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Biodiversity Conservation in Mining Landscapes: a Systematic Review of Assessment Approaches in the Philippines

Bernard Peter O. Daipan[1,2]*, Crusty E. Tinio[2], and Nelson M. Pampolina[2]

[1]Department of Forest Biological Sciences, College of Forestry,
Benguet State University, La Trinidad, Benguet 2601 Philippines
[2]Department of Forest Biological Science, College of Forestry and Natural Resources,
University of the Philippines Los Baños, Laguna, Philippines

Mining is an important sector of the Philippine economy, but it often results in negative impacts on biodiversity. To mitigate these impacts, it is crucial to assess biodiversity in mining areas and integrate conservation efforts into mining operations. As part of the national policy guidelines on biodiversity compliance for mining companies, this study has conducted a systematic review to examine the various biodiversity assessment methods, tools, sampling designs, diversity parameters, values, and indices used in the Philippines' mining sites. Search engines and research databases were utilized in identifying diversity assessment-related research. Based on the eligibility criteria, only 25 of the 100 papers downloaded and two project terminal reports were eligible and considered in the review. It was found that authors commonly used transect line and quadrat methods for floral studies and transect line, mist netting, point count, and opportunistic sampling for faunal studies. Species abundance, relative abundance, dominance, frequency, relative frequency, density, relative density, percent cover, and importance value were the most frequently assessed biodiversity parameters, whereas the Shannon-Wiener diversity index, Simpson index, species richness, and evenness were the most commonly used indices. Endemism, economic importance, invasiveness, and conservation status were additional factors evaluated. Overall, this review provides an overview of the various biodiversity assessment methods used in the country's mining areas and offers guidance for future assessments in other mining landscapes. The limited number of studies related to biodiversity assessment in mining areas in the Philippines over the last decade highlights the urgent need for more research in this field.

Keywords: biodiversity, conservation, mining area, mineral production sharing agreement

INTRODUCTION

The Philippines is regarded as a mineral-rich country, ranking 5th globally in terms of untapped gold, copper, nickel, silver, and zinc reserves, estimated at around USD 1 trillion (Nem Singh and Camba 2020). Currently, the country has 303 mining sites with mineral production sharing agreements (MPSAs), which cover 548,813 ha or 1.8% of the total land area, and the most common minerals mined in the country are gold, limestone, nickel, and copper, according to the DENR-MGB (Department of Environment and Natural Resources–Mines and Geosciences Bureau) statistical report. However, despite the potential economic benefits, the mining industry has not been effectively utilized to benefit society (Promentilla *et al.* 2021). Mining activities have also led

*Corresponding author: bp.daipan@bsu.edu.ph

to the loss of biodiversity, particularly in economically developing countries with high biodiversity like the Philippines (Siqueira-Gay *et al.* 2020). Direct impacts of mining include the destruction of forest areas, alteration of habitat landscapes, and destruction of limestone karst areas, which are important global endemicity hotspots. Indirect impacts include habitat fragmentation caused by mining road construction and heavy metal leakages (Sonter *et al.* 2018).

The first step toward integrating biodiversity conservation in mining areas is to assess the status of biodiversity – including richness, abundance, endemism, ecological status, and diversity indices (IUCN and ICMM 2004). In the Philippines, the DENR recently issued DAO (Department Administrative Order) No. 2022-04, a policy guideline on enhancing biodiversity conservation and protection in mining operations in the Philippines. The policy specifies biodiversity conservation measures at each stage of mining operations. During mineral exploration, biodiversity measures include biodiversity assessment and gathering of baseline information. If assessments have not been conducted, the mining company or third-party consultants must undertake them.

In support of the national policy guideline on biodiversity compliance for mining companies, this study has undertaken a systematic review of biodiversity assessment studies conducted in mining areas across the Philippines. The primary objective of this study is to identify the various tools and methods used to analyze biodiversity values, indices, and parameters in both MPSAs and small-scale mining sites. Moreover, the systematic review aims to provide valuable insights and guidance for future assessments in other mining landscapes, both within the Philippines and abroad. The findings of this study can serve as a useful resource for mining companies and stakeholders involved in the development and implementation of biodiversity management plans.

MATERIALS AND METHODS

Search Strategy

This paper utilized three search engines or databases (SCOPUS, Google Scholar, and ResearchGate) in identifying relevant published articles/ research works and scientific reports for this review without regard to the year of publication. The search terms or strings that were commonly used are "biodiversity assessment; mining areas; Philippines." Only the first 100 relevant articles were considered and downloaded, preferably the open-access articles. Grey literature was also searched for relevant articles such as government/non-government reports, international organization websites, news articles, reports, and policy issuances, among others. Project terminal reports related to biodiversity assessment and/or monitoring in mining sites were purposively collected from the project proponents.

Article Inclusion and Exclusion Criteria

The downloaded articles were screened out based on the eligibility criteria presented in Appendix I, which were adopted and modified from the paper of Roe and colleagues (2013). These criteria, however, were not applied to the project terminal reports that were purposively collected.

Data Extraction

Using the eligibility criteria, a total of 25 studies out of the 100 articles were selected in this paper. For the project terminal reports, two reports were included in the review. The relevant data and information were collected or extracted from these studies during the review process.

The information and/or data extracted from the 25 studies and the two project terminal reports include the location of the mining area where the study was conducted, with geographic coordinates if available; the biodiversity component, taxa, and the type of ecosystem; assessment tools and sampling design used, which include plot size, number of plots, collection methods, among others; biodiversity parameters such as abundance, relative abundance, density, relative density, frequency, relative frequency, dominance, relative dominance, and importance value; diversity indices; and species endemicity, conservation or ecological status, and economic importance, if available.

Data Synthesis and Software Used

The PDF format of the included papers was added to the Mendeley Desktop software for the review process, data extraction, and citation formatting. The spreadsheets were used to enter all of the data and empirical information that had been extracted. Graphs, charts, tables, and a map were created for the purpose of analyzing the data and information derived from the review. The software used in this paper includes the QGIS software for the geographic distribution of the study areas and Microsoft Excel for the graphs and charts. Code numbers (from S1–S25) were assigned for each research article for easier identification of the paper. The overview of the methodological framework of the review process on biodiversity assessment in mining areas is presented in Figure 1.

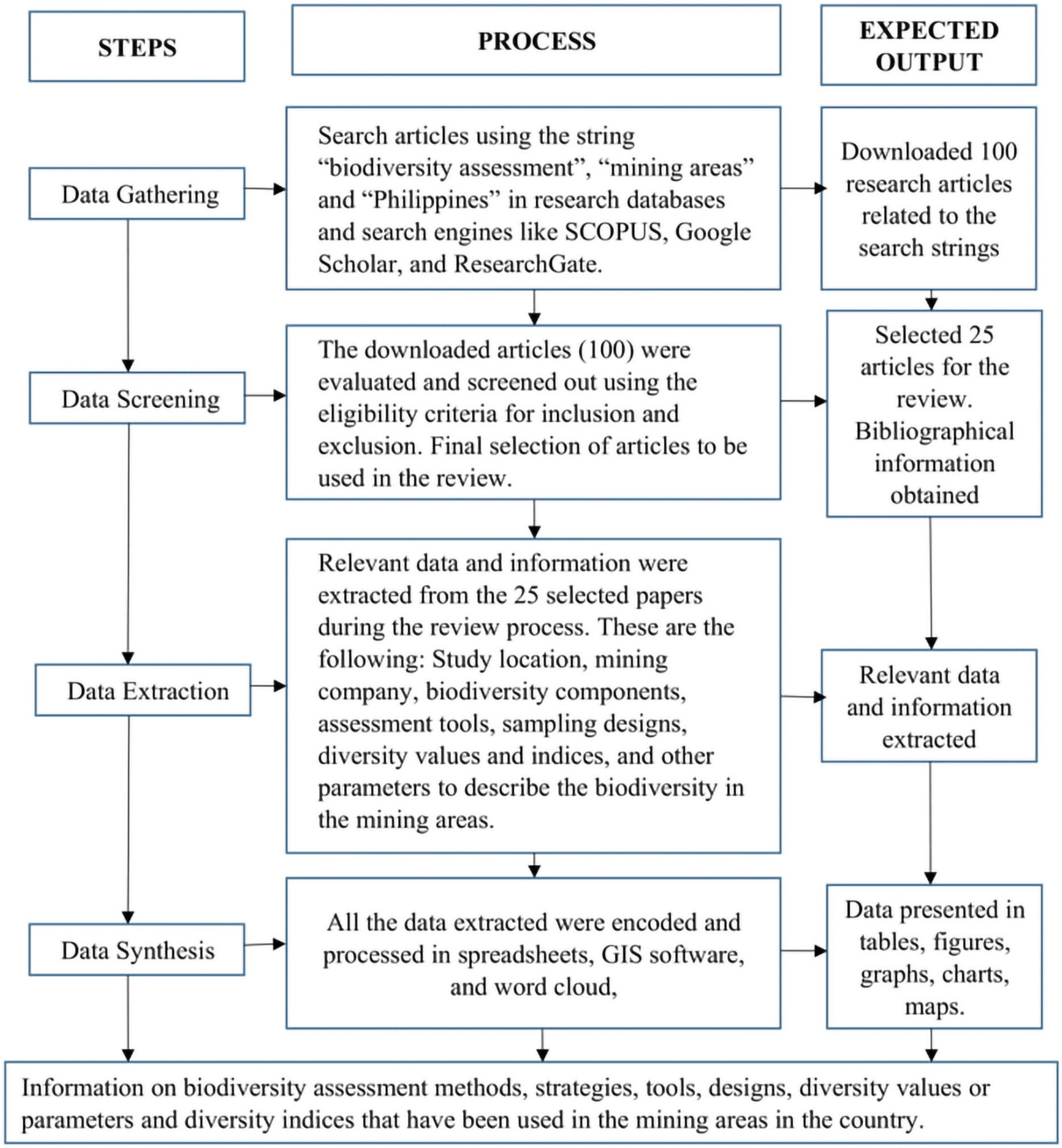


Figure 1. The methodological framework of the systematic review.

RESULTS AND DISCUSSION

Published Articles and Project Terminal Reports Related to Biodiversity Assessment in Mining Areas

The result of the searches and article screening suggest that there are very limited studies related to biodiversity assessment in the mining areas in the country between 2010–2021 (Figure 2). It was observed from the research results produced by search engines that most published biodiversity assessment studies were conducted in protected areas/national parks (Malabrigo *et al.* 2016), various mountain ecosystems and forest types in the Philippines (Gevaña *et al.* 2013), and in the indigenous people's forest reserves or ancestral domains (Pulhin *et al.* 2020). Possibly the lack of field experts, funding constraints, and publishable taxonomic studies are the major factors why there are very limited biodiversity

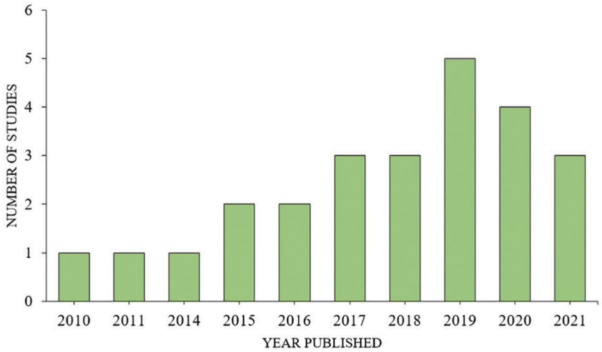


Figure 2. The number of published biodiversity assessment studies in mining areas annually in the Philippines.

studies and information not only on a specific region but on the country as a whole. Of the 25 studies listed in Appendix II, five were conducted in small-scale mining areas – two in S7 and one each in S17, S18, and S21. This brings the total number of small-scale mining sites studied to five. Two studies were conducted in illegal mining areas (S2 and S3), whereas the remaining studies were conducted in areas with MPSAs or adjacent mining areas with 26 mining companies. All in all, there were 33 mining sites under study. The list of the different journals where the papers were published is also presented in Appendix II. With the recently issued policy (DAO 2022-04) concerning biodiversity conservation in mining areas in the country, it is anticipated that studies on species richness baseline information in most of the mining areas, if not all, may increase in the coming years.

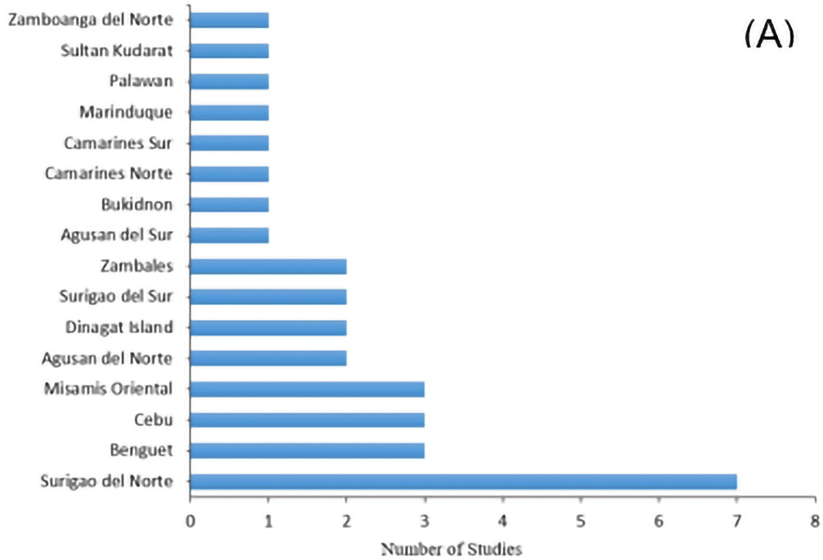
Geolocation of the Study Areas

In this study, information regarding the province, municipality, *barangay*, and geographic coordinates of the study sites was obtained from the papers. While most studies included the provinces and municipalities of their study sites, only a few studies indicated the *barangays* and geographic coordinates of their study areas (Appendix III). However, for the project terminal reports (S26 and S27), the geographic coordinates were listed in all study sites/plots. Indicating the exact geographic location where biodiversity assessments were conducted is crucial in developing effective conservation strategies and conducting species distribution studies. As Sofaer and colleagues (2019) suggest, geographic information on species occurrence is an imperative element of conservation, as it can help in developing site-specific conservation plans that may include reforestation strategies. Additionally, geographic information provides relevant components such as elevation, climate type, and proximity to threats like land use changes, which can significantly affect the survival of species. With this information, conservationists can develop conservation plans tailored to the specific needs of an area and its species. On a negative note, the distribution information in many studies is often incomplete, including the articles reviewed in this study.

The geographic location of study areas should be noted using GPS readings, as recommended by the manual on biodiversity assessment and monitoring system for terrestrial ecosystems published by the DENR and the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH (BMB-GIZ 2017). The specific geolocations could serve as permanent biodiversity monitoring areas, which are valuable in the conservation and sustainable management of biodiversity resources, as well as in the planning and decision-making process (Malabrigo *et al.* 2016). Knowing the exact geographic locations where biodiversity assessments were conducted is also important in identifying or locating biodiversity hotspots and determining which species are present in the area, including threatened species. Pinpointing the exact location can also help in identifying potential threats to biodiversity such as deforestation, pollution, and land use changes.

The study found that Surigao del Norte had the highest number of biodiversity assessment studies in mining areas – followed by Benguet, Cebu, and Misamis Oriental (Figure 3a). It is interesting to note that out of the 55 provinces with mining areas and MPSAs, only 16 provinces have published biodiversity assessment studies inside or adjacent to the mining areas. Moreover, no published articles related to the review topic were found in the mining areas of Rizal province, although it is the second province with the highest number of MPSAs. The distribution of the different biodiversity assessment studies (flora and fauna) and the project sites (DGCP and PMC) is reflected in Figure 3b. Most studies on the Luzon island group focus on the flora diversity assessment in mining areas, whereas on the Mindanao island group, both floral and faunal diversity studies were conducted. On the other hand, only the province of Cebu has published articles on the Visayan island group.

It is highly recommended to include the geographic coordinates of study sites in biodiversity assessments, aside from the *barangay* or *sitios*. This information can help in developing effective conservation strategies, identifying potential threats to biodiversity, and monitoring and evaluating conservation efforts. It is crucial to have accurate and complete information on the geographic location of study sites to aid in species distribution studies, site-specific conservation planning, and sustainable management of biodiversity resources.



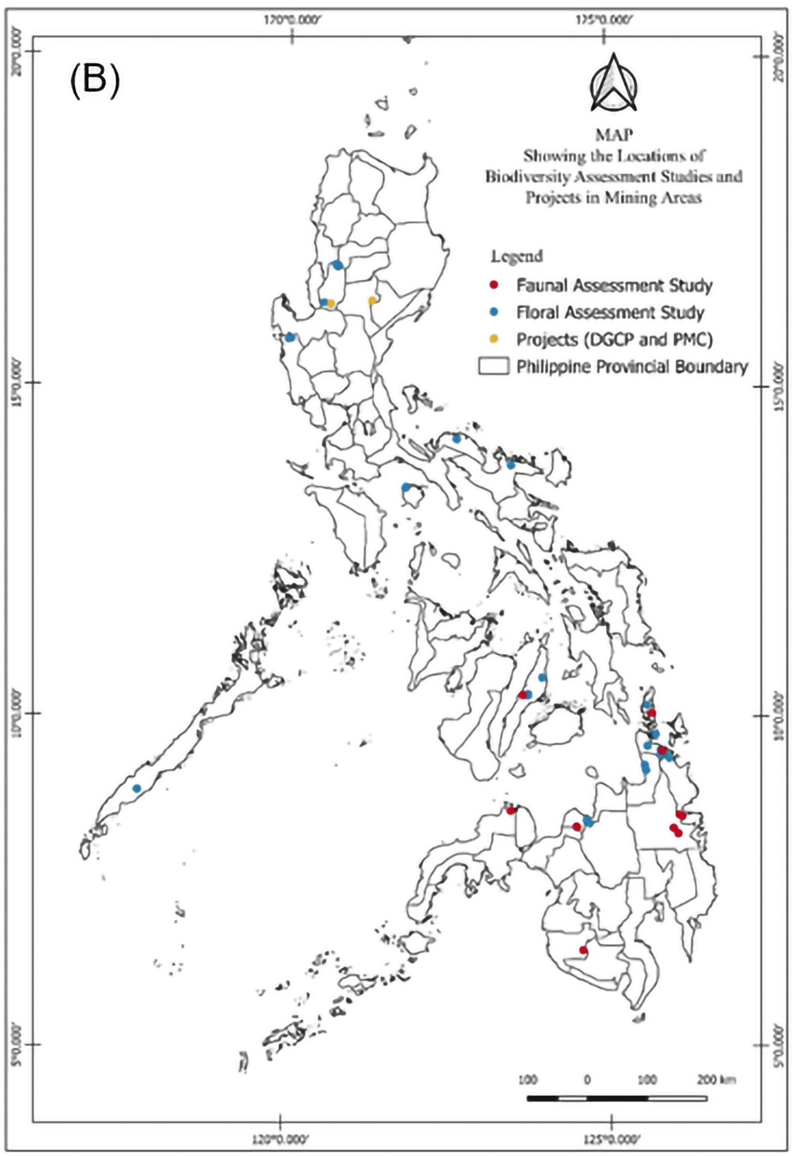


Figure 3. [A] The number of published studies per province; [B] the geographic distribution of the study sites for floral and faunal diversity assessments.

Biodiversity Component, Taxa, Ecosystem Type, and Taxonomic Characterization

In this review, biodiversity assessment studies were categorized based on their focus on either flora or fauna and their ecosystem type, which could be terrestrial, aquatic, or both. Appendix IV provides an overview of these studies, which revealed that 17 studies focused on floral diversity assessment in mining areas, whereas eight studies assessed faunal diversity. The floral studies included different forest types, grassland areas, and specific groups of plants such as ferns, medicinal plants, hyperaccumulating plants, and epiphytes. Interestingly, one study even assessed the diversity of fungi (mycorrhizal) in a mining site. The majority of floral studies were conducted in terrestrial ecosystems, with only one study assessing both aquatic and terrestrial areas.

On the other hand, the faunal diversity assessment studies included amphibians, birds, bats, reptiles, fish, odonates, and nematodes but did not include any other mammals besides bats. This is likely because other forest-dependent mammals avoid mining areas due to the disturbances caused by mining activities, which threaten their habitats (Martins-Oliveira *et al.* 2021). Two project reports in DGCP and PMI assessed a wider range of biodiversity groups – including plants, fungi, fauna, lichen, arthropods, and freshwater ecology. However, conducting more comprehensive biodiversity assessments in other mining sites would require higher financial costs and third-party experts' technical assistance.

The taxonomic characterization in all diversity assessment studies in mining areas mentioned the scientific names of the flora and faunal species assessed. However, only 12 studies included their common names, and only 18 studies included their family names. Only one study indicated the order of the species encountered in the study sites. Taxonomic identification in mining areas, particularly metallophytes, is a challenging task, as pointed out by Pollisco (2018). Therefore, proper and correct taxonomic identification and documentation should be conducted in these mining areas to identify priority species for conservation. Various checklists, websites, and databases such as Co's Digital Flora of the Philippines, Plants of the World Online, and World Flora Online can be used for verifying species identity.

Assessment Tools and Sampling Design

In assessing the diversity of flora in mining areas, the most common sampling methods used by different authors (13 studies) were the line transect and quadrat methods (Appendix V). Other methods included purposive sampling (S5), field survey (S7), and exploratory survey (S8), whereas one study (S10) did not indicate its sampling methods. The quadrat plot sizes used for trees and shrubs were usually 20 m x 20 m with ≤ 5 cm dbh (S4, S16, S19, S20, and S23), with 5 m x 5 m and 1 m x 1 m subplots established for other understory vegetation. Some studies used a 10 m x 10 m plot size (S12, S13, S22, and S24), whereas one study established a 20 m x 10 m plot size (S14). For weeds, grasses, or herbs and ground cover, the usual plot size was 1 m x 1 m. It is noteworthy that the 10 m x 10 m quadrat size used for floral assessment in two project sites (S26 and S27) is considerably smaller than the 20 m x 20 m quadrat size recommended by BMB-GIZ (2017) for assessing species diversity.

On the other hand, faunal diversity assessment studies used various methods, with the transect line method being the most common for birds, amphibians, and reptiles, whereas other methods included mist netting, point count, opportunistic and purposive sampling, cage and pitfall trapping, net sweeping, and modified tray method (Appendix VI).

It is important to note that the sampling design used in measuring species richness is crucial for the accuracy and reliability of biodiversity assessment studies. There is no one-size-fits-all sampling method; instead, the method chosen should depend on the objectives, the type of ecosystem, and the taxa being assessed. Clear and concise objectives are necessary for successful sampling design, and stratified sampling is necessary to ensure proper representation of various land use and cover types found in the area (Gevaña *et al.* 2013).

Biodiversity Values

A number of metrics or parameters were used by some of the papers under review in assessing the biodiversity of the mining regions; these include the species abundance (Ab), relative abundance (Rab), dominance (Dom), relative dominance (Rdom), frequency (F), relative frequency (Rf), density (D), relative density (Rd), percent cover (%C), and importance value (IV). However, not all of these parameters can be found in a single study. For the vegetation assessment, the most frequently used biodiversity parameters were species D and F (Figure 4). The IV was only included in nine floral diversity studies. On the contrary, the usual biodiversity parameters used in the faunal survey studies were the Ab, Rab, D, and Dom. Based on the review, five floral papers (S5, S7, S8, S10, and S17) and one faunal paper (S6) did not use any of the aforementioned parameters in describing or measuring the biodiversity in the mining sites.

Biodiversity Indices

In most biodiversity assessment studies in the Philippine mining areas, various biodiversity indices are calculated to characterize species diversity. The most commonly used indices include the Shannon-Wiener (H') diversity

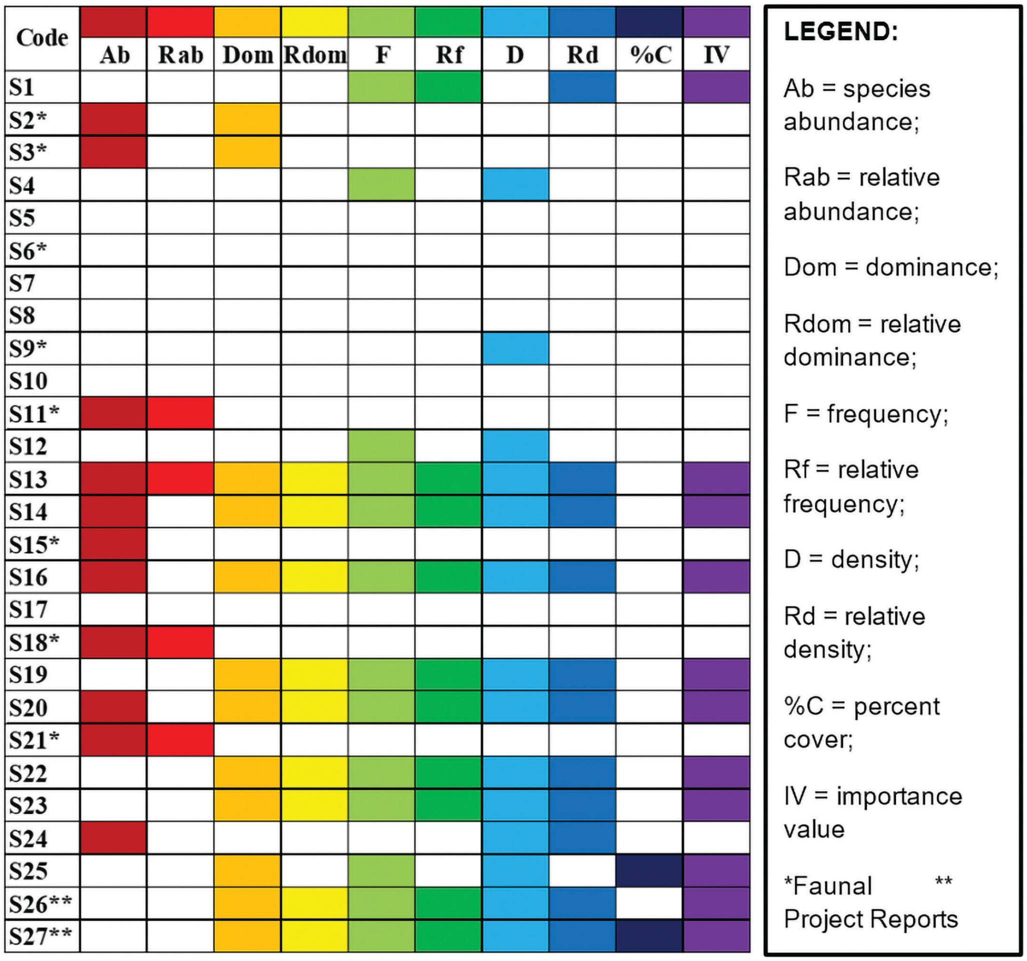


Figure 4. The different values used in diversity assessment studies.

index, Simpson index, species richness, Margalef index, and species evenness using Pielou's index and McIntosh index (Appendix VII). The Shannon-Wiener diversity index is the most widely used index for both floral and faunal assessment, followed by species richness and evenness. However, it is worth noting that the eight papers chosen for this review did not compute or determine any biodiversity index in their research.

The Shannon-Wiener diversity index is a commonly used measure proposed by Shannon and Weaver (1949) that considers both species abundance and evenness. The Simpson diversity index, developed by Simpson (1949), is another common index that considers both evenness and species richness and measures the probability that any two randomly selected individuals belong to the same species. The benefit of using Simpson's index is that it takes both richness and evenness into account and can be used for populations that are both finite and infinite (Bollarapu and Ramarao 2021).

In addition, Brillouin's diversity index was used in one study to describe biodiversity in the mining area. Other biodiversity indices used in mining areas include the Margaleaf and evenness indices. Margalef's diversity index, developed by Margalef (1958), is commonly used to calculate species richness for small samples, whereas evenness indices take into account the species richness and the relative abundance of species in a particular area. Pielou's evenness index, for example, is a standardization of the H' (Shannon index) that measures the degree of diversity within a specific spatial unit and ranges from 0–1.

Jaccard's, Sorensen's, and Bray-Curtis similarity indices are also used to assess the similarity of species within established plots, an important factor in measuring biodiversity (Leinster and Cobbold 2012). The different formulas used to compute biodiversity indices are presented in Appendix VIII.

There is no definitive set of biodiversity indices to be computed in conducting biodiversity assessment studies for flora and fauna in mining areas, as the choice of indices will depend on the specific objectives of the study and the characteristics of the study site. Appendix IX presents the proposed diversity indices for each component to be assessed in mining areas. However, it is important to note that the selection of appropriate biodiversity indices depends on the research objectives, study design, and data collected. Therefore, researchers must carefully evaluate which indices to use based on their specific research questions.

Endemism, Economic Importance, and Conservation/Ecological Status

Appendix X shows that several of the chosen publications had study objectives that focused on species endemism, economic importance, invasiveness, and conservation/ ecological status. Endemism is a well-known concept in conservation science and is important for identifying endemic species and sites with high endemism for conservation efforts (Florentin *et al.* 2022). However, out of the 25 reviewed articles, only nine studies took into account the endemicity of the species found in mining sites, indicating that there is still much work to be done in identifying and compiling a list or database of all endemic species – both flora and fauna – in the nation's mining areas.

One study (the project terminal report) included the invasiveness status of plant species encountered in the area, which is relevant to understanding the potential effect of invasiveness on biodiversity conservation. Invasive plant species can have negative impacts on biodiversity, causing a decline in native biodiversity, economic losses, and loss of aesthetic value (Paclibar and Tadiosa 2019). Therefore, it is crucial to assess invasive animal species in mining areas as well, as they can have similar negative impacts on local ecosystems.

Although estimating the economic importance of species is challenging, it can provide valuable insights and pertinent information on species with significant economic value within mining sites (Gascon *et al.* 2015). Only one research article (S17) evaluated the economic category of the floral species found in mining sites – including medicinal, food consumption, handicraft, and ornamental categories. Other economic importance for floral species includes weeds, soil binders, timber, fodder, and fuel wood (Rahman *et al.* 2015).

Both the project terminal reports (S26 and S27) and 11 studies determined the ecological or conservation status of the flora and/or fauna using the IUCN red list of threatened species and/or the updated list of threatened species in the Philippines prepared by the DENR. However, the IUCN is not intended to define or categorize conservation status at the local or national level, despite being an excellent model for classifying extinction risk at the global level (Crain and White 2011).

Proposed Step-by-step Approaches for Conducting Biodiversity Assessment in Mining Areas in the Philippines

Based on the result of this systematic review, the authors proposed the following guidelines and components for conducting the biodiversity assessment in mining areas: [1] identify the scope and objectives of the assessment (before starting the assessment, it is essential to determine the scope of the study and the specific objectives to be achieved); [2] determine the biodiversity components and taxa to be assessed (as much as possible include the terrestrial plants, terrestrial and aquatic animals, insects, fungi, and microorganisms); [3] identify the ecosystem type and taxonomic characterization (the ecosystem type or land use land cover should be identified to understand the specific habitats that support the biodiversity in the mining area; this can be identified using satellite imageries and GIS applications; in addition, taxonomic characterization should include the FM, SN, and – if possible – the CN or the local name of the species); [4] select the assessment tools and sampling design (several assessment tools and sampling designs can be used as shown in this paper; these may include biodiversity surveys, ecological assessments, and habitat assessments; the sampling design should be representative of the entire mining area and should cover all the habitats and biodiversity components; moreover, exact geolocation of the study sites and sampling plots should always be noted); [5] determine the biodiversity values and indices such as Ab, Rab, Dom, Rdom, F, Rf, D, Rd, %C, and IV (these should also include species richness, species evenness, similarity, and diversity indices such as the H' and/or Simpson's diversity index; these values and indices can help to compare the biodiversity of different habitats and identify areas of high conservation value); [6] consider endemism, economic importance, invasive species (plants and animals), and conservation/ecological status (endemism refers to the presence of species that are unique to a specific geographic region; economic importance refers to the value of biodiversity in terms of the goods and services that it provides; invasive species can have negative impacts on the local ecosystem; the conservation/ ecological status of the biodiversity components can help to prioritize areas for conservation and management actions); [7] analyze the data and interpret the results (after collecting the data, there is a need to analyze and interpret the results; the analysis should include statistical tests and comparisons of the biodiversity values and indices across different habitats and biodiversity components; the interpretation of the results should provide insights into the ecological status of the mining area and identify areas that require conservation and management actions); [8] develop a biodiversity management plan (based on the results of the assessment, the mining companies need to develop a biodiversity management plan for the mining area; the plan should include strategies to conserve and manage the biodiversity of the area, mitigate the impacts of mining activities on biodiversity, and monitor the effectiveness of the management actions over time; the plan should also consider the economic and social impacts of biodiversity conservation and management on the local communities and stakeholders); and [9] publication of the research output (it is essential to publish the research findings in a peer-reviewed journal to enhance the body of knowledge within the country, particularly the status of biodiversity in mining areas).

CONCLUSION

The limited number of studies related to biodiversity assessment in mining areas in the Philippines over the last decade highlights the urgent need for more research in this field. Although most biodiversity studies in the country have focused on protected areas, mountain ecosystems, forest types, and ancestral domains, the recent policy on biodiversity conservation in mining areas is expected to lead to more studies on biodiversity in most, if not all, mining areas. It is observed that biodiversity assessment studies in mining areas have primarily focused on either flora or fauna, with floral diversity in terrestrial ecosystems being the most commonly assessed. Clear and concise objectives and stratified sampling are necessary for a successful sampling design. Also, proper taxonomic identification and documentation are crucial for identifying priority species for conservation. Conducting comprehensive biodiversity assessments in mining areas may require higher financial costs and technical assistance from third-party experts. The choice of appropriate biodiversity values and indices depends on the research objectives, study design, and data collected. Therefore, careful evaluation is necessary to determine the appropriate indices for specific research questions in mining areas. The reviewed articles show that there is still much to be done in identifying and compiling a comprehensive list of biodiversity species in mining areas in the Philippines. Furthermore, more research is needed to assess the invasiveness of plant and animal species in these areas and to understand the economic significance of the flora and fauna found in mining sites. Overall, these findings emphasize the need for more comprehensive and localized research efforts to improve conservation and management practices in mining areas in the Philippines. Biodiversity assessments should be prioritized in mining areas to provide baseline data for conservation efforts and to develop effective management plans that balance economic and environmental concerns.

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STATEMENT ON CONFLICT OF INTEREST

The authors declare no potential conflict of interest regarding the publication of this work.

NOTES ON APPENDICES

The complete appendices section of the study is accessible at https://philjournsci.dost.gov.ph

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APPENDICES

Appendix I. The eligibility criteria for the inclusion or exclusion of research articles.

Eligibility criteria	Included articles	Excluded articles
Population	Published articles related to biodiversity assessment inside or adjacent to the mining area/s in the Philippines, preferably articles indexed in SCOPUS of Web of Science; project terminal reports.	Unpublished articles; articles not conducted in mining areas; articles outside the country
Study design	Studies with clear methods/ tools, and sampling design in assessing the diversity of a certain biota or taxa	Studies without any clear methods or sampling design in assessing the biodiversity
Exposure	Studies that mentioned a link between biodiversity assessment or conservation and mining operations	Biodiversity studies not linked to mining operations
Outcome	Studies with species richness and taxonomic characterization results, biodiversity importance values, and diversity indices	Studies without results relevant to biodiversity assessment and/or characterization

Appendix II. The list of selected published studies and project terminal reports.

Code	Author/s	Year	Journal	Mining area/company
S1	Abanto *et al.*	2011	Journal of Environmental Science and Management	Yinlu Bicol Minerals, Philippines Iron Mines (PIM)
S2	Ascaño II *et al.*	2016	Journal of Scientific Research and Development	Unregulated/unregistered, illegal mining area
S3	Ascaño II *et al.*	2015	Advances in Environmental Biology	Unregulated/unregistered, illegal mining area
S4	Ata *et al.*	2016	Asian Journal of Biodiversity	DMCI Mining Corporation (DMC)/ Taganito Mining Corporation (TMC)
S5	Bayas *et al.*	2018	Philippine Journal of Systematic Biology	Lagonoy ophiolite complex
S6	Cabahug *et al.*	2021	IOP Conference Series: Earth and Environmental Science,	Mining areas in Toledo City, Cebu
S7	Claveria *et al.*	2020	Journal of Sustainable Mining	[1] Acoje Mines, Zambales; [2] Brookes Point Mines, Palawan; [3] Camp 6, Benguet (Small-scale); [4] Philex Mines, Benguet; [5] Lepanto Mines, Benguet; [6] Acupan, Benguet (Small-scale); [7] Carmen Mine, Cebu; [8] Silangan Mine, Surigao; [9] Tompagon, Misamis Oriental; [10] Manila Mining, Surigao
S8	Claveria *et al.*	2019	Environmental Monitoring and Assessment	Lepanto Consolidated Mining Company
S9	December	2010	Odonatologica	Lecing/ Henry
S10	Demetillo *et al.*	2019	Journal of Medicinal Plants Studies	Mining area in Claver
S11	Galolo *et al.*	2021	Proceedings of the International Academy of Ecology and Environmental Sciences	[1] Philsaga Mining Corporation (PMC); [2] Adnama Mining Resources Incorporated (AMRI)
S12	Garcia *et al.*	2017	Journal of Biodiversity and Environmental Sciences	Mining areas in Claver, Surigao
S13	Goloran *et al.*	2020	International Journal of Environmental Sciences and Natural Resources	Platinum Group Metals Corporation (PGMC)
S14	Lillo *et al.*	2019	Journal of Asia-Pacific Biodiversity	Dinagat Island Mining Areas
S15	Martinez *et al.*	2018	Ecological Indicators	Mining areas in Sibutad
S16	Along *et al.*	2020	Journal of Ecosystem Science and Eco-Governance	Agata Mining Ventures, Inc. (AMVI)
S17	Mugot *et al.*	2021	Journal of Ecosystem Science and Eco-Governance	Small-scale mining

Appendix II. Cont.

S18	Quisil *et al.*	2014	Journal of Biodiversity and Environmental Sciences	Small-scale mining
S19	Sarmiento	2020	Ambient Science	Agata Mining Ventures, Inc
S20	Sarmiento and Demetillo	2017	Journal of Biodiversity and Environmental Science	Carrascal Nickel Corporation, Inc. (CNC)
S21	Tanalgo *et al.*	2017	Ecological Questions	Small-scale gold mining
S22	Mante *et al.*	2019	Journal of the International Society for Southeast Asian Agricultural Sciences	Consolidated Mining Inc. (CMI)
S23	Sarmiento	2018	Ambient Science	Hinatuan Mining Corporation
S24	Aggangan *et al.*	2015	Journal of Environmental Science and Management	Atlas Consolidated Mining and Development Corporation (ACMDC)
S25	Cuevas and Balangcod	2020	Environment Asia	Lepanto Consolidated Mining Company (LCMC)
S26[a]	Malabrigo *et al.*	2017		Didipio Gold and Copper Project (DGCP)
S27[a]	Pampolina *et al.*	2019		Philex Mining Corporation (PMC)

[a]Project terminal reports

Appendix III. The study location of the published papers and project reports selected for the review

Code	Province	Municipality	*Barangay*	Coordinates
S1	Camarines Norte	Jose Panganiban	Larap	14° 7.525' and 122° 38.751'
S2	Misamis Oriental	Cagayan de Oro City	Tumpagon	8°19'19"N and 124°28'49"E
S3	Misamis Oriental	Cagayan de Oro City	Tumpagon	8°19'19"N and 124°28'49"E
S4	Zambales, Surigao del Norte	Sta. Cruz, Claver		15° 42' 0" N and 120° 4' 1" E; 9° 30' 0" N and 125° 53' 0" E
S5	Camarines Sur	Lagonoy		13.44° N and 123.31° E
S6	Cebu	Toledo City		
S7	Zambales; Palawan; Benguet; Cebu; Surigao del Norte; Misamis Oriental	Santa Cruz; Brookes Point; Tuba, Mankayan; Carmen; Tubod; Tompagon/CDO		
S8	Benguet	Mankayan		
S9	Dinagat Island			10° 17'33" N / 125°34'58" E ;
S10	Surigao del Norte	Claver		
S11	Agusan del Sur; Surigao del norte	Rosario, Bunawan; Claver	Bayugan San Andres; Urbiztondo	8023'13.2"N and 12600'10.8"E
S12	Surigao del Norte	Claver		
S13	Surigao del Norte	Claver		
S14	Dinagat Island	Whole province		
S16	Agusan del Norte	Tubay	Tinigbasan	
S17	Bukidnon	Libona	Gango	
S18	Surigao del Sur	Barobo	Javier, Tambis	8' 29.114" N 126' 4.990" E; 8'32.234" N 126'2.738" E;
S19	Agusan del Norte	Tubay		8°57'N; 125°32'E
S20	Surigao del Sur	Carascal	Bon-ot	819376 Easting and 1036650 Northing
S21	Sultan Kudarat	Bagumbayan	Kinayao	6°26' 48.1"N, 124°35'7.28"

Appendix III. Cont.

S22	Marinduque	Mogpog	Ino; Kapayang	
S23	Surigao del Norte	Tagana-an	Hinatuan Island, Talavera	9.753367° to 9.813161° N; 125.696155° to 125.741308° E
S24	Cebu	Toledo City	Biga, Bagakay and Lu-ay	
S25	Benguet	Mankayan	Paco, Cabitin	
S26[a]	Nueva Vizcaya	Kasibu	Didipio	With coordinates
S27[a]	Benguet	Tuba and Itogon	Camp 3; Ampucao	With coordinates

[a]Project terminal reports

Appendix IV. The biodiversity categories and taxonomic characteristics.

Code	Target group/ site description	Category/ group		Ecosystem		Taxonomic characterization			
		FL	FA	AQ	TER	CN	SN	FN	OR
S1	Plants/ grassland area	✓			✓		✓	✓	
S2	Avifaunal / birds		✓		✓	✓	✓	✓	
S3	Reptiles		✓	✓	✓	✓	✓	✓	
S4	Plants/ forests over the ultramafic soil	✓			✓		✓	✓	
S5	Nickel hyperaccumulating plants	✓			✓	✓	✓	✓	
S6	Fish		✓	✓		✓	✓		
S7	Ferns	✓			✓		✓		
S8	Plants (ferns, trees, shrubs)	✓			✓		✓		
S9	Odonata/ dragonflies		✓		✓		✓		
S10	Medicinal plants	✓		✓			✓	✓	
S11	Amphibians		✓	✓		✓	✓	✓	
S12	Mesophytes and hydrophytic	✓		✓	✓	✓	✓	✓	
S13	Mangroves	✓		✓	✓	✓	✓	✓	
S14	Plants/ different forest types	✓			✓		✓	✓	
S15	Nematodes		✓		✓		✓		
S16	Plants/ forest over limestone	✓			✓	✓	✓	✓	
S17	Pteridophytes	✓			✓		✓	✓	
S18	Odonata		✓		✓		✓		
S19	Plants	✓			✓	✓	✓	✓	
S20	Trees	✓			✓	✓	✓	✓	
S21	Bats		✓		✓	✓	✓	✓	
S22	Vines, epiphytes, trees, shrubs	✓			✓		✓		
S23	Plants	✓			✓		✓	✓	
S24	Plants and mycorrhizal fungi	✓			✓	✓	✓	✓	✓
S25	Plants	✓			✓		✓	✓	
S26[a]	Plants (ferns, grasses, herbs, palms, shrubs, vines, trees); fungal resources; fauna (birds, reptiles, amphibians, bats, rodents); lichen; arthropods; freshwater ecology (periphyton, macrobenthos, fish, crustaceans)	✓	✓	✓	✓	✓	✓	✓	
S27[a]	Plants; riparian vegetation; macrofungi; fauna (avifauna, mammals, reptiles, amphibians); Terrestrial arthropods; aquatic (plankton, macrobenthos, fishes)	✓	✓	✓	✓	✓	✓	✓	
	Total	17	8	6	22	12	25	18	1

[FL] flora; [FA] fauna; [AQ] aquatic; [TER] terrestrial; [CN] common name; [SN] scientific name; [FN] family name; [OR] order; [a]project terminal reports

Appendix V. The biodiversity assessment tools and sampling designs for flora.

Code	Sampling methods	Plot size	No. of plots	Transect length	No. of transect
S1	Quadrat	1 m x 1 m	20		
S4	Transect line	20 m x 20 m; 5 m x 5 m within the plot	8		
S5	Purposive sampling	Not indicated			
S7	Field surveys	Not indicated			
S8	Exploratory survey	Not indicated			
S10	Not indicated	Not indicated			
S12	Quadrat, line transect	10 m x 10 m	21		3
S13	Quadrat, line transect	10 m x 10 m; 1 m x 1 m for seedling/sapling	18	100–200 m	6
S14	Quadrat	20 m x 10 m; 2 m x 2 m for herbs, vines, seedlings	14		
S16	Modified quadrat, line transect	20 m x 20 m; 5 m x 5 m for understory, shrubs, herbs, grasses	12	2 km	2
S17	Quadrat, line transect	1 m x 1 m	45	2 km	4
S19	Quadrat	20 m x 20 m	4		
S20	Quadrat	20 m x 20 m	3		
S22	Quadrat	20 m x 20 m for vines ephiphytes; 10 m x 10 m for trees; 2 m x 2 m for shrub, seedling, sapling; 1 m x 1 m for grass, ferns	6		
S23	Quadrat	20 m x 20 m			
S24	Quadrat	10 m x 10 m; 5 m x 5 m for wildlings	3		
S25	Quadrat, line transect	1 m x 1 m	10	50 m	3
S26[a]	Quadrats, opportunistic sampling for flora: quadrat and purposive sampling for fungal resources,	10 m x 10 m for flora; 1 m x 1 m for fungi	18		
S27[a]	Quadrats for flora, transect for riparian vegetation, purposive sampling for macrofungi	10 m x 10 m for canopy; 5 m x 5 m for understory; 1 m x 1 m for undergrowth	10	50m for riparian	

[a]Project terminal reports

Appendix VI. The biodiversity assessment tools and sampling designs for fauna.

Code	Sampling methods	No. of plots	transect length	No. of transect
S2	Line transect, point count, mist netting	36	2 km	4
S3	Transect line	10		4
S6	Transect line		25 m	5
S9	Transect line		50 m	39
S11	Transect line		100 m	20
S15	Modified tray method	5		
S18	Opportunistic sampling	8		
S21	misting nets	36	2 km	4
S26[a]	Transect methods, mist netting, cage trapping, opportunistic sampling, and net sweeping			
S27[a]	Line-transect, mist netting, trapping, opportunistic and purposive sampling, pitfall traps, net sweeping,			

[a]Project terminal reports

Appendix VII. The different biodiversity indices used by various authors.

Code	Biodiversity indices					Similarity indices		
	Shannon -Wiener	Simpson	Brillouin	Species richness (Margalef)	Evenness Pielou, McIntosh	Jaccard's index	Sorensen's index	Bray-Curtis
S1	✓			✓	✓			
S2[a]	✓	✓			✓			
S3[a]	✓	✓			✓			
S4	✓	✓			✓			
S5								
S6[a]								
S7								
S8								
S9[a]								
S10								
S11[a]	✓			✓	✓			
S12	✓							
S13	✓			✓	✓			
S14	✓	✓	✓			✓	✓	
S15[a]	✓	✓		✓				
S16	✓			✓	✓			
S17								
S18[a]	✓			✓	✓			
S19	✓	✓		✓				
S20	✓							
S21[a]				✓				
S22				✓				✓
S23	✓			✓	✓			
S24	✓			✓	✓			
S25								
S26[b]	✓	✓		✓	✓			
S27[b]	✓	✓					✓	
Total	17	8	1	12	11	1	2	1

[a]Faunal assessment studies; [b]project terminal reports

Appendix VIII. The various formulas of biodiversity values and indices commonly used.

Diversity value index	Formula/Equation	Remarks
Density (D)	$D = \frac{\text{Number of individuals}}{\text{Area sampled}}$	
Relative density (Rd)	$Rd = \frac{\text{Density for a species}}{\text{Total density for all species}} X\ 100$	
Frequency (F)	$F = \frac{\text{Number of plots where species occur}}{\text{Total number of plots samples}}$	
Relative frequency (Rf)	$Rf = \frac{\text{Species frequency value}}{\text{Total frequency for all species}} X\ 100$	
Dominance (Dom)	$Dom = \frac{\text{Basal area or volume for a species}}{\text{Area sampled}}$	
Relative dominance (Rdom)	$Rdom = \frac{\text{Species dominance}}{\text{Total dominance for all species}} X\ 100$	
Importance value (IV)	$IV = Rd + Rf + Rdom$	
Shannon-Weiner (H')	$H' = \sum_{i=1}^{S} (Pi)(\ln Pi)$	H' = Shannon-Wiener diversity index S = total number of species Pi = the proportion of individuals found in the *i*th species ln = natural logarithm
Simpson diversity (D_s)	$D_s = 1 - \Sigma \left(\frac{n}{N}\right)^\wedge 2$ or $D_s = \frac{\Sigma n\,(n-1)}{N\,(N-1)}$	D_s = Simpson diversity index n = number of individual for each particular species N = total number of individuals of all species
Brillouin diversity index (HB)	$HB = (\ln N! - \sum \ln ni!) / N$	HB = Brillouin's diversity index N = total number of species in the sample ni = number of species in the ith species.
Margalef's diversity index (R)	$R = (S - 1) / \text{In } N$	R = Species richness S = total number of species N = total number of individuals in the sample In = natural logarithm
Pielou's evenness index (J)	$J = H'/Hmax$	J = Pielou's evenness index H' = Shannon diversity index Hmax = the logarithm of the number of age classes with at least one observation

McIntosh evenness index	$M = [\ N - \sqrt{(\sum ni2)}\ ] / [\ N - (N / \sqrt{S})\ ]$	M = McIntosh evenness index ni = number of individuals belonging to species *i* N = total number of individuals
Jaccard's similarity index	$IS_J = \dfrac{a}{a+b+c}$	IS_j = Jaccard's similarity index IS_s = Sorensen's similarity index
Sorensen's similarity index	$IS_s = \dfrac{2a}{2a+b+c}$	a = number of common species in between stands/ plots b = number of species unique to the first plot c = number of species unique to the second plot

Appendix IX. Proposed biodiversity indices to be computed for each component.

Index	**Flora**	**Grass/ under growth**	**Epiphytes**	**Terrestrial Fauna**	**Aquatic Fauna**	**Fungi**	**Insects**	**Micro-organism**
Species richness	✓	✓	✓	✓		✓	✓	
Shannon diversity index	✓	✓	✓	✓	✓	✓	✓	✓
Simpson diversity index	✓	✓	✓	✓	✓	✓	✓	
Evenness index	✓	✓	✓	✓		✓	✓	✓
Chao 1 diversity index	✓		✓					✓
Bray-Curtis similarity index		✓		✓				
Margalef diversity index						✓	✓	
Biological monitoring working party (BMWP) score					✓			
Average score per taxon (ASPT)					✓			

Appendix X. Other parameters used to assess the biodiversity in the mining areas.

Code	Biodiversity endemism	Economic category	Invasiveness status	Ecological/ conservation status	Reference for conservation status
S1					
S2[a]	✓			✓	IUCN
S3[a]	✓			✓	
S4				✓	
S5					
S6[a]					
S7					
S8					
S9[a]					
S10					
S11[a]	✓			✓	IUCN
S12					
S13	✓			✓	IUCN; DAO 2017-11
S14	✓			✓	IUCN ; DAO 2017-11
S15[a]					
S16				✓	IUCN ; DAO 2017-11
S17	✓	✓		✓	IUCN ; DAO 2017-11
S18[a]	✓				
S19				✓	IUCN
S20	✓			✓	IUCN
S21[a]	✓			✓	IUCN
S22					
S23				✓	IUCN
S24					
S25					
S26[b]	✓			✓	
S27[b]	✓		✓	✓	
Total flora	6	1	1	10	IUCN, DAO 2007-01
Total fauna	7	0	0	6	IUCN, DAO 2017-11
Overall total	13	1	1	16	

[a]Faunal assessment studies; [b]project terminal reports