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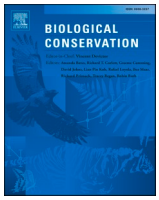

Perspective

Enhancing scientific and community capacity to conserve Central African Lepidoptera

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ABSTRACT

Research on the ecology and conservation of Lepidoptera (and other species) has historically neglected tropical diversity – but the Lepidoptera of tropical Africa have been particularly understudied. Central Africa represents a major centre of biodiversity for butterflies, moths and other taxa but major threats including habitat loss, habitat degradation/ disturbance and climate change are threatening their persistence. Additionally, a range of obstacles to research and conservation are apparent in Central Africa, including major socioeconomic disparity, persistent armed conflicts, corruption, and a lack of local resources (e.g., funding and museums). Here we outline the history of research on the butterflies of Central Africa and highlight the importance of further conservation efforts in maintaining the biodiversity of Lepidoptera and other understudied insects in the region. Proactive measures acknowledging the prevailing regional challenges must be taken immediately. Among the major recommendations, we suggest: 1) enhancing museum collections, 2) facilitating strong scientific collaboration that enhances local capacity, 3) ensuring that funded projects are not disrupted by corruption, and 4) working to advance the socioeconomic status of local communities. Potential for scientific and community advancement in the region is substantial if investment and research efforts are targeted effectively.

1. Introduction

Located in the Afrotropics, Central (or Middle) Africa covers the following 9 countries: Angola, Cameroon, Chad, Equatorial Guinea, Gabon, Central African Republic, the Republic of Congo, Sao Tome and Principe, and the Democratic Republic of Congo (www.unstats.un.org/unsd/methodology/m49/; accessed 16/09/2022). These countries together total over 5.5 million km^2 inland area representing about 28 % of the total land of the Afrotropical region. Central Africa harbors important biodiversity hotspots recognized worldwide (www.iucn.org/our-work/biodiversity; accessed 16/09/2022). For example, the Congo Basin represents the planet's second-largest rainforest block after Amazonia. The region is characterized by an incredible diversity of ecological systems ranging from tropical moist forest, dry forest, montane forest, coastal forests, savanna, steppes and mangroves. For these reasons, animal diversity in Central Africa is among the most important in the world and is represented by an exceptional diversity of vertebrate species (e.g., mammals, birds, and amphibians; Jenkins et al., 2013). While considerable attention has been given to studies and conservation of the diversity of vertebrate species, much less attention by comparison, has been given to the diversity and conservation of invertebrates in the Congo Basin.

Lepidopteran species represent one of the best-studied insect taxa globally, but major gaps exist between the diversity of species in the tropics, relative to the level of scientific research (Bonebrake et al., 2010). The highly diverse butterflies and moths of Central Africa are particularly understudied. Of the total 4000 butterfly (www.lepsocafrica.org) and 9000 moth species (www.afromoths.net) described in the Afrotropics, Central African countries account for more than 50 % of this diversity. Cameroon for example has approximately 1600 butterfly species and more than 3000 moth species (Williams, 2018; Delabye et al., 2020; Sáfián, 2022; De Prins and De Prins, 2022), amounting to about 40 % of the total butterflies and 30 % of the total moths known in the Afrotropics (Fig. 1). These estimates of diversity also very likely underestimates of the total diversity of Lepidoptera in Central Africa.

Research on Lepidoptera (and other insects) in Central Africa is limited by a number of substantial challenges. First, the dearth of baseline surveys and data does not encourage nor facilitate more

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surveys, resulting in a cycle that generates little data. Second, the majority of surveys that have been conducted are mostly in the lowland and mid-altitude tropical moist forests of the Central African countries. While the tropical moist forests, with their high diversity, dominate the ecosystem of the region, other biomes such as savanna, steppes and montane habitats have been poorly investigated (Tropek and Konvicka, 2010). Third, few investigations have addressed molecular, evolutionary and taxonomic aspects of Central African Lepidoptera. These components are particularly important given the complexity of cryptic species and seasonal forms that are especially common in this group and region (McBride et al., 2009; Aduse-Poku et al., 2017).

The concerning reality for lepidopteran insects of Central Africa is that, while their diversity remains poorly understood, anthropogenic threats continue to mount and likely threaten the persistence of species in the region. Implementation of national and international conservation programmes across Central Africa began in the 1960s, during the period of independence for most of the countries in the region. Many protected areas have been created with the implementation of a variety of conservation programmes, primarily targeting charismatic, highly visible and popular vertebrates such as elephants, lions, chimpanzees, gorillas and some bird species. In contrast, very few or almost no conservation programmes have targeted insects. The vast majority of research on Lepidoptera in these countries has generally focused on species of agricultural relevance (reviewed in Ouaba et al., 2022) such as the fall armyworm *Spodoptera frugiperda* (see Goergen et al., 2016; Fotso et al., 2019), the maize stem borer *Busseola fusca* (Kankonda et al., 2014; Calatayud et al., 2014), and the tomato leaf miner *Tuta absoluta* (Mukwa et al., 2021).

Although information on the conservation status of Lepidoptera species in the region is available, it remains insufficient regarding the richness and diversity of its species compared with other regions of the world with relatively low diversity. For example, of the 1565 Lepidoptera species listed within the IUCN Red List of threatened species with different status levels recorded worldwide, 367 species are recorded in Central Africa, with 95 %, 4.4 % and 0.3 % listed as least concern, data deficient and near threatened status respectively (IUCN, 2022). In addition to low coverage of status assessment, these proportions very likely reflect a lack of updated conservation data rather than an absence of endangered species.

Africa is experiencing large growth in human population size, accompanied by expansion of agricultural activities (for food security and economic growth), urbanization, industrialization and changing land use (www.worldbank.org; accessed 16/09/2022), which together with other threats to biodiversity, including climate change (Ludwig et al., 2013) are ever present in Central Africa. For Lepidoptera in the region, the challenge is how to fill massive knowledge gaps and simultaneously develop conservation strategies with limited data. Here, we first present a broad overview of research on Lepidoptera in Central Africa and detail threats to their conservation for context (but note that our review is not systematic nor exhaustive). We then highlight the scope of challenges to conservation and outline recommendations for moving forward to better understand the Lepidoptera in Central Africa and best conserve them – though our perspective here is Lepidoptera focused, the recommendations also have broad relevance to other taxa in the region.

2. Current knowledge of Lepidoptera in Central Africa

While knowledge of Lepidoptera in Central Africa is limited, there is more on the subject than can possibly be covered in one paper. This is not an exhaustive nor systematic review. Instead, we here highlight the history and progress of this work and use key case studies as examples.

The first published studies of Lepidoptera of Central Africa were from the colonial period. The species collected and described scientifically in the region were first conducted by European scientists or citizens such as traders, priests, and shippers that had a strong passion for butterflies and/or moths. Papers were published in scientific journals and typically in the language of respective colonial countries. For example, the first papers describing butterfly species in Cameroon were published in German, during Germany's colonial period starting in 1860 and ending in 1916. Similar trends are apparent in other countries of Central Africa; early papers on Lepidoptera in Gabon, Central African Republic, Chad,

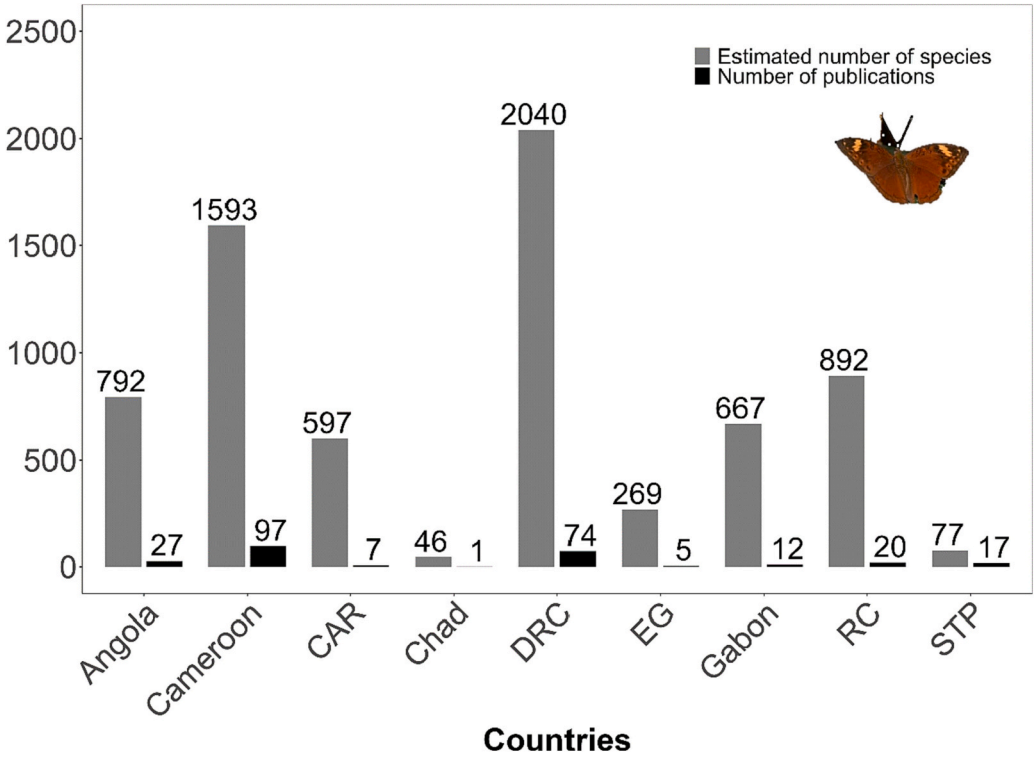

Fig. 1. Estimated number of butterfly species and the associated total number of publications in each Central African country. Data on species richness and literature available in each country were obtained from the African Butterfly Database website (www.abdb.org). The African Butterfly Database contains an updated list of all the butterfly species and bibliography related to the Afrotropical region (Sáfián, 2022). The names of the countries were entered in different languages (French, German, English, Portuguese, and Spanish) into the database as many papers are published using those languages. Other terms like "Belgian Congo", "Congo Belge", "Congo Brazaville" were also used to differentiate between the Democratic Republic of Congo and the Republic of Congo. CAR = Central African Republic; DRC = Democratic Republic of Congo; EG = Equatorial Guinea; RC = Republic of Congo; STP = Sao Tome & Principe.

the Republic of Congo and the Belgian Congo (now the Democratic Republic of Congo) were published in French in entomological society journals of both France and Belgium, representing the colonial power of these countries at that time.

Overall, basic knowledge on Lepidoptera in Central Africa during the colonial period represents a literature dominated by descriptive and taxonomic studies. The oldest paper on the subject in the region was likely published by Latreille and Godart (1819), who reported the presence of *Colotis euippe* and described *Acraea parrhesia servona* in Angola. Following that, Mabille (1877) published the first catalogue on the butterflies of the Republic of Congo. Similarly, Plotz (1880) collected butterflies in the highland region of Cameroon for the first time while Druce (1905) published the oldest paper on Lepidoptera in the Belgian Congo describing new diurnal species. However, one of the most important documentations on Lepidoptera in Central African countries (and other regions) was *Macrolepidoptera of the World* by Seitz (1913, 1925, 1929, 1930). These volumes provided baseline information on the bioecology and the taxonomy of many groups and are still used now by modern lepidopterists.

Many other books were later published on the Lepidoptera of Africa, including those of Central Africa. Examples include Ackery et al. (1995) who published and updated a catalogue on Papilionidae and Hespeioidea of the Afrotropical region, and a recent publication by Hacker (2019) on the systematics of moths in Africa. In the decades between 1960 and 1980, most central African countries became independent (1960 for most except for Equatorial Guinea in 1968, Angola and São Tomé and Príncipe in 1975). Many state universities were then created with entomology as a discipline which led to an emergence of local entomologists trained by already-established European experts. For example, most entomological works carried out and implemented at the University of Yaoundé in Cameroon after independence from France were carried out by Jean-Louis Amiet and Michel Libert, both French entomologists who conducted research in Cameroon for over 20 years, starting in 1963. They established the first zoological laboratory of the University of Yaoundé and conducted numerous studies on the ecology of a variety of taxonomic groups (Libert, 1991; Libert, 1994a, 1994b; Libert, 1996; Amiet, 1998a, 1998b, 2003, 2004; Amiet and Libert, 1995; Amiet and Achoundong, 1996; Amiet et al., 2000). Similarly, Joseph Bequaert, a naturalised American-Belgian, was the first entomologist of the colonial government of the Belgian Congo in 1910, where he spent seven years.

In the past two decades many other lepidopterists have conducted (and still continue to conduct) numerous studies in Central Africa with important contributions to the knowledge of the group, especially taxonomically. Steve Collins and Szabolcs Sáfián have led numerous taxonomic works on the butterflies of Central Africa (Collins, 1998; Collins and Larsen, 2013; Collins and Sáfián, 2014; Sáfián et al., 2015, 2021). Other authors such as Tomasz Pryrz have also substantially contributed to the study of taxonomy of butterflies in Sao Tome and Principe (Pyrcz, 1991a, 1991b, 1991c) while Robert Tropek, Vincent Maicher and others have been intensively investigating the taxonomy, pollination activities and the diversity of Lepidoptera found on Mount Cameroon during the past fifteen years (Maicher et al., 2016, 2019, 2020).

Despite the long history of Lepidoptera research in Central Africa, there exists strikingly few studies on their ecology, evolution and conservation. We conducted a literature search in the African Butterfly Database (www.abdb-africa.org) to explore the number of species and that of publications related to butterflies in each of the Central African countries. We found only 5 publications available for the approximately 600 butterfly species in Central African Republic, and 20 publications relative to the nearly 900 species in the Republic of Congo (Fig. 1). Moreover, if we consider the year 1990 to present, the number of books on Lepidoptera in Central Africa was more prolific during the colonial and postcolonial (1960–1990) periods than during the recent period (1990 to date), a clear illustration of the poor interest (or capacity) of local entomologists in Lepidoptera conservation (Table 1). As a result, only few recent books describing the diversity and the ecological characteristics of Lepidoptera in the region are available. A few examples of these books include the Butterflies of Gabon ("Les papillons du Gabon") written by Weghe (2010), Fauna of the United Republic of Cameroon: the Genus *Charaxes* Ochs. by Darge (1983), and Les papillons du Zaire (actual Democratic Republic of Congo) published by Berger (1981), and a few species from the Korup National Park in Cameroon were covered by Larsen (2005) in the Butterflies of West Africa.

While the available information on Lepidoptera diversity is small compared to their diversity, other sources of documentation on the Central Africa Lepidoptera are available ranging from formal scientific publications by experts to online platforms such as social media and mobile applications administered either by expert Lepidopterists, amateurs or citizens scientists. Obviously, with the current facilities offered by internet access, online platforms have been created where information on given species of Lepidoptera of the Afrotropical region can be found. Two of these websites are well-known and dedicated to African Lepidoptera: the African butterflies database www.abdb-africa.org (Sáfián, 2022), and the Afromoths database www.afromoths.net (De Prins & De Prins, 2022). Additionally, there are many pages or personal blogs on social media where Lepidoptera activities are promoted such as the "Caterpillar Rearing Group – Africa", "African Butterflies and Moths", two Facebook pages well known as sources of information about butterflies and moths of Africa, shared frequently by scientists and amateurs. Moreover, there are other online sources that describe biodiversity more globally and where some specimens from Central Africa are available. Examples of such platforms include the Global Biodiversity Information Facility (GBIF), species 2000 database www.sp2000.org, iNaturalist, and many others (Table 1).

3. Threats to Lepidoptera fauna in Central Africa

Like other species, Lepidoptera are facing serious threats in the Afrotropical region. In Central Africa, these threats include habitat loss, degradation and fragmentation as the result of deforestation, effects of ongoing climate change and potentially the collection of a few charismatic species. Habitat loss and degradation are the most immediate and significant threats to the persistence of these species but other threats (e.g. climate change, overharvesting, fire, pesticides and invasive species) loom significantly and require attention and vigilance.

3.1. Habitat loss and degradation

Deforestation rates in Central African countries have increased during the past two decades (Duveiller et al., 2008; Aleman et al., 2018). This is mostly the result of intensification of intercontinental timber trade, but also due to forest conversion into agricultural land – both intensive and subsistence – for local population and mining projects that have recently intensified. For example, between 2001 and 2021, Cameroon, Democratic Republic of Congo, and Central African Republic have respectively lost 4.2 %, 5.6 % and 2.6 % of their forests, increasing to 48 %, 35 % and 22 % in total respectively (www.globalforestwatch.org; accessed on: 20/08/2022). While intact forest landscapes (IFL) still persist in large areas in Central Africa, the region has also seen the highest rates of loss in IFL in the early 21st century (Fig. 2, Potapov et al., 2016).

Although most of the deforestation concerns lowland forests, recent studies have also highlighted the loss and degradation of montane and submontane forests during the past decades (Bergl et al., 2007). Due to the unique climate and history (volcanic activity) of these habitats, highlands are known to be important diversity hotspots with high endemism (Tropek and Konvicka, 2010). Habitat loss and degradation in the Bamenda highlands, for example, is the consequence of the high human population density around the region combined with very few conservation initiatives and protected areas (Bergl et al., 2007; Cronin

Table 1
Overview of books and online sources on Lepidoptera of Central Africa.

Authors	Title	Year	Type of source	Taxa	Region/Country
Ghesquiere	Lépidoptères, Microlépidoptères (première partie)	1940	Book	Moths	Central Africa
Ghesquiere	Lépidoptères, Microlépidoptères (première partie)	1942	Book	Moths	Central Africa
Berger	Lépidoptères, Rhopalocères. I. Papililnidae	1950	Book	Butterflies	Central Africa
Overlaet	Formes nouvelles ou peu connues des Nymphalydes africains	1952	Book	Butterflies	Central Africa
Kiriakoff	Les Thyretidae du Musée royal du Congo Belge (Lepidoptera Notodontidae)	1953	Book	Moths	Central Africa
Stempffer	Contribution à l'étude des Laecenidae de l'Afrique équatoriale	1954	Book	Butterflies	Central Africa
Kiriakoff	Les Notodontidae Africains (Lepidoptera Notodontidae) Desmeocraera et genres voisins	1958	Book	Moths	Central Africa
Collenette	New and little-known Lymantriidae from the Belgian Congo (Lepidoptera Heterocera)	1960	Book	Moths	Democratic Republic of Congo
Kiriakoff	Notodontidae africains nouveaux	1962	Book	Moths	Central Africa
László Gozmány	The Tineid moths of the Royal Museum of Central Africa, Tervuren, Belgium (Lepidoptera Tineidae)	1967	Book	Moths	Central Africa
Ugo Dall'Asta, Jurate de Prins and Willy de Prins	Preliminary checklist of Gracillariidae of the Afrrotropical region (Lepidoptera)	2001	Book	Moths	Afrotropical (Including central Africa)
Dall'Asta and De Prins	Collections of the Royal Museum of Central Africa: Butterflies and Moths	2006	Book	Butterflies and Moths	Sub-Saharan Africa (Including central Africa)
Gaelle vande Weghe	Les papillons du Gabon	2009	Book	Butterflies	Gabon
Philippe Barge	Faune de la République Unie du Cameroun, volume 1: Le genre *Charaxes* Ochs.	1983	Book	Butterflies	Cameroon
Berger	Les papillons du Zaire	1981	Book	Butterflies	Zaire (actual Democratic Republic of Congo)
The Lepidopterists' Society of Africa	www.lepsoafrica.org	2022	website	Butterflies and moths	Africa (Including central Africa)
Sáfián et al.	www.abdb-africa.org	2022	website	Butterflies	Africa (including central Africa)
De Prins J. & De Prins W	http://www.afromoths.net	2011	website	Moths	Africa (Including central Africa)
The Lepidopterists' Society of Africa	Caterpillar rearing group	2012	Facebook page	Butterflies and moths	Africa (Including central Africa)
Citizen scientists	www.flickr.com	2022	website	Butterflies and moths	World (Including central Africa)
Citizen scientists	www.inaturalist.org	2022	Website and phone application	Butterflies and moths	World (Including central Africa)
The Lepidopterists' Society of Africa	African Butterflies and Moths	2022	Facebook page	Butterflies and moths	Africa (Including central Africa)
GBIF Secretariat	www.gbif.org	2001	Website	Butterflies and moths	World (Including central Africa)

et al., 2014). Such examples can be extended to other landscape like savanna that are subjected to profound changes – bush fires - drive by human activities (Klop and van Goethem, 2008).

Few studies have investigated the consequences of habitat loss and fragmentation on Lepidoptera at the regional level. To our knowledge, such studies have been conducted only in Cameroon (Stork et al., 2003; Bobo et al., 2006; Ferenc et al., 2018; Maicher et al., 2020) and in the Democratic Republic of Congo (Nkongolo and Bapeamoni, 2018). In West Africa, Larsen (2008) highlighted the surprising lack of extinction of forest butterflies despite high levels of deforestation – a positive note of conservation optimism but also acknowledging possible extinction debt and rising deforestation which could change this outcome. Quantifying the effects of these changes on populations of Lepidoptera in Central Africa will be one of the major steps for future conservation in the region.

Even when forests are not lost entirely, disturbance and fragmentation are major forces that drive changes in tropical Lepidoptera. For example, primary (or near primary) forests harbour greater diversity of range-restricted butterflies (and therefore higher uniqueness) relative to forest remnants and secondary forest (Bobo et al., 2006). Interestingly, Maicher et al. (2020) also found that forest sites without elephants also had fewer range-restricted butterflies. Thus, forests must be protected, but so too must the diverse communities (including vertebrates!) and ecosystem processes within those forests be maintained for effective conservation.

3.2. Climate change

Another important threat to Lepidoptera in Central Africa - and the rest of the world - is climate change. According to the 6th IPCC report, the rate of temperature increase is rapid in Africa compared with the global average (IPCC, 2021). The projected mean temperature rise in Central Africa is expected to vary between 1.5 and 4 °C by the end of the 21st century (IPCC, 2021). Insect responses to warming are likely to include a variety of range shifts, community restructuring, and changes in physiological traits (Boggs, 2016). Tropical insects are particularly likely to be vulnerable to warming impacts, given temperatures close to thermal maxima and adaptation to narrower ranges of temperature (Deutsch et al., 2008).

Habitat and climate change interactions will also structure warming responses. For example, Dongmo et al. (2021) found that for *Bicyclus dorothea* reared under laboratory conditions, upper and lower thermal limits of the butterflies are habitat dependent – forest population were more climate-sensitive compared with their ecotone (savanna-forest mosaic) counterparts. In general, forest ectotherms tend to have lower tolerance to warming than open species (Frishkoff et al., 2016; Murray et al., 2021). Given that Central Africa is dominated by tropical rainforest characterized by low climatic variation, Lepidoptera in Central Africa may be particularly vulnerable to future warming.

Temperature rise is not the only climate component that will affect Lepidoptera populations. Most Lepidoptera species depend on host plants on which the immature stages (or adults in some cases) feed. The availability of these plants also depends on the amount of rainfall

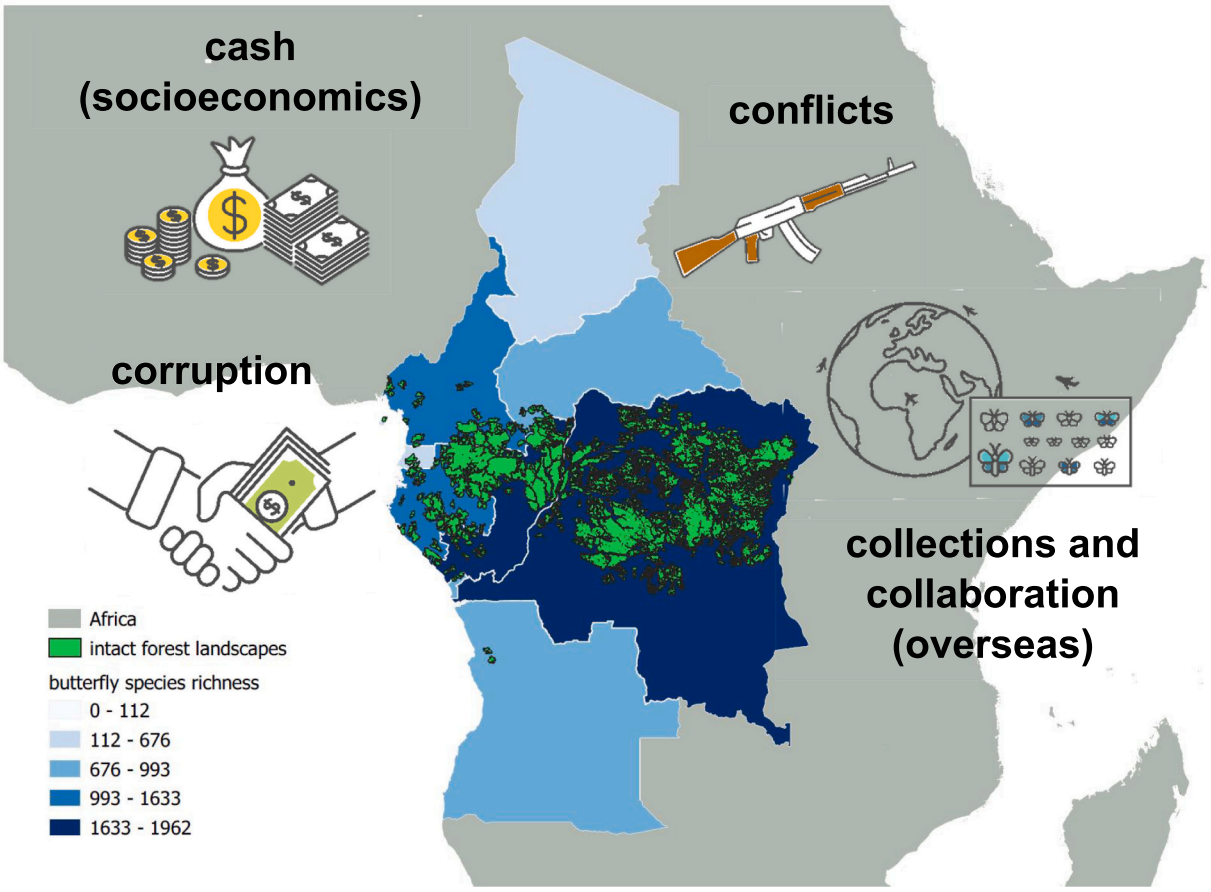

Fig. 2. Major challenges persist for Lepidoptera conservation in Central Africa despite high species diversity (data from Pinkert et al., 2022) and remaining high levels of intact forest landscapes (data from Potapov et al., 2016). Icon illustrations by Kelly Shiu.

(Valtonen et al., 2013; Barton et al., 2019). Precipitation is one of the climate components which also varies because of climate change. Its absence (or perturbation) can drive consequences in the life cycle of many lepidopteran species and is likely behind recent perceived declines in tropical insects (Janzen and Hallwachs, 2019). Such non-temperature related consequences of climate change may be the most important and are also the most difficult to anticipate.

3.3. Overharvesting – edible caterpillars

For many decades, insects have been considered an important source of protein in Africa with more than 500 species recognized as targets for consumption. Among edible insects in Central Africa, Lepidoptera (mostly moth caterpillars) represents the most important group (Kelemu et al., 2015). They are used as an excellent source of proteins and micronutrients but also provide a key source of income for many families in rural areas (Latham, 2005; Meutchieye et al., 2016; Mabossy-Mobouna et al., 2022). About 130 known species of edible caterpillars are consumed in Africa, among which many are found in Central Africa. Generally, edible caterpillars belong to the families Saturniidae, Noctuidae and Notodontidae.

Although Lepidoptera, like many other insects, have high reproductive potential, their consumption by humans can still lead to the decrease of their population over time for at least three reasons: 1) overharvesting: important quantities of almost all edible caterpillars are periodically harvested (generally between May and October) in the forest (Meutchieye et al., 2016) for trade in local markets or for household use. For example, a study conducted in the surrounding villages of Yaoundé (the capital city of Cameroon) revealed that vendors ($N = 32$) can trade up to 70,000 Kg of caterpillars yearly, generating about USD 163,000 in income (Ngute et al., 2019). This amount of money in low-income countries is likely to incite overharvesting of caterpillars with less concern for collection techniques or harvest timing; 2) very few initiatives of domestication of edible caterpillars have been attempted so far (DeFoliart, 1997, 1999); 3) host plants of many edible caterpillars are also threatened either by forest clearing for agricultural activities or for logging. Muvatsi et al. (2018) showed that selective logging of Sapelli (*Entandrophragma cylindricum*) and Tali (*Erythrophleum suaveolens*), the most important trees logged in Democratic Republic of Congo and host plant for caterpillars, had consequences for the quantities of yield in two species, *Imbrasia oyemensis* and *Cirina forda*. Although comprehensive data on the relationship between Lepidoptera consumption and their conservation in Africa is still scarce, some information indicates that the demand is growing (Bomolo et al., 2019; Ngute et al., 2019). Coupled with other threats, this will likely be an important factor affecting their availability (Muvatsi et al., 2021).

3.4. Other threats – fire, pesticides, and invasive species

Fires represent an important disturbance for the environment because they can damage composition, structure, functioning and dynamics of ecosystems by altering vegetation and the movement of animals in landscapes (Whelan, 1995). In Africa and elsewhere in the tropics, fires are intentionally used as slash and burn in agriculture and animal grazing. Whether natural or induced by humans, fires are becoming more frequent and represent a threat to biodiversity - especially insects (McCullough et al., 1998; New, 2014; Koltz et al., 2018). Although no study has investigated the role of fires on Lepidoptera conservation in Central Africa, many other studies have shown that species richness and abundance generally decline following fires

(Tyukavina et al., 2018). Indeed, the high temperatures of fires will lead to direct mass mortality of immature stages (eggs, larvae and pupae) and adults or will force emigration to safer areas.

Pesticides (mainly insecticides) have been used effectively in pest control in agriculture and medicine, but often have harmful effects on non-target species, as has been demonstrated by many studies, with impacts varying from toxicity to the reduction of species richness and abundance (Feber et al., 1997; Gilburn et al., 2015). There is, therefore, an inherent conflict with the use of pesticides, particularly for Lepidoptera species that need conservation actions while a large number of agricultural pests are in fact moth species. To our knowledge, no studies have assessed the impact of the use of pesticides on Lepidoptera conservation at the regional level of Central Africa. However, studies conducted in other regions of the world have revealed that the use of pesticides can affect bioecological aspects of butterflies and moths in various ways (reviewed in Braak et al., 2018) and there is little reason to expect the situation would be different in the afrotropics.

How (or if) invasive species impact Lepidoptera communities in Central Africa is not known. A high diversity of invasive plants estimated throughout Central Africa however (Richardson et al., 2022) suggest that habitat disturbance through invasive species could be cause for concern. For example, *Lantana camara* has been shown to dominate plots and decrease woody plant diversity in Nigeria (Agaldo, 2020) – this plant is also known to decrease butterfly diversity in some of the locations it invades (e.g. India; Jambhekar and Isvaran, 2016). Further study on possible impacts of invasive species could lead to insights into habitat management or whether invasive species pose any substantial threat at all to afrotropical Lepidoptera.

4. Challenges for Lepidoptera conservation in Central Africa

Conservation actions and activities can by impeded by a range of factors at multiple spatial and temporal scales. For Lepidoptera in Central Africa, the major impediment to their conservation is the lack of baseline data or general information compounded by a scarcity in resources to either collect such data or introduce conservation measures. These realities are exacerbated by particular features of Central African conservation including the persistence of armed conflict in the region, a lack of scientific or museum infrastructure, socioeconomic forces, corruption coupled with the incompetence of some local authorities, access to funding, and scientific collaboration (Fig. 2).

4.1. Armed conflicts and political stability

Conservation biology - as a whole discipline - requires intense field work for data collection, field surveys and implementation of conservation actions as well as many other requirements. Scientists are required to travel within or out of their country of residence. These movements are conditioned on the safety of both the scientists and local people that play key roles in conducting research. Security and political stability are vital.

Security questions have been of crucial concern in some countries in Central Africa since their independence. For instance, during the period of 1975 to 2002, a long civil war occurred in Angola, representing a major constraint for Lepidoptera research in the country (Mendes et al., 2019). Many parts of the Democratic Republic of Congo and Central African Republic have been essentially entirely insecure for foreigners and even for local citizens. In other countries such as Cameroon and Chad, armed conflicts and banditry have intensified in the past decade. An illustration are the atrocities committed by Boko Haram, an Islamic radical group initially based in Nigeria. The group has been launching attacks since 2013 in villages of the far north region of Cameroon and in localities close to Lake Chad. During the same year, a political crisis led to the ousting of the president of the Central African Republic, causing complicated security concerns throughout the country. In 2016, Cameroon was confronted with another crisis where groups in the two English-speaking regions of the country have been fighting for cessation from Cameroon and establishment of their own state, causing an armed conflict between separatists' groups and governmental forces. Sadly, these conflicts have happened in regions covering important protected areas and landscapes, e.g., the national parks of Mount Cameroon, Korup and Takamanda. In the Democratic Republic of Congo, the emblematic Virunga National Park, the most biologically diverse protected area, is in north-eastern DRC where insecurity is, unfortunately, widespread.

4.2. Museum collections

Specimen preservation represents an important component of biological conservation. Preserved specimens in museums and natural history collections provide an essential resource for species identification, environmental education for students at universities and local Lepidopterists, and for ecological monitoring of species over time. However, despite the incredible insect (Lepidoptera) diversity in the whole afrotropical realm, there are very few museums specialized in collecting and preserving them, not only in Central Africa, but in the whole continent. A few examples include the collection of the African Butterfly Research Institute in Nairobi, Kenya (east Africa), an initiative of Steve Collins where butterfly specimens from many African countries can be found. In West Africa, there is also a collection of insects at the International Institute of Tropical Agriculture based in Cotonou, the capital city of the Republic of Benin. In Central Africa, there is no major insect collection representing the diversity of the given countries, though small collections existing in the region have never been a subject of detailed study.

In fact, the majority of preserved Lepidoptera (as with many other animals and plants) from the afrotropical region are stored in museums scattered mainly in overseas' countries. The most comprehensive Lepidopteran collections of many Central African countries are housed in the following museums: the Royal Museum for Central Africa in the city of Tervuren, Belgium (www.africamuseum.be) with the majority of about 470,000 Lepidoptera specimens originating from the Democratic Republic of Congo, Burundi and Rwanda; the *Institut Royal des Sciences Naturelles de Belgique* (www.naturalsciences.be), the *Museu de História Natural da Universidade do Porto* (www.mhnc.up.pt), the *Museu Nacional de História Natural e da Ciência* (www.museus.ulisboa.pt) in Portugal for specimens collected in Angola (Mendes et al., 2019), the *Museum National d'Histoire Naturelle* in Paris (www.mnhn.fr), the Natural History Museum of London (www.nhm.ac.uk), and the African Natural History Research Trust (www.anhrt.org.uk) in London, England. These examples do not represent an exhaustive list as there are many existing private collections with limited or no information available online and even in the literature. While these museums exist overseas and house Central African Lepidoptera, none of the Zoology/Biological Sciences Departments of regional universities possess a collection representing valuable preserved specimens, which would be beneficial for the training of local students on Lepidoptera bioecology. The same trend is observed with research institutions or NGOs with objectives dedicated to insect conservation.

4.3. Socioeconomic realities

In Central Africa, as in most countries in the Afrotropics, the rich biodiversity is unfortunately in total disequilibrium with economic wealth of local communities. Many communities, especially those close to protected areas, live in extremely poor conditions. This can lead to conflicts when the resources within protected areas are not freely accessible to the communities that have traditionally relied on the resources.

Although a lot of effort in conserving biodiversity has been spent so far under such circumstances, it is worth noting that these efforts have largely focused on charismatic mammals and bird species. Hence,

convincing local communities to conserve insects such as Lepidoptera might be harder as they do not realize the immediate financial benefits or do not give importance to insects. However, many Lepidopteran species are used to generate income; for instance, the locality of Ebogo in Cameroon is known to be home of many butterfly species that are collected by villagers and sold to people (mainly scientists and private collectors) around the world (author, per. Obs.). Similarly, edible caterpillars derived from diverse moth species are also an important source of revenue for local villagers and vendors located in the cities (Ngute et al., 2019; Meutchieye et al., 2016). For Lepidoptera conservation initiatives, socioeconomic aspects should be considered by showing their importance to local people and by involving them in any action engaged. Hence, besides the scientific interest, there is also strong need to make sure that local community benefits (economically) through their enrolment in the conservation of Lepidoptera. This can be done by empowering small-scale projects such as the domestication of edible caterpillars, and to hire and train some of them as citizen scientists that will help in engaging other members of the community in Lepidoptera conservation actions.

4.4. Corruption

Corruption is prevalent in many developing countries – including many African countries - and is likely one of the major problems limiting the development of economic sectors. Yet, developing countries are those harbouring the richest diversity hotspots on the globe and the high prevalence of corruption in those countries may pose serious challenges for conservation (Peh and Drori, 2010). This is because conservation as a discipline mostly relies on government institutions and their representative for a variety of purposes such as financial resourcing, law enforcement, research permits/ agreements, and political support. Unfortunately, these missions are often administered publicly where personnel have low salaries and are very susceptible to corruption acts such as bribery. Also, many conservation projects are externally funded in relation to local or private research institutions. These financial resources often have issues of embezzlement or inappropriate utilisation by individuals who have the capacity to abuse or corrupt the justice system. Furthermore, bureaucratic obstacles often represent an important barrier for NGOs (both regional and international) as well as scientists and students through the attribution of research permits by government authorities – these processes themselves are often the subject of corruption and the time require to obtain a permit can be delayed more than a year in some cases.

Another aspect limiting the effectiveness of insect conservation is the incompetence often observed in some local governmental authorities appointed to manage protected areas. Authorities are often limited by inadequate equipment and human capital to properly accomplish conservation missions. Some authorities simply don't have the training or capacity to implement effective conservation interventions. As a result, many protected areas are subjected to intensive anthropological activities such as charcoal production, selective logging, and wildlife trade under the ineffective supervision of authorities. A typical illustration of such consequences is highlighted in Ferenc et al. (2018) where authors showed how the mismanagement by government authorities of the Bimbia Bonadikombo community forest, a locality situated on a seashore in the South-West region of Cameroon led to human intervention within the forest which is actually prohibited. Consequently, the species richness and population abundance of butterflies within the community forest is two-fold less than that of the neighbouring study sites located within the Mont Cameroon National Park.

4.5. Access to funding and scientific collaboration

Access to funding remains a crucial concern in conservation biology. Unfortunately, as for many countries in the Afrotropical region, the importance of biodiversity is not in line with economic wealth. Central African countries are no exception. These countries have limited financial resources and, hence, will give top priority or allocate more money to other sectors such as education, public health, agriculture, or security, especially in the context of increasing political crisis. For this reason, many conservation actions in protected areas are often under the financial support of NGOs dedicated to the protection of biodiversity. Furthermore, regardless of the source of funding, low priorities for these activities mean that managers and administrators are rarely well supported (e.g. limited compensation or lack of training), leading to poorly managed protected areas or ineffective conservation measures. Moreover, countries with these financial limitations are not able to build functional natural history museums or to employ more entomologists within universities.

While the lack of funding is a major concern for Lepidopteran research in Central Africa, the redefinition or redirection of current scientific collaboration between international Lepidopterists and local ones (both professionals and students) can also be an important aspect in promoting conservation of biodiversity. From a global view of this collaboration, the first beneficiaries of collaborations are foreign scientists. This can be easily seen in the authorship of most papers published and through the Lepidopteran samples that are stored in museums outside of Central African countries rather than within. Moreover, important funding is mostly attributed to foreign scientists who will then redirect it to African counties for research.

We encourage funding research in Africa, but also strongly recommend direct funding to local principal investigators, not in the spirit of "helping African scientists" but with a real perspective of global science, aiming to effectively tackle questions related to conservation. Improving the situation can lead to an effective win-win collaboration where more local personnel – especially students – can be trained and be a part of conservation projects to avoid "helicopter" or "parachute" research (Asase et al., 2022). During the past decades, some fruitful scientific collaborations have been established between expert foreign Lepidopterists and students belonging to Central African universities. For example, researchers from Charles University of Prague have established a productive research collaboration with the Department of Zoology and Animal Physiology of the University of Buea in Cameroon and with Gabonese institutions (e.g., Maicher et al., 2016, 2019; Ustjuzhanin et al., 2018; Delabye et al., 2019).

Another key problem resides with the fact that Lepidoptera conservation is not of real interest to the majority of local entomologists; most have oriented their research topics on agricultural or medical entomology, leaving the vast majority of Lepidoptera unexplored. Showing great interest to conserve the Lepidoptera fauna is also important because, even if resources are available, without a manifested interest by local entomologists, nothing significant can be achieved. Finally, successful conservation of Lepidoptera cannot be done without the full commitment of local governments. There must be clear biodiversity conservation action plans driven by governments, not only for a few charismatic mammals, but for all groups. Such politics can encourage and implement the training of more committed entomologists/lepidopterists and build museums for insect collection.

5. Conservation actions and the future

To meet the challenges of conservation in Central Africa, specifically conflicts, cash, corruption, and collections (Fig. 2), it is necessary to develop holistic conservation actions alongside economic and political efforts. Critically, conservation solutions will only be effective when the socioeconomic status of communities improves. In this context, we propose two broad actions that represent simple but critical next steps for the conservation of Central African Lepidoptera: protect areas and protect species.

5.1. Protect areas

Lepidopteran species are generally herbivorous during the larval stage, while adult stages can feed on various food sources ranging from dung, carrion, and nectar to decaying fruits in the forest (Ford, 1945; Beck et al., 1999). All of these key points of their life history are closely related to their direct environment. Hence, one of the critical points of Lepidoptera conservation is the conservation of their habitat. Habitats of butterflies, moths and many other organisms can be conserved by the implementation and the proper management of protected areas. Data on Lepidoptera should be used in the design and monitoring of protected areas as implemented in other parts of Africa (e.g. Madagascar; Kremen et al., 1999).

This action can be extended by integrating cultural heritage and practices in villages into modern conservation practices. Sacred forests represent an excellent opportunity (Bossart et al., 2006; Shrestha et al., 2018). These are small forest patches of various types and size that are protected by village communities for religious and cultural reasons. A good example is that of localities situated in the Bamenda highlands of Cameroon where sacred forests have been used as a tool to promote and conserve different animal taxa (Poumie et al., 2021). The landscape there has been intensively altered for agricultural purposes. However, because of the strong consideration of the cultural activities and beliefs of the people, the sacred forests have been maintained as nearly intact despite the modification of the landscape during the past five decades. Although no studies have yet been carried out to understand the role of sacred forests in maintaining the biodiversity of Lepidoptera in Central Africa, these may serve as an important refugia for many species of butterflies and moths to escape from permanent threats created by agricultural activities such as slash and burn and the use of insecticides.

5.2. Protect species

The status of most butterflies and moths in Central Africa remains poorly known (IUCN red list), as is the case for Lepidopteran fauna in most countries of the world, especially tropical species. Multiple surveys are needed to document rare and new species. This task will likely not be done solely by expert lepidopterists; there is a need to train and involve local communities in those surveys to maximize specimen collection and effort. One effective means of training and data collection is the use of parataxonomists (community members trained to sort and identified taxa) as evidenced by its use in Gabon by Basset et al. (2008). Increasing usage of molecular tools to survey diversity (e.g. Delabye et al., 2019) will also accelerate our understanding of the fauna. Furthermore, the conservation status of many of Lepidopteran species used as food or sold by villagers to people around the world is still unknown; such surveys in collaboration with local community members can help.

One of the most important gaps in the conservation of Lepidopotera in Central Africa is the protection status of the majority of the species, which is simply the consequence of a lack of data. To fill this gap, there is an urgent need to conduct coordinated large-scale surveys, not limited to single countries, but at the whole sub-regional level. Such actions will require strong collaboration among local and international experts and will help in updating the protection status of species.

Although Lepidoptera collection is a necessity for scientific research, their commercial collection is becoming very popular in Central Africa and can pose serious threats to these taxa, especially for endemic species when the demand increases (Dinet, 2019). In many rural areas within the region, there exists a downstream business chain with important economic compensation between local butterfly hunters and buyers, which are generally located in foreign countries. Such trade can easily be found on social media where the buyers use specimens mostly for ornamental or for museum collection purposes. However, this trade is generally illegal and is not legislated by local laws of the countries. Clear monitoring and regulation (e.g., permitting pathways by governments) will ensure that trade does not result in the decline or extinction of charismatic species.

6. Conclusion

Despite the important diversity of Lepidoptera in Central Africa, there are still major knowledge gaps and actions that require significant attention, especially in the context of increasing multiple threats to global biodiversity. These gaps include: (1) basic knowledge on their ecology, (2) their conservation status and (3) their economic values. Though some interesting research efforts have been initiated by many Lepidopterists (mostly from overseas), it remains obvious that this has still not benefitted the local scientific community or local communities. A typical illustration of the situation is the lack of major insect collections or museums in any of the Central African countries.

Globally, the conservation of Lepidoptera in the region is still poorly understood for the following reasons: 1) the lack of interest and commitment in conservation goals, design and policies by local government ministries in charge of wildlife management as well as the lack of thematic research on Lepidoptera by entomologists of local universities; 2) conservation programmes of international NGO's implemented in all regional countries tend not to include insects (including Lepidoptera) in their management strategies; 3) lack of funding remains a key factor making conservation action very difficult; 4) unfair international collaboration between foreign lepidopterists and local scientists which needs to be redefined in a win-win context; and 5) security and political stability remains a serious constraint to consider for field work in those countries. These are problems that require the attention of all lepidopterists and governmental engagements to address the issue in a more global way, not only in an isolated country but in the entire region. We are hopeful that concrete steps can be made to reverse these trends and to create equitable conservation solutions for the environments and the people of Central Africa.

CRediT authorship contribution statement

Michel A.K. Dongmo: Conceptualization, Writing – original draft, Writing – review & editing, Visualization. **Rachid Hanna:** Writing – review & editing, Funding acquisition. **Timothy C. Bonebrake:** Conceptualization, Writing – review & editing, Visualization, Funding acquisition, Supervision.

Declaration of competing interest

The authors declare no conflicts of interest.

Data availability

No data was used for the research described in the article.

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Submission declaration

This work described has not been published previously, is not under consideration for publication elsewhere. Its publication is approved by all authors and if accepted, it will not be published elsewhere in the same form, in English or in any other language, including electronically without the written consent of the copyright-holder.

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