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Composition of the Anuran Community in a Forest Management Area in Southeastern Amazonia

Fabrício Otávio do Nascimento Pereira [1], Graciliano Galdino Alves dos Santos [2], Anderson Borges Serra [3], Cleuton Lima Miranda [4,*], Guilherme da Silva Araújo [5] and Emil José Hernández Ruz [1,5]

1 Programa de Pós-Graduação em Biodiversidade e Conservação, Universidade Federal do Pará, Altamira 66075-110, PA, Brazil
2 Programa de Pós-Graduação Bionorte, Instituto de Ciências Biológicas, Belém 66077-830, PA, Brazil
3 Faculdade de Engenharia Florestal, Campus Universitário de Altamira, Universidade Federal do Pará, Altamira 68371-155, PA, Brazil
4 Laboratório de Genética e Evolução Animal (LEGAL), Universidade Federal do Amazonas, Manaus 69067-005, AZ, Brazil
5 Laboratório de Zoologia, Faculdade de Ciências Biológicas, Altamira 68371-155, PA, Brazil
* Correspondence: cleuton85@gmail.com

Abstract: Forest management strategies often compromised the patterns and processes of the naturally dynamic forest ecosystems. As species occurrence and diversity are directly associated with ecological and environment factors, this study evaluated the effect of low-impact forest management on the structure of the anuran community, considering the effects of the environment types generated by the management and the post-exploitation time in the Fazenda Uberlândia, southeastern Amazonia (Portel, Pará, Brazil). Field data were collected in the period of the highest rainfall in the region (February to March 2021) by sampling 84 linear transects (25 m each) at a minimum distance of 500 m between them. The time elapsed since logging that took place in the study sites varied from 2 to 17 years. We analyzed an area without forest management (used as a control) and three environment types formed by logging activities: secondary roads, skid trails, and storage yard. Our results showed no differences in species richness, abundance, and composition of the anuran community with respect to time since exploitation. Meanwhile, we found significant differences across different environment types, suggesting that the observed pattern of richness and abundance may benefit the assembly of anurans in the short term. Still, over a longer period, it may have a homogenizing effect, gradually modifying the anurofauna assemblage in managed areas to favor species adapted to more open environments, resulting in damage to the local diversity of anurans.

Keywords: anurans; Amazon; forest management; forestry generalists; artificial pools

Citation: Pereira, F.O.d.N.; dos Santos, G.G.A.; Serra, A.B.; Miranda, C.L.; Araújo, G.d.S.; Ruz, E.J.H. Composition of the Anuran Community in a Forest Management Area in Southeastern Amazonia. *Land* **2023**, *12*, 1437. https://doi.org/10.3390/land12071437

Academic Editors: Guillermo J. Martinez-Pastur, Michael Manton, Per Angelstam, Andra-Cosmina Albulescu and Mariia Fedoriak

Received: 10 April 2023
Revised: 4 July 2023
Accepted: 5 July 2023
Published: 19 July 2023

1. Introduction

Habitat conversion is the main anthropogenic action responsible for biodiversity loss at a global scale [1]; therefore, it is important to understand and reduce this effect [2,3]. Sustainable forest management has been proposed as an economical alternative to those which degrade forests and reduce their ability to recover [4–6]. Forest management reduces the environmental impact and leads to higher levels of biodiversity while allowing economic activities to occur in forested areas [6]. However, the effects of sustainable forest management on the fauna are still controversial. For instance, research has shown that the effects of sustainable forest management can have both positive and negative impacts on different vertebrate groups on forest biodiversity [7,8].

Species distribution and diversity are directly associated with ecological and environmental factors [8,9]. Amphibians are particularly susceptible to environmental changes [10], and their ability to respond to the changes occurring in the landscape is increasingly important [11]. According to Vaira [12], the distribution and diversity of amphibians are thought to be closely related to reproductive habitats, ecological factors [11], and habitat quality [2,13].

Conventional selective logging results in greater impacts on forests as it removes timber species, usually without proper planning and/or logging techniques. In contrast, selective logging uses requires detailed planning and several techniques that reduce forest damage and shorten the forest recovery period based on the detailed planning of logging activities [14].

Selective logging is the removal of selected trees within a forest based on criteria such as diameter, height, or species. Remaining trees are left in the stand, as opposed to clearcutting, where all trees are felled within a given forest stand. A reduced impact logging is a sustainable harvesting and management method that aims to minimize ecological disturbance. It involves selective logging as well as other practices such as directional tree felling, stream buffer zones, constructing roads, trails and landings to minimum widths, and methods to extract timber with minimal damage [15].

Studies on the impact of forest management on amphibians have found a rapid population decline, an increase in generalist species, and community structuring from forest regeneration (e.g., Refs. [2,10,11,13]). In areas where conventional forest management is practiced, a rapid population decline in amphibians has been recorded. These declines have been associated with losses in habitat, an increased forest light, a decreased relative humidity of air and soil, and decreases in the availability of prey which are important factors for the survival or permanence of a species in a particular locations [15–20].

An increase in the number of generalist species is due to the occupation of new niches generated in the wood exploration process [16,21–23]. Habitat quality [2] and ecological factors [12] strongly influence how a species community will react to the stages of forest succession, given that the community accompanies its regeneration [13]. Therefore, it is important to use refined management strategies that contemplate longer harvest cycles when aiming to conserve and restore the original diversity in exploited forest ecosystems [13].

Currently, the literature does not discuss trends generated by forest management in amphibian communities for the neotropical region [12–15,23–27]. Therefore, it is challenging to understand and quantify the effects of forest management on the presence and abundance of anurans and of their complex life cycles [2], which can occur in disjointed habitats and in different spatial scales [28].

As anurans are ideal models for studying the effects of forest disturbance [13,29,30], we aimed to examine the impact of forest management on the composition of the anuran assembly. The study took place in regions in which forest management had been used for 2 to 17 years. We hypothesized that: (i) the areas with the highest levels of forest management would present a greater species richness and general abundance and (ii) a generalist species would be more represented due to the new environment and the greater water availability.

2. Material and Methods

2.1. Study Area

The study was conducted at a privately-owned farm in Uberlândia (S 3°3′49″ and W 50°5′28″), located in southeastern Amazon, in the microregion of the lower Tocantins River. The farm covers the municipalities of Baião, Portel, Oeiras do Pará, and Bagre. Most of its territory and headquarters are located in Baião, accessed by the Transcametá highway (BR 422). According to the Köppen classification, the predominant climate in the region is of the Am type: humid tropical with a short and dry season [31]. The average annual rainfall is between 1900 and 2400 mm, and the average annual temperature is 27 °C [32].

The study area is predominantly covered by a preserved native forest, where forest management has been taking place for approximately 20 years, as per Brazilian environmental regulations and Forest Certification requirements under the FSC (Forest Stewardship Council). Harvests comply with FSC regulations; each annual production unit (APU) can only be harvested again after a cycle of 30–35 years within a sustainable polycyclic forestry system. According to Silva [33], this cycle is highly recommended for use in dryland forests in the Brazilian Amazon (Figures 1–3).

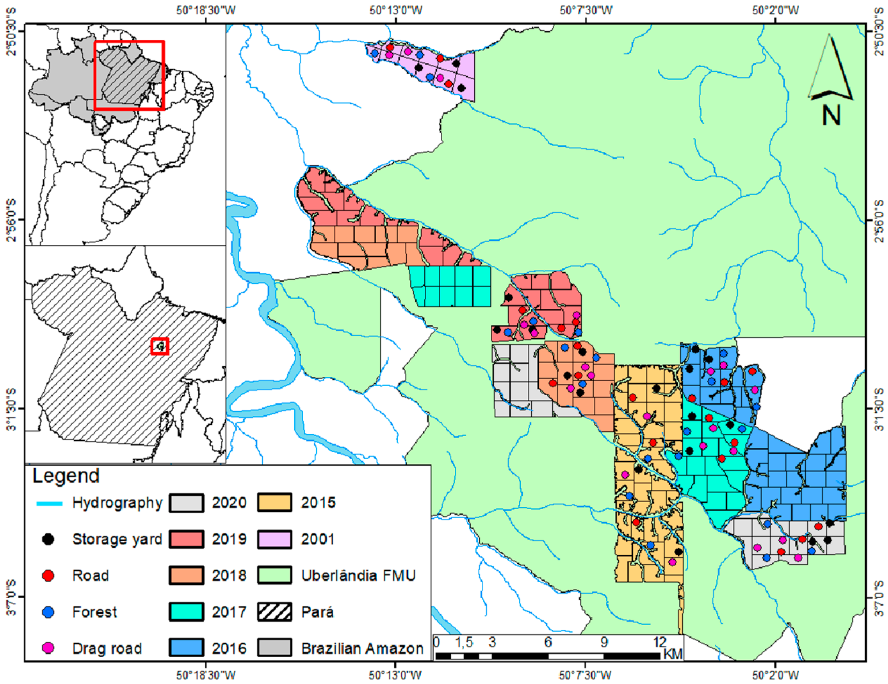

Figure 1. Map representing the transects in the APUs from 2002 to 2020 at the Fazenda Uberlândia Management Unit, southeastern Pará, Brazil, where samples of anurans were collected. Red box in the figure shows the geographic location in the Brazilian Amazon.

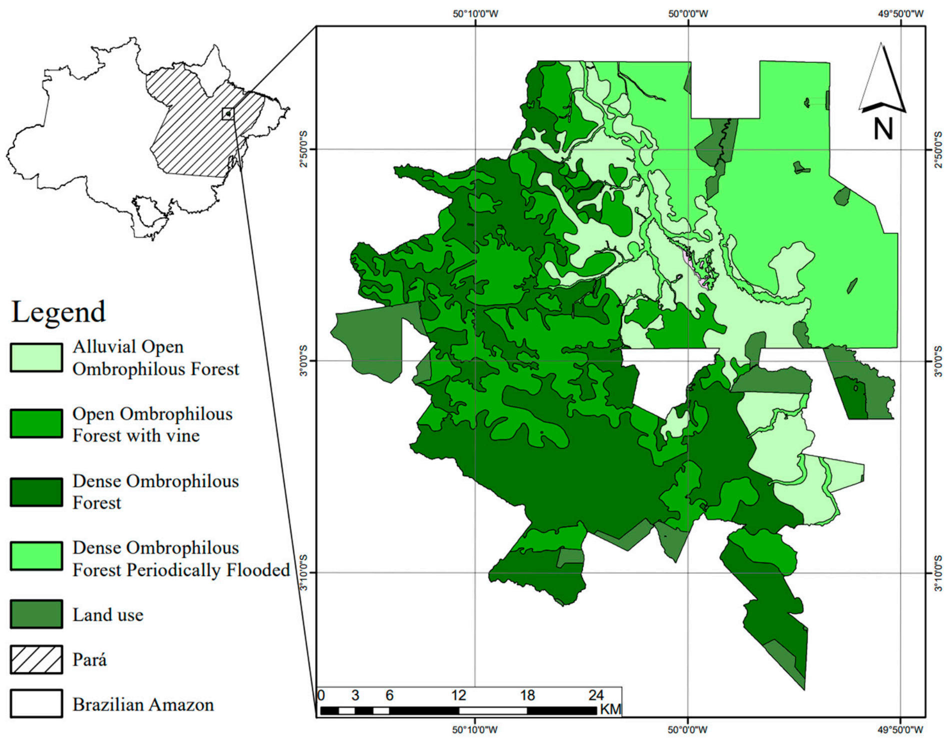

Figure 2. Characterization of the forest covers of the Fazenda Uberlândia Management Unit, southeastern Amazonia, Brazil, according to Santos et al. [34].

Figure 3. Types of environments sampled in the Fazenda Uberlândia Management Unit, southeastern Amazonia, Brazil. (**A**)—Skid trails, (**B**)—forest, (**C**)—secondary roads, (**D**)—secondary roads, (**E**)—storage yard, (**F**)—storage yard.

The area consists of four types of forest ecosystems: alluvial open ombrophilous forest, open ombrophilous forest with vines, dense ombrophilous forest, and periodically flooded dense ombrophilous forest [34] (Figure 2).

The total area of the locality is 153,115.03 ha. The managed area is 128,934.69 hectares, constituting the Fazenda Uberlândia Management Unit. It has 15 APUs that have already been explored, with about 3800 hectares of APU (ha/year) and 24,180.34 ha of natural forests under full protection [34]. In the APUs studied, every tree with a diameter at breast height (DBH) $\geq$ 40 cm is inventoried, and some are chosen for cutting in each work unit (WT), which are subdivisions of the APU where the exploitation occurs. The data provided by the company responsible for the concession indicate that an average of 2.69 trees/ha are removed from each APU.

2.2. Sampling

The effective management area of the Fazenda Uberlândia Management Unit is 128,934.69 hectares. For sampling, we selected seven APUs that had been explored at different time points (17, 7, 6, 5, 4, 3, and 2 years) (Figure 1), considering the final exploration time (maximum time, 17 years; minimum time, two years) and the distance between the APUs (maximum distance, 37 km; minimum distance, 2 km). Twelve transects separated by a minimum distance of 500 m were installed in each APU [11,35], where three transects were placed in each environment (storage yards, secondary roads, skid trails, and forests), totaling 84 transects. The environments types are characterized as follows (Figure 3).

Storage yards: Openings of 20 m $\times$ 25 m [35] located along secondary or main roads, with the function of storing and facilitating the exit of wooden logs from the WT. In these places, all vegetation and surface soil layers are removed to ease the movement of machinery and the storage of logs, which directly influence the local microclimate and soil compaction [36,37].

Secondary roads: Roads that aim to serve the traffic of large vehicles (buses, tractors, and trucks) during the operation period of each APU, connecting the storage yards to the main roads (Figure 3).

Skid trails: Signposted trails that aim to optimize and reduce the impact of log drag from the cutting site to the storage yards, in which skidders (articulated forest tractors, with 4×4, 6×6 or 8×8 traction, which drag trees cut from the trails) circulate. The smaller trees and leaflets are left in these skid trails to avoid direct soil exposure (Figure 3).

Forests: Native vegetation within the APUs, which have not been directly impacted by forest exploitation but are relatively close to the explored environments (Figure 3).

A minimum distance of 500 m between the transects was adopted to avoid pseudo-replication [11,35]. Daily sampling was carried out for 40 days in the middle of the rainy season (February to March) in each APU. We chose to perform this during this period since the sampling was conducted in one of the most intense phases of the COVID-19 pandemic. We used the visual encounter method [38] to capture adults/juveniles and tadpoles with a sieve [38]. Reproduction signs (newly metamorphosed juveniles or nests) were also recorded. Sampling was conducted in the morning (6:00 a.m. to 8:00 a.m.) for logistical reasons [39].

We sampled each environment using a 25 m transect, using the methodology of Ernst and Rödel [40] and Kpan et al. [13]. In order to standardize the size of sampled areas, we considered the sizes of the transects and the Brazilian standard for the size of the storage yards in forest management areas, equivalent to 25 m^2 [36]. In each transect, we measured the following environmental independent variables for statistical analysis: average litterfall height, temperature, and moisture, according to Bitar et al. [11,35], as well as the amount of light. The average litterfall height (cm) was measured with an upright ruler in contact with the ground at three points in each transect (beginning, middle, and end of the transect). Temperature (°C) and moisture (%) were measured using a thermohygrometer (Akso, model AK28) placed on the ground so that external temperatures would not influence the assessments. The amount of light (lux) was computed using a lux meter (lux meter, model MT-30) placed at the ground level, with three measurements made at each transect (start, middle, and end). All measurements were made between 6:00 a.m. and 8 a.m.

2.3. Sample Preparation

Three specimens of each taxon were sampled for collection and reference purposes. They were prepared as described by De Oliveira et al. [41]. Adult individuals were identified through direct comparison with identified specimens from the herpetological collection of the Laboratory of Zoology at the Federal University of Pará (Universidade Federal do Pará—UFPA), Altamira, Pará, Brazil, with the help of experts and using taxonomic keys provided by Cole et al. [42]. To identify tadpoles, we used the taxonomic keys of Hero [43] and Dubeux et al. [44]. All specimens were deposited at the Laboratory of Zoology of UFPA/Altamira. Regarding identification at the species group level, we used the studies of Pereyra et al. [45] for *Rhinella* gr. *margaritifera*, Fouquet et al. [46] for *Boana* gr. *geographica*, and Orrico et al. [47] for *Dendropsophus* gr. *microcephalus.*

2.4. Data Analysis

We performed a non-metric multidimensional scaling analysis (nMDS), using the abundance matrix of anurans (through two dimensions and Bray–Curtis dissimilarity (Figure 3). Subsequently, we applied the ENVIFT function to test the correlation of the following variables: post-exploitation time, environment type, luminosity, average litterfall height, temperature, and moisture on community ordination.

We used the multivariate extension of the generalized linear model (GLM) in the "mvabund" package available in R to analyze the effect of environment types (managed forests and conventional exploitation—secondary roads, skid trails, and storage yards) and time (APUs) on the richness, abundance, and composition of anuran species. In addition, we performed an additive GLM to test the effect of the independent variables on the anurans. Finally, we applied an interactive manylgm to test the effect of the significant variables in the additive GLM to identify which variables and interactions significantly affected each anuran species [13,47–49].

3. Results

We recorded 710 frog specimens from 19 species and/or groups of species (Figure 4), distributed in six families, of which 155 were juveniles (21.82%), 208 were tadpoles (29.30%), and 347 were adults (48.88%). Hylidae had the highest number of species, represented by three genera: *Boana* (one species), *Dendropsophus* (four species), and *Scinax* (one species). The species with the highest number of records was *Rhinella* gr. *margaritifera* (115 individuals in 41 transects), followed by *Leptodactylus mystaceus* (39 transects), and *Adenomera* sp. (29 transects) (Table S1).

Figure 4. Anuran species recorded in the Fazenda Uberlândia Management Unit, southeastern Amazonia, Brazil. (**A**)—*Rhinella marina*, (**B**)—*Pithecopus hypochondrialis*, (**C**)—*Leptodactylus pentadactylus*, (**D**)—*Physalaemus* sp., (**E**)—*Boana geographica*, (**F**)—*Pristimantis giorgii*. Photos at different scales.

The nMDS analysis grouped the anuran samples by environment type (Figure 5), pointing to a tendency of separation in the multivariate space. The ENVIFT result showed a significant effect of the variables' luminosity and environment type between treatments ($p > 0.002$; Figure 5). We also observed a spatial pattern between species (Figure 5): those that occurred in various environments are in the intersection region between the ellipses, e.g., *Amereega* sp. (Amersp), *Leptadactylus mystaceus* (Lepmys), and *Rhinella margaritifera* (Rhimar). Other species, found only at yards or secondary roads, are scattered on the edges of the graph: *Rhinella granulosa* (Rhigra), *Dendropsophus gr. microcephalus* (Denmic), and *Boana geographica* (Boageo).

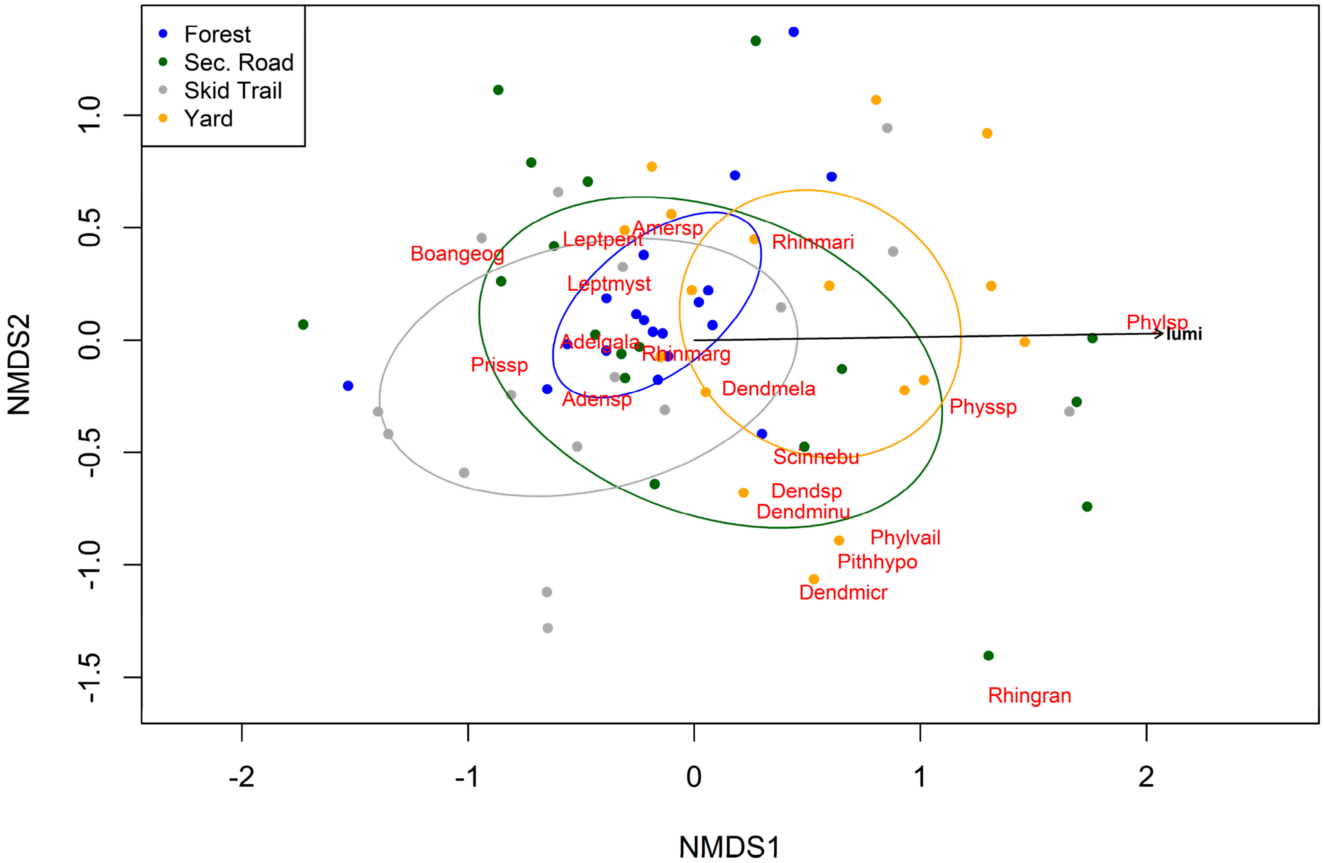

Figure 5. Non-metric multidimensional scaling analysis (nMDS) and ENVIFT based on anuran assemblage composition, considering the four environment types (forests, secondary roads, skid trails, and storage yards) sampled at the Uberlândia Farm Management Unit, southeastern Amazonia, Brazil. The shape and color represent the environmental impact of the forest management and conventional exploitation of the APUs. Amer: *Amereega* sp.; Rhmarg: *Rhinella* gr. *margaritifera*; Prist: *Pristimantis giorgii*; Adegal: *Adelphobates galactonotus*; Phys: *Physalaemus* sp.; Lepent: *Leptodactylus pentadactylus*; Lepmys: *Leptodactylus mystaceus*; Adeno: *Adenomera* sp.; Rhmari: *R. marina*; Scneb: *Scinax nebulosus*; Phyvail: *Phyllomedusa vaillantii*; Phylo sp.: *Phyllomedusa* sp.; Pithyp: *Pithecopus hypochondrialis*; Denmela: *Dendropsophus melanargyreus*; Denmin: *D. minutus*; Denmicr: *D.* gr. *microcephalus*; Dendro. sp.: *Dendropsophus* sp.; Boageo: *Boana geographica*; Rhigran: *R. granulosa*.

The managed forest environments showed little variation compared with the other environment types, as observed in the grouping of points on the graph representing the transects in the different environments (Figure 3). The points in the managed forests were less dispersed than the points in the other environments. Skid trails tended to be more similar to those in the managed forests. The storage yard and secondary road transects were more dispersed.

Regarding the homogeneity of the ellipses, it is notable that the managed forest sites were the most tightly grouped due to the similarity between the species that occur in those sites. In contrast, secondary roads had the least homogeneous ellipse because they showed a high abundance of specific species, causing their points to be far from the center of the ordination.

Our analysis also revealed that the different types of sampled environments affect the richness and abundance of amphibians (GLM: $p = 0.001$; Table 1).

Table 1. GLM model results summarizing the effect of different environment types on the richness and abundance of the amphibian assemblage in Fazenda Uberlândia, southeastern Amazonia, Brazil. Bold print and asterisks indicate statistical significance.

Variable	Res.	Df.diff	Dev Pr (>Dev)
(Intercept)	62		
Environment type	59	3102.6	**0.001** ***

The Anova.manyglm results on the effects of independent variables on the assembly of anurans showed significant differences for the environment type (p = 0.002), temperature (0.013), and APU (0.006) (Table 2).

Table 2. Anova.manyglm model results summarizing the effect of independent variables (environment type, luminosity, litterfall, moisture, temperature, and annual production unit (APU)) on the variability of richness and abundance of amphibian assemblage in the Fazenda Uberlândia. Bold print and asterisks indicate statistical significance.

Variable	Res.	Df.diff	Dev Pr (>Dev)
(Intercept)	62		
Environment	59	3102.56	**0.002** **
Luminosity	58	126.20	0.187
Litterfall	57	123.23	0.436
Moisture	56	117.29	0.771
Temperature	55	147.00	**0.013** *
APU	49	6137.59	**0.006** **

4. Discussion

The greater richness presented by Hylidae and Leptodactylidae in the present study seems to be related to three factors: the fact that these groups are common in neotropical environments [50], that Hylidae has a greater number of species in Brazil [51], and that the genera of these families have a wide geographical distribution in the Amazonia, being frequently recorded in the southeastern region [52].

Species richness, abundance, and composition differed significantly between APUs with different management times (2 to 17 years). These findings are in line with other studies on different taxa (birds and other groups of vertebrates and invertebrates ([53]—review); plants [54]; and anurans [55,56]). The richness, general abundance, and composition were indistinguishable between the forest and skid trail environments after 17 years since exploration activities had been carried out. However, the establishment of anuran communities was the lowest in the first five years after exploration had finished [57].

Hölting et al. [29] studied the effects of forest management on the beta diversity of anurans for the northern Amazonia in forest certified by the FSC. They studied short periods (two to four years after logging had ended) and found no significant differences between the sampling sites. Kpan et al. [13] identified a recovery of an amphibian assembly associated with litterfall in tropical forests in Côte d'Ivoire, French Guiana, detecting an increased similarity about 20 years after the end of forest harvesting and exploration. Although our results cannot be directly compared to those of Hölting et al. [29] since these authors did not analyze the selective cutting of wood and their study involved a short period (four years), they are congruent with the findings of Kpan et al. [13] in Côte d'Ivoire.

These differences in richness, abundance, and composition as a function of the forest management time can be related to the number of trees removed per hectare (approximately three trees/ha) (Table 1), which is in line with Adum [27]. This is reinforced by the study carried out in Côte d'Ivoire, French Guiana [13], which found that the number of trees removed per hectare could explain the similarity between the environments since the assemblies did not recover to previous levels, even 45 years after exploration with an average of 19.5 trees/ha [13,40,58].

The results of the studies mentioned above support our suggestion that a smaller number of trees removed per hectare relates directly to the forest richness, as it generates a greater diversity of plants and more refuges, preventing terrestrial and fossorial anurans (mainly juveniles in the dispersal process) from undergoing desiccation [59] while favoring a greater similarity between the environments. We consider that the water availability in the study sites due to the impacts of logging operations [16] enabled the greater richness of these genera since the success of species reproduction is closely related to the greater water availability [60,61]. Therefore, the reproductive strategy would strongly influence how the species react to environmental disturbances [22].

Landscape characteristics between the environments studied [62] and permanent streams crossing the exploited forests [27] provide evidence that these places serve as reservoirs for forest species. However, the dominance of generalist species was evident, in particular, in storage yard environments and secondary roads, as we recorded several individuals tolerant to disturbances not found in skid trails and forest environments. *Leptodactylous mystaceus*, *Rhinella* gr. *margaritfera*, *R. granulosa*, *R. marina*, *Adenomera* sp., *Pristimantis giorgii*, *Dendropsophus minutus*, and *Physalaemus* sp. are considered generalist species and were recorded only in storage yard and secondary road environments, with a high abundance.

All species cited as generalists, except for *Pristimantis giorgii*, have reproduction stages in standing water [60,61], suggesting that they were favored reproductively in these environments. A greater dispersal capacity added to their adaptation to open environments and their reproductive characteristics related to standing water [63,64] would allow these species to have higher populations in newly formed environments [16,24,65]. In the present study, we found that generalists were able to occupy both the unmanaged environments [11] and the new niches resulting from management [16,24].

Vallan [66] recorded a change in species composition four years after logging had ended in a tropical forest in eastern Madagascar and found that the species characteristic of untouched forests were outnumbered by species adapted to disturbed forests. A similar substitution process from specialist to generalist species was observed in forest fragments exploited for more than 10 years in the Taï National Park in Côte d 'Ivoire, French Guiana [67]. Miranda et al. [24] registered an anuran assembly more characteristic of disturbed forests in the Brazilian states of Acre and Amazonas after logging. They noticed a similar pattern to that of Vitt and Caldwell [16], also in the Amazonia, with a greater number of species found in the post-management period, as well as species reproducing in the new microhabitats. Therefore, species that adapt to disturbed locations are favored in the new environments resulting from management [58].

Vitt and Caldwell [16] reported that *Physalaemus cuvieri*, *Engystomops freibergi*, and several species of Bufonidae and Hylidae were favored reproductively in Central Amazonia through the formation of microhabitats, resulting from forest management operations. Furthermore, in areas where logging activities have degraded the forest, artificial puddles of standing water emerged, leading to an increased abundance of *Boana geographica* tadpoles and adults, suggesting that the reproduction of this species is favored in this environment [16].

From this, we infer that the anurans would use these artificially created environments in our study area as suitable places for reproduction due to the water availability and higher moisture levels that are adequate for their physiological needs [50,68]. In addition, they were the only environments in which tadpoles were present, indicating that the species are reproducing in a certain location. Moreover, in contrast to natural aquatic environments, these new habitats can last much longer, playing an important role in the dynamics of amphibian assemblages after exploration [29].

Popescu et al. [2] evaluated different exploration intensities and times on habitat use by specialist and generalist juvenile anurans. They found that specialist species avoided habitats where clear-cutting or selective management occurred compared to areas with no contrast in anuran composition. Our generalist species were favored by the presence of puddles resulting from forest management. Regarding post-exploitation time, Keenan and Kimmins [57] pointed out that the most significant effects of logging disturbance on amphibian habitat use probably occur in the first five years post-exploitation due to the adverse microclimatic conditions associated with canopy removal.

In addition, Crump [69] highlighted that road construction in managed areas directly influences the dynamics of the anuran community since they reproduce in standing water and are therefore exposed to potential dehydration, predation, and increased pollutants when moving from one reproduction site to another. The impacts of road construction on the anurofauna, specifically in management areas, can destroy the reproduction habitats of many species [12].

Anuran richness and the availability of water bodies are directly related [30,50,68,70], mainly during the reproduction season [71]. Storage yards and secondary roads provide perennial artificial pools for the species, helping to recover post-exploitation fauna [58] and thus favoring species that reproduce both in lotic and lentic environments.

Moreover, the water availability in these environments and the forest surrounding the storage yards make them less susceptible to abrupt changes in temperature and moisture, offering more stable and, therefore, more favorable habitats for a greater number of species in the short term than environments that may be at a successional stage characterized by the recolonization of native species and colonization of invasive species [72,73].

In the present study, species like *Leptodactylus mystaceus* and *Rhinella* gr. *margaritifera* were favored in these environments. This may be due to several factors; both species are larger than the others we found, and some studies point out an increased abundance of arthropods in clearings, showing that large animals, such as grasshoppers and spiders, are favored due to the vegetation complexity, which ranges from exposed soil to places with large accumulations of litterfall [17,18]. These invertebrates could serve as a food source for *Leptodactylus mystaceus* and *Rhinella* gr. *margaritifera* since they are too large to feed on smaller frogs. In addition, *Rhinella* gr. *margaritifera* is not highly dependent on humidity due to its drier skin, allowing it to tolerate the high temperatures and insolation rates caused by clearings [74].

5. Conclusions

Our results indicate that post-exploitation time and different environment types significantly influenced the structuring of the anuran communities in terms of species richness and abundance. In addition, the impacts that make original forest areas more open and more water-available environments lead to the replacement of typical forest species by others usually found in more open environments, which better tolerate disturbances and are better adapted to hydrological stress and high temperatures. Finally, this study shows that the effects of sustainable forest management and the responses of the local environment and their flora and fauna communities must be considered.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/land12071437/s1. Table S1. Table with the richness and abundance of anuran species at the Uberlândia farm, southeastern. Amazon, Brazil, considering the UPA/Year of exploitation and the type of environment. APU: Annual production unit; ENV: Environment (YARD; Secondary road = ROAD, Skid trail = SKID, and Forest = FOR); RIC: Wealth; ABU: Abundance. Amer: *Amereega* sp.; *Rhmarg*: *Rhinella* gr. *margaritifera*; *Prist*: *Pristimantis giorgii*; *Adegal*: *Adelphobates galactonotus*; *Phys*: *Physalaemus* sp.; *Lepent*: *Leptodactylus pentadactylus*; *Lepmys*: *Leptodactylus mystaceus; Adeno*: *Adenomera* sp.; *Rhmari*: *R. marina; Scneb*: *Scinax nebulosus*; *Phyvail*: *Phyllomedusa vaillantii*; *Phylo* sp: *Phyllomedusa* sp.; *Pithyp: Pithecopus hypochondrialis*: *Denmela*: *Dendropsophus melanargyreus*; *Denmin*: *D. minutus*; *Denmicr*: *D.* gr. *microcephalus*; *Dendro.* sp.: *Dendropsophus* sp.; *Boageo*: *Boana geographica*; *Rhigran*: *Rhinela granulosa.*

Author Contributions: Conceptualization, E.J.H.R., G.G.A.d.S., A.B.S. and F.O.d.N.P.; formal analysis, G.G.A.d.S.; data curation, E.J.H.R., A.B.S., G.d.S.A. and F.O.d.N.P.; original draft preparation, E.J.H.R., G.G.A.d.S., A.B.S., C.L.M., G.d.S.A. and F.O.d.N.P.; writing review and edition, E.J.H.R., G.G.A.d.S., A.B.S., C.L.M. and F.O.d.N.P.; visualization: E.J.H.R., F.O.d.N.P. and C.L.M.; supervision, E.J.H.R., G.G.A.d.S. and A.B.S.; project administration, E.J.H.R. All authors have read and agreed to the published version of the manuscript.

Funding: This research was partially funded by a scholarship granted to the first author (PPGCB/UFPA/CAPES); GB Florestal and LN Guerra provided logistical support. This study was supported by the Federal University of Pará-UFPA, through the qualified publication support program-PAPQ for paying the publication fee (process 23073.048269/2023-13).

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Acknowledgments: Programa de Pós-graduação em Biodiversidade e Conservação, Universidade Federal do Pará, Altamira, Pará, Brazil; Programa de Pós-graduação Bionorte, Instituto de Ciências Biológicas, Belém, Pará, Brazil; and Faculdade de Engenharia Florestal, Campus Universitário de Altamira, Universidade Federal do Pará, Altamira, Pará, Brazil; Ministry of Education, CAPES, Brazil. Referees and editors.

Conflicts of Interest: The authors declare no conflict of interest.

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