Data presented for the Amazon biome

The Brazilian statistical agency (Portuguese acronym, IBGE) does not report official statistics for the Amazon biome specifically. In this article, statistics for the biome were calculated by using municipal datasets (IBGE, 2015): municipalities were classified according to their dominant biome (i.e. the biome making up a majority of their area) using the extract function from the *raster* package in [R] (Hijmans et al., 2017). The list of Amazon municipalities used to calculate biome-wide statistics is available in the online supplementary material (zuErmgassen_SOM_biome.csv, where "GEOCODIG_M" is the IBGE municipal code, "UF" is the IBGE state code, "SIGLA" is the two-letter state abbreviation, "NOME_MUNIC" is the municipality name, and "biome_code" is the main biome per municipality").

Risks for cattle intensification

As well as impacts on productivity, greenhouse gases, and deforestation, cattle ranching intensification also has repercussions for animal welfare, nutrient cycling, and farm labor conditions. For a more detailed description of the risks and potential benefits of cattle intensification, readers are directed toward (Latawiec et al., 2014).

Though high-productivity livestock production can compromise animal welfare, there is plenty of opportunity for Brazilian cattle production to simultaneously improve productivity and animal welfare. The productivity increases achieved in the initiatives described in this review rose in large part because of improved nutrition and animal performance. Rainfall is strongly seasonal in the Amazon, and in the dry season grass production is greatly reduced. Without supplementary feeding or active pasture management, cattle gain weight in the wet season, only to lose much of it in the dry season because of nutritional deficiencies (Silva et

al., 2009). As good welfare requires that nutritional and health needs are met (Mellor and Stafford, 2001), addressing these nutritional deficiencies through improved pasture management delivers coupled welfare and productivity gains.

Not all management changes have the same welfare consequences, however, and improved nutrition is not sufficient for good welfare. Cattle in agroforestry systems show more cohesive social behavior and benefit from reduced heat stress as well as improved nutrition (Broom et al., 2013). For feedlots, the picture is however, more mixed. Feedlots in Brazil are becoming more common - Mato Grosso's feedlot capacity grew 48% from 2009-2016 (IMEA, 2016) – and while feedlots provide high-energy nutrition that maximize animal growth rates, careful management is required to ensure adequate welfare. In feedlot systems heat stress, mud, and welfare during dehorning, castration, and branding are key concerns (Grandin, 2016), which can be mitigated through training in good agricultural practices, e.g. training staff to provide analgesia prior to dehorning (Stock et al., 2013). In all systems, welfare continues beyond the farm-gate, with welfare in transport and slaughter also critical. While it is therefore encouraging that Embrapa's good agricultural practices and the Brazilian Roundtable for Sustainable Beef (GTPS) include detailed recommendations on cattle management and welfare both on and off farm (GTPS, 2016; Valle, 2006), animal welfare remains an evolving science. As the study of animal welfare increasingly looks beyond the traditional "five freedoms" – freedom from i) thirst, hunger and malnutrition; ii) discomfort and exposure; iii) pain, injury, and disease; iv) fear and distress and v) the freedom to express normal behavior – to look at new measures of welfare, such as "a life worth living" (Mellor, 2016), cattle production systems must ensure that increases in productivity do not come at the expense of welfare in order to remain acceptable to society today and in future (Broom, 2010).

548 Cattle intensification also faces concerns of increased nutrient run off and water pollution
549 (Latawiec et al., 2014). This challenge is greatest for feedlot systems, which produce large
550 volumes of waste in a concentrated area. Most Brazilian production, like the initiatives
551 described in this review is, however, pasture-based (Strassburg et al., 2014), where urine and
552 manure are deposited directly onto pasture, rather than stored before disposal. In pasture-
553 based systems, the effect of this diffuse nutrient pollution can be mitigated by restricting the
554 access of cattle to streams – riparian areas are in any case protected under the Brazilian forest
555 code, which requires that landowners reforest 5-100m either side of streams (Soares-Filho et
556 al., 2014). The do Campo à Mesa, Novo Campo, and Silvopastoral system initiatives
557 therefore all explicitly require fencing off degraded riparian areas and the installation of
558 pumps to provide cattle with alternative water sources in pasture areas.

559 This review and many sustainable cattle ranching initiatives have a stronger focus on
560 agronomic changes than social impacts of intensification (Alice Ferris et al., 2016), though
561 this does not mean that these initiatives do not consider labor conditions. The do Campo à
562 Mesa and Novo Campo initiatives, for example, both focus on the implementation of
563 Embrapa's good agricultural practices (GAP) which includes consideration of the farmer's
564 social responsibilities and the social function of farming businesses (Valle, 2006). Other
565 initiatives also have a strong focus on working conditions, as seen in the Pecuária Verde
566 program in Paragominas (SPRP, 2014). There, workers reported 15% higher wages and
567 higher work satisfaction than on neighboring farms (da Silva and Barreto, 2014). Though
568 cattle productivity gains are often delivered through training of farmer workers and increases
569 in demand for on-farm labor, the implications of different methods of intensification for
570 labor-markets and rural communities remains understudied.

Additional figures and tables

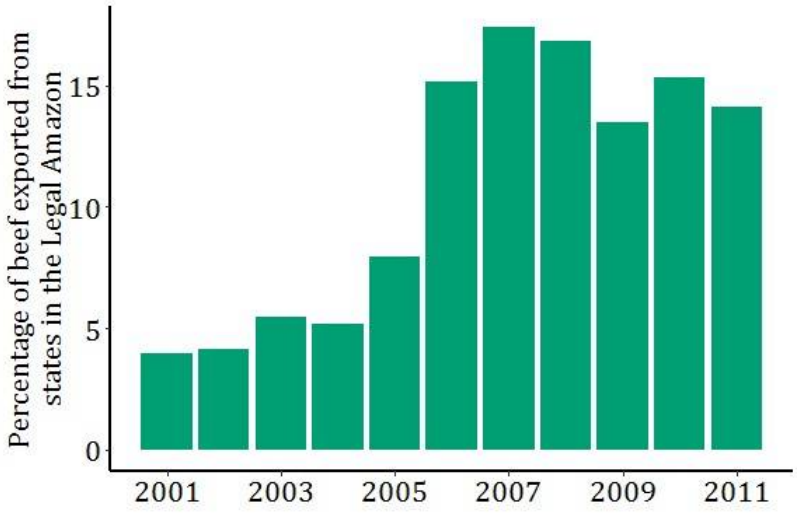

Figure S1– Exports of beef from the Brazilian Legal Amazon have increased since the early 2000s. Data from: (TRASE, 2017).

Table S1 – Grass species successfully planted in Acre in mixed pastures with the legumes Tropical kudzu Pueraria phaseoloides and Forage peanut Arachis pintoi.

Legume	Complementary grass species
Tropical kudzu *Pueraria phaseoloides*	*Brachiaria brizantha cultivares (cv.) Marandu, Xaraés* *Brachiaria humidicola cv. comum* *Brachiaria decunbens cv. Basilisk* *Panicum maximum cv. Tanzânia, Mombaça*
Forage peanut *Arachis pintoi*	*Brachiaria brizantha cv. Marandu, Xaraés* *Brachiaria humidicola cv. comum* *Brachiaria decunbens cv. Basilisk* *Panicum maximum cv. Tanzânia, Mombaça* *Cynodon nlemfuensis cv. Lua* *Brachiaria arrecta x Brachiaria mutica cv. Laguna*

579 *Table S2 – Slaughter ages and weights achieved on intensified farms. . No data were provided from the Florestas de Valor*
580 *initiative.*

Name of initiative	Lead organization	Age at slaughter (months)	Weight at slaughter? (1 liveweight @ = 30kg)
Novo Campo Program	ICV	Steers: 24 (20-40) Cows: 20 (18-36)	Steers: 21 (18-23) Cows: 13.5 (12-17)
Silvopastoral System with Rotational Grazing for Beef	Idesam	24 (22-34)	15 (14-20)
Intensification of beef cattle production systems with the use of mixed grass-legume pastures in Acre	Embrapa	Nelore: 36 (30-42) Crossbreed Nelore x Aberdeen Angus 27 (24-30)	17 (16-20)
Do Campo à Mesa	TNC	~28	16-18

581

Table S3 – Example breakdown of costs in each initiative.

Name of initiative	**Breakdown of typical inputs and costs of intensification**					
	Pasture liming		**Fertilizers**		**Other**	
	Quantity (kg/ha)	**Cost (R$/ha)**	**Quantity (Kg/ha)**	**Cost (R$/ha)**	**Examples:**	**Cost (R$/ha)**
Novo Campo Program	1500	350	400	850	Wire, wood (for fencing), machine rental, seeds, plumbing and operational costs.	1800
Silvopastoral System with Rotational Grazing for Beef	2000-2500	300-750	120-150	360-600	Machine rental for ploughing and application of inputs (e.g. fertilizer), electric fencing, Infrastructure (water pump and in-pasture drinkers), planting of leguminous trees.	4600
Intensification of beef cattle production systems with the use of mixed grass-legume pastures in Acre	<600 kg/ha.	180	300	600	Herbicides, machine rental for ploughing and planting of legumes.	450
Do Campo à Mesa	1500	345	-	-	Seeds, fencing, machine rental for pasture restoration.	1783
Florestas de Valor	1000	367	500	500	Wire, wood (for fencing), insulation for electric fence, grass seed, electrified appliance, solar panel, drinking fountains, machine rental for pasture restoration and maize planting.	1650
Silvopastoral System with Rotational Grazing for Dairy	2000-2500	300-750	120-200	360-600	Machine rental for ploughing, application of inputs, electric fencing, installation of water system, planting of leguminous tress (seeds and seedlings).	4500

Table S4 – Seven other sustainable cattle ranching initiatives in the Amazon biome.

Name of initiative	Number of farms/farm area	Region	Reference
Pecuária Sustentável na Prática	4,547 ha	Rondônia	(GTPS, 2017)
Projeto Balde Cheio	41 farms in Rondônia, unknown number of farms in Pará and Amazonas	Rondônia, Pará and Amazonas	(Novo, pers. Comm)
Intensificação na Produção e Proteção a pequenos proprietários e reservas indígenas na Amazônia	4,000 ha	Novo Santo Antônio (Piauí)	(GTPS, 2017)
Piloto de Pecuária Sustentável no Vale do Araguaia	140,000 ha	Vale do Araguaia (Mato Grosso)	(GTPS, 2017)
Sustainable Agriculture Network	3 farm units	Juruena (Mato Grosso)	(Newton et al., 2015)
Terracerta	2,323,583 ha	Redençao, Paragominas (Pará)	(GTPS, 2017)
Pecuária Verde	5,207 ha on 6 farms	Paragominas (Parà)	(SPRP, 2014; D. Silva pers. Comm)

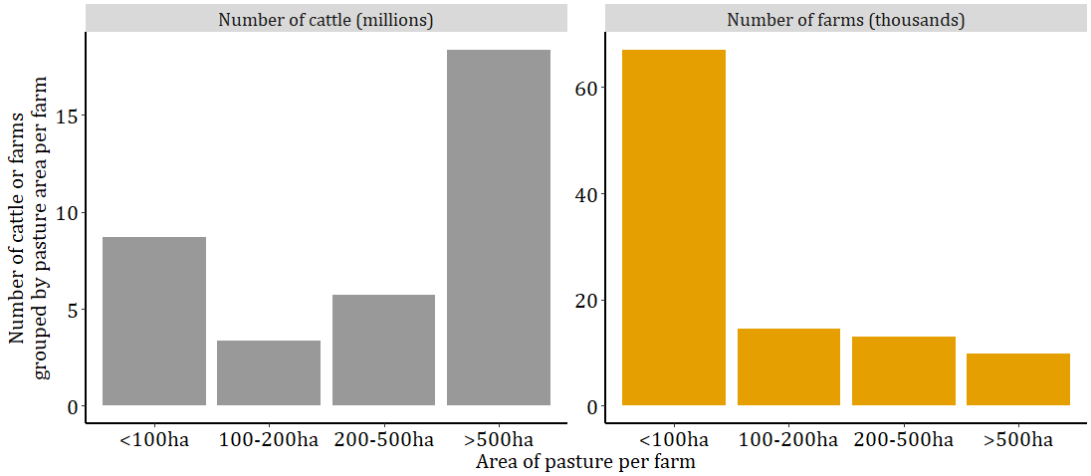

Figure S2 – While half of all cattle (51%) are found on farms of with pasture areas > 500ha (left), these make up only 9.4% of properties (right). Most cattle ranches (78% of properties, rearing 33% of cattle) have pasture areas less than 200 hectares - a size below which some pasture intensification technologies may not be financially viable. Farm size data from: (IBGE, 2006). These data do not include farms with fewer than 50 cattle head, and so probably underestimate the number of small farms.

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