



Proceedings of The Royal Society of Queensland

GUIDE TO AUTHORS 2026

The *Proceedings of The Royal Society of Queensland* (PRSQ) is a peer-reviewed regional journal of record that is indexed by international search engines. It has been in continuous publication since 1884. While the traditional focus has been on the natural sciences, papers on related topics such as the social sciences, managing the natural environment, education, culture, history, philosophy, heritage and policy will be considered. PRSQ publishes articles in a range of formats including research articles with original data, reviews, short communications, and opinion papers. Papers that are significant for Queensland are particularly welcome.

From time to time the Society publishes ‘Special Issues’ on a focused theme. A distinct *Guide to Authors* may apply to each of these issues. If uncertain, please contact the Honorary Editor (editor@royalsocietyqld.org.au) to ascertain whether a proposed article is within the journal’s scope. Occasionally, your query or submission may be handled by another office-bearer such as the Assistant Editor or the Policy Coordinator.

All submitted manuscripts except thesis abstracts will be ‘single-blind’ peer-reviewed prior to a decision on their publication. (The author’s name is known to the referees but the referees are anonymous.) Manuscripts must not contain material that has either been published in a scholarly outlet or is currently under consideration for publication elsewhere. Material that has been published on the internet or in a magazine without scholarly peer review may be considered for the *Proceedings* as the process of editing and peer review will in effect create a different paper. Submissions received by **1 July each year** will be processed for inclusion in that year’s volume. At the Editor’s discretion, a later deadline may be considered for short or uncomplicated papers and for students’ abstracts which have in effect already been peer-reviewed.

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.

The distinctive features of the volunteer-run *Proceedings* are the breadth of its scope, its accessibility, the flexibility as to length and format of articles, the availability of senior members to mentor early-career authors, and its availability open access – free of charge. While author fees are not charged at present, authors with budget capacity are encouraged to make an ex-gratia payment to defray the costs of typesetting and publication.

Articles are published online <https://www.royalsocietyqld.org/publications/proceedings/> as soon as they have been accepted by the Editor and typeset. Articles finalised by December each year are gathered into the annual online/printed volume.

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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). Submission would normally consist of the following files:

1. Manuscript file in Microsoft Word format, formatted for an A4-sized page with wide margins (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 **3.3.7. Figures/Illustrations** 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 past 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. Only in special circumstances will PowerPoint presentations be accepted. 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. In every case the Editor may allow a variation to the word length:

- 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 does not conform to the format of one of the other categories, notably if it 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 requiring 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. Inclusion of an abstract is preferred.
- 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 reiteration of historical literature. Submissions that fail to identify originality will be declined.
- v. **Opinion Pieces:** Short, somewhat informal articles that may take a more journalistic approach in presenting opinion-based scientific and associated views in a narrative format. They focus on current topics that are of significant interest to the wider community and are usually up to 3000 but less than 4000 words. These differ from **Short Communications** in their informal approach, especially regarding there being no prerequisite for entries in the Literature Cited section. They can, however, include seminal references.
- vi. **Opinion Papers:** Substantial manuscripts that present a wide spectrum of scientific and associated opinions, which are usually supported by an author's professional experience and relevant literature. These can be up to 12,000 words or longer at the discretion of the Editor. They are written as a perspective and are independently refereed. They focus on specific scientific or related cross-disciplinary topics. 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 and be fully referenced.
- vii. **Essays:** Whereas essays should comply with the Society's basic house style, they are special cases that may directly relate to a particular award and need to satisfy also the independent assessment criteria of the award. They are refereed taking these parallel requirements into consideration.
- viii. **Book Reviews:** Authors of books on topics within the scope of the 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 if applicable) and include profiles of the book author and reviewer.

- ix. **Thesis Abstracts:** Thesis abstracts aim to disseminate and summarise work performed at the Honours, M.Sc. 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.
- x. **Research Grant Reports:** These should satisfy the requirements of **Short Communications** (see above).
- xi. **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. 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 should comprise text in Word format and a photograph, in JPEG or TIFF format, of the person being recognised (see **3.3.7. Figures/Illustrations** below for file formats and resolution requirements).

Note: For any of the above formats, 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.

Note: Whereas it is not essential, a short **Author Profile** is appreciated and preferred for inclusion at the end of any publication category.

Note: Where justified, the length of an article in any of the above publication categories may be increased at the discretion of the Editor.

Source documents, field notes and datasets not germane to a submitted manuscript may be published online on the Society's website of general science, the Queensland Science Network, <https://www.scienceqld.org/>. Material published there need not be peer-reviewed.

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/>.

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 or discussion of the personal scientific

contributions of the person are not acceptable in the Obituary but may be formatted as a separate paper and submitted to the PRSQ as a review or historical paper or as an item on the Queensland Science Network website (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 McDonald¹, Frederick Smith² and Wendy M. Jones³

Abstract

Abstract text (300 words target).

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)*

Keywords: relevant keywords (lower case and separated by commas)

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 or Conflicts of interest (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: **with Initial Capitals for Principal Words.** Paragraph text runs on . . .

Level 4: ***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, pronominals (e.g. $n = 35$), and Latin words/terms (e.g. *sensu 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

These characters (en dash, degree symbol, mathematical symbols) 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. A citation (author, date and page number) should be provided, usually after the quotation.

3.3.4. New Taxonomic Names

Authors should follow the practices set out in the International Code of Zoological Nomenclature (<https://iczn.org>) or International Code of Nomenclature for Algae, Fungi, and Plants (Melbourne Code) (<https://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:

Taxon name.

Taxon rank (e.g. species, genus, family).

Parent taxon, including author and date (e.g. “*Viverravus* Marsh, 1872”).

Figure numbers in which the taxon is illustrated.

Information about the holotype specimen, including repository, specimen number, brief description of the specimen.

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), with some amendments for Australian practice. Authors should endeavour to avoid references in

footnotes. *Manuscripts containing incorrectly styled references will be returned to the author for amendment.*

Note: Authors should consider using a bibliographic system such as Endnote. Formatting in the text and reference list is automatic, once the style is selected. (However, please remember to adjust measurements to Australian units.)

An extensive range of examples is available at <https://apastyle.apa.org/style-grammar-guidelines/references> but the most common are reproduced below. **Note:** Pay particular attention to italicisation, including where *not* applied to commas, and note the use of en dashes, not hyphens, in page ranges.

Where there are more than six authors, only the first six need be entered, with the others grouped as “et al.”. (This is a PRSQ exception to APA style, as the latter requires the inclusion of *all* names.)

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>

Notes: Where available, middle initials should be included in author’s names. DOIs should be included for journal articles.

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.

Notes: APA’s online Newspaper Article examples use the US date format (*month, date*). The PRSQ uses the Australian/UK format (*date, month*). When available, website or PDF links should be provided for non-journal articles.

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 talent* (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

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 more than two 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 . . .”, with “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

Where possible, DOIs should be provided for all references where they exist, in the format <https://doi.org/10.1037/ppm0000185>. Ensure that 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*. 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 should be inserted in the manuscript (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 Special Issue is complete.

5. COPYRIGHT

Papers published in the PRSQ and Special Issues will be licensed under a Creative Commons AttributionNonCommercial-NoDerivatives 4.0 International Licence. Individual articles may be copied or downloaded for private, scholarly and not-for-profit use. Quotations may be extracted provided that the author(s) and The Royal Society of Queensland are acknowledged. Queries regarding republication of papers, or parts of papers such as figures and photographs, should be sent to the Secretary of The Royal Society of Queensland Inc. (rsocqld@gmail.com).

The right to charge fees for reproduction is transferred upon publication to and retained by the Society.

Revision date: 14.3.2026

APPENDIX

Sample Manuscript

See also final typeset version at:

<https://www.royalsocietyqld.org/proceedings/decadal-changes-in-phragmites-australis-performance-in-lake-eyre-supergroup-spring-communities-following-stock-exclusion>

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

Initial
capitals

Simon Lewis¹ 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.

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

Keywords
lower case

33
34 ¹ *Friends of Mound Springs, South Australia*

Include
state and
postcode.

35 ² *Environment Institute, The University of Adelaide, Adelaide, SA 5005, Australia*

36 ³ *School of Biological Sciences, The University of Adelaide, Adelaide, SA 5005, Australia*

37
38 Main Heading (initial capitals) **Introduction**

39
40 Human-mediated disturbance is reducing the heterogeneity and biodiversity of natural
41 ecosystems around the world (Winter et al., 2009; Aronson et al., 2014). Pastoral settlement is
42 a widespread example of this. Many dryland vegetation communities are heavily impacted by
43 domestic stock (e.g. cattle, *Bos taurus*, or sheep, *Ovis aries*), pest animals and occasionally
44 over-abundant native herbivores. The impacts of their combined grazing pressure (e.g. soil
45 compaction, nutrient enrichment, changes in species composition and abundance, reduced
46 vegetation complexity) are most concentrated around watering points such as troughs and
47 wetlands (Johnes et al., 1996; Landsberg et al., 2002). To reduce these negative effects on
48 wetland communities within landscapes dominated by dryland pastoralism, many have been
49 fenced to exclude stock and other herbivores over the past 40 years (e.g. Dobkin et al., 1998;
50 Yates et al., 2000). The long-term effects of stock removal on wetland vegetation
51 communities within dryland regions, however, are poorly understood.

Style for
in-text
reference

52
53 *Phragmites australis* is a tall-statured grass species native to Australia but with a cosmopolitan
54 distribution, forming monodominant stands in many wetlands throughout temperate and dryland
55 regions of the world (Kobbing et al., 2013; Packer et al., 2017; Canavan et al., 2019). As a
56 woody perennial grass, *P. australis* provides important reedbed habitat for native bird (Tmka et
57 al., 2014; Kane, 2001; Kiviat, 2013), insect (Tschardtke, 1999) and mammal species (Kiviat,
58 2013), and is an important coloniser in the hydroseral succession from aquatic to terrestrial
59 habitats for plant communities (Packer et al., 2017). This broad ecological envelope, together
60 with a tall-statured lifeform, gives it an advantage as one of the most invasive plants in the
61 world (Canavan et al., 2019; Kueffer et al., 2013). *Phragmites australis* competitiveness is
62 closely linked with its ability to persist and thrive in a variety of hydrological (water levels and
63 flow regimes; Deegan et al., 2007; Gotch, 2013) and nutrient (Packer et al., in review)
64 conditions. *Phragmites australis* is also a very important component of many traditional and
65 semi-traditional socioeconomic systems and practices around the world, including its use since
66 prehistoric times for roof thatching (e.g. Kobbing et al., 2013).

67
68 Mechanisms for *Phragmites* reproduction vary in form and success. *Phragmites* can reproduce
69 vegetatively (clonal expansion by rhizomes, or by dispersal of rhizomes or stems by water or
70 animals; Meyerson et al., 2014; Packer et al., 2017) or sexually via seedling recruitment
71 (Kettenring & Wigham, 2009; Kettenring et al., 2011). Water, wind and, to a lesser extent, fauna
72 such as birds disperse the small and light seeds of *Phragmites* (Kiviat, 2013; Packer et al., 2017).
73 Although established *Phragmites* stands are able to expand into many areas, including those with
74 previous ecological disturbance (Moore, 1973; Roberts, 2016; Duffield & Roberts, 2016),
75 germination and seedling establishment are limited as *Phragmites* seeds require particular
76 environmental conditions (Greenwood & MacFarlane, 2006; Gotch, 2013). The few reported
77 cases of new populations established from seed in Australia have been where it has colonised
78 muddy flats through to shallow, still water ± 10 cm above ground level (Packer et al., 2017). The
79 expansion of dense monodominant *Phragmites* has been associated with reduced floristic
80 diversity within some freshwater wetland areas, particularly where the *Phragmites* has colonised
81 as non-native stands (e.g. Hazelton et al., 2014). The three main characteristics that make
82 *Phragmites* an effective competitor are rhizomatous growth and aeration, shoot height and shoot
83 density (Gotch, 2013; Canavan et al., 2019). Direct competition is through space occupancy and
84 shading, and shorter plants are often outcompeted.

85
86 Within Australia, *Phragmites australis* is the most common member of the genus, and natural
87 populations are found in many parts of eastern Australia through to Tasmania (Roberts, 2000;
88 Duffield & Roberts, 2016; Packer et al., 2017). Within South Australia, it occurs in dryland
89 (e.g. Great Artesian Basin springs, River Murray corridor) through to temperate (e.g. Fleurieu
90 Peninsula swamps) climate zones.

91
92 The Great Artesian Basin (GAB) is the largest groundwater basin in Australia and one of the
93 largest in the world. It covers 22% of the Australian continent, including areas in Queensland,
94 New South Wales (NSW), South Australia and the Northern Territory. Great Artesian Basin
95 groundwater supports an estimated 7000 individual springs in 450 spring groups scattered
96 across the basin. Two species of *Phragmites* occur in the Great Artesian Basin springs – *P.*
97 *karka* and *P. australis*. For the most part, this paper is concerned with *P. australis* as one of
98 the most important wetland species internationally and in the Great Artesian Basin springs,
99 and the term *Phragmites* is used hereon.

100
101 *Phragmites* occurs as a natural component in many springs across the GAB. The GAB springs
102 are of enormous cultural significance to Indigenous people, being their only reliable water

103 source in the region for thousands of years. Archaeology in and around spring sites reflects the
104 importance of these permanent water sources in the otherwise dry landscapes (Hercus &
105 Sutton, 1985; Harris, 2002). There is evidence of traditional burning of *Phragmites* stands by
106 Aboriginal people, as well as excavation of areas with *Phragmites* to improve access to water
107 (Hercus & Sutton, 1985).

108
109 Disturbance of spring vegetation associated with European settlement dates from the mid-
110 1800s. Soon after exploration of South Australia's Far North, commencing in the late 1850s,
111 pastoralism was introduced to the region. Pastoralism at Anna Creek Station, for example,
112 dates back to 1863 (Harris, 2002). In the earliest days of pastoralism, the GAB springs
113 provided the only reliable water resource in the region, and many springs were fenced by
114 pastoralists to maintain a clean water supply and prevent bogging of stock. However, from the
115 late 1870s, artesian bores were drilled and these became the main watering points for stock. As
116 a result, most of the early fencing around springs was not maintained. A large number of GAB
117 springs have therefore been subject to pressure from stock and other herbivores for over 130
118 years.

119
120 Within the Great Artesian Basin, exclusion of stock and other introduced herbivores from some
121 wetlands already containing *Phragmites* has led to its expansion and reduced floristic richness
122 of other native spring vegetation (Fensham et al., 2004; Davies et al., 2010; Gotch, 2013).
123 However, the relationship between *Phragmites* and reduced plant diversity is not always
124 straightforward. Invasion and spread of *Phragmites* may not result in reduced diversity if other
125 plants are competitive and capable of out-shading *Phragmites* (Buttery et al., 1965; Keller,
126 2000), or produce biomass earlier in the annual growth cycle (Gussewell & Edwards, 1999).
127 The performance of *Phragmites* also depends on the genotype(s) present, with some *Phragmites*
128 genotypes being more able to thrive in particular conditions (e.g. substrate types) than others
129 (Packer et al., 2017; Saltonstall, 2002). The substrate conditions in which *Phragmites*
130 contributes to wetland diversity rather than monodominance are presently unclear for the Great
131 Artesian Basin mound springs and many other wetlands within dryland regions.

132
133 To investigate the response of *P. australis* to exclusion of stock and other introduced
134 herbivores around permanent artesian-fed springs of the Great Artesian Basin, this paper
135 presents a case study with 35 years of observational data on the Lake Eyre supergroup of
136 mound springs in South Australia. The case study aims to understand how naturally present
137 *Phragmites* populations expand and perform within vegetation communities of GAB springs
138 following stock exclusion. To achieve this aim, three core questions were investigated:

139

140 1. How does the performance of *Phragmites* (above-ground distribution and coverage)
141 respond to exclusion of stock grazing, and how has this changed over the past 35
142 years?

143 2. How does distance to nearest neighbouring springs influence the colonisation of
144 *Phragmites* at hitherto *Phragmites*-free springs?

145 3. What trends in spring vegetation composition are evident where *Phragmites* has
146 become dominant across this spring group and timescale?
147

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

152

153

Materials and Methods

154

155 **Study System**] Level 1

156

Use initial capitals for principal words in main headings and subheadings

157 This case study focused on the natural springs of the Great Artesian Basin in the vicinity of
158 Kati Thanda–Lake Eyre, often described as the Lake Eyre spring supergroup (Figure 1).

159 Within this spring supergroup, approximately 3800 spring vents over many hundreds of
160 springs have been described (Lewis et al., 2013). Here ‘vent’ is defined as a single
161 discharge of artesian water at the land surface and ‘spring’ as the total wetland associated
162 with a vent, or one or more immediately adjacent vents. In many instances, a single
163 ‘spring’ often comprises several spring vents.
164

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Case Study Springs

166

167 The case study focuses on 12 springs fenced to exclude stock and other herbivores, and a
168 large number of springs, described as Finnis Springs, on the former Finnis Springs
169 pastoral lease, now managed by the Arabana Aboriginal Corporation and de-stocked in the
170 mid-1980s (Table 1). The first 10 springs listed in Table 1 were fenced by the South
171 Australian Department of Environment and Planning in the 1980s and were, at that time, on
172 actively grazed pastoral lease land. The fencing comprised timber posts with four strands of
173 barbed wire, predominantly to exclude stock (cattle) as well as donkeys and horses – both
174 present in the area. Other potential pest species – such as camels and wild pigs – do not

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175 occur in the area to any significant extent, and native macropods are very sparse.
 176 *Phragmites* was naturally present at Big Perry, The Fountain, Twelve Mile, Outside,
 177 Nilpinna and Big Cadna-owie Springs, but absent from Blanche Cup, the Bubbler, Tarlton
 178 and the selected Strangways spring. This coordinated fencing program, and the long-term
 179 monitoring of responses, has been one of the major conservation investments for the
 180 region's Great Artesian Basin springs. Two springs on Billa Kalina pastoral lease are also
 181 included in this case study; these were fenced by the pastoral lessee in the early 2000s –
 182 again following a long history of cattle grazing. These springs are less than 100 m apart:
 183 one had *Phragmites* fringing a pool at the time of fencing while, at the second, there was no
 184 *Phragmites*. The springs on Finnis Springs Aboriginal lands were de-stocked in the mid-
 185 1980s, although some horses remain on the property. The Finnis Springs group includes
 186 several hundred springs around Hermit Hill (Hermit, Finnis and West Finnis Springs),
 187 with several others in the near vicinity to the south (e.g. Bopeechee, Beatrice, Venables). In
 188 terms of spring vegetation, Hermit and West Finnis Springs are most noteworthy for the
 189 occurrence of salt pipewort (*Eriocaulon carsonii*), an endangered endemic species limited
 190 to just a few sites in two spring supergroups in South Australia (Lake Eyre and Lake Frome
 191 supergroups). It also occurs at a small number of spring sites in Queensland and NSW
 192 (Davies et al., 2010). The vast majority of springs in the Finnis Springs group have
 193 *Phragmites*.

194
 195 **Table 1.** Case study springs protected from grazing animals since 1980s.
 196

Spring/s	Location	Area protected (ha)*	Year	<i>Phragmites</i> 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	<i>Cyperus laevigatus</i>
The Bubbler	As above	6.3	1984	Absent	<i>C. laevigatus</i> , <i>Schoenoplectus litoralis</i>
Strangways spring	Anna Creek P.L.	0.1	1984	Absent	<i>C. laevigatus</i> , <i>C. gymnocaulos</i>
Big Perry	Peake P.L.	2.7	1986	Present	<i>Typha domingensis</i> , <i>C. laevigatus</i> , <i>C. gymnocaulos</i> ,

Use sentence case for table heads.

					<i>Juncus kraussii</i>
The Fountain	Peake P.L.	0.7	1986	Present	<i>C. laevigatus</i> , <i>C. gymnocaulos</i>
Twelve Mile	Peake P.L.	2.6	1986	Present	<i>C. gymnocaulos</i> , <i>T. domingensis</i>
Outside	Peake P.L.	0.4	1986	Present	<i>C. laevigatus</i> , <i>C. gymnocaulos</i>
Tarlton†	Peake P.L.	9.2	1986	Absent	<i>C. laevigatus</i> , <i>T. domingensis</i>
Old Nilpinna	Nilpinna P.L.	4.0	1986	Present	<i>C. laevigatus</i> , <i>C. gymnocaulos</i>
Big Cadna-owie	Allandale P.L.	0.2	1986	Present	<i>C. laevigatus</i> , <i>C. gymnocaulos</i>
Billa Kalina Springs	Billa Kalina P.L.	~3.0	ca 2001	Present, spring 1; absent, spring 2	Spring 2: <i>C. laevigatus</i> , <i>C. gymnocaulos</i>
Finniss Springs	Finniss Springs Aboriginal Lands	Entire property, approx. 800 springs	ca 1985	Generally present	Predominantly <i>C. laevigatus</i> but with other sedges including <i>Juncus</i> , <i>Baumea</i> , <i>Schoenoplectus</i> and <i>Gahnia</i>

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

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

200 Supply Figures as
201 separate files. Insert
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[Insert Figure 1 near here]

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

206 Measuring the Performance of *Phragmites australis*

207
208 The case study incorporates published and unpublished literature on *Phragmites*
209 performance and management in the Lake Eyre supergroup. Qualitative data on plant
210 communities within the 10 springs fenced by the South Australian Department of
211 Environment and Planning in the mid-1980s were derived from photo-point monitoring
212 records collected by the Department (1984–2005) before and after fencing. The Department
213 established a total of 66 photo-points across the 10 springs. From 2005, the volunteer group

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214 Friends of Mound Springs (FOMS) has maintained some of the photo-points on an
215 opportunistic basis (1–3 yearly). However, many of the original photo-points have become
216 overgrown by *Phragmites*, and FOMS volunteers have reverted to more general observations
217 and photographs to assess trends. At Finniss Springs and Billa Kalina pastoral lease,
218 qualitative vegetation data were obtained from regular (1–2 yearly) site-specific observations
219 and analysis of changes and trends by FOMS from 2006 to the present.

220
221 Soil nutrient levels and *Phragmites* productivity have been surveyed at several GAB mound
222 springs in South Australia, including one of the case study springs – Bopeechee Spring within
223 Finniss Springs. As with the other GAB springs in the Finniss Springs group, Bopeechee Spring
224 has been free of stock pressure since the mid-1980s and has become dominated by *Phragmites*.
225 Bopeechee Spring was selected for a burning trial in 2016. Prior to the burn, soil nutrients and
226 *Phragmites* productivity were recorded. The density, height and survival (proportion aborted) of
227 *Phragmites* stems were recorded in fifteen 1 ⊗ 1 m quadrats in June 2016.

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229 Results

230
231 Monitoring and general observations at the 10 springs fenced by the South Australian
232 Department of Environment and Planning in the 1980s have shown no change in the presence
233 or absence of *Phragmites* at individual springs. This stability has also been noted through
234 qualitative observations at the de-stocked springs on Finniss Springs Aboriginal lands and two
235 fenced springs on Billa Kalina pastoral lease. The results presented here are therefore described
236 under two categories:

237

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

240

241 Springs without *Phragmites* at Time of Stock Exclusion

242

243 *Blanche Cup and the Bubbler*] Level 2

244

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

250 including shore club-rush (*Schoenoplectus litoralis*) and fringing native myrtle (*Myoporum*
251 *montanum*).

252

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

260

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

268

269 *Strangways Spring*

270

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

280

281 [Insert Figure 2 near here]

282

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

286

287 ***Tarlton Spring***

288

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

298

299 ***Billa Kalina Spring***

300

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

304

305 **Springs with *Phragmites* at Time of Stock Exclusion**

306

307 ***Springs Fenced by the South Australian Environment Agency in 1980s***

308

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

318

319 In a somewhat slower process, exemplified by The Fountain Spring, *Phragmites* expanded
320 more slowly down the spring tail, hitherto dominated by the bore-drain sedge (*C. laevigatus*).
321 After approximately 20 years of stock exclusion, further changes occurred at The Fountain

322 and Outside Springs (Figure 4). Since the early 2000s there has been a steady decline in the
323 above-ground growth of *Phragmites* in the main vents at the two springs – to the extent that
324 areas of open water have been emerging since 2017.

325
326 At the other fenced springs containing *Phragmites* (Big Perry, Twelve Mile, Nilpinna and Big
327 Cadna-owie), the dominance of *Phragmites* has continued after the early proliferation
328 immediately following fencing. No open pools are present at these springs. Table 2 provides an
329 overview of vegetation trends at the 10 springs following fencing, while Figures 3A and 3B
330 show the then-and-now situation at Big Cadna-owie Spring.

331 332 *De-stocked Springs on Finnis Springs Aboriginal Lands*

333
334 At Finnis Springs, where most of the springs contain *Phragmites*, regular observations
335 following stock exclusion in the mid-1980s showed a trend similar to the springs fenced in the
336 1980s (Figure 5), as referred to above. Prior to stock exclusion (early 1990s), *Phragmites* was
337 largely restricted to spring vents, surrounded by an extensive halo of *C. laevigatus* and other
338 sedges. Several years after stock exclusion (late 1990s–early 2000s), *Phragmites* growth
339 extended out, with the sedge haloes much reduced. Nearly three decades after stock exclusion
340 (2019), *Phragmites* extended over virtually the whole wetland area, with *C. laevigatus* sedge
341 haloes further reduced or no longer present at several springs.

342
343 Springs within the Finnis Springs group, specifically Hermit and West Finnis Springs,
344 provide habitat for the endangered salt pipewort, *Eriocaulon carsonii* (Figure 6). Qualitative
345 observations have shown a reduced incidence of *E. carsonii* at these springs, associated with
346 the proliferation of *Phragmites*.

347
348 Soil chemistry, nutrient levels and *Phragmites* stem response have been surveyed at one of
349 the springs on Finnis Springs – Bopeechee Spring (Table 3). The figures are not highly
350 informative as a single sampling but are indicative of data that would be useful if collected
351 more widely and systematically to establish relationships between *Phragmites* performance,
352 nutrient levels and soil chemistry.

353

354 [Insert Figure 3 near here]

355

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

358 dominated by *Phragmites*.

359

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

360

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

362

1985 Recently de-stocked	[Insert Figure 5A here]	<i>Phragmites</i> 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 <i>Phragmites</i>	[Insert Figure 5B here]	The <i>Phragmites</i> is spreading into the haloes of sedges (shorter wispy <i>Phragmites</i> surrounding the taller original clump).
2015 Dominant <i>Phragmites</i>	[Insert Figure 5C here]	<i>Phragmites</i> has spread to the outer edges of the spring wetlands to dominate the whole wetland area.

363

364 FIGURE 5. Vegetation sequence at Finnis Springs following de-stocking.

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[Insert Figure 6 near here]

FIGURE 6. Endangered salt pipewort (*Eriocaulon carsonii*) amongst *Phragmites* at Hermit Hill Spring, Finnis 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 <i>Phragmites</i> , interspersed with <i>Cyperus laevigatus</i> . Spring tails dominated by <i>C. laevigatus</i> .	Spring vents totally overgrown with <i>Phragmites</i> , no open water. Spring tails still mainly <i>C. laevigatus</i> but <i>Phragmites</i> starting to colonise towards the tail.	Vents still totally overgrown with <i>Phragmites</i> . Spring tails now dominated by <i>Phragmites</i> with small fringing areas of <i>C. laevigatus</i> .	Some vents showing significantly reduced <i>Phragmites</i> and some open water, majority still overgrown. Spring tails still dominated by <i>Phragmites</i> .

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

	pH	Salinity	Nitrate	Ammonium	Phosphorus	Stems	Stem
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		(ppm)	NO ₃ (mg/kg)	NH ₄ (mg/kg)	P (mg/Kg)	Total	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

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393

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).

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395

Stock and pest animals have a direct impact on spring vegetation and can lead to the loss of

396

plant species, as well as causing pugging and increased nutrient levels (nitrates and

397

phosphates) in spring waters and sediments, thereby affecting habitat quality. There are

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concerns that there have been associated losses of endemic flora and fauna (Fatchen &

399

Fatchen, 1993; Kovac & Mackay, 2009).

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Techniques to prevent damage from stock and pest animals include exclusion fencing around

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springs and de-stocking of spring areas. However, in protected areas that contain *Phragmites*, this

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has resulted in *Phragmites* expansion which excludes other spring vegetation and reduces open-

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water habitat. Findings of this case study within the Lake Eyre supergroup support previous reports

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of *Phragmites* as an effective and rapid expander in disturbed springs within the Great Artesian

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Basin (Fensham et al., 2004; Davies et al., 2010; Gotch, 2013). *Phragmites australis* has flourished

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in the changing post-disturbance hydrological and habitat conditions around spring vents and

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expanded into spring tails. These findings highlight the implications for springs and their flora

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when they are protected from stock and other herbivores after a long history of grazing.

410

411

The main findings in relation to the three key questions on *Phragmites* performance within Lake

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Eyre supergroup springs that have been protected since the mid-1980s are discussed below.

413

414

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

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416

The response of spring vegetation communities to stock exclusion was striking and occurred

417

within 5–10 years. At springs where *Phragmites* was present at the time of stock exclusion,

418

there was a relatively rapid proliferation of *Phragmites* – initially at the spring vent in the

419 first 10 years or so following stock exclusion, then spreading into most of the spring tail
420 over the following 10–20 years.

421
422 The monodominant expansion of *Phragmites* in GAB springs following cessation of grazing
423 pressure is unsurprising and consistent with its post-disturbance performance elsewhere in
424 Australia (Roberts, 2000; Duffield & Roberts, 2016) and beyond (Hürlimann, 1951; Caffrey
425 & Beglin, 1996; Packer et al., 2017). *Phragmites australis* occurs naturally in many of the
426 springs of the Lake Eyre supergroup and in many other GAB springs. It has been present at
427 Warburton Spring in the Lake Eyre supergroup for over 30,000 years (Gotch, 2013). In all of
428 the case study springs where *Phragmites* has proliferated, it was already present at the time of
429 fencing and stock exclusion.

430
431 The case study has also provided important indications of decadal changes in *Phragmites*
432 density within springs protected for over 30 years. In particular, vegetation observation at
433 Outside Spring and The Fountain indicate that above-ground growth of *Phragmites* is
434 diminishing in the main pool. Vegetation succession may be occurring within these protected
435 spring communities: from vegetation-fringed open pools, to complete vegetation cover, and
436 more recently towards *Phragmites* decline and open-water, vegetation-fringed pools again.
437 These observations indicate that, in the longer term, protected springs may sometimes revert to
438 a vegetation community with reduced above-ground *Phragmites*.

439
440 *Phragmites* often has a competitive advantage where it occurs in disturbed sites and where the
441 main source of disturbance – such as stock grazing – has been removed. Less clear, however,
442 is whether, and if so how, physical or chemical conditions might also interact with
443 disturbance and *Phragmites* performance. In particular, many of the case study springs were
444 previously grazed for a century or more prior to exclusion, so nutrient levels in spring
445 sediments are likely to have increased substantially. *Phragmites* is known to thrive in
446 nutrient-rich conditions (Duffield & Roberts, 2016; Packer et al., in review). The apparent
447 relationships between *Phragmites* density, height and cover, nutrient levels and other aspects
448 of sediment and water quality in GAB springs require further investigation.

449
450 **Potential for Establishment of *Phragmites* at Hitherto *Phragmites*-free Springs**

451
452 Although *Phragmites* is common in many spring vents and seeps within Wabma Kadarbu
453 Mound Springs Conservation Park, it has not established at Blanche Cup or the Bubbler.
454 Similarly, at Billa Kalina, there has been no establishment of *Phragmites* at a fenced

455 *Phragmites*-free spring despite its close proximity to a spring with *Phragmites* within the same
456 enclosure. These examples support observations elsewhere (Gotch, 2013) that there is a low
457 probability of colonisation into *Phragmites*-free springs within the Lake Eyre supergroup. In the
458 single recorded case of *Phragmites* establishment at a previously *Phragmites*-free spring in this
459 spring group – the Little Bubbler – its rate of spread has been slow, suggesting that there may
460 be abiotic conditions at the Little Bubbler not conducive to rapid spread.

461

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

463

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

477

478 **Implications for Conservation and Management**

479

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

486

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

491 *Phragmites* and promote the retention or restoration of more diverse wetland communities.

492

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

503

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

513

514 Active management to reduce *Phragmites*, where it is considered overabundant or invasive,
515 has included slashing, burning, cutting, grazing, and herbicide application (Keller, 2000;
516 Saltonstall, 2002; Sun et al., 2007). In general, these treatments were found to have only
517 short-term effects and limited feasibility for scaling up to the extent needed (Sun et al., 2007).

518 The use of fire or other techniques to remove above-ground biomass of *Phragmites* is
519 recommended during summer or early autumn when the nutrient content of their shoots is
520 greatest, thus inflicting physiological stress (Hellings & Gallagher, 1992; Güsewell, 2003).

521 Several studies have highlighted the role of controlled or pulse stock grazing in reducing
522 *Phragmites* growth (e.g. Coates et al., 2010). From observations in GAB springs over several
523 decades, it is clear that grazing by cattle can reduce the biomass of *Phragmites* substantially.

524 Pulse grazing will, however, also add a further infusion of nutrients to the spring
525 environment, which may prolong the cycle of vigorous *Phragmites* growth.

526

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

537

538 **Future Directions to Address Conservation Knowledge and Management Gaps**

539

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

548

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

554

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

562

Acknowledgements

This paper brings together information for the Lake Eyre supergroup of GAB springs collected over the last 40 years, mainly by the South Australian environment agency (currently Department for Environment and Water) and, more recently, by volunteers of the Friends of Mound Springs group. The contributions of the two groups are gratefully acknowledged. SL and JP acknowledge that the collection of field information was also facilitated through the help of the Arabana Aboriginal Corporation. Assistance in the field from Arabana elders is warmly acknowledged with thanks. Many of the springs referred to in this paper are on pastoral lease land, so thanks are due to the lessees and managers of Billa Kalina, Anna Creek, the Peake, Nilpinna and Allandale Stations for their ongoing support for researchers who visit the springs. SL and JP also acknowledge with thanks the two reviewers who provided comprehensive and valuable comments and suggestions, and the untiring efforts of the editors of the *Proceedings of The Royal Society of Queensland* Special Issue on GAB springs. All photographs in this paper were taken by Colin Harris and Simon Lewis.

Initials
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762 Author Profiles

763

764 *Simon Lewis* is a retired South Australian public servant, having spent most of his 34-year
765 career in the State Environment Department. He first travelled to the GAB springs in 1977
766 and, from the early 1980s, was involved in the spring fencing program which is the focus of
767 the case study described in this paper. Simon led the annual spring vegetation monitoring
768 program at these springs from the mid-1980s until 2005. He is a foundation member of
769 Friends of Mound Springs and is the long-standing Secretary of that group.
770

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