Final report

Indian couch invasion: scope, production impacts, and management options

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Abstract

Indian couch, after being introduced into Australia in the 1930s and 1950s, was promoted for amenity use as well as for land reclamation and as a pasture species for grazing. The grass (including different ecotypes) has since naturalised and has spread into grazing lands in eastern Queensland. A range of factors are contributing to its spread, including ecological attributes for competitiveness, land degradation, heavy grazing, adequate source of seed and means of spread, and climatic extremes in rainfall variability. Under severe conditions, such as heavy grazing coupled with drought, Indian couch can replace existing pasture species and change the production system. Understanding the implications of this to beef businesses was a key focus of the project, as was quantifying the extent of Indian couch invasion and testing and identifying possible management options.

Research findings, expert opinion, and producer knowledge showed that while Indian couch has some production value, a major impediment is its reduced drought tolerance. As one producer said, Indian couch is a "*Less reliable feed source, as reasonable production only comes with good seasons*". In addition, the bioeconomic modelling showed average annual profits for an Indian couch pasture enterprise were much more variable than those for native pasture enterprises.

Indian couch mapping was conducted for grazing lands of eastern Queensland using new and existing datasets. An area of 9.6 million hectares, representing ~32% of the total area that makes up the Burdekin, Fitzroy, and Burnett-Mary catchments, was identified as being at risk of Indian couch dominance.

The project also consulted with producers, professional grazing sector advisors and scientists to collate best-management options for established Indian couch pastures, as well as options for minimising Indian couch incursions into native and sown pastures. In order to minimise Indian couch incursions, management options include avoiding over-utilisation of the pasture, maintaining high ground cover, and improving the competitiveness of existing pasture species. For pastures dominated by Indian couch, key strategies for improved production and ecological function include reducing stocking rates, applying more rest to pasture, and incorporating new grasses and legumes into the pasture where possible.

In summary, the project has raised awareness on the issue of Indian couch spread in eastern Queensland and provided an important foundation for future work to build on aimed at improving pasture resilience.

Executive summary

Background: Indian couch (*Bothriochloa pertusa*), also known as Indian bluegrass, is an exotic and invasive tropical grass naturalised in Australia; found in northern Australia, but more so in Queensland. The catchments of interest to the project included the Burdekin, Fitzroy, and Burnett-Mary. Concern from beef producers within these catchments about the potential of Indian couch to significantly reduce carrying capacity on grazing lands provided the impetus for this research.

Objectives: Research objectives included: (i) Identify the factors responsible for Indian couch expansion, (ii) Determine the extent and likely spread of Indian couch invasion in north and central Queensland, (iii) Determine the impacts of Indian couch on production and landscape function, (iv) Conduct preliminary research into control options, and (v) Identify and test best-bet management options to either manage or control the spread of Indian couch on native and sown pastures.

Methods: A range of methods were used by the project, including the review of literature, the collection of producer knowledge and expert opinion, and a range of research activities. Road survey data was used to identify the Grazing Land Management land types affected by Indian couch. The influence of previous management on Indian couch invasion was also assessed using various data derived from QGRAZE pasture monitoring sites. Data collected included Indian couch frequency, producer feedback, and *VegMachine*® ground cover data. Preliminary remote sensing analysis of Indian couch road survey data was also carried out using time series analysis.

A Think Tank was used to capture expert opinion of the knowns and unknowns of landscape function impacts of Indian couch, and to assist in deciding the best field approach to use to quantify landscape function impacts using Landscape Function Analysis.

The pasture production and economic impacts of Indian couch on beef businesses was assessed using a bioeconomic modelling approach. Historical SWIFTSYND pasture data collected for GRASP pasture and animal production simulations was reviewed and pasture parameter sets for native and Indian couch pastures were developed. These parameter sets were modified to include parameters associated with grazing, and then used in GRASP and herd enterprise (CLEM) simulations to determine the modelled impact on beef enterprise profitability of Indian couch relative to native pasture. Five native pasture and Indian couch 'paired' SWIFTSYND sites were also established by the project. The SWIFTSYND site data collected was used for describing potential grass production differences and for analysis of Indian couch cover and height to mass relationships.

Separate collaborative projects conducted research to better understand the seed ecology and grazing ecology of Indian couch. The projects included (i) Stocking rate treatments on long-term trends of plant basal area, (ii) Heat and smoke treatments on seed germination and viability, and (iii) Seed longevity using controlled ageing technology.

Proposed Indian couch management guidelines (best-bet options), regional priorities and future research direction were identified using a synthesis of all project information, including producer knowledge and expert opinion. Critical review and testing of identified best-bets and confirmation of future research needs was carried out using an expert scientific panel and with the project's producer stakeholders.

Results/key findings: A range of factors are contributing to the spread of Indian couch, such as land degradation, heavy grazing, prolific seed production and means of spread, and climatic extremes in rainfall variability. These factors culminate in opportunities for Indian couch to become

established particularly on bare soil and in gaps in pasture. The spatial mapping of Indian couch identified many Grazing Land Management land types in eastern Queensland are at risk from Indian couch dominance. The combined area of the at-risk land types equated to 9.6 million ha: ~6.6 million ha for the Burdekin, ~0.7 million ha for the Burnett-Mary, and ~2.3 million ha for the Fitzroy.

A survey of QGRAZE long-term pasture monitoring sites and comparison with historical data showed an overall increase in Indian couch frequency in pastures in eastern Queensland has occurred over the last 30 years, with this increase being statistically significant ($P<0.05$) for the Fitzroy catchment.

An Indian couch 'Think Tank' used to explore the impact of Indian couch on landscape function showed there is a better understanding of the impact of Indian couch on soil stability compared with understanding of the impacts of Indian couch on water infiltration and nutrient cycling. There is anecdotal evidence to suggest landscape recovery processes and indeed water infiltration will be reduced for Indian couch relative to native 3P (perennial, productive, palatable) tussock grasses due to lower litter accumulation and retention. Furthermore, the effect of Indian couch on soil function and biodiversity is often presumed, thus warrants further investigation. Any reduction in litter retention is expected to have many deleterious flow-on effects such as reduced nutrient cycling and soil function, along with reduced water cycling.

Simulated annual pasture growth, averaged over five locations and 131 years of historical climate, showed that pasture growth for treeless, non-grazed native pastures was 11 to 19% higher than that of Indian couch. While a preliminary whole-farm bioeconomic modelling study suggested that greater profits could be achieved with Indian couch, these results may have been over-estimated due to the 'impacts of grazing' assumptions which favoured Indian couch. Nevertheless, simulated annual economic losses in the most severe drought years were on average 160% worse for Indian couch than for native pastures, and with Indian couch there were 30% more years in total with financial losses compared with native pasture.

Analysis of field measured data combined across sites and seasons indicated no significant difference between total mean yield of Indian couch and native pasture ($P>0.05$). However, analysis of data within a site (at a sample level) indicated significant differences between Indian couch and native pasture production occurred on three out of ten occasions: twice during below average rainfall conditions for heavy soil types in the Burnett-Mary catchment where native dominant pasture was indicated to outyield Indian couch dominant pasture ($P<0.001$), and once during above average rainfall conditions for a sedimentary red earth in the Burdekin catchment where Indian couch dominant pasture was indicated to outyield native dominant pasture ($P<0.05$). These results are consistent with the sentiments of producers that the quality of Indian couch is acceptable at certain times, but overall Indian couch is a less reliable feed source.

Preliminary research tested different aspects of Indian couch ecology. Indian couch cover in monitored paddocks was found to be more closely associated with climatic conditions than grazing treatment, with increased cover of Indian couch occurring in wet seasons. However, both grazing strategies and climate interacted to influence the cover of native 3P grasses. Indian couch seed was shown to be less tolerant of heat compared to Black speargrass which has implications for the potential role of fire in Indian couch management. A seed persistence study showed that Indian couch seed should be classified as long-term persistent (3+ years), similar to native species.

Management options for Indian couch dominant pastures were also identified, including reducing stocking rates, applying rest, and incorporating new pasture species including legumes (esp. *Stylosanthes*).

Finally, and specific to sown pastures, the large Indian couch soil seed banks are expected to be a major hinderance in efforts to suppress/deplete Indian couch, particularly given its long-term persistence. Thus, cultivation and fallow (or cultivate and sow annual forage) before re-seeding with a perennial grass-legume pasture, are being considered by some beef producers.

Benefits to industry: Important management implications have been identified by the project. These are all focussed on managing the health and vigour (i.e., increased competitiveness) of the preferred pasture species to minimise the spread of Indian couch.

The project has addressed a knowledge gap and developed maps to demonstrate the current extent and potential future spread of Indian couch in Queensland's grazing lands.

Candidate management and control options for Indian couch have been identified for producers in two scenarios: (i) managing existing Indian couch pastures and (ii) halting/reducing/removing Indian couch in native and sown pasture. For pastures with highly dominant Indian couch, key strategies for improved production and ecological function include reducing stocking rates, applying more rest to pasture (e.g., wet season spelling), and incorporating new grasses and legumes into the pasture where possible. For pastures with low levels of Indian couch, the best-bet options are yet to be determined but potentially could involve a combination of prescribed fire, stocking rate management, and applying more rest.

Future research and recommendations: A range of areas demanding further research attention can be suggested, as summarised below according to objective.

Factors influencing the spread, persistence, and competitiveness of Indian couch: Identify the optimum germination conditions for Indian couch seed; Develop a plant population model for Indian couch to better understand risk factors associated with its spread; Conduct plant competition studies and determine if Indian couch can directly replace preferred pasture species through adverse allelopathy or through altered soil nitrogen relations.

Indian couch occurrence and adaptation: Build on the QGRAZE database and survey more sites to expand the existing knowledge base of pasture species status and trends across eastern Queensland; Determine the status of Indian couch across northern Australia; Collect plant samples from the diverse areas and conduct genetic studies to determine the variation in Indian couch in Australia.

Landscape function impacts: Ascertain the impact of Indian couch on soil function and biodiversity and water cycling.

Production impacts: Direct further research attention towards the inclusion of SWIFTSYND site data to improve Indian couch pasture model parameters, and to understand drought-tolerance thresholds, yield-cover relationships, and regrowth following simulated grazing. Conduct further R&D into GRASP-CLEM modelling in order to improve estimates of production impacts for grazing enterprises.

Management options: Test the role of fire in managing native pastures to suppress Indian couch. Validate the identified best-bet management options for Indian couch, including conducting a combination of on-property trials along with more controlled and detailed studies on Indian couch biology/ecology.

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Project report overview

The following report addresses five research objectives:

- Identifying the factors responsible for Indian couch expansion
- Determining the extent and likely spread of Indian couch invasion in north and central Queensland
- Quantifying the impacts of Indian couch on carrying capacity and livestock production
- Preliminary research into control options
- Testing and identifying practical options to either manage or control the spread of Indian couch on native and sown pastures

The first two objectives are presented below consecutively as Chapters 1 & 2.

The third project objective has been split into two separate chapters; Chapter 3: Determining the impacts of Indian couch on production, and Chapter 4: Determining the impacts of Indian couch on landscape function.

The final two research objectives are presented consecutively as Chapters 5 & 6.

1. Identifying the factors responsible for Indian couch expansion

1.1 Background

Although heavy grazing has been implicated as the major cause for the spread and dominance of Indian couch (Walker and Weston 1990; McKeon et al. 2004), the limited available research suggests other factors are also involved (e.g., Howden 1988; Scanlan et al. 1996a; Ash et al. 2001). Indeed, Howden (1988) predicted that because of its competitive advantages over native grasses, Indian couch would spread and persist allowing it to become a major community component over a wide range of grazing intensities.

With Indian couch expanding its range (Stacey 2014) and spreading further throughout grazing landscapes in northern Australia (Robyn Cowley, *pers. comm.*), a key aim of this project was to understand the factors responsible for Indian couch expansion.

1.2 Objectives

Specific research questions:

- What effect does land type have on the rate and extent of Indian couch invasion?
- Across land types, what are the soil, climate, management, and other factors e.g., invasion corridors that might explain this?

Outputs: Improved understanding of the management, climate and other factors driving the increase in Indian couch on different land types and regions.

Outcomes: Increased awareness and understanding of the factors driving Indian couch invasion, and a list of possible management options for controlling/reversing Indian couch. Improved grazing management guidelines to manage for Indian couch.

1.3 Methods

1.3.1 Review of literature

A collection of significant literature on Indian couch was reviewed to identify the possible drivers of spread.

Level of success/efficiency of methodology employed

This was achieved and allowed for the consideration of both biotic and abiotic factors influencing the spread of Indian couch in pastures. The ecological traits and adaptability of the grass to aid in its survival and spread were realised.

1.3.2 Review of producer knowledge and expert opinion

A review of producer knowledge collected prior to project execution during a scoping study in 2015 (Spiegel 2016) and DAF information days in central Queensland in 2017 (Spiegel 2019) was used to identify the (i) characteristics of Indian couch invasion according to catchment, (ii) extent of invasion, (iii) potential production impacts, (iv) possible factors contributing to the spread of Indian couch, and (v) management options. Expert opinion was also collected during the scoping study.

The scoping study and DAF information days included a total of eight workshops with producers across three catchments:

- Burdekin catchment: three workshops in the Charters Towers district of north Queensland, covering native pastures on Goldfields and Basalt land types,
- Fitzroy catchment: four workshops covering the Banana Shire and Isaac Region of central Queensland, covering both sown and native pastures,
- Burnett-Mary catchment: one workshop in the North Burnett Region of south-east Queensland, covering mostly native pastures.

At the workshops, DAF staff, and at times external pasture experts (e.g., CSIRO), presented their own research experience and knowledge of Indian couch. Producer feedback was collected by using small break-out groups and working through several predetermined questions, which slightly evolved with each workshop (Appendix 9.1.1). For the DAF information days in central Queensland in 2017, a separate producer questionnaire (Appendix 9.1.2) was also provided to a total of 71 producers (42 in Biloela and 29 in Moura) and captured potential production impacts of Indian couch invasion and management options.

Once the project was formally executed, producer stakeholder groups were formed in each catchment (Burdekin, Fitzroy, and Burnett-Mary) with a minimum of three local producers and three local DAF staff. The purpose of the producer stakeholder groups was to discuss and interpret project findings and consider practical applications of these findings. This allowed for further exchange of information and collection of any new producer knowledge and experience.

Level of success/efficiency of methodology employed

This approach allowed for a fusion of producer and research knowledge and consideration of management options. Both climatic factors and competitive attributes of Indian couch make management of this grass challenging for beef producers. A range of management options needed to be considered, from learning to live with Indian couch and improving its production, to testing possible grazing land management and cultivation options to keep it at lower levels in the feedbase.

1.3.3 Spatial mapping of data and extraction of GLM land type data

Road survey data on Indian couch presence spanning 2004 to 2022 was assembled (refer to sections 2.3.1 and 2.3.2) and medium to high (core habitat) Indian couch presence data (see section 2.3.2) was imported into ArcMAP. Land type data associated with the sites was extracted from the Queensland grazing land management (GLM) land type layer. Extrapolated Indian couch preferred land types were mapped using the most current GLM land type mapping.

'Not at risk' GLM land types were identified where Indian couch dominance was low (less than 10% of the samples) and the number of sites were adequate. Where a land type had a low number of sample sites, it was deemed that it was not possible to make a judgement to the risk of invasion by Indian couch this area was nominated as 'samples too low'. Finally, if a land type had no sample sites it was designated as 'not sampled'. The area of each category ('at risk', 'not at risk', 'samples too low' and 'not sampled') was calculated by totalling the area of the land types in each category, in each catchment, and from this percentages were calculated.

Level of success/efficiency of methodology employed

The method for spatial mapping of data and extraction of GLM land type data was relatively straight forward and successful and did evolve as GLM land type data was being updated for Queensland.

1.3.4 Field assessment of QGRAZE pasture monitoring sites

A desktop review and mapping of historical QGRAZE* data was undertaken by the project. QGRAZE is a long-term monitoring system implemented by the Department of Agriculture and Fisheries (DAF) in 1991 to monitor pasture condition and measure pasture species change of grazing lands in Queensland, yet active monitoring of the sites is not done routinely across Queensland. There are 446 QGRAZE sites in Queensland, with 286 of these sites located in the Burdekin, Fitzroy and Burnett-Mary catchments. QGRAZE sites were established on-property and marked out by 5 star pickets spaced 50m apart and positioned in a north to south alignment.

Each of the 5 star pickets represent the centre of 5x 200m transect lines that run east to west. Each QGRAZE site encompasses a 4 hectare area. The monitoring of sites involves 100 x 0.25m^2 quadrat assessments of pasture species frequency and ground cover along the transect lines. Tree cover, soil surface condition, and pasture species are also monitored.

A subset (n=22) of historical QGRAZE sites were resurveyed. In the Burdekin catchment, 11 QGRAZE sites were selected to represent a range of historical Indian couch frequencies (0 to 75%) across different land types. In the Fitzroy catchment, 11 QGRAZE sites were selected that historically had Indian couch present (frequencies >0 to <5%) and absent on the same land types. Sites were sampled as per QGRAZE methodology (Back 2005), as described above.

The new data collected by the project on Indian couch frequency was compared with historical records; 'Historical' = the last recording taken from 20 to 29 years ago. The change between current Indian couch frequencies and historical records was categorised as either: Absent, Decrease, Low-Medium increase (an increase up to 25%) or High increase (an increase >25%) and mapped. The overall difference between past and current Indian couch frequency for each catchment was also assessed using a paired t-test.

Level of success/efficiency of methodology employed

The value of the QGRAZE database for monitoring the condition of grazed pasture lands is limited by the number of times sites have been surveyed in the past. Notwithstanding these limitations, the value of QGRAZE as a monitoring tool is exceptional at identifying trends or changes in pasture condition of surrounding grazing lands, plus with the advantage of engaging with land holders to better understand their cattle grazing system, observations, and experiences. The experience of the project reflects these values and advantages. A major challenge and shortfall of QGRAZE monitoring has been the lack of site maintenance and ongoing survey of sites and changes in landholders who were not involved in the program. For the project this meant some delays in finding sites and organising visits to sites, with some sites no longer being in existence, disturbed or moved. Furthermore, the survey of sites was a lengthy process, given the distances travelled to a site and the intensive nature of sampling at a site (100 quadrat assessments).

*QGRAZE was implement in 1991 by the Queensland Government, Department of Agriculture and Fisheries to monitor species change and pasture condition of grazing lands throughout Queensland (Back 2005).

1.3.5 Review of QGRAZE findings, ground cover trends and producer feedback

A review of QGRAZE sites sampled in the Fitzroy catchment (n=11) was carried out using *VegMachine®* analysis of ground cover trends at the QGRAZE sites and producer feedback. The producer feedback was collected as per a designed producer questionnaire (see Appendix 9.1.3). The aim of the producer feedback was to help interpret the QGRAZE results and ground cover trends for each site and identify any management and/or climate factors influencing the spread of Indian couch.

***VegMachine®* analysis of ground cover trends:** Shape files of each site were created and imported into *VegMachine®*. Graphs were produced showing the quantiles of cover through time for each of the 11 QGRAZE sites, for total ground cover and the green cover fraction. Plotted values for the average cover (total or green) were ranked against regional ground cover in the same season. This meant the higher the plotted quantile, the greater the proportion of regional ground cover values than average ground cover at the site. For example, a value of 0.6 meant average ground cover on the site was greater than ground cover in 60% of the region. The region was defined as all grazing land within 20km of the site that was also grazing land as determined by QLUMP dataset stratification.

It was assumed that if Indian couch encroachment impacted either the total or the green cover on the site, then this should result in values diverging from 0.5 when Indian couch invades the site. However, if Indian couch invaded the region at the same time/speed no effect will be detected, because the regional benchmark includes the Indian couch signature too. Knowing when Indian couch appeared on each of the sites is important knowledge for interpreting ground cover trends.

Level of success/efficiency of methodology employed

A major impediment of interpreting cover trends was not knowing when exactly Indian couch appeared in the region and at the individual QGRAZE sites. This is attributed to the limited number of times sites were surveyed in the past, but also due to limited records of Indian couch invasion. Due to gaps in the historical data to pinpoint when Indian couch started to invade at different QGRAZE sites meant cover trends could not be linked with Indian couch invasion. Nonetheless, producer feedback proved to be very insightful, especially on the spread of Indian couch in central Queensland and how this is also being compounded by the issue of pasture dieback.

1.4 Results & Discussion

1.4.1 Review of literature

Indian couch [*Bothriochloa pertusa* (L.) A. Camus] is a stoloniferous and fast spreading perennial grass of the Old World tropics. Since its introductions into Australia in the 1930s and 1950s (Bisset 1980), it has spread and become a naturalised pasture species. The early uses and commercial value of Indian couch in Queensland were recognised for amenity purposes, such as for lawns and planting of aerodromes and golf course fairways, as well as for its grazing value (Bisset 1980). Using Indian couch for soil conservation and land reclamation was also recognised (Bisset 1980) and promoted, such as planting of farm waterways, mine sites, and industrial embankments (Truong and McDowell 1985).

Indian couch plant occurrences have been recorded across northern Australia and particularly in Queensland (Alfonso 2010). In some situations, overgrazing, often coupled with drought, has led to the loss of native perennial grasses and replacement by exotic Indian couch (McKeon et al. 2004). This has given rise to novel Indian couch landscapes, such as those found in the Dalrymple Shire of north Queensland on Granodiorite (aka Goldfields) landscapes (Rogers et al. 1999).

Although heavy grazing and the reduction in ground cover have been implicated as the major causes for the spread and dominance of Indian couch (Gardener et al. 1990; Walker and Weston 1990; McKeon et al. 2004), literature also reveals Indian couch can continue to increase even when grazing is removed (Scanlan et al. 1996a).

A major competitive advantage Indian couch has over native tussock grasses is attributed to its low stoloniferous growth (Calvert 2001). Indian couch develops a low, prostrate growth form under grazing, thus providing a high leaf area for photosynthesis and photosynthate supply to roots (Howden 1988). This means Indian couch, being lawn-like, is tolerant of heavy grazing and trampling. This is supported by Scanlan et al. (1996a), where, under high levels of pasture utilisation, the order of magnitude decrease in plant basal area was less for Indian couch dominant pastures when compared with native Black speargrass pastures, and higher pasture cover was maintained for Indian couch compared with Black speargrass at the same biomass. Furthermore, with its good colonising ability, such as rapid growth rates and high seed production (Calvert 2001), Indian couch can exploit gaps in a pasture (McIvor 2007).

Although Indian couch is a perennial grass, it is also referred to as a drought-evading grass (Whyte 1968). This means it has mechanisms, such as high seed production, that ensure its survival. Along with its high regeneration potential, Indian couch is also highly adaptable; being a polyploid, hybridisation in nature is known to occur (De Wet and Higgins 1963) and such adaptive evolution is characteristic of invasive species (Prentis et al. 2008). As highlighted by Whyte (1968): "*Polyploids in general display wider ranges of tolerance of extreme climatic and edaphic conditions; their spread is favoured by the availability of the new ecological niches in rapidly changing environments (due to climatic fluctuation and change, or to increasing aridity following devegetation)*".

In India, where Indian couch originates from, historical records for two grassland cover types ('*Sehima/Dicanthium*' and '*Themeda/Arundinella*') indicate perennial grass shifts favouring the dominance of Indian couch over *Dicanthium* and *Chrysopogon* spp. occurred under conditions of grazing-induced disturbance, i.e., in overgrazed areas; with further excessive grazing also resulting in increases in *Eremopogon foveolatus* and *Cynodon dactylon* (Whyte 1968). Conversely, with protection from grazing, the species most likely to dominate in these cover types of India included *Themeda* spp. and *Heteropogon contortus*. These findings mirror the reports in Australia of Indian couch invading Black speargrass (*H. contortus*) pastures, including in north-eastern Queensland where Kangaroo grass (*T. triandra*) was once a more dominant pasture species (Howden 1988).

The preferred growing conditions of Indian couch include seasonally wet places that have high or moderately high rainfall (Bor 1960), such as within rainfall isohyets of 500 to 1375mm (Skerman and Riveros 1990). Skerman and Riveros (1990) describe the natural habitat of Indian couch to be grassland on clay soils and open woodland and highlighted the ability of this grass to grow on a range of soil types. Soil types can range from poor soils to black cotton soils of India (Skerman and Riveros 1990 after Chinnamani 1968) and Timor (after Whyte 1968), coarse to fine-textured soils with soil pH range of pH 5.8-7.5, and on lateritic soils (after Whyte 1968).

Pengelly et al. (1997), in assessing different accessions from India, reported on provenance to include a range of soil types: loams, clay loams or clays, heavy textured soils with pH ranging from slightly acid to strongly alkaline, sands or sandy loams, and light-textured soils. This covered areas of central and southern Indian with mean annual rainfall ranging anywhere from 520mm to 2100mm.

Finally, more recently published literature on Indian couch spread into native ecosystems in Queensland (see Lebbink 2020) further supports the understanding that grazing induced disturbances facilitates the spread of Indian couch. Habitat suitability studies carried out by Lebbink (2020) also showed preferred growing conditions for Indian couch in Queensland were characteristic of mean growing season temperatures between 23°C and 27°C and in areas with low tree cover (<40% foliage protective cover).

1.4.2 Review of producer knowledge and expert opinion

Producer knowledge

Indian couch invasion was investigated in the Burdekin, Fitzroy, and Burnett-Mary catchments. Many different aspects of Indian couch invasion were addressed according to and within catchment: general features, potential production impacts, drivers of spread, and management options. The current section focusses on general features and drivers. Details on the potential production impacts of Indian couch are presented later (see section 3.4.3), as are the management options (section 6).

A fusion of anecdotes, based on producer feedback spanning 2015-2017 is presented in Tables 1 and 2. This anecdotal evidence indicates that Indian couch occurrence is much more prevalent in the Burdekin catchment, with reduced incidence in the Fitzroy and Burnett-Mary catchments (Table 1). What is evident is the presence of Indian couch in all catchments and the potential for further spread of this grass in native and sown pastures. The further spread of Indian couch would provide an advantage to degraded landscapes by providing soil protection and providing at least some forage. However, the apparent symptomatic presence of Indian couch is not to be ignored or celebrated. As indicated by the anecdotes presented in Table 2, the spread of Indian couch has been linked to overgrazing (as a 'biotic' factor) and other stressors (e.g., drought, soil fertility decline, flooding – as 'abiotic' factors) afflicted upon original or desirable pasture species.

The decline in vigour of preferred pasture species from factors described by producers such as heavy grazing and prolonged drought (Table 2) would lead to the creation of gaps in pasture and thus the opportunity for Indian couch to invade. For the Burdekin, conditions identified for Indian couch incursion included a source of seed and bare ground for establishment (Table 2). Thus, maintaining high ground cover and managing desirable pasture species so that they remain as competitive and vigorous as possible will be important management actions underpinning the slowing down or halting of Indian couch incursions. However, as indicated by one producer: "*Healthy pasture slows it, not stops it*". Thus, other grazing strategies may need to be considered when it comes to controlling Indian couch spread in pastures, such as those that promote evenness of grazing and minimise occurrence of repeat grazing and overgrazed 'patches' forming in the paddock and allow for ample pasture rest.

Feedback from producers in central Queensland also indicated the key time when Indian couch incursions are highly likely and possible climatic drivers, such as after the break of drought; "*Out of dry, into wet – bad for Buffel. Indian couch takes over*".

Table 1. Anecdotal characteristics of Indian couch invasion according to catchment based on feedback collected during producer workshops, and information days (2015-2017).

Item/feature	Catchment		
	Burdekin	**Fitzroy**	**Burnett-Mary**
Indian couch invasion – general features	• History of Indian couch invasion in native pastures, particularly in north-east QLD where Indian couch monocultures exist. • On the Basalt, there has been an increase in Indian couch since the late 80s and early 90s. There was no recollection of the grass in the late 60s.	• Cleared grazing lands, some cultivation, and the incorporation of improved pasture species is a key feature in central QLD, where pasture rundown, Indian couch invasion, and pasture dieback all occur to some extent. • Indian couch can also be found in native pastures.	• Indian couch invasion less of a concern, with the grass not as prevalent.
Extent of invasion	• Anything from properties having isolated occurrences, to pastures dominated by Indian couch.	• Anything from having no Indian couch, to isolated incidences of Indian couch invasion on property, to Indian couch scattered through the pasture. • Some cases of Indian couch dominance, e.g., holding paddocks or old cultivation country. • Full extent not reached.	• Reduced occurrence of Indian couch relative to the Burdekin and Fitzroy catchments. • Found in road reserves, slashed areas, and in inland Burnett. • Planted in washouts. • Found in cultivations in between sorghum and oats, and old cultivation.

Table 2. Anecdotal characteristics of Indian couch drivers according to catchment based on feedback collected during producer workshops, and information days (2015-2017).

Possible factors contributing to the spread of Indian couch		
Burdekin	**Fitzroy**	**Burnett-Mary**
• Overgrazing: Drought feeding in the 80s with molasses and urea saw native grasses being eaten out allowing Indian couch to spread. • High stocking rates: "*Sign of the times – everyone is running more cattle as per economic environment. Indian couch takes advantage of this*". • Indian couch can spread from areas where it first appears, i.e., high traffic/impact areas such as front paddocks or holding yards, at watering points, lanes/ gateways, supplementary feeding points, access tracks. • There are also good sources of seed around these days, such as air strips and lawns. Seed is easily spread by vehicles, bikes and four wheelers. The grass can be found along power lines and a common corridor of spread onto properties has been along roads. • A source of seed and bare ground: Indian couch is a good coloniser. Fire with poor recovery can lead to Indian couch invasion. • Competitive nature of Indian couch: "*Indian couch out-competes native grasses under heavy stocking rates*", "*Indian couch is more prolific than natives*", "*Once it's there, hard for native seedlings*".	• Overgrazing (driven by financial pressure) and droughts; "*Easier to manage pastures and be good managers during good seasons*". • Heavy rains (flooding): spreading seed but also associated with the reduced vigour/death of Buffel grass/and natives during heavy rain; providing an opportunity for Indian couch to invade. • Conditions ideal for Indian couch include dry followed by wet – "*Out of dry, into wet – bad for Buffel. Indian couch takes over*". • "*Healthy pasture slows it, not stops it*". • Cattle, machinery, and vehicles spreading seed. • Nitrogen rundown. • Lack of fire? "*Years ago, burning was common. Stubble left now and natural break down. No fire*". • Roadsides and watering points are a good source of Indian couch seed.	• Indian couch can be easily spread after wet periods and via farm machinery. • Indian couch in road reserves: source of seed. • Heavy grazing and heavily stocked areas such as around water and feed troughs. • Road works. • Spread especially after drought.

Expert opinion

Expert opinion is presented below. Collectively, key findings relating to drivers of Indian couch spread include:

- Land degradation,
- Source of seed, e.g., road reserves,
- Rundown Buffel pastures; low soil nutrient (nitrogen) supply,
- High grazing pressure, heavy stocking rates, and
- Climatic factors and drought-evading mechanisms of Indian couch.

Trevor Hall (retired DAF scientist)

A timeline of events is described, with highlights to roadsides aiding in the spread of Indian couch throughout eastern Queensland.

- 1940s: Indian couch sown around WWII airstrips in Queensland.
- 1960s: Indian couch spreading around the dry tropics of north Queensland such as Bowen region.
- 1970s: After Townsville stylo (*S. humilis*) eradicated by anthracnose & cattle price crash, overgrazing destroyed Black speargrass pastures encouraging Indian couch. Indian couch also spread down Queensland coast to central Queensland.
- 1980s: Extensive Indian couch inland from Bowen – Collinsville on Ironbark. Spreading into north Queensland along roadsides, e.g., Mareeba and to Chillagoe. Spread into Ethridge Shire, Georgetown. Grown at Walkamin Research Station (Ian Staples).
- 1990s: Indian couch spreading into southern Queensland along roadsides. Risk of Indian couch incursion in rundown Buffel pastures, although spread of Sabi grass a bigger problem.
- 2000s: Indian couch spreading throughout Queensland along roadsides. Spreading into rundown Buffel pasture – older pastures on lighter soil (lower fertility). Extensive spread into grazed pastures in north Queensland. Common around homesteads and along property roads. Spreading into old Buffel pastures in Maranoa, e.g., red clay loams, with drought increasing the spread. Initial spread on lighter soils.
- Present: Indian couch can be found in slashed roadsides throughout eastern Queensland.

Bob Shepherd (DAF Principal Extension Officer)

- Indian couch introduced into Queensland in the 1930s, and naturalised by the 1960s (e.g., airstrips).
- Diverse species with six strains: Bowen, Capella, Biloela/Dawson, Emerald/Emerald Downs, Yeppoon/Keppel, and Medway.
- Indian couch is a good coloniser, a prolific seeder, and provides poor quality standing feed during the dry season. Indian couch has poor drought tolerance – although this varies with grazing management and has higher ground cover at low yields when compared with tussock grasses.

Brett Abbott (CSIRO Research Scientist)

- Indian couch can reduce sediment but not reduce overland flow, i.e., infiltration issues under Indian couch.
- Indian couch is susceptible to pest attack, e.g., army worm.
- In the Burdekin there are animal feeding preferences for 3P grasses over Indian couch.
- Indian couch cover is masking land condition. It is also hard to predict biomass via satellite data as Indian couch has high cover at low biomass: changes in biomass vs cover become undetectable at just over 500kg/ha. Existing pasture models do not work. Remote sensing – misleading.

Stuart Buck (DAF Senior Agronomist)

- Indian couch invasion in central Queensland is occurring in forest country and in Buffel grass country.
- Indian couch is a symptom of a range of issues, being tolerant of a range of issues such as high grazing pressure, low soil nutrient (nitrogen) supply, and dry conditions through evasion mechanisms (high seed producer, very quick to respond after rainfall).
- Indian couch is very adapted to a wide range of soil types and rainfall conditions.
- In central Queensland, Indian couch is preferentially grazed in native pastures and left alone in sown pastures.
- Indian couch is very common along roadsides and spreading into paddocks from roadsides.
- Indian couch is spreading from north to south through Fitzroy (Theodore).
- Higher incidence of Indian couch in pastures on old crop/forage cultivation paddocks.
- Increasing incidence of Indian couch in Buffel pastures not used for cropping – some anecdotal evidence suggests spread is worst in 'wet years.'
- Producers are concerned about the spread of Indian couch and believe their business will become unviable if Indian couch keeps spreading.
- The role of legumes: Buffel pastures with a good amount of legume (Caatinga stylo) have been shown to have lower levels of Indian couch when compared with Buffel pastures without legume.
- Graziers need to ensure their preferred grass is what they concentrate on and do what they can to maintain or improve the competitiveness of their preferred grass.
- Indian couch spread is about a range of environmental and managerial aspects, often occurring together: grazing management, soil nutrient (N) supply, and rainfall (dry and wet).
- Once it is in the landscape it will be difficult to remove.

Peter O'Reagain (DAF Principal Scientist)

- Indian couch invasion has occurred at the long-term Wambiana Grazing Trial (WGT) regardless of stocking rate, but the extent was greater for the heavy stocking rate treatment compared with lighter stocking and was soil dependant; far more Indian couch on the box and brigalow than ironbark. This could be attributed to soil fertility and structure.
- Important drivers for Indian couch spread include bare ground, autumn-winter rain, drought breaking rainfall, and on-going heavy grazing. The WGT experience has shown criteria for Indian couch invasion in native pastures is a seed source and means of spread, establishment sites – bare ground, autumn-winter rainfall – well distributed, and on-going heavy grazing.
- Over the life of the WGT there has been very little recruitment of the desirable native 3P grass Desert bluegrass. The little there has seems to be in the moderate stocking rate treatment (based on the work of Paul Jones).
- Indian couch (an exotic Bluegrass) may suppress recruitment of Desert bluegrass. However, there is no WGT data showing that.
- Little indication that improved grazing practices will revert the spread of Indian couch.

Producer stakeholder groups

Producer stakeholder groups (refer to 1.3.2 of methods) allowed for further exchange of information and collection of any new producer knowledge and experience during 2019-2021 and builds on the earlier feedback from producers presented above in Tables 1 and 2. This is described below for each catchment, with a focus on the possible drivers of Indian couch spread in pastures.

Burdekin – *Goldfields*

- Invasion of Indian couch is taking place even on minimally grazed rangeland that had a history of no Indian couch and only low grazing pressure, e.g., property conservatively stocked before becoming Military land.
- CSIRO studies of runoff at Virginia Park have shown that the runoff from Indian couch is clear – a certain amount of infiltration happens but the water then runs off. So lower infiltration because of the dense mat of grass, but low soil loss as well.

Burdekin – *Basalt*

- Cattle grazing behaviour and selection of other grasses over Indian couch during the growing season may facilitate the spread of Indian couch without the early grazing pressure on it: cattle seem to avoid Indian couch during this time and prefer Indian couch a bit later in the season after it has set seed.
- Have not burnt for some years, although in the past it was a regular management practice. Plan is to manage pastures more through rest and controlling grazing pressure. In some circumstances, fire can encourage Indian couch so would not generally be a good control option, but the effectiveness of fire depends on many variables, including what grazing pressure occurs after the burn, the intensity of the burn and follow up rain.

Fitzroy – *Biloela*

- Council slashing is a significant issue for the Fitzroy graziers and Indian couch spread. Can local councils be encouraged to use different grass species at road works or along highways?
- Producers generally have a good understanding of Indian couch invasion, such as invasion on old cultivated country.
- Focus has shifted from Indian couch to pasture dieback issues.
- Are rundown, Indian couch invasion and pasture dieback related and a symptom of a larger issue?

Burnett-Mary

- In some locations, Indian couch dominance has occurred where there has been no history of heavy grazing.
- There are producers in Gin Gin, in the Bundaberg Region, who have seen an increase in Indian couch after 2 wet years.
- Patches of Indian couch on property that are not located immediately roadside.
- More Indian couch around now. It is not going away.
- Indian couch is found along roads and highways, with the occurrence and spread of Indian couch being facilitated by graders. Councils cannot do anything without State funding. Can council be made aware of Indian couch in road reserves? Can something be done about this?

- Even in areas of good 3P coverage, Indian couch can still creep through and invade.
- Indian couch is invasive, it is high seeding and spreads via runners (stolons) and responds to moisture.

1.4.3 Spatial mapping of data and extraction of GLM land type data

To describe and understand the core habitat of Indian couch in eastern Queensland, the Grazing Land Management (GLM) land types associated with Indian couch dominance were mapped. This was done using dominant Indian couch data (refer ahead to next section and Figs. 14, 15 and 16), and extracting the land type data associated with these sites. Figs. 1, 2, and 3 show the potential invasion area (PIA) for Indian couch in the Burdekin, Burnett-Mary, and Fitzroy catchments, respectively. The calculated PIAs include 6,591,476 ha for the Burdekin, 678,187 ha for the Burnett-Mary, and 2,294,970 ha for the Fitzroy catchment. The areas at risk of Indian couch incursion includes extensive coverage of grazing lands in the Upper Burdekin (Fig. 1), inland Burnett (Fig. 2) and much of the Fitzroy catchment (Fig. 3). Collectively, the natural vegetation of these areas at risk are 'Black speargrass', '*Aristidia*/*Bothriochloa* pastures', 'Brigalow pastures', and 'Queensland bluegrass' native pasture communities (DPI 1988).

The land types most at risk for the Burnett and Mary catchments included Ironbark and bloodwood on non-cracking clay, Blue gum on cracking clay, Box on clay, and Silver-leaved ironbark on granite. For the Fitzroy catchment, the 'at risk' GLM land types included Gum-topped box flats, Mountain coolibah woodlands, Poplar box with shrubby understorey, and Silver-leaved ironbark on duplex. Land types highly affected in the Burdekin included basaltic soils, ranges, clayey alluvials and goldfields country.

For many of these GLM land types identified to be at risk of Indian couch invasion, the preferred pasture species include native bluegrasses such as Queensland, Curly, Forest, and Desert bluegrass (i.e., native '*Bothriochloa*' and '*Dicanthium*' spp.), along with Kangaroo grass (*Themeda Triandra*) and Black speargrass (*Heteropogon contortus*), (see FutureBeef 2011). These findings are consistent with historical records of Indian couch dominance in India (see section 1.4.1; Whyte 1968).

Not at risk: A total of eight common land types were identified across all three catchments (Burdekin, Burnett-Mary and Fitzroy) to be 'not at risk' from invasion and dominance by Indian couch: Alluvial brigalow, Box flats, Brigalow softwood scrub, Cypress pine country, Narrow-leaved ironbark with rosewood, Open downs, Poplar box/brigalow/bauhinia, and Spotted gum ridges. Across the eight land types found 'not at risk', a range of preferred or expected pasture species include but are not limited to Black speargrass, Kangaroo grass, Queensland bluegrass, Desert bluegrass, Forest bluegrass, and Mitchell grass species (*Astrebla* spp.), (FutureBeef 2011).

The percentages of each catchments grazing lands 'at risk' versus 'not at risk' from invasion and dominance by Indian couch indicated the issue of Indian couch incursion in pastures to be greater for the Burdekin catchment followed by the Fitzroy catchment, and to a lesser extent the Burnett-Mary catchment (Table 3).

Table 3. Percentage of each catchments grazing lands that are/aren't at risk from invasion and dominance by Indian couch.

Risk factor	Catchment		
	Burdekin	Burnett-Mary	Fitzroy
At risk	72	16	42
Not at risk	23	29	46
Samples too low	4	25	10
Not sampled	0.6	30	2.6

Figure 1. Potential invasion area of Indian couch in the Burdekin catchment, based on Grazing Land Management land types with known Indian couch dominance. Areas within the catchment that are not shaded represent areas with insufficient evidence to suggest Indian couch dominance.

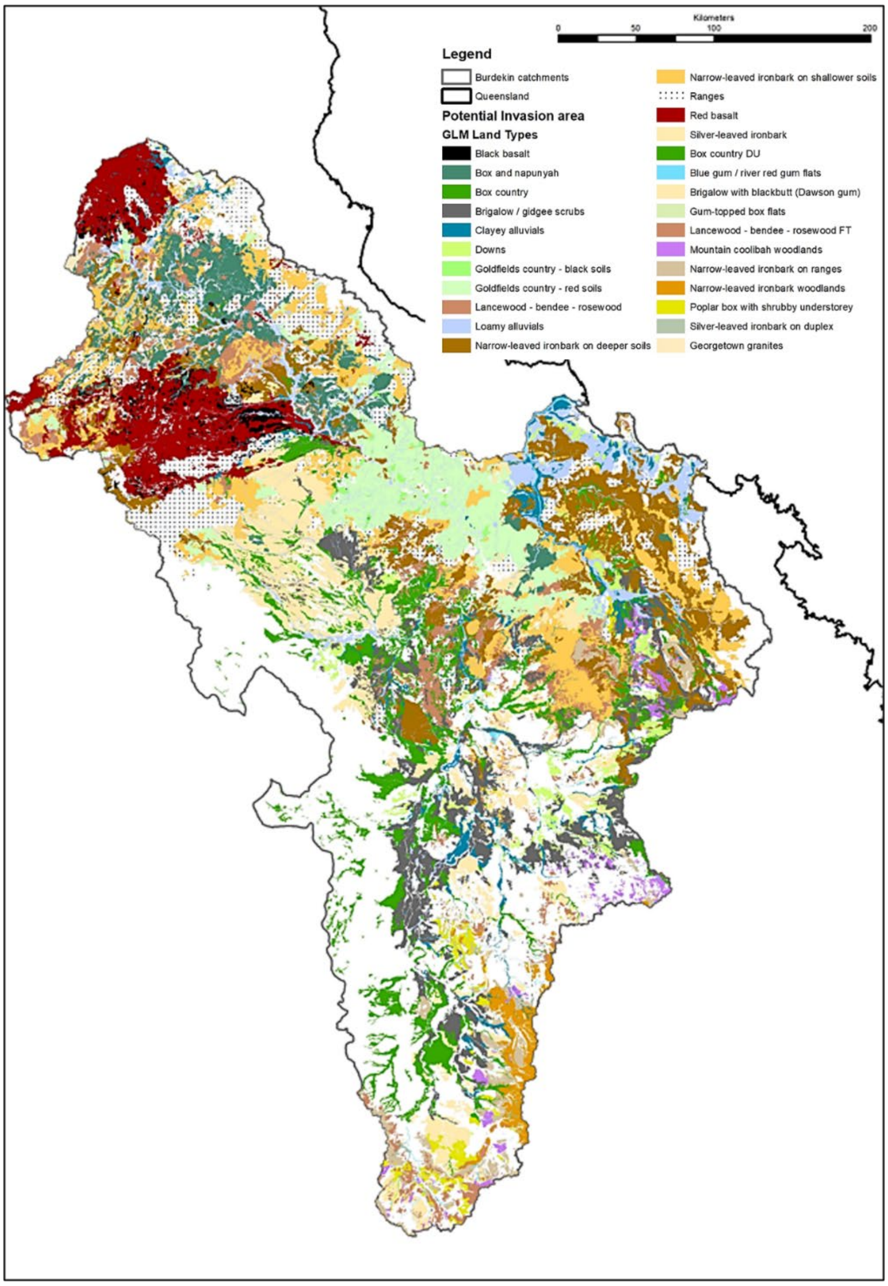


Figure 2. Potential invasion area of Indian couch in the Burnett Mary catchment, based on Grazing Land Management land types with known Indian couch dominance. Areas within the catchment that are not shaded represent areas with insufficient evidence to suggest Indian couch dominance.

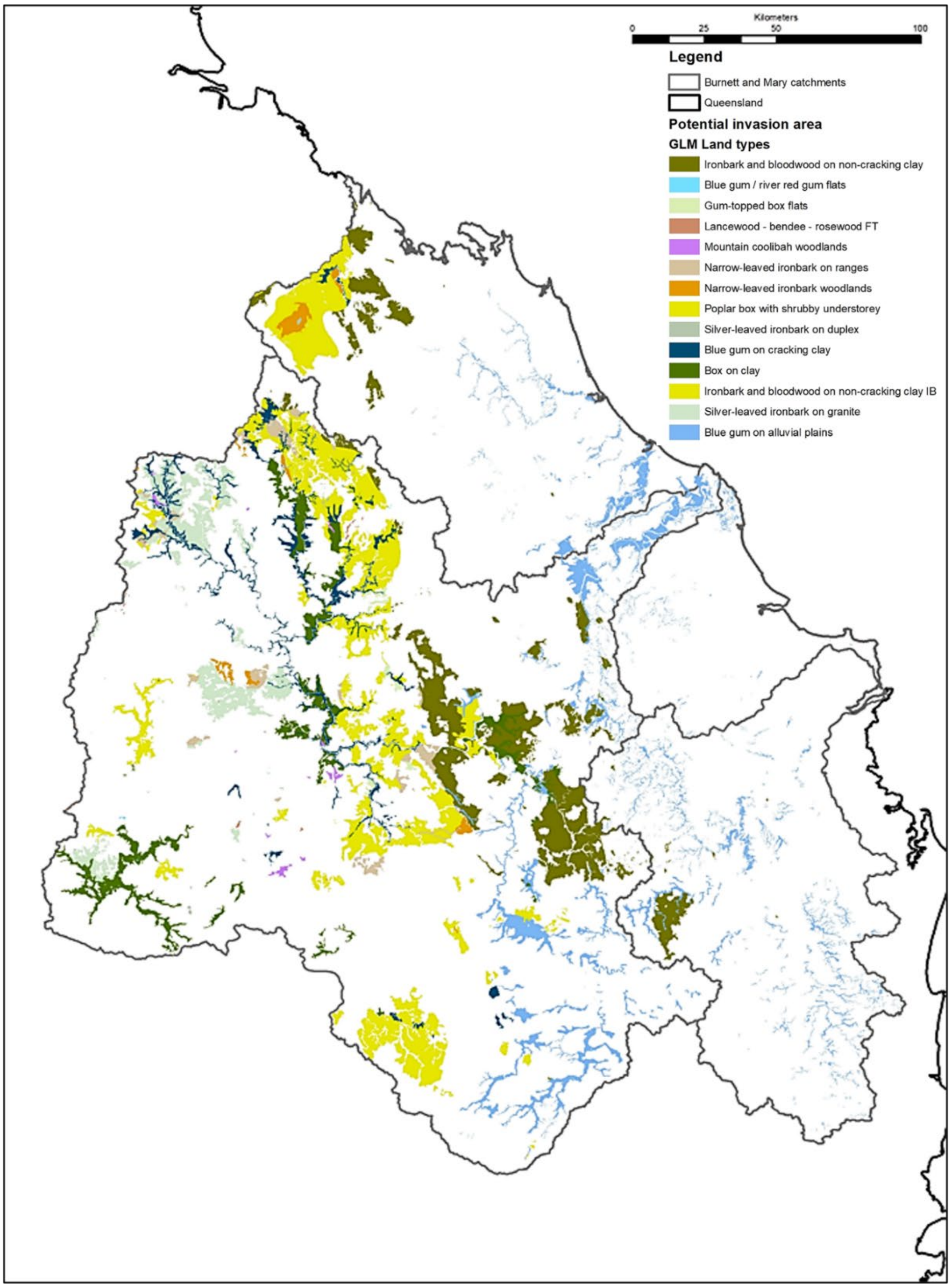
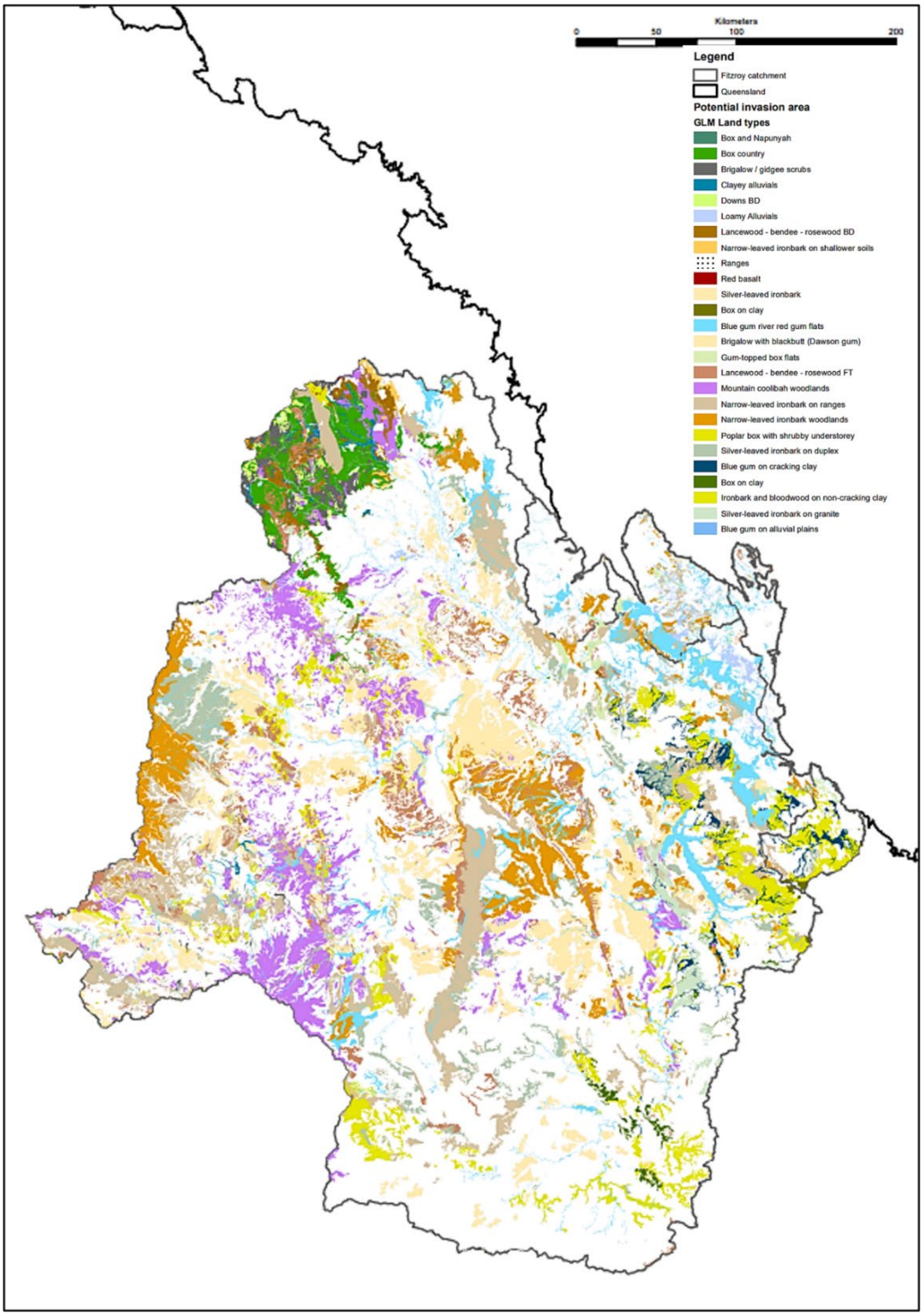


Figure 3. Potential invasion area of Indian couch in the Fitzroy catchment, based on Grazing Land Management land types with known Indian couch dominance. Areas within the catchment that are not shaded represent areas with insufficient evidence to suggest Indian couch dominance.



1.4.4 QGRAZE assessment of Indian couch trends

A desktop review and mapping of historical QGRAZE data was first undertaken prior to selecting a subset of sites for field assessment.

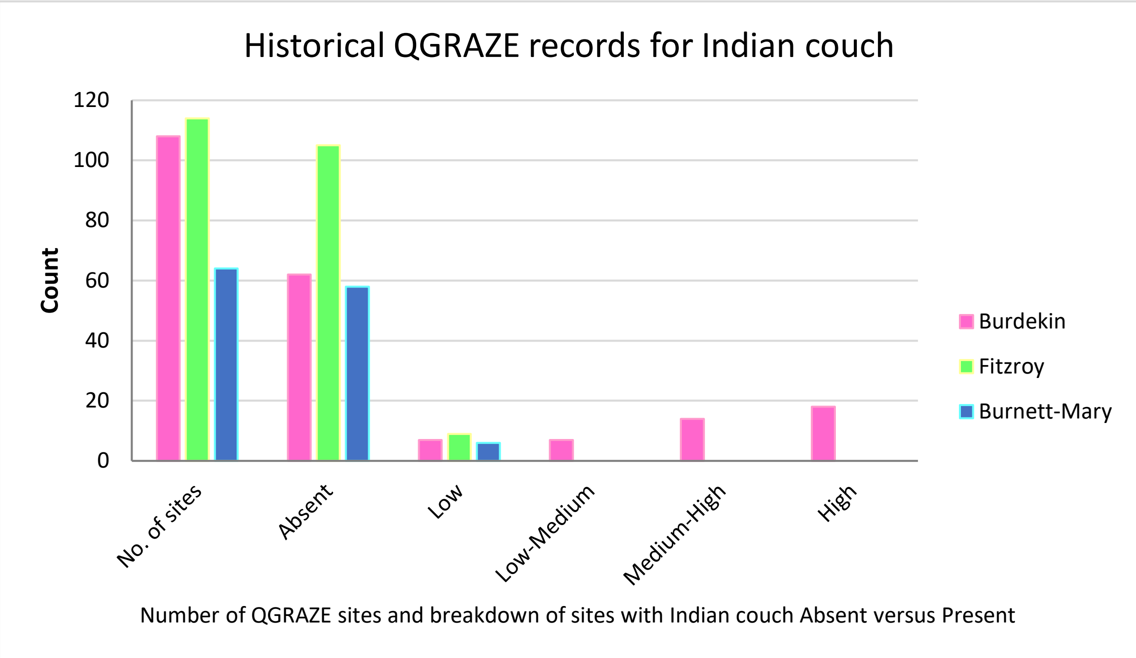
Desktop review of historical data

A total of 446 QGRAZE pasture monitoring sites are recorded in the DAF database, with more than half (64%) being established in the Burdekin, Fitzroy, and Burnett-Mary catchments. There are 286 sites in these three catchments with species percent frequency data recorded at irregular intervals between 1983 and 2014 (Table 4). Over this period Indian couch was recorded at a total of 61 of these QGRAZE sites (21%) with the greatest number of Indian couch sites in the Burdekin (46 out of 108 sites), followed by the Burnett-Mary (6 out of 64 sites) and the Fitzroy catchment (9 out of 114 sites) (Table 4 and Fig. 4, otherwise Appendix 9.2.1 for spatially mapped records).

Table 4. Summary details of QGRAZE sites in three major catchments in eastern Queensland (n=286) and the years in which sites were first and last monitored.

Catchment	Number of sites Total	Number of sites with Indian couch present	First-Last visit (number of years)
Burdekin	108	46	1991-2014 (24)
Fitzroy	114	9	1983-2001 (19)
Burnett-Mary	64	6	1992-1999 (8)

Figure 4. Number of historical QGRAZE sites (i.e. pre-2015) and records of Indian couch frequencies for sites in the Burdekin, Fitzroy, and Burnett-Mary catchments. Frequencies are: Absent (0%), Low (<5%), Low-Medium (5-25%), Medium-High (>25%-75%), High (>75%) at last recording.



Field assessment of QGRAZE pasture monitoring sites

The status of Indian couch in Queensland over the last 20 to 30 years was assessed through the re-survey of a subset of long-term QGRAZE pasture monitoring sites. A total of 16 out of 22 (73%) of all the QGRAZE sites sampled had an increase in Indian couch (Fig. 5). Three sites experienced a decrease in Indian couch, and three sites remained absent of Indian couch (see Appendix 9.2.2). There was a significant increase in Indian couch frequency for the Fitzroy catchment (P=0.022). An overall increase in Indian couch frequency was observed for the Burdekin catchment, however the change was not statistically significant (P=0.109) (Table 5). A large variability in historical Indian couch frequency for the Burdekin (0 to 75%, see Fig. 4) meant the increase in Indian couch frequency observed for this catchment was not statistically significant at $P<0.05$. By contrast, the historical Indian couch frequency and range for the Fitzroy catchment was minimal (0 to <5%, Fig. 4). Overall, results indicated current levels of Indian couch in grazing lands in the Burdekin and Fitzroy to be medium (i.e., sparse: 25 to 50% frequency), (Table 5).

Observations at a site level were also considered. For the Burdekin catchment, there were two sites that experienced a decrease in Indian couch over the last 30 years. The most frequent species currently for one of these sites being introduced *Urochloa mosambicensis* and for the other site forbs. There was also one site that remained free of Indian couch, with the most frequent species at the site currently being *Sporobolus* spp. (refer to Appendix 9.2.2; Table 22 and Figs. 51 & 52).

For the Fitzroy catchment, there were two sites where Indian couch remained absent. The most frequent species currently for these sites included Buffel grass and *Aristida* spp. Across both catchments there were six QGRAZE sites (three per each catchment) where Indian couch has become the most frequent pasture species (refer to Appendix 9.2.2; Table 23 and Figs. 53 & 54). For one of these sites (in the Burdekin) the native 3P grass Desert bluegrass (*Bothriochloa ewartiana*) was historically the most frequent species (frequency 66%) and is now absent at the site – with current species for this site including Indian couch (83% frequency) and Buffel grass (26% frequency).

Figure 5. QGRAZE sites sampled for Indian couch with corresponding frequency change categories shown: Absent, Decrease, Low-Medium increase (up to 25% increase), High increase (>25% increase).

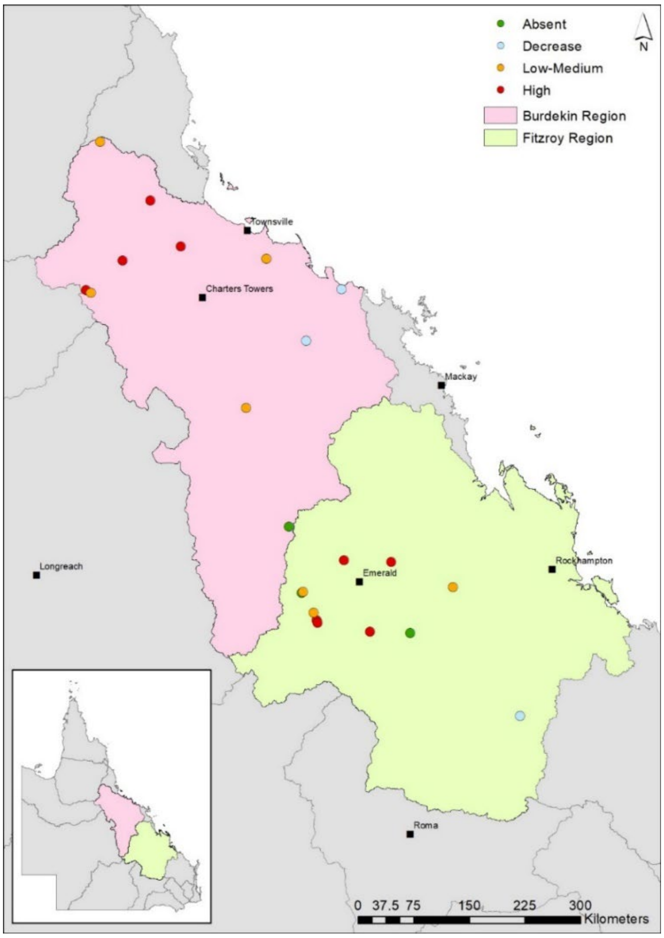


Table 5. Mean Indian couch historical and current frequencies for the Burdekin and Fitzroy catchments based on a subset (n=22) of sites and the assessment of the overall difference.

Catchment	Indian couch frequency (%)		SED	*P*-value	Sites (n)
	Historical	Current			
Burdekin	20	42	13	0.109	11
Fitzroy	0.56	27	9.8	0.022	11

1.4.5 Review of QGRAZE findings, ground cover trends and producer feedback

The review of QGRAZE sites was undertaken for the Fitzroy catchment. A major impediment of interpreting cover trends was not knowing when exactly Indian couch appeared on the sites. Regardless of this gap in knowledge, the graphs of cover trends for each site did not reveal anything unusual (Appendix 9.2.3). Nonetheless, producer feedback did provide new insights on the issue of Indian couch in central Queensland and possible drivers of spread, and how this is being compounded by the issue of pasture dieback:

- "*Indian couch is now invading the areas of buffel that have been killed by dieback*".
- "*Cattle spreading the seed, and the dieback has created patches for it to invade*".
- "*The run of very dry years, together with the rundown of pastures has made Buffel susceptible to the Indian couch*".
- "*Patch grazed areas where Buffel grass is grazed down, together with a run of dry years followed by wet years is what seems to favour the spread*".
- "*Almost completely taken over table drains along bitumen which are regularly mowed which indicates that it would thrive in over-grazing situations*".
- "*Indian couch gets an advantage as the other grasses are eaten down, it seeds readily and comes back in the spaces in the pasture*".
- "*Probably floods from the creek spread it*".
- "*Not being conservative and not looking after ground cover*".
- "*Spread by vehicles*".

Important management implications were also alluded to:

- Look after ground cover.
  - Check pasture availability at key times of the year and mange stocking rates accordingly.
  - "*You need to lighten off if not happy with the amount of grass in April*".
- Minimise the spread of Indian couch seed on property.
  - Avoid driving vehicles through patches of Indian couch; "*We never drive vehicles through these patches*".
- Reduce the likelihood of Indian couch spread in pasture.
  - "*We maintain a good body of grass*".
- Address pasture rundown and pasture dieback.
  - "*Buffel grass is rundown and has lowered available nitrogen, reducing the vigour of the Buffel and making it more susceptible to Indian couch invasion*".

  - "*We are now burning a quarter of the paddock each year to address the dieback problem*".
- Address over-utilisation of pasture and allow for recovery from grazing.
  - Practice pasture spelling and allow pastures to recover from grazing and prioritise good ground cover.
  - "*Light stocking with steers that are turned off about 560kgs. During dry conditions, or when pasture is low they are turned off at 400 kgs and go to feedlot*".
  - "*The paddock gets spelled for several months from March on an irregular basis. This is done when the grass is getting low and it is spelled until it recovers*".
  - "*Good ground cover is a priority*".
  - "We are conservative with breeders and usually have plenty of grass. We summer spell every 3-4 years".
- Manage pastures during drought.
  - "*We do lighten off the numbers in dry years and maintain a good body of grass*".
  - "*Stock numbers are halved in bad drought and bred back over 5 years*".

1.5 Conclusion

1.5.1 Key findings

A range of factors are contributing to the spread of Indian couch, such as land degradation, heavy grazing, good source of seed and means of spread, and climatic extremes in rainfall variability. These factors culminate in opportunities for Indian couch to establish itself, namely bare soil and gaps in pasture providing establishment sites for Indian couch. Drought-evading mechanisms (i.e., ability to escape drought) of Indian couch such as high seed production mean it has high regenerative potential, where Indian couch can grow back from seed during the onset of drought-breaking rains. Once Indian couch has spread into pastures it will be difficult to remove it.

Indian couch is well suited to establish itself and occupy extensive grazing lands of eastern Queensland, such as in the Upper Burdekin, throughout the Fitzroy, and in inland Burnett. Many Grazing Land Management land types are at risk of Indian couch dominance, such as Red basalt in the Burdekin catchment, Ironbark and bloodwood on non-cracking clay in the Burnett-Mary catchment, and Mountain coolibah woodlands in the Fitzroy catchment. Native pasture communities most at risk of Indian couch incursion include Black speargrass, Brigalow pastures, Aristida/Bothriochloa pastures, and Queensland bluegrass.

An assessment of the percentage of each catchments grazing lands that are/aren't at risk of Indian couch dominance showed 23% for the Burdekin, 29% for the Burnett-Mary, and 46% for the Fitzroy are not at risk. Common GLM land types across the three catchments found 'not at risk' included Alluvial brigalow, Box flats, Brigalow softwood scrub, Cypress pine country, Narrow-leaved ironbark with rosewood, Open downs, Polar box/brigalow/bauhinia and Spotted gum ridges. Across these 'not at risk' land types, expected or preferred pasture species include Black speargass, Kangaroo grass, Queensland bluegrass, Forest bluegrass, Desert bluegrass and Mitchell grass. The assessment of each catchments grazing lands at risk/not at risk of Indian couch dominance also indicated the highest risk occurred for the Burdekin (72%), followed by the Fitzroy (42%) and then to a lesser extent the Burnett-Mary (16%).

Although the extent of Indian couch spread is far greater in the Burdekin catchment, the project showed significant increases in the frequency of Indian couch across sites in the Fitzroy catchment have occurred over the last 30 years.

Finally, the influence of cattle grazing behaviour on the spread of Indian couch in pasture is less clear. Expert and producer opinion reveal there are times and situations where Indian couch is preferentially grazed over other grasses and other times and situations when it is not. Furthermore, preferentially grazed areas may provide ideal establishment sites for Indian couch, particularly if repeat grazing is causing a reduction in the competitiveness of preferred pasture species.

1.5.2 Benefits to industry

Important management implications have been identified by the project. These are all focussed on looking after and managing 'for what you want' i.e. managing the health and vigour (i.e., increased competitiveness) of the preferred pasture species to minimise the spread of Indian couch. This means addressing soil fertility (as is the case for rundown in Buffel grass pastures), retaining sufficient ground cover, adjusting stocking rates according to seasonal conditions, spelling pasture to allow for recovery from grazing, wet season spelling to allow for pasture regeneration, and reducing stock numbers in dry years. One producer also mentioned "*Healthy pasture slows it* [Indian couch]*, not stops it*". Thus, testing different grazing strategies that manipulate cattle grazing behaviour and promote evenness of grazing may also be required to keep Indian couch out.

2. Determining the extent and likely spread of Indian couch invasion in north and central Queensland

2.1 Background

To fully appreciate and assess the impact that Indian couch is having on the beef industry, it is first important to know where Indian couch occurs and to what extent, and where there is potential for further spread. Thus, the project sought out to map the scope and extent of Indian couch expansion into grazing lands in eastern Queensland; with a focus on the Burdekin and Fitzroy catchments, but also extending to include the Burnett-Mary catchment. The spread of Indian couch into grazing lands is well documented for north-eastern Queensland (e.g., Mortiss 1995; McKeon et al. 2004), but less so for other areas of the Burdekin catchment as well as the Fitzroy catchment and further south into the Burnett-Mary catchment (Spiegel 2016). In addition, current mapping of Indian couch occurrences in Australia are limited to herbarium records (e.g., Atlas of Living Australia n.d. and AVH n.d.); these herbarium records provide general information, and not more specific information on Indian couch such as frequency and dominance and likely spread.

2.2 Objectives

Outputs: A map(s) and spatial data showing the current extent of Indian couch and its likely spread in major catchment areas in Queensland.

The map(s) will be communicated to producers via media and FutureBeef, to achieve the outcome of increased awareness on the extent of Indian couch spread and dominance in pastures, and identification of 'hot spots' and areas at risk of invasion. By 2022 70% of the producers in north and central Queensland will be aware of the extent of Indian couch spread.

2.3 Methods

2.3.1 Road survey

Road survey of Indian couch presence/absence in grazing lands in the Burdekin, Fitzroy and Burnett-Mary catchments was conducted using mobile mapping technology (ArcGIS Collector). This data capture method ensured all data was spatially referenced for subsequent spatial analysis and mapping. A layer for data capture (see Table 6 for data layer fields) was created using ArcGIS Collector and uploaded to a smart device. Secondary and district roads were driven, with routes determined prior to survey work. Planning of routes considered the area within catchment, roads to travel, and distances to be covered. The planning of routes was also used to calculate the number of possible stops and hence distance between stops but otherwise survey work was a free style of surveying (Gunn et al. 1988). The determined distance between stops meant there was no bias associated with where operators stopped to make assessments. To determine day routes, a general rule of thumb was used: for unsealed roads survey work will typically take one hour to cover a distance of 50km, or otherwise 60km can be covered in an hour for sealed roads.

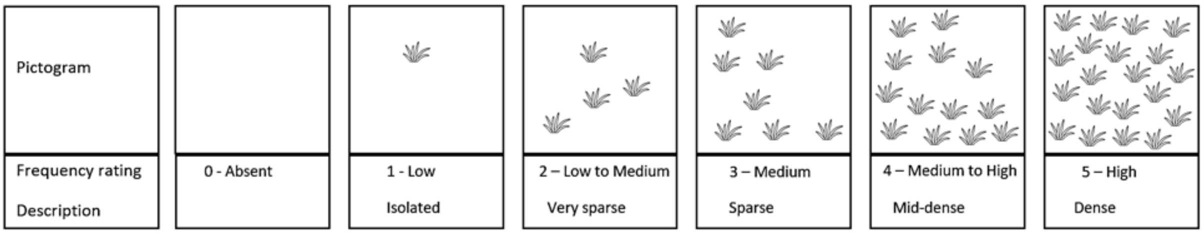
At each stop, the nearby paddocks on both sides of the road were assessed by looking over into the paddock and using a pair of binoculars, assessing a 50m arc area. Data (as per Table 6) was captured using a smart device and photos of the site (left, centre and right) taken. The area was surveyed for Indian couch presence and the frequency assessed as either Absent, Low, Low to Medium, Medium, Medium to High or High frequency; see Fig. 6 for a pictorial representation of different frequencies, similar to pictograms used to assess pasture density (e.g., see Karfs et al. 2009b). Land condition was recorded using the ABCD Framework: A-Good, B-Fair, C-Poor, D-Very poor (Hunt et al. 2014 after Quirk and McIvor, 2003). The road reserves were also assessed for Indian couch presence/absence to identify potential corridors of spread.

The data collected by the project builds on earlier road survey data sets completed in 2004-08 and in 2011 for the Burdekin and Fitzroy catchments. Thus, for these two catchments, priority areas targeted by the project included (i) roads not travelled previously, (ii) where earlier work did not confirm the presence of Indian couch, and (iii) any marked differences in rainfall zones within catchment. The earlier data points were pre-loaded onto smart devices to assist operators with avoiding unwanted repeats.

Table 6. Fields used in the data layer for road survey of Indian couch (IC) presence/absence in nearby paddocks, with Indian couch status in road reserves also assessed.

Field	Description
Indian couch frequency	0-Absent, 1-Low (Isolated), 2-Low to Medium (Very sparse), 3-Medium (Sparse), 4-Medium to High (Mid-dense), 5-High (Dense)
Land condition	ABCD framework: A-Good, B-Fair, C-Poor, D-Very poor
IC in Road Reserve	Yes: RRY, No: RRN

Figure 6. Indian couch frequency was assessed as either Absent, Low, Low to Medium, Medium, Medium to High or High frequency.



Level of success/efficiency of methodology employed

The method of road survey assessment of pasture species and land condition of grazing lands has been adopted in the past with success (e.g., see Karfs et al. 2009a; Beutel et al. 2014), providing a relatively quick and easy broadscale approach to assessing the condition of grazing lands. A major limitation to this approach is that it does not cover inclusively the situation across an entire property, only what is visible from the roadside looking into a property. Furthermore, some Indian couch plants may have been missed by the operator: it is easy to confirm Indian couch plants and density when walking through pasture versus looking into a pasture using binoculars. The trade-off for any error associated with the method is the quantity of data points collected. Thus, the approach provides an approximate appraisal of the situation. More detailed investigation of Indian couch spread in pastures on property was captured by the project through QGRAZE survey work (refer to section 1.3.4).

2.3.2 Review of existing data sets

Historical DAF data sets of 'semi-rapid' road survey data (Reef Rescue Monitoring 2011) and 'rapid' (windscreen) road survey data (Land Condition Monitoring 2004-08) were reviewed and data on Indian couch presence extracted. Other existing data sets reviewed for Indian couch presence included QGRAZE data (1992-2014) and Living Atlas of Australia (1941-2021). All Indian couch presence data points, including the new data collected by the project, were combined into a single database and mapped in ArcMAP.

Indian couch core habitat data was also extracted from all DAF data sets (2004-08, 2011, and current project: 2020-22) for mapping the potential invasion area (PIA) of Indian couch, and for assessing Indian couch dominance at a sub-catchment level. This method employed is described below.

Mapping the level of Indian couch dominance according to catchment and sub-catchment

Data was assembled to identify what sites had Indian couch dominance. Data was extracted from the different datasets: (1) rapid road survey assessments 2004-2008 when Indian couch was the first or second species listed, (2) Reef rescue surveys 2011 when Indian couch was the first or second species listed, and (3) Indian couch surveys 2020-2022 score 3 or above (representing medium, medium to high and high level of occurrence).

The data points from the 2011 reef rescue project and the new 2020-2022 data were then weighted x5 and added to the windscreen-based surveys (2004-08) to get a total number of Indian couch dominant and not dominant paddock sites. The weighting was used for datasets with higher level of accuracy at identifying Indian couch, where operators physically got out of the car and walked into the road reserve and up to the side of the paddocks versus assessment inside the car looking out through the windscreen. The historical data was then assessed on the number of sample sites and the percentage of sites that were dominated by Indian couch. If the sample sites had a moderate % of Indian couch dominance and/or there were a high number of sites this data was used to compare and inform the new road survey data of the current project.

The combined data of all the data sets was then assessed, separately and in combination in terms of number of sites and the percentage of Indian couch dominance. Site numbers were ranked from very low, low, or good. Susceptibility of the land type was rated from, high, moderate, and low. More weight was given to the susceptibility of invasion, so when a land type only had low number of sites with a moderate or high susceptibility it was still included in the potential invasion area.

The determined medium to high (core habitat) Indian couch presence was imported into ArcMAP. Land type data associated with these sites was extracted from the Queensland grazing land management land type layer. Extrapolated Indian couch preferred land types, based on land types where Indian couch is known to be present, were mapped using the most current Grazing Land Management (GLM) land type mapping and from this the potential invasion area (PIA) was calculated for each catchment assessed by the project.

Level of success/efficiency of methodology employed

The methods employed to spatially map and determine core habitat data for Indian couch dominance was very efficient considering the amount of data collected and the widespread nature of the species. This included projections from intensely studied areas into less studied areas, and incorporation and adding to existing data. Furthermore, incorporating a level of core and non-core habitat increased the accuracy of identifying the areas at risk of Indian couch dominance.

2.3.3 Preliminary remote sensing analysis of Indian couch using publicly available remote sensing data across Queensland and timeseries analysis

The project explored the potential for mapping the spread of Indian couch using publicly available remote sensing data across Queensland. This work was contracted to the Remote Sensing Centre, Department of Environment and Science (Healy and Watson 2022). Timeseries analysis, as opposed to single point in time, was used as this allows classification of vegetation based on the differing phenological and seasonal patterns of greenness and total cover over time. The project focussed on identifying whether there were any key differences in cover dynamics between Indian couch and other grasses. The geographical reference points used for this analysis were as per the project's current Indian couch presence/absence road survey data points. However, this did not include the final number of road survey sites as the road survey work was still taking place after the remote sensing analysis was completed.

Study area and field data

The study was focussed on the Burdekin, Fitzroy and Burnett-Mary catchments of eastern Queensland and based on data points of Indian couch presence and absence data collected by the current project (refer to 2.3.1). This included 571 points of presence (263) and absence (308) site data. Analysis in this project focussed on these points as the most recent and consistent observations, and therefore timeseries analysis was limited to 2017-2022.

Remote sensing data

The Joint Remote Sensing Research Program's fractional cover and ground cover products derived from Sentinel-2 and Landsat (JRSRP 2021; DES 2021) were selected for analysis, due to their advantages in cost, timeliness to produce, long available time-series, appropriate temporal and spatial resolution, and coverage of the study area.

The fractional cover product divides each pixel into the proportion of photosynthetic (pv) i.e., green vegetation, and non-photosynthetic vegetation (npv) i.e., dry cover and bare ground. The ground cover product is further derived from the fractional cover product to focus only on the understorey cover (DES 2022). It is not available in areas where woody vegetation cover exceeds 60%. These two products (fractional cover and ground cover) are available as monthly and 3-monthly composites, using Landsat and Sentinel-2. These composites are a robust way to minimise the amount of missing data and contamination by cloud or smoke. The analysis was focussed on the monthly product.

Analysis

The analysis focussed on identifying potential metrics to distinguish Indian couch from other ground cover species. Due to the limited quantitative data on Indian couch cover behaviour over time at remote-sensing-suitable scales, comparisons were made of the patterns of fractional cover between sites with and without Indian couch. A buffer of 50m around each point was created and from this fractional cover and ground cover data for each site from 2017 – 2022 was extracted. Cover values were averaged within each buffer polygon. The timeseries was limited to the 2017-2022 period to minimise uncertainty on the arrival of Indian couch at the sites, and to take advantage of the availability of monthly products, which were first released in 2016.

Different approaches were also utilised to distinguish Indian couch from other grasses, including the use of single date (i.e., every 5 days) Sentinel-2 fractional cover over selected sites. This was chosen to address issues of temporal scale. In addition, and to minimise climatic differences, focus was also made on a particular area (tile 56JLS: covering the Mundubbera and Gayndah area in the Burnett-Mary catchment). Finally, to assess data at a finer spatial scale, 15m buffers around points within this tile were also created.

Level of success/efficiency of methodology employed

The remote sensing analysis of Indian couch was a preliminary investigation based on available resources. Separating a particular grass species from other ground cover species is a complex issue. Thus, the analysis carried out was focussed on identifying any key differences in cover dynamics between Indian couch and other grasses. While the Indian couch presence/absence site data was a very useful dataset for initial investigation, these data were not captured with remote sensing validation as a primary purpose and were unfortunately insufficient for remote sensing application of separating Indian couch present sites from Indian couch absent sites. In future, data for remote sensing purposes needs to be taken on-property (i.e., property access required) and away from confounding features in the landscape such as road reserves.

2.3.4 Raising awareness

The map(s) generated from this activity will be communicated to producers via media and FutureBeef, to achieve the outcome of increased awareness on the extent of Indian couch spread and dominance in pastures, and identification of 'hot spots' and areas at risk of invasion.

By 2022 70% of the producers in north and central Queensland will be aware of the extent of Indian couch spread.

2.4 Results & Discussion

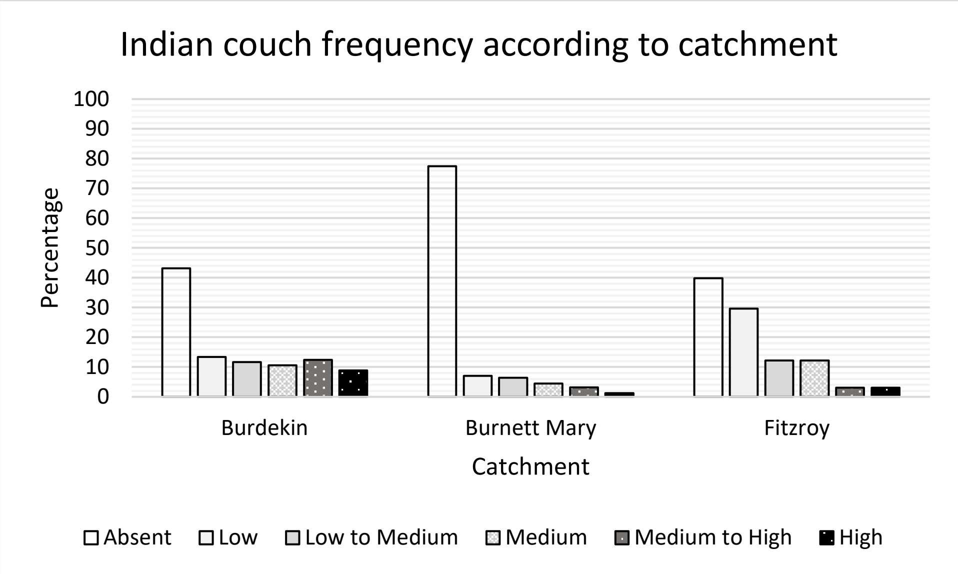
2.4.1 The extent of Indian couch expansion and likely spread in grazing lands in eastern Queensland

Road surveys of Indian couch frequency in grazing lands carried out by the project covered three catchments (Burdekin, Fitzroy and Burnett-Mary) and yielded a total of 692 sample points collected over a three-year period (2020 to 2022); 283 sample points for the Burdekin, 311 for the Burnett-Mary, and 98 sample points for the Fitzroy. Fig. 7 shows the percentage breakdown of Indian couch frequency category according to catchment.

The catchment with the greatest representation of 'absent' Indian couch occurrences was the Burnett-Mary, followed by the Burdekin and Fitzroy catchments (Fig 7). For the Burdekin, although there was a reasonable representation of 'absent' Indian couch occurrences relative to each of the other Indian couch 'presence' categories, and making up 43% of total sampling points for that catchment, all 'present' categories (whether low to high frequency) were evenly represented indicating a greater extent of Indian couch for this catchment. This was not the case for the other two catchments. For instance, in the Burnett-Mary catchment there were few 'high' frequency Indian couch sites, and for the Fitzroy catchment there were few 'Medium to High' and 'High' frequency Indian couch sites. The Fitzroy catchment also had a larger representation of 'Low' Indian couch frequency occurrences when compared to all the other Indian couch 'present' categories for this catchment.

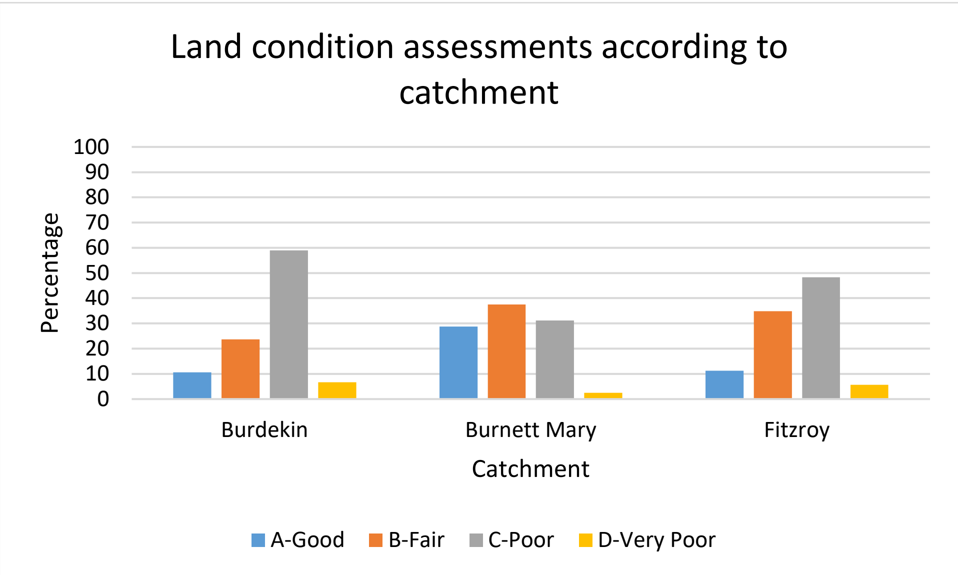
A limitation to the application of these findings is sample size. For instance, the Fitzroy catchment – being the larger of the three catchments, had the least sampling points. Information and data collected by other means in the project (as explored in the previous chapter, such as producer feedback and QGRAZE survey work) helped to provide a more comprehensive picture of the extent and drivers of Indian couch spread in eastern Queensland.

Figure 7. Indian couch frequency according to catchment in eastern Queensland sampled during 2020 to 2022 using road survey assessment.



Land condition was also assessed during road surveys. From the 692 sampling points, land condition was assessed on 657 occasions: 283 occasions for the Burdekin catchment, 285 for the Burnett-Mary, and 89 occasions for the Fitzroy catchment. Fig. 8 shows the Burdekin and Fitzroy catchments had a higher representation of C (Poor) condition land, relative to the other land condition categories and sample size. By contrast, the Burnett-Mary catchment had a higher representation of B (Fair) condition land.

Figure 8. Land condition assessments of grazing land sites sampled during road survey assessment of Indian couch frequencies in the Burdekin, Burnett-Mary and Fitzroy catchments during the period of 2020 to 2022.



The outcome of the background survey work for the Burdekin, Burnett-Mary, and Fitzroy catchments are shown in Fig. 9, 10 and 11, respectively. For the Burdekin (Fig. 9), despite the absence of Indian couch occurring under all land condition states (whether A, B, C or D), a higher occurrence of 'High' Indian couch frequency was associated with C (Poor) condition land. For the Burnett-Mary catchment (Fig. 10), Indian couch absence also occurred under all land condition states. When Indian couch did occur, this was more prevalent in the B (Fair) and C (Poor) condition land states. These findings are also consistent with the Fitzroy catchment (Fig. 11), where Indian couch absence occurred under all land condition states and Indian couch presence occurred under all land condition states but more so for the B (Fair) and C (Poor) land condition states, followed by A (good) land condition.

The presence of Indian couch in all land condition states is an important finding on its own, with implications that even A (Good) land condition is not necessarily immune to Indian couch invasion. Future research should explore further if a nexus exists between pasture condition and Indian couch frequency.

Figure 9. Land condition assessments (n=283) and associated Indian couch frequencies for sites sampled in the Burdekin catchment during road survey work.

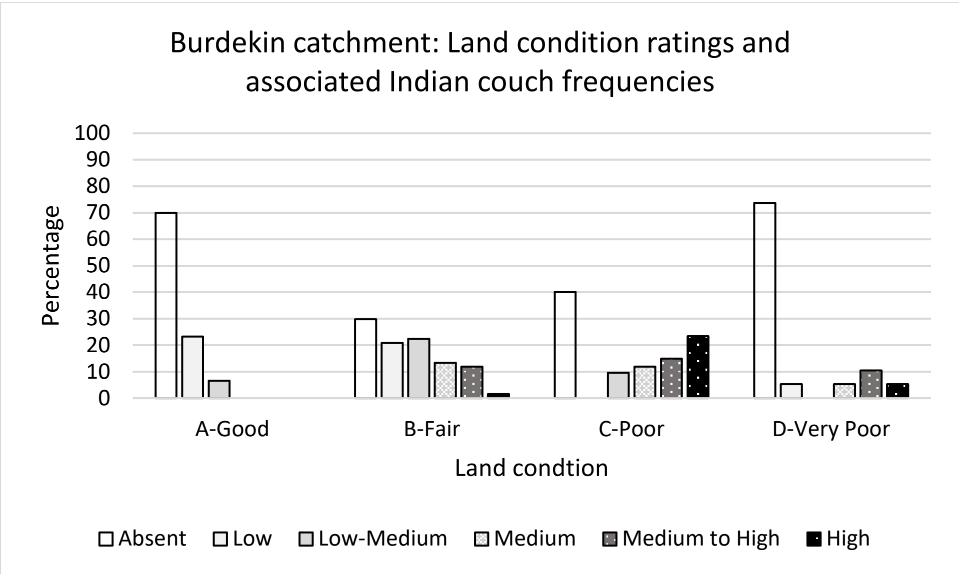


Figure 10. Land condition assessments (n=285) and associated Indian couch frequencies for sites sampled in the Burnett-Mary catchment during road survey work.

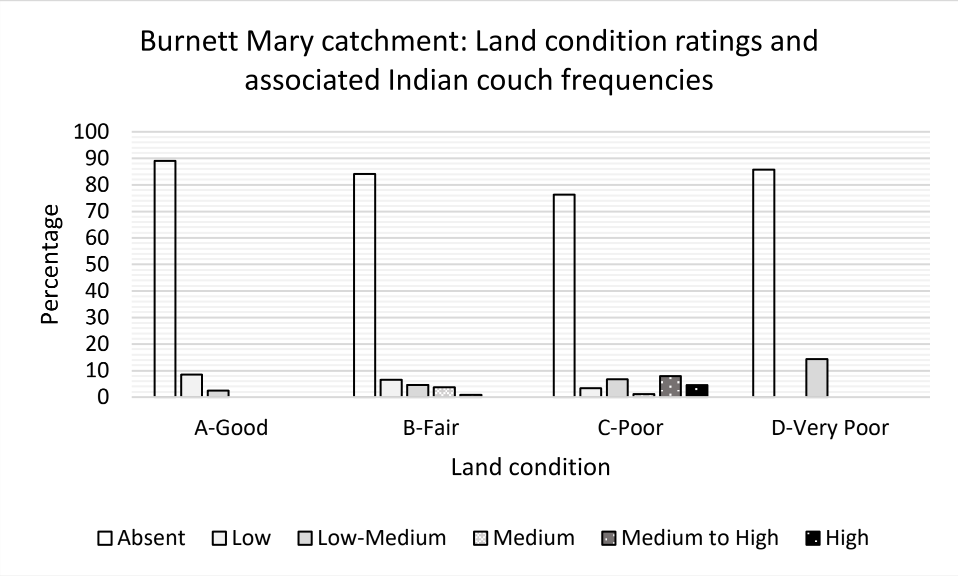
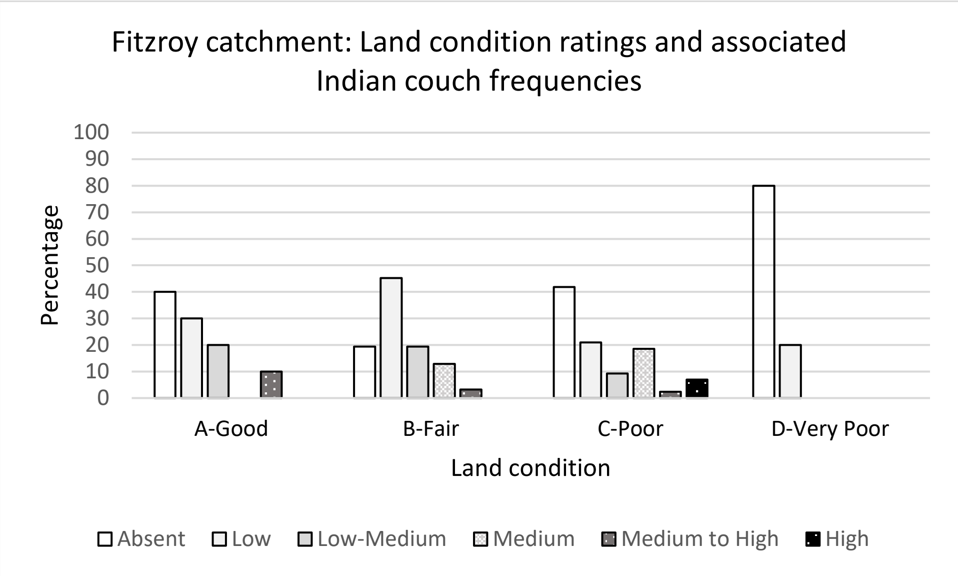


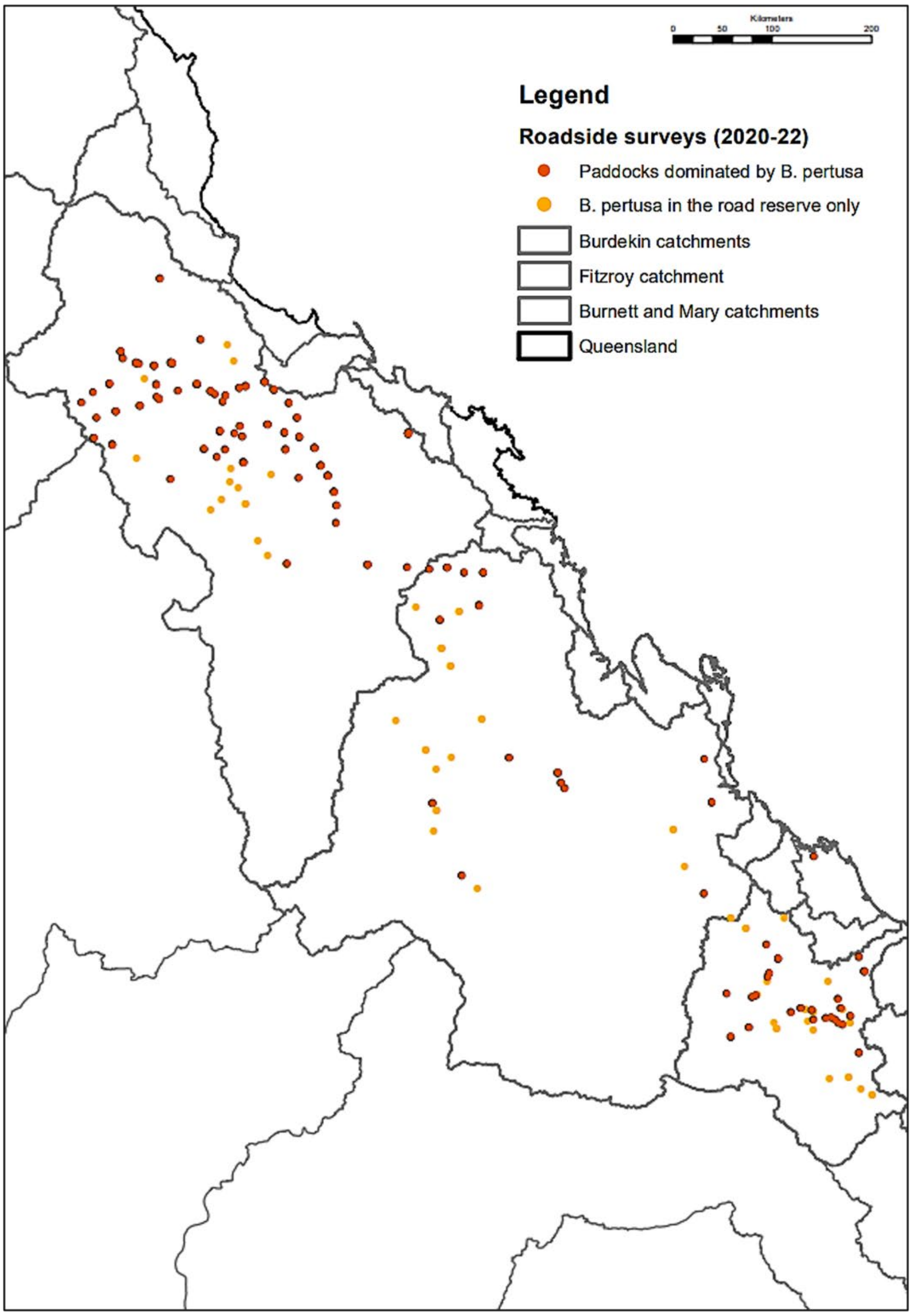
Figure 11. Land condition assessments (n=89) and associated Indian couch frequencies for sites sampled in the Fitzroy catchment during road survey work.



Potential corridors of spread

During the road survey of grazing lands, the opportunity to record presence/absence of Indian couch in nearby road reserves was also taken to investigate corridors for potential spread. Fig. 12 shows both (i) the locations where Indian couch dominance was detected in grazing lands and (ii) where Indian couch was not detected in grazing lands despite the grass being observed in the nearby road reserves, and thus localities where Indian couch may soon appear in paddocks. The risk for further spread, i.e., corridors for further spread, was evident for all three catchments.

Figure 12. Identifying potential corridors for further spread of Indian couch (*B. pertusa*) in grazing lands in the Burdekin, Fitzroy and Burnett-Mary catchments. Roadside survey of Indian couch dominance in grazing lands (looking into the paddock) was mapped and compared with the localities where Indian couch was not detected in paddocks but where Indian couch was found in the nearby road reserves.



2.4.2 Indian couch dominance at a catchment and sub-catchment level

Four mapping outcomes were achieved by the project to identify areas at risk of Indian couch dominance. Firstly, the general occurrence of Indian couch in Queensland was mapped using DAF data on Indian couch presence and records of Indian couch occurrence from the 'Atlas of Living Australia' database (Fig. 13). An eastern seaboard distribution of Indian couch in Queensland can be seen, with fewer occurrences of Indian couch occurring further inland. These records are consistent with the preferred growing conditions of Indian couch being within rainfall isohyets of 500 to 1400mm.

Secondly, medium to high Indian couch frequency data generated by the current project and integrated with pre-existing DAF data sets, shows specific coastal and sub-coastal core habitat areas for Indian couch (see Fig. 14, 15 and 16).

Thirdly, mapping the dominance of Indian couch at a sub-catchment level (Fig. 17) reveals a distinctive 'hot spot' for Indian couch dominance for north-eastern Queensland including, but to a lesser extent, far north Queensland. Two other areas highlighted by Fig. 17 to have a notable, yet lower incidence of Indian couch dominance compared with north-eastern Queensland, include the Fitzroy and Upper and Lower Burnett sub-catchments of inland Burnett.

Lastly, mapping the likely spread of Indian couch in eastern Queensland was completed for each catchment based on five ratings of high, moderate, low, and very low likelihood and unlikely (see Fig. 18, 19 and 20).

Figure 13. The general occurrence of Indian couch (*B. pertusa*) in Queensland based on historical (2004-08, 2011) and current (2020-22) DAF survey data – black triangles and Living Atlas of Australia (1941-2021) data – red dots.

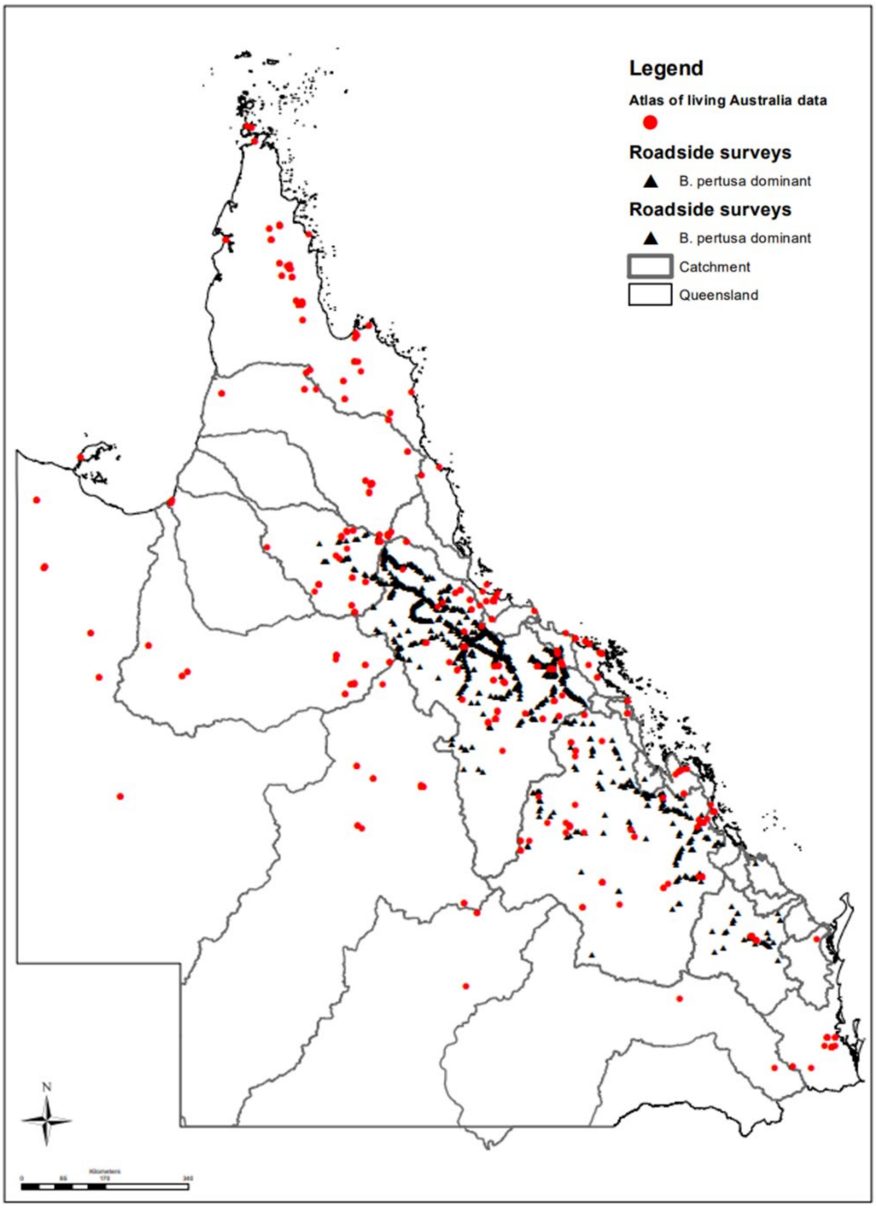


Figure 14. Core habitat distribution of Indian couch (*B. pertusa*) in the Burdekin catchment, as determined from road survey data of Indian couch presence/absence collected since 2004 (sampling times: 2004-08, 2011, 2020-22). White areas on the map are land types with extremely low data point numbers and any points indicated in the white area included isolated patches of Indian couch.

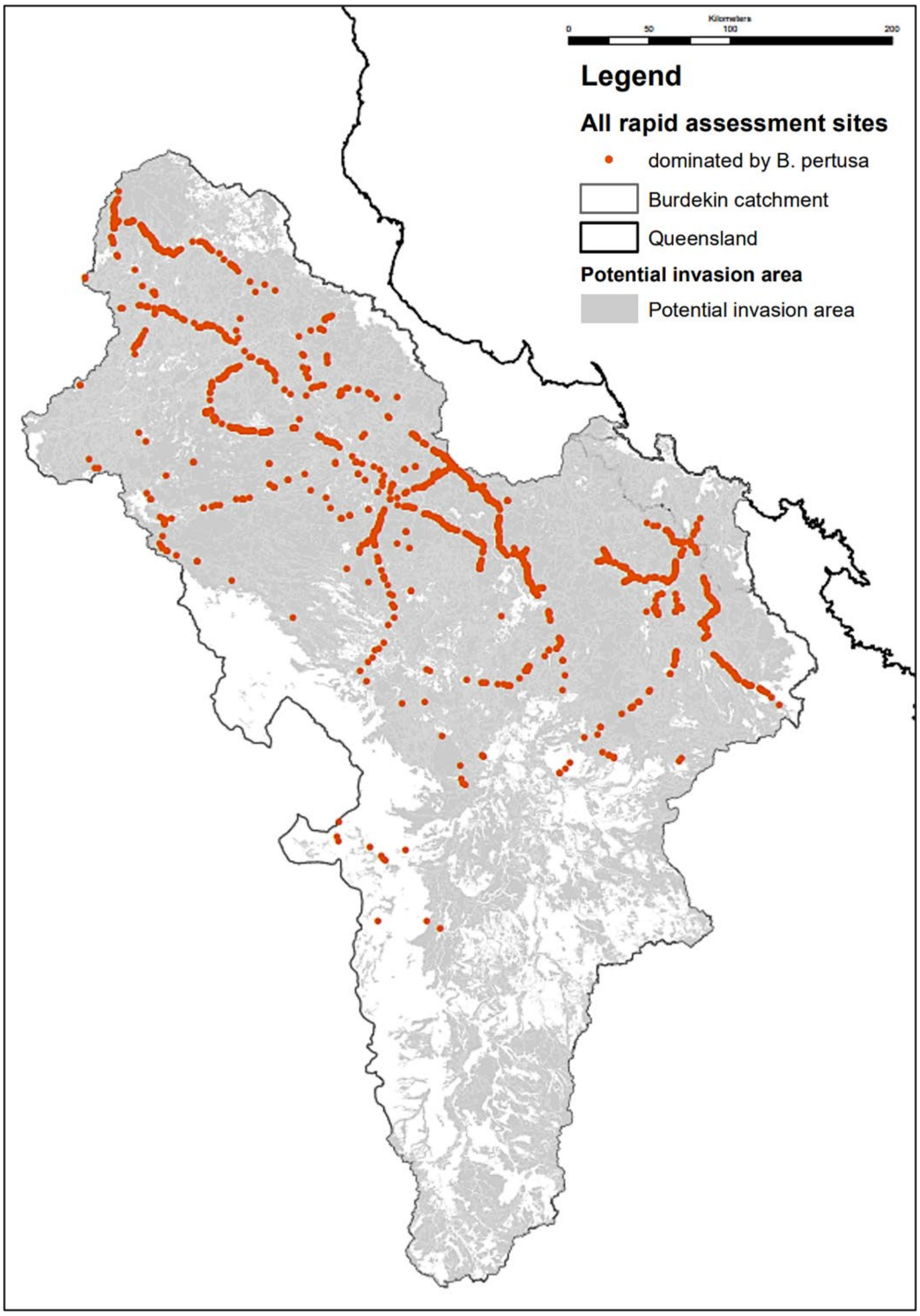


Figure 15. Core habitat distribution of Indian couch (*B. pertusa*) in the Burnett Mary catchment, as determined from road survey data of Indian couch presence/absence collected in 2021-22. White areas on the map are land types with extremely low data point numbers and any points indicated in the white area included isolated patches of Indian couch.

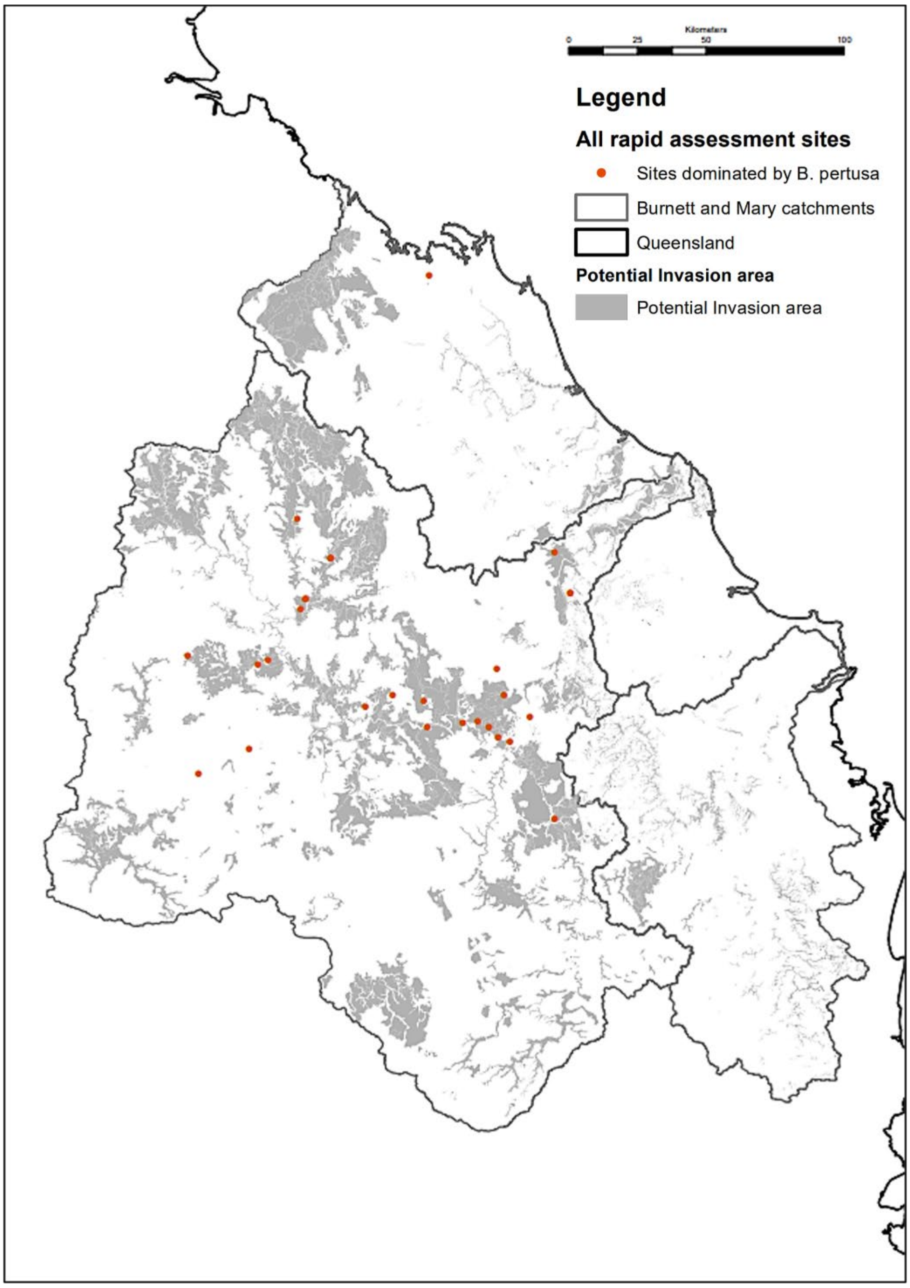


Figure 16. Core habitat distribution of Indian couch (*B. pertusa*) in the Fitzroy catchment, as determined from road survey data of Indian couch presence/absence collected since 2004 (sampling times: 2004-08, 2011, 2020-22). White areas on the map are land types with extremely low data point numbers and any points indicated in the white area included isolated patches of Indian couch.

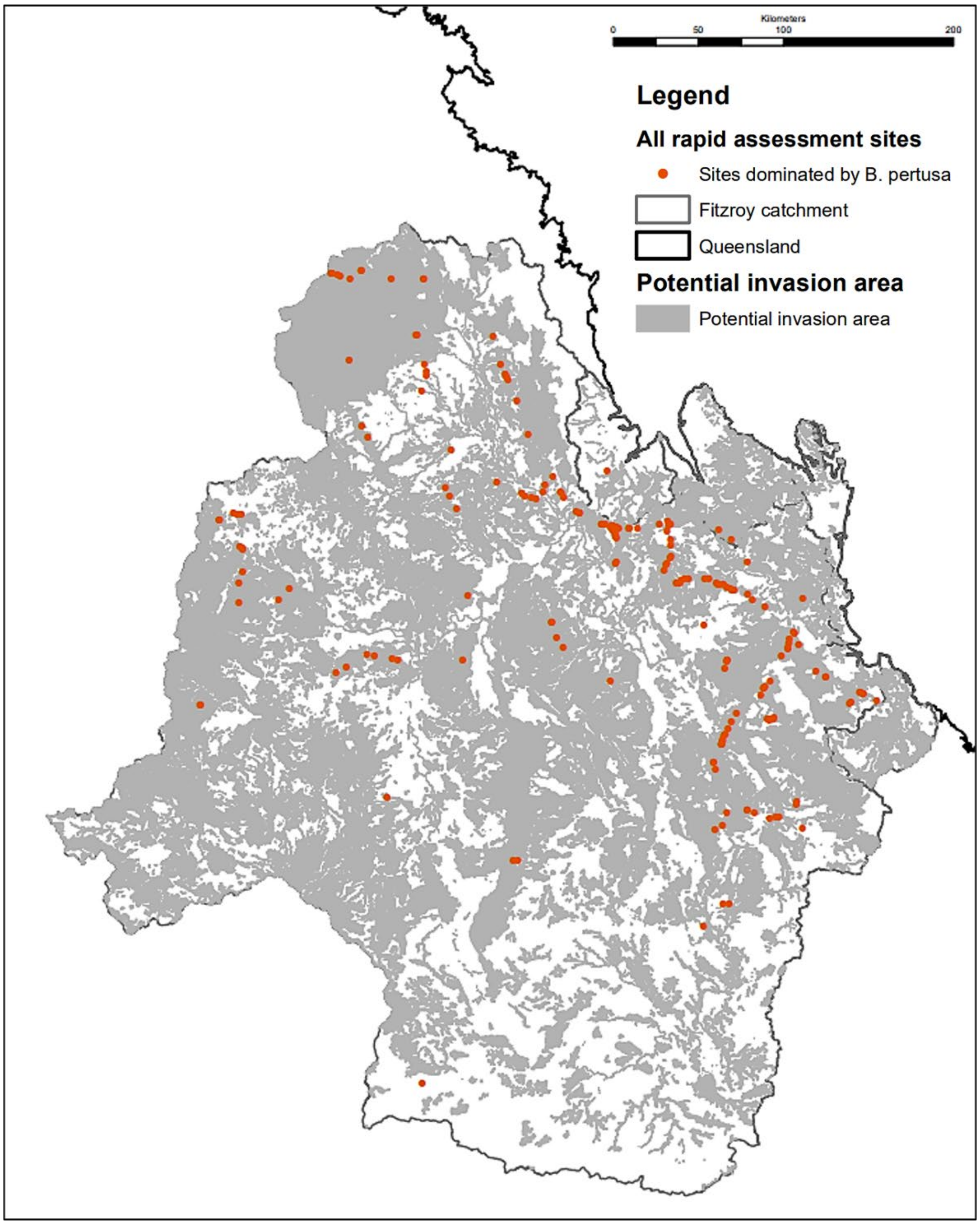


Figure 17. The level of dominance of Indian couch (*B. pertusa*) in grazing lands in eastern Queensland is shown according to sub-catchment, based on DAF data on Indian couch spanning 2004-08, 2011 and 2020-22 for the Burdekin and Fitzroy catchments and 2021-22 for the Burnett Mary catchment.

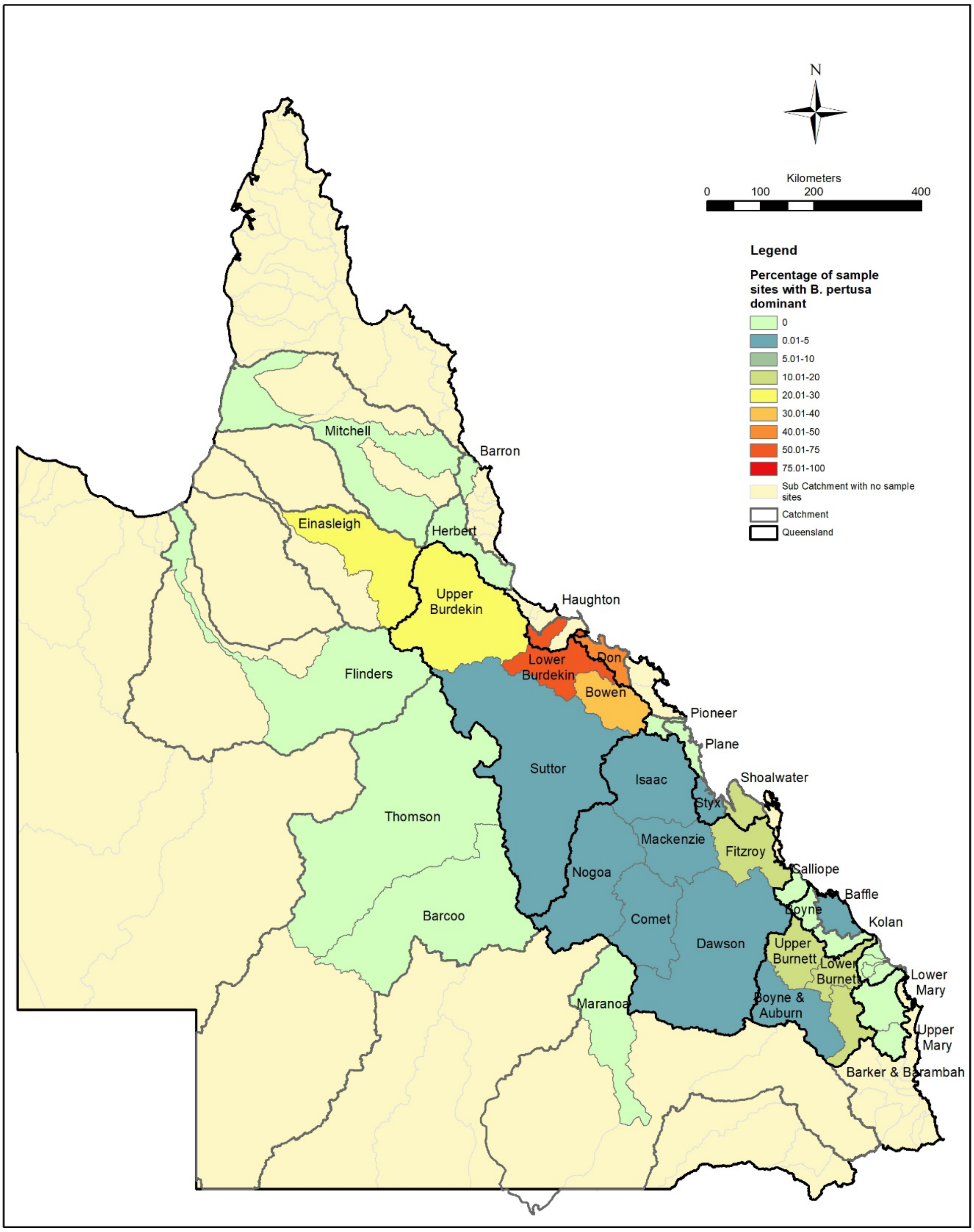


Figure 18. The likelihood (high, moderate, low, very low, unlikely) of Indian couch (*B. pertusa*) spread in grazing lands in the Burdekin catchment, based on DAF data on Indian couch spanning 2004-08, 2011 and 2020-22.

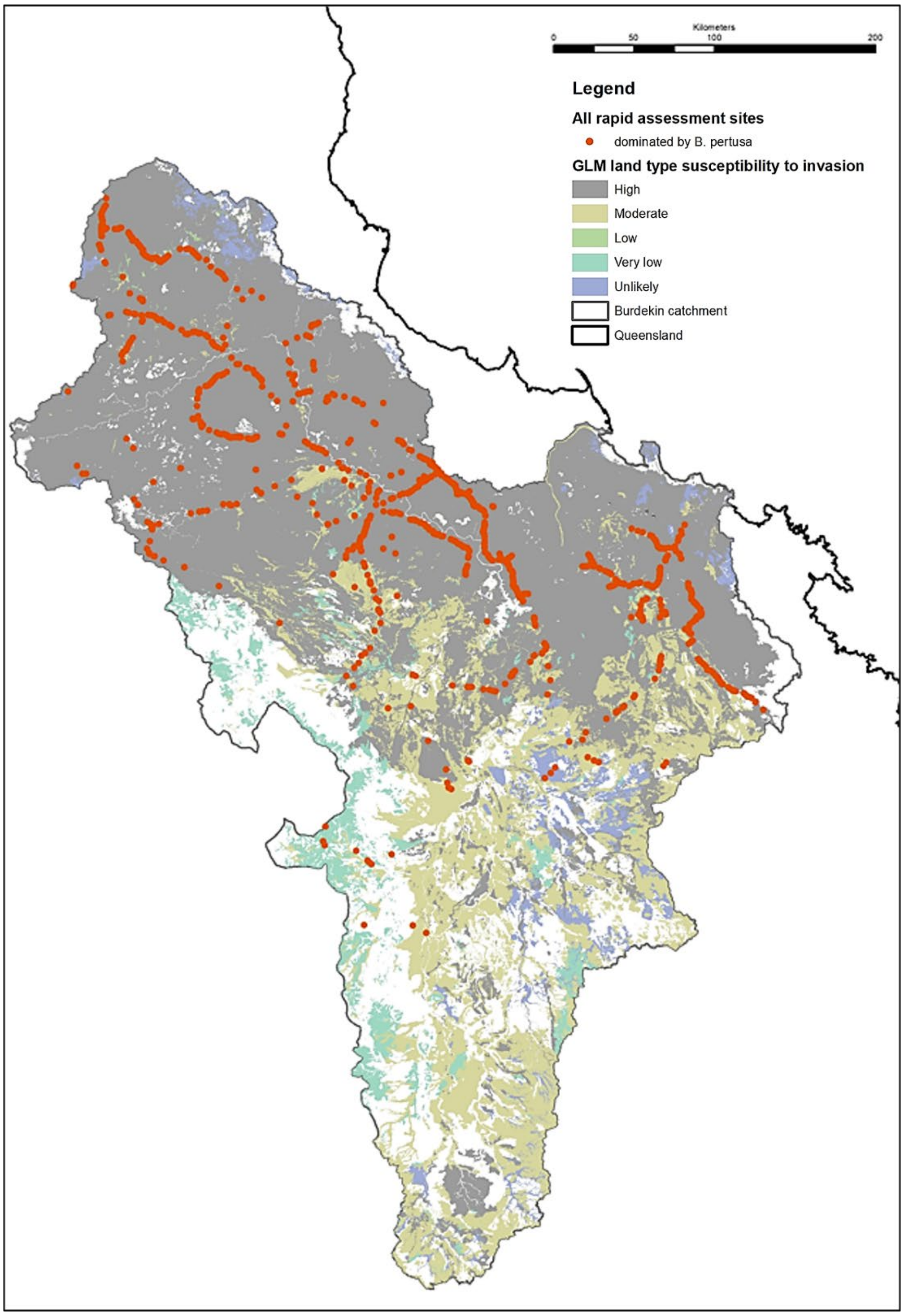


Figure 19. The likelihood (high, moderate, low, very low, unlikely) of Indian couch (*B. pertusa*) spread in grazing lands in the Burnett-Mary catchment, based on DAF data on Indian couch spanning 2020-22.

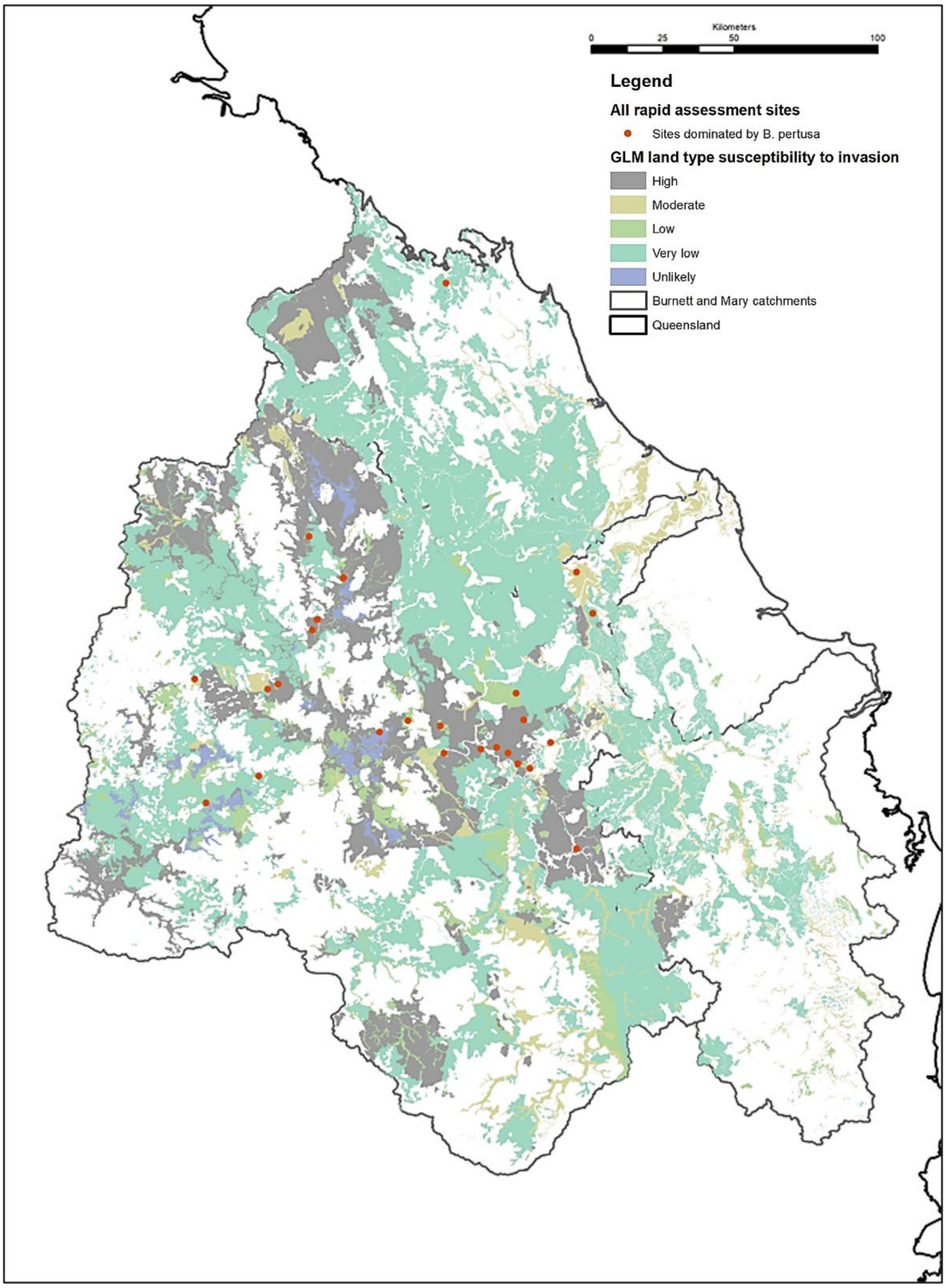
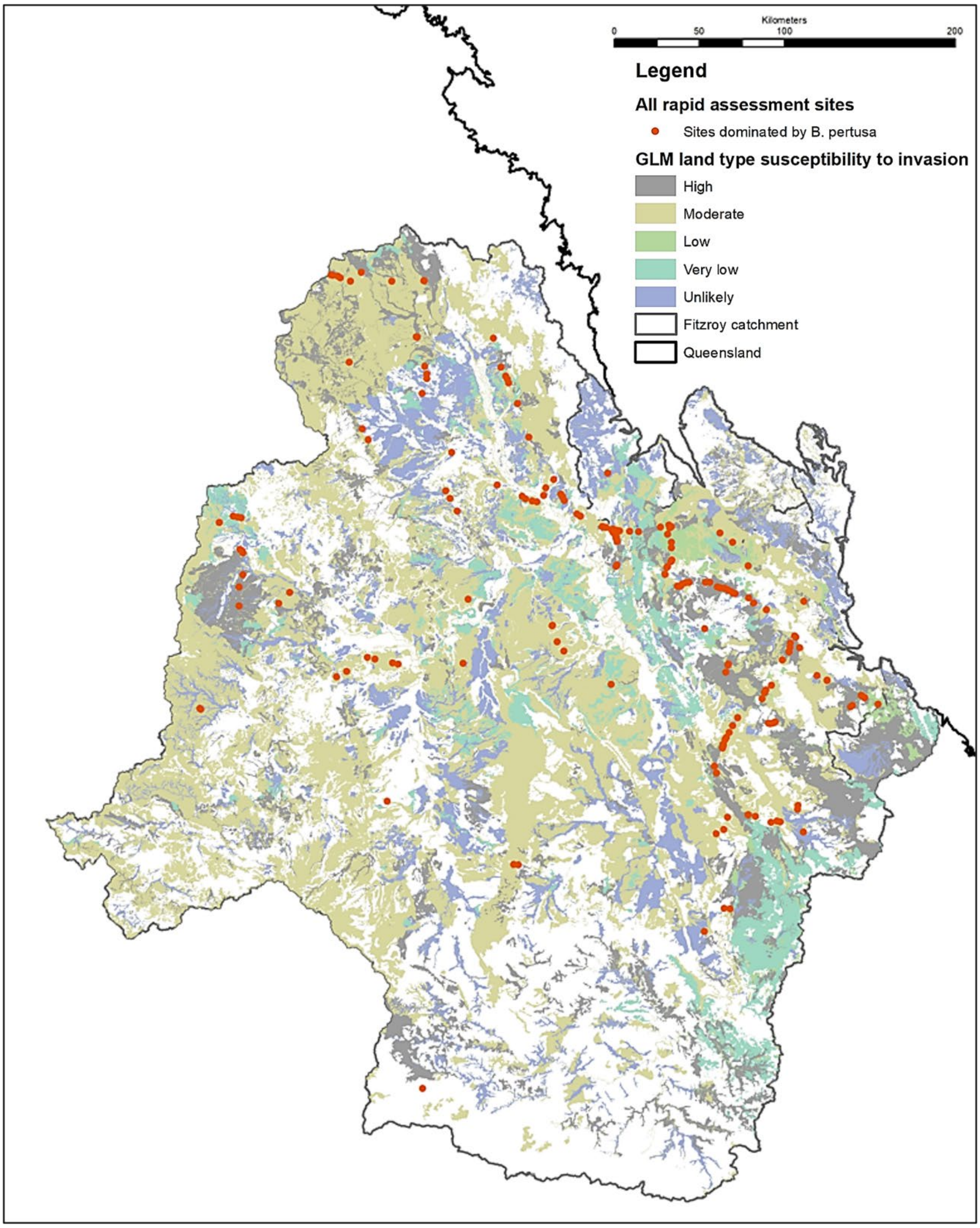


Figure 20. The likelihood (high, moderate, low, very low, unlikely) of Indian couch (*B. pertusa*) spread in grazing lands in the Fitzroy catchment, based on DAF data on Indian couch spanning 2004-08, 2011 and 2020-22.



2.4.3 Assessing the ability of satellites to detect Indian couch

Monthly time series analysis

Initial analysis of the time series shows how the photosynthetic (pv), non-photosynthetic (npv) and bare fractions vary through time (Fig. 21). This data shows that the Indian couch present and Indian couch absent sites have similar temporal patterns in fractional cover, and there is considerable overlap between their distributions. While some years show generally lower npv (i.e., dry vegetation) at Indian couch sites following the summer growth period, this is not a consistently strong pattern across the years.

Fig. 22 summarises this further, using a series of box plots to describe the distribution of a variety of time series statistics calculated from the fractional cover data for each point. For all fractions and metrics there is considerable, if not complete, overlap between the interquartile ranges for Indian couch present and absent sites indicating there is little separability in this data.

A one month lagged residual was also tested (see Appendix 9.3.1; Fig. 58), as anecdotally Indian couch has a more rapid green-up and dry-off phase than other species. However, little separability was demonstrated. In addition, and in case of the possibility of low-density Indian couch sites obscuring the pattern, the same analysis grouped by the Indian couch 'extent' classes was also carried out (see Appendix 9.3.2; Fig. 59). However, even when focussing on the higher density/extent classes, there is still insufficient separability in this dataset.

Figure 21. Patterns in fractional cover through time for photosynthetic (pv), non-photosynthetic (npv) and bare fractions according to Indian couch presence/absence. The ribbon is bounded by 20th and 80th percentiles, while the thicker line is the 50th percentile.

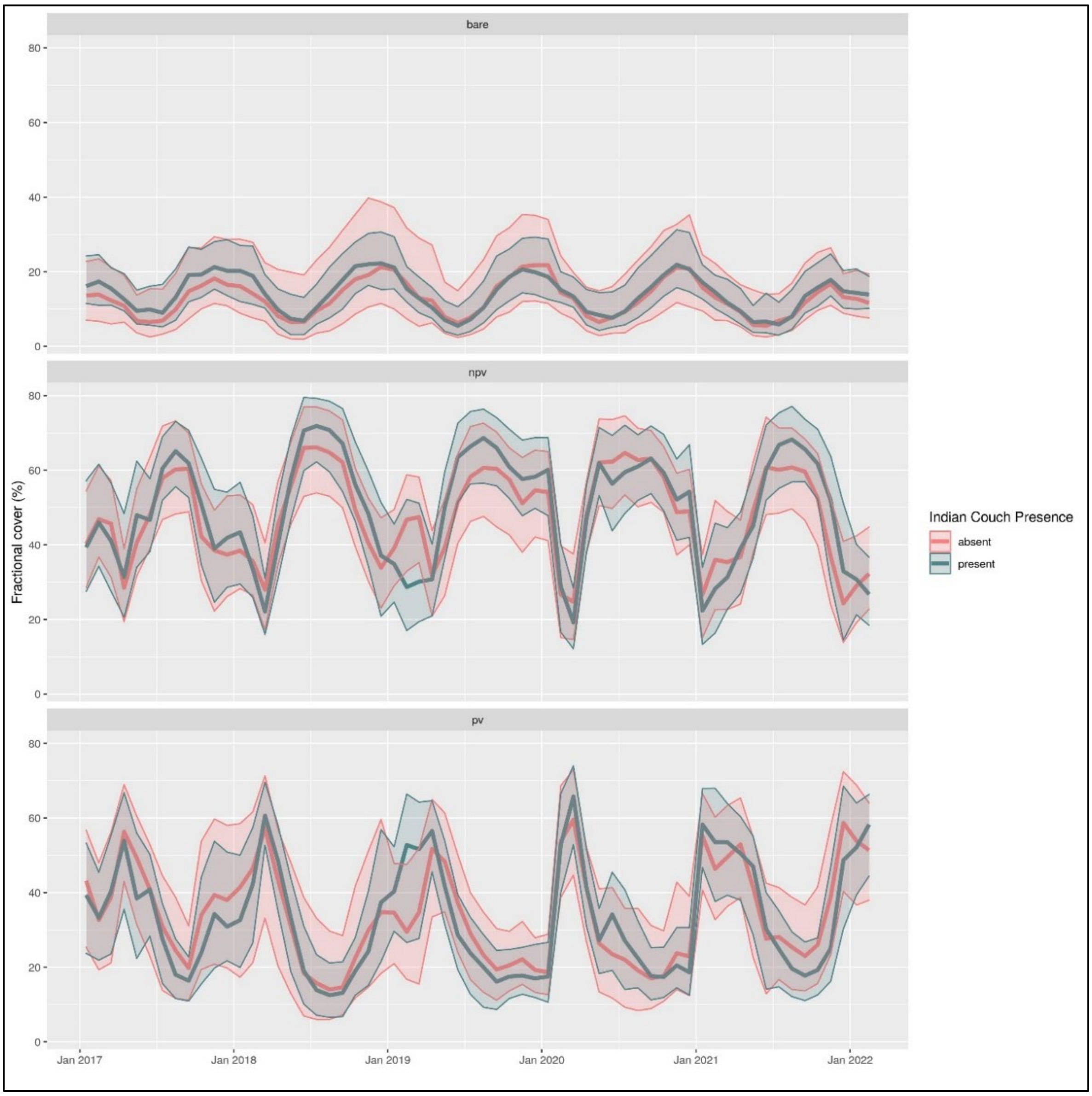
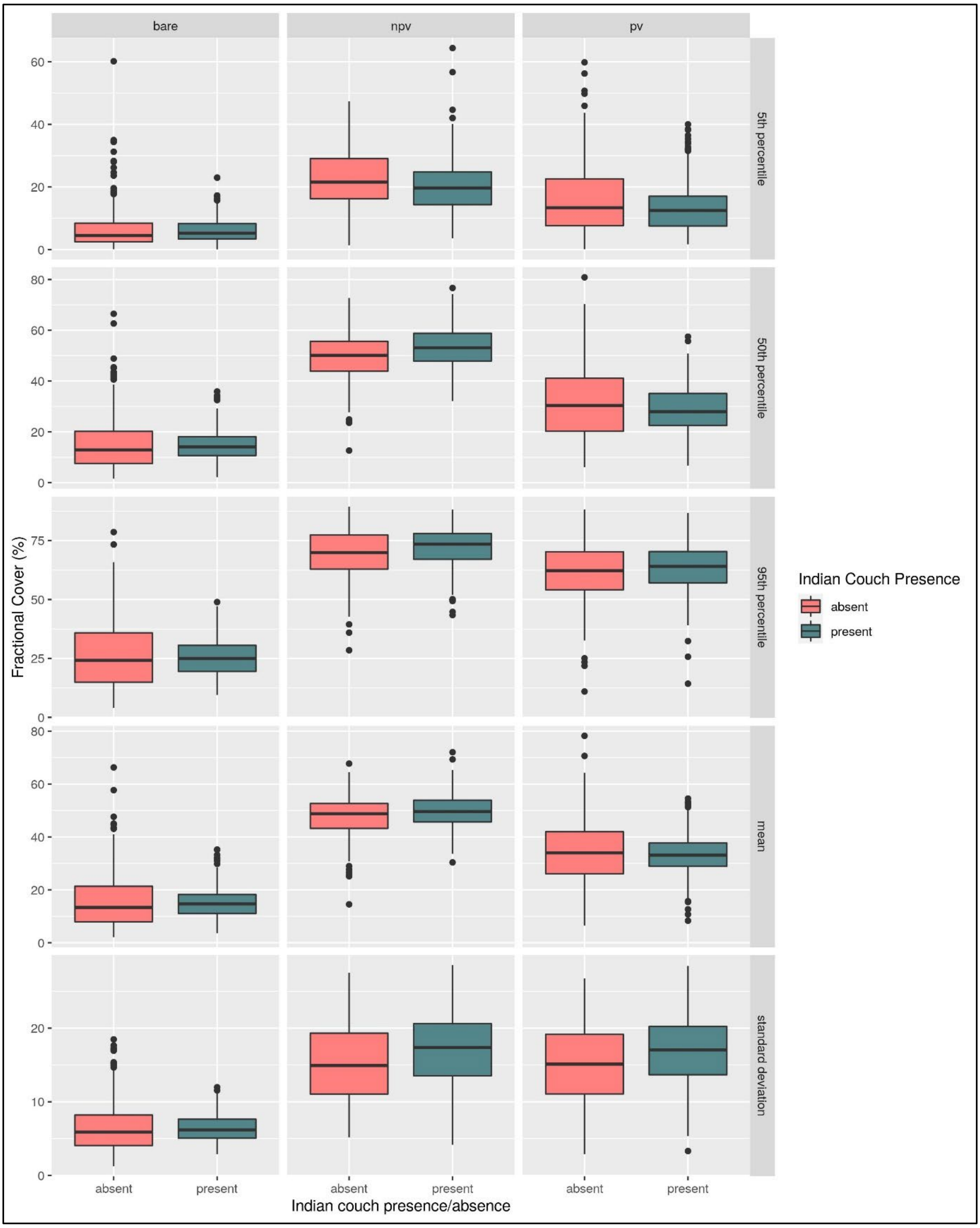


Figure 22. Box plots describing the distribution of a variety of time series statistics calculated from the time series of fractional cover data for each point. Cover fractions are arranged in columns from left to right, and statistics are arranged in rows from top to bottom. For all plots, the lower and upper bounds of the box indicate the 25th and 75th percentiles respectively, with the central line indicating the 50th percentile. The whiskers extend to the largest value within 1.5 x the interquartile range, and outliers are plotted individually. Cover fractions include photosynthetic (pv), non-photosynthetic (npv) and bare fractions.



Higher resolution analysis

As the analysis using a 50m buffer and monthly composite images was unsuccessful in separating Indian couch from other cover types, additional higher resolution analysis was carried out. As this analysis is data intensive, an individual Sentinel-2 tile was trialled: 56JLS, covering the Mundubbera and Gayndah area in the Burnett-Mary catchment, straddling the South-East Queensland (SEQ) and Brigalow Belt bioregions. To capture variability on a shorter timescale than monthly, single date Sentinel-2 fractional cover images were used, providing 10m resolution imagery between 1 January 2020 and 7 April 2022.

Although the satellite acquisitions occur approximately every five days, cloud and cloud shadow mean valid data is rarely available every five days. The buffer around the provided point (i.e., site location) was reduced to 15m, with the aim of achieving greater homogeneity at the site, where the larger 50m buffer would be more heterogenous at this scale of sensor resolution. However, analysis of some of the points indicated they had not been taken within the centre of the area of interest but instead closer to the road. The higher resolution analysis did not suggest any greater separability than the coarser resolution data (see Appendix 9.3.3; Fig. 60). It should be noted that there were many more absent (54) than present (22) sites in this sample.

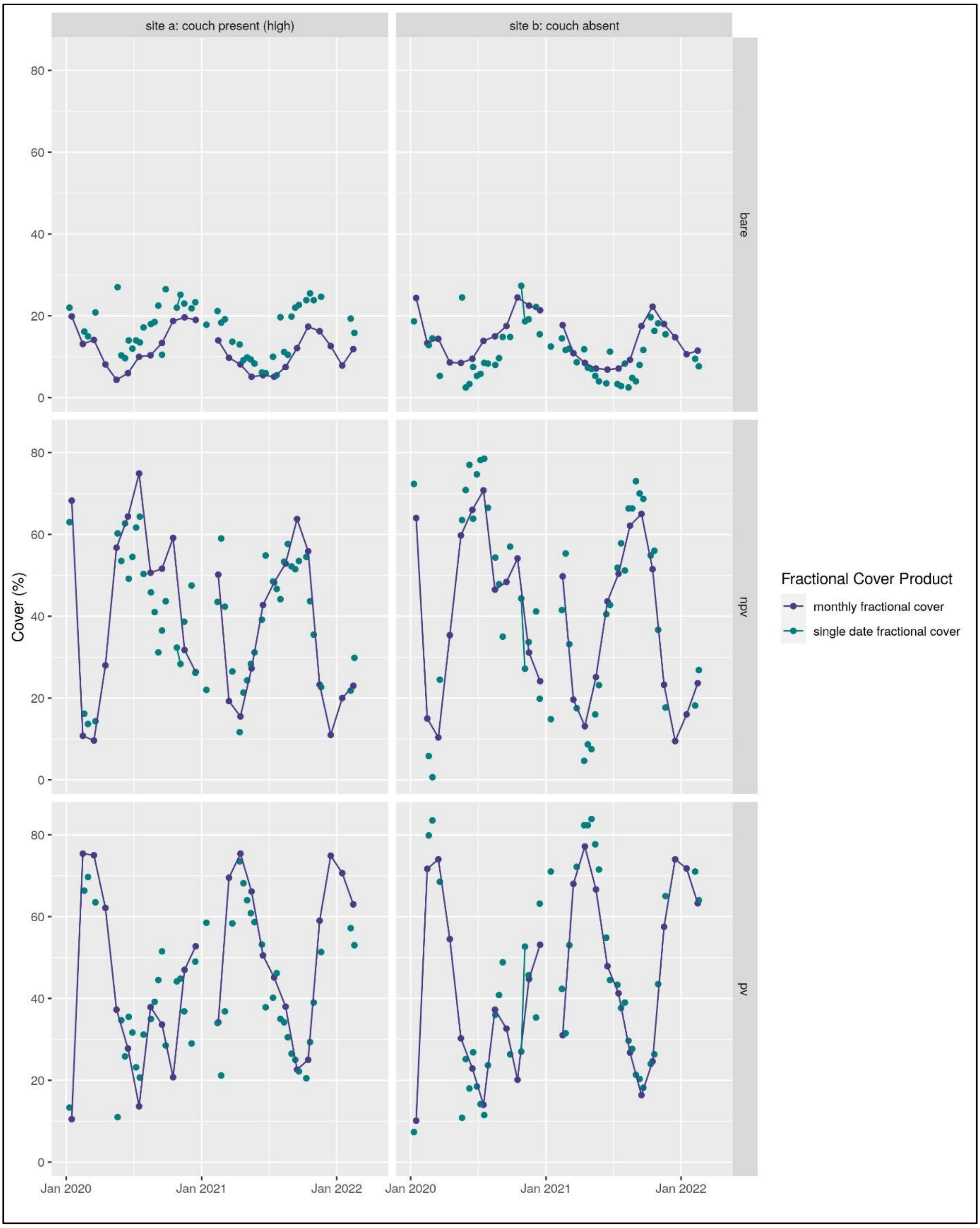
Analysis of two individual sites

The final analysis (Fig. 23) compared two 'paired' sites located near to each other, a 'high' density Indian couch site (site #402) and a non-Indian couch site (site #453). Due to their spatial proximity, they are likely to have similar soils and climatic variability. Unfortunately, despite different densities of Indian couch, their timeseries looked very similar. This plot also shows the differences between the monthly data and single date data. Monthly data gives fewer but more regular time steps. Individual date data gives many more data points and the potential to detect a rapid change in cover but includes outliers that are potentially undetected bad data (e.g., cloud contamination), and is also subject to more missing data and irregular time step. While the monthly data does 'smooth' the data and deals well with outliers, it is not unexpected that it does emulate the general trends of the single date data. This is because contamination or bad data in the single date data is still likely to be an exception, rather than a rule given the corrections and masking (i.e., for cloud, cloud shadow and water) that have been applied to the image datasets during pre-processing.

Future research approach

The remote sensing analysis of Indian couch was a preliminary investigation based on available resources. While the Indian couch presence/absence site data was a very useful dataset for initial investigation, these data were not captured with remote sensing validation as a primary purpose. One issue encountered was sites being sampled close to the road (i.e., within the road reserve looking into paddocks), and thus the results of the remote sensing analysis was confounded. For future purposes, a more suitable dataset would require more points, representative of all possible classes (including presence and absence of Indian couch in different vegetation types), seasonal conditions (i.e., wet and dry years), and more precise data on Indian couch density at a scale relevant to the satellite pixel size (Healy and Watson 2022). It would also be helpful to identify sites where Indian couch has been present for a long period (i.e., decades) compared to more recent arrivals.

Figure 23. Monthly and single date fractional cover for two individual sites: site a with high Indian couch (left panel) versus site b with Indian couch absent (right panel). The fractional cover products from top to bottom for each panel includes bare, npv (non-photosynthetic vegetation: dry cover and bare ground), and pv (photosynthetic vegetation: green vegetation).



2.4.4 Raising awareness

Background

Queensland producers will already be familiar with Indian couch or heard about it, as articles on the grass have featured in the Queensland Country Life; and at times in property sales writeups where descriptions of the property include information on pasture species (e.g., see Farm Weekly 2022). Many past articles (such as Farmonline National 2012; Queensland Country Life 2014) have been the focus of pasture rundown in sown pastures and the subsequent spread of Indian couch. Other articles have included producer views on the grass (such as Queensland Country Life 2015, 2020), shedding light on the spread of Indian couch in native pastures and the need for good pasture management that promotes evenness of grazing and keeps desirable native grasses healthy and competitive.

Project outcomes and reach statistics

The project used different approaches to raise awareness on Indian couch, including newsletter articles and social media – as detailed below, and radio interview (ABC 2021).

The first posting using social media was made on the FutureBeef website in April 2020 to outline the project (FutureBeef 2020). In July 2020, a posting went out on the Queensland Agriculture Facebook page (Appendix 9.4.1; Fig. 61) to spread the word about investment into understanding the spread and impact of Indian couch on grazing businesses. The Facebook posting generated a lot of interest for and against the research endeavour and highlighted the need for better understanding of Indian couch as a pasture pest species and poor grazing management as a catalyst for Indian couch spread (Queensland Agriculture 2020).

A second posting on the FutureBeef website went out in July 2021 (Appendix 9.4.1; Fig. 62) to raise awareness on the extent of Indian couch spread in eastern Queensland. Metrics and reach statistics were captured for this FutureBeef e-bulletin after the article ran for one week. Assuming each 'reach' or engagement counted was an individual, the calculated reach was 4,453 people, with better coverage received through Facebook when compared with Twitter and LinkedIn (Appendix 9.4.1; Table 24). At the time, current subscribers to FutureBeef e-bulletin included 6,174 people (Jodie Ward *pers. comm*.), and with 139 total clicks captured during a one-week period (Appendix 9.4.1; Fig. 63), indicates subscribers were viewing the article.

In summary, all approaches used to raise awareness have a wide reach. For instance, Queensland Country Life, being a major and long-running rural publication, has a reach specifically into agricultural communities and 89% reach to farmers nationally (Australian Community Media 2022). FutureBeef has a specific reach to the north Australian beef industry, via monthly newsletters (e-bulletins), as does the ABC radio's Far North and North Queensland Rural Report.

2.5 Conclusion

2.5.1 Key findings

Project findings show Indian couch is present in the coastal and sub-coastal grazing lands of the Burdekin, Fitzroy, and Burnett-Mary catchments. The risk of further spread of Indian couch into grazing lands in all three catchments exists, as Indian couch can be found along secondary and district roads throughout eastern Queensland, and across different land condition states (ABCD). Further research is warranted in investigating the relationship between the presence of Indian couch and pasture condition. Such investigations may also provide an opportunity to collect data more suitable for remote sensing validation purposes.

2.5.2 Benefits to industry

The spread of Indian couch in grazing lands in Queensland has, previously, not been formally documented on a large scale across multiple landscapes. The current project set out to formally document the occurrence, dominance and likely spread of Indian couch in Queensland, with a focus on three catchments: Burdekin, Fitzroy, and Burnett-Mary. A series of maps have been developed for the purpose of raising awareness and identifying to industry the current scope and extent of Indian couch in Queensland's grazing lands. The maps show the coastal and sub-coastal distribution of Indian couch in Queensland, highlight 'hot spots' for Indian couch, identify areas where further spread might be expected, and show areas in Queensland that are at risk of Indian couch dominance.

As a visual product, the project maps are an impactful and effective communication tool for raising awareness, along with provoking thought and consideration to the further spread of this grass.

3. Determining the impacts of Indian couch on production

3.1 Background

An earlier study carried out by Jones (1997) indicated that the presence of Indian couch in native pastures may not be a cause for concern, as the live weight gains of steers were comparable to those for native pastures under moderate and heavy stocking rate treatments. However, several producers regard Indian couch as a weak perennial grass and a risk to sustainability, particularly if long-term carrying capacities are not reduced in line with the decreased pasture yield caused by Indian couch (Lyons and Lyons 2016). In addition, over-sowing a relatively intact native pasture with Indian couch, as done by Jones (1997), is markedly different to the overgrazed, poorer condition, Indian couch invaded pastures typical of commercial paddocks. Jones (1997) also highlighted some producer anecdotes, with production differences for Indian couch compared with native pastures being of less concern in areas with reliable rainfall, but of more concern in lower rainfall areas. The order of magnitude of differences in production for Indian couch relative to other pasture species is also expected to be influenced by soil type and management.

In general, Indian couch is a moderately yielding grass (Cameron 2013) which can provide feed to cattle regardless of soil fertility, although its productivity can be improved through the incorporation of adapted legumes (Bisset 1980). Feedback from beef producers indicates a major setback with Indian couch was its reduced drought tolerance when compared to native grasses, making it a less reliable source of feed (Spiegel 2016).

Therefore, this activity aimed to build on existing knowledge and quantify production impacts associated with Indian couch invasion of native grass pastures. This required development of a better understanding and quantification of the impacts of Indian couch on the carrying capacity and finances of beef business. This was important for not only confirming producer anecdotes and to better inform Industry on the impacts of Indian couch in pastures, but also to justify management options for beef producers.

3.2 Objectives

Outputs: Quantification of the impacts of Indian couch invasion on carrying capacity and (modelled) animal production.
Outcomes: Increased awareness and understanding by producers on potential impacts of Indian couch on carrying capacity; by 2022, 70% of the producers in north and central Queensland will be aware of the extent of Indian couch spread.

3.3 Methods

Pasture productivity, long-term carrying capacity and profitability of Indian couch dominated pastures relative to native grass dominated pastures were assessed through four separate activities. These were:

- Comparison of pasture production of Indian couch dominated pasture and native grass dominated pasture at a number of sites in the Burdekin and Burnett-Mary catchments, using the SWIFTSYND method (Day and Philp 1997). This enabled comparison of the productivity of these two types of pastures over a range of soil and climatic conditions.

- Using results from the Burnett-Mary SWIFSYND sites, describe the relationships for height with biomass and cover with biomass in Indian couch and native grass dominated pastures. These can be used to improve simulations undertaken in the FutureBeef Stocktake and DES FORAGE applications.
- Collation of producer knowledge of the characteristics and production value of Indian couch.
- Bioeconomic modelling (BEM) of pasture productivity, herd productivity and profitability for a cattle property dominated by Indian couch relative to the same property dominated by native grasses.

The main findings from these combined activities were converted into key messages for Industry.

3.3.1 Sampling of 5 Indian couch and native pasture paired SWIFTSYND sites

To investigate the pasture production impacts of Indian couch, five native pasture and Indian couch 'paired' sites (19m x 19m) were fenced to exclude grazing. This included three pairings in the Burnett-Mary catchment and two paired sites in the Burdekin catchment, covering a range of soil types and geology. Detailed pasture measurements were collected over two years (2018/19 and 2019/20) as per the SWIFTSYND protocol (Day and Philp 1997).

Site descriptions are provided below according to catchment, followed by details of sampling.

SWIFTSYND sites sampled in the Burnett-Mary catchment

All three pairings in the Burnett-Mary catchment were established at the Brian Pastures Research Facility in the north Burnett, covering black basaltic soil ("Rons"), brown basaltic soil ("Bambling"), and gradational loam ("Lady's Mile") (see Fig. 24, 25 & 26, respectively). For each pairing, sites were adjacent to one another. This was possible, as pre-existing historical native pasture sites used by the project were surrounded by Indian couch dominated pasture that was then fenced off as separate sites.

Figure 24. Native pairing with Indian couch (*Bothriochloa pertusa* - BoPer) on a black basaltic soil at the Brian Pastures Research Facility (Rons site) in the north Burnett of Queensland. Sites were sampled over two consecutive years (Y1: 2018/19 and Y2: 2019/20). The photos show corresponding maximum standing biomass across sites and years. The dominant pasture species at the native site was Black speargrass (*Heteropogon contortus* – HeCon).

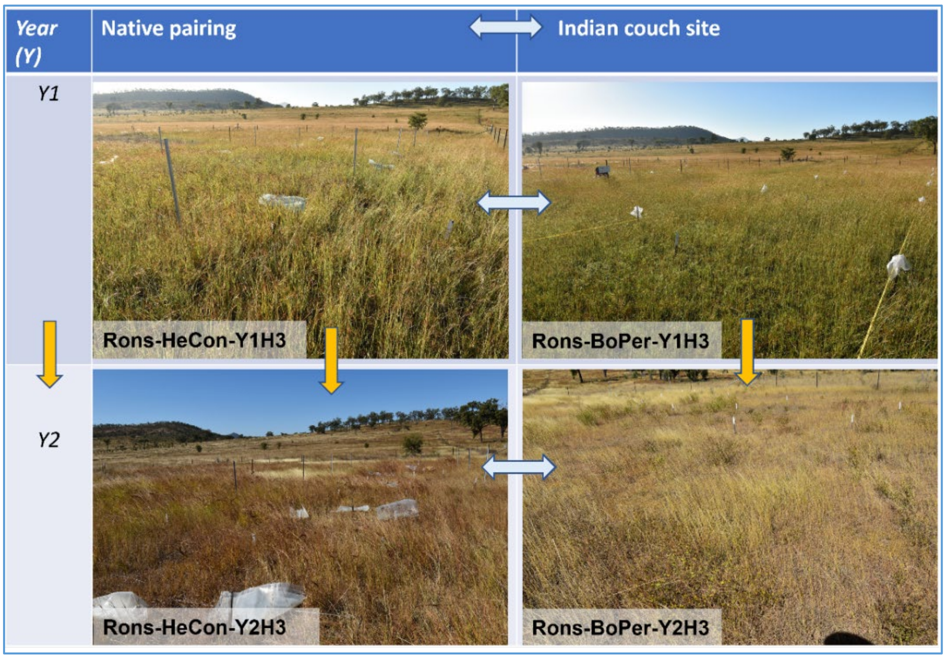
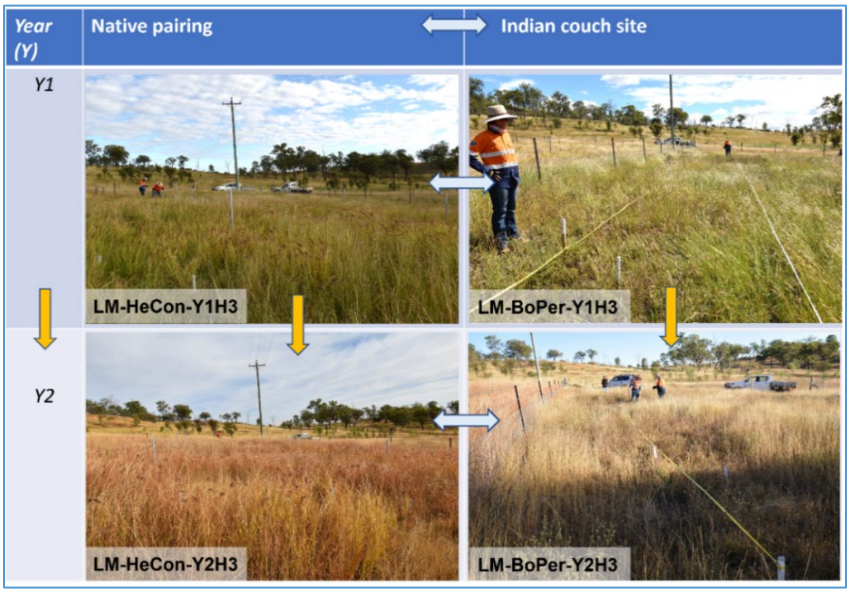


Figure 25. Native pairing with Indian couch (*Bothriochloa pertusa* - BoPer) on a brown basaltic soil at the Brian Pastures Research Facility Bambling (BAM) site in the north Burnett of Queensland. Sites were sampled over two consecutive years (Y1: 2018/19 and Y2: 2019/20). The photos show corresponding maximum standing biomass across sites and years. The dominant pasture species at the native site was Black speargrass (*Heteropogon contortus* – HeCon).

Figure 26. Native pairing with Indian couch (*Bothriochloa pertusa*, BoPer) on a gradational loam at the Brian Pastures Research Facility Lady's Mile (LM) site in the north Burnett of Queensland. Sites were sampled over two consecutive years (Y1: 2018/19 and Y2: 2019/20). The photos show corresponding maximum standing biomass across sites and years. The dominant pasture species at the native site was Black speargrass (*Heteropogon contortus* – HeCon).



SWIFTSYND sites sampled in the Burdekin catchment

For the Burdekin catchment, the pairings were established on sedimentary red earth (at Spyglass Beef Research Facility) and red basaltic soil ("Property #1") (see Fig. 27 & 28, respectively). At "Spyglass", sites were located within 3km of each other, and at "Property #1", sites were located ~100m to one another.

Figure 27. Native pairing with Indian couch (*Bothriochloa pertusa* - BoPer) on sedimentary red earth at the Spyglass (SG) Beef Research Facility. Sites were sampled over two consecutive years (Y1: 2018/19 and Y2: 2019/20). The photos show corresponding maximum standing biomass across sites and years. The dominant pasture species at the native site was Black speargrass (*Heteropogon contortus* – HeCon).

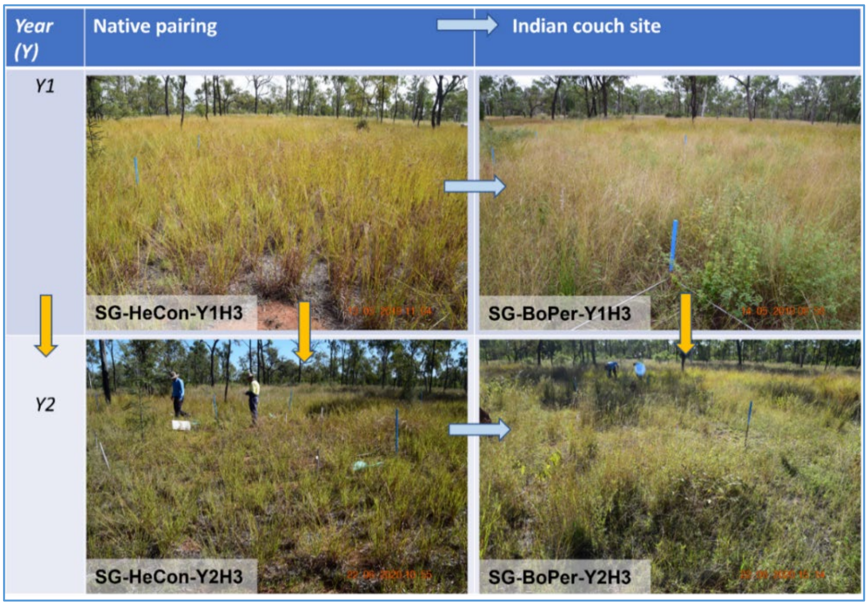
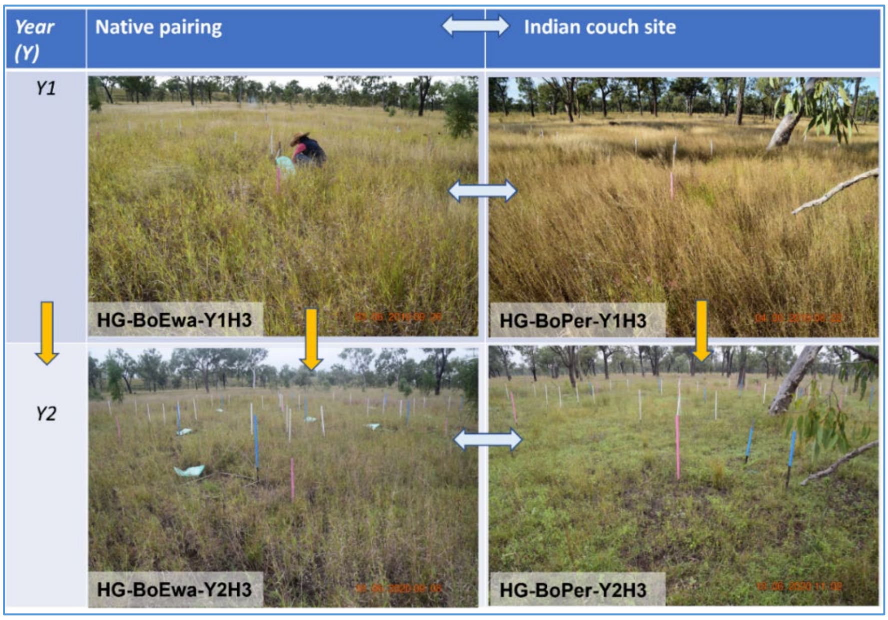


Figure 28. Native pairing with Indian couch (*Bothriochloa pertusa* - BoPer) on a red basaltic soil at Property #1 in north Queensland. Sites were sampled over two consecutive years (Y1: 2018/19 and Y2: 2019/20). The photos show corresponding maximum standing biomass across sites and years. The dominant pasture species at the native site was Desert bluegrass (*Bothriochloa ewartiana* – BoEwa).



SWIFTSYND protocol

The SWIFTSYND protocol (Day and Philp 1997) was used, as this is a protocol developed to allow calibration of the GRASP (Grass Production) model (Littleboy and McKeon 1997). This included four harvests spread across each year with no grazing for the purpose of measuring potential growth. To mimic grazing, 'regrowth' cuts were also taken at the second, third and fourth harvests. As such, at the second harvest, a recut of growth that occurred since the first harvest was made, at the third harvest a recut of growth since the second harvest was made, and at the fourth harvest a recut of growth since the third harvest was made.

Prior to commencing the first harvest for each sampling year, sites were 'reset'. The purpose of 'reset' is to remove all carryover pasture prior to each year's measurement of pasture growth. The reset method of choice should always favour, rather than inhibit, the growth of the pasture species being measured. For native pasture species sampled at the Brian Pastures Research Facility in north Burnett, prescribed fire is common practice and was adhered to by the project. For the native pastures at the Spyglass Research Facility and at "Property #1" in north Queensland, prescribed fire is not commonly adopted in contemporary pasture management, and thus, a cutting method deemed suitable for the specific type of grass was used for the reset of those sites. For "Spyglass" where the native site was Black speargrass, which has greater tolerance to defoliation compared with other native grasses, a mower was used as the cutting method. At "Property #1" where the native site was Desert bluegrass, a grass more susceptible to defoliation, a hedge trimmer was used to carefully reset this site. The reset of Indian couch sites involved using a mower (in north Queensland) or a slasher (in north Burnett).

During the 2-year study period, pasture measurements (called 'harvests') were taken at four strategic times during each year's growth:

- The first harvest (H1) took place ~6 weeks after the break of the season when the initial growth flush was peaking. Plant basal area (PBA) measurements were also taken at this time.
- The second harvest (H2) was timed towards the end of the wet season, around the general onset of pasture flowering.
- The third harvest (H3), also known as 'peak yield', was at maximum standing biomass – after the wet season rains had ceased, and timed ~3 months after H2.
- The fourth harvest (H4) was taken during the dry season, prior to the commencement of spring growth, and timed ~3 months after H3.

At each harvest, nine 1m^2 quadrats were harvested from each treatment in north Queensland, and in north Burnett ten quadrats were harvested from each treatment using 0.25m^2 for the Indian couch sites and 0.5m^2 quadrats for the native sites. During each harvest, measures were taken of pasture height, estimates were taken of cover (pasture, litter, bare, rocks), and pasture was sorted into five separate categories of plants: dominant species of grass, sub-dominant species of grass, other grasses, forbs (non-leguminous dicots), and legumes (leguminous dicots). The dominant category included the dominant pasture species sampled at the site. For an Indian couch site, Indian couch was the dominant grass. For the native grass site it was paired with, Indian couch was the sub-dominant grass, and vice-versa. All other grass species were cut into the 'other' monocot category. As for the forbs, these were either non-leguminous or leguminous. All plant categories were placed into plastic bags, fresh weights were taken for all individual samples, and representative subsamples taken from bulked categories for each site and oven dried at 80°C for 48hrs to determine the average dry matter content. Using fresh weights and average dry matter content, total biomass (i.e., total standing dry matter) for each site was calculated, as was the yield for each plant category contributing to total biomass. Dried plant samples were then sent to the DES Chemistry Centre for protein analysis.

Peak yields (H3: maximum standing biomass produced since 'reset') were used as a key indicator of pasture production, and relative differences between Indian couch and Native pasture were assessed. Results were presented as relative differences (%) for Indian couch. A t-test was performed to test the difference in biomass means for each of the five sites. As these tests were only performed using the four means (of quadrat data) for each year for each pasture type, the limitation of statistical power is recognised due to the low replication. To test the differences between native and Indian couch dominant pasture using data from all sites in the one analysis, an 'across sites' analysis was also carried out using the means and variance from each site. To gain an indication of the within site variability, 95% confidence intervals were calculated based on each site's quadrat data. T-tests using the quadrat data were done for indicative purposes only, as these quadrat data represent samples, not true replicates.

Level of success/efficiency of methodology employed

The SWIFTSYND protocol is a rigorous methodology that has provided the project with an important scientific approach for quantifying the pasture production impacts associated with Indian couch invasion in pastures. The three paired sites established and monitored in the Burnett-Mary catchment allowed for production differences to be tested across three difference soil types. The sites utilised here including historical native pasture sites (now dominated by Black speargrass) paired with well-established Indian couch dominant pasture, of strain most likely to be 'Emerald Downs'.

The two paired sites established and monitored in the Burdekin catchment allowed for production differences to be tested across two different pasture communities: Indian couch ('Bowen' ecotype) against Desert bluegrass on red basaltic soil, and Indian couch ('Bowen' ecotype) against Black speargrass on red sedimentary soil.

The SWIFTSYND style sampling approach enabled the comprehensive assessment of pasture biomass (and other pasture metrics) within a site. However, only one paired site could be established for each soil type. Hence for testing the differences in biomass (using peak yield) for each pasture type at each soil type, the values from the two years were required to be used as the replicate values. The 'across sites' analysis enabled the combining data from all soil types to test for differences in biomass between the two pasture types.

3.3.2 Ancillary data on Indian couch

The correlations between biomass and both height and cover for Indian couch pastures were assessed using site data from the Burnett-Mary SWIFTSYND sites described above. Separate correlations were developed for Indian couch and native pasture. The aim of this activity was to determine if relationships of height with biomass and cover with biomass differed depending on whether the site was dominated by Indian couch or native pasture. This will provide updated model parameters for use in simulations associated with the FutureBeef Stocktake and DES FORAGE applications.

Data in the Burnett-Mary was available from three locations referred to as Bambling, Ladies Mile and Ron's. At each location there was a site dominated by Indian couch and a site dominated by native Black speargrass (HeCon) pasture. Data were collected on eight occasions: two years with four harvests each year. The data values analysed were an average of 10 quadrat measurements. As the sampling process was destructive (i.e., pasture was cut), a different 10 quadrats were assessed at each harvest. Prior to cutting, cover estimates were made and pasture height was measured using a pasture height meter as per the methods described by Day and Philp (1997).

The relationship with TSDM was considered for three variables: grass cover % (calculated as the sum of green % and dead %), botanical cover (calculated as the sum of green %, dead % and litter %) and plant height values. The relationship between cover and TSDM and between height and TSDM for the Indian couch and native species was investigated using grouped linear and exponential regression. The most appropriate regression was assessed by considering the residual plots, the adjusted (adj) R^2 value and the significance of the regression terms. The adj R^2 value indicates the percentage of variability explained by the model (and is listed for both forms of the equations). All analyses were completed in Genstat v22 (VSN International, 2022).

Level of success/efficiency of methodology employed

A key growth attribute of Indian couch is the ability of this grass to take on two different growth forms: upright and stoloniferous. The site data from SWIFTSYND work generated by the project allowed for an assessment of the growth habit of Indian couch relative to native pasture species. This was carried out using an analysis of the height to mass and cover to mass relationships of Indian couch relative to native pasture. The site data used was from the Burnett-Mary sites, being specific to the eco-strain of Indian couch found there. This included three pairings of Indian couch relative to native Black speargrass across three soil types.

3.3.3 Producer feedback

As per section 1.3.2, producer knowledge was collected by various means, including during a scoping study in 2015 (Spiegel 2016), DAF information days in central Queensland in 2017, and during project stakeholder group meetings (2019-2021). Additionally, a producer questionnaire (Appendix 9.1.4), focussed specifically on Indian couch palatability and cattle grazing preferences, was implemented in the Burnett-Mary catchment. All these occasions provided opportunities to collect information from producers on their experiences and knowledge of the production value and production characteristics of Indian couch. The producer knowledge was compiled and reviewed, and key findings identified.

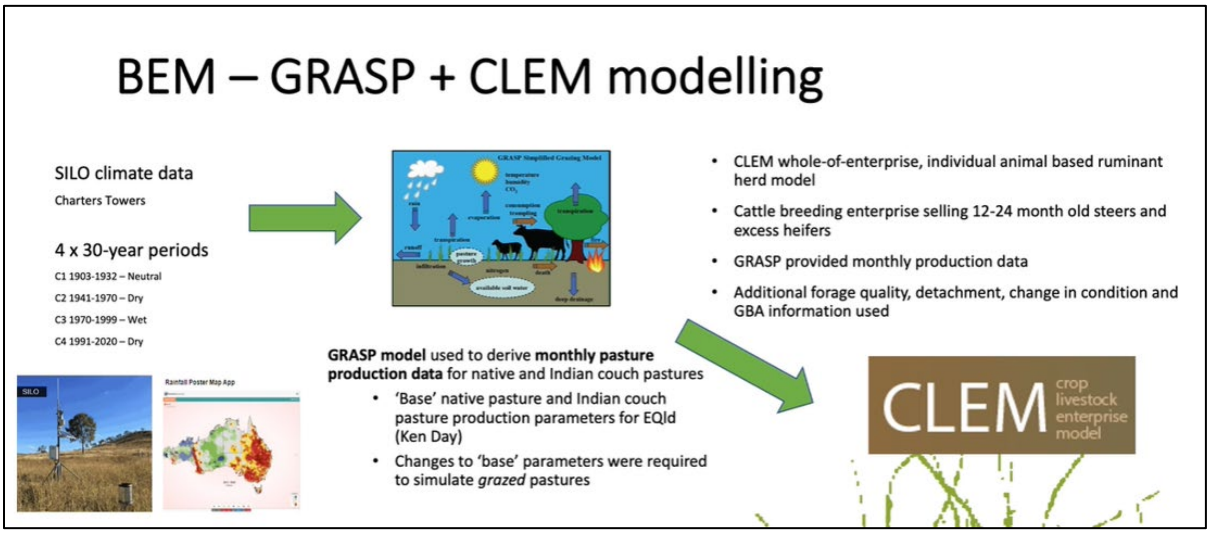
Level of success/efficiency of methodology employed

The project was able to obtain comprehensive producer perspectives on the production value of Indian couch, and on Indian couch palatability and grazing preferences of cattle.

3.3.4 Modelling the impacts of Indian couch invasion on production and enterprise profitability

A bioeconomic modelling (BEM) framework was used to quantify the impacts of Indian couch invasion on the carrying capacity and animal production for a representative beef grazing property in north-eastern Queensland. The BEM framework, consisting of the GRASP pasture and animal production model and the Crop Livestock Enterprise Model (CLEM), is shown in Fig. 29.

Figure 29. The bioeconomic modelling approach used to quantify the potential impacts of Indian couch invasion on pasture and animal production. This work was presented at the Australian Rangeland Society 21st Biennial Conference in Longreach, 4th-8th October 2021.



The empirical, point-based native pasture GRASP model was used to determine the impacts of grazing pressure, climate, and pasture condition on native and Indian couch pastures of northern Australia. Growth of pasture is a function of soil water, potential growth rate, transpiration, nitrogen availability, temperature and tree competition (Day and Philp 1997). Pasture growth in summer rainfall environments is either limited by moisture or soil fertility, primarily nitrogen (McKeon et al 2000). Standing pasture yield is the net result of the processes of pasture growth, death, detachment, consumption and trampling (McKeon et al 2000). The model simulates soil water balance through separate processes of soil evaporation, pasture transpiration (Rickert and McKeon 1982), tree transpiration (Scanlan and McKeon 1993) and runoff (Scanlan et al 1996a). Rainfall is partitioned into infiltration and runoff using functions that relate runoff to surface cover, soil moisture and rainfall intensity. Runoff is calculated and then any rainfall that exceeds predicted runoff is infiltrated into the soil profile.

CLEM is a whole-of-farm enterprise model that can test a range of farm improvement strategies in both crop and livestock systems while tracking impacts on finances, natural resources, and highly constrained resources such as labour (Meier et al 2019). To achieve this, CLEM expands upon the approaches used by its precursors, the Integrated Analysis Tool (IAT) and NABSA (Northern Australian Beef Systems Analyser).

The CLEM model is provided within the APSIM NG (Agricultural Production Systems sIMulator Next Generation) framework (Holzworth et al 2018), thus providing a modern object-orientated and event-based programming environment. The APSIM NG user interface consists of a tree structure that contains the model components needed for simulation, with CLEM providing a suit of additional components (Meier et al 2019). In CLEM, resources are the assets available for use on the farm and can include land, labour, crops, forage resources, livestock, and cash. Ruminant nutrition and growth are based on the Nutrient Requirements of Domesticated Ruminants (Freer et al 2007). CLEM includes an individual animal-based ruminant herd model which operates on a monthly time step. Data files containing crop and forage yields derived from other simulation activities can be used as input to CLEM.

In this BEM study a range of land conditions (0-11), grass basal areas (1 to 9%) and stocking rates (1 to 50 AE/100ha) were run in CEDAR GRASP (version 030420) using the CEDAR default parameter file (cedardefault_v_2_1_02) to provide monthly pasture growth data for use in CLEM. Additionally, forage quality, detachment, and change in land condition and grass basal area parameter values were provided for use in CLEM.

In brief, this BEM approach involved:

- Using 'base' parameters for pasture growth of *ungrazed* native and Indian couch *treeless* pastures developed by Ken Day (DES);
- Further parameterisation of the 'base' parameter sets to enable simulation of grazed pastures in GRASP;
- Developing forage quality functions and detachment, grass basal area and pasture condition responses to grazing pressure for use in GRASP and CLEM;
- Use GRASP to simulate monthly pasture growth data for use in CLEM;
- Using monthly pasture growth data to run herd simulations in CLEM; and
- Capture of CLEM simulation herd and financial outputs.

GRASP parameterisation

For the project to conduct the required simulation modelling, it was necessary for GRASP to be calibrated to represent native and Indian couch pastures. This commenced with base parameter sets for Indian couch and native pasture developed by Ken Day, Science Leader at the Climate Variability Unit, DES. These base parameter sets did not include grazing and the impact of grazing on pasture growth.

Base parameter sets

Ken Day (DES) developed native pasture parameter sets both for individual pasture communities in eastern Queensland, and for eastern Queensland as a whole, using historical GUNSYND and SWIFTSYND site data (Day 2020). A total of 38 pasture production sites were used for developing 'average' native pasture parameter sets for eastern Queensland and communities therein. Native pasture parameter sets were modified to produce comparable Indian couch parameter sets. Adjustments made to the native pasture parameter sets were based on previously calibrated Indian couch sites in northern Queensland (four sites), with particular attention given to the historical native pasture/Indian couch fence line comparison studied at Kirk River/Silver Valley (M. McCaskill and R. Rebgetz unpublished).

Parameter values for the eastern Queensland parameter sets were then revised by Ken Day based on understanding gained from the long-term simulations [Ken] carried out. Simulation studies were conducted at five locations, representing a range of rainfall/climate regions across *Black speargrass* and *Aristida Bothriochloa* pasture zones in eastern Queensland. Three sub-coastal locations were chosen within the Black speargrass zone: (1) Brian Pastures near Gayndah (Southern Speargrass community); (2) Rockhampton (Central Speargrass community); and (3) Charters Towers (Northern Speargrass community). A further two locations were chosen within the *Aristida-Bothriochloa* zone: (1) Emerald (Central *Aristida-Bothriochloa* community) and (2) Roma (Southern *Aristida-Bothriochloa* community).

Revisions carried out by DES were made to the nitrogen parameters, sensitivity to soil water deficit, potential regrowth rate per unit basal area, proportion of dead leaf/stem detached per day over wet/dry season, and soil water parameters.

The two 'base' pasture growth parameter sets developed for treeless, native and Indian couch pastures of eastern Queensland were provided to DAF (as MRX files) to facilitate regional-scale modelling of potential production impacts of encroachment of Indian couch into native pastures.

Adjustment of base parameter sets to include grazing

The 'base' parameter sets were further parameterised to enable grazed pastures to be simulated in GRASP. Literature, site data and expert opinion was used to define the parameters associated with grazing, which included consumption by animals; detachment and trampling; and risks of degradation. The key parameter changes needed to enable grazing of pastures for BEM study are summarised below.

Pasture utilisation: The 'safe' utilisation rate of 25% for native pastures used in this study is representative of the moderate productivity land types in the Burdekin region (see State of Queensland 2019). The 'safe' utilisation for the stoloniferous Indian couch grass was estimated following consultation with GRASP modelling colleagues, and consideration of the high level of utilisation (>65%) of Indian couch after which intake declined (Poppi 2011). In this study, the 'safe' pasture utilisation for Indian couch (35%) was 40% higher than that of native 'safe' pasture utilisation (25%).

Animal intake: Feed intake and quality of diet are critical determinants of animal growth. In GRASP, the potential liveweight for each season is used to determine potential animal intake. Data from the Wambiana trial (Scanlan et al. 2014) and dry matter digestibility and % nitrogen studies (Benvenutti et al 2011, Jones 1997, Poppi 2011) were used to estimate the parameter values for potential liveweight for each season.

Potential intake can be reduced under two possible circumstances. First, intake restriction can occur when there is reduced opportunity for diet selection with increased stocking rate or long durations of grazing e.g., year-round (McKeon and Rickert 1984). Secondly, intake can be reduced when total standing dry matter declines to a minimum threshold.

The default GRASP parameters that simulate the relationship between intake and pasture utilisation were used for both native and Indian couch pastures for this BEM work. Data from a study investigating the effects of species composition and sward structure on the ingestive behaviour of cattle and sheep grazing a low-quality South African grassland (O'Reagain et al. 1996) and data from "Property #1" paired SWIFTSYND sites, were used to determine the pasture yield limitations on intake for native and Indian couch pastures. The South African study found sward structure had a major effect on ingestive behaviour, with bite rates and grazing time negatively correlated with plant height, and bite size and hence intake rate strongly correlated with plant height. Intake restriction for cattle is likely to occur at plant heights of 5-7 cm (Peter O'Reagain *pers. comm*.). For this BEM study, the pasture yield at which intake restrictions no longer operate were set to 300 kg/ha DM for native pastures (Ash et al. 1982) and 700kg/ha for Indian couch pastures estimated for plant height of 5cm.

The influence of forage quality on animal growth is indirectly simulated in GRASP by capturing seasonal effect on diet quality by using potential liveweight for each season (91 days) to determine potential animal intake (McKeon and Rickert 1984). However, the direct influence of forage quality on animal growth can be simulated in CLEM. The CLEM default forage quality parameter values were used for native pastures. Based on dry matter digestibility, % nitrogen studies (Benvenutti et al 2011, Jones 1997, Poppi 2011) and project study data, Indian couch pastures were estimated to have a higher initial nitrogen content and higher monthly loss of nitrogen than native pastures.

Detachment & trampling rates: the detachment rates for grazed native pastures were as provided in the 'base' parameters sets with a uniform rate (0.003 g/g/day) throughout the year. However, it was considered that the detachment rates for grazed Indian couch pastures should be, relative to native pastures, increased to reflect a shorter-lived perennial with reduced drought tolerance. Detachment rates of 0.0032 g/g/day from grazing trials in Barkly Tablelands and Victoria River Downs (Cowley 2017) provided guidance for the detachment rates used for grazed Indian couch pastures.

Pasture degradation: Increased grazing pressure has several effects on pasture production including: (i) reduction in grass basal area, (ii) reduction in photosynthetic area which reduces future pasture growth, (iii) changes in pasture composition (e.g., percent perennials) is affected by heavy grazing of live tissue resulting in loss of perennial species and replacement by annuals with less production and faster senescence, and (iv) increased runoff due to reduced surface cover and fewer preferred infiltration sites e.g., areas occupied by perennial tussocks.

The productivity of native pastures in north-eastern Queensland is strongly and positively correlated with the percentage of perennial grasses in the pasture. In GRASP, the percentage of perennial grasses is a function of pasture 'state,' where pristine land at State 0 has 90% perennial grasses, and degraded land at State 11 has 1% perennial grasses (Scanlan et al. 2014). There is a dynamic link between pasture State and parameters that drive pasture growth in the GRASP model. The pasture utilisation rate determines pasture State. At the 'safe' utilisation rate, the simulated percent of perennial grasses or State does not change. At higher utilisation rates, the percent which is perennial grasses declines and pasture State increases, whereas the opposite occurs at lower utilisation rates.

The safe utilisation rates used for native pastures (25%) and Indian couch pastures (35%) for BEM were described above. The rates of change in condition State for native pastures were based on the Wambiana grazing trial (Scanlan et al. 2014). The rates of change in condition State of Indian couch pastures used in this study were estimated to be less relative to native pastures and are reflective of a species that is more tolerant than native grasses to heavy grazing (e.g., Howden 1988; McKeon et al. 1990; Scanlan et al. 1996a; Spiegel 2016).

GRASP simulations

Four, 30-year climate periods were selected to investigate the potential production impacts of Indian couch grass invasion over a range of seasons and climate cycles. The selection of climate periods was based on the "Queensland's extended wet/dry period" history of rainfall and drought sequences relative to Queensland over the last ~130 years (see https://www.longpaddock.qld.gov.au/rainfall-poster/map-app/). This data classifies 'years' on whether they are 'El Nino', 'La Nina' or ENSO Neutral years. El Nino- and La Nina-year classifications are based on values of the Southern Oscillation Index (SOI) between June and March. El Nino is generally associated with extended drier periods, whilst La Nina with extended wetter periods. Of the selected 30-year periods, whilst two had wet starts and two had dry starts, overall, there was a C1 "Neutral" (1903-1933), two C2 (1941-1970) & C4 (1991-2020) "Dry" and one C3 (1970-2001) "Wet" period for use in simulations.

GRASP simulations of native and Indian couch pastures for the four 'Neutral', 'Wet' and 'Dry' (2) 30-year climate periods using historic SILO climate records (Jeffrey et al. 2001) for Charters Towers were run to derive monthly pasture growth data for use in CLEM. The pasture production data was simulated for a range of land conditions (0-11), grass basal areas (1 to 9%) and stocking rates (1 to 50 AE/100ha) using CEDAR GRASP (version 030420) using the CEDAR default parameter file (cedardefault_v_2_1_02). All simulations were assuming treeless pastures.

CLEM parameterisation

The version of CLEM used for this study was APSIM_2021.07.08_6612. The ApsimX file used for simulation in this study was parameterised to represent a typical cattle breeding property north-east of Charters Towers, as described by Thomson et al. (2020).

Representative property

The representative property was a family run breeding enterprise consisting of 41,277 ha. The property had perennial pastures that included native grasses such as Black speargrass (*Heteropogon contortus*) and Kangaroo grass (*Themeda triandra*) and introduced grasses such as Urochloa and Buffel grass (*Cenchrus ciliaris*). Indian couch (*Bothriochloa pertusa*) was encroaching onto areas of the property.

The herd genetics were around 80 per cent *Bos indicus* with a mixture of Brahman, Droughtmaster and Santa Gertrudis breeds. This property supplied 9-month, 200 kg weaners for growing out on other family properties. Weaner cattle were removed from their main breeder herd in late September to early October. Cull cows were sold at 10 years of age, if dry, averaging 580 kg live weight at sale. Weaner heifers were retained as replacements, which were segregated to allow targeted yearling joining of those that had reached puberty at approximately 18 months or 325 kg live weight. Loose lick rations were used flexibly on the property based on the season and the condition of the cows. Dry season licks started with a 30% urea loose lick reducing to 22-24% urea pre-calving, and phosphorus was increased. This strategy was used to prepare cows for calving and lactation. Typically, the case study property ran 3400 head or 3040 AE of cattle.

Breedcow & Dynama software (State of Queensland 2020) was used to generate the composition of the Charters Towers, Burdekin representative herd (described above) for use in CLEM simulations. The starting representative 3040 AE herd consisted of 1515 weaners, 263 one-two years old heifers, 255 two-three years old heifers, 1700 cows and 64 bulls. Initial simulations in CLEM revealed it was possible to run a much larger herd of around 5,000 to 10,000 AEs on this property, with variation occurring with climate period and pasture type. With herds of this size, the annual pasture utilisation rates fluctuated around the safe utilisation rates used in the models for native and Indian couch pastures (25% and 35% respectively). The higher herd size compared with the representative property was due to the much higher pasture growth rates simulated on A condition land without any competing woody vegetation.

The Charters Towers representative property simulated in CLEM was set up so that it transferred all weaner steers off the property and sold excess heifers when they reached around 350 kg live weight. This was a necessary variation to the representative herd described due to the inability of CLEM to keep replacement breeders when weaner heifers were transferred off the property at the age of 9 months. Hence, female weaners needed to be kept longer so that they reached an age when CLEM was able to select those needed as replacement breeders.

Sale prices were $3/kg live weight for young cattle and around $2.50/kg for older cows. Purchase prices for 24-month old heifers and bulls were set at 30% above sale prices, to reflect the likely increase in demand and prices which occur when enterprises are restocking after dry times. Bulls of age 24 months were purchased as replacements for culled bulls, and heifers aged 24 months were purchased if the herd bred insufficient replacement breeders. Breeders were culled at 10 years or when they had not produced a calf for at least 24 months, and bulls were culled at 8 years. Calves were weaned in May and October when 7 months of age.

In CLEM, minimum and maximum breeder numbers were set which, together with interactions with pasture growth, determine monthly and annual AEs. For example, when a minimum breeder number of 4000 head is set, the herd will try and maintain this annually through breeding and purchases of heifers. However, no heifers will be purchased when there are more than 4000 head of breeders present. The maximum number of breeders set determines the upper limit of breeders and total herd size but reaching this limit can only occur through breeding when more than 4000 head of breeders are present. In all simulations, the maximum number of breeders was set at 15,000, so that this would not constrain the size of herds in any one combination of climate period and pasture type.

The lowest minimum breeder number of 4000 head was used for the combination of native pasture and the C4 'Dry' 1990 to 2019 climate period. This resulted in minimal change in land condition and grass basal area (GBA) over this climate period, even though pasture utilisation rates were occasionally well in excess of 25%.

However, given that the carrying capacity of this enterprise could be considerably higher during other climate periods, especially with Indian couch pasture, it was necessary to use higher minimum breeder numbers. Again, the minimum breeder number set was that which generally achieved the respective safe utilisation rates and best maintained land condition and GBA over a climate period. This varied between 4000 and 6000 head of breeders for native pastures, and between 7000 and 7500 for Indian couch pastures.

The monthly pasture growth files were supplied from GRASP simulations as outlined previously. CLEM has specific forage quality parameters that needed to be defined for native and Indian couch pastures. The CLEM default forage quality parameter values were used for native pastures. Based on project study data, Indian couch pastures were estimated to have a higher initial nitrogen content and higher monthly loss of nitrogen than native pastures. Additionally, forage quality, detachment, and change in land condition and grass basal area parameters values used in CLEM were those used in GRASP. The animal intake restrictions determined for GRASP simulations were not captured in CLEM. Capture of animal intake restrictions in CLEM will be focus of future BEM work.

The CLEM model used to simulate the representative property did not include the majority of costs associated with a cattle breeding enterprise. Consequently, the figures for annual profits generated for the various scenarios were similar to the annual income arising from sales of all classes of cattle.

Level of success/efficiency of methodology employed

Development of base pasture parameter sets: This was successfully achieved through extensive review of historical GUNSYND and SWIFTSYND pasture production study sites in eastern Queensland, and the associated GRASP parameters, and the development of 'average' native pasture and Indian couch parameter sets for eastern Queensland.

Modelling the impacts of Indian couch invasion on production and enterprise profitability:

Using GRASP to generate native and Indian couch pasture growth data for use in CLEM was successful. 'Base' pasture growth parameter sets developed for native and Indian couch treeless pastures did require further parameterisation to enable simulation of grazed pastures. Literature, available site data, and expert opinion informed key relationships associated with grazing, which included consumption by animals; detachment and trampling; and risks of degradation. Use of the project's SWIFTSYND field data to further refine GRASP could improve the Indian couch pasture production estimates, with particular focus on drought-tolerance thresholds, yield-cover relationships, and regrowth following “grazing”. Additionally, enabling the GRASP model to simulate the ’non-harvestable’ component would substantially improve the simulation of grazed Indian couch pastures. Inclusion of trees in the grazed systems will enable more realistic carrying capacity and animal production outcomes. Further advice should be sought, and sensitivity analyses should be conducted, to inform understanding of key drivers of grazed Indian couch productivity and profitability.

The BEM results presented in this report, particularly those from CLEM, are considered preliminary. While CLEM has been built and tested by researchers and programmers with considerable experience in modelling northern Australian beef cattle systems and is based on previous models that were known to accurately simulate these grazing systems (CLEM 2023), it is a relatively new model under continual development. Over time, as CLEM is being used by increasing numbers of researchers, bugs have been identified and resolved and its capacity to meet user requirements is continually being increased. The version of CLEM used for this project had a bug which was not known at that time. A component of CLEM is to select particular classes of female cattle which will be sold each year, such as cows of a maximum age. When selecting these cows in the version of CLEM used for this project, a bug existed that caused CLEM to sell all female cattle, which then were replaced with purchased females in the following year. Furthermore, it was not possible to fully include operating costs associated with management of the herd. This combined with the very high carrying capacity of the property due to the complete absence of woody vegetation greatly inflated the profitability of this enterprise. Consequently, the productivity and profitability of the enterprise with native pasture were compared with those with Indian couch pasture in relative rather than absolute terms.

The accuracy and capacity of CLEM to simulate northern grazing systems have increased substantially since the modelling was undertaken for this project. While other CSIRO herd and financial models, such as Integrated Analysis Tool (IAT), NABSA (Northern Australian Beef Systems Analyser) and ENTERPRISE, were available to link with GRASP pasture output to form bioeconomic modelling frameworks, their ongoing development and accessibility were not supported by any organisation. CLEM continues to be developed by CSIRO and the Agricultural Production Systems sIMulator (APSIM) initiative and is readily accessible to users through the APSIM Next generation modelling environment, where it is one of a suite of models available for simulation of agricultural systems.

The level of knowledge, understanding and skill in using CLEM substantially increased due to this project’s activity. DAF now has the capability to capture GRASP generated data in CLEM and run herd simulations. However, there remains significant gaps in the knowledge and understanding of the complexities of managing herds in CLEM. To this end, several R&D options have been recommended.

3.3.5 Raising awareness

A synthesis of results from field work, findings from producer anecdotes and outcomes from the bioeconomic modelling was used to identify key messages for Industry.

Increased awareness and understanding by producers on potential impacts of Indian couch on carrying capacity; by 2022, 70% of the producers in north and central Queensland will be aware of the extent of Indian couch spread.

3.4 Results & Discussion

3.4.1 Field site data: production differences between Indian couch and native grass pasture

The findings for the sites in the Burnett-Mary catchment, located at the Brian Pastures Research facility, are presented first, followed by the findings for the sites sampled in the Burdekin catchment of north Queensland.

The findings presented below provide insights into the pasture production potential of Indian couch relative to native pastures.

SWIFTSYND sites sampled in the Burnett-Mary catchment

Sampling took place across three native pasture (Black speargrass dominant) and Indian couch paired sites, over two years. Table 7 shows the quarterly and annual rainfall experienced over the 2-year sampling period, with year 2 experiencing higher rainfall (555 to 576mm) when compared with year 1 (~490mm). The median long-term rainfall data (2003-2022) for the district (Gayndah Airport) is also shown in Table 7; with calculated yearly median rainfall being 612mm.

Figs. 30, 31 and 32 show the pasture yield totals, pasture species contribution to total yield, and protein levels of the dominant grass at the four strategic times (harvests H1, H2, H3 and H4) over the growing seasons (wet to dry) for both sampling years and for all three native pasture and Indian couch pairings. Across the three soil types and both seasons in the Burnett-Mary catchment, the native pasture had greater observed yield than Indian couch in 5 out of 6 soil x year combinations. Only in year 2 at the deep andesitic gradational loam site (Lady's Mile) was the Indian couch dominant pasture observed to have greater yields than the native dominant pasture (Fig. 32 and Table 8).

Despite the differences in mean pasture yield totals observed, the mean differences were not statistically significant ($P>0.05$) (Table 8). In addition, the 'across sites' analysis did not show a significant difference between the mean biomass for each pasture type (Indian couch 2256; Native 2201; SED 296; $P=0.861$). However, the analysis of individual quadrat data allowed for further assessment of the variation of the means within sites (see section 3.3.1 of methods), with the acknowledgement of limitations previously mentioned. Appendix 9.5.1 (see Table 25 and Fig. 66) indicated two out of three site pairings in the Burnett-Mary catchment for year 1 were significantly different, with native dominant pasture yield totals at "Rons" and "Bambling" being significantly higher than their Indian couch dominant pasture pairings ($P<0.001$). For year 2, there were no statistically significant differences indicated, although there was a near-significant trend for "Lady's Mile" Indian couch dominant pasture to have higher total biomass than its native dominant pasture pairing ($P=0.087$), (Appendix 9.5.1).

In general, there was higher levels of legume associated with the Indian couch pasture sites when compared to the native pasture sites. This was particularly the case for the "Lady's Mile" site on a gradational loam (Fig. 32). The higher yields obtained over the second year of sampling, regardless of site and pasture type, is consistent with the higher rainfall totals experienced for that year. During the higher rainfall year (Year 2: 2019/20), a general peak in protein of the dominant grass at each site occurred at the second harvest (H2). This corresponds with the general onset of pasture flowering. These peaks in protein at H2 were also higher for Indian couch (7.31 to 8.50%) when compared to native pasture (5.56 to 6.69%).

Table 7. Quarterly and total rainfall (mm) at the Brian Pastures Research Facility (BPRF) during the experiment based on rainfall data from two of the sites ('Lady's Mile' and 'Rons') with native pasture and Indian couch paired sites. Technical issues with the automatic weather station meant there were no rainfall records for the 'Bambling' site; as a surrogate, rainfall records from the site 'Lena' located on the BPRF are presented instead. Median long-term rainfall data sourced from the Bureau of Meteorology is also shown for the nearby Gayndah Airport.

	Oct-Dec	Jan-March	April-June	July-Sept	Total
Lady's Mile					
2018-19	283	148	55	7	493
2019-20	106	352	21	75	555
Rons					
2018-19	272	136	76	6	490
2019-20	93	384	24	75	576
Lena					
2018-19	278	136	80	8	502
2019-20	110	350	24	83	567
Median long-term					
Gaydah airport (2003 – 2022)	228	218	72	59	612

Figure 30. Native pairing with Indian couch (*Bothriochloa pertusa* – 'Pertusa') on a black basaltic soil at the Brian Pastures Research Facility (Rons site) in the north Burnett of Queensland. Sites were sampled over two consecutive years (Year 1: 2018/19 and Year 2: 2019/20). The graphs show pasture yields, pasture species contributing to yields and protein levels of the dominant grass at four strategic times (harvests) over the growing season (wet to dry) for each year. The dominant pasture species at the native site was Black speargrass (*Heteropogon contortus* – HeCon).

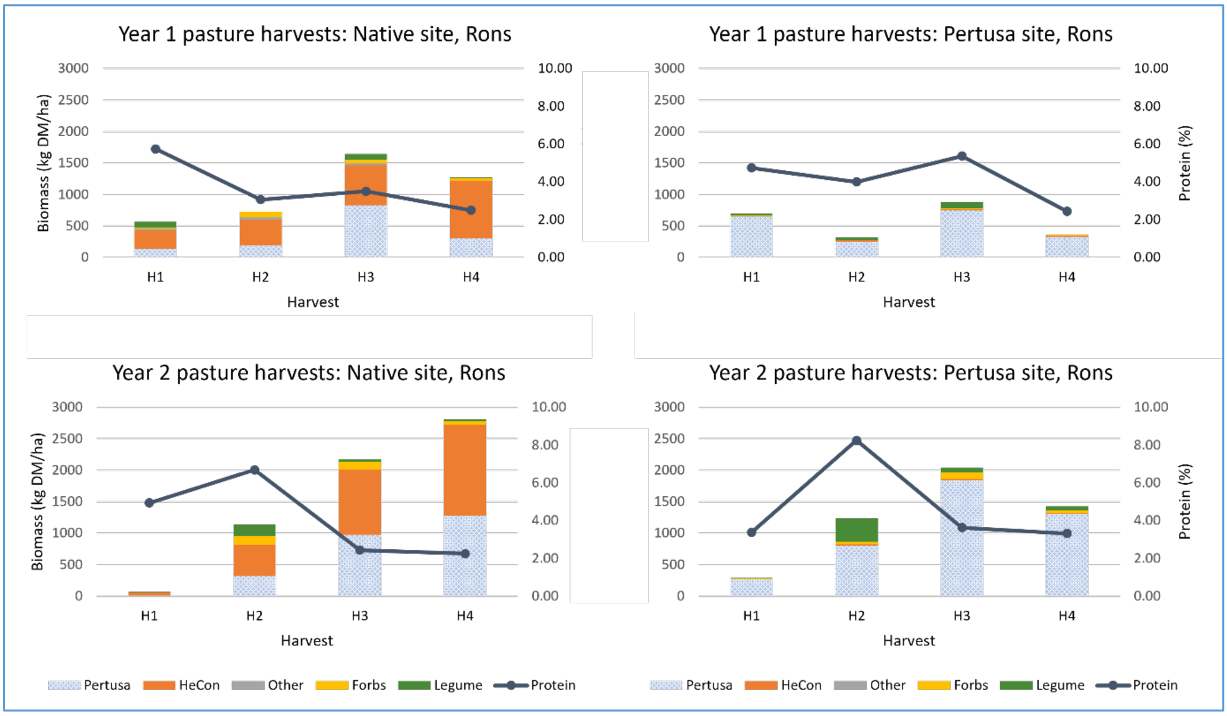


Figure 31. Native pairing with Indian couch (*Bothriochloa pertusa* – 'Pertusa') on a brown basaltic soil at the Brian Pastures Research Facility (Bambling site) in the north Burnett of Queensland. Sites were sampled over two consecutive years (Year 1: 2018/19 and Year 2: 2019/20). The graphs show pasture yields, pasture species contributing to yields and protein levels of the dominant grass at four strategic times (harvests) over the growing season (wet to dry) for each year. The dominant pasture species at the native site was Black speargrass (*Heteropogon contortus* – HeCon).

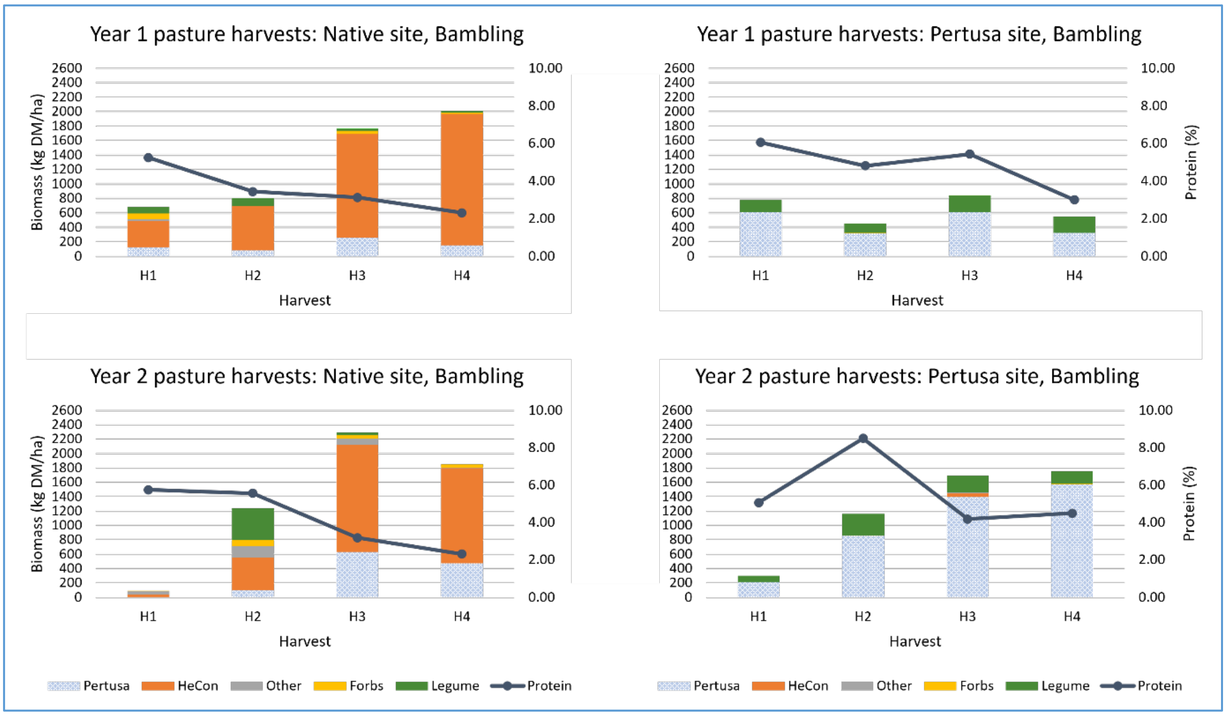


Figure 32. Native pairing with Indian couch (*Bothriochloa pertusa*, 'Pertusa') on a gradational loam at the Brian Pastures Research Facility (Lady's Mile site) in the north Burnett of Queensland. Sites were sampled over two consecutive years (Y1: 2018/19 and Y2: 2019/20). The graphs show pasture yields, pasture species contributing to yields and protein levels of the dominant grass at four strategic times (harvests) over the growing season (wet to dry) for each year. The dominant pasture species at the native site was Black speargrass (*Heteropogon contortus* – HeCon).

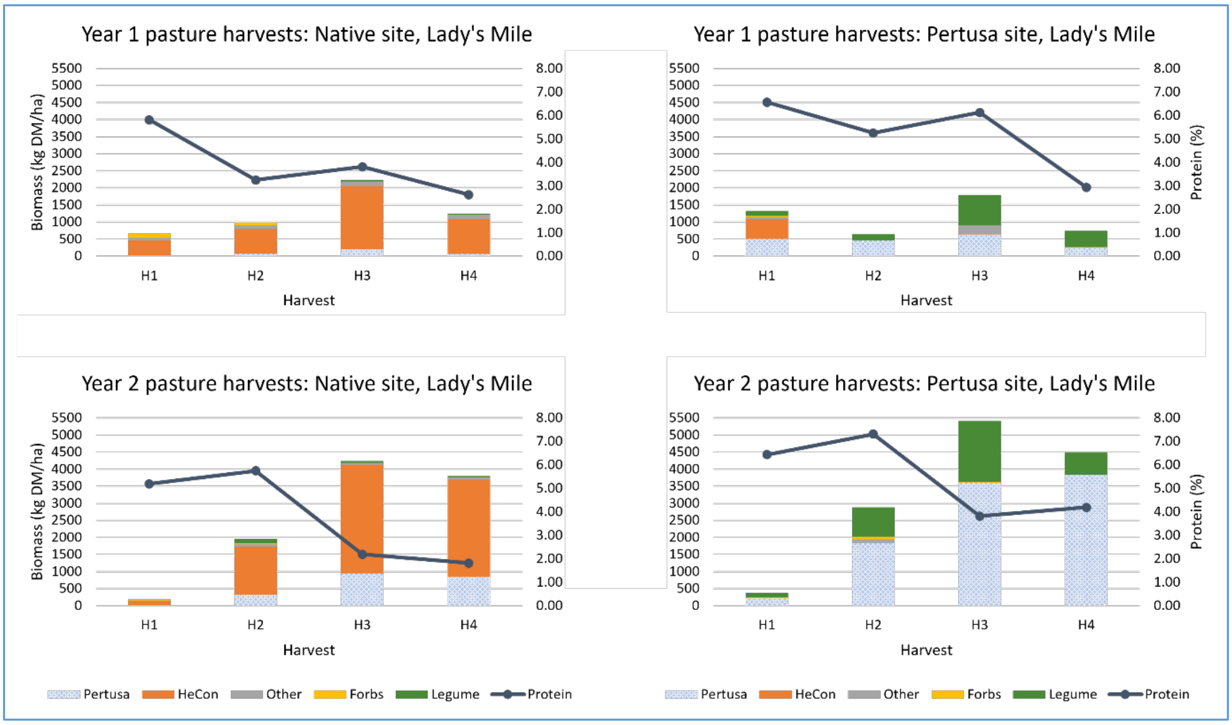


Table 8. An assessment of maximum standing biomass (kg DM/ha) for Indian couch (*Bothriochloa pertusa*) dominant pasture relative to native grass dominant pasture across three soil types and two consecutive years (Y1: 2018/19 and Y2: 2019/20) at Brian Pastures Research Facility, in the north Burnett. The dominant species for the native pasture was Black speargrass (*Heteropogon contortus*). The yield contribution (%) of Indian couch in both the native and Indian couch sites is shown, as is the combined legume and Indian couch contribution for the Indian couch sites.

Shallow basaltic black earth (Rons site):						
Year	Biomass (kg DM/ha) (se)		Difference (%)	Indian couch %		Indian couch site
	Native dominant	Indian couch dominant		Native dominant	Indian couch dominant	Legume + IC %
Y1	1643	883	-46%*	50%	84%	96%
Y2	2174	2043	-6%	45%	90%	94%
Average	*1908 (266)*	*1463 (580)*	*-23% ns*	*48%*	*87%*	*95%*
			P=0.557# (sed=638)			

Deep basaltic brown clay (Bambling site):						
Year	Biomass (kg DM/ha) (se)		Difference (%)	Indian couch %		Indian couch site
	Native dominant	Indian couch dominant		Native dominant	Indian couch dominant	Legume + Indian couch %
Y1	1771	846	-52%*	15%	72%	100%
Y2	2290	1692	-26%	28%	82%	96%
Average	*2030 (259)*	*1269 (423)*	*-38% ns*	*21%*	*77%*	*98%*
			P=0.265# (sed=496)			

Deep andesitic gradational loam (Lady's Mile site):						
Year	Biomass (kg DM/ha)		Difference (%)	Indian couch %		Indian couch site
	Native dominant	Indian couch dominant		Native dominant	Indian couch dominant	Legume + Indian couch %
Y1	2235	1784	-20%	9%	36%	85%
Y2	4237	5407	28%	22%	67%	99.6%
Average	*3236 (1001)*	*3596 (1811)*	*11% ns*	*16%*	*51%*	*92%*
			P=0.878# (sed=2069)			

#The *P*-value and the standard error of the difference (sed) relates to the testing of the difference between the biomass values for native dominant and Indian couch dominant pasture averaged over the two years.

*Significantly different means were determined for these site.year means in the subsequent multi-site analysis (Appendix 9.5.1).

Compared to the median long-term rainfall records (Table 7), both sampling years were characteristic of conditions of lower rainfall years at each location: ~120mm lower for year 2018/19 and ~50mm lower for 2019/20. The greater pasture production of native pastures compared to

Indian couch observed for selected site.year combinations in the 2018/19 period (Table 8) could reflect the reduced ability of Indian couch to remain productive under reduced rainfall conditions. In addition, the reduction in pasture production losses attributed to Indian couch relative to native pastures observed in the 2019/20 period, where rainfall was approaching closer to the median long-term rainfall, could have been attributed to the higher than median long-term rainfall for the January to March quarter (Table 7; compare 350 to 380mm with 218mm).

In summary, at the Brian Pastures site in the Burnett -Mary catchment, Indian couch dominant pasture generally had lower production value than the native pasture, although a near-significant trend was shown for Indian couch dominant pasture to have higher biomass yield in the second year at the lighter textured soil (Table 8; "Lady's Mile" site); a site where legumes were prevalent within the Indian couch pasture but not the native pasture.

Swiftsynd sites sampled in the Burdekin catchment

Sampling took place across two native pasture and Indian couch paired sites, over two years. Tables 9 and 10 show the quarterly and annual rainfall experienced over the 2-year sampling period, respectively for sites located at the Spyglass Research Facility and a nearby property ("Property #1"). During the first year of sampling (2018/19), there were significant rainfall events taking place, namely Tropical Cyclone Owen (December 2018) and an unprecedent Monsoon Trough Event in Jan-February 2019. This is reflected by the high accumulated rainfall totals shown for the Oct-December and the Jan-March periods: with annual rainfall for the 2018/19 period of 878-966mm at the Spyglass sites, and ~805mm at the "Property #1" sites.

The second year of SWIFTSYND sampling (2019/20) had considerably less rainfall during the October to December quarter, i.e., leading up to the growing season, but had higher rainfall totals in the April-June period when compared with the 2018/19 year.

For comparative purposes, the median long-term rainfall records (1993 – 2022) are presented, including for "Property #1" (Table 9, located ~17km south from the Spyglass SWIFTSYND sites, and with yearly median rainfall calculated at 560mm) and for Charters Towers Airport (Table 10, located ~68km southeast of the "Property #1" SWIFTSYND sites, and 538mm being the calculated yearly median rainfall).

The sites set up at Spyglass, although being in the same paddock, were 3km apart and showed differences in rainfall records (Table 9). In contrast, there was very little difference in the rainfall records for the Indian couch versus the native site at "Property #1" (Table 10). This is not surprising given both sites at "Property #1" were established in very close proximity (~100 metres apart).

Table 11 shows pasture production differences between native and Indian couch dominant pastures were greatest during the higher rainfall year of 2018/19 (in the order of 20 to 64%) and in favour of Indian couch in 3 of the 4 soil x year combinations. Despite the differences observed in pasture production for Indian couch relative to native pasture, none of the total biomass differences reported were statistically significant across seasons at a single site ($P>0.05$) (Table 11). Using the quadrat level data, statistically significant differences were indicated in year 1 (2018/19) for the "Spyglass" site (with higher biomass production from Indian couch dominant pasture relative to native dominant pasture; $P<0.05$) and with a near-significant difference for the site at "Property #1" where Indian couch dominant pasture also produced higher yields during 2018/19 ($P=0.091$), (Appendix 9.5.1). The trend for higher yields from Indian couch dominant pastures in the Burdekin catchment during year 1 coincided with the higher monsoonal rainfall events that took place (Tables 9 & 10).

Table 9. Quarterly and total rainfall (mm) at the Spyglass Research Facility during the experiment based on rainfall data from the 'Native' pasture and 'Indian couch' paired sites. Median long-term rainfall data sourced from the Bureau of Meteorology is also shown for the nearby Hillgrove weather station.

	Oct-Dec	Jan-March	April-June	July-Sept	Total
Spyglass – Native					
2018-19	249	571	35	24	878
2019-20	19	448	105	26	597
Spyglass – Indian couch					
2018-19	284	609	45	29	966
2019-20	2	399	120	26	546
Median long-term					
Hillgrove (1993 – 2022)	119	335	56	14	560

Table 10. Quarterly and total rainfall (mm) at "Property #1" during the experiment based on rainfall data from the 'Native' pasture and 'Indian couch' paired sites. Median long-term rainfall data sourced from the Bureau of Meteorology is also shown for the nearby Charters Towers Airport.

	Oct-Dec	Jan-March	April-June	July-Sept	Total
Property #1 – Native					
2018-19	288	408	66	43	804
2019-20	4	360	115	30	508
Property #1 – Indian couch					
2018-19	288	412	66	40	806
2019-20	4	359	116	30	509
Median long-term					
Charters Towers Airport (1993 – 2022)	128	320	61	17	538

Table 11. An assessment of maximum standing biomass (kg DM/ha) for Indian couch (*Bothriochloa pertusa*) dominant relative to native dominant pasture across two sites and two consecutive years (Y1: 2018/19 and Y2: 2019/20) in north Queensland. At the sedimentary red earth site, the dominant native pasture species was Black speargrass (*Heteropogon contortus*). At the red basaltic site, the dominant native pasture species was Desert bluegrass (*Bothriochloa ewartiana*). The yield contribution (%) of Indian couch in both the native and Indian couch sites is shown, as is the combined legume and Indian couch contribution for the Indian couch sites.

Sedimentary red earth (Spyglass site):						
Year	Biomass (kg DM/ha) (se)		Difference (%)	Indian couch %		Indian couch site
	Native dominant	Indian couch dominant		Native dominant	Indian couch dominant	Legume + Indian couch %
Y1	2472	4057	64%*	0.1%	38%	53%
Y2	1296	1509	16%	0.3%	22%	36%
Average	*1884 (588)*	*2783 (1274)*	*48% ns*	*0.2%*	*30%*	*44%*
			P=0.587# (sed=1403)			
Red basaltic soil (Property #1 site):						
Year	Biomass (kg DM/ha) (se)		Difference (%)	Indian couch %		Indian couch site
	Native dominant	Indian couch dominant		Native dominant	Indian couch dominant	Legume + Indian couch %
Y1	2644	3177	20%	14%	75%	86%
Y2	1248	1162	-7%	25%	63%	89%
Average	*1946 (698)*	*2169 (1008)*	*11% ns*	*19%*	*69%*	*88%*
			P=0.872# (sed=1226)			

The *P*-value and the standard error of the difference (sed) relates to the testing of the difference between the biomass values for native dominant and Indian couch dominant pasture averaged over the two years.

*Significantly different means were determined for these site.year means in the subsequent multi-site analysis (Appendix 9.5.1)

The higher maximum standing biomass of 4000kg/ha for the Indian couch site at Spyglass (Fig. 33) is consistent with the higher rainfall records at this site. For the "Property #1" sites, where rainfall between native and Indian couch sites were similar, the non-significant production gain for Indian couch was 20% in 2018/19, with a production loss of 7% in the subsequent 2019/20 year (see Fig. 34). During this second year of sampling at the "Property #1" site, Indian couch growth was from new seedlings (Fig. 28 and Appendix 9.5.2; Fig 67).

The rainfall for the 2018/19 year, ranging between 800 and 970mm across sites, was substantially higher than the yearly median long-term rainfall of 530 to 560mm. In contrast, the rainfall for the 2019/20 year ranged between 500 and 600mm, being more consistent with the median long-term rainfall. The performance of Indian couch related well with the rainfall conditions, with increased production during the wet year of 2018/19 and reduced growth during the average 2019/20 year, relative to native pasture. The performance of the native pasture sites was somewhat inhibited, irrespective of wet or average year, and it is speculated that the reset method or timing of reset had a deleterious impact on the native pasture sites. In addition, for the native pasture site at "Property #1", the presence of Indian couch plants at this native Desert bluegrass dominant site went undetected during the initial set-up phase, but rapid growth of Indian couch plants was witnessed post the initial reset of the site.

Finally, it is worth considering the observations made at the Indian couch site at "Property #1" with regards to pasture resilience and land condition factors. The Indian couch site at "Property #1", rated as a C condition land state, produced yields in the order of 3000kg/ha during the initial 'wet' year. However, as soon as conditions diminished and there was minimal rainfall during the subsequent Oct-December period of 2019/20, Indian couch plants had died off and thus growth captured in the 'average' second year was from new seedlings that resulted in pasture yields in the order of 1000kg/ha (Table 11). The Indian couch seedlings were also observed to be under attack by a native army worm that were not evident in the nearby native pasture site (Appendix 9.5.2; Fig. 68). In contrast, this transient collapse of Indian couch plants observed at "Property #1" was not observed at the Indian couch site at Spyglass – a site rated as 'B' land condition.

Figure 33. Native pairing with Indian couch (*Bothriochloa pertusa*, 'Pertusa') on a sedimentary red earth at the Spyglass Beef Research Facility in north Queensland. Sites were sampled over two consecutive years (Y1: 2018/19 and Y2: 2019/20). The graphs show pasture yields, pasture species contributing to yields and protein levels of the dominant grass at four strategic times (harvests) over the growing season (wet to dry) for each year. The dominant pasture species at the native site was Black speargrass (*Heteropogon contortus* – HeCon).

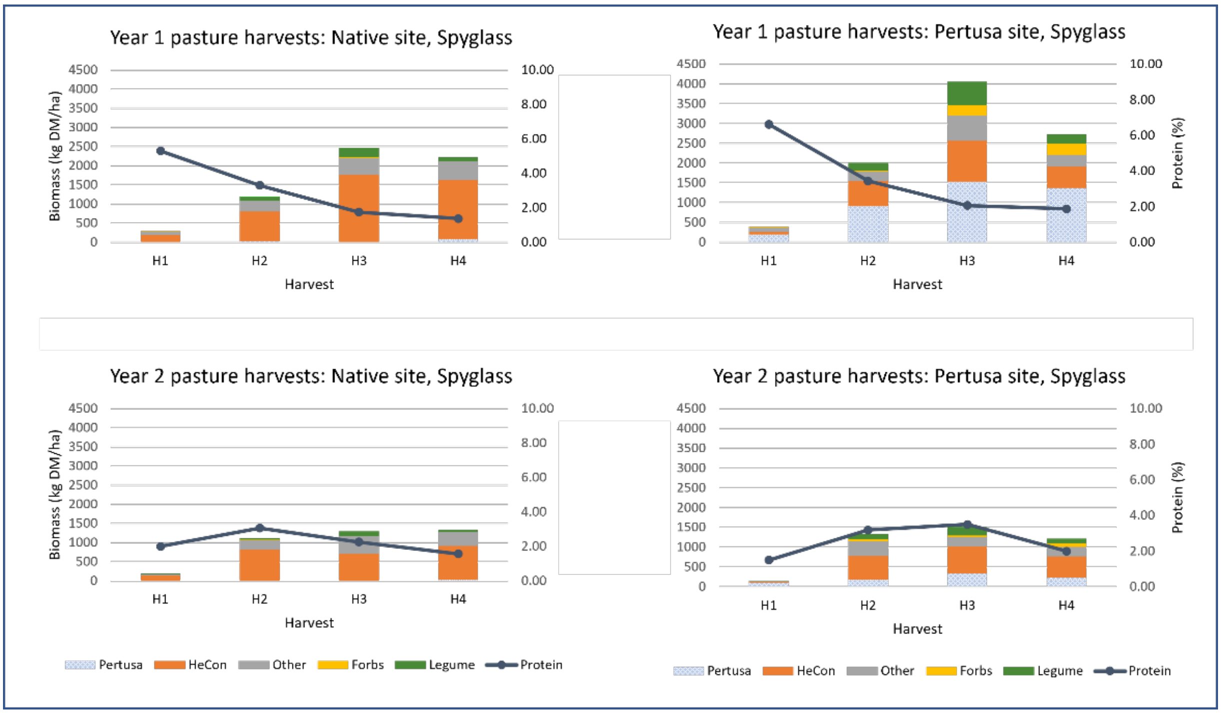
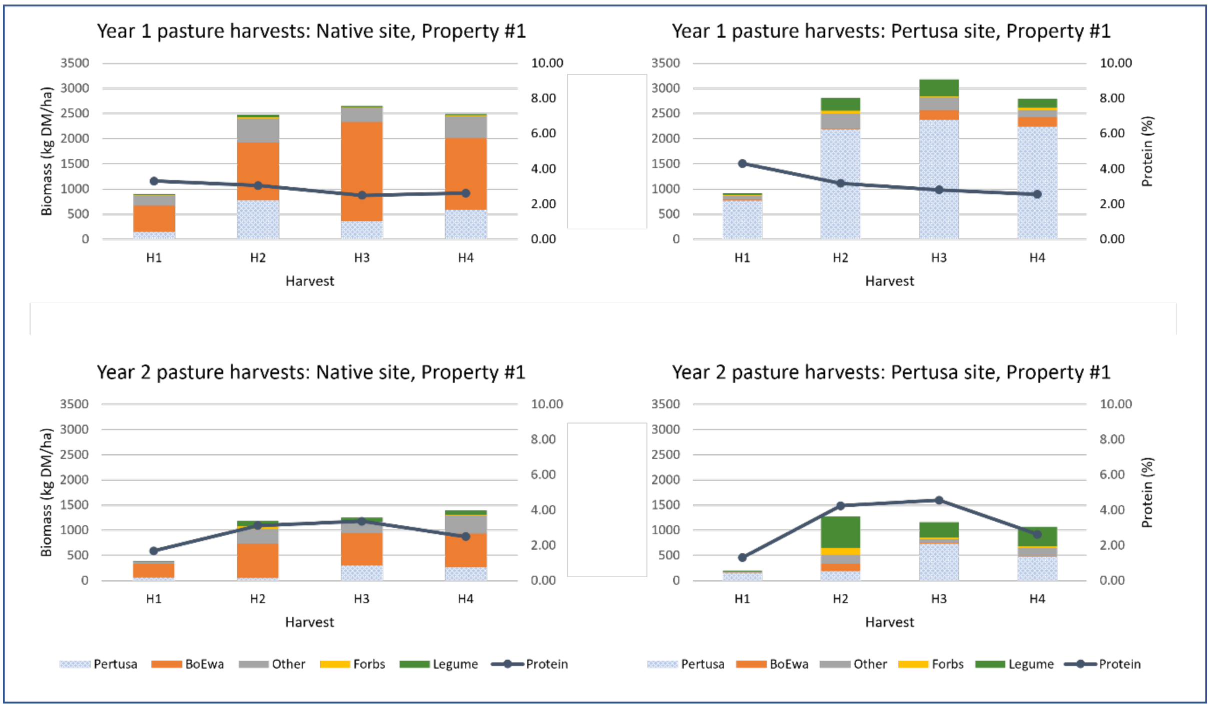


Figure 34. Native pairing with Indian couch (*Bothriochloa pertusa*, 'Pertusa') on a red basaltic soil at a property ("Property #1") in north Queensland. Sites were sampled over two consecutive years (Y1: 2018/19 and Y2: 2019/20). The graphs show pasture yields, pasture species contributing to yields and protein levels of the dominant grass at four strategic times (harvests) over the growing season (wet to dry) for each year. The dominant pasture species at the native site was Desert bluegrass (*Bothriochloa ewartiana* – BoEwa).



3.4.2 Ancillary data on Indian couch

Relationships for cover and height with total standing dry matter (kg/ha) were assessed for all three pairings in the Burnett-Mary, capturing three soil types: Black basaltic soil, Brown basaltic soil, and Gradational loam.

For each site, linear and exponential equations for grass cover and plant height are presented. As botanical cover was of less interest, only the best relationship (linear or exponential) has been given.

The relationship between grass cover and TSDM relationships were best described using an exponential relationship for each site. The plant height versus TSDM relationship was best described using linear relationships for each site. Due to the consistency across sites, only the fitted exponential relationship has been displayed for grass cover (Fig. 35, 37 and 39) and the linear relationship for plant height (Fig. 36, 38 and 40).

Ron's site

The equations for Ron's site for the best fitting model of either the linear or exponential form are shown in Table 12. For grass cover, the exponential was a much better fit to the data. For botanical cover, there was little difference between the linear and the exponential forms. For pasture height, the adj R^2 for the linear model is slighter higher than for the exponential.

Table 12. Relationships of Cover and Plant height with TSDM for Ron's site

Variable		Equations	P-value	Adj R^2
Grass cover (GC)	Linear	*parallel lines* Constant + TSDM + Pasture_type	<0.001	83.2
	Exponential	*constant parameters separate* Hecon: GC = 108.1 – 90.81 x (0.999404^{TSDM}) Pertusa: GC = 128.2 – 90.81 x (0.999404^{TSDM})	<0.001	87.8
Botanical cover (BC)	Linear	*separate lines* Hecon: BC = 35.57 + 0.02249 x TSDM Pertusa: BC = 77.23 + 0.0112 x TSDM	<0.001	87.3
	Exponential	*all linear parameters separate* Hecon: BC = 140.3 – 110.0 x (0.999685^{TSDM}) Pertusa: BC = 125.5 – 49.86 x (0.999685^{TSDM})	<0.001	87.7
Mean height (Ht)	Linear	*parallel lines* Hecon: Ht = 7.44 + 0.004684 x TSDM Pertusa: Ht = 3.106 + 0.004684 x TSDM	<0.001	85.4
	Exponential	*all constant parameters separate* Hecon: Ht = -46.02 + 53.65 x (1.000079^{TSDM}) Pertusa: Ht = -50.32 + 53.65 x (1.000079^{TSDM})	<0.001	84.3

Figure 35. Relationship between Grass cover and TSDM for Ron's site (● — HeCon; ○ - - - Pertusa).

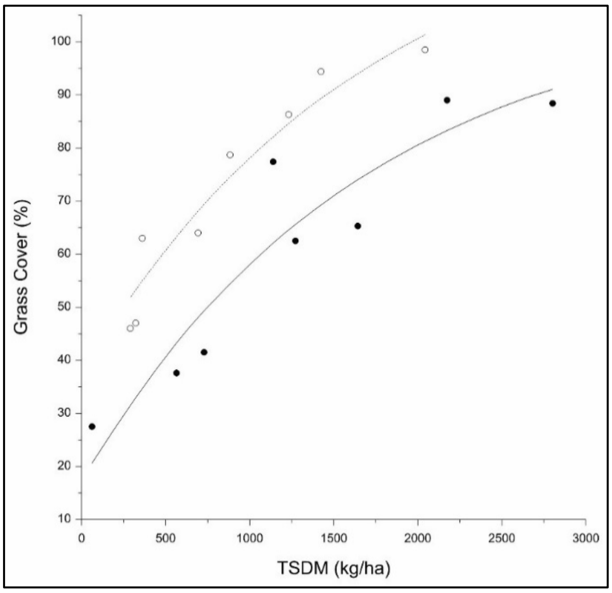
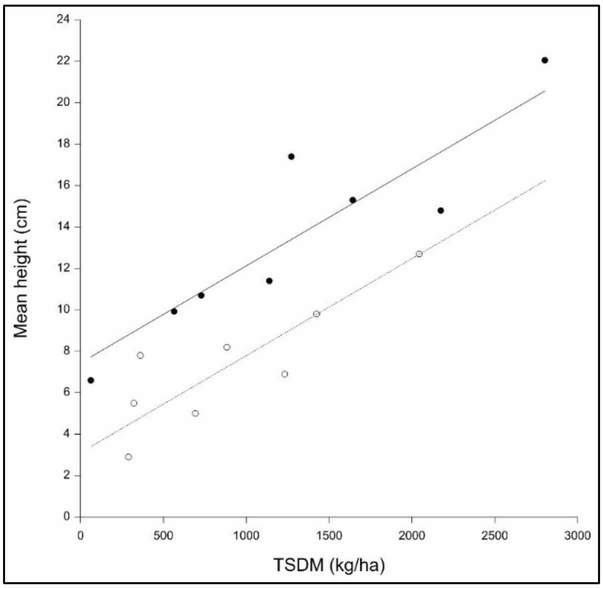


Figure 36. Relationship between Plant height and TSDM for Ron's site (● — HeCon; ○ - - - Pertusa).



Bambling site

The equations for the Bambling site for the best fitting model of either the linear or exponential form are shown in Table 13. For grass cover, the exponential is a slightly better fit and for the pasture height the linear model is a slightly better fit to the data. For botanical cover, the linear model is a much better fit to the data.

Table 13. Relationships of Cover and Plant height with TSDM for Bambling site

Variable		Equations	P-value	Adj R^2
Grass cover (GC)	Linear	*parallel lines* Hecon: GC = 17.12 + 0.02683 x TSDM Pertusa: GC = 43.52 + 0.02683 x TSDM	<0.001	86.6
	Exponential	*constant parameters separate* Hecon: GC = 102.9 – 92.29 x (0.9995^{TSDM}) Pertusa: GC = 127.7 – 92.29 x (0.9995^{TSDM})	<0.001	87.7
Botanical cover (BC)	Linear	*separate lines* Hecon: BC = 11.6 + 0.02474 x TSDM Pertusa: BC = 82.1 + 0.00386 x TSDM	<0.001	92.5
	Exponential	*constant parameters separate*	<0.001	81.4
Pasture height (Ht)	Linear	*parallel lines* Hecon: Ht = 7.80 + 0.004932 x TSDM Pertusa: Ht = 3.98 + 0.004932 x TSDM	<0.001	83.0
	Exponential	*constant parameters separate* Hecon: Ht = -5.093 + 13.39 x (1.000268^{TSDM}) Pertusa: Ht = -8.762 + 13.39 x (1.000268^{TSDM})	<0.001	82.0

Figure 37. Relationship between Grass cover and TSDM for Bambling site (● — HeCon; ○ - - - Pertusa).

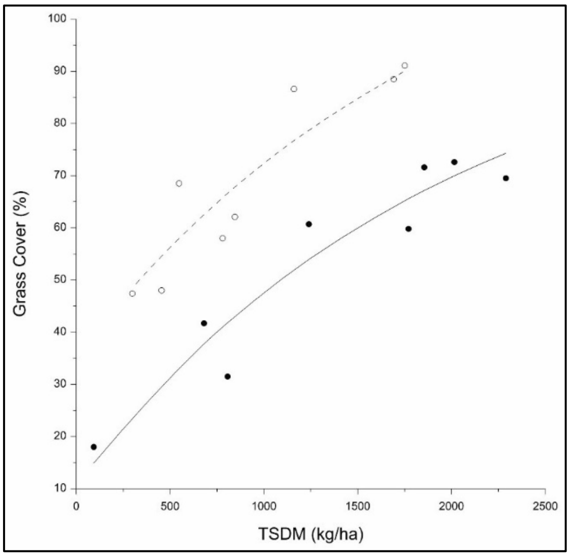
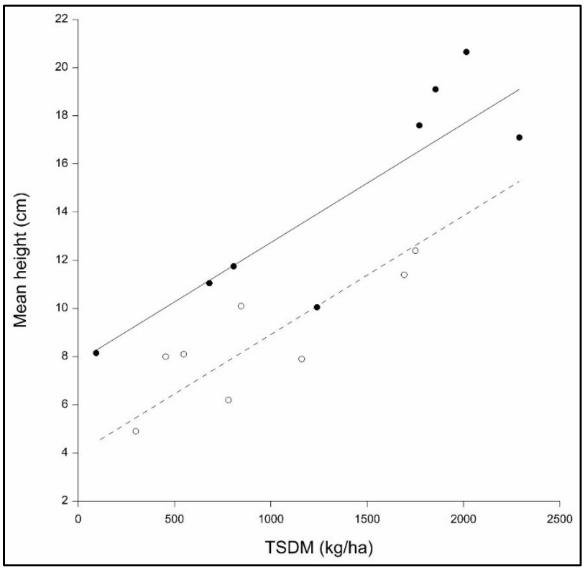


Figure 38. Relationship between Plant height and TSDM for Bambling site (● — HeCon; ○ - - - Pertusa).



Lady's Mile site

The equations for the Lady's Mile site for the best fitting model of either the linear or exponential form are shown in Table 14. For grass cover and botanical cover, the exponential was a much better fit to the data. For pasture height, the adj R^2 for the linear model is slighter higher than for the exponential.

Table 14. Relationships of Cover and Plant height with TSDM for Lady's Mile site.

Variable		Equations	P-value	Adj R^2
Grass cover (GC)	Linear	*parallel lines* Constant + TSDM + Pasture_type	<0.001	65.5
	Exponential	*constant parameters separate* Hecon: GC = 82.45 – 67.90 x (0.999193^{TSDM}) Pertusa: GC = 99.93 – 67.90 x (0.999193^{TSDM})	<0.001	79.0
Botanical cover (BC)	Linear	separate lines Constant + TSDM + Pasture_type + TSDM.Pasture_type	<0.001	79.5
	Exponential	*all linear parameters separate* Hecon: GC = 82.27 – 65.29 x (0.999043^{TSDM}) Pertusa: GC = 98.91 – 10.66 x (0.999043^{TSDM})	<0.001	87.4
Pasture height (Ht)	Linear	*separate lines* Hecon: Ht = 4.52 + 0.00905 x TSDM Pertusa: Ht = 3.42 + 0.00575 x TSDM	<0.001	89.6
	Exponential	*all linear parameters separate* Hecon: Ht = -121.1 + 126.4 x (1.000062^{TSDM}) Pertusa: Ht = -73.03 + 77.26 x (1.000062^{TSDM})	<0.001	88.9

Figure 39. Relationship between Grass cover and TSDM for Lady's Mile site (● — HeCon; ○ - - - Pertusa).

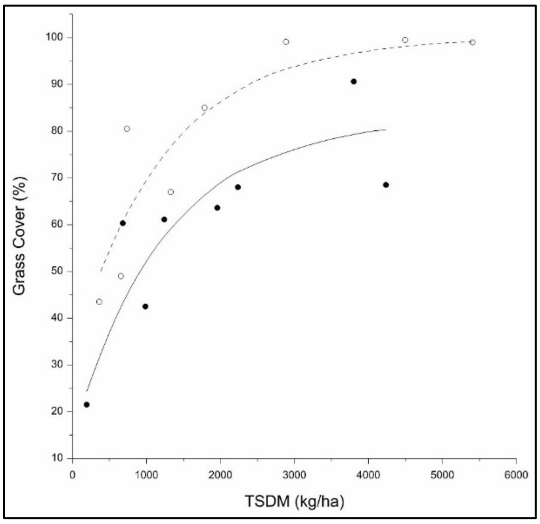
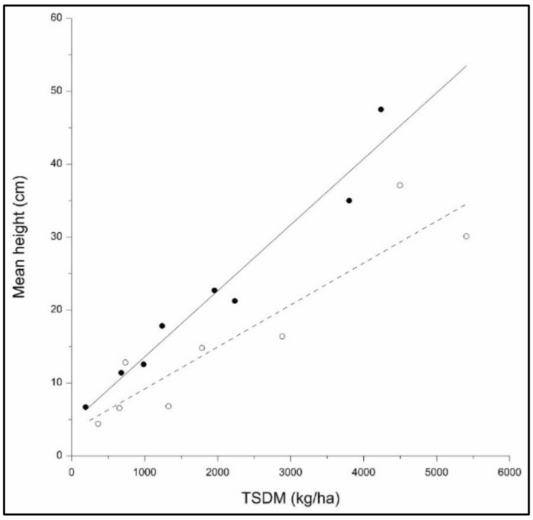


Figure 40. Relationship between Plant height and TSDM for Lady's Mile site (● — HeCon; ○ - - - Pertusa).



Key findings across all three sites

The assessments show Indian couch has high cover, even at low biomass. For example, at 500kg/ha, the modelled cover for Indian couch was around 50 to 60%. In contrast, for native pasture at the same biomass, the cover was around 30 to 40%. A converse relationship is shown for height with mass: at 1000kg/ha for instance, Indian couch height is <10cm, compared with native pasture at >10cm. These results reflect the sprawling growth habit of Indian couch compared with native grasses.

3.4.3 Producer knowledge

Producer anecdotes have provided additional and sometimes conflicting perspectives on the palatability of Indian couch. This is detailed below according to catchment.

Burdekin – Goldfields

- It is not a first-choice grass.
- It is a first-choice grass.

Burdekin – Basalt

- Indian couch is selected after it has set seed.
- Cattle seek out legumes in an Indian couch pasture.

Fitzroy

- Indian couch is not selected over Buffel grass.

Burnett-Mary

- Indian couch is palatable to cattle and selectively grazed over African lovegrass, Black speargrass, Wiregrass and Green Panic, although there are grasses preferred over Indian couch such as Bissett bluegrass, Scented top grass (*Capillipedium spicigerum*), and Tolgar Rhodes (*Chloris gayana*).
- There may be times of the year when cattle prefer Indian couch, otherwise it is not known/unsure.
- Times when cattle might prefer Indian couch include early growth stage pre seeding.
- "[Cattle] *seem to eat less* [Indian couch] *in the Autumn*"

A fusion of anecdotes, based on producer feedback spanning 2015-2017, is presented in Table 15. The indicated impact of Indian couch in pastures to beef businesses varied depending on catchment and situation. For instance, on historically degraded Goldfields landscapes (Granodiorite soils) in north-eastern Queensland, where Indian couch has become an important and dominant pasture species, the grass is driving production and stabilising soil. Indian couch dominant pastures have been inherited by the current generation of beef producers. In the Fitzroy catchment, however, where highly productive introduced grasses such as Buffel grass underpin beef businesses, Indian couch is viewed as an inferior pasture species that would significantly reduce productivity.

Palatability

The 3P nature of the best native grasses mean that they not only produce useful forage (Productive) and live for more than one year (Perennial) but are also preferred and selected by livestock (Palatable) over other pasture species. Palatability of plants is influenced by many factors, such as grazing intensity, growth stage, season, plant leaf to stem ratio, plant structure, plant chemical composition, and the diversity of plants on offer.

Literature reports Indian couch to be only moderately palatable, with cattle known to avoid grazing it whilst other grasses are available (McIvor and Howden 1992). This was later supported by further findings of reduced palatability of Indian couch compared with native grass Golden beard grass (*Chrysopogon fallax*) and introduced grasses Buffel grass (*Cenchrus ciliaris*) and Sabi grass (*Urochloa mosambicensis*), (McIvor 2007). Nevertheless, when compared to Black speargrass, Indian couch provides soft growth in autumn and is grazed in winter when hayed off (Bisset 1980). Thus, the palatability of Indian couch is all relative to what else is available to cattle.

For the Fitzroy catchment, elimination of Indian couch would be challenging. Many factors need to be considered and seed ecology well understood, when trying to deplete Indian couch soil seed banks. For instance, factors to consider would include germination conditions, possible allelopathic effects of Indian couch on competing pasture species, seed viability and persistence, and chemical treatment options, just to name a few. Treatment options are explored in more detail in Sections 5 and 6.

Productivity

The current section focusses on the potential production impacts and management implications. Detail on the features and drivers of Indian couch were presented in section 1.4.2 (see Tables 1 and 2). Detail on Indian couch management options are presented in section 6.

Table 15. Anecdotal characteristics of Indian couch impacts according to catchment based on feedback collected during producer workshops, and information days (2005-2017).

Production impacts of Indian couch – economic and environmental		
Burdekin	**Fitzroy**	**Burnett-Mary**
• Anything from “*It is our value*” and “*Only grass we’ve got*” on granodiorite soils (aka Goldfields) to “*Decreased pasture yield*” and “*Short green feed; some carrying capacity*” on basaltic soils. • Quality OK at certain times. • High ground cover and good soil stabiliser for the Goldfields. • Indian couch is “G*ood at filling in the spaces and much better than a weed*”. • It costs more to have Indian couch: increase in supplements; feed stock or get rid of stock during dry periods. C.f. a bulk of Black speargrass, can use options, e.g., with M8U: during dry period, mature tussocks can withstand increase grazing pressure to balance cattle and cashflow for business. • Less reliable feed source, as reasonable production only comes with good seasons. • Cattle don’t ‘finish’ on Indian couch – Indian couch runs out.	• “*Less biomass, particularly winter standover*”. • The encroachment of Indian couch into sown Buffel grass (*Cenchrus ciliaris*) pastures poses the risk of significant productivity declines – up to 50%. • Cattle graze Indian couch but not selectively like they do Buffel grass. • “*Most expensive pest: greater reliance on lick, lowered productivity, decrease in stocking rate*”. • Some degree of ground cover and provides some value as a feed source, although inferior; “*wet season they do alright but cattle will fall away quicker*”. • Capacity of Indian couch is a reduction in stocking rate and therefore equity and reduced land value. • “*Six months extra to get steers to marketable*”.	• “*Best of a bad bunch*”: Indian couch is better than African love grass, GRT, Grader grass, and green and blue couch. It is even known to out-compete creeping lantana. • On one hand it is a source of palatable feed for cattle but on the other hand it grows less bulk than other pastures and threatens to reduce carrying capacity. • Indian couch can provide good ground cover and stabilise soil. • Poor winter growth.

Producer questionnaire findings for the Fitzroy catchment

Information days in 2017 in central Queensland on Indian couch invasion and pasture dieback provided an opportunity to collect feedback from large groups of beef producers (refer to 1.3.2 for methodology). Feedback from producers on the typical production impacts of Indian couch are shown below, including their corresponding comments.

Fitzroy

Biloela:

- A 20% reduction in carrying capacity:
    - “*Reduce cattle numbers*”.
    - “*Cattle are not growing and finishing as well. Require some supplementary feeding to fatten*”.
    - “*Takes longer to reach weight*”.
    - “*Selling as feeder cattle instead of meatworks*”.
- Decrease in carrying capacity of 10-15%, but increase in cattle weight:
    - “*Provided the rainfall is regular and in 10-15mm amounts, it is an excellent fattening grass for weaner aged cattle*”.
- Decrease in carrying capacity of 50 to 60% but increase in cattle weight:
    - “*Yes, good weight gains but very limited in quantity*”.
- “*In dry periods, it stops producing biomass quickly and becomes useless*”.
- A 50% reduction in carrying capacity:
    - “*Running less cattle to suit paddocks. Rotation grazing being used. Having shorter windows of opportunity to fatten*”.

Moura:

- A decrease in cattle weight:
    - “*Grass [pasture] is not as productive as Indian couch has chocked-out natural species*”.
    - “*Cattle don’t do as well*”.
- “*When it’s raining it* [Indian couch] *is doing well and so are the weight gains* [of cattle]. *Carrying capacity is up too. When its dry, Indian couch dies out quick and has no substance to it so decrease in weight gains/carrying capacity*”.
- Reductions in carrying capacity:
    - Such as 10%, 20% or 30% reduction.
    - 15% reduction: “*Reduction also due to dry weather*”. “*Unsure of cattle weight losses*”.
    - 10 to 15% reduction: “*Less grass, less cattle weight*”.
    - At least 50% compared to 3P.

Producer stakeholder groups

Producer stakeholder groups (refer to 1.3.2 for methodology) allowed for further exchange of information and collection of any new producer knowledge and experience during 2019-2021, building on the earlier feedback from producers presented above in Table 15. This is described below for each catchment, with a focus on the potential production impacts of Indian couch.

Burdekin – *Goldfields*

- Good production can come from an Indian couch pasture providing there is a good amount of Seca Stylo in the pasture. This 'good' production from an Indian couch grass legume pasture includes a significant reduction in supplementation costs and good animal production.

Burdekin – *Basalt*

- The production potential of Indian couch can also be increased if the grass is managed and not constantly being overgrazed; there is value in resting and wet season spelling Indian couch.

Fitzroy – *Biloela*

- It is difficult to think of Indian couch as having production value as there are more desirable pasture species available and suited to this area.

Burnett-Mary

- Indian couch is less of a concern here, but regardless is seen as a threat to carrying capacity, having the ability to invade well established perennial grasses, and losing yield quickly when it gets dry.

3.4.4 Modelling the impacts of Indian couch invasion on production and enterprise profitability

Base parameter sets for pasture modelling of native and Indian couch pastures

Base (or 'average') parameter sets were constructed for eastern Queensland using historical data and through the amalgamation of parameter sets within the *Black speargrass* zone and within the *Aristida-Bothriochloa* zone. A total of 38 historical pasture production study sites contributed to the development of the 'average' native pasture parameter sets for eastern Queensland and communities therein. The base parameter sets were then revised based on understanding gained from long-term simulations carried out by the project team (refer to section 3.3.4 of methods).

Modifications to the native pasture parameter sets were made to produce comparable Indian couch parameter sets based on pre-existing calibrated Indian couch sites in northern Queensland (four sites). Specific native pasture parameters that were modified to develop Indian couch base parameters included: plant growth parameters for regrowth, and sward structure parameters for transpiration, radiation, cover-mass, and height-mass (Appendix 9.5.3; Table 26).

The base parameter sets were used in long-term simulation studies (131-year; 1889-2019) of pasture growth without trees and without grazing. This was done for five locations (refer to methods, section 3.3.4), representing a range of rainfall/climate regimes across *Black speargrass* and *Aristida Bothriochloa* pasture zones in eastern Queensland. Table 16 shows GRASP simulated (131-year) average above ground growth for Native and Indian couch pastures across the five locations. For all locations, average annual pasture growth for native pastures was 11 to 19% higher than those for Indian couch pastures (Table 16).

Table 16. GRASP simulated (131-year; 1889-2019) average annual above ground pasture growth (kg/ha) for 'Native' and Indian couch pastures without trees and without grazing, and the percentage that native pasture was higher than Indian couch.

Climate	Native	Indian couch	% difference
Brian Pastures	4825	4229	14
Rockhampton	5191	4679	11
Charters Towers	3723	3213	16
Emerald	3501	2943	19
Roma	2715	2368	15

The base parameter sets (Appendix 9.5.3) form a foundation for subsequent modelling work. The native parameter sets are robust (Ken Day, *pers. comm.*) and require little if any modification. In comparison, the Indian couch parameters are likely to be improved through the use of this project's SWIFTSYND site data.

Bioeconomic modelling

The bioeconomic modelling (BEM) framework, consisting of the GRASP and CLEM models, was used in this study to quantify the impacts of Indian couch invasion on carrying capacity and animal production for a beef grazing property representative of the Burdekin region in north-eastern Queensland.

It should be remembered that simulation model experiments such as this provide only a prediction. Simulation modelling results should be verified with appropriate field validation over the range of intended management regimes and environments to maximise confidence in their output.

GRASP simulations of native and Indian couch pastures were run for a range of 'fixed' land conditions (0-11), grass basal areas (1-9) and stocking rates (1-50 AE/100ha), for the 'Neutral', 'Wet' and two 'Dry' 30-year climate periods to produce monthly pasture production data for use in CLEM. All simulations assumed *treeless* pastures.

Climate periods: The productivity for native and Indian couch pastures were simulated under four climate periods (C1-C4) at Charters Towers which were rated as wet, neutral and dry. Annual rainfall has been highly variable at Charters Towers, with a variation index (standard deviation/number of years) highest for C3 & C4 (9.9 & 8.9 respectively) and lowest for C1 & C2 (7.2, 6.5 respectively).

For native pastures: with an average stocking rate of 25.5 AE/100ha and average grass basal area of 5%, across the four climate periods and the range of 12 pasture conditions ('0' good to '11' poor condition), average pasture growth ranged from 1220 to 4100 kg/ha, pasture utilisation from 25% to 63% and liveweight gain per head 146 kg/hd to 187 kg/hd.

For Indian couch pastures: with an average stocking rate of 25.5 AE/100ha and average grass basal area of 5%, across the four climate periods and the range of 12 pasture conditions ('0' good to '11' poor condition), average pasture growth ranged from 1430 to 3600 kg/ha, pasture utilisation from 29% to 48% and liveweight gain per head ranged from 142 kg/hd to 180 kg/hd.

Generally, across all climate periods and for good condition pastures, modelled Indian couch pasture growth was 12% less than native pasture. However, for poor condition pastures, there was a 15% increase in growth for Indian couch when compared with native pastures. Similarly, liveweight gains per head for Indian couch pastures were between 3% and 4% lower than those for native pastures for the range of pasture conditions.

Overall, it is apparent that native grass pastures are slightly more productive than Indian couch pastures under the same conditions, and that they support slightly higher liveweight gain per head.

Crop Livestock Enterprise Model (CLEM)

Annual profit and annual AE for the Charters Towers representative property when pastures were dominated by Indian couch were compared with those when it was native pasture. The monthly native and Indian couch pasture biomasses used in CLEM simulations of this property were very high compared with the representative property, as they had been derived without any competing woody vegetation cover for a property that was all A condition land. Consequently, herds which achieved utilisation rates of around 25% for native pastures and 35% for Indian couch pastures were unrealistically large, being two- to three-fold higher than that of the representative property. Likewise, this resulted in unrealistically high annual profits. For these reasons, the representative property based on Indian couch was compared with the representative property based on native pasture in terms of relative rather than absolute differences in annual profits and annual AEs carried for each climate period (Table 17).

Table 17. Minimum, average and maximum annual profits and average annual AE carried for Indian couch enterprises relative to native pasture enterprises for four climate periods.

Climate Period*	**Relative Annual Profit**			**Relative Annual AE**
	Minimum	**Average**	**Maximum**	**Average**
C1 'Neutral'	260% lower	60% higher	70% higher	30% higher
C2 'Dry'	40% lower	40% higher	equal	10% higher
C3 'Wet'	150% lower	50% higher	40% higher	20% higher
C4 'Dry'	190% lower	120% higher	140% higher	70% higher
Average	***160% lower***	***70% higher***	***60% higher***	***30% higher***

*Climate periods include C1 'Neutral' (1903-1932), C2 'Dry' (1941-1970), C3 'Wet' (1970-1999), and C4 'Dry' (1990-2019).

For all climate periods, average annual profits for herds grazing Indian couch were 40 to 120% higher than for herds grazing native pasture. When averaged across the four climate windows, profit for Indian couch was 70% higher than that for native pasture. This was largely due to the 10 to 70% higher herd sizes which were supported by Indian couch pastures in the model, given that their safe pasture utilisation rate was 35% compared with only 25% for native pasture. When averaged across the four climate windows, the herd supported by Indian couch was 30% higher than that for native pasture. In contrast to this, the trend in minimum annual profits were the opposite. In all climate windows, the most severe annual financial losses were 40 to 260% worse for Indian couch compared with native pasture (Table 17). The herd grazing Indian couch also experienced 30% more years when profit was negative compared with that grazing native pastures.

The variability in average annual profits for the Indian couch pasture was of concern. Annual profits when grazing Indian couch ranged from 260% lower to 140% higher than when grazing native pasture. Consequently, the high volatility in finances and significant annual losses makes enterprises with Indian couch pastures riskier than those with native pastures.

It is important to note the influence of the assumptions and parameter values used in this bioeconomic modelling on the productivity of Indian couch pasture relative to native pasture. While Indian couch is widely perceived to be more grazing tolerant than native grasses, its safe utilisation rate has not been determined through grazing trials. Hence, the 40% higher safe utilisation rate for

Indian couch relative to native grasses used in this study may have over-estimated its tolerance to grazing.

Additionally, whilst the stoloniferous nature of Indian couch affords greater tolerance to grazing, the amount of pasture growth that is non-harvestable by cattle is also greater compared to native pastures. For example, indications are that the daily dry matter intake of cattle declines when Indian couch pasture biomass falls below 700 kg/ha, compared to a threshold of 300 kg/ha for native pasture. This was not accounted for in the CLEM modelling.

Furthermore, Indian couch is widely perceived to disappear quickly during dry years and is suspected to have a shallower rooting system than native perennial tussock grasses. While the detachment rates used for Indian couch in this study were slightly higher than those for native grasses, the 'base' sensitivity to soil water deficit parameters for native and Indian couch pastures were the same and, hence, may be underestimating the susceptibility of Indian couch pastures in dry seasons.

The following recommendations for future research would improve the understanding of the impacts of Indian couch on pasture and animal productivity, and how these differences ultimately translate to herd and financial outcomes:

(i) Use the detailed data collected at SWIFTSYND sites during this project to calibrate GRASP parameters for Indian couch pastures;
(ii) Further review of literature and SWIFTSYND data for the Indian couch pasture production estimates, with particular focus on pasture root depth and soil-water thresholds for pasture growth, intake restrictions associated with structure and biomass, yield-cover relationships and regrowth following "grazing";
(iii) Seek further advice to inform parameterisation of key drivers of profit such as safe pasture utilisation rates, rates of change of condition and forage quality;
(iv) Undertake sensitivity analyses of detachment, intake limitations, pasture utilisation rates, rates of change in condition, and forage quality to improve understanding of these key drivers of grazed Indian couch productivity and profitability;
(v) Foster a CLEM user working group to improve knowledge, understanding and skill in using CLEM and extracting useful outputs;
(vi) Investigate approaches to capture non-harvestable forage and animal intake restrictions in CLEM; and
(vii) Develop an easy-to-understand guide to use CLEM to ensure insights gained from this project are transferable.

3.4.5 Raising awareness

The project investigated the potential impacts of Indian couch on production and carrying capacity. This was done through field work, the collection of producer feedback and anecdotes, and through bioeconomic modelling. Field work showed pasture production differences between Indian couch and native pastures were attributed to a range of factors, such as soil type, rainfall, and legume content.

Feedback from beef producers indicated that Indian couch has a significant disadvantage to native pasture in that it has reduced drought tolerance when compared to native grasses, making it a less reliable source of feed: "*Less reliable feed source, as reasonable production only comes with good seasons*"; "*When it's raining it* [Indian couch] *is doing well and so are the weight gains* [of cattle].

Carrying capacity is up too. When its dry, Indian couch dies out quick and has no substance to it so decrease in weight gains/carrying capacity". This is also consistent with the modelling work carried out by the project that showed overall, modelled average annual profits for Indian couch pasture enterprise were much more variable than those for native pasture enterprises, and much lower during extended dry periods.

The bioeconomic modelling work showed the production gains from Indian couch are in part attributed to the higher utilisation rates and less dynamic degradation rates modelled for Indian couch relative to native pastures, as Indian couch is a grazing tolerant species. However, compared with native pastures, Indian couch deteriorates markedly during dry periods and droughts, exacerbating forage deficits on these occasions, leading to high financial losses. Furthermore, it is likely that daily dry matter intake of cattle is more often restricted when grazing Indian couch pasture compared to native pasture. As Indian couch has a greater proportion of un-harvested biomass when compared with upright native tussock grasses, this is likely to only further exacerbate the risks associated with Indian couch pastures.

Appendix 9.4.2 shows a final 'FutureBeef' article prepared for publication for the purpose of disseminating project findings and raising awareness on the spread and impact of Indian couch in pastures.

3.5 Conclusion

3.5.1 Key findings

Field studies conducted by the project showed that pasture production of Indian couch relative to native pastures varied between environments, due to differing responses to climate, soil type, and the presence of legumes. Although observed differences in mean annual production between native and Indian couch dominant pastures were not statistically significant across locations and seasons, an assessment of quadrat level data for each SWIFTSYND site indicated three out of ten significant differences between site.year combinations. Two of these occasions on heavy soil types and under below average rainfall conditions in the Burnett-Mary catchment favoured native pasture, and one occasion on a sedimentary red earth and under above average rainfall conditions in the Burdekin catchment favoured Indian couch.

Findings of production losses for Indian couch during low rainfall years and production gains for Indian couch during high rainfall years is consistent with producer experience which suggested that the productivity of Indian couch pastures is reasonable during good seasons, but poor in dry years. Producer experience also suggested that overall, Indian couch is a less reliable feed resource than native grasses. The GRASP simulations of pasture growth also showed that Indian couch was generally less productive than native grasses, even in the absence of trees. The inconsistent productivity of Indian couch between years was also reflected in the findings of bioeconomic modelling, where annual profits from grazing Indian couch were much more variable than those for native pastures.

While bioeconomic modelling found that, on average, both higher stocking rates and annual profits could be achieved with Indian couch, it is likely that this was over-estimated due to the absence of trees and the use of assumptions which favoured Indian couch. Even so, the most severe simulated annual losses with Indian couch were on average 2.6-fold worse than those when grazing native pastures, and with Indian couch there were 30% more years with financial losses compared with native pasture. In the rangelands of Queensland where climate variability is very high and likely to increase over time, the invasion of native pastures by Indian couch is likely to make beef cattle properties more vulnerable to extended dry periods and drought, during which times very high financial losses will be incurred.

3.5.2 Benefits to industry

The project has provided detailed information on the impacts of Indian couch on pasture productivity, carrying capacity and enterprise finances through a combination of field work, collection of producer feedback and anecdotes, and through bioeconomic modelling.

Indian couch pastures can provide good quality and quantity forage during good seasons which support high cattle productivity. However, compared with native pastures, Indian couch deteriorates markedly during dry periods and droughts, exacerbating forage deficits on these occasions, leading to high financial losses. These findings echo the producer anecdotes captured by the project: "*Quality OK at certain times*" and "*Less reliable feed source, as reasonable production only comes with good seasons*". Overall, Indian couch is a much less reliable and riskier feed resource when compared with native pastures.

The development of base parameter sets for simulating productivity of Indian couch, a large amount of additional field data that can be used to improve these parameters, and the development of bioeconomic modelling skills has provided a solid foundation for further assessment of the value of Indian couch to industry in northern Australia.

4. Determining the impacts of Indian couch on landscape function

4.1 Background

Feedback from beef producers indicates both benefits and shortcomings associated with Indian couch grass. For example, "*it holds soil together*"; being able to provide high ground cover and arrest soil erosion, versus "*it doesn't last*"; having reduced drought tolerance when compared to native grasses and being a less reliable source of feed (Spiegel 2016). The literature suggests there is some benefit of Indian couch on landscapes, particularly on hillslopes, where pastures dominated by Indian couch have been reported to produce less run-off and soil loss than those dominated by native tussock grasses, when compared at the same level of cover (Scanlan et al. 1996b). Supporting these findings, the results of a longer, larger scale study by Bartley et al. (2014) highlighted the ability of Indian couch to control surface erosion under conditions of reduced stocking and wet season rest. However, Bartley et al. (2014) also emphasised the importance of increasing the proportion of deep-rooted native perennial grasses in the pasture to reduce total annual runoff and sediment yields.

An opportunity exists to build on prior knowledge to better understand the landscape function impacts associated with Indian couch in pastures and the effects of management. This will be important for not only confirming producer anecdotes and to better inform Industry on the impacts of Indian couch in pastures, but also to justify management options for beef producers.

4.2 Objectives

Outputs: Analysis of the impacts of Indian couch invasion on landscape function.
Outcomes: Increased awareness and understanding by producers on potential impacts of Indian couch on landscape function; by 2022, 70% of the producers in north and central Queensland will be aware of the extent of Indian couch spread.

4.3 Methods

4.3.1 Review of literature on landscape function impacts

A collection of significant literature on Indian couch was reviewed to identify attributes of Indian couch contributing to landscape function and to consider ways to undertake field work and develop a method to assess the impact of Indian couch on landscape function.

Levels of success/efficiency of methodology employed

Although this was achieved, more questions than answers were revealed. Benefits and shortfalls of Indian couch grass, along with gaps in research knowledge were summarised. In addressing options for field work and for assessing landscape function impacts of Indian couch, the issue of management as a confounding factor was realised. The problem identified was that management histories of pastures now dominated by Indian couch are typically very different to those for intact native pastures. Hence, the project did seek out expert advice to determine the best approach to take for field work. This was done using an Indian couch Think Tank (see below).

4.3.2 Expert opinion captured using an Indian couch Think Tank

A Think Tank was used to determine the best way forward to assess the landscape function impacts of Indian couch grass. This included two facilitated workshops conducted via Zoom and involving the active participation of experts in grazing land management, landscape function, and statistical analysis. The first session took place on the 21st of October in 2020 and was an ideas generator. Separate break-out rooms as well as use of a whiteboard feature in Zoom were utilised. Five questions were presented (as listed below) to the Think Tank participants, with the break-out sessions allowing for smaller group discussions. Groups re-joined so findings from each group could be presented back to the whole group and expert opinion could be captured.

The five questions (Qs) that were addressed by the Think Tank included:

- Q1. What are the most important features/aspects of landscape function?
- Q2. What are the different or common scenarios of Indian couch invasion in pastures?
- Q3. How do Indian couch plants compare (growing features) to more desirable 3P tussock grasses?
- Q4. What do we know and what don't we know about Indian couch impacts on landscape function?
- Q5. How can the landscape function impacts of Indian couch invasion in pastures be best assessed and quantified?

The second session took place on the 18th of November 2020 and was used to confirm the experimental work, as described below (see section 4.3.3).

Level of success/efficiency of methodology employed

The Think Tank proved a valuable exercise to capture expert knowledge and opinion and to assist with project direction. A significant benefit was the realisation that there are many facets to understanding the landscape function impacts of Indian couch, and that such an endeavour would require more resources than were available to this project.

4.3.3 Preliminary landscape function analysis (LFA) on Indian couch and native grass patches

The Think Tank decided the site requirements for preliminary landscape function analysis work. This included selecting and establishing three sites, each of different soil type and all being mixed/intermediate pastures with native grasses and Indian couch (Appendix 9.6.1).

Level of success/efficiency of methodology employed

This was achieved in part. Sites were established and data from each site collected. Due to the complexity of designing treatments to capture key LFA measures in variable environments, effort was redirected to problem solving and the planning and execution of an Indian couch Think Tank as described above. It took time to confirm the experimental approach and subsequent field work meant this activity was not seen through to full completion. Valuable insights were obtained from the Indian couch Think Tank; the approach used to try to capture LFA in a modified and variable environment, and the resulting ideas and recommendations for future research.

4.3.4 Raising awareness

A synthesis of existing knowledge and expert opinion was used to identify key messages for Industry.

4.4 Results & Discussion

4.4.1 Landscape function impacts: Review of literature

Indian couch plants can quickly spread over bare soil by stolons that root at the nodes to grow a network of plants. Indian couch can provide high ground cover and arrest soil erosion, being ideal for soil conservation purposes (Truong and McDowell 1985). A major shortfall, however, is the reduced capacity of this perennial to withstand long periods of drought relative to other perennial grasses (Whyte 1968), thus its cover can be very unreliable.

A challenge when investigating the landscape function impacts of Indian couch in pastures is unravelling cause and effect of Indian couch invasion. Whether Indian couch causes a decline in land condition or invades a landscape because of declining land condition was called into question by the project. For example, the assessment of landscape function impacts of an Indian couch dominated pasture relative to an intact native pasture would be confounded by management histories, where Indian couch is often symptomatic of pasture decline. The management of Indian couch could also promote or conversely limit its potential to contribute to landscape function: the landscape function processes such as water cycling could be affected differently by heavily grazed, short lawn-like Indian couch versus lightly grazed, upright Indian couch. Additionally, reducing utilisation of Indian couch and spelling it, might lead to desirable economic and ecohydrological flow-on effects, despite the ability of the grass to withstand continuous heavy grazing.

4.4.2 Expert opinion captured during the Indian couch Think Tank

Five questions were addressed, as detailed below.

Q1. What are the most important features/aspects of landscape function?

- Landscape organisation, patch organisation, plant-derived litter, soil surface condition, and soil nutrients and biodiversity.
- Erosion process, the perennial densities, plant basal area, plant height, and soil type.
- Litter is very important and drives the landscape function recovery, and a big part of that is water infiltration.
- Previous studies at “Virginia Park” over ten years showed very little litter accumulation under Indian couch (Jeff Corfield, *pers. comm*.); “*if you don’t have litter in the first place, you have nothing for macroinvertebrates to incorporate into the soil*”. It will be worth looking at the number of macropores in the system.
- Plant basal area is also a major driver of landscape function.
- Landscape function could mean different things depending on area of interest, for example water quality outputs versus biodiversity outcomes, versus production outcomes.

Q2. What are the different or common scenarios of Indian couch invasion in pastures?

- Indian couch is an invader of space.

- Indian couch is also a prolific seeder with high seed viability and is [adversely] allelopathic/highly competitive.
- Indian couch can spread onto properties where it is found in the road reserve; Indian couch can spread from fence lines and on the edge of the road.

Q3. How do Indian couch plants compare (growing features) to more desirable 3P tussock grasses?

- A reduced root depth of (for example) 10 to 15cm (Brett Abbott, *pers. comm.*) for Indian couch compared with up to 2m for native tussocks is expected to reduce soil biodiversity.
- A high density of Indian couch is required to ensure adequate basal area.
- Marked fluctuations in biomass and cover can occur for Indian couch depending on growing conditions.
- Indian couch can grow on fertile and poor soils, in well managed and degraded landscapes, and in run-down and Buffel dieback affected pastures.
- Indian couch is stoloniferous, and this growing feature allows for higher leaf area for photosynthesis.

Q4. What do we know and what don't we know about Indian couch impacts on landscape function?

- How Indian couch affects water infiltration, erosion and runoff is not known. It is hard to tease out land condition and plant species effects, especially on water infiltration. Comparative analysis is required, looking at natives versus Indian couch and how effective they are on current landscape condition at capturing water.
- Also, the effect of Indian couch on soil function and biodiversity is presumed, so it is not really known. There is biodiversity work focussing on above the ground (e.g., Kutt and Fisher 2011) – these are associated effects. No work done on below the ground.
- What we know is ground cover provided by Indian couch can be very unreliable. There might be 70% ground cover, and this can drop to 25% during a drought or during a very dry season. This inconsistent ground cover could lead to erosion after a drought and a heavy rainfall event.
- Anecdotally, there is very little litter cover provided by Indian couch and the litter is not well retained as with the natives.
- The influence of trees on water infiltration must be considered and presence of trees recorded during any field work.
- It is not known how management of Indian couch plants or the plant age or growth stage effects water infiltration and runoff, i.e., older plants with higher plant basal areas and with upright growth habit versus younger plants (weakly rooted daughter plants) versus smaller, prostrate-like (lawn-like) plants.

Q5. How can the landscape function impacts of Indian couch invasion in pastures be best assessed and quantified?

- Are paired sites necessary? Take mixed sites and divide these up into patches (e.g., Indian couch and native tussock patches) and then do sampling for soil and other measures within the different patches. Each mixed site is an experimental plot, with same historical treatment, and you sample within that. Repeat the same experiment across different land types and soil types. Use a combination of PatchKey, LFA, infiltration, soil organic matter, number of macropores, and root depth. Consider repeat sampling to capture temporal environmental fluctuations.

- Other ancillary questions were raised such as: How long does it take to recover the landscape? Does wet season spelling work? How do we graze Indian couch dominated pastures, so it is sustainable?

4.4.3 Understanding the impact of Indian couch on landscape function

As stated in section 4.3.3, this was achieved in part. Sites for Landscape Function Analysis (LFA) were established and data from each site collected. Due to the complexity of designing treatments to capture key LFA measures in such variable environments, effort was redirected to problem solving and the planning and execution of an Indian couch Think Tank to collect expert opinion. It took time to confirm the experimental approach and subsequent field work meant this activity was not seen through to completion. Reflection and recommendations are instead detailed below, of which are believed to have important associated management implications.

Future research would ideally investigate the impact of Indian couch on (i) soil function and biodiversity, (ii) water infiltration and run-off – and how this is affected by grazing intensity, and (iii) contribution of litter to landscape recovery. Despite Indian couch providing some landscape function, such as stabilising soil, it is expected that Indian couch alone even as a well-managed pasture will function better with the incorporation of deep-rooted perennial grasses. This is particularly important for carbon accounting and for 'healthy soils' where soil processes such as nutrient and water cycling are functioning optimally to support soil aggregate formation and soil organisms and biodiversity.

In addition, a significant unknown is whether a reduction in stocking rate and implementing wet season spelling can result in the native perennials re-establishing and potentially out-competing Indian couch. The long-term study carried out by Bartley et al. (2014) indicated this is possible, although recovery processes take a long time. Thus, methods to speed up the recovery process are required. The reduction of Indian couch seed loads will be a major challenge when restoring Indian couch dominant pastures, as will a non-existing or depleted native seed bank. Thus, the seed production of Indian couch under different grazing strategies could warrant investigation. Possible treatment options, such as strip ploughing and sowing other grasses and legumes and options to successfully reintroduce native seed or plants back into the landscape should also be explored with associated cost-benefit analysis. As should any possible adverse allelopathic effects of Indian couch on other species (Hu and Jones 1997; Calvert, 2001). Different treatment options are considered in more detail in section 5.

4.4.4 Raising awareness

In a continued effort to raise community awareness on the issue of Indian couch spread in pastures, the project released two feature articles (North Queensland Register 2021; Queensland Country Life 2021) providing insights into the production impacts and reduced drought tolerance of Indian couch and management options (see Appendix 9.4.3; Fig. 64 & 65). Producer views on the subject included "*It's not good! Indian couch doesn't handle drought like native tussock grasses. It's only a surface grass so it needs to come back from seed compared with native grasses that survive and reshoot*", "*One way to maximise value from Indian couch is to compliment it with stylo*".

Building on the two feature articles described above was the social media posting (see FutureBeef 2021 and section 2.4.4) that highlighted both virtues and shortcomings associated with Indian couch. Feedback from producers reveal "*it holds soil together*"; being able to provide high ground cover and arrest soil erosion, but "*it doesn't last*"; having reduced drought tolerance when compared to native grasses and being a less reliable source of feed.

4.5 Conclusion

4.5.1 Key findings

Landscape function is a measure of (i) stability (resistance to erosion), (ii) infiltration (capacity for rain and run-on water to infiltrate) and (iii) nutrient cycling (organic matter decomposition and cycling). The literature review and Think Tank results show there is a better understanding of the impact of Indian couch on soil 'stability' compared with understanding of the impacts of Indian couch on water infiltration and nutrient cycling. For example, Indian couch is a good soil stabiliser and being stoloniferous can provide high ground cover to protect the soil surface, trap sediment, and allow for some level of water infiltration. These desirable attributes to arrest soil erosion, however, are limited by the reduced ability of Indian couch to persist during dry periods to provide consistent and reliable cover.

By contrast, the effect of Indian couch on water cycling is not well documented and difficult to ascertain, given its presence on landscapes is often a symptom of land condition decline. There is anecdotal evidence to suggest landscape recovery processes and indeed water infiltration will be reduced for Indian couch relative to native 3P tussock grasses due to lower litter accumulation and retention. Furthermore, the effect of Indian couch on soil function and biodiversity is often presumed, thus warrants further investigation. Any reduction in litter retention is expected to have many deleterious flow-on effects such as reduced nutrient cycling and soil function, along with reduced water cycling.

4.5.2 Benefits to industry

The importance of ecological functions, such as ecohydrology and nutrient cycling and impacts on landscape function recovery processes have been realised and awareness raised. Much of the benefits of Indian couch to landscape function can be attributed to its ability to stabilise soil and arrest soil erosion. However, this is only the case when it can provide cover. Its ability to stabilise soil is not an indication of its ability to cycle water. Furthermore, landscape recovery processes may be hampered by Indian couch because of reduced litter production and retention when compared to native 3P tussock grasses. This only reinforces the need for producers to, either better manage pastures to prevent Indian couch spread, or otherwise better manage Indian couch dominant pastures to improve landscape function and production potential.

5. Preliminary research into control options

5.1 Background

Many important management implications and challenges have already been alluded to in previous sections, namely the high seed production from Indian couch and its ability to tolerate continuous heavy grazing. To develop control options for Indian couch, it is necessary to first have a better understanding of Indian couch ecology and how this grass responds to different grazing strategies and fire treatments when compared to the native pasture species that it threatens to replace. This chapter reports on the results of separate collaborative projects to gain a better understanding of Indian couch autecology and seed longevity and hence possible control options for Indian couch.

The projects reported herein included (i) Stocking rate treatments on long-term trends of plant basal area, (ii) Heat and smoke treatments on seed germination and viability, and (iii) Seed longevity using controlled ageing technology (CAT).

5.2 Objectives

Outcome: Assessment of the role of fire for controlling Indian couch; preliminary testing of other control options as covered by PhD research; and synthesis of research findings and expert opinions.

5.3 Methods

5.3.1 Stocking rate treatments on long-term trends of plant basal area

The aim of this study (Macor 2019) was to quantify long-term changes in native pasture composition (based on plant basal area measurements) in north Queensland under different grazing strategies, with a particular focus on Indian couch and native 3P (perennial, productive and palatable) grasses. Different grazing strategies were investigated, including heavy stocking rate (SR), moderate SR, rotational spelling, variable SR with wet season spelling and variable SR based on SOI (Southern Oscillation Index) weather forecasts. This investigation took place on the Wambiana Grazing Trial (WGT) located near Charters Towers in north Queensland in May 2019 and builds on pre-existing data sets from previous monitoring carried out in 2004 and 2011 (O'Reagain, unpublished data). The three sampling points over time allowed for the long-term changes in basal composition to be determined, spanning 15 years.

Macor (2019) sampled from a random selection of pre-existing monitoring sites (permanently marked transects) in the ten paddocks (5 different grazing strategies replicated twice) at the WGT on the "box" land type. For each paddock, 2x 50m transects were selected and plant basal data of the predetermined species was collected using the line intercept method. There were, however, slight variations in the transects used between 2004 and 2011 due to extensive pig damage in some sections, resulting in a couple of unaffected sections in spare transects being used (Macor 2019).

During field sampling of transects, a tape measure was stretched out between the permanent star pickets that marked to start and end of a transect to guide operators along the tape. Moving along the transect all 3P plant/tussock and non-annual grasses that intersected the selected edge of the tape, were recorded. As per Macor 2019: *Only one side of the tape was used all the time i.e., the right or left side. The following data was recorded: (i) Start distance of tussock/plant base along tape* *and (ii) End distance of tussock/plant base along tape. Note when distance between tussocks of the same species were less than 1.5 cm apart, they were classified as the same grass plant and included in the recorded measurements. The grasses measured in the species groups included*:

- 3P grasses: *Themeda triandra*, *Heteropogon contortus*, *Dichanthium sericeum*, *Bothriochloa ewartiana*, *Dichanthium fecundum*, *Eulalia aurea*.
- 2P grasses: *Chrysopogon fallax*, *Digitaria browniii*, *Digitaria ammophila*, *Panicum effusum*, *Panicum queenslandicum*, *Paspalidium* spp., *Eragrostis lacunaria*.
- Indian couch (*Bothriochloa pertusa*).

Statistical analysis

As per Macor (2019): *Raw measurements of the start and end distance of tussock/plant base along tape were first converted into basal cover under the transect (m) by subtracting the end from the start. The sum of basal cover under the transect (m) of each species per paddock was then calculated. Using the distance of the transect (~200m) the % basal cover was calculated, (sum cover under the transect / transect length*100). Percent cover was the variable used for analysis*.

Analysis of changes in species composition focussed on Indian couch, 3P and 2P grasses. The data was analysed using two-way ANOVA using Minitab (v19). Residual plots (residual versus fitted values and normal probability plots) were also used to check assumptions for the models. A natural logarithm transformation was applied where necessary to improve these residual plots to an adequate pattern. Comparisons were made for significant differences using the Tukey method.

Level of success/efficiency of methodology employed

The method was an efficient and effective way of assessing long-term trends in grass basal cover, as there was already pre-existing data to build on that was species specific (and including Indian couch data) and covered different grazing treatments and a period with different climatic conditions.

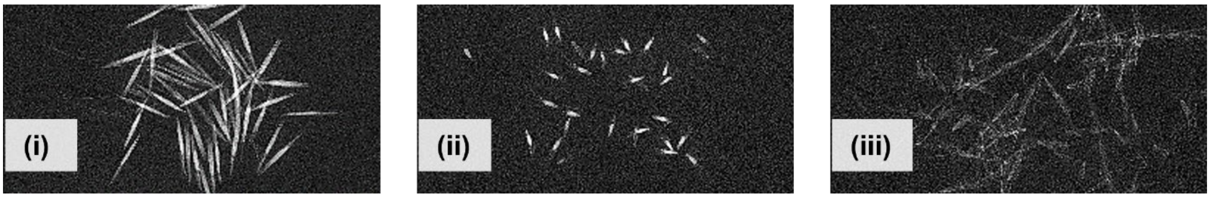
5.3.2 Role of fire on seed germination and viability

Another Honours study from UQ looked at the effects of fire (dry heat and smoke treatments) on Indian couch seed relative to native Black speargrass (Cuzens 2020). This study builds on earlier work carried out by McIvor and Howden (2001) that indicated seed germination of Black speargrass is promoted by heat exposure, compared to Indian couch where heat has a much smaller stimulatory influence on breaking seed dormancy.

The aim of the study was to determine the effects of fire, both heat and smoke, on the germination/viability of Indian couch seed in comparison to Black speargrass. Two laboratory experiments were established at the University of Queensland's Gatton Campus plant science facilities, where a Labec® oven was used to assess dry heat and a handmade smoking chamber to assess plant-derived smoke. Seed, and plant litter for producing plant-derived smoke, was collected at the Spyglass Beef Research Facility in the Charters Towers district and from neighbouring grazing lands.

Originally three test species were to be used: India couch, Black speargrass and Desert bluegrass (a native '*Bothriochloa*' species). However, after putting seed through an X-ray machine, to have a look at the amount of filled seeds as an indicator of viability, revealed very low (<5%) filled seed (i.e., low viability) for Desert bluegrass when compared with Indian couch (60-70% filled seed) and Black speargrass (70-80% filled seed), (Fig. 41). Based on this finding, it was decided to only test the black speargrass and Indian couch in the temperature and smoke experiments.

Figure 41. X-ray machine images of grass seeds to determine the amount of filled seeds as a measure of seed viability for (i) Black speargrass, (ii) Indian couch and (iii) Desert bluegrass. Images courtesy of Dr Shane Campbell, School of Agriculture and Food Science, The University of Queensland.



Experiment 1 tested 56 temperature x duration combinations using a split-split plot design, with temperature being allocated to main plots and heat exposure to sub-plots. There were seven temperatures (50, 75, 100, 125, 150, 175 and 200^{o}C) and eight exposure times (30, 60, 90, 120, 150, 180, 210 and 240 s), with each combination replicated three times. Experimental units comprised 50 randomly selected seeds. Following heat exposure, seed samples were treated with 1% Thiram fungicide solution and placed in a germination cabinet set at a 12 hour 30/20^{o}C temperature cycle and 12 hour day/night lighting regime, to mimic field conditions. Distilled water was added daily to maintain moisture content. Germination recordings were taken daily by removing the germinated seeds once recorded. Seeds were considered germinated once the radicle was at least 2mm long. Black speargrass samples were removed after 12 d as nil germination was recorded for 3 consecutive days. Indian couch samples were recorded for a total of 49 d until germination ceased.

Ungerminated seeds were then subjected to viability testing using a 1% tetrazolium tetrachloride solution. The seeds were placed in small test tubes containing 5 mL of solution and left submerged for at least three days. Following submergence, each seed was cut longitudinally in half to inspect for signs of viability (based on whether they stained pink or not), (Moore 1985; Campbell 1995) and the results expressed as percent viability of total seeds.

Experiment 2 involved exposing seeds to plant-derived smoke and submerging seeds in commercially available smoke water concentrate. There were 8 smoke treatments, comprising a control (0 smoke), 5 direct smoke treatments (1 to 30 min) and 2 smoke water treatments (100ml/L and 200ml/L). Smoke treatments were allocated to main plots and species (Black speargrass and Indian couch) to sub-plots, with each combination replicated four times. Experimental units comprised 30 randomly selected seeds. Smoking involved testing one replicate at a time. After smoking, seeds were immediately removed from the petri dishes and placed in new petri dishes lined with Whatman's filter paper and the treatment recorded.

For the smoke water treatments, Regen 2000 Smokemaster was used at two concentrations, 100ml Smokemaster/L and 200ml Smokemaster/L of deionised water. Allotments of 30 seeds were placed in individual 70ml specimen containers and four replicates of each species were then submerged in either the 100ml/L or 200ml/L concentration. The seeds were left to absorb the smoke water for 24hr inside the germination incubator (described previously for the germination testing). Following this, the seeds were drained from the liquid and placed in petri dishes lined with Whatman's filter paper. Once all direct smoke and smoke water treatments had been applied, petri dishes were moistened with 1% Thiram fungicide solution and subjected to standard germination testing as described previously. Once germination ceased, viability testing was also undertaken using the tetrazolium procedure used for the dry heat experiment.

Statistical analysis

As per Cuzens (2020): *All statistical analysis was undertaken using R Studio, following arcsine transformation of the percentage data. Analysis of variance was used to determine if there were significant differences between treatments, and if there were, either Fishers Least Significant Difference Test or Tukey's test was used to identify which treatments differed from each other at P<0.05. All back transformed data was presented in graphic format*.

Level of success/efficiency of methodology employed

While there were clearly differential responses in germination and viability between the native Black speargrass and the exotic Indian couch following exposure to heat and smoke treatments, the data exhibited high variation. This was particularly the case for the dry heat experiment where experimental units comprised 50 seeds and each treatment was replicated three times. For future studies, seed lots of 30 seeds and a minimum of five replications is recommended.

5.3.3 Seed longevity using CAT

The Tropical Weeds Research Centre (TWRC) in Charters Towers tested the longevity of Indian couch seed collected in 2019 from Spyglass and neighbouring grazing lands. This was conducted using laboratory-controlled ageing, also known as CAT (controlled ageing test; Long et al. 2008). Seeds were aged at 60% relative humidity and 45°C. The time for seed viability to decline depends on the biochemical resilience of seeds to this stress. The resultant seed survival curves allowed the calculation of seed longevity parameters, including P_{50}, which is the time taken for germination to fall to 50% under these specific conditions. Three broad seed-persistence categories were used: <1 year (category *transient*, P_{50}<20 days), 1 to 3 years (category *short-lived*, P_{50}=20 to 50 days, and >3 years (category *long-lived*, P_{50}>50 days).

Results for Indian couch were compared with other CAT test data, including grasses: Grader, Thatch, Giant Rat's Tail, Gamba and African fountain grass.

Level of success/efficiency of methodology employed

Estimates of seed longevity from buried field packet trials require thousands of seeds and run for up to 15 years. The laboratory-based CAT uses much less seed and can be completed in months, with the CAT and buried packet trials providing broadly consistent estimates of seed longevity.

5.4 Results & Discussion

5.4.1 Stocking rate treatments on long-term trends of plant basal area

The UQ Honours project investigated pasture trends as related to different stocking rates, with special emphasis on Indian couch (Macor 2019). This work took place at the WGT in north Queensland, capturing different stocking rate treatments and a "box" land type (refer to methods, section 5.3.1). The key findings from this project are summarised below, focussing on results for the 3P grasses and Indian couch.

Combined grass response: A bulk analysis of all the grass species revealed year significantly (P<0.001) influenced overall basal cover, with 2011 providing the highest average basal cover of 8.9%, compared with 2004 (3.2% average basal cover) and 2019 (a very low 1.6% average basal cover).

Indian couch: Year also had a significant (P<0.001) effect on overall basal cover of Indian couch, with the highest average basal cover of 5.8% for Indian couch recorded in 2011 and a lower average basal cover recorded for Indian couch in 2019 of 0.5%. In 2004, the average basal cover for Indian couch was very low at 0.01%.

3P grasses: In contrast to Indian couch, the average basal cover of 3P grasses was significantly affected by both year (P<0.001) and treatment (P<0.001), and the interaction of year with treatment (P<0.05). The two variable (VAR) treatments (variable stocking rate with wet season spelling and variable stocking rate based on SOI weather forecasts) and the rotational spelling (R/spell) treatment all followed a similar trend increasing slightly from 2004 to 2011, before declining to their lowest respective levels in 2019. All other treatments (i.e., continuous grazing treatments of heavy stocking rate HSR and moderate stocking rate MSR) decreased from 2004 to 2011 then further declined between 2011 and 2019.

By 2019, the greatest differences in the basal cover of 3P grasses were between the HSR treatment and the R/spell treatment, which recorded the lowest and highest proportions, respectively. The SOI treatment also had a significantly greater proportion (P<0.05) of 3P grasses than the HSR treatment and was not significantly different (P>0.05) to the R/spell treatment. The MSR and VAR treatments had a relatively small proportion of desirable 3P grasses and were not significantly different (P>0.05) to the HSR treatment.

Key findings: As this investigation only found a significant difference between years and not grazing treatment when the basal cover of all grasses was analysed as a collective group, it is evident that prevailing climatic conditions had a major impact on the % basal cover of the grass species measured. For instance, the below average rainfall recorded in 2004 at WGT was very different to the above average and well distributed (wet and dry seasons) rainfall recorded in 2011, with drought years returning between 2011 and 2019 (Macor 2019).

When Indian couch was analysed individually, a significant difference in cover was found between years but not grazing treatments. Imposed grazing strategies did not have a significant effect on the basal cover of Indian couch. These results indicate the tolerance to grazing for Indian couch, regardless of stocking rate treatment, and climate as an overarching factor influencing its basal cover. Grazing is, however, facilitating its spread, with the rapid expansion of this grass observed during drought-breaking rains (post 2007) being exacerbated under heavy stocking (Peter O'Reagain, *pers. comm.*).

For the 3P native tussock grasses, a significant (P<0.05) interaction between year and grazing treatment was found to effect cover. Perennial native grasses are extremely susceptible to overgrazing during wet seasons. Often there is synchronisation of tiller production at the onset of the wet season between these grasses (Ash and McIvor 1998). Therefore, moderate to heavy grazing in wet season restricts new growth and reduces standing biomass in the following year and can affect species abundance two years after the grazing event (Ash and McIvor 1998). The R/spell treatment however, spells pastures during the wet season allowing the native perennial grasses to produce ample tillers resulting in a higher biomass in the following season.

5.4.2 Heat and smoke treatments on seed germination and viability

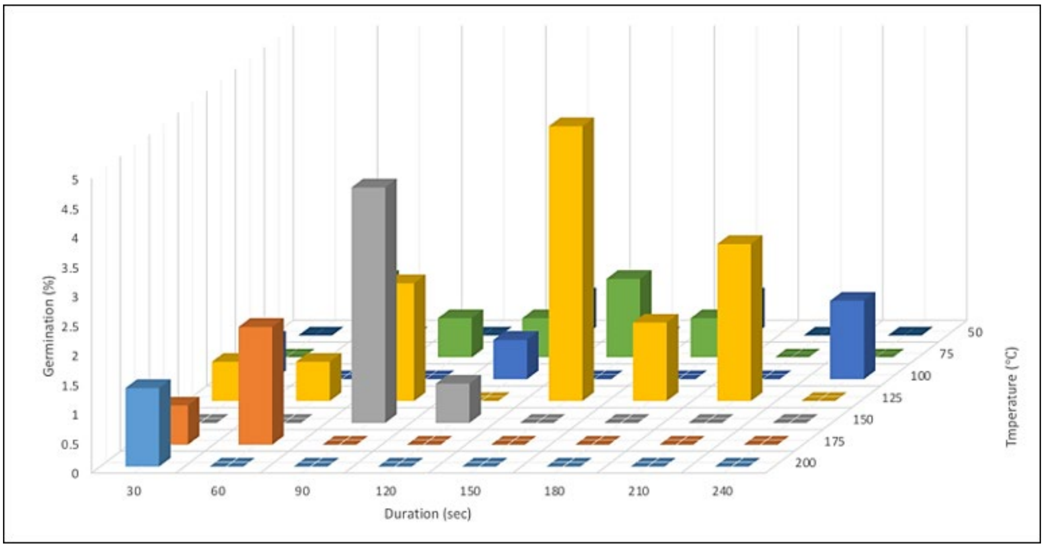
The results outlined below are sourced from Cuzens (2020).

Dry heat experiment: Effect on seed germination and seed viability

Black speargrass

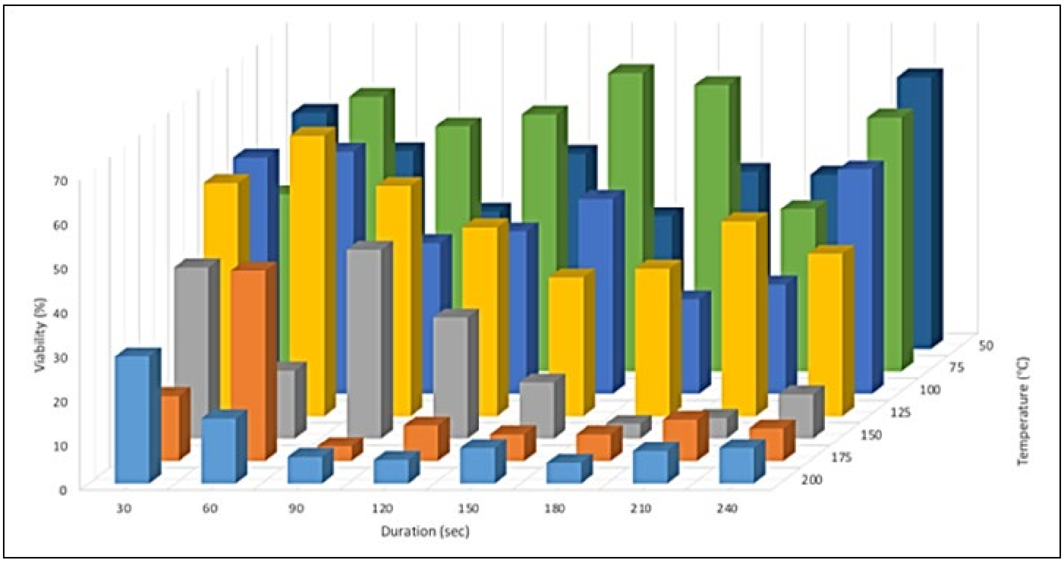
Although germination of this species remained relatively low (≤5%) following heat treatment, a significant (*P*<0.001) temperature x duration interaction still occurred (Fig. 42). Germination averaged ≤1% when seeds were exposed to temperatures between 50-100°C, irrespective of the duration. At 125°C, germination increased significantly to 5% after exposure for 150 sec, indicating a slight stimulatory effect. Similarly, germination peaked (i.e., another slight stimulatory effect) at 4% at 150°C, but at a shorter exposure time of only 90 sec. At 175°C maximum germination of 2% occurred after 60 sec exposure time. At 200°C minimal germination (1%) occurred at the shortest exposure duration of 30 sec, but nil germination was recorded thereafter with increasing exposure.

Figure 42. As per Cuzens (2020): *The relationship between duration (sec) and temperature (^{o}C) on the germination (%) of Black speargrass seed.*



The viability of Black speargrass seed as determined by the tetrazolium tetrachloride (1%) reagent test was significantly impacted (*P*<0.002) by a temperature × exposure duration interaction (Fig. 43). For temperatures between 50 to 125°C high variability was recorded across the various exposure durations which ranged between 21% to 67% viability, but there was no distinct pattern of viability associated with exposure duration. The impact of high temperatures became most pronounced once the temperature reached 150°C with exposure durations of 150 sec or higher reducing viability to ≤13%. At higher temperatures of 175°C and 200°C exposure for 90 sec reduced viability to ≤10%. However, none of the temperature × duration combinations caused complete loss of viability in seed of Black speargrass.

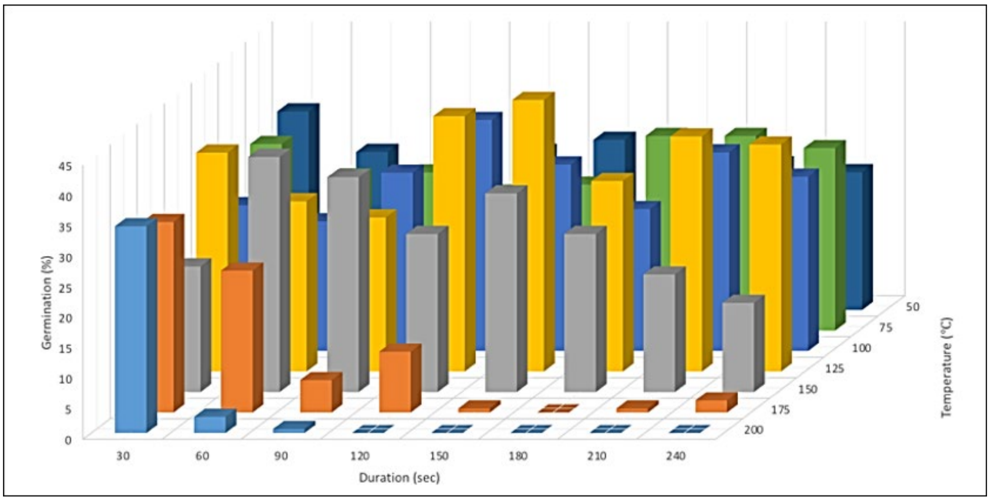
Figure 43. As per Cuzens (2020): ***The relationship between duration (sec) and temperature (°C) on the viability (%) of Black speargrass seeds*.**



Indian couch

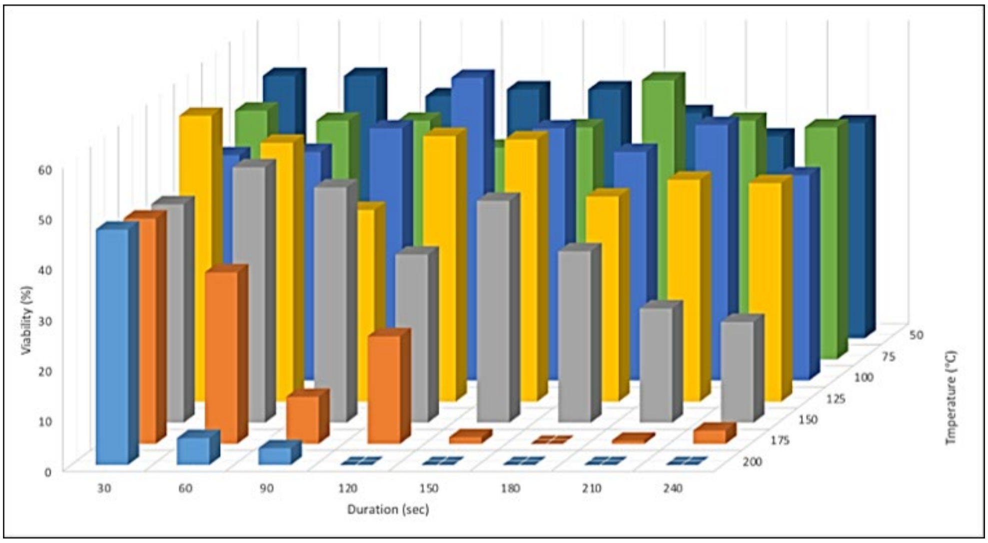
The germination of Indian couch was also significantly affected by temperature and duration of exposure ($P<0.001$); however, the germination level of Indian couch was greater than Black speargrass, which reflected a greater mean germination (22.7%) across all treatments and did not indicate any stimulatory effects (Fig. 44). For Indian couch, germination was variable and averaged between 26-38% when seeds were exposed to temperatures of 50-125°C, with no distinctive trend associated with the duration of exposure. As the temperature increased to 150°C, germination peaked at 35% at 60 sec, before decreasing as duration increased. Similarly, at 175°C, germination peaked at 31% but at a shorter duration of 30 sec. Germination declined significantly thereafter with increasing exposure time, with less than ≤2% germination recorded between 150-240 sec. Similarly, at 200°C germination also peaked at 30 sec (34%), with no germination occurring from 120 sec onwards.

Figure 44. As per Cuzens (2020): ***The relationship between duration (sec) and temperature (°C) on the germination (%) of Indian couch seed.***



Seed viability for Indian couch was also significantly impacted (*P*<0.001) by a temperature × exposure duration interaction (Fig. 45). As for Black speargrass, there was no distinct pattern in viability (ranged between 42-52%) associated with increasing temperatures and exposure durations at temperatures between 50 to 125°C. A significant decline in viability of Indian couch occurred with exposure duration once temperatures reached 150°C, with 50% viability recorded after 60 sec exposure time before decreasing to 20% at 240 sec. Similarly, viability at 175°C was highest (45%) at the lower duration of 30 sec, before reducing considerably as duration increased, with viability dropping to ≤3% after 150-240 sec exposure. At 200°C, viability also peaked at 30 sec (46%), but then dropped to ≤5% for 60-90 sec, with complete loss of viability from 120 sec onwards.

Figure 45. As per Cuzens (2020): ***The relationship between duration (sec) and temperature (°C) on the viability (%) of Indian couch seeds*.**

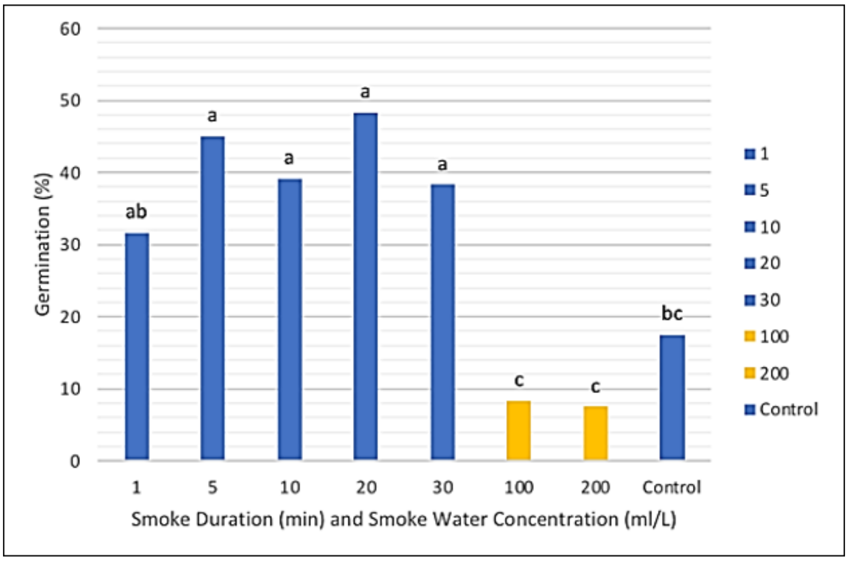


Smoke experiment: Effect on seed germination and seed viability

Black speargrass

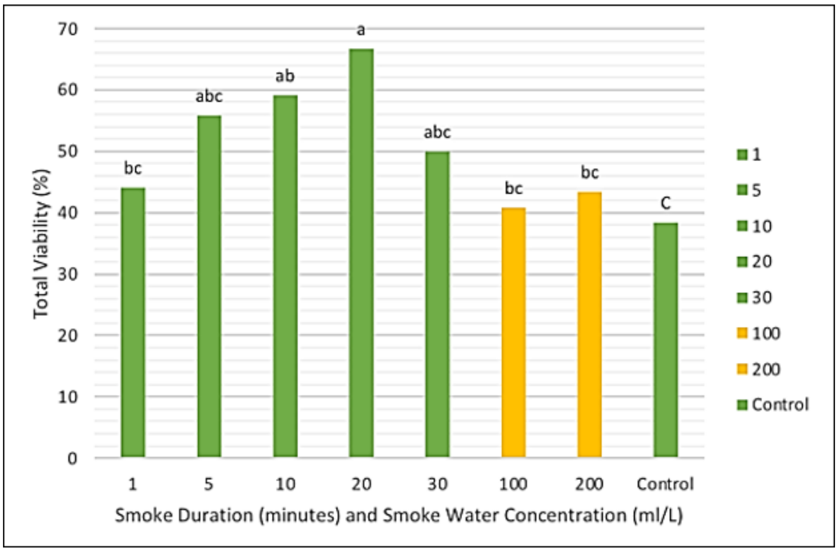
Germination of Black speargrass seed was significantly (*P*<0.001) affected by the direct smoke treatments but not smoke water (Fig. 46). The two smoke water treatments and the one minute of exposure of direct smoke did not significantly (*P*>0.05) alter germination compared to the untreated control. In contrast, significantly higher germination (average germination of 45% compared to the control of 17%; see Fig. 46) occurred once seeds were exposed to direct smoke for five minutes or more. However, any further increases in exposure time did not significantly (*P*>0.05) increase germination beyond that recorded after five minutes exposure.

Figure 46. As per Cuzens (2020): *The effect of duration (minutes) of plant-derived smoke exposure and smoke water concentration (ml/L) on the germination (%) of Black speargrass seeds*.



Exposure of black speargrass seed to smoke water did not significantly (*P*>0.05) affect seed viability compared to the control, at any concentration (Fig. 47). In contrast, viability increased steadily with increasing exposure to direct smoke (Fig. 47). Following 10 and 20 minutes exposure, viability averaged 59 and 66% respectively, which was significantly higher (*P*<0.001) than the control (38%). Viability then declined to 50% after 30 minutes exposure.

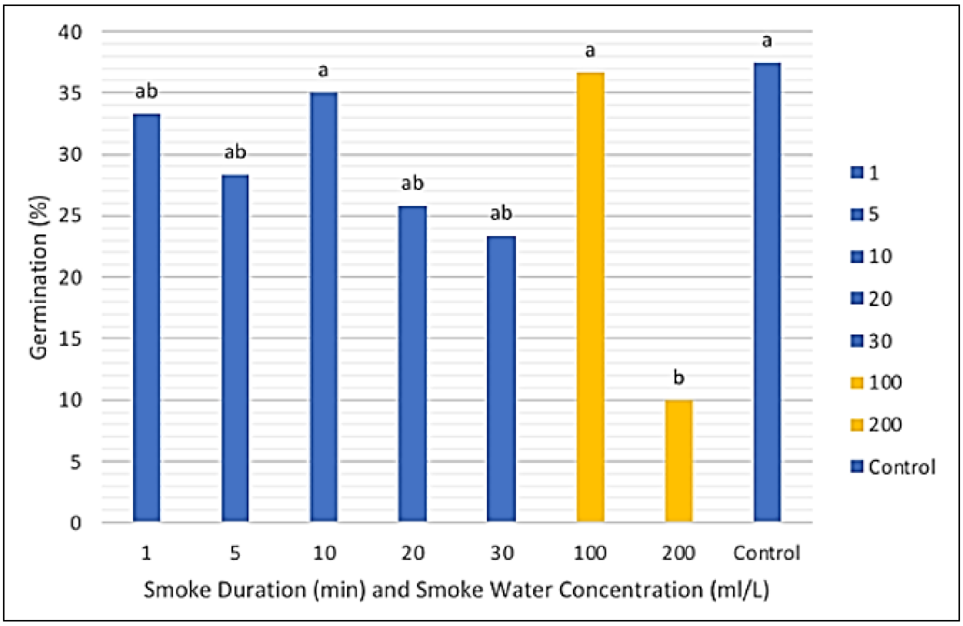
Figure 47. As per Cuzens (2020): *The effect of duration (minutes) of plant-derived smoke exposure and smoke water concentration (ml/L) on the viability (%) of Black speargrass seeds*



Indian couch

The germination of Indian couch seed was not significantly ($P>0.05$) affected by the direct smoke treatments but was significantly ($P<0.05$) affected by the smoke water treatments (Fig. 48). Germination of Indian couch was not significantly different to the control (37%) when the concentration rate of the smoke water was 100ml Smokemaster/L of water (36% germination). However, at a concentration of 200ml Smokemaster/L of water, germination declined significantly to 10%.

Figure 48. As per Cuzens (2020): *The effect of duration (minutes) of plant-derived smoke exposure and smoke water concentration (ml/L) on the germination (%) of Indian couch seeds.*



For Indian couch, neither smoke treatment significantly (*P*>0.05) affected the viability of Indian couch seeds at any exposure duration, with average viability across all treatments being 56% (data not shown).

Implications of results for management and the potential to use prescribed burning as a tool to control Indian couch in pasture: Ideally, prescribed burns would be used to manipulate pasture species composition in favour of desirable and fire-resistant species such as Black speargrass and Kangaroo grass. For these grasses, fire can lead to a rejuvenation of new tillers, through the removal of dense leaf sheaths that are otherwise protecting plant apices and causing plant nodes to be heavily shaded. Having an effective seed burial mechanism is another key fire-tolerant ecological feature, namely a well-formed hygroscopic awn, a fringe of basal hairs and hardened tips that allow seeds to bury beneath the soil surface away from damaging temperatures. The stimulatory effects of fire (particularly plant derived smoke) can then result in large scale recruitment of desirable species such as black speargrass and kangaroo grass, resulting in a positive change in pasture composition.

The greater susceptibility of Indian couch to high temperatures is most likely linked to the morphology of the seed, which is fluffier in nature and lacks a hard seed coat. Even so, Indian couch might be able to survive the extreme temperatures of fire if it had the capacity to become buried in the soil profile before being exposed to fires. It only takes a depth of 1cm for seed to gain adequate protection from fire (Campbell 1995; Vogler 2009). Indian couch seeds do have an awn, and seeds are known to be hygroscopic (field observations), but whether the awn of Indian couch seed can facilitate the burial of seeds is not known and warrants investigation. Future research would ideally determine where seeds of Indian couch are located in the soil profile at the time of burning. As per Cuzens (2020): *Measurements should quantify where Indian couch seeds are located within the soil seed bank and how this will impact on their survival. Recording the effects of fire on different life stages of Indian couch would also be invaluable and help clarify the potential role of fire to control Indian couch.*

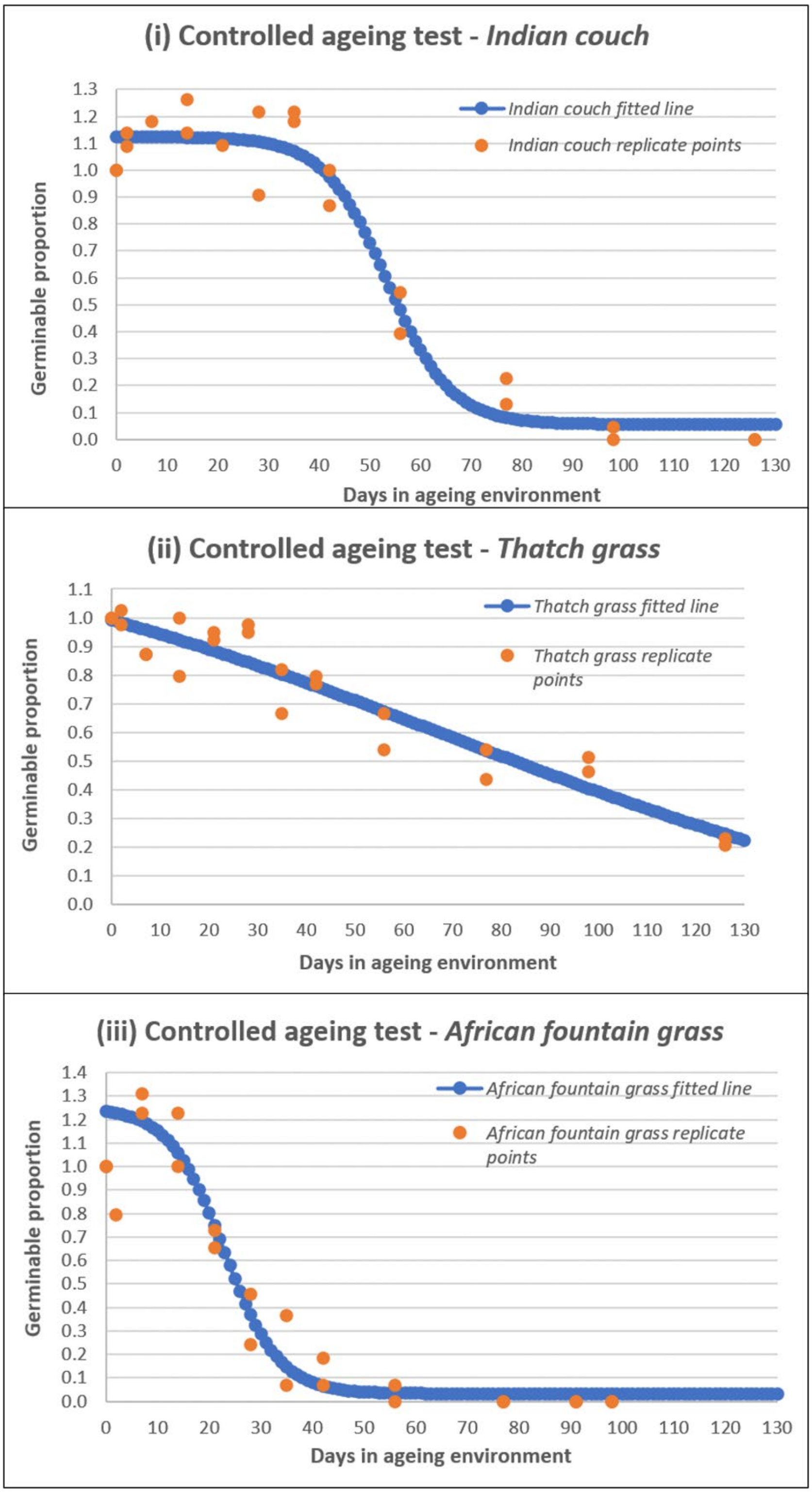
5.4.3 Seed longevity using controlled ageing technology

The TWRC tested the longevity of Indian couch seed using laboratory-controlled ageing, also known as CAT. Fig. 49(i) shows the longevity of Indian couch seed was estimated as long-term persistent (3+ years, P_{50}>50 days), as was Thatch grass: Fig. 49(ii). Gamba and African fountain grass – Fig. 49(iii), came out as short-lived (1 to 3 years, P_{50}=20 to 50 days).

For Fig. 49(i, ii, and iii), the y-axis is the proportion of germinable seed relative to the un-aged seed (day 0). Where 0.5 from the y-axis intersects the fitted line, this corresponds with the days in the ageing environment and on the x-axis the corresponding P_{50} value.

For comparative purposes, literature indicates the seed longevity of Black speargrass seed stored under controlled air-dry conditions is ~3 years (DPI 2017).

Figure 49. Controlled seed ecology studies have shown Indian couch (i) seed to be a long-term persistent seed (Simon Brooks, *pers. comm*.). The trendline for two replicates of controlled ageing for Indian couch crossed 0.5 (50% viable) at day 56 (P_{50}=56). Long et al., (2008) consider any P50 values over 50 days to be persistent (3+ years). The two other grasses shown include Thatch grass (ii) – long-lived (P_{50}=83), and African fountain grass (iii) – short-lived (P_{50}=26). Graphs courtesy of Simon Brooks, Senior Scientist, Tropical Weeds Research Centre, Queensland Government.



5.5 Conclusion

5.5.1 Key findings

Stocking rate treatments on long-term trends of plant basal area

The objective of this study was to quantify long-term changes in native pasture composition in north Queensland under different grazing strategies, with a special emphasis on Indian couch. The study showed that Indian couch basal cover is not directly affected by grazing treatment like 3P grasses are. The study showed highly significant (P<0.001) differences between years in the basal cover of Indian couch, with the highest average basal cover of 5.8% recorded in the wet year 2011, compared with 0.5% in 2019 following several drought years. These results indicate a tolerance to grazing for Indian couch, regardless of stocking rate treatment, and climate as an overarching factor influencing its basal cover. In contrast, for the 3P native tussock grasses, there was a significant interaction between years and treatments (P<0.05): the basal cover of 3P native tussock species in the 'heavy stocking rate' treatment declined almost linearly between the three monitoring periods and in 2019 was significantly lower than the 'moderate stocking rate with rotational wet season spelling' treatment. The interaction of climate with stocking rate treatment reflects the sensitivity of 3P native tussock grasses to frequent long term defoliation. Furthermore, preferential grazing of these grasses may also give Indian couch a competitive advantage and aid its spread particularly as native tussock grasses require rest over the wet season to promote tiller development and maintain vigour and competitiveness.

Heat and smoke treatments on seed germination and viability

Heat treatments: Findings from this preliminary work suggest seed from Black speargrass is more tolerant of heat when compared to Indian couch seed, with lower levels of germination exhibited for Black speargrass (≤5%) when exposed to heat treatments and where the complete loss of viability was not observed regardless of the range of temperature by duration combinations tested. Also, a slight stimulatory effect occurred at certain temperature/duration combinations for Black speargrass: 125^{o}C/150 s and 150^{o}C/90 s. For Indian couch, greater susceptibility to heat was demonstrated, with nil seed viability recorded after exposure to 200^{o}C for 120-240 seconds.

These studies showed that Black speargrass seeds had higher levels of dormancy compared to Indian couch, and this is likely being attributed to its hard seat coat. In contrast, Indian couch seed is fluffy in nature and lacks a hard seed coat, and this could explain its less persistent seed dormancy.

In terms of the overall effect of dry heat on seed viability, the trend for both species was that once a critical temperature threshold was reached, thereafter increasing temperatures resulted in decreased viability. Furthermore, the duration of exposure needed to significantly decrease viability tended to be lower with increasing temperatures. Overall, Black speargrass tended to be more tolerant of higher temperatures than Indian couch.

Smoke treatments: Exposing seeds to plant-derived smoke stimulated the germination of Black speargrass but not Indian couch. The commercially sourced smoke water 'Regen 2000 Smokemaster' reduced the germination of Indian couch at a concentration of 200ml Smokemaster/L of water but had no effect on Black speargrass, regardless of concentration.

Seed longevity using controlled ageing technology

The longevity of Indian couch seed was estimated as long-term persistent (3+ years).

5.5.2 Benefits to industry

The objective was to assess the role of fire for controlling Indian couch, as well as instigate preliminary testing of other control options. Separate collaborative projects were used to gain a better understanding of possible control options for Indian couch; building on the understanding already gained from the literature, expert opinion, and producer knowledge. What is apparent is the difference in response to grazing of Indian couch compared to native 3P grasses, with native 3P grasses less likely to persist under the heavy stocking rates used in this study. Unlike native 3P grasses, Indian couch ground coverage did not vary between the stocking rates tested in this study. Additionally, the seed longevity of Indian couch has been shown to be long-lived (>3 years), as indicated by Controlled Ageing Technology. This, along with a high Indian couch seed bank – given it is a prolific seeder, are critical ecological features when determining control options for Indian couch.

The role that fire might play in reducing Indian couch plant populations is yet to be directly demonstrated, however the preliminary seed ecology work did show Indian couch seed to be more susceptible to high temperatures when compared with seed from Black speargrass. However, if Indian couch has seed burial mechanisms that allow it to escape the heat from fires, then prescribed burns may not be the answer. Future research required includes (1) investigation into the burial ability of Indian couch seed and determining where Indian couch seeds are located within the soil seed bank and how this will impact on seed survival, and (2) investigation into the effects of fire on different life stages of Indian couch.

6. Testing and identifying practical options to either manage or control the spread of Indian couch on native and sown pastures

6.1 Background

Developing Indian couch management options for beef producers: Why this is important

The best-bet options described herein for managing Indian couch pastures are targeted predominantly towards beef producers in three catchment areas of eastern Queensland: Burdekin, Fitzroy, and Burnett-Mary. It is important that management guidelines are available to these producers and that the grazing industry is aware of the spread of Indian couch for many reasons:

- Indian couch can rapidly colonise bare soil and this grass continues to spread and to expand its range in Queensland: the potential invasion area for Indian couch dominant pastures in eastern Queensland is in the order of 9.6 million hectares. This represents ~32% of the total area that makes up the Burdekin, Fitzroy, and Burnett-Mary catchments.
- Indian couch is a moderately yielding exotic perennial grass with comparable nutritional value when compared to 3P tussock grasses.
- However, Indian couch is also an unreliable source of feed as it has reduced drought tolerance and will fail to produce biomass in dry periods when compared with long-lived tussock grasses.
- The production impacts of Indian couch relative to native pastures in terms of biomass production can be high to minimal depending on soil type and rainfall, but in terms of economics and under a variable climate is a riskier production system with fluctuations from productive years to years of significant financial losses.
    - This means the spread of Indian couch threatens the productivity of beef businesses and makes properties dependent on these pastures more vulnerable to drought.
- Indian couch spread and dominance is often associated with land degradation and pasture condition decline.
- Although Indian couch can provide high ground cover and assist in meeting Reef Regulation ground cover targets and arrest soil erosion, the ground cover offered by this grass can be greatly diminished during dry periods and lead to 'leaky' systems. This is because Indian couch does not have the same drought tolerance as native perennial grasses. Being a drought-evading perennial grass, Indian couch is better equipped at escaping rather than enduring drought and can easily come back from seed with the return of improved soil moisture levels. Any reduction in biomass and therefore litter accumulation will only reduce infiltration and hamper landscape function recovery. A shallow root system means water infiltration rates are reduced when compared with deep rooted, long-lived tussock grasses (Brett Abbott, *pers. comm*.).
- Indian couch dominant pastures are novel landscapes that are associated with a loss in biodiversity, such as fauna and flora richness (Kutt and Fisher 2010, 2011; Kutt and Kemp 2012). In addition, Indian couch is potentially adversely allelopathic to other pasture species through its own release of plant chemicals that can inhibit the germination of other pasture species. This has been demonstrated under laboratory conditions (see Hussain et al. 2010). Any effort to increase productivity and diversity should be made to ensure improved ecological function and sustainability of the feedbase.

In summary, Indian couch has both positive and negative effects on both production and landscape function. The positive effect is its ability to stabilise soil and at times provide good production. The negative effect is that it can replace desirable 3P grasses, such as under continuous heavy grazing and lead to the formation of Indian couch dominant pastures and associated losses in biodiversity. Furthermore, under prolonged drought conditions, Indian couch covered landscapes can revert to bare ground. Therefore, it is important that management guidelines are developed to assist beef producers with managing this grass to maintain and increase their carrying capacity and improve pasture resilience.

The following section explores the different best-bet management options that may need to be considered by beef producers in different situations; from managing Indian couch dominant pastures, to minimising the spread of Indian couch in pastures, to possible treatment options for sown pastures with Indian couch.

6.2 Objectives

Based on synthesis of the project work, candidate control options will be outlined and formulation of best-bet management options for producers to (i) manage existing Indian couch dominant pastures, (ii) reverse ongoing invasions in pasture, and (iii) eliminate Indian couch in sown pastures.
Output: A producer facing document practical/easy to read, understand of 'best-bet' guidelines for incorporation into extension materials. Expert technical and producer commentary documented on feasibility, likelihood of adoption (of control scenarios) and recommendations to improve confidence in adoption of control options.
Outcomes: Improved awareness by producers of options for managing and controlling Indian couch, paving the way for adoption.

6.3 Methods

A design thinking approach was used to identify Indian couch best-bet management options, and testing of these best-bets took place using a technical review panel. Firstly, a synthesis of all research findings from the project and from the literature, along with producer feedback, was carried out to develop a framing document. The producer feedback obtained in the past (see section 1.4.2) was consolidated with recent feedback collected by the project during producer stakeholder meetings. Secondly, proposed best-bet management options were identified from this synthesis of information and included in the framing document. Thirdly, the framing document was then reviewed by a scientific panel. Lastly, the best-bet options were then simplified into three categories, ready for review by producers: (i) management of existing Indian couch dominant pastures, (ii) reversal of ongoing invasions in pasture, and (iii) elimination of Indian couch in sown pastures.

6.4 Results & Discussion

The following section first presents the Indian couch management options and 'best-bet' practices according to catchment and then presents more detailed discussion on the three themes of Indian couch management and control: (i) management of existing Indian couch dominant pastures, (ii) reversal of ongoing invasions in pasture, and (iii) elimination of Indian couch in sown pastures.

Indian couch management options and 'best-bet' practices according to catchment

A summary of management options and 'best-bet' practices to either manage (work with) or control (halt/reduce/remove) Indian couch in eastern Queensland as suggested by producers and industry experts is outlined in Table 18. Common themes include providing more rest to pasture (e.g., through rotational grazing or wet season spelling), reducing stocking rates/grazing pressure (regardless of level of Indian couch), and incorporating legumes and other grass species into pasture. Another theme was the potential for prescribed fire. Increasing the legume content and incorporating new grasses into the pasture was a feature for north Queensland. Cultivation techniques were a key feature for central Queensland. For south Queensland, future research ideas were a focus, including remediation of Indian couch patches through ripping and testing fire.

Table 18. Existing Indian couch management options for three catchments located in eastern Queensland recorded from producer and expert interviews (2015-2017).

Burdekin (north Queensland)
• Reduce stocking rates and spell pasture. • Fence to land types where possible to manage grazing pressure. • Testing high intensity, short duration hoof impact across land types and new varieties of grasses. • Establish legumes in native pasture and manage grazing pressure. • Increase legumes with wet season spelling; stylos in lick: move lick troughs around, although it is likely there are more efficient and cost-effective methods to infuse pastures with legumes. • Establish sown pasture paddocks to take pressure off other paddocks during the wet season. • Sown pastures: Sabi (*Urochloa mosambicensis*), Buffel (*Cenchrus ciliaris*), Seca Stylo (*Stylosanthes*) mix. • Improving Indian couch dominant pastures through adding legumes and better grasses. Legumes could include *Stylosanthes*, *Desmanthus* sp, butterfly pea (*Clitoria ternatea*). Determine cost-benefit. • Targeted management options using weaner paddocks and lanes: smaller contained area so easier to manage. Lock up and grow Buffel grass. • Test fire as a tool for managing Indian couch, and where there is still a good level of native pastures; mosaic burning paddocks; combination of fire and seeding.
Fitzroy (central Queensland)
• Don't graze Indian couch as heavy and manage for what you want: spelling and rotational grazing to keep preferred grasses competitive. • Less stock time in paddocks where there is Indian couch. • Stocking to carrying capacity + spell/rest pasture. • Ploughing and incorporating more legumes into Buffel or sowing legume forage crops like Dolichos lablab (*Lablab purpureus*). • Blade ploughing (for sown pastures) – better if smooth out ground after – less Indian couch and more Buffel. • Offsetting/ploughing Indian couch: disc plough, expose all roots, plant Buffel and legume mix. • Pre-emergent spray. • Find other more competitive, creeping grasses. • Turn into farmers. Plough, plant to cereal crops such as sorghum and wheat for years, then plant back to grass such as *C. ciliaris*. Will this deplete the Indian couch seed bank? • Biosecurity on property, including Ergon energy: clean certificates. • Burning rotation.
Burnett-Mary (south Queensland)
• "None. First time to discuss the issue". Instead, ideas for future research were considered: • Ripping through Indian couch patches with a plough and sowing competitive but more desirable grasses such as Rhodes (*Chloris gayana*) and Forest bluegrass (*Bothriochloa bladhii*). • Impact of fire and following management.

Management of existing Indian couch dominant pastures

Aim: Maximise production with retained Indian couch

The concept of managing Indian couch is highly applicable to historically degraded Goldfields landscapes in north-eastern Queensland, now dominated by this grass. The sustainable management of Indian couch pastures should focus on improving ecological function and productivity.

Producer and expert knowledge: Different best-bet management options have been identified for managing and improving Indian couch pastures (Table 18). These include the addition of fertiliser or the incorporation of new grass varieties and legumes and using reducing stocking rates and implementing spelling. For instance, one Burdekin producer from the Goldfields mentioned that "*Good production can come from an Indian couch pasture providing there is a good amount of Seca Stylo in the pasture*", and that "*This 'good' production from an Indian couch grass legume pasture includes a significant reduction in supplementation costs and good animal production*". A Burdekin producer from the Basalt country mentioned "*The production potential of Indian couch can also be increased if the grass is managed and not constantly being overgrazed; there is value in resting and wet season spelling Indian couch*". One way to increase the production from pastures dominated by Indian couch, particularly during the dry season, includes the incorporation of legumes (esp. *Stylosanthes*) (Cox et al. 2022).

There was also interest from producers in the Burdekin to test fertiliser in special use paddocks.

Fertiliser application: Although Indian couch has low fertiliser requirements and will grow on both low and high fertility as well as eroded soils, literature indicates that Indian couch might benefit from the addition of phosphorous, if this mineral is lacking. For sown Indian couch in the Northern Territory, 25-50 kg/ha superphosphate has been recommended as an annual maintenance dressing (Cameron 2013). Indian couch is also known to respond to nitrogen application; however, Cameron (2013) suggested nitrogen is best supplied to the pasture by sowing a legume with Indian couch.

Spelling Indian couch: There might be additional economic benefits with looking after Indian couch, not just in terms of increasing grass growth and performance but also its vigour and root development and ability to withstand drought. There is some speculation that the drought tolerance of Indian couch will vary with grazing management (section 1.4.2), and this was revisited during the Indian couch Think Tank: "*It is not known if the management (e.g., grazing intensity) of Indian couch plants or the plant age or growth stage effects water infiltration and runoff*". The outcomes of the bioeconomic modelling work (see section 3.4.4) also highlighted gaps in knowledge such as drought-tolerance thresholds for Indian couch.

Indian couch is a perennial drought-evading grass (Whyte 1968), and although it is not particularly good at dealing with severe dry periods (Cameron 2013), it has evasion mechanisms to cope with drought – namely high seed production, being quick to respond after rainfall and growing rapidly from seed. Any reference to Indian couch being a weak perennial is akin to producer experiences of "*it doesn't last*"; "*Indian couch runs out*"; "*In dry periods, it stops producing biomass quickly and becomes useless*"; "*Indian couch dies out quick and has no substance to it*"; "*losing yield quickly when it gets dry*". However, this is at variance with reports of Indian couch being long-lived (e.g., see McIvor 2007). Hence, managing Indian couch for increased production may reduce its susceptibility to dry periods, but this is yet to be tested.

Take away message: Management practices of Indian couch dominant pastures that improve both production and ecological function have been identified. These include reducing stocking rates, applying rest, and incorporating new pasture species. There is also producer interest in testing the efficacy of high intensity, short duration hoof impact as an aid in the establishment of new varieties of competitive grasses, however further research is needed before this can be recommended.

Reversal of ongoing invasions in pasture

Aim: Reduce the presence of Indian couch

Challenge: The high seed production from Indian couch and associated management implications was highlighted by the producer anecdotes presented earlier (see section 1.4.2), including sources of seed (such as road reserves), the spread of seed (e.g., by farm equipment, vehicles, and animals – wild and domesticated), and subsequent colonisation of bare soil and high traffic areas on property. This presents major challenges for producers to keep Indian couch off their property. The accidental or unknown introduction of Indian couch on property is likely to spread easily, given grazing facilitates the spread of Indian couch (Lebbink 2020), and given the many attributes of Indian couch: a grass that is tolerant of grazing – through taking on a low prostrate growth habit, is not always being selectively grazed, is a prolific seeder, and can rapidly spread when the conditions are right.

Producer and expert knowledge: Producers have indicated the importance of minimising the spread of seed on property, such as avoiding driving through Indian couch patches: "*We never drive vehicles through these patches*" (section 1.4.5). However, the solution is not that straight forward, as wind, water and cattle can carry and spread seed through the pastures. Another issue is pasture dieback, of which is creating gaps in the pasture for Indian couch to then occupy. Some producers are trying prescribed burns to tackle pasture dieback: "*We are now burning a quarter of the paddock each year to address the dieback problem*" (section 1.4.5) or are interested in implementing a '*burning rotation*' (Table 18). Pasture rundown is another problem that is facilitating the spread of Indian couch: "*Buffel grass is rundown and has lowered available nitrogen, reducing the vigour of the Buffel and making it more susceptible to Indian couch invasion*". A key theme and major priority identified is managing the desirable pasture species so that they remain competitive and have high vigour.

Important pasture management implications: Indian couch is an invader of space, so it makes sense to manage desirable grasses and maintain yield and high ground cover. As described by one producer in the Fitzroy catchment: "*Indian couch gets an advantage as the other grasses are eaten down, it seeds readily and comes back in the spaces in the pasture*". Expert opinion also suggests "*It is all a matter of the degree of reduction where it currently exists. That will be governed by the health & vigour of the existing vegetation and the availability of pertusa seed*" (Richard Silcock, *pers. comm*.). Thus, any stressors inflicted upon the preferred grasses can provide an opportunity for Indian couch to increase. This means beef producers will need to avoid prolonged over-utilisation of pasture and instead will need to adopt good pasture management principles such as matching stocking rate to carrying capacity (if they are not already doing so) and adaptive grazing practices, such as flexible stocking and spelling pasture to ensure recovery from grazing and regeneration.

The presence of Indian couch seed remains a major limiting factor to the success of reducing Indian couch and halting the spread, as does its superior spreading ability and response to climatic-induced disturbances that might occur to shift the balance to favour the rapid spread of Indian couch. Not to mention, pastures with preferred tussock grasses do inherently have gaps in them (i.e., the inter-tussock spaces). So, what else can be done? What proactive and Indian couch-specific management options can be adopted in addition to good pasture management principles already adopted?

Possible management options: Producer feedback and expert opinion presented in Table 18 identifies some possible options for combating the spread of Indian couch, such as:

- Fencing to land types where possible to manage grazing pressure.
- Fencing to spell paddocks.
- Less stock time in paddocks where there is Indian couch.
- Combination of using both fire and seeding of preferred species.

Management and climate factors: A grazing ecology focussed investigation carried out in north Queensland and summarised herein (Macor 2019 and see section 5.4.1) showed grazing strategy is not directly influencing the basal cover of Indian couch; climate is the overarching factor influencing its basal cover. Grazing is, however, facilitating its spread, with the rapid expansion of Indian couch observed during drought-breaking rains (post 2007) being exacerbated under heavy stocking (Peter O'Reagain, *pers. comm*), i.e., poor pasture condition and low soil cover. For the 3P native tussock grasses, the interaction of climate with stocking rate treatment shown by Macor (2019) reflects the sensitivity of 3P grasses to frequent long term defoliation. Furthermore, preferential grazing of these preferred grasses may also give Indian couch a competitive advantage and aid its spread particularly as native tussock grasses require rest over the wet season to promote tiller development and maintain vigour and competitiveness (Ash and McIvor 1998). Preferential grazing of 3P tussock grasses and 'patch grazing' is also heightened during this time therefore potentially producing areas of less competitive pasture with more gaps providing an opportunity for Indian couch establishment. Patch grazing can potentially be remedied with fire (to promote evenness of grazing) or intensive grazing systems (involving short durations of high intensity grazing followed by rest) (Ash and McIvor 1998).

The role of fire: Fire as a tool for grazing land management and pasture improvement can be used for different reasons, such as to remove old, rank pasture, or control woody weeds, or to manipulate pasture species composition. For the latter, fire can be used to create a favourable shift in species composition (Paton and Rickert 1989; Orr and Paton 1997; Kutt and Woinarski 2007). Thus, the effects of fire can be direct (through seed ecology mechanisms or stimulation of new tillers, for example) or associated (through shifts in plant competitiveness). Preliminary seed ecology investigations summarised herein (Cuzens, 2020 and see section 5.4.2) suggested seed from Indian couch has weak dormancy and reduced tolerance to heat when compared with native Black speargrass. In addition, plant-derived smoke was shown to stimulate germination in Black speargrass but this response was not demonstrated for Indian couch. That begs the question of what role can fire play in not only creating favourable shifts in native species composition but also for controlling Indian couch in native pastures?

Take away message: Managing grazing pressure, applying rest from grazing – especially during the wet season, and addressing other pasture issues such as pasture rundown and dieback in sown pastures and uneven/selective utilisation of native and sown pastures are all fundamental aspects of pasture management and underpin improvements in pasture resilience against the incursion of Indian couch. The role of fire in reducing Indian couch in native pastures is yet to be deduced. Importantly, seed burial mechanisms will need to be investigated, but at the very least, prescribed fire could be used to control preferential grazing and potentially reduce the Indian couch seed bank given the susceptibility of seed to heat. If fire is not an option for beef producers or is not shown to be effective, then grazing systems that offer more rest to pastures such as time-controlled or rotational grazing may need to be tested.

Elimination of Indian couch in sown pastures

Aim: Remove Indian couch and re-seed with other pasture species

The remediation of Indian couch pastures using cultivation techniques and re-seeding is explored below.

Is elimination of Indian couch even possible? In the Fitzroy catchment, the extent of Indian couch invasion was anything from no Indian couch to isolated incidences of Indian couch invasion on property, to Indian couch scattered through the pasture, to some cases of Indian couch dominance

(Table 1, section 1.4.2). It was also highlighted that cleared grazing lands, some cultivation, and the incorporation of improved pasture species are key features of this area. Furthermore, key issues affecting the productivity of pastures in central Queensland include pasture rundown, Indian couch invasion, and pasture dieback. Producer knowledge has indicated cause and effects of these issues, such as Indian couch invading rundown pastures (soil fertility decline), Indian couch invading pasture dieback patches (gaps to occupy), and Indian couch invading weakened Buffel pastures (reduced competition), (sections 1.4.2 and 1.4.5).

Producer views: What was also clear from producer knowledge in the Fitzroy catchment was a strong view of Indian couch being a weed or an inferior pasture species: "*It is difficult to think of Indian couch as having production value as there are more desirable pasture species available and suited to this area*", (section 3.4.3). It is no wonder that preferred management options expressed included complete elimination of the grass or biological control. Biological control is problematic, given that Indian couch is a '*Bothriochloa*' bluegrass species and there are many desired native and introduced Bothriochloa species such as Desert bluegrass, Forest bluegrass, Creeping bluegrass, to name a few. Complete elimination may not be possible given the extent of Indian couch spread across Queensland and the many sources of seed such as road reserves, lawns, parks, mine sites, aerodromes, showgrounds, etc.

Cultivation options: The theme of 'cultivation options' was common for the Fitzroy catchment (see dot points below and Table 18). Of key interest being options to remove and re-seed to reduce or remove Indian couch from the pasture, i.e., adding better species to the mix. However, while this was a strong message, different circumstance will still exist in the Fitzroy catchment such as native pastures, or producers with old cultivation country not in a position to cultivate. Thus, best-bet options include a range of options from re-seeding whole paddocks to reduce or replace Indian couch, to planting strips within paddocks to add more production value, to managing what is already there as the simplest form of pasture improvement.

Time frames: Depleting the soil seed bank of Indian couch seed is expected to be a very challenging pursuit, given the high seed load produced by Indian couch plants, the moderate viability of Indian couch seed and the long-term persistence of Indian couch seed. Short-term and long-term cultivation techniques have been suggested, including a long-term option of planting forage crops for a few years before re-seeding back to grass.

Producer and expert knowledge: Based on producer feedback and expert opinion, cultivation techniques to combat Indian couch would ideally involve a spray, plough, fertilise and sow/seed approach. There are also suggestions of sowing into an ash bed or having a fallow period for the purpose of building up the water and nutrient profile of the soil before re-seeding (i.e., resting soil before replanting). Preferred pasture species for re-seeding include grass and legume mixes, with many different species recommend (see dot points below).

A range of options are outlined below and are for situations where Indian couch is already a dominant pasture species, and the objective is to remove or partially remove (e.g., through strips) the existing pasture and re-seed with preferred species.

Producer feedback (Biloela):

- Cutterbar between rows of Leucaena and plant more grass and some legume.
- Light ploughing and fertiliser – *moderately successful*.

- Spray, plough, fertilise & seed – *more successful*.
- Preferred grass species include Purple pigeon grass, Creeping bluegrass, Pangola grass.
- Legumes: Butterfly pea, Aztec siratro, Burgundy bean.
- Renovate with chisel plough and seed with improved pasture.
- Yeoman ripped/Dozer ripped – used to increase water penetration. Cultivation area – returned to forage sorghum and oats for 3 years, continued cultivation.
    - The cultivated area of forage returned to legume and pasture – *determine if a period of cultivation kills the Indian couch out*.
    - Chemical trials – *determine if Indian couch is resistant to chemical types*.
- Ripping and planting of Leucaena in 9-10m rows but is a very slow process. Spraying out and direct drilling pasture but unsuccessful due to contractor applying oil to glyphosate.
- Ploughed 60ha to put in dolichos (lablab bean) for a couple of years then back to creeping blue and Leucaena.
- Deep ripping (e.g., yeomans) and replanting.

Producer feedback (Moura):

- Ripping and seeding.
- Introduce natural species back into the soil.
- Cutterbar, deep ripping, planting native grasses and legumes.
- Plough, spray, seed.
- Spelling paddocks.
- Work up country and plant forage crops for a couple of years in some areas.
- Reduce grazing pressure, e.g., in Leucaena paddocks.
- Off-set ploughing and seeding (improved grasses).
- Cell grazing.
- "*Pasture fertility would be worth investigating*".

Expert opinion (Stuart Buck, pers. comm.): Seven treatments have been proposed for pastures where Indian couch dominates (>50%). Due to the competitive dynamics and high seed bank of Indian couch in this situation, removing the existing pasture and re-seeding with a preferred species is most likely going to be the most effective way forward for landholders. This could be done in a range of ways:

- Burn and re-seed with sown grasses and legumes.
- Cultivate (once) only and re-seed with sown grasses and legumes.
- Spray (once) only and re-seed with sown grasses and legumes.
- Cultivate, fallow, and re-seed with sown grasses and legumes.
- Cultivate, fallow, sow annual forage (or 2), re-seed with sown grasses and legumes.
- Fertiliser (nitrogen) only.
- Implement intensive grazing management (high stocking rates, short period of time).

As for treatment options for pastures where Indian couch does not dominate (<25%): Because there is a high proportion of desired grass pasture in this situation, the concept is managing with the existing pasture base is going to be the most effective way forward. This could be done using:

- Fertilising (nitrogen) only.

- Implementing intensive grazing management.
- Cultivate, fallow and sow legume (only) into prepared strips.

Indian couch management options

The Indian couch management options for producers are summarised below according to (i) managing existing Indian couch dominant pastures (Table 19), (ii) reversing ongoing invasions in pasture (Table 20), and (iii) eliminating Indian couch in sown pastures (Table 21).

Table 19. Managing existing Indian couch dominant pastures

Managing Indian couch *– Management of existing Indian couch dominant pastures (Indian couch >50%) and monocultures*
Reduce stocking rates and spell pasture to increase ecological function and potential for landscape recovery.
Test high intensity, short duration hoof impact across land types and new varieties of grasses. Maximise rest.
Increase production of Indian couch pastures • Sow strips of more preferred, highly competitive grasses. • Test soil fertility and if necessary, apply fertiliser (e.g., 25-50 kg/ha superphosphate). • Incorporate new grass varieties and legumes. • Grasses: e.g., Rhodes, Creeping bluegrass, Forest bluegrass. • Legumes: e.g., stylos, desmanthus, butterfly pea.
Manage pastures during, and post drought • During prolonged drought reduce stock numbers and after drought restock slowly. This will give the pasture a chance to remain productive as long as possible and aid recovery when rains return.
  *Left image: Strips of Buffel grass have been planted (foreground) in an otherwise native pasture in north Queensland with high levels of Indian couch (February 2018).* *Right image: Spelled Indian couch pasture on the same property, photo taken on 'Goldfields' country near Charters Towers in June 2018.*   *Left image: Indian couch pasture (Goldfields) with a good level of stylo (May 2019).* *Right image: Spelled Indian couch pasture (Basalt), photo also taken in May 2019.*

Table 20. Reversing ongoing invasions in pasture

Minimising the spread of Indian couch
– Reversal of Indian couch invasions in pasture (Indian couch <25%)

Maintain yield and high ground cover of desirable pasture species.

- Avoid prolonged over-utilisation of pasture.
- Adopt adaptive grazing practices, such as flexible stocking, pasture rest and wet season spelling.
- Fence to land types to manage grazing pressure.
- Fencing to spell paddocks.
- Reduce stock time in paddocks where there is Indian couch.

Minimise the risk of Indian couch seed transfer as much as possible.

- Avoid driving through Indian couch patches.

Test fire to reduce Indian couch seed loads and to favour the composition of fire-adapted pasture species.

- Combination of fire and grazing; rotational burning with spelling.
- Combination of fire and seeding.

For sown pastures:

- Address pasture rundown: add legumes and manage grazing pressure.
- Address pasture dieback: test burning rotation with spelling.
- With blade ploughing – test smoothing versus no smoothing of ground. Producer experience suggests there is less Indian couch in Buffel grass pastures if ground is smoothed out.

Manage pastures during, and post drought

- During prolonged drought reduce stock numbers and after drought restock slowly. This will give the preferred pasture species a better chance to out-compete any insurgence of Indian couch when rain returns.

Test tactical grazing pressure

- High stocking rates, short periods of time. Maximise rest. Minimise opportunity for preferential grazing and maximise opportunity to reduce Indian couch seed production. Monitor grazing closely and avoid over-utilisation of pasture.




Far left image: High seed loads produced by Indian couch. Photo taken at the Spyglass Beef Research Station, Charters Towers in July 2018.

Left-centre image: Indian couch (golden flower stems) occupying gaps in a native Desert bluegrass pasture on basaltic soils in north Queensland (June 2021).

Right-centre image: Ploughed Buffel grass pasture in south-west Emerald – Indian couch is shown filling in the soil depressions (March 2021).

Far right image: Healthy Buffel grass pasture in south-west Emerald with Indian couch filling in any gaps in the pasture (see small yellow patch in the background on the right), March 2021.

Table 21. Eliminating Indian couch in sown pastures

Treatment options for sown pastures with Indian couch *– Reduction of Indian couch in sown pastures (Indian couch >50%)*
Address pasture dieback • Test burning rotation with spelling.
Address pasture rundown • Improve health and vigour of Buffel grass through fertiliser application and incorporation of legumes.
Test high impact grazing • High stocking rates, short periods of time. Maximise rest. Minimise opportunity for preferential grazing and maximise opportunity to reduce Indian couch seed production.
Test fire and seeding, plus spelling.
Plough and incorporate more legumes into Buffel or sow legume forage crops like lablab bean (dolichos).
Test different cultivation techniques involving spray, plough, fertilise and seed – *with and without a fallow period* • Long-term: planting to forage crops or cereals first and then to pasture. • Short-term: planting straight to pasture. • Legumes: Butterfly pea, Aztec siratro, Burgundy pea. • Grasses: Purple Pigeon grass, Creeping bluegrass, Pangola grass.
Manage pastures during, and post drought • During prolonged drought reduce stock numbers and after drought restock slowly. This will ensure improved pastures are being managed as best as possible to ensure their survival and recovery post-drought.
  *Left image: Buffel grass pasture south-west of Emerald, with Indian couch shown in the background (golden patches) filling in gaps in the pasture after patches of Buffel grass were killed by pasture dieback (March 2021).* *Right image: Indian couch (foreground) occupying disturbed areas of a Buffel grass pasture (March 2021).*

6.5 Conclusion

6.5.1 Key findings

A range of factors are contributing to the spread of Indian couch across eastern Queensland. Ecological attributes for competitiveness, land degradation, heavy grazing, adequate source of seed and means of spread, and climatic extremes in rainfall variability can all culminate in opportunities for Indian couch to rapidly colonise in pastures. These factors also provide insights into management techniques that can slow the spread, namely avoiding over-utilisation of the pasture, maintaining high ground cover, and improving the competitiveness of existing pasture species.

Managing existing Indian couch dominant pastures

For pastures with highly dominant Indian couch, key strategies for improved production and ecological function are recommended, including reducing stocking rates, applying more rest to pasture, and incorporating new grasses and legumes into the pasture where possible. One way to increase the production from pastures dominated by Indian couch, particularly during the dry season, includes the incorporation of legumes (esp. *Stylosanthes*). The possibility of reverting Indian couch dominant pastures to original native species should not be ruled out. However, there is limited information on the success and time frames associated with this.

Reversing ongoing invasions in pasture

For pastures with low levels of Indian couch, the best-bet options are yet to be realised but could involve a combination of prescribed fire, stocking rate management, and applying more rest to pasture. The role of fire in reducing Indian couch in native pastures is yet to be realised. Importantly, seed burial mechanisms will need to be investigated, but at the very least, prescribed fire could be used to control preferential grazing and potentially reduce the Indian couch seed bank given the susceptibility of seed to heat. If fire is not an option for beef producers or is not shown to be effective, then grazing systems that offer more rest to pastures such as time-controlled or rotational grazing may need to be tested.

Eliminating Indian couch in sown pastures

Finally, and specific to sown pastures, the need to address the impacts of pasture rundown and pasture dieback along with good pasture management has been highlighted. Any setbacks to the health and vigour of sown pasture species will increase the opportunity for Indian couch to occupy space and replace these species. Large Indian couch soil seed banks are expected to be a major hinderance in efforts to suppress/deplete Indian couch, particularly given its long-term persistence. Thus, cultivation and fallow (or cultivate and sow annual forage) before re-seeding with a perennial grass-legume pasture, are being considered by some beef producers.

6.5.2 Benefits to industry

The project has summarised producer and expert experience into the types of Indian couch infestation and how to manage in each situation, while identifying areas for future research.

7. Future research and recommendations

Indian couch is an exotic perennial pasture species that is spreading through eastern Queensland. Beef cattle production is negatively impacted especially when preferred long-lived native and exotic tussock grasses are displaced. Ecological studies and research to date has provided valuable insights into the characteristics of this species, and therefore potential management strategies to reduce or halt the spread across pastoral areas. Many knowledge gaps have been identified such as the role that fire might play to control Indian couch in pastures, whether Indian couch dominant pastures can be reverted to original species, and whether more rest to pastures can reduce the spread of Indian couch in pastures.

What is clear is the on-going need to maintain high ground cover, avoid over-utilisation of pastures, and allow for both recovery from grazing and regeneration.

The vulnerability of 3P pasture species to grazing is particularly heightened during the wet season. New ways to assist beef producers manage their pastures during this time may be required, such as the development of specialty production paddocks which are utilised during the wet season to relieve grazing pressure off the rest of the property.

Future research needs were identified by the project:

- Validate the best-bet management options.
- Determine the effect of Indian couch on soil function and biodiversity, water cycling and the impact of grazing intensity, and contribution of litter to landscape recovery.
- Ascertain the potential for adverse allelopathy of Indian couch on other pasture species and the nature of this allelopathy and investigate relative competitiveness between species under different simulated conditions and potential altered soil nitrogen relations of Indian couch compared with native perennials.
- Review SWIFTSYND site data and confirm the relativity between Indian couch and native pasture parameters and carry out refined bioeconomic modelling.
- Using pot trials, test the effect of different defoliation (clipping) and moisture (watering) levels on the above- and below-ground plant production and drought tolerance of Indian couch versus a selection of preferred pasture species.
- Test the role of fire on Indian couch: controlled seed ecology trials, seed bank sampling and field burns across different soil types.
- Identify the optimum germination conditions for Indian couch seed and start developing a plant production model for Indian couch.
- Confirm seed longevity of Indian couch using long-term seed burial.
- Test different cultivation techniques and efficacy to deplete Indian couch seed bank and replace existing Indian couch population. For example, test on Brigalow softwood scrub the efficacy of cropping for 3 years before sowing back to pasture.
- Survey another subset of QGRAZE sites to build on the existing knowledge base of floristics status and trends across the Burdekin, Fitzroy, and Burnett-Mary catchments.
- Test novel field methods for keeping Indian couch out and from colonising bare soil, such as spray-on polymers or seed sprays.

- Test different options to improve Indian couch pastures such as planting in strips of productive native or introduced pasture species. For the reintroduction of native species such as Kangaroo grass, test the effect of seed addition with fire.
- Conduct a nutrient omission/addition pot trial on Indian couch and other grasses to determine nutrient requirements and recommended fertiliser regimes according to different soil fertility.
- Carry out genetic studies to determine the variation in Indian couch in Australia.

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10. Appendices

10.1 Producer feedback forms and questionnaires

10.1.1 Predetermined questions used during 2015 Indian couch scoping study

Agency staff & selected grazier meeting, Charters Towers, 12 November 2015 – Questions to graziers:

- How big is the area of Indian couch on your property (extent of 'problem')? What is the nature of its occurrence (isolated, scattered, dominant, 100%) – has this changed over time?
- When and where did Indian couch invade/spread on your property?
- What were the conditions (rainfall/fire/grazing/management etc.) at property/paddock scale under which this occurred?
- What is your opinion of Indian couch? What are its good points and bad points?
- What management actions have you tried (if any) in an attempt to reverse the Indian couch expansion?
- Was there anything that you would have liked to have tried, but didn't – what were these?
- What effect, if any, does Indian couch in pastures have on animal production?

Agency staff & selected grazier meeting, Charters Towers, 12 November 2015 – Questions workshopped during small breakout sessions (producers one group, agency staff another – separate rooms):

- Indian couch in Basalt and Goldfields land types – are there different conditions/situations? If so, what?
- Ideas/suggestions for management of Indian couch (these may be varied depending on situation, extent, location, etc.).
- "Identify/develop the key R&D questions".

Indian couch and developing an RD&E project – on-property meetings:

- What is the value of Indian couch in your grazing business?
- Has management at the property/paddock scale caused the change to Indian couch? If so, what management practices? If not, what has contributed to or caused the occurrence of Indian couch?
- Do you manage Indian couch differently from other pasture types on your property? Y/N; explain either way.
- Have you tried to reverse or halt the Indian couch expansion with management? If so, give details.
- Are there any management practices you would like to try, but have not? What are they?
- Was Indian couch already there when you acquired the property (when was this?) or have you witnessed the invasion of Indian couch?
- Where does Indian couch mainly occur on your property? Is it isolated, scattered, dominant or 100%? Is it still expanding, or has it reached its maximum extent?
- What has the effect (if any) of Indian couch in pastures on animal production?

- **An addition question was used for central Queensland:** Is Indian couch more prevalent in native (e.g. bluegrass/speargrass) or sown pastures (e.g. buffel)? Or about the same?

10.1.2 Predetermined questions used in producer questionnaire in 2017 during DAF information days

- Do you have Indian couch on your property? Please circle: Yes / No
  - *If yes*:
    - How long has Indian couch been there? Please describe when it invaded or came in, and the actual year (*if known*).
    - Were there any particular event(s) that may have caused it or proceeded it coming in, e.g. fire, heavy stocking, climate, earth works? *Please circle the appropriate answer and provide any details: Yes / No / Unsure.*
    - What proportion (%) of your property is affected? *Please tick the appropriate box*:
      - □<5% □5 to 25% □25 to 50% □50 to 75% □>75%
    - What is the nature of invasion (e.g. broadly scattered, solid/thick, mostly localised and dominant, or specific to a certain land type, etc.)? *Please describe*.
    - Has the area affected changed over time? Remained the same? Increased? Decreased? *Please describe*.
    - What are the main land types affected?
    - Is the affected land cleared &/or timbered country?
      - *If cleared, how long ago was it cleared?*
- What sort of impact (*if any*) is Indian couch having on your grass-fed beef business? *Please describe for*:
  - Carrying capacity (*please circle*): Yes / No *If Yes,* Increase / Decrease, and by what percentage?
  - Cattle weight: Yes / No. *If Yes*, Increase / Decrease, and please describe.
  - Other, please describe.
- Have you tried to control/manage Indian couch? *Please circle*: Yes / No
  - *If Yes*, how? What methods have you tried? What has been the outcome?
  - *If No*, is there anything you would like to try?
- Aside from the ideas in the proposed project, are there any other things relating to Indian couch that you would like researched?

10.1.3 QGRAZE focussed producer questionnaire

- At the site/paddock has there in the past been any disturbances such as clearing, cultivation, fire, etc.? Please circle your answer and provide details. Yes / No
  - Explain the disturbance and if possible, provide time frames of when (year) the disturbance(s) took place.
- Has there been any major climatic events that you can remember, for example prolonged drought, high rainfall years, flooding, other? Yes / No
  - Explain historical climatic events and when these took place

- What grazing management has in the past typically been used at the site/paddock and class of cattle? Please indicate your answers by ticking the relevant boxes.

Previous Grazing management	Previous Paddock use and class of cattle
□Light stocking	□Breeders
□Moderate stocking	□Steers
□Heavy stocking	□Weaners
□Flexible stocking	□Holding paddock
□Rotational grazing	□Grazing paddock
□Prescribed burning	□Fattening paddock
□Pasture spelling	□Horse paddock
□Other (e.g. seasonal grazing)	□Other

- What is the current grazing management and use of site and class of cattle? Please explain.
- Have you noticed Indian couch at the site or in the paddock where the site is? Yes / No
    - *If Yes*, when did Indian couch first occur?
    - What is the amount of Indian couch like in the pasture (isolated, scattered, moderate, dominant)?
    - What is the status of Indian couch like (increasing, decreasing, or staying the same)?
- From your own experience and observations, what do you think favours the spread of Indian couch? This could include management, soil type, location, climate, stock movements, or a whole combination of things.
- Do cattle graze Indian couch?
- Do cattle selectively graze Indian couch?
- Are there times of the year when animals prefer Indian couch? Yes / No
    - Indicate your answer and please explain.
- Is Indian couch being preferred by cattle over other grasses? Yes / No
    - *If Yes*, what grasses are not being grazed when Indian couch is?
    - *If No*, what grasses do cattle prefer over Indian couch?
- Do you have an overall opinion on Indian couch or anything you would like to share from your own observations?

10.1.4 Indian couch palatability and cattle grazing preferences Questionnaire

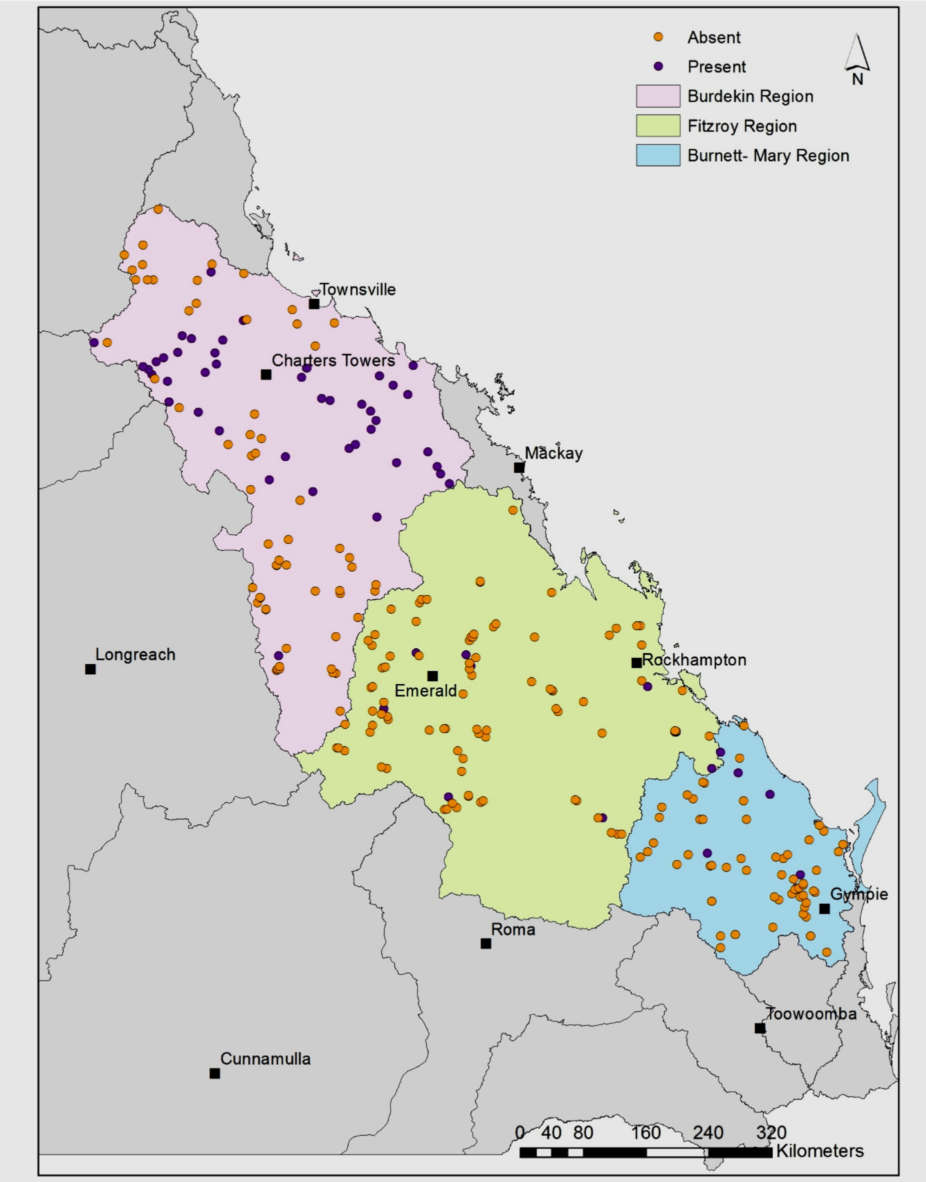
- Have you noticed Indian couch on your property? Yes / No / Unsure. *If yes*:
    - When did Indian couch first occur?
    - What is the amount of Indian couch like in the pasture (isolated, scattered, moderate, dominant)?
    - What is the status of Indian couch like (increasing, decreasing, or staying the same)?
- From your own experience and observations, what do you think favours the spread of Indian couch? This could include management, soil type, location, climate, stock movements, or a whole combination of things.
- Do cattle graze Indian couch? Yes / No / Unsure
- Do cattle selectively graze Indian couch? Yes / No / Unsure
- Are there times of the year when animals prefer Indian couch? Indicate your answer and please explain. Yes / No / Unsure

- Is Indian couch being preferred by cattle over other grasses? Yes / No / Unsure
    - *If Yes*, what grasses are not being grazed when Indian couch is?
    - *If No*, what grasses do cattle prefer over Indian couch?
- Do you have an overall opinion on Indian couch or anything you would like to share from your own observations?

10.2 QGRAZE project work

10.2.1 Spatial mapping of historical QGRAZE records of Indian couch in the Burdekin, Burnett-Mary and Fitzroy catchments

Figure 50. Historical records (Present/Absent) of Indian couch at QGRAZE sites in the Burdekin, Fitzroy, and Burnett-Mary catchments.



10.2.2 QGRAZE field work in the Burdekin and Fitzroy catchments

Table 22. QGRAZE field work in the Burdekin catchment.

			Looking back 30 years					
			Indian couch frequency (%)					Land condition (if assessed) – ABCD
			Past	Present	Change category	Top 3 species frequencies		
Site code	Land type	Soil type	Late 90's/ Early 00's	2020/ 21		Past	Current	
M167	Red basalt	Clay loam	0	24	Low-Medium	HeCon, ThTri, Forbs	HeCon (94%), Forbs (81%), Indigofera spp. (48%)	
N030	Coastal teatree plains	Sandy loam	0	19	Low-Medium	No records	EcCol (75%), Forbs (74%), SeCan (55%)	
N056	Silver-leaved ironbark		37	21	Decrease	Sida spp. (55%), Digitaria spp. (53%), BoPer (37%)	Urochloa (53%), Caribbean stylo (53%), Forbs (44%)	C
N059	Loamy alluvials	Light clay	7	35	High	Sedges (48%), BoEwa (44%), Forbs (42%)	Forbs (84%), ChFal (54%), Sedges (44%)	B
N014	Red basalt	Light clay	65	89	Low-Medium	HeCon (95%), Forbs (50%), Sedges (37%)	BoPer (89%), Native legumes (56%), HeCon (46%)	
SALP	Coastal teatree plains	Gravelly grey clay	71	14	Decrease	Caribbean stylo (92%), BoPer (71%), Digitaria spp. (49%)	Forbs (92%), Shrubby stylo (54%), Other exotic legumes (43%)	C
N084	Box and napunyah		4	65	High	HeCon (78%), BoDec (66%), MeRep (36%)	Forbs (70%), BoPer (65%), HeCon (47%)	C
N044	Red basalt		23	98	High	Forbs (54%), ChFal (53%), HeCon (44%)	BoPer (98%), BoEwa (72%), Indigofera spp. (66%)	B
N025	Narrow-leaved ironbark on shallower soils	Heavy/ med clay	10	83	High	BoEwa (66%), Forbs (20%), MeRep (18%)	BoPer (83%), Forbs (46%), Sida spp. (31%)	
N074	Box country		2	15	Low-Medium	Eriachne spp. (65%), Buffel (46%), Forbs (43%)	Enneapogon (52%), Eriachne spp. (42%), Buffel (30%)	C
CT13	Box country	Clay loam, sandy	0	0	Absent	Sida spp. (72%), BoEwa (31%), Forbs (22%)	Sporobolus spp. (38%), Buffel (31%), Shrubby stylo (30%)	

Figure 51. Current (2020/21) Indian couch frequencies (%) at QGRAZE sites in the Burdekin catchment, including Absent of Indian couch (0%) – site CT13, and Low to Medium Indian couch frequency (5 to 25%) sites: M167, N030, N056, SALP & N074.

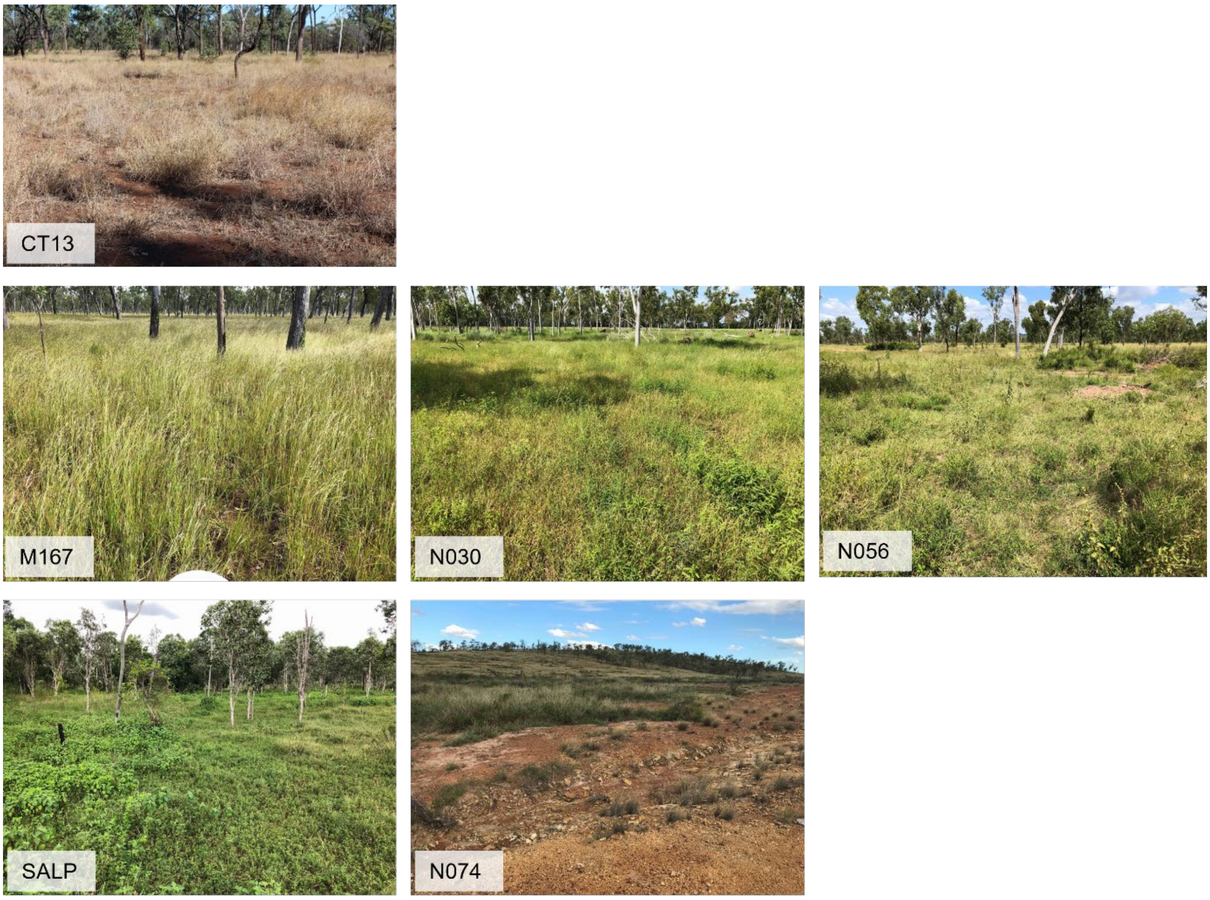


Figure 52. Current (2020/21) Indian couch frequencies (%) at QGRAZE sites in the Burdekin catchment, including Medium to High Indian couch frequency (>25% to 75%) – sites N056 & N084, and High Indian couch frequency (>75%) sites: N014, N044 & N025.

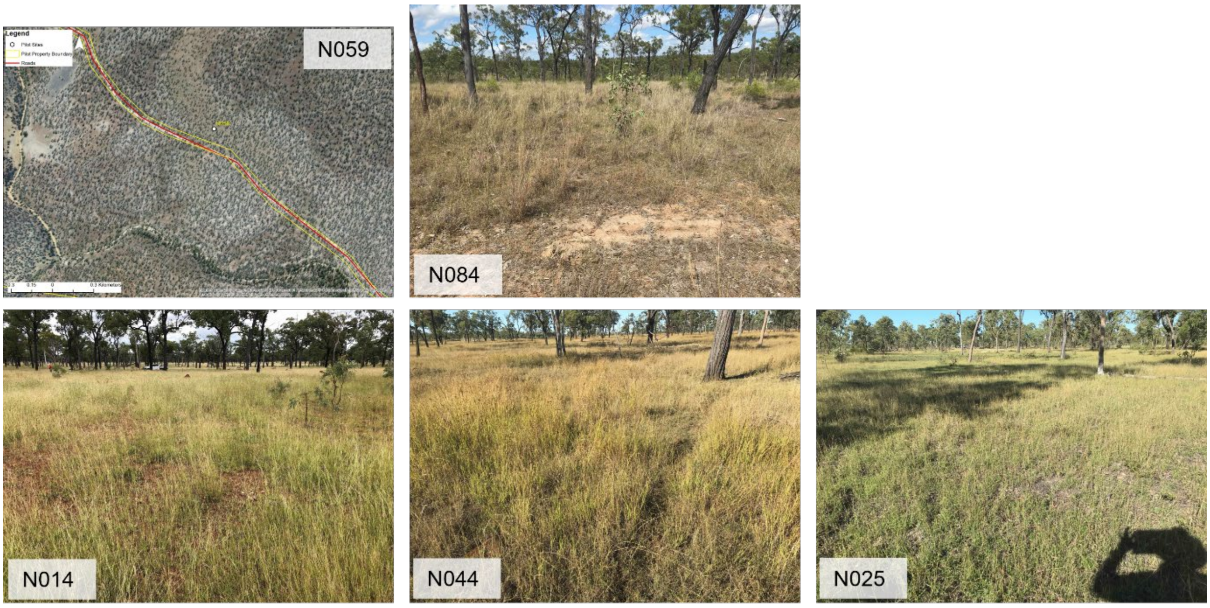


Table 23. QGRAZE field work in the Fitzroy catchment.

			Looking back 30 years				
			Indian couch frequency (%)				
			Past	Present	Change category	Top 3 species frequencies	
Site code	Land type	Soil type	Late 90's/ Early 00's	2020/ 21		Past	Current
C284	Box flats	Clayey sand	0	0	Absent	No records	Aristida spp. (52%), ThTri (47%), BoEwa (45%)
BM03	Box flats	Sandy clay loam	1	0	Decrease	BoBla (69%), Native legumes (45%), HeCon (39%)	Forbs (83%), Buffel (44%), BoBla (41%)
C299	Box flats	Sandy clay loam	0	27	High	Buffel (91%), Forbs (27%), DaRad (16%)	Buffel (94%), BoPer (27%), Forbs (20%)
C264	Brigalow blackbutt	Light sandy clay loam	0	0	Absent	Buffel (83%), ChFal (31%), Forbs (20%)	Buffel (95%), ChFal (39%), Forbs (32%)
C329	Brigalow blackbutt		2	78	High	Forbs (41%), Buffel (40%), HeCon (20%)	BoPer (78%), Buffel (33%), HeCon (19%)
C301	Brigalow with softwood scrub species	Light clay	2	4	Low-Medium	Buffel (97%), Forbs (14%), BrCon (10%)	Buffel (100%), Native legumes (28%), Forbs (25%)
C297	Brigalow with softwood scrub species		0	32	High	Buffel (72%), Enneapogon spp. (28%), Aristida spp. (20%)	Buffel (73%), Forbs (58%), BoPer (32%)
CT11	Narrow-leaved ironbark woodland	Sandy loam	0	7	Low-Medium	Buffel (87%), Forbs (59%), ChFal (56%)	Buffel (96%), Shrubby stylo (31%), UrMos (29%)
C273	Mountain coolibah woodlands	Sandy clay	0	82	High	HeCon (84%), BoEwa (52%), Native legumes (46%)	BoPer (82%), DaRad (43%), BoEwa (42%)
C253	Mountain coolibah woodlands	Medium Clay	1	62	High	BoEwa (62%), Forbs (52%), Urochloa spp. (52%)	BoPer (62%), Buffel (53%), BoEwa (34%)
C283	Eucalypts and bloodwood on clays	Clayey sand	0	5	Low-Medium	No records	HeCon (86%), BoEwa (57%), Forbs (41%)

Figure 53. Current (2020/21) Indian couch frequencies (%) at QGRAZE sites in the Fitzroy catchment, including Absent of Indian couch (0%) – sites C284, BM03 & C264; Low Indian couch frequency (<5%) site C301, and Low to Medium Indian couch frequency (5 to 25%) site CT11.

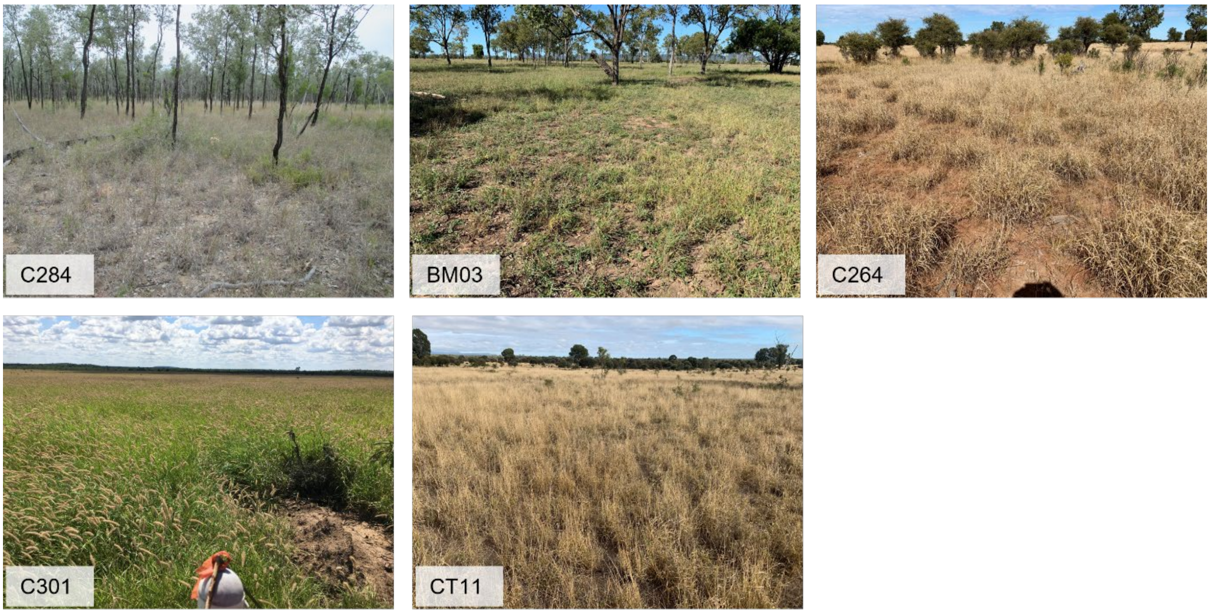


Figure 54. Current (2020/21) Indian couch frequencies (%) at QGRAZE sites in the Fitzroy catchment, including Medium to High Indian couch frequency (>25% to 75%) sites C299, C297 & C253, and High Indian couch frequency (>75%) sites C329 & C273.

10.2.3 *VegMachine®* graphs of cover trends in the Fitzroy catchment

Series of graphs of cover trends for QGRAZE sites sampled in the Fitzroy catchment. Two graphs are shown for each site: green cover and total cover.

Figure 55. Cover trends for QGRAZE sites sampled in the Fitzroy catchment. Two graphs are shown for each site: green cover and total cover.

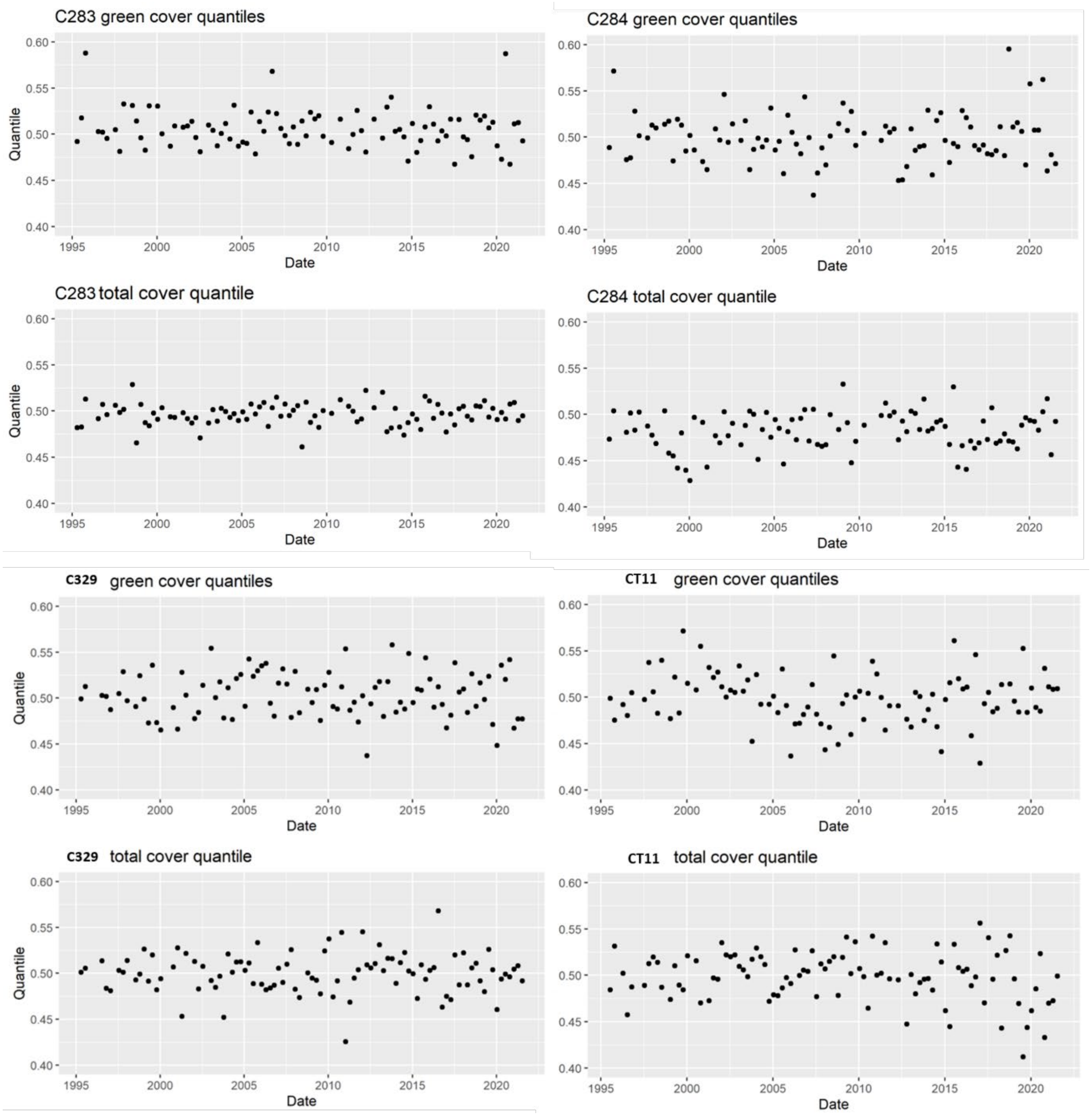


Figure 56. Cover trends for QGRAZE sites sampled in the Fitzroy catchment. Two graphs are shown for each site: green cover and total cover.

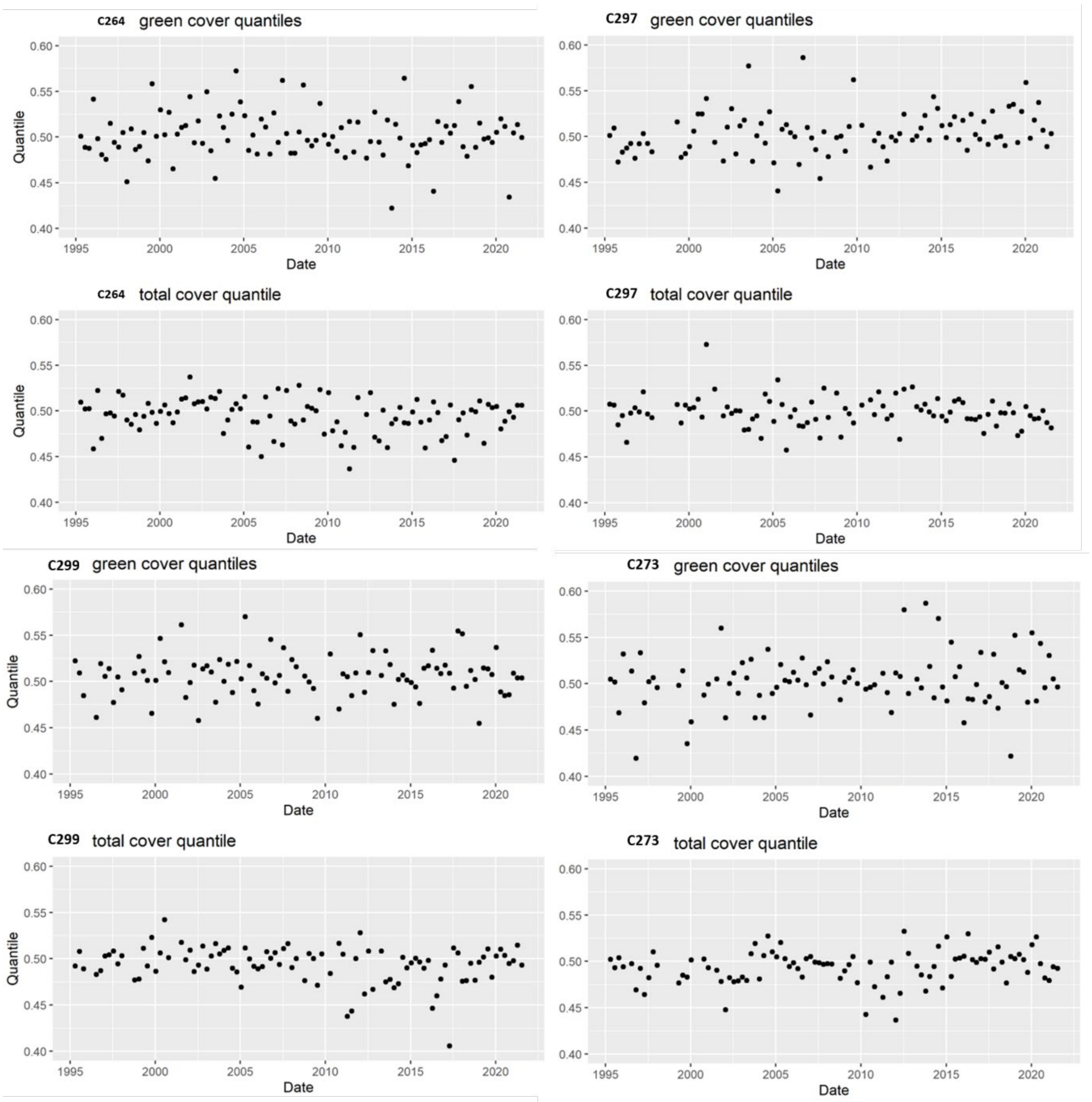
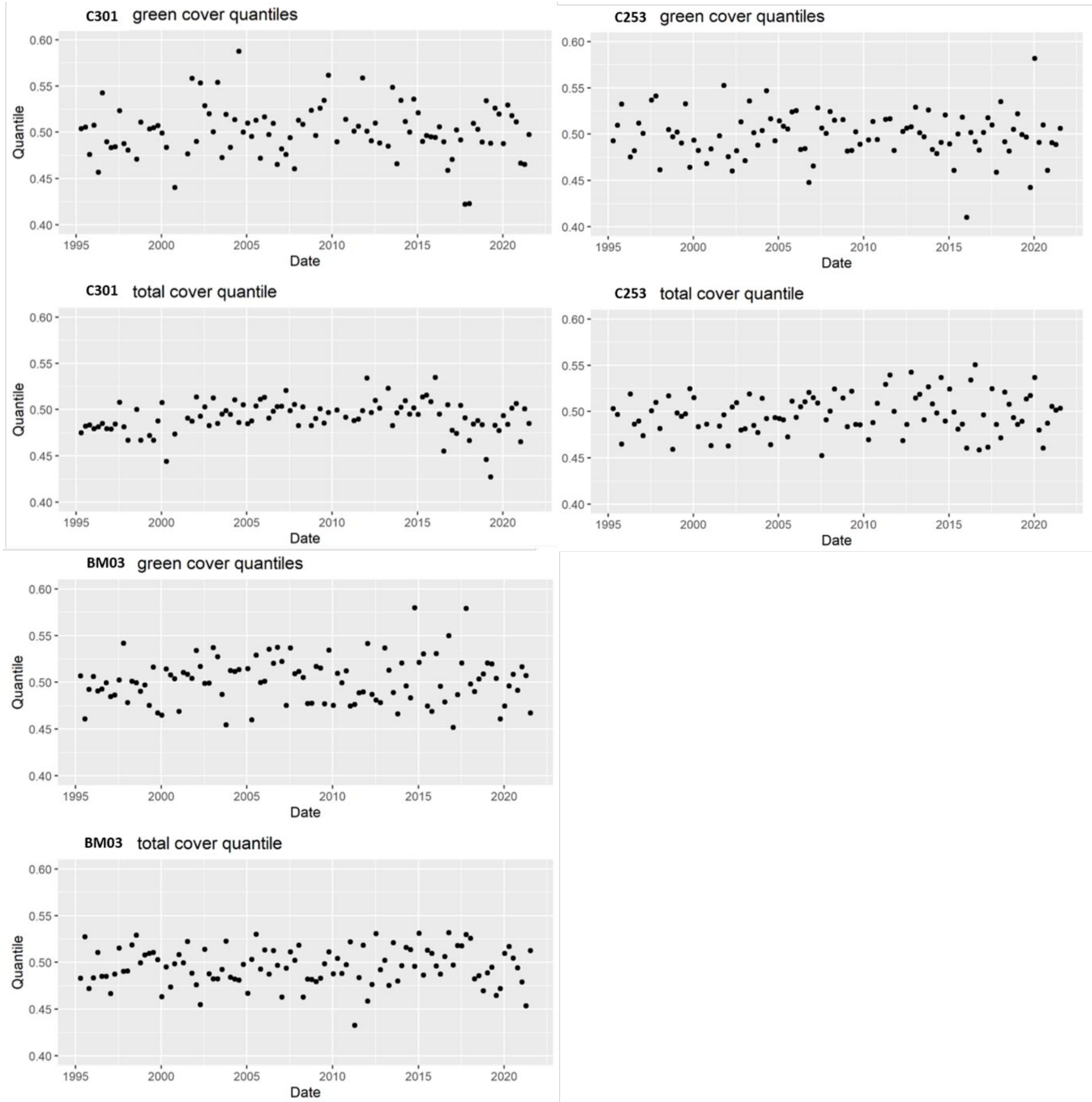


Figure 57. Cover trends for QGRAZE sites sampled in the Fitzroy catchment. Two graphs are shown for each site: green cover and total cover.

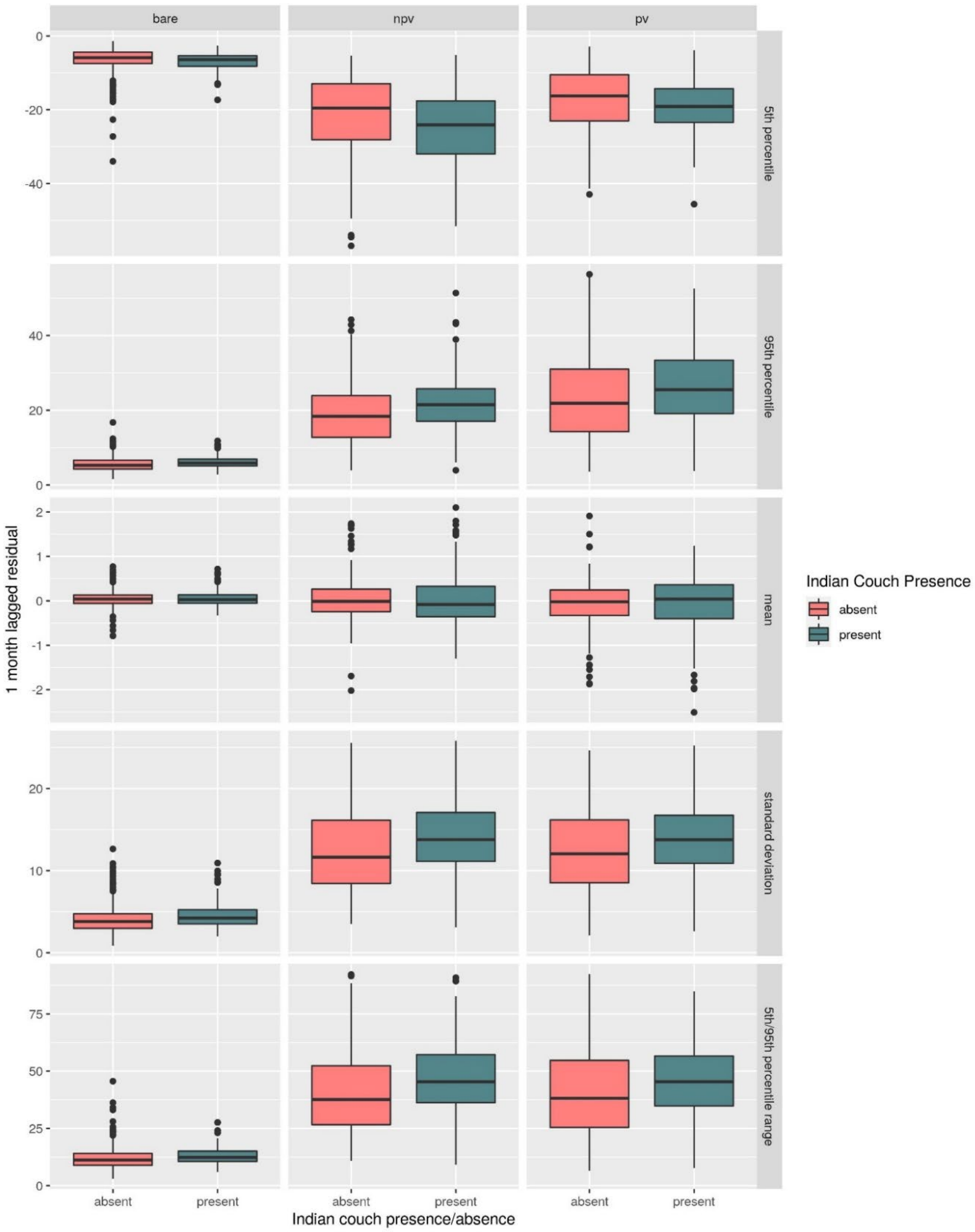


10.3 Remote Sensing Analysis (DES)

10.3.1 One month lagged residual

Monthly time series analysis.

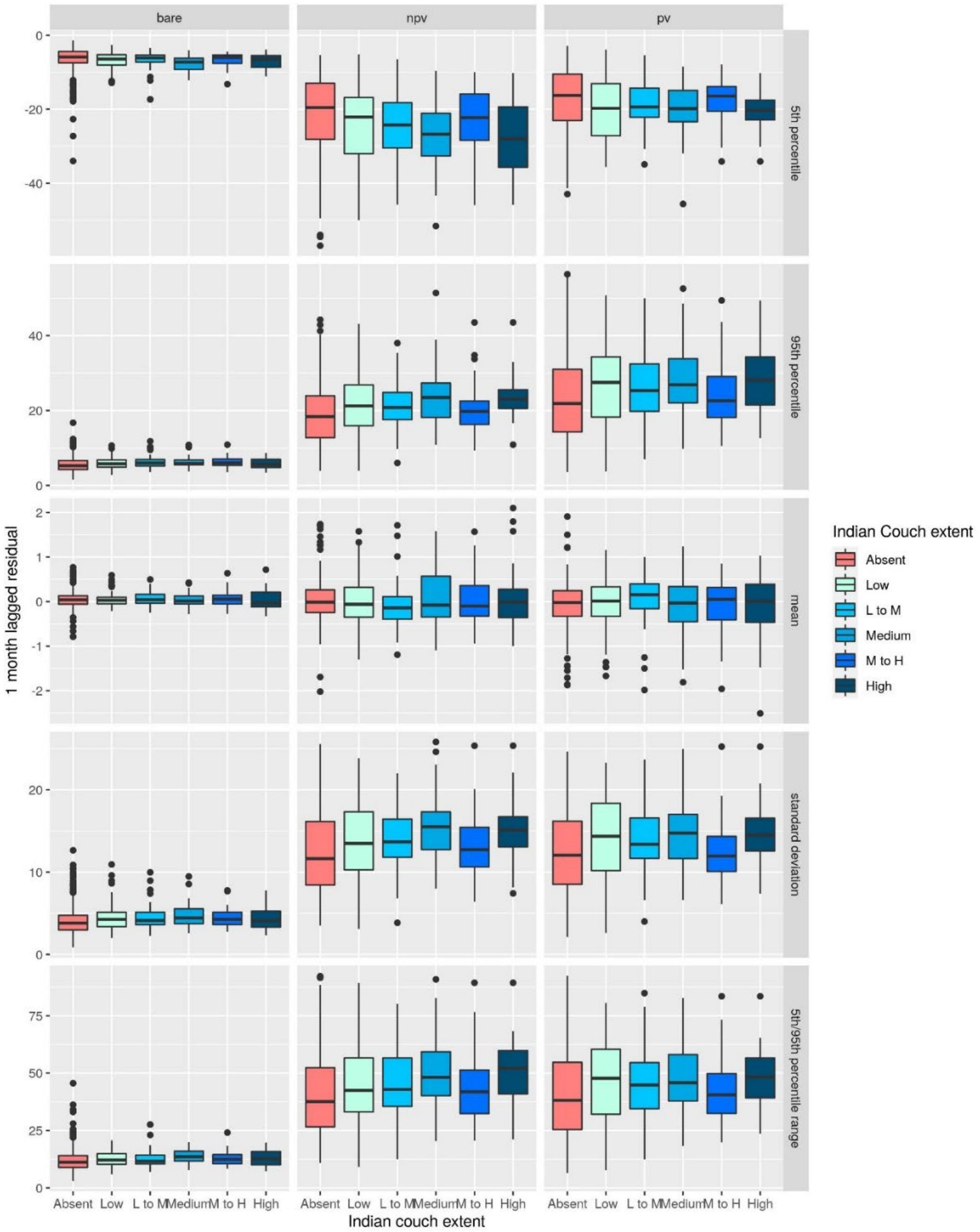
Figure 58. Box plots describing the distribution of a variety of time series statistics calculated from the 1 month lagged residual of cover.



10.3.2 One month lagged residual grouped by the Indian couch 'extent' classes

Monthly time series analysis.

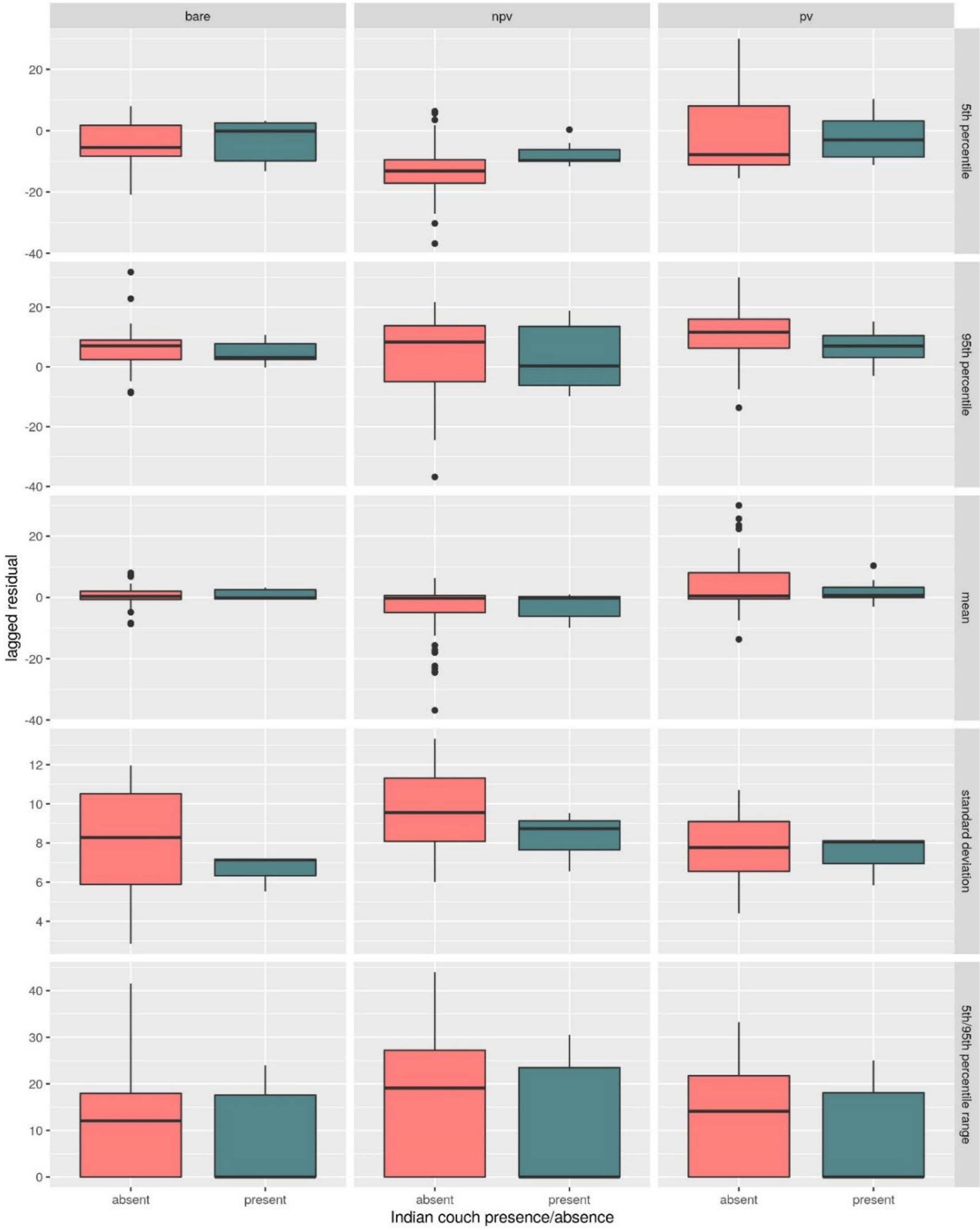
Figure 59. Box plots describing the distribution of a variety of time series statistics calculated from the 1 month lagged residual of cover, grouped by Indian couch extent/density.



10.3.3 Higher resolution analysis

An individual Sentinel-2 tile (56JLS).

Figure 60. Box plots describing the distribution of a variety of time series statistics calculated from the difference between sequential dates.



10.4 Raising awareness

10.4.1 Raising awareness on the extent of Indian couch spread

Figure 61. Social media posting published in July 2020. This posting went out on Facebook on the Queensland Agriculture page to spread the word about investment into understanding the spread and impact of Indian couch on grazing businesses in Queensland.

FutureBeef
July 1, 2020

"There's been very little documented on the spread of Indian couch in Queensland and little is known about its biology, economic impacts, and management options.

To understand where it's spreading, mapping is now underway in road reserves and paddocks as part of a $1 million project to benefit graziers."

Figure 62. A second posting on the FutureBeef website in July 2021 indicated the potential invasion area for Indian couch in eastern Queensland could be in the order of 14 million hectares (based on non-core and core habitat data).

Potential invasion area for Indian couch in Queensland reaches 14 million hectares

Page published: July 30, 2021 | Page reviewed: July 30, 2021

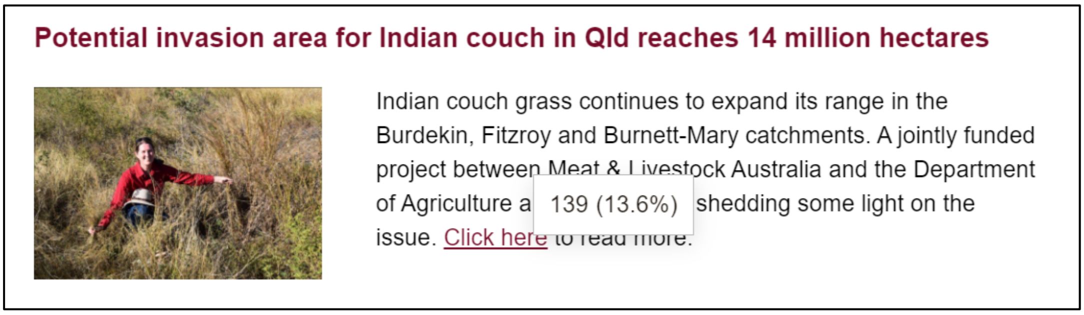
Indian couch grass continues to expand its range in the Burdekin, Fitzroy and Burnett-Mary catchments. The increase in Indian couch could be symptomatic of land condition decline and pasture condition decline, providing incentive to combat, or at least manage this invasive species.

A joint Meat & Livestock Australia and Department of Agriculture and Fisheries funded project, due to end in May 2022, is shedding light on the issue.

Table 24. Reach metrics captured over a one-week period for the July 2021 FutureBeef feature article.

Item	Details
Twitter:	
Date	08/07/2021 04:05 AM AEST +1000
Content	Potential invasion area for Indian couch revised to 14 million hectares. Indian couch grass continues to expand its range in the Burdekin, Fitzroy and Burnett-Mary catchments. Find out more: https://t.co/KjIp2nf2Mr @meatlivestock @DAFQld https://t.co/KZjSuFvDIw
Created by	info@ FutureBeef
Labels	IndianCouch, MLA
Likes	3
Retweets	1
Engagement	4
Url	https://twitter.com/FutureBeef/status/1423706723001511940
Facebook:	
Date	08/07/2021 09:34 AM AEST +1000
Content	Potential Indian couch invasion area revised to 14 million hectares Indian couch grass continues to expand its range in the Burdekin, Fitzroy and Burnett-Mary catchments. A jointly funded project between Meat & Livestock Australia and Queensland Agriculture, is shedding some light on the issue. Read more: https://bit.ly/2VgAAoy
Created by	info@ FutureBeef
Reach	4142
Engaged users	85
Clicks	45
Link clicks	37
Photo views	8
Other clicks	47
Url	https://www.facebook.com/futurebeef/photos/a.411690498887915/4361741870549405/?type=3
LinkedIn	
Date	08/06/2021 06:36 AM AEST +1000
Post content	Potential invasion area for Indian couch revised to 14 million hectares. Indian couch grass continues to expand its range in the Burdekin, Fitzroy, and Burnett-Mary catchments. A jointly funded project between Meat & Livestock Australia and Department of Agriculture and Fisheries (Queensland), is shedding light on the issue. https://bit.ly/2VgAAoy
Account	info@ FutureBeef
Tag	IndianCouch
Reach	201
Clicks	10
Likes	3
Share	0
Comments	0
Engagement	13
Url	https://www.linkedin.com/feed/update/urn:li:share:6829148007972380672

Figure 63. The effectiveness of FutureBeef e-bulletin as a means for reaching out to the grazing community and raising awareness on the issue of Indian couch spread in Queensland's grazing lands. The click rate shown was captured after the article had been released for one week in July-August 2021.



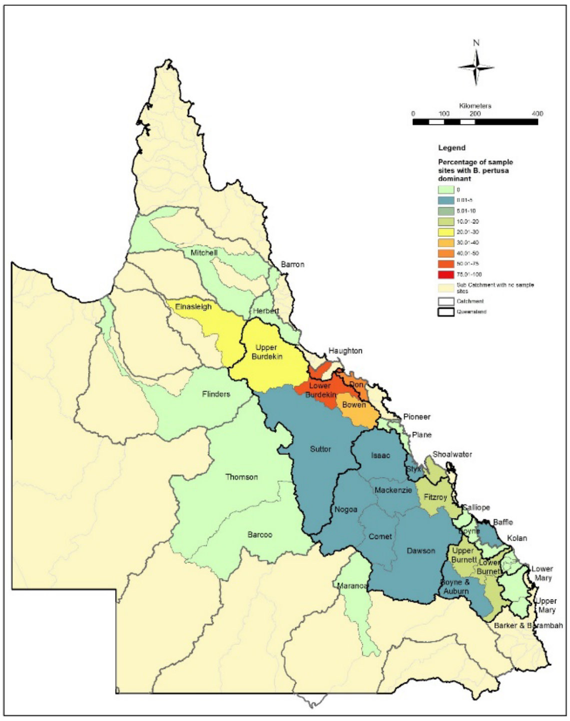
10.4.2 Raising awareness on the potential impacts of Indian couch on carrying capacity

A final 'FutureBeef' article prepared for publication for the purpose of disseminating project findings and raising awareness on the spread and impact of Indian couch in pastures is shown below. Content will be finalised in conjunction with MLA.

Proposed title: The spread of Indian couch grass: what this means for beef businesses and areas most likely at risk from Indian couch dominance

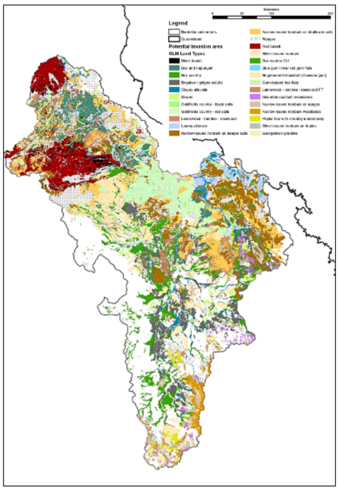
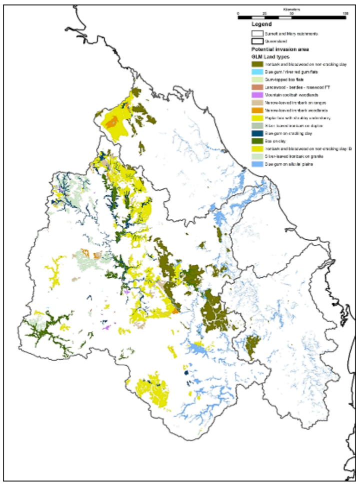
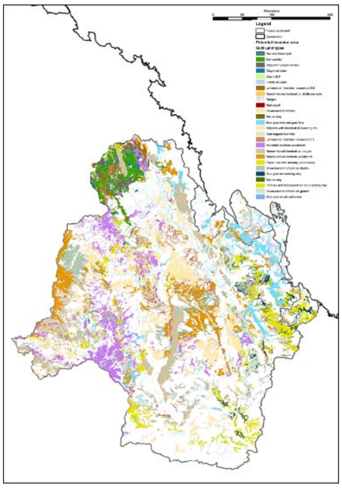
Proposed subtext: Meat and Livestock Australia (MLA) recently partnered with the QLD Department of Agriculture and Fisheries to understand the threat posed by Indian couch to QLD producers.

Indian couch occurrence: this exotic creeping, stoloniferous grass can be found right across northern Australia, but more so in Queensland. In Queensland, Indian couch occurrence is greatest in coastal and sub-coastal locations such as the Burdekin, Fitzroy and Burnett-Mary catchments (see Figure). Across these three catchments, the potential invasion area for Indian couch dominance is in the order of 9.6 million hectares. This represents ~32% of the total area that makes up the Burdekin, Fitzroy, and Burnett-Mary catchments being at risk of Indian couch dominance.



What is driving the spread of Indian couch in pastures? A range of factors are contributing to the spread of Indian couch across eastern Queensland. Ecological attributes for competitiveness, land degradation, heavy grazing, adequate source of seed and means of spread, and climatic extremes in rainfall variability can all culminate in opportunities for Indian couch to rapidly colonise in pastures. Under severe conditions, such as heavy grazing coupled with drought, Indian couch can replace pasture species and form new landscapes, although there is some evidence to suggest that Indian couch can invade well managed pastures. There is a good source of seed around such as in road reserves, and different means of spread, such as seed transfer by wind, water, animals, farm machinery and vehicles. Climatic extremes in rainfall variability also play an important role. During drought-breaking rains, for instance, the opportunity is there for Indian couch to establish itself, particularly on bare soil and gaps in pasture which provide establishment sites for Indian couch. What is not so clear is the effect of animal grazing behaviour on Indian couch spread. Preferential grazing of cattle on particular sections of a paddock may provide ideal growing sites for Indian couch to establish, due to reduced plant competition.

What role does land type and land condition play? Many land types are affected by Indian couch spread (see catchment figures) as are all land condition states (i.e. ABCD). Road surveys showed the land types most at risk for the Burnett and Mary catchments include Ironbark and bloodwood on non-cracking clay, Blue gum on cracking clay, Box on clay, and Silver-leaved ironbark on granite. For the Fitzroy catchment, at risk land types included Gum-topped box flats, Mountain coolibah woodlands, Poplar box with shrubby understory, and Silver-leaved ironbark on duplex. Land types highly affected in the Burdekin included basaltic soils, ranges, clayey alluvials and goldfields country.

What does the spread of Indian couch in pastures mean for beef businesses? The project investigated the potential impacts of Indian couch on production and carrying capacity. This was done through field work, the collection of producer feedback and anecdotes, and through bioeconomic modelling. Field studies showed that pasture production of Indian couch relative to native pastures varied between environments, due to differing responses to climate, soil type, and the presence of legumes. Five site pairings of Indian couch and native dominant pasture were sampled in the Burnett-Mary and Burdekin catchments over two years. Statistically significant differences in pasture production occurred in three out of ten occasions. In the Burnett-Mary catchment, measured pasture growth of native grasses was higher than that of Indian couch on two sites characteristic of heavy soils and during below average rainfall conditions. In the Burdekin catchment, measured growth of Indian couch was greater than that of native grasses at a sedimentary red earth site and during monsoonal rainfall conditions. The findings are reflective of producer experience which suggests that the productivity of Indian couch pastures is reasonable during good seasons, but poor in dry years. Producer knowledge also suggests, that overall, Indian couch is a less reliable feed resource than native grasses.

Reduced drought tolerance is the biggest problem with Indian couch: A combination of research findings, expert opinion, and producer knowledge showed Indian couch has some production value, but a major impediment is its reduced drought tolerance. As one producer said, Indian couch is a "*Less reliable feed source, as reasonable production only comes with good seasons*". Drought-susceptible Indian couch pastures provide little forage during extended dry periods, which makes properties dependent on these pastures more vulnerable to drought.

What producers are saying: "*Less reliable feed source, as reasonable production only comes with good seasons*"; "*When it's raining it* [Indian couch] *is doing well and so are the weight gains* [of cattle]. *Carrying capacity is up too. When its dry, Indian couch dies out quick and has no substance to it so decrease in weight gains/carrying capacity*"; "*Wet season they do alright but cattle will fall away quicker*".

10.4.3 Raising awareness on the potential impacts of Indian couch on landscape function

In a continued effort to raise community awareness on the issue of Indian couch spread in pastures, the project released two feature articles (Queensland Country Life 2021 and North Queensland Register 2021) providing insights into the production impacts and reduced drought tolerance of Indian couch and management options.

Figure 64. Indian couch article featured in the Northern Muster of the North Queensland Register, 25 February 2021.

12 NORTH QUEENSLAND REGISTER Thursday February 25, 2021 northqueenslandregister.com.au

FutureBeef NORTHERN MUSTER *Information for rural business in North Queensland* Queensland Government

Threat of Indian couch

Indian couch in the Burdekin catchment: Why we need to know more!

INDIAN couch (*Bothriochloa pertusa*), also known as Indian bluegrass, is an invasive naturalised grass that has expanded its range in the Burdekin catchment, covering not only Goldfields country, but also north of Charters Towers on the more fertile basaltic soils.

Indian couch tolerates heavy grazing and provides some carrying capacity for beef businesses. It is also a creeping grass with runners, providing good soil surface cover.

However, it is not particularly productive or drought tolerant and has poor root structure when compared to the desired native or improved perennial pasture species, such as native desert bluegrass (*Bothriochloa ewartiana*).

Indian couch grass can also replace the desirable 3P grasses in the paddock and form monocultures with loss of biodiversity and which are inherently unstable and susceptible to collapse through pests and disease.

What can older generation producers tell us about Indian couch expansion in the Burdekin?

On the Basalt, there has been an increase in Indian couch since the late 80s and early 90s. There was no recollection of the grass in the late 60s. The increase in Indian couch might simply be a sign of the times - 'Everyone is running more cattle and Indian couch takes advantage of this'.

There are also good sources of seed around these days, such as air strips and lawns. Seed is easily spread by vehicles, bikes and four wheelers. The grass can be found along power lines and a common corridor of spread into the Basalt has been along roads. Producers expressed concern about what to do if Indian couch renders land unproductive or less productive.

As for the Goldfields, observations of Indian couch in the 70s included 'small patches in the horse paddock'. Drought feeding in the 80s with molasses and urea saw native grasses being eaten out allowing Indian couch to spread.

Initial views of Indian couch were positive as cattle ate it all! 'In those days, Indian couch was good to the last drop - just like Johnny Walker whisky', and 'in 1991 during a big wet there was enormous growth of Indian couch. Seed was harvested because there was a demand for it!'.

Looking back now producers might think differently: 'It's not good! Indian couch doesn't handle drought like native tussock grasses. It's only a surface grass so it needs to come back from seed compared with native grasses that survive and reshoot'.

What are next generation producers in the Burdekin saying?

For producers on the Basalt, Indian couch might not be on everyone's radar. Those that have noticed it describe it as good at filling in the spaces and better than a weed. That said, 3P native grasses such as Desert bluegrass are still preferred. There are serious concerns about productivity and profitability losses associated with increases in Indian couch.

Observations in the paddock reveal Indian couch dominance occurs in areas of high grazing pressure or after a fire where grazing pressure was not reduced. Consideration to management of Indian couch might need to include conservative stocking to give better grasses a chance to remain competitive, and to spell paddocks, and avoid over-utilisation of native pastures during prolonged droughts.

As for current producers grazing Goldfields country near Charters Towers, pastures have high Indian couch prevalence and have had for quite some time now making it more of an inherited issue.

One producer noted that failure to manage 3P grasses will only allow more Indian couch to come in: 'There can be some fluctuations in the amount of Indian couch in the pasture, but overgrazing, and pressure at the wrong time of the year can see pastures default back to Indian couch'.

This same producer also observed that, 'Ploughing in some paddocks really offset Indian couch prevalence as buffel grass grew, but Buffel is hard to sustain'.

They also commented that one way to maximise value from Indian couch is to compliment it with stylo. When Indian couch starts to dry up the stylo can then be browsed. As a result, the management options considered for the Goldfields may need to include a combination of mechanical intervention in conjunction with conservative stocking and resting.

Where to from here?

The development of 'best-bet' management guidelines for producers will take place over the next 12 months as part of a producer-driven research project led by the Department of Agriculture and Fisheries (DAF) and jointly funded by Meat & Livestock Australia.

Advisory and technical panels will be formed and practical solutions will be determined through examination of producer knowledge and research findings.

Dr Nicole Spiegel, DAF, 0436 951 988.

Indian couch dominant pasture on the Basalt, north of Charters Towers. Photo taken on May 7, 2019.

> Indian couch is an invader of space. With a source of seed and the right growing conditions, this grass is capable of invading native pastures irrespective of how they are grazed, with heavy grazing exacerbating the spread.

Figure 65. Indian couch article featured in the Queensland Country Life, 25 February 2021.

22 QUEENSLAND COUNTRY LIFE - SOUTHERN EDITION Thursday February 25, 2021 queenslandcountrylife.com.au

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Threat of Indian couch

Indian couch in the Burnett-Mary: Why we need to know more!

INDIAN couch (*Bothriochloa pertusa*), also known as Indian bluegrass, is an invasive naturalised grass found right across the eastern seaboard of Queensland.

It is a very successful grass that can invade both small and large spaces.

Whilst Indian couch tolerates grazing and provides good ground cover, concerns are that it is replacing desirable 3P (productive, palatable, perennial) grasses to form less productive 'monoculture' systems.

Despite its ability to arrest soil erosion, its shallower root system compared with desirable native or improved grasses is associated with reduced water infiltration, increased run-off, and greater susceptibility to drought making this grass a less reliable feed source.

The spread of Indian couch can also be a symptom of land degradation, with production losses a result of declines in land condition.

In the Burnett-Mary, Indian couch can be found in paddocks and road reserves and can be easily spread after wet periods and via farm machinery. It is believed to have spread since the early 80s, with very low levels observed in pastures at Gayndah in 1986.

On Brian Pastures Research Station in Gayndah, historical records of Indian couch were compared with more recent levels, showing Indian couch increased from zero to 18 per cent over the 80s and 90s, with a further increase to 32pc in 2018.

Indian couch has been observed further south of the Burnett-Mary along roadways in Surat and Roma districts.

What do producers think?

Some Burnett-Mary producers regard Indian couch as a nuisance grass that spreads rapidly. The issue of Indian couch is a double-edged sword.

On one hand, it is a source of feed for cattle but on the other hand, it grows less bulk than other pastures and threatens to reduce carrying capacity.

What is clear is that Indian couch can provide excellent ground cover and stabilise soil, and is a better option when compared to many other grasses found in the Burnett-Mary, such as African lovegrass, GRT, Grader grass, [redacted], [redacted], and green and blue couch. It is even known to out-compete creeping lantana.

What does the science reveal?

Controlled ageing trials conducted by the Tropical Weeds Research Centre, Charters Towers indicate Indian couch seed persists and remains viable for more than three years.

The University of Queensland (UQ) investigated pasture trends as related to different stocking rates. They found relationships for native 3P grasses but not for Indian couch. The proportion of Indian couch in the pasture could not be related to grazing strategy, suggesting grazing alone isn't enough to control Indian couch. In contrast, desirable native pasture species were affected by grazing strategy and preferred being rotationally grazed.

Another study by UQ looked at the effects of fire on Indian couch seed relative to native Black speargrass. This preliminary work showed differential responses in germination and viability following exposure to heat and smoke treatments.

For Indian couch, there was both reduced heat tolerance and no stimulatory effect of plant-derived smoke on seeds compared to Black speargrass. It was speculated that the greater susceptibility of Indian couch to high temperatures is most likely attributed to seed morphology as it lacks a hard seed coat.

Production impacts are being quantified for Indian couch (left) relative to Black speargrass (right) at the Brian Pastures Research Station. Photo taken on May 22, 2019.

> In the Burnett-Mary, Indian couch can be found in paddocks and road reserves and can be easily spread after wet periods and via farm machinery.

Where to from here?

Firstly, make sure you are managing the right grass! Indian couch can be easily mistaken for other tropical perennial grasses such as creeping bluegrass, Sheda and Angleton grass.

Adopting a combination of practices that are targeted at the management of both desirable and undesirable pasture species may be necessary.

The potential role of fire for controlling Indian couch has been implicated and could prove useful in reducing seed loads.

Management of desirable pasture species to ensure their survival in the pasture, such as through resting, will be essential for reducing opportunities for Indian couch invasion.

In situations where Indian couch has become the dominant species, options for management may need to focus on working with the grass rather than against it, such as increasing the productivity of Indian couch pastures with legumes or through a fertiliser regime, or otherwise by sowing competitive but more desirable grasses.

Over the next 12 months, 'best-bet' management guidelines will be developed for producers as part of a project led by the Department of Agriculture and Fisheries and jointly funded by Meat & Livestock Australia.

Both producer and research knowledge will be used to determine practical solutions.

For more information contact Dr Nicole Spiegel, Department of Agriculture & Fisheries, 0436 951 988.

10.5 Production impacts

10.5.1 T-tests on quadrat data

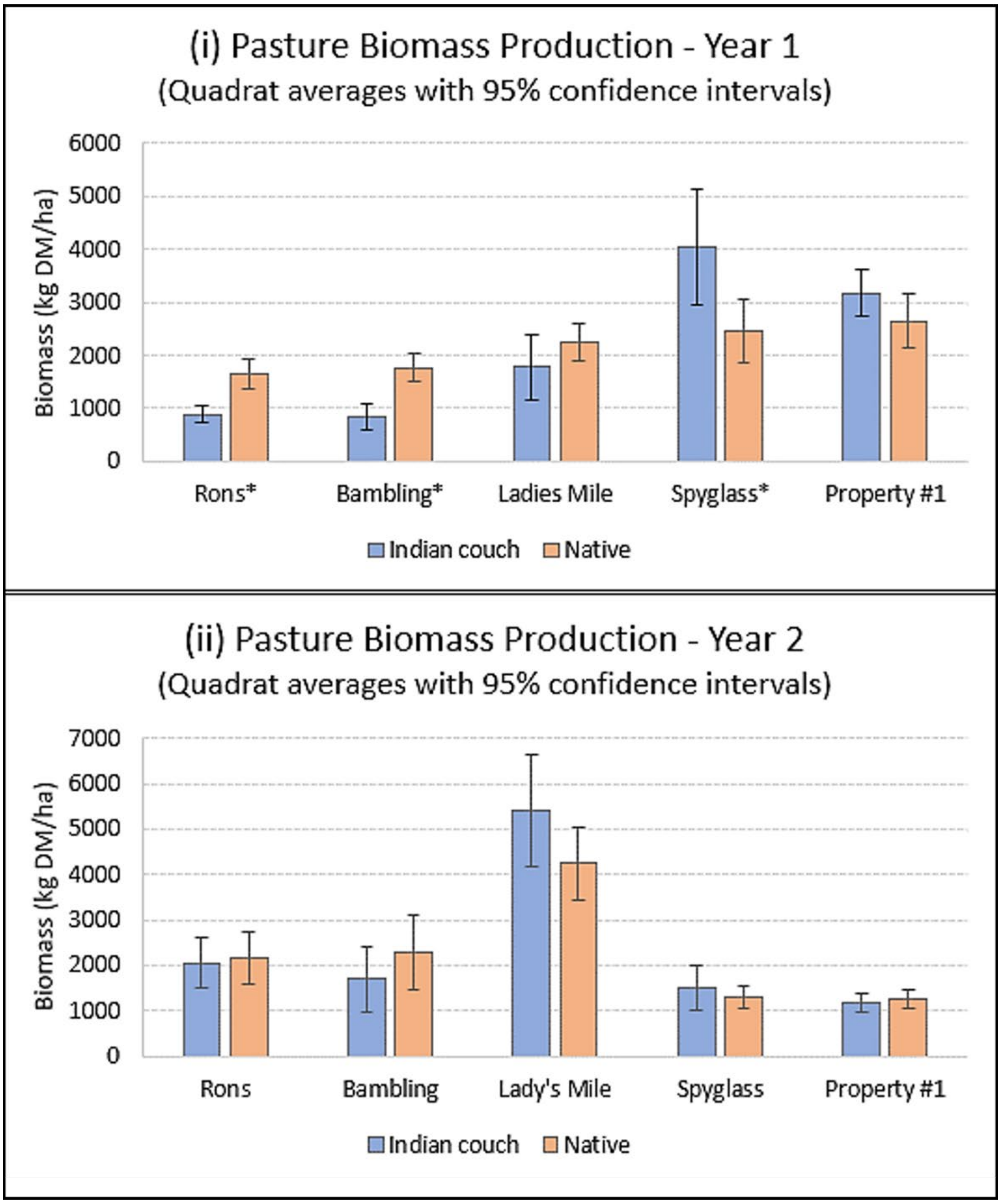
The 95% confidence intervals of the mean and t-tests using the individual quadrat data (for each SWIFTSYND site) were calculated for indicative purposes only, as these quadrat data represent samples, not true replicates of the pasture type. For ease of comparison, Fig. 66 gives a visual display of the confidence intervals quoted in Table 25.

Table 25. Biomass means from t-test using quadrat values. Confidence intervals (CI) and *P*-values are shown.

Year	Site	Pasture				P-value[#]
		Native dominant		Indian couch dominant		Native vs Indian couch
		Biomass mean	95% CI (lower, upper)	Biomass mean	95% CI (lower, upper)	*(based on quadrat data)*
Y1H3	Rons	1643	(1352, 1933)	883	(725, 1040)	<0.001
	Bambling	1771	(1497, 2044)	846	(596, 1095)	<0.001
	Lady's Mile	2235	(1883, 2587)	1784	(1171, 2398)	0.167
	Spyglass	2472	(1870, 3073)	4057	(2961, 5153)	0.010
	Property #1	2644	(2128, 3161)	3177	(2728, 3626)	0.091
Y2H3	Rons	2174	(1598, 2750)	2043	(1489, 2598)	0.715
	Bambling	2290	(1454, 3125)	1692	(970, 2414)	0.236
	Lady's Mile	4237	(3451, 5024)	5407	(4174, 6639)	0.087
	Spyglass	1296	(1036, 1555)	1509	(1007, 2011)	0.397
	Property #1	1248	(1041, 1455)	1162	(960, 1364)	0.502

[#] t-tests are considered to be done for indication purposes only as quadrat data is 'sample' data and hence confidence intervals of the means have been quoted for general comparison.

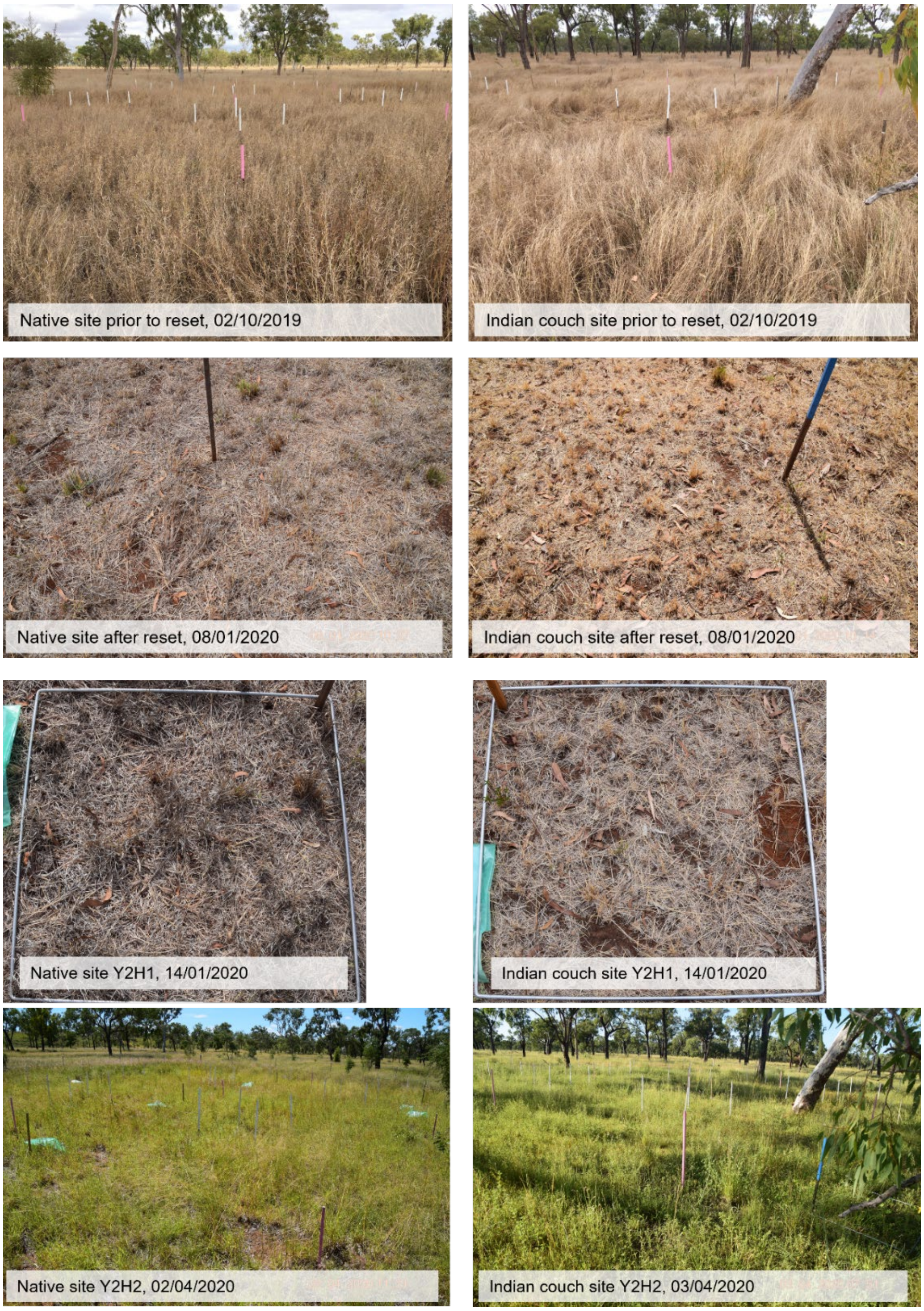
Figure 66. Mean pasture yield (kg DM/ha) with confidence interval shown for five Indian couch and native dominant pasture pairings according to a first year (i) and second year (ii) of sampling.



10.5.2 "Property #1" SWIFTSYND sites

"Property #1" SWIFTSYND sites in north Queensland, on red basaltic soil, during early Y2 (2019/20) sampling.

Figure 67. The left panel of photos are for the native site, compared with the right panel photos of the Indian couch site.



“Property #1” Indian couch SWIFTSYND site in north Queensland, on red basaltic soil, during early Y2 (2019/20) sampling.

Figure 68. The left photo shows an example of a quadrat that was sampled, and the right photos show an example native army worm found at the site.

10.5.3 Base parameter sets

Table 26. GRASP parameters for eastern Queensland native pastures. GRASP parameters *per se* are indicated by parameter number (Par. No.). Default parameters for GRASP are shown (PRV), as are the average C4 grass parameter set based on state wide data (X indicates the parameter was not included in the C4 set). The recommended Indian couch and native pasture parameters are shown for eastern Queensland. Where values are bolded, this indicates differences in the Indian couch value from the recommended native pasture parameter value, with the first value being for native pasture and the second value being for Indian couch pasture.

	Par. No.	PRV	Average C4	Eastern Queensland
Soil depth				
Depth of layer 1 (mm)	020	100	100	100
Depth of layer 2 (mm)	021	400	400	400
Depth of layer 3 (mm)	022	500	500	300
Total depth of soil profile (mm)			1000	800
Limits				
Air dry layer 1 (mm)	019	10	10	3
Wilting point layer 1 (mm)	029	15	10	5
Field capacity layer 1 (mm)	026	36	25	25
Wilting point layer 2 (mm)	030	70	40	45
Field capacity layer 2 (mm)	027	174	100	105
Wilting point layer 3 (mm)	031	65	50	50

Field capacity layer 3 (mm)	028	105	100	95
Water holding capacity				
WHC (fc-wp) layer1 (mm)		21	15	20
WHC (fc-wp) layer2 (mm)		104	60	60
WHC (fc-wp) layer3 (mm)		40	50	45
WHC (fc-wp) lyrs 1-3 (mm)		165	125	125
WHC (fc-wp) (mm/10cm)		16.5	12.5	14.7
Plant growth				
Perennial grass basal area (%)	005	2	1	5.0
Pot. regrowth rate/unit PGBA (kg/ha/day/basal %)	006	15	3.5	**2.5/5.0**
Regrowth rate (kg/ha/day)	P5xP6	30	3.5	**12.5/25.0**
Transp. use eff. (kg/ha/mmT)	007	10	13.5	**12/10**
Radiation use eff. (kg/ha/MJ/m^2)	008	12	12	12
Soil water index at which growth stops	149	0.4	0.3	0.3
Max growth N limit (kg/ha) (P99/(P101/100)		3000	2941	5500
Temp index (1-4)	209	4.0	X	4.0
TIX = 0 if T<P61	061	14	X	14
TIX = 0 -> 1 T P61 -> P62	062	24	X	24
TIX = 1 T P62 -> P63	063	35	X	45
TIX = 1 -> 0 T P63 -> P64	064	45	X	50
Plant death				
Death constant	010	0.002	0.002	0.002
Death slope	051	0.013	0.013	0.013
Death multiplier (leaf)	133	1	1	1
Death multiplier (stem)	134	1	1	1
Detachment				
Leaf-wet season (kg/kg/day)	128	0.002	0.004	0.003
Stem-wet season (kg/kg/day)	129	0.002	0.004	0.003
Leaf-dry season (kg/kg/day)	130	0.002	0.002	0.003
Stem-dry season (kg/kg/day)	131	0.002	0.002	0.003
Rainfall effect leaf detachment	154	0.0	X	0.0
Rainfall effect stem detachment	155	0.0	X	0.0
2-day rain (mm) initiate leaf det.	156	50	X	50
Litter				
Rate of litter breakdown	016	0.04	X	0.04
Coeff. SR on litter breakdown	018	0.0	X	0.0
Sward structure				
Green standing dry matter (kg/ha) at 50% green cover				
Transpiration	045	1600	1000	**1200/800**
Radiation	046	1600	1000	**1200/800**
TSDM (kg/ha) 50% cover (runoff)	271	1150	1150	**1200/800**
Height (cm) 1000 kg/ha TSDM	096	10	20	**11.5/3.4**
VPD multiplier for zero height	094	1.5	X	1.5
Height VPD multiplier = 1	095	20	X	20
Re. supply L3 (root distribution)	106	0.5	X	0.5
Prop. pasture eaten by stock	015	1.0	0.75	0.75

New sward model				
Prop. leaf of leaf + stem	123	0.5	0.5	0.5
Green yield at start stem growth	124	0.0	X	0
Min. temp. green cover = 0%	011	0.0	0.0	0.0
Min. temp. green cover = 100%	125	2.0	2.0	2.0
Min. temp. frost effect	053	2.0	2.0	2.0
Soil water index (max. green cover)	009	0.4	0.3	0.24
% leaf in diet at 50% leaf in sward	132	75	85	75
Nitrogen (N)				
N (kg/ha) per 1000mm of rain	090	0.0	0.0	0.0
N uptake at 0mm transpiration. (kg/ha)	097	5	5	4.0
N uptake per 100mm of transpiration (kg/ha/100mmT).	098	5.8	6	6.5
Prop. of P98 trees (layers 1,2,3)	167	0.0	1.0	0.0
Maximum N uptake (kg/ha)	099	23	20	22
Maximum N (%) in plants	100	2.5	2.5	2.5
N (%) at which growth stops	101	0.4	0.68	0.4
N (%) at which growth is restricted	102	0.5	0.78	0.5
N uptake per 100mm SW	103	1.0	1.0	1.0
Prop. decline per day %N green	108	0.000	0.000	0.000
Prop. decline per day %N dead	109	0.015	0.015	0.015
Min N (%) in green (= max in dead)	110	1.0	1.0	1.0
Minimum N (%) in dead	111	0.4	0.4	0.40
Date N uptake reset	112	915	1001	915
Trees				
Tree basal area (m2)	291	0	0	0.0
Wilting point layer 1 (mm)	292	0.0	10	P019
Wilting point layer 2 (mm)	293	0.0	40	P030
Wilting point layer 3 (mm)	294	0.0	50	P031
Layer 4 available water (mm)	295	0.0	0.0	0.0
Max. rooting depth (cm)	296	100	100	P20+P21+P22
Layer 4 starting value	299	0	X	0.0
Runoff				
0 for free draining soil or 1 for runoff as function of yield	270	0	1	1
Scale (0-1) tree litter effectiveness for runoff	047	0.0	1.0	1
K value	272	0.95	0.95	0.95
Max runoff at zero cover (wet soil)	273	1	1	1.0
% slope land (0-20%)	278	1	1	1
Soil loss model (1-3)	245	1	3	Select
I15 constant (runoff)	104	1.016	1.016 Brian Pastures	0.867 Capella
I15 slope (runoff)	105	0.465	0.465 BP	0.582 Capella
Drainage				
0 for free draining soil or 1 for runoff as function of yield	270	0	1	1
Evaporation				

Upper limit bare soil evap. (mm/day)	033	4.0	5.0	5.0
Cracking (yes/no)	035	0	0	0.0
Evap. when soil cracked (mm/day)	036	0.0	X	0.5
Starting soil moisture				
Layer 1	23	0.0	X	P029
Layer 2	24	0.0	X	P030
Layer 3	25	0.0	X	P031
Layer 4 starting value	299	0	X	0.0

10.6 Landscape function impacts

10.6.1 LFA methodology

Landscape function is a measure of (i) Stability – resistance to erosion, (ii) Infiltration – capacity for rain and run-on water to infiltrate, and (iii) Nutrient cycling – organic matter decomposition and cycling. An Indian couch Think Tank decided the site requirements for rudimentary landscape function analysis work. This included selecting and establishing three sites for three soil types, and all being mixed/intermediate pastures with native grasses and Indian couch.

Determined method and approach

As outlined below:

- Conduct experimental work in the same paddock at an intermediate (i.e., mixed) site and work at a patch level, assessing landscape function characteristics of Indian couch patches relative to 3P tussock patches.
- Using intermediate sites provides an opportunity to explore invasion processes of an alien grass into native pasture; early-stage niche for invasion, and to consider further the impacts of grazing management on further spread.
- Conduct experimental work mid-year, e.g., June 2021.
- Canopy cover scores can be used to record tree drip lines.
- Repeat the same experiment across different land types and soil types; a total of three different soil types.
- The inclusion of 'physical' measures (e.g., water infiltration) is key to strengthening the work and for calibrating surrogate LFA and PatchKey measures but remains outside the scope of the project.
- Additional measures, such as soil biodiversity, soil respiration, etc. would be great but are also outside the scope of the project.

Confirmation of sites for Landscape Function Analysis sampling in 2021

Undertake a site reconnaissance: A total of 3 x 4ha sites to be selected and repeated across 3 soil types: red basaltic, yellow/brown kandosol, and texture-contrast (Sodosol) soil type. A total of 9 LFA 'gradsects' marked out.

Figure 69. An example of one site for Landscape function analysis (LFA) marked out on a red basaltic soil in north Queensland. The LFA 'gradsect' is shown (a), including an example of a native 3P patch on the transect (b) and an Indian patch (c).