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Perspective

Watching the tide roll away – advocacy and the obfuscation of evidence

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Abstract. The Murray–Darling Basin Plan represents the largest investment in an Australian environmental management issue and remains highly conflicted owing to the contested allocation of diminishing water resources. Central to the decision to reallocate consumptive water to environmental purposes was the case made to keep the terminal lakes in a freshwater condition. This freshwater state was identified as the natural condition on the basis of selected anecdotal evidence and was enshrined in the listing of the site under the Ramsar Convention. Independent evidence from water quality indicators (diatoms) preserved in lake and lagoon sediment records, however, attested to an estuarine, albeit variable, condition before the commissioning of near-mouth barrages in 1940. Political pressure saw the interpretation for a naturally estuarine history published after peer review, revised and released under state government sanction without review or acknowledgement of the original research. This act of intellectual suppression was the outcome of scientists succumbing to the temptation of advocacy for environmental flows. In the end the clear contradictions between the published evidence and the advocated interpretation has diminished credibility in the science behind the Basin Plan and acted to fuel discontent in those affected by water reallocations.

Additional keywords: intellectual suppression, ecological condition, Murray–Darling Basin, palaeolimnology, Ramsar wetlands

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Introduction

The Murray–Darling Basin is Australia's largest catchment, spanning more than one million square kilometres. It is also its most productive, hosting over 40% of the nation's agricultural domestic product. This productivity has been underpinned by an extremely high level of water abstraction to drive intensive irrigation agriculture at great cost to water-dependent ecosystems. Originally to sustain navigation, but ultimately to guarantee water supplies, the rivers of the basin became highly regulated after the commissioning of many dams and weirs, mostly after 1922.

The initial efforts at irrigation were limited and focussed in the upper reaches of the Murray and Goulburn Rivers. Nevertheless, concern regarding the impact of off-take on the on-flows to South Australia was sufficient to warrant a presentation and debate within the South Australian Parliament as early as 1886. For example, the honorary Jon Rankine is quoted as saying in the House of Assembly in 1887 that 'Many people imagined that there would be nothing to fear from only flood waters being taken, but this was a great mistake. All the floodwaters were required to drive out the salt water so as to keep the lakes and a portion of the lower river fresh for a few months in the year' (Sim and Muller 2004: 26). This dispute intensified and became an important distraction to the nation's Federation, signed in 1901. The interstate royal commission into the basin (Davis *et al.* 1902) was to resolve this issue and by 1907 the Murray River Commission was instituted to manage cross-state contests over water.

The Coorong and Lower Lakes lie at the mouth of the basin and are a lagoon and estuarine complex (Fig. 1). To preserve freshwater resources in Lake Alexandrina from the penetration of tidal waters barrages were commissioned and completed in 1940. These were situated near the river's mouth and acted to raise the level of the lake and hold back incoming tides. They also slowed river flow, leading to the accumulation of salt-laden sediments, the formation of Bird Island, a tidal delta south of Hindmarsh Island, and the northward migration and ultimate closure of the river mouth (Bourman *et al.* 2000).

In 1985 the Coorong and Lower lakes were listed under the Ramsar Convention owing to the significant fish and waterbird populations and cultural significance. At the time the lakes were described as being mostly fresh (DEH 2000). Reinforcing this, a report entitled 'A Fresh History', funded by a regional government agency, defined the lake as being predominantly fresh (Sim and Muller 2004). This report was largely based on documentary and anecdotal evidence and focussed particularly on the observation that, in 1901, the lake had become salty for the first time. This was attributed to abstraction upstream for irrigation in the eastern states, particularly in neighbouring Victoria.

Advocacy to restore the ecosystems of the Murray–Darling Basin was in full swing by the late 20th century, with several reviews and audits conducted. Among the outcomes are the identification of the volumes required to return the system to

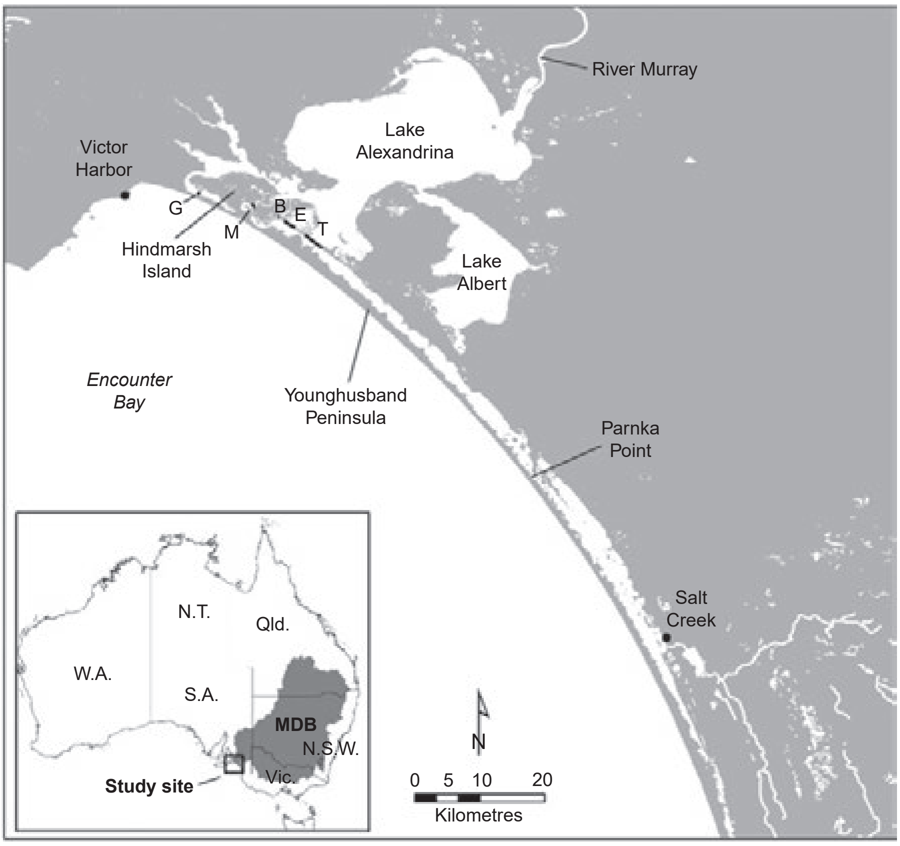

Fig. 1. Lake Alexandrina is a large terminal lake near the mouth of the River Murray, South Australia. Letters mark the locations of barrages.

ecological health (e.g. Jones *et al.* 2002). The South Australian Government argued for the allocation of large volumes of water to retain the lower lakes in a freshwater state. This was advocated on the basis of its natural ecological character, not least because that was the condition defined in the listing under Ramsar. This is the default baseline state under the Ramsar Convention in the absence of evidence for prior natural ecological character (Pittock *et al.* 2010). The decision to return 2750 GL year^{-1} to the river, through buybacks and water transfer efficiencies, was made, in no small part, because it was effectively argued that Australia had an international commitment to retaining Lake Alexandrina as a freshwater lake. Federal and State Governments agreed to allocate a further 450 GL where it can be demonstrated that this would accrue no socioeconomic hardship to communities in the Basin (MDBA 2012).

Palaeolimnological research

Lakes and estuaries contain sediments that accumulate more or less continuously over time (Weckstrom *et al.* 2017). Buried with these sediments are chemical and biological remains that reflect the nature of the wetland at the time of sediment deposition. The collection of sediment cores, the subsampling of sediments and the identification of these remains allows for the condition of the wetland to be inferred. In estuaries this usually allows for a 7000-year history to be outlined as this was the point in geological history that sea levels last stabilised and geomorphic evolution of present-day coastal wetlands commenced. Diatoms are particularly useful fossil bioindicators of estuarine condition (Taffs *et al.* 2017) owing to their abundance, diversity and close association with, and widespread calibration to, water chemistry (e.g. Gell 1997).

Barnett (1994) analysed sediment cores from Lake Alexandrina and concluded that the lake was estuarine from 7000 years ago, but variable on account of climate variability, but was fresher in the modern period. A core taken, but not analysed, by Barnett (LA2), and another collected by Gell and Fluin in 1996 near the river entrance (LA1), formed the basis of analyses in Fluin (2002). The evidence derived from cores collected from the Coorong by Gell and colleagues was reported to the South Australian Department of Water, Land and Biodiversity Conservation in Gell and Haynes (2005) and is detailed in Gell (2017). The interpretation of the interactions between the river, the lakes and the Coorong were presented at the Past Global Changes ‘Salinity, Climate Change and Salinisation’ workshop in Mildura in September 2004 (Gell *et al.* 2007) and subsequently published as Fluin *et al.* (2007). The published records of fossilised diatoms in the two Lake Alexandrina cores reveal changes in key indicator taxa over the last 7000 years. Non-contiguous subsampling leaves out much of the record but the data reveal gradual changes, attributed to hydroclimate change, until the commissioning of the barrages.

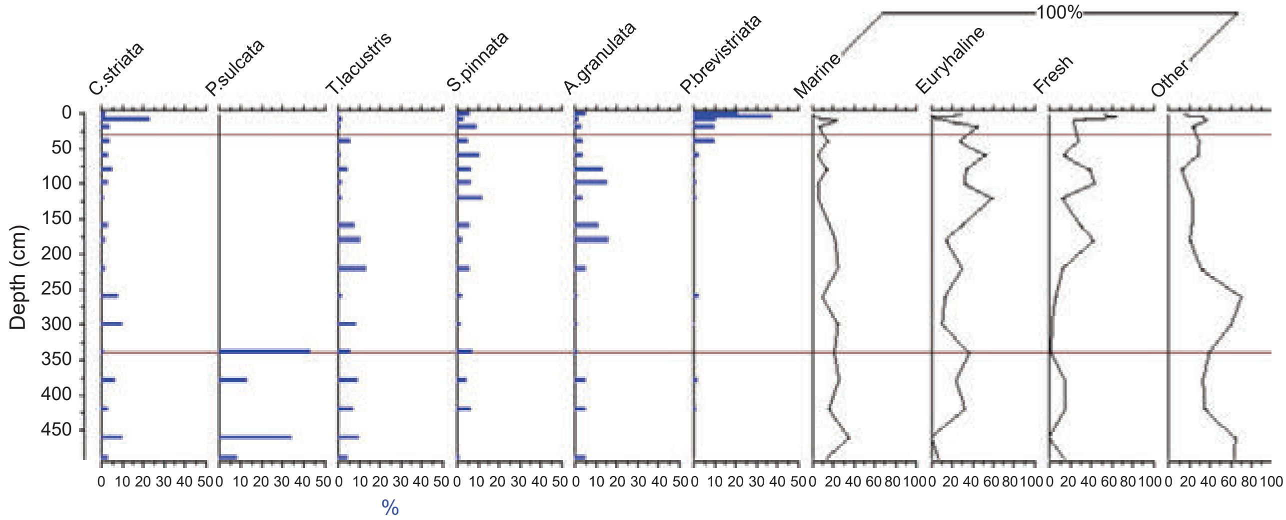

Fig. 2. Summary diagram of the diatom stratigraphy of core LA2 (based on Fluin *et al.* 2007).

Critical to the interpretation of the fossil records is the understanding of the ecological preferences of the taxa preserved in the sediments. This is largely achieved through the collection of modern diatom specimens and the calibration of the relative abundance of these to measured water quality parameters. This was achieved for diatoms from inland salt lakes (Gell 1997) and was completed for some Australian estuaries (Haynes *et al.* 2011; Saunders 2011; Logan and Taffs 2013). As diatoms are ecologically conservative and largely cosmopolitan, interpretation of Australian fossil sequences can benefit from the ecological preferences identified from databases developed elsewhere across the world. It is clear that the taxa considered marine or estuarine in Fluin *et al.* (2007) – *Cyclotella striata*, *Paralia sulcata* and *Thalassiosira lacustris* – are indeed reflective of marine conditions (see Appendix 1 for detailed review of the known ecology of these taxa). None were recorded from inland salt lakes (Gell 1997) and so their presence reflects saline or subsaline conditions influenced by waters of marine (thalassic) origin. Other key taxa in the LA2 record were *Staurosirella* (syn. *Fragilaria*) *pinnata* and *Pseudostaurosira* (syn. *Fragilaria*) *brevistriata*. Both were recorded in inland lakes with weighted average salinity optima of 3.9 g L^{-1} and 1.9 g L^{-1} respectively. Gell and Haynes (2005) and Fluin *et al.* (2007) reported *Staurosirella pinnata* to be abundant in the upper sediments of both the north and south lagoons of the Coorong, which is, and has been in historic times, saline to hypersaline. It was also recorded to be abundant in lakes of 6.3 g L^{-1} and above in Gell (1997). On the basis of this evidence *S. pinnata* appears to be highly salt tolerant; *P. brevistriata*, on the other hand, is regarded as an obligate freshwater taxon. While these diatoms are broadly tolerant, these inferred preferences are used to summarise the change in condition of Lake Alexandrina, as revealed from core LA2, and presented in Fig. 2.

The Fluin *et al.* (2007) interpretation

In reference to the high incidence of thalassic taxa in the early part (~7000–5000 years BP) of the record, Fluin *et al.* (2007: 130) stated 'The presence of *Thalassiosira lacustris*, *Cyclotella striata* and *Paralia sulcata* indicate marine influence at this time …' and '… the change in diatom community [after 5000 years BP] is likely to represent a decrease in lake level and increased penetration of seawater, possibly associated with the variable, dry climate phase after the mid-Holocene wet phase'.

The return to regional wet conditions is reflected in the passage '… The decline in *Thalassiosira lacustris* above 160 cm [~2200 years BP] marks a further increase in freshwater river input conditions, perhaps influenced by the increases in precipitation' (Fluin *et al.* 2007: 130).

Acknowledging the prevalence of athalassic taxa, Fluin *et al.* (2007) stated: 'The Holocene diatom assemblages of Lake Alexandrina reflect relatively freshwater conditions with long-standing and major inputs from the River Murray. Marine water indicators were never dominant in Lake Alexandrina'.

It did, however, clearly articulate the post-barrage change to freshwater conditions, stating: 'The barrages completely separate both lakes from the Coorong, with infrequent fresh water flowing through the barrage gates. As a result, Lake Alexandrina is *presently* [my emphasis] a large, predominantly fresh water system with no salt water input', and 'The greatest change to the diatom flora is again near the surface, at 30 cm, mostly attributable to a strong increase in *Pseudostaurosira brevistriata* coinciding with the estimated time boundary for the onset of river regulation. Further this increase is associated with a small decrease in *Staurosirella pinnata* that may be attributable to the barrages controlling tidal flux to the Lake favouring *Pseudostaurosira brevistriata*, which has a lower salinity tolerance than *Staurosirella pinnata*' (Fluin *et al.* 2007: 130).

In summary, it stated that salinity in the large terminal Lake Alexandrina was only moderately influenced by tidal inflow, particularly over the past ~2000 years. It is now [i.e. today] largely fresh as a result of isolation by a series of barriers completed by 1940 AD. Unequivocally, Fluin *et al.* (2007) stated that, before regulation, Lake Alexandrina was tidal with the balance between marine and river influence attributable to the regional hydroclimate as revealed in the water balance records of the 'rain gauge' lakes of western Victoria. The greatest change in the entire record, as revealed by the cluster analysis, was after the commissioning of the barrages, whereupon the diatom flora reflected unprecedented, freshwater conditions. The interpretation of Fluin *et al.* (2007) is consistent with those presented in Fluin (2002).

The fresh history (Sim and Muller 2004)

Coincident with the compilation of the palaeolimnological research of Fluin on Lake Alexandrina the River Murray Catchment Water Management Board published a document (Sim and Muller 2004: 1) that concluded that 'Prior to European settlement, Lakes Alexandrina and Albert at the terminus of the River Murray were *predominately* fresh …'. Further, it stated (Sim and Muller 2004: 1) that 'Contrary to what many believe today, saltwater intrusions into the Lake environment were not common until after 1900 when significant water resource development had occurred in the River Murray system'.

The interpretations of Sim and Muller (2004) are founded on anecdotes, particularly through the time of the Federation Drought, but also across the years ~1820–1940. As such, it provides a synthesis of the commentary within South Australia as to the changing nature of the lake and the lower reaches of the river. They noted (Sim and Muller 2004: 1) that 'Short-lived intrusions of saltwater would occur during periods of low flow down river resulting in a lowered level of water in the lakes. Even in times of these low flows, it would appear that only small areas of the Lakes were affected' and that 'Saline invasions were more common after 1900 and the development of irrigation works because reduced river flows could not hold back the sea' (Sim and Muller 2004: 1).

The years around 1900 were characterised by one of the more significant droughts in documented history and the reconstruction of hydroclimate since 1788 (Gergis *et al.* 2012) reveals it to have coincided with a substantial shift in the Pacific Decadal Oscillation relative to 230 years of variability. This was conceded thus: 'Irrigation schemes began at the same time as a long lasting, widespread drought that further diminished the amount of water in the river system (Sim and Muller 2004: 1)'.

What Sim and Muller failed to report was the findings of the Interstate Royal Commission that were contrary to their selective position. The Commissioners represented three states and sought counsel from across the Basin, and not just from South Australians. Davis *et al.* (1902) reported many observations including 'One effect of a deep entrance channel would be to increase the saltness of the lakes, which, after a strong north-west or westerly gale, are brackish; the salt water being forced up channels as far as Wellington' (Davis *et al.* 1902: 33). Further, they reported the observations that 'When the winds shift to the south-east it is again blown out of the lake, a greater quantity running out under these circumstances than during any river flood' (Davis *et al.* 1902: 33–34) and that of the master of a trading boat who is quoted as saying 'he had known the water of the lakes as salt in past years' (Davis *et al.* 1902: 34). Ultimately, they concluded that: 'Apart from verbal statements, the evidence of facts is against the hypothesis that there has been any increase in saltness in the Murray Lakes by reason of diversion of water from the river channel' (Davis *et al.* 1902: 34).

Table 1. Alterations to passages found in both Fluin *et al.* (2007) and in Fluin *et al.* (2009)

Passage in Fluin *et al.* (2007: 130)	Passage in Fluin *et al.* (2009)
'The presence of *Thalassiosira lacustris*, *Cyclotella striata* and *Paralia sulcata* **indicate marine influence** at this time' (2007: 130)	'The presence of *Thalassiosira lacustris, Cyclotella striata* and *Paralia sulcata* indicate **minor** marine influence at this time'
'… the change in diatom community [after 5000 years BP] is likely to represent a decrease in lake level and increased penetration of **seawater**, possibly associated with the variable, dry climate …' (2007: 130)	'… the change in diatom community is likely to represent a decrease in lake level and increased penetration of **more brackish water**, possible associated with the variable, dry climate …'

Sim and Muller (2004) does not report on these contrary views reported in Davis *et al.* (1902). Given that this would have been regarded, less parochially, as the authoritative document of the time, it is clear that Sim and Muller (2004) represents a subset of the views available. For Davis *et al.* (1902) to come to a conclusion, on balance, that is so markedly different to that given in Sim and Muller (2004) suggests that the reporting in the latter was highly selective.

The new interpretation from Fluin *et al.* (2009)

From 2010 a new report was posted on the South Australian Government website. Entitled 'An Environmental History of the Lower Lakes and The Coorong', this report on the palaeolimnology of both Lake Alexandrina and the Coorong lagoon was produced by three of the five authors of the 2007 publication but was not published (nor paginated).

Using the same diagrams and descriptions as Fluin *et al.* (2007), Fluin *et al.* (2009) concluded: 'There is no evidence in the 7000 year record of substantial marine incursions into Lake Alexandrina', yet they also stated 'There were substantial alterations to the diatom community in Lake Alexandrina following European settlement and particularly after barrage installation'. In contradiction to the evidence presented in Fluin *et al.* (2007) they asserted that: 'Over the 7000 year record, there are minimal numbers (generally <10%) of estuarine diatoms' and that '… estuarine conditions have essentially been absent from this section (LA1) of the lake (<5%)'.

The entire interpretation of the LA2 record in Fluin *et al.* (2009) can be found, *word for word*, from the same section in the 2007 paper but with two small, but significant, changes (Table 1). Specifically, the words 'marine influence' (Fluin *et al.* 2007: 130) are altered to 'minor marine influence', and 'increased penetration of seawater' (Fluin *et al.* 2007: 130) is altered to 'increased penetration of more brackish water'. Both alterations diminish the interpretation of a tidal influence on the ecological character of Lake Alexandrina. The second alteration creates confusion as the term brackish cannot be qualified, it meaning salty waters, usually the result of freshwater mixing with seawater. So, the use of the terms 'minor' and 'brackish' serve to preclude the ocean as a source of lake water salinity.

Given that the relevant passage in Fluin *et al.* (2009) can be found word-for-word in Fluin *et al.* (2007), except for four

Table 2. Details of seven papers that have used Fluin *et al.* (2007) to argue for a fresh history

Paper	Quote
Mosley *et al.* (2012): 3925	'The river channel discharges into the large (821.7 km^2 total surface area) and shallow Lower Lakes, which are freshwater, eutrophic, and highly turbid (Geddes 1984; Fluin *et al.* 2007; Cook *et al.* 2009)'.
Mahon *et al.* (2015): 1491	'The installation of tidal barrages and weirs near the mouth of the system (~1940–50s) to prevent incursion of marine water resulting from upstream hydrological abstraction, modified the hydrology and ecology of extensive freshwater lakes known as the Lower Lakes (LL) and the Coorong estuary (Fluin *et al.* 2007; Wedderburn *et al.* 2002)'.
Hammer *et al.* (2013): 807	'This [regulation; flow reductions] has jeopardised the future of a long-term freshwater refuge and biodiversity hotspot (Phillips and Muller 2006; Fluin *et al.* 2007; Kingsford *et al.* 2011)'.
Wedderburn *et al.* (2012): 36	'… barrages were constructed in ~1940 in response to river regulation and water abstraction that was causing periodic marine incursion in an otherwise predominately freshwater environment (Fluin *et al.* 2007)'.
Kingsford *et al.* (2011): 257	'Historically, the water in the lake was mainly fresh, indicated by freshwater diatom tests (95%) accumulated in the sediments over the past 7000 years (Barnett 1994; Fluin *et al.* 2007)'.
Brookes *et al.* (2015): 192	'Lake Alexandrina was estuarine prior to construction of the barrages, although paleolimnological evidence suggests it was predominantly fresh (Fluin *et al.* 2007) as river flows restricted the tidal ingress proximal to the Murray Mouth'.
Hammer *et al.* (2010): 221	'In addition, the occurrence of *N. obscura* within MDB only in Lake Alexandrina supports information that this water body has been a predominantly fresh habitat over thousands of years (Sim and Muller 2004; Fluin *et al.* 2007)'.

words that dramatically change the interpretation to one more consistent with a freshwater history, questions can be raised of the authors as to the justification for the new interpretation. Certainly, Fluin *et al.* (2009) offers no new palaeolimnological evidence, or new knowledge of the preferences of the key species, to lead to a reinterpretation. While a motive cannot be ascribed at this point, insight may be gained from a quote from a local from the Lake region cited in Gross *et al.* (2012: 59) who observed 'The incentive for returning large volumes of water as environmental flows is reduced in an 'estuarine' perspective of the lakes'.

How the evidence has been used?

A brief exploration of the Scopus website (www.scopus.com) of instances in which Fluin *et al.* (2007) has been cited in the scientific literature reveals it to have been cited on 44 occasions. Of these, 17 were self cites, 2 were in outputs too obscure to retrieve, 8 were on matters of diatom ecology or related to determinations of sedimentation rate, and 8 pertained specifically to the Coorong and not the lakes. Of the remaining 9 citations, 7 misrepresented the findings reported in Fluin *et al.* (2007). As Table 2 shows, most of these used the evidence from the palaeolimnological record to attest to a permanent freshwater history, when the original paper, while suggesting a fresher condition under wetter climates, and a freshwater state after regulation in 1940, did not state that the lake was 'predominantly fresh' or 'a freshwater refuge'. It remains to be seen whether these authors have sought authority by reference to Fluin *et al.* (2009), but when instructed under review that that paper is neither reviewed nor published, have merely cited Fluin *et al.* (2007), unaware that the two have contrasting conclusions.

As the debate pertaining to the restoration of the Murray–Darling Basin has intensified, a composition (coauthored by Gell) submitted to *The Conversation* (Finlayson *et al.* 2017) drew a particularly misguided post (https://theconversation.com/we-need-more-than-just-extra-water-to-save-the-murray-darling-basin-80188):

> 'This has been studied using remains of diatoms, which neatly signal whether environments are saline, brackish or fresh, and *they show unambiguously that for the last 7000 years Lake Alexandrina was a freshwater environment* with only a few brief incursions of saltwater during extreme drought events (which over a 7000 time-span, you will have a few of). So yes, the lakes were indeed *predominately fresh* before white man modification/water extraction. A dry read but one such paper detailing this evidence is: Fluin J, Gell P, Haynes D, Tibby J, Hancock G. (2007). Paleolimnological evidence for the independent evolution of neighbouring terminal lakes, the Murray Darling Basin, Australia. Hydrobiologia 591: 117–134.'

The author of this post drew a conclusion as to the history of the condition of Lake Alexandrina over the last 7000 years and then cited the paper from which this conclusion was drawn, seemingly unaware that Gell was a coauthor of both the 2007 publication and the piece in *The Conversation*. Remarkably, the author's summary does not reflect the conclusion of the paper cited.

These authors likely have used Fluin *et al.* (2007) to lend authority to a state they themselves had surmised. How did they get it so wrong? Possible alternatives include:

- they read Fluin *et al.* (2007) and concluded that the authors said, or intended to say, that the lake was 'predominently fresh' thereby exhibiting 'confirmation bias' (*sensu* Berger and Johnston 2015);
- they assumed that the condition was 'predominantly fresh' and used Fluin *et al.* (2007) as an authority without checking;
- they took the opinion of Sim and Muller (2004) that the lake was 'predominantly fresh' but sought, or were required under review, to cite peer-reviewed evidence to that effect, and failed to check;
- they had read Fluin *et al.* (2009), which provided them with the evidence that the lake was 'predominantly fresh' but, because it was not a published document, elected, or were required under review, to cite Fluin *et al.* (2007) as the authority;
- they read and fully understood the conclusions in Fluin *et al.* (2007) but elected to state that the lake was 'predominantly fresh' and still elected to cite Fluin *et al.* (2007) as the authority.

These options leave open as to whether these papers, and the post to *The Conversation*, reflect an instance of anything ranging from poor checking of the cited paper, to laziness, to deliberate obfuscation of the evidence presented. Maybe the authors have succumbed to confirmation bias or perhaps they were drawn, independent of the published evidence, to advocate a position that was consistent with the case calling for environmental flows under the Basin Plan. Irrespective, it seems that the science community has interfered with the honest representation of the palaeolimnological evidence and so has manipulated the socio-political decision-making process that has laid down a decision of great consequence.

Advocacy and evidence

Postmodern deconstruction of scientific evidence dispels the myth that science is always entirely objective. Head (1995), for example, neatly portrayed the likely inherent biases in the condition of the author of the *Future Eaters* (Flannery 1994), the celebrated version of the coevolution of the Australian landscape and its people. It is nigh impossible for a scientist to remain absolutely objective and society always ought to contextualise the author or speaker when absorbing the evidence put, particularly when a position is advocated.

In the acute regional contest under the allocation of water under the Murray–Darling Basin Plan, we have here evidence for the intrusion of political stakeholder bias in the reinterpretation of peer-reviewed published science. These interpretations may have been misled by the unpublished Fluin *et al.* (2009) report but this reveals poor attention to detail and a shallow review of the evidence. One fears that these contrary observations have suffered from an inclination to mix science with advocacy and the standards of one have been compromised by the pursuit of the other. In particular, in the absence of a case made to reinterpret the inferences made in Fluin *et al.* (2007), it is difficult to conclude otherwise in the instance of Fluin *et al.* (2009) itself.

While I have been trained to abide the razor edge of representing the evidence and neither advocating for either case in, for example, a development proposal, I personally understand when a scientist lapses into advocacy convinced that the best cause is served. Here, however, is an example, where this fatal step has undermined the credibility of sound science, and steered the debate into further conflict when its original purpose, by way of its unique access to the time dimension, was to resolve the hitherto unresolvable. Perhaps the most critical lesson here is how this saga played out in the media and in the politics. Dr Jennifer Marohasy exposed the duplicitous nature of the interpretation in Fluin *et al.* (2009) and labelled it as 'Junk Science' (Marohasy 2012), only to be pilloried in the ABC program *Media Watch* (19 March 2012; see also http://jennifermarohasy.com/2012/05/media-watch-witch-hunt/). Today, lobbyists seeking to limit the impacts of the Basin Plan on irrigation agriculture make use of this manipulation of evidence to seek to undermine the allocation of environmental flows.

In the end it is reasonable to ask why has a report that used and reinterpreted a published paper, and made conclusions that could not be substantiated by the evidence, been allowed to remain on a State Government website for others to misrepresent the science? The warning for us all in mixing science and advocacy is that the political process has no conscience and reputations are easily dashed. Upholding respect for our science demands that we report it with integrity and then, as members of society, seek to participate in the challenging processes that make decisions that affect people and their places.

Conflicts of interest

PG was an associate supervisor in the production of Fluin (2002) and was a co-author of Fluin *et al.* (2007).

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Appendix 1. Ecological preferences of key fossil indicator taxa

Cyclotella striata

The *Cyclotella striata* species complex includes numerous species and subspecies with similar morphology (Håkansson 1996). Problems exist surrounding the identification of these centric species, in part because, in saline inland lakes, estuaries and lakes with high conductivities, there are a mix of marine and freshwater species and often the nomenclature has been guided by the ecology of the species being named (Håkansson 1996). *Cyclotella* has a wide environmental tolerance, but only eight species have been found in saline waters (Olvia *et al.* 2008), including those in the *C. striata* complex. *Cyclotella striata sensu stricto* has been described as being prevalent in brackish, marine, estuarine and inland saline lakes (Bradbury *et al.* 1981; Jiang *et al.* 1997; Saunders *et al.* 2008; Cook *et al.* 2016). It was regarded by Roetzel *et al.* (2006) as being allochthonous euryhaline (able to adapt to a wide range of salinities). Jiang *et al.* (1997) attributed a rapid increase in *C. striata* in a core from the north-eastern Atlantic margin to a decrease in sea salinity as a result of strong coastal currents and global sea level rise. They also observed it commonly in the spring plankton in estuaries along the North Sea coast. While Pokras (1991) reported *C. striata* as a brackish water species from the Zaire River, Africa, Marshall and Alden (1990) referred to it as being a freshwater species abundant in the estuarine rivers of the Lower Chesapeake Bay, USA. Declining abundance of *C. striata* in Chesapeake Bay cores was associated with increase turbidity and eutrophic conditions following European settlement in the 18th century (Marshall *et al.* 2005).

Paralia sulcata

Paralia sulcata has been reported in waters of varying salinities, from brackish to marine (McQuoid and Nordberg 2003); however, it is widely accepted as being predominantly marine (Snoeijs and Vilblaste 1994) where it inhabits the benthos and plankton zones. It has a widespread cosmopolitan preference for marine littoral zones of the Baltic (Snoeijs and Vilblaste 1994) and has been recorded from the Arctic to the tropics. It preserves well in the sediments of water bodies and can be useful as a palaeoindicator species (McQuoid and Nordberg 2003) but can be resuspended into the water column from the benthos by tidal mixing and wind. This, and its broad tolerance, means that detailed interpretation of the presence of this species can be difficult (McQuoid and Nordberg 2003). Commonly, the occurrence of *P. sulcata* in the sediment record has been interpreted as being an indication of high primary production caused by coastal upwelling (McQuoid and Nordberg 2003). McQuoid and Nordberg (2003) suggest that *P. sulcata* may have a competitive advantage in low light conditions as it is often recorded in increased abundances in winter (Gebühr *et al.* 2009) but this may also indicate an increase in the mixing of the benthos. It has also been found to have a negative correlation with salinity levels in the Inlets of British Columbia, showing its preference for estuarine, rather than marine, conditions and Gebühr *et al.* (2009) suggested that high salinity may be a limiting factor for this species. Declining abundances of *P. sulcata* have been attributed to an increase in deposition of fine, organic sediment (Mills *et al.* 2009), and freshwater or increased sediment flux in Chesapeake Bay (Cooper 1995). However, in contrast to the above studies, Zong (1997) reported *P. sulcata* in greater numbers in areas of fine-grained organic-rich sediments.

Thalassiosira lacustris

The Thalassiosirales (from 'thalassic', meaning 'of marine origin') are known to include marine, planktonic, diatom genera, although there are ~12 fresh or brackish water species recognised (Alverson *et al.* 2011; Hasle 1978). Because of the diversity in valve morphology there is much confusion surrounding the taxonomy of the genus *Thalassiosira* (Smucker *et al.* 2008). *Thalassiosira lacustris* was first described in 1856 as being a freshwater species (Hasle and Lange 1989) but this species has since been recorded from both marine and freshwater environments (Hasle and Lange 1989), as reported by Hustedt as early as 1928. Smucker *et al.* (2006) reported the species primarily in marine coastal regions but also from large rivers around the world. It was reported as spreading in North America, first being noted in environments such as coastal areas and large brackish rivers, but Smucker *et al.* (2008) collected it from several inland streams, although it was not recorded in any great abundance, except where moderate to high stream conductivities were also recorded. They concluded that *T. lacustris* can tolerate a wide range of habitats but is most likely to occur in brackish water as opposed to freshwater environs and was found in large numbers only in waters where moderately high conductivity also existed. Snoeijs and Vilblaste (1994) described it as a freshwater species with a brackish water affinity while Soons *et al.* (1997) used it to infer a freshwater zone above a brackish sediment sequence collected in Canterbury, New Zealand. John (1983) observed it in rivers in Western Australia, where he described its habitat preference to be brackish with a salinity range between 2.5 and 15%, although he found it in the lower part of the Swan River estuary, where salinity levels were between 15 and 35%. The optimum electrical conductivity of *T. lacustris* collected from mostly freshwater samples in the Murray River was found to be 936 $\mu S\ cm^{-1}$ (Tibby and Reid 2004) yet Smucker *et al.* (2008) reported that *T. lacustris* did not reach high numbers when the conductivity was <400 or >2000 $\mu S\ cm^{-1}$.