Australasian Journal of Water Resources

ISSN: (Print) (Online) Journal homepage: https://engineersaustralia.tandfonline.com/loi/twar20

Restoring cultural plant communities at sacred water sites

Valerie Caron, Jayne Brim Box, Veronica P. Dobson, Victor Dobson, Luke Richmond, Ross M. Thompson & Fiona Dyer

To cite this article: Valerie Caron, Jayne Brim Box, Veronica P. Dobson, Victor Dobson, Luke Richmond, Ross M. Thompson & Fiona Dyer (2021): Restoring cultural plant communities at sacred water sites, Australasian Journal of Water Resources, DOI: 10.1080/13241583.2021.1888854

To link to this article: https://doi.org/10.1080/13241583.2021.1888854

Published online: 08 Mar 2021.

Submit your article to this journal

Article views: 64

View related articles

View Crossmark data

Full Terms & Conditions of access and use can be found at
https://engineersaustralia.tandfonline.com/action/journalInformation?journalCode=twar20

AUSTRALASIAN JOURNAL OF WATER RESOURCES
https://doi.org/10.1080/13241583.2021.1888854

Taylor & Francis
Taylor & Francis Group

ARTICLE

Check for updates

Restoring cultural plant communities at sacred water sites

Valerie Caron [a,b], Jayne Brim Box [c], Veronica P. Dobson[b], Victor Dobson[b], Luke Richmond[b], Ross M. Thompson [b,d] and Fiona Dyer [b,d]

[a]CSIRO, Health and Biosecurity, Canberra, ACT, Australia; [b]Institute for Applied Ecology, University of Canberra, Bruce, ACT, Australia;; [c]Department of Environment, Parks and Water Security, Northern Territory Government, Alice Springs, NT, Australia; [d]Centre for Applied Water Science, University of Canberra, Bruce, ACT, Australia

ABSTRACT
Water places have been critical to central Australian Indigenous peoples for thousands of years. However, many waterhole communities have been degraded by factors including invasion by large feral herbivores and non-native plants. We document the restoration of two waterholes near Santa Teresa (Ltyentye Apurte), with a focus on culturally significant plants. We described plant communities around waterholes in 2007, before fences were erected to exclude large feral animals, and again in 2018. Plant cover and diversity were higher after fencing and the occurrence of culturally significant plants greatly increased. However, invasive buffel grass was the dominant ground cover after fencing and will require active suppression to allow culturally significant native plants to proliferate. Traditional Owners identified excellent opportunities to achieve restoration through educating young people, with a focus on sharing intergenerational knowledge and engaging local Indigenous rangers in management, enabling them to meet the traditional obligations to care for country.

ARTICLE HISTORY
Received 13 March 2020
Accepted 8 February 2021

KEYWORDS
Waterhole; arrernte; traditional knowledge; buffel grass; feral animal

1. Introduction

Waterholes are a critical component of Central Australian Indigenous communities' way of life, with water commonly identified as 'the most valued and rarest of resources'(CLC 2015). Local people relied, and continue to rely, on a variety of water features to sustain them. These water places, which range from small isolated springs and soakages to large (>3 km) spring runs, continue to hold great cultural significance (Bayly 1999). Water places are not only vital for the sustainability of local bush foods, but also feature strongly in the *Tjukurpa* (Aboriginal law), which is central to the spiritual and cultural well-being of Indigenous people and communities (James 2015; Judd 2019). Historically water sites were actively managed to limit sediment in-filling, prevent sites from drying out and to maintain their overall integrity in terms of water quality and ecological community composition. These activities had important cultural and ecological benefits (Dobson 2009).

> *"Our old people always looked after and cared for these waters, and we are carrying on this legacy. It's our responsibility because these sites are just as important to our people as other sacred sites."* Veronica Perrurle Hayes (Dobson), Traditional Owner, as quoted from Caring for Country: Hayes Springs, Mparntwenge. Salt Springs, Irlkerteye, Dialogue 28 (2009)

Beyond their cultural values, aboriginal people also recognised the ecological values provided by freshwater systems. Central Australia waterbodies provide distinct and isolated habitats for both aquatic and terrestrial species and support a significant percentage of the biodiversity within the region (Brim Box et al. 2014). Given the floristic and faunal richness of these sites, it is not surprising that Aboriginal people often retreated to areas of permanent water during drought for both water and food (Bayly 1999; Latz 2018).

The plant communities associated with water places in central Australia are extremely important to Aboriginal people (Latz 2018), who had an encyclopaedic knowledge of plant species within their traditional lands. At least 140 plant species are still used by Aboriginal people for food (Latz 2018), with additional plant species used either for medicinal or cultural purposes (Dobson and Nano 2005). Most water places host plant communities that differ from the surrounding landscape, with concomitant differences in faunal biodiversity. For example, wild figs (*Ficus platypoda*) occur throughout central Australia, but grow to their largest (and heaviest fruiting) size near permanent water (Latz 2018). Wild figs are an important bush food for Aboriginal people and are eaten by a variety of bird and mammal species.

Similar to the plight of freshwater ecosystems in other arid regions of the world (Sada, Fleishman, and Murphy 2005), many central Australian waterbodies have been degraded by multiple interacting processes that followed settler colonialism. These include the introduction of herbivores (stock and feral) and non-

CONTACT Valerie Caron Valerie.caron@csiro.au
© 2021 Informa UK Limited, trading as Taylor & Francis Group

native predators, colonisation by invasive plants and groundwater extraction (Brim Box et al. 2008; Brim Box et al. 2016a). In addition, the movement of Aboriginal people off their traditional lands (hereafter 'Country') has meant that many water places are not visited as frequently as in the past (CLC 2015). As a consequence, water place names, locations and associated *Tjukurpa* stories and ceremonies have been lost, as have traditions and practices of managing water sites (CLC 2015). Aboriginal elders, who knew the traditional ways of taking care of water sites, continue to pass and, 'the younger people are not learning their traditional responsibilities for their ancestral land' (Dobson 2009).

Large feral herbivores, mainly cattle, horses and camels, are a particular threat to Central Australian ecosystems (Roberts et al. 2001). Invasive grazing animals are much larger than native animals, with the largest native grazer being the red kangaroo (*Macropus rufus*). Non-native herbivores consume more water than native animals, and often occur in large groups. Impacts from large feral animals occur via several pathways including grazing, trampling and degradation of water quality. For example, unregulated drinking by feral animals with very high water needs can reduce the water availability at springs and waterholes because those sites rely on ground or rain water to be replenished (Brim Box et al. 2010). Furthermore, large feral ungulates have hooves that damage fragile desert soils and can cause major erosion. They also impact on water quality by increasing sediment and nutrients and defaecating directly in the water, which decreases aquatic animal diversity (McBurnie et al. 2015; Brim Box et al. 2016a). In very dry times it is not uncommon for feral animals to perish in waterholes, making the waters unusable for both people and native animals (Edwards et al. 2008). Large feral animals impact on native species directly by outcompeting them for access to water and subsequently, decrease visitation rates of native species that need to drink daily, such as dingoes and seed-eating birds (Brim Box et al. 2019). Large feral animals further impact water sites by affecting vegetation. They graze selectively on vegetation, causing stunting of woody shrub and trees (Brim Box et al. 2016b), suppressing plant recruitment (Edwards et al. 2010) and contributing to weed dispersal (Dobbie, Berman, and Braysher 1993; Ansong and Pickering 2013). As camels can eat 80% of the common plants in central Australia, many with important cultural uses (Edwards et al. 2010), their impact on sacred water places can be profound.

Aboriginal people across Central Australia have clearly identified the need to restore and manage water places within their traditional Countries (Dobson 2009; CLC 2015). Active restoration is often needed to mitigate threatening processes, with local Indigenous rangers groups playing an essential role (e.g.Weston et al. 2012; Dobbs et al. 2016; Waltham et al. 2018). Vegetation cover and diversity are important to the health of the water places and therefore can be used to indicate successful restoration. In addition, intergenerational transfer of both cultural and ecological knowledge is a key component of restoration efforts, because it is vital to long-term management success. Working with Traditional Owners (i.e. Veronica and Victor Dobson, two of the authors), local Aboriginal rangers and school students, our study looked at the outcomes of restoration of two Eastern Arrernte sacred water sites, Salt Springs *Irlkerteye* and Hayes Springs *Mparntwenge*. Our research had two main foci;

(1) To describe restoration outcomes (exclusion of large exotic grazers by fencing) by comparing plant composition and cover before (2007) and after (2018) fencing.
(2) To determine whether fencing can restore native plant taxa which provide a range of cultural ecosystem services, based on a catalogue of culturally significant plants collated more than 50 years ago.

2. Methods

2.1. Sites

Salt and Hayes Springs are located in the Ulampe-Arenye ranges and are part of a five-spring complex near Ltyentye Apurte (aka Santa Teresa). All five spring sites have cultural and ecological significance for the Eastern Arrernte people. Before the Santa Teresa mission was established in the 1950s, people lived near the springs and when conditions were good, could stay for months at a time (V.P. Dobson, traditional knowledge).

Hayes and Salt Springs are approximately 7 km apart, and both occur as a series of small, groundwater-fed shallow pools in small drainage lines surrounded by steep rocky cliffs, forming gorges. The pools at Hayes Springs are freshwater (salinities less than >1,000 mgL), while the pools at Salt Springs range from freshwater to hypersaline (salinity >35,000 mgL). Within both gorges the dominant large woody plant species is paperbark (*Melaleuca glomerata*). While the vegetation at both springs was once diverse, and included many important cultural plants, flora diversity has decreased in recent years, associated with the presence of feral cattle and horses (Dobson 2009).

2.2. Site management

To exclude feral animals, fences were erected at both sites in late 2006. Since then, the fence at Hayes Springs has continued to exclude feral herbivores from within the spring complex, mainly because of the presence of an accessible spring outside the fence which provides an alternative water source for feral animals. In contrast, no alternative water source was available at Salt Springs, and feral animals continually knocked the fencing down to access water from the springs. To provide an alternative drinking source for feral cattle and horses at Salt Springs, a trough sourcing water from a disused bore was installed outside the fence in 2018.

Historically Eastern Arrernte people would keep Hayes and Salt Springs from filling in by the periodic removal of algae and sediment (Dobson 2009). For several years prior to 2006, little maintenance was done at Hayes Spring, and consequently one of the small pools filled with dung and sediments. This was removed in 2006, which restored groundwater flow to the pool. In addition, bulrushes (genus *Typha*), a species not previously known from Salt or Hayes Springs (V.P. Dobson, traditional knowledge) were removed. From 2017, both springs have been maintained to prevent infilling, and the weed grasses couch (*Cynodon dactylon*) and buffel (*Cenchrus ciliaris*) have been periodically removed from inside the fences.

2.3. Vegetation survey

Plant surveys were conducted soon after the fences were erected in 2007 and 11 years later, in 2018. Point-intersect transects at both sites were used to quantify ground cover, in April 2007 and in April 2018. Five transects, 5 m apart, were established at each site, and ran perpendicular to the drainage line from rock face to rock face and across the main water pools. Transect lengths varied from 20 m to 28 m. Point-intersects were established at 1 m intervals along each transect, and all plants as well as substrate (i.e. rock, bare ground, etc.), were identified at these points. A total of 112 points were sampled for Hayes Springs in 2007 and 107 points in 2018, compared to 144 point for Salt Springs in 2007 and 141 in 2018. Percentage cover was calculated as the percentage of points where plants were found.

To assess whether native propagules were present that would allow recovery of native plant communities, a seedbank study was conducted in April 2017 at Salt Springs. Soil samples were taken along the point transects. Six 1 m x 1 m quadrats were placed randomly along transects 1–4. Only three quadrats were sampled from transect 5 because of the rockiness of the transect. Five soil samples were taken from each quadrat using a 9-cm diameter plastic pipe to ensure even sampling of the area. The soil samples were not taken from a standard depth, as soil depth varied greatly across the quadrats. The soil was homogenised and transported to a glasshouse at the University of Canberra. The soil samples were distributed into 8 × 8 x 10 cm (w x l x d) pots, by spreading 3–4 cm (depth) of the soil sample up top of a river sand potting mix. Samples were soaked and watered every 2–3 days and on hot days. Germination was recorded every week and continued until no new plants were germinating. The seedlings were then separated into individual pots to allow for continued growth to aid in identification. All plants were identified using (Cunningham 1992) and PlantNET (http://plantnet.rbgsyd.nsw.gov.au/). Identification was verified by plant experts and the traditional knowledge of Veronica Dobson.

To determine cultural values associated with plant communities, the 2018 plant list was annotated with reference to the traditional ethnobotanical knowledge of Veronica Dobson, a Traditional Owner of the site. Plants with known cultural uses were identified (hereafter 'traditional use plants') and their response to restoration assessed.

2.4. Data analyses

A two-way ANOVA was used to test for differences in plant cover between years (i.e. before and after fencing) and sites. As transects were not placed exactly in the same place, they were considered independent through time. Data were arcsine transformed prior to the analyses to meet assumptions of normality of residuals and homogeneity of variances of the data. To assess the potential for seedbank saturation by buffel grass, a linear regression was used to assess the relationship between the number of buffelgrass seedlings and other seedlings that emerged from the soil samples. All univariate analyses were performed in JMP (version 14).

To assess changes in plant communities through time, percentage cover of plants at each year, transect and site were collated into a single matrix. Similarity percentages (SIMPER) analysis was used to assess which plant taxa increased or decreased, using a two-factor crossed design (site x sampling time). Community similarity between each sampling point was calculated using Bray–Curtis similarities. Very high values were down-weighted through a log (X + 1) transformation. To visualise differences in community composition, the similarity matrix was plotted as a non-metric multi-dimensional scaling ordination. One outlier (a Hayes Spring sample that included only *Typha*) was removed to aid in visualisation. Two-factor analysis of Similarities (ANOSIM) was used with a two-factor crossed design (site x sampling time) to analyse for differences between communities. All analyses were carried out in Primer v7 (Clarke and Gorley 2015) and references therein for specific analyses).

Initial analysis showed that bare ground before fencing and exotic grasses after fencing dominated patterns of community composition. Therefore, the analyses were repeated three more times excluding samples with no plants and firstly excluding grasses, then excluding all non-native plants and finally only including traditional use plants. As a result, four sets of results were produced a) all plants, b) all plants except exotic grasses, c) native plants only and d) traditional use plants only.

3. Results

3.1. Vegetation survey

A total of 21 plant species were identified in the point transects (Table 1). The number of native species found increased at both springs between the two sample periods. In 2007, only four native plant species were identified in the point transects at each spring. In 2018, 10 and 12 native species were found at Salt and Hayes springs, respectively. Native plants found in 2007 were also detected in 2018, with the exception of *Typha*, which was actively managed and removed from the sites and native fuchsia (*Eremophila freelingii*) which was still present on the rocky slopes where it usually grows, but not detected in the transects. All native plants found in 2018 were also present historically, except for *Typha* which did not occur at the two sites. Sow thistle (*Sonchus oleraceus*) is the only exotic species detected in 2018 that also occurred historically (Table 1).

From 2007 to 2018 the percentage cover of plants increased dramatically from 15% to 83% at Hayes Springs and 34% to 82% at Salt Springs (Figure 1, Table 2). This was caused by significant increases in the cover of both exotic species and native shrubs. While there was an increase in native herbaceous cover (from not detectable to 5%), this was not significant (Table 2).

Some of the plants detected in 2018 are important culturally, such as native grasses, paperbark (*Melaleuca glomerata*), ruby saltbush (*Enchylaena tomentosa*), mistletoe (*Amyena* sp.), peppercress (*Lepidium* sp.), pigweed (*Portulaca oleracea*) and sandhill wattle (*Acacia ligulata*) (Table 1). Prior to fencing, with the exception of paperbarks, only two of 10 transects (one at each site) contained traditional use plants. After fencing, 8 of 10 transects (4 of 5 at each site) contained traditional use plants.

There was no significant evidence of differences in vegetation assemblages between sites either before or after fencing (Site effect, Global R = 1, p = 0.333; Figure 2a), although the Hayes Springs site tended to have more paperbark and had no records for couch. Similarities in communities between sites were largely driven by paperbark and non-native grasses (Table 3).

Significant changes in vegetation assemblages occurred between 2007 and 2018, coinciding with the installation of fencing (Fence effect, Global R = 0.312, p = 0.004; Figure 2) at both spring sites. These changes were mainly driven by increases in paperbark, couch and buffel grass, which collectively accounted for 80.1% of the differences between 2007 (pre-fencing) and 2018 (post-fencing) assemblages (SIMPER). We are interpreting this as an effect of removing exotic grazing pressure, as we also measured a reduction in manure presence in quadrats from 4.9% (Salt Springs) and 12.5% (Hayes Springs) in 2007, to not detected in 2018. There was also evidence of reduced variability between samples after fencing, likely due to a reduction in bare ground. This was best illustrated by the Index of Multivariate Dispersion which reduced from 1.20 to 0.92 after fencing.

When the three dominant taxa were excluded from analyses, a number of native taxa were shown to be increasing in abundance between 2007 and 2018 (Table 4). After fencing, and excluding the dominant taxa, plant communities at the two sites differed substantively, with Hayes Springs characterised by tar vine (*Boerhavia diffusa*) and pigweed, and Salt Springs by ruby saltbush, sandy twinleaf (*Zygophyllum ammophilum*), sandhill wattle and mistletoe.

3.2. Seedbank

A total of 147 plants germinated from the soil samples collected; 113 of these were monocot species and 34 were eudicots. Of these, 120 (82%) of the germinated plants survived to a stage where they could be identified. The most frequently identified species were the introduced buffel grass (88 seedlings equivalent to 73% of all seedlings) and sow thistles (16% of seedlings). Introduced couch grass and native paperbark each comprised 3% of all seedlings. Other species that were present included the native species sandy twinleaf, sandhill wattle, ruby saltbush, climbing saltbush (*Einadia nutans*), apple bush (*Pterocaulon sphacelatum*) and peppercress (Table 1). These latter species, with the exception of sandy twinleaf, have traditional uses.

The mean number of buffel grass seedlings was 5.5 per quadrat, equivalent to 865 seedlings per m^2, with a maximum of 17 buffel grass seedlings from one quadrat (2672 seedlings/m^2). The highest species richness for one quadrat was four species. We found no evidence that the presence and abundance of buffel grass seedlings interfered with the abundance of seedlings of other species in this study ($F = 0.5148$; $df = 1, 14$; $p = 0.4849$).

4. Discussion

Excluding feral animals can be an effective first step in the restoration of traditionally valuable plant species to water sites. Results from this study showed that plant communities changed drastically following the installation of fencing to exclude large feral ungulates, with a significant increase in both plant cover and plant diversity. A number of native plants, including

Table 1. Combined list of species detected in the transects and seedbank at site for Salt Springs and Hayes Springs. Species marked with * are exotic species.

Common name	Scientific name	Eastern Arrernte name	Traditional use	Historically present	Detected pre-fencing	Detected post-fencing	Detected in seedbank	No of seedlings
Paperbark	*Melaleuca glomerata*	Ilpeye						3
Sandhill wattle	*Acacia ligulata*	Aterrke						1
Ruby saltbush	*Enchylaena tomentosa*	Ntyemene						1
Native fuchsia	*Eremophila freelingii*	Arrethe						
Climbing saltbush	*Einadia nutans*	Ake-alte						1
Apple bush	*Pterocaulon* sp.	Pintye-pintye						1
Pigweed	*Portulaca oleracea*	Ulyawe						
Tar vine	*Boerhavia diffusa*	Ayepe						
		Ntyarlke						
Peppercress	*Lepidium sp.*	Inmartwe						1
Sandy twinleaf	*Zygophyllum ammophilum*							2
Native grasses	*various*	Ntange name						
Mistletoe	*Amyena* sp.	Ingkwerrpme					n/a	
Bulrush	*Typha domingensis*	n/a						
Sow thistle*	*Sonchus oleraceus*	n/a						19
Buffel grass*	*Cenchrus ciliaris*	n/a						88
Couch*	*Cynodon dactylon*	n/a						3
Fat hen*	*Chenopodium album*	n/a						
Mallow*	*Malva* sp.	n/a						

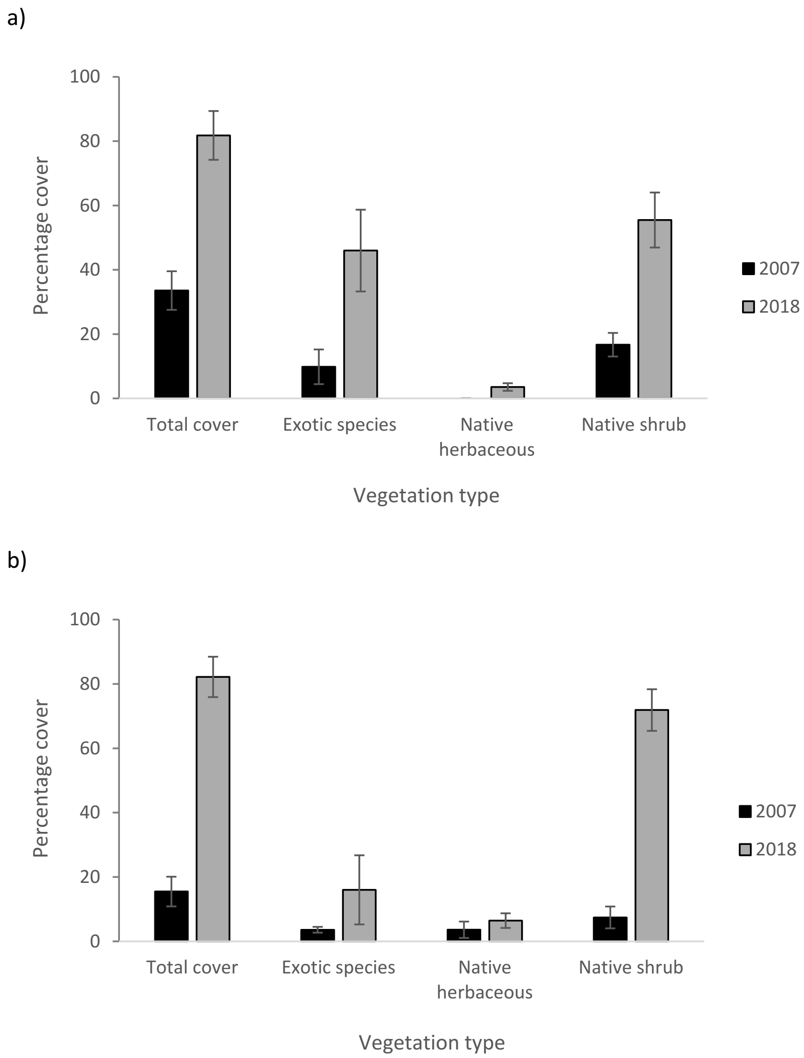

Figure 1. Mean percentage cover for vegetation type at Salt Springs and Hayes Springs in 2007 (black) and 2018 (grey).

culturally significant plants, not detected before fencing were detected following the exclusion of feral animals. This indicates that culturally important plants were still extant in the seed beds of both sites and able to recover when grazing pressure was reduced. With the removal of large feral ungulates, culturally important plants were able to germinate and become part of the floristic community. While our study only looks at two sites at two points in time, our results support observations made by Traditional Owners that both springs are in better condition following fencing (V. P. Dobson, personal observations).

Impacts from large feral animals on central Australian waterholes occur via several pathways including grazing, trampling and degradation of water quality. The significant improvement in vegetation cover and plant growth shown in this study suggests that some of these negative impacts can be mitigated by exclusion in as little as 10 years. Two major drivers of degradation of vegetation communities are likely to be important. First, exclusion of large feral animals reduces soil trampling and further erosion. At both Hayes and Salt springs, the ground was significantly damaged by feral herbivores before fencing, and very few individual plants and species were detected in areas with significant signs of trampling. In contrast, after fencing the incidence of both herbaceous plants and shrubs increased at both sites in these same areas that were once bare ground. This included a number of culturally important plants. Second, excluding large feral herbivores removes grazing pressure, allowing vegetation to regenerate. Several culturally significant plants found at Hayes and Salt springs are palatable to horses, cows and/or camels, including bush plum (*Santalum lanceolatum*), apple bush (*Pterocaulon* sp.) and *Boerhavia* sp. These three species, in particular, are thought to be at moderate to extreme risk of becoming locally depleted by camels (Edwards et al. 2010). While cattle and horses are less polyphagous than camels, in central Australia both species feed on a variety of grasses, forbs and shrubs (Chippendale 1964).

Exotic grasses invaded both Hayes and Salt springs following fencing. This is not surprising given both buffel and couch grass are highly successful invaders

Table 2. Analyses of variance for vegetation cover (total cover, exotic species, native herbaceous and native shrubs) at Salt and Hayes Springs (sites), before and after fencing (year).

	Total cover			Exotic species			Native herbaceous			Native shrub		
Factor	SS	F ratio	P	SS	F ratio	p	SS	F ratio	p	SS	F ratio	p
Site	0.052	1.255	0.279	0.196	4.164	0.058	0.005	3.232	0.091	0.020	0.679	0.422
Year	2.812	67.919	**<0.001**	0.355	7.554	**0.014**	0.005	3.106	0.097	1.750	60.491	**<0.001**
SiteXyear	0.037	0.903	0.356	0.091	1.926	0.184	0.0001	0.0393	0.845	0.122	4.230	0.056

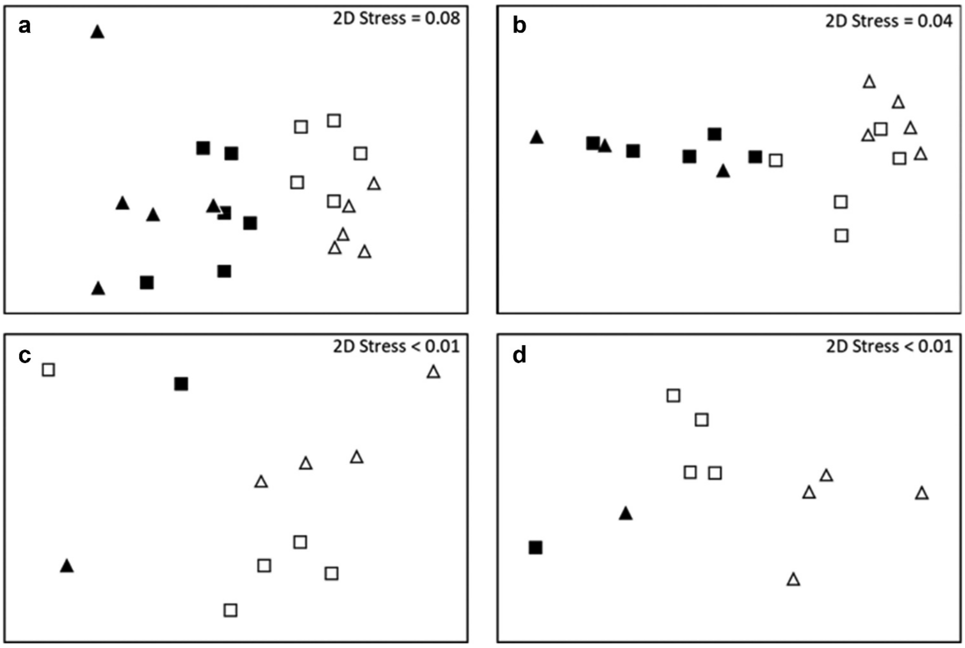

Figure 2. Non-metric multidimensional scaling plots for plant communities within sites in 2007 and 2018. Symbols denotes year of sampling: Open triangle: 2007 Dark triangle: 2018. Labels denotes site: HS: Hayes Springs, SS: Salt Springs.

and their distributions continue to expand across central Australia (Miller et al. 2010; Allan 1997). Both species were present in 2007, but in very small numbers, suggesting that feral grazing suppressed these species. In 2018, both buffel and couch grass comprised a significant proportion of the vegetation cover. Interestingly, couch was only found at Salt Springs, where it likely increased in cover because of release from herbivory. Couch requires humidity and soil moisture, so it is likely that its distribution at Salt Springs will be restricted to areas immediately next to open water. Buffel grass colonised expansive areas around both spring sites, including nearby gorges. Many studies throughout Australia have documented the negative ecological impacts from buffel grass infestations, such as competing with native species, reducing local diversity and changing fire regime (Allan 1997; Franks 2002; Miller et al. 2010). The negative impacts most relevant to Hayes and Salt springs appear to be competition with native grasses and ground cover species (Franks 2002). Buffel also changes fire regimes because when it dries, it provides fuel that supports hotter fires than those that burned historically at these sites. This in turn destroys native foods and refuge areas, and can lead to declines in native mammals, including black-footed rock wallabies and native mice (Schlesinger, White, and Muldoon 2013). Because buffel seeds are not palatable to some finches and parrots, buffel invasion also leads to a decrease in specialist seed-eating bird species (Marshall, Lewis, and Ostendorf 2012). Invasion by buffel grass has also been implicated in reduced reptile diversity because it interferes with food and feeding success of reptiles in buffel-dominated habitats (Sa 2012).

While the seedbank was dominated by buffel grass, the seedbank trial demonstrated the presence of a viable seedbank of native plants, and in particular culturally important species. While the seedbank trials suggested that there was no evidence of buffel grass seedlings interfering with the abundance of other species, elsewhere the invasive nature of buffel grass has been shown to exclude native groundcover species (Franks 2002; Clarke, Latz, and Albrecht 2005; Wardle et al. 2015; see also Marshall, Lewis, and Ostendorf 2012 for review). It is possible that continued buffel suppression/control at Salt and Hayes

Table 4. Changes in SIMPER average abundance for major discriminating taxa between 2007 (before fencing) and 2018 (after fencing) at Hayes and Salt Spring sites. (I) indicates invasive species, (T) indicates traditional use plants (see text for details).

	Before	After	Difference
Paperbark	0.11	0.52	+0.41
Buffel grass (I)	0.03	0.14	+0.11
Couch (I)	0.03	0.13	+0.10
Sow thistle (I)	0.00	0.02	+0.02
Ruby saltbrush (T)	0.00	0.01	+0.01
Unidentified grass	0.00	0.02	+0.02
Sandy twinleaf	0.00	0.01	+0.01
Mistletoe (T)	0.00	0.01	+0.01
Tar vine (T)	0.00	0.01	+0.01
Native fuchsia (T)	0.01	0.00	−0.01
Sandhill wattle (T)	0.00	0.02	+0.02

Table 3. SIMPER average percentage similarity within and between sites (Hayes/Salt) and within and between times (2007/2018) for plant communities. Groups are excluded from the analysis as shown in order to remove the effect of dominant species and detect changes in lower abundance taxa. Grey shading indicates between site or between time comparisons.

ALL SPECIES INCLUDED			
Average similarity by site across all time groups		Hayes	Salt
	Hayes	54.63	
	Salt	56.22	55.80
Average similarity by time across all sites		Before	After
	Before	46.62	
	After	26.09	69.57
NON-NATIVE GRASSES REMOVED			
Average similarity by site across all time groups		Hayes	Salt
	Hayes	55.13	
	Salt	56.22	66.94
Average similarity by time across all sites		Before	After
	Before	52.49	
	After	28.97	69.57
NON-NATIVE GRASSES + MELALEUCA + TYPHA REMOVED			
Average similarity by site across all time groups		Hayes	Salt
	Hayes	7.17	
	Salt	2.82	8.83
Average similarity by time across all sites		Before	After
	Before	0	
	After	0	10.84
TRADITIONAL USE PLANTS			
Average similarity by site across all time groups		Hayes	Salt
	Hayes	9.24	
	Salt	0	17.36
Average similarity by time across all sites		Before	After
	Before	No data	
	After	0	13.40

Springs could lead to even greater native plant cover than found in the current study. The control of buffel grass is difficult (Grice et al. 2012), with approaches generally confined to spraying (which can have detrimental effects on native grasses and should not be used close to water), and manual removal (which is resource intensive).

Successful restoration of sacred water places relies on local knowledge and involvement. There is an emerging understanding of the importance of a social context to ensure successful restoration outcomes (e.g. Robertson et al. 2001; Uprety et al. 2012). Local people have cared for these important water sites for thousands of years, and the sharing of intergenerational knowledge is key for their continued cultural and ecological survival. Local Indigenous ranger groups are a major player in management and restoration of landscape on Indigenous lands (e.g. Ens et al. 2010; Weston et al. 2012; Waltham et al. 2018). At Salt and Hayes Springs, rangers maintain the fence and do occasional weeding. However, as these sites are remote, like many sacred sites in central Australia, and because restoration is an ongoing activity, there is often a lack of resources to effectively manage weed species. The long history of active traditional management of these sites provides an opportunity to carry out resource-intensive restoration practices. Going forward, Traditional Owners prioritised the removal of buffel grass from around the springs, reducing its spread and the inclusion of the local Indigenous ranger group in management decisions and activities. However, all approaches to controlling buffel grass require ongoing investment. As funding is limited and buffel grass is widespread, careful spatial prioritisation of investments needs to be done as to protect the most vulnerable and culturally important assets. The cultural importance of Hayes and Salt Springs to the local Eastern Arrernte population, and the potential for benefit to culturally important species, suggests the currently fenced areas of the springs should be a priority for ongoing investment.

Aboriginal Traditional Owners at the springs indicated an obligation and desire to work with young people to achieve better management outcomes. People who have grown up with the stories associated with the springs need the opportunity to share this knowledge with the newer generations. In this case, the local school has been involved with monitoring the springs, which allows students to meet elders and scientists and share the importance of the springs, water, animals and plants. Traditional Owners emphasised that people have always taken care of these sites and that it is critical for the newer generations to take over this cultural duty. While there have been tremendous efforts by rangers and by elders, more resources to get people on Country are required. The findings of this project reaffirm previous observations (e.g. Ens et al. 2012; Walsh, Dobson, and Douglas 2013) that the active participation and knowledge of Traditional Owners provides a significant management tool for central Australia wetlands.

Acknowledgments

We acknowledge the Traditional Owners of Hayes and Salt springs and thank them for allowing us to work at these important places. We would like to thank the Ltyentye Apurte rangers and their coordinator, Johanna Shand, for their involvement in this project and for their work at the springs. We would like to thank Meg Mooney and Fiona Webb of Tangentyere Council for facilitating trips and activities with the Ltyentye Apurte Catholic School in Santa Teresa, and for the enthusiastic participation of both teachers and students of the school. We thank Will Higgisson and Brooke Parr for their help with plant identification, and Paul Collis, Wayne Appleton and Peter Raddoll for support and useful discussions. We would also like to thank Central Land Council for their support in obtaining permits, and their additional help in all aspects of the project.

Funding

This research was funded through a University of Canberra Collaborative Indigenous Research Initiative (UC CIRI) grant.

ORCID

Valerie Caron http://orcid.org/0000-0003-3462-4607
Jayne Brim Box http://orcid.org/0000-0001-7698-8690
Ross M. Thompson http://orcid.org/0000-0002-5287-2455
Fiona Dyer http://orcid.org/0000-0003-4658-9247

References

Allan, C. 1997. “A Brief History of Buffel Grass in Central Australia.” *Alice Springs Rural Review* 27:2.

Ansong, M., and C. Pickering. 2013. “A Global Review of Weeds that Can Germinate from Horse Dung.” *Ecological Management & Restoration* 14 (3): :216–223. doi:10.1111/emr.12057.

Bayly, I. A. E. 1999. “Review of How Indigenous People Managed for Water in Desert Regions of Australia.” *Journal of the Royal Society of Western Australia* 82: 17–25.

Biosecurity SA (2012). South Australia Buffel Grass Strategic Plan: A plan to reduce the weed threat of buffel grass in South Australia. Government of South Australia.

Brim Box, J., J. Davis, K. Strehlow, G. McBurnie, A. Duguid, C. Brock, K. McConnell, C. Day, and C. Palmer. 2014. “Persistence of Central Australian Aquatic Invertebrate Communities.” *Marine & Freshwater Research* 65 (6): :562–572. doi:10.1071/MF13131.

Brim Box, J., L. Bledsoe, P. Box, A. Bubb, M. Campbell, G. Edwards, J. D. Fordyce, et al. 2019. “The Impact of Camel Visitation on Native Wildlife at Remote Waterholes in Arid Australia.” *Journal of Zoology* 309 (2): 84–93. doi:10.1111/jzo.12688.

Brim Box, J., T. Guest, P. Barker, M. Jambrecina, S. Moran, and R. Kulitja. 2010. “Camel Usage and Impacts at a Permanent Spring in Central Australia: A Case Study.” *Rangeland Journal* 32 (1): :55–62. doi:10.1071/RJ09042.

Brim Box, J., A. Duguid, R. E. Read, R. G. Kimber, A. Knapton, J. Davis, and A. E. Bowland. 2008. “Central Australian Waterbodies: The Importance of Permanence in a Desert Landscape.” *Journal of Arid Environments* 72 (8): :1395–1413. doi:10.1016/j.jaridenv.2008.02.022.

Brim Box, J., C. E. M. Nano, G. McBurnie, D. M. Waller, K. McConnell, C. Brock, R. Paltridge, A. McGilvray, A. Bubb, and G. P. Edwards. 2016b. “The Impact of Feral Camels (Camelus Dromedarius) on Woody Vegetation in Arid Australia.” *Rangeland Journal* 38 (2): :181–190. doi:10.1071/RJ15073.

Brim Box, J., G. McBurnie, K. Strehlow, T. Guest, M. Campbell, A. Bubb, K. McConnell, et al. 2016a. “The Impact of Feral Camels (Camelus Dromedarius) on Remote Waterholes in Central Australia.” *Rangeland Journal* 38 (2): :191–200. doi:10.1071/RJ15074.

Chippendale, G. M. 1964. “Determination of Plant Species Grazed by Open Range Cattle in Central Australia”. Proceedings of the Australian Society of Animal Production 5:256–257.

Clarke, K. R., and R. N. Gorley. 2015. Getting started with PRIMER v7.“ PRIMER-E: Plymouth, Plymouth Marine Laboratory 20.

Clarke, P. J., P. K. Latz, and D. E. Albrecht. 2005. “Long-term Changes in Semi-arid Vegetation: Invasion of an Exotic Perennial Grass Has Larger Effects than Rainfall Variability.” *Journal of Vegetation Science* 16 (2): :237–248. doi:10.1111/j.1654-1103.2005.tb02361.x.

CLC. 2015. *Ngura Nganampa Kunpu Kanyinma: Keep on Looking after Our Country Strongly - Katiti-Petermann Indigenous Protected Area Plan of Management. Page 167 In* C. L. Council.ed. Alice: Springs.

Cunningham, G. M. 1992. *Plants of Western New South Wales*. Collingwood, Victoria: CSIRO Publishing.

Dobbie, W. R., D. M. Berman, and M. L. Braysher. 1993. *Managing Vertebrate Pests: Horses*. Canberra: Australian Government Publishing Service.

Dobbs, R. J., C. L. Davies, M. L. Walker, N. E. Pettit, B. J. Pusey, P. G. Close, Y. Akune, et al. 2016. "Collaborative Research Partnerships Inform Monitoring and Management of Aquatic Ecosystems by Indigenous Rangers." *Reviews in Fish Biology and Fisheries* 26 (4): :711–725. doi:10.1007/s11160-015-9401-2.

Dobson, V. P., and A. Nano. 2005. *Apmere Apwerte Urrtharenye-kenhe: The Country of the Limestone People. In C. L. C. A. N. T. P. A*, ed. W. Service. Alice: Springs.

Dobson, V. P. 2009. "Caring for Country: Hayes Springs, Mparntwenge, Salt Springs, Irlkirteye." *Dialogue (Academy of the Social Sciences in Australia)* 28: 33–39.

Edwards, G. P., B. Zeng, W. K. Saalfeld, and P. Vaarzon-Morel. 2010. "Evaluation of the Impacts of Feral Camels." *Rangeland Journal* 32 (1): :43–54. doi:10.1071/RJ09037.

Edwards, G. P., B. Zeng, W. K. Saalfeld, P. Vaarzon-Morel, and M. McGregor. 2008. *Managing the Impacts of Feral Camels in Australia: A New Way of Doing Business*. Alice Springs: Desert Knowledge Cooperative Research Centre.

Ens, E. J., M. Finlayson, K. Preuss, S. Jackson, and S. Holcombe. 2012. "Australian Approaches for Managing 'Country'using Indigenous and non-Indigenous Knowledge." *Ecological Management & Restoration* 13 (1): 100–107. doi:10.1111/j.1442-8903.2011.00634.x.

Ens, E. J., P. Cooke, R. Nadjamerrek, S. Namundja, V. Garlngarr, and D. Yibarbuk. 2010. "Combining Aboriginal and non-Aboriginal Knowledge to Assess and Manage Feral Water Buffalo Impacts on Perennial Freshwater Springs of the Aboriginal-owned Arnhem Plateau, Australia." *Environmental Management* 45 (4): 751–758. doi:10.1007/s00267-010-9452-z.

Franks, A. J. 2002. "The Ecological Consequences of Buffel Grass *Cenchrus Ciliaris* Establishment within Remnant Vegetation of Queensland.." *Pacific Conservation Biology* 8 (2): 99–107. doi:10.1071/PC020099.

Grice, A. C., M. H. Friedel, N. A. Marshall, and R. D. Van Klinken. 2012. "Tackling Contentious Invasive Plant Species: A Case Study of Buffel Grass in Australia." *Environmental Management* 49 (2): 285–294. doi:10.1007/s00267-011-9781-6.

James, D. 2015. "Tjukurpa Time." In *Long History, Deep Time: Deepening Histories of Place*, edited by A. McGrath and M. A. Jebb, 33–44. Canberra: ANU Press.

Judd, B. 2019. "Kapi Wiya: Water Insecurity and Aqua-nullius in Remote Inland Aboriginal Australia". Thesis Eleven 150 :102–118.

Latz, P. K. 2018. *Bushfires and Bushtuckers - Aboriginal Plant Use in Central Australia*. 2 edition ed. Alice Springs: IAD Press.

Marshall, V. M., M. M. Lewis, and B. Ostendorf. 2012. "Buffel Grass (Cenchrus Ciliaris) as an Invader and Threat to Biodiversity in Arid Environments: A Review." *Journal of Arid Environments* 78: 1–12. doi:10.1016/j.jaridenv.2011.11.005.

McBurnie, G., J. Davis, R. M. Thompson, C. Nano, and J. Brim Box. 2015. "The Impacts of an Invasive Herbivore (Camelus Dromedaries) on Arid Zone Freshwater Pools: An Experimental Investigation of the Effects of Dung on Macroinvertebrate Colonisation." *Journal of Arid Environments* 113: 69–76. doi:10.1016/j.jaridenv.2014.09.011.

Miller, G., M. Friedel, P. Adam, and V. Chewings. 2010. "Ecological Impacts of Buffel Grass (*Cenchrus Ciliaris* L.)." *Invasion in Central Australia - Does Field Evidence Support a Fire-invasion Feedback? Rangeland Journal* 32: 353–365.

Roberts, R. G., T. F. Flannery, L. K. Ayliffe, H. Yoshida, J. M. Olley, G. J. Prideaux, G. M. Laslett, et al. 2001. "New Ages for the Last Australian Megafauna: Continent-wide Extinction about 46,000 Years Ago." *Science* 292 (5523): 1888–1892. doi:10.1126/science.1060264.

Robertson, M., P. Nichols, P. Horwitz, K. Bradby, and D. MacKintosh. 2001. "Environmental Narratives and the Need for Multiple Perspectives to Restore Degraded Landscapes in Australia." *Ecosystem Health* 6 (2): 119–133. doi:10.1046/j.1526-0992.2000.00013.x.

Sada, D. W., E. Fleishman, and D. D. Murphy. 2005. "Associations among Spring-dependent Aquatic Assemblages and Environmental and Land Use Gradients in a Mojave Desert Mountain Range." *Diversity & Distributions* 11 (1): 91–99. doi:10.1111/j.1366-9516.2005.00131.x.

Schlesinger, C., S. White, and S. Muldoon. 2013. "Spatial Pattern And Severity Of Fire In Areas With And Without Buffel Grass (*Cenchrus ciliaris*) and effects on native vegetation in central Australia." *Austral Ecology* 38 (7): 831–840. doi:10.1111/aec.12039.

Uprety, Y., H. Asselin, Y. Bergeron, F. Doyon, and J.-F. Boucher. 2012. "Contribution of Traditional Knowledge to Ecological Restoration: Practices and Applications." *Écoscience* 19 (3): 225–237. doi:10.2980/19-3-3530.

Walsh, F. J., V. P. Dobson, and J. C. Douglas. 2013. "Anpernirrentye: A Framework for Enhanced Application of Indigenous Ecological Knowledge in Natural Resource Management." *Ecology and Society*, 18(3): 18. http://dx.doi.org/10.5751/ES-05501-180318

Waltham, N. J., J. Schaffer, J. Buist, M. Geyle, and D. Toby. 2018. "Working with Land and Sea Rangers to Tackle Tropical Wetland Restoration and Conservation on the North-western Islands, Torres Straits, Australia." *Wetlands Ecology and Management* 26 (6): 1143–1156. doi:10.1007/s11273-018-9637-4.

Wardle, G. M., A. C. Greenville, A. S. K. Frank, M. Tischler, N. J. Emery, and C. R. Dickman. 2015. "Ecosystem Risk Assessment of Georgina Gidgee Woodlands in Central Australia." *Austral Ecology* 40 (4): 444–459. doi:10.1111/aec.12265.

Weston, N., C. Bramley, J. Bar-Lev, M. Guyula, and S. O'Ryan. 2012. "Arafura Three: Aboriginal Ranger Groups Protecting and Managing an Internationally Significant Swamp." *Ecological Management & Restoration* 13 (1): 84–88. doi:10.1111/j.1442-8903.2011.00626.x.