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Tradeoffs between pasture production and plant diversity and soil health attributes of pasture systems of central Queensland, Australia

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Abstract

Clearing land of trees and introduction of exotic pastures to enhance pasture production and hence monetary gains is generally practised in Queensland. Large areas of land have been cleared in the past and clearing continues currently. The results from many previous studies on tree clearing emphasised the gains in pasture production, but over periods of less than 10-15 yrs after clearing, thus potentially misleading land managers who plan to continue grazing beyond that time. The present research follows an integrated approach to study the pasture yield and the ecological effects of tree clearing over time-since-clearing on a grazing property in central Queensland, and to evaluate the implications of our findings for the region. The cleared pasture systems were taken at three different times of clearing i.e. 5 yr, 11-13 yr and 33 yr, in comparison to their paired uncleared pastures for three major types of tree communities (representative of the region) Eucalyptus populnea, Eucalyptus melanophloia and Acacia harpophylla, selected on a grazing property.

The effects of clearing were determined for pasture production, pasture plant species, soil properties (organic carbon, available N (NO_3^-), pH_w and microbial biomass (C and N)), and litter production across three different ages of clearing and uncleared treatments of each tree community. With clearing, pasture production generally increased but, plant diversity, litter production and potential return of N and P through litter decreased. Among soil attributes, clearing of trees adversely impacted upon soil pH and microbial biomass, which play an important role in nutrient availability and mineralisation.

The paper evaluates the effects of clearing on individual attributes as well as an integrated effect of these attributes, i.e., overall ecological services. The multivariate analysis for the above mentioned ecological attributes suggested that at the 33 yrs age of clearing, the ecological state of pasture systems changed compared to that at 5 yr or 11-13 yr or at uncleared system. Most likely, a disturbed pasture system may take longer to revert to the original state compared to the time that would have taken to harvest the benefits. Tree clearing may project initial production gains for developing pastures, but these gains are not sustainable over time and are accompanied with loss of plant diversity, soil microbial biomass and nutrient return through litter, and change in soil pH. The results are important for landholders and policy makers to understand the actual benefits or losses of tree clearing for pasture development over a long term.

Key words: Tree clearing, soil organic carbon, soil pH, soil nitrate, soil microbial biomass, pasture yield, litter production, ecosystem functions

1 **1. Introduction**

2 Tree clearing has commonly been practised for greater pasture production and monetary
3 gains in grazing systems of Queensland until recently. Most of the cleared land is then
4 sown to exotic grass species such as Cenchrus ciliaris L. following raking and burning of
5 wooden logs, thus sets up monoculture pastures. The high rates of clearing in the past
6 especially after 1950s, and even lately in 1999-2001, 577,000 ha of land cleared per year
7 (Department of Natural Resources and Mines, 2003), was mainly to develop pastures (94%
8 of total cleared land in 1999-2001). Until 1985, even government policies favoured
9 clearing to develop land for pastoral and agricultural systems (Boulter et al., 2000).
10 Recently, a change in government policies to stop land clearing from 31st of August 2004
11 was implemented, based mainly upon the losses of biodiversity, without much access to
12 information on the long term effects of clearing on productivity of pasture systems or on
13 soil properties which are equally important for a landholder. Thus, it becomes difficult for
14 the landholders to understand and adapt to the change in governmental policies from
15 clearing (until 1985; Boulter et al., 2000) to that more recently of no clearing, without
16 provision of information on the long-term effects of clearing.

17 Most studies to date (Scanlan and Burrows, 1990; Burrows, 1993; Burrows et al., 1999)
18 have highlighted the production gains from clearing, but these were limited to <10 years of
19 age of cleared pastures (Scanlan, 2002). Indeed, the initial gain in pasture production with
20 clearing is the only attractive phase for the landholders to clear land for pastures. These
21 earlier studies highlighted the gains in pasture production, but without considering the
22 associated loss of other ecological services. There are increasing concerns that most of the

1 development that occurred in the past involved little understanding of ecosystem functions
2 and of the inherent potential of natural resources available on the Australian continent
3 (Boulter et al., 2000).

4 For this, three major woodland communities, each dominated by Eucalyptus populnea F.
5 Muell., E. melanophloia F. Muell. and Acacia harpophylla F. Muell. ex. Benth. were
6 selected on one property to quantify the impacts of clearing on pasture production and
7 composition, soil properties (organic carbon, available N (NO_3^-), pH_w and microbial
8 biomass (C and N)), and litter production. The impacts were measured over time of at
9 recent (<5 years), medium (11-13years) and old (>30 years)) age of cleared pastures in
10 comparison to their uncleared (intact) woodland pastures of each tree community.

11 Our aim was to study the sustainability of cleared and uncleared pastures in terms of:

- 12 • pasture yield
- 13 • plant diversity, and litter production and N and P return
- 14 • soil health (soil organic carbon, soil NO_3^- , soil microbial biomass and pH)

15 The present research provides important information for the landholders and the policy
16 decision makers to help them to take the correct decisions for the good of future pasture
17 systems based upon the integrated effects of long term clearing on production and other
18 ecological attributes of pasture systems. It is based upon a detailed study conducted on a
19 grazing property in central Queensland region.

1

2 **2. Materials and methods**

3 Paired sites of cleared and uncleared woodlands for E. populnea (poplar box), E.
4 melanophloia (silver-leaved ironbark) and A. harpophylla (brigalow) communities were
5 selected across three age groups of clearing i.e. recent (5 yr), medium (11-13 yr) and old
6 (33 yr) on a property “Avocet” (30 km. south of Emerald) in central Queensland, Australia.
7 The sites were selected with the guidance of research staff at Department of Natural
8 Resources and Mines, and at Environmental Protection Agency, Emerald, to be the
9 representative vegetation types of the region.

10 The study represents a 3 (types of tree communities) x 3 (time since clearing) x 2 (cleared
11 v/s uncleared) factorial design. The paired cleared and uncleared sites were selected in
12 close proximity with the assumption to have similar original biophysical characteristics
13 (soil type, slope and vegetation) before clearing (according to information provided by the
14 landholder), and to some extent to minimize variation in grazing management for the same
15 cattle grazed the cleared and their paired uncleared sites. The methods of tree clearing
16 applied to sites slightly differed, along with number of cattle grazing these sites (Table 1).

17 At each site, a representative area of one ha of the total area (minimal >20 ha) at each site
18 was marked for data collection.

19 **2.1 Above-ground pasture biomass and pasture composition**

20 At the centre of the selected 1 ha area at each site, a fenced plot of 10 m x 10 m (enclosure
21 – to exclude grazing) was marked to determine pasture above-ground biomass and

1 composition. The quadrat method (Kent and Coker, 1992) was used and a quadrat size of 1
2 m x 1 m, derived from the stable number of species per unit area based upon preliminary
3 analysis, was chosen. Measurements were taken from five randomly assigned quadrats
4 located at different positions across sampling dates for different seasons in a year; in
5 March 2001, July 2001 and November 2001 and March 2002. All the plant samples from
6 each quadrat were harvested just above-ground level, taken to the laboratory and dried at
7 60 °C for 48 hours to determine their biomass. Average quantity of pasture above-ground
8 biomass for grazing was calculated over a year from the seasonal measurements. For
9 repeated measurements i.e. March 2001 and March 2002, their average was considered
10 along with the July 2001 and November 2001 seasonal measurements. All types of plants
11 in a quadrat were identified to study the species composition.

12 The data were collected from both the fenced and unfenced sites however the results are
13 presented inhere for fenced plots only, since the trends were similar at both the fenced and
14 unfenced sites (Sangha, 2003).

15 **2.2 Litter production**

16
17 Litter production was measured at unfenced sites (each of one ha) using the paired-plot
18 technique (Wiegert and Evans, 1964). The measurements started in March 2001 and were
19 taken at regular 4 monthly intervals until March 2002. On each occasion, three random
20 quadrats of 1 m x 1 m were laid in three different directions and these quadrats were
21 marked for the next set of readings in their adjacent (paired) quadrats. In each quadrat, the
22 standing green herbage was removed and dead litter fallen on the ground was collected.
23 The samples were screened to exclude large sticks of circumference >1 cm, air dried, and

1 weighed. For the next sampling date in July 2001, litter was collected from the quadrats
2 adjacent to ones that were used in the previous season i.e. March 2001. Samples were
3 processed in the same way as in March 2001. The same procedure was followed in
4 November 2001 and March 2002. To measure the quantity of litter produced per season,
5 amount of litter decomposed during that season was taken into account (Table 2), for
6 example amount of litter produced at time t_0 was X_0 and at t_1 time was X_1 , and R_1 was the
7 rate of decomposition for t_0-t_1 , so total litter produced during $t_0-t_1 = X_1-X_0+R_1$.
8 Decomposition of litter was studied using the litter bag technique over the same sampling
9 dates as for litter production. This was necessary to account for the loss of litter that
10 underwent decomposition between two successive sampling dates, to ensure accurate
11 estimation of the total amount of litter produced over a particular season. The average
12 amount of litter produced over a year was computed from litter produced during different
13 seasons.

14 Litter samples collected in March 2001 (without decomposition) from each site were
15 thoroughly mixed, ground, and analysed for N (using CHN analyser) and P (using ICP)
16 (standard methods described by Carter, 1993; Peverill et al., 1999) at the soil laboratories
17 of Incitec Ltd, Brisbane, Queensland.

18 **2.3 Soil properties**

19 Soil samples were taken (bulked for 8 cores per site) from unfenced sites (1 ha area) in
20 January 2002 using hydraulic soil rig, for different depths (0-5, 5-10, 10-20, 20-30, 30-60
21 cm). Samples were processed to remove visible roots and pebbles, and analysed at the soil
22 laboratories of Incitec Ltd (Brisbane) for soil organic carbon (SOC) (Walkey and Black

1 method using H_2SO_4 and $\text{K}_2\text{Cr}_2\text{O}_7$ in 1:100 dilution, measured colorimetrically), soil pH_w (1
2 to 5, soil to water dilution using combination electrode), and soil NO_3^- (1:5 soil to water,
3 centrifuged nitrate measured colorimetrically in segmented flow analyser) (according to
4 methods described in Carter, 1993; Peverill et al., 1999).

5 To determine the microbial biomass of C (SMB-C) and N (SMB-N), samples were taken
6 from the top 0-5 cm soil in March 2002, immediately stored in cold container, and
7 analysed using the chloroform fumigation extraction method (Vance et al., 1987) at the
8 Natural Resource Sciences Laboratories (Department of Natural Resources, Mines and
9 Energy, Indooroopilly, Brisbane, Queensland).

10 **2.4 Statistical analysis**

11 Individual effects of tree clearing on pasture biomass and litter production were analysed
12 using Genstat ver 6.0 (2002). The residual maximum likelihood (REML) (Patterson and
13 Thompson, 1971) method was used. The main effects for type of tree community and
14 uncleared-cleared (recent, medium and old) treatments within each tree community were
15 analysed. Models included the fixed effects of community, clearing treatments plus their
16 interaction (community*cleared-uncleared), and the random effects of age since clearing
17 and uncleared treatments within a community. If the interaction between community and
18 cleared-uncleared treatments was not significant ($P < 0.05$) then it was removed from the
19 fixed model to test the main effects. The variance matrix derived from REML analysis was
20 used to calculate approximate LSDs (least significant differences of means) at $P < 0.05$.
21 The means from REML analysis were used in presenting the results.

1 For species diversity, Shannon Wiener's index was calculated using species diversity and
2 richness software (Henderson and Seaby, 1998; PISCES Conservation Ltd).

3 For soil properties, the same tool REML was used as for pasture biomass and litter data.
4 The main effects (fixed terms) of tree community (E. populnea, E. melanophloia and A.
5 harpophylla), cleared (recent, medium, old age of clearing) and uncleared treatments, and
6 soil depth (each for 0-5, 5-10, 10-20, 20-30 and 30-60 cm depth) plus their interactions
7 were analysed. The correlation within a treatment across different depths was analysed for
8 all the main effects by applying the most suitable variance model AD2 (Antedependence
9 order 2). There was a significant ($P < 0.05$) three-way interactions (tree
10 community*cleared-uncleared*depth) for main effects in all the soil variables. For each
11 variable, LSDs (least significant differences of means) were used to compare cleared
12 (recent, medium, old) and uncleared treatments for each specific depth in a particular tree
13 type. The means from REML analysis were used to present the results.

14 To examine the integrated effect of studied attributes (pasture yield, species diversity, litter
15 production, SOC, NO_3^- , pH_w and soil microbial biomass (C and N)) in cleared and
16 uncleared pasture systems, data were analysed using multivariate analysis technique i.e.
17 canonical variates analysis (CVA) in Genstat (ver. 6.0) across all tree communities. All the
18 data were standardised for analysis.

19 The CVA was applied to determine the overall effect of clearing, as well as the attribute(s)
20 that would have been strongly influenced by clearing and could lead to differentiate
21 between cleared and uncleared treatments in all tree communities. There were not enough

1 replicates for cleared and uncleared treatments within a tree community to apply CVA to
2 examine the effects in each tree community. However, the data were analysed for all the
3 cleared and uncleared treatments irrespective of tree community. The CVA analysis finds
4 linear combinations of the original variables that maximize the ratio of between-group to
5 within-group variation where groups are cleared and uncleared treatments. Two canonical
6 variates (CV1 and CV2) were considered to explain variation between treatments. The
7 output from CVA presents an integrated impact of clearing in pasture systems.

8 **3. Results**

9 **3.1 Pasture above-ground biomass**

10 On average, pasture biomass was greater at cleared compared to uncleared sites, with
11 maximum production at medium age of clearing for E. populnea and A. harpophylla, and
12 at recent age of clearing for E. melanophloia (Table 3). However, the gains in pasture
13 biomass were not consistent over time-since-clearing and showed a trend to decline at old
14 compared to medium (in E. populnea and A. harpophylla) or recent age (in E.
15 melanophloia) of clearing in all the tree communities. Interestingly, in E. melanophloia,
16 the uncleared and old cleared sites did not differ significantly ($P < 0.05$) in pasture yield.

17 Although the pasture yield was greater at cleared than uncleared sites, pasture plant
18 diversity (Shannon Wiener's index of diversity) was significantly greater at uncleared
19 compared to all the cleared treatments in all tree communities (Table 3). Within cleared
20 sites, species diversity declined at medium and old cleared sites compared to recent cleared
21 sites.

1 **3.2 Litter production**

2 The total amount of litter produced over a year (kg ha^{-1}), important to account for the
3 return of nutrients for pasture growth, was greater at uncleared compared to the cleared
4 sites in all the tree communities except the medium cleared treatments (in E. populnea and
5 E. melanophloia) (Table 4). The cleared treatments did not differ significantly ($P < 0.05$)
6 from each other in total amount of litter produced per year.

7 The potential amount of N stored in litter produced (yearly) was greater at uncleared
8 compared to cleared sites in all tree types. P content was greater in litter produced at
9 medium cleared site compared to uncleared site in E. populnea and E. melanophloia. In A.
10 harpophylla, litter produced at uncleared sites had significantly ($P < 0.05$) greater P content
11 than any of the cleared treatments (Table 4).

12 **3.3 Soil properties (soil organic carbon (SOC), NO_3^- , pH_w , and soil microbial biomass** 13 **(SMB-C and SMB-N))**

14 Tree clearing had no significant effect on SOC except for recent or medium clearing had
15 greater SOC in 0-10 cm and 30-60 cm depths than uncleared sites in E. populnea and A.
16 harpophylla (Fig. 1). The paired t-test between cleared and uncleared treatments
17 (irrespective of age group or tree type) for the average SOC in 0-60 cm depth also did not
18 suggest any significant effect of clearing. Similarly, the differences between cleared and
19 uncleared treatments were not evident for available N (NO_3^-) which was highly variable in
20 the top 0-10 cm depth (Fig. 2).

21 Clearing strongly influenced soil pH_w across all tree communities. Soil pH_w increased
22 significantly ($P < 0.05$) with clearing in the top 0-5 cm for E. populnea and A. harpophylla

1 (Fig. 3). A significant increase in pH_w ($P < 0.05$) due to clearing at 30-60 cm depth
 2 especially at medium and old clearing was evident in all three tree types. The increase in
 3 soil pH_w across all depths was closely related to time since clearing across all tree types (at
 4 $P < 0.05$, Y (increase in soil pH) = $a + (-1.29)^{(-0.041 * \text{time-since-clearing})}$; $R^2 = 0.42$, where a varies
 5 from 7.0 -7.9 for different tree communities).

6 The SMB-C was significantly ($P < 0.05$) greater in uncleared soils (386 ± 37 (standard error
 7 of means) mg kg^{-1}) than cleared soils ($254 \pm 37 \text{ mg kg}^{-1}$) and similarly for SMB-N (greater
 8 at uncleared (40.17 ± 3.29) than cleared (29.87 ± 3.45)) sites, when analysed for all the
 9 cleared and uncleared sites irrespective of age of clearing or tree type.

10 **3.4 Integrated effect of studied ecological attributes on the stability of a pasture** 11 **system**

12 The combined effect of clearing for various attributes on a pasture system was determined
 13 with CVA (Canonical Variates Analysis). Two canonical variates (CV1) and (CV2) were
 14 selected for recent, medium, old cleared and uncleared treatments across all tree
 15 communities. The first canonical variate (CV1) distinguished the oldest cleared treatment
 16 from medium and recent cleared, and uncleared treatments (CV1 explained 90 per cent of
 17 variation among these treatments) (Fig 4). The old age of clearing was different to other
 18 treatments mainly due to the combined effect of soil NO_3^- , pasture biomass, litter
 19 production, species diversity and soil pH_w (Table 5). Comparatively greater values of
 20 positive loadings for these attributes than the others suggested that recent and medium
 21 cleared, and uncleared treatments had better soils with greater pasture biomass and litter
 22 production than that the old cleared treatments. The greater value of negative loading for

1 pH_w demonstrated that pH_w was greater at the oldest clearing than at medium and recent
2 cleared, and uncleared treatments (Table 5).

3 Only a further 7 % of the variation between cleared and uncleared pasture systems was
4 explained by CV2. CV2 showed that the medium cleared treatment was different to the
5 recent and old cleared, and uncleared treatments (Fig 4). The species diversity and SMB-C
6 and SMB-N had a greater influence (positive loadings) on CV2 than did the other
7 attributes (Table 5). However, the differential response across species between age of
8 clearing for pasture yields obscured further meaningful interpretation of CV2.

9 **4. Discussion**

10 In the woodlands of east-central Queensland, the increase in pasture yield upon clearing
11 has been demonstrated in earlier studies by Burrows, (1993), Burrows et al., (1999), and
12 Scanlan and Burrows, (1990), and was also evident in the present study. The present
13 research furthermore demonstrated that more of such benefits exist over the initial years of
14 clearing not over a longer term (>30 years). From pasture production for cattle point of
15 view, the cleared exotic pastures are more beneficial. But the question is how long will the
16 increased pasture production benefits from clearing be maintained? The present study
17 suggested a trend for decline in pasture yield over time-frame since clearing. The benefits
18 of clearing for increase in pasture yield between cleared and uncleared treatments
19 narrowed with age of clearing especially from 13 years to 33 years. The duration of benefit
20 was in fact very short for E. melanophloia. Most importantly, the gains in pasture yield due
21 to clearing are associated with some tradeoffs, for example, loss of some ecological
22 attributes such as:

- 1 1. Decline in pasture plant diversity which may affect ecosystem stability.
- 2 2. Lesser return of nutrients through litter decomposition, which can imbalance the
- 3 nutrient cycle in cleared pastures compared to woodland pastures.
- 4 3. Changes in soil properties that could, by implication, affect the growth of pasture
- 5 species over a longer term.

6 **4.1. Impacts of clearing on plant diversity**

7 There is a trade-off between production and species diversity since most of the cleared
8 pastures are sown to one dominant exotic grass species that sets up mono-culture pastures.
9 The diversity of native plant species, important in maintaining various ecosystem functions
10 for the stability of a pasture system (Tilman *et al.*, 1997), is often compromised with high
11 production gains from exotic grass species in cleared pastures.

12 Reduced species diversity in cleared pasture systems could adversely affect the ecosystem
13 function such as hydrology and soil stability. Tilman *et al.* (1997) conducted a detailed
14 study on the diversity-productivity and diversity-sustainability in American grasslands, and
15 reported higher functional diversity in high diversity plots supported higher productivity.
16 The plots with higher number of species had greater functional diversity and were more
17 efficient in allocation of soil nutrients compared to the less diverse plots. The reduced
18 species diversity may affect the use of resources in cleared pastures as the diverse systems
19 possess better potential for use of resources due to greater functional diversity (Tilman,
20 1997). Ash *et al.* (1997) reported that C sequestration in soils improved with grass species
21 which were adapted to the edapho-climatic conditions (mostly native) of pasture systems

1 in northern Queensland. Diversity of native plant species can help in maintaining the
2 ecosystem functions of pasture systems in Queensland, but barely any report is available.
3 A detailed study on species diversity and productivity in native pastures in this context
4 may be very valuable.

5 **4.2. Impacts of clearing on litter production and nutrient return**

6 With clearing, the steady return of nutrients through litter (as in uncleared pastures) was
7 disturbed because of the lesser production of ground litter at cleared sites compared to
8 uncleared sites with a change in vegetation from woodlands to cleared pastures. This could
9 lead to a change in the natural equilibrium of nutrient return to the system that could affect
10 the pasture growth (Williams et al., 1993). The change in litter composition may lead to
11 further changes in microbial communities and in return of nutrients to soil through litter
12 decomposition (Kutsch and Dilly, 1999; Vetaas, 1992).

13 **4.3. Impacts of clearing on soil properties**

14 We acknowledge that there would have been more nutrients released in soil at the time of
15 clearing that would have been taken up quickly by the plants sown to cleared land, but we
16 could not notice the significant effect ($P < 0.05$) of clearing on SOC and NO_3^- , most likely
17 due to time factor, since even our recent cleared sites were 5 years old. If the recent
18 clearing would have been 1 or 2 years old, it could be possible to notice increases in soil
19 nutrients, as Lawrence et al., (1988) reported an increase in P content in *A. harpophylla*
20 just after clearing.

21 A prominent effect of clearing was evident on soil pH_w for increase with age of clearing
22 that adversely affected the availability of soil nutrients (Sangha, 2003). The change in

1 microbial biomass is also an important indicator of any change in soil health for greater
2 SMB is responsible for mineralisation of organic matter and hence the return of nutrients
3 for pasture growth (Jenkinson and Ladd, 1981). Loss of soil stability in terms of soil pH_w
4 and soil microbial biomass, thus, compromised pasture production gains.

5 The changes in soil pH_w or soil microbial biomass occur mainly due to change in soil
6 processes which are the result of change in vegetation structure from woodlands to open
7 grasslands (Sangha, 2003; Vetaas, 1992; Bruce et al., 2000). The composition and eco-
8 physiological traits of plant species in an ecosystem affect the soil properties through
9 availability and quality of root exudates which are an important nutrient source for
10 microbes (Klein et al., 1988), and through alterations in nutrient competition (Bardgett et
11 al., 1999). Introduction of exotic grass species such as C. ciliaris, and clearing of native
12 vegetation would have disturbed the plant-soil relationship in cleared pasture systems.

13 A change from a multi-species system in native woodlands to monocultures of C. ciliaris
14 (predominantly, and with some other species; Sangha, 2003) results in a loss of species
15 diversity, litter composition, nutrient return to soil that affects the rate of mineralisation of
16 nutrients and their availability for pasture growth. Decline in microbial biomass at cleared
17 compared to uncleared sites may be the result of the integrated effect of litter composition,
18 decomposition of organic matter, change in soil properties, and in part may be due to
19 differences in soil micro-climate. The impact of clearing on overall ecosystem stability was
20 evident from the CVA (Fig 4) as the old pastures were situated differently than the
21 uncleared pastures. More importantly, over a long term, these effects (of nutrient return,
22 soil pH_w or microbial biomass) will become more apparent as they intensify with time. If,

1 in order to maximize production gains some of these soil properties such as pH_w (increased
2 about 1-2 units at all old cleared sites) or soil microbial biomass (decreases) change, then,
3 would the restoration of original capacity of land be possible over the same period of time
4 for which the benefits (e.g. 13 to 30 years) were harvested? Quite possible, it may take
5 longer than that. Thus, the opportunity cost for the lost ecosystem functions that were
6 traded for short-term monetary gains, will increase with time. It is important to note that
7 trees also provide other ecosystem services such as shade from sun and shelter in rain for
8 cattle that contribute to improvement in their health conditions (Daly, 1984).

9 Despite the loss of plant diversity and soil health attributes with clearing, if we just account
10 for the visible monetary benefits, they are not sustainable either. The monetary value of
11 pasture biomass produced per year (assuming if all to be consumed) was also calculated
12 according to the amount of beef produced from the amount of pasture consumed over a
13 year per cattle (182.5 kg weight gain/yr from 3139 kg/yr dry matter uptake; Minson and
14 McDonald, (1987), valued at the rate of AUD 1.50/kg of livestock weight). The yearly
15 maximum monetary gains were obtained at medium age of clearing for E. populnea (AUD
16 331 ha^{-1}) and A. harpophylla (AUD 371 ha^{-1}), and at recent age of clearing (AUD 552 ha^{-1})
17 for E. melanophloia (Fig 4). However, the increased benefits were not sustained over time-
18 since-clearing and declined at old clearing in all tree communities. Indeed, for E.
19 melanophloia, after 33 yrs of clearing, the monetary gains (AUD $246 \text{ ha}^{-1} \text{ yr}^{-1}$) were less
20 than that at uncleared site (AUD $328 \text{ ha}^{-1} \text{ yr}^{-1}$) (Fig 5).

21 Clearing led to a notable change in the ecological state of pastures from the uncleared to 33
22 years cleared pasture systems. The old cleared pastures differed significantly from

1 uncleared pastures in terms of ecological attributes, thus, suggesting that trees in uncleared
2 pastures are important for maintaining pasture systems in the long-term. Trees provide a
3 stable environment due to their shade, litter, stable hydrological cycle, recycling of
4 nutrients, and by providing substrate for various soil microbial activities that results in
5 improved physical and chemical conditions of soil. Williams et al. (1993) suggested that
6 clearing of trees influences and disturbs the equilibrium of soil processes (nutrient
7 recycling and decomposition). Once a natural woodland system is disturbed, it becomes
8 more difficult to restore. Although, we agree that the production gains are important but
9 the time frame for those gains and the associated loss of ecosystem functions suggest that
10 these gains could be easily offset.

11 **5. Conclusions**

12 Increase in pasture production upon clearing occurred at the cost of loss of plant species
13 diversity (hence the functional diversity of various plant groups), and loss of litter
14 production and nutrient return. Together with the loss of soil microbial biomass and
15 increase in soil pH these could also notably affect other associated ecosystem functions
16 such as nutrient mineralisation, and hence the soil processes that support plant growth. A
17 compromise must be searched for and struck when clearing to maintain ecosystem
18 functions for sustainable pasture systems.

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4 manuscript.

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Table 1. Details of time of clearing (all sites were chain pulled) and annual average stocking rate (SR) at cleared and uncleared sites for E. populnea, E. melanophloia and A. harpophylla communities.

| Tree community | Cleared treatments | | Uncleared (intact) treatments |
|-------------------------------|--------------------|----------------------|-------------------------------|
| | Time of clearing | SR (adult cattle/ha) | SR (adult cattle/ha) |
| <u>E. populnea</u> | | | |
| Recent clearing | May 1996 | 1/5 | 1/5 |
| Medium clearing | Dec 1987 | 1/3 | 1/4.8 |
| Old clearing | July 1967 | 1/6 | 1/4.8 |
| <u>E. melanophloia</u> | | | |
| Recent clearing | May 1996 | 1/5 | 1/5 |
| Medium clearing | Oct 1990 | 1/3 | 1/3 |
| Old clearing | July 1967 | 1/6 | 1/6 |
| <u>A. harpophylla</u> | | | |
| Recent clearing | May 1996 | 1/5 | 1/11 |
| Medium clearing | Dec 1987 | 1/3 | 1/4.8 |
| Old clearing | July 1967 | 1/6 | 1/4.8 |

Table 2. Calculations for litter production during different seasons.

| Amount of litter collected | Seasonal decomposition | Amount of litter produced during different seasons |
|----------------------------|---------------------------|--|
| Mar 2001 = X_0 | | |
| July 2001 = X_1 | Apr 2001-Aug 2001 = R_1 | Mar 2001-July01 = $X_1 - X_0 + R_1$ |
| Nov 2001 = X_2 | Aug 2001-Dec 2001 = R_2 | July 2001-Nov01 = $X_2 - X_1 + R_2$ |
| Mar 2002 = X_3 | Dec 2001-Apr 2002 = R_3 | Nov 2001-Mar02 = $X_3 - X_2 + R_3$ |

Table 3 Yearly average pasture biomass (kg ha^{-1}), and Shannon Wiener's index of species diversity at uncleared, and at recent, medium and old age cleared treatments of E. populnea, E. melanophloia and A. harpophylla communities.

| Tree type | Pasture biomass* | Shannon Wiener's index |
|------------------------|--------------------|------------------------|
| <u>E. populnea</u> | | |
| Uncleared | 1222 ^c | 2.5201 ^a |
| Recent | 1855 ^{bc} | 2.2478 ^b |
| Medium | 4019 ^a | 0.3217 ^d |
| Old | 2974 ^{ab} | 0.7941 ^c |
| <u>E. melanophloia</u> | | |
| Uncleared | 2879 ^{ab} | 2.3881 ^a |
| Recent | 4174 ^a | 1.6142 ^b |
| Medium | 2519 ^{ab} | 1.2675 ^c |
| Old | 2231 ^b | 1.1236 ^d |
| <u>A. harpophylla</u> | | |
| Uncleared | 1035 ^b | 2.4751 ^a |
| Recent | 2458 ^{ab} | 1.7729 ^b |
| Medium | 4700 ^a | 0.2068 ^d |
| Old | 3294 ^a | 0.6318 ^c |

*different superscripts in a column represent significant difference at $P < 0.05$ for cleared and uncleared treatments within a tree community.

Table 4. Litter production ($\text{kg ha}^{-1}\text{yr}^{-1}$) and potential content of N and P (kg ha^{-1}) stored in annual amount of litter produced at uncleared and cleared (recent, medium and old) sites for E. populnea, E. melanophloia and A. harpophylla communities.

| Site | | Uncleared | Recent | Medium | Old |
|------------------------|-------------------|--------------------|-------------------|--------------------|---------------------|
| <u>E. populnea</u> | Litter production | 1732 ^a | 866 ^b | 1299 ^{ab} | 949 ^b |
| | N | 15.30 ^a | 8.04 ^b | 6.63 ^b | 4.49 ^b |
| | P | 0.58 ^b | 0.60 ^b | 1.10 ^a | 0.50 ^b |
| <u>E. melanophloia</u> | Litter production | 1948 ^a | 1107 ^b | 1515 ^{ab} | 1226 ^b |
| | N | 11.40 ^a | 4.38 ^b | 6.56 ^b | 10.39 ^{ab} |
| | P | 0.84 ^{ab} | 0.50 ^b | 0.95 ^a | 0.51 ^b |
| <u>A. harpophylla</u> | Litter production | 2596 ^a | 1346 ^b | 1191 ^b | 1084 ^b |
| | N | 29.97 ^a | 6.55 ^b | 5.49 ^b | 6.32 ^b |
| | P | 0.87 ^a | 0.55 ^b | 0.63 ^b | 0.67 ^b |

*different superscripts in a row represent significant difference at $P < 0.05$ between any two treatments in each of the tree community.

Table 5. Loading values for various variables from the canonical variate analysis for recent, medium and old cleared, and uncleared treatments.

| Variables | Loading values for CV1 | Loading values for CV2 |
|-----------------------------------|------------------------|------------------------|
| Pasture biomass | 3.60 | -0.47 |
| Species diversity | 2.54 | 0.86 |
| Litter production | 3.40 | -0.39 |
| Soil organic carbon | -1.80 | -0.07 |
| Soil pH _w | -3.24 | 0.09 |
| Soil NO ₃ ⁻ | 3.82 | -0.27 |
| Soil microbial biomass-C | 1.86 | 0.25 |
| Soil microbial biomass-N | 0.72 | 0.55 |

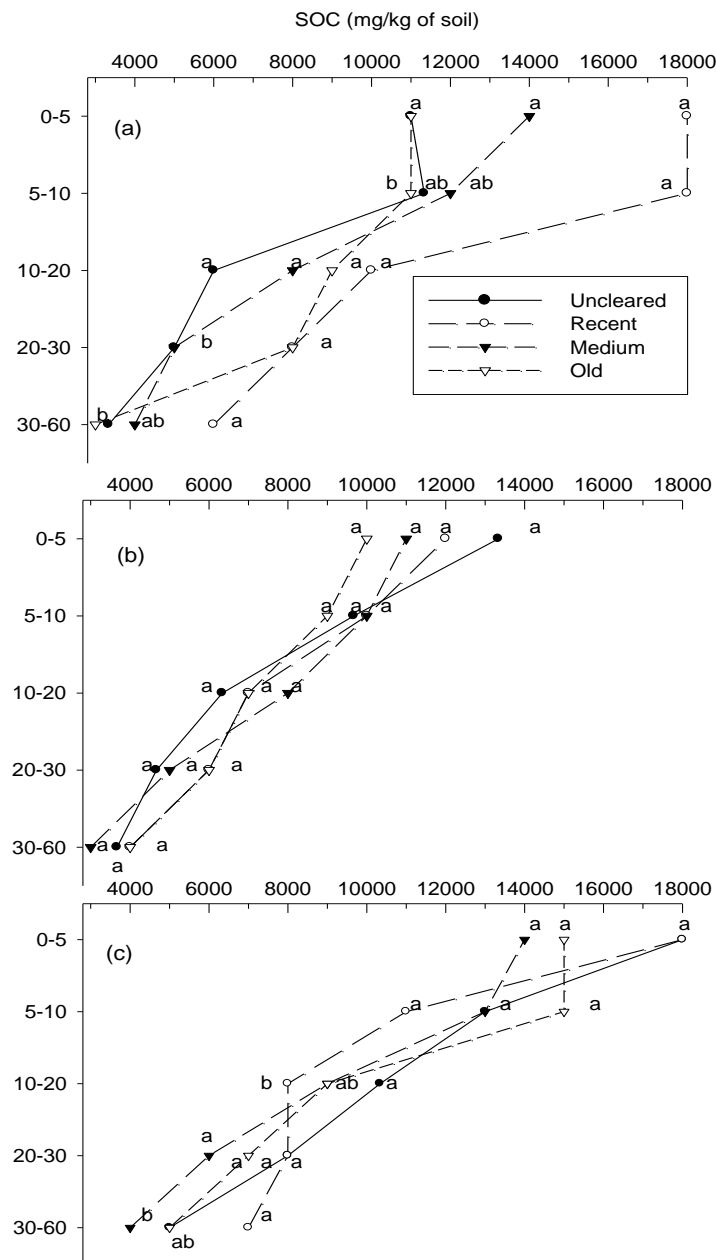


Fig. 1. Soil organic carbon (SOC) at recent, medium and old cleared, and uncleared treatments for a) *E. populnea*, b) *E. melanophloia* and c) *A. harpophylla* communities.

The same letter at any one sampling depth denotes no significant difference at $P < 0.05$ between any two cleared or uncleared treatments within a tree community.

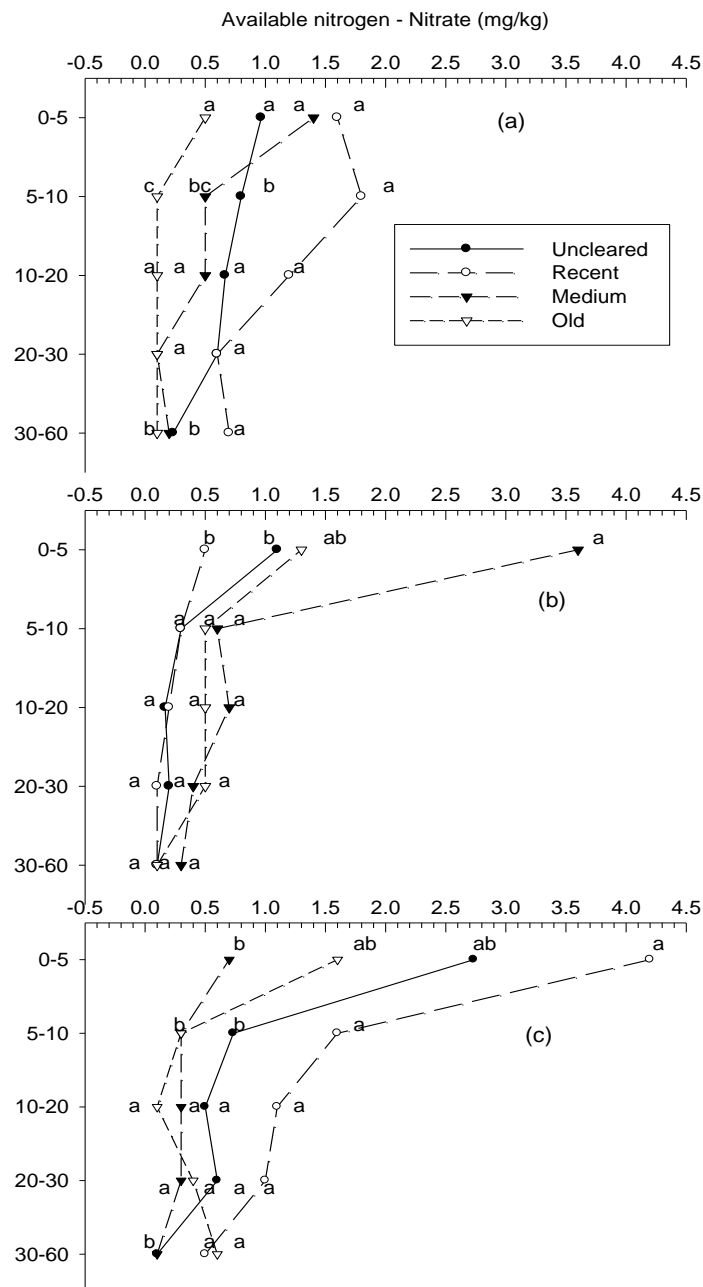


Fig. 2. Soil available nitrogen (NO_3^-) at recent, medium and old cleared, and uncleared treatments for a) *E. populnea*, b) *E. melanophloia* and c) *A. harpophylla* communities.

The same letter at any one sampling depth denotes no significant difference at $P < 0.05$ between any two cleared or uncleared treatments within a tree community.

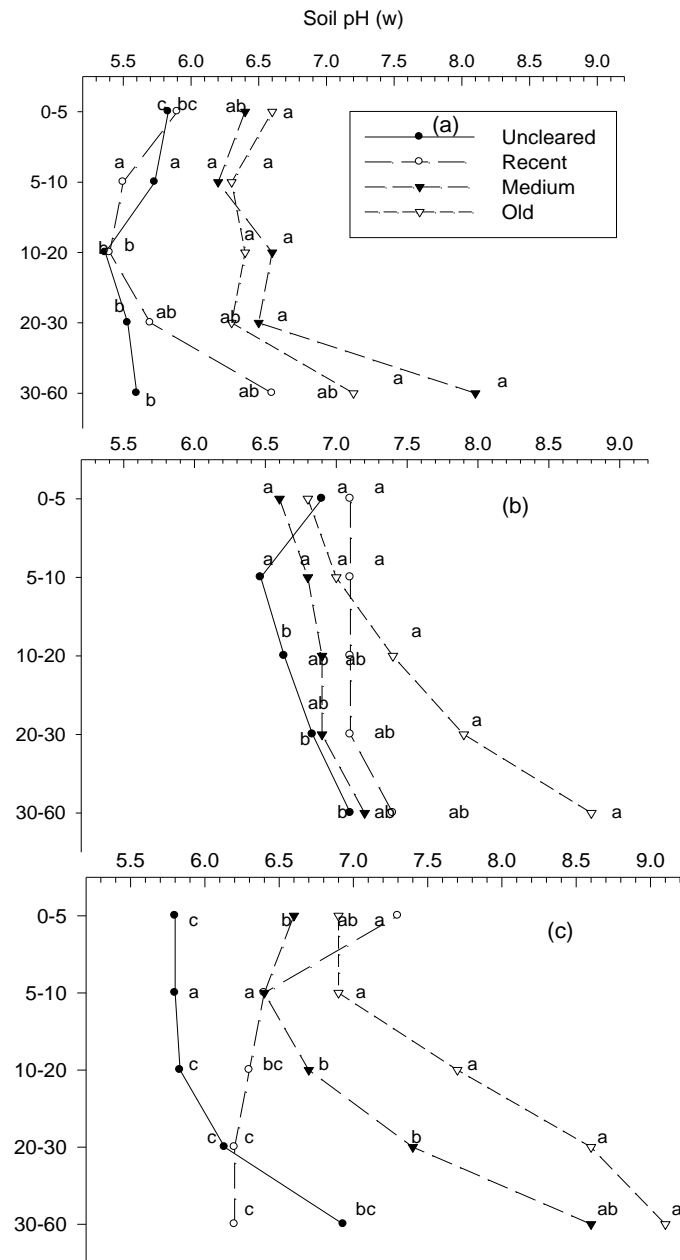


Fig. 3. Soil pH_w at recent, medium and old cleared, and uncleared treatments for a) *E. populnea*, b) *E. melanophloia* and c) *A. harpophylla* communities.

The same letter at any one sampling depth denotes no significant difference at $P < 0.05$ between any two cleared or uncleared treatments within a tree community.

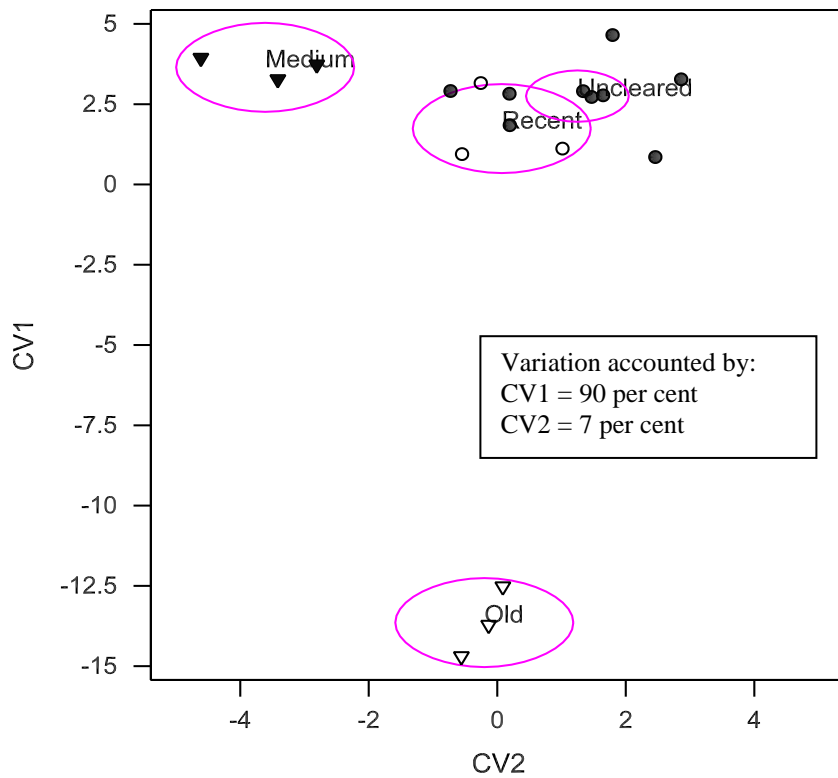


Fig 4. Relationship between first and second canonical variates for cleared (recent, medium and old) and uncleared treatments (with 95 per cent confidence regions around means).

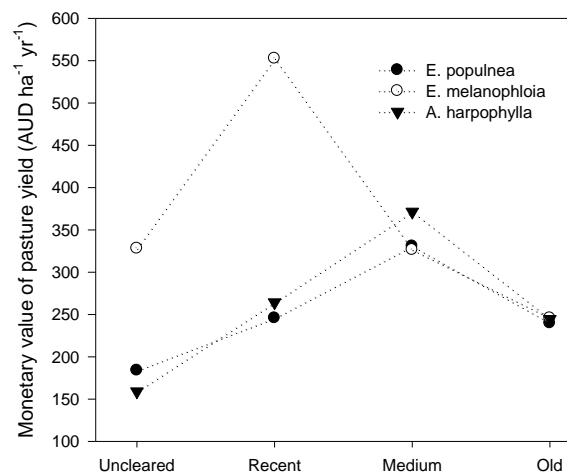


Fig 5. The monetary value of pasture yield produced at uncleared, recent, medium and old cleared sites for *E. populnea*, *E. melanophloia* and *A. harpophylla* communities.