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Emerging opportunities for developing a diversified land sector economy in Australia's northern savannas

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Abstract. We explore sustainable land sector opportunities for Australia's 1.2 million km^2 northern savanna rangelands where extensive beef cattle pastoralism is the predominant contemporary land use. Our focal region is characterised by mean annual rainfall exceeding 600 mm, ecologically bountiful wet season water availability followed by 6 8 months of surface water deficit, mostly nutrient poor soils, internationally significant biodiversity and carbon stock values, very extensive dry season fires in pastorally unproductive settings, a sparse rural population (0.14 persons km^{-2}) comprising a high proportion of Indigenous people, and associated limited infrastructure. Despite relatively high beef cattle prices in recent seasons and property values escalating at a spectacular ~6% p.a. over the past two decades, long term economics data show that, for most northern regions, typical pastoral enterprises are unprofitable and carry significant debt. Pastoral activities can also incur very significant environmental impacts on soil and scarce dry season water resources, and greenhouse gas emissions, which currently are not accounted for in economic sustainability assessments. Over the same period, the conservation sector (including National Parks, Indigenous Protected Areas) has been expanding rapidly and now occupies 25% of the region. Since 2012, market based savanna burning projects aimed at reducing greenhouse gas emissions occur over a further 25%. Returns from nature based tourism focussed particularly on maintaining intact freshwater systems and associated recreational fishing opportunities dwarf returns from pastoralism. The growth of these latter industries illustrates the potential for further development of profitable 'ecosystem services' markets as part of a more environmentally and socially sustainable diversified regional land sector economy. We outline some of the imminent challenges involved with, and opportunities for developing, this new industry sector.

Additional keywords: carbon economy, ecosystem services, land use, Northern development, pastoral enterprise, pasture systems.

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Introduction

Across north Australia's savanna rangelands experiencing long term mean annual rainfall in excess of 600 mm, land use today is dominated by extensive (as opposed to intensive, grain fed) beef cattle pastoralism. By some estimates pastoral activities occur over as much as 90% of the region (Northern Australia Land and Water Task Force (NALaWTF) 2009), albeit including various locations supporting large numbers of feral water buffalo, cattle, horses and donkeys. Despite the beef industry's geographic compass, all is not economically, socially, nor environmentally well. A landmark northern Australian industry situation report covering the period 2001 2012 found that most pastoral enterprises were neither economically viable, nor sustainable (McLean *et al*. 2014). Average operating profitability across the northern pastoral industry over the 12 year assessment period was just 0.2%, and 2.6% for the top 25% of business performers; average return on assets was <1%. Even with relatively high cattle prices over the most recent years, the latest authoritative independent industry assessment covering the period 2004 2016 indicates that, if anything, average regional business returns have slightly worsened (Holmes *et al*. 2017). Despite this poor economic performance, over the past 20 years there has been a trend of exponentially increasing land values, averaging ~6% annually for a median priced northern pastoral property subject to significant regional market fluctuations such as occurred with the 2011 collapse of the Indonesian live export market (Rural Bank Ltd 2016).

These generally marginal levels of annual business profitability reflect conditions across the industry of typically low fertility soils, seasonal access restrictions, limited infrastructure, high labour and input costs, limited financial management skills, and distant and volatile markets (Stone *et al*. 2007; SoEC 2011; Gleeson *et al*. 2012; Novelly and Warburton Northam 2012; McLean *et al*. 2014; Ash *et al*. 2015; Crowley 2015*a*; Rolfe *et al*. 2016). Such conditions, combined with fluctuating land values and significant debt levels extenuated by prolonged drought conditions in some regions, have led to major financial stresses on many typical pastoral businesses (Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) 2014; Thompson and Martin 2014; Bray *et al*. 2015; Rolfe *et al*. 2016). At the family level, such stresses can contribute to serious emotional health issues including high rates of suicide in north Australian rural and remote communities (Kõlves *et al*. 2012). The ongoing impacts of dispossession on regional Aboriginal people, communities, their health and wellbeing are well recognised and documented (COAG 2009; Pedersen and Phillpot 2018).

The pastoral industry also generates significant long term environmental liabilities, which are not accounted for in current market pricing, including: land degradation (Caitcheon *et al*. 2012; Novelly and Warburton Northam 2012; Hunt *et al*. 2014; Aubault *et al*. 2015; Crowley 2015*a*, 2015*b*; Edwards *et al*. 2015; Segoli *et al*. 2015; Star *et al*. 2015); gully erosion (Loughran *et al*. 2004; Lal *et al*. 2013; Shellberg *et al*. 2013) and associated downstream siltation effects on maritime systems (DoEHP 2012; Brodie and Pearson 2016; GBRWST 2016); impacts on freshwater resources and quality, including failure to manage stock access to ecologically fragile springs and soaks (Abel and Rolfe 2009; Zaar 2009; DNREAS 2010; SoEC 2011); impacts on native species biodiversity, including granivorous birds and small mammals (Franklin 1999; Woinarski and Ash 2002; Franklin *et al*. 2005; Legge *et al*. 2011); increasing rates of land clearing and associated greenhouse gas (GHG) emissions, particularly in pastorally marginal situations (DSITI 2017); and ruminant GHG emissions, which are estimated to contribute 4% of national emissions (DoE 2015). However, significant weed and feral animal management issues are common to all types of land use (Crowley 2015*a*, 2015*b*).

Collectively, the above issues point to a pressing need for assessing the value proposition of current land sector activities, and to explore novel approaches for developing sustainable land use practices and broader community benefits as part of a more diversified regional economy. In this contribution we: first, briefly address salient physiographic, environmental, land use and demographic features describing our focal region; second, assess the current economic condition of the regional pastoral industry and associated impacts on supporting ecosystem services based on available documented sources; and third, consider emerging opportunities and challenges associated with developing a more diversified, supportive and inclusive ecosystem services based regional land sector economy. Our purpose is to provide evidence that an ecologically, socially and economically sustainable diversified land sector serves an essential component of the contemporary Northern Australian development agenda (CoA 2015).

Regional context

Our geographic focus is concerned especially with the vast (~1.2 M km^2), very sparsely populated, savanna landscapes extending across north Australia from around Broome on the west coast, to the Burdekin region south of Townsville on the east coast, excluding north Queensland's (Qld) relatively well watered Wet Tropics. North Australia as defined here is broadly comparable with the 'Northern Australia' region (1.2 M km^2) defined by water catchments (NALaWTF 2009), and a more restricted subset of the 1.9 M km^2 Australian 'tropical savannas' based on a biogeographic regionalisation (Fig. 1*a*).

North Australia thus defined encompasses an apparently little modified region receiving an average of at least 600 mm annual rainfall, and as much as 2000 mm in some northern locations, predominantly during the wet season months from November to March. The 600 mm rainfall isohyet is significant here in that it distinguishes between generally more settled, productive and viable cattle country to the south (especially in the eastern sector and the Barkly Tableland), and, to the north, rapidly developing novel ecosystem services opportunities on internationally significant biodiverse, but generally less pastorally productive, lands.

Most of the region is of low elevation and topographically subdued, but comprises a 'ridge' of relatively high country extending from the eastern Kimberley to Cape York. This higher country comprises mostly rugged terrain derived from low fertility sedimentary and metamorphosed rocks, supporting high biodiversity values. Soils are mostly infertile rudosols, kandosols and tenosols, and fertile vertosols in restricted areas with generally low to moderate agricultural potential (Petheram *et al*. 2014), and predominantly low pasture capability (Fig. 1*b*). The natural vegetation cover comprises mostly eucalypt dominated open woodlands (<10% woody cover) in lower rainfall regions, with increased proportions of woodlands (10 30% cover) and open forests (30 70% cover) under higher rainfall and more favourable site conditions. The remainder of the savanna matrix comprises lesser components of grasslands and floodplains, shrublands, closed canopy rainforests and dense riparian vegetation (Fox *et al*. 2001).

Today, the major enterprise activity at landscape scales is beef cattle pastoralism, typically occurring on very large property sizes as reflected in the contemporary cadastre (Fig. 1*c*), varying in median size from 100 000 to 200 000 ha in the Top End (Northern Territory NT), Cape York (Qld) and Kimberley (Western Australia WA), and from 15 000 70 000 ha in the rest of Qld. Most properties are under either freehold, or long term perpetual (99 year) pastoral lease, with tenure arrangements depending upon respective State or Territory legislation. Annual rental lease payments are low (0.75 1.5% of the land value, depending upon 'term' or 'perpetual lease' arrangements). Average stocking rates vary from <1 to 15 head/km^2, depending upon soil potential, pasture species and infrastructure (McLean *et al*. 2014). Available data indicate that there are ~4 million cattle in our focal area, with a 'northern Australian' (including all of Qld) herd of ~13.7 million, and a national herd of ~25 million (Meat and Livestock Australia 2017). The pastoral industry in our focal area generates ~$414 million gross value (based on average returns given in Holmes *et al*. 2017) from ~650 pastoral enterprises with ~2800 direct employees, of whom, based on 2016 census data, ~390 are Indigenous (ABS 2016).

As of 2017, a significant proportion of the region (56%) comprises legally recognised Indigenous interests in land; half of which is under forms of freehold title, the other half under non exclusive Native Title arrangements, which recognise ongoing affiliation with traditional estates but without granting economic property rights (Fig. 1*d*). The formal conservation estate (e.g. National Parks (NP), Indigenous Protected Areas

(IPA)), including Indigenous owned lands, comprises 28% of the region. Although confined to relatively few, and small sites compared with pastoral properties but with potentially very extensive and lasting impacts, mining is the major regional land sector industry, generating at least $6 billion annually (Brereton *et al*. 2009). However, multipliers (measures of the extent to which money circulates and stimulates additional activity in the economy) from mining are low, because local communities are often poorly placed to provide the goods or services sought by these industries, including labour (Welters 2010; Gerritsen *et al*. 2018). North Australia supports a thriving nature based tourism industry, anticipated to be worth $2.8 billion in 2018 (Clark *et al*. 2009). That industry is based particularly on maintaining intact freshwater systems and associated recreational fishing opportunities (Clark *et al*. 2009; Warfe *et al*. 2011).

Although regional savannas are little modified by international standards, losses of ecological function, chiefly evidenced in biodiversity declines, are increasingly observed at several levels and across large areas (Franklin *et al*. 2005; Woinarski *et al*. 2011). More reliably productive environments (like wetlands and riparian habitats) are valued highly by many different interests or sectors. Rivers are mostly unregulated. Most rivers carrying high wet season flows cease flowing during parts of the annual dry season so that many water dependent ecosystems are maintained by springs or other near surface groundwater. Primary industries (agriculture and mining) rely heavily on groundwater extraction even in the high rainfall areas, and so can readily impact these systems (NALaWTF 2009).

North Australia is characterised also by frequent fires, especially extensive wildfires in the late dry season (Fig. 1*e*). In some areas, but especially in regions receiving >1000 mm of annual rainfall, fires currently recur at frequencies greater than once every 2 years (Felderhof and Gillieson 2006; Edwards *et al*. 2015). In absence of marked grazing pressure and other grassy fuel limiting conditions (e.g. closed canopy vegetation, rock platforms), fires have been observed to recur annually even in areas receiving at least 600 mm rainfall (Russell Smith *et al*. 2010; Whitehead *et al*. 2014). This recurrent fire management problem has resulted in novel economic opportunities becoming available in recent years through the development of market based, landscape scale, 'savanna burning' carbon farming projects. Importantly, savanna burning projects serve as an illustration of the regional potential of the ecosystem services industry sector generally, and especially for remote Indigenous land owners and managers.

The total northern population [including major towns such as Cairns, Ingham, Townsville, Mt Isa, Ayr and Home Hill (Qld), Darwin, Palmerston, Katherine (NT), and Broome (WA)] comprised 900 900 people in the 2016 census, of whom 14% were Indigenous (ABS 2016). Outside of towns, the remote population was around 272 000, with Indigenous people comprising a much greater proportion of the population. In the Kimberley and Top End savannas, about half of the rural population is Indigenous, and in very remote regions generally, more than 90%. Nationally, 45% of the population living in areas classified by the Australian Bureau of Statistics as very remote is Indigenous (ABS 2011). Average population density of ~0.75 persons km^{-2} is low by Australian (3.0 persons km^{-2}) and global standards. Excluding major town centres, there is ~1 person for each 700 ha (0.14 persons km^{-2}). By any standard, northern Australia is sparsely populated.

Economic status and environmental impact of the north Australian pastoral industry

Economic assessment

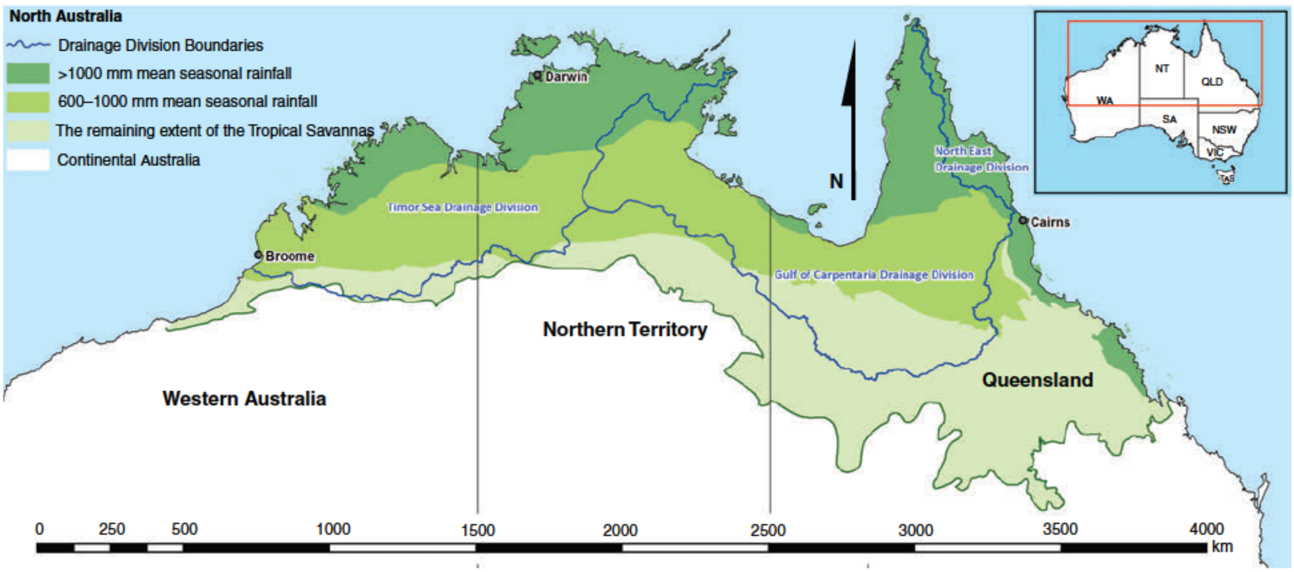
We conducted a detailed economic analysis of an average regional beef cattle producing enterprise integrating available published data, mostly from ABARES farm survey data (www.agriculture.gov.au/abares/surveys), beef situational analyses reports by McLean *et al*. (2014) and Holmes *et al*. (2017), detailed northern pastoral production data from Bray *et al*. (2015), and other sources as noted. For this assessment (except where indicated), we used eight regions as identified by Bray *et al*. (2015) based on productivity potential, amalgamated from 18 Australian Bureau of Statistics SA2 sub regions. All values cited are in 2015 2016 $AUS.

Financial assessments (EBIT Earnings Before Interest and Tax; EAIBT Earnings After Interest Before Tax) were based on long term data, 2004 2005 to 2015 2016, for average pastoral businesses in each region, following Holmes *et al*. (2017). Although our analyses focus on an average pastoral business, we acknowledge that the 25% top performers, and some businesses in the remainder, operate profitably (at least before environmental liabilities are taken into consideration). Holmes *et al*. (2017) note that profitable enterprises tend to operate at larger economies of scale.

Over the 12 year assessment period the average gross margin for a beef property in different regions ranged from $200 000 to $976 000 year^{-1}, with relatively greater returns evident from the Barkly and Kimberley (McLean *et al*. 2014; Holmes *et al*. 2017). However, after deducting the total costs of production, average annual EBIT was substantially lower (<$50 000) for an average business across the NT and most of Qld, $70 000 for the Qld Mitchell grass region, $138 000 for the Kimberley, and $219 000 for the Barkly (Fig. 2*a*). After accounting for debt (Fig. 2*b*), average annual EAIBT (i.e. EBIT less annual interest repayments calculated conservatively at 5%) was negative across most of the focal region with the exception of the Kimberley (mean = $93 000) and the Barkly (mean = $26 000) (Fig. 2*c*).

Over the 12 year study period, an average pastoral business across the entire northern region returned a mean annual EBIT of $27 400, and a mean annual EAIBT of $26 900 (Fig. 3; Holmes *et al*. 2017). These data translate to regional average EBIT returns of $10.84 per Adult Cattle Equivalent. When the top 25% performers are removed from this assessment, the remainder operated at a mean annual EBIT of $66 000 year^{-1}, and an estimated EAIBT of $222 900 year^{-1}. These latter enterprises produce 45% of the total northern output. Holmes *et al*. (2017) suggest that economically viable enterprises, comprising ~28% of the total, typically maintain herd sizes of 1600 5400 head or above, with operating efficiencies typically resulting in costs of $0.60 kg^{-1} of beef produced and generating at least $78 97/adult equivalent. As noted above however, infertile soils and low quality pastures mitigate against high

(a)



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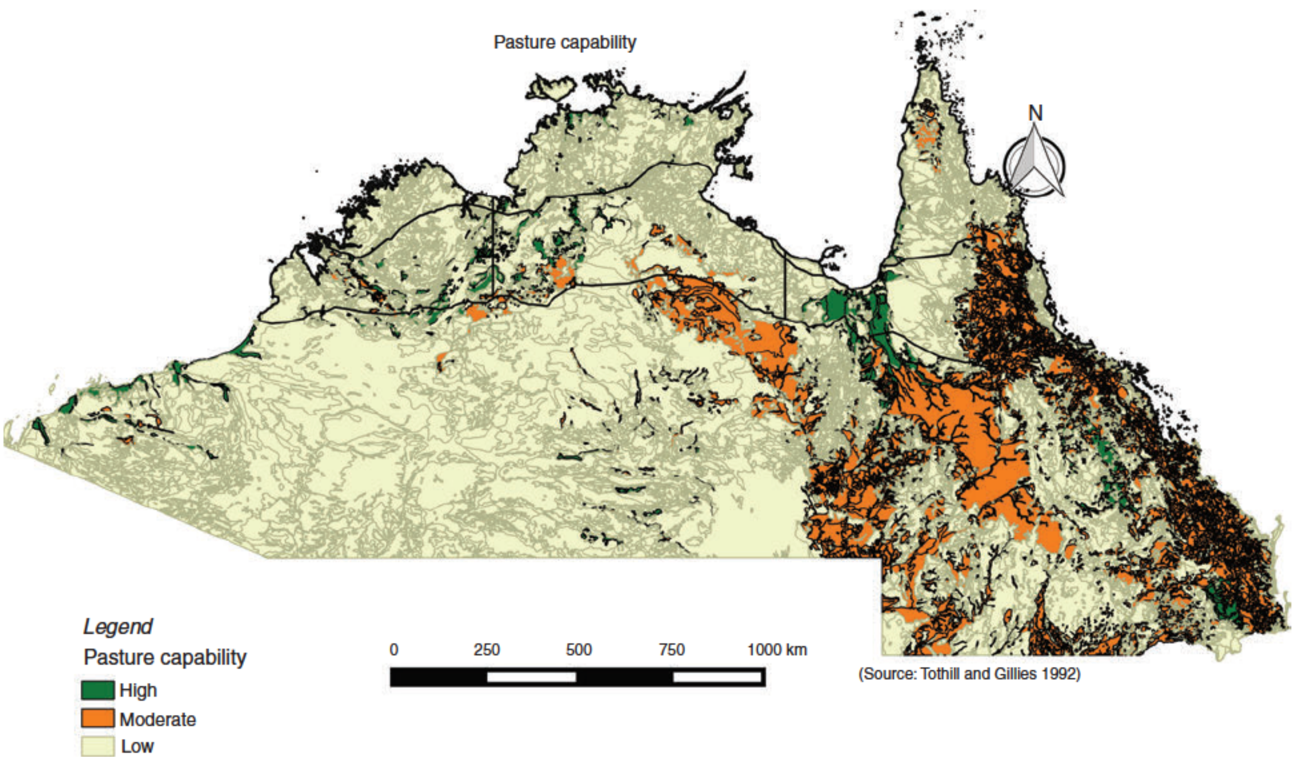

Fig. 1. North Australia focal study area. Dark and medium green colours indicate the long-term mean annual rainfall in 1000-mm and 600-mm regions, respectively, where the latter defines the southern boundary, but excluding the Queensland Wet Tropics. (*a*) Northern Australian region (as defined by the NALaWTF 2009) and our focal study area above 600 mm. (*b*) Pasture capability based on soil types, pasture and vegetation types, and land management, following Tothill and Gillies (1992) and expert opinion of regional scientists. (*c*) Cadastre using land tenure data from each of the jurisdictions in Western Australia, Queensland and the Northern Territory. Sources: State and Territory Spatial Data Portals: WA https://data.wa.gov.au/; Qld http://qldspatial.information.qld.gov.au/catalogue/custom/search.page?q cadastre; and the NT https://nt.gov.au/property/land/get-land-information-online. (*d*) Indigenous land titles (as at June 2017) and population distribution centres (ABS 2016). (*e*) Late dry season fire frequency, 2000 2015 (fires that occur after July). Source: North Australia Fire Information website (www.firenorth.org.au)

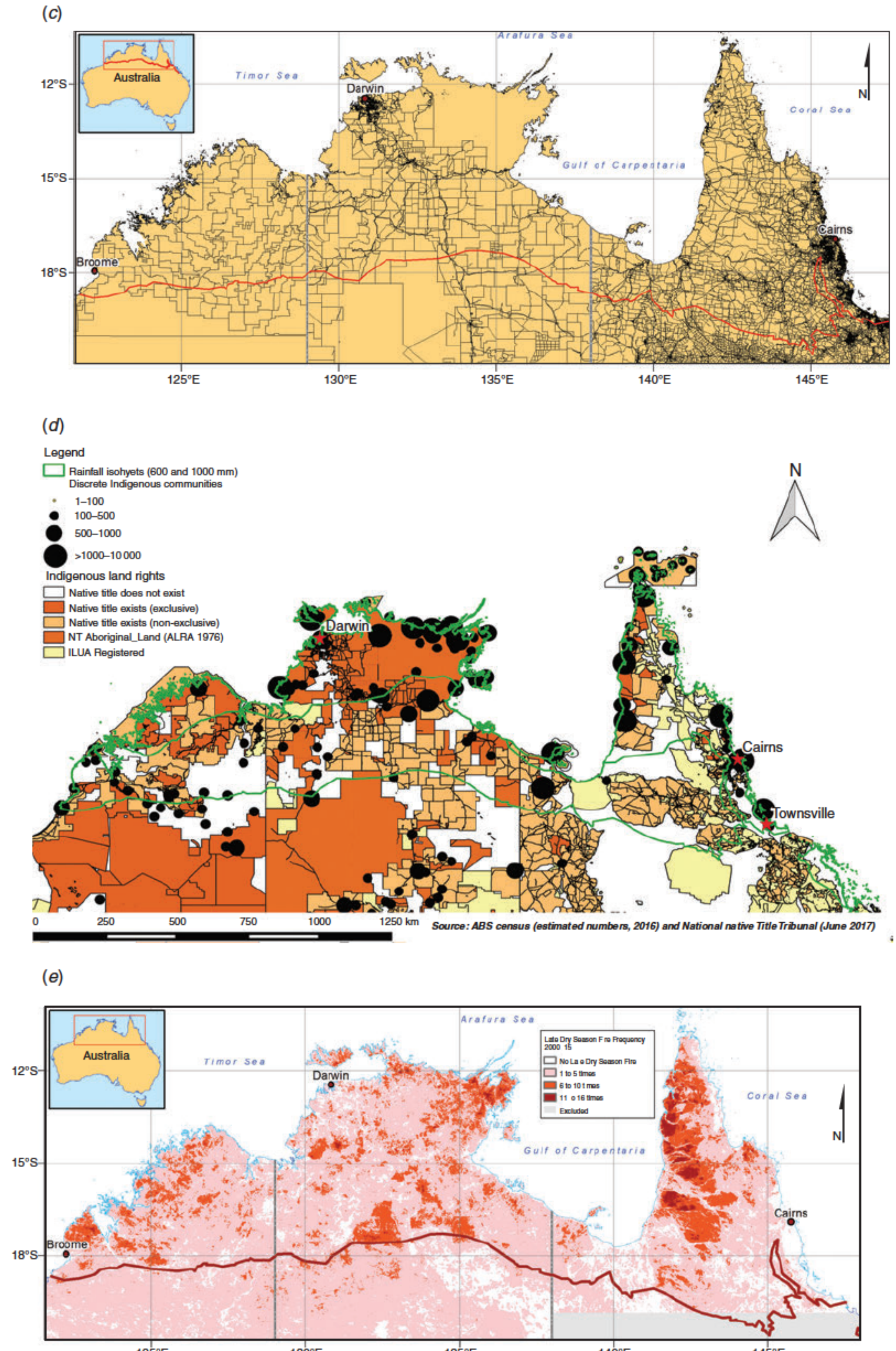

Fig. 1. *(continued)*

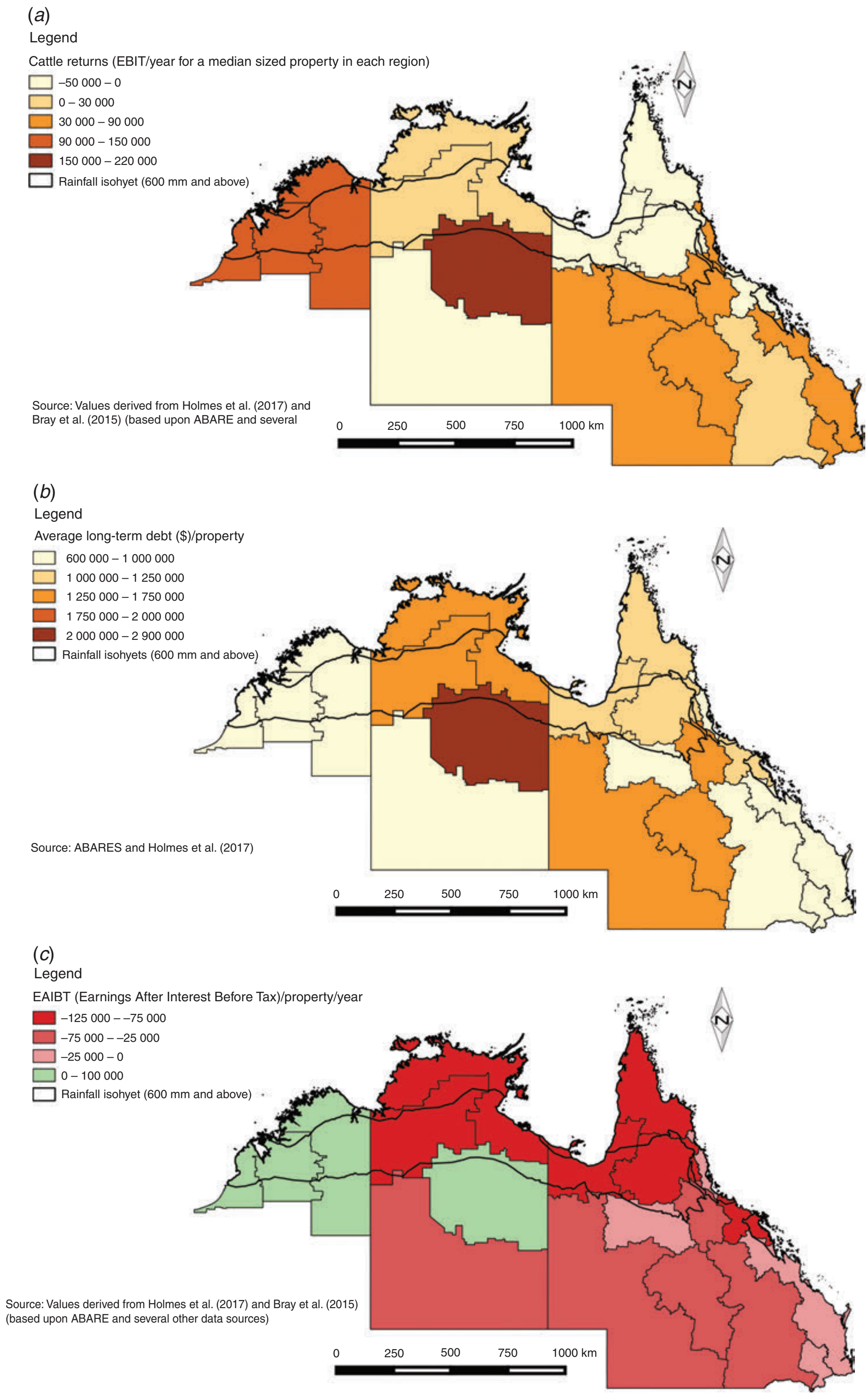

Fig. 2. Annual long-term (2004 05 to 2015 16) economic returns from an average pastoral business in the north: (*a*) Earnings Before Interest and Tax (EBIT) year ^{1}; (*b*) Debt (total liabilities); (*c*) Earnings After Interest but Before Tax (EAIBT) year ^{1} (Sources: ABARES data, McLean *et al*. 2014; Bray *et al*. 2015; Holmes *et al*. 2017). Notes: The underlining ABARES boundaries are amalgamated into three regions in the NT, four in Queensland, and one in the WA (as per Bray *et al*. 2015; based on underlying biophysical parameters) to present average economic returns across the region while acknowledging variations at the property scale.

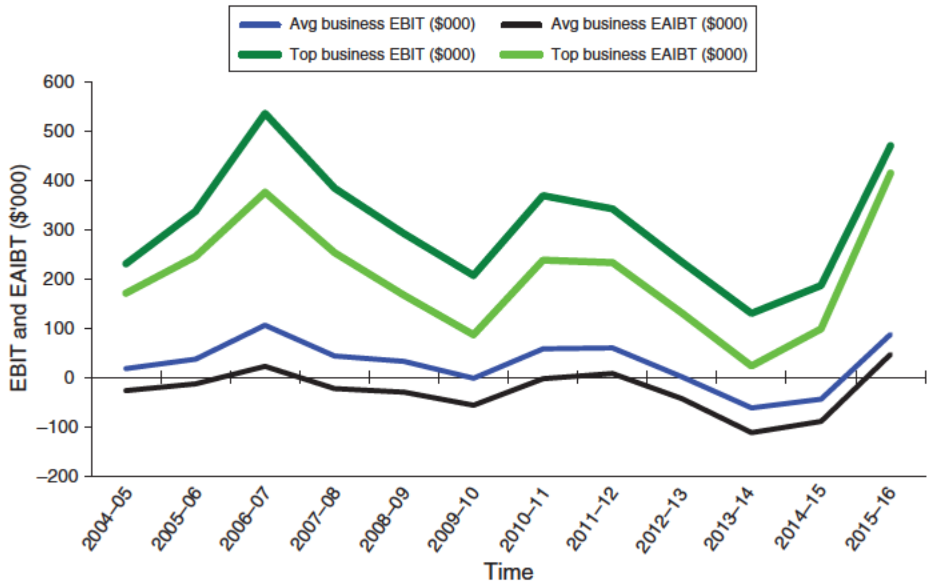

Fig. 3. Average annual long-term EBIT and EAIBT for an average, and top 25% pastoral business, in north Australia (Source: Holmes *et al.* 2017).

productivity levels being realised over the great majority of the focal region.

Environmental costs

Although recognising that well managed pastoral enterprises can provide many positive ecosystem services (e.g. reducing weed, feral animal, fire impacts), heavy grazing by cattle (and associated livestock and feral animals such as horses and Asian water buffalo) causes well known impacts on savanna systems which typically are neither accounted for in conventional financial assessments, nor in establishing the real long term costs (and benefits) of the pastoral industry and its products. Such environmental impacts can be exacerbated by financial imperatives of poorly performing and managed pastoral enterprises to overstock in an endeavour to meet crippling debt (ABARES 2014; McLean *et al.* 2014).

The character and magnitude of these landscape scale impacts is immense, contributing to: land degradation resulting in reduced landscape function and consequent lost pastoral production, through losses of topsoil, soil organic matter, nutrients, and surface water retention, and, in severe cases, surface deflation and associated gully erosion; downstream effects of sedimentation on coastal and marine ecosystems; impacts on the quality and quantity of ecologically precious perennial and seasonal surface water resources; GHG emissions directly associated with land clearing, cattle rumination and dung; spreading of weeds and facilitating undesirable woody thickening; and significant impacts on vulnerable flora, fauna, and critical habitats. Effects are ubiquitous but vary in intensity across the landscape.

To illustrate the magnitude of such impacts, in this assessment we consider the environmental costs associated just with aspects of pasture condition and GHG emissions from cattle given ready availability of accepted environmental accounting procedures. Indicative environmental costs associated with GHG emissions from land clearing are also feasible to undertake given established relationships between pre clearing savanna biomass and resultant emissions from burning of debris (Bristow *et al.* 2016). These estimates are not included here given that, until very recently, land clearing in our focal region has been limited (e.g. DSITI 2017). However, applying a current carbon price of ~$10 t.$CO_2$ e to GHG emissions derived from clearing typical savanna vegetation as given in Bristow *et al.* (2016), the environmental costs associated with clearing 1000 ha would typically be in excess of $1M; currently, these environmental costs are not borne by the pastoral lessee but by the Australian public through international climate change commitments. Over 45 000 ha was cleared in north Qld's savanna Gulf rivers catchments in 2015 2016 (DSITI 2017). Costing of other environmental impacts listed above, although feasible to do, has either not yet been undertaken for north Australia savanna conditions or poses significant challenges for example, how to put monetary values on biodiversity components and ecologically critical surface and ground water resources.

For pasture condition, the total area of degraded pastoral land was assessed using data from a regional study published in 1992 (Tothill and Gillies 1992), classifying northern pastoral lands as being in 'A' (good), 'B' (deteriorating) and 'C' (degraded) states. Although somewhat dated, expert advice suggests that this condition assessment is still broadly representative if conservative. Given established relationships that pastures in 'B' and 'C' condition result in reduced productivity (Stone *et al.* 2007; Caitcheon *et al.* 2012; Scanlan *et al.* 2013; McLean *et al.* 2014), we first estimated losses (opportunity costs) in pasture production and consequent cattle returns for both 'B' and 'C' areas (EBIT/year). As suggested by pastoral scientists (Scanlan *et al.* 2013; Bray *et al.* 2016), we assumed that pastoral lands in 'B' condition reduced pastoral productivity by 25%, and by 50% when in 'C' condition. Overall, average opportunity costs for cattle production from pasture degradation were $7408/property year^{-1} (range: $1000 $18 000 per property year^{-1}). It is notable that pasture condition in our focal region is generally much better than for the broader northern Australia pastoral estate (Tothill and Gillies 1992; Hunt *et al*. 2014; McLean *et al*. 2014).

Costs associated with GHG emissions from cattle across the region were determined using regional cattle numbers (Bray *et al*. 2015), region specific cattle GHG emissions ranging from 0.023 to 0.311 t.CO_2 e year^{-1} ha^{-1} (Eady *et al*. 2016), and applying a conservative carbon price of $10 per tonne (following carbon auctions by the Clean Energy Regulator, Australian Government 2017). Costs of GHG emissions from cattle for an average property were estimated at $97 000 year^{-1}. The average annual costs for most properties in Qld and the NT ranged between $38 332 and $91 000/property, $138 000/property in the Kimberley, and $264 000/property in the Barkly region.

Taking into account above environmental costs associated with lost pastoral production from land degradation and GHG emissions, we can derive a conservative, indicative estimate of the net economic returns of typical pastoral properties in our focal region (Fig. 4). Net mean annual returns (i.e. EBIT less assessed environmental liabilities) for the focal region as a whole were $48 500 per property year^{-1}, ranging from $14 471 per property year^{-1} for the Kimberley to $121 011 per property year^{-1} for Cape York (Fig. 4).

Based on recommended carrying capacity data given in Tothill and Gillies (1992), we determined the potential returns for developing sustainable beef operations in the region. For this, we first estimated region specific cattle numbers based on carrying capacity data, and then EBIT by applying an average EBIT of $29/AE for highly productive pastures (derived from Barkly, Kimberley and Victoria River District sub regions), and average EBIT of $10.84/AE for less productive pastures over the remainder, from data given in Holmes *et al*. (2017). Based on these data, sustainable financial returns for the cattle industry in our focal region can be estimated as being $63M year^{-1} (Table 1). However, taking into account conservative land degradation and GHG emission liabilities, the estimated net return is just $31.4M year^{-1} (Table 1).

Towards a diversified land sector economy

The analyses above reinforce several recent informed assessments concerning the poor financial and environmental performance and sustainability of much of the northern beef industry (McCosker *et al*. 2010; McLean *et al*. 2014; Bray *et al*. 2015; Crowley 2015*a*; Holmes 2015; Rolfe *et al*. 2016; Holmes *et al*. 2017). Policy imperatives which flow from this assessment include: first, recognition that fundamental land sector change is required to accommodate for multifunctional landscape enterprise opportunities; and consequently, recognition that more culturally, economically, and environmentally sustainable regional options need to be supported and developed. In practical terms, a key regional sustainable development challenge is to embrace a more diversified ecosystem services based land sector economy.

Far from being a landscape endowed with homogenous high pastoral potential (e.g. unlike the Barkly and Qld's Mitchell grasslands; sections of the Victoria River District and WA's Fitzroy Basin), north Australia instead supports very significant

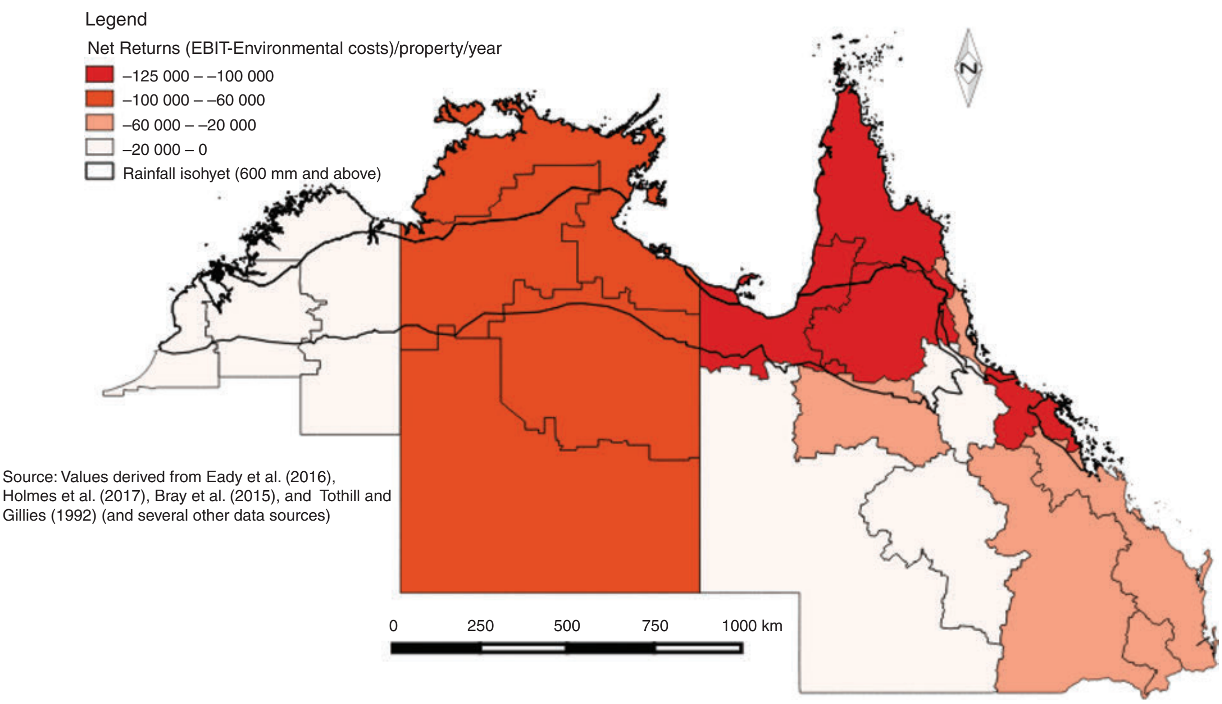

Fig. 4. Net annual returns (EBIT) for an average northern pastoral property, adjusted for costs of losses in production due to land degradation and GHG emissions.

Table 1. Estimated net sustainable economic benefits (EBIT less environmental liabilities associated with GHG emissions from cattle and land degradation) in focal north Australian sub-regions

Sub-regions[A]	Total potential returns from pasture enterprise (EBIT) ($/year × 1000)[B]	Cost of GHG (@$10/t CO_2-e)/year) ($/year × 1000)[C]	Loss of production from degraded land (accounting 25% for 'B' (deteriorating) and 50% for 'C' (degraded) land condition) ($/year × 1000)[C]	Total environmental costs GHG emissions and loss of production from degraded land ($/year × 1000)	Net sustainable benefits (EBIT Total environmental costs) ($/year × 1000)
NT DTE (M)	2188	1239	65	1304	883
NT VRD (M)	13 207	4814	165	4978	8228
Qld Gulf (M-H)	23 742	8132	4036	12 167	11 574
Qld CYP (L)	4004	1768	690	2458	1546
Qld Coast (L+H)	9515	2999	1665	4664	4851
WA East Kimberley (L)	6752	3282	928	4210	2541
WA Kimberley (L)	3565	1526	294	1819	1745
Total costs/benefits ($)/year × 1000)	62 976	23 759	7845	31 604	31 372

[A]Based on ABARES sub-regions for our focal area.
[B]Calculation based on (*a*) region-specific carrying capacity data (from Tothill and Gillies 1992), (*b*) proportion of respective regions with areas of high and low productive pastures (after Tothill and Gillies 1992), and (*c*) average EBIT data for high ($29/AE) and low ($10.84) productive pastures (from Holmes *et al*. 2017).
[C]Refer environmental costs text for calculation details.

cultural, biodiversity conservation, and global carbon stock values, which contribute significantly to the socioeconomic wellbeing of local and regional communities. North Australia is dominated by lands of international conservation significance (Fig. 5*a*), where 76% of 0.5° cells ($n = 573$) encompass lands where at least half the cell area is either managed currently for conservation purposes (e.g. NP, IPA), savanna burning fire emissions abatement project areas (ERF 2017), or comprise high conservation value riparian areas and biodiversity rich, topographically rough, hilly terrain (Woinarski *et al*. 2009, 2011; Russell Smith *et al*. 2012*a*).

As noted previously, the relatively little structurally modified north Australia landscape (by global standards) supports a significant nature based tourism industry, based particularly on maintaining intact freshwater systems and associated recreational fishing opportunities (Clark *et al*. 2009; Warfe *et al*. 2011). Maintaining the integrity and quality of flow regimes is vital also for the productivity of the northern commercial fishing industry (Clark *et al*. 2009), the multi billion dollar tourism industry, and very significant cultural, livelihood, and economic dependencies and aspirations of Indigenous people (Finn and Jackson 2011; Stoeckl *et al*. 2013).

In our focal region the formal conservation estate (e.g. NP, IPA) occupies ~400 000 km^2, and savanna burning projects are registered over 331 000 km^2 (as at January 2017; Emissions Reduction Fund (ERF) 2017) (Fig. 5*b*), with a combined net area of 595 030 km^2, or 50% of the total region (Table 2) (Sangha *et al*. 2018). Both estates deliver many economic, social and cultural values to local people. For example, it is estimated that at least 650 Indigenous full time equivalent positions currently are available (mostly through Commonwealth commitments to Working on Country and IPA funding programs) to service the north Australia conservation land sector economy (Sangha *et al*. 2018); contrasting with ~390 Indigenous positions currently available through the pastoral industry (ABS 2016). In a diversified north Australia land sector economy, market based ecosystem services enterprises offer significant opportunities for growing Indigenous employment opportunities, and concomitantly reducing public expenditures (Burgess *et al*. 2005; Garnett *et al*. 2009; SVA 2016; Sangha *et al*. 2017; Gerritsen *et al*. 2018).

The rapid expansion in market based savanna burning GHG emissions abatement projects since the introduction of the Australian Government's Carbon Farming Initiative in 2012, and its current iteration as the publicly funded ERF, points to the potential both for ongoing expansion in savanna burning projects and the ecosystem services sector generally. Notably, the distribution of current (Fig. 5*b*) savanna burning projects overlaps markedly with areas identified as having high conservation significance (Fig. 5*a*), but has limited overlap with areas identified as supporting (relatively) high pastoral carrying capacity (Fig. 1*b*). Savanna burning projects can be undertaken profitably also on pastoral properties with eligible fuel types, especially in more fire prone, pastorally marginal situations (Walsh *et al*. 2014), whereas there are genuine concerns about the application of prescribed, relatively low intensity, early dry season fires on pastorally productive grasslands which can, in combination with grazing, result in undesirable woody invasion and thickening (Crowley *et al*. 2009; Cowley *et al*. 2014; Russell Smith *et al*. 2014).

Using the SavBAT calculation tool (NAFI 2017), we estimate that an annual average of 7.5 M t.CO_2 e of accountable GHG was emitted from savanna fires over the decadal period 2000 2009. Assuming that well implemented savanna burning projects typically can reduce GHG emissions by at least one third (Russell Smith *et al*. 2013, 2015), collectively such projects could realise $20 30 M/year based on a currently conservative average carbon price of $10 15 t.$CO_2$ e. Over the next few years it is proposed that additional carbon sequestration opportunities will become available for savanna burning projects through development of methodologies accounting for storage of carbon in woody debris and in living trees. Initial estimates suggest that,

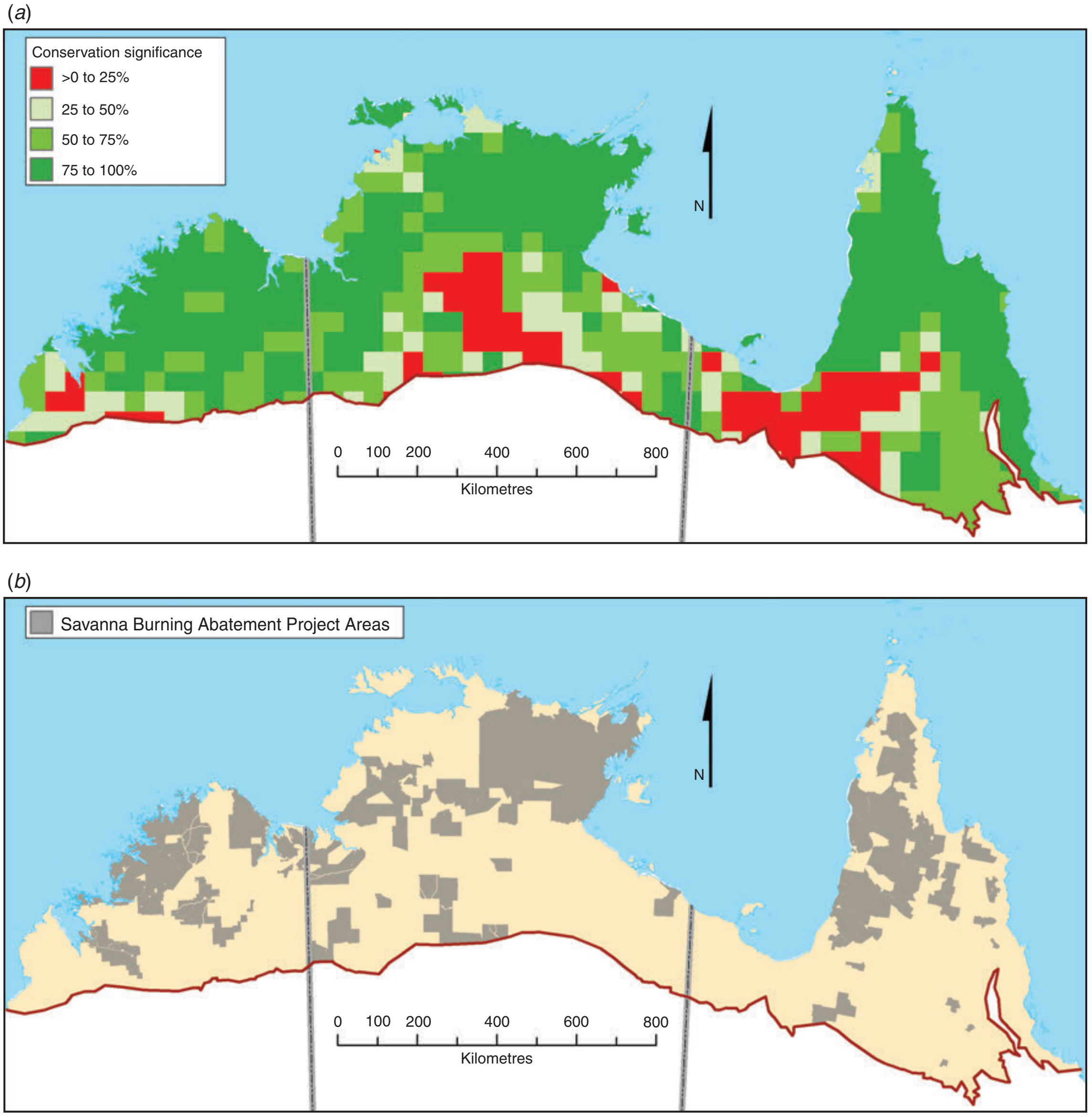

Fig. 5. Towards a more sustainable land sector economy: (*a*) conservation significance, mapped as proportion of 0.5-degree cells comprising all lands managed for conservation purposes, buffered riparian areas, high topographic roughness. (*b*) Registered 79 savanna burning GHG emissions abatement projects (total area 331 000 km^2), as at January 2017 (http://www.cleanenergyregulator.gov.au/ERF/project-and-contracts-registers/carbon-abatement-contract-register, accessed 6 May 2018).

for every carbon credit (1 t.CO_2 e) generated by savanna burning emissions abatement projects, complementary sequestration methods could provide an additional three credits for woody debris sequestration (Cook *et al*. 2016) and at least that quantum for sequestration in living trees (Murphy *et al*. 2009). One evident risk to this scenario is the potential spread of highly flammable, high fuel load exotic pasture grasses, which are relatively difficult to manage and contain (Adams and Setterfield 2013).

The emergence of the savanna burning industry highlights opportunities for developing further innovative ecosystem services markets and activities based on north Australia's natural and cultural assets. For the pastoral industry, already we are seeing a rapid expansion of carbon market opportunities, including: reducing livestock emissions; increasing efficiency of fertiliser use; enhancing carbon in agricultural soils; sequestering carbon through revegetation and reforestation (Wiedemann *et al*. 2016). It has been suggested also that carbon markets could assist with developing more sustainable grazing practices through incentivising both the restoration and maintenance of productive pastures (Steven Bray, pers. comm). These developments complement other industry sustainability initiatives such as auditable grazing best management practice standards, for example as established by the Fitzroy Basin Association's (FBA 2014) market chain accreditation scheme. However, unlike the carbon market, the market potential of such systems is yet to be realised.

Table 2. Area of conservation estate (Indigenous Protected Areas, National Parks and other areas of conservation significance) using CAPAD (2014)[A] and Savanna Burning Projects in our focal region

Category	Northern Territory	Queensland	Western Australia	Total area in our focal region
Indigenous Protected Area (km^2)[B]	74 214	9451	70 842	154 507
National Parks (km^2)	52 443	42 519	14 089	109 052
Other areas of conservation significance (biodiversity hotspots, conservation reserve/area, nature refuge/reserve, etc.) (km^2)	7840	29 416	18 592	55 847
Riparian and wet land area (km^2)[C]	14991	52 990	5218	73 139
Savanna Burning Projects area (as at January 2017) (km^2)[D]	160 448	94 510	75 950	330 909

[A]See Collaborative Assessment of Protected Area Database (CAPAD 2014 www.environment.gov.au/land/nrs/science/capad/2014; Commonwealth Government).
[B]Source: Department of Prime Minister and Cabinet, April 2017.
[C]Including wetland area acknowledging partial overlap of CAPAD dataset using IPA, NP, and so on.
[D]An overlap of 128 374 km^2 area between the conservation estate and savanna burning projects.

Challenges and opportunities

Savanna burning for GHG emissions abatement provides a currently unique example of a marketable savanna ecosystem service where it is readily defined as an effective *indicator* of ecosystem condition, is readily *measurable* using accepted methodological approaches, and enjoys an accepted *valuation* through formal *market* instruments. Although it is not our intent here to address in detail the challenges and opportunities associated with the development of other mature ecosystem services products and markets, several issues are salient at this point in time.

A first point is that, by definition, ecosystem services opportunities apply not just to biophysical components (e.g. freshwater quality, quantity; land condition, soil processes; habitat condition), but to a variety of characteristics, functions, or processes that directly or indirectly contribute to human wellbeing the benefits people derive from functioning ecosystems (Costanza *et al*. 1997; MEA 2005). These latter benefits include not only ecotourism and recreational values, but also a range of less tangible socio cultural values including health and wellbeing benefits derived from people's interactions with natural systems (TEEB 2010; Milcu *et al*. 2013; Sangha *et al*. 2017).

To develop effective indicators, the design and application of appropriate measures and condition metrics poses self evident challenges. Accounting of GHG emissions from savanna fires has necessitated significant sustained research addressing: a range of fuel load, combustion, and gaseous emissions parameters under a range of vegetation fuel type, seasonal, and fire severity conditions; development of reliable fire mapping and monitoring tools; and establishment of decadal scale pre project baselines to benchmark any derived benefits (i.e. reduction in emissions) delivered by project activities (Russell Smith *et al*. 2009; Whitehead *et al*. 2014; Murphy *et al*. 2015). GHG emissions from savanna fires can thus be calculated using a quantitative measure, expressed in t.CO_2 e. More typically, however, the state or condition of respective ecosystem services components may be more conveniently expressed ordinally, for example: the widely applied ABCD grazing land condition framework (Chilcott *et al*. 2003) and subsequent refinements, and adaptations describing the quality of soil or water management practices (e.g. CYNRM 2017); and the Vegetation Assets, States and Transitions framework, which orders vegetation by degree of anthropogenic modification as a series of condition states, from an unmodified or base line condition through to total transformation (Thackway and Lesslie 2008). Other potential approaches include natural (or ecological) capital accounting, as applied for assessing changes in natural stocks and assets of pastoral enterprises (Ogilvy 2015; Ogilvy *et al*. 2017). Appropriately defined, baseline conditions in these framework examples can be readily characterised and changes in state monitored over time.

Remote sensing applications afford a potentially powerful landscape scale, cost effective means for monitoring fire regimes, and various key aspects of land condition (ground and soil cover, including change over time), and vegetation or habitat cover state, but currently cannot capture critical species level components (e.g. threatened species, productive versus non productive pasture species, noxious weeds, feral animals) (Wallace *et al*. 2006; Karfs *et al*. 2009; Ogilvy *et al*. 2017). Although field based assessments may be required for addressing various fine scale condition (e.g. stream bank erosion, water quality) and species level issues, metrics addressing species level effects may be derivable from modelling approaches; for example, predicting the trajectory of fire vulnerable flora and fauna populations (Woinarski *et al*. 2005; Yates *et al*. 2008) based on reliable remotely sensed fire history mapping data (Russell Smith *et al*. 2012*b*; Edwards *et al*. 2015). For the focal study area, fire mapping data are readily obtained from the NAFI website (www.firenorth.org.au, accessed 6 May 2018), and paddock property scale land condition map data (including changes in ground and bare soil cover over time; land type; soil erosion potential; safe carrying capacity) through the VegMachine (https://vegmachine.net/, accessed 6 May 2018) and FarmMap4D (https://www.farmmap4d.com.au/, accessed 6 May 2018) sites.

Similarly, given growing demand, it can be anticipated that further novel approaches for measuring ecosystem services components will be developed. For assessing water quality for example, in addition to standard assessments of nutrient and suspended sediment loads derived from agricultural and grazing activities (Brodie and Mitchell 2005; Brodie and Pearson 2016;

GBRWST 2016), a feasible complementary measure targeting critical dry season freshwater resources is to use microbial source tracking techniques (Neave *et al*. 2014) to measure the faecal signatures and quantity of inputs from cattle and other feral animals (McLellan and Eren 2014; Jardé *et al*. 2018). Equally, recent experience with measuring and valuing socio cultural benefits associated with IPA (Ens *et al*. 2010; SVA 2016), and an Indigenous owned former pastoral estate (Sangha *et al*. 2017), indicate that credible accounting of the interests and values of Indigenous residents is achievable, if currently exploratory.

In this assessment we have presented regionally accepted, albeit conservative valuations associated with pasture land condition and GHG emissions from savanna fires. In the absence of primary valuation data for many regionally pertinent savanna ecosystems services components, standard valuation practice often relies on transferring values derived from international case studies available in The Economics of Ecosystems and Biodiversity (TEEB 2010) global database (de Groot *et al*. 2012). However, without due qualification such valuations can present significant comparability and credibility issues (Richardson *et al*. 2015), and, apart from recreational and eco tourism services, typically fail to incorporate appropriate estimates of socio cultural services derived from natural systems. For example, taking a broader definition of land degradation as affecting a variety of ecosystem services including agricultural products, clean air, fresh water, soil fertility, disturbance regulation, climate regulation, and recreational opportunities, an authoritative recent international assessment of the loss of ecosystem services from degraded lands estimated an average annual indicative cost of \$156 ha^{-1} $year^{-1}$ (ELDI 2015). When applied to our focal region at a full rate for degraded (Land Condition 'C') lands, and a 50% discount to partly degraded (Land Condition 'B') lands, annual losses of associated ecosystem services based on the ELDI (2015) valuation would amount to \$3 billion $year^{-1}$.

Since significant challenges are associated with monetising various core ecosystem services components (e.g. biodiversity, spiritual values) we suggest, as recommended by others, that a hybrid approach for valuing ecosystem services is appropriate, incorporating: (a) assessment of monetary values for those values that directly or indirectly relate to monetary inputs/outputs; and (b) ranking and mapping others that cannot be readily monetised (MEA 2005; Kumar and Kumar 2008; Seppelt *et al*. 2011; Milcu *et al*. 2013).

Given the international conservation significance and growing recognition of the ecologically and culturally based tourism potential of north Australia, practical incentive and regulatory approaches are needed to support sustainable land management practices on public (typically pastoral leasehold) and Indigenous lands, including: the maintenance and restoration of critical aquatic systems (Abel and Rolfe 2009); riparian fencing and alternative watering point infrastructure; critical habitat and cultural site protection and management. The recent Great Barrier Reef Water Science Taskforce final report provides a considered example of an appropriate dual public (Government sponsored) incentive and regulatory approach (GBRWST 2016). Public market based incentives can include grants, subsidies and tenders, as well as stewardship payments, stamp duty relaxation, and insurance schemes to underwrite the risks of practice change. Compulsory environmental insurance could be used to promote sustainable development as well as mitigate remediation costs, which typically are borne by governments and the environment (Garnett 2001). Public policy initiatives are obviously critical for fostering and supporting new industry opportunities; for example, reinvigoration and refocusing of Commonwealth and State/Territory environmental offsets policies incorporating 'development by design' principles (Kiesecker *et al*. 2010) would provide a major boost to the regional ecosystem services economy (Gerritsen *et al*. 2018).

Salient examples concerning public funding of the carbon market include: the Commonwealth Government's ERF, which incentivises GHG emission reduction activities in order to meet Australia's international commitments; and the Qld Government's CarbonPlus Fund, which focuses on building the capacity of Indigenous communities to participate in the carbon market as well as creating jobs, new sources of income, and generating additional social and environmental benefits (www.qld.gov.au/environment/climate/carbon farming, accessed 6 May 2018). Carbon financing has been proposed as a means for enhancing regional biodiversity conservation outcomes on the pastoral estate through supporting stewardship arrangements (Douglass *et al*. 2011).

Significant complementary funding opportunities for ecosystem services also exist in voluntary and regular financial markets. Examples of the former include voluntary funding arrangements made as part of corporate social responsibility provisions; for example, the contractual arrangement made by a multinational energy corporate with Indigenous land owners to fund a major savanna burning project in western Arnhem Land (Whitehead *et al*. 2009). Grazing best management practice market chain accreditation schemes (e.g. FBA 2014) afford considerable, as yet little developed, market potential; for example, sale of branded processed products into high value international markets. As with publicly funded ecosystem services activities, the market requires confidence in the quality and verifiability of services delivered and a key issue concerns the development of appropriate industry Standards. For savanna burning activities, formally approved ERF methods and processes provide that market surety, including internationally. Development of other ecosystem services markets, for example focussed on delivery of biodiversity, water quality, community wellbeing outcomes, will require similar levels of accountability.

Conclusion

Extensive beef cattle pastoralism is currently the predominant land use of north Australia's savannas. Our analyses reinforce other recent authoritative industry assessments concerning the poor financial and environmental performance, and sustainability, of most regional pastoral enterprises. Fundamental land sector change is required, and more culturally, economically, and environmentally sustainable regional options need to be implemented. Far from being a region with extensive pastoral potential, north Australia is endowed with significant cultural, biodiversity, environmental and global carbon stock values. The economic significance of the water based tourism industry, the ongoing growth of Indigenous ranger groups and

Indigenous owned conservation lands and seas, and rapid regional uptake of market based savanna burning GHG emissions abatement projects, all illustrate the appetite and potential for further development of market based ecosystem services opportunities. Although significant technical and policy challenges are involved, we demonstrate that a substantial diversity of foundational work is now being progressed which will support further development of a diversified, more sustainable regional land sector economy.

Conflicts of interest

The authors declare no conflicts of interest.

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