SPATIAL DISTRIBUTION AND LANDSCAPE IMPACT ANALYSIS OF QUARRIES IN A HIGHLY FRAGMENTED ECOSYSTEM

Irati Carabia-Sanz[1], María V. Simoy[1], Agustina Cortelezzi[1], Clara Trofino-Falasco[1], and Igor Berkunsky[1]

[1]Universidad Nacional del Centro de la Provincia de Buenos Aires

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Abstract

Mining activity generates significant changes in the ecosystems in which it takes place, affecting the atmosphere and the surrounding aquatic and terrestrial systems, causing the destruction of landscapes, the loss of vegetation, and altering native environments. As it is an impact associated with increasing urbanization and population growth, the area occupied by quarries has increased worldwide. In the province of Buenos Aires, quarries are often abandoned without any remediation, leading to further deterioration of the ecosystem. This work aims to analyze quarrying activity's spatiotemporal effect on the Pampean grassland in the Tandilia mountains (Buenos Aires province, Argentina). Based on Landsat 5, 7, and 8 satellite imagery, from 1996 to the present, and using QGIS software, we identified the location and extension of quarries, and we analyzed their evolution through time. Quarries currently occupy an area of 6428 ha, which was originally part of the Pampean grassland. The number of open quarries increased by 129%, from 69 in 1996 to 158 in 2022, and the area used for this activity increased by 172%, with a greater expansion being detected in the last ten years. These results conclude that this extractive activity represents a major threat to the Pampean grassland with the consequent loss of biodiversity and invasion of exotic plants capable of colonizing areas altered by human activity.

TITLE PAGE

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Irati Carabia-Sanz

Instituto Multidisciplinario sobre Ecosistemas y Desarrollo Sustentable, UNICEN - CICPBA, Paraje Arroyo Seco s/n, Tandil (7000), Argentina. Email: irati.casanz@gmail.com

María Verónica Simoy

Instituto Multidisciplinario sobre Ecosistemas y Desarrollo Sustentable, UNICEN - CICPBA, Paraje Arroyo Seco s/n, Tandil (7000), Argentina. Email: vsimoy@gmail.com

Agustina Cortelezzi

Instituto Multidisciplinario sobre Ecosistemas y Desarrollo Sustentable, UNICEN - CICPBA, Paraje Arroyo Seco s/n, Tandil (7000), Argentina. Email: aguscorte@gmail.com

Clara Trofino-Falasco

Instituto Multidisciplinario sobre Ecosistemas y Desarrollo Sustentable, UNICEN - CICPBA, Paraje Arroyo Seco s/n, Tandil (7000), Argentina. Email: claratrofino@gmail.com

Igor Berkunsky

Instituto Multidisciplinario sobre Ecosistemas y Desarrollo Sustentable, UNICEN - CICPBA, Paraje Arroyo Seco s/n, Tandil (7000), Argentina. Email: igorberkunsky@gmail.com

Data availability statement

The data supporting this study's findings are available from the corresponding author upon reasonable request.

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Conflict of interest disclosure

The authors have no conflict of interest to declare.

Ethics approval statement, Patient consent statement & Clinical trial registration

Those were not needed because of the study type: this article does not contain any studies with human or animal participants.

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This was not needed.

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Instituto Multidisciplinario sobre Ecosistemas y Desarrollo Sustentable, UNICEN - CICPBA, Paraje Arroyo Seco s/n, Tandil (7000), Argentina.

Correspondence: Irati Carabia-Sanz, Instituto Multidisciplinario sobre Ecosistemas y Desarrollo Sustentable, UNICEN - CICPBA, Paraje Arroyo Seco s/n, Tandil (7000), Argentina.

Email:*irati.casanz@gmail.com*

KEY WORDS: Environmental threats; quarries; habitat destruction; native ecosystem; land cover change; conservation.

Running title: Impact of quarries in a fragmented ecosystem

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ABSTRACT **-** Mining activity generates significant changes in the ecosystems in which it takes place, affecting the atmosphere and the surrounding aquatic and terrestrial systems, causing the destruction of landscapes, the loss of vegetation, and altering native environments. As it is an impact associated with increasing urbanization and population growth, the area occupied by quarries has increased worldwide. In the province of Buenos Aires, quarries are often abandoned without any remediation, leading to further deterioration of the ecosystem. This work aims to analyze quarrying activity's spatiotemporal effect on the Pampean grassland in the Tandilia mountains (Buenos Aires province, Argentina). Based on Landsat 5, 7, and 8 satellite imagery, from 1996 to the present, and using QGIS software, we identified the location and extension of quarries, and we analyzed their evolution through time. Quarries currently occupy an area of 6428 ha, which was originally part of the Pampean grassland. The number of open quarries increased by 129%, from 69 in 1996 to 158 in 2022, and the area used for this activity increased by 172%, with a greater expansion being detected in the last ten years. These results conclude that this extractive activity represents a major threat to the Pampean grassland with the consequent loss of biodiversity and invasion of exotic plants capable of colonizing areas altered by human activity.

KEYWORDS: Environmental threats; quarries; habitat destruction; native ecosystem; land cover change; conservation.

INTRODUCTION

Quarrying is an extractive activity that causes major environmental changes (Lameed & Ayodele, 2010; Gbedzi et al., 2022). The environmental impacts of these changes range from pre-operational mining activities (e.g., construction of access roads, conduits, and installation of drains and ditches) to the mining activity itself (e.g., creation of openings, perforation, blasting, machinery movements; Matías et al., 2007; Souza & Sánchez, 2018). Quarrying impacts result in severe modifications of land cover at the local scale and affect the whole environment, including the lithosphere (rock excavation and geomorphic changes of the landscape), atmosphere (dust and air pollution), hydrosphere (changes in surface water), and biosphere (habitat destruction and biodiversity loss; Lameed & Ayodele, 2010; Bétard, 2013). The habitat destruction and fragmentation severely reduce the environment's ability to provide ecosystem services, severely impacting the native flora and fauna surrounding the quarries (Sala et al., 2010). For example, successional processes cannot proceed in areas affected and are stuck at the early stages of colonization, mainly due to thin topsoil, without seed banks and rootstocks (Flavenot et al., 2015; Lamare & Singh, 2016).

The rapid population growth coupled with industrialization has increased tremendous pressure on natural resources resulting in the rapid exploitation of mineral resources worldwide (Bhatnagar et al., 2014). For example, in Lebanon, quarrying had an increase of 117% in 20 years (Darwish et al., 2011), while Bijolia (India) showed an increase of 3570% in land use from 1971 to 1992 (Sinha et al., 2000) and Odublasi quarry in Ghana 107,66% increase from 2007 to 2014 (Koranteng & Adu-Asare, 2018) even when quarrying affects small areas at the regional scale (e.g., less than 1% of French national territory; Bernaud & Le Bloch, 1998), this extractive activity still has important consequences on the local scale (Flavenot et al., 2014).

In the Pampa ecoregion, one of the largest grassland regions of the world, the effect of quarries has been overlooked, and the evolution of this activity could be following the global trend. The quarrying activity in Pampa has more than a century of history. The number of deposits and grassland remnants affected by the activity has increased in the last decade (Secretaría de minería, 2020). This area is typical granite and limestone opencast mining, where topsoil is removed to expose the rock to be extracted (Cingolani, 2011). Opencast mining usually requires the removal of large quantities of soil and rock. It involves the use of machinery and explosives, which has a negative impact on the landscape, air, and water quality (Iwanoff, 1998). The rainwater fills these opencast mine pits dissolving the minerals such as calcium and magnesium, which percolate downwards through fractures and joints. This increases groundwater pollution by increasing the calcium and magnesium, along with their carbonates, sulfates, and chlorides affecting its hardness (Milgrom, 2008; Bhatnagar et al., 2014). All these described impacts are intensified when the lack of control by governmental authorities results in abandoned pits without mitigation actions (Marchevsky et al., 2017; Zhang et al., 2018). The latter is the case of many abandoned quarries along the Tandilia mountains.

Considering the overall context, the general objective of this study is to accomplish a spatiotemporal analysis of habitat loss due to opencast mining activities in the Tandilia Mountains, southern of the Pampa ecoregion. Our specific objectives were: (1) to identify the locations where quarrying takes place, (2) to determine the area of active and inactive quarries, their expansion speed, and their evolution over the last 20 years, and (3) to assess the impact of the extractive activity on the landscape. These objectives are achieved by processing satellite images with Geographic Information Systems.

MATERIALS AND METHODS

Study area

The Tandilia Mountains extend along a 350 km long diagonal in the Province of Buenos Aires (Argentina), covering the districts of Azul, Balcarce, Benito Juárez, General Pueyrredón, Lobería, Necochea, Olavarría and Tandil (figure 1). The maximum width is in its central part and reaches an extension of 63 km, and the maximum height is 525 m (Cerro la Juanita, Benito Juárez district). The whole region occupies an area of approximately 1.231.400 ha, including scattered hills separated by valleys and plains (Herrera et al., 2019). The agricultural expansion and other anthropogenic activities (such as mining), added to the lack of natural protected areas (Nanni et al., 2020), produce changes in grassland species richness, composition, and abundance, and the increase of exotic species (Filloy & Bellocq, 2007). Of a total of 505 plant species that have been found in the Highland grassland of the Pampa, 139 are exotic (27%) (Sánchez & Núñez, 2004; D'Alfonso et al., 2014). Despite the significant impact, the Tandilia Mountains continue to be considered one of the last refuges of Pampa grassland and one of the most biodiverse sites in the Province of Buenos Aires (Chebez, 2005; Pedrana et al., 2008).

Due to the fragmentation of this habitat, the Pampa grassland has been relegated to remnants of different sizes, mainly on hills where the presence of rock and shallow soils makes it impossible to use plows to cultivate annual crops (Herrera & Laterra, 2007). However, other activities, such as quarrying and forestry, remain as important threats.

Image analysis

The satellite imagery used in this study was of Landsat 5, Landsat 7, and Landsat 8 satellites (30x30 resolution) obtained from Google Earth Engine (GEE) website. Different satellites were necessary to obtain images from different years, so Landsat 5 was used for 1996, 1999, and 2002 maps, Landsat 7 for 2005, 2008, and 2011 maps, and Landsat 8 for 2013, 2016, 2019, and 2022 maps (Chandler et al., 2009). In recent times Google Earth Engine has become an important database of earth observation data and land cover classification in many mining-related studies and other applications such as vegetation mapping and monitoring, agricultural application, disaster management, and earth science (Gbedzi et al., 2022). In addition to these satellite images, information obtained from the remnants of Pampean grassland identified and delineated with Google Earth Imagery was added.

Images from 27 October to 27 May in each year of study were used to analyze the different land uses. This date was chosen due the spring/summer season is when the vegetation associated with the quarry is in bloom. NDVI index (Normalized Difference Vegetation Index) in GEE was applied, paying special attention to the threat posed by quarries in the Tandilia Mountains. The NDVI index has been used to monitor characteristics of vegetation cover and health status and detect changes in an ecosystem over time (Paruelo, 2008; Tong et al., 2016). Calculation of NDVI for a given pixel always results in a number that ranges from minus one (-1) to plus one (+1): bare soils (quarries in that case), giving a value close to zero, and very dense green vegetation have values close to +1 (Musa & Jiya, 2011). In general, land covers are often mixtures of several types, so even fine-resolution remote sensing data do not measure pure spectra but mixed reflectance of vegetation and non-vegetation, making it challenging to identify exposed bedrock (Yue et al., 2012). For this reason, the satellite images were then processed with QGIS software.

The image was processed using QGIS 3.24.2, a Geographic Information Systems (GIS) software. QGIS allows the input, manipulation, analysis, and presentation of data and information related to a place on the earth's surface and therefore works with geo-referenced points (Ershad, 2020). This tool could locate and characterize quarries (dimensions and associated threats). To do this, a visual interpretation of land use was made: quarries with a lot of vegetation or water are considered inactive, and quarries with bare soil are active. The resulting maps show the evolution of the quarries during the years of the study. Some characteristics of the quarries, such as the state of their activity, only were reliable in the current year (2022). The quarrying activity was confirmed from the information obtained in the Mining Cadastre of the province of Buenos Aires (Subsecretaría de Minería, 2023). Moreover, the area of each remnant and the total amount of Highland grassland were calculated using the QGIS software.

Quarrying impact

The quarrying environmental impact, focused on the impact on vegetation cover and the loss of Highland grassland (Darwish et al., 2011), was evaluated using QGIS software and cadastre information (Subsecretaría de Minería, 2023). This government agency records the materials extracted from each quarry. This information, added to the degree of permeability of the rocks of the Tandilia Mountains in each quarry site, was used to associate the type of extraction to the impact level. A higher level of permeability increases the vulnerability of groundwater due to the increased passage of water contaminated with heavy metals, other minerals, and toxic waste (Darwish et al. 2011; Zhang 2013).

The area of Highland grassland affected by mining activity in each county was estimated, and it was possible to obtain a quotient indicating the loss of native habitat due to extractive activity and its percentage.

Finally, to measure the impact of all quarries in the Tandilia Mountains, an Impact index which includes a set of qualitative variables, was used (Soriano et al., 2015). These variables are the extent of the impact, the periodicity, the intensity, the reversibility of the impact, and the recoverability of the environment. Each variable has a value according to the degree of impact on the landscape. The sum of these values will give a level of importance to the impact, which allows us to characterize it. There are four categories of the levels of impact: Irrelevant (0-25), Moderate (25-50), Several (50-75), and Critical (75-100).

RESULTS

The mining activity has increased over the years in the Tandilia Mountains. Based on the satellite imagery, the increase is in the area occupied by the quarries and in the number of quarries (Table 1, Figure 2). Some of these quarries are active, and others have been abandoned without carrying out a mitigation plan.

In the satellite imagery of 1996, 69 quarries were observed; for 2022, the increase was more than double: 159 quarries. The total area of native Highland grassland is fragmented in 1971 remnants, and they cover a surface of 116580.76 ha, of which 6428.41 ha are affected by this mining activity (5.2%).

Table 2 and Figure 3 show the area affected by mining activity and the current Highland grassland area in each county comprising the Tandilia Mountains. Olavarría and Benito Juárez are the most affected counties: they have lost 35.4% and 12.4% of Highland grassland because of the extractive activity. Balcarce and Lobería are the counties with less percentage of habitat loss by quarrying activity (0.3% and 0.8%, respectively). Also, Olavarría is the county with the most significant number of quarries (63), followed by Tandil (31) (Table 1). In Olavarría, most of the quarries are clay (19) and granite (18); in Tandil, there are nine granite quarries and one clay quarry; for the other quarries from Tandil, there is no information on the materials they exploit. The percentage of the area used to extract the different types of materials in the Tandilia Mountains is shown in Figure 4. Table 2 also shows that in 2022 the number of active quarries is 71, corresponding to 44.93% of the total.

More than 80% of the area occupied for this extractive activity is associated with clay, granite, and limestone extraction. Those are the materials with the highest permeability. result of the impact index was 69, which categorizes as Severe the landscape impact of quarries (Table 3). The intensity of the impact, effect, periodicity, and moment were the top contributing variables to the index.

DISCUSSION

In the last 28 years, the number of quarries in the Tandilia Mountains doubled. Likewise, the area occupied by quarries also increased, three times larger than in 1996. This trend towards an increase in this extractive activity is also reflected in the mining cadastre of the Province of Buenos Aires, which shows quarries already exploited and quarries being explored to start extraction works. In this cadastre, the projected area to be exploited in the future in the Tandilia mountains is 6142.66 ha, representing an increase of the affected area of 95.6%.

This increase in the area and number of quarries in the Highland grassland areas indicates that quarrying activity is indeed a threat to the conservation of the native ecosystem of the Tandilia Mountains. The abundance and richness of native species have decreased, with invasive woody vegetation being the most present in the study area (D'Alfonso et al., 2014). Less vegetation exposes the soil to erosion, resulting in a greater loss of substrates that enable growth. This reduces the ability of the surrounding area to support plant life and makes it impossible for native species to colonize the area, leading to their displacement or disappearance (Akanwa et al., 2017; Said et al., 2016).

Active quarries in 2022 represent a relatively low percentage of the total number of quarries: many of them are abandoned, but the environmental problem is not solved; those related to the destruction of the landscape, vast losses of vegetation, and the alteration of the native ecosystem remain (Chase et al., 1999; Akanwa et al., 2017). So, the ecosystem changes induced by the mining activity are multiplied by the risk of further ecosystem deterioration in and around abandoned sites (Darwish et al., 2011). All of these inactive quarries have exotic vegetation present, and some of them are invaded by such vegetation, which is the first with the capacity to colonize the disturbed substrate (Lake & Leishman, 2004; Xu et al., 2022). In addition to this, many exploration points still impact the ecosystem, although not selected for material extraction.

The results show that Olavarría and Benito Juárez are the counties the most affected, with one-third and one-sixth (respectively) of their native habitat lost. Mainly Olavarría is an area with a strong mining culture. This extractive activity gained strength in the 1850s when new techniques were introduced, which were the basis for the take-off of the large-scale capitalist mode of production, forming the original capital of numerous productive enterprises. Understanding the different processes that determined regional growth makes it possible to explain how the Human Society-Nature mediation took place in the region and clearly shows an environmental rationality based on progress and increased productivity (Paz, 2000). This anthropic activity, closely linked to the region's culture, has been maintained and increased over time, as can be seen in the area affected.

On the contrary, Lobería and Balcarce are the counties with the least habitat loss due to extractive activity, with a tiny percentage that could indicate that they are exemplary conservation sites for the Highland grassland of the Tandilia Mountains. Finally, Tandil County is another example of an attempt to conserve its native ecosystem, with only 0.9% of habitat lost to mining activity. Due to different social protests since 2010, there has been an environmental protection law (Law 14.126) aiming to conserve and preserve the integrity of the geographical, geomorphological, touristic, and urban landscape around Tandil city only (Grosman & Kristensen, 2012).

Inconsistency can be seen between the governmental information and the results obtained from analyzing the materials extracted from the quarries. On the one hand, 52 of the quarries found by visual interpretation are not registered in the Province of Buenos Aires mining cadastre. On the other hand, according to the bibliography, limestone rock is the most extracted material from quarries in the province. In contrast, the cadastre shows that only four quarries in the Tandilia Mountains extract it (3.8%). The limestone rock is used for construction in the entire province, so urbanization and population growth demand a hike in the extraction (Bhatnagar et al., 2014). Although a low percentage of quarries are dedicated to extracting limestone rock, their exploited area is high. The same happens with iron oxide, its extraction in the whole Tandilia Mountains is 0.9%, while the surface area taken up by its extraction is ten times bigger. This means that these two mining exploitations, particularly, have a considerable impact on the Tandilia Mountains: they require a lot of surface area, and the amount of extraction is insignificant.

The Impact index that categorized the landscape impact as Severe could significantly affect the following environmental parameters: air quality, noise and vibrations, soil quality, groundwater quality, water resource depletion, diversity and abundance of fauna and flora, and habitat alteration (Soriano et al., 2015). Moreover, the most extracted materials are the most permeable. That means that those allow access to water possibly contaminated with heavy metals and other chemicals in the groundwater and lead to a larger ecosystem-wide problem and human consumption of water (Darwish et al., 2011; Milgrom, 2008). This qualitative impact assessment shows that the threat to the native ecosystem and the environment is significant (Duinker & Greig, 2007).

This work has confirmed these tools' usefulness by visually interpreting the quarries themselves and their state of activity and studying their evolution over time by measuring geometric parameters. However, the need for studies on the environmental impacts of mining and remote sensing in the Tandilia Mountains indicates the under-utilization of those tools in this sector.

CONCLUSION

After this analysis, it can be concluded that mining activity in the Tandilia Mountains is a major threat to the area, which has increased in recent decades, and that the tendency (as at the global level) will continue to increase. This threat involves the fragmentation and loss of the Pampa grassland with the consequent loss of biodiversity and the invasion of exotic plants capable of colonizing areas altered by human activity. In addition to this, quarries produce a landscape impact that must be addressed. This threat is aggravated by the lack of control by governmental agencies, whose official data related to the number of quarries do not coincide with the results obtained in this study. Furthermore, despite the existence of a law that obliges the remediation of natural areas affected by mining activity, there needs to be control to ensure that this process of ecological restoration is carried out. Quarrying operations without environmental control could affect the very existence of ecosystems and the hydro-geological conditions of the area to a greater extent. Therefore, extractive management plans must be developed based on the capacity of ecosystems that support life. This study has also shown that using remotely sensed images provides data and allows the temporal evolution of different land uses to be known, thus enabling better management of human activities in natural systems. This is why the visualization of remotely sensed data and its processing into maps with software such as QGIS is used as good analytical tools to understand the impairment of nature by human activities and to be able to determine the magnitude or degree of the threat. Analysis of vegetation and detection of changes in vegetation patterns are keys to natural resource assessment and monitoring. Thus, it is no surprise that green vegetation detection and quantitative evaluation is one of the most important applications of remote sensing for environmental management and decision-making. Enforcement agencies could use these same tools to monitor threats impacting the native ecosystem to be protected.

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CONFLICT OF INTERESTS

The authors have no conflict of interest to declare.

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TABLES

Table 1. Number of detected quarries by year and county in Tandilia Mountains, southern Argentinean Pampa.

County	1996	1999	2002	2005	2008	2011	2013	2016	2019	2022
Olavarría	30	38	41	43	45	47	49	51	59	63
Benito Juárez	12	13	13	15	16	15	15	15	15	16
Azul	7	7	7	7	7	7	7	7	7	11
General Pueyrredón	4	6	9	9	10	11	12	12	12	18
Necochea	0	1	1	4	4	4	5	5	5	5
Tandil	16	16	16	17	17	17	17	21	22	31
Lobería	0	6	8	8	10	10	10	11	11	12
Balcarce	0	0	0	1	1	2	2	2	2	3
Total	69	87	95	104	110	113	117	124	133	159

Table 2. Impact of mining activity on the Tandilia Mountains during 2022, separated by county.

County	Total quarries	Active quarries	% of active quarries	Affected Area by quarries (ha)	Current Hi
Olavarría	63	28	44	3124	5698
Benito Juárez	16	5	31	1522	10777
Azul	11	8	72	818	12679
General Pueyrredón	18	11	61	362	7670
Necochea	5	3	60	21	1902
Tandil	31	6	19	394	41995
Lobería	12	8	67	110	13971
Balcarce	3	2	67	77	21889
Total	158	71	45	6428	116581

Table 3. Landscape impact values of the qualitative variables to categorize the landscape impact of all Tandilia Mountains quarries, southern Argentinean Pampa.

Qualitative variable	Degree of impact
Nature of the impact	Harmful (-)
Intensity	Total (12*3)
Extension	Partial (2*2)
Moment	Critical (8)
Persistency	Temporary (2)
Reversibility	Medium term (2)
Synergy	Without synergy (1)
Accumulation	Accumulative (4)
Effect	Direct (4)
Periodicity	Continuous (4)
Recoverability	Mitigable (4)
Importance (sum of all variables)	I = 69

FIGURES

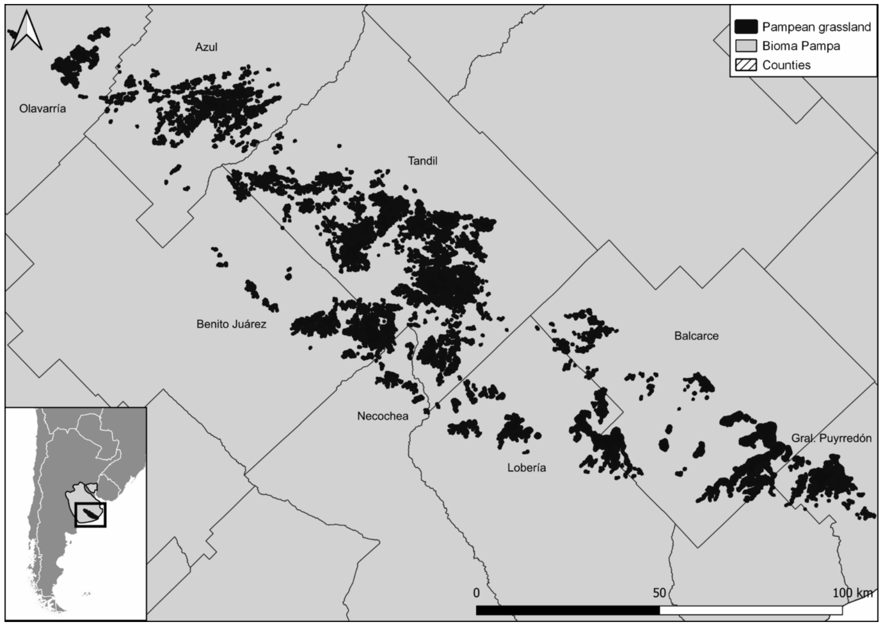

Figure 1. Highland grassland remnants in Tandilia Mountains, Province of Buenos Aires, southern Argentinean Pampa.

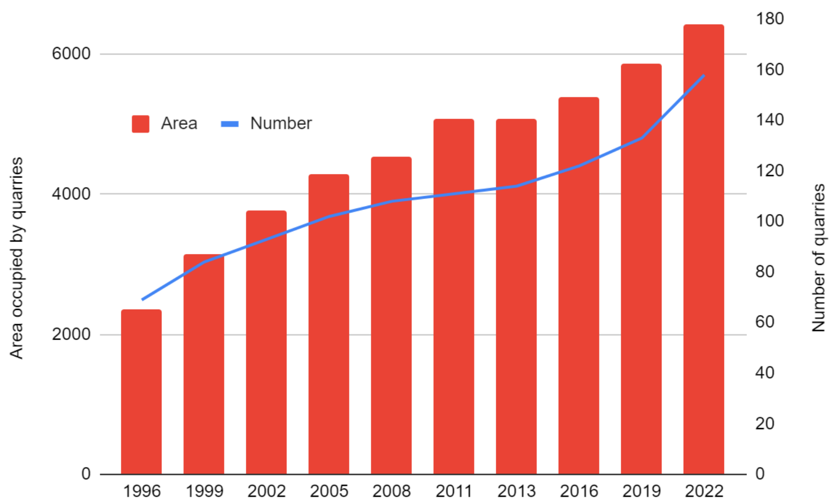

Figure 2. Area and number of quarries in Tandilia Mountains, Province of Buenos Aires, southern Argentinean Pampa.

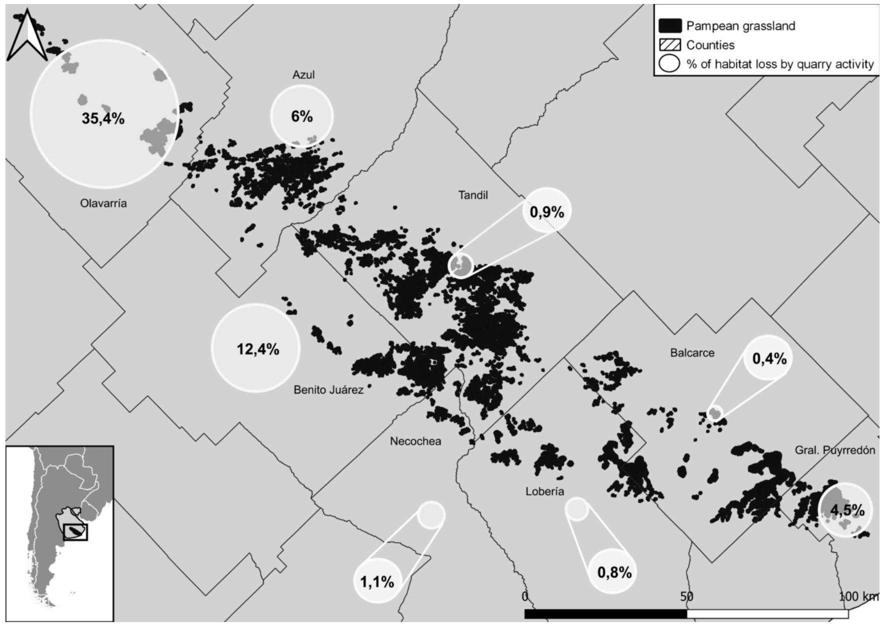

Figure 3. Percentage of the Highland grassland loss by the quarry activity in the Tandilia Mountain System, Province of Buenos Aires, Argentina.

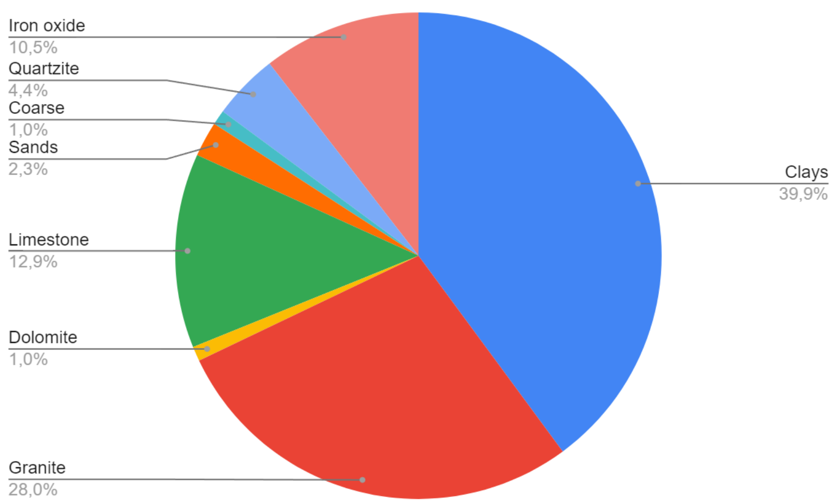

Figure 4. Percentage of the area occupied by each type of extracted material in the Tandilia Mountains in 2022 (Subsecretaría de Minería, 2023).

Figure legends

Figure 1. Highland grassland remnants in Tandilia Mountains, Province of Buenos Aires, southern Argentinean Pampa.

Figure 2. Area and number of quarries in Tandilia Mountains, Province of Buenos Aires, southern Argentinean Pampa.

Figure 3. Percentage of the Highland grassland loss by the quarry activity in the Tandilia Mountain System, Province of Buenos Aires, Argentina.

Figure 4. Percentage of the area occupied by each type of extracted material in the Tandilia Mountains in 2022 (Subsecretaría de Minería, 2023).