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Scientific Knowledge on *Vitellaria paradoxa*, A Vulnerable Species: State of Research Works and Perceptive

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Abstract: *Vitellaria paradoxa is a species from sub-Saharan Africa of ecological interest. Given its importance, the species is subject to several threats and constraints of domestication. In order to propose research perspectives for the domestication of the species it is important to note the current scientific knowledge on the species. This article provides a review of research work on Vitellaria paradoxa in general but more particularly on its morphological, genetic characterization and its juvenile growth. The information from the articles consulted in different search engines shows that various themes have been addressed on Vitellaria paradoxa which is a species of great importance for rural communities, especially women. However, the species is subject to many threats and constraints that hinder its domestication. This work shows research studies already done and offers perspectives for new potential research works. From the articles consulted, it appears that various methods are used to improve the slowness of juvenile growth of shea. It is a question of sexual and asexual reproduction, provenance test, fertilization but also through morphological and genetic characterizations for a genetic improvement of species. Despite various methods used to improve juvenile growth of shea, other aspects such as climatic variability of the areas where which the seeds come from; the identification of favorable doses of mineral and organic fertilizer and the best fungal strains must be studied in order to better understand these constraints to domesticate the species.*

Keywords: *Sapotaceae, Shea tree forestry, Fruit species, Seedling, Agroforestry*

1. INTRODUCTION

Forest resources play an essential role in the life of communities. They are sources of income and food. One of these resources is *Vitellaria paradoxa* C. F. Gaertn (Figure 1 and Figure 2) which is an endemic tree to the Sudano-Sahelian zone. It is a source of food, plays an ecological role, and it is of economic and medicinal importance. It is a species of the Sapotaceae family that extends from Senegal to the northwest of Uganda. The species is present in 19 countries across Africa namely Benin, Ghana, Chad, Burkina Faso, Cameroon, Central African Republic, Ethiopia, Guinea Bissau, Ivory Coast, Mali, Niger, Nigeria, Senegal, Sierra Leone, Sudan, Togo, Uganda, Zaire and Guinea (Figure 3). In Benin there are five shea parklands according to density and the climatic gradient

(Gbédji, 2003; Gnanglè, 2005). There are two subspecies of *Vitellaria paradoxa* of which one *Vitellaria paradoxa* subsp paradoxa extends from Senegal towards the East until the Central African Republic (Boffa, 1999) and the other *Vitellaria paradoxa* subsp *nilotica* occurs in Sudan, South Sudan, Ethiopia, Uganda and North East of Democratic Republic of Congo (Vermilye, 2004; Okullo and Hall, 2004; Byakagaba et al., 2011). It is a typical tree of dry forests and wooded savannas of Sudanese zone (Schnell, 1976). Shea tree is a slow-growing tree but which has a long lifespan of 300 years (Jøker, 2000). Without grafting generally, it produces fruits from 15–20 years, with maximum fruit production after 25–40 years of growth (Sanou et al., 2004), but when grafted productivity begin at five years. The annual production of *Vitellaria paradoxa* is 15–30 kg per tree (Greenwood, 1929; Ruyssen, 1957; Agbahungba and Depommier, 1989). Shea is the pivot of the park system; it is omnipresent in farms and fallows. It plays an essential role in the socio-economic and ecological balance of traditional agroforestry systems (Bayala et al., 2006). The tree produces wood and fruits very appreciated locally. However it is especially known for the quality of the butter extracted from its almonds (kristensen and Lykke, 2003). Shea products (almond and butter) are the subject of a flourishing international trade which brings important currencies to producing countries and generates substantial income for the rural populations involved in the collection and processing of fruits (Ahouansou et al., 2009). Likewise, the shea pulp is rich in nutrients (Ahouansou et al., 2012) and plays an important nutritional role during the dry season in rural communities. Nevertheless, despite the importance of the species, it is still semi-domesticated because of constraints that hinder its domestication. These constraints are biological but also socio-cultural (Azongnidé et al., 2019). Consequent, the species is classified as vulnerable according to IUCN. Thus, in order to improve its conservation and enhancement, several research studies have been carried out on the species in many fields.

Figure 1. *Overview of Vitellaria paradoxa.*

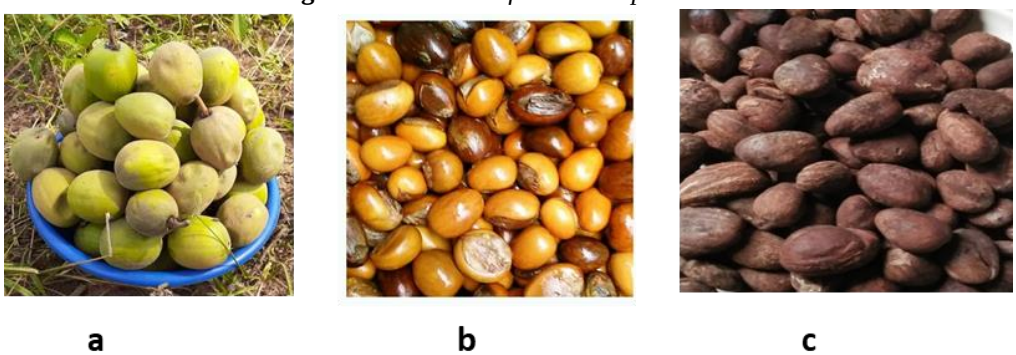

Figure2. *Various organs of Vitellaria paradoxa, (a) mature fruits, (b) seed, (c) almond, (Source: Azongnidé, 2019)*

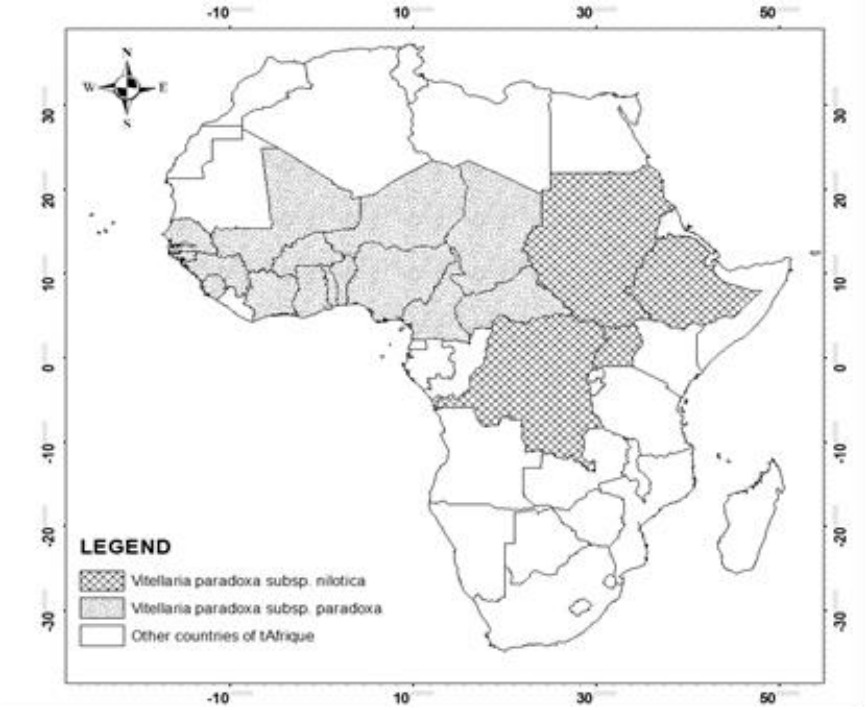

Figure3. *Geographical distribution of Vitellaria paradoxa*

The aim of this article is to summarize current scientific knowledge on *Vitellaria paradoxa* more precisely on aspects such as germination capacity of seeds, threats and constraints of domestication, morphological and genetic diversity as well as the techniques used to improve juvenile growth of *Vitellaria paradoxa*. This will allow to identify research perspectives to improve the juvenile growth of shea which will result in the domestication of the species.

2. DATA COLLECTION

The methodological approach used in writing this literature review consists of carrying out documentary searches in search engines such as Scopus (2009 to 2020) and then supplemented by publications not older than one year in Google Scholar. The keywords used are as well in English as in French and are the following: *Vitellaria paradoxa*, Shea tree, karité, seedling, croissance, growth, morphological characterization; genetic characterization. The combinations of these keywords are as follows, *V. paradoxa* or Shea tree or karité; *V. paradoxa* or karité or shea tree and seedling and growth; *V. paradoxa* or karité or shea tree and morphological characterization and genetic characterization.

The different combinations made it possible to identify 155 documents in total, of which 125 documents in Scopus and 30 documents in Google Scholar. From these results, a selection was made and allow to retain out of the 155 documents, 70 documents taking into account the theme addressed by them which is sufficiently focused on the area of interest of this bibliographical synthesis. It is followed by the reading of scientific articles.

3. NAME OF *VITELLARIA PARADOXA* IN LOCAL LANGUAGES

The tree is better known by its past name: *Butyrospermum parkii* (G. Don) Kotschy (*Butyrospermum* meaning "butter seeds"; the epithet "parkii" honoring Mungo Park, who "discovered" the tree while

exploring Senegal). Table 1 summarizes the various Benin's local language appellations.

Languages	Names
Mahi	Kotoble
Yoruba	Emi
Dendi	Bulamna
Bariba	Bu Samba

Table1. *Calling Vitellaria paradoxa in some local languages;* ***Source.*** *Neuenschwander et al, (2011)*

4. USES *VITELLARIA PARADOXA*

Vitellaria paradoxa is a multiple-use species. It plays an important role for food (Ahouansou et al., 2012; Gnangle et al., 2012; Raimi et al., 2014; Dembélé et al., 2016), in ecology (Bayala et al., 2006), economically (Pouliot, 2012) and medicine (Gnangle et al., 2012; N'Danikou et al., 2011).

These uses are many and diverse, the pulp of shea fruits is edible and presents a significant nutritional contribution during the lean season (Ahouansou et al., 2012). This pulp is very rich in nutrients such as macronutrients, minerals (Ca, Fe, K, Mg, Mn, p, Na, Zn, in vitamin B and C as well as more than a dozen amino acids (Asparagine/aspartic acid, Threonine, Serine, Glutamine/glutamic acid, Proline, Glycine, Alanine, Valine, Cysteine, Methionine, Isoleucine, Leucine, Tyrosine, Phenylalanine, Lysine, Histidine) (Honfo et al., 2014). It is used to prepare drinks and jam, which are very popular in Mali and Burkina Faso (Arbonnier, 2000). Parts of the tree such as roots, wood used for medicine, construction materials fuel wood and carving wood (Hall et al., 1996; Boffa, 1999).

Shea has honey flowers particularly sought after by bees. It represents a privileged location for hives for traditional beekeeping. Shea butter is obtained after drying and crushing the nuts, crushing the almonds with a pestle and churning. This butter is widely used locally for cooking as a source of vegetable fat (Dembélé et al., 2016), this butter is very rich in nutrients (Raimi et al., 2014) however its composition varies from one area to another (Ugese et al., 2008). According to Arbonnier, 2000, this butter extracted from almonds is also used as lighting oil, for the manufacture of soaps, in pharmacopoeia (healing and transcutaneous vector) and for cosmetic care. For export, raw almonds or almonds already transformed into shea butter are used in cosmetology (basis of many skin and hair treatment products), in pharmacology (excipient for ointments used for the treatment of dermatoses, burns, cracks, etc.) and in pastry as a substitute for cocoa butter.

5. SOCIO-ECONOMICS IMPORTANCE'S OF *VITELLARIA PARADOXA*

Vitellaria paradoxa is a species of great socio-economic value through export raw almonds or shea butter which are the products of the tree. The commercialization of these products represents an important source of income for the local community including women who are the key players in the shea sector. To the northwest in Benin, rural households derive 46% of their income from shea (Dah-Dovonon and Gnangle, 2006; Sokpon and Yabi, 2006). Between August 2014 and September 2016, the Global Shea Alliance facilitated the export of 121,000 MT dry shea kernels with a market value of US $43 million from Africa (GSA, 2016). When completed, a change in FDA chocolate labelling requirements could yield an increase in the demand for shea up to 500,000MT and a 20% increase in West African shea exports, translating into over US$85 million additional income across the producing countries (GSA, 2019). It is estimated that there are 16 million women engaged in shea

collection and processing across the producing regions of Africa (GSA, 2019).

6. Conservation States, Threats And Constraints Of Domestication Of *Vitellaria Paradoxa*

Vitellaria paradoxa is a pivotal species of the park system, it is ubiquitous in fields and fallows in its range. The species is often associated with others species such as *Parkia biglobosa*, *Terminalia avicennioides*, *Acacia senegalensis* and *Annona senegalensis* (Boffa, 1999).

In Benin shea represent up to 70% of the woody vegetation (Agbahungba and Depommier, 1989) 80% in parts of northern Ghana (Lovett and Haq, 2000) and Burkina Faso (Boffa 1999). The Sudanian savanna zone which recorded the highest population of Shea trees in the 1940 with estimates of 230 trees ha-1 (Chevalier, 1946). In 1952, the Institution of Seed Oil Research (I.R.H.O) reported that the densest stands were found in southern Mali, Burkina Faso, northern Côte d'Ivoire, Ghana, Togo, Benin and Nigeria. But since these last decades this density knew a decreases and is 11 trees ha-1 (Nikiema et al., 2001), while West Africa has numbers dwindling to 5 tree ha-1 (Djossa et al., 2008). In Benin, too, this density is declining in many shea parks according to the PARASEP study report (Figure 4) (Gnangle, 2017).

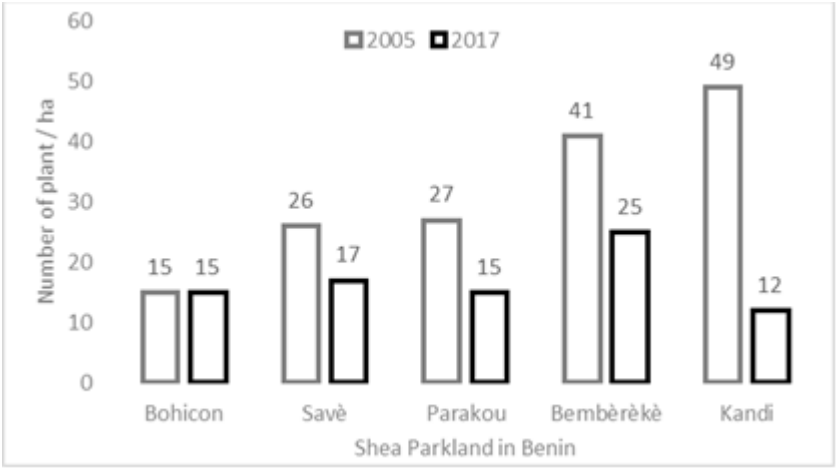

Figure4. *Comparison of average densities of shea trees between 2005 and 2017, Benin (Gnangle, 2017)*

The decline in shea populations may be due to Human pressures, in particular the felling of trees for fuelwood, bushfires, deforestation of forests for the benefit of agriculture, drought, cultural practices including the reduction of the fallow period, the agricultural mechanization and climate change are threats to *Vitellaria paradoxa* in its range (Maïga and Kologo, 2010; Neuenschwander et al., 2011). Local overexploitation of seeds influences the natural regeneration as well as the genetic diversity of the species resulting in a low-density rate of juveniles in shea parks. The structure and regeneration status of *Vitellaria paradoxa* populations under different land development regimes in the Atacora department in Benin by Aleza et al., 2015 shows that the type of land management influences the structure and the natural shea regeneration rate. Parasitic attacks, in particular Loranthaceae (Ahamidé et al., 2017), the non-existence of shea plants among nurserymen for the reforestation of aging shea parks (Ouoba et al., 2018) also constitute threats to the species. Based on these threats, the species is classified on the list of vulnerable species according to the International Union for Conservation of Nature (IUCN) at global and national level according to the red list of Benin (Neuenschwander et al., 2011).

Apart from all these threats, several constraints hamper the domestication of the species. These

constraints are of several orders, namely biological constraints and socio-cultural constraints (Azongnidé et al., 2019; Seghieri, 2019). Due to the recalcitrant nature of shea seeds, the slow juvenile growth of the seedlings, the first late fruiting, the lack of technicality for the production of quality seedlings which constitute biological constraints, lead to the reluctance of farmers to planting shea trees, but there are taboos against planting the tree constituting socio-cultural constraints. All of this highlights the need to select and distribute improved and adequate materials that meet farmers' needs for the domestication of the species.

7. GERMINATION OF *VITELLARIA PARADOXA* SEEDS

Shea is a species whose fresh seeds have a good germination capacity with a rate of 98% (Picasso, 1984; Aderounmu and Asinwa, 2019). However, this capacity depends on several factors such as the shelf life and the temperature which strongly influence the germination capacity of the seeds of the species leading to a low germination rate (Aderounmu and Asinwa, 2019). Taking into account the viability of the *V. paradoxa* seeds, the fresh seeds must be sown immediately or after 7 days of collection in order to guarantee a good germination capacity of these seeds. The mode of germination of shea has been particularly studied by Jackson, 1968 and recently by Iddrisu et al., 2018. It differs from conventional schemes because the organ that sinks into the soil is cotyledon in nature (Figure 5) and the stem originates underground, at the level of the pivot, 6 or 7 cm deep (Figure 5). This mode of germination, described as cryptogeal by Jackson, 1968, is a type of germination characteristic of pyrophytes in arid regions. This helps protect the bud and the seedling against drying out and bush fires. During the first years the seedling growth is extremely slow (Picasso, 1984). Various factors affect the germination of shea seeds. The origin of the seeds and the depth of sowing can affect the germination of shea seeds. Provenances with larger seeds germinate at a depth of 4 - 8 cm, while small seeds germinate at a depth of 2 - 8 (Ugese et al., 2009). The morphology of the seeds affects their germination, larger seeds germinate quickly than small seeds (Iddrisu et al., 2018). In terms of seedling maintenance techniques, mulching or not of *Vitellaria paradoxa* seedlings does not affect the germination capacity of the seeds (Ugese et al., 2009).

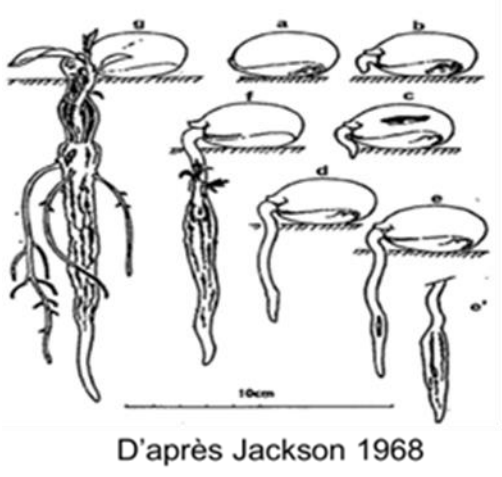

Figure5. *Germination of the shea seed; Source: Jackson 1968*

8. MORPHOLOGICAL AND GENETIC DIVERSITY OF SHEA

Vitellaria paradoxa being a species of high importance, several themes in various fields were discussed on the species namely: morphological and genetic diversity, juvenile growth, ecology and management, population structure, chemical and nutritional composition, socio-economics, medicine

and pharmacology.

The study of morphological and genetic diversity of forest species is done through various methodological approaches. They are the perception of populations as well as, phenotypic and genetic evaluation. Considering shea tree these three approaches are used. For example, populations' perceptions on the morphological variability made it possible to determine ethno-varieties in Burkina Faso and Uganda (Gwali et al., 2011; Sandwidi et al., 2018). Also, the evaluation of tree phenotypes by taking dendrometric and morphological measurements (Kakaï et al., 2011; Gwali et al., 2012; Abdulai et al., 2017) and finally the molecular evaluation by developing new microsatellites or using microsatellites already developed (Allal et al., 2011; Gwali et al., 2015; Abdulai et al., 2017) can be used to confirm or invalidation the results obtained from the two study approaches mentioned above.

Nevertheless, very few works have really combined these three approaches to provide very explicit results and which can allow a selection of effective plant material that meets the needs of populations in the domestication of the species.

Studies of local perception on the morphological variability of shea butter, carried out in Burkina-Faso and Uganda respectively by Sandwidi et al. (2018); Gwali et al. (2011) shown that local populations have great knowledge of the morphological variability of shea tree. These communities use morphological characterizations of the leaves and fruits to identify and describe morphological variabilities among shea trees.

The works of (Allal et al., 2011; Logossa et al., 2011; Soro et al., 2011; Abdulai et al., 2017) on shea populations on the vegetative growth relate to morphological diversity on one hand, and on the measurements of leaves and fruits for molecular diversity on the other hand. For the morphological characterization of shea leaves and fruits, there are variabilities between countries (Table 1). This is linked to various factors such as climatic variability, soil conditions, type of land use (Aleza et al., 2015) as well as cross-pollination which creates shea hybrids at random (Soro et al., 2011) influencing the morphological characterization of populations. The selection of trees with high productivity of specific local fruit characters by farmers also contributes to the large variation observed in the quality and quantity of shea fruit (Lovett and Haq 2000). Similarly, geography position also affects species production. This was noticed by separating populations from western region and those from eastern part of the area which correspond to the distinction between subspecies (Allal et al., 2013). All these great variabilities are an opportunity for an efficient selection of plant materials in order to improve juvenile growth, late fruiting but also improve shea productivity.

9. JUVENILE SHEA GROWTH

Various methods have been used to improve the performance of juvenile shea growth mainly through sexual reproduction (Aderounmu and Asinwa, 2019; Aderounmu and Musa, 2019; Sandwidi et al., 2019), asexual reproduction (Lovett and Haq, 2013; Aderounmu, 2019) and fertilization, in particular mineral fertilization (Yakubu et al., 2015, Azongnidé et al., 2019, Aderounmu and Musa, 2019) which is the most used to the detriment of organic and biological fertilization (Dianda et al., 2010). Some provenance tests of plant material were also carried out in order to increase the performance of juvenile shea growth (Dianda et al., 2010; Ugese et al., 2011; Bayala et al., 2018; Sandwidi et al., 2019; Azongnidé et al., 2019). However, very few of these provenance tests take into account the climatic variability of the areas of provenance. They are also based on other criteria such as morphological diversity of shea tree perceived by the local communities.

These various studies carried out on juvenile growth of shea have shown that at juvenile stage the

growth of *Vitellaria paradoxa* is very slow because of the development of its root system for reproduction by seed and by root cuttings. However, that is a strategy of adaptation of the species against the unfavorable conditions of their environment such as aridity; vegetation fires (Picasso, 1984).

This slow growth is one of the causes that hinders the domestication of the species, leading to the non-production of plants in nurseries for the reforestation of shea parks which are affected by different cropping systems.

The growth performance of shea seedlings depends on several factors, namely the climatic variability of the areas where seed come from, the phenotypic and genotypic characterization of adult trees but also the environmental conditions of the areas of origin.

Thus, according to recent work, the growth rate could be stimulated by the selection of plant material adapted to local environmental conditions or by biological and mineral fertilization (Bayala et al., 2009; Dianda et al., 2010; Yakubu et al., 2015; Bayala et al., 2018; Azongnidé et al., 2019). The various fertilization methods used to increase the juvenile growth of shea have different effects on seedling growth of the species. In terms of mineral fertilization, the most used minerals are nitrogen, phosphorus, potassium but also urea. The different doses of minerals have a positive impact on the growth in height and diameter at the neck of the seedlings (Aderounmu and Musa, 2019). However, at a certain dose that is too high, this causes burning of the aerial part (Azongnidé et al., 2019). Regarding biological fertilization, the most used strain is the genus Glomus (Dianda et al., 2010; Agele et al., 2016). However, it would be preferable to test other strains of fungus in order to compare their effect on the juvenile growth of shea to make the selection of the best fungal strains.

10. RESEARCH PERSPECTIVES

Following this review, we suggest as perspective research to:

- Test the effect of provenance of shea seeds on its juvenile growth while taking into account the climatic zones of the provenance of the seeds;
- Evaluate the effect of organic fertilization on the juvenile shea growth;
- Identify favorable doses of mineral and organic fertilizers to improve the juvenile growth of shea;
- Identify the symbiotic fungi of *Vitellaria paradoxa*;
- Study the effect of controlled mycorrhization on the juvenile growth of *Vitellaria paradoxa* in nursery but also in real environment.

11. CONCLUSION

At the end of this review, it appears from the publications consulted that *Vitellaria paradoxa* is a species of great importance for populations, especially rural populations. However, the species is subject to numerous threats which make it vulnerable in its range with constraints that hinder its domestication. Nevertheless, various research works are carried out in order to conserve the species and to remove the constraints which undermine its domestication in particular the slowness of its juvenile growth through tests of provenances, fertilization, morphological and genetic characterization for the genetic improvement of the species.

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