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The Sahara from the Bioclimatic Viewpoint: Definition and Limits

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Abstract : The Sahara occupies an area of almost nine million sq. km in Africa and lies in the zone of less than 100 mm mean annual rainfall. It offers a great bioclimatic diversity. There is a Mediterranean Sahara in the north, a Tropical Sahara in the south, a Central Plains Sahara, a Montane Sahara and an Oceanic Sahara, all of which have their own distinctive climatic pattern and biological diversity. Distribution pattern of plants and animals is closely linked with the climatic parameters, particularly the amount and seasonality of rainfall and temperature. The latter may play as important a role as the former in controlling animal and plant distribution since Mediterranean species may dominate in higher elevations under tropical rainfall regimes, whereas Tropical species may intrude the Mediterranean rainfall regions wherever winter temperature is mild or warm.

Key words : Desert, arid land, bioclimatology, biodiversity, biogeography, Sahara.

Stretching across the northern third of Africa lies the Sahara desert. To most people, this immense area, comparable to the United States, Canada, China or Australia in size, is one of uniform aridity, searing heat and little or no vegetation. Yet botanists have for long held very different perceptions of this vast area of some 8.6 million sq. km. Their classical view is that the Sahara is a transition zone between Mediterranean and tropical climates, with winter rains in the north and summer rains in the south. To them, the northern Sahara belongs to the Mediterranean Region of the Holarctic Floristic Empire, whereas the southern Sahara belongs to the Soudano-Deccanian Region of the Palaeotropical Floristic Empire. The eremitic transitional zone of the central Sahara is usually referred to as the Saharo- Arabian, a term which includes the Arabian and Persian deserts (Eig, 1931). It borrows its flora from both the Mediterranean and the Sudano-Deccanian regions. The central Sahara contains no flora of its own. All its flora are adapted from Holarctic or Palaeotropical groups to extreme ecological conditions. The overall flora of the Sahara amounts to 2800 species of Phanerogams (Le Houerou, 1992a and b).

Within this generally accepted framework, the situation is less simple than this sketch might suggest; the Sahara is very diverse and full of contrasts - latitudinal, altitudinal and longitudinal - all being further complicated by variations in the geology and landscape (Fig. 1).

Northern Limit of The Sahara

Different borders between the arid north African steppes/semi-deserts and the Sahara have been discussed by a number of authors from various disciplines - the northern limit of palm tree cultivation, the southern limit of olive tree cultivation, the 200 mm isohyet and so forth. The best definition was given by the geographer Capot-Rey (1952) as being the southern limit of the alfa grass, *Stipa tenacissima*. Yet alfa grass steppes have greatly receded over the past 100 years due to over-exploitation, clearing for cultivation and other questionable management practices. The natural southern limit of alfa grass is approximately the 100 mm isohyet, a limit corresponding to a number of other botanical, ecological, edaphic and physiographic features, as well as some cropping and land use practices (Le Houerou, 1959).

The 100 mm isohyet corresponds to the northern extension of a few hundred eremitic plants characteristic of the Sahara and the Near Eastern deserts. The most common among these are listed in Table 1.

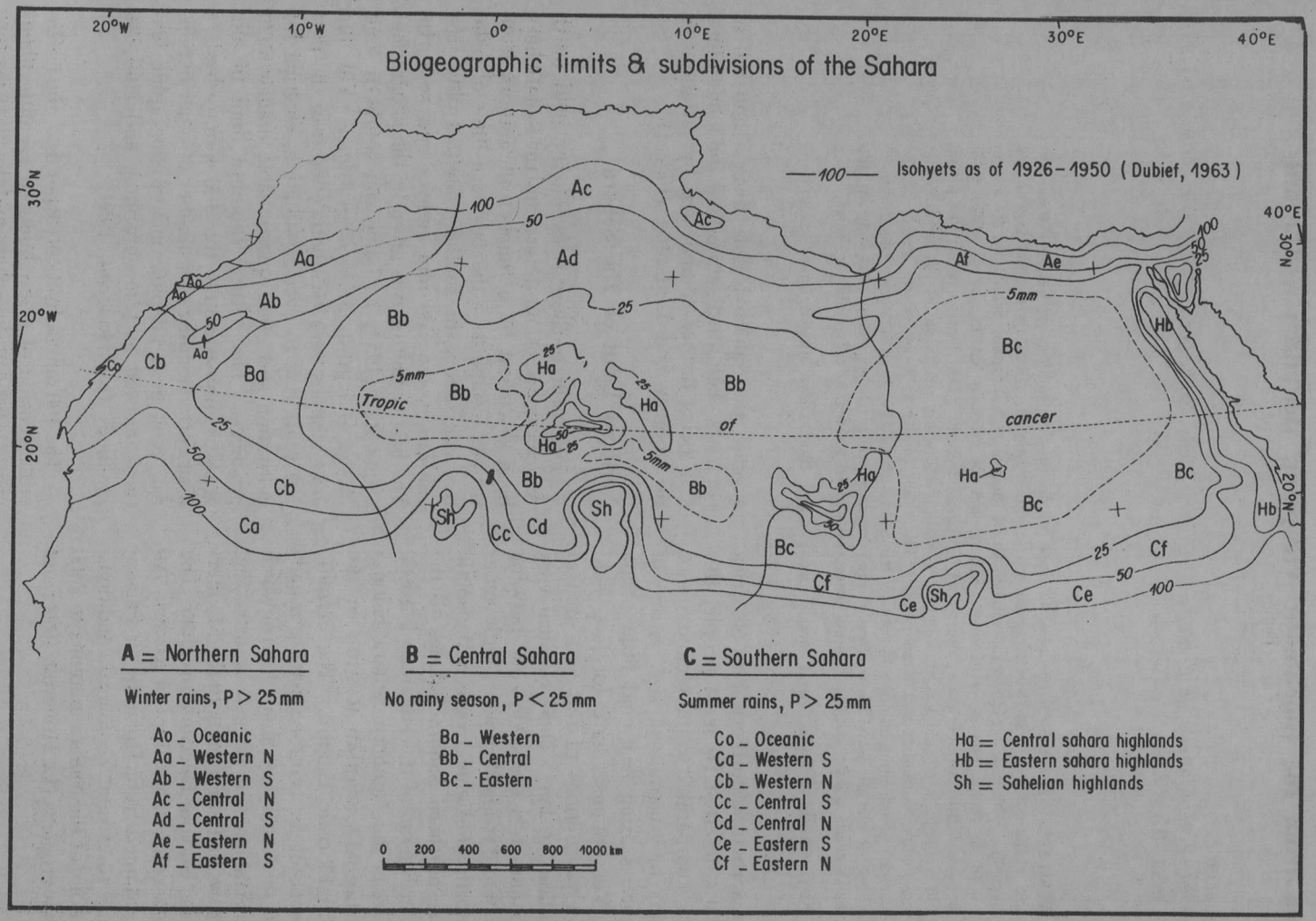

Fig. 1. The Sahara : limits and subdivisions.

Table 1. Some common and characteristic plants of the northern Sahara and the Near Eastern deserts

Plant	Family	Plant	Family
Tree/tall shrubs			
Calligonum arich	Polygonaceae	*Astragalus gyzensis*	Leguminoseae
C. azel	Polygonaceae	*Brocchia cinerea*	Compositeae
C. Calvescens	Polygonaceae	*Centaurea furfuracea*	Compositeae
Tall shrubs		*Launaea glomerata*	Compositeae
Ephedra alata	Ephedracaeae	*Matthiola livida*	Crucifereae
Genista saharae	Leguminoseae	*Megastoma pusillum*	Boraginaceae
Helianthemum confertum	Cistaceae	*Monsonia nivea*	Geraniaceae
Retama (Lygos) retam	Leguminoseae	*M. heliotropioides*	Geraniaceae
		Morettia canescens	Crucifereae
Tall shrub/shrub		*Oligomeris linifolia*	Resedaceae
Calligonum comosum	Polygonaceae	*Ormenis lonadioides*	Compositeae
		Plantago ciliata	Plantagianaceae
Dwarf shrubs		*Pseuderucaria clavata*	Crucifereae
*Anabasis articulata**	Chenopodiaceae	Savignya parviflora	Crucifereae
Pulicaria crispa	Compositeae	*Stephanochilus omphalodes*	Compositeae
Randonia africana	Resedaceae	*Volutaria leucantha*	Compositeae
*Salsola baryosma**	Chenopodiaceae	Zygophyllum simplex*	Zygophyllaceae
*S. tetragona**	Chenopodiaceae		
		Dwarf shrub/perennial grasses	
Perennial forbs		Panicum turgidum	Gramineae
Androcymbium gramineum	Liliaceae	Pennisetum divisum	Gramineae
Astragalus gombiformis	Leguminoseae		
Euphorbia guyoniana	Euphorbiaceae	**Perennial grass**	
Farsetia hamiltonii	Crucifereae	*Aristida foexiana*	Gramineae
Moltkia ciliata	Boraginaceae		
Oudneya africana	Crucifereae	**Perennial graminoid**	
Reseda villosa	Resedaceae	*Cyperus conglomeratus*	Cyperaceae
Trichodesma calcaratum	Boraginaceae		
Urginea noctiflora	Hyacinthaceae	**Perennial forbs/dwarf shrubs**	
		Antirrhinum ramosissimum	Scrophulariaceae
Perennial/annual forbs		*Astragalus pseudo-trigonus*	Leguminoseae
Fagonia microphylla	Zygophyllaceae	*Bubonium graveolens*	Compositeae
		*Cornulaca monacantha**	Chenopodiaceae
Annual forbs		Zilla macroptera	Crucifereae
Ammodaucus leucotrichus	Umbellifereae	*Z. spinosa*	Crucifereae

* Crassulescent species.

Table 2. (Contd.)

Plant	Family	Plant	Family
Bassia muricata	Caryophyllaceae	*Plantago ciliata*	Plantaginaceae
Brochhia cinerea	Compositeae	*Robbairea prostrata*	Caryophyllaceae
Caylusea hexagyna	Resedaceae	*Rumex spp*	Polygonaceae
Centaurium pulchellum	Gentianaceae	*Savignya parviflora*	Crucifereae
Chrysanthemum macrocarpum	Compositeae	*Sclerosephalus arabicus*	Caryophyllaceae
Cressa cretica	Convolvulaceae	*Seetzenia africana*	Zygophyllaceae
Diplotaxis acris	Crucifereae	*Senecio falvus*	Compositeae
D. pitardiana	Crucifereae	*Silene villosa*	Caryophyllaceae
*Fagonia spp.***	Zygophyllaceae		
Forskhalea tenacissima	Urticaceae		
Launaea glomerata	Compositeae	***Perennial Grasses***	
Lotus glinoides	Leguminoseae	*Danthonia forskhalei*	Gramineae
Lotus jolyi	Leguminoseae	*Danthonia fragilis*	Gramineae
Matthiola maroccana	Crucifereae	*Lasiurus hirsutus*	Gramineae
Monsonia nivea	Geraniaceae	*Stipagrostis brachyptera*	Gramineae
Morettia canescens	Crucifereae	*Stipagrostis ciliata*	Gramineae
Neurada procumbens	Neuradaceae	*Stipagrostis obtusa*	Gramineae
Notoceras bicorne	Crucifereae	*Stipagrostis plumosa*	Gramineae
Oligomeris linifolia	Resedaceae	*Stipagrostis pungens*	Gramineae

* Crassulescent ; ** perennial/annual forbs.

is well beyond the dry limit of rainfed cropping and resident animal husbandry, which lies around the 200-250 mm isohyet in the Sahel.

In the southern fringe of the Sahara contracted vegetation is found between the 50 and 150 mm isohyets, depending on the soils and substratum. Again, the figure of 100±50 mm emerges.

Subdivisions of The Sahara

There are three main latitudinal divisions within the Sahara - the northern part with winter rains and Mediterranean plant species representing over half of the flowering plant number; the southern part with summer rains and mainly tropical plants and animal species; and the central Saharan transition zone, where the other two zones tend to merge in a biological quasi-void with very low (below 20-25 mm per annum) average rainfall (Fig. 1). The flora and fauna in these conditions are extremely poor. Monod (1958) found only 7 species of flowering plants over 150,000 sq. km in the eastern 'empty quarter' of Mauritania, while Quezel (1965) found only 50 species over a same size area in N.E. Chad. The eastern Libyan and Egyptian deserts are also extremely poor.

The central Sahara is not entirely void of vegetation, because the high altitudes of the Ahaggar, Tibesti, Tassili and other mountains and plateaux trigger rainfall, so inducing runoff and permanent vegetation along the wadis. The region can be longitudinally subdivided into five zones (Monod, 1956, 1957, 1968; Quezel, 1965). Each of these zones is characterised by ergs, regs, hammadas, rocky hills and mountains. Similar subdivisions could be applied to the northern and southern Sahara also. The three main divisions and the zones within them are discussed below.

Central Sahara

The Oceanic Zone (70,000 sq. km) is a 50 km wide strip along the Atlantic shore, char-

Table 3. Characteristic species of the Oceanic zone in Central Sahara

Plant	Family	Plant	Family
Tall shrub		**Dwarf shrub/prennial forb**	
Hedysarum argentatum	Leguminoseae	*Limoniastrum feei**	Limoniaceae
Dwarf shrubs		**Perennial forbs**	
Barleria schmitii	Acanthaceae	*Anethum theurkauffii*	Umbelliferae
Convolvulus trabutianus	Convulvulaceae	*Inula lozanoi*	Compositeae
Echiochilon chazalici	Boraginaceae		
Echiochilon simonneaui	Boraginaceae	**Annual forbs**	
Ephedra rollandi	Ephedaceae	*Andrachne gruvellei*	Euphorbiaceae
*Limoniastrum ifniense**	Limoniaceae	*Convolvulus heterotrichus*	Convolvulaceae
Limoniastrum weygandiorum	Limoniaceae	*Mesembryanthemum theurkauffii**	Aizoaceae
*Salsola gemmascens**	Chenopodiaceae	*Senecio massaicus*	Compositeae
Teucrium chardonianum	Labiatae	**Cactoid/succulent**	
*Zygophyllum waterlotii**	Zygophyllaceae	*Euphorbia echinus*	Euphorbiaceae

* crassulescent.

acterized by lower and more moderate temperatures, no frost, relatively moist air, and the presence of occasional mist. Mean annual rainfall varies from 20 to 50 mm. This strip is characterized by a number of endemic, zonal plant species and communities belonging largely to the so- called 'macaronesian' flora shared by the Atlantic islands and the south-western shores of North Africa (Morocco and Mauritania). The most characteristic species are listed in Table 3.

Because of the relatively mild climatic conditions the flora is richer than in most parts of the Sahara. Some 350 species occur over 300,000 sq. km in the former Spanish Sahara - a species density quite comparable to the montane zones of Ahaggar and Tassili, and 50% more than the Fezzan, which is twice the area.

Western Sahara (800,000 sq. km) has a more moderate climate than the areas in central and eastern Sahara on similar latitudes. Mean annual rainfall varies from 20 to just over 50 mm. Summer rainfall occurs more in the south and winter rains in the north, with a continuum in between. Of particular interest are the occasional winter depressions and storms south of the Tropic of Cancer along the Atlantic shores. Birouk *et al.* (1991) found 480 species of flowering plants in the S W Moroccan Sahara, the former Spanish Sahara. Some characteristic common plant species of the Western Sahara are listed in Table 4.

As for the Atlantic Sahara the flora and vegetation are a mixture of Mediterranean and tropical genera and species, the proportions of which vary from north to south. The same applies to animals; tropical species reach north almost to 30°N, while Mediterranean species reach south to 20°N.

The Central Plains (1.25 million sq. km) occur around the central mountains and plateaux, and are among the most arid parts of the Sahara, containing Tanezrouft, Tenere, Touat, Tidikelt, Tinghert. Rainfall is below 25 mm per annum. Temperatures are extremely high with a mean hottest month daily maximum between 40 and 45°C and absolute maxima around 55°C. Flora and vegetation are extremely poor; the total number of plant species is well below 600 for the

Table 6. Some typical plants of the Eastern Sahara

Plant	Family	Plant	Family
Trees/tall shrubs		**Dwarf shrubs**	
Acacia tortilis raddiana	Leguminoseae	*Achillea fragrantissima*	Compositeae
Balanites aegyptiaca	Balanitaceae	*Anabasis setifera*	Chenopodiaceae
Maerua crassifolia	Capparaceae	*Artemisia monosperma*	Compositeae
Tamarix nilotica	Tamariaceae	*Astragalus echinus*	Leguminoseae
		Ast. ragalus spp.	Leguminoseae
Tall shrubs		*Chenolea arabica*	Chenopodiaceae
Lycium shawii	Solanaceae	*Cornulaca ehrenbergeri*	Chenopodiaceae
Moringa peregrina	Moringaceae	*Crotataria thebaica*	Leguminoseae
Ochradenus baccatus	Resedaceae	*Launaea spinosa*	Compositeae
Periploca aphylla	Periplocaceae	*Pituranthos rholfsianus*	Umbellifereae
P. angustifolia	Periplocaceae	*P. tortuosus*	Umbellifereae
Pistacia khinjuk	Pistaciaceae	*Salsola delileana**	Chenopodiaceae
Tamarix mannifera	Tamariaceae	*Schanginia aegyptiaca**	Chenopodiaceae
		*Sedlitzia rosmarinus**	Chenopodiaceae
Shrubs		*Sevada schimperi**	Chenopodiaceae
Atriplex farinosa	Chenopodiaceae	Suaeda monoica	Chenopodiaceae
Capparis aegyptiaca	Capparaceae	*S. setigera*	Chenopodiaceae
Euphorbia nubica	Euphorbiaceae	*S. volkensi*	Chenopodiaceae
Perennial grasses		**Annual forbs**	
Aeluropus legopoides	Gramineae	*Aegialophila pumila*	Compositeae
Stipagrostis scoparia	Gramineae	*Arnebia hispidissima*	Boraginaceae
		A. tetrastigna	Boraginaceae
Annual grass		*Bassia eriophora*	Chenopodiaceae
Taeniatherum crinitum	Gramineae	*Cleome chrysantha*	Cleomaceae
		C. droserifolia	Cleomaceae
Perennial forbs		*Dipterygium glaucum*	Cruciferae
Erodium arborescens	Geraniaceae	*Echium rauwolfii*	Boraginaceae
Heliotropium digynum	Boraginaceae	*Enarthrocarpus lyratus*	Crucifereae
*Limonium tunetanum**	Plumbaginaceae	*E. pterocarpus*	Crucifereae
Moretia philaenae	Crucifereae	*E. strangulatus*	Crucifereae
Moricandia nitens	Crucifereae	*Erucaria pinnata*	Crucifereae
M. sinaica	Crucifereae	*Gundelia tournefortii*	Compositeae
Paronychia desertorum	Caryophyllaceae	*Gyposophila capillaris*	Caryophyllaceae
Phagnalon barbeyanum	Compositeae	*Heliotropium pterocarpum*	Boraginaceae
P. nitidum	Compositeae	*Hyoscianus desertorum*	Solanaceae
P. schweinfurthii	Compositeae	*Launaea massauensis*	Compositeae
P. sinaicum	Compositeae	*Mesembryanthemum Forskhalei**	Aizoaceare
Reaumuria hirtella	Tamariaceae	*Reseda kahirina*	Resedaceae
Salvia graveolens	Labiateae	*R. orientalis*	Resedaceae
S. palaestina	Labiateae	*R. Petrovitchiana*	Resedaceae
S. spinosa	Labiateae	*Robbairea delileana*	Caryophyllaceae
Verbascum letourneuxii	Scrophulariaceae	*Salsola inermis**	Chenopodiaceae
		*S. volkensii**	Chenopodiaceae
Annual forbs/legumes			
Agyrolobium abyssinicum	Leguminoseae		
Medicago aschersoniana	Leguminoseae		
Trigonella aschersoniana	Leguminoseae		

* Crassulescent.

Table 7. Some typical plants of the western Northern Sahara

Plant	Family	Plant	Family
Tree		**Dwarf/shrub/perennial forb**	
Argania spinosa	Sapotaceae	*Limoniastrum feei**	Limoniaceae
Tree/tall shrub		**Perennial grass**	
Acacia gummifera	Leguminoseae	*Digitaria nodosa*	Gramineae
Tall shrubs		**Perennial forbs/legumes**	
Periploca loevigata	Periplocaceae	*Crotalaria saharae*	Leguminoseae
Warionia saharae	Compositeae	*Lotus simonae*	Leguminoseae
Shrub/dwarf shrub		**Perennial forbs**	
Foleyola billotii	Crucifereae	*Battandiera amoena*	Hycianthaceae
		Salvia jaminiana	Libiateae
Dwarf shrubs		*Withania frutescens*	Solanaceae
*Anabasis aretiodes**	Chenopodiaceae		
Fagonia harpago	Zygophyllaceae	**Annual forbs**	
Helianthemum hirtum	Cistaceae	*Asteriscus pinifolius*	Compositeae
sub sp. bergevini		*Fagonia latifolia*	Zygophyllaceae
*Kleinia anteuphorbium**	Compositeae	*Plantago akkensis*	Plantaginaceae
Launaea arborescens	Compositeae	*Reboudia erucoides*	Crucifereae
Pituranthos battandieri	Umbellifereae		
Rhanterium adpressum	Compositeae	**Cactoids**	
Teucrium chardonianum	Labiateae	*Euphorbia echinus***	Euphorbiaceae
*Zygophyllum gaetulum**	Zygophyllaceae	*E. regis-jubae***	Euphorbiaceae
		*E. resinifera***	Euphorbiaceae
		*E. baumierana***	Euphorbiaceae

* Crassulescent species : ** Succulent species.

enough rainfall to create permanent streams and underflow in wadis, e.g., the Draa, Saoura, Dades, Rheris and Guir. Some of the characteristic/endemic flora are listed in Table 7.

Central Northern Sahara corresponds roughly to southern Algeria and Tunisia. Rainfall pattern is similar to that of North-Western Sahara, but temperature is somewhat lower in winter with mean daily January minimum varying from 2° to 5° C. Flora and vegetation are only differentiated by the absence of western and eastern species. The Biskra area is a special case, as its warmer winters result in vegetation more similar to that of the western Sahara (Le Houerou, *et al.* 1975).

Oriental Northern Sahara includes the Saharan parts of Tunisia, Libya and Egypt north of the 50 mm isohyet. There are local differences depending on winter temperature; the mean daily January minimum may vary from 2° to 9°C. The rainfall varies from west to east with clear demarcation at 19°E. To the west of it rainfall is more or less evenly distributed between autumn, winter and spring; to the east it is more concentrated in winter, i.e., more than 50% of the annual total (Le Houerou, 1984). Botanically this area is characteristed by a number of oriental species, as listed in Table 8.

Southern Sahara (1.5 million sq. km)

The climate of southern Sahara has two very important characteristics. First, the mean daily January minimum rarely drops below 10°C and there is virtually no frost under shelter at lower elevations (although light frost may occur in the open at night, due to radiation and low air

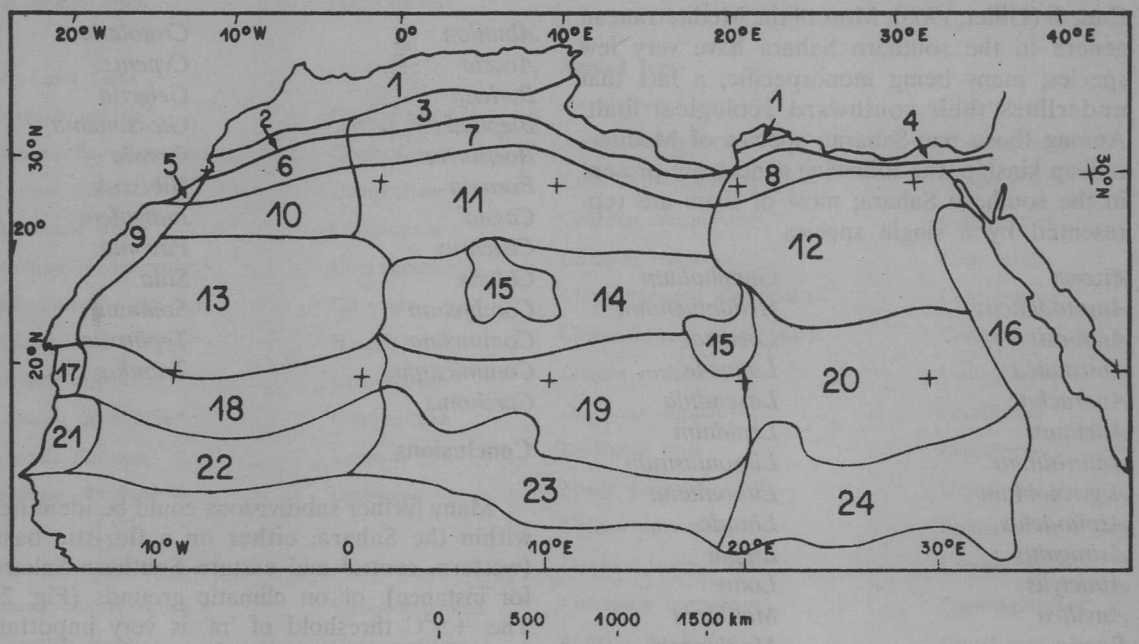

Fig. 2. Sketch of the phytogeographic subdivisions of the Sahara and neighbouring territories (from Quezel, 1978 and from Le Houerou, 1992).

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1.	Mediterranean region (Semi-arid and hyper-humid zones)	Mediterranean Region
2.	Western arid steppic zone	Ibero-Maghribian Domain
3.	Central arid steppic zone	
4.	Eastern arid steppic zone	
5.	Oceanic Northern Sahara transition zone	Saharo-Arabian Region
6.	Western Northern Sahara Transition zone	Northern Sahara
7.	Central Northern Sahara Transition zone	
8.	Eastern Northern Sahara Transition zone	
9.	Oceanic Central Sahara	Saharo-Arabian Region
10.	N-W Central Sahara	Central Sahara Plains
11.	Northern Central Sahara	
12..	N-E Central Sahara	
13.	Western Central Sahara	
14.	Central Sahara	
15.	Central Sahara Highlands	Saharo-Arabian Region
16.	Eastern Sahara Highlands	Sahara Highlands
17.	Oceanic Southern Sahara	
18.	Western Southern Sahara	Saharo-Arabian Region
19.	Central Southern Sahara	Southern Sahara
20.	Eastern Southern Sahara	
21.	Oceanic Sahel	
22.	Western Sahel	Sudano Angolan Region
23.	Central Sahel	Sahelian Domain
24.	Eastern Sahel	
25.	Eastern Sahara Zone, Red-Sea Shores Saharo-Arabian Region	
26.	Sudano-Angolan Region, Eastern African Domain, E-A Montane Zone	

rates. A number of tropical species are harboured in northern Sahara where the mean daily January minimum is above 5°C and in situations where the topography creates favourable local conditions, e.g., around Biskra and Tindouf in Algeria.

Conversely, when low winter temperature as induced by altitude, occurs in the tropical zones, the Mediterranean species become numerous and dominant, as above 2000-2500 m in the Ahaggar, Tibesti, Mouydir and Ahnet mountains. It shows that the distribution of Mediterranean taxa or Mediterranean kinship is linked as much to winter temperature as to the rainfall regime. This point alone dispels the popular stereotype of the Sahara being just a hot desert. We have provided other evidence to dispel the notions of it being uniformly dry or devoid of vegetation.

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