Moira the merrier: Vegetation recovery following grazing reduction in the Barmah Forest Ramsar Wetland

Stephanie Phillips[1], Jamie Kaye[1], Johanna Slijkerman[1], Tim Barlow[2], Keith Ward[2] and Matthew Crawford[2]

1 Water Technology Pty Ltd, Wangaratta, Victoria, 3677. Email: stephanie.phillips@watertech.com.au

2 Goulburn Broken Catchment Authority, Shepparton, Victoria, 3630

Key points

- Grazing by feral animals, particularly horses, has contributed to a dramatic decline in the extent of Moira Grass dominated wetlands in Barmah Forest
- The Limit of Acceptable Change to Barmah Forest's Ramsar ecological character was at risk of being exceeded.
- Long-term monitoring of grazing exclosures demonstrated the deleterious impacts of feral herbivores on wetland condition and key ecological values within the Barmah Forest Ramsar site.
- Control of feral horses has resulted in improved condition and expansion of Moira Grass.

Abstract

The Barmah Forest National Park is an internationally significant Ramsar wetland that once supported the most extensive Moira Grass *Pseudoraphis spinescens* dominated floodplains in the Murray-Darling Basin. Moira Grass is highly palatable and provides important fauna habitat while also supporting ecosystem functions such as nutrient cycling, sediment entrapment, and primary production. Its extent has undergone a major decline in the National Park since the 1930s largely due to altered flooding regimes and grazing by large, introduced herbivores. In 2020, fences were constructed at four wetlands to assess the effects of grazing cessation. This study reports on five years of monitoring of vegetation composition and wetland condition. Paired vegetation quadrats inside and outside exclosures were assessed annually in Autumn for species cover, bare ground, soil disturbance, hydrological phase, and biomass. Analyses incorporated generalised linear models and linear mixed effects models to account for strong site-level variation. Excluding feral horses and other large herbivores led to lower bare ground, higher biomass, and increased Moira Grass cover inside exclosures. Vegetation outside fences also improved after horse eradication commenced in 2022-23, with gains in Moira Grass and other native species. However, the magnitude and speed of recovery varied between wetlands, reflecting differences in grazing legacy, hydrology, and ecological condition.

Keywords

Ramsar, Barmah, Moira Grass (*Pseudoraphis spinescens),* grazing, wetlands, feral horses

Introduction

The Barmah Forest[5] is a Ramsar-listed wetland, comprising over 28,500 ha of River Red-gum *Eucalyptus camaldulensis* floodplain forest and treeless wetlands. It is located on the Victorian side of the Murray River between Echuca and Tocumwal. Ramsar listing recognises the site's international significance and requires the ongoing management to maintain its ecological character, including its hydrological processes, vegetation communities, and associated fauna (Parks Victoria, 2020).

The Barmah Forest has historically supported one of the most extensive areas of Moira Grass *Pseudoraphis spinescens* plains in Australia's Murray–Darling Basin (Aust. Gov. 2021). Beyond Barmah, Moira Grass is widely distributed along the Murray–Darling Basin, as well as occurring in northern parts

[5] Barmah Forest is used in a general sense to cover both the National Park and Ramsar site areas.

of inland and coastal mainland Australia, but not in semi-arid areas or central Australia (Roberts & Marston, 2011). The species is an aquatic or semi-aquatic perennial grass that occupies wetlands and floodplains, spreading vegetatively via trailing stems that root at the nodes on exposed mud as floodwaters recede (VicFlora, 2026; Colloff et al., 2014). Its dense growth provides important foraging habitat for birds, fish, frogs, and invertebrates, while also contributing to primary productivity and nutrient cycling within floodplain ecosystems (Roberts & Marston, 2011). The species is highly palatable to herbivores, and prolonged grazing pressure can substantially reduce biomass, cover and regenerative capacity (Colloff et al., 2014).

The extent of Moira Grass in the Barmah Forest has declined substantially since regulation of the Murray River commenced in the late 1930s, with losses continuing following its Ramsar listing in 1982 (Parks Victoria, 2020). Prior to river regulation, the Barmah–Millewa floodplain experienced regular winter and spring inundation driven by rainfall and snowmelt, which maintained extensive Moira Grass plains and floodplain wetlands. Construction of dams, weirs and regulators altered these hydrological patterns, reducing the frequency, duration, and extent of flooding across the forest (Parks Victoria, 2020; Hale & Butcher, 2011).

The decline of Moira Grass has also been strongly associated with grazing pressure from large herbivores, particularly cattle and feral horses, and to a lesser extent pigs and deer (Ward, pers. comm.). Although cattle grazing ceased during the 2007 drought and did not resume following declaration of the site as a National Park in 2010, impacts from feral herbivores have persisted. Altered hydrological conditions and grazing disturbance have also promoted the encroachment of Giant Rush *Juncus ingens* and River Red-gum, further reducing the extent of Moira Grass grasslands (Colloff et al., 2014).

By 2021, approximately 16% of the Moira Grass community mapped at the time of Ramsar listing in 1982 remained within the Barmah Forest. This decline exceeds the Limits of Acceptable Change (LAC) identified in the Ramsar Ecological Character Description for the site (Hale & Butcher, 2011), highlighting the need for improved protective management.

A range of management actions have been implemented to restore hydrological processes and reduce grazing pressure within Barmah Forest. Feral horse removal was identified as a priority management action to support the maintenance of ecological character within the Barmah Forest Ramsar site, with the long-term objective of removing horses from the National Park completely (Parks Victoria, 2020). An evaluation completed in 2023 reported that subsequent control programs reduced horse numbers between 2020 and 2024 (with over 800 animals removed), with management now focused on removal of remaining animals (Parks Victoria, 2024). Concurrently, environmental watering and modified flow management have increasingly aimed to restore more natural inundation patterns across the floodplain. Recent “translucent regulator” operations allow waterways to reconnect with the Murray River during winter and spring, better mimicking the seasonal rhythms to which its floodplain vegetation, fish, waterbirds, and wetland function are adapted (GBCMA, 2024).

To investigate vegetation responses to reduced grazing pressure, the Goulburn Broken Catchment Management Authority (GBCMA) established grazing exclosures within the Barmah Forest in 2020 at four wetlands – Steamer Plain, Harbours Lake, Top Lake, and Hut Lake (Figure 1). The exclosures were designed to exclude large feral herbivores, including horses and pigs, and Water Technology was engaged to undertake annual vegetation monitoring each Autumn from 2020 to 2025. The study aimed to assess changes in Moira Grass extent, vegetation condition, bare ground, and biomass inside and outside exclosures over time, with the hypothesis that reducing grazing pressure would promote Moira Grass recovery and improve overall wetland condition.

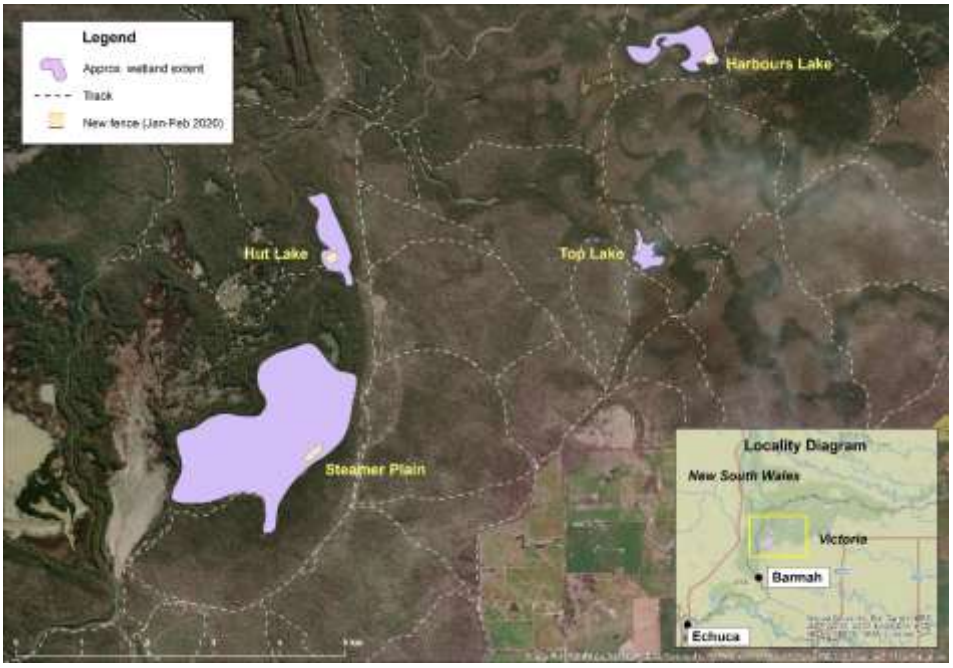

Figure 1 Location of the four wetlands for exclosure monitoring within the Barmah Forest

Method

Quadrat establishment

Paired vegetation monitoring quadrats (1 metre x 1 metre) were established at each of four wetlands between 6 and 20 February 2020 (Table 1). At all sites except Hut Lake, five quadrats were established inside the exclosure and five outside the exclosure. Hut Lake contained one paired inside and outside quadrat only, as the wetland already supported extensive Moira Grass cover and given the comparatively intact condition of the site, available project funding and monitoring effort were prioritised toward the more degraded wetlands. The inside and outside quadrats were located in similar elevation and vegetation. Monitoring was conducted annually during May from 2020 to 2025 to assess changes in vegetation composition and wetland condition.

Table 1 Size of the four wetlands for exclosure monitoring and date of fence installation for each one

Wetland	Size (ha)	Date of fence installation
Harbours Lake	2.25	13 January 2020
Top Lake	0.71	28 January 2020
Hut Lake	2.28	6 February 2020
Steamer Plain	2.95	20 February 2020

Cover and abundance

A modified Braun-Blanquet cover and abundance rating (Table 2) was used to quantify all species, bare ground, litter, and manure within the quadrats.

Table 2 Modified Braun-Blanquet cover abundance rating

Cover rating	Description	Foliage cover	Mid-point
+	Low abundance and Low cover	<1% cover	0.5%
1	Rare	1-5% cover	3%
2	Seldom present	5-25% cover	15%
3	Often present	25-50% cover	37.5%
4	Mostly present	50-75% cover	62.5%
5	Constantly present	75-100% cover	87.5%

Cover rating data was used to give an indication of changes over 5-years in species cover and diversity, and bare ground, at each wetland inside (treatment) and outside (control) the exclosures (Water Technology, 2025). The comparison was conducted at two levels (i) between the inside and outside paired quadrats at each wetland, and (ii) trends at the whole of site level.

Falling plate biomass measure

Vegetation biomass was assessed using a falling plate, which provides an indirect measure of dry matter yield based on compressed vegetation height (Rayburn & Lozier, 2003). This method was introduced in 2022 and has been implemented every year since. Plate height measurements were recorded within paired quadrats inside and outside exclosure fences.

General site observation

In addition to vegetation cover and abundance assessments, the hydrological phase, water depth, and soil disturbance severity rating (DELWP 2020) were recorded at each quadrat to provide contextual information for interpretation of vegetation responses. Photographs were also taken of each quadrat, and permanent photopoints were established at the four corners of each exclosure fence. At each photopoint, photographs were taken along adjoining fence lines and toward the centre of the exclosure to document changes in vegetation condition and biomass over time.

Statistical analysis

Following each survey, field data were entered into spreadsheets for processing, summarisation, and graphical presentation. Changes in vegetation cover, species richness, biomass, and other wetland condition indicators (e.g. bare ground) were compared between monitoring years and between quadrats. For analyses involving Braun-Blanquet cover-abundance classes, the mid-point value of each cover class was used and averaged across quadrats within treatment groups.

Statistical analyses were undertaken in RStudio (R Core Team, 2025). Generalised linear models (GLMs) and linear mixed-effects models (LMMs) were used to assess temporal changes in vegetation condition variables while accounting for variability between wetland sites. Wetland site was incorporated as either a fixed or random effect depending on the analysis, and post-hoc pairwise comparisons were undertaken using estimated marginal means (emmeans; $p < 0.05$).

Results

The results of vegetation assessments at Hut Lake, Harbours Lake, Top Lake, and Streamer Plain are presented below. Items such as macropod manure, and unknown dicot and monocot germinants where they were <1% cover, have not been included. The emphasis of the analysis below is on key features (e.g. bare ground and palatable or sensitive species) whose composition and growth may be altered by the exclusion of feral gazing animals.

Cover abundance assessment

Combined quadrat data from Harbours Lake, Top Lake and Steamer Plain were used to assess overall trends in bare ground and Moira Grass cover between 2020 and 2025 following the exclusion of feral grazing animals (Figure 2). Hut Lake was excluded from the combined analysis due to the presence of only one paired quadrat, which remained consistently dominated by Moira Grass throughout the monitoring period.

Across all wetlands, bare ground inside the exclosures declined substantially over time, while bare ground outside exclosures remained comparatively higher and more variable during the earlier monitoring years. However, from 2023 onwards, bare ground outside exclosures also declined, coinciding with substantial reductions in feral horse numbers.

In contrast, Moira Grass cover generally increased inside exclosures throughout the study period, supporting the hypothesis that reduced grazing pressure promotes the persistence and recovery of this highly palatable species. Outside exclosures, Moira Grass cover remained relatively low during the earlier years of monitoring but increased substantially between 2023 and 2025 following reductions in feral horse abundance. A slight decline in Moira Grass cover inside exclosures between 2024 and 2025 was likely associated with drier conditions, lower river flows and increased competition from other vegetation species at some wetlands.

Statistical analyses highlighted considerable variability in vegetation responses between wetlands. A generalised linear model (GLM) incorporating wetland site as a fixed factor and post-hoc pairwise comparisons using estimated marginal means (emmeans; $p < 0.05$) detected no significant difference in bare ground cover inside exclosures between May 2020 and May 2025 ($p = 0.9940$). However, when ‘site’ as a factor was removed from the model, the same GLM identified a significant overall decline in bare ground cover inside exclosures ($p = 0.0049$). For Moira Grass, the GLM identified a significant increase in cover inside exclosures between May 2020 and May 2025 ($p = 0.040$), while no significant change was detected outside exclosures ($p = 0.83$). Linear mixed-effects models (LMMs), with site included as a random effect, similarly identified an overall decline in bare ground and increase in Moira Grass cover inside exclosures while accounting for spatial variability between wetlands.

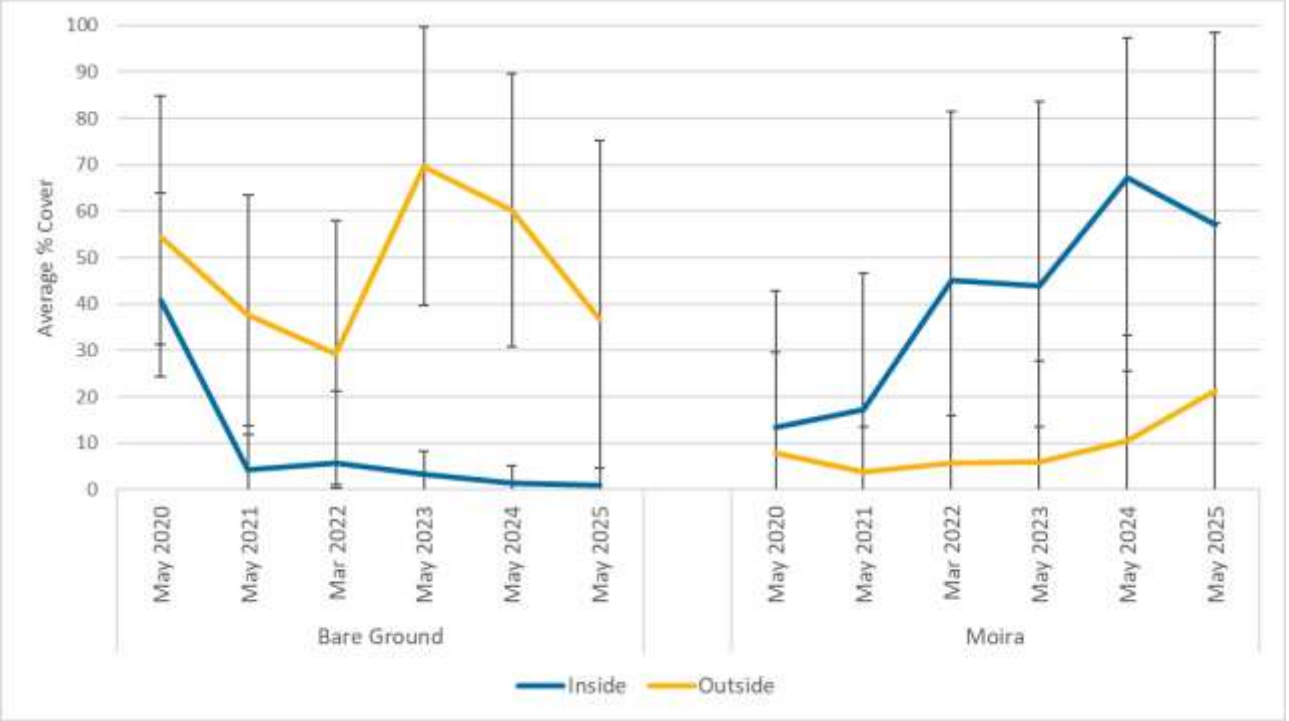

Figure 2 Comparison of average percentage of bare ground and Moira Grass inside and outside the exclosure at all sites (excluding Hut Lake), Autumn 2020-2025. Error bars represent variability in cover abundance across quadrats and wetlands

Given the considerable site-to-site variability identified in the GLM and LMM analyses, individual wetland trends were also examined to better understand the ecological responses occurring at each site (Figure 3). Several aquatic and herbaceous species, including Upright Water-milfoil *Myriophyllum cripatum*, Water Primrose *Ludwigia peploides*, Pacific Azolla *Azolla filiculoides*, Lesser Joyweed *Alternanthera denticulata* and Matted Starwort *Stellaria angustifolia subsp. tenella* fluctuated between years. These species were generally more abundant during wetter years associated with the 2022 and 2023 unregulated floods and declined during the drier conditions observed between 2023 and 2025 (Murray–Darling Basin Authority, 2025).

Hut Lake remained strongly dominated by Moira Grass throughout the study period, with limited bare ground recorded both inside and outside the exclosure during later monitoring years (Figure 3, A). Harbours Lake showed substantial increases in Moira Grass cover within exclosures over time, while outside quadrats remained more variable and were often dominated by bare ground or herbaceous species (Figure 3, B). At Top Lake, Moira Grass recovery inside the exclosure was slower and vegetation dynamics were strongly influenced by Creeping Knotweed *Persicaria prostrata* which remained dominant throughout the monitoring period (Figure 3, C; Colloff et al., 2014).

Steamer Plain exhibited notable shifts in vegetation structure following grazing exclusion. Moira Grass progressively expanded within the exclosure and increasingly extended into deeper sections of the wetland. Common Spike-sedge *Eleocharis acuta* remained abundant within exclosures throughout the study and also recovered substantially outside exclosures during the later years of monitoring, coinciding with reduced feral horse impacts across the wetland system (Figure 3, D).

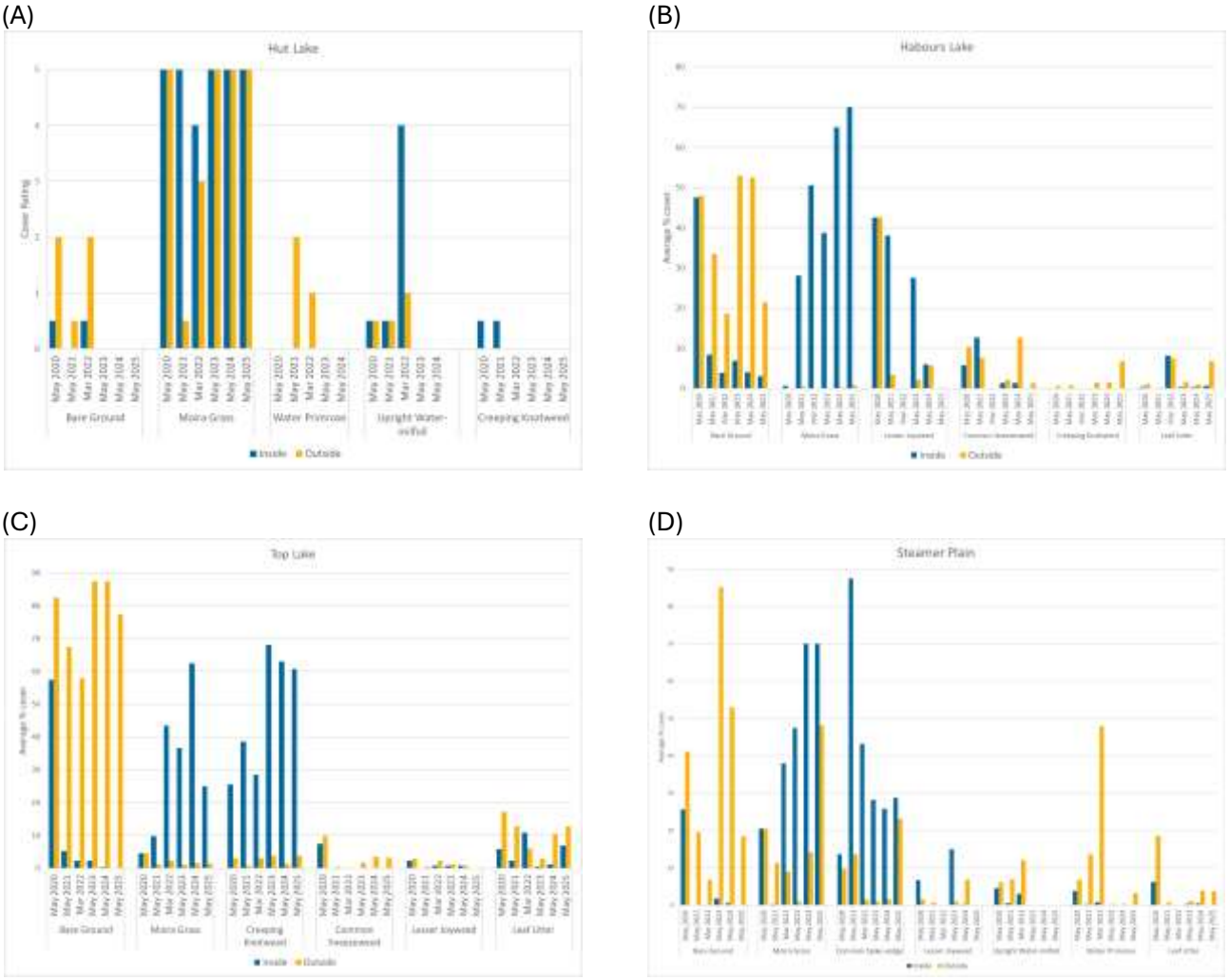

Figure 3 Cover ratings for inside and outside quadrats at Hut Lake (A), Harbours Lake (B), Top Lake (C) and Steamer Plain (D), Autumn 2020-2025

Falling plate biomass assessment

Falling plate assessments indicated that vegetation height, and therefore estimated biomass, was consistently greater inside exclosures compared to outside across the monitoring period (Figure 4). In May 2025, vegetation height inside the exclosures was significantly greater than outside (GLM with emmeans post-hoc comparisons; $p = 0.0009$), supporting the notion that exclusion of feral herbivores resulted in greater vegetation biomass.

Despite this difference between treatments, no significant temporal change in vegetation height was detected inside the exclosures between 2022 and 2025, or between 2024 and 2025, indicating that biomass levels may have stabilised during the later years of monitoring. Similarly, no significant temporal changes in vegetation height were observed outside the exclosures over the same period.

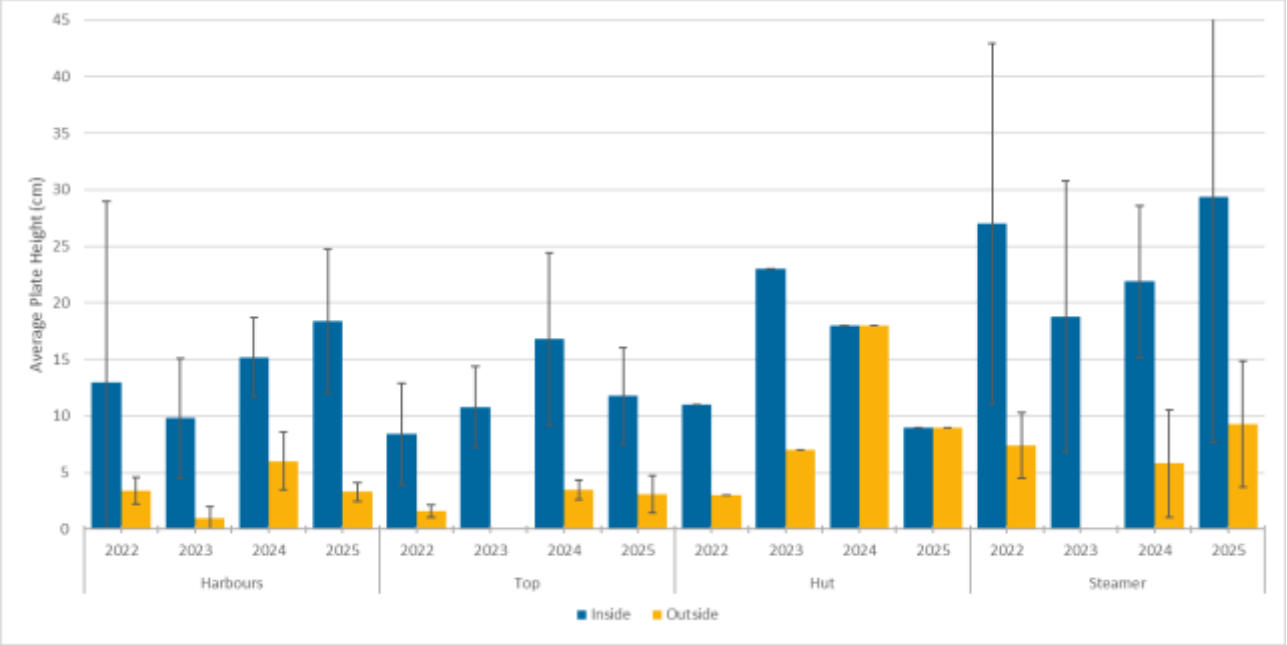

Figure 4 Average Plate Height at all wetlands, Autumn 2020–2025. Error bars represent the standard deviation of vegetation height measurements within quadrats at each site

General site observations

General site observations and photopoints showed clear changes in vegetation condition inside and outside exclosures throughout the study period and Steamer Plain provided a clear example of this (Figure 5). In 2020, there was substantial ground disturbance and bare ground both inside and outside the exclosure. By 2023, dense Moira Grass and improved vegetation condition were evident inside the exclosure, while still looking disturbed on the outside where feral horse activity was still common. By 2025, vegetation condition had improved both inside and outside the exclosure with dense Moira Grass cover and reduced signs of grazing disturbance across the wetland.

Figure 5 Photopoint comparison at Steamer Plain showing vegetation condition inside and outside the exclosure in 2020, 2023 and 2025

Discussion

Effects of grazing exclusion on wetland condition

The results of this five-year study demonstrate that feral herbivores negatively impact Moira Grass vigour and contribute to increased bare ground and soil disturbance within Barmah Forest wetlands through grazing, trampling, and pugging. These findings support previous observations that grazing pressure is a major driver of degradation within the Moira Grass plains of the Barmah Forest Ramsar site (Colloff et al., 2014).

Across all wetlands, bare ground within exclosures declined following fence installation, while soil disturbance also generally improved. In contrast, bare ground outside exclosures remained higher and more variable throughout much of the monitoring period, particularly during the earlier years when feral horse impacts were greatest (Parks Victoria, 2024).

Inside the exclosures, Moira Grass generally remained stable or increased in cover throughout the study period, while vegetation biomass remained consistently greater than outside exclosures. Although slight declines in Moira Grass cover were observed at some wetlands during later years, these changes were more likely associated with seasonal drying and hydrological variability than renewed grazing impacts. Overall, vegetation condition inside exclosures remained substantially improved relative to grazed areas.

Vegetation recovery following reduction in grazing pressure

The ecological benefits of grazing exclusion became apparent within the first few years of monitoring and continued through to the final assessment period in 2025. Fencing reduced direct grazing, trampling, and pugging impacts, allowing vegetation cover and biomass to recover across all wetlands. These findings align with broader studies of plant defoliation, which show that repeated grazing can substantially reduce plant growth, particularly root and rhizome development (Schuster, 1964). Reduced root growth and soil penetration likely limit the capacity of wetland plants to recover, expand, and persist.

While the strongest vegetation responses initially occurred inside exclosures, recovery outside exclosures also became increasingly evident but only after substantial reductions in feral horse numbers occurred. Outside fences, bare ground declined markedly after 2023, while Moira Grass cover and vegetation biomass increased. By May 2025, vegetation cover in some outside quadrats approached levels similar to that recorded inside exclosures.

Although many of the changes outside exclosures were not statistically significant, the trends observed in quadrat data, falling plate biomass assessments and fence corner photopoints collectively suggest that broad-scale feral horse control programs improve wetland condition beyond fenced areas. These findings support the management actions implemented under the Barmah Forest Strategic Action Plan (Parks Victoria, 2020; Parks Victoria, 2024) and indicate that reducing grazing pressure can contribute to recovery of wetland vegetation and ecological character across the Ramsar site.

Importance of site-level variability

Considerable variability in vegetation responses was observed between wetlands, highlighting the importance of accounting for site-level differences when interpreting ecological trends. While combined analyses of bare ground and Moira Grass cover provided a useful overview of broad patterns, averaging data across wetlands also masked important site-specific responses.

Statistical analyses showed that accounting for site substantially influenced interpretation of vegetation trends. GLM analyses, which treated site as a fixed factor, reduced the significance of several apparent trends, indicating that responses varied among wetlands, while LMM analyses identified broader-scale trends while accounting for site-level variability. These differences likely reflect variation in hydrology, ecological condition, grazing history, and disturbance among wetlands. Consequently, combining all wetlands into a single average has the potential to oversimplify complex ecological dynamics and obscure important localised responses. Together, the GLM and LMM approaches provided a more robust assessment of vegetation trends and management outcomes across the study area.

Management implications and future monitoring

Overall, the 2025 results suggest that reducing feral grazing pressure, both through exclosure fencing and feral horse population control, is contributing to measurable improvements in wetland condition

within the Barmah Forest Ramsar site. These improvements include reductions in bare ground, increased vegetation biomass, and recovery of key native wetland species, particularly Moira Grass.

The findings support ongoing management actions aimed at maintaining the ecological character of the Barmah Forest Ramsar wetland and promoting recovery of Moira Grass communities. However, the variability observed between wetlands also highlights the importance of considering hydrology, site condition and local disturbance history when evaluating management effectiveness.

Continued long-term monitoring will remain essential for determining whether these recovery trends persist over time and for improving understanding of evolving vegetation dynamics within and beyond the exclosures under changing hydrological and management conditions.

Conclusion

This five-year monitoring study demonstrated that reducing feral herbivore grazing pressure through exclosure fencing and broader feral horse control programs contributed to improved wetland condition within the Barmah Forest Ramsar site. Across the monitored wetlands, grazing exclusion was associated with reductions in bare ground, increased vegetation biomass and improved persistence and recovery of Moira Grass communities. The results also indicated that vegetation responses varied between wetlands, reflecting differences in hydrology, grazing history, and pre-existing ecological condition.

Hydrological conditions are considered an important driver of vegetation dynamics, influencing the abundance and distribution of wetland species. However, the expansion and persistence of Moira Grass within exclosures, and increasingly within some unfenced areas following reductions in feral horse numbers, demonstrate that grazing pressure has been a major negative influence on the extent and vigour of this important wetland species.

Overall, the findings support ongoing feral herbivore management and environmental watering initiatives aimed at maintaining the ecological character of the Barmah Forest Ramsar wetland and supporting the long-term persistence of Moira Grass communities. Continued improvement in wetland condition will be important to ensure the site retains the ecological character, values, and functions for which it was internationally recognised under the Ramsar Convention. Long-term monitoring will remain essential for understanding vegetation responses under changing hydrological conditions and for evaluating the effectiveness of future management actions across the floodplain.

Acknowledgements

The project team would like to respectfully acknowledge the key personnel of the Yorta Yorta Nation Aboriginal Corporation (NAC), Parks Victoria and their local rangers, the Department of Energy, Environment and Climate Action (DEECA) including the Ramsar program staff and Goulburn Broken CMA for their valuable input, collaboration and support throughout this study.

References

Australian Bureau of Meteorology (BOM) (2025). Climate statistics for Australian locations: Echuca Aerodrome. *Australia Government*. https://www.bom.gov.au/climate/averages/tables/cw_080015.shtml last access May 30, 2025.

Australian Government (2021) Australian Wetlands Database Ramsar wetlands: Barmah Forest https://www.environment.gov.au/cgi-bin/wetlands/ramsardetails.pl?refcode=64 last accessed May 14, 2026

Center, T.D., Van, T.K., Dray, A.J., Franks, S.J., Rebelo, M.T., Pratt, P.D. & Rayamajhi, M.B. (2005). Herbivory alters competitive interactions between two invasive aquatic plants. *Biological Control* 33, 173-185

Colloff, M.J., Ward, K.A. and Roberts, J. (2014) Ecology and conservation of grassy wetlands dominated by spiny mud grass Pseudoraphis spinescens in the southern Murray–Darling Basin, Australia. *Aquatic Conservation: Marine and Freshwater Ecosystems* 24 (2), 238–255

DELWP (2020) Index of Wetland Condition (IWC) Field Assessment Procedure December 2020. Department of Environment, Land, Water and Planning, East Melbourne, Victoria

Goulburn Broken Catchment Management Authority (GBCMA) (2024). Barmah Forest (Murray System) Seasonal Watering Proposal 2024-25. *Goulburn Broken CMA*. Shepparton, Victoria

Hale, J. & Butcher, R. (2011) Ecological Character Description for the Barmah Forest Ramsar Site. *Report to the Department of Sustainability, Environment, Water, Population and Communities, Canberra*

Just, K., Bennetts, B. & Wright, T. (2025). Barmah-Millewa Forest Wetland Vegetation Condition Monitoring 2025. *Report prepared for the Goulburn Broken Catchment Management Authority, Shepparton*

Murray–Darling Basin Authority (2025). River Murray Data: Water Information for the River Murray system (Tocumwal (Murray)) https://riverdata.mdba.gov.au/list-view/tocumwal last accessed May 30, 2025

Parks Victoria (2020). Protection of floodplain marshes Barmah National Park and Barmah Forest Ramsar site: Strategic Action Plan 2020 – 2023. *Parks Victoria*. Melbourne

Parks Victoria (2024). Protection of Floodplain Marshes in Barmah National Park and Barmah Forest Ramsar Site – Strategic Action Plan EVALUATION 2020-2024. *Parks Victoria*: Melbourne, Australia

R Core Team (2025). R: A language and environment for statistical computing. *R Foundation for Statistical Computing*, Vienna, Austria. https://www.R-project.org/ last accessed May 22, 2025.

Rayburn, E. & Lozier, J.(2003) A Falling Plate Meter for Estimating Pasture Forage Mass. West Virginia University Extension Service

Roberts, J., & Marston, F. (2011). Water regime for wetland and floodplain plants: a source book for the Murray–Darling Basin. *National Water Commission*, Canberra

Schuster, J. (1964) Root Development of Native Plants Under Three Grazing Intensities. *Ecology* 45 (1), 63-70

VicFlora (2021). Flora of Victoria. *Royal Botanic Gardens Victoria*, https://vicflora.rbg.vic.gov.au last accessed May 14, 2026

Water Technology (2025) Barmah Exclosure Monitoring*, a report for the Goulburn Broken Catchment Management Authority*. Water Technology. Wangaratta, Victoria