Royal Society of Queensland

Proceedings of The Royal Society of Queensland

GUIDE TO AUTHORS 2023

The *Proceedings of The Royal Society of Queensland* (PRSQ) publishes papers with rigorous scholarly approaches. Papers on topics in the natural sciences that are significant for Queensland and Queenslanders are particularly welcome. Papers on related topics including the social sciences, managing the natural environment, education, culture, history, philosophy, heritage and policy will be considered. PRSQ regularly publishes research articles, reviews, short communications, and outlook papers. From time to time the Society publishes "Special Issues" on a focused theme. A distinct *Guide to Authors* will apply to each of these issues. Please contact the Honorary Editor, Associate Professor Julien Louys (editor@royalsocietyqld.org.au) to ascertain whether a paper is within the journal's scope. Occasionally, your query or submission may be handled via the above e-mail address by Honorary Associate Editor, Dr Justyna Miszkiewicz.

All submitted manuscripts except thesis abstracts will be peer reviewed prior to a decision being taken on their publication. Manuscripts must not contain material that has either been published or is currently under consideration for publication elsewhere. Submissions received by **1 July 2023** will be processed for inclusion in PRSQ volume 132.

Whilst membership of the Society is encouraged, it is not a requirement for authors who submit papers to the *Proceedings* to be members of the Society.

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1. SUBMISSION OF MANUSCRIPTS

Lead authors should submit their papers electronically by 1 July each year to the Editor, PRSQ (editor@royalsocietyqld.org.au). The submission would normally consist of the following files:

1. Manuscript file in Microsoft Word format, formatted for an A4-sized page with wide margins (at least 2.5 cm). Text should be 12pt Times New Roman, 1.5 line spaced, with every page and line (including the title page) numbered. The file name should include the lead author's surname, e.g. SMITH_Alien_fish_ paper.docx.
2. Figures, saved as individual images and/or vector graphics (see 'Figures/Illustrations' on page 7 of this Guide for file formats and resolution requirements). The file name should include the lead author's surname, e.g. SMITH_Alien_fish_Figure_1.jpg. *Figures embedded in Word files will not be accepted*.
3. Cover letter, including the names and contact details of at least three individuals who are qualified to review the manuscript. These individuals should not have published with any author of the paper within the last three years.

Submissions that comprise notes, dot points, brief outlines, or text requiring revision are not acceptable. Nor are multiple submissions from a group compiling one of these papers. Manuscripts not conforming to the *Guide to Authors* may be sent back to the lead author without review, and may not be considered until the Editor is satisfied all reasonable efforts to comply with the Guide have been made. Accuracy in calculations, figures, tables, names, quotations, references, etc., is the complete responsibility of the lead author.

2. TYPES OF MANUSCRIPT

The following types of manuscript will be considered:

(i) **Scientific Papers:** Full papers containing substantial new data or a substantial review. Submitted papers should not exceed 10,000 words of text including tables and reference list.

(ii) **Occasional Papers:** Full papers containing substantial new data or a substantial review, but where the manuscript significantly exceeds the above 10,000-word limit. This category may be suitable for monographs, where the content has to be extremely detailed and niche; or long manuscripts that deal with significant topics that require broad coverage. This type of submission may be edited by a Guest Editor. To publish in this category, contact the Editor to discuss prior to submission.

(iii) **Short Communications:** A maximum of 4000 words including tables and reference list. Primary research articles reporting discrete items of completed research or topical reports of developments within the scope of the journal. Tables, figures, and reference entries should be kept minimal.

(iv) **Historical Papers:** Full papers covering historical topics and containing novel insights from a historical perspective (maximum of 6000 words including tables and reference list). Please avoid simple re-iteration of historical literature. Submissions that fail to identify originality will be declined.

(v) **Opinion Papers:** An opinion piece (maximum of 6000 words including tables and reference list) should be written as a perspective, not a formal review. It should be of interest to a broad readership, with an emphasis on Queensland. A brief review and critique of past and current work should be given, but the author's own outlook on the subject should be included, in addition to their view on new directions in the field and how it should progress. The author does not have to agree with conventional thought, but should present a balanced side of any debate supported with insightful analysis or evidence. These papers should include an abstract, introduction and conclusion as well as the appropriate headed sections within the paper.

(vi) **Book Reviews:** Authors of books on topics within the scope of PRSQ may contact the Editor to arrange for a book review by a mutually agreed reviewer who has demonstrated expertise in the topics covered. Such reviews may be up to 2000 words (including reference list should if applicable), and include profiles of the book author and reviewer.

(vii) **Thesis Abstracts:** A maximum of 500 words. Thesis abstracts aim to disseminate and summarise work performed at the Honours, MSc and PhD level. The author must provide evidence that the thesis is complete and has been accepted (there will be no peer review of thesis abstracts).

(viii) **Obituaries, Citations and Award Recognitions:** PRSQ encourages the submission of obituaries, citations (RSQ Life Member awards) and other awards to persons who have made significant contributions to science in Queensland. Responsibility for the preparation of such papers is with a single lead author, who should submit a final version to the Editor PRSQ. The lead author would normally be the person who made the nomination for life membership or who was a close associate of the individual being recognised. The submission to the Editor PRSQ should comprise text in Word format and a photograph, in JPEG or TIFF format, of the person being recognised (see 'Figures/Illustrations' on for file formats and resolution requirements).

Note: If necessary, a large bibliography or additional tables/figures may be included in Supplementary Material. Supplementary Material will be published in the online version only. The printed paper will include the URL of the online Supplementary Material.

3. STYLE GUIDE

3.1. Sample Papers

A sample manuscript, ready for submission, is provided as an Appendix to this document.

Typeset versions of PRSQ papers and volumes can be accessed at https://www.royalsocietyqld.org/proceedings-131/

3.2. Obituaries, Citations and Award Recognitions

Obituary of (full name) (dates, e.g. 1942–2020)

Institution making the award (e.g. University of Queensland Gold Medal), date of the award (e.g. 2020), full name of the recipient

The Royal Society of Queensland, Award of Life Member, full name of recipient, date of the award

Body text may have headings and sub-headings, and may be up to 2000 words in length. The academic, scientific and other awards (e.g. Order of Australia Awards) should be described, as well as publications and other scientific contributions, and scientific/academic leadership roles. Special mention should be made of contributions to science or research in Queensland. Family details may be briefly described. Please keep detailed references to publications to a minimum. Long reference lists are not acceptable. If there is a need to review and discuss the personal scientific contributions and publications relevant to Queensland, then this could be done and submitted to PRSQ as a review or historical paper (see above for details).

3.3. Manuscript versions of scientific and occasional papers, and short communications

Title of Paper

(Bold, centred, with Initial Capitals for Principal Words)

Josephine B. McDonald[1], Frederick T. Smith[2] and Wendy M. Jones[3]

Abstract

Abstract text (300 words maximum).

[1] *Faculty/division, University/organisation, Street address or PO Box, State and postcode* (e.g. *QLD 4000*), *Country (optional email address in brackets)*

[2] *Faculty/division, University/organisation, Street address or PO Box, State and postcode* (e.g. *QLD 4000*), *Country (optional email address in brackets)*

[3] *Faculty/division, University/organisation, Street address or PO Box, State and postcode* (e.g. *QLD 4000*), *Country (optional email address in brackets)*

3.3.1. Main Headings (Bold, centred, with Initial Capitals for Principal Words)

Introduction, Materials and Methods (including study area), **Results, Discussion** *or* **Results and Discussion, Conclusions** *or* **Summary, Acknowledgements, Funding** (where appropriate), **Literature Cited, Author Profile(s)**

The PRSQ acts to highlight research and researchers relevant to Queensland. To further this, an Author Profile(s) should appear at the end of each paper. It contains brief details of the author(s) and their research interests. Each profile can be up to a maximum of 100 words in length.

3.3.2. Subheadings

Level 1: **Left Align, Bold, with Initial Capitals for Principal Words**

Paragraph text underneath . . .

Level 2: ***Left Align, Bold Italic, with Initial Capitals for Principal Words***

Paragraph text underneath . . .

Level 3: **Bold with Initial Capitals for Principal Words.** Paragraph text runs on . . .

Level 4: ***Bold Italic with Initial Capitals for Principal Words*.** Paragraph text runs on . . .

3.3.3. Body Text

Paragraphs should be separated by one line with no indentation, and text should be 1.5-line spaced 12pt Times New Roman.

Use of Italics

Italics should be used for genera and species, names of journals, books, newspapers and websites, pronumerals (e.g. $n = 35$), and Latin words/terms (e.g. *senso stricto*, *ad infinitum*, *per se*). *Note*: "et al.," should be roman, not italic.

Numbers

Numbers below 10 should be spelt out (with the exception of measures, weights, etc., or when referencing data), as should numbers beginning sentences. Numbers containing five or more digits should include a comma (e.g. 50,000); however, four-digit numbers should not include a comma (e.g. 5000). Monetary values are an exception, as are columns of numbers in tables. Units of measure, weight, etc., should be spaced (e.g. 200 mm; 20 cm; 100 km; 4.5 g). Ranges of measure, years, pages, etc., should include an en dash rather than a hyphen (e.g. 20–30 cm; 2019–2020; pp. 354–360).

Special Characters

The characters (en dash, degree symbol, mathematical symbols) below can be accessed via Microsoft Word's Advanced Symbol function (in the Insert menu) or inserted directly using keyboard shortcuts.

Quotations

Block quotations should be indented from the left, should be roman (not italic), and should *not* be enclosed in quotation marks. Quoted passages or words *within* a body-text paragraph should be enclosed in double quotation marks (with single quotation marks inside doubles where appropriate). Quotation marks around terms, etc., should be singles.

3.3.4. New Taxonomic Names

Authors should follow the practices set out in the International Code of Zoological Nomenclature (http:// iczn.org) or International Code of Nomenclature for Algae, Fungi, and Plants (Melbourne Code) (http:// www.iapt-taxon.org/nomen/main.php). Electronic (online first) publications of new names have special requirements. Zoological names need to be registered in ZooBank to obtain an LSID. Registration of new names in Zoobank should be done in consultation with the Editor and only after the manuscript has been accepted, but prior to typesetting. Authors will be required to provide the following information prior to publication:

1. Taxon name.
2. Taxon rank (e.g. species, genus, family).
3. Parent taxon, including author and date (e.g., "*Viverravus* Marsh, 1872").
4. Figure numbers in which the taxon is illustrated.
5. Information about the holotype specimen, including repository, specimen number, brief description of the specimen.
6. Geographic information about the type locality.

3.3.5. References

In the Literature Cited section, references must follow APA style (see examples below and in the Appendix to this Guide). Manuscripts containing incorrectly styled references will be returned to the author for amendment. An extensive range of examples is available at https://apastyle.apa.org/style-grammar-guidelines/references, but the most common are reproduced below:

Journal Article

Grady, J. S., Her, M., Moreno, G., Perez, C., & Yelinek, J. (2019). Emotions in storybooks: A comparison of storybooks that represent ethnic and racial groups in the United States. *Psychology of Popular Media Culture*, *8*(3), 207–217. https://doi.org/10.1037/ppm0000185

Journal Article with an Article Number

Jerrentrup, A., Mueller, T., Glowalla, U., Herder, M., Henrichs, N., Neubauer, A., & Schaefer, J. R. (2018). Teaching medicine with the help of "Dr. House". *PLoS ONE*, *13*(3), Article e0193972. https://doi.org/10.1371/journal.pone.0193972

Newspaper Article

Carey, B. (2019, 22 March). Can we get better at forgetting? *The New York Times*. https://www.nytimes.com/2019/03/22/health/memory-forgetting-psychology.html

Harlan, C. (2013, 2 April). North Korea vows to restart shuttered nuclear reactor that can make bomb-grade plutonium. *The Washington Post*, A1, A4.

Note: APA's online Newspaper Article examples use the US date format (*month*, *date*). The PRSQ uses the Australian/UK format (*date, month*).

Whole Authored Book

Jackson, L. M. (2019). *The psychology of prejudice: From attitudes to social action* (2nd ed.). American Psychological Association. https://doi.org/10.1037/0000168-000

Sapolsky, R. M. (2017). *Behave: The biology of humans at our best and worst*. Penguin Books.

Note: APA style dictates that locations of book publishers not be included in the reference.

Whole Edited Book

Hygum, E., & Pedersen, P. M. (Eds.). (2010). *Early childhood education: Values and practices in Denmark. Hans Reitzels Forlag*. https://earlychildhoodeducation.digi.hansreitzel.dk/

Several Volumes of a Multivolume Work

Harris, K. R., Graham, S., & Urdan, T. (Eds.). (2012). *APA educational psychology handbook* (Vols. 1–3). American Psychological Association.

Chapter in an Edited Book

Aron, L., Botella, M., & Lubart, T. (2019). Culinary arts: Talent and their development. In R. F. Subotnik, P. Olszewski-Kubilius, & F. C. Worrell (Eds.), *The psychology of high performance: Developing human potential into domain-specific tale*nt (pp. 345–359). American Psychological Association. https://doi.org/10.1037/0000120-016

Dillard, J. P. (2020). Currents in the study of persuasion. In M. B. Oliver, A. A. Raney, & J. Bryant (Eds.), *Media effects: Advances in theory and research* (4th ed., pp. 115–129).
Routledge.

Note: When listing names of editors, initials *precede* surnames, as above.

Report by a Government Agency

National Cancer Institute. (2019). *Taking time: Support for people with cancer* (NIH Publication No. 18-2059). U.S. Department of Health and Human Services, National Institutes of Health. https://www.cancer.gov/publications/patient-education/takingtime.pdf

Report with Individual Authors

Stuster, J., Adolf, J., Byrne, V., & Greene, M. (2018). *Human exploration of Mars: Preliminary lists of crew tasks* (Report No. NASA/CR-2018-220043). National Aeronautics and Space Administration.
https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20190001401.pdf

Conference Presentation

Evans, A. C., Jr., Garbarino, J., Bocanegra, E., Kinscherff, R. T., & Márquez-Greene, N. (2019, 8–11 August). *Gun violence: An event on the power of community* [Conference presentation]. APA 2019 Convention, Chicago, IL, United States. https://convention.apa.org/2019-video

Conference Proceedings Published in a Journal

Duckworth, A. L., Quirk, A., Gallop, R., Hoyle, R. H., Kelly, D. R., & Matthews, M. D. (2019). Cognitive and noncognitive predictors of success. *Proceedings of the National Academy of Sciences, USA*, *116*(47), 23499–23504. https://doi.org/10.1073/ pnas.1910510116

Conference Proceedings Published as a Whole Book

Kushilevitz, E., & Malkin, T. (Eds.). (2016). *Lecture notes in computer science: Vol. 9562. Theory of cryptography*. Springer. https://doi.org/10.1007/978-3-662-49096-9

Conference Proceedings Published as a Book Chapter

Bedenel, A.-L., Jourdan, L., & Biernacki, C. (2019). Probability estimation by an adapted genetic algorithm in web insurance. In R. Battiti, M. Brunato, I. Kotsireas, & P. Pardalos (Eds.), *Lecture notes in computer science: Vol. 11353. Learning and intelligent optimization* (pp. 225–240). Springer. https://doi.org/10.1007/978-3-030-05348-2_21

Dissertation or Thesis

Zambrano-Vazquez, L. (2016). *The interaction of state and trait worry on response monitoring in those with worry and obsessive-compulsive symptoms* [Doctoral dissertation, University of Arizona]. UA Campus Repository. https://repository.arizona. edu/handle/10150/620615

Jones, L. D. (2018). Instructional leadership perceptions and practices of company board members [Unpublished thesis]. University of Queensland.

References in the body text should also follow APA style, e.g. Mather (1994); (King, 1993); (Fletcher, 1947; Anderson, 1954; Jones, 1966); Fletcher & Anderson (1967). Use “et al.,” to shorten in-text citations with three or more authors. Works by the same author(s) in the same year should be referenced as Jones (1993a), Jones (1993b). Use Jones (1993a,b) where a single reference is to two or more of the same author’s works. Note that the letters are not assigned at random or based on their first appearance in the body text. The works are arranged in the Literature Cited section alphabetically by the first *principal* word of the title (i.e. not “A . . .” or “The . . .”, and the “a”, “b”, etc., assigned in that order). For direct in-text quotations, include the author, year, and page number for the quotation, e.g. (Mather, 1994, p. 45).

3.3.6. Digital Object Identifiers

These need to be provided in the format https://doi.org/10.1037/ppm0000185 for all references where they exist. Ensure the link works and redirects to the correct page or object. DOIs can generally be found in the reference section of the paper, or alternatively can be searched through https://www.crossref.org/

3.3.7. Figures/Illustrations

Photographic figures should be saved in TIFF or JPEG format and supplied as individual image files, *i.e. not embedded in a Microsoft Word file*, and have good contrast and a high resolution (at least 300 pixels per inch (ppi) at the text width of the typeset document: 141 mm). JPEG files should be saved with image quality set to maximum, i.e. minimum compression.

Other figures (graphs, maps, etc.) should be saved in TIFF, PDF, EPS or Adobe Illustrator (.ai) format and supplied as individual files, *i.e. not embedded in a Microsoft Word file*. TIFF images should be of high resolution (at least 300 ppi at 141 mm wide double column/68 mm wide single column for colour or greyscale images; and preferably 1200 ppi for black and white images, i.e. images with no shades of grey). Vector graphics, being mathematically defined, are resolution independent and may be supplied in PDF, EPS or Adobe Illustrator format. As JPEG is a ‘lossy’ format, it should be avoided for graphs, maps, etc.

Graphs, maps, etc. should be printed by the author at the desired PRSQ column width (141 mm double column or 68 mm single column) to determine legibility of text labels. Should re-keying of text or other changes to submitted figures prove necessary, the cost may be passed on to the author.

Numbered figure captions should be inserted immediately after the first paragraph that mentions the figure. The captions should be brief (**Figure 1.** Figure description . . .). ***Do not embed figure images in the manuscript file or in any other Microsoft Word file.*** Insert a red catchline under the caption to alert the typesetter (e.g. [Insert Figure

1 near here]). Figures should be restricted to two-dimensional representations. Do not forget the labels and units. Captions for the figures should give a precise description of the content and should not be repeated within the figure.

If a figure is composed of several images requiring superimposed identifiers, e.g. "A", "B", "C", etc., do *not* embed the identifiers in the supplied images. In this case, supply a separate mockup in Word or PowerPoint, showing the layout of the images and the required lettering/numbering. The typesetter will reproduce the layout using the supplied images and insert the identifiers using desktop publishing software.

3.3.8. Tables

Excessive use of tables should be avoided, as should large tables. Tables should be created using Microsoft Word's table function and inserted immediately after the first paragraph that mentions the table. They should be numbered and have a brief title (**Table 1.** Table description . . .). The positions of figures/tables may differ in the typeset document, but they will always appear after their first mention in the text.

If a table is very wide, it should be supplied in a separate Microsoft Word file and a red catchline inserted in the text (e.g. [Insert Table 1 near here]). *Note*: Wide tables may be typeset in landscape format. Note also that tables containing an excessive number of columns may need to be typeset in a very small type size and legibility may suffer.

4. PROOF CORRECTIONS, COSTS AND OFFPRINTS

After typesetting, a proof will be sent to the author via email as a PDF (portable document format) file. The email server must be able to accept attachments up to 8 MB in size. Authors are requested not to make major changes to their papers at typeset proof stage, unless there are errors requiring correction. Return the corrections to the Editor as soon as possible. Minor changes should be indicated using Acrobat Reader's Sticky Notes function (see https://helpx.adobe.com/acrobat/using/commenting-pdfs.html). If absolutely necessary, lengthy changes may be supplied as Microsoft Word files.

There are no page charges for publication in the PRSQ; however, where major changes are requested at typeset proof stage, authors may be asked to pay for the associated typesetting costs. Authors of papers with colour figures or photographs may also be asked to pay for the associated costs. Papers will be published online as soon as they have been accepted and typeset. Print publication will follow when the annual volume of the PRSQ or a Special Issue is complete.

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Revision date: 22.8.2022

APPENDIX
Sample Manuscript
(See also final typeset version at https://www.royalsocietyqld.org/wp-content/uploads/Proceedings%20126%20v2/13_Lewis_Packer_Web.pdf)

Initial capitals

Genus and species name italicised
Genus name capitalised

Decadal Changes in *Phragmites australis* Performance in Lake Eyre Supergroup Spring Communities Following Stock Exclusion

Simon Lewis[1] and Jasmin G. Packer[2,3]

Abstract

Many ecosystems around the world are vulnerable to competitive expansion by cosmopolitan colonisers (e.g. *Phragmites australis*, common reed) where human-mediated disturbance increases nutrient levels. Yet our understanding of the long-term dynamics within vegetation communities once this disturbance has been excluded, and how best to reduce the residual negative effects, is limited. The Great Artesian Basin (GAB) springs in South Australia offer a useful case study of vegetation responses post-disturbance because they form a collection of semi-independent ecosystems with a rich management history, from burning by Aboriginal people to pastoralism and stock exclusion from some springs since the 1980s. This paper presents a case study based on 35 years of observational data on the response of *P. australis* and other wetland vegetation at protected GAB springs of the Lake Eyre supergroup. The case study aims to understand how naturally present *P. australis* performs within GAB spring communities following stock exclusion. Where *P. australis* was present at the time of stock exclusion, it became monodominant across the main pool of several springs within the first decade, and expanded throughout the spring tail during the second and third decades. The endangered salt pipewort (*Eriocaulon carsonii*) appears to have been reduced in distribution and abundance where *P. australis* became monodominant. However, in two promising cases, *P. australis* dominance waned after 30+ years of stock exclusion and, in another, has not colonised a spring free of *P. australis* at the time of de-stocking despite the presence of source populations in a neighbouring spring. These findings suggest that decadal cycles of above-ground dominance followed by decline may occur in some GAB springs where *P. australis* was present at the time of stock exclusion. Active management of *P. australis* may be required, particularly where its dominant expansion phase poses a threat to species of conservation significance.

Not 'eg.'

Keywords: Great Artesian Basin springs, conservation and management, pastoral lands, *Phragmites australis*, endangered species

Keywords lower case

[1] *Friends of Mound Springs, South Australia*

[2] *Environment Institute, The University of Adelaide, Adelaide, SA 5005, Australia*
[3] *School of Biological Sciences, The University of Adelaide, Adelaide, SA 5005, Australia*

Include state and postcode

Main Heading

Introduction

Style for in-text citing. List by year not author name, and do not italicise 'et al.,'

Human-mediated disturbance is reducing the heterogeneity and biodiversity of natural ecosystems around the world (Winter et al., 2009; Aronson et al., 2014). Pastoral settlement is a widespread example of this. Many dryland vegetation communities are heavily impacted by domestic stock (e.g. cattle, *Bos taurus*, or sheep, *Ovis aries*), pest animals and occasionally over-abundant native herbivores. The impacts of their combined grazing pressure (e.g. soil compaction, nutrient enrichment, changes in species composition and abundance, reduced vegetation complexity) are most concentrated around watering points such as troughs and wetlands (Johnes et al., 1996; Landsberg et al., 2002). To reduce these negative effects on wetland communities within landscapes dominated by dryland pastoralism, many have been fenced to exclude stock and other herbivores over the past 40 years (e.g. Dobkin et al., 1998; Yates et al., 2000). The long-term effects of stock removal on wetland vegetation communities within dryland regions, however, are poorly understood.

Phragmites australis is a tall-statured grass species native to Australia but with a cosmopolitan distribution, forming monodominant stands in many wetlands throughout temperate and dryland regions of the world (Kobbing et al., 2013; Packer et al., 2017; Canavan et al., 2019). As a woody perennial grass, *P. australis* provides important reedbed habitat for native bird (Tmka et al., 2014; Kane, 2001; Kiviat, 2013), insect (Tscharntke, 1999) and mammal species (Kiviat, 2013), and is an important coloniser in the hydroseral succession from aquatic to terrestrial habitats for plant communities (Packer et al., 2017). This broad ecological envelope, together with a tall-statured lifeform, gives it an advantage as one of the most invasive plants in the world (Canavan et al., 2019; Kueffer et al., 2013). *Phragmites australis* competitiveness is closely linked with its ability to persist and thrive in a variety of hydrological (water levels and flow regimes; Deegan et al., 2007; Gotch, 2013) and nutrient (Packer et al., in review) conditions. *Phragmites australis* is also a very important component of many traditional and semi-traditional socioeconomic systems and practices around the world, including its use since prehistoric times for roof thatching (e.g. Kobbing et al., 2013).

Consult with Editor for inclusion of 'in review' sources.

Mechanisms for *Phragmites* reproduction vary in form and success. *Phragmites* can reproduce vegetatively (clonal expansion by rhizomes, or by dispersal of rhizomes or stems by water or animals; Meyerson et al., 2014; Packer et al., 2017) or sexually via seedling recruitment (Kettenring & Wigham, 2009; Kettenring et al., 2011). Water, wind and, to a lesser extent, fauna such as birds disperse the small and light seeds of *Phragmites* (Kiviat, 2013; Packer et al., 2017). Although established *Phragmites* stands are able to expand into many areas, including those with previous ecological disturbance (Moore, 1973; Roberts, 2016; Duffield & Roberts, 2016), germination and seedling establishment are limited as *Phragmites* seeds require particular environmental conditions (Greenwood & MacFarlane, 2006; Gotch, 2013). The few reported cases of new populations established from seed in Australia have been where it has colonised muddy flats through to shallow, still water ±10 cm above ground level (Packer et al., 2017). The expansion of dense monodominant *Phragmites* has been associated with reduced floristic diversity within some freshwater wetland areas, particularly where the *Phragmites* has colonised as non-native stands (e.g. Hazelton et al., 2014). The three main characteristics that make *Phragmites* an effective competitor are rhizomatous growth and aeration, shoot height and shoot density (Gotch, 2013; Canavan et al., 2019). Direct competition is through space occupancy and shading, and shorter plants are often outcompeted.

Within Australia, *Phragmites australis* is the most common member of the genus, and natural populations are found in many parts of eastern Australia through to Tasmania (Roberts, 2000; Duffield & Roberts, 2016; Packer et al., 2017). Within South Australia, it occurs in dryland (e.g. Great Artesian Basin springs, River Murray corridor) through to temperate (e.g. Fleurieu Peninsula swamps) climate zones.

The Great Artesian Basin (GAB) is the largest groundwater basin in Australia and one of the largest in the world. It covers 22% of the Australian continent, including areas in Queensland, New South Wales (NSW), South Australia and the Northern Territory. Great Artesian Basin groundwater supports an estimated 7000 individual springs in 450 spring groups scattered across the basin. Two species of *Phragmites* occur in the Great Artesian Basin springs – *P. karka* and *P. australis*. For the most part, this paper is concerned with *P. australis* as one of the most important wetland species internationally and in the Great Artesian Basin springs, and the term *Phragmites* is used hereon.

Phragmites occurs as a natural component in many springs across the GAB. The GAB springs are of enormous cultural significance to Indigenous people, being their only reliable water source in the region for thousands of years. Archaeology in and around spring sites reflects the importance of these permanent water sources in the otherwise dry landscapes (Hercus & Sutton, 1985; Harris, 2002). There is evidence of traditional burning of *Phragmites* stands by Aboriginal people, as well as excavation of areas with *Phragmites* to improve access to water (Hercus & Sutton, 1985).

Disturbance of spring vegetation associated with European settlement dates from the mid-1800s. Soon after exploration of South Australia's Far North, commencing in the late 1850s, pastoralism was introduced to the region. Pastoralism at Anna Creek Station, for example, dates back to 1863 (Harris, 2002). In the earliest days of pastoralism, the GAB springs provided the only reliable water resource in the region, and many springs were fenced by pastoralists to maintain a clean water supply and prevent bogging of stock. However, from the late 1870s, artesian bores were drilled and these became the main watering points for stock. As a result, most of the early fencing around springs was not maintained. A large number of GAB springs have therefore been subject to pressure from stock and other herbivores for over 130 years.

Within the Great Artesian Basin, exclusion of stock and other introduced herbivores from some wetlands already containing *Phragmites* has led to its expansion and reduced floristic richness of other native spring vegetation (Fensham et al., 2004; Davies et al., 2010; Gotch, 2013). However, the relationship between *Phragmites* and reduced plant diversity is not always straightforward. Invasion and spread of *Phragmites* may not result in reduced diversity if other plants are competitive and capable of out-shading *Phragmites* (Buttery et al., 1965; Keller, 2000), or produce biomass earlier in the annual growth cycle (Gussewell & Edwards, 1999). The performance of *Phragmites* also depends on the genotype(s) present, with some *Phragmites* genotypes being more able to thrive in particular conditions (e.g. substrate types) than others (Packer et al., 2017; Saltonstall, 2002). The substrate conditions in which *Phragmites* contributes to wetland diversity rather than monodominance are presently unclear for the Great Artesian Basin mound springs and many other wetlands within dryland regions.

To investigate the response of *P. australis* to exclusion of stock and other introduced herbivores around permanent artesian-fed springs of the Great Artesian Basin, this paper presents a case study with 35 years of observational data on the Lake Eyre supergroup of mound springs in South Australia. The case study aims to understand how naturally present *Phragmites* populations expand and perform within vegetation communities of GAB springs following stock exclusion. To achieve this aim, three core questions were investigated:

1. How does the performance of *Phragmites* (above-ground distribution and coverage) respond to exclusion of stock grazing, and how has this changed over the past 35 years?
2. How does distance to nearest neighbouring springs influence the colonisation of *Phragmites* at hitherto *Phragmites*-free springs?
3. What trends in spring vegetation composition are evident where *Phragmites* has become dominant across this spring group and timescale?

These insights are important to inform management of the community of native species dependent upon natural discharge of groundwater from the GAB – declared as an endangered ecological community under the *Commonwealth Environment Protection and Biodiversity Conservation Act 1999*.

Materials and Methods

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Study System

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This case study focused on the natural springs of the Great Artesian Basin in the vicinity of Kati Thanda–Lake Eyre, often described as the Lake Eyre spring supergroup (Figure 1). Within this spring supergroup, approximately 3800 spring vents over many hundreds of springs have been described (Lewis et al., 2013). Here 'vent' is defined as a single discharge of artesian water at the land surface and 'spring' as the total wetland associated with a vent, or one or more immediately adjacent vents. In many instances, a single 'spring' often comprises several spring vents.

Four digits, no comma; five or more digits, include comma.

Case Study Springs

The case study focuses on 12 springs fenced to exclude stock and other herbivores, and a large number of springs, described as Finniss Springs, on the former Finniss Springs pastoral lease, now managed by the Arabana Aboriginal Corporation and de-stocked in the mid-1980s (Table 1). The first 10 springs listed in Table 1 were fenced by the South Australian Department of Environment and Planning in the 1980s and were, at that time, on actively grazed pastoral lease land. The fencing comprised timber posts with four strands of barbed wire, predominantly to exclude stock (cattle) as well as donkeys and horses – both present in the area. Other potential pest species – such as camels and wild pigs – do not occur in the area to any significant extent, and native macropods are very sparse. *Phragmites* was naturally present at Big Perry, The

Spell out numbers below 10, except measures, weights, etc.

Fountain, Twelve Mile, Outside, Nilpinna and Big Cadna-owie Springs, but absent from Blanche Cup, the Bubbler, Tarlton and the selected Strangways spring. This coordinated fencing program, and the long-term monitoring of responses, has been one of the major conservation investments for the region's Great Artesian Basin springs. Two springs on Billa Kalina pastoral lease are also included in this case study; these were fenced by the pastoral lessee in the early 2000s – again following a long history of cattle grazing. These springs are less than 100 m apart: one had *Phragmites* fringing a pool at the time of fencing while, at the second, there was no *Phragmites*. The springs on Finniss Springs Aboriginal lands were de-stocked in the mid-1980s, although some horses remain on the property. The Finniss Springs group includes several hundred springs around Hermit Hill (Hermit, Finniss and West Finniss Springs), with several others in the near vicinity to the south (e.g. Bopeechee, Beatrice, Venables). In terms of spring vegetation, Hermit and West Finniss Springs are most noteworthy for the occurrence of salt pipewort (*Eriocaulon carsonii*), an endangered endemic species limited to just a few sites in two spring supergroups in South Australia (Lake Eyre and Lake Frome supergroups). It also occurs at a small number of spring sites in Queensland and NSW (Davies et al., 2010). The vast majority of springs in the Finniss Springs group have *Phragmites*.

Table 1. Case study springs protected from grazing animals since 1980s.

Use sentence case for table heads.

Spring/s	**Location**	**Area protected (ha)***	**Year**	***Phragmites* presence/ absence**	**Other predominant wetland plant species**
Blanche Cup	Then Stuart Creek Pastoral Lease (P.L.), now Wabma Kadarbu Mound Springs Conservation Park	1.0	1984	Absent	*Cyperus laevigatus*
The Bubbler	As above	6.3	1984	Absent	*C. laevigatus*, *Schoenoplectus litoralis*
Strangways spring	Anna Creek P.L.	0.1	1984	Absent	*C. laevigatus*, *C. gymnocaulos*
Big Perry	Peake P.L.	2.7	1986	Present	*Typha domingensis*, *C. laevigatus*, *C. gymnocaulos*, *Juncus kraussii*
The Fountain	Peake P.L.	0.7	1986	Present	*C. laevigatus*, *C. gymnocaulos*
Twelve Mile	Peake P.L.	2.6	1986	Present	*C. gymnocaulos*,

Include tables in manuscript unless very wide.

					T. domingensis
Outside	Peake P.L.	0.4	1986	Present	*C. laevigatus*, *C. gymnocaulos*
Tarlton†	Peake P.L.	9.2	1986	Absent	*C. laevigatus*, *T. domingensis*
Old Nilpinna	Nilpinna P.L.	4.0	1986	Present	*C. laevigatus*, *C. gymnocaulos*
Big Cadna-owie	Allandale P.L.	0.2	1986	Present	*C. laevigatus*, *C. gymnocaulos*
Billa Kalina Springs	Billa Kalina P.L.	~3.0	ca 2001	Present, spring 1; absent, spring 2	Spring 2: *C. laevigatus*, *C. gymnocaulos*
Finniss Springs	Finniss Springs Aboriginal Lands	Entire property, approx. 800 springs	ca 1985	Generally present	Predominantly *C. laevigatus* but with other sedges including *Juncus*, *Baumea*, *Schoenoplectus* and *Gahnia*

* All but Finniss Springs fenced with timber posts and four strands of barbed wire, primarily to exclude cattle, donkeys and horses.

† Tarlton Spring subsequently determined to be fed from local groundwater, not GAB.

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[Insert Figure 1 near here]

FIGURE 1. GAB springs and protected springs and spring groups in the Kati Thanda–Lake Eyre region.

Measuring the Performance of *Phragmites australis*

The case study incorporates published and unpublished literature on *Phragmites* performance and management in the Lake Eyre supergroup. Qualitative data on plant communities within the 10 springs fenced by the South Australian Department of Environment and Planning in the mid-1980s were derived from photo-point monitoring records collected by the Department (1984–2005) before and after fencing. The Department established a total of 66 photo-points across the 10 springs. From 2005, the volunteer group Friends of Mound Springs (FOMS) has maintained some of the photo-points on an opportunistic basis (1–3 yearly). However, many of the original photo-points have become overgrown by *Phragmites*, and FOMS volunteers have reverted to more general observations and photographs to assess trends. At Finniss Springs and Billa Kalina

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pastoral lease, qualitative vegetation data were obtained from regular (1–2 yearly) site-specific observations and analysis of changes and trends by FOMS from 2006 to the present.

Soil nutrient levels and *Phragmites* productivity have been surveyed at several GAB mound springs in South Australia, including one of the case study springs – Bopeechee Spring within Finniss Springs. As with the other GAB springs in the Finniss Springs group, Bopeechee Spring has been free of stock pressure since the mid-1980s and has become dominated by *Phragmites*. Bopeechee Spring was selected for a burning trial in 2016. Prior to the burn, soil nutrients and *Phragmites* productivity were recorded. The density, height and survival (proportion aborted) of *Phragmites* stems were recorded in fifteen 1 × 1 m quadrats in June 2016.

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Results

Monitoring and general observations at the 10 springs fenced by the South Australian Department of Environment and Planning in the 1980s have shown no change in the presence or absence of *Phragmites* at individual springs. This stability has also been noted through qualitative observations at the de-stocked springs on Finniss Springs Aboriginal lands and two fenced springs on Billa Kalina pastoral lease. The results presented here are therefore described under two categories:

- Springs without *Phragmites* at time of stock exclusion.
- Springs with *Phragmites* at time of stock exclusion.

Springs without *Phragmites* at Time of Stock Exclusion

Blanche Cup and the Bubbler

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Wetland structure and floristic composition at Blanche Cup (Figure 2A) and the Bubbler (Figure 2B) changed relatively little in the 35 years since these springs have been protected from stock grazing. Both springs continue to have an open pool fringed by bore-drain sedge (*Cyperus laevigatus*) and a wetland tail of plant species that includes *C. laevigatus* and, in the case of the Bubbler's extensive wetland outflowing tail, a diversity of other aquatic species including shore club-rush (*Schoenoplectus litoralis*) and fringing native myrtle (*Myoporum montanum*).

Both Blanche Cup and the Bubbler are within 100 metres or less of other springs and seeps that contain *Phragmites*, but there has been no sign of colonisation by this species at either spring. A point of interest is that both Blanche Cup and the Bubbler are subject to heavy visitation as feature springs within the Wabma Kadarbu Mound Springs Conservation Park. At both springs there has been significant trampling of *C. laevigatus* around the open pools, a situation that prompted the construction of boardwalks by the SA National Parks and Wildlife Service approximately 10 years ago.

It is relevant to note that another spring close to Blanche Cup and the Bubbler – Little Bubbler (not included in the original fencing program but subsequently protected within the Wabma Kadarbu Mound Springs Conservation Park) – was, until the early 2000s, free of *Phragmites*. Its vegetation comprised almost entirely *C. laevigatus*. In the early 2000s, *Phragmites* was noted at the spring vent. Since that time, *Phragmites* has spread very gradually to occupy about five square metres at the Little Bubbler vent. This is the only recorded incidence of *Phragmites* colonising a previously *Phragmites*-free spring in the Lake Eyre spring supergroup.

Strangways Spring

The Strangways spring, fenced as part of the 1980s program, has remained free of *Phragmites*. Its wetland vegetation is dominated by *C. laevigatus*, with some spiny flat-sedge (*Cyperus gymnocaulos*) and brown-head samphire (*Halosarcia indica*). The Strangways spring is approximately 500 metres from the nearest spring that contains *Phragmites*. While there have been no flow measurements at this fenced spring, visual observations have shown the outflow down the spring tail has diminished. During the 1980s and 1990s, the spring flow extended along the tail and through the protective fencing, but now the spring tail is dry well within the fenced area. This is consistent with observations at the other active springs (approximately 80) in the Strangways Springs group.

[Insert Figure 2 near here]

FIGURE 2. (A) Blanche Cup Spring with fringing bore-drain sedge (*Cyperus laevigatus*), no *Phragmites*, and extinct mound spring Hamilton Hill in the background; (B) The Bubbler vent and extensive tail with vegetation dominated by *C. laevigatus*, but no *Phragmites.*

Tarlton Spring

Tarlton Spring is an individual spring that is not now regarded as a GAB spring but as one tapping into more localised aquifers. However, the response of the native bulrush (*Typha domingensis*) to stock exclusion is relevant to this study of GAB springs. At the time of fencing in the mid-1980s, the three main spring vents at Tarlton Spring each had a small patch of *Typha* with spring tails dominated by the bore-drain sedge (*C. laevigatus*). The response to stock exclusion was rapid proliferation of *Typha* down the spring tails, similar to the pattern of invasion by *Phragmites,* with *C. laevigatus* reduced to a narrow fringe of growth. Tarlton is a very isolated spring, and *Phragmites* has remained absent. In recent years the vents at Tarlton have virtually dried up, reflecting the effects of seasonal variations in the local aquifers.

Billa Kalina Spring

One of the two springs fenced by the Billa Kalina lessees in the early 2000s has remained free of *Phragmites,* despite being within 100 metres of the other fenced spring which has abundant *Phragmites*.

Springs with Phragmites at Time of Stock Exclusion

Springs Fenced by the South Australian Environment Agency in 1980s

At the springs that included *Phragmites* at the time of protection in the 1980s (Big Perry, The Fountain, Twelve Mile, Outside, Nilpinna and Big Cadna-owie), substantial changes followed the fencing. At the time of fencing, the majority of these springs comprised open pools fringed by a mix of *C. laevigatus* and *Phragmites*, along with a low diversity of other wetland species such as the sedge *Cyperus gymnocaulos*. Figure 3A provides a typical example of this situation at Big Cadna-owie Spring. The first noticeable change was the relatively rapid and dense growth of *Phragmites* over the first five years post-fencing. Within about five years, rapid and dense growth of *Phragmites* expanded over the main spring vents, leaving no pools of open water (Figure 3B).

In a somewhat slower process, exemplified by The Fountain Spring, *Phragmites* expanded more slowly down the spring tail, hitherto dominated by the bore-drain sedge (*C. laevigatus*). After approximately 20 years of stock exclusion, further changes occurred at The Fountain and Outside Springs (Figure 4). Since the early 2000s there has been a steady decline in the above-ground growth of *Phragmites* in the main vents at the two springs – to the extent that areas of open water have been emerging since 2017.

At the other fenced springs containing *Phragmites* (Big Perry, Twelve Mile, Nilpinna and Big

Cadna-owie), the dominance of *Phragmites* has continued after the early proliferation immediately following fencing. No open pools are present at these springs. Table 2 provides an overview of vegetation trends at the 10 springs following fencing, while Figures 3A and 3B show the then-and-now situation at Big Cadna-owie Spring.

De-stocked Springs on Finniss Springs Aboriginal Lands

At Finniss Springs, where most of the springs contain *Phragmites*, regular observations following stock exclusion in the mid-1980s showed a trend similar to the springs fenced in the 1980s (Figure 5), as referred to above. Prior to stock exclusion (early 1990s), *Phragmites* was largely restricted to spring vents, surrounded by an extensive halo of *C. laevigatus* and other sedges. Several years after stock exclusion (late 1990s–early 2000s), *Phragmites* growth extended out, with the sedge haloes much reduced. Nearly three decades after stock exclusion (2019), *Phragmites* extended over virtually the whole wetland area, with *C. laevigatus* sedge haloes further reduced or no longer present at several springs.

Springs within the Finniss Springs group, specifically Hermit and West Finniss Springs, provide habitat for the endangered salt pipewort, *Eriocaulon carsonii* (Figure 6). Qualitative observations have shown a reduced incidence of *E. carsonii* at these springs, associated with the proliferation of *Phragmites*.

Soil chemistry, nutrient levels and *Phragmites* stem response have been surveyed at one of the springs on Finniss Springs – Bopeechee Spring (Table 3). The figures are not highly informative as a single sampling but are indicative of data that would be useful if collected more widely and systematically to establish relationships between *Phragmites* performance, nutrient levels and soil chemistry.

[Insert Figure 3 near here]

FIGURE 3. (A) Big Cadna-owie Spring, Allandale Station, 1983 prior to fencing, with *Phragmites*, *C. laevigatus* and some open water areas present; (B) Big Cadna-owie, 2013, dominated by *Phragmites*.

>100 years: 1860s–1970s **Pastoralism**	[Insert Figure 4A here]	1978: Open water with mixed vegetation community, including *Phragmites.*
1980s–1990s (10 years after stock exclusion) ***Phragmites* dominance**	[Insert Figure 4B here]	1999: With complete cover of *Phragmites.*
2000–2010 (20–25 years exclusion) ***Phragmites* senescing**	[Insert Figure 4C here]	2008: *Phragmites* in centre of vent senescing and matting down.
2010–2015 (25–30 years exclusion) **Open water re-emerging**	[Insert Figure 4D here]	2014: Continued senescence of *Phragmites* in main vent area.
2015–2020 (>30 yrs exclusion) **Open water dominance**	[Insert Figure 4E here]	2016: *Phragmites* in vent declining in above-water cover and areas of open water re-emerging.

FIGURE 4. Vegetation sequence at Outside Spring before and after stock exclusion.

1985 **Recently de-stocked**	[Insert Figure 5A here]	*Phragmites* present at vents (olive-green, middle ground) but surrounded by large haloes of sedges (foreground). The endangered salt pipewort occurred commonly on the inner (damper) edges of the haloes.
2007 **Spreading *Phragmites***	[Insert Figure 5B here]	The *Phragmites* is spreading into the haloes of sedges (shorter wispy *Phragmites* surrounding the taller original clump).
2015 **Dominant *Phragmites***	[Insert Figure 5C here]	*Phragmites* has spread to the outer edges of the spring wetlands to dominate the whole wetland area.

FIGURE 5. Vegetation sequence at Finniss Springs following de-stocking.

[Insert Figure 6 near here]

FIGURE 6. Endangered salt pipewort (*Eriocaulon carsonii*) amongst Phragmites at Hermit Hill Spring, Finniss Springs group, 2015.

Billa Kalina Spring

In the spring where *Phragmites* was present at the time of fencing, it has proliferated to dominate the entire spring. The neighbouring fenced spring, less than 100 metres away and free of *Phragmites* at the time of fencing, remains free of *Phragmites* (Figure 7).

[Insert Figure 7 near here]

FIGURE 7. Adjoining springs at Billa Kalina fenced in early 2000s, photographed in 2017: (A) with dense stands of *Phragmites*; (B) with no *Phragmites*. Wetland vegetation comprises *Cyperus gymnocaulos* surrounded by samphire species.

Table 2. Indicative timeline for vegetation changes in Lake Eyre supergroup springs containing *Phragmites australis*, fenced or de-stocked in the 1980s.

Mid-1980s before fencing	**Mid-1990s 10 years after fencing**	**Early 2000s 20 years after fencing**	**2019 30+ years after fencing**
Open pools fringed by *Phragmites*, interspersed with *Cyperus laevigatus*. Spring tails dominated by *C. laevigatus*.	Spring vents totally overgrown with *Phragmites*, no open water. Spring tails still mainly *C. laevigatus* but *Phragmites* starting to colonise towards the tail.	Vents still totally overgrown with *Phragmites*. Spring tails now dominated by *Phragmites* with small fringing areas of *C. laevigatus*.	Some vents showing significantly reduced *Phragmites* and some open water, majority still overgrown. Spring tails still dominated by *Phragmites*.

Table 3. Soil chemistry, nutrient levels and *Phragmites australis* stem response at Bopeechee Spring, Finniss Springs. Data recorded in 1 × 1 m quadrats in June 2016.

	pH	**Salinity (ppm)**	**Nitrate NO_3 (mg/kg)**	**Ammonium NH_4 (mg/kg)**	**Phosphorus P (mg/Kg)**	**Stems Total**	**Stem Maximum length (mm)**
Mean (SE)	7.74 (0.10)	1120 (77)	<1.0	<1.0	—	22.6 (3.3)	4062 (285)
Minimum	7.29	758	<1.0	<1.0	5.0	4	3050
Maximum	8.37	1518	2.1	2.1	6.0	38	5280

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Discussion

Within South Australia, the majority of GAB springs occur on pastoral lease land used predominantly for cattle production over the last 120–150 years (Lewis & Harris, 2020). Stock and pest animals have a direct impact on spring vegetation and can lead to the loss of plant species, as well as causing pugging and increased nutrient levels (nitrates and phosphates) in spring waters and sediments, thereby affecting habitat quality. There are concerns that there have been associated losses of endemic flora and fauna (Fatchen & Fatchen, 1993; Kovac & Mackay, 2009).

Techniques to prevent damage from stock and pest animals include exclusion fencing around springs and de-stocking of spring areas. However, in protected areas that contain *Phragmites*, this has resulted in *Phragmites* expansion which excludes other spring vegetation and reduces open-water habitat. Findings of this case study within the Lake Eyre supergroup support previous reports of *Phragmites* as an effective and rapid expander in disturbed springs within the Great Artesian Basin (Fensham et al., 2004; Davies et al., 2010; Gotch, 2013). *Phragmites australis* has flourished in the changing post-disturbance hydrological and habitat conditions around spring vents and expanded into spring tails. These findings highlight the implications for springs and their flora when they are protected from stock and other herbivores after a long history of grazing.

The main findings in relation to the three key questions on *Phragmites* performance within Lake Eyre supergroup springs that have been protected since the mid-1980s are discussed below.

Performance of *Phragmites* in GAB Springs Following Exclusion of Stock Grazing

The response of spring vegetation communities to stock exclusion was striking and occurred within 5–10 years. At springs where *Phragmites* was present at the time of stock exclusion, there was a relatively rapid proliferation of *Phragmites* – initially at the spring vent in the first 10 years or so following stock exclusion, then spreading into most of the spring tail over the following 10–20 years.

The monodominant expansion of *Phragmites* in GAB springs following cessation of grazing pressure is unsurprising and consistent with its post-disturbance performance elsewhere in Australia (Roberts, 2000; Duffield & Roberts, 2016) and beyond (Hürlimann, 1951; Caffrey &

Beglin, 1996; Packer et al., 2017). *Phragmites australis* occurs naturally in many of the springs of the Lake Eyre supergroup and in many other GAB springs. It has been present at Warburton Spring in the Lake Eyre supergroup for over 30,000 years (Gotch, 2013). In all of the case study springs where *Phragmites* has proliferated, it was already present at the time of fencing and stock exclusion.

The case study has also provided important indications of decadal changes in *Phragmites* density within springs protected for over 30 years. In particular, vegetation observation at Outside Spring and The Fountain indicate that above-ground growth of *Phragmites* is diminishing in the main pool. Vegetation succession may be occurring within these protected spring communities: from vegetation-fringed open pools, to complete vegetation cover, and more recently towards *Phragmites* decline and open-water, vegetation-fringed pools again. These observations indicate that, in the longer term, protected springs may sometimes revert to a vegetation community with reduced above-ground *Phragmites*.

Phragmites often has a competitive advantage where it occurs in disturbed sites and where the main source of disturbance – such as stock grazing – has been removed. Less clear, however, is whether, and if so how, physical or chemical conditions might also interact with disturbance and *Phragmites* performance. In particular, many of the case study springs were previously grazed for a century or more prior to exclusion, so nutrient levels in spring sediments are likely to have increased substantially. *Phragmites* is known to thrive in nutrient-rich conditions (Duffield & Roberts, 2016; Packer et al., in review). The apparent relationships between *Phragmites* density, height and cover, nutrient levels and other aspects of sediment and water quality in GAB springs require further investigation.

Potential for Establishment of *Phragmites* at Hitherto *Phragmites*-free Springs

Although *Phragmites* is common in many spring vents and seeps within Wabma Kadarbu Mound Springs Conservation Park, it has not established at Blanche Cup or the Bubbler. Similarly, at Billa Kalina, there has been no establishment of *Phragmites* at a fenced *Phragmites*-free spring despite its close proximity to a spring with *Phragmites* within the same exclosure. These examples support observations elsewhere (Gotch, 2013) that there is a low probability of colonisation into *Phragmites*-free springs within the Lake Eyre supergroup. In the single recorded case of *Phragmites* establishment at a previously *Phragmites*-free spring in this spring group – the Little Bubbler – its rate of spread has been slow, suggesting that there may be abiotic conditions at the Little Bubbler not conducive to rapid spread.

Impacts of *Phragmites* Proliferation on the Composition of Spring Vegetation

Within the GAB springs, there is evidence of reduced floristic richness in wetlands where *Phragmites* has proliferated (Fensham et al., 2004; Davies et al., 2010; Gotch, 2013). Observations at the recently protected Lake Eyre case study springs tend to support this. Observations and vegetation photo-point monitoring have shown that the distribution and abundance of other spring-dependent plant species are being significantly reduced. At several springs, the formerly common and often dominant bore-drain sedge (*C. laevigatus*) has been reduced in distribution and abundance, while other sedges such as *Baumea* and *Bolboschoenus* have also reduced in abundance. The occurrence and possibly the abundance of endangered salt pipewort (*Eriocaulon carsonii*) at the GAB springs at Hermit Hill (Hermit and West Finniss Springs) have apparently declined. Observations in the early 2000s showed *E. carsonii* at several springs, whereas in 2015 just one occurrence was identified despite a comprehensive search (FOMS, 2015). This supports other findings that the proliferation of *Phragmites* can take over the habitat formerly occupied by *E. carsonii* (e.g. SA Arid Lands NRM Board, 2010).

Implications for Conservation and Management

Historically, one of the cornerstones of conservation of native plant and animal communities has been exclusion of impacts by stock and other introduced animals, and this approach has been applied to GAB springs. For springs without *Phragmites* – and possibly other tall macrophytes such as *Typha* – this appears to be a reasonable strategy. However, the proliferation and dominance of *Phragmites* in springs containing *Phragmites* at the time of stock and other animal exclusion does raise questions about the management of those springs.

In broad terms, the two main options following exclusion of stock and other herbivores are: (a) do nothing on the assumption that *Phragmites* dominance will eventually decline, leading to increased abundance of other wetland plant species and possibly even the re-establishment of open-water pools; or (b) apply an active management regime to reduce the dominance of *Phragmites* and promote the retention or restoration of more diverse wetland communities.

The case study presented in this paper provides information about the results stemming from the ‘do nothing’ option over a timeframe of up to 35 years. In two cases out of six amongst *Phragmites* springs fenced in the mid-1980s, there was eventually a reduction in density of above-ground *Phragmites* over 30+ years. In the remaining four cases, *Phragmites* continues to be dominant and it is not at all clear whether its density will eventually follow the same trend. If *Phragmites* growth is responding to elevated nutrient levels following more than a century of stock access, then a decline may eventually occur, but the likely timing of this is unclear and more research is needed into the relationships between *Phragmites* proliferation and elevated nutrient levels. A broad, coordinated program to measure the parameters presented in Table 3 would be a useful start in assessing these relationships.

The need for active management of GAB springs with prolific *Phragmites* becomes more relevant where that proliferation may impact upon other wetland species that are of particular conservation significance. The observational evidence suggesting a reduction in distribution and abundance of the endangered *E. carsonii* at Finniss Springs is an example of this. Where species of particular conservation significance are involved, there may be a case for active reduction of *Phragmites* – in effect to hasten the cycle through to reduced incidence and density of this species. According to the hypothesis that *Phragmites* responds to elevated nutrient levels post-grazing, active management could hasten the reduction in nutrient levels and thus the reduction in *Phragmites* monodominance.

Active management to reduce *Phragmites*, where it is considered overabundant or invasive, has included slashing, burning, cutting, grazing, and herbicide application (Keller, 2000; Saltonstall, 2002; Sun et al., 2007). In general, these treatments were found to have only short-term effects and limited feasibility for scaling up to the extent needed (Sun et al., 2007). The use of fire or other techniques to remove above-ground biomass of *Phragmites* is recommended during summer or early autumn when the nutrient content of their shoots is greatest, thus inflicting physiological stress (Hellings & Gallagher, 1992; Güsewell, 2003). Several studies have highlighted the role of controlled or pulse stock grazing in reducing *Phragmites* growth (e.g. Coates et al., 2010). From observations in GAB springs over several decades, it is clear that grazing by cattle can reduce the biomass of *Phragmites* substantially. Pulse grazing will, however, also add a further infusion of nutrients to the spring environment, which may prolong the cycle of vigorous *Phragmites* growth.

A further method with potential to reduce *Phragmites* dominance and hasten the decline in GAB spring nutrient levels is slashing the above-ground *Phragmites* biomass to protect and promote the growth of threatened plants (e.g. *E. carsonii*) (J. Packer, unpublished data). *Phragmites* is often used in phytoremediation because it is an efficient remover of nutrients and heavy metals (Tanner et al., 2006). Removing the cut biomass could therefore help to reduce nutrient levels in the spring community. While the after-use of harvested thatch is unlikely to be a practical option in remote springs country, trials using this method at selected springs could be considered. As a single management event, either burning or slashing is not likely to have a lasting effect for *Phragmites* management. A long-term commitment to repeated interventions over many years is likely to be necessary.

Future Directions to Address Conservation Knowledge and Management Gaps

Our case study findings and related literature suggest that elevated nutrient levels in spring substrates, following more than a century of stock disturbance and grazing, may be an important factor in promoting prolific regrowth of *Phragmites* following stock exclusion. Further research is required to monitor nutrient levels directly and test our prediction of their influence on *Phragmites* performance. We suggest two GAB spring groups where this prediction could be tested: (1) the 12 fenced case-study springs described in this paper, where protected springs can be compared with nearby unfenced springs; and (2) Hawker Springs where a large spring group is subject to various levels of stock pressure.

Hawker Springs, on the Peake pastoral lease, comprises up to 100 spring vents in a relatively tight grouping. Observations by FOMS volunteers and others suggest that the outer springs in this group are most frequented by stock, while the inner springs are much less impacted. This is a very suitable spring group for a coordinated study of grazing impacts, trends in nutrient levels, and *Phragmites* distribution, density and growth performance.

Over 35 years of observations across the Lake Eyre supergroup case study of GAB springs suggest that small-scale fencing of individual springs provides limited conservation return for a relatively high cost. It is preferable from a conservation viewpoint to protect groups of springs. We therefore recommend prioritising protection of groups of springs that include a mosaic of springs with vegetation communities where *Phragmites* is present, and other springs where it is absent. Protecting this landscape mosaic may result in greater heterogeneity and vegetation diversity over time than protection of a group of springs which all contain *Phragmites*.

Acknowledgements

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Author Profiles

Each profile can be max. 100 words.

Simon Lewis is a retired South Australian public servant, having spent most of his 34-year career in the State Environment Department. He first travelled to the GAB springs in 1977 and, from the early 1980s, was involved in the spring fencing program which is the focus of the case study described in this paper. Simon led the annual spring vegetation monitoring program at these springs from the mid-1980s until 2005. He is a foundation member of Friends of Mound Springs and is the long-standing Secretary of that group.

Jasmin Packer has been fascinated by Great Artesian Basin springs since visiting several during her childhood. She is a Research Fellow at the Environment Institute, The University of Adelaide, and involved in international research collaborations on invasion science, including *Phragmites australis* as a global model species. Jasmin is passionate about protecting our threatened communities and species by bringing together world-class science with on-ground management. Jasmin and Friends of Mound Springs have been collaborating since 2017 to progress this shared vision.