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Recovery of Orchids in the Post Gold Mining Landscape of Combretum-Terminalia Woodland Ecosystem

Dereje Mosissa, Hailu Atinafu

Abstract: *Benishangul Gumuz Region stands out for its remarkable endemism and diversity of orchids, in which 63 different orchid species have been recorded so far. However, this wealth of diversity is potentially at risk due to habitat loss caused by the newly booming mineral mining industry and other regional developments. Consequently, species extinction is occurring at an alarming rate, one year shorter than projected. Therefore, it is necessary to periodically assess the status of orchid diversity to determine the extent of the threat and devise the appropriate conservation measures. To address this issue, the researcher utilised preserved forests bordering abandoned post-mineral exploitation areas as a model to determine the status of orchids through systematic field surveys conducted over four years (2021-2024). For the Orchids survey purpose, a total of 90 quadrant sample plots, each 10 x 10 m in size and spaced at an interval of 50 meters along six parallel transects, were established. The survey result revealed that of the previous 63 orchid species known, only 42 were found, of which only 20 were recorded in post-mining sites. There was a significant difference (P < 0.05) between the orchid species diversity at all sites surveyed, except for the diversity comparison between the mining site abandoned for five and ten years (P > 0.05). Moreover, the orchid diversity of the region was depicted as medium (H' = 3.969) for the unmined area and low (H' = 2.73) for post-mining sites. According to the data on summed dominance ratio (SDR), Nervilia simplex (SDR = 4.10), Habenaria aethiopica (SDR = 5.88), and Bulbophyllum scaberulum (SDR = 9.47) were the top three dominant species in the post-gold mining sites and were considered disturbance opportunists. Concerning elevation parameters, the total number of orchid species follows a unimodal pattern with elevation. The highest species number (127 individuals) was observed at elevations of 861–925 meters and 926–1153 meters, while the lowest species number (72 individuals) was found at elevations below 860 meters. In this study, the number of orchid species was significantly lower than the number in the initial research conducted at the exact location, and we were unable to find most of the previously described endemic orchids. This may be due to difficulty in establishing themselves even in the oldest abandoned gold mining sites as a result of Sevier degradation. Based on the study results, we recommend establishing an effective regulatory mechanism to ensure the proper rehabilitation of gold mining sites through appropriate biological treatments before investors abandon leased project sites.*

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Abbreviations:
BGRS: Benishangul Gumuz Regional State
BGR: Benishangul Gumuz Regional
SDR: Sum of dominance ratio
H': Shannon Wiener Diversity index
IUCN: International Union for Conservation of Nature
RD: Relative Density
RF: Relative Frequency

I. INTRODUCTION

Sub-Saharan Africa is a global biodiversity conservation priority due to its rich biodiversity. In this region, there are approximately 1,373 species belonging to 88 genera. The results show that of the four phytogeographic zones, Central Africa is the richest with 708 species, followed by Southern Africa and East Africa with 637 and 583 species, respectively. West Africa, with 413 species, is the least rich area. At the same time, it is the region that contains "crisis" and "very high risk" eco-regions, characterised by severe habitat conversion and minimal protected area coverage [1]. The impact of mining on biodiversity has been of worldwide concern for many decades [2]. Recently, the total number of orchids has decreased worldwide [3]. Orchids are sensitive to environmental changes [4]. They are often amongst the first plant species to disappear in response to anthropogenic disturbances [5], making orchids relevant bio-indicators of the ecological quality of ecosystems [6]. Furthermore, climate change may affect temperate terrestrial orchids in different ways.

Depending on the species and region, they may respond positively or negatively to changes in climate parameters [7].

In 2017, the IUCN Global Red List included assessments for 948 orchid species, of which 56.5% are threatened. [8]. Current studies in Ethiopia indicate that, in addition to minerals exploitation, conversion of wetland habitats into irrigated agriculture is degrading sensitive wetland areas of endemic orchid habitats [9], which the national wheat production program has long threatened due to the upland massive wheat wetland irrigation [10].

The presence, abundance, growth, and symbionts of orchids can be used as indicators of ecosystem health. However, further work is needed to refine the understanding of their response to specific disturbances [11].

Regeneration of geophytes from a disturbed area may occur either through seed dispersal from nearby forest

[13] or from dormant organs that remain buried to survive adverse environmental conditions, such as drought, fire, or soil disturbance. In most cases, after mining, many indigenous geophytes either fail to reestablish or do so very slowly [14]. The successful recruitment of orchids depends on habitat quality characteristics, including well-drained soil, suitable levels of light, humidity, and a favourable microclimate [15]. Some orchid species, such as Polystachya confusa, have a higher population density in disturbed areas than in natural forests [16]. These conditions enable adequate inoculation potential of the appropriate orchid mycorrhizal fungi [16]. As a result, the re-establishment of orchid populations in the highly disturbed post-mining area will be dependent not only on the production and dispersal of viable seed from nearby remnants of woodland/bushland, but also on the recovery of inoculum potential of the appropriate mycorrhizal fungi in the soil and re-establishment of suitable habitat through regrowth of vegetation.

The ability of terrestrial orchid species to recolonise an ecosystem after disturbance is highly variable. Some orchids reestablish quickly, others are slow to return, while some remain absent for at least several decades after disturbance [17], and some others equally invade all areas irrespective of the anthropogenic factors [18]. Some species of orchids, such as Caladenia huegelii, Paphiopedilum sp., and Caladenia flava, have the highest density in forest areas. Similarly, Caladenia huegelii and Caladenia flava have reestablished in rehabilitation areas, with densities reaching 10% of those in forested areas in regions that are more than 10 years old. However, the occurrence of other orchid species, particularly of epiphytic orchids, was generally at a much lower percentage in the logged forest than the wetland orchids [19].

In Africa, there are more than 3,545 species of orchids, with Central Africa being the wealthiest region, boasting 708 species of orchids. Ethiopia is home to 710 species of orchids, which comprise approximately 12% of the country's flora. [20]. Of these orchids, 63 species have been recorded (twelve of them are new to Ethiopia) in Benishangul Gumuz Regional State. In this regional state, orchid species exist in three ecological groups: wetland species (i.e., orchids which are strictly confined to wetlands); species of open bush and woodland (Combretum-Terminalia wood and bush lands with rocky outcrops); and grazed grasslands or semi-open places of Oxytenanthera abyssinica thickets and epiphytic species [21]. Unfortunately, most of those specific areas where orchids naturally occur in this regional state have been under massive mining operations for the past few decades.

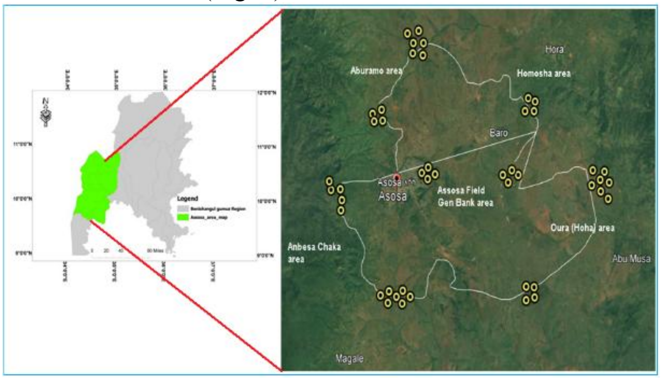
Despite these extensive mining operations having inevitably resulted in the depletion of orchid species diversity, no recent studies have been conducted to report the exact impact. The characteristics of orchid diversity in Benishangul Gumuz Regional State were only assessed over 17 years ago [21], and the current status of orchids is unknown. Therefore, this study was designed to examine the reestablishment of orchid populations on abandoned gold mining areas and the adjacent ruminant forests of Benishangul Regional State, and to suggest any necessary conservation measures.

The specific objectives of the study were: 1) to investigate the status of orchid species rehabilitation on the post mining sites; 2) to examine population size and species richness of orchids existing in the post mining site; 3) to assess the possible seed sources of orchid species in the post mining site

II. MATERIALS AND METHODS

A. Study Area

This study was conducted in Assosa Zone, one of the three administrative zones of the Benishangul-Gumuz Regional State (BGRS). It is located 675 km northwest of Addis Ababa, the capital of Ethiopia. The zone has borders with Sudan to the west, Metekel to the north, Oromia Regional State to the east and southeast, and with West Wellega to the south. Geographical coordinates of the zones range from a minimum latitude of 10°37' N to a maximum latitude of 11°13'N ' N and from a minimum longitude of 34°46'E to a maximum longitude of 35°58'E, with an elevation ranging from 568- 1223 meters above sea level. It covers an area of about 10,548 km2 (Fig. 1).



[Fig.1: Map of the Study Sites (Note: Circles Are the Points of the Post Gold Mining Areas and the Nearby Forest Sites from Where the Orchid Survey Was Made)]

This study was particularly focused on the peripheries of the Assosa area, stretching to Bamabsi woreda (Anbessa Chaka area) in the south, Abrahamo woreda in the west, and Oura woreda in the north (Hoha valleys). These sites were chosen because, although this area is known to harbour diverse types of indigenous and endemic orchids, it has also been the site of more than 62 small-scale gold mining projects and 4 large-scale gold operation projects, including numerous agricultural investments. According to the survey results of [22], forests previously covered this area, and there exist more than 112 gold pits (holes) that cover 560 hectares of land, which were left abandoned without rehabilitation.

B. Climate

According to the classification of rainfall regimes given, Benishangul-Gumuz lies in Zone B2, which is characterised by a wet season from April to May to October to November [23]. Besides the latitude, altitude has a considerable influence on the amount of precipitation, which increases with increasing altitude. Thus, at an altitude of 1,550 m, Assosa has an average annual rainfall of 1,275 mm, whereas

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Menge, at an altitude of 900 m, receives only 960 mm of rainfall [42].

C. Vegetation Cover

The study region falls under the western escarpment of Ethiopia and represents a recognizable vegetation unit, classified by and described as ''Combretum-Terminalia deciduous woodland and Savannah zone [24]. Combretum-Terminalia woodlands are the primary vegetation type of Benishangul Gumuz Regional State. They occur between 500 and 1900 m above sea level (a.s.l.) and receive rainfall of 800 to 1400 mm per year. Dominant species of the Menge area (Shegole) include *Terminalia brownii, Combretum molle, Celtis africana, Ekebergia capensis, Pterocarpus lucense, Senna welweschii, Cassia africana, Kigalea africana, Accacia seyal, Stericulia africana, Ficus spp*, and long grass such as *Penisetum unicetum and Penisetum thumbergii* [24]. Moreover, shallow soils over rocks, which are not arable, and the bushy meadows are habitats for several orchid species, such as *Aerangis Rchb.f. Angraecopsis Kraenzl. Brachycorythis Lindl. Bulbophyllum Thouars, Calyptrochilum Kraenzl. Disa Bergius Habenaria Willd. Polystachya Hook and Pteroglossaspis Rchb.f.* [20].

D. Sampling Procedures and Data Collection

i. Orchid survey

For this study, the study area was first categorised into three groups based on the post-mining age of the operation sites. Accordingly, a post-mining site abandoned for one year was designated as Category 1, a post-mining site abandoned for five years as Category 2, and a post-mining site abandoned for ten years as Category 3. This categorisation was conducted by obtaining data on the age of abandonment of gold mining areas from the database records of the Benishangul Gumuz Regional (BGR) Mineral Resources Development Bureau, as well as through field surveys.

To assess orchid species recovery on those three categories and those species found on the nearby adjacent forests, the transect line sampling technique was deployed. Accordingly, the assessment of orchid species on post-mining sites and nearby forests was carried out on a total of 90 quadrat sample plots of size 10 x 10 m, spaced at an interval of 50 meters along six parallel transects with an average length of 765 m. From the total of 90 sample plots examined in this study, 40 were located on abandoned gold mining sites, and the remaining 50 were positioned on the nearby unmined forest area. Each type of orchid species found in each sample plot was then noted, identified, and inventoried.

$$H = \sum_{i=1}^{s} (pi)(\ln pi) \quad \ldots \quad (1)$$

Timing of data collection: to consider all types of orchids, sampling procedures were taken for two types in this study: Accordingly, the first survey was taken over the main orchid flowering period of mid-April for dry month orchids, while the second survey was taken in October for rainy season orchids, between the years 2023 and 2024

Nomenclature: In this study, plant identification was accomplished to the genus and species level. The scientific nomenclature used in this study was based on the current generic and species names of the flora of Ethiopia and Eritrea. Herbarium specimens were collected for those species that were not identified in the field and identified at the Ethiopian Biodiversity Institute Herbarium.

E. Data Analysis

Orchid species frequency, density, and diversity data were log-transformed before analysis by STATA version 14.2. Moreover, the orchid's value of the importance index of diversity was calculated following the Shannon-Wiener diversity index equation:

Where:

$$i = \frac{\sum ni}{N}$$

H = Shannon − Wiener diversity index
Pi = The total number of a species
Ni = The amount of x species
N = The total number of individuals

Analysis was adjusted to the Shannon-Wiener biodiversity index, considering three criteria. These include (1) $H < 2.3026$, indicating low diversity, distribution of individual genus is low, community stability is low and the community is disturbed by environmental factors; (2) $2.3026 < H < 6.7078$, where diversity is moderate, distribution of individual genus is moderate, community stability is moderate and the community is easy to change; and $H > 6.7078$, indicating that diversity is high, distribution of individual genus is high, community stability is high and favorable environmental condition for all the species in the habitat [25].

Moreover, species density, frequency, and the sum of dominance ratios [15] were calculated as follows:

$$\text{Species relative density (RD)} = \frac{ni}{N} x100\% \quad \ldots \quad (2)$$

Where ni is the number of individuals of an orchid species and N is the total number of all individuals of the orchid species in the entire community.

$$\text{Species frequency (F):} = \frac{wi}{Wi} \quad \ldots \quad (3)$$

Where wi is the number of occupied plots for the orchid species, and N is the total number of plots in the entire community.

Species relative frequency (RF):

$$= \left(\frac{Fi}{\sum_{i=1}^{s} Fi}\right) x100\% \quad \ldots \quad (4)$$

Where Fi is the frequency of individual orchid species, and $\sum_{i=1}^{s} Fi$ is the summation of frequencies of all orchid species in the entire community.

$$\text{Sum of the dominance ratio (SDR)} = \frac{RD + RF}{2} \quad \ldots \quad (5)$$

III. RESULTS

A. Orchid Recovery Status

Of 42 orchid species recorded from the bordering forest, 20 were also found in the abandoned gold mining sites, and these species were found to have recovered in all post-mining sites except the 1-year-old sites. A few orchid species, such as *Habenaria ichneumonia, Nervilia kotschyi, Bulbophyllum lupulinum, Eulophia cristata, Eulophia mil*nei, and

Cyrtorchis erythraeae, were identified as pioneer species that first appeared in 1-year-old sites. Most of the recorded orchid species were climax invaders that appeared in post-mining sites older than 10 years (Table 1, Fig. 2).

Table-I: The Orchid Species and Their Distributions Across Surveyed Land Uses

Orchid Species	Number of Individual Orchids	Forest Area	Gold Mining Sites, With the Years, Sites Left Abandoned		
			1yrs	5yrs	10+yrs
Brachycorythis pubescens	5	5	-	-	-
Brachycorythis buchananii	4	4	-	-	-
Brachycorythis ovata	8	8	-	-	-
Habenaria distantiflora	6	6	-	-	-
Habenaria bracteosa	11	11	-	-	-
Habenaria filicornis	3	3	-	-	-
Habenaria platyanthera	7	7	-	-	-
Habenaria zambesina	14	9	-	2	3
Habenaria aethiopica	14	14	-	-	-
Habenaria egregia	12	12	-	-	-
Habenaria malacophylla	18	18	-	-	-
Habenaria chirensis	8	8	-	-	-
Habenaria ichneumonia	10	6	1	1	2
Habenaria cornuta	8	5	-	-	3
Habenaria clavata	14	7	-	7	0
Habenaria holubii	10	10	-	-	-
Habenaria cirrhata	16	16	-	-	-
Habenaria perbella	18	18	-	-	-
Habenaria vaginata	13	13	-	-	-
Habenaria longirostris	9	9	-	-	-
Platycoryne crocea	4	4	-	-	-
Disa aconitoides	3	3	-	-	-
Disa cryptantha	11	11	-	-	-
Disa facula	12	12	-	-	-
Disa hircicornis	10	10	-	-	-
Nervilia bicarinata	10	6	-	-	4
Nervilia kotschyi	6	4	1	-	1
Nervilia simplex	3	2	-	-	1
Satyrium aethiopicum	1	1	-	-	-
Satyrium crassicaule	2	2	-	-	-
Satyrium sacculatum	1	1	-	-	-
Nervilia bicarinata	11	11	-	-	-
Nervilia kotschyi	20	20	-	-	-
Nervilia simplex	23	23	-	-	-
Polystachya tessellata	17	11	-	3	3
Polystachya steudneri	10	10	-	-	-
Polystachya eurychila	9	9	-	-	-
Polystachya aff. albescens	9	2	-	3	4
Bulbophyllum lupulinum .	22	22			
Bulbophyllum scaberulum	52	32	-	6	14
Pteroglossaspis eustachya	5	5	-	-	-
Eulophia guineensis	14	8	-	2	4
Eulophia stachyodes	11	6	-	-	5
Eulophia adenoglossa	41	31	-	1	9
Eulophia horsfallii	24	24	-	-	-
Eulophia angolensis	18	18	-	-	-
Eulophia caricifolia	14	14	-	-	-
Eulophia flavopurpurea	27	12	-	5	10
Eulophia cucullata	54	33	-	8	13
Eulophia cristata	8	6	1	1	-
Eulophia livingstoniana	8	8	-	-	-
Eulophia schweinfurthii	9	9	-	-	-
Eulophia pyrophila	5	5	-	-	-
Eulophia milnei	21	12	1	4	4
Eulophia odontoglossa	17	17	-	-	-
Eulophia zeyheri	11	11	-	-	-
Eulophia kyimbilae	13	13	-	-	-
Calyptrochilum christyanum.	16	9	-	-	7
Microcoelia globulosa	15	8	1	-	6
Diaphananthe candida	11	6	-	3	2
Aerangis brachycarpa	5	5	-	-	-
Cyrtorchis erythraeae	10	5	1	4	-
Angraecopsis trifurca	9	9	-	-	-
Total Number of Individuals	**816**	**665**	**6**	**50**	**95**

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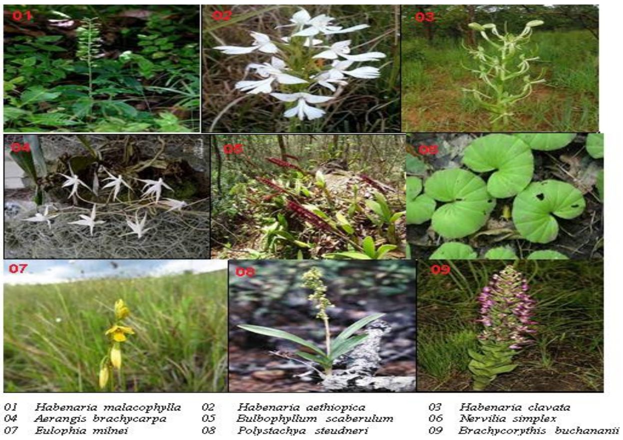
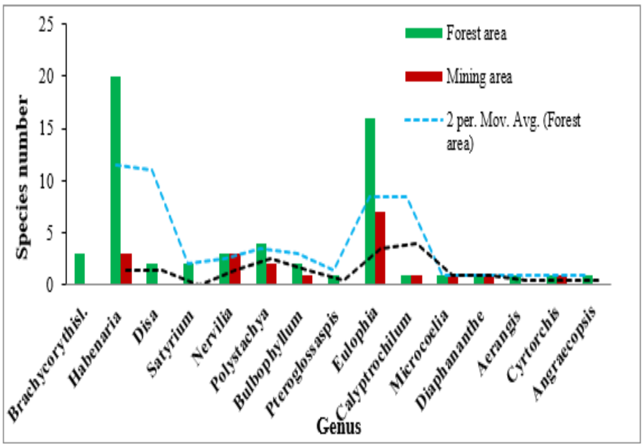
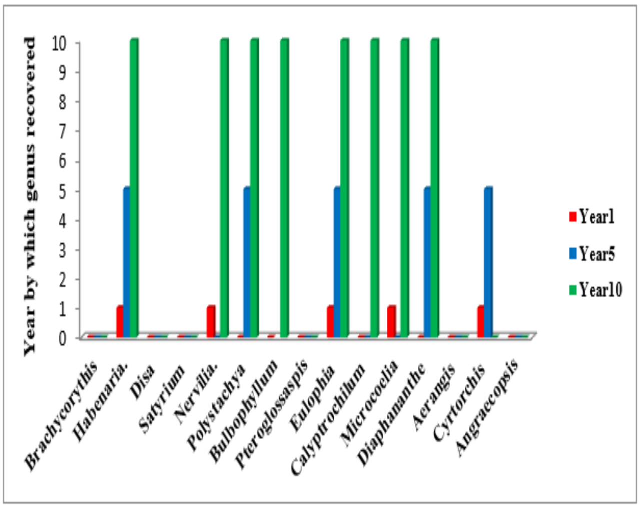


[Fig.2: Some of the Orchid Species Encountered During the Survey]

Analysis showed that, of 15 genera recorded from the region, 9 were found to be present within post-mining sites (Fig. 3). Despite heavy disturbance by gold mining, 6 genera of orchid were present in sites after one year of abandonment from mining. They can be considered tolerant of high disturbance. However, the remaining three genera were considered intolerant to disturbance, and the six that were absent may take several years to reestablish or may remain locally extinct (Fig. 4).



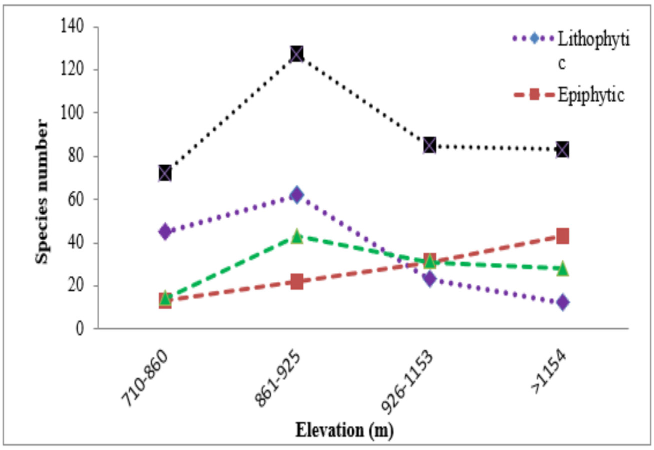
[Fig.3: Graph Showing the Recovered Genera Against the Region's Known Orchid Flora]



[Fig.4: The Age of the Abandoned Gold Mining Site at Which the Genus Was Recorded]

B. Orchid Species Distribution Pattern

The total number of orchid species follows a unimodal pattern with elevation. The highest species number (127 individuals) was observed at elevations of 861–925 meters and 926–1153 meters, while the lowest species number (72 individuals) was found at elevations below 860 meters. The life types of all epiphytic, terrestrial, and lithophyte orchids also depict a unimodal pattern with elevation. Terrestrial and lithophytic orchids have the highest species number (62, 43 individuals) at elevations ranging from 861 to 925 meters. In comparison, epiphytic orchids have the highest species number (43 individuals) at elevations above 1154 meters and the lowest (14 individuals) at elevations below 860 meters. Terrestrial and epiphytic orchids, on the other hand, have their lowest species number at 710-860 meters (Fig. 5).



[Fig.5: Orchid Species Richness Relative to Elevation]

C. Analysis of Species Dominance Ratio (SDR)

Out of the total orchid species recorded from the Forest, 70% of them had not recovered. Moreover, only two species of orchid were found to have more than 50 individuals, i.e., *Eulophia cucullata* (54 individuals) and *Bulbophyllum scaberulum* (52 individuals). Species frequency per plot showed a similar pattern, with 50% of orchid species occupying greater than 10 plots and only one species occupying greater than 20 plots (Table 2). For the sum of dominance ratios, *Nervilia simplex* (SDR=4.10), *Habenaria aethiopica* (SDR=5.88), and *Bulbophyllum scaberulum* (SDR=9.47) are the top three dominant species in the post gold mining sites.

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Table-II: Composition of Orchid Species in Post-Mining Areas

Species Name	Plot No.	Plot Size	No of Individuals	D	RD	F	RF	SDR
Bulbophyllum scaberulum	6	600	32	0.0533	8.9493	1.5	1.0381	9.4683
Bulbophyllum lupulinum	7	700	22	0.0314	5.2737	1.8	1.2111	5.8792
Eulophia cucullata	20	2000	33	0.0165	2.7687	5	3.4602	4.4988
Eulophia adenoglossa	18	1800	31	0.0172	2.8899	4.5	3.1142	4.4470
Eulophia odontoglossa	8	800	17	0.0213	3.5657	2	1.3841	4.2578
Nervilia simplex	13	1300	23	0.0177	2.9688	3.3	2.2491	4.0933
Eulophia horsfallii	16	1600	24	0.0150	2.5170	4	2.7682	3.9012
Habenaria perbella	11	1100	18	0.0164	2.7458	2.8	1.9031	3.6974
Nervilia kotschyi	14	1400	20	0.0143	2.3971	3.5	2.4222	3.6082
Eulophia zeyheri	6	600	11	0.0183	3.0763	1.5	1.0381	3.5954
Eulophia angolensis	12	1200	18	0.0150	2.5170	3	2.0761	3.5555
Calyptrochilum christyanum	5	500	9	0.0180	3.0204	1.3	0.8651	3.4529
Habenaria cirrhata	12	1200	16	0.0133	2.2373	3	2.0761	3.2754
Habenaria aethiopica	10	1000	14	0.0140	2.3492	2.5	1.7301	3.2142
Eulophia kyimbilae	9	900	13	0.0144	2.4238	2.3	1.5571	3.2023
Habenaria vaginata	11	1100	13	0.0118	1.9831	2.8	1.9031	2.9346
Eulophia caricifolia	13	1300	14	0.0108	1.8071	3.3	2.2491	2.9316
Habenaria egregia	10	1000	12	0.0120	2.0136	2.5	1.7301	2.8786
Disa facula	10	1000	12	0.0120	2.0136	2.5	1.7301	2.8786
Eulophia flavopurpurea	11	1100	12	0.0109	1.8305	2.8	1.9031	2.7821
Eulophia milnei	11	1100	12	0.0109	1.8305	2.3	1.9031	2.7821
Eulophia schweinfurthii	7	700	9	0.0129	2.1574	1.8	1.2111	2.7630
Microcoelia globulosa	6	600	8	0.0133	2.2373	1.5	1.0381	2.7564
Nervilia bicarinata	11	1100	11	0.0100	1.6780	2.8	1.9031	2.6296
Polystachya tessellata	11	1100	11	0.0100	1.6780	2.8	1.9031	2.6210
Angraecopsis trifurca	8	800	9	0.0113	1.8877	2	1.3841	2.5798
Habenaria bracteosa	12	1200	11	0.0092	1.5382	3	2.0761	2.5762
Polystachya steudneri	15	1500	10	0.0067	1.1187	3.8	2.5952	2.4162
Habenaria holubii	13	1300	10	0.0077	1.2908	3.3	2.2491	2.4153
Disa hircicornis	13	1300	10	0.0077	1.2908	3.3	2.2491	2.4153
Habenaria zambesina	10	1000	9	0.0090	1.5102	2.5	1.7301	2.3752
Polystachya eurychila	10	1000	9	0.0090	1.5102	2.5	1.7301	2.3752
Brachycorythis ovata	8	800	8	0.0100	1.6780	2	1.3841	2.3700
Habenaria longirostris	12	1200	9	0.0075	1.2585	3	2.0761	2.2966
Habenaria platyanthera	7	700	7	0.0100	1.6780	1.8	1.2111	2.2835
Eulophia livingstoniana	9	900	8	0.0089	1.4916	2.3	1.5571	2.2701
Eulophia guineensis	13	1300	8	0.0062	1.0326	3.3	2.2491	2.1572
Habenaria chirensis	12	1200	8	0.0067	1.1187	3	2.0761	2.1567
Eulophia cristata	8	800	6	0.0075	1.2585	2	1.3841	1.9505
Eulophia stachyodes	14	1400	6	0.0043	0.7191	3.5	2.4222	1.9302
Habenaria ichneumonia	12	1200	6	0.0050	0.8390	3	2.0761	1.8771
Diaphananthe candida	12	1200	6	0.0050	0.8390	3	2.0761	1.8771
Habenaria distantiflora	11	1100	6	0.0055	0.9153	2.8	1.9031	1.8668
Cyrtorchis erythraea	9	900	5	0.0056	0.9322	2.3	1.5571	1.7111
Aerangis brachycarpa	9	900	5	0.0056	0.9322	2.3	1.5571	1.7108
Habenaria cornuta	10	1000	5	0.0050	0.8390	2.5	1.7301	1.7041
Pteroglossaspis eustachya	10	1000	5	0.0050	0.8390	2.5	1.7301	1.7041
Eulophia pyrophila	10	1000	5	0.0050	0.8390	2.5	1.7301	1.7041
Brachycorythis buchananii	9	900	4	0.0044	0.7458	2.3	1.5571	1.5243
Habenaria humilior	6	600	3	0.0050	0.8390	1.5	1.0381	1.3580
Habenaria filicornis	8	800	3	0.0038	0.6293	2	1.3841	1.3213
Polystachya aff. Albescens	9	900	2	0.0022	0.3729	2.3	1.5571	1.1514
Habenaria peristyloides	8	800	2	0.0025	0.4195	2	1.3841	1.1115
Habenaria schimperiana	9	900	1	0.0011	0.1864	2.3	1.5571	0.9650
Satyrium aethiopicum	9	900	1	0.0011	0.1865	2.3	1.5571	0.9650
Satyrium sacculatum	5	500	1	0.0020	0.3356	1.3	0.8651	0.7681

D. Species Diversity

Orchid species diversity of the forest site (study area) based on the Shannon-Wiener Index (H') is 3.969, which indicates medium diversity. The orchid species diversity at the abandoned gold mining site is 2.73, indicating high habitat disturbance and low diversity. The independent-samples t-test was conducted to compare orchid populations among post-gold mining sites and forest sites by age of abandonment. There was a significance difference (DF = 65, P = 0.000, 0.000, 0.000, 0.001, 0.003, 0.001$<$0.05) between the orchid species diversity in all the sites surveyed except for the diversity between the mining site abandoned for five and ten years (DF=130, P= 0.184$>$0.05) depicting the highest population of orchids species number variation in the study forest area and the gold mining sites studied (Table 3).

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Table-III: Two-Sample Independent t-Test for The Study Sites

Variables	Observation	Mean	Std. Err.	Std. Dev.	[95% Conf. Interval] Lower	[95% Conf. Interval] Upper	t	df	Sig.
Forest – One year old	66	10.07576	.897301	7.290269	8.283586	11.86793	11.1180	130	0.00*
	66	.0909091	.035675	.2896827	.0196962	.162122			
Forest – Five-year-old	66	10.07576	.897301	7.290269	8.283586	11.86793	10.0873	130	0.00*
	66	.7575758	.219196	1.780757	.319811	1.19534			
Forest – Ten-year-old	66	10.07576	.897371	7.290269	8.283586	11.86793	9.0030	130	0.00*
	66	1.333333	.371057	3.014495	.592278	2.074389			
One year – Five-year-old	66	.0909091	.035655	.2896827	.0196962	.162122	-3.0020	130	0.003*
	66	.7575758	.219196	1.780757	.319811	1.19534			
One year – Ten-year-old	66	.0909091	.035655	.2896827	.0196962	.162122	-3.1165	130	0.01*
	66	1.333333	.3710587	3.014495	.592278	2.074389			
Five-year-old – Ten-year-old	66	.7575758	.219196	1.780757	.319811	1.19534	-1.3360	130	0.184
	66	1.333333	.3710587	3.014495	.592278	2.074389			

*Significantly different at 95% confidence level

IV. DISCUSSION

A. Orchid Population Status

The number of orchids found in this study was significantly lower than the initial research conducted by [21] at the exact location, but it was formerly an intact forest. In a previous study conducted in a similar geographic range, 63 orchid species were identified [26], which is lower than the number found in a survey done in sub-Saharan Africa [27]. These are both much higher compared to our findings, specifically 42 in the forest area and only 20 orchid species from abandoned gold mining sites. The study was unable to locate any of the recently described, endemic orchids.

Orchid recovery from post gold mining of the Assosa area follows the "initial floristic composition model" [26], where all the species that are likely to be involved in a succession are present at the beginning, though some are dominant early on and others later (because of their reproduction, dispersal, germination and/or growth characteristics). The floristic composition immediately following disturbance determines the future species dominance [12], similarly, antropogenic factors may induce or sapress orchids regeneration [4]. However, the level and degree of disturbance is a matter for species recover [13], But depending on the habitates sensetivity few species may not recavore at all [15], and this might accelerate the projected trend of species extinction over the last 150 years [28]. Generally, species recruitment on an abandoned gold mine is uncertain [6], because mining activities immensely compromise soil structure and hydrology [29]. The overall rate of orchid recovery of the study site is significantly lower but increasing over time for some species compared to the previous survey from nearby intact forests [30]. Out of the 42 orchid species recorded in the nearby forest, only 22 are likely to be found in either age of post-gold mining sites. This result is consistent with the study by [5], which states that some orchid species, such as Polystachya confusa, have the highest population density in disturbed areas compared to natural forests. However, the result is far from the outcomes reported by [31], recorded around 78% of their coal mine sites had been fully recovered and 22% had been partially recovered, suggesting that the ecological restoration measures taken by the companies and local district have been generally effective. This difference may indicate that rehabilitation brings the previously removed species back quickly than simply abandoning the sites. Compared to the level of degradation of abandoned gold mining sites, orchid species recruitment was promising [32]. Seedlings' recruitment of some degraded areas is not only dependent on the mycorrhizal association for seed germination and growth, but also on the seed set in the surrounding forest and dispersal potential [16], and establishment of orchid taxa in post-gold mining sites of different ages will affect both the future orchid species richness and the population size within them. The ability of terrestrial orchid species to recolonize an ecosystem after disturbance is highly variable [32], and terrestrial orchids are more resistant to disturbances than wetland orchids [34]. Some orchids reestablish quickly, others are slow to return [17], while some remain absent for at least several decades after disturbance, and some others equally invade all areas irrespective of the anthropogenic factors [29]. Similarly, in this study, a few species of this type *(Habenaria ichneumonia, Nervilia kotschyi, Eulophia cristata, Eulophia milnei, Globulosa microcoelia, Cyrtorchis hrythraeae*) were abundant in abandoned gold mining sites of 1 and 5 years of age. Still, they were rare in 10-year-old sites and in the forest. Collins, with his friends [19], found that some species of orchids, such as Caladenia huegelii, Paphiopedilum sp., and *Caladenia flava*, have the highest density in forest areas. Similarly, *Caladenia huegelii* and *Caladenia flava* reestablished in rehabilitation areas, with densities reaching 10% of those in forested areas in regions that were more than 10 years old. However, the occurrence of other orchid species (excluding disturbance opportunists) was generally at a much lower percentage in the forest. Similarly, the orchid species which were regenerated after disturbance were natural. However, the orchid species regeneration should follow tuber re-introduction manually to fasten their rehabilitation [33]

B. Orchid Species Distribution Pattern

Three patterns have been identified in the relationship between species richness and elevation: a monotonically decreasing pattern, where species richness decreases as elevation increases; a hump-shaped pattern, characterized by high diversity at mid-elevations; and a diversity plateau, where species richness remains relatively stable at low elevations [35]. The current study follows a unimodal pattern of orchid richness with elevation. A similar

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justification was made by Yandi She and his colleagues, stating that species diversity follows the stability of the community [36]. The highest species richness was observed at middle elevations, and the lowest species richness was found at the lowest elevation. These results are consistent with previous research on Himalayan orchids [37]. Endemic epiphytes there showed a peak in elevation zones similar to total richness. However, the peak for endemic terrestrial species was at a higher elevation. Elevation was found to be the most significant factor in determining orchid diversity and distribution patterns. This is due to variations in environmental factors, such as temperature, water vapour pressure, and precipitation, with elevation changes [38]. The highest air humidity is usually found at mid-elevations, with a notable decrease in the lowlands and a moderate decrease at high elevations [39]. In the present study area, lower elevations (<860m) are severely disturbed by the current small- and large-scale gold mining operations in the region. Likewise, the general decline in orchid diversity at lower elevations has been associated with factors like harsher climatic conditions [8], reduced habitat areas due to human activity, and higher propagule pressures [40],

C. Orchid Species Diversity

The level of humidity, the presence of permanent and temporary wetlands, and alluvial plains with gravel and granite outcrops have significantly contributed to the diversity and endemism of orchid species in the Benishangul Gumuz Region [21]. For example, in the Assosa area, 66 species of orchids within 20 genera have been recorded. Moreover, the existence of more complex terrain, the presence of different tectonic and eustatic histories, degrees of isolation, and incidences of random events also contribute to endemism and diversity of orchids [41]. In this study, 20 species within 9 genera were recorded in a similar area dominated by *Bulbophylum scaberulum and Eulophia cuculata*. The distribution density of the study area is 0.029 km-2, which is lower than the Saharan orchid density of 0.08 km-2, both of which are in similar tropical climate zones [42]. Moreover, the value is significantly lower than that of a similar study in the area (density of 0.067 species km-2) by Errmann [21].

V. CONCLUSION AND RECOMMENDATIONS

The number of orchids found in this study was lower than the number found in the initial research conducted at the exact location. This study also did not locate any of the newly described endemic orchids. One reason for this may be habitat destruction for mining, agricultural investment, and human settlement. Moreover, sensitive wetland areas of endemic orchid habitats have long been threatened by the national wheat production program due to the massive irrigation of upland wheat and wetland farmlands. It appears that a pattern exists where different orchid species colonise abandoned investment areas. However, orchid species have been unable to establish themselves, even in the oldest abandoned gold mining sites that have been studied. The sporadic absence of an orchid species from the abandoned gold mining area over time could be due to the severe degradation of the natural habitat of orchids resulting from gold mining, which deters mycorrhizal fungi (land use change), or the limited sample size may also influence this. Orchids were not present in abandoned gold mining areas that were only 1 year old, and the population size and diversity of species in all other abandoned investment areas of the same age were similar to those in adjacent un-mined forest sites. Twenty-one orchid species were not encountered in their previously recorded area or in gold mining sites. This may be due to the natural rarity of these orchid species or other factors, such as the absence of specific pollinators or mycorrhizal fungi that could be limiting their recruitment.

The results of this study indicate that the ruminant forests of the Assosa area are home to a rich variety of orchids; however, their status is not comparable to the previous population, where terrestrial orchids dominated the other orchids. The highest number of orchid species was found at middle elevations. Epiphytic species were mostly observed on the higher mountain peak, while terrestrial species were more commonly found on the middle peak. Despite the protection provided in natural reserves or community- and government-protected forest areas, over three-quarters of the orchid species found in the woodland of the Benishangul Gumuz Region, Ethiopia, are currently threatened, particularly those prized for their medicinal value. Although the study indicated the recovery of some orchids, the presently increasing resource demand and agricultural expansion into nearby forests may not allow sufficient space and time for orchids to reproduce and regenerate. Therefore, the habitat of endemic orchids and other plant species in Benishangul Gumuz Regional State requires greater attention and conservation efforts. Moreover, as observed, most investors abandon their mining sites rather than rehabilitating them. Vigorous law enforcement should be in place to ensure compliance with environmental management plans for mineral and other development projects.

The fluctuations in orchid availability can result in gaps in our data, as some surveys may capture a full range of species while others may not. This inconsistency can hinder our ability to make reliable comparisons and draw conclusions across different areas and time periods. Therefore, I would like to recommend that other researchers address these deficiencies by extending the survey timeframe to cover multiple seasons, to capture a more comprehensive dataset. Moreover, implementing a flexible approach by incorporating seasonal forecasts can help plan data collection efforts more effectively.

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After aggregating input from all authors, I must verify the accuracy of the following information as the article's author.

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