Detecting declines of West African Goliath beetle populations based on interviews

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Abstract

Goliath beetles (genus *Goliathus*) are among the largest and most charismatic insects in the world. In West African forests, two species (*G. cacicus* and *G. regius*) and natural hybrids are found. These beetles are widely collected for the entomological trade. We carried out standardized interview campaigns in Liberia and Ivory Coast to explore local persons' perceptions of the status and population trends of these beetles, as well as information on their ecology and use by humans. Only relatively few interviewed communities reported the presence of beetles, all agreed that Goliath beetle populations were declining, especially *G. cacicus*. On the other hand, *G. regius* was generally considered less rare by the interviewees and was also known in a larger number of communities than *G. cacicus*. Because of the high deforestation rates in Liberia and Ivory Coast, as well as the impact of the international trade at specific collection localities, we suggest that these species are in peril of extinction if no immediate conservation actions are taken to reverse their status.

Implications for conservation. Since our study detected a likely dramatic decline of *G. cacicus* and, to a lesser extent, also of *G. regius*, we suggest that: (i) their IUCN Red List status should be assessed as soon as possible, (ii) their current distribu-tion should be studied more properly in the field given that many collection specimens are old and with incomplete labeling details, and (iii) their international market should be regulated as soon as possible by appropriate legislation.

Keywords Africa · Face-to-face interviews · *Goliathus* · Local ecological knowledge · Population trends

Introduction

Despite its biological importance, West African tropical forests are arguably the most critically fragmented regions in the planet (Mallon et al. 2015). These forests are threatened by logging, mining and hunting wildlife for meat, and by rising human population numbers. As a result, only 10% of the original tropical forest cover remains (Ola and Benjamin 2019). Deforestation has been especially devastating in regions that are globally strategic for natural resource exploitation. This is the case of the Niger Delta in southern Nigeria, where crude oil and natural gas multinational companies operate, and in the Ivory Coast where cacao production at the expense of natural forest is now the largest in the world. Much remaining forest is still exploited for timber (Mallon et al. 2015). In addition, hunting is prevalent in the forest and also in savannah habitats that often result in a catastrophic decline of wildlife, especially large mammals and reptiles (Mallon et al. 2015; CILSS 2016). Highly biodiverse habitats and most endangered species in West Africa today are confined to protected areas (PAs). According to the CILSS (2016), there are close to 2000 nationally designated PAs, covering around 9.6% of the region. This percentage is significantly short of the "at least 17% of terrestrial and inland water areas" recommended by the Aichi Target 11 (Dinerstein et al. 2017). Most PAs in West Africa are small, varying widely in size from < 1 km^2 to $> 97{,}000$ km^2, including 17 Biosphere Reserves (CILSS 2016). Large PAs, including clusters of sites, are however critical to support viable populations of larger species or to ensure fully-functioning, dynamic ecosystems (Mallon et al. 2015).

Threats to insect biodiversity include habitat destruction, agricultural intensification and use of pesticides but also climate change, invasive species, atmospheric nitrification and droughts (for a review see Wagner 2020; Halsch et al. 2021; Wagner et al. 2021; Blüthgen et al. 2022). Although there is mounting evidence that forest animals, especially large mammals and reptiles in West Africa are declining in numbers particularly due to habitat loss and trade (for example, the forest tortoises of the genus *Kinixys*, see Luiselli and Diagne 2014), little information is available on less charismatic species such as insects. For many insect species determining true declines is difficult, especially in the tropics where gathering robust data on temporal and spatial trends of insect populations is logistically problematic.Given the logistic and economic costs of doing field research in West Africa, many such species remain unreported and unknown from studies in the wild. Indirect data gathering methods can be useful to assess the status, threats and conservation perspectives of target species that are difficult to study in the wild. Campaigns that use face-to-face interviews with persons that have knowledge of the species of interest (for instance hunters, or even herders and farmers) can provide noteworthy information on the status of the populations of West African species (Luiselli et al. 2021a, b). For instance, face-to-face interviews in southern Nigeria have been used to demonstrate a decrease in population abundance of snakes, and have been then corroborated by more intensive capture-mark-recapture methods for the same areas (Reading et al. 2010; Akani et al. 2013). Interviews with over 2000 rural people in three West African countries mostly uncovered that forest tortoises (genus *Kinixys*) are heavily declining in Togo and Nigeria and that snail gatherers are the main providers of tortoises to the wild meat trade (Luiselli et al. 2018). Likewise, market and field surveys confirmed that tortoises are in heavy decline throughout West Africa (Luiselli et al. 2021a), and in Nigeria there was a positive correlation between number of wild snails traded by individual sellers and tortoises sold in their 'shops' (Luiselli et al. 2018).

The Goliath beetles (genus *Goliathus*, Scarabaeidae: Cetoniinae), one of the largest coleopterans in the world, are tropical insects primarily found in West and Central Africa. Exceeding 11 cm in the largest males (weighing 50 g at the adult stage and larvae over 100 g), and with extravagant colourations, Goliath beetles have been of great interest to entomologists for centuries. The Upper Guinean forests of West Africa (Mallon et al. 2015) are inhabited by two species of Goliath beetles, i.e. *Goliathus regius* and *Goliathus cacicus* (Le Gall 2010; De Palma et al. 2020), and by their rare natural hybrid (*G. "atlas"*) (Kraatz 1897, 1898; De Palma et al. 2020). These beetles are among the most charismatic insects in the world because of their very large size and conspicuous coloration (De Palma et al. 2020) and are also among the most expensive and sought after by collectors worldwide. Other *Goliathus* species do occur throughout Africa: the most widespread species is *G. goliatus* that can be found throughout the central African equatorial forests from south-east Nigeria to Uganda and western Kenya; *G. meleagris* (considered a subspecies of *goliatus* by some authors; De Palma et al. 2020) from the forest-savannah mosaics of Lualaba and ex Katanga regions in the Democratic Republic of Congo; *G. orientalis* from the wet savannahs of Tanzania; and *G. albosignatus* in the southern African savannahs (De Palma et al. 2020).

West African Goliath beetles live in rainforests and moist forest patches (Lachaume 1983; Croizat 1994; Le Gall 2010). Due to deforestation, some populations of these beetles are already perceived to be declining in Cameroon and Nigeria (Muafor and Le Gall 2011; Muafor et al. 2012). In these countries, collection pressure is likely to be greater given that some colour morphs (white morphs) here are more spectacular than colour morphs in

other regions (brown morphs), thus expensive in the international entomological market, and as a result exploited much more intensively (Dendi et al. 2021). During the last few decades, populations of these giant beetles have been anecdotally described as declining by hunters and dealers as they are: (i) less frequently exported from their countries of origin and (ii) are much more expensive to buy, than before (e.g. < http://www.collector-secret.com/insect/coleoptera/goliathus>, last accessed: 26th May 2022).

Knowledge of the general ecology of Goliath beetles in areas where they are still found is severely lacking (Le Gall 2010; Luiselli et al. 2021a). Most of the material currently available for study, even in large public museums, has been obtained through the international commercial trade and therefore lack pertinent data such as geographic coordinates of collection and elevation of capture, date of collection, associated plant species, associated vegetation communities, etc. (Mawdsley 2013).

In this paper, we present indirect information gathered from face-to-face interviews with local communities to investigate whether there is any evidence that Goliath beetles are declining in their natural habitats in West Africa. We use standardized questionnaires applied to experienced local persons in villages and settlements within the known range of these species. Because Goliath beetles are well known to local communities and are heavily gathered by local hunters and collectors (Muafor and Le Gall 2011; Muafor et al. 2012), such interviews can allow us to cost-effectively determine the status of these species as well as assess threats affecting them.

Materials and methods

Study area

We undertook interviews in 61 distinct villages in Cote d'Ivoire and Liberia (Fig. 1). These villages were randomly selected within the known distribution of the two species in the two studied countries. For each village, we also evaluated (i) its distance from the nearest mature forest exceeding 5 ha area (DIST), (ii) its population size (based on Ivorian/Liberian population census data) (POP), (iii) distance from the nearest protected area (PROT). Because our study species are heavily collected for a lucrative international trade, the precise location of villages are not reported in this paper. In each study site we also carried out field research to locate Goliath beetles and collected data on their ecology. These data will be reported in a separate article.

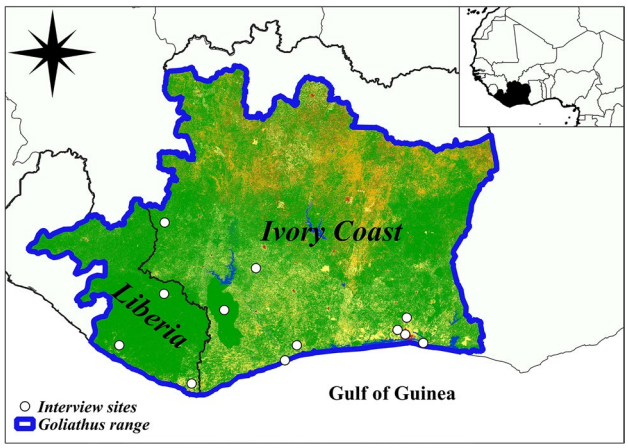

Fig. 1 Map of Cote d'Ivoire and Liberia showing the various communities where face-to-face interviews with positive answers concerning the presence of *Goliathus* were carried out, and in relation to the known native range of the two *Goliathus* species in these countries. *Goliathus* range is established on the basis of the museum labels of several specimens inspected by us and our unpublished data. Landuse is also presented in the map: from yellow to green, it is represented a growing forest coverage

Protocol

Interviews were conducted during different periods from 2015 to 2020, covering both wet (April to September) and dry (October to March) seasons. We interviewed persons (> 21 years old) in each study village that were reported by the elders as being farmers, or part-time hunters or forest products collectors and that, therefore, may be experienced with the study species. All interviewees were assured their anonymity and informing them of the goals and methods used in our study before applying the questionnaire. We asked the following questions :

(1) Do you have large beetles in your forests? We showed the interviewee what we considered "large" (at least 6 cm body length).
(2) If yes: are they lucanid-like, or dynastid-like, or cerambycid, or *Mecynorhina*-like or *Goliathus*-like? We displayed photos of the main beetle "types" that were potentially present but without showing species that are found within the study areas. So, for instance, for *Goliathus* we showed a photo of *Goliathus meleagris* male (a Congolian species), for lucanid-like a photo of *Lucanus cervus* male (a European species), for dynastid-like a *Dynastes neptunus* male (a South American species), for cerambycid a *Titanus giganteus* male (a South American species), and for a *Mecynorhina*-like, we showed a *Mecynorhina oberthuri* male (a Tanzanian species).

(3) For those respondents confirming that they could identify *Goliathus* we asked how many "types" (= species) can you find at your place? The interviewees were allowed to choose one of these alternatives: (i) 1, (ii) 2, (iii) 3, (iv) more than 3.
(4) Can you identify which one of the following *Goliathus* "types" you can find in your locality? This question was applied with photos of males and females of *G. goliatus, G. regius, G. orientalis, G. meleagris, G. cacicus, G. atlas* and *G. albosignatus*, thus showing the respondent both species potentially occurring at their locality as well as species with an entirely different distribution range (for instance *G. orientalis* from East Africa). In this case, we also asked the respondents whether they have any *Goliathus* individuals they have collected to confirm their identification.
(5) For those respondents confirming that they could identify *G. regius* and/or *G. cacicus* (i.e. the species potentially occurring in West Africa): Do you think they are common/rare/very rare in your locality?
(6) How would you describe the trend in giant beetle populations in your area? In your locality are beetles more commonly encountered, less commonly encountered or no different than several years ago (15 years or more for older respondents, 5 years or more for younger ones)? In this case we explained to the interviewees that, to answer to this question, they should think very carefully how often they encounter these beetles compared to the past. Although not perfect, this lack of standardization was necessary given the different ages of the interviewees and the number of years (= expertise) they had in in bushcraft.
(7) How many *Goliathus* beetles do you see each year? Here, although interviewees were free to report any numbers they wished, for the statistical analyses we pooled all values into four categories: (i) less than 1 per year, (ii) 1 to 10, (iii) 11 to 29, (iv) 30 and more, (v) don't know/cannot quantify.
(8) When was the last time that you saw one of these beetles? For the analyses, we divided the answers into the following categories: (a) last month; (b) 2–6 months ago; (c) 7–12 months ago; (d) last 3 years; (e) more than 3 years ago.
(9) In which months (or season) do you usually see these beetles? We pooled the reported periods of sightings into three categories: dry season (October to March), wet season (April to September), no specific season/not able to answer.
(10) Do these beetles live in (i) forest (bush), or in (ii) plantation/agricultural lands, or (iii) villages/urban areas, or (iv) are they present everywhere?
(11) What do you do with them if you see any of these beetles?

Goliathus beetles that were kept dried by the interviewees/villagers were also examined to determine species and sex. For all specimens found, we measured total body length with a calliper (precision ± 0.1 mm). About 50 specimens, that were obtained by the collectors, are now kept in the Luiselli private entomological collection in Rome, Italy for further examination.

Statistical analyses

DIST was grouped into three categories: (a) less than 1 km (scored 1), (b) 1.1–3 km (scored 2), (c), 3.1–6 km (scored 3), and ≥ 6 km (scored 4). POP was grouped into four categories: (1) ≤ 500 (scored 1), (2) 501–2000 (scored 2), (3) 2001–6000 (scored 3), (4) more than 6000 (scored 4). PROT was grouped into three categories: (i) less than 1 km distance (scored 1), (ii) 1.1–5 km (scored 2), (iii) more than 1 km (scored 3). Mann Whitney U-test were used to evaluate the differences in the mean scores between villages with and without large beetles.

Statistical differences in the frequencies of answers given by respondents to each question were assessed by an observed-versus-expected contingency table χ^2 test. The correlation between the numbers of men and women reporting the presence of a given species within their own communities was assessed by Pearson's correlation coefficient. These tests were run with a PAST Software 4.0 version, with alpha set at 5%.

Results

We interviewed a total of 3726 men and 1882 women of several age-classes in the 61 study villages. Within the 12 villages where interviewees answered there were beetles in their locality, a total of 567 men and 177 women were interviewed: 250 men and 104 women in the 21–40 years age class, 206 men and 57 women in the 41–65 years age class, and 111 men and 16 women in the > 65 years old age class. The number of men exceeded that of women because men (i) do work in the forests much more frequently than women and (ii) they are less shy and more ready to be interviewed. Interviewee numbers per village ranged from 18 to 186 in the case of men and 3–105 for women. These inter-village differences were entirely related to the size of each community. Most persons (> 70%) approached were happy in answering our questionnaire. Many men (n = 499 men, 88% of the total interviewed sample) and women (n = 138, 78%) answered that there were large beetles in their area.

Question 1: Do you have large beetles in your forests?

Persons in only 12 villages (19.7% of all villages) mentioned the presence of large beetles in their locality. Villages with and without beetles differed significantly in both DIST (median score = 1 for presence sites and 3 for absence sites; Mann-Whitney U-test, U = 63, z = 4.75, P < 0.0001) and PROT (median score = 1 for presence sites and 2 for absence sites; Mann-Whitney U-test, U = 126, z = 4.06, P < 0.001), whereas they did not differ in terms of POP (median score = 1.5 for presence sites and 2 for absence sites; Mann-Whitney U-test, U = 269, z = 1.59, P = 0.111).

Amongst men, there were no statistical differences in mean percentage of respondents confirming presence of large beetle either by age class ($\chi^2 = 0.78$, df = 2, P = 0.676) or by study site ($\chi^2 = 13.69$, df = 11, P = 0.105). These percentages were 81.8% in the youngest age class, 91.1% for the intermediate age class, and 92.8% for the oldest age class. For women, there was no effect of age class ($\chi^2 = 0.08$, df = 2, P = 0.971) but there was a very strong effect of the study site ($\chi^2 = 30.1$, df = 10, P < 0.0001).

Question 2: If yes: are they lucanid-like, or dynastid-like, or cerambycid, or Mecynorhina-like or Goliathus-like?

Since respondents may have identified multiple "types" of large beetles in their locality, for this question we considered the total number of positive answers for each beetle "type". There was a consistently similar interviewee response by site, with dynastid beetles (identified as *Augosoma centaurus* and *Oryctes* spp. based on photos and descriptions provided) being dominant (Online Supplementary Fig. S1). Cerambycid beetles (genera *Tithoes* and *Mallodon*) were the second most frequently selected beetle group, whereas *Goliathus* were the least frequently chosen among all available beetle "types". Answers for both men and women were similar. The numbers of men and of women reporting the presence of a given species in their communities were significantly correlated (r = 0.916, n = 5, P < 0.05), thus showing that both sexes answered this question consistently.

Focus on *Goliathus*—Questions 3 and 4: how many "types" (= species) can you get at your place?, and can you identify which one of the following *Goliathus* "types" are found in your locality?

We pooled the responses from men and women given that they answered similarly to the previous question (see above). Overall, 75.4% of the total interviewees identifying *Goliathus* (total n = 138) agreed that there was only one species in their localities (in all cases they identified *G. regius*), with relatively little variation across communities (Fig. S2) but a significant difference in frequency of the four answer options ($\chi^2 = 188.8$, df = 3, P < 0.0001). However, in only one community (situated not far from a very large protected rainforest area in Cote d'Ivoire) the interviewees suggested that multiple *Goliathus* species co-occur "sympatrically": 36.7% of respondents considered only *G. regius* as present, but 26.7% both *G. regius* and *G. cacicus*, 23.3% the former two and either *G. "atlas"* or the females of *G. cacicus*, and 13.3% more than three species (with respondents

Table 1 Distribution of the number of respondents by age class (years) and site correctly identifying *Goliathus regius, Goliathus cacicus* and *Goliathus "atlas"* to be present in their place

Age class	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10	Site 11	Site 12	Total
G. regius													
21–40	0	3	0	0	0	0	0	6	0	2	6	1	18
41–65	9	6	3	2	1	0	0	7	0	5	11	2	46
over 65	21	7	6	3	6	0	3	7	0	5	11	5	74
Total	30	16	9	5	7	0	3	20	0	12	28	8	138
G. cacicus													
21–40	0	0	0	0	0	0	0	0	0	0	0	0	0
41–65	4	0	0	0	0	0	2	0	2	0	0	0	8
over 65	15	2	0	0	0	0	5	0	4	0	0	0	26
Total	19	2	0	0	0	0	7	0	6	0	0	0	34
G. "atlas"													
21–40	0	0	0	0	0	0	0	0	0	0	0	0	0
41–65	4	0	0	0	0	0	0	0	0	0	0	0	4
over 65	7	0	0	0	0	0	3	0	3	0	0	0	13
Total	11	0	0	0	0	0	3	0	3	0	0	0	17

considering *Goliathus* females as different species from the males).

After having corrected identification errors (for instance, *G. cacicus* females to another species) *G. regius* was identified as present by 138 interviewees in the 12 communities, *G. cacicus* by 34 interviewees in 4 communities, and *G. "atlas"* by 17 interviewees in 3 communities (Table 1). At one site, the interviewees identified the presence of both *G. cacicus* and *G. "atlas"* but not *G. regius*.

In the case of *G. regius*, there was a statistically significant increase in the frequency of respondents positively identifying this species with increasing interviewee age ($\chi^2 = 34.1$, df = 2, $P < 0.0001$). Despite a relatively small sample size, the same pattern was also typical of *G. cacicus* ($\chi^2 = 31.3$, df = 2, $P < 0.0001$), with no young respondents (21–40 years old) able to identify this species as present in their locality. For *G. "atlas"* the pattern was nearly identical to that of *G. cacicus*: not only the three age class categories differed significantly in their responses ($\chi^2 = 15.6$, df = 2, $P < 0.001$), but no young respondent was able to correctly identify this taxon as present in their community.

Goliathus population trends: questions 5, 6, and 7

Men and women and age classes were pooled to increase sample sizes for statistical analyses. Out of 189 answers only one respondent (0.53%) claimed that these *Goliathus* beetles were increasing in abundance, 15.9% that they were stable, 67.2% that they were declining, while 18% could not answer the question (Table 2). The species' effect by site was statistically significant ($\chi^2 = 19.45$, df = 6, $P < 0.01$): more precisely, *G. regius* was perceived to be stable by almost 22% of interviewees, whereas the option "declining" was selected by the remaining proportion of respondents for both *G. cacicus* and *G. "atlas"*, and also for *G. regius* (although at a lower percentage; see Fig. 2).

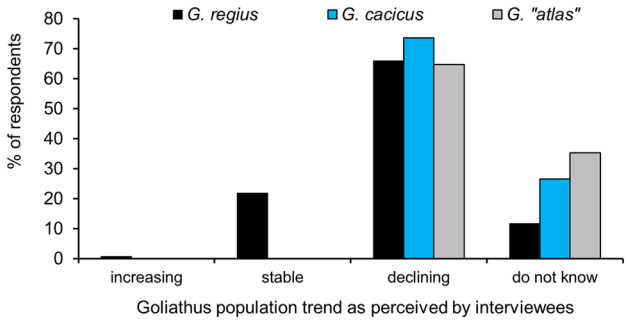

Fig. 2 Distribution of the answers concerning the population trends of *Goliathus* species at the study areas as perceived by the interviewee sample (total n = 189)

Only 1.1% of the interviewees (total n = 189) reported to see 30 or more *Goliathus* beetles per year, 2.1% from 11 to 29 individuals per year, 47.6% from 1 to 10 individuals, 23.3% less than one per year, and 25.9% was not able to quantify (Table 3). These frequencies were significantly different by species ($\chi^2 = 61.48$, df = 8, $P < 0.0001$; Figure S3).

Table 2 Distribution of the answers by site concerning the perceived population trend of *Goliathus* beetles at their place. For statistical details see the text

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10	Site 11	Site 12	Total
G. regius													
Increasing	0	0	0	0	0	0	0	0	0	0	1	0	1
Stable	7	4	0	1	2	0	0	4	0	1	11	0	30
Declining	20	9	9	4	5	0	3	12	0	7	16	6	91
Do not know	3	3	0	0	0	0	0	4	0	4	0	2	16
Total	30	16	9	5	7	0	3	20	0	12	28	8	
G. cacicus													
Increasing	0	0	0	0	0	0	0	0	0	0	0	0	0
Stable	0	0	0	0	0	0	0	0	0	0	0	0	0
Declining	13	2	0	0	0	0	6	0	4	0	0	0	25
Do not know	6	0	0	0	0	0	1	0	2	0	0	0	9
Total	19	2	0	0	0	0	7	0	6	0	0	0	
G. "atlas"													
Increasing	0	0	0	0	0	0	0	0	0	0	0	0	0
Stable	0	0	0	0	0	0	0	0	0	0	0	0	0
Declining	8	0	0	0	0	0	0	0	3	0	0	0	11
Don't know	3	0	0	0	0	0	3	0	0	0	0	0	6
Total	11	0	0	0	0	0	3	0	3	0	0	0	

Table 3 Distribution of the answers by site to the question: "How many *Goliathus* beetles do you see each year?" For statistical details see the text

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10	Site 11	Site 12	Total
G. regius													
30 or more	1	0	0	0	0	0	0	1	0	0	0	0	2
11 to 29	2	0	0	0	0	0	0	2	0	0	0	0	4
1 to 10	21	10	4	4	4	0	1	11	0	4	14	6	79
One every few years	2	2	0	0	2	0	0	3	0	4	8	2	23
Don't know	4	4	5	1	1	0	2	3	0	4	6	0	30
Total	30	16	9	5	7	0	3	20	0	12	28	8	138
G. cacicus													
30 or more	0	0	0	0	0	0	0	0	0	0	0	0	0
11 to 29	0	0	0	0	0	0	0	0	0	0	0	0	0
1 to 10	6	0	0	0	0	0	1	0	0	0	0	0	7
One every few years	4	2	0	0	0	0	4	0	2	0	0	0	12
Don't know	9	0	0	0	0	0	2	0	4	0	0	0	15
Total	19	2	0	0	0	0	7	0	6	0	0	0	34
G. "atlas"													
30 or more	0	0	0	0	0	0	0	0	0	0	0	0	0
11 to 29	0	0	0	0	0	0	0	0	0	0	0	0	0
1 to 10	4	0	0	0	0	0	0	0	0	0	0	0	4
One every few years	4	0	0	0	0	0	3	0	2	0	0	0	9
Don't know	3	0	0	0	0	0	0	0	1	0	0	0	4
Total	11	0	0	0	0	0	3	0	3	0	0	0	17

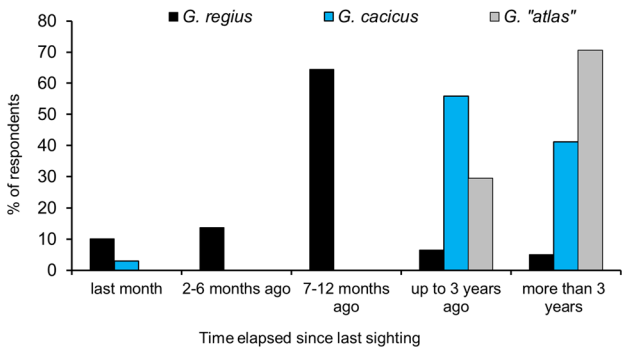

Fig. 3 Distribution of the answers concerning the time elapsed since the last *Goliathus* sightings by the various interviewees at their own places (total n = 138)

Goliathus population trends: question 8

Concerning the time elapsed since the last sighting of a Goliath beetle, there were significant differences by species ($\chi^2 = 263.3$, df = 8, $P < 0.0001$), with the majority of respondents (over 64%) reporting seeing *G. regius* between 7 and 12 months before the interview took place, whereas both *G. cacicus* and *G. atlas* were seen 1–3 years previously (Fig. 3).

Goliathus phenology: question 9

A high percentage of respondents was not able to clearly define the season of activity for these beetles (60% for *G. regius*, n = 135; 47% for *G. cacicus*, n = 34; 33.3% for *G. "atlas"*, n = 15). However, among the interviewees that could answer this question (n = 54 for *G. regius*, 18 for *G. cacicus* and 10 for *G. "atlas"*), there was agreement that all the *Goliathus* species were especially found in the wet season (87% versus 13% for *G. regius*; 94% versus 6% for *G. cacicus*; 100% versus 0% for *G. "atlas"*).

Goliathus habitat: question 10

The synopsis of the answers provided by interviewees (Table 4) clearly shows that (i) there was a clear consensus that all species do occur in forests only and that (ii) many people cannot indicate whether they observed them in any specific habitat types.

Goliathus usage: question 11

To this question, five persons overall answered that they eat on these beetles, 11 that they capture and eventually sell these beetles to intermediaries on occasions (but never as a primary occupation), and 61 answered that they do not do

Table 4 Distribution of the answers by site to the question: "Do *Goliathus* beetles live in (i) forest (bush), or in (ii) plantation/agricultural lands, or (iii) villages/urban areas, or (iv) are they present everywhere?

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10	Site 11	Site 12	Total
G. regius													
Forest	17	6	1	2	3	0	3	12	0	8	17	5	74
Plantation	2	0	3	1	0	0	0	1	0	0	0	0	7
Urban	1	0	4	0	0	0	0	0	0	0	0	0	5
Everywhere	2	0	0	1	0	0	0	3	0	0	4	0	10
Don't know	8	10	0	2	4	0	0	4	0	4	0	3	35
Total	30	16	8	6	7	0	3	20	0	12	21	8	131
G. cacicus													
Forest	11	2	0	0	0	0	4	0	5	0	0	0	22
Plantation	0	0	0	0	0	0	1	0	1	0	0	0	2
Urban	0	0	0	0	0	0	0	0	0	0	0	0	0
Everywhere	0	0	0	0	0	0	0	0	0	0	0	0	0
Don't know	8	0	0	0	0	0	2	0	0	0	0	0	10
Total	19	2	0	0	0	0	7	0	6	0	0	0	34
G. "atlas"													
Forest	7	0	0	0	0	0	3	0	2	0	0	0	12
Plantation	0	0	0	0	0	0	0	0	0	0	0	0	0
Urban	0	0	0	0	0	0	0	0	0	0	0	0	0
Everywhere	0	0	0	0	0	0	0	0	0	0	0	0	0
Don't know	4	0	0	0	0	0	0	0	1	0	0	0	5
Total	11	0	0	0	0	0	3	0	3	0	0	0	17

anything with them, or they kill them just because they are impressively big and thus frightening people.

Discussion

Our interviews indicate that *Goliathus* beetles are far less common (or more observable) than any other large sized beetle in the forests of West Africa. *Goliathus* beetles were reported as present in only 19% of the 61 surveyed villages, and there was a clear consensus among interviewees. The fact that *Goliathus* individuals were consistently reported as much rarer than *Mecynorhina* by most interviewees also suggests that lack of observability (perhaps of more secretive behaviour) was an unlikely reason to explain our results since the two genera share very similar behaviour and ecological traits.

Our data not only indicates a patchy occurrence of *Goliathus* beetles (especially *G. cacicus*, with its presence being reported in just a few sites) but also suggest a clear temporal abundance of these species. The two factors that clearly positively affected the presence of these beetles were DIST and PROT, showing that protected forests are crucial for their survival in the wild. The results of our interviews suggest that *G. cacicus* and *G. "atlas"* used to be more common, given that in several communities, older respondents knew them compared to the young interviewees who rarely did so. The same "stratification of answers" by interviewees (elders typically knowing a species but not the young persons) has already been shown for other animal species in West Africa (the tortoise *Centrochelys sulcata*, see Luiselli et al. 2021b) confirming a decline in populations and a corresponding increased threatened status. Obviously, one cannot assume a species' decline based simply on age of respondents. Youngsters, even in isolated rural communities in Africa, often lack the same experience in foraging and hunting as their elders simply because the younger generation is less dependent on food from the surrounding forests due to the proximity of larger towns and depots that might not have been available during their parent's younger years. Thus, they venture less into the forest and have less experience with free ranging animals. However, our results are likely to confirm a genuine population decline of West African *Goliathus* (especially *G. cacicus*) because there was a consensus that even in sites inhabited by *Goliathus* their numbers were relatively low and/or that the time elapsed since a last sighting was considerable. Few interviewees even reported (because comments were not standardized they were not included in the questionnaire, but noted) that *Goliathus*, including *G. cacicus*, were common until the 1990s with "hundreds" of individuals observed each year, whereas nowadays less than 10 individuals can be observed in the same sites. The perceived

status of *G. regius* was different from that of *G. cacicus*, as the former species was reported as more widespread, with more stable populations than the latter. It is possible that *G. regius*, being larger and with higher tendency to "fly" from a tree to another than *G. cacicus* (our unpublished data), is less secretive and so that its apparent abundance is perceived to be comparatively higher also for this reason. Thus, species detectability needs to be accounted for with purposely designed field studies to demonstrate whether *G. regius* is really more widespread and common than *G. cacicus*.

There was a lack of consensus among our interviewees, with most persons unable to confirm that Goliath beetles were seen during certain periods of the year; others reported they were seen especially after rains or in the wet season. Given this uncertainty in response, we cannot determine whether there is a well-defined period of above-ground activity throughout the year for beetles. Further field observations are needed to verify temporal activity patterns. In most cases Goliath beetles are encountered by chance as individuals by villagers. Interviewee's Information on the phenology of Goliath beetles may not be reliable because they are less likely to remember encounters with individual beetles than with a throng of them.

Our interviewees clearly converged in mentioning that forests were the primary habitat for Goliath beetles, suggesting also that they do not occur in plantations or urban/altered habitats. Available published data from the field are scarce and anecdotal but generally point to these giant beetles inhabiting the forest canopy, with several records from inside rainforest patches. The distribution of the whole *Goliathus* genus in Africa mostly overlaps with the Guinean-Congolian rainforest block (e.g. see Croizat 1994; De Palma et al. 2020), and both *G. regius* and *G. cacicus* have already been described as typical inhabitants of rainforests in West Africa (e.g. see Croizat 1994). However, because no study has examined whether these beetles are forest specialists, we are unable to conclude whether the information given by our interviewees is correct. Nonetheless comments made by the interviewees point to these giant beetles being forest specialists, and thus may be threatened by the high deforestation rates typical of the Ivory Coast and Liberia (Mallon et al. 2015).

These beetles are not much used by the communities we interviewed. Occasionally Goliath beetles are eaten but they are more frequently captured for sale for the international insect collectors market. According to our observations, we presume that this activity is not widespread in Ivory Coast and Liberia although the Ivory Coast has been the primary exporting country for *G. cacicus* in the 70s and 80s when thousands of these beetles were exported to Europe and North America. So, Goliath beetle exports are currently mainly due to the activity of single hunters/collectors than to a organized hunting scheme as that present, for instance, in some villages in Cameroon for *Goliathus goliatus* (Muafor and Le Gall 2011; Muafor et al. 2012). However, more organized collecting activities may have occurred in the recent past. Indeed, three independent interviewees (from two well-distinct sectors of the Ivory Coast) reported that, in those years, not only these beetles were much more common than today, but also that they used to sell them at a very cheap price (1 USD or so) in large amounts to exporters. This massive exploitation may have compromised many of the natural populations of these beetles in their preferred habitat types, where likely their frequency was higher and the harvest of adults was economically more effective. For instance, Banco Forest (Abidjan) was one of the classical exploitation sites for *G. cacicus* till the 90s, but the species seems to have been locally extirpated (or at least being presently very rare) as we are unaware of any single individual collected or exported from this locality since about the year 2011 (unpublished observations). Since most of the *G. cacicus* specimens were exported from coastal localities (Banco forest and the surroundings of Abidjan, Sassandra and San Pedro; our unpublished observations), we suggest that eventual extirpations should have occurred at the local scale more within the coastal forest patches than in the inner forests of the Ivory Coast. In fact, surfing the internet we were able to find photos of a few *G. cacicus* individuals that were captured after 2010, respectively in Issia (in 2017, see https://www.pinterest.fr/pin/537617892896600 80/), Comoé National Park near to Dedi City, and Divo Forest (october 2010, https://bioquipbugs.com/sell-your-collection/), all these being non-coastal localities. Conversely, Liberia has never been a main export country for Goliath beetles, and so it is very unlikely that the international entomological trade may have compromised in any way their beetle populations. Overall, we consider that goliath beetles populations (especially *G. cacicus*) may have been heavily affected by deforestation, cacao industry and locally by over-collecting in the Ivory Coast, but almost only by deforestation in Liberia.

Face-to-face interviews, although certainly useful to assess potential conservation issues and the status of given species/populations, should always be considered carefully as the information provided is generally unverified. This applies even to the present study case. It should be mentioned, however, that in the two villages very close to rainforest patches, where we obtained more positive answers on the presence of *G. cacicus* (one in Cote d'Ivoire and one in Liberia) we were able to find respectively 12 and 5 individuals of this species, indicating that the apparent abundance of these beetles was much higher than in the other surveyed sites (where no even single individuals were observed). This fact may indicate that the information provided by our interviewees can be considered reliable. It also indicates that we can still turn the tide on declines of large beetles in Africa,

where large forests are adequately protected, and collection regulated.

Conservation suggestions

The two *Goliathus* species studied here are not evaluated in the IUCN Red List; they should be assessed as soon as possible to provide the scientific basis for further conservation actions and legal decisions by the pertinent governmental authorities. In addition, *Goliathus* beetles are potentially excellent flagship species that can be used to rally support for local conservation initiatives by local villagers. Because these animals are attractive and charismatic and linked to the forest habitat, they can be used as potential target species for ecotourism activities to be led local persons (who are knowledgeable of these animals because they may have even participated in their collection in the past). We therefore suggest that (i) ad hoc community projects for the conservation of these beetles should be considered and (ii) feed-back meetings with local headmen and villagers are organised to raise awareness about the decline of *Goliathus* species and even other insect species inhabiting the West African forests. In addition, the protection of forest patches, including that of specific plants (like large *Vernonia*) is essential given that these beetles do not occur across the whole forest patch but are generally confined to few specific trees, so that the eventual extirpation of these few trees may represent a serious reason for catastrophic collapse and even local extinction of the *Goliathus* populations.

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Author contributions Study design: LL, GA; fieldwork: SNA, LL, TFL, GSD, EAE, GHS, DD; data analysis: LL, DD; writing the article: LL, JEF, GA, DD; reviewing the various drafts: SNA, TFL, GSD, EAE, GHS; final review: all authors.

Data availability The data that supports the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

Declarations

Conflict of interest The authors have not disclosed any conflict of interest.

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