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Scorpion mud turtle breeding in the Amazon: zootechnical and environmental activity for the species conservation

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Commercial captive turtle breeding is an opportunity for *Kinosternon scorpioides scorpioides* conservation, as predatory hunting, destruction and habitat degradation are the main threats to its natural populations. In this sense, the goal of this study is to provide a synthesis of knowledge about the species Embrapa-developed captive breeding system. Below, we have set up the themes in a way that makes sense in the captivity flow, discussing important information about the species in the environmental context and its management from the initial breeding stock formation up to reproductive aspects, highlighting animal behaviour and the environmental approach of the activity, to support commercial breeding from the species conservation perspective. The discussion and conclusions have shown that the species has a low invasive potential in Brazilian biomes; the captivity site needs not much space, facilities or water; captive breeding is a zootechnical and environmentally appropriate activity for the species' conservation because it is a way to avoid spending on programs that are made only for this purpose; and increasing knowledge of reproduction using molecular genetic tools is important.

Keywords: conservation, chelonian, *Kinosternon scorpioides*, jurará, turtle breeding

INTRODUCTION

In Brazil, *ex-situ* captive breeding of wildlife has been encouraged by public authorities to generate income and conserve species, within categories that include commercial, scientific, conservation and zoological purposes (Le Pendu et al., 2011).

The Chelonians are the third-most commercial group in the 438 commercial captive breeding present in the country (Trajano & Carneiro, 2019). Although this commercial activity is centred on the species *Trachemys dorbigni* and *Podocnemis expansa* (Trajano & Carneiro, 2019; Dantas-Filho et al., 2020; Andrade et al., 2021), the semiaquatic turtle *Kinosternon s. scorpioides* (also known as scorpion mud turtle in English and jurará or muçuã in Portuguese) has been standing out with progressive advances in the knowledge of its biology and parts of captivity management (Araújo et al., 2013a; 2013b; Costa et al., 2015; 2017; Ferreira et al., 2020a; 2020b; Andrade et al., 2021; Silva et al., 2021). This knowledge can promote the activity for commercial purposes, providing a great opportunity for species conservation in the Amazon (Le Pendu et al., 2011; Parry et al., 2014; Dantas-Filho et al., 2020) due to the threat of predatory hunting motivated by its meat (Alves et al., 2012; Cristo et al., 2017).

There are many studies and most of them do not consist of comprehensive knowledge and experience guides that holistically support new projects (Rocha & Molina, 1987; Rodrigues et al., 2017), with little emphasis on the environmental issues of the activity (Ferreira et al., 2020b) despite its importance (Boyd et al., 2020). The species has not yet been bred in captivity for commercial purposes and, therefore, research has only been conducted in zoos and scientific captive breeding for research purposes (such as Embrapa Eastern Amazon, which has been studying and conserving these species in its biological collection since 2004). However, animals cannot be commercialised within these two categories, thus favouring the illegal trade of *K. scorpioides* (Cristo et al., 2017), not contributing to the food safety of native Amazonian people.

Currently, the species has two possibilities to be commercialised as an income resource, that is, for meat consumption (Smith, 1979; Baía Júnior et al., 2010; Marques, 2016; Cristo et al., 2017) or as a pet (Avendaño et al., 2002; Shiau et al., 2006; Berry & Iverson, 2011; Bedoya et al., 2018).

Given the interest in understanding the species biology, this study aimed to provide a synthesis of knowledge about the Embrapa-developed *K. scorpioides* captive breeding system. To achieve this, we have organised the themes in a manner that enhances the workflow in captivity by discussing important information about the species, including its environmental requirements and

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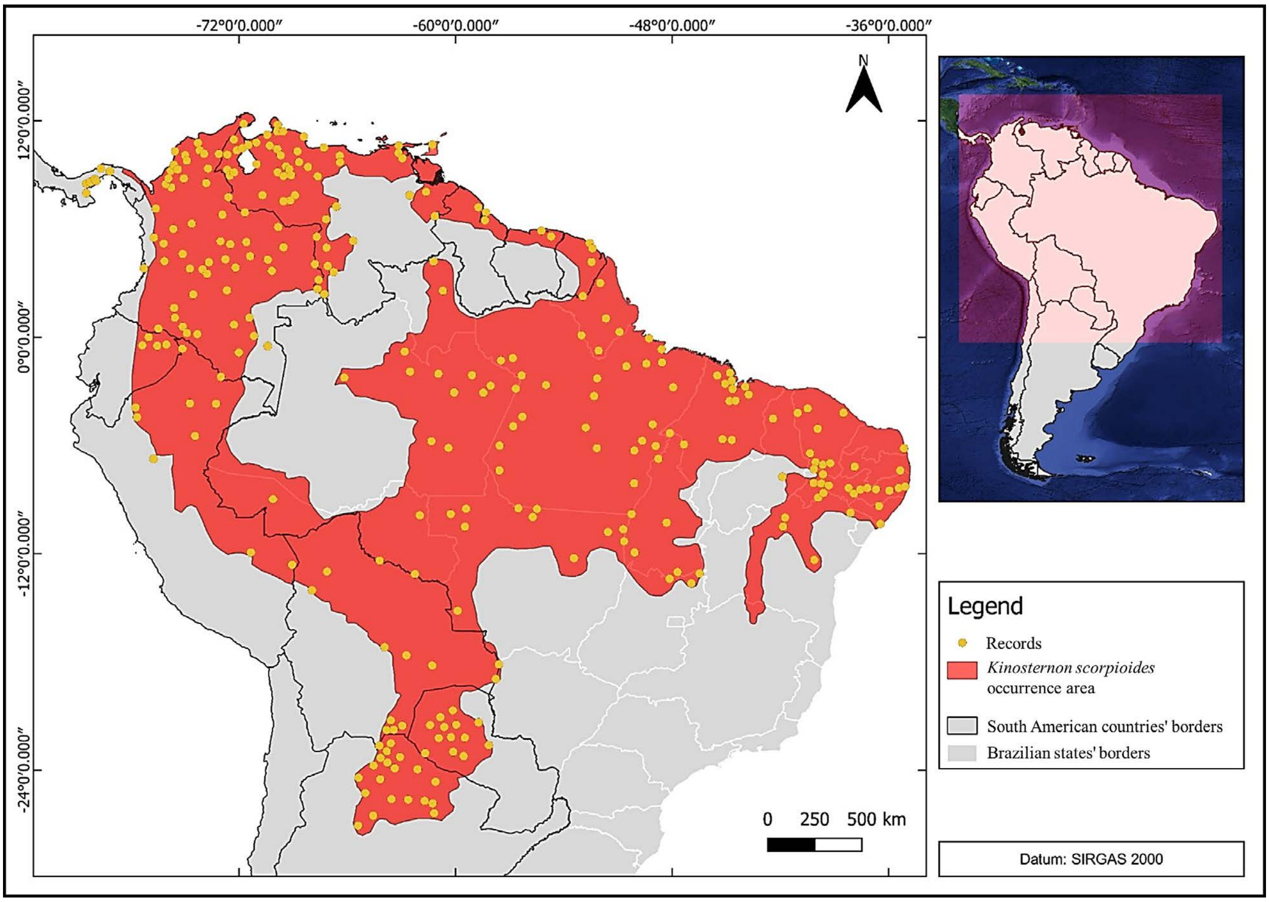

Figure 1. *Kinosternon s. scorpioides* geographical distribution: Argentina (Chaco, Formosa, Jujuy, Salta, Tucumán), Bolivia, Brazil (Acre, Alagoas, Amapá, Ama¬zonas, Bahia, Ceará, Goiás, Maranhão, Mato Grosso, Mato Grosso do Sul, Minas Gerais, Pará, Paraiba, Pernambuco, Piauí, Rio Grande do Norte, Rondônia, Sergipe, Tocan¬tins), Colombia (Amazonas, Antioquia, Arauca, Atlántico, Bolívar, Boyacá, Caldas, Caquetá, Casanare, Cauca, Cesar, Chocó, Córdoba, Cundinamarca, Guainía, Guaviare, Huila, La Guajira, Magdalena, Meta, Nariño, Norte de Santander, Putumayo, Quindío, Risaralda, San Andrés, Providencia y Santa Catalina, Santander, Sucre, Tolima, Valle del Cauca, Vaupés and Vichada), Ecuador, French Guiana, Guyana, Panama, Paraguay, Peru (Amazonas, Huánuco, Loreto, Madre de Dios, Ucayali), Suriname, Trinidad, Venezuela (Amazonas, Apure, Aragua, Bolívar, Cojedes, Falcón, Guárico, Lara, Monagas, Portuguesa, Sucre, Táchira, Trujillo, Yaracuy, Zulia). According to Berry & Iverson (2011), Dijk et al. (2014); Andrade (2019); Rhodin et al. (2021); Cassano & Alcade (2022) and Páez et al. (2022). Adapted from Rhodin et al. (2021).

management, from the formation of the initial breeding stock to reproductive aspects. Additionally, we highlighted their behaviour to support commercial captive breeding for species conservation.

Scientific breeding categories and authorisation aspects

The Embrapa scientific breeding for research purposes complies with one of the *ex-situ* categories of species captive breeding and use of allowed wildlife, according to Brazilian environmental legislation, especially by Resolution 489 of 26 October 2018, by the Environment National Council (CONAMA, in its original Portuguese acronym). The project is located on Marajó Island, city of Salvaterra, Pará, Brazil. Currently, the breeding stock numbers 599 animals, which supports all information and local studies with the species *K. scorpioides*.

All research with animals has been conducted under controlled conditions and following the national animal welfare criteria, and the specific projects have been approved by the internal technical committee under the Embrapa internal Seg Codes 22.1306023.00.00/01-2016 and 21159.002097/2022-85.

The species and its environmental requirements

The scorpion mud turtle is a native species of South American wildlife that is not listed in critical categories of threatened species of the International Union for Conservation of Nature (IUCN, 2023). Currently, the species has three subspecies (*K. s. scorpioides*, *K. s. cruentatum* and *K. s. albogulare*), and *K. s. scorpioides* has a wide distribution mainly in South America, part of Central America, and the Caribbean island of Trinidad (Fig. 1), ranging from eastern Panama to northern Argentina, excluding Chile (Rhodin et al., 2021). Cassano & Alcalde (2022), sampled 207 units from three regions in Argentina and confirmed the absence of records of the subspecies in the humid portion of the Chaco region. Contrarily, Páez et al. (2022) expanded the occurrence record mainly towards the western region of Colombia in 14 new locations where the subspecies had not been previously documented. Moreover, Andrade (2019) expanded the knowledge of its occurrence in the north-east region of Brazil, filling the distribution gap between the States of Maranhão and Ceará and reporting the first record in the State of Piauí.

The species is distributed in almost all Brazilian continental biomes (Rhodin et al., 2021), habiting in a wide variety of environmental conditions. This fact is an advantage for the policies of environmental agencies that restrict their authorising acts on the condition to places where this animal naturally occurs (according to IBAMA Normative Instruction 07 of 30 April 2015). This management is essential to prevent species invasion (Boyd et al., 2020), leading to achieving aquaculture sustainability.

The Brazilian Chico Mendes Institute for Biodiversity Conservation (ICMBIO) classified the species conservation status as 'Least Concern (LC)', considering that there was no evidence of threats that could affect the species and risk the populations. Thus, *K. scorpioides* received less attention for the species population protection in management programs despite its strong hunting pressure for consumption and illegal trade in several places (Marques et al., 2008; Berry & Iverson, 2011; Frugoli et al., 2015; Auliya et al., 2016; Balestra, 2016; Cristo et al., 2017). It represents an advantage for captive breeding due to the absence of restrictions imposed on officially threatened species categories. However, it also means that the animal is underrated in the country, as reported by Lemos-Espinal & Smith (2020).

In addition to the already-mentioned benefits, *K. scorpioides* is a good species model because it can be maintained in captivity due to its small size, semiaquatic lifestyle and low environmental requirements (Berry & Iverson, 2011). These traits allow for low area requirements for facilities and water demand, important limiting factors that constitute a challenge in aquaculture to reduce environmental impact (Boyd et al., 2020).

Initial breeding stock recruitment

In 2004, a total of 175 individuals (43 males and 132 females) were recruited from Marajó island to make up the initial breeding stock at Embrapa, according to IBAMA authorisation. Animals in wildlife captive breeding projects must be obtained in three different ways: from other ready and authorised captivity, deposits of environmental agencies or collected from nature (Fig. 2). In the latter case, following the requirements of Chapter IV in CONAMA Resolution 489 of 26 October 2018 is necessary. Being careful with the degrading collection practices exposed by Cristo et al. (2017), such as fire implementation and extraction in the reproductive period, is required because they represent environmental crimes. Once the initial breeding stock is decided, the next step is to separate and manage the herd in different categories.

Animal categorisation

The first research records in Embrapa have already mentioned the separation of the breeding stock into zootechnical categories for easier handling (Marques et al., 2008). It is essential to avoid cannibalism and competition, which occur at all life stages but mainly when there is a clear difference in size. In this situation, older turtles attack hatched ones, biting the thinnest and softest parts such as the folds of the paws, eyes and the base of the neck and tail. Guimarães et al. (2016) confirmed these observations and demonstrated that soft tissue injuries in females and males account for between 60% and 81% of lesions in captivity. For this reason, four categories are determined by density, reproductive stage, and feeding management:

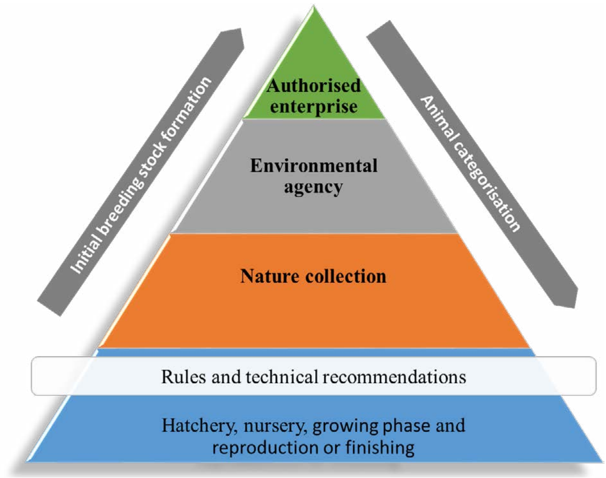

Figure 2. A scheme showing the different ways to obtain the initial breeding stock and the necessity for categorisation within the enterprise.

i) Hatchery: It is the egg incubation place until hatching takes place. The area should be closed, and the ceiling lined to avoid ant attacks and egg predation by rodents, birds and other reptiles.

ii) Nursery: It comprises all newly hatched individuals kept until 150 g of weight. Costa et al. (2017) examined 1,835 pups up to 12 months old and demonstrated that the average weight of this category is 36.54 g. In many cases, redividing them into two other nursery categories to keep individuals weighing 60 g and the largest up to 100 g, respectively, is necessary. This phase requires total care because the individuals are more susceptible to predation and ant attacks, especially the genus *Dinoponera*. In the latter case, the bite of a medium-sized ant can immobilise small individuals of scorpion mud turtle, allowing other ants to intervene and, in a matter of minutes, cause their death.

iii) Growing phase: Category in which animals weigh between 150 and 250 g. The analysis of 921 animals around 24 months old displayed an average weight of 199.20 g in this category (Costa et al., 2017). This phase allows to designate animals for the pet trade if there are legal permits for this purpose.

iv) Reproduction or finishing: Category in which animals weighing more than 250 g are kept, corresponding to two-year-old animals. Adult animals need to be separated in a commercial enterprise according to the purpose, whether reproduction or pet trade.

Breeding densities

There is no specific legal rule determining individual density for *Kinosternon s. scorpioides*. However, the literature shows flexibility in this aspect (Table 1),

Table 1. Stocking density of *Kinosternon s. scorpioides* in captivity, classified by breeding phase, as reported in the literature.

	Specimen density/m²		
	Nursery	Growing phase	Finishing
Castro (2006)	-	-	7.65
Silva (2015)	-	-	3.27
Costa et al. (2017)	73.5	2.3	12.64
Ferreira (2017)	7.14	2.61	1.92

which can be explained by the gregarious behaviour and rusticity of the animal, supported by pulmonary respiration, which allows several chelonians to survive without breathing for hours if necessary (Girling, 2013). Up to 100 animals per m^2 with 10 cm of water depth are allowed in the breeding site until they reach 50 g, remaining at the bottom of the tank for a long period.

Sanitary problems and prophylaxis

As mentioned above, cannibalism and predator attacks are the most common causes of health problems. However, prophylaxis is fundamental and legally indispensable in breeding animals, requiring a trained responsible person. Disease prevention is the most crucial, economical and long-lasting procedure, as it is as important as trying to mitigate disease propagation in the breeding stock (Flosi et al., 2001). Footbaths, environmental disinfection and water quality monitoring should be considered. Guimarães et al. (2016) proposed that periodical clinical evaluations would be increased during the reproductive period to prevent mild lesions from progressing to systemic complications.

Additionally, individuals collected from the wild must be cleaned and quarantined because they usually contain helminths or ticks that disperse *Salmonella* (Pereira et al., 2018). However, Silva (2019) found that *Salmonella* bacteria is not very common in wildlife samples from Marajó Island.

Individual system identification

Animals in chelonian captive breeding systems can be individually identified with a transponder (microchip), an electronic radiofrequency marking consisting of a sterile microcircuit with 0.43″ x 0.08″ of dimensions and operating in a frequency range of 134.2 kHz (FDX-B).

These devices (Partners®) have been used in the Embrapa biological collection since the first days of life to almost 15 years without problems. Generally, it is implanted above the forelimb, below the carapace, away from vital organs. The anti-migratory capsule system, made of polypropylene, protects the fixation at the applied site.

CONAMA Resolution 487, dated 15 May 2018, has confirmed that these tools and aluminum band tags are the only two acceptable ways to mark reptiles in various captive breeding categories.

Figure 3. Overview of the reproductive infrastructure area, depicting the central tank. The white arrow indicates the shading mesh above the water area.

Area, facilities and water demand

The total area available at Embrapa for the captive facility is 200 m^2 divided into Nursery (9 m^2), Growing phase (18 m^2), Reproduction or finishing (50 m^2), Hatcheries (9 m^2) and Quarantine (8 m^2).

There is a low structural requirement for species management compared to other Amazon chelonian breeding facilities (Dantas-Filho et al., 2020). The facility conditions are reflected in lower area demand, which was defined here as the facility portion required to be constructed. Given that Brazil faces deforestation threats (Azevêdo & Vieira, 2018), the development of productive activities in smaller spaces requires less suppressed vegetation for new enterprise establishment.

As required by Normative Instruction IBAMA 07 of 30 April 2015, the area is composed of 60% water and 40% sandy beach, with a little vegetation shade. Nevertheless, concerning the amount of water and depth of the tank, the species demands no more than 20 cm of depth. However, an interval between 50 and 70 cm by the regulation is recommended to avoid intense water temperature variations. For this reason, a shade is provided at Embrapa over the tank area (Fig. 3).

Rocha & Molina (1987), Molina (1992) and Rodrigues et al. (2017) also observed this low demand for water and facilities. This advantageous environmental condition is important because land and freshwater are limited resources in aquatic organism breeding programs (Boyd et al., 2020).

Kinosternon scorpioides has tolerance to survive in a variety of human-altered aquatic environments (Berry & Iverson, 2011; Cassano & Alcalde, 2022), supporting wide variations of ammonia, nitrite and nitrate, as well as slightly acidic pH, without physiological or respiratory harm. However, monitoring water quality indicators during breeding, ensures an environment suitable for growth, reproduction, health and survival, ensuring the species' welfare (Ferreira et al., 2020b).

Compared to other types of captive breeding, the amount of water required to produce one kilogram of scorpion mud turtle, with a semi-aquatic habit, is about

Table 2. The estimated water consumption in litres associated with one kilogram of mud turtle meat production, in comparison to other farming.

	Protein retention (%)	Edible meat per 100kg feed	Freshwater consumption L/Kg edible meat
Beef	15	4–10	15.400
Pork	18	17	6.000
Chicken	21	21	4.300
Mud turtle	20.44	26	4.871

Source: Adapted from Boyd et al. (2020)

Table 3. Summary of the environmental approach to mud turtle captive breeding

Considered Aspect	Environmental Advantages	Implications
Area	Possibiilty to avoid vegetation suppression	Non-conversion of green areas
		Project complexity reduction and increased environmental agency demand
Infrastructure	Possibility of breeding outside the countryside	Production outflow is accessible
		Inspection and regulatory access
	Low solid waste generation	Reduced labour demand
		Reduced building construction input use
Water demand	Possibility of using public or ground water	Exemption of unenforceability of granting water resources
		Reduction in the environmental agency demand
	Reduction of effluent generation	Non-contamination of natural water resources

13% more than the demand to produce the same amount of meat of terrestrial animals, which has less demand for water (Table 2). This estimate is based on the Embrapa captive breeding management, according to previous studies on carcass yield by Fernandes-Neto (2013) and feed conversion by Ferreira et al. (2020b). Therefore, measuring it according to a specific water footprint methodology is important.

This amount of water would be reduced with treatment and reuse, ensuring the recommended range for species tolerance. Table 3 shows the benefits of *K. scorpioides* captive breeding for the environment and its effects.

Food management

The animals have been fed commercial omnivorous fish feed since 2007. This food contains 42% protein levels during the nursery and growing phases or 32% protein levels during the reproduction phase. Generally, individuals fed 1% of their live weight once a day, around midday when the photoperiod accelerates the metabolism of chelonians (Souza, 2004; DeNardo, 2006; Girling, 2013; Guimarães et al., 2017). This pattern has also been found in the giant Amazonian turtle captive breeding population *Podocnemis expansa* (Dantas-Filho et al., 2020). Ferreira et al. (2020a) demonstrated that scorpion mud turtles expressed better growth when receiving 0.6% of their live weight three times a week and 0.5% five times a week in the dry and rainy periods, respectively. An optimal food composition requires a high protein content (20.44% ± 8.02), low lipid composition (1.86% ± 0.61) and high moisture content (77.29% ± 2.12) (Ferreira, 2017).

The animals remain in the hatchery for varying periods during birth, from 24 hours up to 7 days, deprived of food until complete absorption of the residual yolk (Guimarães et al., 2017). After this period, each individual is implanted with a microchip and placed at the nursery site.

Feed management in the growing phase is conducted according to the production goals. The feeding system can be intensified if the production is focused on meat, causing turtles to obtain a minimum of 14% of their weight (Costa et al., 2015). In contrast, feed with a 5% average weight is recommended when the objective is for the improvement to guarantee the mean weight of the species (Castro, 2006). Fruits and vegetables are alternative feed resources that can be used (Souza, 2004; Anjos et al., 2014; Silva et al., 2021; Cassano & Alcalde, 2022). The authors tested the feed predilection among 13 Amazonian and non-Amazonian fruits in the reproduction and finishing phases and the animals preferred peach palm (*Bactris gasipaes* Kunth), followed by melon (*Cucumis melo* L.) and mango (*Mangifera indica* L.). However, some fruits are highly nutritious whereas others are not and can be toxic to some reptiles (DeNardo, 2006).

Moreover, the diet can be supplemented with calcium and phosphorus, which facilitates the optimal development of morphological structures in the growth (2.015 ± 0.115 Ca:P) and finishing (1.92 ± 0.26 Ca:P) phases (Fernandes-Neto, 2013). Egg laying performance can be improved during the reproduction phase in terms of frequency and shell thickness by incorporating diets containing proteins of animal origin with 70% commercial fish feed (22% crude protein) associated with 30% of a paste mix of bovine offal, fish and shrimp three times a week (Araújo et al., 2013a).

Furthermore, previous studies have exposed that the supplementation with 4.2% calcium in the reproductive phase increases the quality and quantity of eggs (Fernandes-Neto, 2018). However, the author emphasised the importance of avoiding excess when supplying nutrients, as it can cause problems for individuals and the environment. Boyd et al. (2020) attempted to show that increasing the amount of feed does not lead to more production because most of the feed consumed is not turned into protein. Instead, it goes into the water as waste, which reduces the environmental quality.

Table 4. General information about *K. s. scorpioides* raised under controlled conditions in the Embrapa's captivity, Marajó, Pará, Brazil

Reproductive variables	Information	Measurement
Ideal male/female ratio	1:10	Specimen
Mating starts	December (end)	Days
Reproductive period	January–June	Months
Mating peak	March–June	Months
Mating amount/period	1–3	Unit
Average nesting time	0.03–3.35	Hours
Laying period	April–October	Months
Laying peak	June–August	Months
Laying amount	1–2	Unit
Embryonic development	26	Stages
Egg incubation period	129.31	Days
Eggs number/female	4–5	Unit
Egg viability	20.5	Percentage
Average eggs measure (L x W)*	34.5 C x 18 L	Millimetre
Average egg weight	1.60–13.40	Grams
Birth period	April–October	Months
Births Peak	June–July	Months
Embryonic specie differentiation	18	Stage number

Source: Compiled information from Costa et. al. (2017) and Braga et al. (2021). * (L x W) = length x width in cm.

The puppy and juvenile stages have a preference for feed of animal origin but they accept fruits and vegetables without compromising their weight gain (Anjos et al., 2014). However, Assad & Bursztyn (2000) pointed out to be careful with the carnivorous diet by assessing environmental quality and economic demand. In this case, waste increases turbidity due to emissions of effluents rich in organic matter and suspended solids (Valenti, 2002; Valenti et al., 2018). Also, it undermines conservation, as non-competitive prices do not grace the reduction of hunting pressure on chelonian due to their inability to replace illegal trade (Rebêlo & Pezzuti, 2000). Nutrition accounts for more than half of rearing costs, that is, the highest in the system, similar to other turtles (Andrade et al., 2021).

Reproductive management

Table 4 summarises the data about the reproduction of *K. scorpioides* in Embrapa. The control and reproductive planning, as well as neonatal care, are conducted through direct observation in Embrapa. The individuals are separated and placed in the reproduction tank during the reproductive management, maintaining the ratio of one male to ten females. This ratio avoids injuries caused by mating behaviours, such as female persecution, pre-coupling and copulation (Molina, 1992; Guimarães et al., 2016).

Figure 4. Photograph of failed hatching when the egg was covered with a layer of compacted sand larger than two centimetres. Scale bars: 2 cm.

Eggs are laid in the morning. They are carefully collected in the same position and transported to the artificial hatchery, wrapped in plastic storage bins with white construction sand slightly hydrated with 3 ml of water poured onto the substrate around the eggs (Guimarães et al., 2017). The eggs should be completely buried with a layer of two centimetres of sand to avoid difficulties during hatching (Fig. 4). This artificial incubation is necessary to ensure successful breeding in *ex-situ* programs (Ferreira, 2017).

The average number of eggs laid by a female is four, the incubation period is approximately 122.98 ± 45.38 days, and the embryo develops in 26 stages, with speciation occurring at stage 18 (Costa et al., 2017; Braga et al., 2021). The literature shows similar records about laying values in captive breeding (Silva, 2011), even values up to six and seven eggs (Rocha & Molina, 1990; Castro, 2006). As previously stated, mineral and protein supplementation provided twice the average number of eggs in the Embrapa scientific breeding and more resistant eggs in other captive breeding, respectively (Araújo et al., 2013a; Fernandes-Neto, 2018).

Previous research has found low egg viability, with an average of 20.5% in the studied stock (Costa et al., 2017). This was attributed to primiparous females, egg predation, ant attacks, unfertilised eggs and embryonic death after hatching (Alves et al., 2014). The eggs have been opened at around the 122nd day of egg incubation to assist in hatching and prevent embryo death, thus minimising this low viability. Importantly, this low egg viability represents an 8-year average, in which the maximum reached 45.15%. Moreover, adjustments were performed in incubation management through the application of Good Incubation Practices and Standard Operating Procedures (SOPs), which showed a small improvement in the hatchability rate (Silva & Ferreira, 2017). In contrast, Leal (2018) studied four incubation protocols, changing the temperatures and humidity, and reached 54.2% egg viability with a handmade incubator. However, higher values have been reported in the literature, including 67.8% and 83.3% (Anunciação et al., 2011; Castro, 2006).

In general, males and females are born due to the average annual temperature (27.3 °C) of Salvaterra, located in the eastern region of Marajó (Lima et al., 2005). This is related to the pivotal (or threshold) temperature-dependent sex determination (TSD) of the species, in which both sexes develop in equal proportions around 27.5 °C (Ewert et al., 2004; Júnior-Ferreira, 2009).

Reproductive age is reached at 250 g of live weight, consistent with previous findings for animals maintained in a zoo in the capital of the State of Pará (Castro, 2006). In general, higher weight and female age result in larger and more numerous eggs, favouring individual selection and genetic improvement initiatives, although there is no molecular marker available for this purpose (Costa et al., 2017).

A relevant tool to be considered in the reproductive management of the species is assessing the genetic variability in the founder individuals to manage the genetic diversity of the captive-bred chelonian population, which is lost in each generation due to an inbreeding rate maintained below 2% (Williams & Osentoski, 2007). Silva et al. (2011) observed that the captive-bred population at Embrapa is not at risk of genetic erosion due to the high level of genetic variability, which aids in the genetic improvement and conservation of the species.

This information associated with advanced knowledge about the morphology of male and female reproductive systems (Machado-Júnior et al., 2006; Carvalho et al., 2010; Anunciação et al., 2011; Chaves et al., 2012), embryonic development (Braga et al., 2021) and mating behaviour (Costa et al., 2017) provides a satisfactory overview of the zootechnical and reproductive responses of the species. It is important because the number of births in captive breeding for commercial purposes is the most important indicator of the program's success (Trajano & Carneiro, 2019).

However, He et al. (2010) and Francisco & Silveira (2013) pointed out some instances in which reproduction does not occur. The authors attribute the absence of courtship behaviour in males and oviposition in females to inadequate facilities in captivity. This is manifested in reduced gonadal development, lack of reproductive hormones and/or insufficient nutrition to promote ovarian follicle maturation. The latter contributes to reproductive success outside the natural environment given individual ecological and physiological needs, such as nutrition, space, light, humidity, temperature, shelters, nests and social structure.

CONCLUSIONS

The scorpion mud turtle *K. scorpioides* is naturally found in almost all Brazilian biomes and is easy to contain and breed in a captivity environment, making it less likely to spread into other parts of the country so that the captive breeding activity can comply with the law.

The physical facilities require not much space and water compared to other Amazon species.

The knowledge about how the individuals are cared for, behave, breed, and affect the captive environment indicates their management as an alternative to turtle breeding in the Amazon. However, the economic aspects still need to be further examined.

The *Kinosternon s. scorpioides* captive breeding is a zootechnical and environmentally suitable activity for the conservation of the species because it helps to avoid spending on programs created exclusively for this purpose.

Enhancing our understanding of reproduction by employing molecular genetic tools is important to facilitate control and genetic improvement initiatives.

CONSERVATION APPROACH

Turtle captive breeding is considered a conservation strategy (He et al., 2010; Dantas-Filho et al., 2020; Andrade et al., 2021; Kim et al., 2022), as the *ex-situ* program mitigates the population decline generated by hunting, habitat destruction and degradation. In Brazil, the muçuã activity comprises large-scale capture using degrading methods without estimating natural population sizes. This activity is detrimental to population size because individuals remain under hunting pressure even if hunters know about biology and animal behaviour (Cristo et al., 2017). Therefore, there is a need for strategies that prioritise its conservation, associated with its legalised commercialisation (Marques et al., 2008; Berry & Iverson, 2011; Alves et al., 2012; Marques, 2016; Cristo et al., 2017; Bedoya et al., 2018).

Another preventative approach to captive breeding programs is to ensure the genetic identity and variability of the turtle population originating from certain areas (Williams & Osentoski, 2007). Recently, Kim et al. (2022) showed that turtles born in captivity can contribute to the conservation of globally threatened species, as they present migration behaviour similar to those born in the wild.

Officially, these animal captivity breeding practices are recognised, supported and mandated by several countries that have joined the Convention on Biological Diversity (CBD), of which Brazil is also a party. In this sense, Trajano & Carneiro (2019) stated that commercial breeding must be seen as an instrument for conserving Brazilian biodiversity in a unified manner, as international agreements and federal regulations have been pointing in this direction for some time.

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Author Contributions

Palmira Francisca Gonçalves Ferreira, Ednaldo da Silva Filho and José Ribamar Felipe Marques were involved in the conception, planning, methodology, development and design, as well as the article writing. The last two people oversaw the survey and were also in charge of the formal analysis. José Ribamar Felipe Marques, Larissa Coelho Marques and Relionan Pimentel Leal were involved in the provision of study materials, the curation of animals, estimations and the provision of all documents relevant to the data and information research. All authors discussed the results, commented, assisted in interpreting and worked on the manuscript.

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