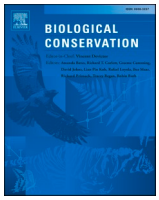
Biological Conservation 283 (2023) 110101

Contents lists available at ScienceDirect

Biological Conservation

journal homepage: www.elsevier.com/locate/biocon



Systematic review

Systematic review of bushmeat surveys in the tropical African rainforest and recommendations for best scientific practices: A matter of protocol, scale and reporting

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ARTICLE INFO

Keywords:
Africa
Bushmeat trade
Survey methodology
Systematic review

ABSTRACT

The bushmeat trade in tropical African rainforests is a pressing, multi-scale and multifaceted conservation issue. In order for bushmeat surveys to capture the complex dynamics of the trade and ultimately, its sustainability, there is a need for scale-adapted survey design and adequate reporting of results. We performed a systematic review of bushmeat survey methodology published in scientific literature from 1983 to 2021, with a focus on conservation biology articles reporting quantifiable data on the bushmeat trade (148 articles). Studies were predominantly biodiversity-oriented, whereas fewer focused on economics, modelling sustainability and conservation policy. Bushmeat survey efforts were mostly North-driven and biased towards high GDP African countries. Surveys generally suffered from narrow spatiotemporal design and limited market.day efforts, and consistently omitted intermediary wholesalers from the commodity chains. Species identification was mostly based on indirect approaches (interviews) and when combined with direct observations, failed to report the taxonomic reference used. We observed blatant gaps in reporting on survey efforts, species numbers and volumes, and conservation status. The number of surveyed species – highly biased towards mammals – was generally low, the proportion of unidentified species was high in turtles and amphibians, and the implementation of DNA-typing has remained anecdotal. Lack of rigor in reporting and weaknesses in survey design globally challenge the repeatability of the bushmeat surveys conducted in tropical African rainforests and their ability to question the sustainability of the trade. Updating and harmonizing bushmeat surveys through regional monitoring systems may be key to a better diffusion of bushmeat trade issues into state agendas.

1. Introduction

The illegal wildlife trade is a major issue for global conservation, with an estimated 100 million organisms traded annually, comprising around 6000 species (Harfoot et al., 2018; UNODC, 2020), and with a yearly global value of US$7–23 billion (Coad et al., 2019). The bushmeat trade – i.e., the trade of wildlife species hunted for human consumption and use (Nielsen et al., 2017) – is a significant contributor to such offtakes. As well as posing threats to public health (Fa et al., 2019), the bushmeat trade seriously threatens the conservation of tropical biodiversity (Nasi et al., 2011), contributing to wildlife declines, with knock-on effects on ecosystem functioning and services (Effiom et al., 2013; Ripple et al., 2016).

West and central African rainforests are a particular hotspot for the trade, where bushmeat has traditionally been a vital source of protein and income for rural communities (Chausson et al., 2019; Ingram et al., 2021). Struggling economies, increasing demand from growing urban centres and advances in hunting methods have shifted the bushmeat trade into a lucrative, national and international trade that now supplies large urban markets across tropical Africa (Ingram et al., 2019). In West and central Africa, offtakes have reached unsustainable rates, with an estimated 5 million tonnes of game – mostly mammals – harvested from rainforests annually (van Vliet et al., 2011). Given that tropical Africa is home to the second largest extent of rainforest in the world (Somorin et al., 2012), it is likely that such unsustainable trade – sometimes coined the "bushmeat crisis" (Bennett et al., 2002) – is contributing to

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https://doi.org/10.1016/j.biocon.2023.110101
Received 11 November 2022; Received in revised form 24 February 2023; Accepted 24 April 2023

the Holocene extinction (Ripple et al., 2016).

The bushmeat trade in tropical Africa is a challenging conservation issue for scientists to address; multi-scale and multifaceted in nature, and spanning several disciplines (Blair et al., 2017; Bowen-Jones et al., 2003; Salafsky et al., 2002). As conservation biology is action-oriented (Knight et al., 2006), bushmeat surveys must adopt strategies and methodologies that will allow for the efficient reporting of their results and conclusions, and full capture of the trade scale. A considerable number of scientific studies have been published on the nature and context of the trade, which include accounts of species offtakes and consumption. However, the ability of such studies to assess the sustainability of the bushmeat trade remains limited (van Vliet et al., 2011). This is largely due to the general lack of long-term temporal surveys in bushmeat market places, the absence of or weak circumscription of the areas sourcing the markets, the taxonomic bias towards mammals, the non-collection of meta-data representing factors driving the trade (e.g., efficiency of hunting techniques and consumers' demand for bushmeat) and the general lack of surveys of the resource populations (Taylor et al., 2015; Van Vliet et al., 2010). Finally, the correct identification of bushmeat species that is required to accurately understand the trade is challenged by potentially important levels of species misidentification (Gaubert et al., 2015; Gombeer et al., 2021). This is in part caused by the implementation of survey protocols themselves and the post-processing of the bushmeat carcasses (Din Dipita et al., 2022; Minhós et al., 2013).

To date, bushmeat surveys have predominantly focused on bushmeat markets at the local level, and recent efforts to investigate a bigger picture of the bushmeat issue in Africa still rely on these local surveys for their meta-analyses (see Ingram et al., 2021). However, in order to capture the full dynamics and range of the trade, as well as ultimately its sustainability, scale-adapted studies are required. With this in mind, reviewing and quantifying the scientific practices applied to bushmeat surveys in the tropical African rainforest would allow for the identification of trends in survey design and methodology. Here, we performed a systematic review of scientific literature since 1983 (first referenced paper on the topic) to explore how bushmeat surveys have been conducted in tropical African rainforests. Specifically, we aimed at (i) describing the general patterns and trends in bushmeat trade surveys (who, what, where and when?), (ii) delineating the spatiotemporal characteristics of the studies (scale, scope, temporality), (iii) characterizing the methodology used in market surveys and how methodology and results were reported (sampling effort, numbers counted, nomenclature, conservation status), and (iv) quantifying the taxonomic scale of the studies and accuracy of species identification. Insights gained from our review will help guide the scientific community and related actors in improving the conservation reach and application of future bushmeat trade surveys. Through the first systematic review of this kind, on the design and reporting of wildlife trade surveys, we also hope to provide a canvas for assessing the quality and repeatability of survey efforts that would be applicable to any survey of the wildlife trade.

2. Material and methods

2.1. Database on the bushmeat trade in African tropical rainforests

This study was conducted in line with the current systematic review guidelines of conservation literature (Collaboration for Environmental Evidence, 2022). We focused our bibliographical search on articles published in scientific journals, as we were interested in studying how scientists perform bushmeat trade surveys and because science should provide the knowledge required for conservation action (Mair et al., 2018). We acknowledge that there are also online reports available on bushmeat trade surveys. However, the latter do not necessarily report their survey protocols to the same extent of detail as those found in scientific articles, probably due to differences in objectives, readership target and editorial constraints (e.g. lack of formal peer reviewing). Various books have also been dedicated to the bushmeat trade, but after a first screening (random reading of 10 book chapters) we concluded that they rarely present original data. Relying on the original data and formatted protocols provided in peer-reviewed scientific articles, allows us to capture how science has been conducted on the bushmeat trade in tropical Africa and how repeatable the survey protocols are. Only studies on rainforest taxa were considered, in order to focus on the trade that has particularly been identified as a major threat to the conservation of biodiversity (the bushmeat crisis). This also ensured the maintenance of similar climate-vegetation constraints across the study zone (which influence access to wildlife, and thus market dynamics).

The bibliographical search was completed between March 2021 and January 2022, fully covering the publication years from 1983 to 2021. Boolean search terms were used to collect literature on the bushmeat trade in the African tropical rainforests from two databases. Articles containing “bushmeat” AND “Africa” in their titles, abstract or topic, were first extracted from the Web of Science (WoS) (N = 788; extracted from “all databases”) (Fig. 1). These two terms were able to capture all the in-subject references (except one) returned when replacing “bushmeat” with “wild meat” or “wildmeat”, or “Africa” with “Congo”, or “bushmeat” and “Africa” with the equivalent terms in French, Spanish and Portuguese (data not shown). The focus of each article was manually examined by reading titles and abstracts. Surveys not directly dealing with the bushmeat trade or rainforest taxa were then removed (N = 358). Secondly, articles were extracted from Google Scholar combining the terms “bushmeat trade”, “market”, “Africa”, as the combination “bushmeat” AND “Africa” used in WoS would return too many articles (N = 3080 versus 16,600, respectively). Off subject articles and duplicates of articles already extracted from WoS were removed manually before extraction, resulting in 150 additional articles. Overlapping papers were included, however data was only extracted from the article reporting the most exhaustive information.

The use of the two databases allowed us to include literature from different domains, journals and accessibility. There is a possibility that articles were missed, however, given the overall quantity of extracted literature, this is unlikely to have significantly altered our results. A final database of 580 articles was assembled on 21/01/2022. Information on the basic patterns of bushmeat trade publications were collected to investigate hemisphere dominance in authorship (first and last author together with their North/South affiliations at the time of publication), where research is mainly published (journal) and temporal trends in publication volumes (year of publication). The articles were assigned to three broad fields of research: “conservation biology”, “health” and “human and social sciences”, by manually examining their titles and abstracts. As conservation biology was the scope of interest, articles within that field were assigned to one of six thematic categories: “biodiversity”, “practices”, “modelling”, “economy”, “genetics” and “policy” (Online Appendix Table A1). Category assignment was independently vetted by two co-authors (BG and PG) after which final category definitions were drawn. This was repeated again with a smaller subset of literature during the assignment process.

The 400 conservation biology articles were reviewed manually to identify those reporting quantifiable data on the bushmeat trade, with the minimum being an account of species diversity. Review articles were not further processed. Following this criteria, we retained 143 articles, to which we added two and three articles from Health and Human and Social Sciences, respectively, as they also contained quantifiable data on the bushmeat trade. We extracted from the 148 final articles a series of variables (detailed in Online Appendix Document A1 and Table A2) providing information on the geography of the bushmeat trade surveys (place and scale), characteristics of the trade sites, the type of information and material supporting the surveys, the temporality of the surveys, the sampling effort, the numbers reported (number of items and biomass), the nomenclature used to identify the species, the number of taxa reported per class (Mammals, Birds, Amphibians) or order (Squamates, Crocodiles, Turtles) after visual identification, and the number of entries per class or order as reported in genetic studies whenever

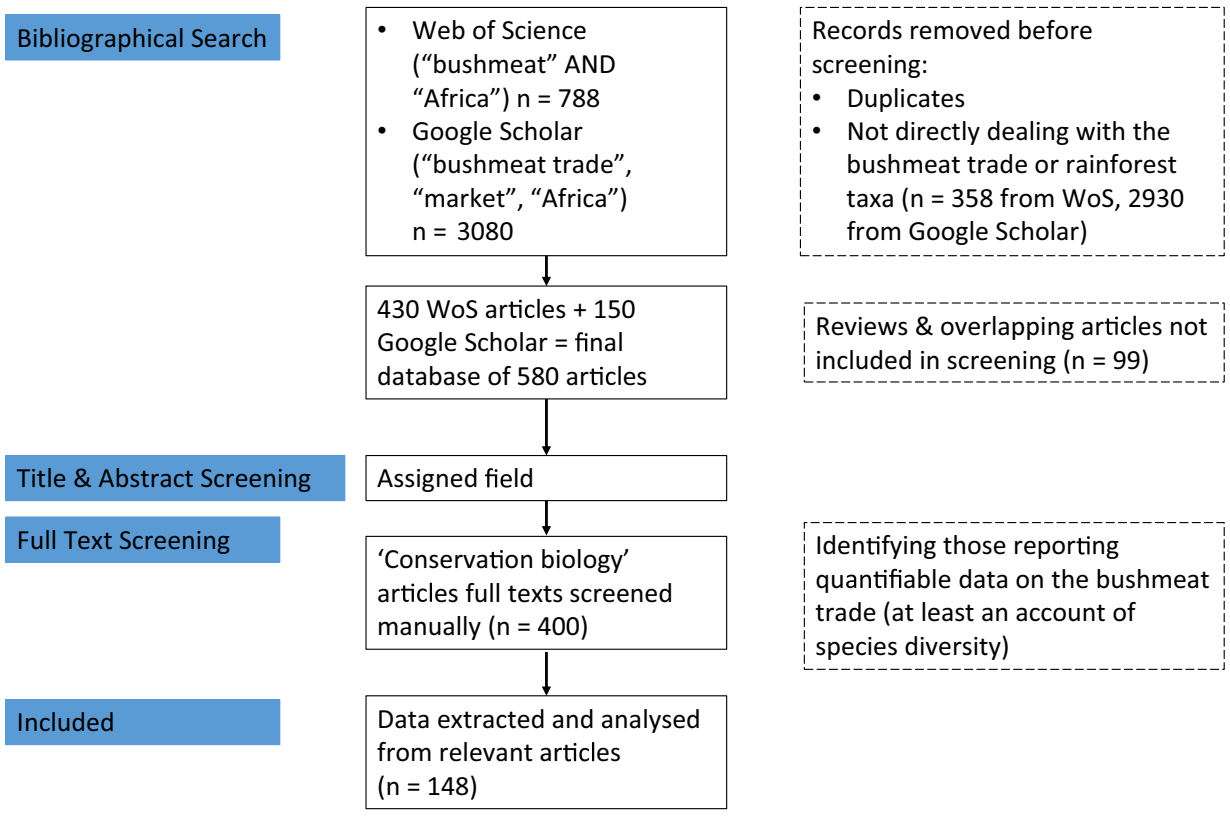

Fig. 1. Flowchart of scientific literature search, screening and inclusion followed as part of this systematic review.

available. In the two latter cases, the number of taxa not identified to the species level was also reported. The conservation status of the species sold as part of the bushmeat was assessed through the IUCN Red List of Threatened Species (https://www.iucnredlist.org/), the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) and the EU Wildlife Trade Regulations (https://speciesplus.net/).

Several reviews on the bushmeat trade in tropical Africa have recently been published. However, these focus on different topics, including the production of a database of study sites, harvest data and data type (Taylor et al., 2015), ecological implications of extraction rates (Petrozzi et al., 2016), savannah regions (van Velden et al., 2018), key actors involved in the bushmeat commodity chain (Wilkie et al., 2016) and links between bushmeat and emerging diseases (Peros et al., 2021). Whereas our systematic review is the first to assess bushmeat survey methodology in such detail, exploring a greater range of variables.

Data analysis.

From herein only focused data from the 148 articles containing studies on the bushmeat trade in West Africa were analysed. For descriptive analyses of the variables, graphic quantifications were conducted in Excel 2016 using dynamic tables, as well as in RStudio (RStudio Team, 2020), using the *ggplot2* package. XLSTAT 2021.4.1 (Addinsoft, 2022) was used to investigate the factors driving the numbers of scientific publications per country of study. We conducted a multiple linear regression analysis, modelling numbers of scientific publications as a function of the following quantitative explanatory variables: GDP (https://data.worldbank.org/), which is known to influence scientific production in southern countries (e.g., Heighton and Gaubert, 2021), and diversity of mammals and number of threatened species in each country (https://rainforests.mongabay.com/03mammals.htm), which is expected to be correlated with a higher interest or priority in research. Population number was correlated to GDP and thus was not considered (data not shown). We mapped the number of bushmeat studies per country as well as the location of study sites in QGIS v3.22.3 (https://qgis.org). The following statistical analyses were conducted in RStudio. We compared the temporal distribution of the number of publications per year for Conservation Biology, Health and Human & Social Sciences, using the *segmented* package (Muggeo, 2017) and function to statistically identify break points in the distribution (three breakpoints allowed). Delays in publishing results through time (delta between the year of publication and the end of the survey) were described using a scatter plot and linear regression (lm function; Hastie and Pregibon, 1992). A Pearson's correlation test was used to measure correlation between this delay and the distribution of publication years. The *VennDiagram* package (Chen and Boutros, 2011) was used to generate multi-set Venn diagrams synthesizing the spread of data for several variables on the characteristics of surveys and related supporting information (purpose of the trade, data type and study scope).

3. Results

3.1. General patterns and trends in bushmeat survey publications

We extracted an overall database of 580 articles on bushmeat surveys in the tropical African rainforest, where "conservation biology" was the dominant research field (400 articles; c. 69 %), far ahead of "health" (121) and "human and social sciences" (59). Temporal distribution trends within the three research fields showed a gradual increase in number of publications since the late 1990s (conservation biology), early 2000s (health) and early 2010s (human and social sciences) (Fig. 2). All three fields peaked between 2017 and 2019. A subsequent decrease in the number of publications from 2019 was identified as a distribution breakpoint for the fields of conservation biology and health. For the three fields combined, 2017 was the third estimated breakpoint that led to a global decrease in number of publications.

Within the field of conservation biology, "biodiversity" was the main thematic category (240 articles; c. 60 %), followed by "practices"

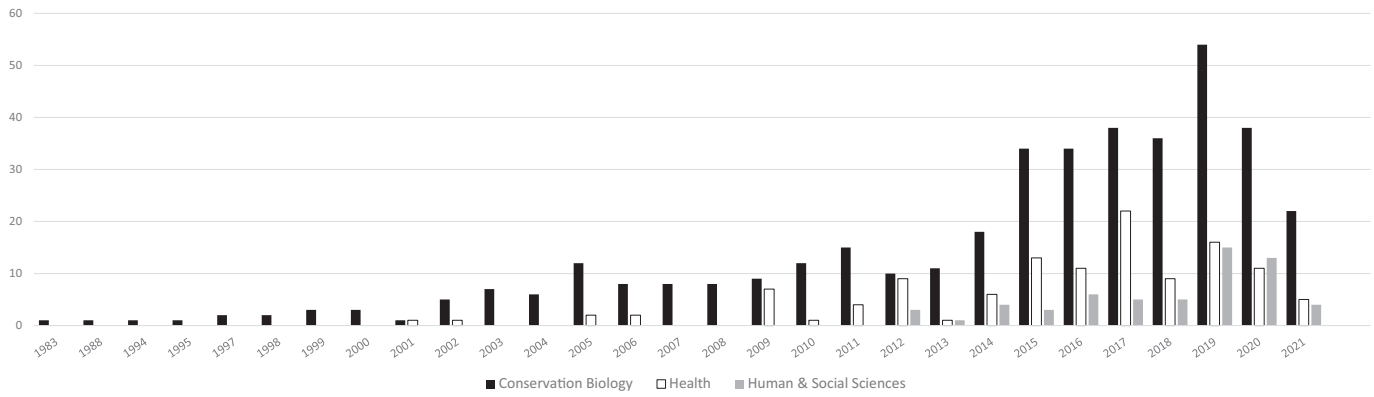

Fig. 2. Temporal trend of yearly publications volumes on the bushmeat trade in tropical African rainforests from 1983 to 2021, per main research fields.

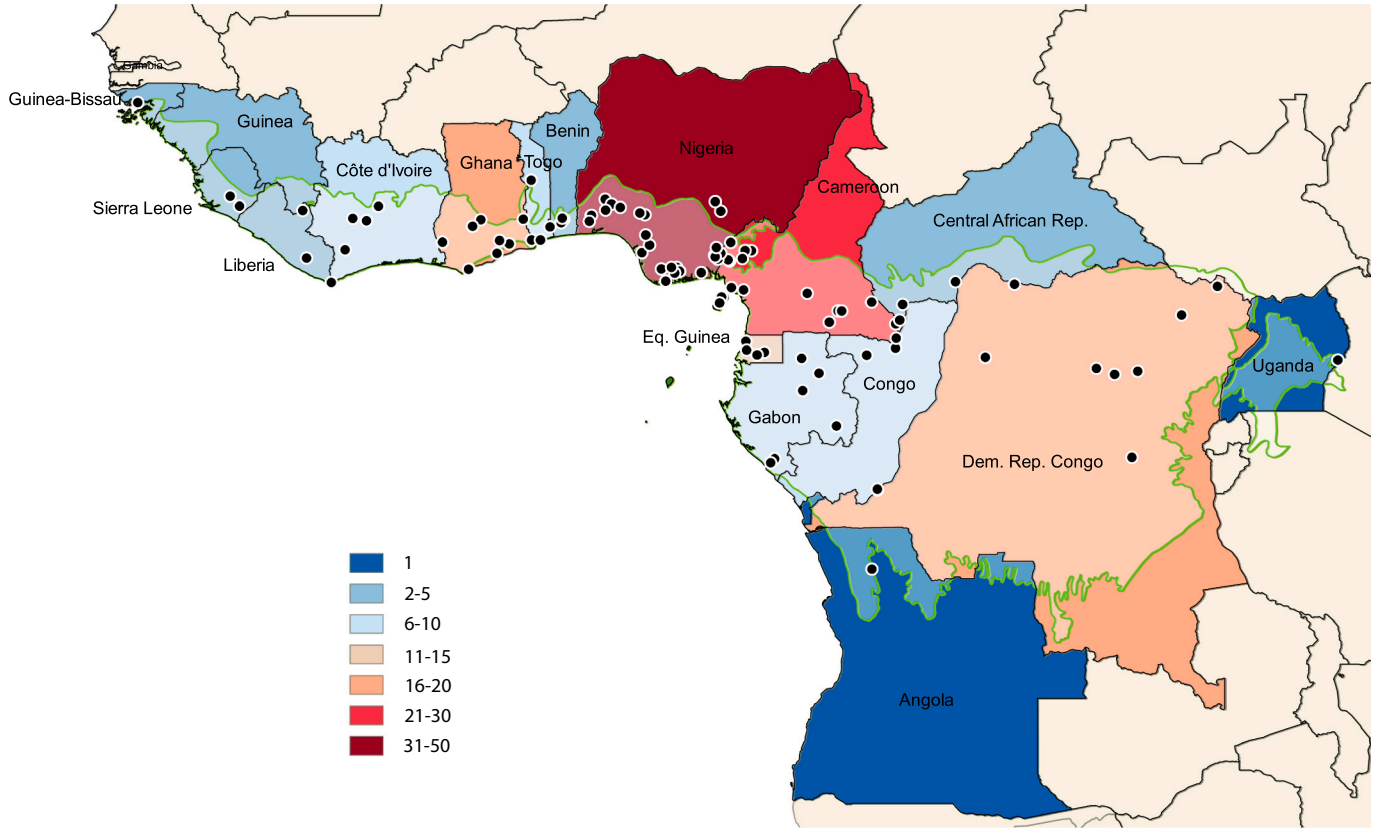

Fig. 3. Effort in bushmeat surveys across tropical African rainforests as measured per number of scientific publications per country reporting quantifiable data on the trade (1983–2021).
Study sites are given as black circles with white contour. Where articles conducted multiple studies across a same country, a middle point was chosen. Green contour and shaded white delimitate the tropical African rainforest zone. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

(56),"modelling" (39), "economy" (36), "genetics" (15) and "policy" (14) (Online Appendix Document A1: Fig. A1). Three out of the 176 scientific journals that contained articles on aspects of the bushmeat trade published >20 % of the available articles: *Biological Conservation* (7.5 %), *Conservation Biology* (7.0 %) and *Oryx* (6.0 %) (Online Appendix Table A3). Of the 272 first authors and 265 last authors, c. 65 % and 64 % were affiliated to northern institutions, respectively, resulting in c. 64 % being first-last authors northern affiliations (Online Appendix Table A4). Nigeria (25.0 %) and Cameroon (16.3 %) were the most studied countries (Fig. 3, Online Appendix Table A5). In the multiple regression analysis, GDP appeared as the only significant, positively correlated contributor to the number of publications per country ($P <$ 0.0001) (Online Appendix Table A6).

3.2. Spatiotemporal characteristics of the bushmeat surveys

The 148 articles reporting quantifiable data on the bushmeat trade represented a total of 113 specific study sites spread over 18 countries (Fig. 3). Most of the bushmeat surveys (85.1 %) focused on the local scale (Online Appendix Document A1: Fig. A2) and local trade networks (local origin of the trade = 63.5 %), although the destination of the trade was poorly assessed (local = 46.6 %; not given = 40.5 %; Online Appendix Document A1: Fig. A3). Study sites varied but were dominated by large urban markets (c. 31 %), hunting sites (c. 30 %) and household

communities (c. 21 %) (Online Appendix Document A1: Fig. A4), with c. 63 % of the surveys investigating at a single type of study site. Bushmeat trade as a food source was the most studied type (60.1 %), while 12.8 % of the surveys did not report the purpose of the trade (Online Appendix Document A1: Fig. A5). Most of the surveys were limited to a single type of trade purpose (c. 76 %). Bushmeat surveys generally focused on a reduced number of study sites (mean = 5.0, SD = 26.5), mostly being conducted on a single site (28.3 %) while 15.5 % of them did not report any site numbers (Online Appendix Document A1: Fig. A6).

The studied bushmeat products included fresh and smoked (and unspecified) carcasses, chopped meat and live animals, with similar numbers of studies focusing on single and multiple product types (Online Appendix Document A1: Fig. A7). Most of the bushmeat surveys were conducted within a year (38.3 %) or two (32.5 %), while the maximum duration was 27 years (Online Appendix Document A1: Fig. A8). Time to publish the results after the end of the survey period ranged from 1 to 15 years, with a delay of 1 to 3 years contributing to c. 58 % of the publications. There was a significant, negative correlation between this delta and the year of publication ($r = -0.497$, $P < 0.0001$) (Online Appendix Document A1: Fig. A9).

3.3. Methodology and reporting of the bushmeat surveys

The approaches used to collect bushmeat trade data ranged from interviews to direct observation, genetic sampling, photographs and online surveys. Surveys mainly relied upon a single approach (c.61 %), with interviews being the dominant one (42.6 %). Both interviews and direct observation were used in 33.1 % of the studies (Fig. 4). Mean number of market.days, reflecting the survey effort, was 171.1 but amplitude among surveys was large (min = 6; max = 9072; SD = 1317.4). Approximately 66 % of the studies did not report the number of market.days (Online Appendix Document A1: Fig. A10). Mean number of reported bushmeat carcasses/items was 2212.2 but again variation was large (min = 15; max = 46,769; SD = 9286.6), with 40.0 % of the surveys not quantifying the bushmeat sold (Online Appendix Document A1: Fig. A11). When reported (19 % of the cases), total biomass per survey varied between 188 and 470,087 kg (mean = 7082.2; SD = 87,139.3) (Online Appendix Document A1: Fig. A12).

The nomenclature (books of taxonomic reference) used to describe the bushmeat species was only given in 16 % of the surveys. The conservation status of the species traded as bushmeat was addressed in 37.8 % of the studies, whereas the studied species were of conservation concern (from vulnerable to critically endangered) according to the IUCN Red List in 91.2 % of the studies, and were listed by CITES (appendices I and II) and EU Wildlife Trade Regulations (annexes A, B and C) in 89.9 % of the cases.

3.4. Taxonomic scale and accuracy of species identification

A total of 137 surveys included mammals, which represented 92.6 % of the articles. Mammals were followed by squamates (52 articles), birds (50), crocodiles (43), turtles (32) and amphibians (4) (Online Appendix Document A1: Fig. A13). Bushmeat surveys only recording mammals represented 49.6 % of the publications including mammals and other taxa (and 45.9 % of the 148 articles quantifying the bushmeat trade). Most of the surveys listing taxonomic groups other than mammals were published together with mammalian taxa (87.5–100 % of the cases). Mean number of species-level taxa in the bushmeat surveys was 19.2, but with a huge amplitude between minimum (1) and maximum (193) numbers (SD = 19.8). Mean number of mammals was 15.7 (SD = 11.7), followed by amphibians (mean = 7.0; SD = 11.3), birds (mean = 5.1; SD = 8.7), squamates (mean = 4.5; SD = 11.3), turtles (mean = 2.3; SD = 4.8) and crocodiles (mean = 1.4; SD = 0.8) (Online Appendix Document A1: Fig. A13).

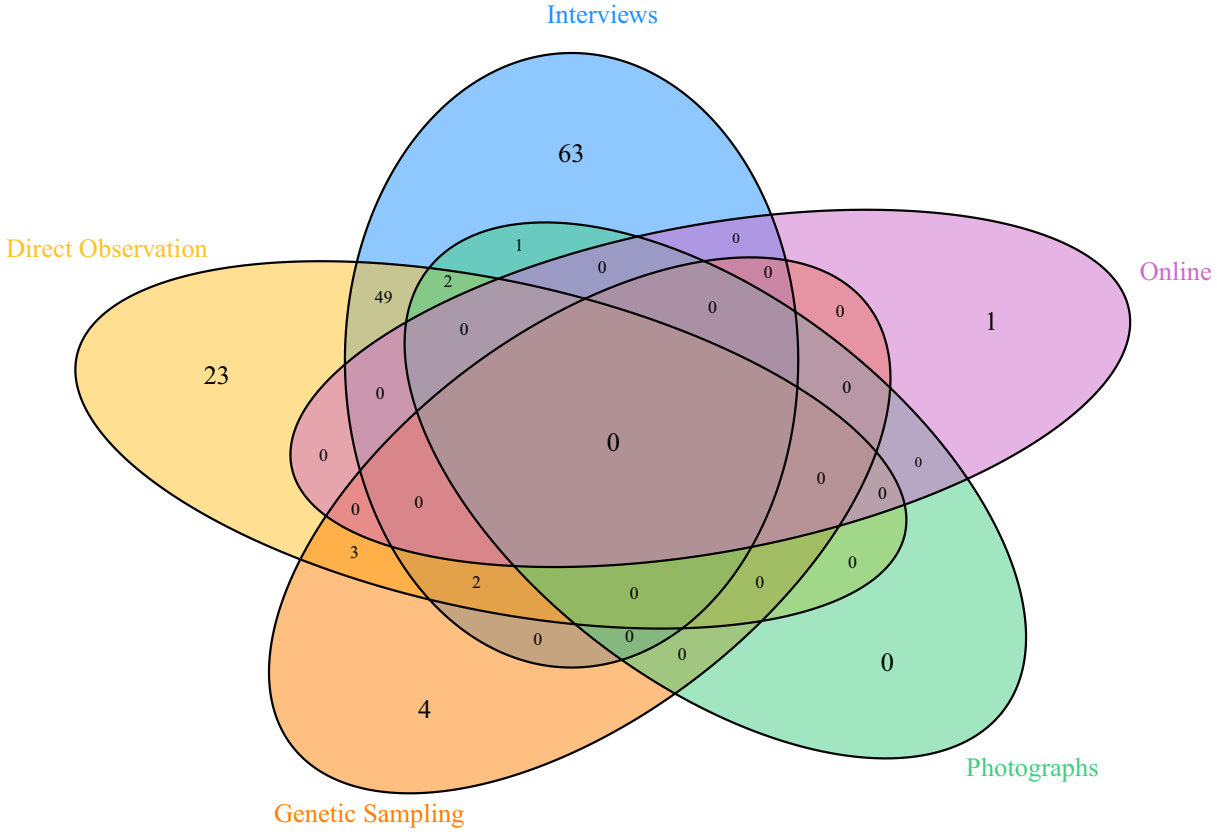

Fig. 4. Venn diagram representation of the type of approaches used to collect quantifiable data in bushmeat surveys from tropical African rainforests (in the field of conservation biology; see Materials and Methods).

Mean percentage of species-level identification reported in bushmeat surveys was 83.9 % (min = 0.0 %; max = 100.0 %). On morphological grounds, mammals and crocodiles reported the greatest percentages of species-level identification (83.1 % and 81.4 %, respectively). Birds and squamates reported 76.7 % and 74.1 %, respectively, while turtles and amphibians only reached 51.1 % and 45.8 %, respectively (Fig. 5).

Only 6 % of the bushmeat surveys used DNA for species identification. The nine articles focused on mammals, with a single article also targeting birds and squamates. Mean number of species-level taxa (based on morphological grounds) in the genetic surveys was 13.1 (min = 1; max = 60; SD = 18.5). Mean number of mammals was 12.9 (SD = 17.7), while birds and squamates only represented one species each. Mean number of samples was 51.3 (min = 1; max = 304; SD = 96.7). Mammals had a mean of 54.0 (SD = 94.8), whereas birds and squamates were each represented by a single sample. Mean percentage of species-level identification using DNA was 86.1 % (min = 66.7 %; max = 100.0 %). Mammals reported a mean value of 86.1 % (same range as for the total analysis), whereas identification success reached 100.0 % for the bird and the squamate. DNA improved or corrected morphological identification of bushmeat carcasses by an average of 17.6 % (min = 0.0 %; max = 53.3 %).

4. Discussion

Our systematic review is the first attempt at quantifying how bushmeat surveys are conducted in tropical African rainforests and more broadly, the first questioning how survey design may result in failure to assess the sustainability of the wildlife trade. As a discipline of action (Soulé, 1985), conservation biology requires both scientific rigor (repeatability) and appropriate study scaling, to provide usable outputs for conservation policies (e.g., Romanelli et al., 2021). Despite the bushmeat trade being one of the main drivers of the Holocene extinction in the tropics (Ripple et al., 2016), we found that rigor in reporting protocols and primary data of surveys was generally lacking or insufficient in the scientific literature, therefore hindering repeatability and comparative analyses between bushmeat studies. We also found weaknesses in survey design, resulting in failure to capture the complex reality of the bushmeat trade, as most studies were conducted on a local and short-term scale. As our review is, to our knowledge, the first of its kind, we lack comparative data from other continents, areas, or types of wildlife trade to assess whether such methodological bias is unique to this study system or could be more of a general issue.

4.1. Global patterns and trends in bushmeat survey publications

Our review revealed that conservation biology was the research field that dominated studies (c. 69 %) on the bushmeat trade in the African tropical forest, and within that field biodiversity was the main theme (c. 60 %). This dominance of conservation- and biodiversity-oriented studies was not necessarily expected given the globally recognized risks that the bushmeat trade poses to human health (Karesh and Noble, 2009); a recognition that has definitely become more apparent since the COVID-19 pandemic (Peros et al., 2021). The significant decrease observed in the number of publications from 2017 to 2019 in all three research fields (conservation biology, health and human and social sciences) is concerning, but its origin remains uncertain. It is however possible that whilst reshuffling global scientific priorities, the COVID-19 pandemic slowed the acceptance process of non-COVID-19 manuscripts (Aviv-Reuven and Rosenfeld, 2021) and the funding of conservation programs (Kideghesho et al., 2021).

The fact that the majority of studies focused on conservation aspects of the bushmeat trade is a positive sign, likely indicating that scientists have fully recognized the urgency surrounding the bushmeat crisis (Bennett et al., 2002). This said, a large number of biodiversity-focused studies were very descriptive in nature (e.g., species count), while fewer studies focused on economics, modelling sustainability and conservation policy. Without a systemic approach that extends beyond single domains and considers the multiple aspects of the bushmeat trade, the available scientific knowledge may contribute poorly to management policies and conservation actions (Blair et al., 2017; van Vliet and Mbazza, 2011).

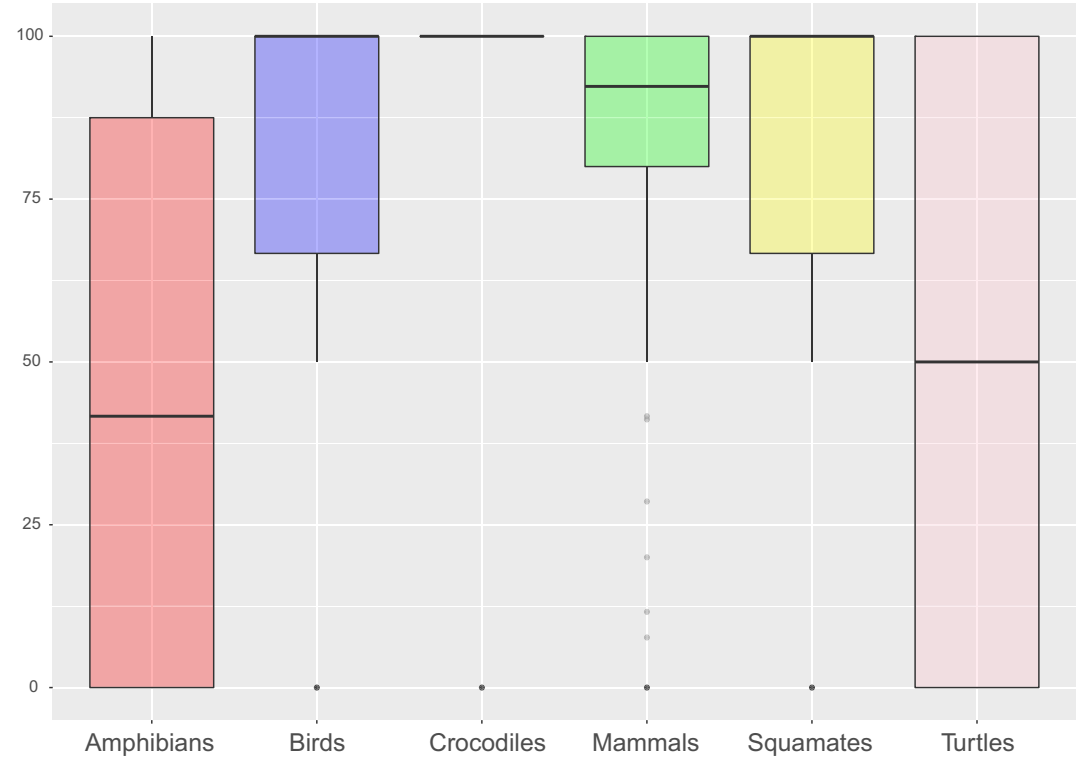

Fig. 5. Box plot representation of proportions of bushmeat taxa identified to the species level per class or order as reported from bushmeat surveys based on morphological identification.

The majority of the publications were North-driven, and >20 % were concentrated into three major conservation biology journals, guaranteeing high visibility of the bushmeat issue in scientific literature, as well as facilitating awareness and funding. However, good science does not necessarily result in informed wildlife management and conservation strategies (Salwasser, 1993). Moreover, the under-representation of southern researchers in bushmeat surveys – in line with the global pattern of unequal knowledge structures in conservation sciences (Trisos et al., 2021) – may prevent the establishment of long-term studies and capacity building that could translate into locally adapted, durable management plans and law enforcement (Reboredo Segovia et al., 2020). Bushmeat survey efforts – as measured per number of studies – were geographically biased towards high GDP countries, including Nigeria and Cameroon; a similar pattern recently observed in studies on pangolins (Heighton and Gaubert, 2021). This further emphasizes the need for a reallocation of scientific resources across the African tropical forest in order to form an unbiased picture of geographic trends of the bushmeat trade (Taylor et al., 2015), especially in biodiversity-rich, low income countries.

4.2. Spatiotemporal characteristics of the bushmeat surveys

Time taken to publish bushmeat surveys was generally reasonable, with c. 58 % of articles being published within 1–3 years after study completion. The fact that publication time has significantly decreased in recent years is encouraging, as conservation biology is "a mission-driven discipline" (Meine et al., 2006) that requires rapid diffusion of knowledge in order to update conservation actors and state authorities on current situations. Conservation biology, long seen as a discipline with slow publication rates within organismal biology (Kareiva et al., 2002), may have benefited from the digital transformation of the publication ecosystem (Hurd, 2000), which has allowed for results to be published more quickly. A trend that appears necessary, given the rapid, global expansion of the bushmeat trade (Ingram et al., 2019) and the urgency to report on the bushmeat trade dynamics.

However, our review highlighted several weaknesses in the design of bushmeat surveys. The bushmeat trade is a complex network with various scales of influence and fluctuating dynamics over time (Bowen-Jones et al., 2003). It has a multiscale connexion network, linking source forests to urban centres and beyond (such as international trade; Chaber et al., 2010). Thus, bushmeat surveys require a design appropriate for capturing the complexity of the trade. We report that the majority (c. 85 %) of surveys focused on the local scale and on a reduced number of study sites. The fact that bushmeat surveys suffer from narrow-scale design has already been emphasized, and may be due to lack of sufficient funding and difficulties to access survey sites (Blair et al., 2017; Taylor et al., 2015). Studies also poorly assessed the final destination of the trade. Given that accurate information on spatial patterns of harvesting is particularly important for apprehending wildlife resource sustainability (Jones et al., 2008), bushmeat surveys as currently designed generally poorly capture the complexity of the trade.

Although the range of study sites and bushmeat products investigated was diverse and relatively balanced, surveys mostly focused on the top (hunting sites, household communities) and bottom (chop bars, urban markets) ends of the bushmeat commodity chain. Surveys generally omit intermediary wholesalers, who handle the largest per capita market share and are involved in most of the supplying networks connecting the sources to the clients (Mendelson et al., 2003). Wholesalers can be difficult to track, but excluding this social category from bushmeat surveys may hinder the complete understanding of trade dynamics. Most studies were limited to a single type of trade purpose and investigated the bushmeat trade as a food source. However, bushmeat is also sold in large volumes for medicinal and cultural purposes on traditional medicine markets (Djagoun et al., 2013). Thus, we encourage the scientific community to design surveys that embrace the commercial connection between the two different kinds of market (Petrozzi, 2018), in order to increase our understanding of the bushmeat trade network complexity in the tropical African rainforest zone.

Our review also highlighted that most bushmeat studies were conducted within a short timeframe (1–2 yrs) and with limited survey efforts, despite a few notable exceptions (Buij et al., 2016; McNamara et al., 2015). This clearly represents limitations of survey design in characterizing temporal trends of the bushmeat trade in the long term (Taylor et al., 2015). Given the significant importance of time-series data in conservation planning (García-Barón et al., 2021), we advocate for long-term bushmeat surveys, which may be able to better account for the scale of the trade network and identify shifts in trading routes and patterns over time (Harfoot et al., 2018). This again involves securing long-term funding and collaboration with range state scholars, which often remains a challenge for conservation biology projects conducted in southern countries (Lindsey et al., 2020).

4.3. Methodology and reporting of the bushmeat surveys

Although bushmeat surveys used a variety of direct and indirect approaches to collect information on volumes and species sold, the majority used a single approach, dominated by interviews. Despite the maturation of TEK/LEK-based methodologies (Traditional/Local Ecological Knowledge; Shackeroff and Campbell, 2007), relying on interviews alone may prove problematic because of limitations or inaccuracy involved with data collection, especially when such expert knowledge is required on the abundance and diversity of harvested species (Ruddle and Davis, 2011). Although interviews were combined with direct observations in approximately one third of the studies, the taxonomic references and protocols used to identify the species were only given in c. 16 % of the cases. Lack of combined approaches and protocol reporting may render bushmeat surveys less accurate in terms of biomass and species diversity assessment, and thus reduce their reach on downstream conservation policy (Friess and Webb, 2011).

We also observed blatant gaps in reporting on survey efforts, species numbers and volumes that challenge the utility and repeatability of a large part of the bushmeat surveys conducted in the tropical African forest. Approximately 66 %, 40 % and 81 % of the studies did not report number of market.days, number of carcasses and biomass estimates, respectively. The publication of detailed protocols and accurate reporting of the data is prerequisite to any properly led, reproducible science (Munafò et al., 2017). Without rigorous, standardized protocols and data reporting, bushmeat surveys as they are generally conducted by the scientific community might fail to address the global stakes surrounding the bushmeat trade, and less efficiently influence state policies.

Our review also highlighted a concerning lack of reporting species' conservation status in 62 % of the studies, despite a huge majority of the surveys including species of conservation concern or species regulated by international laws. By not reporting conservation status, bushmeat surveys may involuntarily fail to emphasize the direct threat that the bushmeat trade poses to threatened wildlife, notably to non-expert policy makers who require this information to take action (Lauber et al., 2011).

4.4. Taxonomic scale and accuracy of species identification

Bushmeat encompasses four classes of terrestrial vertebrates (Mammalia, Aves, Reptilia and Amphibia) and may impact at least 500 different species from the tropical African forest (Redmond et al., 2006). However, bushmeat surveys remain highly biased towards mammals as confirmed through our review. Although such a pattern may reflect socio-economic preferences for mammals (Gonedelé Bi et al., 2017), we argue that efforts are still insufficient to capture the full taxonomic spectrum affected by the bushmeat trade, as other classes such as birds and reptiles are also important constituents of the trade (e.g., Buij et al., 2016). Efforts to capture the full species diversity sold on the bushmeat

trade also remain insufficient, as the mean number of species listed in bushmeat surveys was <20. A single outlier study peaked at 193 species, however, this was based on an online survey of exported animals (Harrington et al., 2021). The fact that the number of species surveyed was mostly low, again questions the magnitude of survey efforts and the potential methodological flaws reported above. This partial sampling of the taxonomic diversity sold on bushmeat markets may also reflect genuine difficulties in accessing the trade network, the status of which remains unclear to most state authorities (Gossé et al., 2022) and is thus less easily investigated than official meat markets.

Accurate species identification is an upstream, central component of any conservation strategy (Balakrishnan, 2005). Yet, bushmeat surveys mostly relied on interviews and morphological observations to identify the species traded. Such approaches can be seriously challenged by factors including the cryptic diversity of African mammals (e.g. small carnivores and primates, rodents, turtles), carcass processing (such as butchering and smoking) and the level of expertise of people involved in species identifications (Din Dipita et al., 2022; Schilling et al., 2020). Approximately 16 % of the studies reported unidentified species, although this might be underestimated as the surveys were not designed to specifically report on this particular issue. Turtles and amphibians proved to be the most challenging taxa, with approximately half of the species being unidentified. Such a pattern could be related to the relative lack of taxonomic studies and experts on African turtles and amphibians (compared to mammals), but also to the levels of cryptic diversity within these two groups (e.g., Deichmann et al., 2017; Luiselli et al., 2021).

As inaccurate identification of bushmeat species can hamper the design of prospective conservation strategies (Ogden et al., 2009), surveys must implement efficient tools for taxonomic recognition. DNA-typing has shown to be efficient in improving species-level identification of bushmeat surveys conducted in tropical African rainforests (e.g., Eaton et al., 2010; Gaubert et al., 2015; Minhós et al., 2013). Our review showed that DNA-typing improved levels of species identification. However, only nine studies used this approach, which was also only applied to a restricted number of species and samples. Although the representation of DNA-based studies remains low, recent publications provide evidence that DNA-typing is a promising and realistic avenue for bushmeat surveys in the tropical African forest, allowing for improved rates of species identification of 43–57 % (Din Dipita et al., 2022; Gossé et al., 2022). Our review reports a similar rate of species-level identification for DNA-typing (mean = 86 %) compared to standard survey methods. However, Din Dipita et al. (2022) and Gossé et al.'s (2022) studies demonstrate that DNA-typing efficiency, at least in mammals, can be much higher (93–98 %) when using a standardized protocol and reference database (Gaubert et al., 2015). The utility of DNA-typing in bushmeat surveys – and hence its implementation in an African context – cannot yet be fully appreciated however, given the comparatively low amount of available data.

4.5. Better scientific practices in bushmeat surveys for improved conservation action

The weaknesses in survey design that were highlighted by our systematic review should be considered within the context of global failure (i) in management policies to mitigate the expansive dynamics of the bushmeat trade (Morton et al., 2021) and (ii) of conservation science to fill the "implementation gap" (Mair et al., 2018). It is important to acknowledge that such failure is not only the responsibility of scientists, as state corruption and lack of institutional support affecting the long-term involvement and productivity of scientists from the South also plays a role (Reboredo Segovia et al., 2020). Failure "is not all bad" in conservation (Knight, 2009); our review and the provided database could form a starting point for improving bushmeat survey design and ultimately, achieving a greater impact in terms of conservation action, as rigorous and scale-adapted scientific protocols shall provide more informative results for trade regulation.

Given the complexity of the bushmeat commodity chain, we advocate for a systemic approach in bushmeat survey design that includes all aspects of the bushmeat socio-ecological system. In general, reviewed studies were blatantly monodisciplinary. Inter- to transdisciplinary approaches, such as those developed within the EcoHealth framework (Rapport, 2007), could be a better alternative for translating knowledge from bushmeat surveys into sustainable conservation-based solutions. Long-term funding of bushmeat surveys and involvement of researchers from the South, notably from diversity-rich, low GDP countries, is key for the establishment of long-term studies on the bushmeat trade, and will be crucial for successful conservation action (Kainer et al., 2009).

Time and space aspects of bushmeat survey design should be adapted to the scale of the issue that is being addressed (local vs. national, regional or global market). This requires an upstream understanding of the studied system and/or preliminary investigations on its range. Surveys should be designed in order to (i) fully capture the commodity chain of the bushmeat trade being investigated, including intermediary positions such as wholesalers, but also end-points contributing to the global demand such as local diasporas (e.g., Zanvo et al., 2021) – which are regularly omitted from studies – and (ii) to encompass the likely inter-connected different types of wildlife markets (and chop bars) occurring in, or linked to the study zone. Given that determining temporal trends in the bushmeat trade is crucial to understanding its dynamics and assessing its sustainability (Ávila et al., 2019), it will be important to design long-term surveys on bushmeat trade systems that could be used as reference study sites. Such surveys have proven extremely rare in the reviewed scientific literature, and constitute the missing baseline on which efficient policy strategies could rely (Koricheva and Kulinskaya, 2019).

Given the lack of rigor in reporting protocols and primary data, we strongly recommend that bushmeat surveys systematically provide detail on their protocol and report basic data that are required for reproducible science. This includes data on the nature and purpose of the trade, the number of sites studied, the survey effort (market.days), the numbers (items) and volumes (biomass) of bushmeat, as well as the taxonomy used to identify species. Without such precautions, most of the studies may end up as useless for informing bushmeat management strategies. We also observed that the national protection status of the species was generally not given. Yet, providing such information may help to further emphasize the conservation implications provided by bushmeat surveys, and in return, highlight the inconsistencies between national and international conservation status lists (see Gossé et al., 2022).

Our review also argues for an expansion of the taxonomic spectrum of bushmeat surveys, in order to address the current bias towards mammals. Although mammals constitute the main biomass of the trade (Petrozzi et al., 2016), the relative number of studies on other taxa remains low compared to the large volumes of birds, reptiles and amphibians that are sold in West African traditional medicine markets (e.g., Buij et al., 2016; Petrozzi, 2018). There is also a need for improved taxonomic identification of the traded species through the use of combined, direct approaches of identification and the training of local experts in taxonomy and related technology. This includes the development of accurate, national or regional taxonomic references, as well as capacity-building and training on modern approaches such as DNA-typing and high-throughput sequencing, but also online surveys and X-ray devices. All of which are likely to increase the accuracy of taxonomic identification, and at the same time allow for the rapid screening of the traded diversity (e.g., Pirotta et al., 2022; Sung and Fong, 2018; Vasiljevic et al., 2021).

Future efforts of the scientific community to improve and standardize bushmeat surveys should aim for a better diffusion of the bushmeat trade issue into state agendas and should translate into more South-driven, long-term studies. Whether or not some of the reviewed bushmeat surveys served as a basis to produce roadmaps for conservation planning addressed to public authorities is unknown. In the future,

the establishment of regional monitoring systems of the bushmeat trade could be important in contributing to guaranteeing protocol harmonization and the long-term stability of bushmeat surveys in tropical African forests. This will require collaboration among states and a will to prioritize the bushmeat issue on national and regional agendas, which certainly remains a challenging task.

Supplementary data to this article can be found online at https://doi.org/10.1016/j.biocon.2023.110101.

CRediT authorship contribution statement

BG: Data curation; Formal analysis; Validation.

PT: Conceptualization; Formal analysis; Supervision; Validation.

PG: Conceptualization; Data curation; Formal analysis; Funding acquisition; Project administration; Resources; Supervision; Validation.

BG and PG co-wrote the original draft version. All authors reviewed and edited the final draft version.

Declaration of competing interest

The authors have no competing interests to declare.

Data availability

Data is shared in the appendices related to the article

Acknowledgments

BG was funded by PANGO-GO (ANR-17-CE02-0001). PG received support from Fundação para a Ciência e a Tecnologia (BUSHRISK – IC&DT 02/SAICT/2017; no 032130). We thank Jordi Salmona and Sean P. Heighton (EDB) for assistance in R applications and fruitful discussions, and Fanny Juillard and Valentina Soto for early contributions in building the database. The comments from one reviewer significantly improved the quality of our original draft.

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