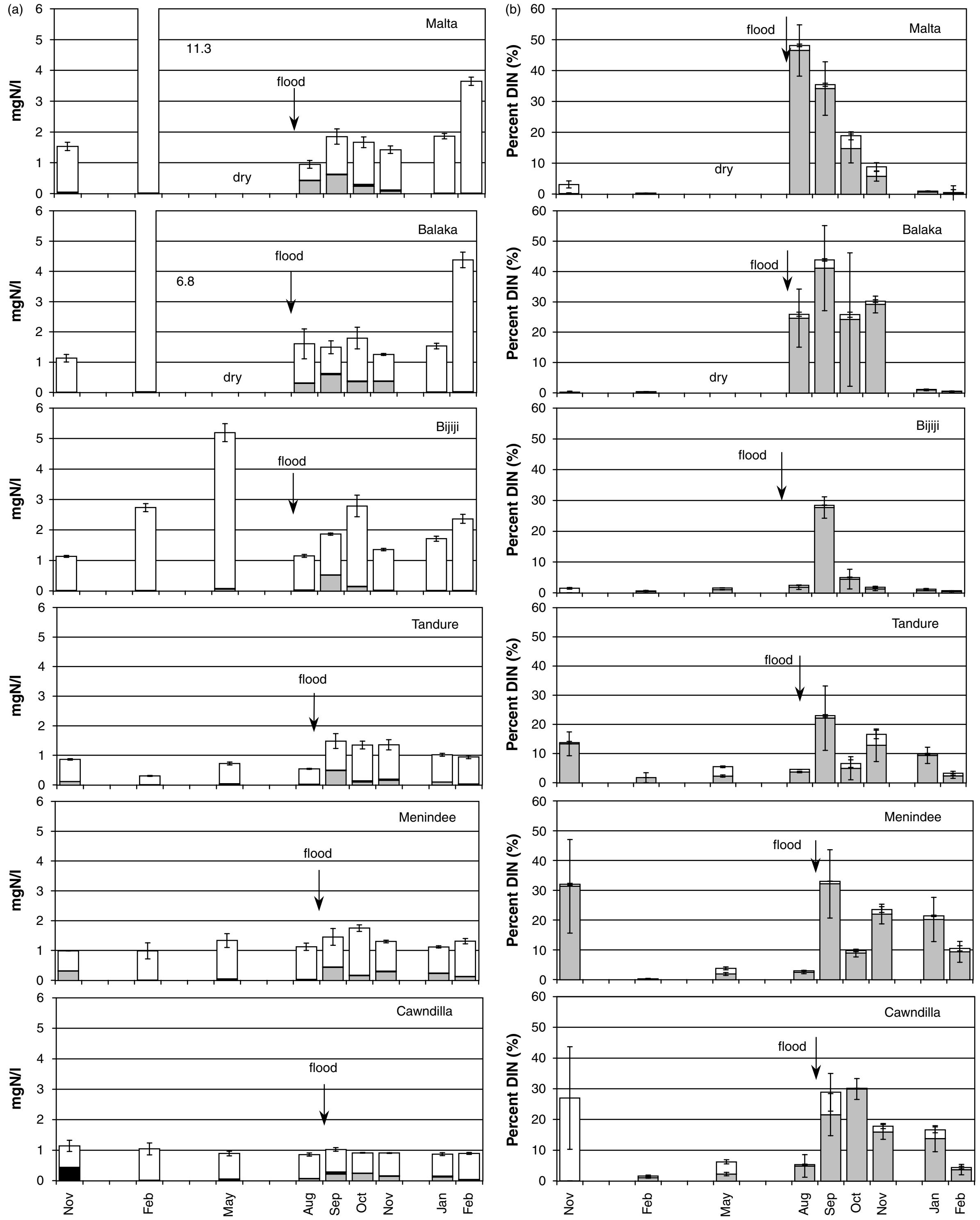

Figure 3. (a) Total suspended nitrogen concentrations for each lake showing contributions of the organic fraction (unshaded), NOx fraction (light shading) and NH_3 fraction (dark shading) from November 1997 to February 1999 (mean ± s.e., $n = 3$). (b) Percentage contributions of NOx (light shading) and NH_3 (unshaded) to total suspended nitrogen concentrations (mean ± s.e., $n = 3$) (dry = no surface water present). The onset of flooding is indicated by an arrow

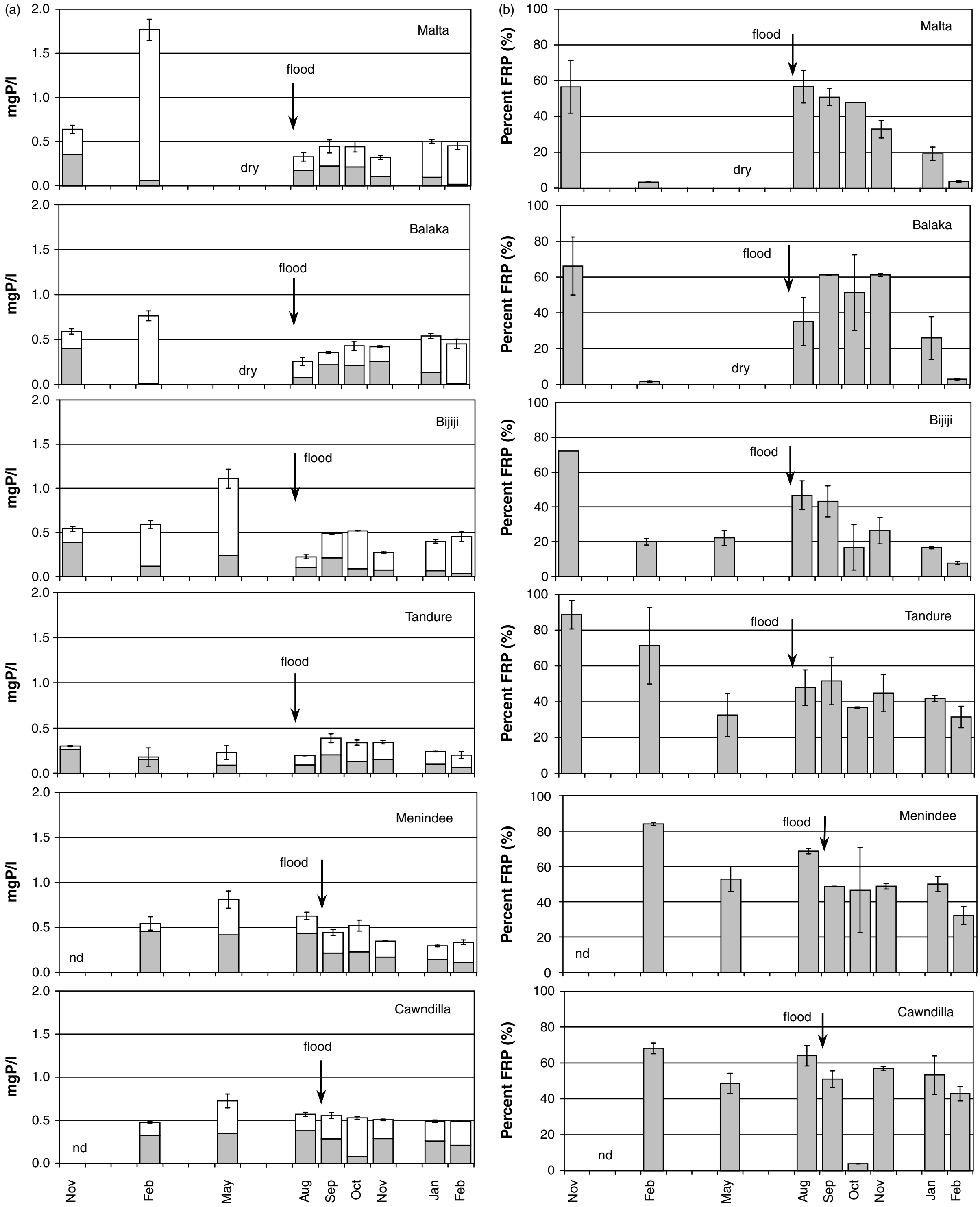

Figure 4. (a) Total suspended phosphorus concentrations for each lake showing contributions of the organic fraction (unshaded) and FRP fraction (light shading)) from November 1997 to February 1999 (mean ± s.e., $n = 3$). (b) Percentage contributions of FRP to total suspended nitrogen concentrations (mean ± s.e., $n = 3$) (dry = no surface water present; nd = not determined). The onset of flooding is indicated by an arrow

months. This nutrient pulse was short-lived, declining to 1.30 ± 0.05 mgN l^{-1} by November, and did not appear to flow through to Lake Cawndilla where TN concentrations remained below 1 mgN l^{-1}. Regulated flows carrying TP concentrations of 0.29 ± 0.05 mgP l^{-1} into Lake Menindee from Lake Pamamaroo diluted lake TP concentrations from 0.63 ± 0.04 mgP l^{-1} to 0.44 ± 0.03 mgP l^{-1} within the first month. No pulse of TP occurred initially on flooding as was noted for TN. Differences in TP concentrations between Lake Cawndilla and the inflows from Lake Menindee were small and did not impact upon lake TP concentrations.

Ammonia (NH_3) constituted only a small fraction of the post-flood N-pool, remaining mostly below 0.05 mgN l^{-1} in all lakes. NOx concentrations, in contrast, rose sharply following flooding and constituted a greater percentage of the N pool in all lakes (Figure 3b). NOx concentrations peaked within a month of the first flooding inflows in all lakes: Malta (0.61 ± 0.08 mgN l^{-1}), Balaka (0.58 ± 0.12 mgN l^{-1}), Bijiji (0.52 ± 0.06 mgN l^{-1}) and Tandure (0.49 ± 0.12 mgN l^{-1}). These NOx concentrations were within the range identified for Lake Wetherell floodwaters (0.42–0.95 mgN l^{-1}). NOx concentrations also peaked within a month of the first flooding inflows into Lake Menindee, increasing from 0.026 ± 0.003 mgN l^{-1} to 0.44 ± 0.08 mgN l^{-1}. NOx concentrations did not peak until October in Lake Cawndilla, rising from 0.067 ± 0.048 mgN l^{-1} prior to flooding to 0.24 ± 0.03 mgN l^{-1}. The post-flood NOx pulse was rapidly assimilated, declining to 0.16 ± 0.03 mgN l^{-1} in Lake Menindee by October and to 0.145 ± 0.024 mgN l^{-1} in Lake Cawndilla by November. NOx concentrations were not recorded for the inflowing waters of either of these lakes, preventing comment on the relative significance of allochthonous NOx inputs and releases from the sediments.

FRP concentrations also increased in response to flooding, peaking a month after the commencement of inflows in lakes Malta (0.22 ± 0.02 mgP l^{-1}), Balaka (0.22 ± 0.01 mgP l^{-1}), Bijiji (0.21 ± 0.04 mgP l^{-1}) and Tandure (0.20 ± 0.03 mgP l^{-1}) (Figure 4a). Differences between lakes at this point were not significant (one-way ANOVA: $F = 0.113$, $p = 0.949$) and concentrations were within the range measured over the same period in Lake Wetherell (0.12–0.32 mgP l^{-1}). FRP concentrations in Lake Menindee declined from 0.43 ± 0.03 mgP l^{-1} to 0.22 ± 0.02 mgP l^{-1} within a month of releases from Lake Pamamaroo commencing. FRP concentrations in Lake Cawndilla were also diluted from 0.38 ± 0.03 mgP l^{-1} to 0.075 ± 0.055 mgP l^{-1} during the two months following the initial releases from Lake Pamamaroo during August and September. FRP : TP ratios were highest in all lakes shortly after flooding, with FRP constituting 43–61% of the TP pool (Figure 4b).

DISCUSSION

Drying

Drying in lakes Malta, Balaka and Bijiji was driven primarily by evaporation once they became disconnected from the mainstream after a flood event. As drying progressed, TN concentrations increased at a faster rate and TP concentrations increased at a slower rate than did EC and, therefore, than could be attributed to evaporation alone. Changes in TN concentrations in these lakes may have been assisted by N_2 fixation from the atmosphere by the developing blue-green algal populations (e.g. Scholz *et al.* 1999) and the re-mobilization of nitrogen from the sediments through increasing turbulence as water levels dropped. The slower rates of change in TP concentrations are more difficult to explain, however, but indicate that a net loss of phosphorus is occurring, possibly through the precipitation of insoluble phosphorus–cation or phosphorus–iron complexes. These processes were less distinct in lakes Menindee and Cawndilla, where evaporative concentration factors were smaller, and Lake Tandure, where connection with Lake Wetherell was continuous.

As the lakes dried, DIN and FRP constituted a small and decreasing component of the TN and TP pools. This occurred irrespective of the severity of lake drying and is indicative of increasingly tight coupling of biotic and abiotic release and uptake mechanisms. During this period also, DIN:FRP ratios were at their lowest, establishing conditions favourable to cyanobacterial development (Smith, 1983; Horne and Commins, 1987; Sherman *et al.*, 1998; Bulgakov and Levich, 1999).

Flooding

The strong similarities in total and inorganic N and P concentrations identified within and between lakes directly connected to Lake Wetherell during a flood event (lakes Malta, Balaka, Bijiji and Tandure) and the inflowing flood waters are highly indicative of the significance of river flood pulses in establishing post-flood total suspended nutrient levels. That such uniformity was apparent despite between-lake differences in the frequency or severity of lake drying and lakebed organic content (refer to Scholz *et al.*, 1999) adds further weight to the importance of flood pulses in providing nutrients for these lakes.

In contrast to the lakes above the Main Weir, nutrient concentrations of inflows into Lake Menindee tended to be lower than that of the main flood pulse due to the sedimentation of entrained particles and biotic assimilation during its passage via Lake Wetherell and Lake Pamamaroo. Inflows of water with lower nutrient concentrations than those already present in Lake Menindee resulted, as might be expected, in the net dilution of TP concentrations within the lake. They did, however, stimulate a 75% rise in TN concentration above pre-flood levels. Maximum TN concentrations recorded during October were preceded by a NOx peak during September. The development of a post-inundation N pulse greater than that which could be attributed to external inputs is highly suggestive of significant releases from the sediments. Although water flowed from Lake Menindee into Lake Cawndilla throughout this period, no similar NOx or TN pulse was recorded in Lake Cawndilla. Firstly, it is possible that much of the post-flood N flowing from Lake Menindee was assimilated by the connecting wetlands. Secondly, the absence of a discernible sediment-derived nutrient pulse may have been attributable to less of Lake Cawndilla's sediment having been exposed during drying and to its lower organic matter content than that in Lake Menindee (Table I).

Wet/dry nutrient model

EDBL are naturally subject to periods of drying and re-flooding. Despite their geomorphic similarities, the hydrologic regimes experienced by individual EDBL may vary greatly depending upon factors such as sill heights, lake morphometry and regulation. The regulation of water regimes within the Menindee Lakes system has effectively decreased the frequency and duration of drying events in each of the lakes. A reduction or even complete loss of a dry phase as a consequence of regulation is considered to impact adversely upon wetland productivity through a reduction in nutrient bio-availability (e.g. Boulton and Lloyd, 1992). Both the flood-pulse and sediment-release mechanisms outlined earlier adequately account for such declines. Firstly, regulation of inflows may reduce the net influx of nutrients by limiting the volume of flows or by limiting inflows to non-flood periods, when mainstream nutrient concentrations are likely to be lowest. Secondly, any reduction in the frequency or severity of lake drying will reduce lakebed exposure and thus inhibit the potential for nutrient releases from the sediments on flooding. Similarly, both models satisfactorily account for observed increases in post-flood aquatic productivity by increasing the bio-availability of N and P.

Data presented here indicate the operation of both the flood-pulse and sediment-release mechanisms. For lakes Malta, Balaka, Bijiji and Tandure, which receive flooding flow pulses directly from the mainstream, riverine nutrient inputs masked any sediment releases. The reverse was true for Lake Menindee, whose inflows carry less nutrients than the mainstream flood pulse.

Irrespective of source, flooding in all lakes examined resulted in increases in the bio-availability of nitrogen, and to a lesser extent of phosphorus, which is in agreement with the observations of Mitchell and Baldwin (1998). Earlier studies have indicated post-flood NOx releases from the sediments to be rapid, peaking within a few days (Briggs *et al.*, 1985; Qiu and McComb, 1996), whereas FRP releases tend to be slower (Qiu and McComb, 1994). It is possible that our monthly observations may have missed much of the initial NOx pulse and that sediment releases were more important in lakes Malta, Balaka and Bijiji than was indicated. Indeed, small-scale inundations of dried lakebed sediments collected from lakes Menindee and Balaka confirmed that both NOx and FRP were being released from the sediments and that the release of NOx was more rapid, peaking after three to five days, than was FRP, which peaked after one to two weeks (Gawne and Scholz, unpublished data).

Nutrient releases from newly inundated sediments are, however, by no means universal (e.g. Jacoby *et al.*, 1982; Baldwin, 1996; Mitchell and Baldwin, 1999). Nutrient transformations within the sediments are the net result of numerous interdependent interactions between physical, chemical and biological processes causing the sediment to act as nutrient sinks and/or sources. Identifying the links between wetting/drying and nutrient cycles in EDBL is an important first step towards developing management protocols aimed at preserving ecosystem integrity. Increases in the frequency and duration of river flood pulses increase the potential for allochthonous inputs to floodplain wetlands. It also reduces the severity of drying events and thus also the potential for sediment nutrient transformations. Under these circumstances, organic matter may be expected to accumulate in EDBL causing them to function as net nutrient sinks. Indeed, this appears to be the case in lakes Malta, Balaka and Bijiji where significant deposition has been noted since the imposition of altered hydrological regimes in the late 1960s (Table I). Management actions, therefore, need be aimed at reducing nutrient loading of the sediments in these lakes. Conversely, the inappropriate timing of releases from Lake Menindee, for example shortly after a major flood event, may inadvertently result in the export of significant quantities of sediment-derived nutrients. This may lead to net nutrient depletion and a concomitant reduction in productive potential of the lake.

Although direct evidence is still limited, the re-imposition of drying phases has been recommended for a number of regulated wetlands within the Murray–Darling Basin in an attempt to promote wetland values (e.g. Briggs, 1998; Hydrotechnology, 1995). Other options include manipulating biotic processes, such as avian fish predation and/or grazing of exposed lake beds. However, the efficacy of such tools cannot be established until appropriate numerical models that encapsulate the interrelations among the various pools and processes in EDBL have been developed.

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