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Supporting Information

Additional, web-only material may be found in the online version of this article at http://onlinelibrary.wiley.com/doi/10.1002/fee.2197/suppinfo

Renewed threats to Brazilian biodiversity from sugarcane

On 5 November 2019, Brazilian president Jair Bolsonaro repealed a land-use policy that has – since 2009 – safeguarded environmentally sensitive areas from agricultural expansion by sugarcane (*Saccharum* spp). This controversial action threatens to negatively impact many biodiverse and carbon-rich natural (largely undeveloped) ecosystems, including those in the Amazon and Pantanal biomes, and jeopardizes the reputation of Brazil's sugar and ethanol industries as biofuel producers that have been largely compliant with environmental regulations. Called sugarcane "agro-ecological zoning" (AEZ), this now-defunct land-use policy was originally developed by the Brazilian Agricultural Research Corporation (Embrapa) in response to rampant expansion of the domestic ethanol sector and subsequent concerns about land clearance (Fargione *et al.* 2008). Recent evidence clearly demonstrates that the sugarcane AEZ was effective in promoting land intensification and controlling deforestation in Brazil while meeting future scenarios of ethanol demand (de Andrade Junior *et al.* 2019). Moreover, while Brazilian companies complied with the sugarcane AEZ, Brazilian sugarcane-based ethanol became an effective alternative to fossil fuels in the transport sector (Jaiswal *et al.* 2017).

Targeting the sugar and ethanol industries in Brazil, Manzatto *et al.* (2009) developed the sugarcane AEZ to guide the sustainable expansion and production of the nation's sugarcane crops. The authors identified specific areas for cultivation, including former agricultural fields and pasturelands, as well as locations with the appropriate biophysical and climatic conditions for sugarcane, particularly areas with minimal irrigation requirements and with suitable slope for mechanical harvesting. The zoning excluded biodiverse regions – such as the Amazon and Pantanal biomes, along with the Upper Paraguay River basin – from sugarcane expansion. Previously, the Brazilian government promoted the adoption of the sugarcane AEZ by offering government-subsidized loans to stakeholders in the sugar and ethanol industries who agreed to expand their operations only within the predefined zoning areas (the lands intentionally set aside from the biodiverse regions).

The repeal of the sugarcane AEZ exposes many natural ecosystems within the Amazon, Pantanal, and Upper Paraguay River basin to sugarcane cropland expansion. As of 2017, there were 15 sugar and ethanol processing plants operating within or along the border of these important ecological systems (ANA 2017) (Figure 1). Assuming that sugarcane harvesting sites are typically located 30 km from the nearest processing plant (Sant'Anna *et al.* 2016), we demonstrate that at least 1.2 million hectares of Brazilian forests and natural grasslands are now directly imperiled by sugarcane cropland expansion. Populations of as many as 126 vertebrate species of conservation concern (that is, those listed as Near Threatened, Vulnerable, Endangered, and Critically Endangered according to IUCN [2019]) depend on these habitats and are now at serious risk of extirpation. These taxa include the black-bearded saki (*Chiropotes satanas*) in the Amazon, the crowned solitary eagle (*Buteogallus coronatus*) in the Pantanal, and the blue-eyed ground dove (*Columbina cyanopis*) in the Upper Paraguay River basin. Besides imposing direct threats to these sensitive species, land clearance will also trigger indirect impacts such as an increase in small rodent populations, which could facilitate the spread of infectious diseases (Gheler-Costa *et al.* 2012; Verdade *et al.* 2015).

Using an aboveground carbon stock dataset (Englund *et al.* 2017), we found that 314 million metric tons of carbon dioxide equivalents are stored in these natural ecosystems and are now under risk of being released. However, this figure likely represents an underestimate, given that Maxwell *et al.*'s (2019) more holistic "full carbon accounting" approach – which considered emissions beyond those attributed only to direct

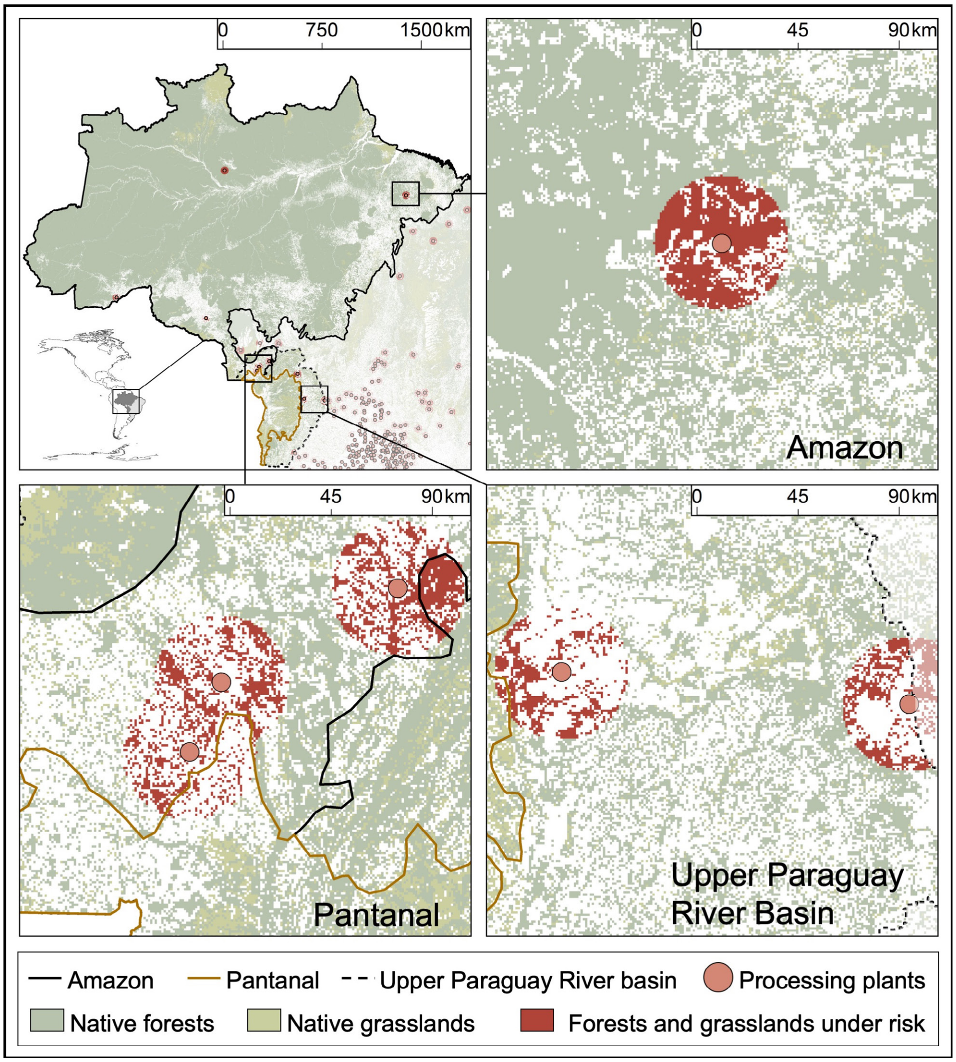

Figure 1. Natural habitats in the Amazon and Pantanal biomes, as well as in the Upper Paraguay River basin, under risk of sugarcane expansion (cells in red). Land-cover data from MapBiomas (2019): identifiers 3 and 4 for forests (forest formation and savanna formation), identifiers 12 and 13 for grasslands (grassland formation and other non-forest natural formation). Data on sugar and ethanol processing plants from Brazil's ANA (2017). Each cell (pixel) is 1 km × 1 km.

clearance, such as emissions associated with selective logging and edge creation – estimated the net carbon impact of clearing intact, old-growth tropical forests to be six times higher. Moreover, Brazilian forests and grasslands outside the Amazon, Pantanal, and Upper Paraguay River basin are also now susceptible to direct sugarcane expansion.

Worryingly, Brazil's pledges to the Paris Agreement (Brazil 2016) and Brazil's biofuels policy "RenovaBio" approved in late 2017 (Brazil 2017) are expected to increase future supply and consumption of ethanol within the country. As a strategy to promote a more efficient and less carbon-intensive ethanol production in Brazil, RenovaBio has introduced decarbonization credits (CBIOs). Eligible fuel producers can obtain – and financially benefit from trading – CBIOs, if producer activities refrain from clearing native vegetation. Although RenovaBio restricts clearing land for the purposes of ethanol development, the recent repeal of the sugarcane AEZ not only allows sugar and ethanol producers to regain access to the before-mentioned loans while expanding sugarcane cropland into environmentally sensitive areas, but also is in direct opposition to RenovaBio's main objective of reducing the environmental footprint of the Brazilian ethanol production. Clearly, in an era of rapid climate change, ensuring that land-use policies such as the sugarcane AEZ and RenovaBio are promoted and enforced by the government, as well as obeyed by the industry, is crucial to maintain a sustainable Brazilian ethanol sector (Souza *et al.* 2015).

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Deep-sea ecosystem engineers

Most people associate corals with the colorful, stony species that construct iconic reefs (eg the Great Barrier Reef in Australia). However, surprisingly beautiful corals live in deep waters – 250–6000 meters below sea level – and are found globally in the aphotic zone, where sunlight does not penetrate. Deep-sea corals are vibrant and colorful, but their deep ocean habitat subjects them to crushing pressure, no light, and low oxygen. Yet they've managed to persist and thrive for long periods of time: some are estimated to be over 4000 years old.

Compared to their shallow-water cousins, most deep-sea corals don't build big reef structures but still serve similar ecological roles, such as providing three-dimensional benthic structure and habitat. For example, the left photo shows a brittlestar (class Ophiuroidea) on a *Hemicorallium* coral species; the brittlestar uses the coral to gain elevation to enhance food capture. Deep-sea corals must also maximize their ability to capture food particles as they float by, and many have therefore evolved unique and unusual growth forms, such as the spiral structure of *Iridigorgia* coral species (right photo).

Despite the depths at which they occur, deep-sea corals are not immune to anthropogenic stressors such as pollution, marine debris, and habitat destruction. Plastics and derelict fishing gear are found globally in the deep sea, and seafloor mining poses new threats to these long-lived ecosystem engineers. Additionally, deep-water corals rely mainly on the surface for food, which is subject to anthropogenic impacts. Taxonomists and ecologists are still discovering and describing these delicate, ancient corals that have persisted for thousands of years, but the key question is whether they will be able to survive the next 100 years of the Anthropocene. And, if so, will their resilience mechanisms parallel what we see in shallow and terrestrial ecosystems? Or will their longevity and unique habitat give rise to new ecological principles?

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