Invisible treasures in the herbarium and their potential role in water quality research in tropical Africa

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Keywords

Diatoms, herbarium, tropical Africa, water quality

Abstract

The water quality of rivers and lakes can be determined among others using diatoms, single-celled microscopic algae, which is a mandatory part of the Water Framework Directive in Europe. Comparison with the previous status of the water bodies can be done using previously taken samples at the same location for the study of these organisms. In many tropical areas, however, such samples are not available. Here, herbarium material can possibly provide a solution as certain diatom species live attached to aquatic plants. These diatoms remain present when aquatic plants are collected, dried, mounted and classified in the herbarium. However, studies of diatoms on herbarium specimens are scarce. For tropical Africa, for instance, only two publications can be mentioned. We explore what possibilities, apart from determining past water quality, the investigation of diatoms present on herbarium material from tropical Africa can offer, such as the study of biodiversity. Finally, the advantages and disadvantages using epiphytic diatom studies on herbarium material of aquatic macrophytes sampled in the Democratic Republic of the Congo for past water quality studies are discussed.

Introduction

Water is essential for life on earth. Therefore it is important to take care of the water resources, and to ensure its good quality, both surface and groundwater. To ensure the safety of water resources and water quality, Europe created the Water Framework Directive in 2000, a programme that includes measures to be taken as well as environmental standards. One of the mandatory components of the Water Framework Directive is the study of diatoms for determining the water quality. In this programme, water quality is reduced to 5 categories, ranging from one, very poor, over poor, moderate and good to five, very good, with only good and very good quality being acceptable. Consequently, good to very good quality should be targeted. The use of diatoms as biological indicators is not restricted to Europe but is also used in many countries worldwide, such as Australia (Lane, 2005), Brazil (Lobo et al., 2002), Canada (Lavoie et al., 2008), India (Kartick et al., 2013), Japan (Watanabe, 2005), South Africa (Taylor et al., 2007), United States of America (Ramstack Hobbs et al., 2022). In tropical Africa, on the other hand, this is still in its early stages. In this paper, we want to show that despite the fact that no analyses were carried out in the past, water quality can still be determined provided that aquatic plants were collected and deposited in herbaria in the past. This is demonstrated here through studies carried out on material from the Democratic Republic of the Congo (DR Congo). In addition, the materials can also be used for taxonomic diatom studies.

In Flanders, the Dutch-speaking northern part of Belgium, for example, the results of analyses carried out by the "Vlaamse Milieu Maatschappij" on the phytobenthos, in this case the diatoms that live attached to several substrates, show that 49% of the Flemish waterbodies scored good, some even very good, in 2023. Very poor water quality was observed in he the basin of River Lys in West Flanders, for the period 2016-2018. Fortunately, an increasing trend towards better quality can be observed from 2007 to 2018. (Vlaamse Milieumaatschappij, 2019). For Wallonia, the French-speaking southern part of Belgium, the results of the "Etat de l'environnement wallon" for 2018, show that good to sometimes very good water quality is present in a large part of the area, especially in the south, while very poor quality is located in the north-west (http://etat.environnement.wallonie.be).

Diatoms are small single-celled algae, roughly between 4 and 200 µm in size, so they can only be observed under the microscope. They possess chlorophyll and are photosynthetic hence among the primary producers at the base of the aquatic food webs. As a result, they react immediately to changes in their environment. Moreover, they are important in the carbon cycle and responsible for about 40% of the organic carbon produced in the oceans. Around 20% of all oxygen produced on earth comes from marine diatoms.

About 35,000 species are currently known, but their number is estimated to exceed 200,000. A characteristic feature of these organisms is their cell wall, composed of opaline silica, which has a typical structure, a skeleton consisting of two valves, similar to a cheese box or petri dish (Tayor & Cocquyt, 2016). To illustrate these beautiful skeletons, which explains the word “treasures” in the title, Figure 1 shows some pictures of diatoms taken with a scanning electron microscope.

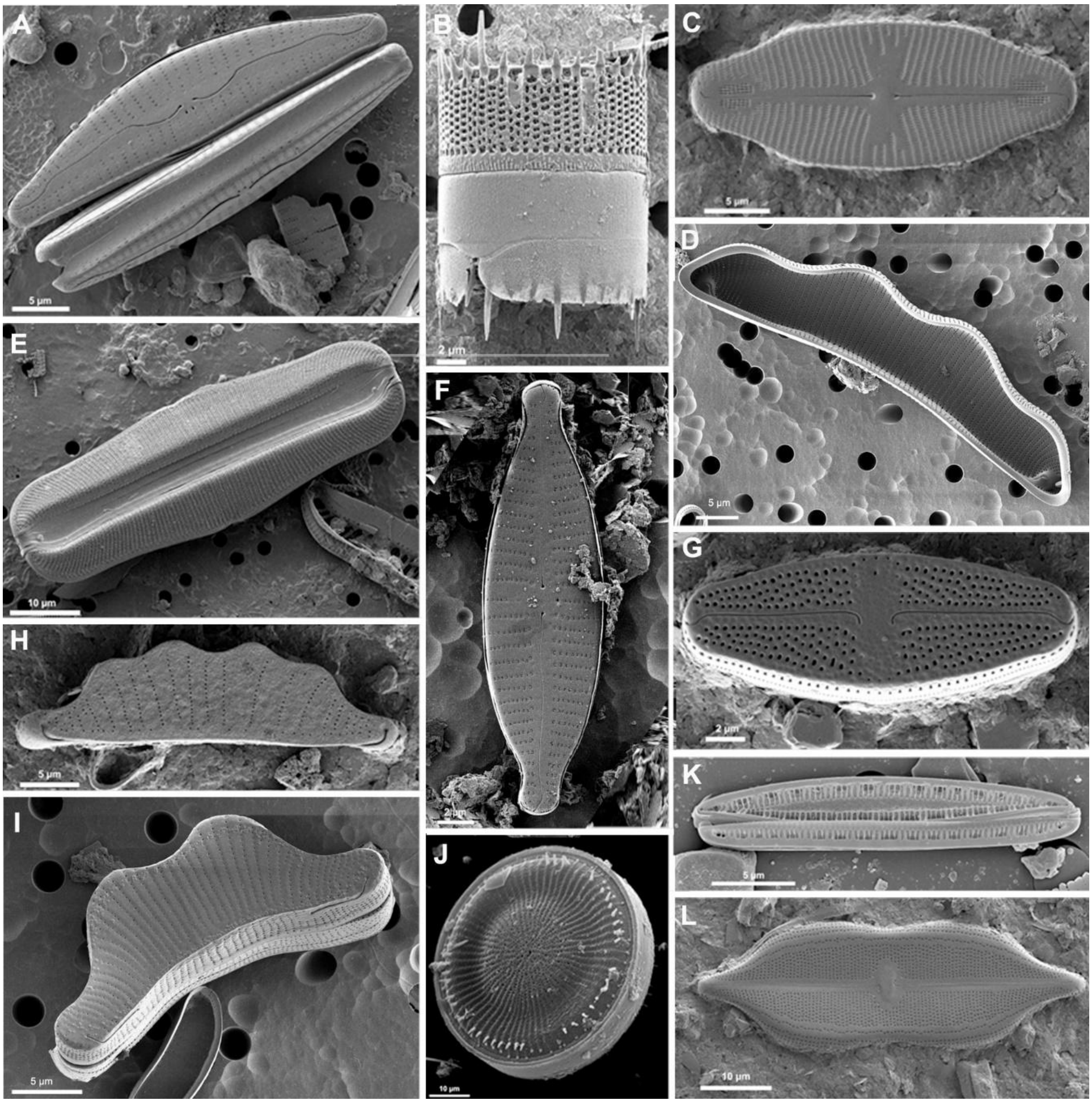

Fig. 1. Some photographs of diatoms from D.R. Congo taken with a Scanning Electron Microscope. A: *Cymbella cymbiformis* C.Agardh; B: *Aulacoseira muzzanensis* (F.Meister)

Krammer; C: *Geissleria lubiluensis* Cocquyt & Lokele; D: *Eunotia zygodon* Ehrenb.; E: *Epithemia gibba* (Ehrenb.) Kütz.; F: *Gomphonema lagenula* Kütz.; G: *Luticola* sp.; H: *Eunotia rudis* Cocquyt & M.de Haan; I: *Eunotia vanderystii* (Kufferath) Cocquyt; J: *Stephanodiscus* sp.; K: *Stenopterobia* sp.; L: *Neidium apiculatum* var. *australis* Manguin.

As primary producers they react immediately to changes in their environment and because many species can only live in a well-defined environment, they are ideal biological indicators, among others, for determining water quality and for reconstructing past climate changes.

Diatoms and water quality

Much research has already been conducted worldwide on the role of diatoms in determining water quality and the applications of various developed indices (e.g. Kelly 1998; Prygiel & Coste, 2000; OIEau, 2001; Prygiel et al., 2002; Lobo et al., 2002;, Watanabe, 2005; Taylor et al., 2007; Lavoie, 2008; Kartick et al., 2013; Cantonati et al., 2017).

To get an idea of how much research on water quality is being conducted worldwide, we can consult the Web of Sciences (Table 1). It should be noted, however, that not all published results are included in the Web of Sciences and that we can only show trends in the investigations undertaken. In our search for the DR Congo, we used “Congo” as few or any results were obtained with “Democratic Republic of the Congo”. A quick check of the publications obtained, shows that most are related to DR Congo, and all when diatoms are incorporated.

Table 1. Number of publications listed on the Web of Sciences for the topic “Water quality” and different continents or some African countries, and with the keyword “diatoms” added to the search query. Some other countries, such as Brazil, Belgium, France and the Netherlands, were added for comparison (assessed in August 2023).

Water quality		+ diatoms		Water quality		+ diatoms
worldwide	316,814	3,226		+ South Africa	2,206	67
+ Europe	3,949	111		+ Kenya	679	9
+ America	2,791	59		+ Tanzania	414	1
+ Asia	1,910	21		+ Uganda	288	4

+Africa	4,227	98		+ Cameroon	206	1
+ tropical Africa	251	16		+ Congo	119	3
+ Brazil	4,735	77		+ Rwanda	86	0
+ France	2,080	86		+ Angola	37	1
+ Netherlands	1,203	16		+ Burundi	21	0
+ Belgium	539	18		+ Gabon	13	0

The search results on the Web of Sciences, assessed in August 2023, show that a lot of attention is paid to water quality with about 317,000 publications. A search for water quality combined with the different continents surprisingly shows that Africa has the highest number of publications (Table 1). However, when the keyword "diatoms" is added to the search, the number of publications listed is quite low indicating that there is little research on water quality using diatoms. But more attention is paid to, for example, chemical analyses or studies on macroinvertebrates. If we consider some African countries, we see that in tropical Africa (e.g. Angola, Burundi, Cameroon, Democratic Republic of the Congo, Gabon, Kenya, Rwanda, Tanzania, Uganda) this research is quasi non-existent. This in contrast to South Africa, which already has a long tradition of water quality research, which started in the 1970s just before or simultaneously with research in Europe (Taylor & Cocquyt, 2015).

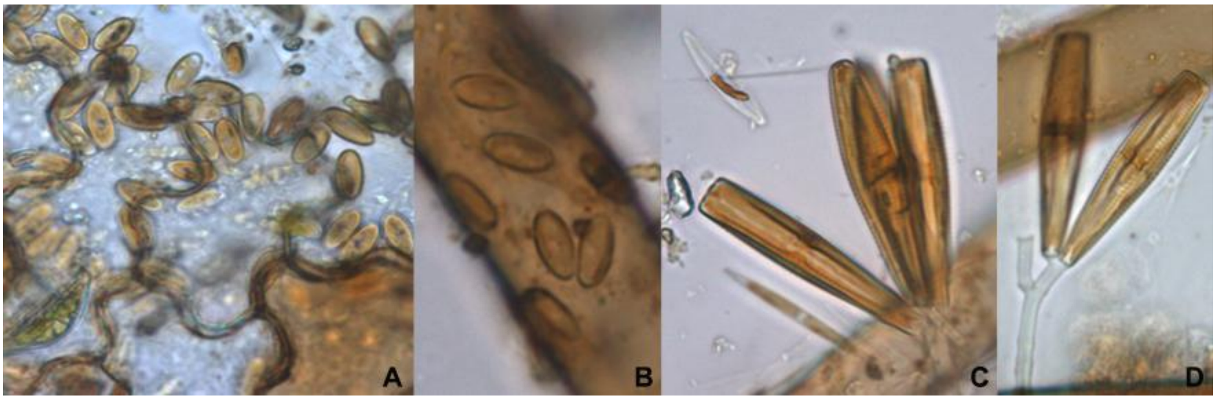

Fig. 2. Diatoms attached to a substrate, seen under an inverted light microscope. A, B: flat against the substrate. C, D: attached by short or longer, branched or unbranched mucus stalks.

Collecting materials for epiphytic diatom studies

Besides the planktonic species living free in the water column, many diatoms live attached to a substrate. This can be flat against the substrate or by means of mucus stalks (Figure 2) where several layers can be formed, similar to a forest where a herb, shrub and tree layer can be present. For diatom-based water quality studies, the preferred substrate in riverine environments consists of cobbles and small boulders or rocks. Although this type of substrate is generally widely available, this is not always the case for many tropical rivers, such as in the Democratic Republic of the Congo, for example, where the riverbeds often consist of sandy substrate. Even if such a substrate is present, the river depth and flow velocity often make obtaining samples very dangerous. Permanently submerged parts of plants can provide a solution here by sampling and studying the diatom communities growing on them. Submerged macrophytes, such as *Potamogeton* spp. and *Ceratophullym* spp., or emergent macrophytes (e.g. *Phragmites* spp., *Vossia cuspidata* (Roxburgh) Griffith, *Papyrus* spp.) can serve as substrate in tropical Africa, for example (Taylor & Cocquyt, 2016). The protocol to collecting the epiphytic diatom communities is given by STOWA (2014) and Taylor & Cocquyt (2016), among others.

When macrophytes are collected, dried, mounted on bristol sheet and deposited in the herbarium, the attached diatoms also remain on the plant specimens. These can then be sampled years, even decades and centuries afterwards for diatom studies. However, this must be done carefully without damaging the herbarium specimen (Fig. 3). The plant material to be collected is limited because the herbarium specimen should be damaged as little as possible, unlike when macrophytes are only sampled in the field for the study of diatoms and a lot of material can be collected.

The materials obtained after sampling in the field or on herbarium specimens are subjected to oxidation treatment to remove all organic material (Taylor & Cocquyt, 2016). The silica skeleton of the diatom frustule remains and perforations and ornamentations, such as spines, become visible in LM for the larger structures and in SEM for more details. For light microscopic investigation, an aliquot of the cleaned material is mounted on a microscope slide using Naphrax or Pleurax. For scanning electron microscopy, part of the oxidized sample is mounted on a aluminium stub, whether or not filtered through a Millipore filter, air-dried and sputter-coated with platinum or gold. (Taylor & Cocquyt, 2016).

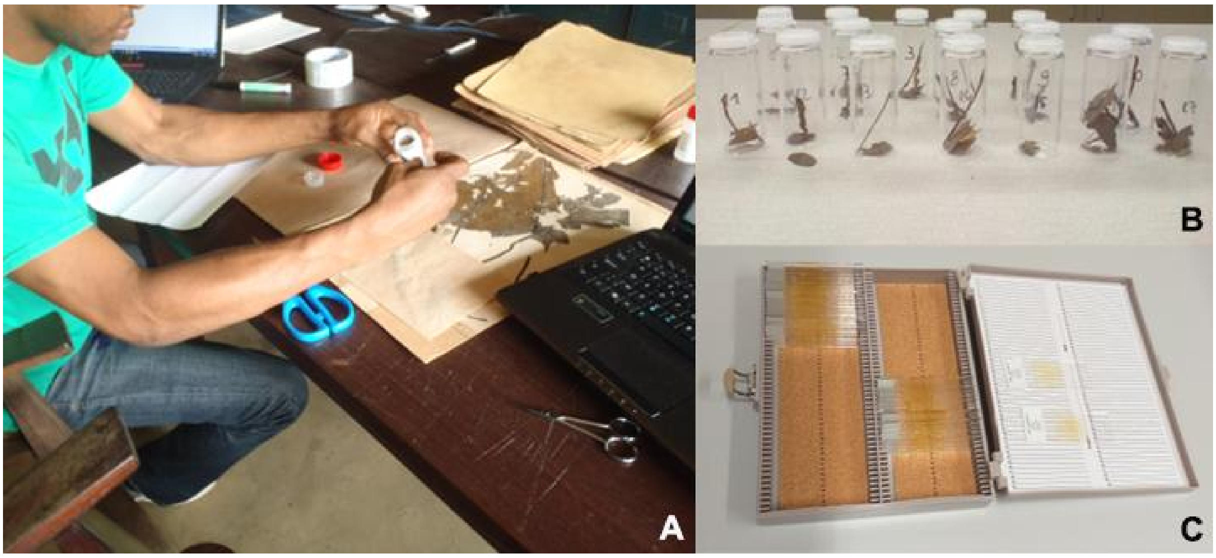

Fig. 3. Diatoms from herbarium material. A: Collection of material for diatom investigation from a mounted *Nymphaea* specimen at the herbarium in Yangambi, D.R. Congo. B: Small vials containing the collected material from different *Nymphaea* herbarium specimens in the herbarium at Meise Botanic Garden, Belgium. C: Permanent microscope slides for diatom investigation, made from *Nymphaea* herbarium materials in the herbarium at Meise Botanic Garden, Belgium. (B: image courtesy of Madder).

There are few publications dealing with such research (e.g. van Dam & Mertens, 1993; Denys, 2003, 2007, 2009; Vogel et al., 2005). For tropical Africa we can mention two studies, one conducted on material from Lake Naivasha in Kenya (Cocquyt & De Wever, 2002), and one on plant specimens collected in D.R. Congo and deposited in the herbarium at Meise Botanic Garden (BR) in Belgium and in the herbarium at Yangambi (YBI), D.R. Congo (Okito et al., 2021).

Diatom studies based on epiphytic materials from herbarium specimens collected in D.R. Congo

The plant specimens, used for the research of epiphytic diatoms, were collected between 1907 and 1987 in the Central Forest phytogeographic region (VI) (Bamps, 1982) and deposited in the herbarium of Meise Botanic Garden (BR) and in the herbarium at Yangambi (YBI). The vast majority of sampled aquatic macrophytes consisted of *Nymphaea lotus* L. (21) as well as a few specimens of *Ceratophyllium demersum* L. (3), *Utricularia benjaminiana* Oliv. (1), *U. inflexa* Forssk. (7), *U. foliosa* L. (2), *U. mannii* Oliv. (1) and *Utricularia* sp. (1). A total of 132

diatom species were observed belonging to 44 genera. The highest species richness was observed on *Nymphaea lotus* sampled in 1938 in the Yangambi area (Fig. 4) (Okito et al., 2021). Overall, *Eunotia*, a genus typical to occur in acid waters, was by far the most dominant with a relative abundance of 61.47% for all herbarium specimens sampled. Among the species of this genus observed on the studied herbarium specimens are *E. zygodon* Ehrenb. Figure 1 D) and *E. vanderystii* (Kufferath) Cocquyt (Figure 1 I). *Frustulia* with a relative abundance of 8.43% was the second most commonly observed genus.
There are many other genera that often live epiphytically on submerged parts of plants such as *Epithemia* and *Gomphonema* (Figure 2 C, D). These two genera were present on the studied herbarium specimens from D.R. Congo including *Epithemia gibba* (Ehrenb.) Kütz. (Figure 1 E) and *G. lagenula* Kütz.(Figure 1 F).

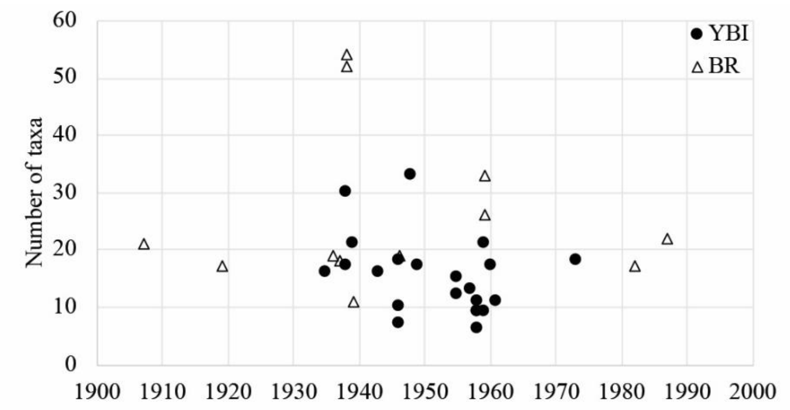

Fig. 4. Overview of the observed number of specific and infraspecific diatom taxa on macrophyte herbarium materials sampled between 1907 and 1987 in the Central Forest phytogeographic region (VI) and deposited in the herbarium of Yangambi (YBI) and Meise (BR). (from Okito et al., 2021)

Since the diatom flora of the Congo basin, but also of entire tropical Africa, is still poorly known it is not unlikely that new diatom species could be discovered during the study of the epiphytic diatoms on herbarium specimens of macrophytes. This indeed appears to be the case, and we can give as an example *Eunotia magnaparva* J.C.Taylor & Cocquyt (Taylor et al., 2024), a species recently described and found so far only on a bladderwort (*Utricularia foliosa*) and water lilies (*Nymphaea lotus*) collected near Eala in the in the Equateur Province (in the Bokele river between Bamanya and Ilenge and in Bamanya and the Ruki river respectively).

Besides their importance in diatom taxonomy, the diatoms sampled from the macrophyte herbarium specimens can also be used to calculate the water quality at the time the macrophytes were collected by means of several indices. As many diatoms from tropical Africa and the ecological preference of species especially from pristine habitats, are unknown, the calculations of various indices, mainly developed for Europe, are limited to genus level. As Taylor & Cocquyt (2015) discussed more in detail the use of diatoms as indicator organisms and the application of European diatom-based indices in Southern African, we do not elaborate further on this.

One of the indices calculated based on the epiphytic diatom investigation of the Congolese macrophyte specimens is the trophic diatom index (TDI). The TDI, developed by Martin Kelly et al. (2001) for Great Britain, is a measure for determining nutrient richness, where values below 20 indicate no organic pollution of the water, values between 21 and 40 that there is some evidence of organic pollution and values above 40 that there is organic pollution. Despite this index being designed for Europe, good results were obtained for tributaries of Lake Tanganyika (Bellinger et al., 2006). In the study of Okito et al. (2021) only three out of the 20 samples are on the edge of the free of organic pollution limit and only one sample reaches a value of 30 indicating that some organic pollution has occurred (Fig. 5 A). This sample was from a macrophyte specimen (*Utricularia inflexa*) collected in the early 1960s in a swamp in Yangambi. The higher TDI value (29.2) can be explained by the habitat, a swamp, where nutrients are retained compared to running waters of streams and small rivers (Okito et al., 2021). Overall, we can state that in most of the waterbodies there was almost no eutrophication at the time the aquatic macrophytes were collected.

The same results are obtained if another index is calculated, namely the Generic Diatom Index (GDI) developed as early as 1988 in France by Rumeau and Coste (as the Indice générique diatomique, IDG; Rumeau & Coste, 1988) and regularly updated thereafter. The scale for this index is from 0 to 5 where 0 represents the lowest and 5 the best water quality. As for the TDI, the 1960 sample from the marsh in Yangambi also scores the least good (Fig. 5 B). Both indices have been calculated using the software OMNIDIA v.5.0 (Lecointe et al., 1993).

In addition to these water quality indices, diatom communities can also be looked at and diversity indices can be calculated, such as the Shannon diversity index (H) and the Evenness of Equitability (J) (Hill, 1973). In the studied epiphytic diatoms on herbarium specimens collected in the Central Forest region in D.R. Congo the highest values for the Shannon diversity index, which gives the diversity of species and their abundances in a community, were obtained on specimens collected between 1935 and 1960 (Okito et al., 2021). The highest values for the evenness, the extent to which each species is represented among the community, were also attained there during this period (Okito et al., 2021). Diatoms are also an important proxy in paleolimnology to reconstruct, for example fluctuations in lake water levels based on changes in salinity (e.g. Verschuren, et al. 1999; Kröpelin et al., 2006).

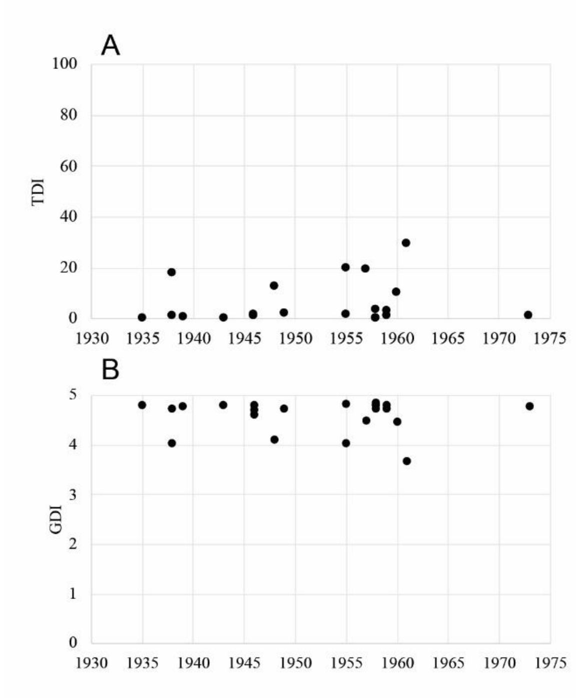

Fig. 5. Overview of (A) the Trophic Diatom Index (TDI) and (B) the Generic Diatom Index (GDI) values on genus level as derived from the diatom analyses of macrophyte herbarium specimens collected between 1935 and 1973 in the Central Forest phytogeographic region (VI) and deposited in the herbarium of Yangambi (YBI). (from Okito et al., 2021)

Herbaria used for the epiphytic diatom study on herbarium macrophyte specimens

The herbarium of two institutions were used for this study. On the one hand the herbarium housed at the Meise Botanic Garden in Belgium, and on the other hand the herbarium of INERA (Institut national pour l’étude et la recherche agronomique) housed at Yangambi in D.R. Congo.

The history of the Meise Botanic Garden goes back to the beginning of the 18th century when Belgium was under Dutch rule and part of the (United) Kingdom of the Netherlands (Diagre-Vanderpelen, 2011). Its herbarium was founded in 1826 (Diagre-Vanderpelen, 2011) and currently contains about 4,000,000 specimens (Meise Botanic Garden, 2023; Index Herbariorum, 2024), of which ca. 3,100,000 specimens are vascular plants. This makes it the 15th largest herbarium worldwide. African vascular plants account for 35% and are mainly from Central Africa collected in the 20th century, during the Belgian colonial period of the Congo. The number of African aquatic macrophytes currently present in the herbarium is estimated at about 6,000, accounting for 0.5% of the African vascular plant specimens. Best represented are the Eriocaulaceae (ca. 1,360 specimens) and the Lentibulariaceae (ca. 1,140 specimens) followed by the Nymphaeaceae (ca. 850 specimens) and the Hydrocharitaceae (ca. 740 specimens). Potamogetonaceae, Alismataceae, Pontedericeae and Ceratophyllaceae are represented by ca. 550, 450, 200 and 200 specimens respectively.

The herbarium at Yangambi is the most important herbarium in D.R Congo, and the number of specimens present is estimated at about 150,000 (Ndjele & Lituka, 2023). Especially during the period from 1933 to 1962, when the herbarium was part of INEAC (Institut national pour l'étude agronomique du Congo belge), it was the main repository for plant specimens in Central Africa (Leliaert et al., in press). A large number of the specimens in the herbarium of Yangambi, but not all, have a double in the herbarium of Meise Botanic Garden. Currently, we have no idea of the number of specimens of African aquatic macrophytes. Extrapolation of the percentage present in the Meise Botanic Garden indicates that about 290 specimens could be present. But this is mere conjecture. It is certain that at least 9 specimens of Nymphaeaceae and 3 specimens of Ceratophyllaceae are present in good condition as was observed during the sampling of the aquatic macrophytes for the diatoms in the frame of the study of Okito et al. (2021).

Herbaria in tropical Africa

Herbaria specimens can thus be play an important role for determining water quality and its changes over time. Especially when no samples have been taken for water analyses in the previous century, which is certainly the case in many developing countries. Moreover, in some of these countries, diatoms have been studied sporadically or not at all. We can take Rwanda as an example: not including Lake Kivu and apart from some studies of the mid-20th century (e.g. rapids of the Rusizi river near Bugarama on the border with Burundi and D.R.

Congo (Kufferath, 1957) and of waterbodies on the Karisimbi volcano (Hustedt 1949, Zanon 1938)) no research on diatoms was conducted in this country until a few years ago (Fischer, 2024) and as part of a phytoplankton study in Rwandan lakes (Descy, 1995). In 2021, a PhD student, among others, started investigating the water quality of the Akagera River using diatoms.

There are more than 3,100 official herbaria worldwide, which together house about 390 million plant specimens (Index Herbariorum, 2023). The largest collections are in Europe and North America. Their collections contain material from the earliest exploration times when knowledge of botanical diversity grew rapidly (Leliaert et al., in press). The largest collections are at the Muséum national d'Histoire naturelle in Paris, France, at the Royal Botanic Gardens in Kew, England and at the New York Botanical Gardens in the United States with around 7 million specimens each. Missouri Botanic Gardens in the United States follows with ca. 6 million specimens. With its around 4 million specimens, Meise Botanic Garden is among one of the most important herbaria worldwide.

For the study of epiphytic diatoms on macrophytes, aquatic plants are the most important. As already mentioned above, there are 6,000 African aquatic macrophytes present in the herbarium of the Meise Botanic Garden and at least 12 in the herbarium of Yangambi. Although Yangambi was in the past the most important herbarium in Central Africa, the herbarium of the University of Nairobi (NAI) (Kenya), founded in 1961, houses ca. 300,000 specimens (Index Herbariorum, 2023), and currently holds the largest number of specimens for tropical Africa. It is one of the three officially recognised herbaria of Kenya and most of its specimens were collected in the country itself. The herbarium of the Makarere University in Uganda (MHU) and the herbarium of the University of Dar es Salaam in Tanzania (DSM) with 95,000 and 75,000 specimens respectively, follow in importance based on the number of specimens in their collections. Compared to Kenya, there are more herbaria present in Tanzania (7), while Uganda with four herbaria is in the same range (Index Herbariorum, 2023).

Table 2. Herbarium collections in DR Congo, Burundi and Rwanda with numbers of herbarium specimens present according to the Index Herbariorum (2023) or updated according to information from several projects of the Meise Botanic Garden. Numbers in italics are the digitized specimens according to Leliaert et al. (in press).

Herbarium code	Institution	Location	Number of specimens
EBV	Laboratoire de Biologie Générale et de Botanique	Lubumbashi	inactive
IUK	Université de Kinshasa	Kinshasa	ca. 29,000 *3,157*
YBI	Institut National pour l'Étude et la Recherche Agronomique	Yangambi	ca. 150,000 *11,723*
KIS	Université de Kisangani	Kisangani	ca. 10,000
EALA	Jardin Botanique d'Eala	Mbandaka	ca. 7,000 *17*
KIP	Institut National pour l'Etude et la Recherche Agronomique	Kipopo, Lubumbashi	ca. 25,000 *1,434*
EPU	Centre de Formation et de Recherche en Conservation Forestière	Epulu	ca. 12,000 *190*
LWI	Centre de Recherche en Sciences Naturelles (CRSN/Lwiro)	Lwiro	ca. 15,000 *2,891*
LUKI	Institut National pour l'Etude et la Recherche Agronomiques	Boma	ca. 12,000 *329*
MLGU	Insitut National pour l'Etude et la Recherche Agronomiques	Bukavu	ca. 10,000 *618*
KISA	Institut Congolais pour la Conservation de la Nature	Kisantu	ca. 7,900 *184*
LSHI	Université de Lubumbashi	Lubumbashi	ca. 20,550 *1,021*
HNYUOB	Université Officielle de Bukavu	Bukavu	ca. 2,200
BJA	University of Burundi	Bujumbura	ca. 20,000 *3,000*
NHR	University of Rwanda	Huye (Butare)	ca. 20,000
DFGFI	Diane Fossey Gorilla Fund International	Musanze	ca. 1,100

Of the thirteen herbaria officially recognised in D.R. Congo (Table 2), Yangambi is by far the most important, followed by the herbarium of the University of Kinshasa, the herbarium of Kipopo and the herbarium of the University of Lubumbashi. A limited number of the specimens have been digitised so far among others in the frame of the Global Plant Initiative project, and available on JSTOR Global Plants (Table 2; Leliaert et al., in press). We can mention here that in Rwanda, with a herbarium with more than 20,000 specimens, there is a potential to study the diatom diversity of its water bodies in the past and a possibility of using it as a reference for current and future water quality research.

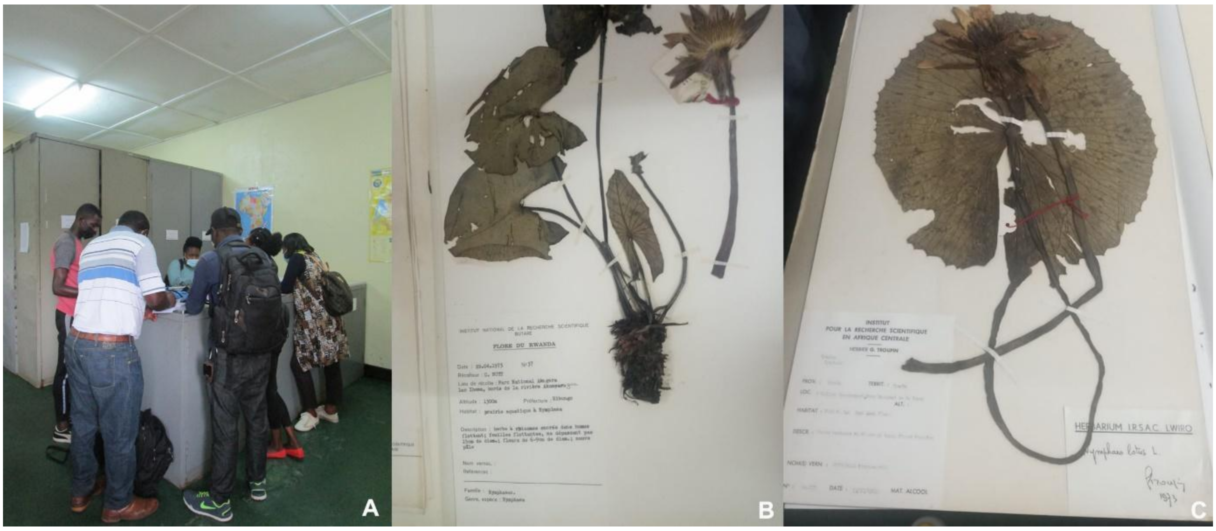

Fig. 6. National Herbarium of Rwanda housed in the University of Rwanda (NHR) in Huye. A. Students working in the herbarium. B: Mounted specimens of *Nymphaea* sp. collected by C. Nuyt in 1973 on the banks of the Akagera river in the Akagera National Park C : *Nymphaea lotus*. collected by G Troupin in 1967, double from the herbarium of Lwiro (LWI). (C, D: image courtesy of Yvonne Bigengimana)

Although we have no idea of the number of aquatic macrophytes present in the herbaria, there is certainly potential to collect diatoms on herbarium specimens in most of these herbaria. In Rwanda, for example, several aquatic macrophytes were found in the collections of the National Herbarium of Rwanda (Fig. 6 B, C). Young scientists there were given a demonstration of collecting epiphytic diatoms on herbarium specimens at this herbarium located at Huye (formerly Butare) (Fig. 6 A).

It is strongly recommended to continue collecting aquatic plants, even common species such as *Nymphaea*, especially in countries where determination of water quality is still quasi non-existent or at an early stage. These newly collected plants could potentially play an important role in the future and be used as a reference when monitoring changes in water quality based on the epiphytic diatom community present. An important condition, however, is that the collected plants are well documented and the exact location is given using geographical coordinates.

Conclusions

There is huge potential in herbaria worldwide to possibly serve as reference material for current and future diatom based water quality research. Especially for countries where diatom research is lacking or has been very limited in the past.

However, there are some drawbacks with such research. Such as the small area that can only be sampled to avoid damaging the herbarium specimen. We have no idea of the colonisation stage of the diatoms on the aquatic plant at the time of collection. Only a limited number of herbarium specimens are available from aquatic plants in the herbaria. Moreover, the herbarium specimens are not always in good condition, such as eaten by insects, mouldy due to high humidity, etc. Especially in the tropics, this is a big problem.

But there are significant advantages: Ability to go back in time when classical sampling for diatom surveys is not available. Information on diatom species richness for areas and countries where such data are lacking. A huge amount of material is available for taxonomic diatom research. Moreover, and not unimportant, herbaria in developing countries are accessible to local researchers without having to travel north.

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