Australian Government

Department of Climate Change, Energy, the Environment and Water

Background document for the threat abatement plan for ecosystem degradation, habitat loss and species decline due to invasion of northern Australia by introduced gamba grass (*Andropogon gayanus*), para grass (*Urochloa mutica*), olive hymenachne (*Hymenachne amplexicaulis*), mission grass (*Cenchrus polystachios*) and annual mission grass (*Cenchrus pedicellatus*)

Consultation Draft 2025

Front cover images (from top left in clockwise direction)

Gamba grass. Image: Colin G. Wilson

Perennial mission grass, Rum Jungle Nature Reserve NT. Image: Colin G. Wilson

Annual mission grass, Fannie Bay, Darwin, NT. Image: Colin G. Wilson

Para grass, Munmalary, Kakadu, NT. Image: Colin G. Wilson

Hymenachne, Scott Creek, Djukbinj National Park, NT. Image: Colin G. Wilson

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Acknowledgement of Country

We acknowledge the Traditional Owners of Country throughout Australia and recognise their continuing connection to land, waters and culture. We pay our respects to their Elders past and present.

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1 Introduction

1.1 Threat abatement plans

This is the background document to accompany the draft threat abatement plan for ecosystem degradation, habitat loss and species decline due to invasion of northern Australia by introduced gamba grass (*Andropogon gayanus*), para grass (*Urochloa mutica*), olive hymenachne (*Hymenachne amplexicaulis*), mission grass (*Cenchrus polystachios*) and annual mission grass (*Cenchrus pedicellatus*). This document will replace the 2012 background document and provides an overview of the biology of these grass species, their ecological impacts, agricultural use and management.

The draft threat abatement plan (TAP) establishes a national framework to guide and coordinate Australia's response to these invasive grasses. It identifies the research, management and other actions needed to ensure the long-term survival of native species and ecological communities impacted by these invasive grasses.

'Ecosystem degradation, habitat loss and species decline due to invasion of northern Australia by introduced gamba grass (*Andropogon gayanus*), para grass (*Urochloa mutica*), olive hymenachne (*Hymenachne amplexicaulis*), mission grass (*Cenchrus polystachios*) and annual mission grass (*Cenchrus pedicellatus*)' was listed as a Key Threatening Process (KTP) under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) in 2009 (TSSC 2009). A key threatening process is a process that threatens or may threaten the survival, abundance or evolutionary development of a native species or ecological community.

1.2 Names and terminology

The current scientific name for each grass species in the threat abatement plan are in Table 1, along with synonyms and common names. There have been changes to the naming convention for the two mission grasses since the key threatening process was listed, and the updated scientific names are used throughout this document and the threat abatement plan.

Hymenachne amplexicaulis is referred to as hymenachne throughout this background document and the plan. There is also a hybrid between the native *Hymenachne acutigluma* and the invasive *Hymenachne amplexicaulis*, which is referred to as *Hymenachne* x *calamitosa*.

The term perennial mission grass is used for *Cenchrus polystachios*. The term mission grass is used when the available information does not differentiate between annual mission grass (*C. pedicellatus*) or perennial mission grass (*C. polystachios*).

Table 1 Scientific names for the invasive grasses covered in the threat abatement plan as specified by the Australian Plant Census. Common names, subspecies and hybrids present in Australia are also indicated.

Scientific name	Synonyms	Sub species or hybrid	Common name
Andropogon gayanus Kunth. Enum.	-	-	Gamba grass
Cenchrus pedicellatus (Trin.) Morrone	*Cenchrus pedicellatum* *Pennisetum pedicellatum* (name in KTP listing)	*Cenchrus pedicellatus* (Trin.) Morrone subsp. *pedicellatum* *Cenchrus pedicellatus* subsp. *unispiculus* (Brunken) Morrone	Annual mission grass
Cenchrus polystachios (L.) Morrone.	*Pennisetum polystachyum* (name in KTP listing) *Cenchrus polystachion*	-	Mission grass Perennial mission grass
Hymenachne amplexicaulis (Rudge) Nees	*Hymenachne pseudointerrupta*	*Hymenachne* x *calamitosa*	Hymenachne Olive hymenachne
Urochloa mutica (Forsk.) Nguyen.	*Brachiaria mutica* *Panicum muticum*	-	Para grass

Gamba grass, perennial mission grass and annual mission grass are all tropical, terrestrial, high biomass, tussock forming grasses, that typically invade woodlands, savannas and riparian vegetation (Table 2). Para grass and hymenachne are semi-aquatic or aquatic grasses (macrophytes) that grow in waterlogged soil, or in permanent or semi-permanent water. This includes tropical, sub-tropical or temperate wetlands, floodplains and other waterways. Para grass and hymenachne are perennial stolon forming grasses (Table 2). Stolons are horizontal, above-ground, creeping stems which can form roots and shoots. These 5 species are collectively referred to as invasive grasses throughout this document.

The term waterway is used throughout the plan, and this background document, to indicate any river, creek, stream, including its floodplain, watercourse, drainage feature or estuary. This includes systems that flow permanently, for part of the year or occasionally.

Table 2 Features of the invasive grasses, including how they reproduce, how long seeds remain viable for *in situ* (in their natural place) and if the introduction was deliberate or accidental. Territorial islands are included (Lohr et al. 2016). Stoloniferous means having horizontal, above-ground, creeping stems that can form roots. Gamba grass and hymenachne are part of eradication programs in WA.

Name	Life form	Reproduction	Seed bank viability	Jurisdictions present	Introduction	Origin
Andropogon gayanus Gamba grass	Perennial tussock Up to 4 m tall	Seed	Less than 1% after 12 months, 0% after 24 months	NT, Qld, WA	1931 'Kent' cultivar 1978 deliberate	Africa
Cenchrus pedicellatus Annual mission grass	Annual or perennial Up to 1.5 m tall	Seed	Greater than 1.5 years	NT, Qld, WA	1940s Unknown if deliberate or accidental	Africa
Cenchrus polystachios Perennial mission grass	Perennial tussock Up to 3 m tall	Seed	Between 1 and 2 years	NT, Qld, presence in WA unknown	1930s deliberate	Africa
Hymenachne amplexicaulis Hymenachne	Semi-aquatic Perennial, upright or semi-upright stems from a creeping base Up to 3.5 m tall	Seed and vegetatively via stem fragments	Greater than 8 years	NSW, NT, Qld, WA	1970s deliberate	South and Central America
Urochloa mutica Para grass	Semi-aquatic Perennial, upright or semi-upright stems from a creeping base Up to 2 m tall	Seed and vegetatively via stolons and stem segments	Unknown	Christmas Island, Cocos Keeling Island, NSW, NT, Qld, WA	1880s deliberate	Africa

1.3 Introduced pasture grasses and invasiveness

Over 2,200 species of grass have been introduced into Australia since European colonisation (1788) (Cook and Dias 2006). Around 400 of these species have naturalised in Australia (Grice et al. 2013), including 155 species of tropical grasses (van Klinken et al. 2015). Approximately 180 of the grass species that have been introduced to Australia are thought to be invasive (Virtue et al. 2004). Most invasive grasses present in Australia were deliberately introduced for use as either pasture or turf, with a small proportion introduced as ornamental garden plants. Many of the forage species were deliberately introduced to increase pasture productivity (Cook and Dias 2006).

In the late nineteenth century, government agencies and acclimatisation societies actively sourced and imported new grass species and promoted the conversion of native vegetation to improved pasture in northern Australia (Cook and Dias 2006; van Klinken et al. 2015). There was an early preference for finding perennial, high biomass grass species that could produce self-sustaining populations (Lonsdale 1994) and were suitable to the climate (Driscoll et al. 2014). There is still a continuing push towards the intensification of agriculture by increasing production without using more land, and there is ongoing global development and marketing of new forage plants designed to increase pasture productivity. However, the plant traits that increase production, generally also increase invasion risk (Driscoll et al. 2014). In addition, having a grass with fast growth rate and large biomass can increase fuel loads and change fire regimes (Beggs 2010) (see sections 2.1.4 and 4.1). The deliberate selection of grasses with certain plant traits has contributed to Australia having numerous introduced grass species with environmental impacts (van Klinken et al. 2015).

The environmental impacts of invasive grasses were not raised until the 1980s, and governments started to address these impacts in the 1990s (van Klinken et al. 2015). Today, most Australian ecosystems are subject to invasion by one or more introduced grass species, with northern Australia having numerous naturalised species that originated from tropical Africa, Asia, and the Americas (Grice et al. 2013). It is critical that the risk of further invasions into natural areas by invasive pasture grasses is reduced to avoid further threats to the environment and culture, and increased management costs.

1.4 Overview of distribution

All 5 species of invasive grass in the threat abatement plan are established in the Northern Territory (NT) and Queensland (Qld) (Table 2). Annual mission grass and para grass are also established in Western Australia (WA), and para grass and hymenachne in New South Wales (NSW). There are no official reports of gamba grass in NSW, however as of 18 May 2023, there were records of gamba grass in NSW on the Atlas of Living Australia from the citizen science web platform WeedScan. It is not known if perennial mission grass is present within WA.

The limited distribution data available, combined with observations from people managing these grasses, indicates all 5 invasive grass species have spread since the last threat abatement plan was released in 2012. In many locations, these grasses have also increased in density. These grasses only occupy part of their modelled potential distribution (Duursma et al. 2013; Setterfield et al. 2018; Wearne et al. 2013), and if management efforts are not increased, each species has been predicted to have a potential distribution of over 1 million square kilometres (Pintor et al. 2018; Pintor et al. 2019).

More detailed information on the distribution of each grass species can be found in chapter 2 under the section for each species. This includes information on offshore islands where these grasses have been detected. There are hundreds of islands offshore from WA, NT and Queensland and it is likely these grasses are present on additional islands, especially where there is movement of machinery, vehicles or livestock.

1.5 Weed status

The weed declaration status of the 5 grasses varies immensely across Australia (Table 3 and 4). Para grass is not a declared weed in any jurisdiction and is only a priority environmental weed in 3 Natural Resource Management regions in Queensland. On the other end of the spectrum, gamba grass and hymenachne have some level of weed declaration in every state and territory, including jurisdictions where they are currently not present. Hymenachne and gamba grass are also Weeds of National Significance (WoNS), with hymenachne listed in 1999 and gamba grass in 2012. Being identified as a WoNS indicates these two grasses are some of Australia’s worst weeds in terms of invasiveness, spread, economic and environmental impact. Their WoNS identification has assisted in raising awareness of these weeds and assisted with weed declaration in some jurisdictions.

The NT has a gamba grass eradication zone (Class A Zone) and a control zone (Class B Zone). Gamba grass can be kept with a permit within the gamba grass eradication zone, however, in 2022 there were only 2 permits remaining in this zone (DEPWS 2022). There is also a statutory weed management plan for gamba grass in the NT. There are eradication plans in action in WA for gamba grass and hymenachne, with gamba grass having an eradication declaration (C2), and hymenachne an exclusion declaration (C1) (see Tables 3 and 4 for details).

Table 3 Classification of the invasive grasses under state and territory legislation. See Table 4 for an explanation of weed classifications for each legislation.

Species	State	Classification	Legislation	Weed of national significance
Gamba grass *Andropogon gayanus*	NT	Class A/B (zoned)	*Weeds Management Act 2001*	Yes
	Qld	Category 3 restricted invasive plant	*Biosecurity Act 2014*	
	WA	Declared pest s12, C2	*Biosecurity and Agriculture Management Act 2007*	
	ACT	Notifiable	*Pest Plants and Animals Act 2005*	
	NSW	Prohibited Matter - must not be sold anywhere in NSW (currently not in NSW)	*Biosecurity Act 2015*	
	SA	Category 3 (Class 68), whole of state	*Landscape* *South Australia Act 2019*	
	Tas	Declared weed	*Tasmanian Weed Management Act 1999*	
	Vic	Schedule 2 restricted weed (whole of state)	*Catchment and Land Protection Act 1994*	
Annual mission grass *Cenchrus pedicellatus*	NT	Class B	*Weeds Management Act 2001*	No
Perennial mission grass *Cenchrus polystachios*	NT	Class B	*Weeds Management Act 2001*	No
	WA	Declared Pest, Prohibited - s12, C1	*Biosecurity and Agriculture Management Act 2007*	
	Qld	Not a prohibited or restricted invasive plant. Considered an Environmental Weed	-	
Hymenachne *Hymenachne amplexicaulis* including hybrid *Hymenachne* × *calamitosa* in most jurisdictions	NT	Class B	*Weeds Management Act 2001*	Yes
	Qld	Category 3 restricted invasive plant (including hybrid)	*Biosecurity Act 2014*	
	WA	Declared Pest, Prohibited/Excluded s12, C1 (including hybrid) whole of state	*Biosecurity and Agriculture Management Act 2007*	

Species	State	Classification	Legislation	Weed of national significance
Hymenachne (continued) *Hymenachne amplexicaulis* including hybrid *Hymenachne* × *calamitosa* in most jurisdictions	NSW	Prohibition on certain dealings (sale, import) including hybrids Regional eradication – specific areas Regional prevention – specific areas	*Biosecurity Act 2015*	
	Tas	Declared weed (Including hybrid) (not in Tasmania)	*Tasmanian Weed Management Act 1999*	
	ACT	Prohibited	*Pest Plants and Animals Act 2005*	
	SA	Category 3 (Class 68)(including hybrid), whole of state	*Landscape South Australia Act 2019*	
	Vic	Schedule 2 restricted weed (whole of state)	*Catchment and Land Protection Act 1994*	
Para grass *Urochloa mutica*	-	-	Not declared/ prohibited/ restricted in any jurisdiction	No

Table 4 Definitions of weed classifications used in table 3 under state and territory legislation

State/territory and legislation	Definition of classification
Northern Territory *Weeds Management Act 2001*	Class A weed: to be eradicated in all areas except where it isclassified as Class B Class B weed: growth and spread to be controlled Class C weed: not to be introduced into the Northern Territory (prevent entry)
Queensland *Biosecurity Act 2014*	Category 3: Restricted invasive plant. A person must not distribute the invasive plant either by sale or gift, or release it into the environment. Under the general biosecurity obligation a person must take all reasonable and practical measures to minimise the biosecurity risks of invasive weeds under their control.
Western Australia *Biosecurity and Agriculture Management Act 2007*	Declared Pest, Prohibited: s12 may only be imported and kept subject to permits. Permit conditions applicable to some species may only be appropriate or available to research organisations or similarly secure institutions. Declared Pest: s22(2) may also be subject to control and keeping requirements once within Western Australia. C1 Exclusion: Organisms which should be excluded from part or all of Western Australia. C2 Eradication: Organisms which should be eradicated from part or all of Western Australia.
NSW *Biosecurity Act 2015*	Prohibited Matter: A person who deals with prohibited matter or a carrier of prohibited matter is guilty of an offence. A person who becomes aware of or suspects the presence of prohibited matter must immediately notify the Department of Primary Industries. Regional Priority: Eradication: Land managers should mitigate the risk of the plant being introduced on to their land. The plant should be eradicated from the land and the land kept free of the plant. Prevention: Land managers should mitigate the risk of new weeds being introduced to their land. The plant should be eradicated from the land and the land kept free of the plant. The plant should not be bought, sold, grown, carried or released into the environment. Notify local control authority if found.
South Australia *Landscape South Australia Act 2019*	Category 3: entry, sale and movement of the plant and seed is prohibited into specific regions in South Australia.
Victoria *Catchment and Land Protection Act 1994*	Schedule 2 Restricted Weed: Need to prevent the growth and spread of regionally controlled weeds. Trade in these weeds and their propagules (either as plants, seeds or contaminants in other materials) is prohibited.
ACT *Pest Plants and Animals Act 2005*	Notifiable pest plant: chief executive of ACT must be notified of presence of pest plant that must be suppressed and contained. Prohibited pest plant: pest plant whose propagation and supply is prohibited. It is an offence to commit reckless use of vehicle or machinery contaminated by a prohibited pest plant or recklessly dispose of a pest plant.

2 Invasion history and biology of the savanna grasses

2.1 Gamba grass

2.1.1 History

Gamba grass is native to the tropical savannas of Africa, occurring from Senegal in the west to Sudan in the east. It has been imported into Australia multiple times, including to the NT in 1931 and Queensland in 1942. The gamba grass growing in northern Australia is a cultivar known as cv. ‘Kent’ that was developed for use as cattle fodder, possibly through the crossing of material considered to be var. *squamulatus* and a second unknown variety (Oram 1990). Preliminary agricultural trials on gamba grass were conducted at the Katherine Research Station from 1946. It was released through the NT Herbage Plants Liaison Committee in 1978 and was listed in the Register of Australian Herbage Cultivars in 1986. It was not widely used as a pasture grass until 1983, when commercial quantities of seed became available (Csurhes 2005).

The earliest record of gamba grass in Queensland is a specimen collected from a Commonwealth Scientific and Industrial Research Organisation property near Rockhampton in 1942. The first record of a naturalised specimen was from Bamaga in 1992, although it was probably naturalised elsewhere in Cape York by that time (Csurhes and Hannan-Jones 2016). Gamba grass, but not the Kent cultivar, has naturalised in other regions of the world, including Brazil.

A comprehensive synthesis of gamba grass knowledge can be found on the National Environmental Science Program Resilient Landscapes Hub gamba grass webpage.

2.1.2 Distribution and habitat

Gamba grass and the mission grasses are all C4 grasses. The C4 photosynthetic pathway (how plants capture carbon dioxide during photosynthesis) is more efficient than the C3 photosynthetic pathway in high light, high temperature or drought conditions. C4 grasses tend to grow in the warmer months of the year, are more common in the tropics and have low frost tolerance.

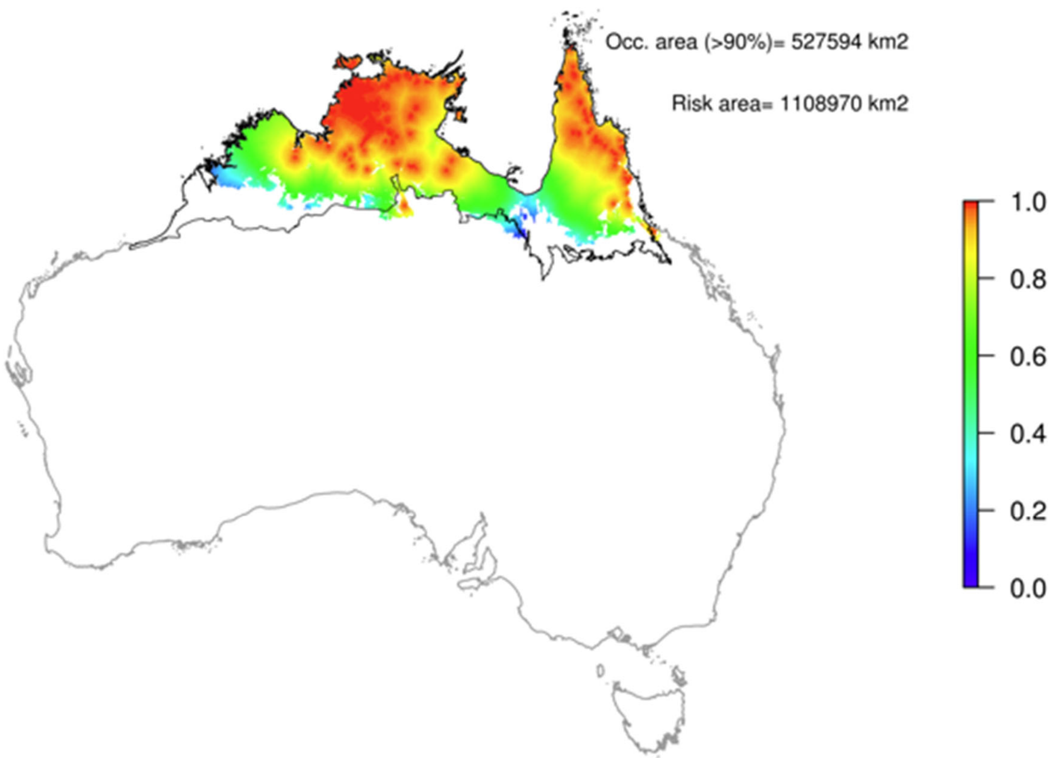
Gamba grass is well suited to northern Australian conditions, and can establish across a wide range of habitats, from open woodland to closed forests on floodplain margins and on a range of soils including sandy soils and floodplain black soils (Flores et al. 2005). Ephemeral drainage lines and margins of the seasonally inundated floodplains are highly suitable areas for gamba grass. Gamba grass can establish without soil or canopy disturbance (Setterfield et al 2005; van Klinken et al. 2013).

After seeding, gamba grass plants begin to senesce and dry out, a process known as curing. This happens during the mid-to-late dry season (June–August). The native grasses cure at the end of the wet season, means that gamba grass can be easier to detect around April, when the gamba grass is generally still green and upright, and the native grasses have dried and fallen over.

Gamba grass invasion can change soil properties and the microclimate to its own advantage at the expense of the native shrubs and trees (Ens et al. 2015; Rossiter-Rachor et al. 2009). Gamba grass can spread at explosive rates (Petty et al. 2012), and in one protected area alone, gamba grass spread by 9,463 ha between 2014 and 2021 (Rossiter-Rachor et al. 2023). Gamba grass has an extremely wide potential distribution and has only invaded a small proportion of its modelled potential range in Australia (Setterfield et al. 2010).

Gamba grass has naturalised in the northern parts of the NT, and in coastal and sub-coastal areas of north Queensland, and as far south as Rockhampton (Figure 1). Gamba grass is widespread throughout the greater Darwin rural area, including large areas of Litchfield National Park. Gamba grass had been detected on the Tiwi Islands, NT, but it is now thought to have been eradicated. Gamba grass is only known to occur in one location in WA and this infestation is part of an eradication program which is progressing well (Murphy et al. 2021). Gamba grass has not yet spread to cover all the potential habitat in northern Australia, with Figure 2 depicting the areas predicted to be at risk of gamba grass invasion.

Figure 1 The current area of occupancy of gamba grass in northern Australia. The likelihood of being present is represented on a scale from zero (dark blue) through to one (red). Modelling was only conducted for northern Australia. Source: Pintor et al. (2018) and Pintor et al. (2019).



2.1.3 Dispersal pathways

Gamba grass plants produce a large number of viable seeds, and this helps them to establish and spread into new areas. A single mature plant can produce up to 244,000 seeds per year, and average infestations produce around 70,000 seeds per square metre (Flores et al. 2005). In comparison, native grasses produce around 50 to 6,300 seeds per metre square, and have lower seed viability.

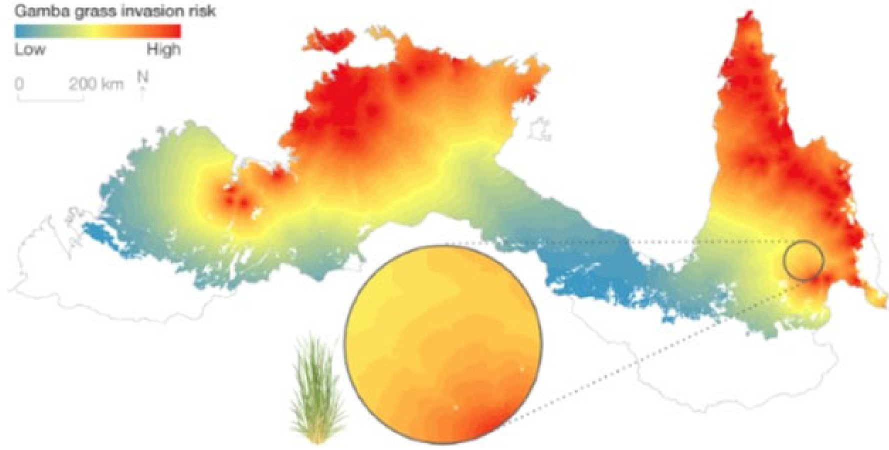
Gamba grass seed is spread in two main ways; human mediated spread (deliberate and accidental spread by people), and natural spread by wind, water and animals. Gamba grass seeds are light and fluffy, and can be dispersed by wind up to 100 m into undisturbed ecosystems (Petty et al. 2012). Dispersal over longer distances, up to hundreds of kilometres, is mainly by vehicles, machinery and in transported hay. Long-distance dispersal is the most common way that gamba grass reaches new areas and it can greatly accelerate the invasion of gamba grass in a region and result in re-infestation of sites after control. Seeds are often deposited along transport corridors (e.g. roads, rail), infrastructure easements (e.g. powerlines, communications) and other disturbed sites (e.g. gravel pits, campgrounds), with higher levels of disturbance assisting establishment. Slashers, graders and soil and fill can also contain seed. Riparian corridors are also an important pathway for gamba grass to spread into remote areas, and, riparian areas should be a priority for monitoring and control works (Petty et al. 2012).

Gamba grass usually seeds in the early dry season. If early dry season burning occurs, seeds can spread from fire updraughts and germinate in bare ground. Hot fires facilitated by gamba grass can create more bare ground, providing space for the seeds to germinate. Gamba grass seed is relatively short lived with viability dropping to less than 1% after 12 months (Flores et al. 2005) and no seeds are viable after 24 months (Bebawi et al. 2018). Seedling establishment is increased with soil disturbance by animals and tree removal, and is decreased by flooding (inundation).

Fodder and hay contaminated with invasive grasses is another known dispersal pathway for all the grass species in the plan. Several stakeholders had observed bales of gamba grass and mission grasses in the NT and Queensland, which had been baled while the grasses were seeding. Bales can be moved between properties, and in some cases, used as mulch under in horticulture.

Areas where gamba grass is already present as scattered, isolated plants are at high risk of becoming densely invaded by gamba grass. There are reports of new gamba grass seeds dispersing into locations where gamba grass has been previously controlled, such that there is a need for ongoing monitoring to prevent reintroduction into conservation assets.

Figure 2 The predicted risk of gamba grass invasion across northern Australia. Risk is on a sliding scale from low (blue) through to high (red). Modelling was only conducted for northern Australia. Source: Pintor et al. (2018) and Pintor et al. (2019).



2.1.4 Fire

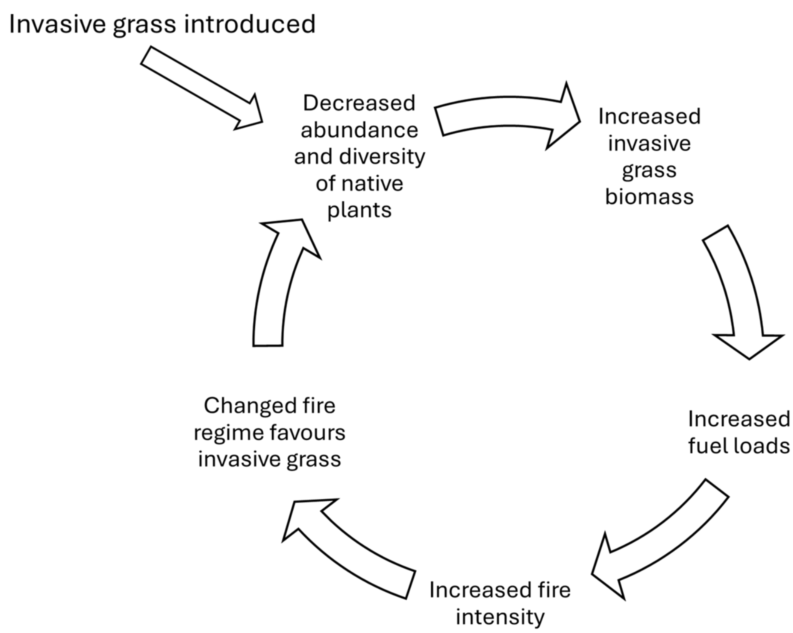
Fire has a positive effect on gamba grass and the mission grasses, with invasion and establishment of all 3 species encouraged by repeated burning. The positive feedback loop between fire and invasive grass expansion is known as the grass fire cycle (D'Antonio and Vitousek 1992). Another term, the human grass fire cycle, has also recently been used to indicate the role people have in the introduction and spread of introduced grasses with fuel characteristics different to the plants they out compete (Fusco et al. 2022). A simplified version of the grass fire cycle is shown in Figure 3.

Savanna vegetation heavily invaded by gamba grass has a greater amount of dense fine fuel, up to 30 tonnes per hectare (Rossiter et al. 2003; Setterfield et al. 2010). In comparison, native grasses only produce up to 3 to 8 tonnes per hectare of fuel. The increased fine fuel from gamba grass and the mission grasses, combined with these grasses curing later in the dry season than native grasses, can cause high intensity dry season wildfires that can reach into the canopy of trees. Gamba grass fires burn with up to 8 times the intensity of native grass fires, and fire intensity is high in invaded woodlands even when they are burnt early in the dry season (Rossiter et al. 2003).

Repeated high intensity fires, lead to a reduction in tree and shrub canopy cover, and eventually death of trees, transforming savanna woodlands into invasive grasslands (Brooks et al. 2010; Setterfield et al. 2010). Areas invaded by gamba grass have been known to carry two fires in one dry season. More information on impacts of gamba grass invasion and ecological impacts of changed fire regimes is covered in section 4.1. Updraughts from fire can disperse seeds, and intense fire can create bare ground for seedling establishment. Gamba grass fires can threaten human safety, property and ecosystems. Fire management measures in northern Australia have needed to change as a result of gamba grass invasion, and it is now more costly and dangerous to manage these more frequent and severe gamba grass fires (Setterfield et al. 2013).

Field trials in the Mary River National Park, NT, within savanna woodlands invaded with gamba grass indicated that exclusion of fire for a number of years is beneficial to managing gamba grass for conservation outcomes (Rossiter-Rachor and Setterfield 2019). In the absence of fire, the health of the gamba grass declined, tree health increased, and the increase in tree canopy cover reduced the sunlight reaching the gamba grass. The increase in tree canopy helped maintain a dense layer of leaf litter, which inhibited the germination of gamba seeds (Rossiter-Rachor and Setterfield 2019).

Figure 3 A simplified representation of the invasive grass fire cycle. Adapted from Fusco et al. (2022).



2.1.5 Livestock grazing

Many graziers in northern Queensland still consider gamba grass as highly valuable for pasture and hay production, describing it as being soft, palatable and productive. This can be the case if it is managed well and kept below knee height, but it requires consistent high stocking densities of cattle to keep the grass short and palatable.

Growing gamba grass for fodder was seen by some stakeholders as a way of helping to protect livestock herds against drought, natural disasters and reducing transport miles for supplementary fodder during the dry season. Many people in the grazing industry had the perception that gamba grass was not as invasive or problematic in Queensland as it is in the NT, and that gamba grass growing south of Townsville (Lower Burdekin catchment) did not reach the same biomass as gamba grass growing in far north Queensland. Preliminary research suggests that gamba grass can grow to a large biomass in Queensland.

Some representatives of farming groups expressed frustration about the need to comply with biosecurity obligations to control gamba grass and keep it away from fence lines, especially when their perception was that gamba grass infestations on neighbouring conservation estates may not be adequately managed. In the NT, properties in the containment zone (Zone B) must have a minimum of 15 m wide buffer zones free of gamba grass around all infrastructure, property boundaries, and along either side of driveways and tracks.

Gamba grass requires intensive management to remain palatable (Cook et al. 2006). When it grows above knee or waist height, cattle are reluctant to walk into it and are less likely to graze it. This is when the gamba grass is more likely to becomes a fire risk that threatens biodiversity, cultural assets, infrastructure and people.

An industry led code of conduct has been drafted to assist the containment of gamba grass to grazing systems, but this has not been finalised or endorsed. Containment of gamba grass within the boundaries of a grazing property is extremely difficult, due to how easily the lightweight seed disperses. It also only takes one plant to flower, and the seeds to be dispersed by wind, water or animals to create a new incursion (CSIRO 2022 pers. comm., 20 June).

2.1.6 Management

Effective control of invasive grasses often requires an integrated management approach, involving multiple control methods. Best practice invasive grass management can differ in conservation, agricultural and urban areas. For example, the herbicides that are feasible for use in conservation areas can be different to what you can use on the side of the road. In some conservation areas, it is only possible to treat invasive grasses once per year with herbicide on foot, whereas infestations on the side of the road can have good year-round access (CSIRO pers. comm., 20 June 2022).

A management barrier that affects all 5 invasive grass species, is that control work often cannot be done in the wet season when the grasses are actively growing, because flooding restricts access. Crocodiles can also make operations more challenging and dangerous.

The short-lived seedbank of gamba grass means that new infestations can potentially be managed with one year of intense action (herbicide or physical removal) and one year of follow up monitoring and control of seedlings (Flores et al. 2005). Existing infestations can potentially be controlled with ongoing management over approximately 3 years, plus ongoing monitoring. There is currently an eradication plan in place for the one known gamba grass infestation in WA. This infestation is on track for eradication, and the success of control work is partly related to the good access to the plants, year-round.

Fire alone will not kill gamba grass, and as mentioned in section 2.1.4, inappropriate fire regimes can lead to more gamba grass. Fire can be used as part of an integrated management approach in limited situations. Fire has been used to reduce the grass biomass and therefore reduce the amount of herbicide required. Herbicide is applied to the new green growth emerging post-burning. It is important that gamba grass is not burnt when in seed, or in the late dry season.

The use of non-chemical methods for invasive species management is especially important in areas of high conservation value, as most of the herbicides currently used are non-selective. Physical removal, such as digging up plants can be effective, but it is also important to limit soil disturbance to minimise new recruitment.

Gamba grass is less competitive in shaded areas, and restoration of the tree canopy can help to manage gamba infestations (Rossiter-Rachor and Setterfield 2019). Fire exclusion combined with judicious herbicide use, has been shown to increase tree canopy cover, increase the leaf litter layer, and reduce gamba grass health and recruitment of new gamba grass plants.

There is a heavy reliance on herbicides to control all invasive grasses in the threat abatement plan. Herbicides can be one of the most cost effective and efficient means of invasive grass control, but consideration should be given to the impact on non-target flora and fauna, herbicide resistance and the need for post treatment rehabilitation. Dependence upon herbicides may impede the development of other management techniques.

Glyphosate is the herbicide most commonly used to control gamba grass. Glyphosate is more effective when applied to young green plants up to waist height, or when applied to regrowth after mature plants have been burnt, slashed, mowed or grazed. Mature tussocks can be sprayed up until the early dry season when flowering, but before seed set, however this requires more herbicide than spraying young plants. Mature plants with a lot of thatch (old stalks) often require follow up spraying.

Spraying all of the vegetation (global spraying) is more efficient in terms of time and cost, than spot spraying just the invasive grasses within native vegetation. There is a trade-off however, between killing the invasive grasses and also killing the native vegetation. Glyphosate is non-selective and has moderate to high off target impacts, meaning it will kill many desirable plants.

A residual, pre-emergent herbicide trial found no other chemical tested could selectively control gamba grass amongst native grasses (Murphy et al. 2021). In addition, no other herbicide tested was found to be as effective as glyphosate at killing gamba grass. Choosing a suitable herbicide, balancing killing gamba grass and limiting off target impacts, is very context dependent, affected by factors like soil type and rainfall. It is likely there is no one herbicide that is suitable for all these invasive grasses under all situations (CSIRO 2022 pers. comm., 20 June 2022).

In Australia, pesticides and herbicides are nationally authorised and regulated, up to – and including – the point of sale by the Australian Pesticides and Veterinary Medicines Authority (APVMA). The APVMA is responsible for product evaluation and registration, including approval of product labels describing allowed use, storage and disposal. The APVMA also issues permits where use of a chemical is different from the product label, and for limited use of unregistered chemicals. After the point of sale, state and territory government agencies further regulate the use, storage and disposal of pesticides and herbicides. Not all herbicides that are allowed to treat environmental weeds in bushland are allowed to be used on agricultural land. In some cases, the herbicides have not been tested to determine if they are safe for use around livestock. The permitting system for herbicides for invasive grasses is complicated, and often involves short term minor use permits, and the use of environmental weed 'off label' permits.

In the NT, there are two community groups that help control gamba grass and provide information on gamba grass management to the community, Gamba Grass Roots and the Gamba Army. The Gamba Army is administered by Territory NRM and funded by the NT Government and assists in managing gamba grass in the greater Darwin area. Also in the NT, the Gamba Action Program loans equipment and provides free herbicide to landholders who want to manage gamba grass on their property.

2.2 Mission grasses

Numerous *Cenchrus* species have naturalised and become invasive in Australia and worldwide. Annual and perennial mission grass are phenotypically similar to each other and to numerous other introduced grasses in the *Cenchrus* genus. This means they are often misidentified. Unfortunately, most of the information available on annual and perennial mission grass in Australia, does not distinguish between the two species. There is little information available on the current distribution and density of both mission grass species to determine if their distribution is changing over time.

Similar to gamba grass, the mission grasses continue growing well into the dry season (Douglas et al. 2004). They can form large infestations in disturbed and undisturbed areas, and growth is encouraged by repeated burning. The mission grasses tend to be a lower priority for management compared to gamba grass. This is partly because they do not exacerbate fire intensity and frequency as much as gamba grass does, and they have a larger distribution than gamba grass, to the extent that some stakeholders think that control is not feasible.

2.2.1 Annual mission grass

Annual mission grass is native to tropical Africa and Asia. It was imported into northern Australia from Africa in the 1940s as a potential pasture grass (Cook and Dias 2006), and several varieties are thought to have been introduced. By the 1970s, annual mission grass had become widespread across northern Australia, including northern and eastern Queensland, northern Western Australia (including islands within the Ashmore Reef) and the northern parts of the Northern Territory (Figure 3).

Annual mission grass is also known to occur on islands off the coast of the Pilbara and Kimberley regions of Western Australia (Koolan Island, West Island) (Lohr 2016). It has also been detected on the Torres Strait Islands, and islands offshore from Queensland (Palm Island), and the Northern Territory (Bickerton Island, Groote Eylandt, Tiwi Islands) (GBIF Secretariat 2023a). Isolated infestations have been detected further south in the Northern Territory towards central Australia, and in Southeast Queensland. It has also naturalised in New Caledonia, and the USA including Hawaii.

Some varieties of annual mission grass grow to 50 cm in height, whereas others can grow up to 2.5 m in height and become a short-lived perennial, which is similar to the height reached by perennial mission grass. Annual mission grass is known to invade areas where perennial mission grass has been controlled. Stakeholders have observed that annual mission grass does sometimes die out in undisturbed sites over time (NAQS 2021. pers. comm. 14 December).

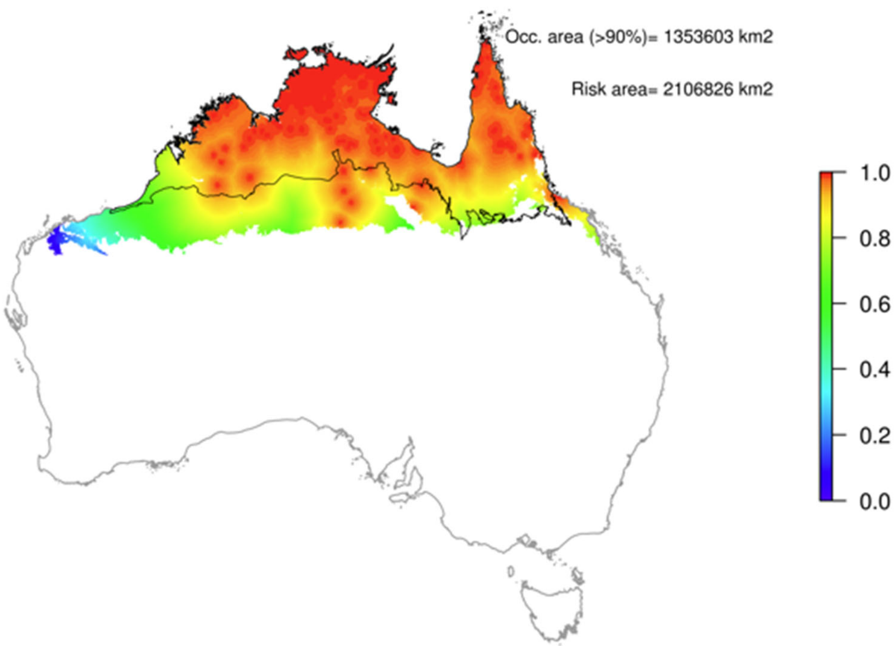
Annual mission grass will grow in shady areas where native grasses typically will not grow, thereby facilitating the spread of fires beneath sensitive trees and shrubs. It also grows well on moist soils and tends to invade creek lines.

Annual mission grass has a high seed output (Setterfield et al. 2006), and produces more seed than perennial mission grass, and this can make it harder to control. Seeds are hairy on the lower half, making them ideal for dispersal by wind, and on animals and vehicles. Seeds are known to be viable after 1.5 years, but the overall length of time that seeds may be viable for is not known. A better understanding of seed longevity would help to understand how long control work and monitoring are required for.

The mechanisms of spread of annual and perennial mission grass are similar to those of gamba grass, and both species of mission grass are known to spread along transport corridors. For example, mission grass was once confined to communities, outstations and camping areas on the Tiwi Islands, but increased development and traffic across the islands has led to spread into natural areas.

Annual mission grass is not valued as a pasture grass, and community awareness of it as an invasive weed is low. This is despite it possibly having the greatest area of occupancy of the 5 grass species covered by the threat abatement plan. Stakeholders in the NT mentioned that annual mission grass was so common around some communities, that it had become ‘accepted’, especially because it was not as damaging as gamba grass.

Figure 4 The current area of occupancy of annual mission grass in northern Australia. The likelihood of being present is represented on a scale from zero (blue) through to one (red). Modelling was only conducted for northern Australia. Source: Pintor et al. (2018) and Pintor et al. (2019).



2.2.2 Perennial mission grass

Perennial mission grass is native to tropical Africa and may also be native to Asia (India). Parker (2008) lists over 20 different scientific names that this species has been known by in different regions of the world. It is frequently attributed incorrectly on websites.

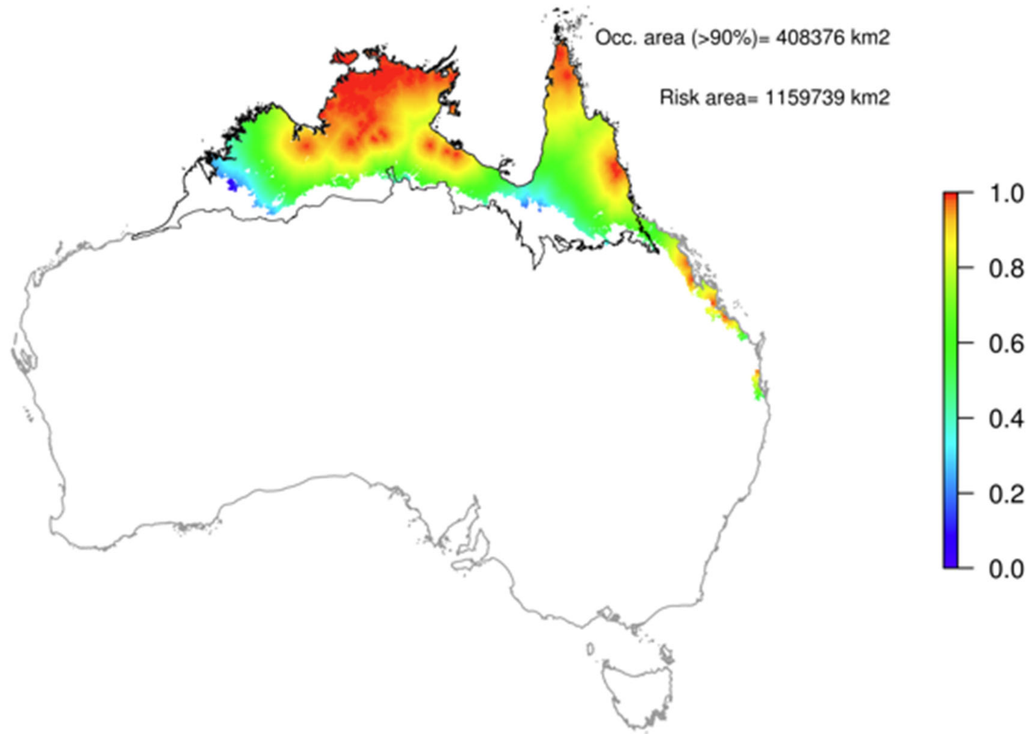
Perennial mission grass was introduced into Australia in the 1930s (Cook and Dias 2006), and it is unclear if the introduction was accidental or deliberate for use as a pasture species (Miller 2006). It is grown as a forage crop in Asia and South America (Parker 2008).

The first record of perennial mission grass as a weed in the Northern Territory was in the 1970s, and this is also around the time it was deliberately introduced to Queensland. Soon after this sighting, perennial mission grass spread quickly into Katherine, Arnhem Land, Kakadu National Park and the Tiwi Islands. Perennial mission grass is thought to have a similar but slightly smaller distribution than annual mission grass, that extends to southeast Queensland (Figure 4). It is known to also be present on several islands in the NT (Croker Island, North Goulburn Island, South Goulburn Island) and the Torres Strait Islands (Woinarski and Baker 2002). It is invasive throughout tropical, subtropical and warm temperate regions worldwide including the USA, Fiji and Thailand, and can also grow as an annual.

Perennial mission grass is shade tolerant and adapted to low fertility soil (Parker 2008). Perennial mission grass produces abundant light, fluffy seeds seed with bristles, which are dispersed by wind, water, and by attaching to animals, clothing and vehicles (Parker 2008). Perennial mission grass has been observed to form roots at the nodes of branches, facilitating vegetative spread. It may also be spread as a contaminant in hay and grain. Perennial mission grass has a short-lived soil seed bank, similar to gamba grass. This means that it could be possible to eradicate new infestations within 2 to 3 years of detection with intensive action.

In northern Australia, the seeds germinate any time after the initial rains of the wet season (October-November). The mission grasses have been observed to often seed before the plants are accessible to people and vehicles, when there is still a lot of flood waters present (Territory NRM 2021 pers. comm. 28 January). Rapid growth follows seedling establishment, and flowering commences in late January or February and continues into the early dry season. Growth ceases in June or early July.

Figure 5 The current area of occupancy of perennial mission grass in northern Australia. The likelihood of being present is represented on a scale from zero (dark blue) through to one (red). Modelling was only conducted for northern Australia. Source: Pintor et al. (2018 and 2019).



2.2.3 Fire

Annual and perennial mission grasses are both high biomass forming grasses, and can change an ecosystem by altering the fire regimes and nutrient dynamics (Miller 2006; Brooks 2010). Perennial mission grass has a biomass that is up to 5 times greater than uninvaded native vegetation, with a grass fuel load of around 8.6 ± 1.0 tonnes per hectare (Douglas and O'Connor 2004). Mission grasses can form dense stands, with continuous cover under trees. Similar to gamba grass, the mission grasses stay green and upright and grow later into the dry season than the native grasses.

Perennial mission grass has been known to carry two fires in one dry season, and for the flames to reach up to 5 metres in height. The flames are sometimes high enough to reach into the tree canopy. The biomass and fuel load of annual mission grass is not known and is likely to vary greatly between varieties.

The mission grasses can change the grass fire cycle in a similar way to what gamba grass does, but the magnitude of impact on fire frequency and intensity is less for the mission grasses, as they produce less fuel than gamba grass (see section 2.1.5 for general information on invasive savanna grasses and the grass fire cycle).

2.2.4 Management

Management of the mission grasses is best undertaken before the grasses set seed, and small infestations can be hand pulled. On roadsides, repeated slashing or mowing before the grass sets seed can be effective in suppressing flower and seed development. This is more effective with annual mission grass, as the adult plants will not survive to the following year. Perennial mission grass regrowth can be treated with herbicide. Burning promotes further mission grass establishment and is not a recommended control tool. Post-fire regrowth can be followed up with herbicide application.

There are a wide range of herbicides that are effective in controlling mission grass. Glyphosate and imazapyr are registered for use for tussock grass control, and fluproponate can currently be used under a minor use permit. There are other herbicides permitted under various environmental weed permits, that allow use the herbicide to be used in native vegetation, non-crop areas and public spaces.

Herbicides appear most effective when applied in the summer wet season, on young mission grass plants or on regrowth following slashing or mowing. Imazapyr can provide the longest control, but it tends to act slowly. Spot application of flupropanate has been shown to be an effective and practical method for controlling mission grass in areas such as revegetation sites, sites in the early stages of invasion with limited or scattered infestations and sites where the northern wet season can limit access for high-volume herbicide application (Vogler et al. 2017). Flupropanate activity depends upon subsequent rainfall for systemic uptake and soil residual control but has the advantage of being available as a granular pellet that can be applied before the wet season.

Controlling the mission grasses around Darwin where it has been present for many years is considered challenging, as there are abundant seed sources in the landscape. Price et al. (2008) concluded that control actions may need to be repeated regularly and indefinitely due to the ongoing propagule pressure within the landscape.

3 Invasion history and biology of the semi aquatic grasses

3.1 Ponded pasture

Ponded pasture systems involve planting pasture grasses into artificial wetlands or into modified wetlands by constructing banks (bund walls) or levees to retain freshwater and surface run-off. In the past, ponded pasture was constructed on the edges of marine plains, in saltmarshes and melaleuca and eucalyptus coastal tree swamps of coastal Queensland, and along parts of the dry tropical coast of the Great Barrier Reef and Gulf of Carpentaria, NT. Ponded pasture was also built in the rangelands of Queensland, but many of these inland systems have been abandoned or disbanded as they were not effective. In coastal areas, ponded pasture systems prevent upstream movement of saline tidal water, while prolonging freshwater inundation on the upstream side.

Ponded pasture was created to provide cattle with access to high quality fodder during the late dry season and was an attempt to 'drought-proof' farms (Abbott et al. 2020). The three invasive semi-aquatic grass species commonly planted in ponded pasture were hymenachne, para grass and Aleman grass, which is also known as creeping river grass (*Echinochloa polystachya*).

Artificial pond areas do not adequately contain exotic pasture species, and escape easily occurs into adjacent waterways, especially if there is heavy rainfall or flooding (Csurhes et al. 1999). Cattle tend to only graze the introduced grasses once the water has dried out and are reluctant to graze grasses in areas under water all year round.

In June 2001, the Queensland Government released the *Queensland Policy for Development and Use of Ponded Pastures*, recommending against the use of hymenachne and para grass in ponded pasture. This policy, combined with the *Queensland Fisheries Act 1994,* controls the construction of barriers to tidal flows (ponded pasture) in wetlands subject to tidal inundation. New ponded pasture works in Queensland must comply with accepted development requirements or a development application under the *Queensland Planning Act 2016*. There is no similar ponded pasture policy in the Northern Territory.

Ponded pasture systems have a range of ecological impacts, some of which are discussed under the ecological impacts of hymenachne and para grass in section 5.2. Overall, the dense stands of invasive grasses and the bund walls impede the movement of aquatic animals and reduce water quality.

3.2 Hymenachne

3.2.1 Invasion history

Hymenachne is native to tropical and sub-tropical South and Central America (Table 2). The Commonwealth Scientific and Industrial Research Organisation (CSIRO) imported hymenachne from Venezuela, South America in the 1970s for assessment as a ponded pasture species for cattle feed (see section 3.1). There were at least 3 separate introductions of plant material into Australia, and the ‘Olive’ variety was approved for release as a pasture grass in 1988. Hymenachne was promoted and deliberately planted in the NT, central and coastal Queensland on tropical wetlands, floodplains and artificial ponded pasture systems. There are anecdotal reports of it being planted in the Kimberley region of WA but failing to establish.

In Queensland, hymenachne was widely promoted within the grazing industry as well as to the grazing industry by government agencies. Before it was declared a noxious weed in the NT, plantings occurred in catchments near Kakadu National Park, and it was first reported within Kakadu National Park in August 2001 (Setterfield et al. 2013). A 1997 survey of pasture practices of northern Australian beef properties indicated that within 10 years of being commercially available, hymenachne had been widely planted across the NT and Queensland, and to a lesser extent in WA (Bortolussi et al. 2005). Hymenachne had been planted at 55% of surveyed properties in the NT and 44% of surveyed properties in North Queensland.

Hymenachne escaped cultivation and invaded cane-growing areas soon after it was released. By 1997, dozens of infestations had been reported (Csurhes et al. 1999), and there were numerous reports of it spreading naturally in areas of Queensland and the NT with more than 1,000 mm of annual rainfall (Bortolussi et al. 2005).

In the NT, hymenachne was also deliberately planted as a competitive cover crop as part of mimosa (*Mimosa pigra*) control programs. Mimosa is another highly invasive aquatic Weed of National Significance (WoNS). Hymenachne is no longer recommended for planting after mimosa control, and it has been known for some time that revegetation with hymenachne will not suppress all mimosa seedlings. Hymenachne was also promoted and planted to remove nutrients from polluted wastewater (Csurhes et al. 1999).

3.2.2 Distribution and habitat

Hymenachne can grow in deeper water than para grass. It is typically found in water up to 1.5 m deep but has been observed growing as a floating raft or within other aquatic vegetation in water over 4 m in depth. Hymenachne tends to only survive in deep water that then recedes in the dry season, and it can cope with changes in water level and nutrient addition into waterways from nearby agricultural activities.

Hymenachne mainly invades low-lying areas along the edges of permanent water, but it has also established across waterways. It can withstand prolonged flooding, up to 40 weeks, by growing above floodwaters, and there are reports of hymenachne persisting in standing water year round. It can form dense monocultures that impede the movement of water, boats and animals and it may exacerbate flooding.

Hymenachne has established across a range of land tenures, including conservation, pastoral and land under Indigenous management, including wilderness areas within Kakadu National Park and Arnhem Land, Queensland’s Wet Tropics and Cape York Peninsula (Figure 5). The Northern Territory and cape region of northern Queensland are ideal habitat for hymenachne, with high rainfall, warm temperatures and extensive wetland areas (Wearne et al. 2013).

Maps of hymenachne distribution and density in Queensland derived through expert elicitation, indicate there has been an increase in hymenachne distribution in every coastal Queensland council region between 2012 and 2023 (QDAF 2023). The density of infestations within South East Queensland is thought to be lower than in the other coastal regions to the north. Local eradication of hymenachne is thought to have occurred in very small areas within the North Queensland (Townsville area) and Central Queensland (Rockhampton – Gladstone area) council regions (QDAF 2023).

While hymenachne prefers tropical and sub-tropical areas, it has also established in cooler inland southern Queensland and northern NSW. It has spread further south within NSW since 2012, and this includes isolated occurrences of hymenachne in the Murray Natural Resource Management region near the Victorian border, and spread into what had been identified as a spread prevention zone in NSW (Grice et al. 2011). The occurrence of hymenachne in NSW is the furthest south hymenachne has been recorded worldwide (Jacono 2014), and this is beyond the climatic range of the native distribution in South America (Wearne et al. 2013). Hymenachne is highly invasive in Florida, USA, where it is also growing outside the native climatic range.

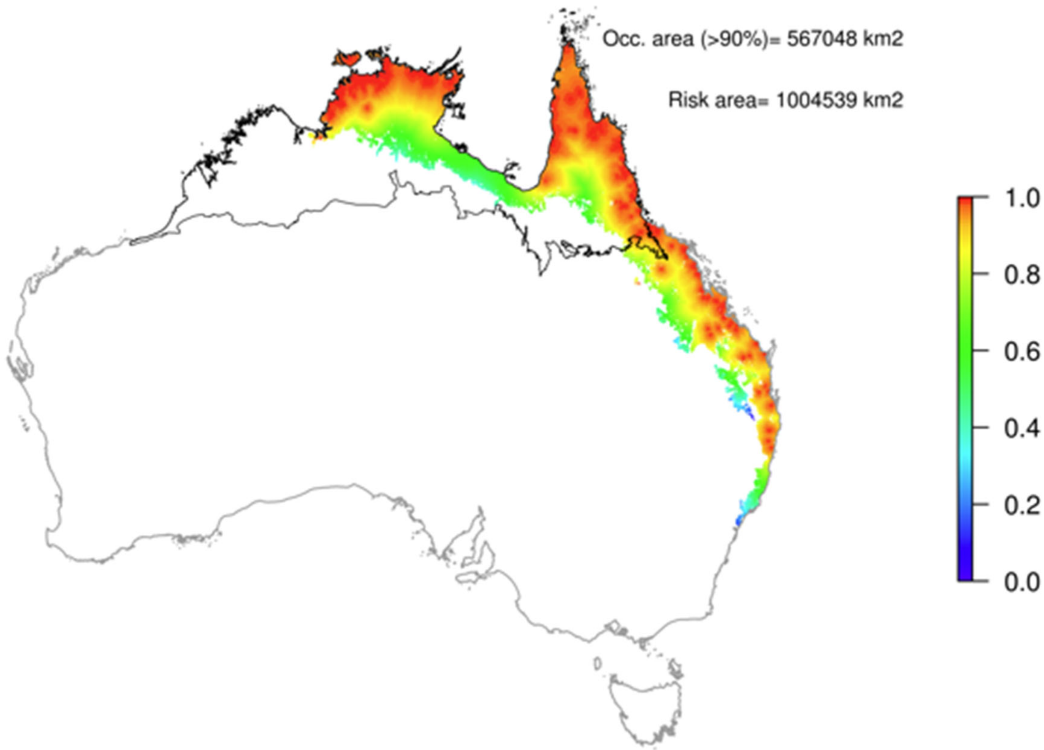
Hymenachne uses a C3 photosynthetic pathway, whereas the other four grass species in the plan use a C4 pathway. C3 grasses generally have poor water use efficiency, and in some tropical habitats might be less competitive than C4 grasses. However, hymenachne appears highly competitive in northern Australia. Being a C3 grass, hymenachne could be more frost tolerant than para grass, and be able to establish in the cool season. This aligns with it successfully establishing in NSW. Hymenachne has the potential to colonise a much larger area than the area it currently infests. Modelling has indicated that most of the Wet Tropics streams and wetlands are moderately (58%) or highly (32%) suitable for hymenachne (Januchowski-Hartley 2011). Low habitat suitability was found in steep terrain and along the immediate coastline, with hymenachne unable to survive in highly saline water (Januchowski-Hartley 2011). Hymenachne spread from approximately covering 1,000 ha to 11,000 ha between 2000 and 2011 (AWC 2012), but the total area currently infested is unknown.

A small hymenachne infestation was discovered in the East Kimberly region of WA in 2017. A plant or plant fragment is thought to have been brought into the area on a tourist's vehicle. This infestation is part of an eradication program, and hymenachne has not been detected in WA since around 2019.

Hymenachne and para grass invade agricultural areas under irrigation, including sugar cane and banana, and can block drains and irrigation storages. Infestations maybe more invasive when there is a high influx of nutrients and sediments from agricultural sources upstream. Runoff from agriculture is likely to have contributed to the establishment and competitive advantage of hymenachne, para grass and Aleman grass over native wetland plants (Pearson et al. 2010).

In 2007, plants were observed in Abattoir swamp near Julatten in Far North Queensland, which appeared intermediate in appearance to the invasive *Hymenachne amplexicaulis*, and the native hymenachne, *Hymenachne acutigluma* (Clarkson et al. 2011). Genetic analysis confirmed these plants were a hybrid, now known as *Hymenachne × calamitosa* J.R. Clarkson, *sp. nov*. This hybrid is thought to be an aggressive competitor to native wetland vegetation (QPWS 2022 pers. comm. 9 February). Little is known on how best to control this hybrid species, or the long-term impacts of invasion.

Figure 6 The current area of occupancy for hymenachne in Australia. The likelihood of the grass being present is represented on a scale from zero (dark blue) through to one (red). Source: Pintor et al. (2018) and Pintor et al. (2019).



3.2.3 Spread

Apart from deliberate planting for agricultural use, hymenachne is mainly spread by natural means, notably flooding. When ponded pastures are close to creek systems, a flood can easily spread plants, stem fragments or seed to an adjacent creek or stream (Rolfe et al. 2007). Waterbirds, particularly magpie geese (*Anseranas semipalmata*) may spread the seed in their droppings or transport seed or vegetation fragments. Vegetation fragments and seed are also accidentally spread by boats, vehicles, and machinery. In Brazilian wetlands, native fish are known to disperse seeds (Jacono 2014).

Floating mats of the grass can become dislodged in floods and be transported downstream (Housten and Duivenvoorden 2002). These rafts of hymenachne can establish in new areas or block streams.

One hymenachne plant produces thousands of seeds which are readily dispersed by water. Hymenachne seed germination is thought to be triggered by removal of above ground plant material through burning or heavy grazing (Wearne et al. 2010), with seeds requiring moist or waterlogged soil for germination.

Hymenachne seeds are still viable after being immersed in fresh, salt or brackish water for 98 days (Setter et al. 2022). After adult plants have been removed, the remaining seedbank has been found to still be viable after 8 years (Wearne et al. 2010).

3.2.4 Livestock Grazing

In the NT and Queensland, some graziers still view hymenachne as an important resource for cattle, to the point where they think cattle “need” hymenachne during the late dry season (Greening Australia 2021 pers. comm. 3 February 2021; NT Government pers. comm. 8 January 2021). There does appear to be a decline in the use of hymenachne for pasture in some areas of NT and central Queensland, with some pastoralists viewing the plant as a weed that needs to be controlled (Kinnear et al. 2008). During consultation for the threat abatement plan, divergent views were expressed from a range of stakeholders, from this grass being a highly invasive weed through to it being a beneficial pasture grass.

A code of conduct was drafted for containing hymenachne to ‘genuine grazing systems’, and the guidelines were endorsed by peak industry bodies (Magnussen 2012). Genuine grazing systems were considered to be existing grazed ponded pastures in Queensland and planted floodplains in the NT. Containment to genuine grazing systems would require any hymenachne outside these systems to be removed by landholders, as it does not provide grazing benefit. However, as time has shown, exotic ponded pasture grasses cannot be contained within artificial ponds or pasture.

Cattle are highly reluctant to graze hymenachne while standing in water, and usually only the edges of a patch are grazed. Such that hymenachne that is under water most of the year provides little to no value as feed. Despite this, many graziers are reluctant to commit resources towards removing an invasive plant they may view as another pasture grass.

3.2.5 Management of hymenachne

Hymenachne is extremely difficult to control because it can reproduce vegetatively and the seeds remain viable for a long time. Eradication of a population is thought to take at least 10 years of consistent effort (Grice et al. 2011), and often involves a combination of approaches. The chances of successful control are greatly improved when hymenachne is in the early stages of invasion. Like most weeds, surveillance, early detection, and immediate control once discovered produces the best outcome (Magnussen 2012).

Management should focus on preventing spread into new catchments, and new infestations should be treated promptly, when small and manageable, with upstream infestations being a priority. The connectively of waterways and floodplains is important to consider when managing hymenachne and para grass, and ongoing monitoring is recommended for at least 5 years after the last management intervention.

Where infestations are upstream on private property, all landholders need to be involved in control projects for efforts to be effective. Past projects have indicated that it can be challenging gaining access and cooperation from all private landholders (Kinnear et al. 2008). In central Queensland, some landholders gave up controlling hymenachne because reinfestations kept occurring from nearby properties (Kinnear et al. 2008). Hymenachne has been extensively controlled in the Burdekin, however, there are ongoing propagule sources from higher in the catchment and it has continued to reinvade and establish (Greening Australia 2021, pers. comm. 3 February).

Queensland stakeholders indicated that active control of hymenachne and para grass is rare outside of conservation areas, as they are still considered ‘good cattle feed’. There is little active planting of para and hymenachne, but nor are they being controlled on private grazing properties. Some people are also reluctant to remove hymenachne when mimosa is also in the area, as they think it helps to suppress mimosa.

Under the Weeds of National Significance initiative, a national strategy for the management of hymenachne was released in 2000 and a National Hymenachne Management Group was formed in 2004 to oversee implementation of the strategy. Grice et al. (2011) proposed a refinement of the management strategy in 2011. There have been no further updates, and the management group came to an end.

Herbicide

There is a lack of effective and affordable chemical control options for hymenachne, and currently no herbicide is registered for use on hymenachne. Off-label minor use permits allow the use of glyphosate in non-agricultural areas, and the use of haloxyfop, but only by licensed operators. High rates of glyphosate are required (Wearne et al. 2010), as well as repeated application to control regrowth. Herbicide application can increase the area of open water, but aquatic weeds are often present again months after spraying (Abbott et al. 2020). Herbicide treatment just prior to the onset of the wet season, where treated plants are likely to go under water (become inundated) can have better outcomes than herbicide alone, but it can be hard to time treatment with flooding.

Drones have been trialled to apply herbicide on hymenachne within high conservation value wetlands in the Northern Territory and Queensland. When deployed by experienced trained users, drones can fly low, and the speed and flow rate of herbicide can be adjusted. Drones have also been successfully used to survey hymenachne and para grass in wetlands. Obstacles and the need to keep the drone within the line of sight can limit the use of drones in invasive grass management.

Spraying extensive areas of hymenachne or para grass can lead to a large input of dead organic matter into a waterway. This can deplete the oxygen in the water, reduce water quality and kill aquatic organisms.

Fire

Hymenachne infestations have been found to have up to 30 times greater plant biomass than the native plants they replace, with a biomass of approximately 6.2 kg per metre squared (Houston and Duivenvoorden 2003). Hymenachne will readily burn once the plants have dried, such as at the end of the dry season. The dry biomass can fuel intense fires, and the plants generally survive burning (Clarkson et al. 2012), reshooting from below ground stolons.

Fire may be a useful management tool in some circumstances when used in combination with flooding or herbicide (Wearne et al. 2010). Fire can destroy hymenachne seeds on the surface of the soil of wetlands that have dried out, but it does not kill buried seeds (Wearne et al. 2011). While fire alone does not kill hymenachne, it can be used to expose seedlings and reshoots of para grass and hymenachne for follow up herbicide application (Clarkson 2012). The timing of fire can be critical, and it appears best if it is used right before the start of the wet season, when flooding can lead to death of the burnt plants (Wearne et al. 2010).

Grazing

It may be possible to reduce hymenachne seed production with heavy cattle grazing. However, when an infestation is inundated (in standing water), it is unlikely that cattle will graze it heavily enough to eliminate seed production. Seed production may be reduced if an infestation is grazed very heavily immediately before the start of the wet season, and the plants are then flooded (Grice et al. 2011).

In the wet tropics, grazing is not a suitable control technique as the preferred habitat of hymenachne is waterlogged year round. These areas are often inaccessible to stock for a large part of the year and are generally avoided by cattle as there is ample alternative feed available (FNQROC 2009). Cattle grazing can also have other ecological impacts.

Physical removal

Mechanical or physical removal of hymenachne and para grass can be used to open up waterways to allow people, boats and wildlife access. This needs to be done regularly to be effective. Some local governments in Queensland have purchased mechanical aquatic weed harvesters to remove aquatic weeds on a regular basis. Mechanical harvesters are useful for removing impenetrable floating mats of invasive grasses, which will then allow boat access to spray infestations (Wearne et al. 2010). Prompt and complete removal of all cut weeds is required as decaying plant material can decrease water quality. Physical removal has been used to reduce plant bulk prior to the wet season, when the plants may get flooded, with sustained inundation reducing plant growth and survival (Wearne et al. 2010).

Amphibious floating excavators have been used to remove shallow aquatic weeds. This can help remove the physical barrier dense grass infestations cause, which can limit fish movements (Waltham et al. 2020). Heavy earth moving machinery has been used to remove invasive grasses from drains and irrigation channels, with repeated regular treatment required.

Physical removal on its own will not eradicate hymenachne, because of its ability to reproduce vegetatively from very small pieces. Insufficient attempts at management, can lead to spread as this increases the number of plant fragments which are potential propagules (Kinnear et al. 2008).

Shading or competition from trees is thought to reduce growth and competition from hymenachne. Shading has been investigated as a form of control for para grass and hymenachne, with both the revegetation of stream banks and the use of shade cloth been shown to decrease invasive aquatic grass cover. These could be useful tools as part of a long-term management program in areas where there has been a loss of riparian vegetation.

Hazards such as seasonal flooding and crocodiles makes controlling hymenachne and para grass in northern Australia difficult. Every fragment of vegetation needs to be removed to eradicate hymenachne or para grass from a waterway. The current success of eradication efforts of the single hymenachne infestation in the Kimberly region of WA was partly attributed to it being safe for people and equipment, to get into the water and physically remove and collect the plants and stolons (WA DBCA 2022 pers. comm. 19 September).

3.3 Para grass

3.3.1 Invasion history

Para grass is native to tropical areas and floodplains of western and northern Africa (Rojas-Sandoval and Acevedo-Rodríguez 2014). It was introduced into Queensland around 1884, the NT in the early 1900s (Cameron 2008), and WA sometime before 1996 (Bortolussi et al. 2005). It was initially used to control erosion along riverbanks and was later promoted as a pasture grass for waterlogged or seasonally inundated areas throughout northern Australia, including central Queensland (Clarkson 1995).

Some of the earliest plantings as a pasture grass were on the coastal plains of Queensland in the 1930s. In the NT, para grass was deliberately planted in the areas now known as Kakadu National Park (Douglas and O'Connor 2004a) and Arnhem Land (Grace et al. 2004). This was usually following control of mimosa, as para grass and hymenachne were thought to stabilise wetland surfaces.

Para grass was observed to have spread from deliberate plantings and have negative impacts in the 1930s (Hannan-Jones and Csurhes 2012). Some areas outside of agriculture, have been invaded by para grass for over 60 years.

Para grass was planted extensively in ponded pasture systems (see Section 3.1) and is still promoted as a pasture grass for wet and flooded soils in some areas. Para grass is also an invasive weed in the United States of America, Mexico, and Central America, and widely distributed in New Zealand, Asia, South America and the West Indies (Rojas-Sandoval and Acevedo-Rodríguez 2014).

3.3.2 Distribution and habitat

Para grass is a warm climate grass that stops growing under 15°C. It will grow on a wide range of soils, provided there is adequate moisture. It can grow in humid and sub-humid areas with annual rainfall of 1,200-4,000 mm, or in swampy areas of drier environments down to 900 mm rainfall. It has limited growth during dry conditions. Para grass has been reported to spread from improved pasture in areas with rainfall greater than 500 mm, but that it is more likely to spread in areas with greater than 1,000 mm annual rainfall (Bortolussi et al. 2005).

Para grass is tolerant of a range of conditions and grows in wet or seasonally flooded areas including creek banks, wetlands, floodplains and even drainage lines and ditches. It prefers freshwater but will tolerate brackish water. Sedgeland and grassland habitat is at greatest risk of para grass invasion. Para grass can form a thick, uniform grass cover that impedes water flow, and is known to form monocultures and dense floating mats 1 to 2 m thick (Winderlich 2010). Discrete patches of para grass can increase in size and coalesce to form larger patches (Boyden et al. 2019).

Para grass is best adapted to the shallower parts of wetlands but will grow in depths from 10 cm to 200 cm of water (Ferdinands et al. 2005). Within Kakadu National Park, para grass has been observed to grow "everywhere, even in deeper water" (Kakadu National Park 2021, pers. comm. 5 February). Areas most at risk of invasion are characterised by water 1.1 m to 1.4 m deep, elevation of 2.0 m to 2.7 m and the water tends to drain earlier at the end of the wet season. These sites also tend to be drier and burn more frequently (Boyden et al. 2019). Floating mats of para grass can survive short times in very deep water, and para grass is known to invade areas previously inhabited by hymenachne (Abbott et al. 2020).

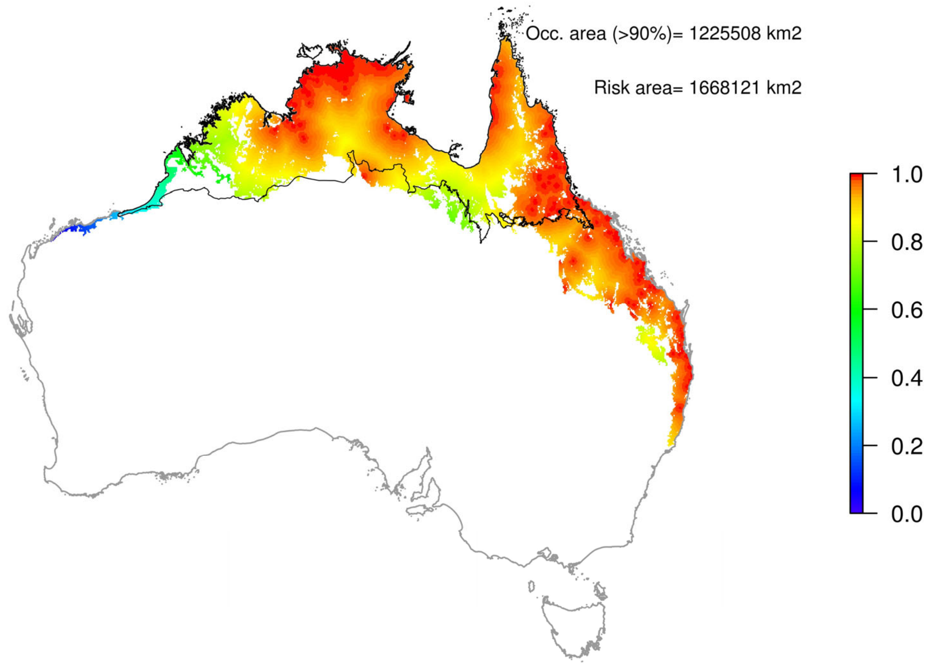
Para grass covers hundreds of hectares in the wetlands of Kakadu National Park (Ferdinands et al. 2005) and is widespread on low lying country in Queensland (Figure 6). It occurs within the Wet Tropics World Heritage site in Queensland, where it was first detected as naturalised back in 1973. Para grass is present on Christmas Island and West Island in the Cocos Islands (Lohr 2016). It is also known to be on the Tiwi islands (Bathurst and Melville), islands offshore from the Northern Territory (Croker Island, Groote Eylandt) and the Torres Strait Islands (Thursday Island, Badu Island) (GBIF Secretariat 2023b).

There is some thought that para grass has spread over much of its potential range, but that it could now become more abundant or denser within the tropical wetlands it has already invaded (Hannan-Jones and Csurhes 2012; Queensland Parks and Wildlife Service 2022 pers. comm. 9 February). However, detailed monitoring for parts of Kakadu National Park, show that para grass is continuing to expand in distribution and density on the freshwater floodplains (Boyden et al. 2019). Para grass has also spread further south within NSW since 2012 (NSW NPWS 2022 pers. comm. 29 June). Modelling indicates that there is also highly suitable habitat for para grass along the eastern coastline of Australia, which is further south than where it is currently growing.

Similar to hymenachne, para grass can block drains and irrigation storage, and this has impacts for agricultural industries, such as sugar cane cropping.

Para grass reaches its greatest aboveground biomass at the end of the wet season when the water starts to recede (Pettit et al 2011). Para grass produces 16 to 49 tonnes per hectare of fine fuel, which is far greater than that of the native wild rice, a species it commonly replaces, which produces 5.6 tonnes per hectare (*Oryza* spp.) (Douglas and O'Connor 2004). Para grass has a similar fuel load to the native perennial *Hymenachne acutigluma*, but the fuel is taller and drier, and this can increase fire severity and intensity and enable fire to reach into tree canopies. Para grass invasion can lead to high intensity fires at the end of the dry season on seasonally inundated floodplains. When floodplains dry out, dry grass material lodged in wide cracks in the clay soil can sustain a fire, making them hard to control (Cameron 2003).

Figure 7 The current area of occupancy of para grass in Australia. The likelihood of the grass being present is represented on a scale from zero (dark blue) through to one (red). Source: Pintor et al. (2018) and Pintor et al. (2019).



3.3.3 Spread

Agricultural use of para grass has greatly contributed to its geographic spread. Para grass has been promoted and used as an alternative pasture grass to hymenachne, probably because it is not a declared weed or a WoNS. Seasonal flooding, usually associated with northern Australia summer, facilitates the spread of para grass, with most new outbreaks thought to be from vegetative reproduction and not from seed.

A single para grass plant can naturally spread up to 5 metres in a year through its long stolons (Rojas-Sandoval and Acevedo-Rodríguez 2014). Similar to hymenachne, several stakeholder groups thought wetland birds assisted in the spread of para grass, with one person describing the vegetative spread of para grass by birds like “embers in front of a fire” (Kakadu National Park 2021 pers. comm. 5 February). Feral pig wallowing can disturb riparian areas and create bare ground, and this is also thought to facilitate the spread of para grass (Ferdinands et al. 2005).

Seeds are predominately dispersed via water. Para grass on the Magela floodplain in NT produced approximately 12,000 seeds per metre squared during the peak biomass period (May), and there were around 7,000 seeds per metre squared in the sediment seed bank (Knerr 1998). In laboratory trails, less than 3% of seeds germinated after three weeks, but approximately 80% of the remaining ungerminated seeds appeared viable. It has been hypothesised that the seeds could have a dormancy mechanism. The maximum lifespan of the seeds in the seedbank is unknown (Walden and Bayliss 2003).

Clearing of natural riparian vegetation decreases the shade on streams, and this appears to facilitate invasion by para grass, similar to hymenachne (Csurhes et al. 1999). Nutrient and sediment input from sugar cane farming can also assist para grass establishment and spread (Waltham et al. 2020).

3.3.4 Livestock and feral water buffalo

Para grass was extensively planted for use in improved pasture and ponded pasture systems. It is still promoted as pasture grass, with extension material stating that it is highly palatable to cattle and capable of supporting a larger stock carrying capacity than native pastures, however some stakeholders contested such claims. Native hymenachne is now known to be a more nutritional grass than para grass.

Some stakeholders stated it is now rare for para grass to be actively planted, or for its growth to be encouraged by graziers, however it is also uncommon for it to be actively removed from agricultural land. Para grass is still highly valued by pastoral industry, especially as it is not a declared weed. Existing pasture provides an ongoing source of propagules.

Para grass has been known to be impacted by the condition known as pasture dieback in both NSW and Queensland. Pasture dieback causes premature death of tropical and sub-tropical grasses, and is likely caused by a complex interaction of factors, and insects may play a role (NSW DPI 2021).

Previous culling or large scale harvesting of water buffalo in northern Australia is thought to have led to an increase in invasive grass biomass, and consequently an increase in fire frequency and intensity (Gill et al. 2000). Stopping traditional Indigenous burning practices on floodplains, in combination with buffalo culling in the late 1980s and early 1990s, is thought to have led to an increase in para grass in drier areas of floodplains in the NT (Ferdinands et al. 2005). These patterns were also mentioned by stakeholders during development of the plan, and similar concerns were raised regarding how the control of buffalo in swamps could remove the grazing pressure on hymenachne. There were approximately 160,000 feral buffalo in the Top End in 2019, and only a small number are currently commercially harvested.

3.3.5 Management of para grass

Para grass is very difficult to control, and generally requires an integrated management approach, including prescribed fire, flooding and herbicide treatment, with multiple treatments required. There is a large overlap in the management approaches taken for hymenachne and para grass, with both invading waterways and able to reproduce by seed and vegetation fragments. Mechanical removal is also a management option, and the information on mechanical removal for hymenachne (section 3.2.5) is also applicable for para grass.

The herbicides glyphosate and bromacil are registered for use on para grass, and the grass specific herbicide, fluazifop, can currently be used in bushland and wetlands under a minor use permit. Repeated application of herbicide is required while the plant is actively growing, and there have been reports of herbicide resistance in para grass in other countries (USDA 2015). In aquatic areas, only formulations registered for aquatic use are allowed.

Fire only kills some para grass tussocks within an infestation (Grice and Nicholas 2011), and plants tend to sprout within weeks of being burnt. It is not known if para grass seeds are killed by fire. There was no reduction in para grass cover after 5 years of annual, high severity prescribed fire in the Everglades National Park in USA (Stone 2010). A combination of prescribed fire and herbicide application appears to be more effective in controlling para grass than either treatment alone. Prescribed fire applied to areas that have dried out in the late dry season, increases the chance of plants becoming inundated (flooded) while short, and decreases para grass survival (Grice and Nicholas 2011).

In a long-term trial in Queensland, burning and cattle grazing in wetlands heavily invaded with para grass increased the amount of open water and decreased para grass cover. This benefited waterbirds (Grice et al. 2006) but decreased the abundance of common reptile and frog species (Bower et al. 2014).

Nutrient rich waters encourage aquatic weed growth, and as such preventing the input of nutrient run off away from agriculture will assist in the long-term management of invasive aquatic weeds, including para grass and hymenachne. In the Lower Burdekin, it was concluded that as long as sugarcane production occurs, there will be additional nutrient input into the lagoons, and aquatic weed management will need to continue (Waltham et al. 2020).

Reintroduction of tree cover along riparian areas has been proposed as one method of control, similar to what has been outlined for hymenachne (see section 3.2.5). In the Wet Tropics, rainforest species, such as *Sygysium* sp. have been planted along some waterways to provide substantial canopy cover to try and shade out para grass. This technique has been used on conjunction with other control tools, such as herbicide.

3.4 Removal of tidal barriers for management of invasive grasses

Removal of barriers such as bund walls or levees, put in as part of ponded pasture systems, has been tested as a natural form of freshwater weed control in coastal wetlands invaded by invasive grasses, or historically planted with invasive grasses. Removing a bund wall can reinstate tidal flows and allow seawater to penetrate a waterway creating saline water conditions. How saline the water becomes, and for how long the water remains saline can affect vegetation composition, including the weed cover and composition (Abbott et al. 2020).

The impact of saltwater on weeds appears to depend upon the water depth in the waterway, and how high the tide needs to be for the saltwater to penetrate. Bund wall removal may be successful where there are big waters flows (e.g. king tides), but it can also increase the spread of hymenachne at lower flows (Greening Australia 2021, pers. comm. 3 February).

One study in Queensland achieved a major reduction in hymenachne cover and an increase in native vegetation. However, there was also an increase in para grass and Aleman grass, which partly replaced the hymenachne. The three common ponded pasture grasses appear to have varying tolerance to saltwater.

Different studies have shown variability in the tolerance of invasive grass species to saline water. Reid et al. (2018) found that it is difficult to eradicate para grass and hymenachne using saltwater alone, as they could tolerate long periods (21 days) in high salinity (>70%) without all plants being killed. Hymenachne has also been observed to spread on the freshwater lens on top of saltwater (Greening Australia 2021, pers. comm. 3 February). Aleman grass appears more tolerant of marginally brackish conditions, and it can reinvade when there is lower tidal ingress.

Saltwater inundation does reduce the growth rates of para grass and Aleman grass, and this may reduce their competitiveness (Abott et al. 2020). Para grass and Aleman grass are C4 plants, and their photosynthetic and growth rates are higher (at similar light levels) than those of C3 species, such as hymenachne and native freshwater sedges. Saline conditions can also be introduced to freshwater areas invaded by para grass and hymenachne by pumping up saline groundwater (saltwater bore), but this may impact water quality.

Removal of earth bunds or levees to reinstate tidal flow generally improves water quality, fish diversity, and overall wetland health. It could be a method that needs to be used in conjunction with other invasive grass control methods. However, landholders and government need to take care to fully consider tidal boundary laws and amendments when considering ponded pasture reconversion projects (Bell-James and Lovelock 2019).

3.5 General invasive grass spread prevention

Spread prevention is an important part of management for all the invasive grass species in the threat abatement plan. Mapping and monitoring are also part of spread prevention and integral components of any weed management program. There are many great existing guidelines that cover the prevention of spread of invasive grasses and other weeds (e.g. Clean down procedures and Vehicle hygiene).

General weed spread prevention involves:

- Following strict hygiene regimes to prevent weed spread into clean areas
- Having and using designated wash down areas for vehicles, machinery, equipment and boats, to remove seed, vegetation fragments and/or mud
- Avoiding driving through seeding plants, and avoid mowing seeding plants
- Mowing/slashing from clean areas into infested areas
- Making sure mulch and hay purchased is free of weed seeds
- Controlling infestations before seeds mature.

Being able to identify a weed, and seek assistance with management is also crucial. A beta version of the WeedScan app was released in late 2023. The WeedScan app aims to help users to identify around 450 weed species from a digital image, including all the invasive grasses in the threat abatement plan. Users also have the option to alert selected state biosecurity agencies and local land managers of new incursions.

Some states, territories and councils have online forms, or hotlines to report invasive plants categorised as a priority weed in a particular region. In Queensland, the Weed Spotter App allows you to email photographs of plants to the Queensland Herbarium for identification. In the Northern Territory, the NT WeedMate app can be used to collect location data points and note density, plant growth stages and control work. This app is predominately used by local and territory government weed officers and weed contractors. In Western Australia, the MyWeedWatcher section within the

WA MyPestGuide® Reporter app online surveillance system, currently has limited functionality for reporting weeds. In NSW, invasive grasses can be reported to the Local Land Services Exotic Plant Pest phone hotline, or the NSW Department of Primary Industries through an online notification.

3.6 Monitoring and mapping

The monitoring and mapping of invasive grass infestations is an integral component of a coordinated management strategy. Knowing a weed's location and area of cover is crucial information to share within an organisation and with relevant agencies. It can also form the basis of monitoring to determine the effectiveness of control methods and allow people to work out future weed management requirements. Some of the apps mentioned in section 3.5 can also assist with monitoring and mapping.

There are several ways to map and monitor invasive grasses, the most suitable approach will depend on the scale of the infestation, resourcing and equipment availability. On a small scale, it could involve a mobile phone or tablet with an appropriate app to capture weed data on foot. On a larger scale helicopter surveys can be effective to aerially detect invasive grasses, especially in the early to middle dry season when they are actively growing whereas the native grasses have senesced ('hayed off') (usually March–May) and fallen over to form a low grass layer. Helicopter surveys may fail to detect very small populations of less than 1% cover (Petty et al. 2012).

Unmanned aerial vehicles (UAV or drones) can be used for mapping and monitoring in inaccessible terrain. Drones can fly lower than aeroplanes or helicopters, and can capture high quality coloured images with GPS coordinates embedded in the file. The use of drones is regulated by the Civil Aviation Safety Authority (CASA) and must be kept within visual line of sight. To fly beyond visual line-of-sight (BVLOS), the operator must have CASA approval. Drones have been used to map and spray para grass and hymenachne, but their use is still not standard or common practice, especially in treed areas.

Manual photo processing of digital imagery from aerial surveys is time consuming and costly. For some weeds, specifically designed algorithms have been developed for use with image analysis software to automate the weed detection process, which lowers the costs.

Invasive grasses can also be mapped and monitored using remote sensing, by analysing purchased medium-resolution multispectral satellite imagery. Shendryk et al. (2020) developed a methodology for gamba grass using VHR WorldView-3 imagery, which could differentiate gamba grass from other vegetated and non-vegetated areas, with accuracies of up to 91%. Technical expertise is required for this approach.

4 Ecological and cultural impacts of invasive grasses

The ecological and cultural impacts of these 5 species of invasive grass vary, as do the habitats they invade. One thing all these invasive grass species have in common, is that they all have the capacity to dominate the vegetation they invade, and to alter the resources (e.g. water, nutrients and light) that are available to other plant species, such that the plant species richness tends to decline following the of invasion of one or more of these 5 invasive grass species (Grice et al. 2013). Research focused on biodiversity impacts of para grass and gamba grass concluded that “very few species stand to benefit from the on-going presence of these exotic pasture grasses” (p 325, Beggs 2010).

4.1 Ecological impacts of invasive savanna grasses

Gamba grass and the mission grasses impact native species and communities through a range of direct (e.g. competition for resources, loss of food source, loss of habitat) and indirect mechanisms. Gamba grass invasion is thought to reduce landscape biodiversity on a scale similar to broadacre agriculture (Godfree et al. 2017). The most common and severe indirect impact on threatened species and ecological communities is via increased fire intensity, frequency and/or extent (Rossiter et al. 2003; Setterfield et al. 2010; Setterfield et al. 2013; Winderlich and Woinarski 2014). The direct impact these invasive grasses have on native flora and fauna can also be amplified by their influence on fire.

A range of threatened and non-threatened species are impacted by gamba grass invasion, with a lower diversity of vertebrates, including birds and reptiles and ground-dwelling invertebrate species, found within invaded woodlands (Beggs 2010). Some bird and reptile species have been found to decrease in abundance as the cover of gamba grass increases, including the threatened yellow-snouted gecko (*Diplodactylus occultus*) (Beggs 2010).

There are 38 threatened species listed under the EPBC Act that are known to be potentially threatened by gamba grass and the mission grasses (see Appendix 1 of the Threat abatement plan). The species of mission grass thought to be impacting these species is rarely noted in the literature. These threatened species cover a range of taxa including plants, insects, reptiles, birds and mammals. There are an additional 14 threatened species where the threat is recorded as “invasive pasture grasses” and it is not known which grass species is the threat. There are at least another 15 species listed as vulnerable, endangered or critically endangered under state or territory legislation that are also known to be threatened by gamba grass and the mission grasses (see Table A3, Appendix A of the Threat abatement plan).

Most of the listed species impacted are thought to be threatened due to changes in fire regimes. This is the case for many species within lowland woodlands in the NT which are typically impacted by increased fire severity following grass invasion (Woinarski and Winderlich 2014).

Some of the impacts of these grasses are also thought to be due to changes in habitat quality or habitat structure. For example, the change in vegetation structure following gamba grass and mission grass invasion may inhibit northern quoll (*Dasyurus hallucatus*) ground movements and hunting. More intense fire may also cause direct mortality, reduce availability of shelter and reduce habitat heterogeneity. Similarly, the golden-shouldered parrot (*Psephotus chrysopterygius*) is thought to be impacted by gamba grass and mission grass due to a loss of nesting, feeding and roosting sites due to grass invasion changing the vegetation composition and structure.

Impact on soil properties

Gamba grass invasion and mission grass invasion to a lesser extent, can change how nitrogen cycles through invaded ecosystems (Douglas et al. 2004; Rossiter-Rachor et al. 2009). Gamba grass can grow to a large biomass and out compete native vegetation on low nutrient soils by changing where nitrogen is stored in the ecosystem, and by changing how nitrogen moves between parts of the ecosystem (Rossiter-Rachor et al. 2008). Soil ammonium can be up to 3 times greater where gamba grass has invaded, and gamba grass can take up ammonium at a faster rate than native grasses (Rossiter-Rachor et al. 2009). Gamba grass fires can also lead to a net loss of 20 kg of nitrogen per hectare per year (Rossiter-Rachor et al. 2008), and in the long term can deplete above ground carbon stocks (Brooks et al. 2010). Perennial mission grass invasion also reduces nitrate availability compared with native grasses (Douglas et al. 2004). The threatened shrub *Helicteres macrothrix*, is thought to be impacted by changes in soil hydrology and soil nitrogen after gamba grass and mission grass invasion, in addition to changes in fire regimes (Woinarski et al. 2007).

Impact on vegetation

Gamba grass and the mission grasses can outcompete native grasses even without human disturbance. To the untrained eye, these invasive grasslands may resemble native grasslands (Godfree et al. 2017), however they have significantly lower plant diversity, and the relative abundance of different plant groups can also change (Beggs 2010; Brooks et al. 2010; Douglas et al. 2006). In invaded savanna woodland, gamba grass invasion can lead to a loss of heterogeneity or variation in the ground-layer vegetation. Having spatial variation in the understorey (e.g. a mix of dense vegetation, sparse vegetation, and gaps) is important for habitat provision and biodiversity conservation (Beggs 2010).

Perennial mission grass invasion also leads to a decline in plant species diversity, but the changes are thought to not be as severe as for gamba grass invasion (Brooks et al. 2010). The impacts of annual mission grass invasion on native vegetation have not been quantified, nor have the impacts of multiple invasive grass species invading a vegetation community.

Impact on fire

Gamba grass and mission grass invasion can change the seasonality, frequency, and intensity of burning, and changes to these factors can impact the species within the invaded ecosystem. The fires from gamba grass and perennial mission grass can reach into the tree canopy, and scorch the entire tree canopy, increasing tree mortality. Even in areas with low gamba grass biomass, fires often lead to reduced canopy cover of trees (Bowman et al. 2014). The heat from these fires can kill the savanna eucalypts (Rossiter-Rachor and Setterfield 2019), and gamba grass fires have led to the decline of *Callitris intratropica* and other fire sensitive plant species (Bowman et al. 2014). Gamba grass invasion reduces the recruitment of eucalypt seedlings, which contributes to the transformation of savanna woodland to an invasive grassland ecosystem (Setterfield et al. 2018).

High intensity late dry season fires fuelled by mission grass are thought to lead to ecosystem degradation, habitat loss and decline in biodiversity (Winderlich 2010). Mission grass has invaded rainforest areas in the NT following disturbance by cyclones. A significant decline in monsoon rainforest near Darwin was attributed to mission grass invading damaged rainforests after three successive cyclones. Following invasion, the high intensity fires caused further damaged to the rainforest, converting some areas from forest into grassland dominated by mission grass (Low 2008).

There is currently a lack of information on the ecological impacts of annual mission grass. Given its high biomass, it is thought to have similar impacts to those of gamba grass and perennial mission grass. This includes out-competing native plant species and contributing to increased fuel loads, resulting in intense late-season fires (TSSC 2009).

Restoration

The species richness of the emergent soil seed bank was found to be similar between sites invaded with gamba grass and mission grass for up to 20 years, and uninvaded sites (Brooks et al. 2010). There was, however, a lower density of native plants that emerged in invaded sites. The relatively intact soil seed bank indicates that there is some potential for natural establishment of vegetation after control of gamba grass and mission grass. The seeds of the invasive grasses will also be present but appear to have a shorter viability than the native seeds. This indicates there is a window of time where natural restoration from soil seed bank is possible, however in long invaded sites, active restoration (e.g. seed addition, tree planting) is likely to be required.

4.1.1 Savanna fire management and carbon

Without fire management, the savannas in northern Australia burn predominantly in the late dry season, resulting in large, hot and intense fires. These fires produce more greenhouse gas emissions and burn a greater proportion of dead organic matter than fires that occur under cooler, moister conditions in the early dry season.

Emissions Reduction Fund savanna fire management projects aim to reduce the frequency and extent of late dry season fires in savannas, resulting in fewer greenhouse gas emissions and more carbon being sequestered in dead organic matter. The savanna fire method recognises the traditional burning methods used by Australia's Indigenous traditional owners for thousands of years, and traditional patchwork burning in the early dry season is often used. There are two different types of savanna fire management, emissions avoidance and sequestration, and emissions avoidance, both of which are administered by the Clean Energy Regulator.

Carbon Projects registered under the Carbon Farming Initiative using one of the savanna fire management methods can earn Australian carbon credit units (ACCC). Only specific vegetation types are eligible, and areas invaded by gamba grass are not eligible. This stipulation may motivate people to control gamba grass, but it can also lead under reporting of gamba grass. High fire intensity gamba grass fires can produce very high greenhouse gas emissions, including carbon emissions and particulate matter. Registered projects are required to monitor for the presence of gamba grass.

Around 75% of land across northern Australia that is eligible for enrolment in savanna burning projects is highly suitable for gamba grass. It was estimated that an average of 290 ha of uninvaded land would need to be enrolled in carbon credits to fund the control of 1 ha of gamba grass infested land (Adams and Setterfield 2013).

Gamba grass is deep rooted and is thought to sequester more carbon than some native grasses, however it does not sequester as much carbon as the native shrubs or trees that die from high intensity gamba grass fires. Eradicating gamba grass from savanna woodlands will help maintain existing native trees and shrubs which can be lost due to intense gamba grass fires (see section 4.1), and restoring savanna woodland would sequester more carbon in the long-term than allowing gamba grass to dominate the vegetation (Csurhes and Hannan-Jones 2016).

4.2 Ecological impacts of the semi-aquatic grasses

Para grass and hymenachne invade and pose a threat to a range of freshwater ecosystems, including sedgelands, grasslands and forblands. Invaded wetlands can look almost like a lawn, with decreased plant species richness and less open water (Grice et al. 2013; Setterfield et al. 2013; Wearne et al. 2010) and this can occur even without human disturbance (Godfree et al. 2017). Para grass and hymenachne invasion can alter the resources available to other plant species, and multiple stakeholders reported that para grass and hymenachne “choke out native grasses”.

Invasion by alien macrophytes, including hymenachne and para grass, tends to decrease the diversity of macroinvertebrates and fish, and alter the structure and function of the aquatic ecosystems they invade (Tasker et al. 2022). This probably has consequences for other taxa, especially mammals, reptiles, frogs and specialist wetland bird species that prefer to forage in open, shallow water with low density vegetation.

There are 11 EPBC Act listed species known to be threatened by para grass, and 9 EPBC Act listed species threatened by hymenachne. However, 8 of these listed species are thought to be impacted by both species of invasive grass. Few Australian freshwater species are listed as threatened under the EPBC Act, and it is thought that freshwater species are underrepresented on national and state threatened species lists (Lintermans et al. 2020). There is often a lack of data on freshwater taxa, with freshwater flora and fauna generally receiving less attention and conservation effort than terrestrial and marine species (Birnie-Gauvin et al. 2023; Januchowski-Hartley et al. 2011).

The listed species impacted by these two invasive grasses are wide ranging (see Table A1, Appendix A of the Threat abatement plan) but are all dependent upon fresh water or riparian habitats, including the water mouse (*Xeromys myoides*), several species of sedge (e.g. *Eleocharis retroflexa*) and fish (e.g. *Chlamydogobius micropterus*). One of the threats to Lake Eacham rainbowfish (*Melanotaenia eachamensis*) is para grass smothering the riparian zones and slowing the flow of water. Para grass and hymenachne also pose a threat to spring wetlands in Queensland within part of the listed Great Artesian Basin aquifer system. These wetlands are of conservation significance as they are home to a range of species found in only a small area, but para grass and hymenachne are spreading from ponded pastures, and now dominate parts of this wetland system (Fensham and Fairfax 2003).

4.1.2 Ecological impacts of hymenachne invasion

Hymenachne competes aggressively with other plants, growing rapidly and forming dense stands that exclude other vegetation. It is a nutrient and litter accumulator, and a thick layer of leaf litter can form at the base of the plant (Sheppard et al. 2010). The water in areas with greater than 70% cover of hymenachne tends to have very low oxygenation levels (anoxic) (Kinnear et al. 2008). Invasion generally reduces plant diversity (Winderlich 2010), with few native plants found in sites where hymenachne dominates (Kinnear et al. 2008). There are also reports of this weed "smothering" or growing over the top of other aquatic macrophytes. The reduced plant diversity following invasion could reduce habitat availability for wildlife.

Hymenachne infestations have been found to have a lower diversity of benthic macroinvertebrates (small aquatic animals and insect larvae) than uninvaded areas (Kinnear et al. 2008), and a different assemblage of macroinvertebrates, including fewer true bugs (Hemiptera) and dragonflies (Odonata) (Houston and Duivenvoorden 2003). The reduction is likely due to reduced oxygen levels for those organisms with an aquatic life stage, and the reduced diversity of plant habitats and food sources (Kinnear et al. 2008).

Hymenachne and para grass infestations in the wet tropics also tend to be avoided by native fish species due to changes in microhabitat structure (Pearson et al. 2010). The fish community associated with hymenachne was found to be less diverse and made up of different species to those that occurred within the native sedges and herbs of lagoons. In another study on the Fitzroy River in Queensland, the change in vegetation structure following hymenachne invasion was also thought to change the fish community composition. An introduced fish species, *Xiphophorus maculatus*, comprised 75% of the fish captured in hymenachne beds, with this introduced fish not found in the native plant beds (Houston and Duivenvoorden 2003).

Hymenachne invasion can prevent fish movements, and impact nursery areas for fish species such as barramundi (*Lates calcarifer*). This impact is more pronounced where ponded pastures systems have been created, and fish are unable to move between freshwater and saltwater. There have been observations that thick mats of hymenachne prevent fish from feeding on mosquito larvae, which could lead to increases in mosquito populations (Magnussen 2012).

There appears to be a general information gap surrounding the effects of hymenachne on amphibians, turtles, water birds and other semi-aquatic and semi-terrestrial fauna (Kinnear et al. 2008).

Ponded pasture systems also have a range of ecological impacts which are separate, but may overlap with the impacts of para grass and hymenachne invasion in natural waterways. Ponded pasture systems tend to have poor water quality with low oxygen, high temperature and high pH (Hyland 2002). Fish often get entrapped in ponded systems constructed across remnant tidal channels when the water levels drop, or the water dries out.

4.1.3 Ecological impacts of para grass invasion

Para grass will grow over the top of existing native vegetation, and in long invaded wetlands, para grass creates a heavy thatch consisting of decomposing material, adventitious roots and interwoven stolons (Wearne et al. 2011). Invasion can change river sediment accumulation, streambed morphology and water discharge, and may increase the risk of localised flooding. These hydrological changes are all thought to have indirect effects on the riparian vegetation (Godfree et al. 2017). Para grass can have a high growth rate and a high oxygen demand, such that low dissolved oxygen levels are often found in the water within dense para grass infestations (Douglas et al. 2001).

Undisturbed wetlands provide a diversity of habitats, but similar to gamba grass invasion, para grass invasion can simplify wetlands, and reduce biodiversity (Godfree et al. 2017). In floodplain habitat with greater than 40% cover of para grass, approximately 87% of native plant species and 66% of native animal species found in uninvaded areas, were absent (Beggs 2010). In heavily invaded areas, para grass can form a monoculture, where all native emergent macrophytes are absent (Adams et al. 2018; Ferdinands et al. 2005).

The diversity and abundance of reptiles has been found to decline as para grass cover increases, with it thought that the dense stands of para grass stands may not provide enough bare areas for reptiles to bask (Beggs 2010). Areas invaded by para grass were also found to have lower diversity and abundance of terrestrial invertebrates than areas of the native *Hymenachne acutigluma*, with differences possibly due to the lower nutritional quality of para grass (Douglas and O'Connor 2004).

Dense para grass stands block aquatic ecosystems to such an extent that it makes it hard for fish migrate (Waltham et al. 2020). Some fish species have a diadromous lifecycle, which means they need freshwater for part of their lifecycle and saltwater for another part of their lifecycle.

Para grass produces little edible seed for birds, and the seeds are of lower nutritional value than those of wild rice, which is one of the species para grass displaces. The dense thatch layer can restrict birds, such as waterfowl, accessing water and soil to feed (Ferdinands et al. 2005), and make the habitat unsuitable for species such as the yellow chat (*Epthianura crocea*) (DES 2023). The diversity and abundance of birds, including magpie geese, has been found to decrease as the level of para grass cover increases, with only around half the bird species found where para grass was present on the Mary River wetlands (Beggs 2010). An expert elicitation process came to a similar conclusion, that a dense para grass infestation would reduce the probability of ducks, small grebes, wading birds and shore birds persisting by 50 to 70% in the Daly River Catchment (Cattarino et al. 2018).

Para grass is a threat to wetlands in a large proportion of protected areas in northern Australia, including the Bowling Green Bay wetlands, Magela floodplain and the Mary River wetlands (Mary River Catchment), with all or part of these areas listed under the Ramsar Convention on Wetlands of International Importance.

Para grass contains phytotoxic phenolics (Chou 1989), and there have been observations in other countries of it being allelopathic to other plants. Para grass invasion has led to a significant decrease in the amount of native wild rice (*Oryza* spp.) on invaded floodplains including the Magela floodplain in Kakadu National Park (Boyden et al. 2019). Invasion reduces the germination and emergence of wild rice (Bellairs et al. 2015). It is thought that para grass changes the soil profile and aboveground biomass structure to such an extent that this prevents wild rice seeds from receiving dormancy-breaking or germination cues (Wurm 2007). Additional site treatments may be required after para grass control to allow for reestablishment of the wild rice species *O. meridionalis*, in wetlands managed for biodiversity.

The invasion history of para grass appears to influence the diversity of native species in the soil seed bank, with large persistent patches of para grass leading to a loss of native seedbanks (Boyden et al. 2019), such that only one or two native species remain (Wearne et al. 2011). The depth of the water also appears to influence whether restoration is possible from the soil seed bank, with areas exposed to wet/dry periods having a greater chance of being restored from the seed bank then areas with deep water or constantly under water (Wearne et al. 2011).

Intense fires have been observed in para grass and it is likely that the ecosystem-transforming effects of this species will increasingly be seen as a major problem for landscape conservation (Godfree et al. 2017). The increased flame heights can damage fire sensitive trees and shrubs, such as Melaleucas, and rainforests on floodplain or wetland margins (Douglas and O'Connor 2004). Following hot late-season para grass fires, many of the native plant species do not re-establish, however, para grass does (Hunter et al. 2010). Invasion and subsequent changes to the fire regime are one factor contributing to a reduction in monsoon vine forest adjacent to invaded floodplains in parts of the NT (Setterfield et al. 2013) and may also cause a decline in the fire sensitive *Hymenachne acutigluma*.

Para grass poses a threat to the turtles and frogs that have a period of hibernation or dormancy (aestivate) in the sediments on the floodplain during the dry season. The increased fire intensity can increase soil temperatures to lethal levels for these animals (Adams et al. 2018; Pettit et al. 2011), and they may be unable to dig through the physical barrier para grass creates (Setterfield et al. 2013).

4.2 Impacts of invasive grasses on people and culture

The social wellbeing of First Nations people may be affected by these invasive grasses, as they have the potential to interrupt both physical and spiritual connections to country. This is partly due to their high biomass and the ability of these grasses to transform the landscape. The impacts of these invasive grasses on Indigenous culture are less documented and reported than the ecological impacts of these grasses.

Most Indigenous land managers consulted during the plan's development (see Section 5.1) reported wide-ranging cultural impacts due to these invasive grasses. Physical access to country and sacred sites was hindered by these grasses, with one Indigenous ranger stating it is now "difficult to take elders out to where they use to go to when young". The invasive grasses were also preventing access to resources including bush tucker, medicine and water and were restricting or preventing hunting. For example, para grass invasion makes the harvesting of turtles within the floodplains of Kakadu National Park very difficult (Adams et al. 2018). This can have flow on effects, such as increased hunting pressure in non-invaded sites.

During development of the plan, there was a lot of concern raised around invasive grasses and fire management, with both changes to traditional fire management and inappropriate fire management raised. First Nations people had observed intense fires damaging sacred sites and painting galleries, and there was ongoing concern about fires coming too close to rock art sites.

Many wetlands and floodplains in northern Australia invaded by para grass and/or hymenachne are of cultural significance, with invasion reducing the opportunity for First Nations people to traditionally use the natural resources these areas provide (Bangalang et al. 2022; Grice et al. 2012;

Winderlich 2010). Some First Nations people do not want hymenachne or para grass on their Countryas they impact highly valued natural resources including fish, freshwater turtles (Grice et al. 2012) and file snakes (Bangalang et al. 2022). Para grass and hymenachne invasion are also known to impede magpie goose hunting and prevent barramundi migrating from the floodplains after their breeding season. One ranger stated “olive hymenachne altered native feed for animals, potential to change water flow, choke up billabongs and habitat alterations”.

The cultural risks from invasive grasses threating Country and interrupting or preventing story and knowledge transfer to future generations (including about totems and seasonal calendars), were also recognised by the Indigenous land managers consulted.

During consultation to develop the plan, Indigenous land managers mentioned 23 native bird, reptile and plant species that were impacted by these invasive grasses (see Table A4, Appendix A of the Threat abatement plan). Most of these species are not listed as threatened under the EPBC Act but are of cultural significance. This indicates that broader invasive grass management actions that focus on improving the health of Country, or connection with Country could be more applicable than a threatened species approach on some land tenures.

Weed control and restoration of degraded wetlands may assist some First Nations people to re-establish links with their Country, which was the case for some Nywaigi people of Mungalla, Queensland (Grice et al. 2012). Renewed access to important sites and the return of some culturally important species has also been observed following para grass management (Bangalang et al. 2022). Invasive grasses can transform ecosystems and landscapes, and it is likely that their impacts on people and culture are wider ranging than is noted here, and this requires further consultation and research.

Social impacts

These invasive grasses are often called environmental weeds and have also been termed commercial weeds (Grice et al. 2008). This is because these grasses have a real or perceived net benefit to one industry, while they also impose costs on other enterprises, industries or sectors. Outside the pastoral industry, introduced grasses have significant negative economic impacts on other primary producers, for example, they can invade sugarcane crops and irrigation infrastructure, potentially resulting in increased production costs and reduced yields. Large grass infestations also lead to loss of amenity and can significantly affect recreational activities and tourism. For example, hymenachne invasion impacts recreational users of waterways, including those who fish, boat and bird watch.

The intense fires these grasses can fuel are difficult to control and pose a serious threat to human life, property and infrastructure. Controlling gamba grass fires comes with an increased economic burden compared to native grass fires, with the average cost of managing a gamba grass wildfire ($25,609 ± $5,134 in 2017) estimated to be 26 times greater than an equivalent native grass wildfire ($938 ± $252) (Setterfield et al. 2018). One gamba grass wildfire near Darwin cost $102,130 for one day of control in 2017 (Setterfield et al. 2018). It is extremely difficult to put a monetary value on the loss of biodiversity or a loss of connection to a local place due to weed invasion, so the overall costs (monetary/non-monetary) are likely to be higher.

4.3 Distribution under anthropogenic climate change

Modelling predicts that the area of suitable habitat for both annual mission grass (Figure 8) and perennial mission grass (Figure 9) will increase by the year 2050 under global warming projection representative concentration pathway (RCP) 8.5 (Pintor et al. 2018; Pintor et al. 2019). Representative concentration pathway 8.5 refers to the relative concentration of carbon that delivers global warming at an average of 8.5 watts per square meter. This is what is forecast to happen if these is little curbing of emissions.

Figure 8 Annual mission grass median likelihood of occupancy modelled under future climatic conditions (RCP8.5) in year 2050. Likelihood of occurrence is indicated from zero (blue) through to 1 (red). Modelling was only done for northern Australia. Source Pintor et al. (2018) and Pintor et al. (2019).

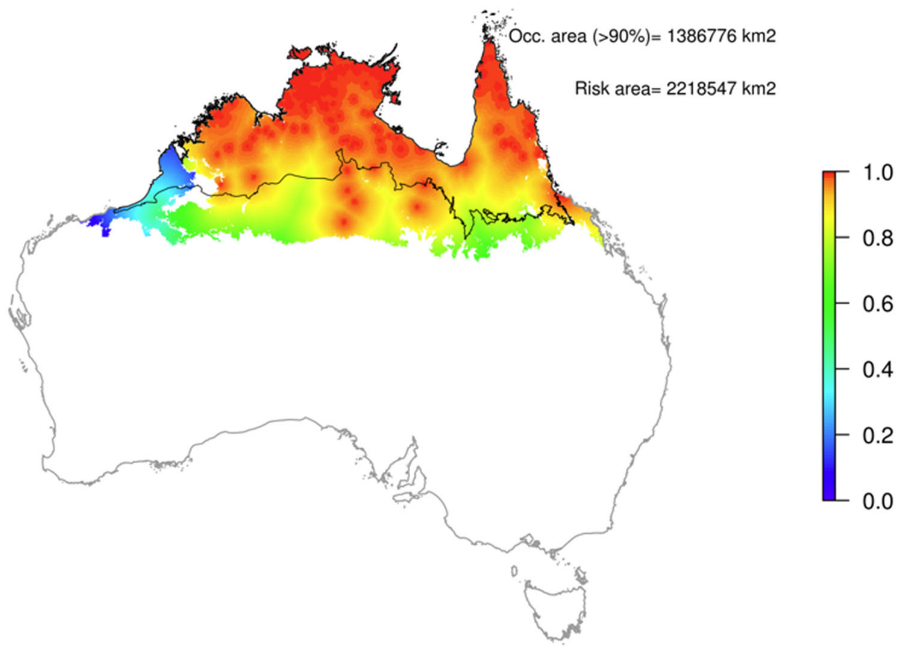
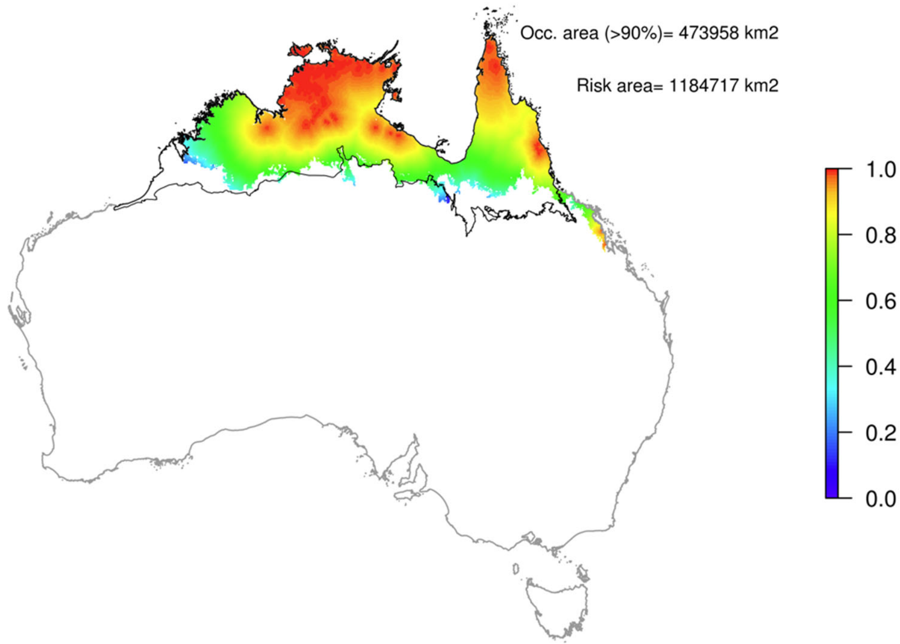


Figure 9 Perennial mission grass median likelihood of occupancy modelled under future climatic conditions (RCP8.5) in year 2050. Likelihood of occurrence is indicated from zero (blue) through to 1 (red). Modelling was only done for northern Australia. Source Pintor et al. (2018) and Pintor et al. (2019).



Modelling conducted by one research group under representative concentration pathway 8.5, indicates there could be an increase in suitable habitat for hymenachne by year 2070, and an increase in suitable habitat for gamba grass by year 2065. There was little change predicted in the para grass distribution by year 2065 (Weed Futures, Duursma et al. 2013). In contrast, modelling by another research group also under representative concentration pathway 8.5 for year 2050, predicted a decrease in the potential distribution for hymenachne, para grass and gamba grass (Pintor et al. 2018; Pintor et al. 2019). These two contrasting sets of results indicate that there is still some uncertainty about how climate change could impact grass invasion and spread.

Gamba grass, para grass and the mission grasses are all C4 grasses. C4 grasses tend to dominate in northern Australia and are expected to respond positively to a warming climate. A study conducted on data collected over 15 years, showed there had already been a significant increase in the proportion of C4 grasses in southeastern Australia, and a decrease in the proportion of C3 grasses (Xie et al. 2022). We do not know how the growth rates and reproduction of these invasive grasses will change in a future climate. In general, an increase in carbon dioxide is thought to increase plant biomass under anthropogenic climate change. Suggestions have been made that the growing season for gamba grass could increase in the NT, leading to an increase in biomass, which in turn could create more fuel for fire.

Lopes et al. (2023) modelled the predicted distribution of 10 invasive grasses under various climate change scenarios in the neotropics and found not all invasive grasses would be equally affected by climate change. For example, for *Andropogen gaynus* (not the Kent variety in Australia) both expansions and contractions of the climatically suitable area were predicted depending upon the climate scenario. The analysis did, however, conclude that under most future climate scenarios, invasive grass species were likely to shift to areas not yet occupied.

5 Indigenous consultation

5.1 Indigenous consultation methodology

To inform the objectives and actions of the updated threat abatement plan, Territory Natural Resource Management Incorporated (TNRM) undertook a consultation process that considered how these invasive grasses impact Indigenous groups and how these invasive grasses are relevant to Indigenous groups in northern Australia. This information was used to help inform the objectives and actions of the threat abatement plan. The aspirations of Indigenous land management groups and individuals who hold and/or feel the responsibility for managing the threat of the invasive grasses were also considered. The survey and consultation were undertaken by Rachael Thurlow and Susanne Casanova from TNRM in 2022. A summary of the key results is presented in section 5.1.1.

Information was collected through a desktop study of Indigenous ranger groups' Healthy Country Plans or plans of management, an online survey for Indigenous land management groups and meetings either face-to-face or by phone with TNRM staff and Traditional Owners from Indigenous land management groups.

Indigenous land management groups which manage land north of the Tropic of Capricorn were targeted. Groups across Western Australia, the Northern Territory and Queensland, from the Yawura Indigenous Protected Area (IPA) in the western Kimberley region WA, to the East Trinity-Mandingalbay Yidinji IPA in Cairns Qld, and north to the islands in the Torres Strait. TNRM scoped out which stakeholders operated within the parts of northern Australia which matched the grasses' potential distributions, as per Climax suitability assessments for the grasses. Most of the survey respondents were from the Northern Territory (27), followed by Western Australia (4) and Queensland (7). The groups worked across diverse habitats, most commonly woodlands and coastal environments, but also rocky country/escarpments, waterways and rivers, rainforests, sand dunes and monsoon vine thickets.

5.1.1 Findings

Analysis of Healthy Country Plans revealed that about half the groups regarded invasive grasses as a threat, with actions to address invasive grasses mentioned in 24 of 49 plans. Gamba grass was the species mentioned the most in plans (17 times), followed by perennial mission grass, annual mission grass, both mentioned on 12 occasions. For the Indigenous land management groups that did not have a Healthy Country Plan, half had grassy weed management in their work plan. Three responders said the grasses were in the work plan, but on-ground management often does not happen.

Table 5 shows which of the grass species the respondents had on Country, with 5 groups having all the species present. Perennial mission and annual mission were the two species most often recorded as being on Country for the longest time (over 10 years). Many responders had one or more of the invasive grasses present for more than 3 years, but often the length of time the invasive grass had been present was not known.

Table 5 Responders indicating which of the invasive grasses they thought were on the Country they work on, with 38 people answering this question.

Invasive grass	Number of respondents
Annual mission grass	23
Perennial mission grass	23
Gamba grass	23
Hymenachne	13
Para grass	10

The dry area grasses were commonly thought to occur along road corridors and tracks. For the semi-aquatic area grasses, floodplains were identified as where they were most often found, followed by billabongs and important/sacred sites.

The main pathways responders thought invasive grasses were being spread into and around Country were via people and vehicle movement. Native and feral animal movements, fire removing seeds and removing competition, and the wet season and water movement were also commonly identified as spreading weedy grasses. One responder mentioned that “our lands are difficult to access, yet we still see no management of human movement on the Country”, and another group mentioned “illegal hunters spreading seeds and people not cleaning cars or being aware of vehicle hygiene”. Ranger groups also paid a special mention to fire management, stating that “sometimes after fires have been through, [invasive grass] seeds will come through” and “I think there needs to be more awareness around early burning”.

Threats to species and Country

Most responders thought these invasive grasses are a threat to Country and that they were out competing native flora and caused an increased risk of destructive fires (Table 6). One ranger commented that “They also affect our enterprises such as crocodile egg collection”, whilst a regional manager of another group stated that, “Gamba, compounded by other grassy weeds, are landscape transformers”.

Table 6 The number of responders identifying how they thought the invasive grasses threaten to change Country, with a total of 27 people answering this question.

Threat to Country	Number of responders
Out compete native flora	23
Increase risk of destructive fires	23
Remove habitat for native animals	18
Remove food resources and other resources for people	15
Provide food for feral animals	8
Restrict movement onto and around Country	7
Unsure	1

Most responders reported that culture is threatened by the invasive grasses, with resources (bush tucker, medicine, water) important/sacred sites selected by the most people (Table 7). One Aboriginal Corporation representative stated that inappropriate fire management (including lack of consultation with rangers and Traditional Owners) is damaging sacred sites and painting galleries. A ranger from an IPA also stated that “fire close to rock art sites/ sacred sites. Paint damaged on rock site from fire”. Whilst rangers from multiple areas reported that hunting and fishing was threatened by the grasses, restricting access for species traditionally found on Country, including the life cycle of barramundi migrating from floodplains after breeding season. One ranger said it was “difficult to take elders out to where they use to go to when young”, and another reported that “olive hymenachne altered native feed for animals, [had the] potential to change water flow, choke up billabongs and habitat alterations”.

Table 7 The number of responders reporting which aspects of Culture are threatened by the invasive grasses. 27 people answered this question.

Aspect of culture	Number of responders
Resources (bush tucker, medicine, water)	23
Important/sacred sites	21
Fire management	21
Physically accessing Country	18
Seasonal calendar knowledge	11
Knowledge transfer to next generation	10
Stories	9
Totemic	8

Most responders knew they had threatened species or a threatened ecological community on Country, with most people identifying they had threatened bird and/or mammals.

Hymenachne and para grass were most reported to occur mainly in floodplains, billabongs, creeks and important or sacred sites. They were also noted to occur in community, coastal areas, outstations and transport corridors.

There were a range of other invasive grasses and weed species that were mentioned during the consultation period (Table 8 and Table 9). Often conflicting priorities for weed management are at play, and this may influence management outputs for invasive grass management.

Table 8 Other invasive grass species responders were concerned about on Country.

Invasive grass	Species scientific name
Red natal grass	*Melinis repens*
Rat's tail	*Sporobolus pyramidalis*
Guinea grass	*Megathyrsus maximus*
Mossman river grass	*Cenchrus echinatus*
Itchgrass	*Rottboellia cochinchinensis*
Tully grass	*Urochloa humidicola*
Navua sedge	*Cyperus aromaticus*
Asbestos grass	*Cenchrus basedowii*
Razor Grass	*Gahnia grandis*

Table 9 Other invasive plant species responders were concerned about on Country.

Common name	Scientific name
Mimosa	*Mimosa pigra*
Siam Weed	*Chromolaena odorata*
Hyptis	*Hyptis suaveolens*
Neem	*Azadirachta indica*
Guava	*Psidium guajava*
Pond apple	*Annona glabra*
Singapore daisy	*Wedelia trilobata*

Monitoring

Most responders actively looked out for the presence of invasive weeds on the Country they manage. This included undertaking dedicated surveys for one or all of the invasive grass species, or surveying for these invasive weeds whilst conducting other works on Country.

Of the 25 responders who said they do look for invasive grasses on Country, 21 were actively looking for gamba grass, 14 were actively looking for both annual and perennial mission grass, 9 for hymenachne and 5 for para grass.

Around half of the respondents monitored the impacts these grasses cause. One quarter said they did not, but would like to. Monitoring was undertaken for a range of reasons, including to see if the invasive grasses had spread, to see where control may be required and to assess effectiveness of control. People who said they did not monitor the impact or spread of grasses said this was because they did not have enough staff or did not know the monitoring techniques. For those that currently do not monitor invasive grasses on Country but would like to, the responders said they would like to monitor gamba grass, annual mission grass and perennial mission grass.

Additional funding for employment or equipment, training and help for experts were all items respondents indicated could assist their group to monitor invasive grasses on Country. One ranger commented "we have good access to experts but not the internal funds to carrying out controls", and another that “this is poorly managed currently as resources to monitor the locations are not available”.

Managing invasive grasses on Country

Most responders had a control program in place for gamba grass, perennial mission, and/or annual mission grass. Control projects for invasive grasses on Country were undertaken by 20 of 27 responders, with 5 of 27 not currently doing any control work but wanting to. Gamba grass control programs were the most common, followed equally by annual and perennial mission grass control programs. Para grass and hymenachne were less commonly controlled. A Savanna Fire Coordinator stated that “resources for other species (apart from Gamba) are a little harder to come by”. Half the responders reported that they control invasive grasses on Country because “they are not meant to be there” and “it is in their work plans”. The development of work plans are usually a result of participatory planning with Traditional Owners, Rangers, Corporation support staff and community members. Chemical treatment was the main form of invasive grass control (Table 10).

Table 10 The number of respondents using each of the common invasive grasses control or prevention methods, with 20 people answering this question.

Management type	Number of respondents
Fire management	6
Aerial Spraying	4
Wash down bays	4
Surveys and patrolling	8
Physical removal	11
Chemical treatment	17

Places were prioritised for treatment or protection based on what was in a workplan, in fee-for-service contracts, based on Traditional Owner requests, and sometimes based on external organisations or advisory committees. ‘Fee-for-service’ was sometimes used as a way of prioritising work, with a comment made by one ranger group “no money, so no employment and no land management”.

All responders identified rangers as the people who primarily manage invasive grasses in their community. Government departments, Traditional Owners, other contractors were also involved in invasive grass management. One ranger group commented “we do not have enough funding to manage [invasive grasses] effectively especially Olive Hymenachne” and another group stated “this is poorly managed currently as resources to monitor the locations are not available”.

Numerous reasons were selected for why a group did not control invasive species on Country. The responses ranged from, it is not a priority for our group, it has not been identified as an issue by Traditional Owners, we do not know the options available for control, we do not have enough equipment, and we do not have enough funding. One ranger group commented “prevention is better than cure”, and another ranger group commented that they would like “better access to management practices that work to help control. Olive [hymenachne] is too far gone right now and spraying is not effective, maybe it needs a biocontrol method?”.

Over two thirds of responders thought that more work need to be done to protect Country from the threat of invasive grasses. When participants were asked about the best ways to keep Country safe from the spread of invasive grasses, the most preferred option for a group was to have a coordinated approach across land tenures, followed by having more funding or incentives, more support from experts, or training on weed management.

When asked who they would want to work with to increase their capacity to control invasive grasses on Country, responders had a similar preference for working with government agencies, working with other ranger groups, and working with natural resource management organisations. Responders were also happy to work with researchers.

Information Pathways

Less than half of responders found information around invasive grasses management easy to find and use. Some groups reported that information was easy to find but not easy to use, and others thought that information was not easy to find or use.

When asked to identify who should be educating people about the impact of the invasive grasses on Country, most responded with ‘government agencies’. Other avenues for communicating impact were ranger forums, land councils, and experts (NRM groups and researchers). Weed committees, school, elders and training organisations were also identified.

The preferred way for people to learn and share information about invasive grasses management were videos and visiting other places doing weeds management. On Country visits, forums, and face to face meetings were also identified as ways to learn and share information.

Most groups knew that these invasive grasses are a threat because they have seen their impacts firsthand. People were also aware of the threat from attending forums, reading communication material, and talking to experts. The issue was also communicated through rangers and stories from elders. The key ways in which people learnt about invasive grass control methods was through existing knowledge and expertise within their ranger team and training. Consulting experts, written resources and ranger exchanges were also identified as other avenues for learning about invasive grass control.

Very few responders thought that the 2012 threat abatement plan was useful or relevant, with most having not heard of it.

Abbreviations

Abbreviation	Full name
APVMA	Australian Pesticides and Veterinary Medicines Authority
DPI	Department of Primary Industries
EPBC Act	*Environment Protection and Biodiversity Conservation Act 1999*
IPA	Indigenous Protected Area
KTP	Key threatening process
NAQS	National Australian Quarantine Service
NPWS	National Parks and Wildlife Service
NSW	New South Wales
NRM	Natural Resource Management
NT	Northern Territory
Qld	Queensland
RCP	Representative Concentration Pathway
TAP	Threat abatement plan
WA DBCA	Western Australia Department of Biodiversity, Conservation and Attractions
WA	Western Australia
WoNs	Weeds of National Significance

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