themselves in it. These spines are very sharp and are known to easily cause nasty infections as they are covered in a biofilm of algae, fungi, bacteria,protozoa etcetera. I also check the four corner pockets of the beating sheet before taking it apart, a scorpion or something else might be hiding there.

I would love to hear the experiences of other people using this method, and also if beating sheets can be used in other unconventional ways. And please be sure to let me know if you ever plan to visit Suriname!

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On the origin of *Goliathus atlas* Nickerl, 1887 (Scarabaeidae: Cetoniinae: Goliathini)

by

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An entomological enigma has persisted for more than a century. What is *Goliathus atlas* Nickerl, 1887? Is it a good species, a natural hybrid between *G. regius and G. cacicus,* or simply a morphological aberration of *G. regius?* There are three major morphological features that collectively define *G. atlas:* 1. A light yellow pronotum and scutellum. 2. A partial suture stripe. 3. Interrupted lateral bands. An additional feature can be observed. The white on the elytra of *G. regius* is minimally reflective of light while that of *G. cacicus* is highly iridescent. The white on the elytra of *G. atlas* is moderately reflective of light. All of the above features are intermediate traits between G. *regius and G. cacicus.* The true identity *of G. atlas* may be unveiled by either of two approaches: One is to perform a genetic analysis on specimens of *G. atlas,* and the other is to cross *G. regius with a G. cacicus* in captivity and see what happens. Although the first option is straightforward, it is extremely difficult if not impossible as *G. atlas* has not been sighted for approximately 50 years, probably due to massive deforestation across West Africa. The second option is much more involved, but still feasible to carry out.

In 2014, the decision was made to collect live G. *regius and G. cacicus* in West Africa, maintain them in captivity, and finally attempt to cross their virgin offspring *to see if G. atlas* can be produced experimentally. In 2015, an expedition was assembled and live *G. regius* was obtained in Ghana. Our team subsequently visited Ghana in 2016 and 2017, but *no G. cacicus* were found. During subsequent years (2018 and 2019), local

Fig. 1. Male *Goliathus cacicus* used for the crossing experiments.

Fig. 2. Male *Goliathus regius.*

team members were continuously funded to make numerous expeditions extending to Ivory Coast and Liberia. All the formerly known ranges of *G. cacicus* were explored. Sadly, all of the expeditions were met with massive deforestation attributed to cacao plantation, oil palm plantation, rubber tree plantation, and timber production. Ivory Coast and Ghana are the number one and number two cacao producers in the world, respectively. It is heartbreaking to learn that a non-essential food such as chocolate can have such a catastrophic effect on nature. By 2019, *G. cacicus* had not been sighted for nearly 10 years. After searching for 5 years without any trace of *G. cacicus,* our team decided to steer away from the historical known distribution and explore primary forests far away from the coast where *G. cacicus* was once abundant according to old literature and anecdotal accounts from Europeans who collected extensively in Ivory Coast in the latter half of the 20th Century. Finally, in November 2019, *G. cacicus* was discovered in a new location.

Historically, G. *cacicus* mainly occupied coastal forests while G. *regius* mainly dwelled in inland forests. However, there are records *of G. cacicus* found more than 150 kilometers inland, and in 2019, our team discovered a population of *G. regius* right on the coast. In Ghana, *G. regius* feeds on the free-flowing sap of the Oba Tree (local name, scientific name unconfirmed, not *Vernonia sp. or Acacia* sp.). In Ivory Coast, *G. cacicus* had been observed to congregate on *Vernonia conferta and Acacia mangium* (introduced from Australia in the 1970s as a plantation tree). The newly discovered population of *G. cacicus* is approximately 80 kilometers from the coast. Incidentally, G. *regius* is also found here. Surprisingly, both *G. regius and G. cacicus* from this locality congregate exclusively on a species of tree that is different from the ones mentioned above, despite *V. conferta and A. mangium* both being present in this region. Although the identity of the beetles' mutual tree has not been confirmed, it may be a species belonging to *Vernonia.* However, it is neither *V. guineensis nor V. senegalensis.* Given G. *regius and G. cacicus* coexist in this region and even share the same species of tree, one could not help but wonder "Could there be *G. atlas?"* About 2 weeks after the rediscovery *of G. cacicus, a* wild specimen *of G. atlas* was collected among *G. regius and G. cacicus* for the first time in

approximately 50 years! This strongly supports the hypothesis that G. *atlas* is a natural hybrid of *G. regius and G. cacicus.* Our team also managed to record a video of this living specimen of *G. atlas,* which has never been done before. Shortly after filming, this *G. atlas* flew away! It was a small *G. atlas,* perhaps around 6 cm. But that little body held the genetic information that would put the mystery to rest once and for all. With no DNA to analyze, and with breeding stock in hand, the initial plan was to attempt to cross wild males of *G. cacicus* to virgin females *of G. regius* in captivity.

In December of 2019, the authors had available quite a few virgin females *of G. regius* from captive breeding. In total, 3 wild males *of G. cacicus* mated with 6 virgin females *of G. regius.* The males were placed directly on the dorsum of the females. The males very quickly recognized the scent of the females with their antennae as they would with females of their own species and proceeded to mate with no hesitation, the females also accepted the males readily. The copulations occurred as if the beetles were of the same species with no anomalies observed. Each mating lasted anywhere from 20 minutes to over 6 hours. Most of the pairs exhibited consecutive mating sessions. Several hundred eggs were produced, yet not a single one was viable! in this regard the example of the hinny came to mind. When a male donkey mates with a female horse, the offspring, mules, are easy to produce. However, when a male horse mates with a female donkey, the offspring, the hinny, is very difficult to obtain. Does this phenomenon also apply to *G. atlas?* Perhaps G. *atlas* is only possible when a male G. *regius* mates with a female G. *cacicus.* Given that *G. regius, G. cacicus and G. atlas* were found together on the same species of tree in this locality, the possibility that *G. atlas* was a hybrid between the other two species was the most likely possibility, though we would have to wait for one or two years before we could have virgin females of *G. cacicus* available for the crossings.

Luckily, in January of 2020, another specimen of *G. atlas* was found and successfully collected. The *88 mm G. atlas* specimen was sent to Dr. Jen Pan Huang (Academia Sinica, Taiwan) who carried out the genomic and mitochondrial DNA analyses. Since mitochondrial DNA comes solely from the maternal side, and the combination of *G. cacicus* male crossing *G. regius* female failed to produce viable eggs, the prediction was that the mitochondrial DNA of this specimen of *G. atlas* must have come from *G. cacicus,* assuming G. *atlas* is a hybrid. However the results of Dr. Huang's analysis were surprising. The mitochondrial DNA belonged to *G. regius.* This was unexpected, because all of the eggs from our hybrid experiment *(G. cacicus* male crossing *G. regius* female) were not viable. Furthermore, the genomic DNA revealed that the majority of the genes belonged to *G. regius,* which suggests that the atlas specimen was not the product of recent hybridisation but rather that it had occurred several generations prior. This meant that this G. *atlas* specimen was not an F1 hybrid and that *G. atlas* is fertile or at least capable of backcrossing with *G. regius.* This may explain why it is not uncommon to see specimens of *G. regius* with certain traits *of G. atlas,* such as a yellow pronotum and scutellum, a partial suture line, or thinning of lateral bands.

There are four species within *Goliathus* that can attain massive sizes: *regius, goliatus, orientalis, and cacicus.* All of them can hybridize with each other. This has been proven experimentally through captive breeding over the past 2 decades. F1 hybrids between *goliatus and orientalis,* as well as F1 hybrids between *regius and goliatus,* were produced in the early 2000s by a Japanese breeder and a German breeder, respectively. The German breeder attempted to propagate the F1 hybrids, but none of the eggs hatched. The first author produced F1 hybrids between *regius and orientals* in 2019, some of which very much resemble *G. atlas* morphologically. The F1 hybrids were fertile and went on to produce F2 hybrids, which display an array of morphological characters: some resemble either *regius or orientals* while others take on intermediate forms. Recently, the first author was able to cross a wild male *of G. cacicus* to a virgin female of *G. goliatus to* obtain 5 hybrid larvae. However, these larvae developed poorly and only one made a cocoon which died during the pre-pupa stage. Interestingly, the hatching rate for the F1 hybrid eggs between G. *regius and G. orientals,* as well as the hatching rate for the subsequent $2 hybrid eggs, were nearly 100°/0. However, the hatching rate for the F1 hybrid eggs between G. *cacicus and G. goliatus* was only about 10%. This may be attributed to the increased genetic distance between *G. cacicus and G. goliatus.*

In early 2021, we attempted making G. *atlas* again by crossing several *G. cacicus* males to 4 virgin

Fig. 3. Mating *of G. cacicus* males and virgin G. *regius* females.

G. regius females. Dr. Huang's genetic analysis showed this can be done. This time around, about 400 eggs were obtained. Again, the hatching rate was extremely low. Only 40 eggs hatched. They came from two females. The poor hatching rate may explain the rarity of *G. atlas* despite *G. regius and G. cacicus* congregating on the same species of tree and mating with each other readily in captivity as if they were the same species. The genetic distance between *G. regius and G. cacicus* may be large, thus causing the observed low hybrid hatching rate. In August of 2021, the first *G. cacicus and G. regius* hybrid made a cocoon and in December of 2021, it successfully eclosed. The entomological mystery since 1887 was finally solved. The hybrid, a male specimen, corresponded perfectly with the holotype of Nickerl's Beetle. This result, together with Dr Huang's molecular data, confirmed beyond doubt that G. *atlas* is indeed the hybrid *of G. cacicus and G. regius.*

In this new locality, *G. cacicus* is observed from June through December. After December, the trees on which G. *cacicus and G. regius* congregate shed their leaves and the beetles do not come anymore. It is unclear if the adult beetles have died or they are congregating on other species of trees. According to collection data that our team has compiled from various experienced collectors who have found *G. cacicus* in the past, *G. cacicus* congregates on at least five species of trees *(Acacia mangium, Ficus sp., Vernonia conferta,* and two or three more species whose scientific names are unconfirmed). This is contrary to literature from colonial times that G. *cacicus* only congregated on one species of tree. Furthermore, specimens of *G. cacicus* collected in December appeared very fresh (sharp claws, no missing parts, highly energetic, minimal scratches, etc.), they do not look like they are in the terminal stage of life. As a result, it is highly speculated that *G. cacicus* from January to June congregates on other species of trees.

Lastly, we want to convey our enormous relief to know that G. *cacicus-and* astonishingly G. atlas-are still flying in the remaining patches of the vanishing West African Upper Guinean Forests. Every effort will be exhausted to establish G. *cacicus* in captivity. It is only a matter of time before the last paradise is engulfed by human encroachment.

Fig. 4. Female *Goliathus atlas* produced by the hybridisation of a male *cacicus* and *a* female *regius.*

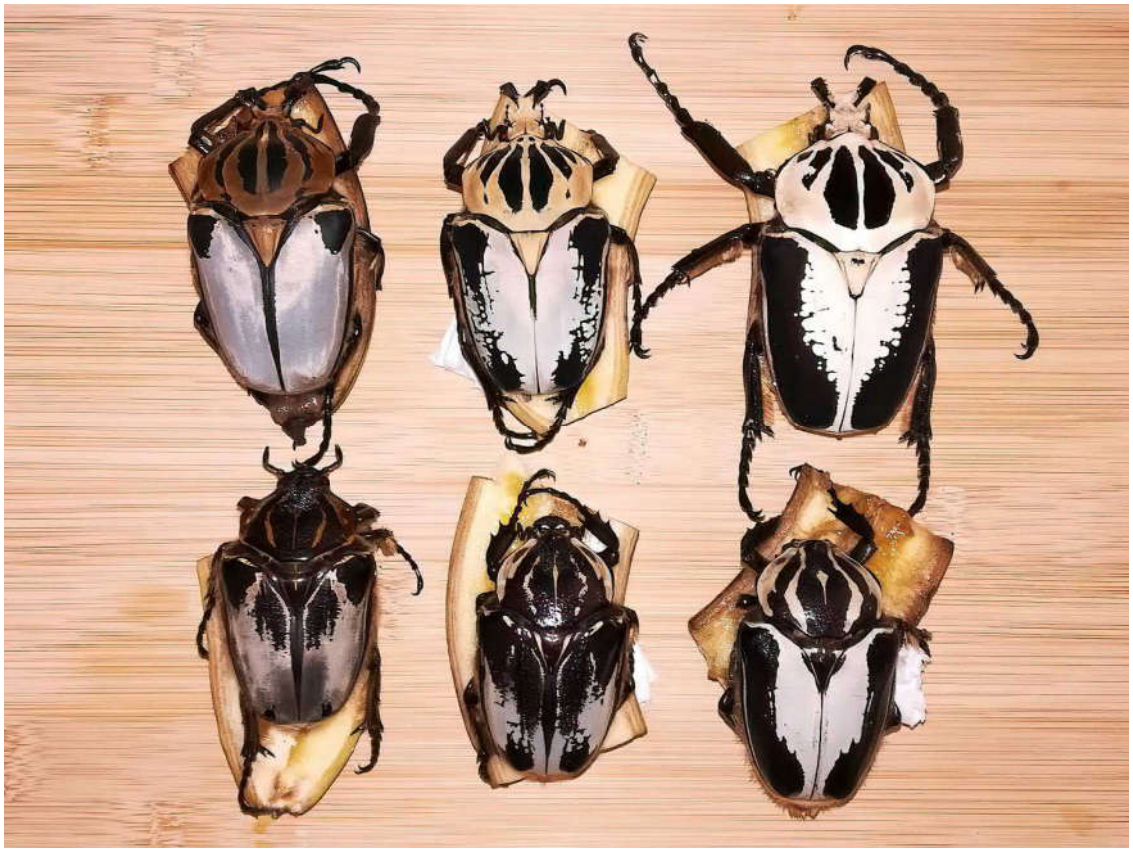

Fig. 5. Comparison of the hybrid F1 generation G. *atlas* (middle column, male above and female below) with the parental stock *of Goliathus cacicus (left) and Goliathus regius* (right).

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