Diatoms as ecological indicators in lakes and streams of varying salinity from the wheatbelt region of Western Australia

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Abstract

Secondary salinisation has adversely affected the water quality of lakes and streams in the wheatbelt region of Western Australia. This study involved sampling 51 waterbodies in 1999, with the aim of determining the distribution pattern of diatoms in relation to salinity. In total 72 taxa were recorded, with an inverse trend observed between species richness and salt loading. Multivariate analysis (semi-strong-hybrid multidimensional scaling) revealed that salinity was a key factor (PCC r=0.62) influencing species distribution. Diatom assemblages characteristic of different salinity regimes have been identified. For example, *Amphora coffeaeformis*, *Hantzschia baltica* and *Navicula salinicola* were commonly associated with hypersaline conditions. Diatoms proved to be useful biomonitors of salinisation, with the research presented currently being expanded to develop a predictive model for salt-affected wetlands in WA.

Keywords: diatoms, wheatbelt area, secondary salinisation, wetlands, indicators

Introduction

Secondary salinity can be attributed to land clearing followed by dryland agriculture and is considered to be a significant form of wetland degradation in the wheatbelt region of Western Australia. The fundamental cause of salinisation in WA is the replacement of perennial, native vegetation with annual crops and pastures used in agriculture (Smith & Finlayson 1988). This has allowed rainwater that was previously being used by deep-rooted plants to enter groundwater, mobilising salts stored in subsoils. As a result, water tables have risen, bringing dissolved salts to the surface producing saline seepage (Stoneman 1976; Hartley & de Vries 1983; Frost *et al.* 2001). Subsequent overland and subsurface flow of this saline water into wetlands and river systems has led to increased salinity concentrations (Schofield *et al.* 1988; Davis *et al.* 2003).

The impact of salinisation in waterbodies throughout the wheatbelt region is considered to be particularly severe, accounting for more than 70 % of Australia's salinity problem (National Land & Water Resources Audit 2001). Major catchments subjected to agricultural clearing continue to show increasing salinity trends, the rate of which is higher in low rainfall areas (Kay *et al.* 2001). In terms of salinity regimes, wetlands can be classified as freshwaters, with salinity less than 3 ppt, brackish, 3–10 ppt, saline, 10–50 ppt and hypersaline systems, with salinity greater than 50 ppt (Halse *et al.* 1993). Changes to the hydrological equilibrium as a result of salt loading adversely affect the biota of aquatic ecosystems (Stoneman 1976; Schofield *et al.* 1988). For example, Pinder *et al.* (2005) showed a negative relationship between invertebrate species richness and salinity, and Blinn *et al.* (2004) found a similar inverse trend for diatoms from wheatbelt wetlands.

Diatoms are one of the most effective groups of organisms successfully used for biological monitoring of wetlands and rivers. They display a wide range of morphological types represented by over 900 genera (Fourtanier & Kociolek 1999), occurring in both fresh and saline environments. They are also one of the most species rich components of aquatic communities, playing a fundamental role in many food webs (Bold & Wynne 1978; Stevenson & Pan 1999).

Diatoms have a restricted distribution in relation to salinity of water, the limits of which have been extensively documented throughout the world (Compere 1994; Snoeijs 1999; Blinn & Bailey 2001). However, there has been little research on establishing the tolerance of different taxa to varying salt levels in Western Australia. Therefore the objective of this study was to gather data on the response of diatom species to salinity through sampling representative waterbodies in the wheatbelt region. A number of species indicative of varying salinity regimes were also identified, with potential applications for future biomonitoring protocols. The baseline data obtained from this research may be incorporated into a predictive model that can be used in future management strategies for lakes and streams impacted by secondary salinisation.

Methods

Sampling of 51 sites from lakes and streams in the wheatbelt region of Western Australia was carried out between January and September 1999. The GPS coordinates of the study sites (and allocated codes) are shown in Table 1, with the locations indicated on Fig. 1.

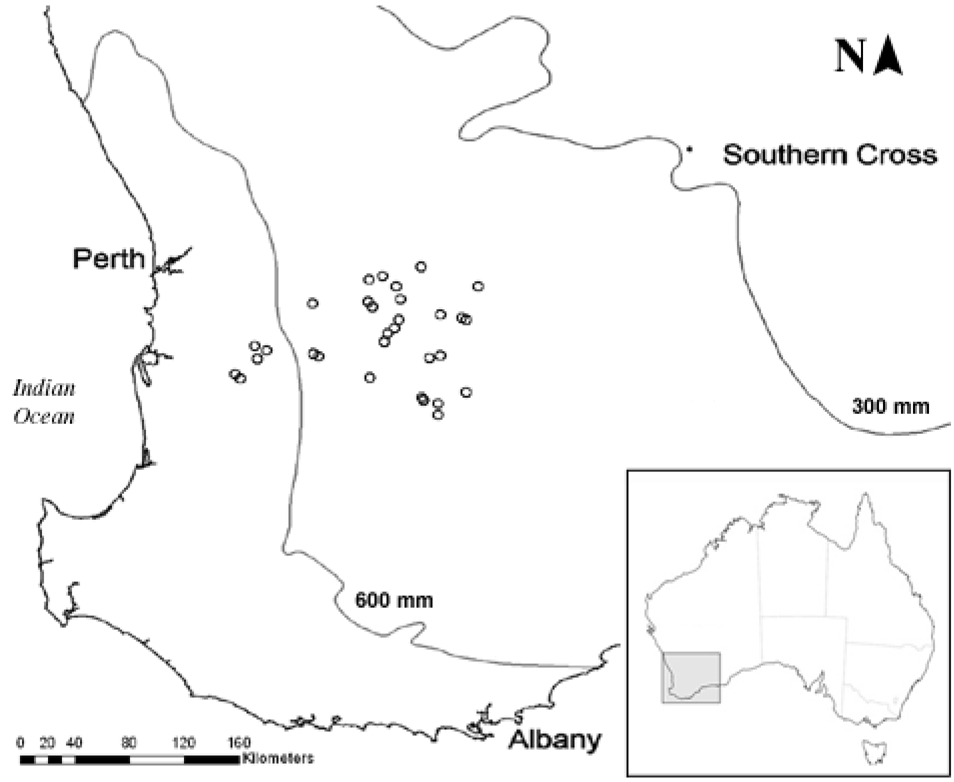

Figure 1. Location of study sites in the wheatbelt region of the south-west of Western Australia, approximately defined by the 600 mm and 300 mm annual isohyets. Sites were situated within a 250 km radius from the Perth metropolitan region.

Table 1

List of study sites and codes, where W designates wheatbelt, and number indicates order of sampling. GPS coordinates are shown for each site.

Code	Site Name	Coordinates	Code	Site Name	Coordinates
W01	Avon River: Gwambygine Pool A	32° 16.51' S – 117° 10.54' E	W27	Yenyening Lakes	32° 14.51' S – 117° 09.06' E
W02	Avon River: Gwambygine Pool B	31° 58.40' S – 116° 47.87' E	W28	Lake Mears	32° 13.61' S – 117° 21.59' E
W03	Avon River: Gwambygine Pool C	31° 59.13' S – 116° 48.26' E	W29	Yornaning Dam	32° 44.44' S – 117° 09.51' E
W04	Avon River: Gwambygine Pool D	31° 59.40' S – 116° 48.33' E	W30	Toolibin Lake Inflow	32° 54.58' S – 117° 36.57' E
W05	Avon River: Gwambygine Pool E	31° 59.51' S – 116° 48.41' E	W31	Ibis Lake	32° 59.05' S – 117° 36.57' E
W06	Avon River: Boyagarra Pool A	32° 14.51' S – 117° 09.06' E	W32	Nomans Lake	33° 00.16' S – 117° 30.30' E
W07	Avon River: Boyagarra Pool B	32° 16.51' S – 117° 10.52' E	W33	Lake Dumbleyung	33° 19.21' S – 117° 37.49' E
W08	Avon River: Mears Five Mile Pool	31° 50.11' S – 116° 48.15' E	W34	Lake Coomelberrup	33° 21.51' S – 117° 47.80' E
W09	Avon River: Suspension Bridge	31° 38.56' S – 116° 40.19' E	W35	Parkeyerring Lake	33° 21.56' S – 117° 21.17' E
W10	Avon River: Peel St Bridge	31° 38.50' S – 116° 40.19' E	W36	Lime Lake Rd West Lake	33° 24.83' S – 117° 19.38' E
W11	Avon River: Katrine Bridge	31° 36.59' S – 116° 33.11' E	W37	Norring Lake	33° 26.83' S – 117° 17.16' E
W12	Avon River: Glen Avon Pool	31° 36.52' S – 116° 32.59' E	W38	Flagstaff Lake	33° 30.22' S – 117° 15.56' E
W13	Mortlock River: Wongan Hills	31° 02.14' S – 116° 44.26' E	W39	Collie Changerup Rd Lake	33° 36.09' S – 116° 49.25' E
W14	Mortlock River: Goomalling	31° 21.02' S – 116° 45.89' E	W40	Towerrining Lake	33° 35.05' S – 116° 47.52' E
W15	Walymouring Lake Inlet	31° 08.25' S – 116° 52.56' E	W41	Williams Darkan Rd Lake	33° 14.85' S – 116° 46.93' E
W16	Lake Campion	31° 08.31' S – 118° 20.01' E	W42	Morangup Rd Dam A	31° 41.11' S – 116° 18.24' E
W17	Lake Brown	31° 04.30' S – 118° 14.51' E	W43	Morangup Rd Dam B	31° 41.12' S – 116° 18.15' E
W18	Lake Yealering	32° 35.67' S – 117° 37.61' E	W44	Morangup Rd Dam C	31° 41.18' S – 116° 18.06' E
W19	Ardath Lake	32° 05.75' S – 118° 09.37' E	W45	Toodyay Bailup Rd Lake	31° 43.58' S – 116° 16.60' E
W20	Kevills Lake A	31° 52.56' S – 117° 30.43' E	W46	Utah Rd Lake	31° 43.20' S – 116° 16.32' E
W21	Kevills Lake B	31° 53.26' S – 117° 30.77' E	W47	Toodyay Soak Well	31° 32.15' S – 116° 24.01' E
W22	Goomalling Lake A	31° 18.45' S – 116° 55.19' E	W48	Mistake Creek	31° 32.09' S – 116° 23.93' E
W23	Goomalling Lake B	31° 18.46' S – 116° 40.03' E	W49	Toodyay Rd Lake	31° 34.03' S – 116° 28.77' E
W24	Goomalling Lake C	31° 18.46' S – 116° 40.07' E	W50	Jimperding Brook	31° 37.04' S – 116° 24.94' E
W25	Goomalling Lake D	31° 18.47' S – 116° 40.02' E	W51	Bailup Rd Lake	31° 44.74' S – 116° 18.16' E
W26	Goomalling Lake E	31° 18.58' S – 116° 39.57' E			

Sites were sampled once only and included lotic and lentic waters due to the intermittent nature of aquatic systems in the area. Environmental parameters measured at each site were pH, salinity (ppt), dissolved oxygen (ppm) and temperature (°C). Water quality measurements and diatom collection were conducted from the deepest accessible point of a waterbody to provide stable sampling conditions.

An artificial substrate collector known as the JJ Periphytometer (John 1998) was placed at each site, providing a uniform surface for colonisation by diatoms from periphytic, benthic, epiphytic and planktonic habitats. This method ensured that the diatom assemblages reflected the water quality at the time of sampling. After a minimum 14-day immersion period samples were retrieved and prepared using the nitric acid digestion technique described by John (1998). Permanent slides of diatoms have been deposited at the Curtin University International Diatom Herbarium, School of Environmental Biology for future reference. Species were identified using the following specialised literature: Patrick & Reimer (1966); Patrick & Reimer (1975); Czarnecki & Blinn (1978); Foged (1978); Foged (1979) John (1983; 1998); Hustedt (1985); Ehrlich (1995); Sims (1996). A minimum of 300 diatom valves were counted and converted to a percentage frequency for statistical analyses.

The community structure of diatoms was assessed using indices including species richness and the Shannon-Wiener diversity index (Zar 1996). Multivariate statistical analysis was employed to determine the relationship between sites and environmental parameters based on diatom community structure. Ordination was carried out in PATN (Belbin 1993), using semi-strong-hybrid multidimensional scaling (SSH MDS). Correlation coefficients were generated using the principal axis correlation (PCC) routine and tested for significance with 100 Monte Carlo randomisations.

Description of Study Sites

Study sites included 28 lakes, the majority of which are intermittent, 16 sites that are tributaries or part of the Avon River system, two small inlets/inflows close to larger wetland areas and five small artificial dams.

Lentic waters comprised of a range of smaller wetlands such as Lake Coomelberrup – W34 (less than 100 ha), moderately sized lakes such as Lake Campion – W16 (approximately 600 ha) and very large wetlands such as Lake Dumbleyung – W33 (over 5500 ha) (Halse *et al.* 1993). Many of the waterbodies in this region have been affected by secondary salinisation, and are experiencing loss of fringing vegetation due to increasing salt loads or waterlogging (Cramer & Hobbs 2002). Drainage channels were present at some of the lentic sampling sites including Ardath Lake (W19), having the potential to impact water quality and aquatic biota (Cale *et al.* 2004).

The majority of the lotic sites were situated along the Avon River, or in smaller streams and tributaries. The catchment of this extensive river system covers an area of approximately 120 000 km^2 (Weaving 1999). Sites located further inland such as Mortlock River: Wongan Hills – W13 commonly dry out in summer months, compared to sites such as Avon River: Katrine Bridge – W11, which experiences a more consistent flow throughout the year. With over 75 % of the region cleared for agriculture the Avon has been affected by problems including salinisation, siltation and the destruction of riparian vegetation (John 1998).

Results

Water quality measurements displayed a wide variation over the sampling period. A condensed list of coded sites and corresponding pH and salinity readings is presented in Table 2. The pH of wheatbelt sites ranged

Table 2

Water quality readings of pH and salinity (ppt) from 51 coded wheatbelt sites where (*) are freshwater sites <3 ppt, (+) are brackish sites 3-10 ppt, (o) are saline sites 10-50 ppt and (^) are hypersaline sites > 50ppt. Measurements were taken between Summer and Spring 1999.

Code	pH	Salinity	Code	pH	Salinity	Code	pH	Salinity
+ W01	9.41	7.70	^ W18	7.26	96.20	^ W35	8.07	81.00
+ W02	9.40	7.70	o W19	3.99	26.30	^ W36	7.82	80.80
+ W03	9.40	7.70	^ W20	7.22	59.40	^ W37	7.92	100.30
+ W04	9.71	7.70	^ W21	6.89	68.30	^ W38	7.78	130.00
+ W05	8.90	6.70	o W22	8.44	19.80	+ W39	8.36	9.66
o W06	7.20	40.00	o W23	8.78	26.30	+ W40	8.56	5.83
o W07	7.61	18.60	+ W24	8.55	6.59	o W41	7.97	18.50
o W08	8.39	13.63	+ W25	8.14	3.64	* W42	5.88	0.21
+ W09	8.48	6.53	+ W26	7.69	5.04	* W43	6.98	0.13
+ W10	8.57	6.54	o W27	8.64	17.70	* W44	6.97	0.77
o W11	8.00	15.80	^ W28	8.67	62.60	* W45	7.97	0.76
o W12	7.71	14.60	+ W29	9.07	3.33	* W46	8.61	0.73
+ W13	8.29	6.77	^ W30	8.48	51.30	* W47	6.51	0.17
+ W14	7.15	3.84	o W31	8.06	12.52	* W48	7.97	2.52
+ W15	8.97	7.88	o W32	8.15	36.60	* W49	7.06	0.14
^ W16	6.21	73.70	^ W33	8.64	154.10	+ W50	7.82	3.20
^ W17	6.55	50.20	^ W34	5.74	87.20	* W51	7.19	1.47

Table 3

List of diatom taxa identified from wheatbelt study sites, presented in alphabetical order.

Taxa Name		
Achnanthidium lanceolatum Bréb. *ex* Kütz.	*Diploneis subovalis* Cl.	*Nitzschia gracilis* Hantzsch
Achnanthidium minutissimum (Kütz.) Czarn.	*Entomoneis alata* Kütz.	*Nitzschia hummii* Hust.
Achnanthidium oblongella Oestrup	*Entomoneis tenuistriata* John	*Nitzschia linearis* W.Smith
Achnanthidium reidensis Foged	*Eunotia curvata* (Kütz.) Lagerstedt.	*Nitzschia obtusa* var. *scalpelliformis* Grun.
Amphora acutiuscula Kütz.	*Eunotia pectinalis* (O.F. Müller) Rabh.	*Nitzschia palea* (Kütz.) W.Smith
Amphora australiensis John	*Fallacia pygmeae* (Kütz.) Mann	*Nitzschia pusilla* Grun.
Amphora coffeaeformis (Ag.) Kütz.	*Gomphonema parvulum* (Kütz.) Kütz.	*Nitzschia sigma* (Kütz.) W.Smith
Amphora holsatica Hust.	*Gyrosigma kutzingii* (Grun.) Cl.	*Pinnularia lata* (Bréb.) W.Smith
Amphora mexicana A. Schmidt.	*Hantzschia baltica* Simon.	*Pleurosigma elongatum* W.Smith
Amphora montana Kütz.	*Mastogloia braunii* Grun.	*Pleurosigma salinarum* Grun.
Amphora turgida Hust.	*Mastogloia halophila* John	*Rhaphoneis surirella* (Ehr.) Grun. *ex* V.H.
Amphora veneta Kütz.	*Mastogloia pumila* (Grun.) Cl.	*Rhopalodia gibberula* (Ehr.) O.F.Müller
Amphora ventricosa Greg.	*Mastogloia smithii* Thwaites.	*Rhopalodia gibberula* var. *globosa* Hust.
Bacillaria paxillifer (O.F. Müller) Hendey	*Navicula auriculata* Hust.	*Rhopalodia musculus* (Kütz.) O.Müller
Brachysira aponina Kütz.	*Navicula cryptocephala* (Kütz.)	*Stauroneis dubitabilis* Hust.
Camphylodiscus clypeus Ehr. var. *bicostata* (W.Smith) Hust.	*Navicula elegans* W.Smith	*Stauroneis pachycephala* Cl.
Cocconeis placentula (Ehr.) Hust.	*Navicula ramosissima* (Ag.) Cl.	*Stauroneis spicula* Hickie
Cocconeis placentula var. *euglypta* (Ehr.) Cl.	*Navicula salinarum* Grun.	*Surirella ovalis* Bréb.
Ctenophora pulchella (Ralfs *ex* Kütz.) Williams & Round	*Navicula salinicola* Hust.	*Synedra acus* Kütz.
Cyclotella atomus Hust.	*Navicula subrhynocephala* Hust.	*Synedra rumpens* Kütz. var. *scotica* Grun.
Cyclotella meneghiniana Kütz.	*Navicula tripunctata* (O.F. Müller) Bory.	*Synedra ulna* (Nitzsch) Ehr.
Cyclotella striata (Kütz.) Grun.	*Nitzschia acicularis* (Kütz.) W.Smith	*Tabularia tabulata* (Ag.) Snoeijs
Cymbella minuta Hilse *ex* Rabh.	*Nitzschia amphibia* Grun.	*Thalassiosira weissflogii* (Grun.) Fryxell & Hasle
Cymbella pusilla Grun.	*Nitzschia fasciculata* Grun.	*Tryblionella hungarica* Grun.

from acidic (3.99) to alkaline (9.71), and salinity from fresh (0.12 ppt) to hypersaline (154.10 ppt). Dissolved oxygen varied from near anoxic (0.11ppm) to well oxygenated (13.62 ppm) and a temperature range of 10.0 °C to 24.7 °C was recorded.

The diatom taxa identified were diverse with over 70 species representing 27 genera (Table 3). The species richness recorded from each site is presented in Table 4 and the number of sites in which these species occurred is shown in Appendix 1. An inverse relationship was apparent with species richness being highest in freshwater and brackish sites (Fig. 2a). Once the salinity concentration reached approximately 40 ppt, species numbers were limited to less than 10. The results of the Shannon-Wiener diversity index also displayed a similar trend (Fig. 2b). Species richness and diversity were also related to pH (Fig. 2c & 2d), with the maximum number of species occurring when pH was close to neutral. There appeared to be no relationship between these indices and the environmental variables of dissolved oxygen and temperature.

Correlation coefficients derived from the ordination determined that salinity and pH were the two most important variables (PCC r=0.62 and 0.52 respectively), followed by dissolved oxygen (PCC r=0.36) and temperature (PCC r=0.36). The SSH biplot was generated using the statistically significant (P<0.5) variable of salinity, which was subsequently superimposed onto the ordination (Fig. 3). A clear gradient was evident with the separation of freshwater sites (<3 ppt) and hypersaline sites (>50 ppt). In comparison, some overlap was apparent between the brackish (3–10 ppt) and saline sites (10–50 ppt).

Correlation coefficients for the most common diatom species related to the wetland sites were also calculated. Nine species were shown to have statistically significant (P<0.05) correlation coefficients of greater than 0.6, which were then superimposed onto the SSH biplot (Fig. 4). *Achnanthidium minutissimum* (PCC r=0.79), *Synedra rumpens* var. *scotica* (PCC r=0.61) and *Gomphonema parvulum* (PCC r=0.71) were highly correlated to freshwater sites. *Amphora turgida* (PCC r=0.65) was found to be strongly associated with brackish water sites as were *Navicula tripunctata* (PCC r=0.65) and *Achnanthidium reidensis* (PCC r=0.63). Species related to hypersaline sites included *Hantzschia baltica* (PCC r=0.68), *Navicula salinicola* (PCC r=0.60) and *Amphora coffeaeformis* (PCC r=0.82).

Discussion

The study showed that 9 sites were freshwater (<3 ppt), 17 brackish (3–10 ppt), 12 saline (10–50 ppt) and 13 hypersaline (>50 ppt). The majority of wetlands were considered to be saline, following previously documented research on waterbodies in this region (Geddes *et al*. 1981; Williams 1983; Schofield *et al.* 1988; Kay *et al.* 2001; Cale *et al.* 2004). However, salinity at the sites varied greatly as a result of the season in which one-off sampling took place, as well as the intermittent nature of many of the lakes and streams situated in the wheatbelt. The warmer temperatures experienced over summer and autumn cause a rise in salinity as more salt is concentrated, a process that is exacerbated by the shallow nature of inland systems (Williams 1983; Chhabra 1996). With the onset of winter rains the

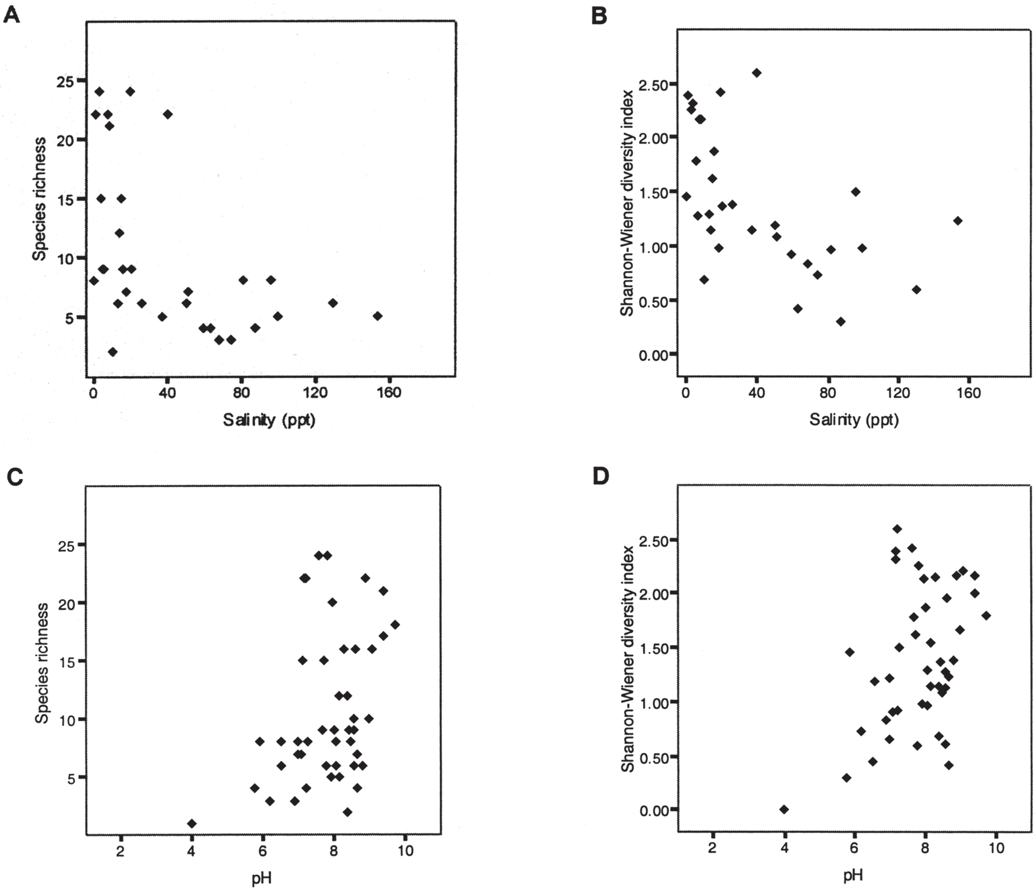

Figure 2. Scatterplots of diatom species richness and Shannon-Wiener diversity index for wheatbelt sites in relation to salinity (A & B), and pH (C & D).

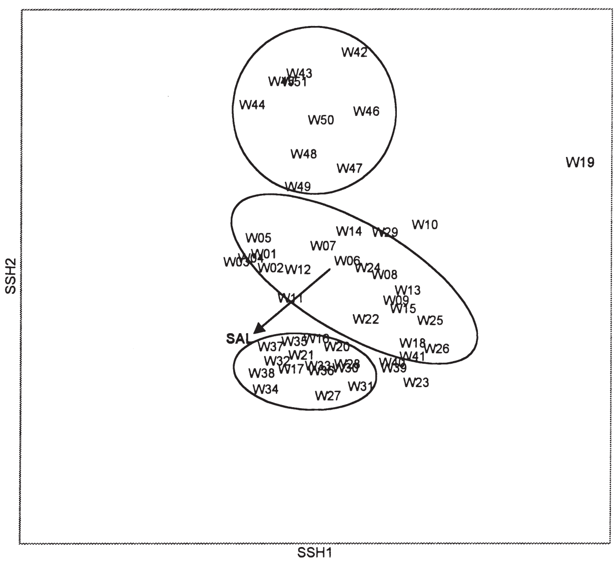

Figure 3. SSH biplot for salinity using >10 % frequency of natural log diatom species from 51 wheatbelt sites. The salinity vector (SAL) has been superimposed, showing the gradient from low to high salinity concentration. Upper circle represents freshwater (3 ppt) sites, middle circle indicates brackish (3-10 ppt) and saline (10-50 ppt) sites; lower circle denotes hypersaline (> 50 ppt) sites.

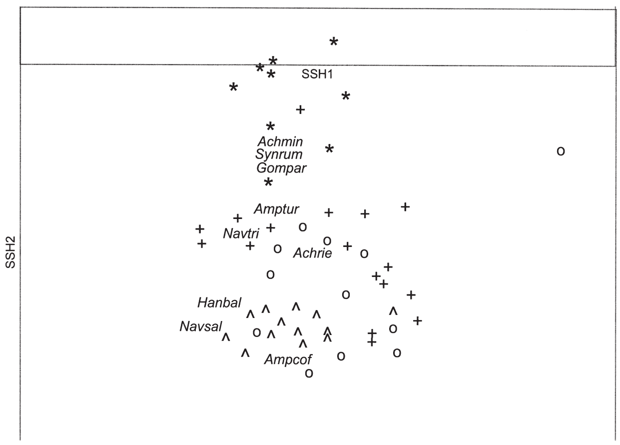

Figure 4. SSH biplot displaying indicator species with >0.6 correlation coefficient for natural log transformed diatom abundances and >10 % frequency of species, where (*) are freshwater sites, (+) are brackish sites, (o) are saline sites and (^) are hypersaline sites. *Achmin – Achnanthidium minutissimum, Synrum – Synedra rumpens* var. *scotica, Gompar – Gomphonema parvulum, Amptur – Amphora turgida, Navtri – Navicula tripunctata, Achrie – Achnanthidium reidensis, Hanbal – Hantzschia baltica, Navsal – Navicula salinicola, Ampcof – Amphora coffeaeformis.*

majority of wetlands are subjected to an influx of freshwater, generating flushing and lowering salinity levels. This was the case for sites such as Yenyening Lake (W27), which was sampled immediately following heavy rainfall, recording a salinity of 17.70 ppt – a marked decrease from its usual hypersaline condition (Weaving 1999).

The salinity of waterbodies is also affected by surrounding land use practices. Drainage channels from surrounding farmland generate saline runoff that increases stream salinities and enters larger river systems. This situation commonly occurs at sites along the Avon River such as Katrine Bridge (W11) and Glen Avon Pool (W12), which experience a rise in salinity as a result of hypersaline inflows from surrounding tributaries (Schofield *et al.* 1988; Avon River System Management Committee 1993).

Diatom assemblages from the wheatbelt lakes and streams varied greatly, with the highest number of species from the genera *Nitzschia*, *Amphora* and *Navicula*. An inverse relationship was shown between species richness/Shannon-Wiener diversity index and salinity. This supports findings from studies on groups of biota including riparian vegetation (Halse *et al.* 1993; Lymbery *et al.* 2003), invertebrates (Geddes *et al.* 1981; Halse *et al.* 2003; Cale *et al.* 2004) and waterbirds (Cale *et al.* 2004) conducted on wetlands in this area.

The ordination indicated that salinity was a key factor influencing diatom community structure, with a clear distinction between freshwater and hypersaline sites. The substantial difference in the species composition between these two categories is to be expected due to the large variation in salinity, which ranged from less than 0.15 ppt to almost 155 ppt over the sites. The distinction between brackish and saline sites however was less apparent, showing diatom assemblages within these water bodies have broader tolerance limits. Williams (1998) has previously stated that biota typical of freshwaters generally have a lower salinity tolerance, compared to species inhabiting saline conditions, which can withstand a wider range of concentrations.

Ardath Lake (W19) was completely isolated from all sites according to the ordination procedure. This was due to its acidic (pH<4) and saline (>25 ppt) nature resulting in a single species of diatom (*Nitzschia pusilla)* occurring at this site. This species has been shown to have a preference for acidic environments as well as having a high salinity tolerance (Sims 1996). Naturally acidic/saline wetlands are common in the Bruce Rock area where Ardath Lake is located and are caused by local hydrogeochemical characteristics (Mann 1983). However, the problem of acidification due to fertiliser use and the installation of deep drains that promote acidic runoff is becoming cause for concern (Archer 2001; Halse *et al.* 2003).

The ordination also generated indicator species that were highly correlated with site groupings. Diatoms correlated with freshwater sites included *Achnanthidium minutissimum*, *Synedra rumpens* var. *scotica* and *Gomphonema parvulum*. These diatoms have been previously documented from freshwater lakes and streams by Fontes *et al.* (1995), Ehrlich & Ortal (1979) and John (1984). Taxa associated with brackish waters included *Achnanthidium reidensis, Amphora turgida* and *Navicula tripunctata*, which have been found to tolerate high salinity conditions by Foged (1978). The latter two species have also been described from brackish/saline environments by Patrick & Reimer (1966; 1975). Hypersaline waterbodies were dominated by *Hantzschia baltica, Navicula salinicola* and *Amphora coffeaeformis*. In particular *Amphora coffeaeformis* has been recognised as a highly salt tolerant diatom throughout the world as well as in the eastern states of Australia (Gell & Gasse 1990; Gell *et al.* 2002) and Western Australia (John 1998).

The distribution pattern of diatoms is influenced by many factors including physical conditions as well as water chemistry. However, this study concentrated on salinity, analysing the distribution pattern of diatoms through the investigation of species tolerance ranges. The results obtained from this study reinforce the advantages of using diatoms as indicators to monitor salinisation of

Table 4

Species richness of diatoms from the 51 coded wheatbelt sites, where (*) are freshwater sites, (+) are brackish sites, (o) are saline sites and (^) are hypersaline sites.

	Site	Species richness		Site	Species richness		Site	Species richness
+	W01	17	^	W18	8	^	W35	8
+	W02	21	o	W19	1	^	W36	5
+	W03	16	^	W20	4	^	W37	5
+	W04	18	^	W21	3	^	W38	6
+	W05	22	o	W22	9	+	W39	2
o	W06	22	o	W23	6	+	W40	9
o	W07	24	+	W24	6	o	W41	3
o	W08	12	+	W25	12	*	W42	8
+	W09	8	+	W26	9	*	W43	7
+	W10	10	o	W27	7	*	W44	8
o	W11	9	^	W28	4	*	W45	14
o	W12	15	+	W29	16	*	W46	16
+	W13	16	^	W30	7	*	W47	8
+	W14	15	o	W31	6	*	W48	20
+	W15	10	o	W32	5	*	W49	7
^	W16	3	^	W33	5	+	W50	24
^	W17	6	^	W34	4	*	W51	22

waterbodies in the wheatbelt area. With an increased database of diatom distribution in wheatbelt lakes and streams of Western Australia a comprehensive predictive model could potentially be derived for salinisation. This model is currently being developed for incorporation into future management plans to assess the effectiveness of remediation measures undertaken for secondary salinity in WA.

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Appendix 1

List of diatom taxa identified from the 51 wheatbelt lakes and streams, indicating the number of sites in which they occurred, in order from the most common to least common.

Taxa Name	Number of occurrences	Taxa Name	Number of occurrences
Amphora coffeaeformis (Ag.) Kütz.	40	*Nitzschia fasciculata* Grun.	5
Cocconeis placentula (Ehr.) Hust.	21	*Surirella ovalis* Bréb.	5
Navicula tripunctata (O.F. Müller) Bory.	20	*Amphora acutiuscula* Kütz.	4
Hantzschia baltica Simon.	19	*Brachysira aponina* Kütz.	4
Navicula salinicola Hust.	19	*Camphylodiscus clypeus* Ehr. var. *bicostata* (W.Smith) Hust.	4
Entomoneis tenuistriata John	16	*Cocconeis placentula* var. *euglypta* (Ehr.) Cl.	4
Navicula salinarum Grun.	15	*Cyclotella striata* (Kütz.) Grun.	4
Nitzschia acicularis (Kütz.) W.Smith	15	*Entomoneis alata* Kütz.	4
Tryblionella hungarica Grun.	15	*Mastogloia halophila* John	4
Achnanthidium reidensis Foged	14	*Nitzschia pusilla* Grun.	4
Cymbella pusilla Grun.	14	*Pleurosigma elongatum* W.Smith	4
Thalassiosira weissflogii (Grun.) Fryxell & Hasle	14	*Tabularia tabulata* (Ag.) Snoeijs	4
Amphora veneta Kütz.	13	*Amphora montana* Kütz.	3
Bacillaria paxillifer (O.F. Müller) Hendey	12	*Eunotia curvata* (Kütz.) Lagerstedt.	3
Cyclotella atomus Hust.	12	*Navicula subrhynocephala* Hust.	3
Pleurosigma salinarum Grun.	11	*Nitzschia amphibia* Grun.	3
Amphora turgida Hust.	10	*Nitzschia gracilis* Hantzsch	3
Cyclotella meneghiniana Kütz.	10	*Nitzschia palea* (Kütz.) W.Smith	3
Mastogloia braunii Grun.	10	*Pinnularia lata* (Bréb.) W.Smith	3
Synedra ulna (Nitzsch) Ehr.	10	*Rhaphoneis surirella* (Ehr.) Grun. *ex* V.H.	3
Amphora holsatica Hust.	9	*Stauroneis pachycephala* Cl.	3
Navicula cryptocephala (Kütz.)	9	*Achnanthidium lanceolatum* Bréb. *ex* Kütz.	2
Navicula elegans W.Smith	9	*Amphora mexicana* A. Schmidt.	2
Rhopalodia gibberula (Ehr.) O.F.Müller	9	*Cymbella minuta* Hilse *ex* Rabh.	2
Stauroneis spicula Hickie	9	*Eunotia pectinalis* (O.F. Müller) Rabh.	2
Achnanthidium minutissimum (Kütz.) Czarn.	8	*Navicula auriculata* Hust.	2
Gyrosigma kutzingii (Grun.) Cl.	8	*Fallacia pygmeae* (Kütz.) Mann	2
Achnanthidium oblongella Oestrup	7	*Nitzschia linearis* W.Smith	2
Amphora ventricosa Greg.	7	*Rhopalodia musculus* (Kütz.) O.Müller	2
Diploneis subovalis Cl.	7	*Amphora australiensis* John	1
Nitzschia hummii Hust.	7	*Mastogloia pumila* (Grun.) Cl.	1
Gomphonema parvulum (Kütz.) Kütz.	6	*Mastogloia smithii* Thwaites.	1
Nitzschia sigma (Kütz.) W.Smith	6	*Navicula ramosissima* (Ag.) Cl.	1
Rhopalodia gibberula var. *globosa* Hust.	6	*Nitzschia obtusa* var. *scalpelliformis* Grun.	1
Ctenophora pulchella (Ralfs *ex* Kütz.) Williams & Round	6	*Stauroneis dubitabilis* Hust.	1
Synedra rumpens Kütz. var. *scotica* Grun.	6	*Synedra acus* Kütz.	1