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Stakeholders' perspective on the economic cost of managing the invasive Navua sedge in tropical Queensland, Australia

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Note

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Abstract

Weeds incur up to A$4 billion in economic loss annually to Australian agriculture. Despite this knowledge, few quantitative data exist on yield loss and control costs caused by weeds. This article discusses the economic cost of managing the invasive Navua sedge weed to the grazing and cropping (sugarcane) industries of northern Queensland, Australia, following its introduction into the region in the 1970s. Between 2020 and 2022, through a survey questionnaire distributed to affected farmers, information on control cost, yield loss, and infestation history were documented. Collated data were analyzed using primarily nonparametric statistics due to the skewed or qualitative nature of many of the responses. The weed has invaded farming properties over the past 10 to 20 yr, the infestation level is considered to be low to moderate (median, 22.5%), and it varies appreciably among properties. The median cost of managing Navua sedge was A$72.91/ha when the study was conducted (the current value is now A$82.06). Neither this cost nor the type of management tactics (chemical vs. integrated weed management [IWM]) did not vary between land use types; however, labor, relative to chemical and machinery costs, was the greatest expense. The currently approved herbicide, halosulfuron-methyl (Sempra), is largely ineffective in controlling the weed due to its inability to deplete the weed's belowground tubers. Correlation analyses suggest that control costs will continue to increase with increasing Navua sedge infestation over time, especially in grazing lands. Farmers are highly aware of the challenge of managing this new weed. Farmers are using a myriad of strategies, including being willing to impose strict biosecurity measures and IWM tactics, while waiting for more effective herbicides and promising biocontrol agents to minimize the spread and impact of the weed.

Introduction

Navua sedge, a native of equatorial Africa, the Seychelles, Mauritius, and Madagascar, is a monocot weed of a relatively recent incursion in the northern part of the State of Queensland, Australia (Osunkoya et al. 2021; Shi et al. 2021). Following its introduction into the region in the 1970s, the weed had a relatively short lag time of ~23 yr and thereafter exploded in spread and abundance (Osunkoya et al. 2021; Figure 1). Navua sedge has since become an aggressive weed, affecting the beef, dairy, and crop (especially sugarcane) industries in both coastal and upland parts of the Queensland wet tropics (see Shi et al. 2021). The weed is known to spread through both seeds and underground rhizomes into agricultural and natural landscapes, including riparian corridors and along roadsides and railway lines, and can form dense monospecific stands, often replacing palatable tropical pasture species of the region (Chadha et al. 2022a; Shi et al. 2022).

In the Cairns region of far northern Queensland, some sugarcane farmers have switched to growing rice because blocks of their farms undergo recurring reinfestation, in part due to the inability of the planted canes to strike nodes in conditions of relatively high rainfall and soil wetness (see Figure 2). What the economic cost is and whether such a change in land use should be encouraged is an open-ended question. Despite these trends and challenges, data on the yield loss or control cost to the grazing and/or cropping industries caused by Navua sedge do not exist. This study aims to fill this knowledge gap. The primary purpose of this report is to assess the perspectives of affected stakeholders on the economic cost of weed management through quantifying control cost and property productivity loss. Such weed impact measures on agriculture are essential because northern Queensland is a significant beef cattle production area, with more than 150,000 cattle exported yearly (Beef Central 2017). The region also produces the largest amount of sugarcane (20,600,000,000 kgs yearly) in Australia (Australian Bureau of Statistics 2020).

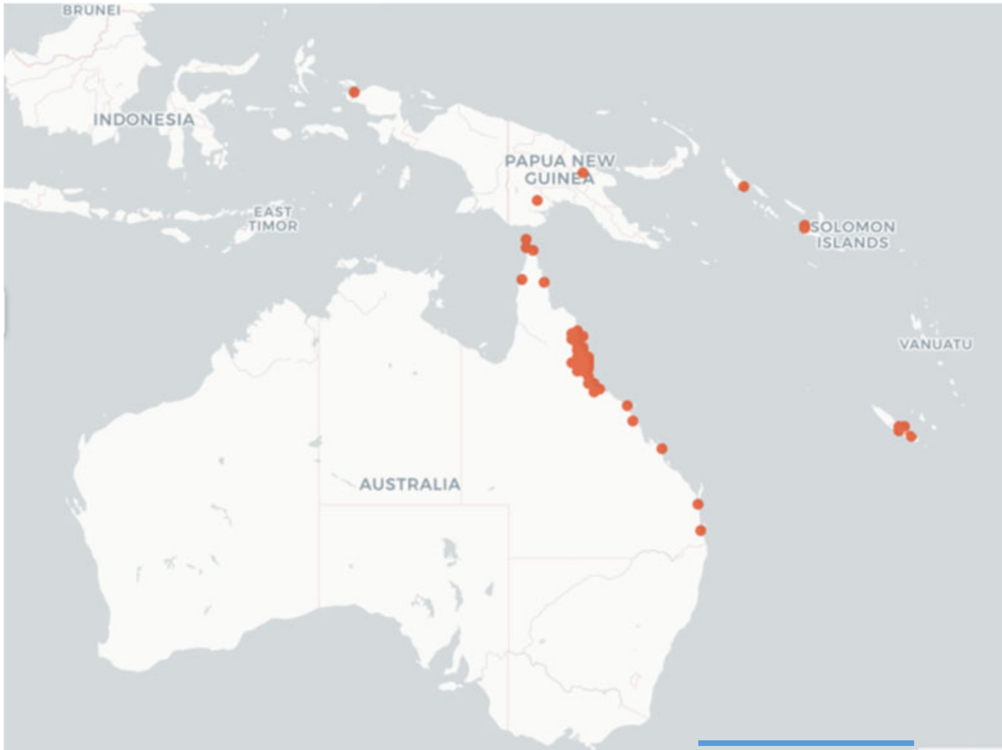

Figure 1. Spatial extent of distribution of the invasive Navua sedge in Australia (dots are current and confirmed extent of the weed in the State of Queensland and neighboring oceanic island nations). Spatial map generated from Atlas of Living Australia (https://www.ala.org.au/). The blue line at the lower right represents 1,500 km.

Figure 2. An abandoned block of a flooded sugarcane farm overran by Navua sedge infestation near Cairns, Far North Queensland, Australia.

Materials and Methods

In consultations with field biosecurity officers, research scientists within the Queensland Department of Agriculture and Fisheries (DAF), pest management officers of northern Queensland local governments, and farmers who grow crops and graze animals, we formulated a simple survey questionnaire consisting of 20 questions relating to Navua sedge weed management cost and tactics (Table 1). In early 2020, the questionnaires were screened

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Table 1. Survey questionnaire presented to farmers regarding Navua sedge infestation.

General
- A: Please provide your name, address, and details of your farm property (e.g., Lot/Plan, property no.)
- B: Please provide your phone contact, e-mail, and postal address
- C: Can we contact you for further discission on impact and management of Navua sedge?

Area impacted and management tactics
- 1: How long have you farmed the property?
- 2: What is the total area farmed in hectares or acres (choose one)?
- 3: What is the nature of agriculture on your property (grazing, cropping, horticulture, organic etc)?
- 4: How long has your property (in years) been affected by Navua sedge?
- 5: What proportion (%) of your property is impacted by Navua sedge?
- 6: Do you control Navua sedge on your property?
- 7: What are the methods you use in control of Navua sedge on your property?
  - a. Physical/mechanical: Please explain
  - b. Chemical: Please explain
- 8: Do you use combinations of various management options (i.e., integrated weed management options, e.g., combinations of machinery rollers, rotational grazing, burning, sowing, replanting with competitive pasture grass, chemical etc)?
  Please explain:

Control cost

How much do you spend controlling Navua sedge on your property:
- 9: In labour (hours and estimated $) (yearly or monthly)?
- 10: In chemical ($) (yearly or monthly)?
- 11: In machinery ($) (yearly or monthly)?
- 12: Following chemical treatment of Navua sedge on your farm, do you lock up (spell) whole or part of the farm?
- 13: If yes to Question 12, how long is your pasture spelling period?
- 14: How much do you lose ($/annum) by spelling the paddock?
- 15: Overall, how confident are you in your assessment of costs (on a scale between 100% being accurate and 0% being inaccurate)?

Epilogue
- 16: Any other (additional) comments you would like to make?

through a series of iterations with local government pest management officers and DAF biosecurity field personnel before final approval by the DAF in-house ethics committee. The survey questionnaire was typically a mix of close- and open-ended questions bordering on property location. The questionnaire requested farmers' names, property address, and farming type; invasion history of the weed on their properties; the proportion of area affected; and management tactics and cost, including property spelling (lock-up/withholding) duration and dollar cost (opportunity lost) following herbicide treatment, if applicable. The choice of survey respondents was specific because only grazing and crop farmers with Navua sedge infestations on their properties were invited to participate. Questionnaire responses were collected via individual and group interviews, telephone conversations, and online participation. Group interviews were undertaken during town hall meetings of farmers, during which survey questionnaires were given to individual farmers, and hence responses were transcribed as individual responses. The respondent jurisdictions cover the main extent of the current spread (~600 km stretch) of the weed (Figure 1) from Ingham in the southern part of northern Queensland, to Cooktown in far northern Queensland, and included farmers who farm upland (Atherton tablelands) and costal (Cairns to Daintree) areas of the region. No financial incentives were offered to participants. Collated data were analyzed using the SPSS-IBM statistical package (v. 27) using primarily nonparametric statistics due to skewed or qualitative responses. A series of Kruskal-Wallis nonparametric statistics were used to test for differences in levels of infestations, spelling (withholding) period, and control costs between land use types. Within and across land use types, nonparametric (Spearman rank) correlation analyses were also carried out on relationships between control cost and infestation level.

All values are reported in Australian dollars (A$). The derived control cost gathered in the 2020–2022 period was integrated forward into present/future values (Costanza et al. 2014) using the expression:

$$\text{Future value} = \text{present value} * (1+\text{inflation rate})^{\wedge\ \text{number of years}} \quad [1]$$

Results and Discussion

Survey respondents included those who grazed animals (56%, n = 22), grew crops (sugarcane) (28%, n = 11), and those who practiced both (15%, n = 6). Three farmers who grew other crops (banana and sweet potatoes) responded to the study, but their numbers were very low (one and two, respectively), hence their responses were excluded from further analyses. Following this exclusion, overall, the sample size was moderate (n = 39), and confidence in stakeholders' responses was very high and consistent (mean 80.8% ± SE 3.63%). The recorded high confidence in the scoring and assessment by the stakeholders (minimum confidence of 70%, irrespective of land use type) suggests the high reliability of the information provided. Very few studies have included confidence measures in examining the costs of controlling invasive alien species (e.g., Finger et al. 2023; Osunkoya et al. 2019). The high confidence reported here reflects farmers' awareness of the problem, the level of proactiveness/preparedness rather than reactiveness to the challenge, and indicates that farmers have the competencies to manage the challenge (Campbell et al. 2023; Schrader et al. 2024). However, such assertions could have resulted from sampling bias because only affected farmers were surveyed. In addition, more research is needed in this sector because the responses reported here did not require the assessor to justify a confidence score (Andreu et al 2009; Vanderhoeven et al. 2017).

Property size varied somewhat, but not significantly (Kruskal-Wallis test, $X^2_2 = 1.68$; P = 0.43) between land use type (mixed farm [mean 494.15 ha ± SE 184.35 ha] ≥ grazing farm [294.71 ha ± 95.20 ha] > sugarcane farm [143.30 ha ± 139.36 ha]). The spread of Navua sedge is a recent event (10 to 20 yr; median12.86 yr) and did not vary between land use types. Consequently, the proportion of stakeholders' land infested by the weed is currently at a low-medium level (median 22.5%, mean 30.81% ± SE 7.38%). We noted that the distribution of property proportion infested appeared to be skewed. More than half of the respondents (26 out of 39) reported that the weed infested less than 20% of their properties, while three property owners reported extreme values (~100%). In general, infestation was of the following order: grazing land ≥ mixed-use land of grazing and cropping > cropping (sugarcane), but the large variation in infestation level within land use type results in only marginal significant differences (P = 0.056) between these land use types (Figure 3).

Mechanical and cultural methods for controlling Navua sedge, such as integrated weed management (IWM) and sole use of herbicides, are being employed in similar frequencies to curtail the growth, abundance, and spread of the weed. These frequencies did not differ between land use type ($X^2_{2,36}$ Fisher-Freeman exact test = 2.48: P = 0.19). Halosulfuron-methyl (Sempra; UPL Europe Ltd, Warington, U.K. with Banjo; Nufarm Australia, Melbourne, Vic as the wetting agent) is the dominant postemergence herbicide registered for use against Navua sedge, but farmers have reported little success with this treatment. Survey respondents mentioned

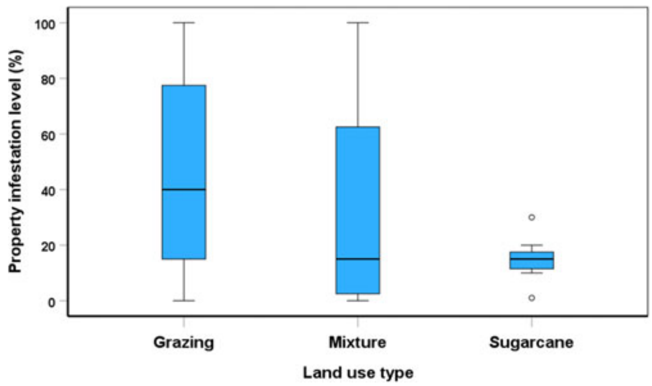

Figure 3. Box plot indicating proportion of properties of Australia farmers in northern Queensland infested by Navua sedge weed as a function of land use type. Mixture refers to properties that are used in both grazing (cattle) and sugarcane production. The median values between land use type are only marginally significantly different (P = 0.056) based on Kruskal-Wallis nonparametric test.

using other chemicals, including glyphosate (Roundup; Bayer Crop Science, Pymble, NSW), hexazinone (Velpar; Novasource, Chandler, AZ, USA), picloram and triclopyr (Access; Dow Agrosciences Australia, Frenches Forest, NSW), paraquat (Gramoxone; Syngenta, Greensboro, NC, USA) and imazapic (Ranga; Conquest Crop Protection, Osborne Park, WA, Australia). Thus, farmers reported use of both registered (e.g., Sempra) and other experimental and trial herbicides listed above to manage the weed. Many farmers indicated using these other experimental formulations because, from their experience, Sempra, the herbicide registered for use against Navua sedge, has not proven to be effective due to persistent belowground rhizomes and a large soil seedbank population of the weed, both of which lead to a high probability of reinfestation (see Chadha et al. 2022b). Research is ongoing to develop other, more effective herbicides given this concern (Chauhan and Mahajan 2022; Fillols 2024; F. Singarayer, personal communication).

Along with various herbicides, the type of IWM tactics also varied widely among farmers, including rotational grazing, minimal tillage and disking, targeted spot-spray herbicide applications using backpacks and quad bikes, replanting following herbicide treatment with desirable pastures of Humidicola [*Brachiaria humidicola* (Rendle) Schweickerdt], para grass [*Brachiaria mutica* (Forsskål) Stapf], and signal grass [*Urochloa decumbens* (Stapf) R.D. Webster], riparian corridor fencing, strict on-farm biosecurity protocols such as vehicle washdown, and minimal/no slashing of nature strips where farm properties abut roadsides maintained by local government councils. The latter tactic (i.e., slashing) refers to the use of a tractor to cut grass and vegetation on roadsides to reduce the risk of fire and improve traffic safety.

Thus, in general, there was a considerable variation among respondents in their weed management strategies. Nonetheless, tabulation using frequency analysis indicated that at least 50% of the respondents used multiple approaches to control the weed, which often resulted in lower costs, especially for chemicals (Miller 2016). The use of mechanical or cultural methods for control (i.e., no slashing, limited tillage, rotational grazing, fencing, and imposition of strict biosecurity measures) are least harmful to the environment (Andreau et al. 2009; Miller 2016) and are proven management tactics that can help to slow the spread of the weed while also minimizing cost.

Although the focus of this study was to tabulate weed control costs, some respondents mentioned the importance of prevention, identification of pathways of transmission/spread (e.g., via slashing of roadside infestations, flooding, and bird dispersal), restoration following weed removal, and the need to work across property boundaries and with stakeholders whose land use varies to achieve weed management objectives (Abeysinghe et al. 2024; Schrader et al. 2024).

Overall, the annual median control cost per stakeholder was A$11,630 (95% CI A$2,279 to A$35,609), translating to a median value per hectare of A$72.91 (95% CI, A$33.87 to A$103.97) after standardization by property size (Figure 4A). The greatest component of control cost per year per hectare is labor (median, A$34.88; 95% CI, A$14.46 to A$152.61), followed by chemical usage (median A$14.00; 95% CI, A$10.59 to A$29.09) followed by machinery usage and maintenance (median, A$11.61; 95% CI, A$2.46 to A$34.20) (Figure 4, A and B). Farmers who used their land for grazing animals spend significantly more on labor in weed control than those who use their land for other purposes (Figure 4B). Chemical and machinery usage and maintenance costs are the same across land use types. Labor was the main driver of total control cost, increasing more linearly with greater proportions of property infested with the weed (Spearman rank $r = 0.50$, P = 0.01) than that between infestation level and chemical ($r = 0.46$, P = 0.02) or machinery cost ($r = 0.27$, P = 0.19). That labor is the most expensive part of weed control is not new (see Ansong et al. 2021; Wenger et al. 2018; Yadav et al. 2003) and can be expected to increase even more with time in an industrialized economy like Australia where wages are often high. Thus, labor must be automated if farmers are to reduce their overall control costs (e.g., via the use of drones and remote sensing to map weed distribution at the farm and landscape scales) such that spot applications of herbicides is more precise and less time-consuming (see Costello et al. 2022).

It appears that sugarcane farmers are spending less money per hectare to control Navua sedge (median, A$54.66; 95% CI, A$0.00 to A$108.55) compared with farmers who use their land for animal grazing (median, A$84.72; 95% CI, A$58.86 to A$139.31) (Figure 4B), even after adjusting for property size. Reasons for this are hard to deduce from this study, although factors such as level of awareness and belief that sugarcane grows taller and hence outcompetes the weed in the long run, might have farmers believing there is no need to spend money on the challenge, or that other, well-established weeds of higher priority may be affecting their industry. These weeds include, for example, nut grass [*Cyperus rotundus* Linnaeus], kikuya grass [*Pennisetum clandestinum* (Hochst. ex Chiov.)], johnsongrass [*Sorghum halepense* (L.) Pers.], and sicklepod [*Senna obtusifolia* (Linnaeus) Irwin & Barneby]) (Ross & Fillols 2017). Another factor could also be that existing weed management practices are able to control Navua sedge. Because just a few farmers reported who grow other crops (e.g., sweet potato, banana) participated in the survey, the costs of controlling the weed on those types of land deserves investigation.

In the grazing industry, the average spelling (withholding) time of the paddock (the period when grazing pressure is removed from a paddock to allow pasture plants to recover and replenish their root reserves) following a herbicide application to manage the weed was approximately 2 to 6 wk (Figure 5A). Economic loss per hectare following spelling appeared to be negligible for farmers who graze animals (median, A$13.25; 95% CI, A$0 to A$463.09), but this estimation has a very wide band (Figure 5B). In contrast, the few sugarcane farmers (n = 7) who reported spelling their field

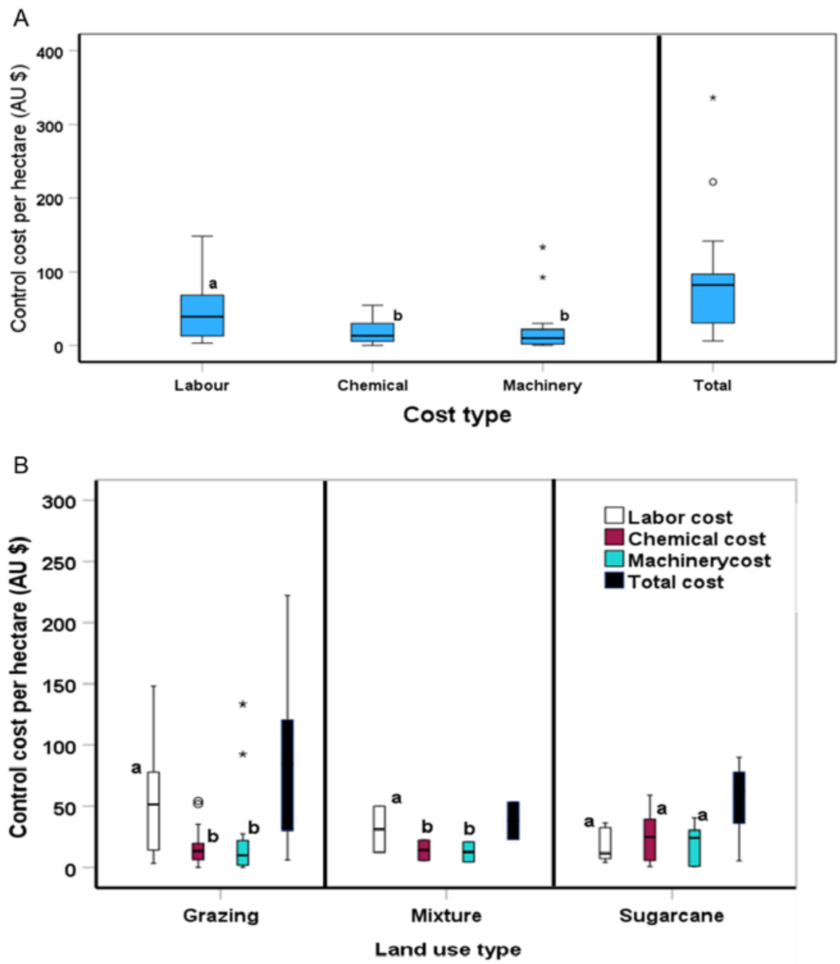

Figure 4. Box plots of three components of annual control cost of Navua sedge weed infestation, with data pooled across land use type (A), and data for each land use type (B). Median values (A: between control cost type; B: within land use type) that are significantly different ($P < 0.05$) are indicated by different letters on the plots based on Kruskal-Wallis nonparametric test.

blocks following a herbicide treatment do so for longer time (12–16 wk), and consequently experience greater economic loss (median, A$2,100.35 per ha; 95% CI, A$1,846.81 to A$3,437.01) (Figure 5, A and B). The finding of a longer spelling period and its attendant economic loss will suggest that Navua sedge invasion in cropping lands might have greater effect on yield than in the grazing environment (Figure 5), though such an assertion must be taken with caution because there were so few sugarcane respondents ($n = 7$). The shorter spelling period (approximately 4 wk) by farmers who graze cattle following a herbicide application to manage Navua sedge has been reported in a previous study (Shi et al. 2021). However, more research is needed. Some farmers who graze animals listed no spelling but said they prefer to shift their animals around paddocks depending on pasture growth rates. In general, previous studies (e.g., MacLean 1958; McIvor 2012) have suggested that longer spelling (>6 wk) following herbicide application should be discouraged due to the development of unwanted consequences, including increased competition from other undesirable plant species; that is, simply eliminating an alien plant from an ecosystem may not always lead to restoration of the original community, and sites can often be colonized by other alien species (Hulme and Bremner 2006).

We found moderate ($0.05 < P < 0.10$) or no significant relationship ($P > 0.05$) between control cost and infestation level or time at each land use type (Figure 6A), although it appears that the cost of control increases with increasing weed infestations, up to 40% to 60% for grazing land, and then decreases thereafter; for sugarcane and mixed farmlands, this threshold appears to be 20% to 25%. Nonetheless, pooled data suggest that control costs increase with increasing Navua sedge weed infestation on properties (Figure 6B). It should be noted that the estimation (via input from stakeholders) of a property's level of infestation is crude, because density (abundance per unit area) was not considered. This coarse scale of measure might have contributed to the weak link observed between infestation level or time of year and many measures of Navua sedge weed control cost and ecology (see also Chadha et al. 2022a for a similar deduction). It is thus an area that needs more study, including exploring changes in the soil seedbank and tuber density of the focal weed following control treatments as measures of management efficacy. Nonetheless, the increasing proportion of farms infested by the weed appeared to require more control inputs of labor and chemicals, especially for grazing lands (Shackleton et al. 2015; Wenger et al. 2018; Yeneayehu et al. 2023).

In conclusion, through consultations with stakeholders, the median cost to control Navua sedge is A$72.91 ha^{-1}. This value, derived between 2020 and 2022 period, was integrated forward into

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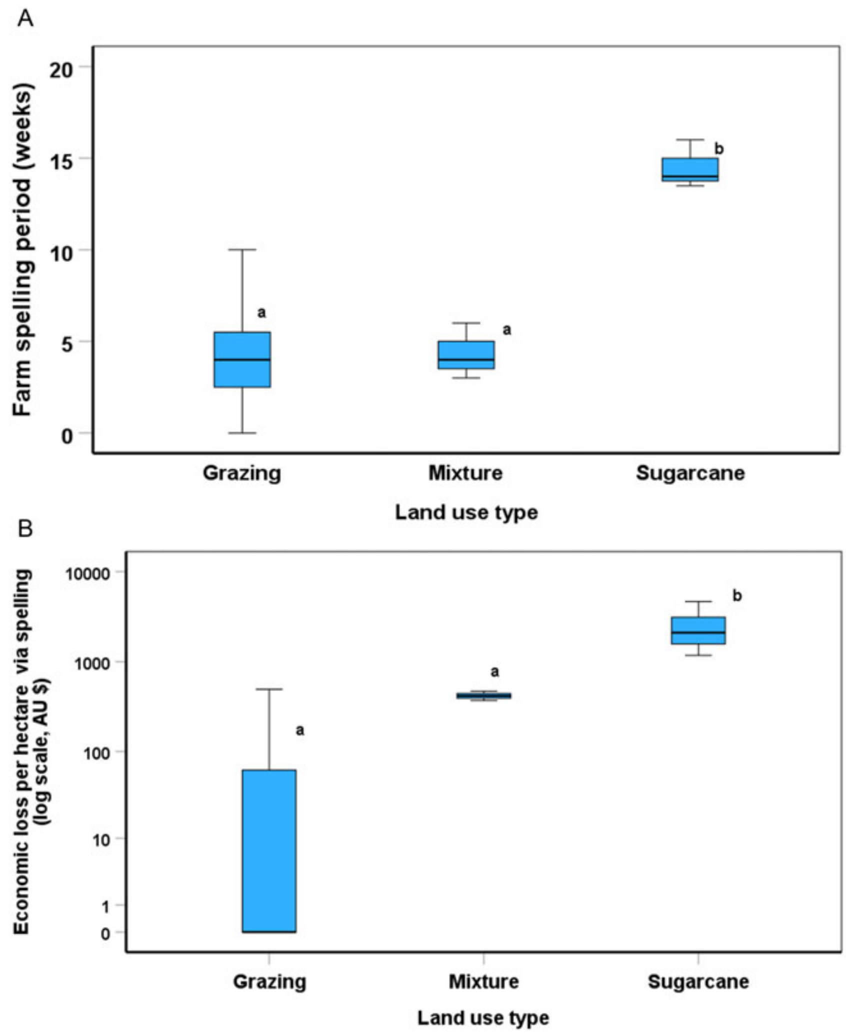

Figure 5. Box plots of property spelling (withholding) period (A), and productivity loss (log scale) by land use type (B) following herbicide treatment of Navua sedge weed infestation. Median values that are significantly different ($P < 0.05$) are indicated by different letters on the plots based on Kruskal-Wallis nonparametric test.

present and future values using the expression in Equation 1, resulting in a current cost of A$82.06 ha^{-1}. These costs, when integrated backward, are similar to the values reported at the Australian commonwealth and State levels for control of weeds in both cropping and grazing lands (see Llewellyn et al. 2016; Sinden 2004). The derived yield loss due to spelling for grazing land was low. Still, this median value of A$13.25 per hectare has a wide range (A$0 to A$463) because some farmers do not spell at all, and hence they report no or minimal dollar cost to spelling, but instead rotate cattle between blocks, perhaps due to the large size of their properties and their willingness to impose strict biosecurity measures. Stakeholders' concerns for the economic impact, spread pathways, and control options for invasive Navua sedge were captured in this study. Labor (compared to chemicals and machinery) is the more expensive component of weed control costs. The herbicide (Sempra) currently registered for use against the weed has low efficacy. Consequently, while they wait for more effective chemical and promising biological control agents (see Dhileepan et al. 2022), many farmers seem to have developed strong biosecurity protocols and experimental management tactics as part of their short-term arsenals to minimize the spread of the weed.

Practical Implications

Weed impacts can be measured in direct financial costs in herbicides, machinery use, and labor; and in losses in production, changes in net financial benefits, and changes in welfare. In this study, we addressed some of these issues for controlling Navua sedge, a recent monocot weed that is spreading and negatively affecting both natural and agricultural landscapes in northern Queensland, Australia. The level of awareness of the spread and impact of the weed is very high (>80%) among stakeholders who have property that is infested with the weed. Currently, most farmers reported a low-medium level of infestation on their properties (~22.5%) but are fearful of the increasing spread of the weed with time and across multiple land-use types and jurisdictions. Farmers identified multiple pathways of transmission and spread, and the need for cooperation across property boundaries and among stakeholders to achieve weed management objectives. Control cost per unit area for Navua sedge did not significantly vary between land use types (although costs were marginally higher for grazing lands) and is chiefly driven by labor demand and, to a limited extent, by chemical (herbicide) use. However, farmers reported that the approved herbicide, Sempra, is

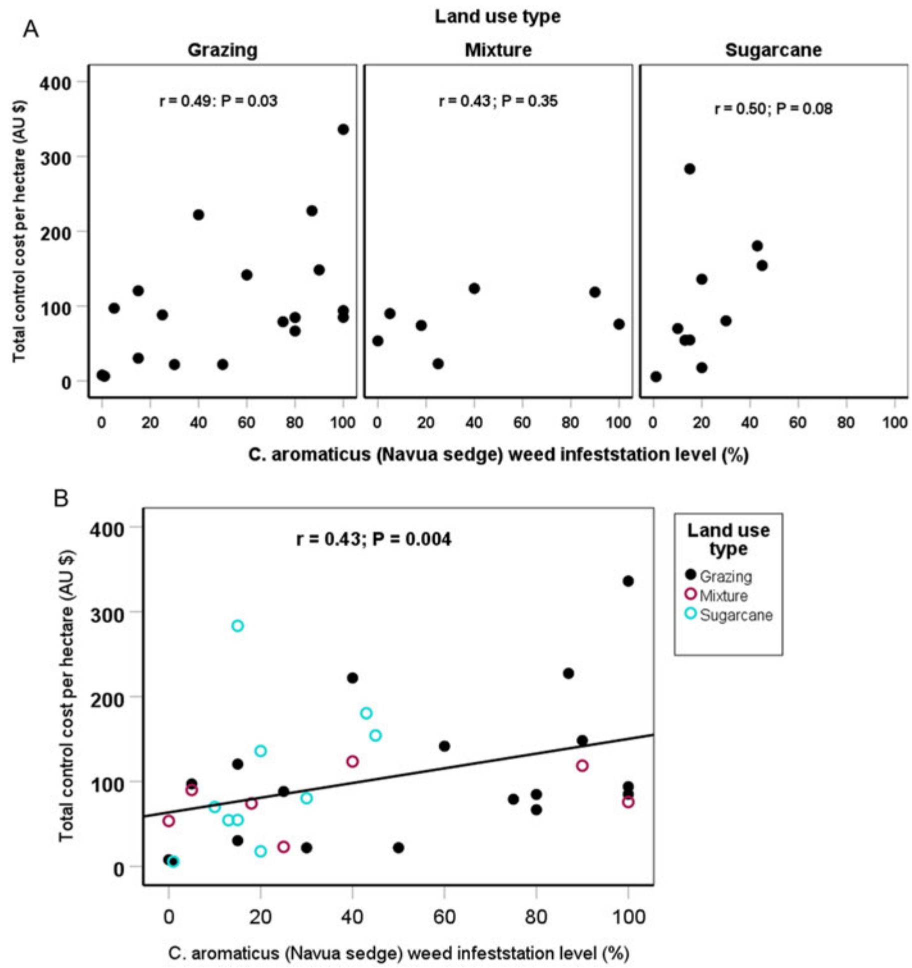

Figure 6. Total (annual) control cost (in Australian dollars) of Navua sedge weed infestation as a function of the fraction of individual northern Queensland property infested for each of the three land-use types (A) and for pooled data (B). Significant ($P < 0.05$) regression lines are in bold continuous lines, while non-significant trends are in broken lines; r = nonparametric (Spearman rank) correlation value.

largely ineffective in controlling the weed due to its inability to deplete belowground tubers and the seed bank population of the weed. To that extent, many farmers, while waiting for promising chemicals and biocontrol agents, have integrated cultural and mechanical methods for managing the weed, including minimal or no slashing of pasture weeds abutting their properties, limited farm tillage and herbicide usage, rotational grazing, riparian corridor fencing, replanting following herbicide treatment with desirable pastures, and imposition of strict biosecurity measures such as washdown facilities to minimize the weed's impact and spread.

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