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Are Australian wetlands less productive than Northern Hemisphere wetlands under the same nutrient concentrations?

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Introduction

Wetland management in Western Australia (WA) has been hampered by limited monitoring programs and a largely reactive approach to problems. Little use has been made of the range of predictive models now available (e.g. VOLLENWEIDER 1968, OECD 1982) with a few exceptions such as CONGDON (1986) and BAYLEY et al. (1989). This is despite the successful use of these models for the restoration of North Lake (WA) by BAYLEY et al. (1989).

WILLIAMS & WAN (1972) outlined a range of variables that were different for Australian wetlands, including the importance of saline wetlands and often high phosphate levels (mean or peak). The determination of trophic status based on OECD (1982) probabilities in WA frequently assigned a higher trophic status (based on phosphorus levels) than was warranted, based on their own qualitative criteria. This has led to a perception that Australian wetlands in general were less productive than their Northern Hemisphere counterparts at the same nutrient concentrations. FERRIS & TYLER (1985) in a detailed study compared the chlorophyll *a*–total phosphorus (TP) relationships observed in Lake Burragorang, with published data from both hemispheres. They concluded that Northern Hemisphere-derived models were suitable for use in Australia, if non-algal turbidity was taken into account. Lake Burragorang, as it is a large impoundment, cannot be considered typical of most Australian natural wetlands. Their study was based on an annual algal-growing season and not just the summer or spring, as is typically used in most Northern Hemisphere studies. The annual growing season is the result of high minimum water temperatures. This has led DAVIS et al. (1993) to suggest that the warm-water trophic state model of SALAS & MARTINO (1991) maybe a more appropriate tool for the determination of trophic status of WA wetlands than systems derived for temperate wetlands.

This study aims to determine whether Australian wetland managers should adopt the models for trophic status and chlorophyll *a*–TP relationships from Northern Hemisphere studies and specifically:

1. Re-evaluate the findings of FERRIS & TYLER (1985) using data from natural wetlands,
2. Evaluate the use of the SALAS & MARTINO (1991) classification scheme, and
3. Comment on the applicability of Northern Hemisphere models for use in Australian wetlands.

Methods

The Swan Coastal Plain (SCP), located on the south-west coast of Australia, covers <5% of the WA landmass yet houses over 50% of the population. The SCP contains numerous wetlands that are typically fresh, often dystrophic and groundwater dominated (with minimal surface water inputs). Urbanisation and agriculture has resulted in eutrophication of many of these wetlands. Many wetlands are seasonally dry (from late October to April) due to their shallow depths and the Mediterranean climate. Only wetlands classified as lakes (permanently inundated), sumplands (seasonally inundated), or artificial wetlands have been included in this study (as per SEMENIUK, 1987).

The importance of retention times and areal P loadings cannot be assessed from the data currently available in the State, but the data outlined below do permit an analysis of chlorophyll *a*–TP relationships. The data were transformed into natural logarithms and simple linear regressions calculated using maxima, individual results or annual means (as in FERRIS & TYLER 1985). Conductivity (µS cm^{-1}) was converted to salinity (g L^{-1}), using a conversion coefficient of 1,600, and Hazen and True Colour units to gilvin, using conversion coefficients of 0.1733 (DAVIS et al 1993) and 0.22 (based on unpublished data from the Water and Rivers Commission, Perth), respectively, to improve comparability between data sets. Three data sets were analysed:

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1. A water sample (0.2 m deep) taken in spring 1996 from 123 wetlands within the Perth metropolitan area. An aliquot was frozen for later determination of Total P and another was filtered through Whatman® GF/C filter paper. The paper and filtrate were frozen prior to analysis for chlorophyll *a*, and soluble reactive phosphorus, nitrate/nitrite and ammonia respectively (as per APHA 1997). Chlorophyll *a* determinations used dimethylformamide instead of acetone as the solvent. Gilvin (g440) was determined from the filtrate as outlined in KIRK (1986).
2. Monitoring data for Lake Monger were compiled for 1975–1993 (see LUND 1992). These data were used individually and as annual means/maxima. The latter data were supplemented by data from Hyde Park (1993/94) (LUND unpublished data) and Jackadder Lake (1989) (LUND & CHESTER 1991).
3. STOREY et al. (1993) provides data from 135 wetlands distributed across the SCP. Only Total soluble N (TsN) and P (TsP) were determined which will underestimate the total values and possibly change N:P ratios.

Results and discussion

Seasonal drying has a limiting effect on algal growing seasons, as these wetlands are dry during the period of maximal growth. The drying process results in large changes in salinity due to evapo-concentration of salts, which may limit algal growth in late spring. Wetlands on the SCP show the relative dominance of cations noted by WILLIAMS & WAN (1972), with 33 out of 40 with the order Na>Ca>Mg>K or with Ca and Mg reversed (DAVIS et al. 1993). Eighty-eight percent of Perth wetlands were not saline (<3 g L^{-1}) and are not representative of many inland waters (Table 1).

The majority of wetlands (87%) had turbidity <10 NTU, below which threshold primary production is not impacted by light limitation (see FERRIS & TYLER 1985). Turbidity was poorly correlated ($r = 0.237$, $P < 0.05$) to chlorophyll *a*, a result also found by DAVIS et al (1993) ($r = 0.35$) indicating that turbidity was not due to algal cells. Only 8% of Perth and 31% of SCP wetlands are dystrophic having gilvin levels >52 (DAVIS et al, 1993). A wide range in pH was recorded (Table 1), with low pH typical of highly coloured wetlands and high pH found in wetlands with high primary productivity and calcium carbonate concentrations (LUND & RYDER 1998).

Table 1. Selected mean (± S.E.) and range data for wetlands on the SCP

Parameter	Mean ± S.E. (n)	Range
Depth (m)	1.03 ± 0.11 (135)	0.1–12.15[b]
Salinity (g L^{-1})	1.9 ± 0.3 (123)	0.006–23.76[a]
	1.8 ± 0.3 (135)	0.05–32.14[b]
Turbidity (NTU)	4.3 ± 0.5 (135)	0–40[b]
pH	7.4 ± 0.1 (123)	2.7–9.7[a]
	7.6 ± 0.1 (135)	3.6–9.4[b]
Gilvin (g440)	23 ± 5 (105)	1.61–355.58[a]
	90 ± 31 (134)	1.65–4026[b]
Total P (µg L^{-1})[c]	256 ± 79 (108)	10–7762[a]
	668 ± 204 (135)	3–21233[b]
Soluble reactive P (µg L^{-1})	140 ± 72 (99)	0–6871[a]
Total N (µg L^{-1})[c]	2892 ± 206 (135)	330–15133[b]
Nitrate/nitrite (µg L^{-1})	223 ± 130 (101)	1–13077[a]
Ammonia (µg L^{-1})	171 ± 44 (99)	8–2762[a]
Chlorophyll *a* (µg L^{-1})	5.9 ± 1.1 (109)	0–81[a]
	38.3 ± 6.8 (135)	0–666[b]

[a]Data collected this study.
[b]Data from STOREY et al (1993).
[c]Data from STOREY et al (1993), this represents total soluble N or P.

Comparability was maintained with FERRIS & TYLER (1985) by excluding wetlands with salinity >3g L^{-1}, turbidity >10 NTU, gilvin >52 and TsN:TsP or TN:TP ratios <17. The latter was used to remove N-limited wetlands (DAVIS et al. 1993). The equations for the regressions are shown in Table 2. The slopes of the regressions ranged from 0.505 to 1.537, well within the range reported in FERRIS & TYLER (1985). Total P only explains 23% (r^2) of the variance in chlorophyll *a* using the individual wetlands sampled once in spring, even after removing outliers. Data from Lake Monger (1975–95) when used individually (excluding only times when N was limiting) produced an r^2 of 0.49. The annual mean data of STOREY et al. (1993) which was based only on seasonal sampling accounted for 50% of the variance. Over 80% of the variance was explained when the Lake Monger data set (combined with Hyde Park and Jackadder) was

Table 2. Equations for linear regressions determined from a variety of different WA data sets

Data Source	Equation	n	r^2	Exclusions
This study	$\mathrm{LnChla}_{Spl} = -1.043 + 0.505\mathrm{LnTP}_{Spl}$	81	0.230	Gilvin<52, Salinity<3 g L^{-1}
STOREY et al (1993)	$\mathrm{LnChla}_{M} = -0.078 + 0.830\mathrm{LnTsP}_{M}$	45	0.497	Gilvin<52, Salinity<3 g L^{-1}, Turbidity<10 TsN:TsP>17
Lake Monger 1975–93 LUND (1992) and unpublished data	$\mathrm{LnChla}_{I} = -3.221 + 1.398\mathrm{LnTP}_{I}$	51	0.490	TKN:TP>17
LUND (1992), LUND & CHESTER (1991) and unpublished data	$\mathrm{LnChla}_{A} = -3.843 + 1.530\mathrm{LnTP}_{A}$	12	0.804	
	$\mathrm{LnChla}_{M} = -2.791 + 1.537\mathrm{LnTP}_{A}$	12	0.875	

[I]Individual values for different lakes or temporally for the same lake.
[A]Annual arithmetic mean.
[M]Maximum value recorded in the year (only years where a good coverage of data were included).
[Spl]Spring samples.

reduced to annual means and maxima. These wetlands are permanently inundated, eutrophic, and not saline, with low gilvin and turbidity levels. This indicated that water permanency might be an important determinant in the relationship. Perth wetland data were reanalysed, dividing the wetlands into lakes (including artificial wetlands) and sumplands, this did not improve r^2 values or substantially alter the slopes or intercepts. Repeating this analysis on the data of STOREY et al. (1993) produced similar results for lakes but increased r^2 to 0.648 (n = 17) for sumplands. This did not indicate that seasonal drying was an important factor.

The majority of regressions produced lower r^2 values than FERRIS & TYLER (1985). This is probably the result of the high temporal and spatial variability in the first data set (Fig. 1). The temporal variability is reduced in STOREY et al. (1993) which improves the r^2. The long-term data set for Lake Monger produced a very similar r^2 value through reductions in spatial variability. Only when annual means or maxima were used, as for the Lake Monger (Jackadder and Hyde Park) was a high r^2 value produced. In this case both spatial and temporal variability had been substantially reduced. The use of maximum chlorophyll *a* values explained over 85% of the variance compared to 80% when annual mean values were used. This could be accounted for by the presence of large bodied cladocerans in the Lakes in winter/spring suppressing algal biomass. The maximum chlorophyll *a* values recorded for these lakes are mainly the result of cyanobacterial blooms, which are not readily controlled by zooplankton. The possible reasons that spatial and temporal variability may significantly reduce the strengths of the regressions includes growth of submerged macrophytes, zooplankton grazing, time lags, sampling methodologies and differences in analytical procedures.

Annual means of TP appear necessary to obtain reasonable predictive power for chlorophyll *a*, which is not ideal for pre-emptive wetland management. They are useful for long term remediation programs, but require comprehensive data collection. Pre-emptive management requires an assessment of the risk prior to the event, and one possibility is to base the predictions on winter means which would allow sufficient time for management actions to occur. Regressions of TP winter means versus annual mean and maximum chlorophyll *a* produced r^2 values that were both close to 0.6, but the sample sizes were small (n = 6). This suggests that TP winter means maybe a useful indicator of maximum chlorophyll *a*.

The exclusion of saline wetlands from these analyses limited the broad applicability of these results to wetlands across Australia. Analysis of chlorophyll *a*–TP relationships in saline, dystrophic, turbid and N-limited wetlands was

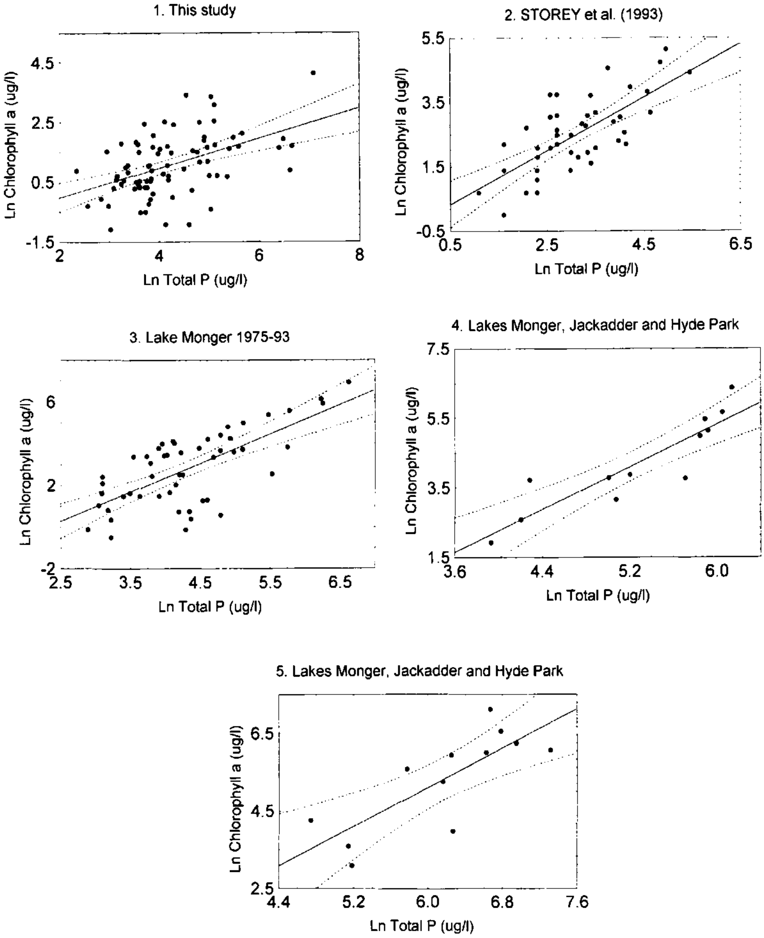

Fig. 1. Simple linear regressions (solid line) with 95% confidence intervals (dashed lines) for natural logarithms of chlorophyll *a* and total P (Title numbers correspond to equations in Table 2).

limited by low sample size, but all the significant ($P < 0.05$) r^2 values were <0.25. Further work is required to evaluate algal productivity in saline wetlands.

The trophic level of wetlands was investigated using the criteria of OECD (1982) and either the TP ranges of Salas & Martino (1991) or OECD (1982). Application of the scheme of Salas & Martino (1991) to the data of Storey et al. (1993), which used arithmetic rather than geometric means of TsP, found 45% oligotrophic, 37% mesotrophic, 16% eutrophic and 2% hypereutrophic, using the same set of wetlands used in the regressions. There was the general shift upwards in trophic status seen in Davis et al. (1993) using OECD (1982). The high proportion of oligo/mesotrophic wetlands on the SCP is in stark contrast to the high proportions of eut/hypereutrophic found in Davis et al. (1993) for the Perth urban area, indicating the negative effects of urbanisation.

Conclusions

The wetlands of the SCP are not less productive than

Northern Hemisphere wetlands at the same nutrient concentration based on TP-chlorophyll *a* regressions, although there is an annual algal growing season. As water temperatures rarely drop below 10 °C, they are warm-water rather than temperate wetlands and the trophic classification scheme of SALAS & MARTINO (1991) appears more appropriate than temperate schemes. More research is required to evaluate the applicability of the scheme across Australia, given its climatic range (temperate to tropical). Wetlands in Australia that are turbid, dystrophic, N-limited or saline do not appear to conform to the typical chlorophyll *a*–TP relationship. As a considerable number of wetlands have one or more of these characters, the impact of nutrient enrichment on these systems needs investigation to enable effective management.

Collection of the appropriate monitoring data would allow the models of VOLLENWEIDER (1968) to be thoroughly tested. The results from this study show that r^2 values for chlorophyll *a*-TP regressions were generally lower than those recorded in the Northern Hemisphere, unless annual mean or maximum values were used. This illustrates the high variability in SCP wetlands and the need for a better understanding of processes to enable managers to use or modify Northern Hemisphere-derived predictive tools and move from being reactive to pro-active.

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