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Three new records of fern species (Polypodiopsida) in Senegal, from Dindefelo Falls, Kedougou region

Paterne Arnaud Bernard Mingou[1*], Mathieu Gueye[2], Komla Elikplim Abotsi[3], Théophile Bayet[4], Christophe Cambier[4], Germinal Rouhan[5]

1 Laboratoire de Botanique, Institut Fondamental d'Afrique Noire, Université Cheikh Anta Diop, Dakar, Senegal • mingoupaterne@hotmail.fr
2 Laboratoire de Botanique, UMI 3189, Environnement, Santé et Société, Institut Fondamental d'Afrique Noire, Université Cheikh Anta Diop, Dakar, Senegal • gueye_guirane@yahoo.fr
3 Laboratoire de Recherche Forestière, Université de Lomé, Lomé, Togo • abotsikomlaelikplim@yahoo.fr
4 Unité Mixte Internationale de Modélisation Mathématique et Informatique des Systèmes Complexes, Sorbonne Université, IRD, UMI UMMISCO, Paris, France • theophile.bayet@ird.fr
5 Institut de Systématique, Evolution, Biodiversité (ISYEB), Muséum national d'Histoire naturelle, CNRS, Sorbonne Université, EPHE, Université des Antilles, Paris, France • rouhan@mnhn.fr
* Corresponding author

Abstract
Blotiella currorii (Hook.) R.M.Tryon. (Dennstaedtiaceae), *Dicranopteris linearis* (Burm.F.) Underw. (Gleicheniaceae), and *Aleuritopteris farinosa* (Forssk.) Fée (Pteridaceae) are reported for the first time in the flora of Senegal. They represent not only three more species but also two new families, Dennstaedtiaceae and Gleicheniaceae, for Senegal. Data on species, morphology, taxonomy, ecology, and geographic distribution are included. These three species were found in the interstices of the cliff of the 100-m Dindefelo Falls, which is in Kedougou region.

Keywords
Aleuritopteris farinosa, *Blotiella currorii*, Dennstaedtiaceae, *Dicranopteris linearis*, Dindefelo Falls, Gleicheniaceae, Pteridaceae, pteridophytes, West Africa

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Introduction

Pteridophytes, grouping the two distinct evolutionary lineages Polypodiopsida (ferns, also referred to as "monilophytes") and Lycopodiopsida (Pryer et al. 2001; Smith et al. 2006; Christenhusz 2011; PPG I 2016), are free-sporing vascular plants that are widespread around the world but particularly in tropical countries. The species diversity of pteridophytes is estimated at 11,916 species distributed in 337 genera, 51 families, 14 orders, and two classes (PPG I 2016).

In Senegal, 3,500 plant and algae species distributed in 1,000 genera (Bâ and Noba 2001; MEPN 2010) have been identified. The phanerogams make up around 71% of the species and the remaining 29% are distributed among pteridophytes, bryophytes, and algae. However, since the great botanical explorations of the region dating back to the colonial period (Mingou 2014), collection efforts have been very variable depending the plant groups. In particular, little research has been conducted on pteridophytes; Bâ and Noba (2001) and Roux (2009) report 38 and 32 species for the country, respectively, and Mingou and Gueye (2017) provided partial taxonomic data for some humid areas in Kedougou region. Even though, more studies are needed to assess the actual diversity of Pteridophytes in the country.

Biophysically, Senegal is generally fairly flat with altitudes below 50 m a.s.l. over 75% of the territory, with a culminant peak rising to 581 m a.s.l. in the extreme southeast Fouta Djallon (CSE 2005). The ecological contrasts in Senegal (Saharan, Sahelian, and sub-Guinean climates) offer a high diversity of habitats and ecosystems for biodiversity, and especially for pteridophytes.

The objective of this study is to present and describe three species of ferns discovered for the first time in Senegal. We provide information about the ecology and novel distribution maps for these species in Africa, including the new records in Senegal.

Methods

Several sites were inventoried in different administrative regions: Kedougou and Tambacounda (south-eastern Senegal), Ziguinchor, Kolda and Sedhiou (south Senegal), Fatick, Kaffrine and Kaolack (center Senegal), Dakar (west Senegal), and Saint-Louis (north Senegal).

We especially focused our explorations on the Kedougou region due to its singular mountainous relief and its geographical position bordering on Guinea to the southeast and within the Guinean zone, which is made up of forest savannas with galleries (Trochain 1940). Kedougou is juxtaposed with the Afro-mountain region of West Africa, which is one of the seven mountain systems and major mountain blocks in the regions of Africa (White 1978). Kedougou is located in southeastern Senegal, where the foothills of Fouta-Djalon extend, and has strong ecological affinities with neighbouring Guinea. Although Senegal is considered a Sahelian country with climatic vicissitudes, the Kedougou region is one of the best-watered regions, with waterfalls and humid forests. Dindefelo Falls, a graceful waterfall over 100 m high, approximately 30 m wide, has a 2–3-m deep pool around which there is a microclimate characterized by relatively high humidity and low temperature.

Random sampling was adopted depending on the specificity of the environment, namely rice fields, palm groves, ponds, forests and gallery forests, mountains, and waterfalls.

The rice fields and a palm grove were explored in their entirety due to their size. In the forest environment, we focused our prospections in large-vegetation cover where humidity is high, including ravines and banks of the water bodies; the gallery forest were prospected in their entirety, following the stream. Cliffs of waterfalls were prospected by two climbers and sampled over their entire height from top to bottom, stopping every 10 m in a vertical transect and including 5m to each side horizontally (Fig.1). Geographic coordinates, as well as photographs (whenever possible) of the grouping of plants, were taken at each stop along the vertical transect.

Figure 1. Two climbers collecting ferns along the cliff of the Dindefelo Falls. **A.** Left side of waterfall. **B.** Right side of waterfall.

For systematic study, fully developed, and, as much as possible, fertile plants were collected and prepared and kept as herbarium specimens. A small fragment of lamina was systematically taken from a specimen representing each collection number and stored in silica gel for future molecular studies, following the sampling protocol supported by Gaudeul and Rouhan (2013). In addition to collections, we photographed entire plants in nature and noted the ecology, habitat type, and altitude. Silica gel and herbarium specimens are kept at the IFAN Herbarium Ch. A. Diop Senegal (IFAN; herbarium codes following Thiers 2018). Duplicates were sent to the Herbarium (P) of the National Museum of Natural History in Paris (MNHN) as part of an international exchange program.

Identification of the specimens was first done in the field and then confirmed or corrected in the laboratory by comparison with the IFAN and DAKAR herbaria in Senegal and by using floras and monographic works (Tardieu-Blot 1953, 1964; Berhaut 1967; Roux 2001, 2003). The Paris Herbarium (P) and its database, Sonnerat, were also consulted (https://science.mnhn.fr/institution/mnhn/search), as P stands as one of the most important collections for African specimens and especially Western African specimens, including many types (Le Bras 2017).

Morphological descriptions of the species newly discovered in Senegal were based on observations using a Leica M80optical microscope, and data through Jstor (https://plants.jstor.org/) and Pteridophytes of Africa (https://www.fernsofafrica.com/). As a taxonomic framework, we used the classification of the Pteridophytes Phylogeny Group (PPG I 2016) also used by Hassler (2019). Distribution maps were created using occurrence data obtained from the Global Biodiversity Information Facility (GBIF) (http://www.gbif.org/occurrence/search?taxon), in addition to our new Senegalese data.

Results

The pteridoflora of Senegal is enriched with three new species of ferns collected during our inventories: *Dicranopteris linearis* (Burm.F.) Underw. (Gleicheniaceae, Fig. 2A), *Aleuritopteris farinosa* (Forssk.) Fée (Pteridaceae, Fig. 2B), and *Blotiella currorii* (Hook.) R.M.Tryon. (Dennstaedtiaceae, Fig. 2C). These three species represent two fern families found for the first time in Senegal (Dennstaedtiaceae and Gleicheniaceae).

The elevation distribution of these three species on both sides of the cliff (Fig. 1), left side (Fig. 1A) and right side (Fig. 1B), is as follows:

Level 1: none is present at level 1, which corresponds to the lower stratum at 0–35 m high, which especially has bryophytes and other pteridophytes (e.g., *Selaginella versicolor* Spring, *Christella dentata* (Forssk.) Brownsey & Jermy, and *Bolbitis heudelotii* (Bory ex Fée) Alston;

Level 2: two species are present at 35–65 m: *Blotiella currorii* (60 m left side) and *Aleuritopteris farinosa* were collected only at this level (50 m high right side and 60 m left side), in sympatry with angiosperms, *Selaginella versicolor*, and bryophytes;

Level 3: two species are present at the upper level above 65 m: *Blotiella currorii* on the left side at 90 m and 100 m, and right side at 70 m and 100 m, and *Dicranopteris linearis* only on the right flank at 90 m.

All three levels differ in amount of spray from the waterfall. The spray and local humidity increase progressively towards the lower cliff face. Furthermore, the north side of the cliff face is the sunniest. At all levels, the cliff is formed by an alternating sandstone-clay sedimentary formation with a strong predominance of sandstone.

Figure 2. New records of ferns from Senegal. **A.** *Dicranopteris linearis* (Burm.F.) Underw. (PABM0264). **B.** *Aleuritopteris farinosa* (Forssk.) Fée (PABM0284). **C.** *Blotiella currorii* (Hook.) R.M. Tryon (PABM0263) collected in the cliff of the Dindefelo Falls.

***Dicranopteris linearis* (Burm.F.) Underw., 1907**
Figures 2A, 3

New record. SENEGAL – **Kedougou** • interstice of the cliff of Dindefelo Falls; 12°21′54.0″N, 012°19′29.7″W; 385 m alt.; 23.IX.2019; P.A.B. Mingou et al. PABM0264 (IFAN 63014)**.**

Identification. Fronds spaced apart. Stipe up to 1 m long, golden brown, glabrous. Lamina 2–3 times dichotomously divided with a pair of reduced pinnae present at each fork of the divisions; pinnae narrowly lanceolate, deeply pinnatifid. Pinnule lobes ca. 38 × 5 mm, linear-oblong, glabrous on both surfaces, borne only on the ultimate branches, the other axes naked. Sori subcircular or circular, ca. 1 mm in diameter, arranged in two rows along the midrib of the pinnule lobes (Fig. 2A).

Distribution in Africa. Species widely distributed in West Africa (Benin, Ghana, Guinea, Ivory Coast, Liberia, Nigeria, Senegal, Sierra Leone, Togo) throughout Southern Africa, Central Africa, East Africa, Comoros, and Madagascar (Fig. 3A).

Ecology and Distribution in Senegal. Lithophyte, at 90 m high on the left part of the cliff of Dindefelo Falls. This right part of the cliff is humid and sunny, with a few tree species (Fig. 3B).

***Aleuritopteris farinosa* (Forssk.) Fée, 1850–52**
Figures 2B, 4

New record. SENEGAL – **Kedougou** • interstice of the cliff of Dindefelo Falls; 12°21′52.0″N, 012°19′25.6″W; 369 m alt.; 23.IX.2019; P.A.B. Mingou et al. PABM0284 (IFAN 63017).

Identification. Rhizome erect, with fronds in tufts of 3–15, narrow scales with elongated cells. Stipe 8 cm long, brown to almost black, shiny, bearing mainly at the base but almost over its entire length, narrow brown scales. Lamina deltoid outline, 15 cm long by 5, bipinnate–tripinnatifid. 5 pairs of pinnae, lanceolate to

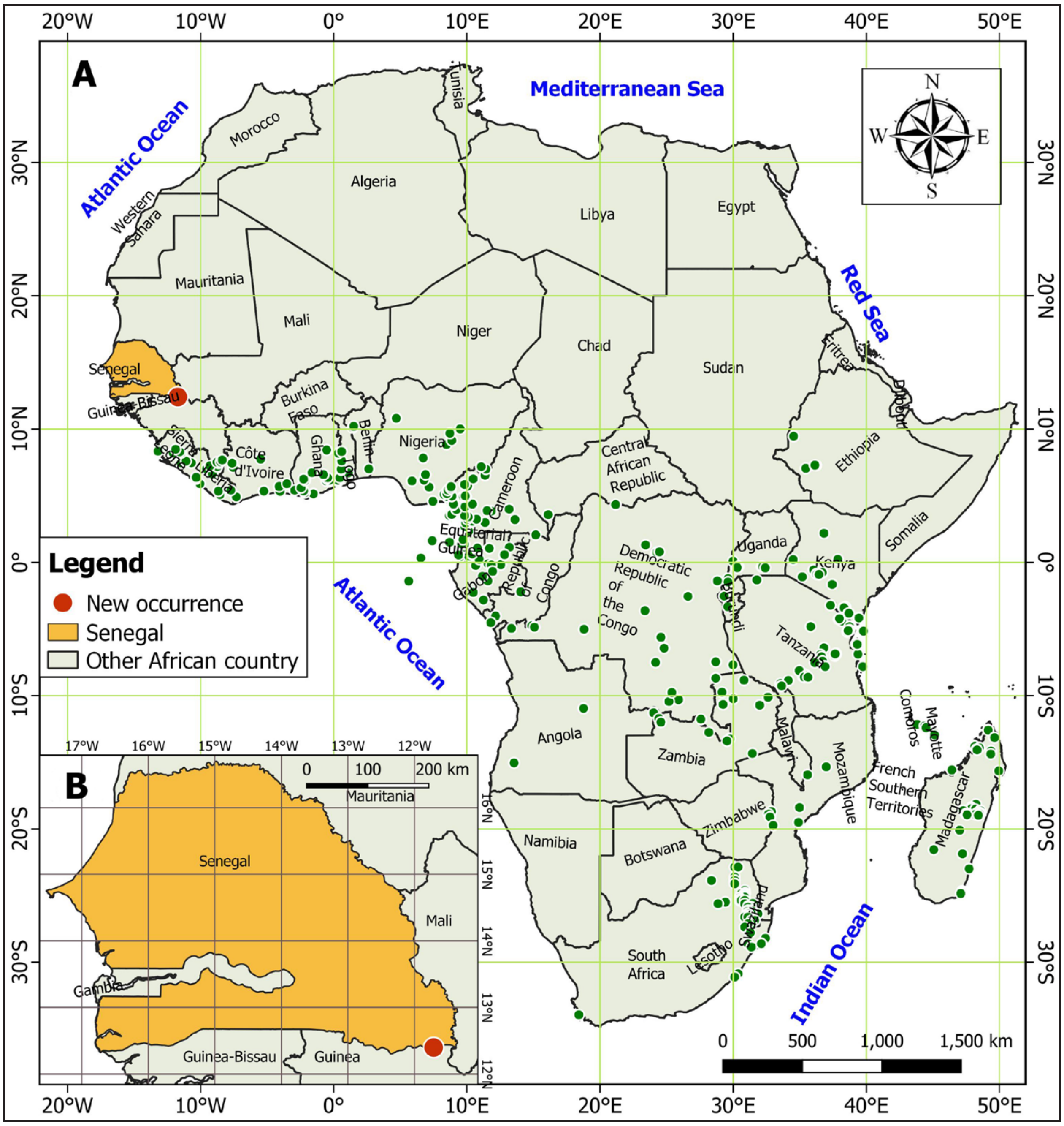

Figure 3. Distribution map of *Dicranopteris linearis* (Burm.f.) Underw. in Africa (**A**), including new record for Senegal (**B**).

slightly triangular in range, resistant pinnae more or less developed basiscopically, upper pinnae recurrent, opposite, sessile, glabrous, dark green, covered with a white powder at lower side. Rachis naked, winged at the top. Sori small, marginal, contiguous to scarious (Fig. 2B).

Distribution in Africa. Rare species in West Africa (Guinea, Ivory Coast and Senegal) and Central Africa, and more common in Southern Africa, East Africa, and Madagascar; known also from Comoros (Fig. 4A).

Ecology and Distribution in Senegal. Lithophyte, on both sides of the cliff of the Dindefelo Falls, 60 m at the left side and 50 m the right side. Strongly anchored in the rock. On the right side, this species was exposed to the sun and more developed than that found on the left, more humid and shaded side (Fig. 4B).

Blotiella currorii **(Hook.) R.M.Tryon, 1862**
Figures 2C, 5

New record. SENEGAL – **Kedougou** • interstice of the cliff of Dindefelo Falls; 12°21′54.3″N, 012°19′30.1″W; 391 m alt.; 23.IX.2019; P.A.B. Mingou et al. PABM0263 (IFAN 63018).

Identification. Rhizome erect, bearing dense ferruginous or golden hairs. Fronds tufted, firmly herbaceous. Stipe straw-coloured or brownish, up to 15 m with a dense felt of brown hairs, sparsely set with short hairs pubescent or hairless above. Lamina broadly ovate or oblong-lanceolate in outline, up to 25 × 12 cm, deeply 2 pinnatifid to 2-pinnate. Pinnae sub-opposite to alternate, sessile, lanceolate, pointed acute, 6 cm long and 1.0–1.2

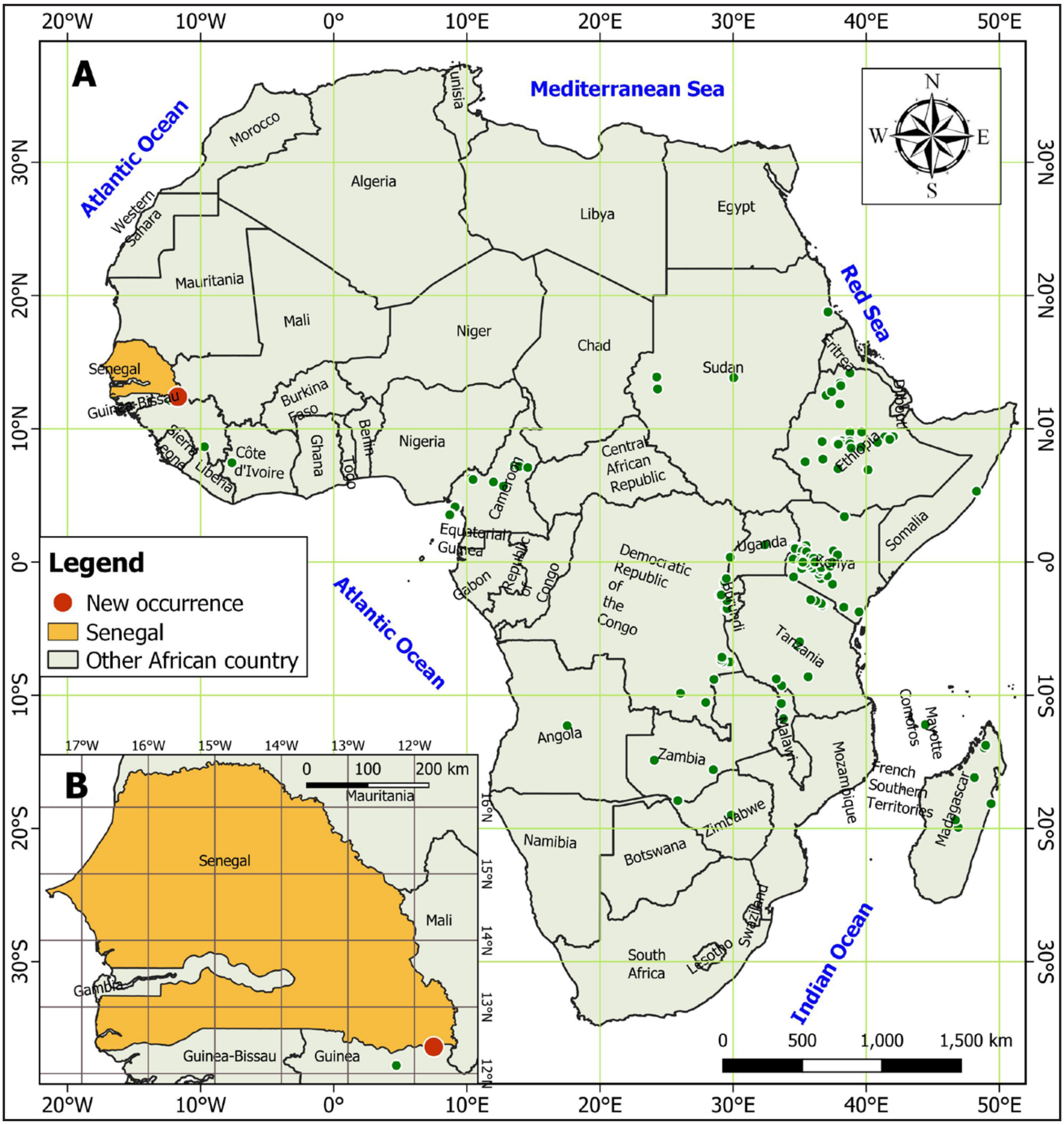

Figure 4. Distribution map of *Aleuritopteris farinosa* (Forssk.) Fée in Africa (**A**), including new record for Senegal (**B**).

cm wide, with wavy margins, with rounded sinuses between the lobes, pubescent. Rachis straw-coloured, with short hairs especially around the bases of the pinnae. Sori narrow, linear, continuous or interrupted (Fig. 2C).

Distribution in Africa. Species present in West Africa (Benin, Ghana, Guinea, Ivory-Coast, Liberia, Senegal, Sierra Leone, and Togo) and Central Africa; rare in Southern Africa; present in Comoros and Madagascar (Fig. 5A).

Ecology and Distribution in Senegal. Lithophyte, on both sides of the cliff of the Dindefelo Falls but more confined on the left side at 100 m, 90 m, 60 m high, and 100 m, and on the right side at 70 m. Strongly anchored in the rock (Fig. 5B).

Discussion

Three fern species were recorded for the first time in Senegal (*Aleuritopteris farinosa*, *Blotiella currorii*, and *Dicranopteris linearis*). They were only observed and collected in the Kedougou region, more precisely on the cliff of the 100-m Dindefelo Falls. These three species grow between 369 to 391 m a.s.l.. Ecologically, these species are lithophytes, growing in the interstices and concaves of the cliff. They were sometimes so strongly anchored in the rock that we were unfortunately not able to collect the rhizome, especially for *D. linearis* and *A. farinosa*. The latter species is characteristic of arid environments, and, indeed, it was collected only on the northern flank of the cliff, which is the sunniest part. *Blotiella*

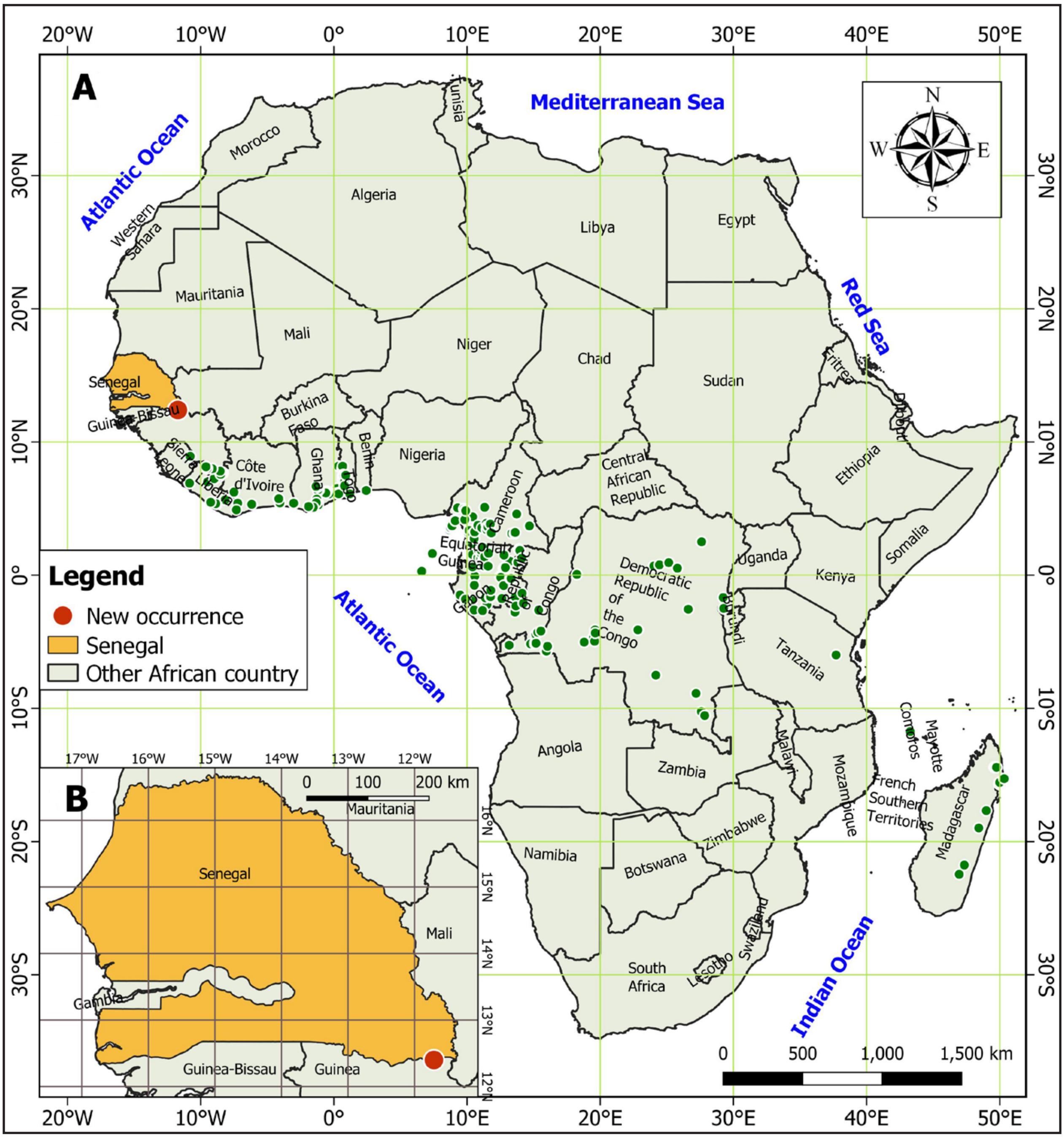

Figure 5. Distribution map of *Blotiella currorii* (Hook.) R.M.Tryon in Africa (**A**), including new record for Senegal (**B**).

currorii is densely pubescent on both laminar surfaces and shows a dwarf morphology (about 30 cm) at Dindefelo Falls; elsewhere, fronds of this species are known to be more than 2 m long. *Dicranopteris linearis*, which is known as a pioneer species and can proliferate quickly in degraded environments, was only collected on the north side of the falls at 385 m a.s.l., which is almost at the top of the cliff at 90 m high; this single collection point on the cliff for shows fairly significant woody covering with the presence of especially *Selaginella versicolor* and bryophytes.

These three widespread African species show uneven and disjunct distributions, which varies from one species to another. *Dicranopteris linearis* and *B. currorii* have similar distributions in West Africa, Central Africa, and Madagascar. However, *D. linearis* is much more frequent in the mountains of East Africa than *B. currorii*, which is more common in West and Central Africa. As for *A. linearis*, it is known only from Guinea, Ivory Coast, and Senegal in West Africa and from Cameroon in Central Africa, but it is more frequent in East Africa. *Blotiella currorii* is a linking taxon from the Afro-mountain/Afrotropical regions (Mangambu 2013), but *D. linearis* is subcosmopolitan in that it occurs in Asia, South America, and Western Australia (GBIF 2021a) and *Aleuritopteris farinosa* is paleotropical, known not only from Africa but also tropical Asia (GBIF 2021b). In tropical countries, there is lack of precise information on the distribution of pteridophytes, which is often incomplete due to lack of local (Linder 2001) and sometimes regional inventories (in Western Africa) (Abotsi et al. 2019), where the data are fragmentary. However, pteridophytes generally are distributed along a latitudinal gradient, with the greatest diversity in the tropics and there mainly in mountainous areas (Kornas 1993; Linder 2001).

Ferns are very diverse in Africa in the eastern mountainous arc and less in the western mountains (Schelpe 1983). This suggests that the Dindefelo Falls cliff could be a refuge for these species or a simple formation with abiotic singularities. According to Colyn and Deleporte (2002: 46), “there are a good number of species whose distribution in tropical Africa is not directly linked to the forest fragmentation of the Upper Quaternary, but rather to the presence of caves, rocky areas or to particular ecological skills (ubiquitous species, partial migratory, riparian, with great dispersal capacity)”.

Out of all the sites explored, only the cliff of the Dindefelo Falls shelters these species. However, five other waterfalls remain to be explored in Senegal and may habor pteridophyte species of interest: Afia 2, Dimboli, Malinda, Ségou, and Kounssy. The three species that we report here for the first time from Senegal have gone unnoticed until now because of the inaccessibility of the cliff face at Dindefelo Falls. The cliff has remained natural and undisturbed by human activities, and our professional climbers even found it difficult to access, and they were not able to reach some areas of the cliff that might have additional species. The environmental factors of the site fit the needs of ferns, including sufficient moisture (precipitation to 1500 mm), altitude, shade, and rocky substrate. A similar study in Peru by Sundue et al. (2015) led to the discovery of a new species of *Moranopteris* R.Y.Hirai & J.Prado (Polypodiaceae) on an understudied ledge which could only by accessed by climbers. This shows that cliff sites with difficult access are worth exploring using rock-climbing equipment to find unexpected diversity of rare species.

The unique presence of *A. farinosa*, *B. currorii*, and *D. linearis* in the Kedougou region of Senegal raises concerns about their national conservation status. It is therefore urgent that ecological characterization be made so as to carry out an exhaustive inventory which can prepare for the establishment of regular monitoring.

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Authors’ Contributions

Conceptualization: PABM. Funding acquisition: PABM, GR. Investigation and Methodology: all authors. Project administration: MG. Supervision: MG, GR. Writing—original draft: PABM. Writing—review and editing: all authors.

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