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# Technification in Dairy Farms May Reconcile Habitat Conservation in a Brazilian Savanna Region

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**Abstract:** The assessment of the relationships between farm management systems and nature conservation may help in the design of more efficient strategies to uphold economic benefits and biodiversity conservation. To our knowledge, this is the first work in Brazil to study the relationship between farm conservation status and technification level. Here, we test the hypothesis that dairy farms with higher levels of technification have a higher percentage of natural vegetation and connectivity, and that differences in environment features between farms explain their conservation status. We obtained variables related to the level of technification such as feed, milking, sanitary control and breeding management systems. We show that farmers with a higher level of technification, such as artificial insemination in cattle breeding, tended to conserve a higher percentage of natural vegetation, as well as larger farms with a higher percentage of riparian forest. The adoption of artificial insemination is associated with other technification systems such as a forage diet, milking method and frequency and sanitary control. It is also significantly related to higher milk productivity. Our novel results point to a positive effect of technification on the conservation of natural vegetation, suggesting that economic incentives and programs aimed at increasing technification in cattle breeding may increase dairy production and conservation within the study area. Our findings also show an effect of larger areas of riparian forests, which are protected by Brazilian policy, in the conservation status of dairy farms.

**Keywords:** agricultural landscapes; Conefor; connectivity; legal reserve; long-term ecological research; spatial-temporal heterogeneity

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## 1. Introduction

The trade-off between food production and biodiversity conservation is one of the major challenges for policymakers in the Anthropocene [1]. The expansion of agriculture and the use of unsustainable practices are the main threats to terrestrial natural habitats [2] and to biodiversity conservation in tropical and temperate regions [3]. The global agricultural land area was 4.9 billion hectares (Gha) in 2016—38% of the global land surface [4]. Two thirds (3.3 Gha) of the agricultural land were used as pastures for livestock.

Pastures are the main anthropic disturbances world-wide and have expanded more rapidly than cropland. While agriculture expanded from 265 ha to 1471 million ha from 1700 to 1990, pastures expanded from 524 ha to 3451 million ha in the same period [5] and to 3340 million ha by 2005 [6]. This expansion is mainly due to the increasing pressure to produce animal protein, mainly from cattle. The global cattle livestock population was estimated to be 1.5 billion in 2012, producing 67 billion kg of beef carcass and 625 billion kg of milk [7]. The expected increase in animal protein demands of 1.3% per year until 2050 may lead to a 40% increase in cattle population [8].

Besides deforestation, livestock farming may cause high environmental impacts such as soil degradation [9,10], water eutrophication [11], water scarcity due to intense use and water spring deterioration [12]. In addition, livestock raising requires the use of fossil fuels in the entirety of the productive chain, leading to high emissions and pollution [13]. Methane is the main greenhouse gas in cattle raising and is responsible for 15% of global warming, representing ~14.5% (7.1 Gt $CO_2$ per year) of all anthropic emissions [14]. Livestock raising is largely viewed to be an unsustainable activity [15]. However, the direct impacts of livestock raising on biodiversity loss are still contentious. For instance, most studies in Europe show that livestock raising for meat or milk production in intensive farming systems has negative impacts, while livestock raising for land management or conservation has positive impacts [16]. In addition, the use of sustainable methods and technology to increase productivity has been suggested to increase and conserve on-farm biodiversity (e.g., [17,18]).

In Brazil, pastures for cattle livestock increased in the last 33 years from ~118 million ha $\pm$ 3.41% to ~178 million ha $\pm$ 2.53% [19]—an increase of nearly 60 million ha—leading to the rapid deforestation of Brazilian ecosystems. Presently, most of the pasture area is degraded (60%) or exhibits a reduced carrying capacity [20]. The increase of pasture productivity is of utmost importance to restrain the ongoing expansion in Brazil [21,22], using more technology in both cattle raising and pasture restoration. For instance, the restoration of degraded pastures in 2006 would have prevented the occupation of 147.5 million ha of new area in the Amazonia and Cerrado biomes [22].

The Cerrado biome in central–west Brazil is one of the major cattle raising regions, with 44% of the Brazilian cattle population and 60 million ha of pasture, which is the most dominant anthropic land use class [23]. From 2002 to 2013, the pasture area in the Cerrado increased by 11% and contributed to the consolidation of the anthropization of 50% of the biome [24], considered one of the world hotspots of biodiversity [25].

The expansion of cattle raising in the Brazilian Cerrado has been characterized by low levels of technification, such as free grazing and low pasture management, and has usually been associated with the primary land occupation [26]. As a consequence, degraded pastures currently represent 39% of Cerrado pastures [27]. Identifying the levels of technification—i.e., practices and management systems in feeding, pasture improvement, milking, sanitary control, stocking rates and animal selection and breeding—in livestock farming is a challenge in Brazil due to the wide variety of systems and technologies employed [28]. This diversity is mainly exhibited in feeding [29], milking management and breeding practices [30]. In Brazil, most dairy farmers still apply traditional production systems with low levels of technification, such as the natural service breeding method [31].

The relationship of the technification level in dairy farms and the conservation of natural vegetation is still overlooked in Brazil, especially in the Cerrado. Despite its huge biodiversity, the lack of information on how technification affects conservation limits sound conservation planning for this biome. The low productivity of pastures is a major driver of deforestation in Brazil, leading to overall environmental and socio-economic impacts [32,33]. Cattle ranching is mostly extensive and uses low-productivity systems, leading to pasture degradation [34]. However, although the adoption of technologies that improve production efficiency may also decrease impacts on natural resources and minimize greenhouse gas emissions, a rebound effect may lead to a loss of initial resource savings over time due to the increase in total resource use driven by socio-psychological adaptation ([35]; but see [36]). However, technification in pasture management in the Brazilian Amazonia, for instance, increased livestock and milk productivity and reduced environmental impacts such as soil degradation [37]. Because increasing the efficiency of livestock farming can reduce pasture expansion and deforestation [38], understanding how technification levels in farms can reduce deforestation is of utmost importance for Cerrado conservation and decreasing greenhouse gas emissions, as we investigate here.

Here we address the relationship between the level of technification and conservation in dairy farms in an intensive-farming landscape (Figure 1). We specifically test the hypothesis that dairy farms with higher levels of technification have higher amount of natural vegetation and connectivity. Alternatively, to account for the effects of environment, we test whether farm area and differences in environment features among farms, such as slope, percentage of riparian forest along water courses, percentage of agriculture and pasture explain conservation of natural vegetation in dairy farms. Riparian forests, i.e., forests adjacent to water courses, are Areas of Permanent Protection (APPs) meant to protect sensitive ecosystems by Brazilian environmental law. We hypothesize that farms with more water courses, and thus with higher amount of riparian forest and lower amount of agriculture or pasture have higher amount of natural vegetation and connectivity, despite the technification level. For this, we applied questionnaires to characterize dairy production and farm management system, and to obtain variables related to the level of technification in feed and milking management, sanitary control, and genetics and breeding systems. Using the Brazilian SICAR (Brazilian System of Rural Environment) database of rural properties, we obtained farm boundaries and mapped the area of natural vegetation remnants and estimated the connectivity among these remnants to predict the effects of technification on natural vegetation conservation.

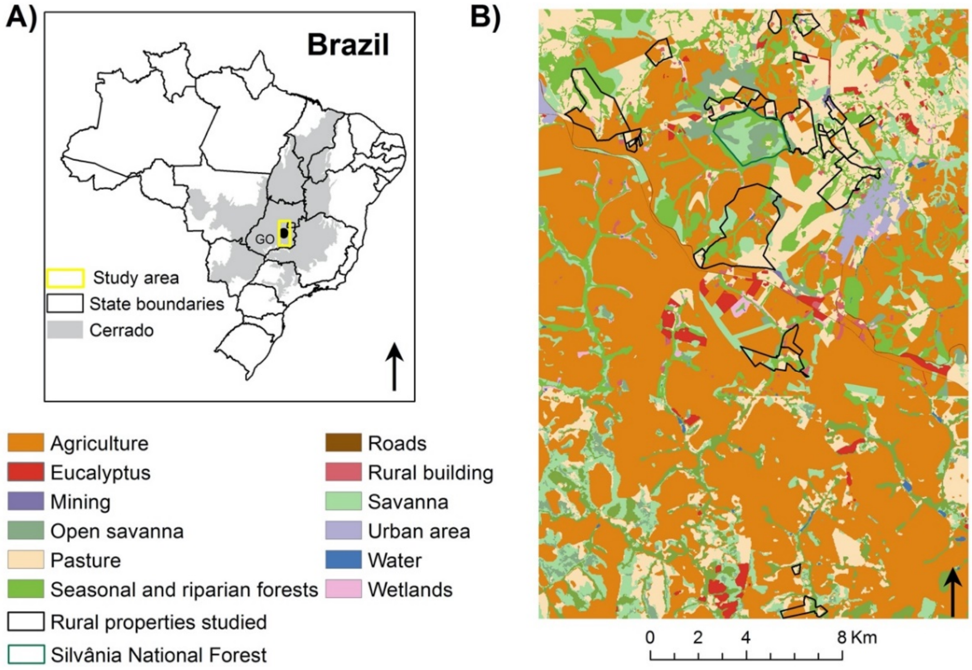


**Figure 1.** Spatial distribution of the 25 dairy farms in the COFA-LTER long-term project landscape. (**A**) Map of Brazil highlighting the study area. (**B**) Land use map of the COFA-LTER landscape highlighting the 25 dairy farms. Land use categories are in legends. The National Forest reserve is also highlighted in the map.

## 2. Materials and Methods

### *2.1. Study Area*

The study was carried out in a Brazilian intensive-farming landscape comprising a Long-Term Ecological Research (LTER) project called COFA-LTER (Functional Connectivity in an Agricultural Landscape, Figure 1), in the Central-West Brazil, one of the most important Brazilian agribusiness regions (Figure 1). The COFA-LTER landscape comprises a reserve (Silvânia National Forest), the urban area of the city Silvânia, and the rural area with farms.

We mapped the land cover in COFA-LTER landscape using visual digitalization and manual classification of high-resolution images of Google Earth from 2019, freely available at the Geographic Information Systems QGis 2.4, with validation by field checking. The final map corresponded to 5 m spatial resolution, comprising 11 different land cover classes (Figure 1): (i) water courses; (ii) savanna and open savanna; (iii) seasonal and riparian forests; (iv) wetland; (v) pasture; (vi) agriculture (corn or soybean); (vii) rural building; (viii) mining; (ix) urban area; (x) road and train rail, and (xi) *Eucalyptus* spp. plantation.

All dairy farms in the COFA-LTER landscape (25 farms) were identified and mapped (Figure 1, Supplementary File S1, Table S1). Farm boundaries (Supplementary File S2, Figure S1) were obtained in the Brazilian SICAR (Brazilian System of Rural Environment) database of rural properties (http://www.car.gov.br/publico/imoveis/index, accessed on 15 February 2020) from 2019, or were manually digitalized in Google Earth.

We classified the farms according to the rural fiscal module of Silvânia (1 fiscal module = 30 ha; http://www.incra.gov.br/pt/, accessed on 15 February 2020): family farms < 30 ha); small size farms (1 to 4 modules); medium (4 to 15 modules); large (>15 modules).

### 2.2. Technification Variables and Farm Characteristics

We obtained variables related to the level of technification in the dairy farms and farm management practices using face to face interviews with farmers (25 farmers) in 2019. Before the interviews, we had several meetings with local stakeholders, including local government, non-governmental organizations (NGOs), researchers, farmers and technical assistants, to design a robust research approach in COFA-LTER project. All farmers signed an informed consent before interviewing.

We measured five different characteristics of technification in dairy production (Table 1), following the milk production systems prevalent in Brazil [39]: (i) productivity [40], measured by daily milk production; (ii) feed management [41,42], measured by primary forage diet, fertilizer pasture management, time of supplementary feed, criterium to supplement, and addition of vitamins to supplement; (iii) milking management [43], measured by milking method, milking frequency, and farm infrastructure for milking; (iv) sanitary control [44], measured by cleaning of udder before milking and CMT test (California Mastitis Test); (v) genetics and breeding [45], measured by breeding program for productivity improvement, selective breeding method and pregnancy diagnosis. We used daily milk production as a measure of productivity because farmers had no information on milk production per cow.

**Table 1.** Variables related to the level of technification and to overall milking management characteristics in dairy farms in COFA-LTER landscape.

| Group | Variable | Possible Outcomes |
|---|---|---|
| **Productivity** | Daily milk production | Quantitative variable |
| **Feed management** | primary forage diet | (1) pasture-raised dairy (free grazing); (2) pasture-raised with rotational grazing; (3) semi-confinement; (4) confinement (compost Barn or free-stall) |
| | fertilizer pasture management | (1) yes (use fertilizers); (2) no (do not use) |
| | time of supplementary feed | (1) everyday; (2) dry season; (3) random; (0) not applicable (do not provide supplementary feed) |
| | criterium to supplement | (1) do not use; (2) technical calculation; (3) productivity; (4) random; (0) not applicable |
| | add vitamins to supplement | (1) yes; (2) no |
| **Milking management** | milking method | (1) full hand; (2) machine with bucket; (3) automatic machine |
| | milking frequency | (1) once-a-day; (2) twice-a-day; (3) three times a day |
| | farm infrastructure for milking | (1) milking pit; (2) milking parlor with roof and cement floor; (3) milking parlor without roof or cement floor; (4) milking parlor without roof and cement floor; (5) without a specific place to milk |

**Table 1.** *Cont.*

| Group | Variable | Possible Outcomes |
|---|---|---|
| **Sanitary control** | cleaning of udder before milking | (1) no cleaning; (2) water; (3) commercial sanitizer (pre-dipping) |
| | CMT test (California Mastitis Test) | (1) weekly; (2) biweekly; (3) monthly; (4) do not perform; (5) eventually with the suspicious of the disease |
| **Genetics and breeding** | breeding program for productivity improvement | (1) yes (perform breeding); (2) no |
| | selective breeding method | (1) natural service with selected breeding bulls; (2) artificial insemination; (0) do not perform selective breeding |
| | pregnancy diagnosis | (1) ultrasound; (2) transrectal palpation; (3) do not perform |
| **Overall characteristics** | Cattle breed composition | (1) holand; (2) gir; (3) girholand; (4) crossbred cattle |
| | Pasture restoration during the last decade | (1) yes (perform); (2) no (do not perform) |
| | Milk cooling tank | (1) bulk milk tank; (2) farm milk tank; (3) not applicable (do not use milk tank) |
| | Milk quality-based payment | (1) yes; (2) no |
| | Management separating pregnant cows | (1) yes; (2) no |

Besides technification variables, we obtained variables related to the overall milking management to describe dairy farms in the studied area (Table 1): (i) cattle breed composition; (ii) pasture restoration during the last decade (iii) milk cooling tank; (iv) milk quality-based payment; (v) management separating pregnant cows.

### 2.3. Environment Feature Variables

We obtained the slope map from the TOPODATA INPE (National Institute for Space Research, http://www.dsr.inpe.br/topodata/acesso.php) database with 30 × 30 m spatial resolution. For each farm, we used the mean slope of all pixels. Using farm boundaries (Supplementary File S2, Figure S1), we identified areas of natural vegetation in each farm and calculated the farm area, the percentage of riparian forest, and percentage of agriculture and pasture. The available soil maps for the studied area were performed in small scale with few details (1:250,000) and show that the region is comprised mostly by dystrophic red oxisol with low variation among farms; thus, soil type could not be used as explanatory variable.

### 2.4. Conservation Status of the Dairy Farms

We used percentage of natural vegetation and connectivity as proxies of the conservation status of each farm (response variables). To verify the conservation status of natural vegetation that exceeds riparian forests in farms, we calculated the legal reserve area, which are areas of natural vegetation that should be preserved following Brazilian environmental law, corresponding to 20% of the total farm area in the Cerrado biome. To calculate legal reserve area, which is independent of APPs (Areas of Permanent Protection) such as riparian forests, we obtained the total percentage of natural vegetation and extracted the percentage of riparian forest. The highest slope in the 25 farms analyzed was ~13%, lower than the slope considered as APP by Brazilian environmental law (>45° in hillsides or 25° in hilltops). Thus, all APPs in our study area are riparian forests.

Connectivity is a measure of the landscape permeability to species movement among habitat patches [46,47]. To measure connectivity among remnant patches of natural vegetation in farms we used the Integral Index of Connectivity (IIC, [48]) implemented in Conefor [49] available in R version 3.6.1. [50]. The IIC, implemented in Conefor software [49], is based on the concept of graph theory and habitat availability, integrating habitat amount and the connectivity among patches of habitat [48]. IIC ranges from 0 (no connectivity among patches within the landscape) to 1 (high connectivity between remnant patches).

We calculated IIC considering each farm as a different landscape and habitat as all categories of natural vegetation. We used the mean value of IIC among four spatial distances as the response variable (100, 300, 500 and 1000 m), because most farms in the studied area were small and IIC values for all distances evaluated were very similar (Table S1).

### 2.5. Statistical Analyses

To analyze the effect of technification and environment features in conservation of dairy farms we first verified the multicollinearity among explanatory variables. For technification variables we used the generalized variance-inflation factor (Gvif), and for environment features we used the variance-inflation factor (Vif), excluding in this step the farm size which is a categorical variable. We used the *car* package [51] implemented in R version 3.6.1. For technification, we ran one model per variable group (Table 1). We used a stepwise approach eliminating the models with Gvif or Vif > 5.0 [52]. Gvif is equivalent to Vif for categorical variables, the inflation in size of the confidence ellipse or ellipsoid for the coefficients of the predictor variable in comparison with what would be obtained for orthogonal, uncorrelated data [53].

We then analyzed the effects of technification and environment features on farm conservation status using linear models. We defined all categorical variables as "factors," except daily milk production and environment variables, which correspond to continuous variables. To select the best variable explaining percentage of natural vegetation or IIC, we used the function *drop1* in R version 3.6.1. [50] with stepwise backward selection and Chi-Square distribution to calculate the significance of each variable per group, considering technification and environment variables separately. We considered as significant all variables with $p \leq 0.05$, and marginally significant variables with $p \leq 0.10$.

We tested the significance of association between pairs of technification variables using Kendall's coefficient of concordance (Kendall's tau-b) to test for concordance or attribute agreement between variables. Analyses were performed using the software Minitab®18.

## 3. Results

### 3.1. Dairy Farm Characteristics

Although farmers declared legal reserve area equal to the minimum required by Brazilian environmental law in Central-Brazil (20% of the farm area, Table S1), 84% of the farms had lower percentage of natural vegetation than the minimum required for legal reserve (Figure 2a, Supplementary Table S1). The total area of natural vegetation (Figure S2, Table S1) comprised 5.42 to 46.55% of the farm area (mean = 24.84%, SD = 11.45%), and only 16% of the dairy farms had proportion of natural vegetation > 20%, excluding riparian forests (Figure 2a).

Most dairy farms (80%) were family or small size, and only one was a large dairy farm (Figure 2b, Table S1, Figure S2). Mean IIC ranged from 0.0023 to 0.2141 (Figure S3, Table S1), and the mean overall farms was very low, 0.0646 (SD = 0.0561), meaning that the connectivity among remaining patches of natural vegetation within farms was very low (Figure 2c).

Most dairy farms use free grazing (pasture-raised dairy) and semi-confinement as primary forage diet system (Table S2). They use fertilizers in pasture management and perform pasture restoration, and provide supplementary feed during the dry season (Table S2). Most farmers use productivity as the criterium to give supplement to the cattle. Machine with bucket is the most used milking method, and milking twice-a-day is more frequently used (Table S2). Most farmers milk in a milking pit or in a milking parlor with roof and cement floor, use farm milk cooling tank and can receive milk quality-based payment (Table S2). Most farmers use commercial sanitizer to cleaning udder before milking and do not perform CMT test or perform monthly (Table S2). Most farmers use selective breeding method with natural service with selected breeding bulls and pregnancy diagnosis with transrectal palpation (Table S2). Farmers have Holland or crossbreed dairy cattle and do not separate pregnant cows.

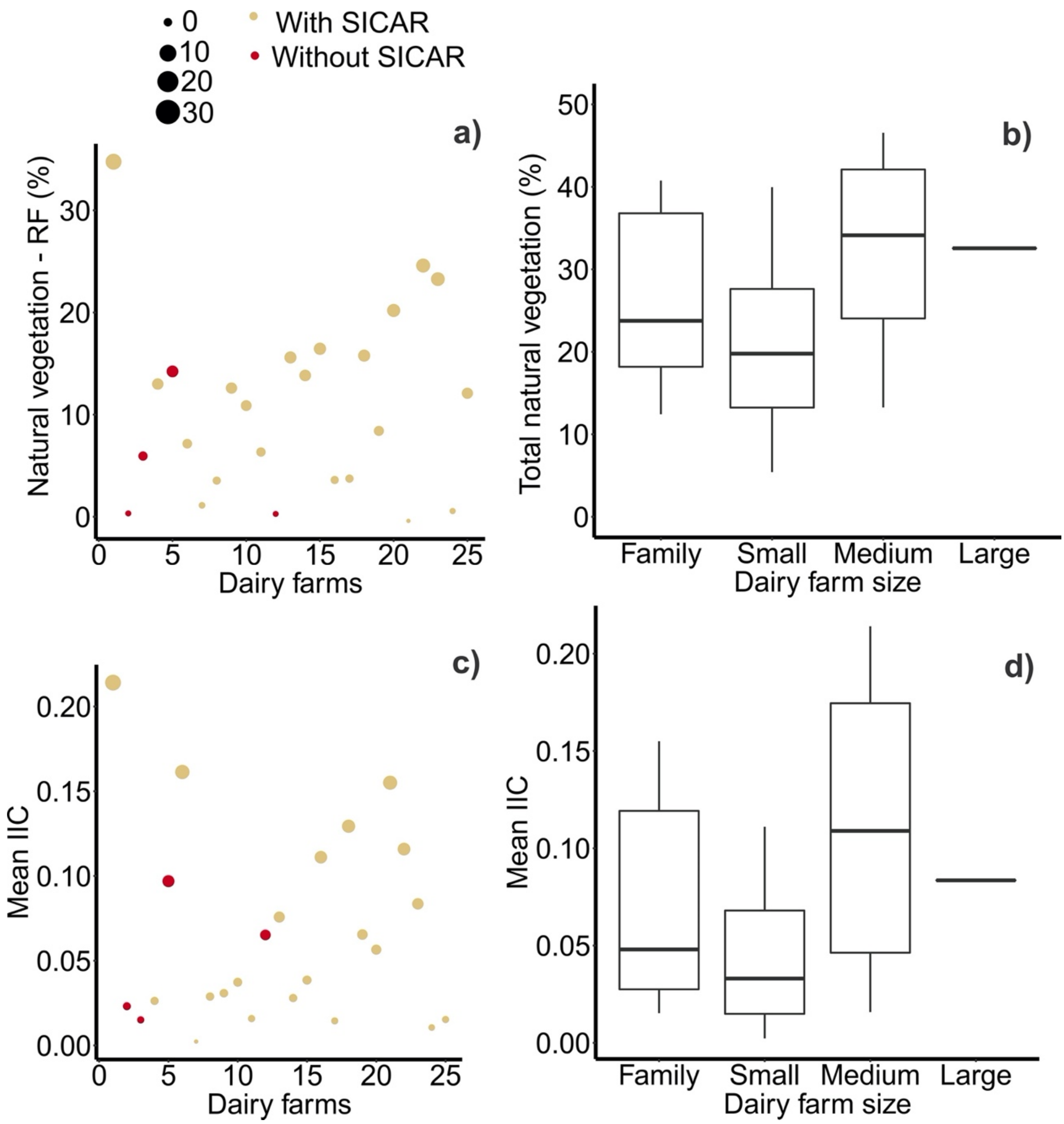


**Figure 2.** Percentage of natural vegetation and connectivity in the dairy farms of the COFA-LTER long-term project landscape. (**a**) Distribution of the percentage of legal reserve (total natural vegetation-riparian forest (RF)) in dairy farms with (dark red circles) and without SICAR (Brazilian System of Rural Environment, CAR, dark yellow circles). (**b**) Relationship between the total percentage of natural vegetation and dairy farm size (fiscal module). (**c**) Distribution of the Integral Index of Connectivity (IIC) in dairy farms with and without SICAR. (**d**) Relationship between IIC and dairy farm size. The box plot represents the median (dark bar), the third quartiles (the box) and the minimum (lower bar) and maximum (above bar) values.

### *3.2. Technification and Conservation Status*

We excluded the variables primary forage diet (Gvif = 8.974) for feed management (Table S3), and milking method (Gvif = 5.093) for milking management (Table S3) due to collinearity. For sanitary control and genetics and breeding we kept all variables (Gvif < 5.0, Table S3).

We found that selective breeding method ($p = 0.046$) significantly explained the variation in percentage of natural vegetation among dairy farms (Tables 2 and S4). Dairy farms applying artificial insemination (Figure 3a) had higher proportion of natural vegetation. Breeding program for productivity improvement was marginally significant ($p = 0.059$) and daily milk production did not explain variation in percentage of natural vegetation ($p = 0.789$). When analyzed in the final model (Table 2), feed and milking management, and sanitary control variables did not explain farm conservation status (all $p > 0.05$; Table S4). Connectivity (mean IIC) was not explained by feed and milking management or sanitary control variables, or daily milk production (all $p > 0.05$; Table S5).

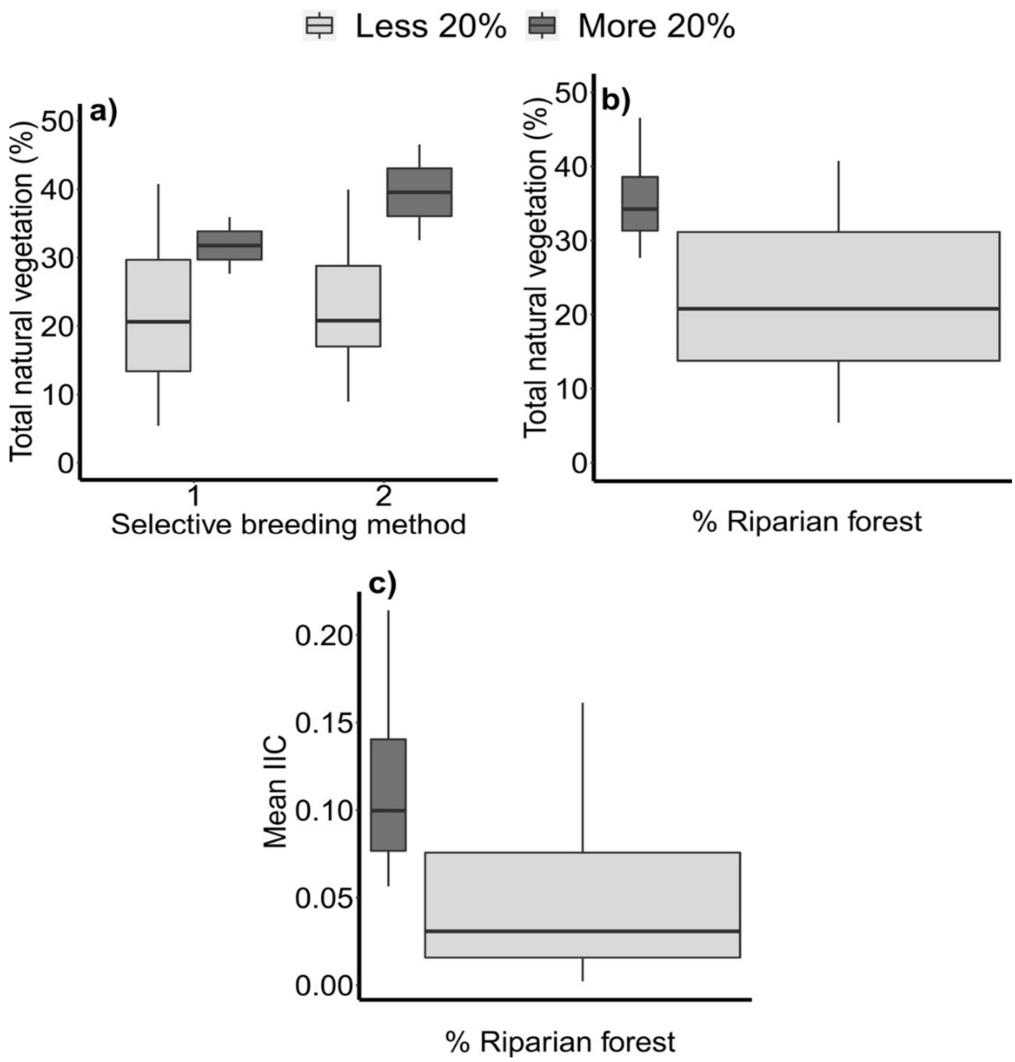


**Figure 3.** Relationship between conservation status and technification variable related to genetics and breeding, and environment feature in the 25 dairy farms in the COFA-LTER long-term project landscape. The relationships are shown for farms with less (light gray) and higher (dark gray) minimum percentage of legal reserve required by Brazilian law (20%). (**a**) Percentage of natural vegetation and selective breeding method. (**b**) Percentage of natural vegetation and riparian forest. (**c**) Integral Index of Connectivity (IIC) and percentage of riparian forest. 1, natural service with selected breeding bulls; 2, artificial insemination. The box plot represents the median (dark bar), the third quartiles (the box) and the minimum (lower bar) and maximum (above bar) values.

**Table 2.** Relationship between technification variables and conservation status measured by the percentage of natural vegetation in dairy farms in COFA-LTER landscape. Df, degrees of freedom, RSS, residual sum of square, AIC, Akaike Information Criterion.

| Model | df | Sum of Square | RSS | AIC | *p* |
|---|---|---|---|---|---|
| Breeding program for productivity improvement | 1 | 395.86 | 2996.4 | 125.66 | 0.059 * |
| Selective breeding method | 1 | 448.57 | 3049.1 | 126.09 | 0.046 ** |
| Daily milk production | 1 | 7.49 | 2608.1 | 122.19 | 0.789 |

** significant ($p \leq 0.05$), * marginally significant ($p \leq 0.10$).

We found significant association between selective breeding method and primary forage diet ($p = 0.001$, Table S6). In addition, daily milk production was significantly higher ($t = 2.73$, $p = 0.026$, Figure 4) in farms that used artificial insemination (mean production = 1023 l, SD = 933.0 l) than in farms that used natural service with selected breeding bulls (mean production = 166.0, SD = 165.0).

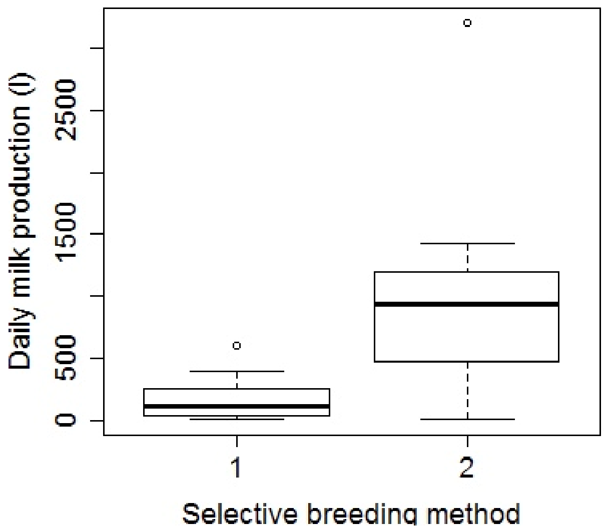


**Figure 4.** Relationship between selective breeding method and daily milk production in the 25 dairy farms in the COFA-LTER long-term project landscape. 1, natural service with selected breeding bulls; 2, artificial insemination. The box plot represents the median (dark bar), the third quartiles (the box) and the minimum (lower bar) and maximum (above bar) values.

### *3.3. Environment Features and Conservation Status*

We excluded percentage of agriculture (Vif = 7.945) due to collinearity (Table S7), keeping slope, percentage of riparian forest and pasture in the models (Vif < 5.0, Table S7).

Percentage of riparian forest ($p < 0.001$) and farm size ($p = 0.041$) significantly explained the percentage of natural vegetation conserved in dairy farms (Table 3, Table S8). Farms with higher percentage of riparian forest (Figure 3b) or larger farms (Figure 2b) had higher percentage of natural vegetation. Slope and percentage of pasture did not explain the percentage of natural vegetation conserved in dairy farms (all $p > 0.05$, Table S8). We found similar results for IIC (Table 3, Table S9). Farms with higher percentage of riparian forest ($p < 0.001$, Figure 3c) and larger farms ($p = 0.019$, Figure 2d) had significantly higher connectivity.

**Table 3.** Relationship between environment feature variables and conservation status measured by the percentage of natural vegetation and the Integral Index of Connectivity (IIC) in dairy farms in COFA-LTER landscape. Df, degrees of freedom, RSS, residual sum of square, AIC, Akaike Information Criterion.

| Model | df | Sum of Square | RSS | AIC | *p* |
|---|---|---|---|---|---|
| **Percentage of natural vegetation** | | | | | |
| Percentage of riparian forest | 1 | 1420.24 | 2652.5 | 124.61 | $1.198 \times 10^{-5}$ ** |
| Size of rural property | 3 | 483.08 | 1715.3 | 109.71 | 0.041 ** |
| **IIC** | | | | | |
| Percentage of riparian forest | 1 | 0.0314 | 0.0603 | −142.66 | $1.851 \times 10^{-5}$ * |
| Size of rural property | 3 | 0.0139 | 0.0429 | −155.16 | 0.019 * |

** significant ($p \leq 0.05$), * marginally significant ($p \leq 0.10$).

## 4. Discussion

Here we show for the first time that farmers using cutting edge technology such as artificial insemination in cattle breeding tend to conserve higher percentage of natural vegetation in the COFA-LTER landscape. However, larger dairy farms and with higher percentage of riparian forest also showed higher conservation status. Cattle raising farms in Brazil use predominantly extensive pasture-raised (free grazing) system with low productivity, which may hamper conservation of natural vegetation due to the constant need for new pasture areas [21,54]. In the Cerrado biome, ~39% of pastures are degraded [27]. In the COFA-LTER landscape, most dairy farmers use pasture-raised with free grazing or semi-confinement that includes free grazing and free-stall or Barn systems, which is similar to the most used feed management system in Brazilian dairy farms (e.g., [55]). The predominance of these feed management systems may contribute to the relatively low percentage of natural vegetation and connectivity among patches of vegetation in dairy farms due to the demand of pasture and grain plantation for cattle feeding. Few dairy farmers (16%) had higher proportion of vegetation remnants than 20%, which is the minimum determined by Brazilian environmental law (see Figure 2a). Moreover, larger farms with higher percentage of riparian forest preserved higher percentage of natural vegetation, and had higher connectivity (see Figure 2b,c). However, it is important to note that overall connectivity was very low, which may compromise biodiversity conservation in the landscape.

Indeed, this result was not a surprise, because farmers do not have technical support to design priority areas for conservation within the rural property that would maximize the trade-offs between ecological and economic benefits, such as improving connectivity. Usually, farmers in Brazil conserve unproductive areas, or with technical limitations for management that will not interfere in daily management practices (see [56]). The higher conservation status in larger farms with higher percentage of riparian forest suggests that in the COFA-LTER landscape farmers are not preserving vegetation above the required by Brazilian environmental law. Farmers may adopt conservation practices based mainly on short economic benefits and in other factors such as previous experience, familiarity with technologies, perceived risks, labor requirements, and interactions with peers and advisors [57]. In addition, public visibility and the influence of neighbor farmers that use conservation practices can drive the decision of surrounding farmers to adopt new or more ecological management practices [57]. To our knowledge, the local government has no economic incentives to guarantee conservation, restoration or sustainable practices to improve local and regional connectivity and conservation.

Furthermore, the adherence of farmers to the SICAR (Brazilian System of Rural Environment) seems to be more related to restrictions to credit and rural financing and insurance imposed by Brazilian policies than to conservation. SICAR declaration is related to the access to rural credit and adoption of practices to improve pasture management in cattle farms in Brazil [32]. In the COFA-LTER four dairy farms have no register in the Brazilian government database SICAR, that requires the information of legal reserve area or which area will be restore in the future to comprise the legal reserve and APPs. However, even with the SICAR declaration, most of the dairy farmers in the COFA-LTER landscape (84% of the dairy farms) do not conserve the minimum of natural vegetation established by law, suggesting that the current environmental policies provide no additional incentive to conservation in the study area.

However, it is important to highlight that positive outcomes can be identified at regional scales, as we found higher percentage of natural vegetation in a set of dairy farms that use higher levels of technification (see Figure 3). Furthermore, planned interventions with few interferences on the production systems can favor local biodiversity and ecosystem services [58,59]. Some of these interventions support the restoration of strips of natural vegetation between the crop fields [60] and the reduction of agrochemical inputs [61]. In the COFA-LTER landscape farmers are prone to restore areas of natural vegetation, particularly farmers with ecosystem service awareness and with higher number of springs in their properties [62].

Feed management may affect greenhouse gas emission directly due to both the forage production and feed conversion rates [63], and indirectly due to expansion of new areas of pasture and grain plantation for animal feed leading to deforestation [64,65]. However, we found no relationship between feed management and the percentage of natural vegetation, and also no relationship of percentage of pasture and conservation status. It is possible that farmers may have cleared their farms for pasture planting before the adoption of cutting-edge technology, and then turned to higher levels of technification [21,32,66] such as insemination, milking using automatic machines and confinement.

The increase in productivity of cattle raising and in general, the ecological intensification of agriculture [57] may improve not only direct economic incomes but also conservation of vegetation remnants [22]. In fact, our results evince that increasing technology and cattle raising efficiency may improve economic benefits. Artificial insemination was directly related to productivity in COFA-LTER landscape, i.e., dairy farms applying artificial insemination tended to have higher daily milk production (see Figure 4), which may increase economic benefits. The benefits of applying technification can also be detected in other important indicators of productivity, for instance, dairy farms adopting artificial insemination (mean = 48.6, SD = 30.5) have higher number of dairy cows ($t = 3.25$, $p = 0.012$) than those with natural service with selected breeding bulls (mean = 14.9, SD = 7.4).

However, although our novel findings indicate opportunities to improve economic and ecological benefits on dairy farms, these opportunities may vary throughout Brazilian territory, restricting our conclusions to the study area. Also, it is not easy to establish patterns in the production systems in Brazil. The country is very heterogeneous in a set of factors such as the environment, technology availability and adoption, which may establish patterns utterly different in the same production system such as dairy farms.

Sustainable intensification in Brazil can potentially increase 113% in pasture grazing beef and milk production without increasing land demand and sparing areas for biodiversity conservation [67]. Our findings point to important outcomes about technification and conservation in the COFA-LTER landscape, showing that additional economic incentives and programs aimed at improving technification in cattle breeding can increase dairy production and, consequently, may lead to additional incentives to the conservation and restoration of vegetation remnants. Besides artificial insemination, our results suggest that practices such as confinement and semi-confinement may contribute to less land demand. However, it is essential to mention that non-ecological intensification practices may reduce pasture area, but may cause a set of additional impacts on the environment. Farmers tend to adopt new management practices when they do not require high modification in the establish farming systems [57]. Furthermore, evidence-based new management systems have higher chances of adoption when the most relevant costs and benefits to the farmers are clear [57]. In this context, we are providing evidence that technification may bring positive income to dairy farms in the COFA-LTER region.

## 5. Concluding Remarks

This is the first study in Brazil showing that dairy farms using cutting edge technology in cattle breeding, such as artificial insemination, significantly conserve higher proportion of natural vegetation in their farms. Therefore, technification affected positively the conservation of natural vegetation in the COFA-LTER landscape. Farmers adopting artificial insemination had higher daily milk production and tended to use other technification systems related to dairy farm management more frequently than the other farmers, such as confinement and semi-confinement, and milking with automatic machine.

Brazil harbors a diversity of social, environmental, and economic conditions with can provide different perspectives to other parts of the territory and other productive systems (see an example in [32]). Our dataset provides evidence that incentives to technification may promote economic benefits to dairy farmers and can provide opportunities to preserve or restore habitats in COFA-LTER landscape. Our dataset can be a starting point to design successful strategies aimed at the conservation and dairy production in the study area. However, the use of new practices or strategies can be seen as a barrier if enable conditions are not offered safely, like technical assistance and training for labor [32,67].

The significant relationships between farm size and percentage of riparian forest and farm conservation status highlight the importance of riparian forests to maintain the connectivity at farm level, and to favor conservation status in productive dairy regions. Ecological initiatives should be designed at local and regional levels to favor essential components such as connectivity and designing farms and landscapes more permeable to organism's movement. Additional incentives of local government are essential to support the dairy farmers to achieve economic benefits, sustainable intensification, maintain or restore habitats, and ensuring ecological benefits within farms. These initiatives are necessary independently of farm size, to promote a conservation status at landscape level. We acknowledge the limitations of our results due to the sampling size, i.e., the number of dairy farms analyzed, and the dairy farm sizes. Most farms in the COFA-LTER region are family, small or medium size, thus our results may be used with caution to large size and very large states. Also, the specific environmental conditions of the region may also influence the results, since riparian forests are important landscape components in the region due to the topography and geomorphology. Also, more studies are necessary at the farm level to understand the relationship between technification and conservation, identify barriers, and promote efficient strategies to fix it.

**Supplementary Materials:** The following are available online at https://www.mdpi.com/article/10.3390/su13105606/s1, Supplementary File S1: Tables S1–S9, Supplementary File S2: Figures S1–S3, Video S1: video. abstract. Supplementary S1 Tables (Tables S1–S9) with raw data and results of IIC, Gvif, Vif and GLM models. Supplementary S2 Figures (Figures S1–S3) with the spatial distribution of the 25 dairy farms in the COFA-LTER long-term project landscape, distribution of dairy farms size and natural vegetation and distribution of IIC.

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**Informed Consent Statement:** The present work involved face to face interviews with farmers. All farmers signed an informed consent for before being interviewed, as stated by Brazilian law.

**Data Availability Statement:** Data and additional supporting information may be found in the online version of this article as supporting information.

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## References

1. Johnson, C.N.; Balmford, A.; Brook, B.W.; Buettel, J.C.; Galetti, M.; Guangchun, L.; Wilmshurst, J.M. Biodiversity losses and conservation responses in the Anthropocene. *Science* **2017**, *356*, 270–275. [CrossRef]
2. Laurance, W.F.; Sayer, J.; Cassman, K.G. Agricultural expansion and its impacts on tropical nature. *Trends Ecol. Evol.* **2014**, *29*, 107–116. [CrossRef]
3. Newbold, T.; Hudson, L.N.; Hill, S.L.L.; Contu, S.; Lysenko, I.; Senior, R.A.; Börger, L.; Bennett, D.J.; Choimes, A.; Collen, B.; et al. Global effects of land use on local terrestrial biodiversity. *Nature* **2015**, *520*, 45–50. [CrossRef]
4. FAO. *The State of the World's Biodiversity for Food and Agriculture*; Bélanger, J., Pilling, D., Eds.; FAO: Rome, Italy, 2019; ISBN 978-92-5-131270-4.
5. Goldewijk, K.K. Estimating global land use change over the past 300 years: The HYDE database. *Glob. Biogeochem. Cycles* **2001**, *15*, 417–433. [CrossRef]
6. Hurtt, G.C.; Chini, L.P.; Frolking, S.; Betts, R.A.; Feddema, J.; Fischer, G.; Fisk, J.P.; Hibbard, K.; Houghton, R.A.; Janetos, A.; et al. Harmonization of land-use scenarios for the period 1500–2100: 600 years of global gridded annual land-use transitions, wood harvest, and resulting secondary lands. *Clim. Chang.* **2011**, *109*, 117–161. [CrossRef]
7. LEAP Environmental Performance of Large Ruminant Supply Chains: Guidelines for Assessment. Draft for Public Review. Livestock Environmental Assessment and Performance (LEAP) Partnership. Available online: http://www.fao.org/3/a-bl094e.pdf (accessed on 17 May 2021).
8. Alexandratos, N.; Bruinsma, J. World Agriculture towards 2030/2050: The 2012 Revision. Available online: http://www.fao.org/3/a-ap106e.pdf (accessed on 17 May 2021).
9. Clegg, C.D. Impact of cattle grazing and inorganic fertiliser additions to managed grasslands on the microbial community composition of soils. *Appl. Soil Ecol.* **2006**, *31*, 73–82. [CrossRef]
10. Kolbek, J.; Alves, R.J.V. Impacts of cattle, fire and wind in rocky savannas, southeastern Brazil. *Acta Univ. Carolinae Environ.* **2008**, *22*, 111–130.
11. Burt, C.; Bachoon, D.S.; Manoylov, K.; Smith, M. The impact of cattle farming best management practices on surface water nutrient concentrations, faecal bacteria and algal dominance in the Lake Oconee watershed. *Water Environ. J.* **2012**, *27*, 207–215. [CrossRef]
12. Conroy, E.; Turner, J.N.; Rymszewicz, A.; O'Sullivan, J.J.; Bruen, M.; Lawler, D.; Lally, H.; Kelly-Quinn, M. The impact of cattle access on ecological water quality in streams: Examples from agricultural catchments within Ireland. *Sci. Total Environ.* **2016**, *547*, 17–29. [CrossRef]
13. De Boer, I.J.M.; Cederberg, C.; Eady, S.; Gollnow, S.; Kristensen, T.; Macleod, M.; Meul, M.; Nemecek, T.; Phong, L.T.; Thoma, G.; et al. Greenhouse gas mitigation in animal production: Towards an integrated life cycle sustainability assessment. *Curr. Opin. Environ. Sustain.* **2011**, *3*, 423–431. [CrossRef]
14. Gerber, P.J.; Steinfeld, H.; Henderson, B.; Mottet, A.; Opio, C.; Dijkman, J.; Falcucci, A.; Tempio, G. *Tackling Climate Change through Livestock—A Global Assessment of Emissions and Mitigation Opportunities*; FAO: Rome, Italy, 2013.
15. Perfecto, I.; Vandermeer, J. Biodiversity conservation in tropical agroecosystems: A new conservation paradigm. *Ann. N. Y. Acad. Sci.* **2008**, *1134*, 173–200. [CrossRef]
16. Kok, A.; de Olde, E.M.; de Boer, I.J.M.; Ripoll-Bosch, R. European biodiversity assessments in livestock science: A review of research characteristics and indicators. *Ecol. Indic.* **2020**, *112*, 105902. [CrossRef]
17. Alkemade, R.; Reid, R.S.; Van Den Berg, M.; De Leeuw, J.; Jeuken, M. Assessing the impacts of livestock production on biodiversity in rangeland ecosystems. *Proc. Natl. Acad. Sci. USA* **2013**, *110*, 20900–20905. [CrossRef]
18. Broom, D.M.; Galindo, F.A.; Murgueitio, E. Sustainable, efficient livestock production with high biodiversity and good welfare for animals. *Proc. R. Soc. B Biol. Sci.* **2013**, *280*. [CrossRef]
19. Parente, L.; Mesquita, V.; Miziara, F.; Baumann, L.; Ferreira, L. Assessing the pasturelands and livestock dynamics in Brazil, from 1985 to 2017: A novel approach based on high spatial resolution imagery and Google Earth Engine cloud computing. *Remote Sens. Environ.* **2019**, *232*, 111301. [CrossRef]

20. Nogueira, S.F.; Macedo, M.C.M.; Poccard-Chapuis, R.; Da Silva, G.B.S.; Victoria, D.C.; Andrade, R.G.; Aguiar, D.A.; Bolfe, E.L. Geotechnologies for monitoring pasture degradation levels in Brazil. In *A Produção Animal Frente às Mudanças Climáticas e Tecnológicas, Proceedings of the 51 Reunião Anual Da Sociedade Brasileira De Zootecnia, Barra dos Coqueiros, Brazil, 19 December 2014*; Sociedade Brasileira de Zootecnia: Barra dos Coqueiros, Brazil, 2014.
21. Latawiec, A.E.; Strassburg, B.B.N.; Valentim, J.F.; Ramos, F.; Alves-Pinto, H.N. Intensification of cattle ranching production systems: Socioeconomic and environmental synergies and risks in Brazil. *Animal* **2014**, *8*, 1255–1263. [CrossRef]
22. Strassburg, B.B.N.; Latawiec, A.E.; Barioni, L.G.; Nobre, C.A.; da Silva, V.P.; Valentim, J.F.; Vianna, M.; Assad, E.D. When enough should be enough: Improving the use of current agricultural lands could meet production demands and spare natural habitats in Brazil. *Glob. Environ. Chang.* **2014**, *28*, 84–97. [CrossRef]
23. Scaramuzza, C.A.d.M.; Sano, E.E.; Adami, M.; Bolfe, E.L.; Coutinho, A.C.; Esquerdo, J.C.D.M.; Maurano, L.E.P.; Narvaes, I.S.; Oliveira Filho, F.J.B.; Rosa, R.; et al. Land-Use and Land-Cover Mapping of the Brazilian Cerrado Based Mainly on Landsat-8 Satellite Images. *Rev. Bras. Cartogr.* **2017**, *69*, 1041–1051.
24. Sano, E.E.; Rosa, R.; Scaramuzza, C.A.d.M.; Adami, M.; Bolfe, E.L.; Coutinho, A.C.; Esquerdo, J.C.D.M.; Maurano, L.E.P.; Narvaes, I.d.S.; Filho, F.J.B.d.O.; et al. Land use dynamics in the Brazilian Cerrado in the period from 2002 to 2013. *Pesqui. Agropecuária Bras.* **2019**, *54*. [CrossRef]
25. Myers, N.; Mittermeier, R.A.; Mittermeier, C.G.; da Fonseca, G.A.B.; Kent, J. Biodiversity hotspots for conservation priorities. *Nature* **2000**, *403*, 853–858. [CrossRef] [PubMed]
26. De Sy, V.; Herold, M.; Achard, F.; Beuchle, R.; Clevers, J.G.P.W.; Lindquist, E.; Verchot, L. Land use patterns and related carbon losses following deforestation in South America. *Environ. Res. Lett.* **2015**, *10*. [CrossRef]
27. Pereira, O.J.R.; Ferreira, L.G.; Pinto, F.; Baumgarten, L. Assessing pasture degradation in the Brazilian Cerrado based on the analysis of MODIS NDVI time-series. *Remote Sens.* **2018**, *10*, 1761. [CrossRef]
28. De Oliveira Silva, R.; Barioni, L.G.; Queiroz Pellegrino, G.; Moran, D. The role of agricultural intensification in Brazil's Nationally Determined Contribution on emissions mitigation. *Agric. Syst.* **2018**, *161*, 102–112. [CrossRef]
29. Oliveira, C.A.; Millen, D.D. Survey of the nutritional recommendations and management practices adopted by feedlot cattle nutritionists in Brazil. *Anim. Feed Sci. Technol.* **2014**, *197*, 64–75. [CrossRef]
30. Costa, J.H.C.; Hötzel, M.J.; Longo, C.; Balcão, L.F. A survey of management practices that influence production and welfare of dairy cattle on family farms in southern Brazil. *J. Dairy Sci.* **2013**, *96*, 307–317. [CrossRef] [PubMed]
31. Balcão, L.F.; Longo, C.; Costa, J.H.C.; Uller-Gómez, C.; Filho, L.C.P.M.H.; Hötzel, M.J. Characterisation of smallholding dairy farms in southern Brazil. *Anim. Prod. Sci.* **2017**, *57*, 735–745. [CrossRef]
32. Latawiec, A.E.; Strassburg, B.B.N.; Silva, D.; Alves-Pinto, H.N.; Feltran-Barbieri, R.; Castro, A.; Iribarrem, A.; Rangel, M.C.; Kalif, K.A.B.; Gardner, T.; et al. Improving land management in Brazil: A perspective from producers. *Agric. Ecosyst. Environ.* **2017**, *240*, 276–286. [CrossRef]
33. Latrubesse, E.M.; Arima, E.; Ferreira, M.E.; Nogueira, S.H.; Wittmann, F.; Dias, M.S.; Dagosta, F.C.P.; Bayer, M. Fostering water resource governance and conservation in the Brazilian Cerrado biome. *Conserv. Sci. Pract.* **2019**, *1*, 1–8. [CrossRef]
34. Dias-Filho, M.B. Diagnóstico das Pastagens no Brasil. *Embrapa Amaz. Orient.* **2014**, *22*. [CrossRef]
35. Gillingham, K.; Rapson, D.; Wagner, G. The rebound effect and energy efficiency policy. *Rev. Environ. Econ. Policy* **2016**, *10*, 68–88. [CrossRef]
36. Paul, C.; Techen, A.K.; Robinson, J.S.; Helming, K. Rebound effects in agricultural land and soil management: Review and analytical framework. *J. Clean. Prod.* **2019**, *227*, 1054–1067. [CrossRef]
37. zu Ermgassen, E.K.H.J.; de Alcântara, M.P.; Balmford, A.; Barioni, L.; Neto, F.B.; Bettarello, M.M.F.; de Brito, G.; Carrero, G.C.; Florence, E.d.A.S.; Garcia, E.; et al. Results from on-the-ground efforts to promote sustainable cattle ranching in the Brazilian Amazon. *Sustainability* **2018**, *10*, 1301. [CrossRef]
38. Steinfeld, H.; Wassenaar, T.; Jutzi, S. Livestock production systems in developing countries: Status, drivers, trends. *Rev. Sci. Tech. l'OIE* **2006**, *25*, 505–516. [CrossRef] [PubMed]
39. Neto, M.C.; Campos, J.M.d.S.; de Oliveira, A.S.; Gomes, S.T. Identification and quantification of benchmarks of milk production systems in Minas Gerais1. *Rev. Bras. Zootec.* **2012**, *41*, 2279–2288. [CrossRef]
40. de Andrade Ferrazza, R.; Lopes, M.A.; de Oliveira Prado, D.G.; de Lima, R.R.; Bruhn, F.R.P. Association between technical and economic performance indexes and dairy farm profitability. *Rev. Bras. Zootec.* **2020**, *49*. [CrossRef]
41. Bargo, F.; Muller, L.D.; Delahoy, J.E.; Cassidy, T.W. Performance of high producing dairy cows with three different feeding systems combining pasture and total mixed rations. *J. Dairy Sci.* **2002**, *85*, 2948–2963. [CrossRef]
42. Sairanen, A.; Khalili, H.; Virkajärvi, P. Concentrate supplementation responses of the pasture-fed dairy cow. *Livest. Sci.* **2006**, *104*, 292–302. [CrossRef]
43. Gouvêa, F.L.R.; Cardozo, L.L.; Canal, J.; Troncarelli, M.Z.; Pantoja, J.C.F. A descriptive study of teat morphology, milking machine characteristics, and milking practices in a sample of Brazilian dairy herds. *Livest. Sci.* **2020**, *241*, 104196. [CrossRef]
44. Candiotto, L.; Adelaide, D.; Elejalde, G. Milk quality in small farms from Southern Region of Brazil. *Cienc. Rural* **2020**, *50*, 1–5. [CrossRef]
45. Giordano, J.O.; Kalantari, A.S.; Fricke, P.M.; Wiltbank, M.C.; Cabrera, V.E. A daily herd Markov-chain model to study the reproductive and economic impact of reproductive programs combining timed artificial insemination and estrus detection. *J. Dairy Sci.* **2012**, *95*, 5442–5460. [CrossRef] [PubMed]

46. Taylor, P.D.; Fahrig, L.; Henein, K.; Merriam, G. Connectivity is a vital element of landscape structure. *Oikos* **1993**, *68*, 571–573. [CrossRef]
47. Tischendorf, L.; Fahrig, L. On the usage and measurement of landscape connectivity. *Oikos* **2000**, *90*, 7–19. [CrossRef]
48. Pascual-Hortal, L.; Saura, S. Comparison and development of new graph-based landscape connectivity indices: Towards the priorization of habitat patches and corridors for conservation. *Landsc. Ecol.* **2006**, *21*, 959–967. [CrossRef]
49. Saura, S.; Torné, J. Conefor Sensinode 2.2: A software package for quantifying the importance of habitat patches for landscape connectivity. *Environ. Model. Softw.* **2009**, *24*, 135–139. [CrossRef]
50. R Core Team. *R: A Language and Environment for Statistical Computing*; R Foundation for Statistical Computing: Vienna, Austria, 2019.
51. Fox, J.; Weisberg, S. *An R Companion to Applied Regression*, 3rd ed.; SAGE: Newbury Park, CA, USA, 2019; ISBN 978-1544336473.
52. Zuur, A.F.; Ieno, E.N.; Elphick, C.S. A protocol for data exploration to avoid common statistical problems. *Methods Ecol. Evol.* **2010**, *1*, 3–14. [CrossRef]
53. Fox, J.; Monette, G. Generalized collinearity diagnostics. *J. Am. Stat. Assoc.* **1992**, *87*, 178–183. [CrossRef]
54. Soares-Filho, B.; Rajão, R.; Macedo, M.; Carneiro, A.; Costa, W.; Coe, M.; Rodrigues, H.; Alencar, A. Cracking Brazil's Forest Code. *Science* **2014**, *344*, 363–364. [CrossRef]
55. dos Santos, G.; Bittar, C.M.M. A survey of dairy calf management practices in some producing regions in Brazil. *Rev. Bras. Zootec.* **2015**, *44*, 361–370. [CrossRef]
56. Ranieri, V.E.L. Reservas Legais: Critérios para localização e aspectos de gestão. Ph.D. Thesis, Universidade de São Paulo, São Paulo, Brazil, 2004.
57. Kleijn, D.; Bommarco, R.; Fijen, T.P.M.; Garibaldi, L.A.; Potts, S.G.; van der Putten, W.H. Ecological Intensification: Bridging the Gap between Science and Practice. *Trends Ecol. Evol.* **2019**, *34*, 154–166. [CrossRef]
58. Weibull, A.-C.; Ostman, O.; Granqvist, A. Species richness in agroecosystems: The effect of landscape, habitat and farm management. *Biodivers. Conserv.* **2003**, *12*, 1335–1355. [CrossRef]
59. Popescu, V.D.; Hunter, M.L. Clear-cutting affects habitat connectivity for a forest amphibian by decreasing permeability to juvenile movements. *Ecol. Appl.* **2011**, *21*, 1283–1295. [CrossRef] [PubMed]
60. Concepción, E.D.; Díaz, M.; Kleijn, D.; Báldi, A.; Batáry, P.; Clough, Y.; Gabriel, D.; Herzog, F.; Holzschuh, A.; Knop, E.; et al. Interactive effects of landscape context constrain the effectiveness of local agri-environmental management. *J. Appl. Ecol.* **2012**, *49*, 695–705. [CrossRef]
61. Donald, P.F.; Evans, A.D. Habitat connectivity and matrix restoration: The wider implications of agri-environment schemes. *J. Appl. Ecol.* **2006**, *43*, 209–218. [CrossRef]
62. Lima, F.P.; Bastos, R.P. Perceiving the invisible: Formal education affects the perception of ecosystem services provided by native areas. *Ecosyst. Serv.* **2019**, *40*, 101029. [CrossRef]
63. Gerosa, S.; Skoet, J. Milk availability Trends in production and demand and medium-term outlook. *ESA Work. Pap.* **2012**, 1–40. [CrossRef]
64. Batista, E.; Soares-Filho, B.; Barbosa, F.; Merry, F.; Davis, J.; Van Der Hoff, R.; Rajão, R.G. Large-scale pasture restoration may not be the best option to reduce greenhouse gas emissions in Brazil. *Environ. Res. Lett.* **2019**, *14*. [CrossRef]
65. de Léis, C.M.; Cherubini, E.; Ruviaro, C.F.; Prudêncio da Silva, V.; do Nascimento Lampert, V.; Spies, A.; Soares, S.R. Carbon footprint of milk production in Brazil: A comparative case study. *Int. J. Life Cycle Assess.* **2015**, *20*, 46–60. [CrossRef]
66. Lambin, E.F.; Meyfroidt, P. Global land use change, economic globalization, and the looming land scarcity. *Proc. Natl. Acad. Sci. USA* **2011**, *108*, 3465–3472. [CrossRef]
67. Santos, J.S.; Feltran-Barbieri, R.; Fonte, E.S.; Balmford, A.; Maioli, V.; Latawiec, A.; Strassburg, B.B.N.; Phalan, B.T. Characterising the spatial distribution of opportunities and constraints for land sparing in Brazil. *Sci. Rep.* **2020**, *10*, 1–11. [CrossRef]