Study of the bryological flora at the archaeological site of Chellah, Morocco

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Abstract—The Chellah archaeological site in Rabat, listed as a cultural asset since 2012 on UNESCO's World Heritage List, is subject to significant biodeterioration. The aim of this study is to identify the bryophytes that have an important impact on the destruction of the substrate. For this purpose, three prospectuses were carried out in autumn 2014, spring 2015 and winter 2016. The systematic sampling carried out allowed us to identify 20 species of bryophytes belonging to 10 botanical families, of which 4 are dominant with 13 species equivalent to 65% of the total. The four families are Pottiaceae, Brachyceciaceae, Funariaceae and Bryaceae; they belong to the class of Musci. The liverworts are represented by only 6 species, representing 30% of the total population.

Among the 20 species inventoried, 3 are newly observed in the region of Rabat: Entosthodon pulchellus (H. Philib.) Bragués; Dydimodon Fallax Hedw. and Trichostomum crispulum Bruch. When bryophytes settle on substrates, a preliminary soils initiated to the detriment of the quality of materials and their durability.

Keywords—Biodeterioration, bryophytes, historical site, Chellah, Morocco.

I. INTRODUCTION

Like other historical sites in Rabat such as the Hassan tower or the Kasbah of the Udayas, the Chellah archaeological site, a melting pot of several civilizations (Phoenician, Carthaginian, Roman and finally Islamic) is one of the highlights of the capital's history.

The site of Chellah, also known as Chellah necropolis due to its transformation into a royal necropolis by the Marinids sultans, has undergone several archaeological excavations since 1917 that allowed uncovering the different occupations of the site (Basset H. & Levi-Provençal E., 1929, Basset H. & Terrasse H., 1932, Boube J., 1966).

Regarding the state of conservation of sites, a preliminary diagnosis by Benharbit M. in 2017, identified the main factors degrading the historical monuments of Rabat, including Chellah. These are climatic, dynamic, biological and anthropogenic factors. Among the biological factors, Benharbit M. (2017), cite lichens, plant roots and bird droppings. Nettah et al. (2015) worked more particularly on the lichens installed on the construction stones of Chellah. They identified six encrusting species, known as important agents of biodeterioration of building materials: Aspicilia calcarea, Verrucaria nigrescens, Toninia aromatica, Verrucaria calciseda (syn. Bagliettotia calciseda), Placidum squamulosum and Lecanid spadicea. With regard to weeds, 91 species have been recorded in Chellah; their presence on buildings generally indicates the presence of moisture in the joints of materials (Taleb et al., 2005). However, no investigation has yet been carried out on bryophytes, but it is agreed that these plants are pioneer plants that initiate plant succession by participating in pedogenesis; their installation on old masonry participates in their biodeterioration. The aim of this study is thus to draw up a list of bryophytes species that are in the necropolis of Chellah and to see up to what extent they take part in the biodeterioration of the substrates.

II. MATERIAL AND METHOD

The archaeological site of Chellah is located within Rabat at 4 km from the Atlantic coast; it overhangs the Bouregreg valley and occupies an intramural area of about 7 hectares.

Carthaginian had occupied the site in the 12th century BC and Phoenician in the 6th century BC. Later, Romans settled there and founded a city, mentioned by the Greek
astrologer and astronomer Ptolemy under the name of Sala, and a river port serving as a Mediterranean counter. The site was then deserted and given up before being again occupied by the Marinids sultans who built there a necropolis named Al-Ribat Al Mubarak. An inscription in kufic script on the front gate indicates that the work was completed in 739 after hijri (AD 1339). The Marinids wall, which encircles the site, currently contains characteristic vestiges of the Roman city, including in particular the capitol, the forum, the thermal baths, a nymphaeum and a triumphal arch. From the Marinids occupation, there remain a mosque, a madrasah (Islamic school), a mausoleum, halls for ablutions and several funerary rooms (Fig. 1). The site, state-owned property, is protected since November 19, 1920 by the royal decree that defines as national historical monument all the complex of Chellah. Since 2012, Chellah is part of the sites of Rabat inscribed in the list of World Heritage of UNESCO as cultural asset.

III. METHODOLOGY
We carried out prospections in the Chellah archaeological site during three seasons: autumn 2014, spring 2015 and winter 2016. These prospections allowed us to follow the biological cycle of the encountered bryophytes, in particular their sporulation. Further investigations were concentrated on the spring season, which is the most favorable period for observing the species with the sporophyte that is necessary for identification. The sampling is systematic and the harvest is therefore carried out at each encountered bryophyte population taking care not to pick up the entire population in order to preserve the species. We sorted and identified the collected samples in the laboratory. The bryophytes are reviviscents plants that preserve very well after dehydration. Therefore, they are moisturized progressively for the identification. Species recognition was done using the following identification keys: Augier (1966), Boulay (1884 and 1904), Casas et al., 2006, Coudreuse (2005), Pierrot and 2004). For each sample, morphological and histological characteristics were studied.

IV. RESULTS AND DISCUSSION
Based on the three prospections carried out in Chellah (fall 2014, spring 2015 and winter 2016), 20 species have been inventoried relating to 18 genera, 10 families and 8 orders and belonging to two classes: Muscinae and liverworts. Muscinae are dominant with 14 species (70%) grouped in 5 orders: Bryales, Fissidentales, Funariales, Pottiales and...
Hypnales. On the other hand, liverworts are represented by only 6 species (30%) grouped in 3 orders: Marchantiales, fossombroniales and sphaerocarpales. Over the 10 encountered families, 4 clearly dominate the site (Figures 2 and 3): Potiaceae with 5 genera and 6 species, Brachytheciaceae with 3 genera and 3 species, Funariaceae and Bryaceae with 2 genera and 2 species each. These families alone account for 13 species, or 65% of the total. The other 6 families contribute only by 35%.

Fig. 2: Specific richness per family

Fig. 3: Spectrum of encountered families

Among the 20 inventoried species, 3 are newly described in Rabat region: Entosthodon pulchellus (H. Philib.) Bruguès; Didymodon fallax (Hedw.) R.H. Zander and Trichostomum crispulum Bruch. They are illustrated in figures 4 to 6.
4.1. Phylum of Muscinae (Bryophyta)

This phylum contains 14 species that will be presented per family.

4.1.1. Family of Brachytheciaceae

*Rhynchosporium megapolitanum* (Bland. ex F. Weber & D. Mohr) Schimp. (*Brachythecium cardotii* Winter; *Eurhynchosporium megapolitanum* (Bland ex F. Weber & D. Mohr) Milde; *Hypnum confertum* var. *megapolitanum* (Blandow ex. H. Weber & D. Mohr) Hampe; *Hypnum megapolitanum* Blandow ex F. Weber & D. Mohr; *Hypnum megapolitanum* var. *meridionale* Schimp; *Hypnum megapolitanum* var. *septentrionale* Boulay; *Rhynchosporium megapolitanum* f. *julaceum*...
Rhynchostegiella curviseta (Brid.) Limpr. (Eurhynchium curvisetum (Brid.) Delogne: Hypnum curvisetum Brid.; Hypnum rigidulum Bruch; Rhynchostegiella curviseta var. laeviseta (W.E. Nicholson & Dixon) Podp.; Rhynchostegiella letourneuxii (Besch.) Broth.; Rhynchostegium curvisetum (Brid.) Schimp.; Rhynchostegium curvisetum var. fastigiatum Bott.; Rhynchostegium letourneuxii Besch.; Rhynchostegium curvisetum Schimp.).

It has been reported on limestone rocks of streams and on wet walls (Hamada et al., 2002); Which is in agreement with Augier (1966) who also observed it on calcareous stones. Smith (2004) noticed it on rocks, wet stones, top of trees, walls, streams, rivers, canals, lakes, and shady shores. At Chellah, it was harvested on limestone rocks.

Rhynchostegiella curviseta (Brid.) Limpr. is a Pleurocarpus moss with a creeping stem, irregularly ramified by more or less drawn up branches from 5 to 10 mm length and unequally spaced. The drawn up leaves, lanceolate, narrow, and gradually narrowed leaves in the upper half are weakly toothed and have a vein that reaches the middle of the leafblade. The middle limb cells are relatively short (3 to 4 out of 1). It was harvested in a vegetative state.

4.1.2. Family of Bryaceae

Ptychostomum capillare (Hedw.) Holyoak & N. Pedersen (Bryum capillare Hedw.; Bryum aschersonii Müll. Hal.; Bryum capillare var. platyloima (Schwägr.) Schimp.; Bryum capillare var. ruffifolium (Dixon) Podp.; Bryum capillare var. meridionale Schimp.; Bryum capillare var. macrocarpum Huebener; Bryum capillare var. tectorum Warnst.; Bryum capillare var. triste (De Not.) Limpr.; Bryum capillare var. ustulatum G. Roth.; Bryum capillare var. majus Bruch & Schimp. illeg. nom. incl. var. prior; Bryum capillare subsp. meridionale (Schimp.) Podp.; Bryum cochlearifolium (Brid.) Hartm.; Bryum ruffifolium (Dixon) Demaret & R. Wilczek; Bryum torquoiseens var. gracile Besch.; Bryum validicostatum Cardot & Dixon; Mnium capillare (Hedw.) With.).

In Morocco, this species was found on siliceous substrates (High-Atlas) (Werner, 1932; Gattefossé, 1932); on granite (Zaïan) (Gattefossé, 1931-1932), cited by Gattefossé & Werner, 1932) and on granitic and porphyritic rocks (Mayor, 1924). It has been reported on sandstones in Tangier; on sands in the Mamora forest near Rabat and on quartzites near Benslimane (Maire & Werner, 1934). Outside Morocco, (Ros et al., 2000) observed it on the edges and cracks of granitic and quartzitic rocks and on peats between 2100 and 3300 m. It was collected on the shady limestone rocks of the studied site.

Ptychostomum capillare (Hedw.) Holyoak & N. Pedersen, is a Pleurocarpus moss with a creeping stem, irregularly ramified by more or less drawn up branches from 5 to 10 mm length and unequally spaced. The drawn up leaves, lanceolate, narrow, and gradually narrowed leaves in the upper half are weakly toothed and have a vein that reaches the middle of the leafblade. The middle limb cells are relatively short (3 to 4 out of 1). It was harvested in a vegetative state.

Scorpiurium circinatum (Bruch) M. Fleisch. & Loeske (=Scorpiurium circinatum var. julaceum (Brizi) Latzel.); Hypnum circinatum subsp. meridionale (Schimp.) Giacom.; Hypnum cirrhatum subsp. meridionale Schimp.)

In Morocco, the brachytheciaceae was reported on limestone substrates (Braun-Blanquet, 1954, Jelenc, 1955a, 1955b, 1967, Braun-Blanquet, 1954, cited by Ros et al., 1999). Elsewhere, it was reported on gravel and coastal sand by Augier (1966), and on sandy soil, or on old walls according to Boulay (1884). Smith, (2004) described it as a calcic species. In the studied site, it was harvested on clay-sandy soil.

Rhynchostegium megapolitanum (Bland, ex F. Weber & D. Mohr) Schimp. is a lying stemmed moss harvested in a vegetative state, with unequally spaced branches of irregular length. The horizontal stem, spread out, carries branches of different thickness. The leaves are spread, drawn up, sharp, dentate and slightly concave with a relatively sharp and long pointed tip and with a simple or bifid vein that extends to about the middle of the leafblade. The cells of the leaf blade measure 8/1 and have membranes of the same thickness.

Rhynchostegiella curviseta (Brid.) Limpr. (Eurhynchium curvisetum (Brid.) Delogne: Hypnum curvisetum Brid.; Hypnum rigidulum Bruch; Rhynchostegiella curviseta var. laeviseta (W.E. Nicholson & Dixon) Podp.; Rhynchostegiella letourneuxii (Besch.) Broth.; Rhynchostegium curvisetum (Brid.) Schimp.; Rhynchostegium curvisetum var. fastigiatum Bott.; Rhynchostegium letourneuxii Besch.; Rhynchostegium curvisetum Schimp.).

It has been reported on limestone rocks of streams and on wet walls (Hamada et al., 2002); Which is in agreement with Augier (1966) who also observed it on calcareous stones. Smith (2004) noticed it on rocks, wet stones, top of trees, walls, streams, rivers, canals, lakes, and shady shores. At Chellah, it was harvested on limestone rocks.

Rhynchostegiella curviseta (Brid.) Limpr. is a Pleurocarpus moss with a creeping stem, irregularly ramified by more or less drawn up branches from 5 to 10 mm length and unequally spaced. The drawn up leaves, lanceolate, narrow, and gradually narrowed leaves in the upper half are weakly toothed and have a vein that reaches the middle of the leafblade. The middle limb cells are relatively short (3 to 4 out of 1). It was harvested in a vegetative state.

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Ptychostomum capillare (Hedw.) Holyoak & N. Pedersen, is a Pleurocarpus moss with a circular to
sightly polygonal stem. The twig has a helical shape. Leaves are spatulate, twisted in the dry state, drawn up and spread apart in the wet state. They are cagged at the apex with an excurrent vein, margined on most of their length and mainly on the upper part of the limb where two rows of longer elongated cells are observed, the other cells are less elongated (2-3 of 1 at least), of hexagonal-loasangic shape, having tips at the ends of their major axis. The middle of the limb has a large and loose areolation with cells of 2 to 3 on 1 in general. The sporophyte is well developed with an orange smooth silk of 2.5 cm and a rust-colored capsule of 4 mm, hanging with a double peristome.

_Bryum radiculosum_ Brid (Bryum duriae Schimp. ex Besch.;Bryum murorum (Schimp.) Berk; Bryum eurythrocarpum var. murorum Schimp.;Bryum atrovirens var. radiculosum (Brid.) Wijk & Margad.; Bryum eurythrocarpum var. limbatumBerth.;Bryum eurythrocarpum var. murale Wils. ex Hunt. err. pro B. eurythrocarpum var. murorum Schimp.; Bryum eurythrocarpum var. radiculosum (Brid.) Bruch & Schimp.; Bryum murale Wilson ex Hunt. illeg.hom.).

In Morocco, it was observed on land in the Oued El Abid gorges at Bin ElOuidane (Mayor & Werner, 1934, Mayor and Werner, 1932, quoted by Gattefosse & Werner, 1932); (Jelenc, 1967, Jelenc, 1955b, cited by Ros et al., 1999); on the edges of the granitic rocks, between 2210 and 2400 m (Ros et al., 2000). It was first described in the Anti Atlas by Cano et al.in 2002. Elsewhere, it was reported on stony soils or on the wall mortar by Augier (1966) and Smith (2004) who considered it as a calcareous species. On the site of Chellah, it was harvested on limestone rocks.

_Bryum radiculosum_ Brid is a yellowish-green acrocarpus moss, dioecious in compact tufts 4-10 mm high, with well-differentiated stem, oval-lanceolate leaves of about 2 mm, acuminate, denticulate at apex, the brown-russet-red veins excurrent, the limb is smooth with a narrow and tightly bounded area around the middle (cells measure 6/1 at least). This plant was harvested in a vegetative state during the three prospections.

4.1.3. Family of Fissidentaceae

_Fissidens bryoïdes_ Hedw (Dicranum bryoïdes (Hedw.) Sw. (Fissidens arcticus Bryhn, hypnum bryoïdes Linn.). It was seen on the walls of Rabat (Braun-Blanquet & Maire, 1924), on non-calcareous shallow ground by Augier (1966), on slopes, along the paths, on wet stones, Boulay (1884). Smith (2004), found it on neutral to acid soils or more rarely on wood or stones in open areas. At Chellah, it was harvested on concrete and wet soil.

_Fissidens bryoïdes_ Hedw (Dicranum bryoïdes (Hedw.) Sw.,is a small acrocarpus moss of 1 cm of length, with a short, drawn up and simple stemfixed on the substrate by fine and dense rhizoids. The leaves are spread out, inserted over two rows on both sides of the stem. They are oblong to lanceolate, acute, with a dorsal blade (sheath) shorter than the limb measuring about 1/3 of the length of this one and margined byvery narrow cells that are lengthened and hyaline. The cells of the limb are isodiametric and short, square almost round. The vein is simple, excurrent in a small mucron. (5 mm). The silk is short (5 mm), red, the capsule is ellipsoidal, drawn up and green with a simple peristome made up by red teeth divided up to the middle.

4.1.4. Family of Funariaceae

_Funariella curviseta_ (Schwägr.) Sérgio (Funaria curvseta (Schwägr.) Milde, Gymnostomum curvisetumSchwägr.,Physcomitrium curvisetum (Schwägr.) Bruch & Schimp., Entosthodon curvisetus (Schwägr.) Müll. Hal.)

It was reported on limestone (Braun-Blanquet, 1954, Jelenc, 1955a, 1967, Braun-Blanquet, 1954, quoted by Ros et al., 1999); In the cracks and crevices of limestone rocks on wet sites with maritime influence. It was collected between the cracks of the limestone rocks of the studied site.

_Funariella curviseta_ (Schwägr.) Sérgio, is a small acrocarpic moss of 5 mm of height, forming grass between the cracks of limestone rocks, with toothed leaves in the upper part, acuminate and without clear margin. The isolation is smooth in the upper part of the limb, is more or less translucent with rectangular cells and a vein finishing close to the top. The silk is about 2 mm long. The mature capsule is brown, symmetrical, pyriform, sloping at pendulum before dehiscence and drown up at maturity with reticulated spores of 20 μm in diameter. The capis well developed, swollen and has a long beak. The peristome is absent. It forms a stand in association with Targionia hypophylla in the studied site.

*Entosthodon pulchellus* (H. Philib.) Brugués (*Funaria pulchella* H. Philib.)

It has been reported on the cracks of granitic rocks at 2100 m a.s.l. (Ros et al., 2000). It was observed on basic soils in meadow and between rocks, and referred to as calcicoole by Smith, (2004). It was picked up on rocks and limestone groundsof the studiedsite.

*Entosthodon pulchellus* (H. Philib.) Brugués is an 8 to 12 mm acrocarpus moss, forming loose turf on moist soil, the apical leaves, being larger than the others, formoval and whole rosettes. The limb is more or less translucent and terminated in a long filiform point; theareolation is smooth in the upper part, comprises rectangular cells more or less elongated from 2 to 3 in 1 at least. The vein does not reach the top of the limb. The silk is rectilinear; the capsule is oblique, and the urn is smooth. The spores are finely papillose and are about 20 μm in diameter.
4.1.5. Family of Pottiaceae

*Barbula unguiculata* Hedw. (Barbula apiculata Hedw.; Barbula fastigiata Schultz; Barbula gattefossei P. de la Varde; Barbula microcarpa Schultz; Barbula obtusifolia Schultz illeg.hom.; Barbula unguiculata var. apiculata (Hedw.) Bruch & Schimp.; Barbula unguiculataf. apiculata (Hedw.) Mönk.; Barbula unguiculataf. cupspidata (Schultz) Mönk.; Barbula unguiculata var. cupspidata (Schultz) Brid.; Barbula unguiculata var. fastigiata (Schultz) Huebener; Barbula unguiculata var. latifolia Bréb.; Barbula unguiculata var. microcarpa (Schultz) Huebener; Barbula unguiculata var. minus Hillier; Barbula unguiculataf. obtusifolia Mönk.; Barbula unguiculata var. robusta Lindb.; Bryum unguiculatum (Hedw.) With.; Dialytrichia canariensis Bryhn; Streblotrichum unguiculatum (Hedw.) Loeske.; Tortula unguiculata (Hedw.) P. Beauv. illeg. nom.)

It was seen on the edges of granitic rocks, on quartzic soils near streams (Ros et al., 2000); as well as on the bases and trunks of *Quercus rotundifolia* (Draper et al., 2006). It was described as a mesicole by Augier (1966), which described it as a pioneer plant on clay soil and limestone sand. It was seen on very diversified substrates by Boulay, (1884), who observed it particularly on disturbed soils or on landfills. It was collected on limestone rocks and on clay-sandy soil of the studied site. *Barbula unguiculata* Hedw. is an acrocarpus moss of 1.5 to 2 cm of length. The leafed stem is about 1 cm of length. The basal leaves are revolved and measure 1.5 to 3 mm, with an excurrent vein with two steroids bands. The leaves are helically and strongly twisted in a dry state. The top of the limb is flat and obtuse and has numerous C-shaped papillae. The sporophyte is made up of a red silk and a 1.5 mm capsule. The spores are smooth, yellowish green and 10 to 12 µm in diameter. The teeth of the peristome describe 2 to 3 spiral turns. *Didymodon fallax* (Hedw.) R.H. Zander (*Barbula acuminata* Hedw.; *Barbula adriatica* Baumgartner; *Barbula brevicaulis* Schwägr.; *Barbula brevifolia* (Dicks. ex With.) Brid.; *Barbula fallax*; *brevicaulis* (Schwägr.) Podp.; *Barbula fallax var. brevicaulis* (Schwägr.) Huebener; *Barbula fallax var. brevifolia* (Dicks. ex With.) Schultz; *Didymodon fallax var. adriatica* (Baumgartner) Dill; *Didymodon fallax var. brevifolius* (Dicks. ex With.) Ochyra; *Tortula fallax* (Hedw.) Schrad. ex Turner; *Barbula Fallax* Hedw.).

It has been seen on fresh rocks in a sterile state (Jahandiez, 1923); at the bottom of limestone rocks, on damp ground; on porphyritic rocks (Maire & Werner, 1934); on limestone (Braun-Blanquet, 1954); Ros et al., 2001 describe it as a terricole species; and according to Jiménez et al., (2002b), it would develop on cracks of rock and on sandy soils. Smith, (2004) noticed that it can be present on clay-rich soils and on sand dunes at altitudes ranging from 0 to 490 m. It was collected on clay-sandy soil of the studied site. *Didymodon fallax* (Hedw.) R.H. Zander is an acrocarpuss moss harvested in a vegetative state from 1 to 3 cm in height; It is rust-colored. The stem is ramified, with a differentiated axial beam. Partially revolved leaves are acute and lanceolate 2-3 mm in length, spread-arched, more or less squarrose, in the wet state. The top of the limb is plane and acute with conical papillae that make areolation quite distinct. The base of the limb shows some rectangular and elongated cells whereas others are a little longer than the cells of the higher half of the limb, with thick membranes.

*Timmia barbuloides* (Bríd.) Mönk (*Barbula cirrhata* Arn.; *Timmia barbula* Limpr illeg. nom.; *Timmia barbula var. minor* Schimp. ex Luigier; *Trichostomum Barbula* Schwägr. illeg. nom.; *Trichostomum barbuloides* Bríd.).

It develops on limestone rocks (Mayor, 1924) and (Augier, 1966); at the bottom of walls and maritime cliffs of Rabat, as well as on travertines at Taza (Braun-Blanquet and Maire, 1924). It has been reported on siliceous groundo wet places (Maire & Werner, 1934); in tufa caves at Zalagh Mount near Fez and in Taza Gorges (Braun-Blanquet, 1954, Jelenc, 1955a, 1955b, 1967, Ros et al., 1990, Braun-Blanquet, ., 1999); on clay soil, at the bottom of rocks and walls and in ravines according to Boulay, 1884. At Chellah, it was collected on limestone rocks.

*Timmia barbuloides* (Bríd.) Mönk, is a 3cm acrocarpus moss. The tuft is of a dark green shining in the dry state. The stem, of 5 mm, is not ramified. The sheathing leaves, involute, of hooked form in the dry state, carry on the upper face high projections each formed by a cell. The limb is largely bistratified with a vein including two bands of steroids. The capsule presents a rudimentary ring with a very little twisted peristome with 32 long and fine teeth. *Tortula marginata* (Bruch & Schimp.) Spruce (*Barbula marginata* Bruch & Schimp.; *Desmatodon meridionalis* Luigier; *Tortula limbata* auct.).

It has been described as calcicole by Augier (1966) and has been observed on limestone rocks (Ahayoun et al., 2007). Boulay, 1884, observed it on the walls, the rocks and in the shaded and little covered places. Smith (2004), noticed it on wet and shaded basic rocks as well as on the walls of natural and artificial habitats. It was taken from the limestone rocks at Chellah.

*Tortula marginata* (Bruch & Schimp.) Spruce is a 10 mm acrocarpuss moss. It organizes small stands with lichen in the studied site. The leafed stem is about 2 mm high. The leaves are very little revolved, lingulate and narrow from
2 to 3 mm length with an excurrente vein in a rather long point. They are margined on almost all their contour by two strata of cells. The latter are more elongated and narrower than those of the rest of the limb. The areolation is papillose and opaque in the upper part of the limb, where the cells are quadrangular, almost square; it is smooth and translucent in the lower part of the limb, where the cells are rectangular and elongated. The capsule, of about 2 mm, is without cover and contains yellowish smooth spores of 10 µm in diameter.

**Tortula muralis** Hedw.  (Barbula heribaudii)Corb.;Barbula muralis (Hedw.) Crom.;Barbula muralis var. incana Bruch & Schimp.; Barbula muralis var. obcordata Schimp.; Barbula muralis var. rapestris Schultz; Bryum murale (Hedw.) With.; Syntrichia muralis (Hedw.) Raab; Tortula aestiva var. vulcanicola Schiffn.; Tortula muralisf. incana (Bruch & Schimp.) Sapjegin; Tortula muralis var. incana (Bruch & Schimp.) Wilson; Tortula muralis var. obcordata (Schimp.) Mönk.; Tortula muralis var. obcordata (Schimp.) Limpr.; Tortula muralis f. rapestris (A. Chev.) Sapjegin; Tortula muralis var. rapestris A. Chev.

It has been reported on granite (Gattefossé, 1931-1932, quoted by Gattefossé & Werner, 1932); On the Roman ruins of Volubilis (Braun-Blanquet, 1954, Jelenc, 1955a, 1955b, 1967, Braun-Blanquet, 1954, cited by Ros et al., 1999). Cano et al. (2002) described it for the first time in the Anti Atlas on bare soils. Its presence was also noted on the banks of the Bou Regreg river; on granite; on limestone rocks; as well as on limestone slopes (Ahayoun et al., 2007). Boulay, (1884) and Smith (2004) cite very diverse substrates such as walls, roof tiles and cracks in rocks. Smith, (2004) argues that *Tortula muralis* tends to prefer basic substrates and is found more rarely on acidic substrates and is more common in urban areas where it is able to resist atmospheric pollution. At Chellah, it was harvested on limestone rocks.

**Tortula muralis** Hedw is an acrocarpus moss about 2cm. The leaves are more or less drawn up-isolated in the wet state, contracted and twisted in the dry state, with a strong vein all along the leaf, showing in cross-section a single band of stereids, dorsal, excurrent in one hair smooth or slightly dentil, often flexuous hyaline, long; formed hyaline point, partly at least, by the vein itself. The limb is very papillose at the top, and revolute up to near the summit. The cells of the upper part of the leaf are furnished with many papillae, they are square-subaronded, very chlorophyllian, elongated towards the middle. The basal cells are hyaline, rectangular and longer. The drawn up cylindrical capsule takes on a blackish color at maturity with a long beak opercula (½length of the capsule), and a cupped headress. The peristome has completely divided teeth up to the basilar membrane; it then appears formed of 32 bristles, twisted in whorl with 1-3 turns. The spores are spherical with a smooth wall about 10 µm in diameter.

**Tortula muralis** var. *aestiva* Brund. ex Hedw. (Barbula aestiva (Brund. ex Hedw.) Schultz; Barbula muralis var. aestiva (Brund. ex Hedw.) Röhrl; Tortula aestiva (Brund. ex Hedw.) P. Beauv.; Tortula muralis subsp. aestiva (Brund ex Hedw.) Meyl.

It is a bright green plant with the same characteristics as *Tortula muralis* Hedw except in the shape of the leaf, which is tightly linate, spatulate with an excurrente vein in a yellowish green tip.

**Trichostomum crispulum** Bruch. (Mollia crispula (Bruch) Lindb.; Trichostomum brevifolium Sentdn. ex Müll. Hal.; Trichostomum crispulum var. acuminatum Meyl.; Trichostomum crispulum var. angustifolium Bruch & Schimp.; Trichostomum crispulum subsp. brevifolium (Sentdn. ex Müll. Hal.) Giacom.; Trichostomum crispulum var. brevifolium (Sentdn. ex Müll. Hal.) Bruch & Schimp.; Trichostomum crispulum var. cicutatum (Cardot ex G. Roth) Podz.; Trichostomum crispulum var. elatum Schimp.; Trichostomum crispulumf. longifolium Bouvet; Trichostomum crispulum var. pseudoweisia Schimp.; Trichostomum crispulum var. viridulum (Bruch) Dixon; Trichostomum hammerschmidii Loeske & H.K.G. Paul; Trichostomum viridulum Bruch)

It develops on the ground and in the cracks at the base of moist granitic rocks (Ros et al., 2000). It has been described as a pioneer on limestone rocks, on gravelly soil and on coastal dunes by Augier (1966). Boulay, (1884), notes its presence on the sandy or marly soil of the hills, in the hollows of the rocks, on the old walls and on the fixed sands of the old dunes. According to Smith 2004, it is found in shaded or exposed basic habitats, on the ground, rocks, rocky banks, cliffs, old wall mortar, and sandy dunes. It was collected on limestone rocks of the studied site.

**Trichostomum crispulum** Bruch. is an acrocarpusmoss, harvested in a vegetative state, light green to yellowish on surface, brown inside. The leafed stem is 1 to 1.5 cm long with mucronate acute leaves at the apex and strongly tight in the dry state; they are lanceolate from 3 to 4 mm, very papillose-opaque in the upper 2/3 of the limb. The limbs a little curved at the edges, and terminates in small cap, more or less mucronate, with a vein that is not very excurrente; it has two bands of stereids. Cells in the upper limb have thin membranes and generally square cellular contours becoming rectangular and thick membrane towards the lower part.

4.2. Phylum of liverworts (Marchantiophyta)

4.2.1. Family of Lunulariaceae

**Lunularia cruciata** (L.) Lindb. (Dichomimum cruciatum (L.) Trevis.; Lunularia cruciata (L.) Dum.; Marchantia...
4.2.2. Family of Targioniaceae

*Targionia* hypophylla L. (Targionia michelii Corda; Targionia convoluta Lindeb. & Gottsche; Targionia bifurca Nees & Mont.; Targionia germanica Corda inval. nom.; Targionia hypophylla var. fimbriata (Müll. Frib.) Müll. Frib.).

In Morocco, it has been reported on fresh rocks (Braun-Blanquet & Wilczek, 1923); schistose rocks (Braun-Blanquet & Maire, 1924); on the siliceous substrates of Djebel Guedrouz in Haut-Atlas, at 1850 m a.s.l. (Werner, 1932); as well as along cracks on limestone rocks at Adar-Ouaman in the Anti-Atlas (Mayor & Werner, 1934). This mesicole species according to Augier, 1966, has been described as a pioneer on argillaceous soil and calcareous sand. According to Boulay, 1984, it is found on clay-sandy soil, on old walls owing to cracks and on limestone rocks. In Chellah, this species was collected on limetubble stone masonry or clay-sandy soil.

*Targionia hypophylla* L. is a hepatic with a dark green thallus of 10 to 15 mm long and 4 mm wide. The thallus is clearly differentiated, in two parts: that on the dorsal side contains a very green assimilative tissue, and that on the ventral side consists of a parenchyma little or not chlorophyllian. The assimilative tissue is formed by chambers filled with chlorophyllous bristles regularly drawn up on their floor, closed or opening by pores. The ventral scales are large, and violet. The stomata are surrounded by 2 to 3 circles of cells very different from the epidermal cells. The capsule located on the ventral surface of the thallus is contained in a bivalve envelope. It contains elaters with 2-3 whorls and spores from 50 to 60 μm of diameter.

*Targionia lordeeriana* Müller Frib. (Targionia hypophylla var. lordeeriana (Müll. Frib.) Aleffi & Schumacker inval. nom.).

In Morocco, it has been reported on calcareous ground and rocks, siliceous ground, granite rocks (Jovet-Ast, 1956c). This species was harvested on limestone rocks in the studied site.

*Targionia lordeeriana* Müller Frib., is a hepatic with glaucous thallus with some 4 mm wide lobes. Thallus is clearly differentiated, on a transverse section, into parts like the previous species. The oval stomata are surrounded by 1 to 2 rings of about 7 large reniform cells. The capsule located on the ventral surface of the thallus is protected by a bivalve envelope. The spores are about 80 μm in diameter. It organizes dense stands on limestone rocks and between their cracks.

4.2.2. Family of Ricciaceae

*Riccia crystallina* L. emend. Raddi (Riccia crystallina subsp. austrigena Schiffl.; Riccia crystallina var. major Lindeb.; Riccia crystallina var. vulgaris Lindeb.).

In Morocco, it has been reported on mud (Corbiere, 1913a, Corbiere, 1913b, quoted by Gattefossé & Werner, 1932); on calcareous red ground, on ways (Jovet-Ast, 1955, Jelenc, 1955a, 1967, Jovet-Ast, 1965, quoted by Ros et al., 1999); on mud of dried marshes (Augier, 1966, Boulay, 1984, Hamada et al., 2002).

*Riccia crystallina* L. emend. Raddi, is a hepatic with radial sling thallus, with obtuse lobes, 1 to 4 mm wide, light green above, pale in lower part. The assimilative tissue is made of laminary parenchyma. The thallus is one to two times dichotomous. The spores of 70 μm diameter on average carry on their convex face a network of alveoli. It is met with *Sphaerocarpos michelii* forming a same stand.

4.2.3. Family of Fossombroniaceae

*Fossombronia angulosa* (Dicks.) Raddi (Jungermannia angulosa Dicks.).

In Morocco, it has been reported on different substrates: on siliceous soil, on siliceous soil at the edge of a stream; on soil covering rocks of granite, on fresh ground in the shade, on shady rocks partially covered with soil; or on siliceous red soil at the edge of a runoff (Jovet-Ast, 1956c). According to Augier 1966, this species has been reported on non-calcareous wet soil, on the slopes of
hedges, paths and in rather dry places. It is cosmopolitan in the Mediterranean region according to Boulay, 1984. In Chellah, it is found between the rocks of the studied site. *Fossombronia angulosa* (Dicks.) Raddi, is a hepatic with leaves of 1-3/0.5 cm with a creeping stem bearing succubus leaves and purple rhizoids. The silk is short with a round capsule containing spores of about 40 μm. The spore has a hemispherical face and a pyramidal face.

### 4.2.4. Family of Sphaerocarpaceae

*Sphaerocarpus michelii* Bellardi (*Sphaerocarpus terrestris* (Micheli) J.E.Sm.).

It has been reported on soil covering a granite rock (Jovet-Ast, 1956c); on sandy soil and on the granitic rock above the hot spring of Oulmès (Ahayoun et al., 2007). Augier, (1966) describes it as a messicoleand indicates its presence on clay soil. It was harvested on the clay-sandy soil of the studied site.

*Sphaerocarpus michelii* Bellardi, is a dioecious hepatic with light green thallus with unistratified margins. Antheridia and archegones are located on the dorsal side of the thalli, each is surrounded by an involucre with the pyriform male and the globular female, tightened in the upper part and presenting a small opening. The dehiscence of the capsule is irregular. The spinous spores are united in tetrads of dark brown color measuring approximately 100 μm in diameter.

### 4.3. Bryophytes and Biodeterioration

Bryophytes are reviviscent plants that settle as soon as the substrate is moistened (fig. 7 and 8); they can occupy very poor environments in organic matter. The samples were taken at different locations in Chellah site (Fig. 1). The obtained results show that bryophyte colonize both the moistened soil, the concrete of steps, the zellig, the terracotta brick made up essentially of calcarenite dating from antique and Islamic times (fig. 9, 10 and 11). This rock was extracted from the quarries of Sidi Bou-Knadel, about ten kilometers to the north of Salé, from plio-quaternary age and belonging to the dune cords that extend along the Atlantic coast between El Jadida and Larache. It is a compact, yellow-beige detritic sedimentary rock made up of two detrital fractions: a bioclastic fraction (shell fragments) and a terrigenous fraction composed of millimetric quartz grains bound by a limestone cement.

According to the bioreceptivity criteria described by Guillite (1995), Salé calcarenite offers a set of characteristics favorable to biocolonization. Indeed, the surface quality of Salé calcarenite has a large roughness allowing the anchoring of rhizoids. This surface roughness is also associated with a high porosity of about 24% and an estimated capillarity of 12.37 (El Amrani El Hassani & El Azhari, 2009), which is conducive to retention of water and favorable for the installation and growth of bryophytes.

![Fig 7](image1.png)

Fig 7: Development of bryophytes on zellij tiles of a tomb in Chellah necropolis contributing to the destruction of the enamel

![Fig 8](image2.png)

Fig 8: Terracotta brick wall of the gate covered with bryophytes that maintain a high degree of moisture on the masonry
Once the supports have been colonized, the bryophytes cause initially a chromatic alteration and thus an aesthetic biodeterioration (Deruelle, 1991; Warscheid & Braams, 2000; Gaylarde et al., 2003; Allsopp et al., 2004).

The bryophyte binding system will develop in the pores of material, exerting pressures inside the structure that may modify the porosity of the support and in the long term to make material to burst (Warscheid & Braams, 2000; Gaylarde et al., 2003). This is called physical biodeterioration.

Other chemical processes are involved: the dissolution of limestone substrate minerals by acidic secretions produced by plants as well as the assimilation of the substrate as a nutrient (Warscheid & Braams, 2000). This is referred to as a chemical biodeterioration.

V. CONCLUSION

The archaeological site of Chellah has been subject to few scientific researches in botanical matter, in particular with regard to the bryophytes. Therefore, our objective consists in describing and identifying the species of bryophytes present in this site and then to establish a list of taxa of these species.

The harvest of the bryophytes allowed us to identify 20 species distributed as follows:

- Fourteen species belonging to the Moss class divided into 5 orders and families and 13 genera, the most widely represented order being the Pottiaceae with Fissidens bryoides, the most widespread species in the site;
- Six species belonging to the Hepatic class including one leaf hepatic. They are distributed in 3 orders, 5 families, and genera, with Lunularia cruciata, the most encountered species.

The colonization of archaeological materials by bryophytes leads to their aesthetic, physical and chemical biodeterioration due to the acid secretions produced by these plants. All these processes have an important role in pedogenesis and thus in the initiation of plant succession. This fact, without gravity in the natural environment, becomes a source of issues when it concerns materials used in historical monuments whose durability is then threatened.

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