Title: **Fire assisted pastoralism vs. sustainable forestry - the implications of missing markets for carbon in determining optimal land use in the wet-dry tropics of Australia.**

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Abstract

Using Cape York Peninsula, Queensland, Australia as a case study, this paper combines field sampling of woody vegetation with cost-benefit analysis to compare the social optimality of fire-assisted pastoralism with sustainable forestry. Carbon sequestration is estimated to be significantly higher in the absence of fire. Integration of carbon sequestration benefits for mitigating future costs of climate change into cost-benefit analysis demonstrates that sustainable forestry is a more socially optimal land use than fire-assisted pastoralism. Missing markets for carbon, however, imply that fire-assisted pastoralism will continue to be pursued in the absence of policy intervention. Creation of markets for carbon represents a policy solution that has the potential to drive land use away from fire-assisted pastoralism towards sustainable forestry and environmental conservation.

Key words: Carbon sequestration; Climate change; Land use policy; Fire; Cost-benefit analysis

1. Introduction

Socially optimal allocation of land between alternative, competing uses represents an important policy choice that economic theory treats as an issue of resource allocation. An allocation is perceived optimal when aggregate discounted social returns from alternative uses over time are maximised. In practice, however, the existence of complex socio-political processes which dominate the policy making process and do not conform to the rational, utilitarian principals underpinning economic theory, together with the presence of externalities (costs or benefits not captured by markets), often result in a sub-optimal land use allocation. The inherent lack of markets for external costs and benefits makes them difficult to quantify, increasing the likelihood of them being ignored in private and public land use decisions (for example, Reed, 1993; Sedjo et al., 1995).

The choice between converting forested land to pasture, or pursuing land uses such as sustainable forestry which maintains woody vegetation cover, is an example of a frequent decision faced by policy makers in many tropical countries. Fire-assisted pastoralism is a major land use world-wide. For example, satellite data suggests that there was a 50-percent increase in the number of forest fires related to fire-assisted pastoralism in the Brazilian Amazon between 1996 and 1997, representing one of the principal means of deforestation in the region (Schwartzman, 1997). Burning as a land clearance tool is also thought to be one of the principal causes of the 1997-1998 Indonesian fires (Stolle & Tomich, 1999).

2. The Problem

There is widely expressed concern that current rates of tropical forest conversion to pasture are too high, resulting in socially sub-optimal land use allocation (Barbier & Burgess, 1997). As fire-assisted pastoralism represents one of the principal forms of forest conversion, key considerations are the negative environmental externalities at both the local and global scale that are associated with anthropogenic burning. Whilst local externalities are extensive (Gullett & Touati, 2003; Hoffmann et al., 2003; Hulme & Kelly, 1993; Kammen & Marino, 1993; Loomis et al., 2003; Nepstad et al., 1999; Piccolo et al., 1994; Prange et al., 2003; Reiners et al., 1994; Sastry, 2002; Shakesby et al., 2003), this paper focuses on two principal global externalities associated with fire-assisted pastoralism. Firstly, it is often observed to impact on biodiversity (Cassel-Gintz & Petschel-Held, 2000; Kinnaird et al., 2003; Kozlowski, 2000). For example, Taylor et al. (1999) implicate the increasingly frequent use of fire as threatening biodiversity hotspots in rain forests on the Sunda shelf of Southeast Asia. Secondly, fire-assisted pastoralism has direct implications for climate change from emissions of CO_2 and reducing the carbon sequestration potential of forest vegetation and soils (de Koning et al., 2003; House et al., 2002; Jaramillo et al., 2003; Kauffman et al., 2003; Page et al., 2002). In the Brazilian Amazon, for example, it is estimated that the use of fire may have doubled the magnitude of CO_2 sources in the region (Houghton et al., 2000).

This paper focuses on the choice between fire-assisted pastoralism and sustainable forestry in Cape York Peninsula, Queensland, Australia (Figure 1) where rates of deforestation resulting from fire-assisted pastoralism are high. Roughly equivalent in size to England, with a population of just 18,000 people, Cape York Peninsula is subject to annual burning that is estimated to affect around 80% of its total area (Cape

York Peninsula Sustainable Fire Management Programme, personal communication, 2001). The Australian National Greenhouse Inventory (1999) observed rates of long-term conversion of forested land to pasture in the area as high as 350,000 ha yr^{-1} between 1996 and 1997.

Figure 1. Map of Cape York Peninsula and sampling location

Fire-assisted pastoralism is the dominant land use in Cape York Peninsula, supported by heavy government subsidies. There are also significant areas set aside as national park and wildlife reserves under the control of the Queensland Parks and Wildlife Service (QPWS) who use fire with the intention of encouraging habitat diversity by preventing advancement of closed rainforest into areas of open sclerophyll woodland, fire-climax heath and turkey scrub (Crowley, 1994; QPWS, 2000, 2001). Fire thus constitutes an important tool in government land management policy.

Land use choices regarding the use of fire in Cape York Peninsula are further complicated by the fact that Northern Queensland is thought to have a long history of anthropogenic fires stretching back at least 40,000 years (some estimates date it as far back as 70,000 years), coinciding with the arrival of the first Aborigines (Stocking & Mott, 1981). These early burning practices are thought to consist of traditional 'fire-stick' farming where low-intensity, early dry-season burning was used across small areas to drive game into specific hunting grounds and to increase the productivity of resource rich areas such as monsoon forests. More recently this pattern of burning has changed, coinciding with the displacement of Aborigines by European settlers, to late dry-season, high-intensity burns with increased fuel loads over larger areas (Gill et al., 1990). What is currently lacking in Cape York Peninsula is an objective, rational analysis of whether fire-assisted pastoralism is the socially optimal land use choice when compared to alternative land uses that preclude the use of fire, such as sustainable forestry.

3. Goals and Hypothesis

This paper tests the hypothesis that fire-assisted pastoralism in Cape York Peninsula represents a socially sub-optimal land use by using economic analysis based on data from woody vegetation sample plots. We use a simple cost-benefit analysis of fire-assisted pastoralism and sustainable forestry. Data from the vegetation sample plots is used to estimate carbon sequestration, which in turn is used to estimate mitigation of future costs associated with climate change in the cost-benefit analysis. This permits analysis of the impact of missing markets for carbon on land uses in Cape York Peninsula and is used to inform a discussion of policy options for encouraging more socially optimal land uses.

4. Methods

Woody vegetation sample plots were assessed biannually between 1997 and 2003 with and without the presence of fire in the Wattle Hills area of Cape York Peninsula. This data was used in conjunction with income and expenditure statistics for fire-assisted pastoralism and sustainable forestry to conduct a cost-benefit analysis of these competing land uses with and without the inclusion of the social value of carbon sequestration.

4.1 Study site

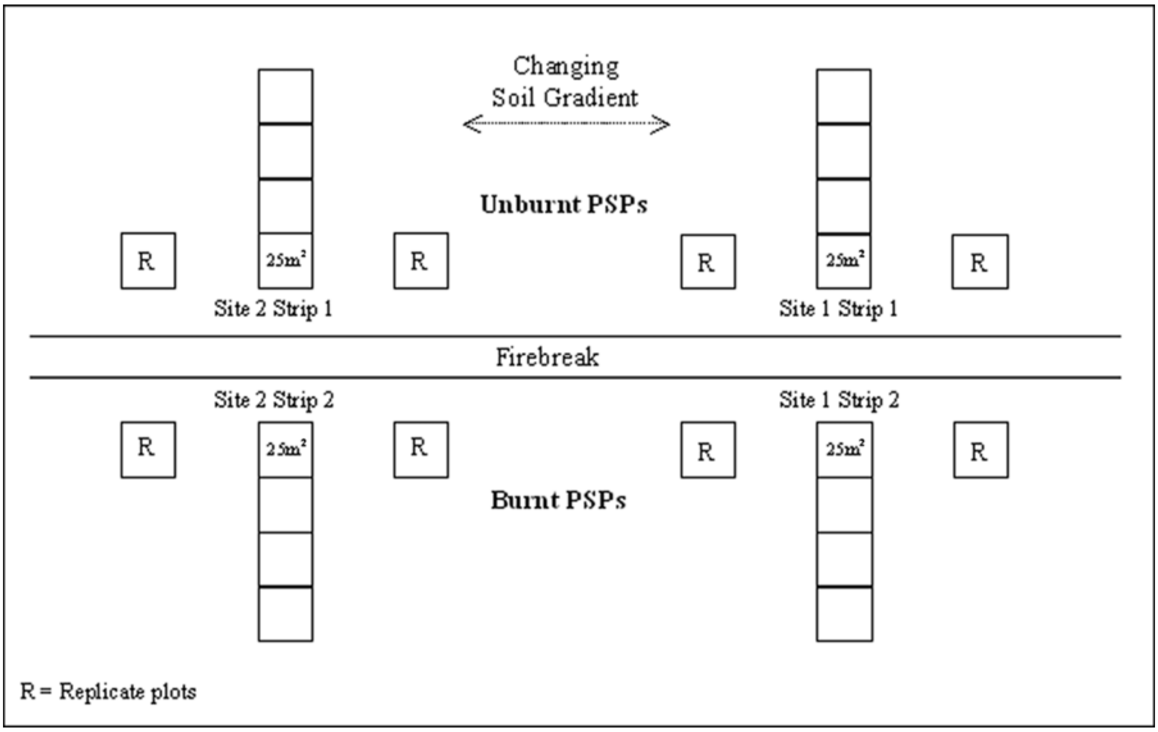
Sampling of woody vegetation was undertaken at Wattle Hills, a 35,650 ha property in the northeastern part of Cape York Peninsula from which fire has been excluded in parts of the property since 1990 (Figure 1). The eastern boundary lies along 143^{o}12’ E, the northern boundary along 12^{o} 30’ S, the southern boundary along the Pascoe River and the western boundary in the Great Dividing Range. There is a rainfall gradient from east to west, with rainfall highest in the east. Woody vegetation within the property's protective firebreaks has undergone a process of natural, fire-free regeneration. Vegetation outside of the firebreaks, on the other hand, has continued to be subjected to periodic burning from fires encroaching from elsewhere in Cape York Peninsula.

The leaseholders of Wattle Hills are prevented from deriving income from selective timber extraction by the terms of the lease that state any timber extraction must be on the basis of clearly delineated, single species stands. They do, however, derive some income from other non-timber forest products such as seed from valuable tree species like *Acacia mangium* and *Callitris intratropica*.

4.2 Environmental sampling

A total of 16 permanent sample plots was established at Wattle Hills in July 1997. The plots were arranged in strips of 4 at two separate sites of differing soil type in sclerophyll *Eucalyptus* dominated woodland either side of, and perpendicular to, one of the property's western firebreaks (Figure 2). They thus cover two levels of variation, namely burning regime and soil type.

Figure 2. Layout of permanent sample plots across burning regime and soil-type
A stratified random sample of 16 permanent sample plots was established at Wattle Hills in July 1997 in sclerophyll *Eucalyptus* dominated woodland. Plots were arranged in strips of 4 at two separate sites of differing soil type either side of, and perpendicular to, one of the property's western firebreaks. The plots thus cover two levels of variation, namely burning regime and soil type. 8 temporary outlying replicate plots (2 for each strip of 4 plots) were also sampled in 1997 to test whether plots contained representative vegetation.



All plots were established and data collected according to existing sampling protocols (Sheil, 1995; Synott, 1979; Whitmore, 1989). Individual plots measure $25m^2$ and each is further divided into $12.5m^2$ quarters. Data was collected biannually between 1997-2003, measuring species composition, height and diameter at breast height (dbh) of woody vegetation with dbh > 3cm within the plots. Eight temporary outlying replicate plots (2 for each strip of 4 permanent sample plots) were also sampled in 1997 to test if vegetation in the plots was representative of the site in general (Figure 2).

Plots and replicates were ordinated using Detrended Correspondence Analysis (DECORANA) to compare similarity of the plots and elucidate patterns of association throughout the study site (Hill & Gauch, 1980). Analysis was weighted by; (A) species presence/absence, (B) species distribution weighted by basal area of each individual plant enumerated – basal area being proportional to biomass, (C) change in basal area per species. DECORANA output is in the form of four false axes arranged in order of greatest variation. The axes are thus a proxy for variation in the vegetation and can be correlated with environmental variables such as presence/absence of fire and soil type.

Carbon sequestration was estimated using conical stem volume, assuming that $1m^3$ of stem volume is associated with $1.6m^3$ of tree biomass (including stemwood, roots, branches, and so on), and that $1m^3$ of biomass contains 0.26 tons of carbon (Brown et al., 1986; Sedjo, 1989). By multiplying carbon content by 44/12, the relative weight of a CO_2 molecule compared to a carbon atom, CO_2 fixation was also estimated (Hoen & Solberg, 1994).

4.3 Cost-benefit analysis

Cost-benefit analysis was conducted based on an assumption of two identical 35,000 ha properties. The net present value of the two alternative land uses was calculated at three different discount rates – 0%, 3% and 6%. Income and expenditure was obtained via a combination of published sources and personal communication with Cape York Peninsula land managers (Table 1). Standard forestry management accounting techniques were applied in calculating costs associated with sustainable forestry (Price, 1989, pp. 66-75). This accounts for depreciation in capital value as well as the opportunity cost of investing in machinery, assuming a 10% market rate of interest. Availability, utilisation and rate of output are also accounted for. Costs include machinery for implementing and maintaining firebreaks (bulldozer, tractor with blades, fire truck, four wheel drive support vehicle, fuel) and labour costs. Income from sustainable forestry is based on income from timber production and the sale of *Acacia mangium* and *Callitris intratropica* seed.

Table 1. Net costs and benefits associated with fire-assisted pastoralism and sustainable forestry in Cape York Peninsula

		Sustainable Forestry		Fire-assisted pastoralism	
		Cost	Benefit	Cost	Benefit
Market costs and benefits					
Livestock production[a]					45,801
Timber production[b]			23,420		
Sale of seed[c]			12,507		
Firebreaks[d]		37,332*			
Missing-market costs and benefits					
Carbon Sequestration ha^{-1}					
Nordhaus[e]	2001-10		6.8		6.8
	2011-20		8.6		8.6
	2021-30		10.0		10.0
Fankhauser[f]	2001-10		22.8		22.8
	2011-20		25.3		25.3
	2021-30		27.8		27.8

*$41982 in year 1, $37,172 thereafter
Values are quoted in $US yr^{-1} at 2002 prices
[a](ABARE, 2000), [b](RIRDC, 1998), [c,d](Scudo PLC, 2000, personal communication),

[e](Nordhaus, 1993a, 1993b)' [f](Fankhauser, 1995)

Carbon sequestration for the two properties was calculated on the basis of the environmental data obtained from the plots at Wattle Hills. It was assumed that if the DECORANA analysis demonstrated that the vegetation sampled was representative of the area as a whole, then carbon sequestration figures obtained from the eight plots under each burning regime (0.5 ha per regime in total) would be representative of the total 35,000 ha under investigation and factored up accordingly.

Due to uncertainty regarding the actual value of carbon sequestration in mitigating future costs associated with climate change, two alternative and widely cited values for carbon sequestration were used. The lower figure was based on Nordhaus (1993a; 1993b) and the higher based on Fankhauser (1995) (Table 1). These values increase each decade as the marginal effect of climate change mitigation is magnified over time owing to an increasing stock of atmospheric CO_2.

5. Problems and progress

There are three areas where assumptions might lead to error. Firstly, factoring up carbon sequestration data based on a 0.5 ha sample area to indicate carbon sequestration on a 35,000 ha property may not properly account for variation in the vegetation. For example, a property pursuing fire-assisted pastoralism may still incorporate large areas of semi-natural, rough pasture that could potentially store large amounts of carbon (Adger et al., 1992). It is, however, unlikely that these areas would store as much carbon as the relatively well wooded burnt plots that the findings of this paper are based on. This implies an overestimation of carbon sequestration on properties pursuing fire-assisted pastoralism. The use of replicate sample plots and application of DECORANA analysis helps to demonstrate the representative nature of the sample plots.

The second problem of representation is the exclusion of soil sampling and non-woody vegetation. Soil carbon is an important element of carbon sequestered by forests and future sampling of soil carbon fluxes in the plots could enhance the accuracy of the carbon sequestration figure presented in this paper. Carbon content of soils in undisturbed forests is significantly higher than that in disturbed forests or pasture land (Jaramillo et al., 2003; Santos et al., 2003), implying that we have under estimated carbon sequestration under the sustainable forestry land use option. Exclusion of under-story vegetation and woody vegetation with dbh < 3cm also suggests an underestimation of actual levels of carbon sequestration, especially in the unburnt plots where under-story vegetation has become relatively dense in the absence of fire. These under-estimations add further weight to the implications of the paper's overall findings.

The final problem is the lack of primary data on the value of timber production for the study site due to the lease restrictions discussed in Section 4.1. The value used in the cost-benefit analysis is based on an estimate for farm forestry which may be lower than the possible income derived from a property devoted solely to sustainable forestry (RIRDC, 1998). Whilst this may be an underestimate it does not affect the overall findings of this study and remains the best available estimate until lease restrictions are revised in Cape York Peninsula and actual income from sustainable timber extraction can be obtained.

6. Results

6.1 Vegetation analysis

Each false axis produced by DECORANA analysis has an associated eigenvalue that indicates the degree to which that axis captures the variation within the sampling points. A value of one would indicate perfect capture, a value of zero indicates no representation at all. Table 2 contains Axis 1 & 2 eigenvalues for all three levels of analysis undertaken.

Table 2. Related eigenvalues for DECORANA Axis 1 and Axis 2 output

	Eigenvalues	
	Axis 1	**Axis 2**
Presence / Absence	0.28	0.14
Basal Weighted	0.20	0.088
Change in Basal Area	0.39	0.14

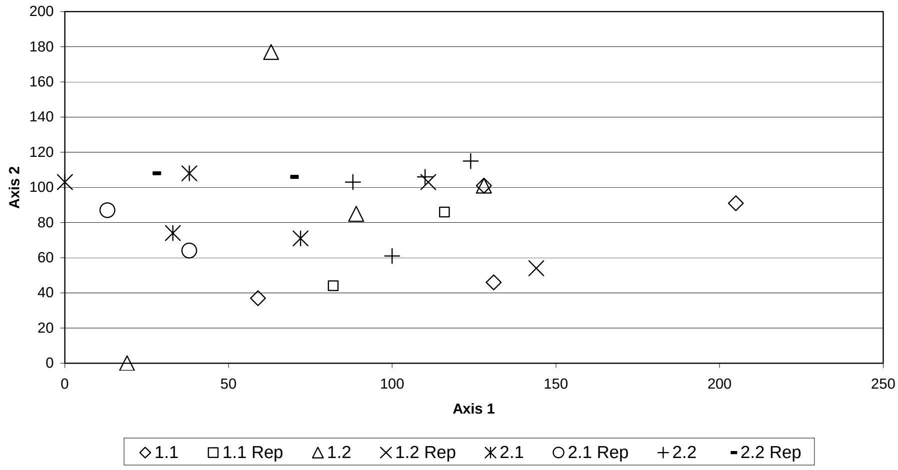
Note: Each false axis produced by DECORANA analysis has an associated eigenvalue that indicates the degree to which that axis captures the variation within the sampling points. A value of one would indicate a perfect capture, a value of zero indicates no representation at all.

The low eigenvalues at each level of analysis indicate that information is widely distributed between all four axes. Plotting Axis 1 against Axis 2 for both species presence / absence (Figure 3A) and basal weighted species distribution (Figure 3B) yields a relatively random distribution suggesting no significant variation between plots and replicate vegetative structure at each site. Analysis of DECORANA output for change in basal area (having been attributed the highest Axis 1 eigenvalue of 0.39) indicated significant grouping of burnt and unburnt plots. This is illustrated in Figure

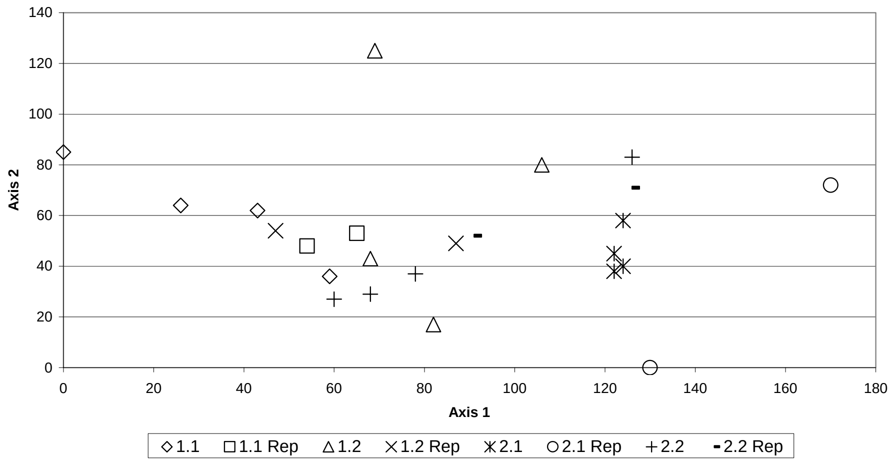
3C. Excluding the two outlying burnt plots, all unburnt plots are grouped in the lower half of Axis 1 (< 150) and the remaining burnt plots in the upper half (> 150). Correlation of Axis 1 scores with presence / absence of fire yielded a weak correlation (R = 0.487). However, upon exclusion of the two anomalous outlying burnt plots, a strong correlation (R = 0.833) was observed.

Figure 3. DECORANA analysis of permanent sample plot vegetative representation
Each false axis produced by DECORANA analysis has an associated eigenvalue that indicates the degree to which that axis captures the variation within the sampling points (Table 2). A value of one would indicate a perfect capture, a value of zero indicates no representation at all. Plotting Axis 1 against Axis 2 for both species presence / absence (A) and basal weighted species distribution (B) yields a relatively random distribution suggesting no significant variation between plots and replicate vegetative structure at each site. Analysis of change in basal area (having been attributed the highest Axis 1 eigenvalue of 0.39045) indicates significant grouping of burnt and unburnt plots (C). Vegetative representation can therefore be assumed for the plots. Key: 1.1 and 2.1 = Burnt plots; 1.2 and 2.2 = Unburnt plots; Rep = Replicate plot

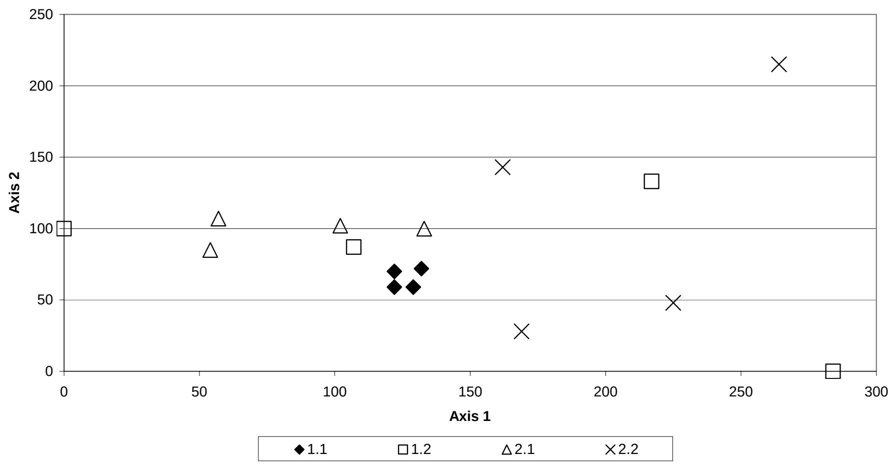
A. Axis 1 vs Axis 2 - Species Presence / Absence



B. Axis 1 vs Axis 2 - Basal Weighted Species Composition



C. Axis 1 vs Axis 2 - Change in Basal Area



6.2 Carbon sequestration

Carbon sequestration in the unburnt plots was 102.6 tonnes of carbon (376 tonnes of CO_2) per ha per year on average over the six years of the study. This was significantly higher (Student's t: $P < 0.001$, df = 63) than in the burnt plots, which sequestered an average of 33.6 tonnes of carbon (103.4 tonnes of CO_2) per ha per year.

6.3 Cost-benefit analysis

Table 3 illustrates that at all rates of discount, when the benefits of carbon sequestration are not included, sustainable forestry at the assumed levels of income has a negative net present value. When benefits from carbon sequestration are included, sustainable forestry has a considerably higher net present value than fire-assisted pastoralism. This remains true using both Nordhaus' lower and Fankhauser's higher values for carbon.

Table 3. Cost-benefit analysis of sustainable forestry vs. fire-assisted pastoralism with and without the value of missing markets for carbon

	Discount Rate					
	0%		**3%**		**6%**	
	Sustainable forestry	Fire-assisted pastoralism	Sustainable forestry	Fire-assisted pastoralism	Sustainable forestry	Fire-assisted pastoralism
Net Present Value ($US thousands) excluding carbon:						
	- 42.2	1374.0	-29.1	897.7	-21.7	630.4
Net Present Value ($US millions) including carbon:						
Nordhaus carbon values[a]	912.1	300.1	573.9	188.9	389.0	128.0
Fankhauser carbon values[b]	2,725.5	894.0	1,746.5	572.9	1,205.1	305.3

[a]**(Nordhaus, 1993a, 1993b),** [b]**(Fankhauser, 1995)**

7. Discussion of results

7.1 Vegetation analysis

DECORANA analysis demonstrates that the plots contain representative vegetation (Figure 3). The low eigenvalues (Table 2) are likely to be due to the relatively homogeneous nature of the vegetation. The grouping of unburnt and burnt plots based on change in basal area when the two anomalous burnt plots where excluded (Figure 3C) suggests a high degree of comparative similarity within the separate burning regimes. This gives an indication of good vegetation representation in terms of biomass, which is of relevance to carbon sequestration. It also points towards the presence of a single underlying dominant environmental factor that is influencing the relative distribution of the plots with regard to the rate of increase in basal area. The strong correlation between Axis 1 scores and presence / absence of fire ($R = 0.833$) implies that fire is the dominant environmental factor. The two anomalous burnt plots (1.2.1 and 1.2.4) may have been subject to environmental influences differing from the other burnt plots. The incursion of fire at Site 1 in 1997 is the most likely explanation as this will have imposed environmental stress that was not experienced at Site 2 at that time.

7.2 Socially optimal land use in Cape York Peninsula

The cost-benefit analysis demonstrates the influence consideration of environmental externalities, such as carbon sequestration, can have in terms of determining optimal land use. Without the inclusion of carbon, the negative net present value of sustainable forestry (Table 3) implies that this is not a socially desirable land use as costs outweigh benefits. Integration of the benefits derived from carbon sequestration reverses this conclusion. At all levels of analysis, using both Nordhaus' (1993a; 1993b) conservative values and Fankhauser's (1995) more generous values, sustainable forestry demonstrates a far higher net present value than fire-assisted pastoralism implying that sustainable forestry is the more socially optimal land use (Table 3). It should be noted that considerable uncertainty exists within the literature as to the true social value of carbon sequestration in mitigating future costs associated with global warming. Appropriate valuation is obviously highly dependent on realistic modelling of these potential costs.

Whilst the range of existing value estimates emphasises uncertainty surrounding carbon sequestration values, it also confirms a trend of increasingly higher estimates over time. Nevertheless, even if Nordhaus' (1993a; 1993b) relatively conservative values are to be accepted, the results presented in this paper clearly demonstrate that sustainable forestry still emerges as the more socially optimal land use (Table 3).

Another important observation is that relative difference between net present value of the two land uses increases as discount rate decreases (Table 3). The substantial decrease in net present value with increasing levels of discount rate observed in Table 3 illustrates the large effect that discounting can have on land use decisions. Considerable convergence is observed in the net present value of the two land uses at higher discount rates potentially making choices less clear.

Choice of discount rate adds another aspect of uncertainty to land use choices based on economic analysis, particularly when applied to issues of environmental significance such as the potential impacts of global warming. For example, high discount rates might be argued appropriate due to the large time scale involved in global warming. The benefits of reducing atmospheric CO_2 emissions will not be realised for a long time into the future with implications for intergenerational equity. Perceptions of benefits will also vary. Developing countries, for example, will be more inclined to discount future benefits from greenhouse mitigation at a higher level than more developed nations as countries whose economies are heavily reliant on income from, and the development of, heavy industry will have to bear greater relative costs of atmospheric CO_2 reduction.

High rates of discount could be argued to be applicable in the case of Cape York Peninsula, or other areas where fire is frequent, due to uncertainty attached to the risk of losing carbon sequestered by forests as a result of catastrophic future events such as naturally occurring fire. Future catastrophic losses could also result from pests or diseases. This risk is, however, less of an issue for the kind of mixed species forests that this paper focuses on than for trees in industrial monocultures (Pinard & Putz, 1996). Nevertheless, the regular use of fire on surrounding properties in an area such as Cape York Peninsula does pose an inherent risk of fire ‘jumping’ firebreaks and entering properties from outside. Indeed, just such an event was observed at Wattle Hills in October 2003 shortly after the 2003 data collection reported here.

Conversely, the possibility of high impact events (as are incorporated in Fankhaser’s (1995) modelling of the value of carbon sequestration) may also play an important part in justifying the use of low rates of discount, especially regarding climate change. It has often been noted that a future climate catastrophe cannot be excluded with any certainty because of the complexity of the climatic global system and the unprecedented stress imposed on it (Fankhauser, 1995). Worst-case scenarios include a redirection of the Gulf Stream, melting of the Antarctic ice-sheet and release of methane from previously frozen materials through the melting of permafrost soils (Cline, 1992; Fankhauser, 1995; Howarth & Monahan, 1992). There is a possibility that failure to mitigate atmospheric CO_2 concentrations could result in major suffering for future generations thus favouring low rates of discount. The potential for achieving rapid early uptake of CO_2 through the saturation of global carbon sinks is also undervalued at high rates of discount (Fankhauser, 1995). Such arguments provide a strong case for rejection of pure time preferences on ethical or empirical grounds and in favour of applying a zero rate of discount. Indeed, some authors have argued that discounting is inappropriate to any matters of significance to the global environment (Broome, 1992; Price & Willis, 1993).

7.3 Missing markets and optimal land use policy

No matter which of the existing estimates of the value of carbon sequestration we adhere to and whether we accept the need for a zero rate of discount or opt for one far higher, the analysis presented in this paper clearly demonstrates that sustainable forestry is a socially more optimal land use than the fire-assisted pastoralism that currently dominates land use in Cape York Peninsula. The lack of a market for carbon, however, implies that, without policy intervention, fire-assisted pastoralism will be seen as the economically rational choice for Cape York Peninsula land users.

Considering the global extent of fire-assisted pastoralism and its associated environmental impacts outlined in Section 3, there is a need to consider policy options that address the socially undesirable use of fire as a land management tool. One initial option available to policy makers in Queensland would be to remove subsidies for fire-assisted pastoralism. This would, however, have an immediate negative effect on the welfare of the majority of land users in Cape York Peninsula. The more socially and politically acceptable option would be to provide incentives for sustainable forestry practices such as removing tenancy clauses that effectively prevent mixed species, selective timber extraction and improving the infrastructure in Cape York Peninsula to facilitate transport of timber to market. Reducing or absolving the use of fire by government agencies such as the Queensland National Parks and Wildlife Service might also be argued as desirable. Enforcing a system of accountability for cross-boundary impacts of fires started by pastoralists and other land users in Cape York Peninsula would be valuable in providing security for foresters against catastrophic fires incurred from outside their own properties.

The analysis in this paper points most obviously to development of a market for carbon as a policy option. If sale of carbon credits were to be permitted by owners of land for carbon sequestered on those properties to offset against emissions, fundamental changes in land use would be observed away from fire-assisted pastoralism and towards land uses of a more socially optimal nature such as sustainable forestry. Carbon trading has already been established in various forms in different parts of the world, such as Europe’s Emissions Trading Scheme.

Australia has followed the US in not ratifying the Kyoto protocol, although the Government does have a strategy in place to address climate change (NGS, 2000). The method of emissions calculation used within Kyoto allows for emissions to be offset against carbon sinks such as forests which has meant that, due to the current extent of its forested areas, Australia is on target to meet the short term emissions targets that would have been required under Kyoto. Australia is, however, unlikely to meet Kyoto targets beyond 2008 without fundamental changes in industrial and land use practices. Whilst the Australian Government's Greenhouse Office explicitly recognises the importance of sustainable land management practices and re-vegetation of natural native vegetation to increase greenhouse sinks (AGO, 2002), and has made it a central part of Module 6 of Australia's National Greenhouse Strategy (NGS, 2000), this does not conform with Australia's recent decision to abandon a proposed international emissions trading scheme.

8. Conclusion

Fire-assisted pastoralism is a widely pursued land use associated with many negative environmental impacts. The analysis presented in this paper suggests that, in the case of Cape York Peninsula, fire-assisted pastoralism is a socially sub-optimal land use choice when the value of carbon sequestration in mitigating future costs associated with global warming is considered.

Missing markets for carbon therefore imply that alternative, more socially optimal land uses, such as sustainable forestry, are unlikely to be pursued in the absence of policy intervention. To address this, policy makers in Australia, and most likely elsewhere where fire is widely used, would need to focus on developing policy solutions that discourage anthropogenic burning. This paper suggests that the creation of markets for carbon sequestration is one possible policy solution that could drive a fundamental shift towards more socially optimal and sustainable land uses.

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References

ABARE. 2000. *Australian Bureau of Agriculture and Resource Economics*. Available: www.abare.gov.au.

Adger, W. N., Brown, K., Shiel, R. S., & Whitby, M. C., 1992. Carbon Dynamics of Land Use in Great Britain. *Journal of Environmental Management, 36*, 117-133.

AGO. 2002, 17/11/02. *Natural resources, forests and agriculture*, [Web site]. Australian Greenhouse Office, Australian Government. Available: http://www.greenhouse.gov.au/naturalresources.html [2004, 27/01/04].

Barbier, E. B., & Burgess, J. C., 1997. The economics of tropical forest land use options. *Land Economics, 73* (2), 174-195.

Broome, J., 1992. *Counting the cost of global warming*. Cambridge: White Horse Press.

Brown, S., Lugo, A. E., & Chapman, J., 1986. Biomass of Tropical Tree Plantations and Its Implications for the Global Carbon Budget. *Canadian Journal of Forest Research-Revue Canadienne De Recherche Forestiere, 16* (2), 390-394.

Cassel-Gintz, M., & Petschel-Held, G., 2000. GIS-based assessment of the threat to world forests by patterns of non-sustainable civilisation nature interaction. *Journal of Environmental Management, 59* (4), 279-298.

Cline, W. R., 1992. *The Economics of Global Warming*. Washington DC: Institute for International Economics.

Crowley, G. M., 1994. *Fire on Cape York Peninsula*. Cairns: Queensland and Commonwealth Governments Land Use Programme.

de Koning, G. H. J., Veldkamp, E., & Lopez-Ulloa, M., 2003. Quantification of carbon sequestration in soils following pasture to forest conversion in northwestern Ecuador. *Global Biogeochemical Cycles*, *17* (4), art. no.-1098.

Fankhauser, S., 1995. *Valuing Climate Change*. London: Earthscan.

Gill, A. M., Hoare, J. R. L., & Cheny, N. P., 1990. Fires and their effects in the Wet-Dry tropics of Australia. In J. G. Goldammer (Ed.), *Fire in the tropical biota* (pp. 159-178). Berlin: Springer-Verlag.

Gullett, B. K., & Touati, A., 2003. PCDD/F emissions from forest fire simulations. *Atmospheric Environment, 37* (6), 803-813.

Hill, M. O., & Gauch, H. G., 1980. Detrended Correspondence analysis, an improved ordination technique. *Vegetatio, 42,* 47-58.

Hoen, H. F., & Solberg, B., 1994. Potential and Economic-Efficiency of Carbon Sequestration in Forest Biomass through Silvicultural Management. *Forest Science, 40* (3), 429-451.

Hoffmann, W. A., Schroeder, W., & Jackson, R. B., 2003. Regional feedbacks among fire, climate, and tropical deforestation. *Journal of Geophysical Research-Atmospheres, 108* (D23), art. no.-4721.

Houghton, R. A., Skole, D. L., Nobre, C. A., Hackler, J. L., Lawrence, K. T., & Chomentowski, W. H., 2000. Annual fluxes or carbon from deforestation and regrowth in the Brazilian Amazon. *Nature, 403* (6767), 301-304.

House, J. I., Prentice, I. C., & Le Quere, C., 2002. Maximum impacts of future reforestation or deforestation on atmospheric CO2. *Global Change Biology, 8* (11), 1047-1052.

Howarth, R. B., & Monahan, P. A., 1992. *Economics, Ethics and Climate Policy.* Berkeley, CA: Mimeo, Lawrence Berkeley Laboratory.

Hulme, M., & Kelly, M., 1993. Exploring the Links between Desertification and Climate-Change. *Environment, 35* (6), 4-&.

Jaramillo, V. J., Ahedo-Hernandez, R., & Kauffman, J. B., 2003. Root biomass and carbon in a tropical evergreen forest of Mexico: changes with secondary succession and forest conversion to pasture. *Journal of Tropical Ecology, 19,* 457-464.

Kammen, D. M., & Marino, B. D., 1993. On the Origin and Magnitude of Preindustrial Anthropogenic Co2 and Ch4 Emissions. *Chemosphere, 26* (1-4), 69-86.

Kauffman, J. B., Steele, M. D., Cummings, D. L., & Jaramillo, V. J., 2003. Biomass dynamics associated with deforestation, fire, and, conversion to cattle pasture in a Mexican tropical dry forest. *Forest Ecology and Management, 176* (1-3), 1-12.

Kinnaird, M. F., Sanderson, E. W., O'Brien, T. G., Wibisono, H. T., & Woolmer, G., 2003. Deforestation trends in a tropical landscape and implications for endangered large mammals. *Conservation Biology, 17* (1), 245-257.

Kozlowski, T. T., 2000. Responses of woody plants to human-induced environmental stresses: Issues, problems, and strategies for alleviating stress. *Critical Reviews in Plant Sciences, 19* (2), 91-170.

Loomis, J., Wohlgemuth, P., Gonzalez-Caban, A., & English, D., 2003. Economic benefits of reducing fire-related sediment in southwestern fire-prone ecosystems. *Water Resources Research, 39* (9), art. no.-1260.

National Greenhouse Inventory. 1999. *Land Use Change and Forest Sector 1990-1997*. Australia: National Greenhouse Inventory Committee.

Nepstad, D. C., Verissimo, A., Alencar, A., Nobre, C., Lima, E., Lefebvre, P., Schlesinger, P., Potter, C., Moutinho, P., Mendoza, E., Cochrane, M., & Brooks, V., 1999. Large-scale impoverishment of Amazonian forests by logging and fire. *Nature, 398* (6727), 505-508.

NGS. 2000. *The National Greenhouse Strategy*. Australian Commonwealth and State and Territory Governments. Available: http://ngs.greenhouse.gov.au/index.html [2004, 27/01/04].
Nordhaus, W. D., 1993a. Optimal Greenhouse-Gas Reductions and Tax Policy in the Dice Model. *American Economic Review, 83* (2), 313-317.
Nordhaus, W. D., 1993b. Rolling the Dice - an Optimal Transition Path for Controlling Greenhouse Gases. *Resource and Energy Economics, 15* (1), 27-50.
Page, S. E., Siegert, F., Rieley, J. O., Boehm, H. D. V., Jaya, A., & Limin, S., 2002. The amount of carbon released from peat and forest fires in Indonesia during 1997. *Nature, 420* (6911), 61-65.
Piccolo, M. C., Neill, C., & Cerri, C. C., 1994. Net Nitrogen Mineralization and Net Nitrification Along a Tropical Forest-to-Pasture Chronosequence. *Plant and Soil, 162* (1), 61-70.
Pinard, M. A., & Putz, F. E., 1996. Retaining forest biomass by reducing logging damage. *Biotropica, 28* (3), 278-295.
Prange, J. A., Gaus, C., Weber, R., Papke, O., & Muller, J. F., 2003. Assessing forest fire as a potential PCDD/F source in Queensland, Australia. *Environmental Science & Technology, 37* (19), 4325-4329.
Price, C., 1989. *The Theory and Application of Forest Economics*. Oxford: Blackwell.
Price, C., & Willis, R., 1993. Time, discounting and the valuation of forestry's carbon fluxes. *Commonwealth Forestry Review, 72* (4), 265-271.
QPWS. 2000. *Fire Management System*. Brisbane: Queensland Parks and Wildlife Service.
QPWS. 2001. *Draft Protected Area Policy*. Brisbane: Queensland Parks and Wildlife Service.
Reed, W. J., 1993. The Decision to Conserve or Harvest Old-Growth Forest. *Ecological Economics, 8*, 45-69.
Reiners, W. A., Bouwman, A. F., Parsons, W. F. J., & Keller, M., 1994. Tropical Rain-Forest Conversion to Pasture - Changes in Vegetation and Soil Properties. *Ecological Applications, 4* (2), 363-377.
RIRDC. 1998. *Trees for Profit-An Integrated Model, a Regional Study*. BARTON ACT: Rural Industries Research & Development Corporation.
Santos, A. J. B., Silva, G., Miranda, H. S., Miranda, A. C., & Lloyd, J., 2003. Effects of fire on surface carbon, energy and water vapour fluxes over campo sujo savanna in central Brazil. *Functional Ecology, 17* (6), 711-719.
Sastry, N., 2002. Forest fires, air pollution, and mortality in Southeast Asia. *Demography, 39* (1), 1-23.
Schwartzman, S., 1997. *Fires In the Amazon: An Analysis of NOAA-12 Satellite Data, 1996-1997*. Washington D.C: Environmental Defense Fund.
Sedjo, R. A., 1989. Forests - a Tool to Moderate Global Warming. *Environment, 31* (1), 14-20.
Sedjo, R. A., Wisniewski, J., Sample, A. V., & Kinsman, J. D., 1995. The Economics of Managing Carbon via Forestry: Assessment of Existing Studies. *Environmental and Resource Economics, 6*, 139-165.
Shakesby, R. A., Chafer, C. J., Doerr, S. H., Blake, W. H., Wallbrink, P., Humphreys, G. S., & Harrington, B. A., 2003. Fire severity, water repellency characteristics and hydrogeomorphological changes following the Christmas 2001 Sydney forest fires. *Australian Geographer, 34* (2), 147-175.
Sheil, D., 1995. A critique of permanent sample plot methods and analysis with

examples from Budongo Forest, Uganda. *Forest Ecology and Management, 77*, 11-34.

Stocking, G. C., & Mott, J. J., 1981. Fire in the tropical forests and woodlands of northern Australia. In A. M. Gill & R. H. Groves & I. R. Noble (Eds.), *Fire and the Australian biota*. Canberra: Australian Academy of Science.

Stolle, F., & Tomich, T. P., 1999. The 1997-1998 fire event. *Nature & Resources, 35* (3), 22-30.

Synott, T. J., 1979. *A manual of permanent plot proceedures for tropical rain forests. Tropical Forestry Papers, 14*: Commonwealth Forestry Institute.

Whitmore, T. C., 1989. Guidelines to Avoid Remeasurement Problems in Permanent Sample Plots in Tropical Rain Forests. *Biotropica, 21* (3), 282-283.