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DIVERSITY INDEX OF *ARGANIA SPINOSA* L. SKEELS PLANT FORMATION IN THE ALGERIAN WESTERN SAHARA

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Abstract

The argan (*Argania spinosa*) is a xerothermophilous tree, endemic in North-West Africa. In Algeria, it is found as wild in the northwest of the Hamada du Drâa of Tindouf (Algerian Western Sahara), where it is characterized by a great floristic diversity. Several indices were calculated in this study to have a better knowledge on the state of biological diversity of the argan tree ecosystem. It is characterized by a floristic richness composed of 123 taxa belonging to 38 families including the dominance of three major floristic families: Asteraceae, Brassicaceae and Amaranthaceae. Biologically, the study area is dominated by therophytic species. This therophytization is marked by a general invasion of annual species. The diversity index of Shannon-Weaver (4.42) associated with that of Pilou's equitability (0.843) are relatively high, which showed that the flora of the argan forest of Tindouf is highly diverse. The disturbance index is high (76%) which reflects a significant degree of disturbance of the plant formation and also a strong anthropozoic influence.

Introduction

Biodiversity conservation is, now-a-days, an imperative for any society in the perspective of sustainable development. The knowledge of plant diversity of species of socio-economic and ecological interest is necessary to carry out adequate actions (Sèwadé 2017, Kechairi 2018). Among the species, the argan tree (*Argania spinosa* L.), a forest-fruit and fodder tree is a botanical curiosity and a real phytogeographical paradox. At first Linne (1737) named the argan tree as "*Sideroxylon spinosum* L." under the genus *Rhammus* (Sapotaceae). Then (Roemer and Schultes 1819) named the argan tree as *Argania sideroxylon*, after its Arabic and Berber name which is argan and the name *sideroxylon* is justified by the wood of the tree which is extremely hard.

In Algeria, the argan tree is observed in the northwest of the wilaya of Tindouf, from Jebel Ouarkziz to Hamada de Drâa (Kechairi 2009). So, there are about 10 000 trees that are distributed on wadi beds for an area of 56 000 hectares, between 320 and 630 m altitude (Kechairi 2009, Kechairi and Abdoun 2016, Kechairi 2018, Kechairi 2021). The argan tree occupies the beds of dry wadis. It contributes to the fertility and restoration of the soils and the stabilization of watercourses on the edge of the wadis and thus constitutes a habitat for wild fauna in its distribution area in Tindouf (Kechairi 2009-2018). In the north of the country, six vigorous planted trees are encountered in the coast of Mostaganem, and a one planted tree well coming in the wilaya of Mascara (Benaouf 2009, Kechairi and Lakhdari 2002, Miloudi 2006, Miloudi and Belkhodja 2009).

In general, the northwest of the wilaya of Tindouf is the natural environment for the spread of the argan tree and its floral procession, where it colonizes the formations of the desert rockery (Kechairi 2009, 2018, 2021, Kaabèche *et al.* 2010, Kechebar *et al.* 2013). In which, the argan tree

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also harbors a wealth of fauna (Lakhdari and Kechairi 2009). On the other hand, the wilaya of Tindouf, by its geographical location, Saharo-mediterranean transition zone, allows finding a mixture of Mediterranean, Saharan and subtropical specie (Kechairi 2018).

Diversity takes into account not only the number of species, but also the distribution of individuals within these species. Two main indices have been developed: the Shannon-Weaver index and the Simpson index. Through the study of the response of these indices to variations in virtual populations, (Peet 1974) classified them into two categories:

Shannon's index in type I indices, sensitive to variations in the importance of the rarest species;

Simpson's index in type II indices, sensitive to variations in the importance of the most abundant species.

This study aims to assess plant biodiversity through the phytoecological synthesis of the floristic list of the argan grove of Tindouf (Kechairi 2018). An analysis of the floristic procession was carried out to assess the impact of anthropozoic factors on the argan tree plantation of Tindouf. The measurements made at the level of specific richness, floristic diversity, have shown a beneficial effect on the maintenance and conservation of the arganeraie ecosystem.

Material and Methods

In the Algerian Western Sahara, the argan grove is located northwest of the wilaya of Tindouf (Fig. 1). The region is located in a Saharan climate that suffers from a maritime influence (mainly in the northwest of the Wilaya) under the effect of humid winds coming from the Atlantic Ocean. These climatic conditions give the region a great floristic originality (Chevalier 1943).

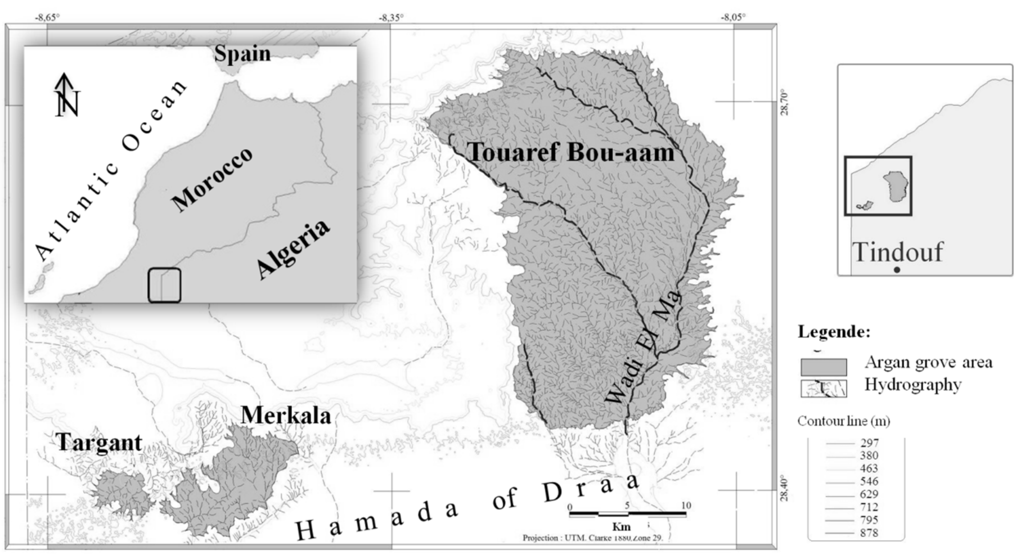

Fig. 1. Location map of *Argania spinosa* in Tindouf (Algeria) (Kechairi 2021).

According to Kechairi (2018) herbariums and a collection of photos were made and the identification of the species collected was carried to the laboratory of Plant Ecology and Environment at the USTHB (Algiers). For the identification of species, the Flora of Algeria and Sahara Quezel and Santa 1962-1963 and the Flora of the Sahara (Ozenda 1977) were exploited.

The biological types are considered as an expression of adaptation strategy of the flora to the environmental conditions and at the same time, they constitute a privileged tool for the description of the physiognomy of the vegetation (Dahmani 1996).

According to Dajoz (2003) these biological types can be applied also to the plants of regions where the unfavorable season was the dry season. After knowing the biological importance of the species inventoried in the three studied perimeters, it is interesting to establish the classification according to the biological types which allows us to learn about the height of the species and in particular the stratification of the vegetation (Raunkiaer 1937).

The specific diversity gave an account of the richness and the distribution of specific abundance of the phytocenoces (Danais 1982). It was defined by the specific richness and the Shannon diversity index (Channeton *et al.* 1997). In accordance with the sigmatist method, the surveys were carried out on homogeneous areas from the physiognomic, floristic and ecological point of view (Guinochet 1973, Géhu and Rivas-Martínez 1981). To estimate the biological diversity of the plant formations studied, 123 phytosociological surveys were carried out according to the sigmatist method of Braun-Blanquet (1932). The biological types related to the phenological model distinguished, are those defined according to the classification of Raunkiaer (1934) and modified by Lebrun (1947). This classification includes: Phanerophytes (Ph), Chamaephytes (Ch), Geophytes (Ge), Hemicryptophytes (He), Therophytes (Th). The phytogeographical types adopted correspond to the major chorological subdivisions of Lebrun (1947) modified by White (1983) and accepted for Africa.

Specific richness (S): It is represented by the total or average number of species recorded per unit area. S = number of species in the study area. This S index can be used to analyze the taxonomic structure of the stand (e.g. number of plant taxa families, etc.).

Specific richness (S):

$$S=sp1+sp2+\cdots+spn.$$

S: specific richness; sp: plant species observed (Ramade 2003).

To be able to compare the diversity of the flora present and knowing that the diversity of the elements of a community is a quality immediately necessary for the analysis of the environment (Frontier and Pichod-Viale 1995), indices related to this method was used, including Shannon's (H), Piélou's equitability (EH), Simpson's (Is), Simpson's equitability (Es), and finally Margalef's index (Dmg).

Margalef diversity index has the advantage of being simple to calculate. However, it can be sensitive to sampling effort (Magurran 2004). It is less common in diversity work and is calculated using the formula:

$$Mg = S\text{-}1 / \ln N$$

S = number of species, N = total number of individuals

Values below 2.0 are considered to be low biodiversity areas and values above 6.0 are considered to be high biodiversity indicators

Shannon-Weaver Index:

$$H' = -\Sigma\, pi \log_2 pi$$

$$H' = -\Sigma(ni/N) \log_2(ni/N)$$

Where ni is the coverage of species i in the survey while N is the sum of the coverages of all species. H=0 corresponds to the minimum value when the sample contains only one species and the diversity increases as the number of species increases. A Index lower than 2, the diversity is low. A Index of 2 to 3, the diversity is average, A Index of 4 to 5, diversity is high and A Index greater than 6, diversity is exceptional. The level of diversity achieved at the level of each plant grouping was measured using the equitability index of Pielou (E):

$$E=H'/\log_2 S$$

This index of equitability makes it possible to compare the diversity between two stands with different species richness. For a species that is largely dominant in a stand, this index tends towards zero. However, if the species have the same abundance, this index is equal to 1 (Dajoz 1996).

The difference between the two methods of calculating the diversity index is based on the value placed on species. Simpson's index favors common species, while Shannon's favors rare species (Odum 1976). The Hill index has the advantage of combining the two preceding diversity indices H' and D, which gives an even more accurate view of the diversity observed on each facies. By using the sensitivity of Shannon's index to rare species and the sensitivity of Simpson's index to abundant species, Hill's index seems to be the most synthetic.

Loisel and Gomila disturbance index (PI) (Loisel and Gamila 1993), and the net biological spectrum are used for quantify the therophytization of these forests; we calculated the following two indices.

PI = number of chamaephyte + number of therophyte / total number of species.

Results and Discussion

The sampling of the vegetation carried out in the northern region of the Hamada du Draa has allowed to make several surveys, in order to highlight an interesting floristic richness. These surveys are distributed on 123 species of different strata and 38 families distributed heterogeneously (Table 1)

The number of species by families varied i.e., Amaranthaceae (10 spp); Fabaceae, Zygophyllaceae and Poaceae (9 spp) and Boraginaceae (5 spp). The highest species richness was obtained in Brassicaceae and Asteraceae with 15 species. Boudy (1952) reported that the plant association of the Argan tree was complex due to a mixture of species of Atlantic and Saharan tropical origin, in addition to Mediterranean species, and may be due to the effect of Environmental factors, which have an influence on the physiognomy, structuring and distribution of plant formations (Lacoste and Roux 1972, Djègo 2006, Djègo and Oumorou 2009).

The study area showed a dominance of Therophytes followed by Chamaephytes, Phanerophytes, Geophytes and finally Nano phanerophytes and Hemicryptophytes with the same percentage. The analysis of the biological types reveals the dominance of Therophytes. This therophytization was confirmed by the high rate of the disturbance index. This dominance is explained by the degradation of the environment which is due mainly to the action of man through its various activities, grazing and fires including climate change. Despite the importance of Therophytes, Chamaephytes keep an important place in the plant formations because they are better adapted to the aridity. Hemicryptophytes are very poorly represented. This can be explained by the poverty of the soil in organic matter.

Chamaephytes and therophytes are the biological types that dominate in the station. This shows the strong anthropozoic pressure that the plant formations are under. the index of disturbance being of the order of 76% and this clearly shows the strong degradation generated by the action of the man. This index is proportional to the dominance of therophytic species, linked to the invasion of these annual species. In this situation (Barbero *et al.* 1990) emphasize that the disturbances caused by man and his herds are numerous and correspond to two situations of increasing severity ranging from matorralization to desertification through steppisation.

Table 1. Inventory of species encountered in the station of Tindouf in the formations with *Argania spinosa* (Kechairi 2018).

Name of Families	Name of species	Biological types	Biogeographical types
Amaranthaceae	*Anabasis aretioîdes Coss. et Moq.*	*Ch.*	*End.*
	Atriplex halimus L.	*Ch.*	*Cosmop.*
	Cornulaca monacantha Del.	*Ch.*	*Sah.Sind.*
	Fredolia artioides Coss. et Dur.	*Ch.*	*End.*
	Haloxylon scoparium Pomel	*Ch.*	*Sah.Med.*
	Salsola foetida Del.	*Ch.*	*Sah.Sind.*
	Salsola tetragona Del.	*Ch.*	*Sah.*
	Anabasis articulata (Forssk.) Moq.	*Ch.*	*Sah.Sind.*
	Anabasis articulata Ssp. oropediorum	*Ch.*	*Sah.Sind.*
	Pancratium saharae Cosson	*Geo.*	*Afr.Trop.*
Anacardiaceae	*Rhus tripartitus R. Sch.*	*Ph.*	*Sah.Med.*
Apiaceae	*Eryngium ilicifolium Lam.*	*The.*	*Ibero.Maur.*
	Pituranthos battandieri Maire	*Ch.*	*End.*
	Pituranthos chloranthus Benth. Et Hook.	*Ch.*	*End.*
Apocynaceae	*Nerium oleander L.*	*N.Ph.*	*Med.*
Arecaceae	*Phoenix dactylifera L.*	*Ph.*	*End.*
Asclepiadaceae	*Calotropis procera Ait.*	*Ph.*	*Sahelo.Sah.*
	Pergularia tomentosa L.	*Ch.*	*Sah.Sind.*
	Periploca laevigata Ait.	*N.Ph.*	*Sah.Med.*
Asphodelaceae	*Asphodelus tinuifolius Cavan.*	*Geo.*	*Med.*
Asteraceae	*Anvillea radiata Coss. et Durr.*	*Ch.*	*End.*
	Atractylis babelii Hochr.	*The.*	*End.*
	Atractylis delicatula Batt.	*The.*	*Sah.*
	Bubonium graveolens (Forssk) Maire	*Ch.*	*Sah.Sind.*
	Carduncellus devauxii Batt.	*Hem.*	*End.*
	Centaurea pungens Pomel	*Ch.*	*Sah.*
	Cotula cinerea Del.	*The.*	*Sah.*
	Echinops spinosus L.	*Hem.*	*Sah.Med.*
	Ifloga spicata (Vahl) C.H Schultz	*The.*	*Sah.Sind.*
	Launaea arborescens (Batt.) Maire.	*N.Ph.*	*Ibero.Maur.Sah.*
	Launaea nudicaulis (L.) Hook.	*The.*	*Med.Sah.Sind.*
	Matricaria pubescens (Desf.) Schultz	*The.*	*Sah.*
	Picris albida Ball.	*The.*	*Sah.Med.*

	Pulicaria undulata (L.) DC.	*Ch.*	*Sah.Sind.*
	Rhantherium suaveolens Desf.	*Ch.*	*End.*
Boraginaceae	*Echium pycnantum Pomel*	*Hem.*	*Sah.Med.*
	Echium trygorrhizum Pomel.	*The.*	*End.*
	Heliotropium luteum	*The.*	*Sah.Sind.*
	Heliotropium undulatum (Lehm.) DC.	*The.*	*Sah.Sind.*
	Trichodesma africanum (L.) Lehm. Al.	*The.*	*Sah.Trop.*
Brassicaceae	*Anastatica hierochuntina L.*	*The.*	*Sah.Sind.*
	Diplotaxis harra (Forssk.) Boiss.	*The.*	*Med.Iran.Tour.*
	Diplotaxis pitardiana Maire	*The.*	*End.*
	Eruca sativa Mill. Sous esp. Vesicaria (L.)Thell.	*The.*	*Med.*
	Farsetia aegyptiaca Turra.	*Ch.*	*Sah.Sind.*
	Farsetia hamiltonii Royle.	*Ch.*	*Sah.Sind.*
	Farsetia ramosissima Hochst.	*Ch.*	*Sah.Sind.*
	Foleyola billotii Maire	*The.*	*End.*
	Malcolmia aegyptiaca Spr. Var. longisilique	*The.*	*Sah.Sind.Trop.*
	Matthiola livida DC.	*The.*	*Med.Sah.Sind.*
	Morettia canescens Boiss.	*The.*	*Sah.Sind.*
	Nasturtiopsis coronopifolia (Desf) Boiss.	*The.*	*Med.*
	Pseuderucaria sp.	*The.*	*Sah.Med.*
	Zilla macroptera Coss.	*Ch.*	*Sah.Sind.*
	Zilla spinosa (L.) Prantl	*Ch.*	*Sah.Sind.*
Capparaceae	*Capparis spinosa L.*	*Ch.*	*Med.Sah.Sind.*
	Cleome arabica L.	*The.*	*Sah.Sind.*
Cistaceae	*Helianthemum lipii (L.) Pers.*	*Ch.*	*Sah.Med.*
Colchicaceae	*Androcymbium punctatum (Schlecht) Cavan.*	*Geo.*	*Sah.Sind.*
Convolvulaceae	*Convolvulus fatmensis Kunze.*	*The.*	*End.*
	Convolvulus trabutianus Schw. & Musch	*Ch.*	*End.*
Cucurbitaceae	*Colocynthis vulgaris (L.) Schrad.*	*The.*	*Trop.Med.*
Euphorbiaceae	*Euphorbia calyptrata (Coss. et DR.) Var.*	*The.*	*End.*
	Euphorbia granulata Forsk.	*The.*	*Sah.Sind.*
	Euphorbia guyoniana Boiss. Et Reut.	*The.*	*End.*
Fabaceae	*Argyrolobium uniflorum Jaub.et Spach*	*Ch.*	*Sah.Med.*
	Astragalus gombo Coss.et Dur. Bunge.	*Ch.*	*End.*
	Astragalus mareoticus Del.	*The.*	*Sah.*
	Crotalaria saharae Coss.	*Ch.*	*End.*
	Hippocrepis multisiliquosa Well.	*The.*	*Med.*

	Lupinus pilosus Murr.	*The.*	*Sah.Med.*
	Medicago laciniata Mill.	*The.*	*Med.Sah.Sind.*
	Psoralea plicata Del.	*Ch.*	*Afr.Trop.*
	Retama retam Webb.	*N.Ph.*	*Sah.Sind.*
Geraniaceae	*Erodium sp.*	*The.*	*End.*
	Monsonia heliotropioides (Cav.) Boiss.	*The.*	*Sah.Sind.*
Hyacinthaceae	*Battandiera amaena (Batt.) Maire.*	*Geo.*	*End.*
Illecebraceae	*Gymnocarpos decander Forsk.*	*Ch.*	*Sah.Sind.*
	Paronychia arabica L.	*The.*	*Med.*
Juncaceae	*Juncus maritimus Lam.*	*Geo.*	*Cosmop.*
Lamiaceae	*Marrubium deserti De Noë.*	*Ch.*	*Sah.*
	Salvia aegyptiaca L.	*Ch.*	*Sah.Sind.*
Menispermaceae	*Cocculus pendulus (Forst.) Diels*	*N.Ph.*	*Trop.*
Mimosaceae	*Acacia albida Del.*	*Ph.*	*Afr.Trop.*
	Acacia raddiana Savi.	*Ph.*	*Afr.Trop.*
Neuradaceae	*Neurada procumbens L.*	*The.*	*Sah.Sind.*
Plantaginaceae	*Linaria aegyptiaca ssp fruticosa Desf*	*The.*	*Sah.*
	Plantago albicans L.	*The.*	*Med.*
	Plantago amplexicaule Cav.	*The.*	*Med.*
	Plantago sp.	*The.*	*Med.*
Plumbaginaceae	*Limonium sinuatum (L.) Miller.*	*The.*	*Med.Sah.Sind.*
Poaceae	*Aeluropus littoralis (Gouane) Parl.*	*Hem.*	*Med.*
	Andropogon laniger Desf.	*Ch.*	*Sah.Trop.*
	Aristida plumosa L.	*Hem.*	*Afr.Trop.*
	Danthonia forskahlii (Vahl) R .Br	*Ch.*	*Sah.*
	Panicum turgidum Forsk.	*Ch.*	*Sah.Trop.*
	Phragmites communis Trin.	*Geo.*	*Cosmop.*
	Polypogon monspeliensis (L.) Desf.	*The.*	*Paleo.Subtrop.*
	Schismus barbatus L. Thell.	*The.*	*Med.*
	Stipa parviflora Desf.	*Hem.*	*Med.*
Polygonaceae	*Emex spinosa Campdera*	*The.*	*Med.*
	Rumex simpliciflorus Murb.	*The.*	*Sah.Sind.*
Pteridaceae	*Adiantum capillus-Veneris L.*	*Geo.*	*Med.*
Resedaceae	*Caylusea hexagyna (Forsk.) Green.*	*The.*	*Trop.*
	Reseda sp.	*The.*	*Med.*
Rhamnaceae	*Zizyphus lotus (L.) Desf.*	*Ph.*	*Med.*
Rubiaceae	*Gaillonia reboudiana Coss. et Dur.*	*Ch.*	*End.*

Sapotaceae	*Argania spinosa (L.) Skeels*	*Ph.*	*End.*
Solanaceae	*Lycium afrum L.*	*Ph.*	*Sah.*
	Lycium intricatum Boiss.	*N.Ph.*	*Ibero.Mar.*
	Solanum nigrum L.	*The.*	*Cosmop.*
Tamaricaceae	*Tamarix articulata Vahl.*	*Ph.*	*Sah.Sind.*
	Tamarix gallica L.	*Ph.*	*Trop.*
Urticaceae	*Forskahlea tenacissima L.*	*The.*	*Sah.Sind.*
Zygophyllaceae	*Fagonia bruguieri DC.*	*The.*	*Sah.Sind.*
	Fagonia glutinosa Del.	*The.*	*Sah.Sind.*
	Fagonia latifolia Del.	*The.*	*Sah.Sind.*
	Fagonia longispina Battandier	*The.*	*End.*
	Fagonia sp.	*The.*	*Sah.Med.*
	Seetzenia africana R. Br.	*The.*	*Sah.Sind.*
	Tribulus alatus Del.	*The.*	*Sahelo.Sah.*
	Tribulus terrester L.	*The.*	*Cosmop.*
	Zygophylum gaetulum Emb. & Maire	*The.*	*End.*

On the biogeographic level the predominance of species of (Sah.Sind) type followed by End elements then Mediterranean elements then (Sah.Med). The rest represents a small participation but contribute to the diversity and richness of the phytogeographic potential of the region.

The study of the evolution of *Argania spinosa* has highlighted the effect of human activities on the argan tree and its flora. The setting in defense accompanied by appropriate silvicultural treatments remains an effective means for the recovery of this ecosystem. The argan tree is the only representative of sapotaceae in Morocco and Algeria. It plays a very important ecological role in the maintenance of fragile ecosystems.

Biodiversity indices: On the basis of the phytoecological surveys the rate of each biological type and eco-biological indices of the study area was determined. The values of these parameters are summarized in (Table 2).

Table 2. Result of the biological indices of the study area.

Index	$D_{(Mg)}$	(H')	(E_H)	(I_s)	(E_s)	IP
Value	7.6888	4.4252	0.843	17.07	0.4343	0.76

- The Margalef index is 7.68 and it shows that each individual belongs to a different species, and thus proves that they are individuals of different species and that the higher the D index, the greater the specific diversity. This index is in direct relation with the specific richness and the total number of individuals.
- The Shannon-Weaver index associated with the equitability index, is realized on the global list of species. It allows to have a better idea on the state of the biological diversity of an ecosystem. In this study area, their respective values are 4.4252 and 0.843. This shows that the groupings described within the station are more diverse in species. On the other hand, the Piélou

regularity index shows a good equitability, because the value obtained is high and close to 1. This confirms the balance of the species found within their respective families.

- As for Simpson's equitability (SI), it is certainly higher than 1 but clearly lower than its maximum value. To the latter is attached the equitability index (ES) with a calculated average of 0.43 the value obtained is less, indicating the difference in abundance of individuals between each species

The use of several complementary methods provides a broad view of the evolution of communities: the indices used make it possible to observe variations in specific diversity. The study revealed that the anthropogenic gradient has an influence on the floristic diversity of our species in the study area.

Biodiversity indices were calculated to give the state of biodiversity of the species in the study area. The results obtained on the diversity indices calculated by Shannon associated with the equitability index, is carried out on the global list of species. It gives a better idea of the state of biological diversity of the ecosystem.

In conclusion, the study of the floristic procession shows a remarkable specific richness associated with *Argania spinosa* in its natural distribution area in Tindouf (Algerian Sahara). The vegetation of the study area reveals the dominance of three major floristic families: Asteraceae, Brassicaceae and Amaranthaceae. It constitutes different biogeographic influences. The study of biological types represents a physiognomy of a wooded steppe.

The use of several indices allowed us to have a vision on the variations of the specific diversity within the argan grove of Tindouf. Also, any disturbance of the structure of the plant formation is probably due to the anthropic effect.

Through this study, it is very important to increase protection measures to preserve these valuable and threatened ecosystem. We urge, with that, the authorities concerned to urgently take necessary measures at the international and national levels for the sustainable conservation of our most vulnerable heritage.

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