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Mining threatens isolated indigenous peoples in the Brazilian Amazon

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ABSTRACT

The largest concentration of isolated indigenous peoples in the world is in the indigenous lands of the Brazilian Legal Amazon. However, the right to self-isolation and the survival of these societies are at risk because powerful interests want to exploit the natural assets of their relatively untouched areas. These ambitions are reflected in a recent bill (PL191/2020), which proposes opening up indigenous lands to mining. We assess the threat imposed by mining to isolated peoples and the indigenous territories they occupy. Specifically, we cross data on mining requests received by the National Mining Agency with information on the distribution of isolated indigenous groups recorded by the Socio-Environmental Institute, in order to evaluate the number and aerial extent of requests for mineral prospecting and operation registered in indigenous lands with isolated groups. We also analyze whether mining requests are related to the presence of isolated groups, the state of knowledge about them, and the current existence of illegal mining operations. Our results indicate that, even though mining is not yet allowed in indigenous lands, mining companies are very active in the search for exploitable areas in these territories. If bill PL191/2020 passes, mining operations would affect more than 10 million hectares in 25 indigenous lands in the Legal Amazon region that are home to 43 isolated groups. We found that the situation is especially worrisome for 21 isolated groups whose lands concentrate 97% of all mining requests. Mineral-rich areas overlap remote areas where more indigenous peoples persist in isolation, so that mining requests are significantly related to the presence of isolated groups. Nonetheless, we show that companies are hesitant to invest in lands with well-known isolated groups that could impede the licensing process and pose reputational risks to the companies. Brazil's mechanisms for environmental and indigenous protection have been dismantled by the current presidential administration and offer no guarantees for a safe coexistence between extractive operations and isolated peoples. Thus, the approval of bill PL191/2020 could lead to undesired contact and the extinction of a large number of unique peoples, societies and cultures.

1. Introduction

The Brazilian Amazon is home to more isolated indigenous societies than any other region on the planet, with at least 120 groups that live isolated from the majority society (Black, 1992; Hemming, 1978, 2003; Ricardo and Gongora, 2019; Leal Filho et al., 2020) and speak approximately 50 native languages (Velden, 2010). These indigenous groups lack permanent relations with other societies, whether indigenous or not. Many of them are aware of the existence of other societies but have voluntarily chosen to exercise their right to self-isolation as a survival strategy after suffering historical episodes of contact associated with

violence or epidemics (OACNUDH, 2012; Amorim, 2016; FUNAI (Fundação Nacional do Índio), 2021). Thus, their isolation constitutes express manifestation of their autonomy and their will. Their rights of self-determination and self-isolation are protected in Brazil by the oldest and one of the most robust sets of policies in Latin America. These policies were established in 1987 after the tragic consequences of practices whose paradigm was to contact isolated groups (Amorim, 2016). The National Indian Foundation (FUNAI) even has a specific department dedicated to the identification and monitoring of isolated indigenous groups (FUNAI - General Coordination of Isolated and Recently Contacted Indigenous Peoples). In spite of this, these peoples

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are poorly known: the majority of records are just notifications by third parties, and only one-quarter of them have been verified through overflights or other means by FUNAI (Ricardo and Gongora, 2019).

The persistence of isolated societies is closely connected to protection of indigenous lands, as three-quarters of the known uncontacted groups occur in these territories (90 of 120 groups; Ricardo and Gongora, 2019). Indigenous lands were designed to defend the rights of both isolated and non-isolated indigenous peoples and cover 23% of Brazil's Amazon forest (ISA (Instituto Socioambiental), 2019a). Despite their effectiveness in providing protection, indigenous territories have historically been under pressure from the exploitation of their natural resources (Albert, 1992; Finer et al., 2008; Zhou, 2010; Bolanos, 2011; Ricardo and Gongora, 2019). Land invasion for ranching, logging and mining has resulted in undesired contact and the extinction of many indigenous peoples in the past, and invasion continues to threaten the groups that remain isolated (Walker et al., 2015, 2016; Walker and Hamilton, 2014; CIMI, 2018; Leal Filho et al., 2020; Vaz, 2013). One-third of the indigenous lands in the Brazilian Amazon have a registered interest for mining, and the region is one of the world's largest potential suppliers of minerals (Ferreira et al., 2014; Cordani and Juliani, 2019). Mining in Brazilian indigenous lands is not officially permitted, in spite of which numerous mining requests are continuously sent to Brazil's National Mining Agency (Villén-Pérez et al., 2018; ANM (Agência Nacional de Mineração), 2021), suggesting that mining companies are confident of future approval. The mining lobby has been pressing since 1996 to get regulating legislation passed, so far without success.

In 2020 Brazil's far-right president Jair Bolsonaro submitted bill PL191/2020 to the National Congress that would allow both mining and hydroelectric dams in indigenous lands. The President promised to open up the Amazon for business and specified indigenous lands as the main target (Abessa et al., 2019; Artaxo, 2019). Bolsonaro has repeatedly pledged not to demarcate "a single centimeter" of new indigenous territory and to integrate the indigenous peoples into the Brazilian society; both of these statements flout Brazil's Constitution of 1988 and legal obligations under international agreements on human rights to which the country is signatory, including the Indigenous and Tribal Peoples Convention ILO 169 (ILO, 1989). While bill PL191/2020 is under discussion in the National Congress, the president is preparing a decree to allow mining by international companies in 177 indigenous lands located near the country's borders, and the USA has been specifically encouraged to invest in this exploitation (Teodoro, 2020). The Brazilian government is also supporting legislative proposals that seek to paralyze the demarcation of new indigenous lands (Constitutional Amendment Proposal PEC 215) and to reduce already demarcated lands, opening the way for privatization and illegal invasion (PL490/2007). Bill PL490/2007 even opens the door to contact without the consent of isolated indigenous groups in case a given area is considered of *public utility*, a concept wide enough to include any development project, such as mining operations.

The Bolsonaro presidential administration has also worked to make environmental policy more permissive and to dismantle government agencies in charge of containing deforestation, conserving biodiversity and protecting indigenous peoples (i.e., IBAMA, ICMBio and FUNAI; ISA (Instituto Socioambiental), 2020; Barbosa et al., 2021). These institutions have been restructured, military officers have been appointed to many of the key positions, and the personnel and budgets have been reduced to the point that their activities have almost completely halted (Ferrante and Fearnside, 2020b). This directly threatens the isolated indigenous groups of the Brazilian Amazon (ISA (Instituto Socioambiental), 2020). For instance, authorizations for FUNAI expeditions to indigenous lands have been greatly bureaucratized, hindering *in situ* activities of the agency (INA (Indigenistas Associados), 2019). Moreover, a total of 35 groups were left unprotected when the official supervision of indigenous lands with incomplete demarcation was cancelled (Biasetto, 2019) and when the monitoring bases in the

Yanomami and Vale do Javari indigenous lands were shut down (Angelo, 2020). In addition, FUNAI has now opened the possibility of contacting isolated groups even during the COVID-19 pandemic, violating their right to self-determination and threatening their health (CIMI, 2020). Finally, a former evangelical missionary was appointed to head the FUNAI division for isolated Amazonian indigenous groups (Phillips, 2020). His previous participation in an extremist sect that focused its activity on contacting isolated indigenous groups makes him an obvious threat to the 120 indigenous groups that are voluntarily isolated in the Brazilian Legal Amazon and could see their numbers decimated due to epidemics derived from contact, whether intentional or not.

Mining can affect isolated indigenous peoples in multiple ways. First, extractive operations drive deforestation, reducing the territory usable by isolated groups and boosting the chances of undesired contact (Angelo, 2020; Siqueira-Gay et al., 2020; Quijano-Vallejos et al., 2020). About 20% of Brazil's Amazon forest has already been lost (INPE (Instituto Nacional de Pesquisas Espaciais), 2020; da Cruz et al., 2020), and approximately 9% of this is due to the direct or indirect consequences of mining (Sonter et al., 2017). Areas surrounding mining operations typically undergo an expansion of urbanization and transport infrastructure, and increased deforestation rates can be perceived up to 70 km from the mining operations (Sonter et al., 2014, 2017). Moreover, demographic changes associated with the arrival of the workforce contribute to the depletion of food resources in the forests and rivers in the area, compromising the livelihoods of the isolated communities (Hilson, 2002; Ricardo and Gongora, 2019). Mining can also affect isolated peoples through environmental pollution (Fernández-Llamaras et al., 2020). As a result of intensive gold mining, Amazonian people are among the most exposed to mercury in the world and report severe health problems (Passos and Mergler, 2008), and there is no reason to expect that these health problems have not reached isolated peoples through polluted waters and food resources. Finally, the invasion of indigenous territories by non-indigenous people brings diseases that can decimate indigenous populations (Walker et al., 2015). Isolated peoples do not have immunity to diseases that are common in the majority society, which means that even a brief contact can provoke a demographic catastrophe, as has repeatedly occurred in the past (Amorim, 2016). For instance, the massive recent invasion of the Yanomami Indigenous Land by goldminers has propagated COVID-19, provoking hundreds of indigenous deaths (Ferrante and Fearnside, 2020a; Santos et al., 2020; Palamim et al., 2020). Mining could have also driven the infection of isolated groups close to mining operations during the incursions of isolated members that have been reported in mining camps (Ricardo and Gongora, 2019; Fellows et al., 2021). Even in the absence of direct interaction, isolated peoples may suffer from regional increases in malaria incidence driven by mining camps (Valle and Tucker Lima, 2014). Thus, opening the door to mining in indigenous lands with isolated groups is expected to result in a chronicle of a death foretold.

Given the extended mining interests in indigenous lands, it is obvious that mining poses a threat to the 90 isolated groups that occupy indigenous territories in the Brazilian Legal Amazon (Ricardo and Gongora, 2019). However, the exact magnitude of the threat has never been assessed before. This will depend on the spatial coincidence between mining requests and isolated groups, and our hypothesis is that lands occupied by isolated peoples are not necessarily the most attractive for mining companies for various reasons. First, mining can be expected to be more profitable in more-developed regions with better operational and transport infrastructures (e.g., Duffy, 2012). These developed regions are less likely to maintain large numbers of isolated groups, given that indigenous peoples have predominantly remained isolated in remote areas (Kesler and Walker, 2015). Second, the establishment of mining operations in regions occupied by isolated indigenous groups has the risk of negatively affecting the reputation of the company. As a consequence, companies may avert planning mining operations close to

isolated groups. Moreover, given the controversy around regulating mining activities in lands with recognized isolated peoples, mining companies may prefer to invest in areas without isolated peoples or where these are poorly known. The controversy started when FUNAI recommended prohibiting mining operations in indigenous lands with isolated groups; a recommendation that was disregarded in bill PL191/2020 (Prazeres, 2020). The bill excludes operations only within the perimeter frequented by the isolated groups (PL191/2020, Art. 1° § 2°). The text specifies that FUNAI will be in charge of delimiting this perimeter, but this is very difficult given that only very scant information exists for 60 of the 90 isolated groups identified in the indigenous lands of the Brazilian Legal Amazon to date, and this information does not include any quantification of the territory they occupy (Ricardo and Gongora, 2019). In a scenario of policy uncertainty in which bill PL191/2020 is under discussion, mining companies may anticipate greater trouble in obtaining operating licenses in indigenous lands with well-known isolated peoples, which may reduce their interest in these areas.

Legal and illegal gold mining play a central role among the mineral commodities exploited in the Amazon (Sonter et al., 2017) and have provoked social and environmental impacts in successive gold-rush periods (Malm, 1998; Asner et al., 2013; Kahhat et al., 2019). In 2021 the price of gold has reached unprecedented values after increasing by ca. 800% in 20 years of successive world crises (Goldprice, 2021). The international demand for gold is increasing the pressure on relatively unexploited areas such as the Brazilian indigenous territories (Alvarez-Berríos and Aide, 2015) and has turned Brazil into one of the top ten producers of gold in the world (Reuters, 2020; World Gold Council, 2020). Most mining requests in Amazonian indigenous lands are for gold mining (Barros et al., 2016; Rorato et al., 2020), and these territories are currently experiencing an explosion of illegal gold-mining activity (MAAP (Monitoring of the Andean Amazon Project), 2020; Nascimento and Faleiros, 2020; Yeung, 2020; Tollefson, 2021). In a scenario of a new gold-rush, the interests of illegal and official mining are expected to coincide, such that illegal goldmining in indigenous lands should mirror official mining companies' requests. Mining companies could even study the location of illegal activities to identify potentially profitable spots. If this is the case, the approval of PL191/2020 would affect indigenous groups that are currently in a vulnerable situation due to illegal activities.

Many researchers have documented the impact that mining and other development projects have historically had on contacted and isolated indigenous peoples of the Amazon (e.g., de Carvalho, 1982; Fearnside, 1989, 2018; Passos and Mergler, 2008; Quijano-Vallejos et al., 2020; Ricardo and Gongora, 2019; Walker et al., 2015), and have called attention on the pervasive consequences of weakening environmental protection and regulating mining activities in Brazilian indigenous lands (Villén-Pérez et al., 2018; Ferrante and Fearnside, 2019; Siqueira-Gay et al., 2020; Villén-Pérez et al., 2020). However, none has analyzed the near-future consequences of these policy changes for isolated indigenous peoples.

Here we present the first quantification of the risk that the remaining isolated groups of the Brazilian Legal Amazon will confront in the near future if mining is legalized in indigenous lands. We also perform a novel analysis to understand whether the presence of isolated groups or the level of knowledge about them influences the preference of mining companies for an indigenous territory. We combine spatially explicit databases on mining requests (from the National Mining Agency), isolated indigenous groups (from the Socio-Environmental Institute), and indigenous lands (from FUNAI), to analyze the number and geographical extent of mining requests on indigenous lands where isolated indigenous peoples have and have not been reported. First, we test whether the presence of isolated groups is significantly related to the number of mining requests across all indigenous lands in the Brazilian Legal Amazon. We then focus on the subset of indigenous lands with isolated groups to assess the relative impact suffered by each land and to test whether the number of mining requests is related to the number of

isolated groups, to the level of knowledge about these groups and to the previous presence of illegal mining activities. These results are essential for discussions of bill PL191/2020 and for developing strategies to mitigate the potential impact of future mining operations on isolated peoples.

2. Methods

2.1. Indigenous lands and isolated indigenous groups

We compiled information on 90 isolated indigenous groups registered in the Brazilian Legal Amazon's indigenous lands, according to a study by the Socio-environmental Institute (ISA) (Ricardo and Gongora, 2019) that includes all FUNAI records and some derived from ISA's independent research. The resulting database included: (1) the name of the isolated group; (2) the indigenous land or lands in which the group is found; and (3) whether there is any reported impact of illegal wildcat mines (in Portuguese, *garimpos*) affecting the area. Also included was a classification of isolated groups into three categories based on the level of knowledge about them: *i*) "initial information" records are those that have been registered by FUNAI's General Coordination of Isolated and Recently-Contacted Indigenous Peoples (CGIIRC/FUNAI) but lack any further study; *ii*) "being studied" records are those registered by FUNAI that have stronger evidence of truthfulness but still lack a systematic study; and *iii*) "confirmed" records are those verified by FUNAI through overflights, field expeditions or other means (Ricardo and Gongora, 2019; FUNAI (Fundação Nacional do Índio), 2021). We excluded from this study 32 isolated indigenous groups whose territories are in the Brazilian Legal Amazon but outside of the boundaries of official indigenous lands and are located either in conservation units (27 records) or outside of any protected area (5 records). Finally, we considered that an indigenous land has illegal mining activity if Ricardo and Gongora (2019) reported that the activity affects any of the isolated indigenous groups recorded in the indigenous land in question.

We combined this database with a spatialized database of all Brazilian Indigenous Lands obtained from FUNAI (see Supplementary Fig. 1). This database includes information on the Regional Coordination Office of FUNAI in charge of each indigenous land and on the stage of the demarcation process of the indigenous land (i.e., "being studied," "delimited," "declared," "homologated" and "regularized"). The 90 records of isolated indigenous groups include four records that correspond to two groups where the same group was reported in two different indigenous lands. These were considered as independent groups for all analyses performed at the level of the indigenous land.

2.2. Mining requests

We obtained spatialized information on mining requests reported to the National Mining Agency (ANM (Agência Nacional de Mineração), 2021) by 28 August 2020. We therefore obtained additional information on those mining operations that are not yet active but are in a planning phase (see Villén-Pérez et al. (2018) for an interpretation of the different phases of the Brazilian licensing system). We made a distinction between (1) "research" (mineral prospecting) requests, which seek permission to investigate the mining interest of an area; and (2) operating requests, which are asking for permission for operation. These phases are consecutive, so an enterprise is expected to first investigate the potential of the area and then ask for an operating license. It has been shown that, upon licensing in Brazilian protected areas, most mining enterprises start their operations within eight years (Villén-Pérez et al., 2018). These mining requests can therefore be considered to represent mining planned for the near future.

Mining requests located outside indigenous lands were discarded, as were mining-request polygons located inside indigenous lands but smaller than 1 ha. When a mining request affected several indigenous lands, it was considered as a separate request in each land. We found

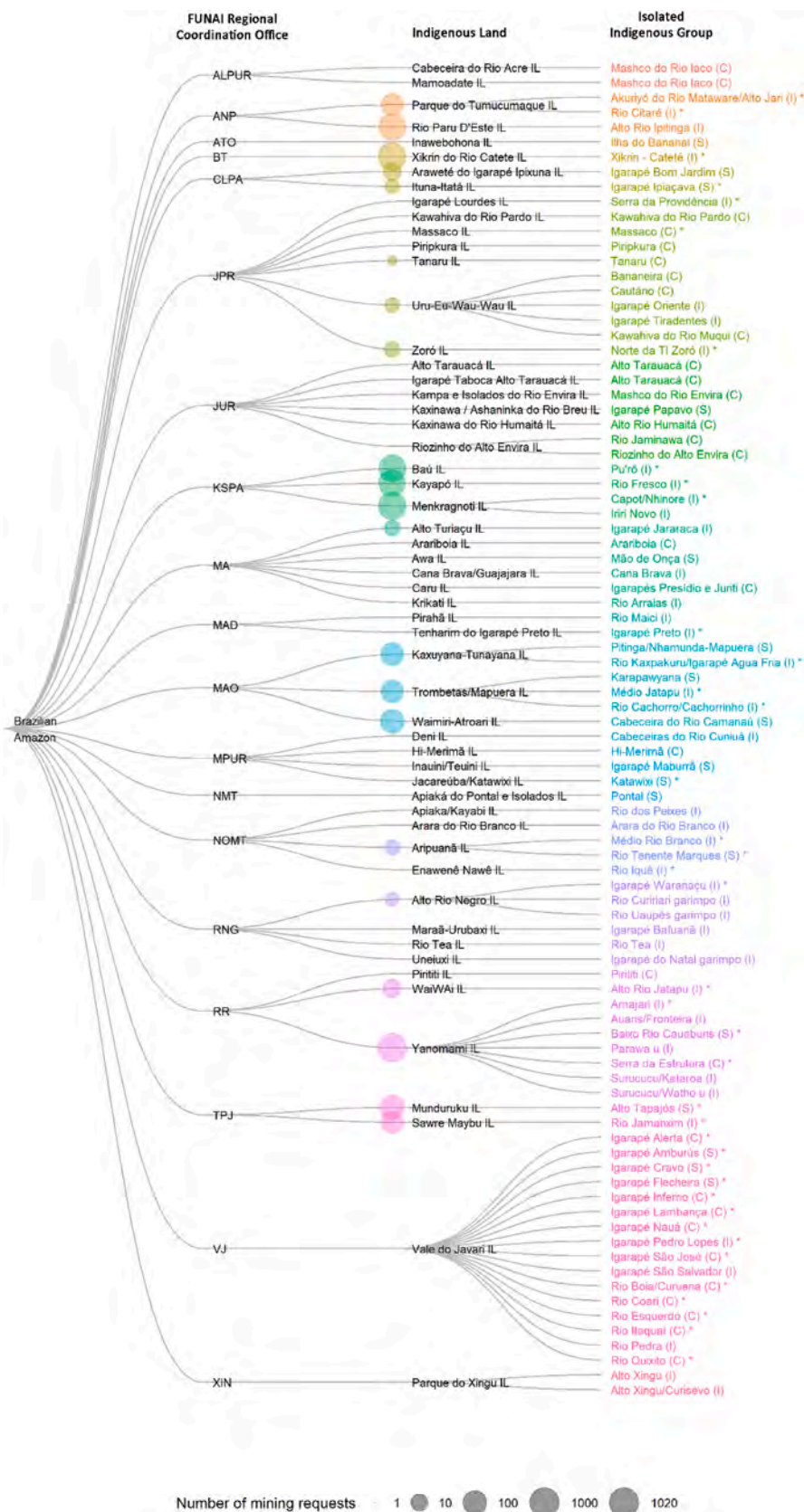


Fig. 1. Number of mining requests in indigenous lands in the Brazilian Legal Amazon that contain isolated indigenous groups. Indigenous lands are grouped by the FUNAI Regional Coordination Office in charge (see complete names in Supplementary Fig. 1). Isolated groups are classified into three categories: “confirmed” (C), “being studied” (S) and “initial information” (I). Asterisks indicate whether illegal mining activity has been previously reported in the isolated group’s territory. Mining requests include both research and operating-license requests.

spatial overlapping among mining requests, as well as between mining requests and mining projects that are already operative (see Villén-Pérez et al., 2018). Overlaps were corrected in order to avoid overestimating

the extent of the affected area. First, the area of research requests that overlap areas with operative mining was discarded, assuming that new requests will not progress in locations that are already being exploited.

Second, when two mining requests overlapped, the one in the earlier licensing phase was eliminated (i.e., operating requests prevailed over research requests) or either of the two in cases where both requests were in the same phase. Overlap correction affected only estimates of aerial extent of mining requests; no correction was applied in assessing the number of requests.

2.3. Analysis

We studied 55 indigenous lands in Brazil’s Legal Amazon region in which one or more isolated indigenous groups had been identified. For each indigenous land, we obtained the number of mining requests in the research and operating licensing phases and the area that would be occupied by these activities. We also calculated the size of each indigenous land. The boundaries of the polygons representing the mining requests delimit the area in which the mining operation is intended to be established. This area does not include any associated development such as transportation, urbanization or mineral processing infrastructure. The number of requests in an indigenous land is highly correlated with their total area of impact (see results below) so, for the sake of simplicity, we focused on the results for the number of requests.

We tested the relationship between the number of mining requests in indigenous lands and the presence or absence of isolated indigenous peoples, controlling for the size of the indigenous land. The sample for this analysis was all of the 386 indigenous lands in the Brazilian Legal Amazon. The number of mining requests across all indigenous lands follows a negative binomial distribution, with mean = 12.31, variance = 5,256 and theta parameter = 0.098 (standard error = 0.010). We developed a generalized linear model (GLM) specifying the log link function. The covariance matrix of estimated coefficients was produced using a method that takes into account the effect of leverage points and

the heteroscedasticity of residuals (Cribari-Neto and da Silva, 2011); specifically, we used the *vcovHC* function in the *sandwich* package in R software, defining type “HC4m.” The generalized variance inflation factor (GVIF) value was 1.0004 for all predictor variables.

We also tested the relationship between the number of mining requests in indigenous lands and the number of isolated groups, the level of knowledge about isolated groups, and the presence of illegal mining activity, controlling for the size of the indigenous land. In this case the sample size was 55 indigenous lands in the Brazilian Legal Amazon with reported isolated indigenous groups. The level of knowledge of the isolated groups was an ordered factor with three levels, considering that Confirmed > Being studied > Initial information. The level assigned to each indigenous land was the highest level of knowledge for the isolated groups in that land. The number of mining requests across these indigenous lands follows a negative binomial distribution, with mean = 66.3, variance = 32,569 and theta parameter = 0.169 (standard error = 0.040). We developed a generalized linear model and specified the log link function. The covariance matrix of the coefficient estimates was produced using the same method as in the analysis of presence or absence described earlier. GVIF values were 2.59, 1.29, 1.37 and 2.62 for the number of isolated groups, the level of knowledge of isolated groups, the presence of illegal mining activity and the size of the indigenous land, respectively. We used ArcGIS version 10.1 (ESRI Environmental Systems Research Institute, 2012) and R Software version 3.6.2 (R Core Team, 2019) for database processing and analyses.

3. Results

About half of the indigenous lands that contain isolated groups in the Brazilian Legal Amazon (25 lands, 45%) have registered interest for mining. These lands contain ca. half of the total number of isolated

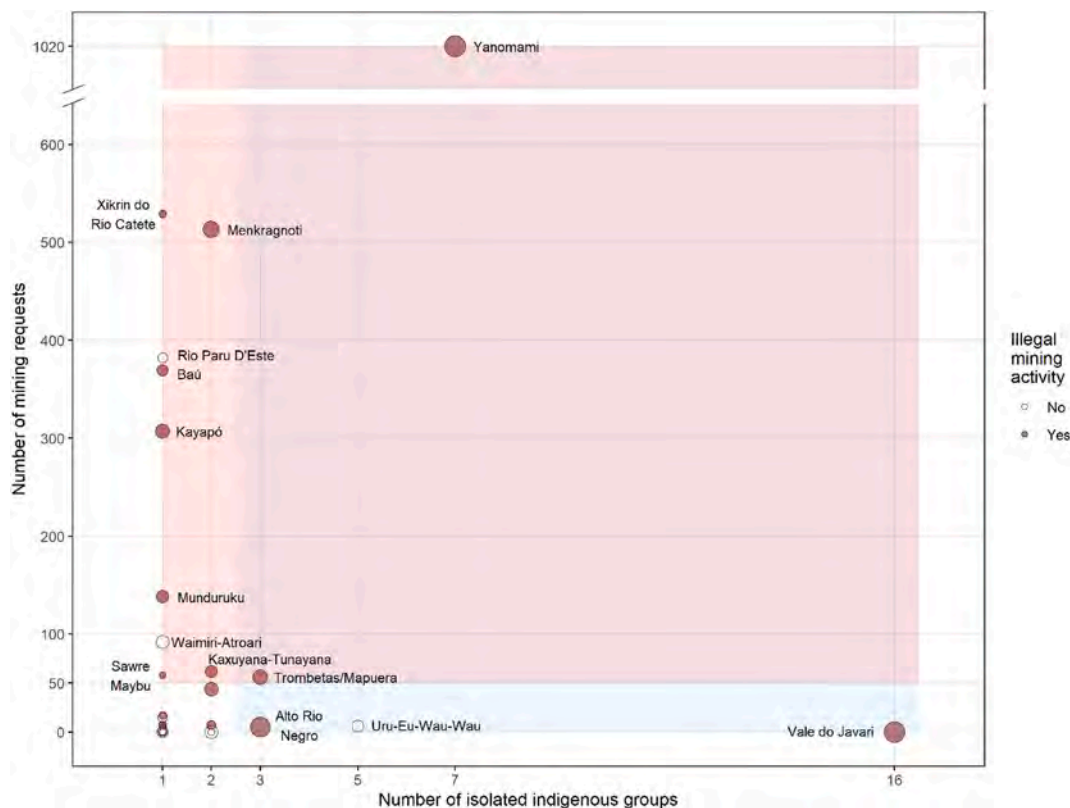


Fig. 2. Relationship between the number of mining requests in indigenous lands and the number of isolated indigenous groups reported in these territories. Each point represents an indigenous land, and the size of the point is proportional to the area of the territory. Red points indicate indigenous lands where illegal mining activity has been reported. The red area highlights the region with over 50 mining requests; the blue area highlights the region with 3 or more isolated groups; the purple area shows the region that met both conditions. Indigenous lands falling within the limits of any of these rectangles are labeled.

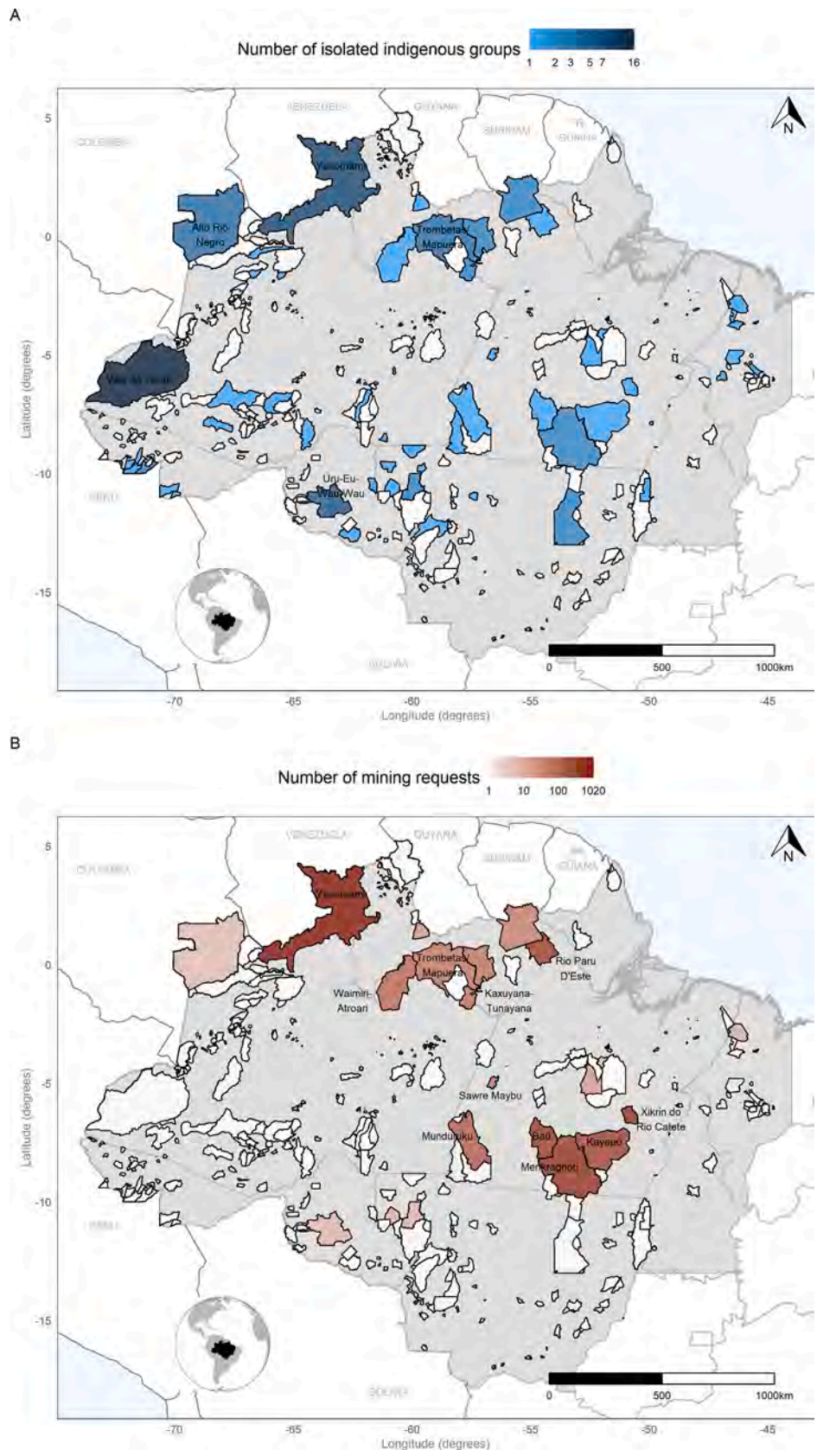


Fig. 3. Geographical distribution of indigenous lands in the Brazilian Legal Amazon, the number of isolated indigenous groups (A) and the number of mining requests (B). Indigenous lands with no isolated groups are in white in both maps. The Legal Amazon region is in gray. Indigenous lands with >3 isolated groups or >50 mining projects are labeled.

Table 1

Results of the GLM model for the number of mining requests across all indigenous lands in the Brazilian Legal Amazon. * = significant effect.

	<i>d.f.</i>	<i>Estimate</i>	<i>Std. Error</i>	<i>z value</i>	<i>Pr(> z)</i>
Intercept	383	3.014	0.316	6.189	<2·10 ⁻¹⁶ *
Isolated indigenous peoples (Presence Absence)	383	-1.591	-6.102	-5.480	<2·10 ⁻¹⁶ *
Size of indigenous land (ha)	383	-8·10 ⁻¹¹	-0.936	1.587	0.349

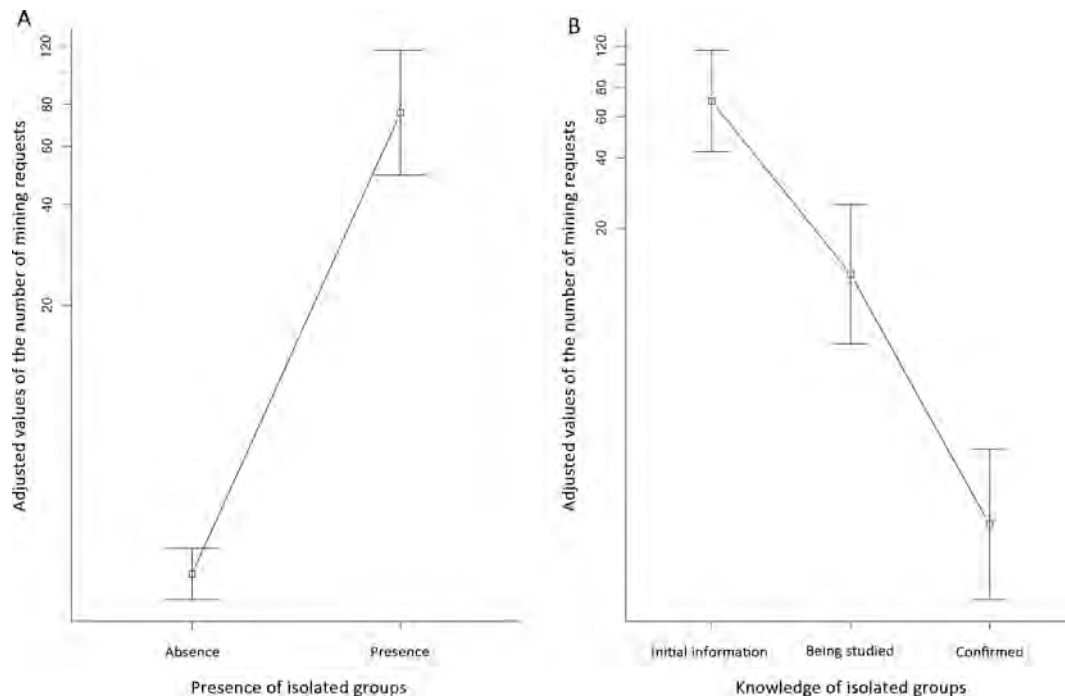


Fig. 4. Partial effects of significant factors affecting the number of mining requests in all 386 indigenous lands in the Brazilian Legal Amazon (A) and in 55 indigenous lands in the Brazilian Legal Amazon with reported isolated indigenous groups (B). A) Adjusted values for the presence or absence of isolated groups in the indigenous land. B) Adjusted values for the three levels of knowledge of indigenous isolated groups. Squares and intervals represent adjusted means and standard errors, respectively. The level of knowledge of the isolated group indicates the highest level of knowledge of the isolated groups in the indigenous land, considering that Confirmed > Being studied > Initial information.

Table 2

Results of the GLM model for the number of mining requests across indigenous lands in the Brazilian Legal Amazon with isolated indigenous groups. * = significant effect.

	<i>d.f.</i>	<i>Estimate</i>	<i>Std. Error</i>	<i>z value</i>	<i>Pr(> z)</i>
Intercept	49	1.460	1.030	1.417	0.156
Number of isolated indigenous groups	49	-0.155	1.008	-0.153	0.878
Knowledge of isolated groups (Being studied Confirmed)	49	-2.761	0.661	-4.179	< 2·10 ⁻¹⁶ *
Knowledge of isolated groups (Initial information Being studied)	49	-0.158	0.484	-0.327	0.744
Illegal mining (Presence Absence)	49	-0.506	0.436	-1.159	0.246
Size of indigenous land (ha)	49	8·10 ⁻⁷	4·10 ⁻⁷	2.063	0.039

indigenous groups (43 groups, 48%; Fig. 1). Eleven of these lands (20% of the total) have more than 50 mining requests (Fig. 2) and account for 96.7% of all mining requests (i.e., 3526 requests). These highly threatened indigenous lands contain 21 isolated groups (24% of the total). Isolated groups are distributed in indigenous lands all across the Brazilian Legal Amazon, although the indigenous lands with the highest numbers of isolated groups are located in the western half of the region (Fig. 3A, Supplementary Fig. 2). Mining requests are concentrated in indigenous lands in the central and northern parts of the region (Fig. 3B).

Indigenous lands with isolated indigenous groups have a total of 3645 mining requests occupying 10.6 million ha. Mining requests occupy a substantial portion of some indigenous lands. Specifically, they affect more than 20% of the area of nine lands, occupying up to 82% of a

single land (Supplementary Fig. 3). Most requests (93.5%) are research requests (Supplementary Fig. 4), and these occupy most of the affected land (95.5%). In each affected indigenous land, the number of mining requests ranges from 1 to 1020 and the total area of impact ranges from 11 ha to 3.3 million ha (Supplementary Fig. 5). The number of mining requests registered in an indigenous land is highly correlated with the area they occupy regardless of the type of request, considering all requests (Spearman correlation coefficient $\rho = 0.986$, Supplementary Fig. 6A), only research requests ($\rho = 0.995$, Supplementary Fig. 6B) or only operating-license requests ($\rho = 0.990$, Supplementary Fig. 6C).

The number of mining requests across all indigenous lands in the Brazilian Legal Amazon is significantly and positively correlated with the presence of isolated indigenous peoples, but not with the area of the indigenous land (Table 1, Fig. 4A). This model is globally significant (p-

value $\ll 0.001$, d.f. = 383, Chisq = 58.57) and explains 21.6% of the variation.

The number of mining requests in the indigenous lands that contained isolated indigenous groups is significantly and negatively related to the level of knowledge about isolated groups (Table 2, Fig. 4B). This model was globally significant (p-value $\ll 0.001$, d.f. = 49, Chisq = 23.88), and explained the 41.7% of the variation. Illegal mining reported by Ricardo and Gongora (2019) affects 39 isolated groups (43% of the total) located in 21 indigenous lands (Figs. 1 and 2), although this factor is not significantly related to the number of mining requests in indigenous lands.

4. Discussion

Mining companies have declared interest in ca. 10 million ha of indigenous land in the Brazilian Legal Amazon, where 43 indigenous groups persist in isolation. The implementation of these operations is pending approval of bill PL191/2020 that would open up indigenous lands to mining. The situation is especially worrisome for 21 isolated groups whose lands concentrate 97% of all mining requests, and the Yanomami land, which protects seven isolated groups on the frontier with Venezuela, is the most affected in terms of both the number of requests and potential area of impact (Fig. 2 and Supplementary Fig. 5). Mining requests affect 15% of the total extent of the indigenous lands that protect isolated groups in the Brazilian Legal Amazon, a percentage similar to the effect for the complete set of indigenous lands (Rorato et al., 2020). Remarkably, mining requests in some lands leave little space for the original purpose of protecting indigenous rights. This is the case for medium-size lands, such as Xikrin do Rio Catete or Baú, which have reported mining interests that cover ca. 80% of the area. PL191/2020 does not specify any upper limit on occupation of indigenous lands by mining, so these numbers could be achieved if the bill is approved by the National Congress.

Mineral-rich areas coincide with those where indigenous groups have persisted in isolation, so that the number of mining requests is significantly correlated with the presence of isolated indigenous groups (Table 1, Fig. 4A). Mining requests are concentrated in two parts of the region: one in Roraima state and the far-northern portions of Amazonas and Pará states, and the other in southern Pará (Fig. 3B). These areas correspond to the Guiana and Brazilian shields, respectively, which are more mineral rich than the sedimentary areas either along the Amazon River or in Acre and neighboring areas in Amazonas (Klein et al., 2018; Cordani and Juliani, 2019). The isolated indigenous peoples are mostly along Brazil's western and northern borders, where there has been relatively little presence of non-indigenous Brazilians as compared to the other parts of the region (Kirby et al., 2006). The areas that have long been exposed to non-indigenous contact along the Amazon River and in the eastern part of the region have few isolated peoples (Fig. 3A). Where the concentration of isolated groups and the concentration of minerals intersect, as in the Yanomami Indigenous Land in Roraima and in the Mundurucu areas in southern Pará, the result is disastrous. In addition to the shield areas where igneous rocks associated with the cratons result in mineral concentrations, the sedimentary areas are also threatened due to a different mineral attraction: oil and gas. The "Solimões Sedimentary Basin" project now poses a threat to isolated indigenous peoples in the western part of the state of Amazonas (Fearnside, 2020a–c).

Notably, we found that mining companies are hesitant to invest in lands with a confirmed presence of isolated groups (Table 2, Fig. 4B). This is probably both because a mining licensing could be more likely to be barred if the project affects well-known isolated peoples and because of greater reputational risk to the companies. The current text of bill PL191/2020 specifies that mining operations will not be allowed within

the perimeter frequented by isolated groups, but it does not specify any priority status to isolated groups that are categorized as confirmed, in comparison with those being studied or initial information. Nonetheless, mining companies may be aware that, at best, FUNAI will be able to provide information about the perimeter used by groups categorized as confirmed, for which more information is available (Ricardo and Gongora, 2019; FUNAI (Fundação Nacional do Índio), 2021). As a consequence, they are avoiding requesting mining licenses in lands with confirmed isolated groups but not in those with groups being studied or initial information.

The behavior of corporations and other economic actors has been the subject of considerable research and theory in the field of economics. One important factor in these decisions is the degree of risk aversion of the different actors, and this is related to the type of risk and the size of the company or other actor that is considering a venture. Larger actors have consistently been found to be less willing to take major risks (e.g., Chen and Lin, 1998). This can be expected to be particularly important for reputational risks (Holzman, 2020; RMF, 2020). Damage to a large company's reputation can affect profits in a wide range of the company's activities beyond the specific area of the venture in question. In terms of mining in Amazonia, actors range from individual wildcat gold miners (*garimpeiros*) to large international companies. Wildcat gold miners have little concern for their reputation, but actors applying for prospecting and operational permits are generally corporations. Our finding that applications are significantly less likely to be filed for indigenous areas with well-known isolated groups than in areas either without isolated groups or that lack reliable information on these groups is consistent with the expected effect of reputational risk aversion.

This novel result highlights the urgent need to study and confirm the existence of all isolated groups for their protection, first to dissuade companies from investing in their lands and then to be able to provide information about their location if bill PL191/2020 is approved. Even in recent times, new isolated groups are recorded at a much faster rate than they are studied: in the decade from 2006 to 2016, the number of groups with initial information or being studied increased by 36, while only 7 groups were confirmed (Amorim, 2016). Only one more group was confirmed by 2019 (Ricardo and Gongora, 2019), and this type of FUNAI activity has been almost completely paralyzed since Bolsonaro took office in January 2019 (Ferrante and Fearnside, 2020b). Here we empirically demonstrate that the activities of FUNAI's General Coordination of Isolated and Recently Contacted Indigenous Peoples and non-governmental organizations such as the Socio-Environmental Institute (ISA) are essential for the protection of isolated indigenous groups. We therefore urge the government to provide the operational and financial conditions to the National Indian Foundation to keep on studying the 91 unconfirmed records of isolated indigenous groups in the Brazilian Legal Amazon.

Our results indicate that, even though mining is not yet allowed in indigenous lands, mining companies are very active in the search for exploitable areas (see proportion of research requests in Supplementary Figs. 3 and 4). It seems that these companies want to be well-positioned for the opening of indigenous lands to mining (Angelo and Jordan, 2020). Even though the pressure on indigenous lands is lighter than is the case for conservation units (protected areas for biodiversity) where mining activity is explicitly permitted (Villén-Pérez et al., 2018), it seems that the costs of investing in indigenous lands are seen as financially justified. Government policy positions and decisions are key to protecting isolated indigenous groups. Illegal invasions and mining in indigenous lands increased greatly in 2019, 2020 and 2021, together with deforestation rates (HRW, 2019; da Cruz et al., 2020; Angelo, 2020; INPE (Instituto Nacional de Pesquisas Espaciais), 2020; MAAP (Monitoring of the Andean Amazon Project), 2020). The increase stems from

the general lack of supervision in the Amazon together with the perverse discourse of Brazil's President and his Environmental Minister¹ (Ferrante and Fearnside, 2019; *Jornal Nacional*, 2020). Hundreds of indigenous leaders and scientists have raised their voices against President Bolsonaro's policies, illegal mining and bill PL191/2020, which they consider to be a project for genocide, ethnocide and ecocide (de Almeida et al., 2019; Fórum de Lideranças Yanomami e Ye'kwana, 2019; Forsetto, 2020; Hutukara Associação Yanomami, 2020; INPE (Instituto Nacional de Pesquisas Espaciais), 2020; Raoni, 2020; SBPC (Sociedade Brasileira para o Progresso da Ciência) and INPA (Instituto Nacional de Pesquisas da Amazônia), 2020; UNIVAJA, 2020; Ferrante and Fearnside, 2021). Isolated indigenous peoples are even more vulnerable to human-rights violations (ISA (Instituto Socioambiental), 2020; Phillips, 2020) and to the consequences of pandemics such as the COVID-19 (Ferrante and Fearnside, 2020a; COIAB, 2020; Wallace, 2020; Campanha Fora Garimpo Fora Covid, 2021).

We initially hypothesized that official mining requests would coincide with illegal mining spots, increasing the pressure on areas that are already suffering the impact of illegal activities, but our results show that this is not a generalizable pattern (Table 2). For instance, the Vale do Javari Indigenous Land, which protects 16 isolated groups, has been repeatedly invaded by illegal miners (UNIVAJA, 2020) even though there are no official mining requests registered for this territory. This decoupling may be explained because illegal mining focuses on a smaller set of minerals than industrial mining run by companies and, as a consequence, their distributions do not necessarily overlap (Quijano-Vallejos et al., 2020). Nonetheless, special attention should be paid to the territories where mining requests do add to current illegal mining. The most striking example is the Yanomami land, which has historically suffered from illegal mining invasions. Mortality during a massive invasion of this land by wildcat goldminers, best known for the 1993 Haximu massacre, left a clear mark on the demographic structure of the surviving Yanomami (Nilsson and Fearnside, 2017). In 2021 the Yanomami are facing a new large-scale invasion by illegal gold miners (Survival, 2019; Montel, 2021). They have asked for help in their struggle against the invasion of miners and the associated risks of epidemics (ISA (Instituto Socioambiental), 2019b; Campanha Fora Garimpo Fora Covid, 2021), but are "utterly abandoned" by Brazilian government authorities in facing this threat (Branford, 2020). Isolated groups in the Yanomami Indigenous Land may be at high risk of contact, as airstrips for illegal mining and miners are reported to be only 5 km away from some of them (Ricardo and Gongora, 2019; Palamim et al., 2020).

5. Conclusion

Here we show that, if bill PL191/2020 is passed, indigenous lands of the Brazilian Legal Amazon could be legally invaded for mining and other activities, even to the point of completely occupying many of these territories. This would cause incalculable damage not only to indigenous peoples but also to the ecosystem services provided by these protected forests. For the first time, we have quantified the threat that mining imposes to isolated peoples in the Brazilian Amazon in the near future. Indigenous lands with isolated groups are threatened by more than 3600 mining requests to date, and the National Mining Agency of Brazil is working to attract even more investors. Interest in Brazil's indigenous lands is expected to peak if mining activity is officially allowed, as

¹ This refers to Brazilian Environment Minister Ricardo Salles, who quit on 23 June 2021 facing a criminal investigation of whether he allowed and profited from illegal wood exports from the Amazon rainforest. He was replaced by Joaquim Álvaro Pereira Leite, who was the head of the ministry's department of "Amazonia and Environmental Services" where he implemented the Bolsonaro administration's policies favoring agribusiness in the Amazon region (Chiappini, 2021).

occurred in the Amazonian portions of neighboring countries. Even though Brazil has robust policies aimed at protecting isolated indigenous peoples, governance difficulties in the Amazon have been aggravated in the current Brazilian political scenario, and there is no guarantee of a safe coexistence between mining operations and isolated indigenous peoples. Moreover, we have demonstrated that the paralysis of the activities of FUNAI put them at risk on the long-term because the now-paralyzed study of isolated groups serves to protect them. Our results indicate that the government should invest in studying the locations and vulnerabilities of the isolated indigenous groups reported in the Brazilian Legal Amazon, and should not permit any increased development pressure that could result in undesired contact and consequent extinction of unique peoples, societies and cultures.

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CRedit authorship contribution statement

Sara Villén-Pérez: Conceptualization, Methodology, Software, Formal analysis, Data curation, Writing – original draft. **Luisa Anaya-Valenzuela:** Data curation, Software, Validation. **Denis Conrado da Cruz:** Writing – original draft. **Philip M. Fearnside:** Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.gloenvcha.2021.102398>.

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Mining threatens isolated indigenous peoples in the Brazilian Amazon

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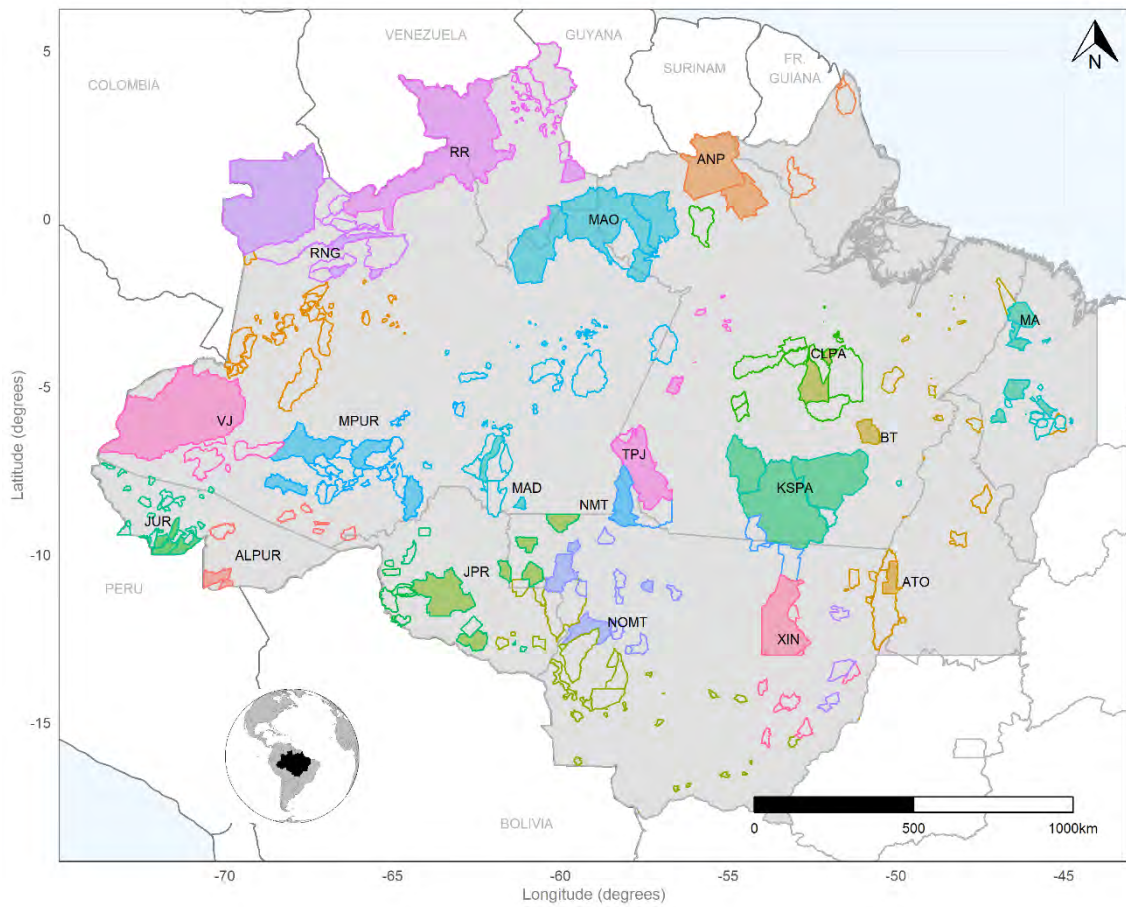
SM Fig. S-2. Geographical distribution of isolated indigenous groups under information, under study and confirmed within indigenous lands in the Brazilian Legal Amazon.

SM Fig. S-3. Percentage of the area of indigenous lands in the Brazilian Legal Amazon with reported isolated indigenous groups that is affected by mining requests.

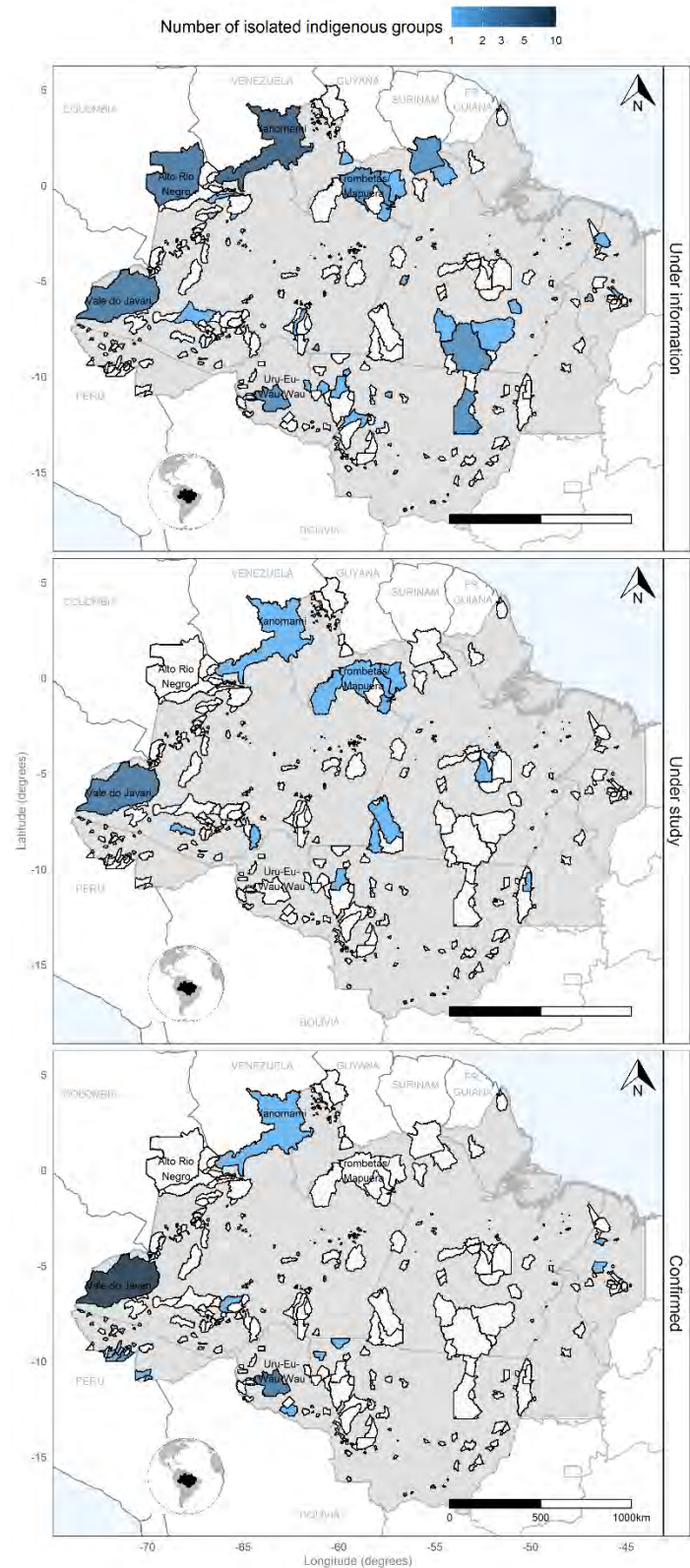
SM Fig. S-4. Number of research and operating-license requests in eleven indigenous lands that have more than 50 mining requests.

SM Fig. S-5. Number and area of mining research and operating-license requests in indigenous lands that have reported isolated indigenous groups.

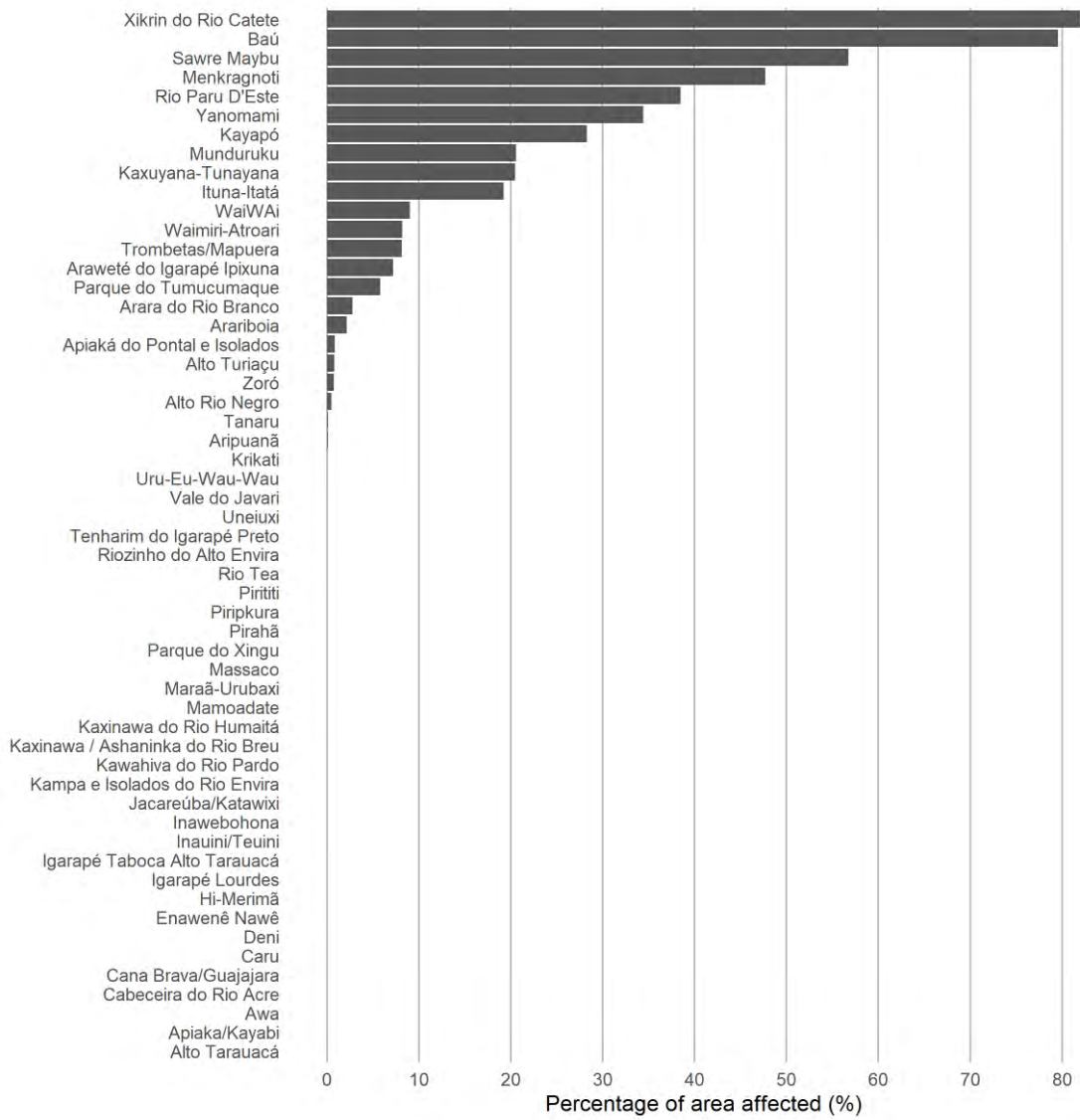
SM Fig. S-6. Correlation between the number of mining requests and their area of impact in indigenous lands that contain isolated groups.



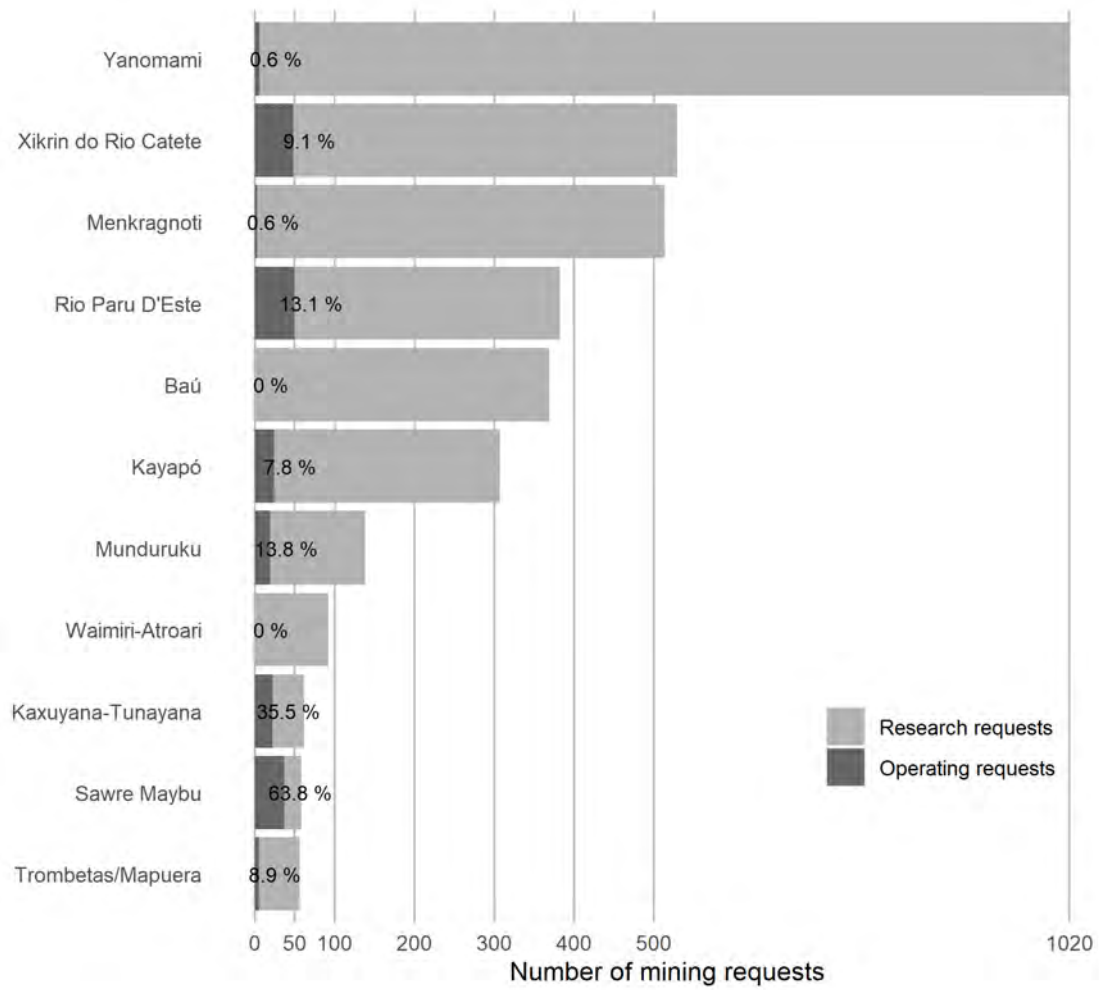
SM Fig. S-1. Geographical distribution of indigenous lands with isolated indigenous groups (filled) and with no isolated groups (open). All indigenous lands are colored in accord with the FUNAI Regional Coordination in charge of them, as in Figure 1 in the main text. The acronyms of Regional Coordinations with any record of isolated indigenous groups are indicated. The gray area represents the Legal Amazon. Brazilian state boundaries are indicated with light gray lines and international countries are represented with darker gray lines. ALPUR - Alto Purus; ANP - Amapá e Norte do Pará; ATO - Araguaia Tocantins; BT - Baixo Tocantins; CLPA - Centro-Leste do Pará; JPR - Ji-Paraná; JUR - Juruá; KSPA - Kayapó Sul do Pará; MA - Maranhão; MAD - Madeira; MAO - Manaus; MPUR - Médio Purus; NMT - Norte do Mato Grosso; NOMT - Noroeste do Mato Grosso; RNG - Rio Negro; RR - Roraima; TPJ - Tapajós; VJ - Vale do Javari; XIN - Xingu.



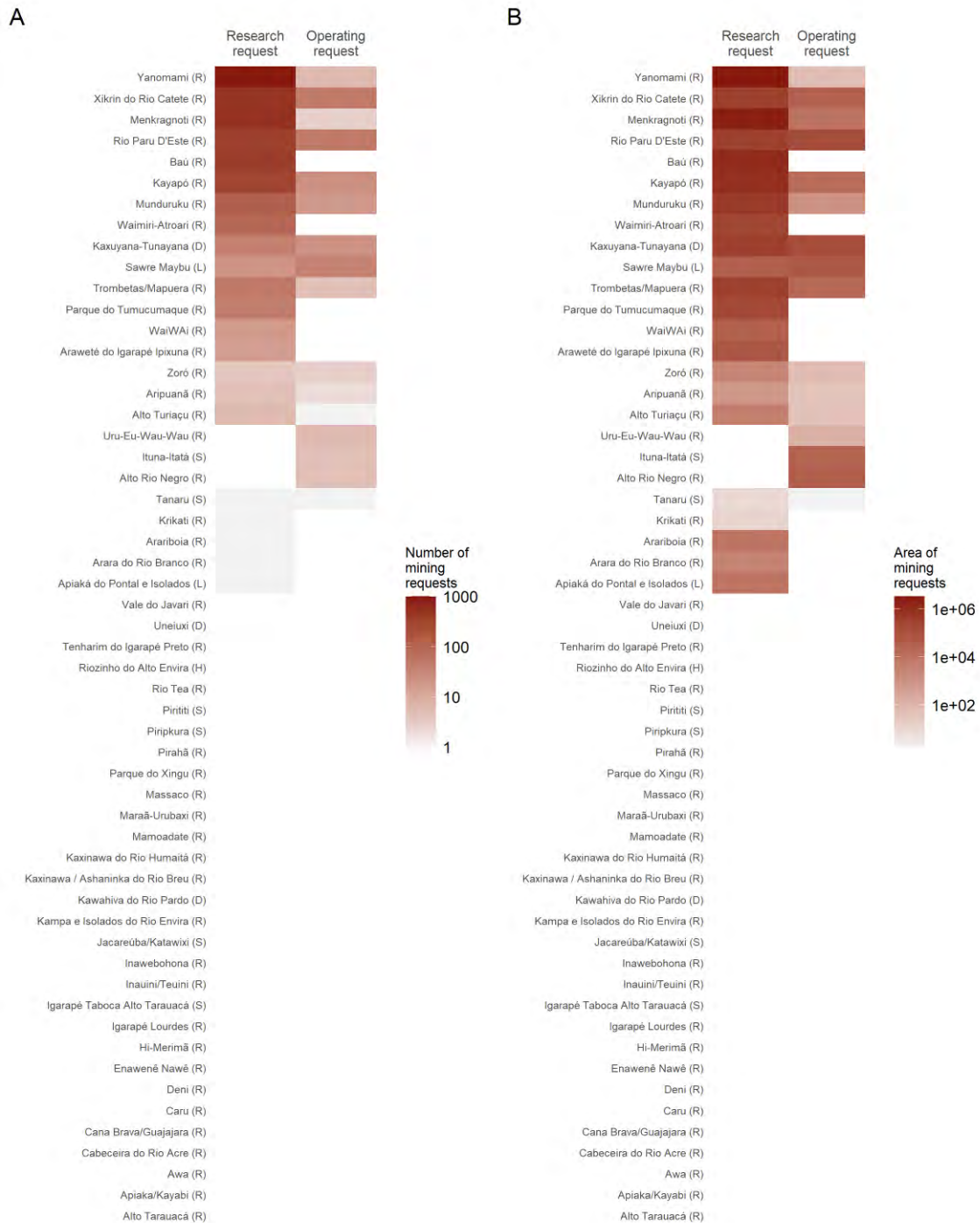
SM Fig. S-2. Geographical distribution of indigenous lands in the Brazilian Legal Amazon, and the number of isolated indigenous groups separated by level of knowledge. Indigenous lands with no isolated groups are in white in all maps. The Legal Amazon is in grey. Indigenous lands with a total of >3 isolated groups or >50 mining projects are labeled.



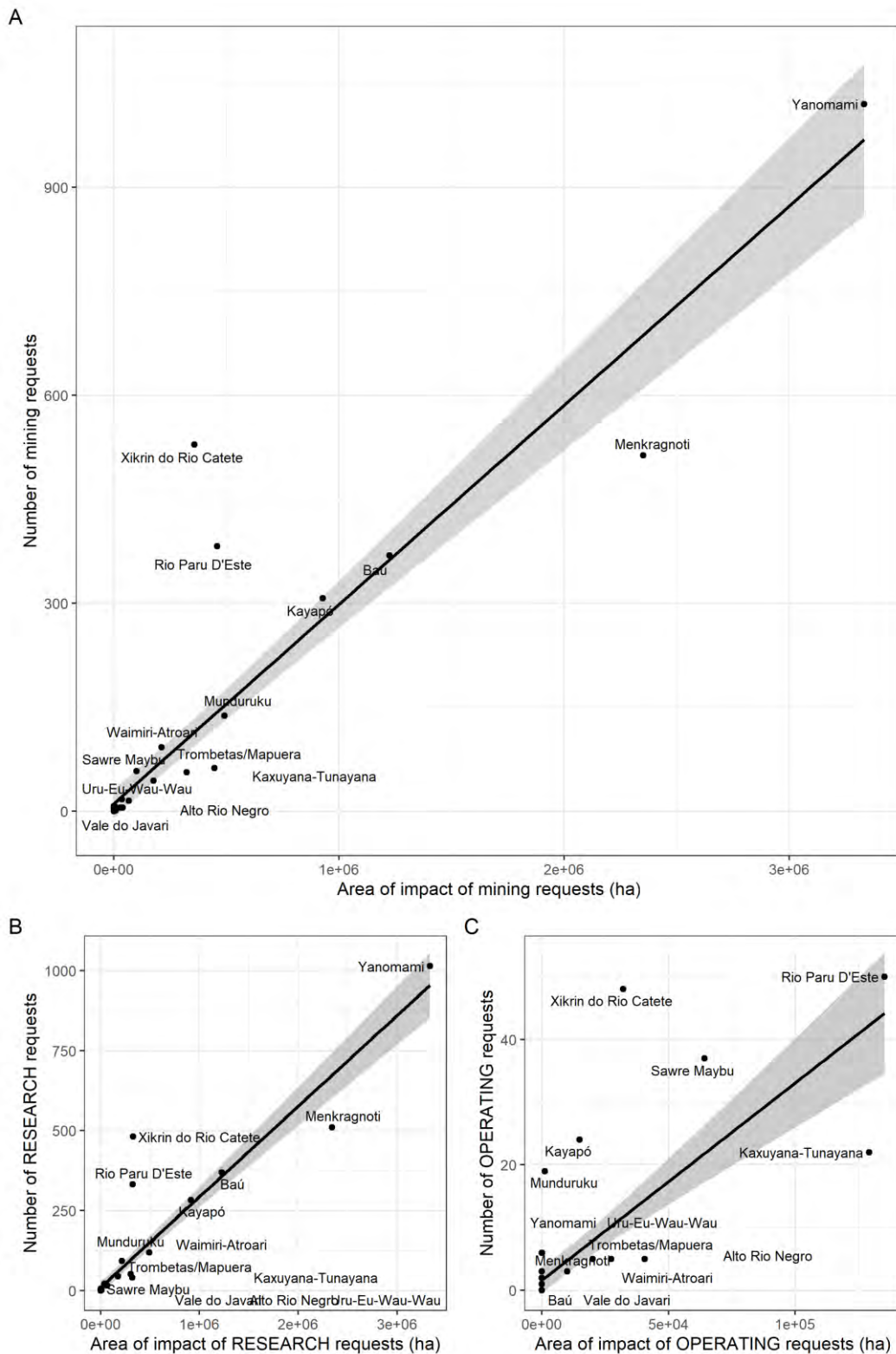
SM Fig. S-3. Percentage of the area of indigenous lands in the Brazilian Legal Amazon with reported isolated indigenous groups that is affected by mining requests.



SM Fig. S-4. Number of research and operating-license requests in eleven indigenous lands that have more than 50 mining requests. Percentages represent the operating-license requests (those more advanced in the licensing process) as percentages of the total.



SM Fig. S-5. Number (A) and area (B) of mining research and operating-license requests in indigenous lands that have reported isolated indigenous groups. Indigenous lands are ordered by the total number of mining requests in both graphs. Capital letters in parentheses indicate the stage of the demarcation process of the indigenous land: under study (S), delimited (L), declared (D), homologated (H) and regularized (R).



SM Fig. S-6. Correlation between the number of mining requests and their area of impact in indigenous lands that contain isolated groups, considering all requests (A), research requests (B) and operating-license requests (C) separately. Indigenous lands with >3 isolated groups and/or >50 mining requests are labeled. Shaded areas indicate the 95% confidence intervals of the linear regression model.

Mining threatens isolated indigenous peoples in the Brazilian Amazon

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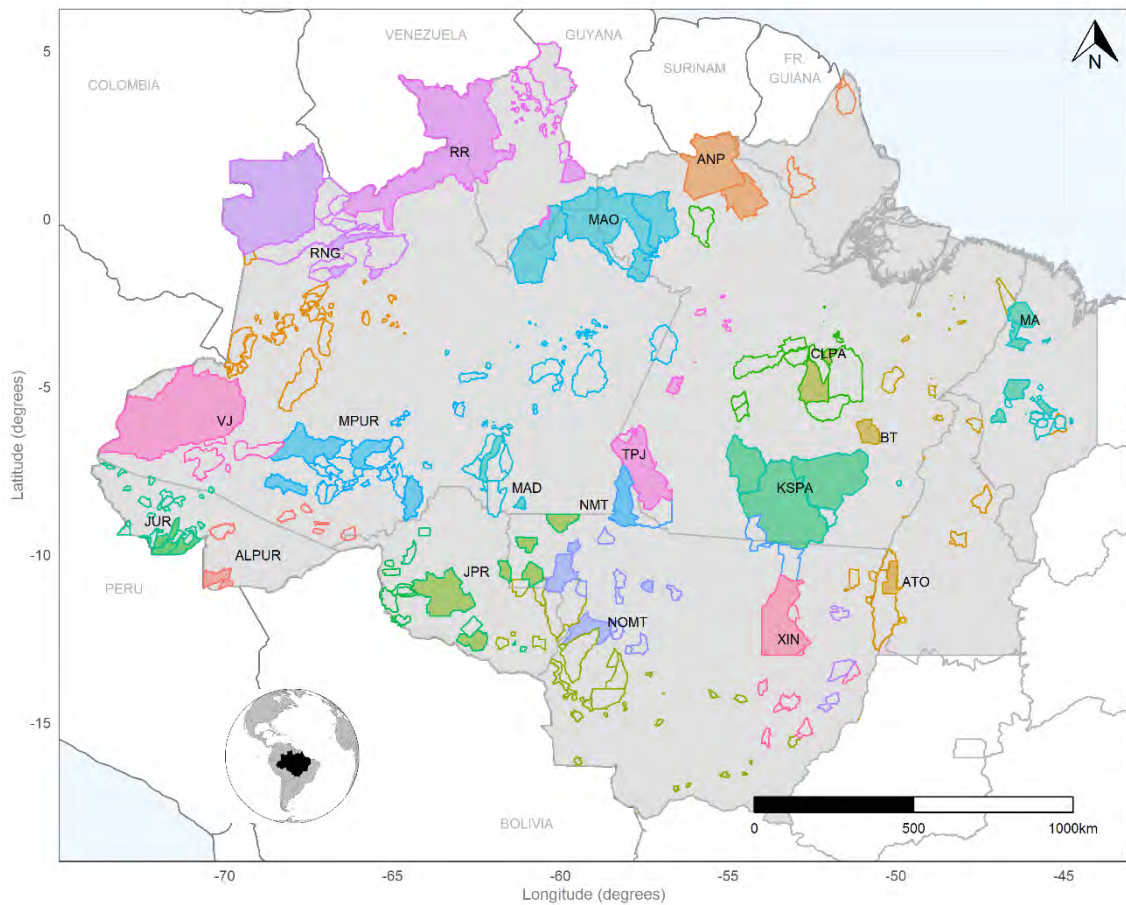
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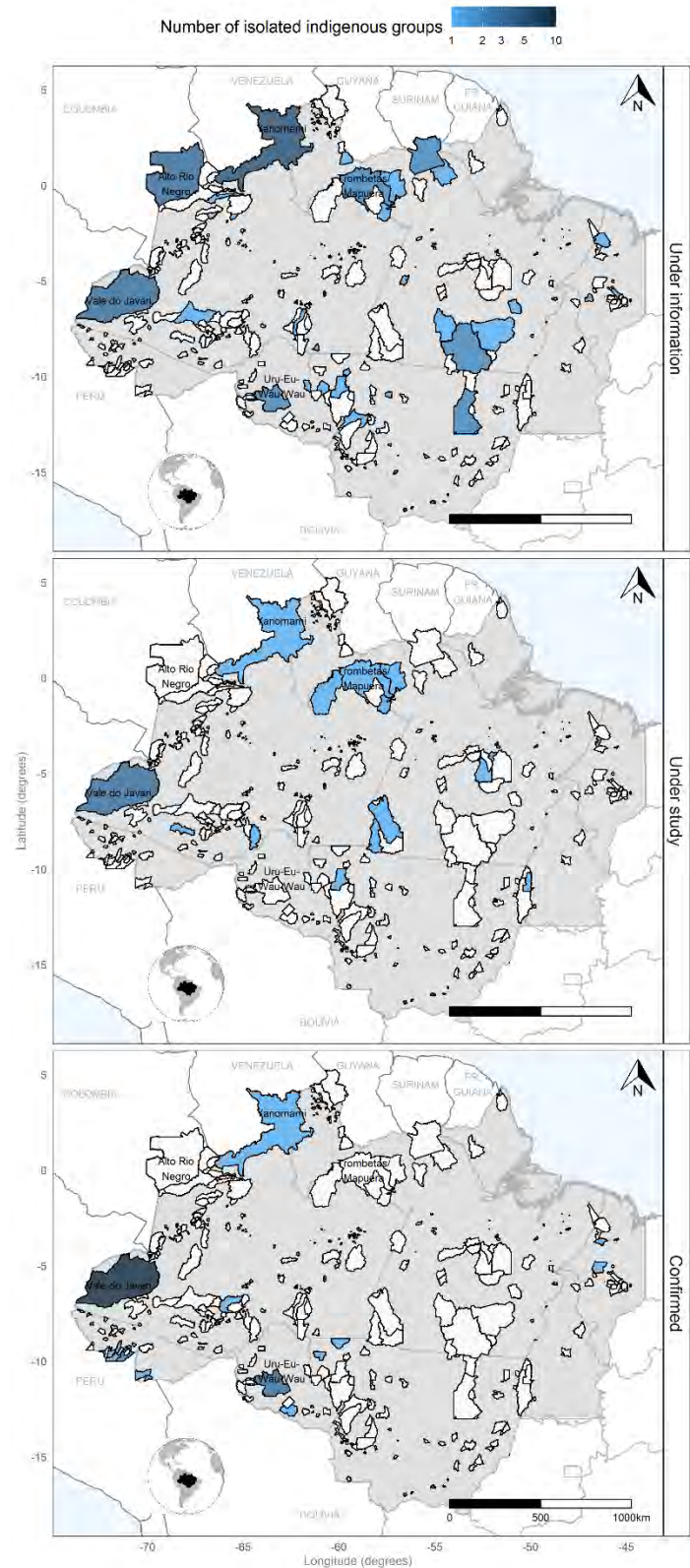
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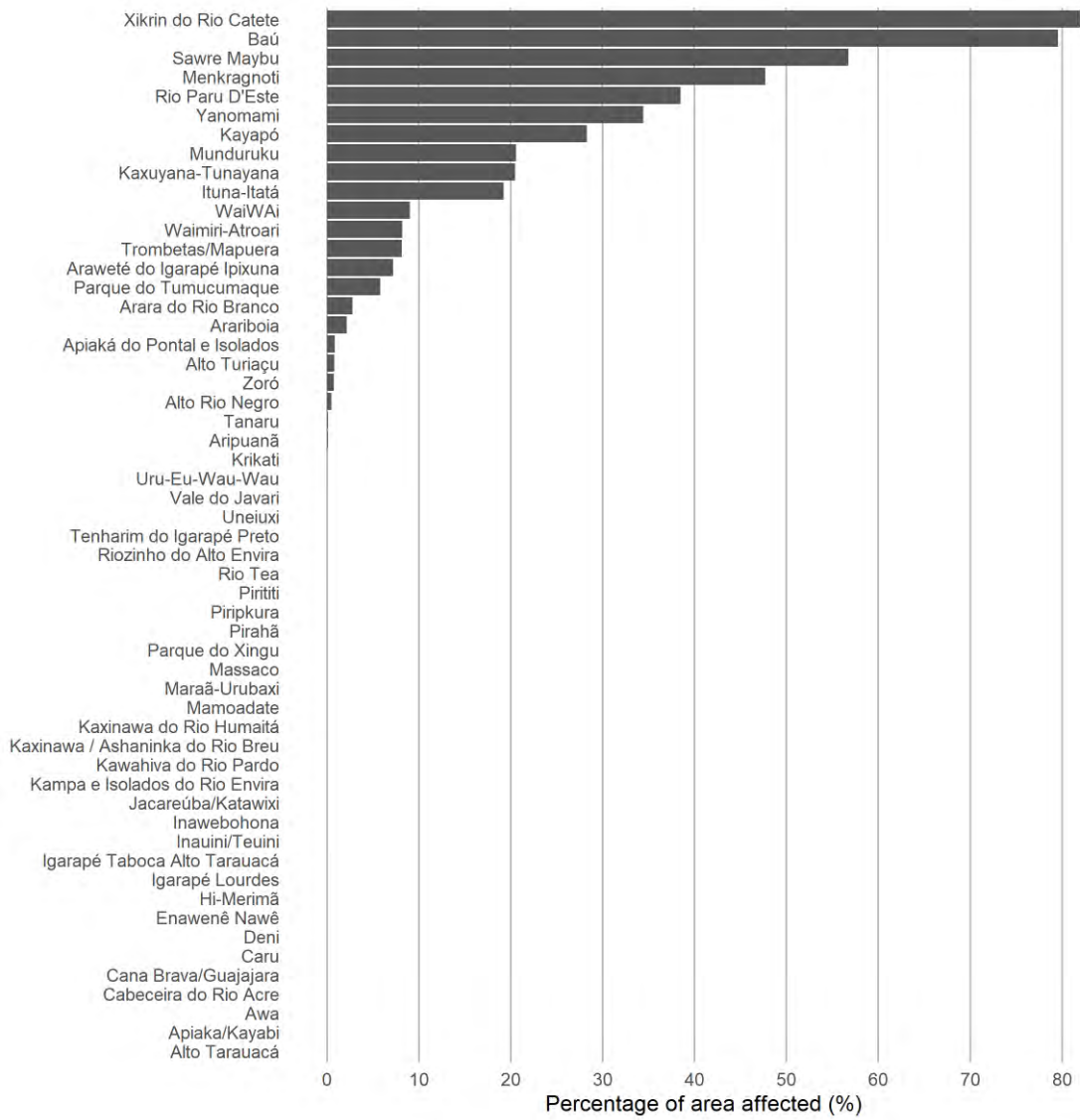
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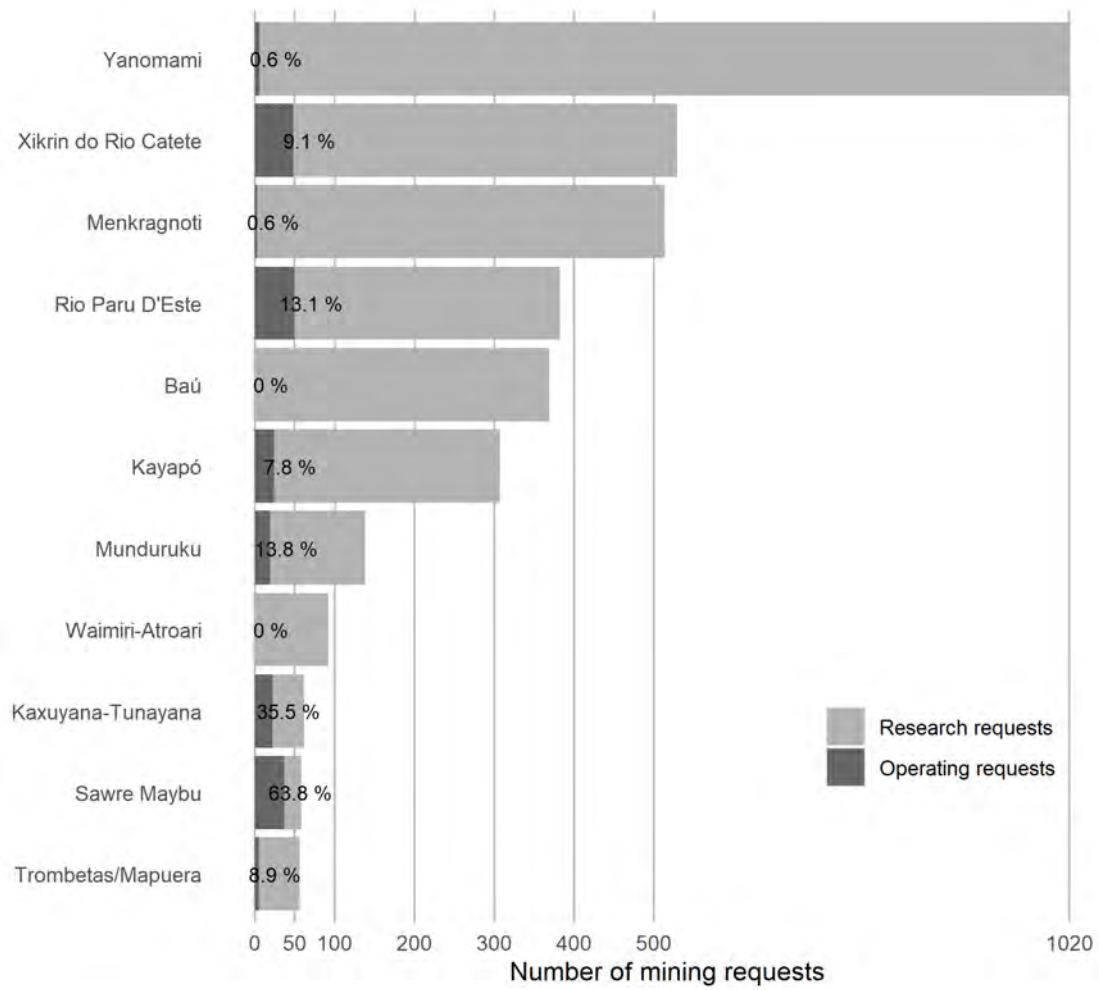
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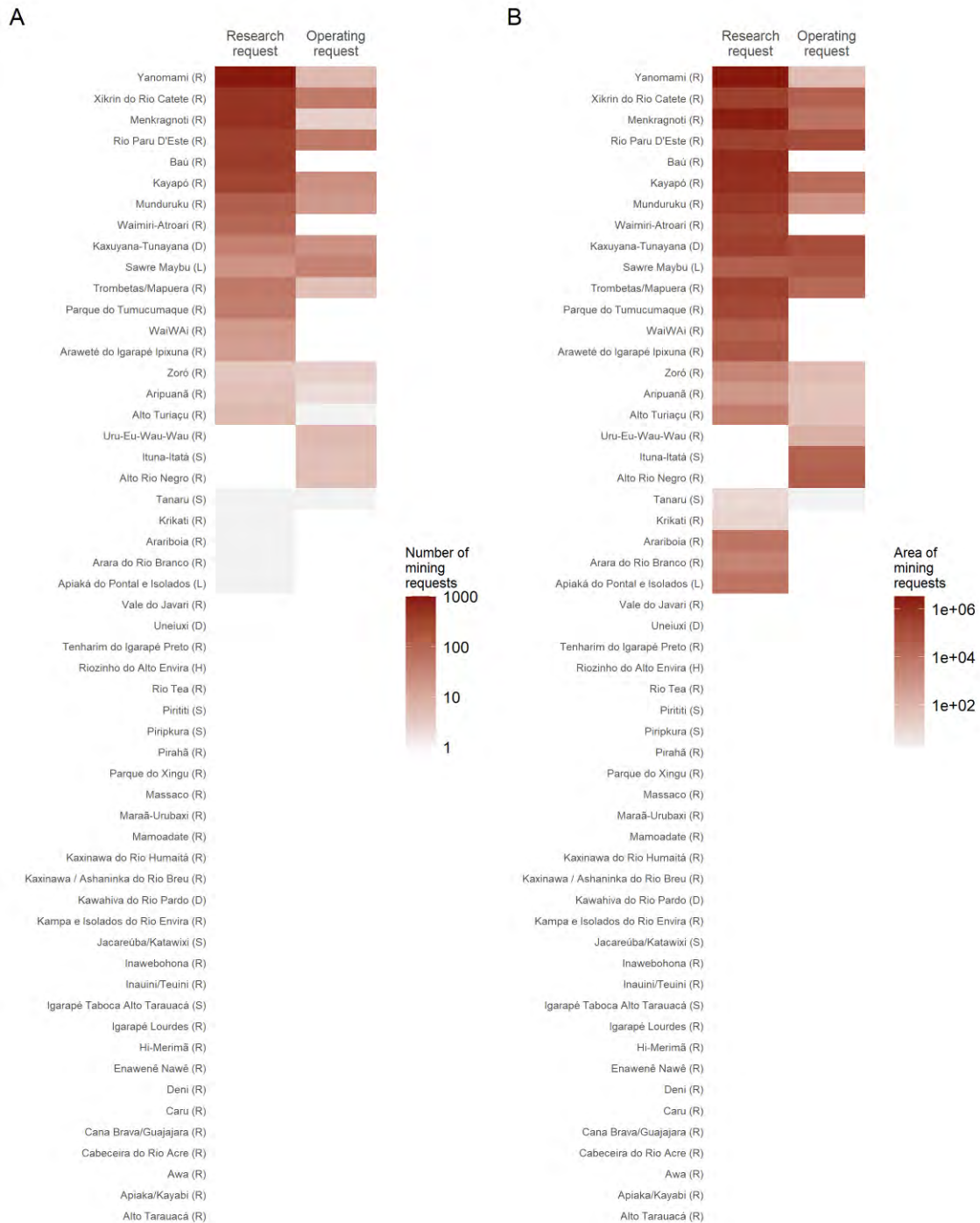
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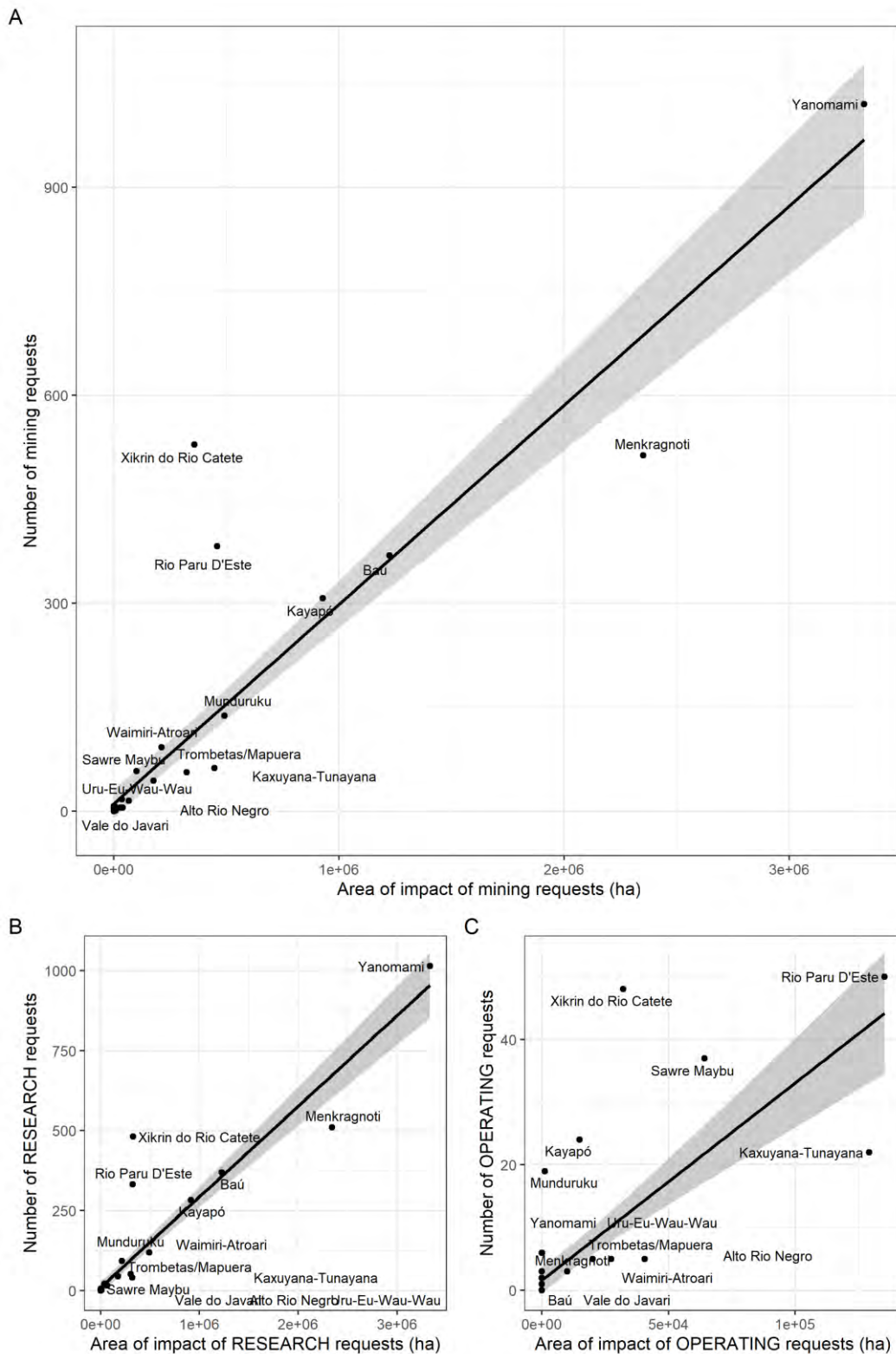
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