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„*Crocodylus moreletii* in captivity; a study in cooperation with the Tiergarten Schönbrunn in Vienna "

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Abstract

This study documents results of the husbandry of *Crocodylus moreletii* in captivity, in cooperation with the Tiergarten Schönbrunn in Vienna.

The first chapter reveals the incubation methods and proves that temperatures above 34°C in the first third of the incubation period will lead to abnormalities and even to the death of crocodile embryos, while lower temperatures cause much longer development. Furthermore, it shows the structure of hatchling calls of juveniles with massive snout deformations, compares them to calls of healthy individuals and proves that this disability influences the calls.

To find out how *C. moreletii* behaves in captivity the adult pair in the Vienna Zoo was monitored over a period of 37 days for 579 hours. The focus was on activity phases, daily distances travelled, dive times and intraspecific interactions as well as interactions with the fish. To make the species more attractive for the visitors of the zoo the efficiencies of different enrichment like acoustic calls, new objects, scattered food, jump enrichment and training were examined. Additionally, a way to integrate an efficient training program on a regular basis in the weekly routine of the zookeepers was created. Finally, it was proven that all three individuals could be trained to reliably follow a target in 14 days.

The last chapter gives an overview about the European zoos that currently house *Crocodylus moreletii*. It also provides the data about how many individuals are living in Europe, as well as their sex ratio and reveals that in eight of the 17 zoos breeding this species is theoretically possible.

This study should be mentioned as a first impact for further studies in other zoos to gather more information about this interesting species in captivity.

1. Introduction

1.1 Background

Crocodylus moreletii is one of the 24 currently recognized crocodile species in the world. With an average size of about three meters it is the smallest of the four New World Crocodylus, the genus that includes half the world's extant species of crocodylians (J. R. Wagner, 2005; Brazaitis, 1973; Ross 1998). Although knowledge of it has increased over the past decades (Platt et al. 2010) it still is not a well-studied species and many aspects of its life cycle are fairly unknown (Platt et al. 2008). Because often being mistaken with *Crocodylus acutus* and *Crocodylus rhombifer, C. moreletii* was not accepted as a distinct species when it was first described by Duméril in 1851, until Karl Schmidt proved their uniqueness in 1924. This species is commonly known as Morelet's Crocodile, Mexican Crocodile, Belize Crocodile, and Central American Crocodile, among other names (Trutnau & Sommerlad, 2006). It mainly inhabits freshwater habitats like marshes, swamps, ponds and rivers but can also be found occasionally in brackish or saline environments in the northeast of Mexico, through the Yucatan Peninsula towards central Belize and northern Guatemala (Ross, 1998; Sigler et al. 2002; Platt et al. 2010). In the early and mid-20th century the populations of Morelet's crocodiles were greatly reduced in their dispersal area due to uncontrolled hide hunting and heavy exploitation. However, populations have recovered substantially and this species has been assessed as Least Concern by the IUCN and is listed in Appendix I in the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES).

Nevertheless, the IUCN recommends the monitoring of this species to ensure that a future population declines are noted in time (Platt et al. 2012; Cedeño-Vázquez et al., 2012).

In zoological institutions *C. moreletii* is a rather rare species. Just five of the 370 Zoos of the European Association of Zoos and Aquaria and 12 non-member zoos engage in taking care of this species (EAZA Website, 2016). Because few places are able to keep a reproductive pair, breeding is possible in only seven institutions. To maintain this species in a healthy condition in European zoos over a longer period of time it is important to keep the husbandry conditions as optimal as possible and to establish a stable system of monitoring breeding.

One of the very basic purposes of zoological institutions is species-appropriate husbandry of the animals, meaning animals in captivity should be able to express their natural behaviours (Dollinger, P., Verband Deutscher Zoodirektoren e.V. Website, 2016).
This thesis aims at giving a closer look at *Crocodylus moreletii* in captivity and focuses especially on breeding problems, hatchling acoustics, as well as behaviour and enrichment based on the individuals in the Tiergarten Schönbrunn. Furthermore, it provides information about the population of Morelet's Crocodiles across European zoos. The obtained results can help to optimise the husbandry conditions and simplify the work of the zookeepers who take care of this fascinating species.

1.2 Research aims, objectives and questions

For any study, research questions play a major role in setting clear boundaries for literature review. They enable the researcher to facilitate a choice of suitable methodology and structured analysis as well as help to formulate specific conclusions and recommendations. They therefore constitute an essential guideline for a study (Wilson, 2010; Bryman and Bell, 2007).
As mentioned previously, the aim of this paper is to examine *Crocodylus moreletii* in captivity. In order to accomplish this aim, research questions and corresponding objectives have been developed for this dissertation, as illustrated in figure 1.

Research aim
To consider the husbandry of *Crocodylus moreletii* in captivity

Research Objectives	Research Questions
1. Examining occurred breeding problems	1.1 What caused the deformations of the Crocodile embryos?
2. Work out information about the vocalization of hatchlings	2.1 How are hatchlings calls built up? 2.2 Does the deformation affect the call?
3. Find out more about the behaviour in captivity and how the life of the crocodiles can be enriched by the zookeepers	3.1 How does *C. moreletii* behave in captivity? 3.2 How can their lives be enriched? 3.3 Is it possible to establish an efficient training in the working routine?
4. Evaluate the bloodline research to give indications of the status of this species in European zoos	4.1 Where are the Crocodiles in Europe from and how are they related?

Figure 1: Research aim, objectives and questions Source: Author's own work, 2017

1.3 Relevance of the Thesis

As shown previously there is a lack of scientific research on *Crocodylus moreletii* in zoological institutions. This thesis aims at minimizing this gap and shedding light on the problems and benefits of taking care of this crocodile species. The Tiergarten Schönnbrunn is one of the few European zoos which houses Morelet's Crocodiles and is the only one in Austria. It also has the best preconditions: a well-structured enclosure (see Chapter 4.1), three individuals, an open-minded team and already some experience with breeding these crocodiles. The insights gained from this study help to optimize the husbandry conditions and help to establish a healthy breeding population in European zoos on a long-term basis. Furthermore, this study helps the Tiergarten and other institutions to review their current conditions and consider possibilities to improve them.

2. Literature Review

2.1 About *Crocodylus moreletii*

C. moreletii is one of the 24 currently recognized Crocodile species in the world. With an average size of about three meters it is the smallest of the four New World Crocodylus, the genus that includes half the world's extant species of crocodylians (J. R. Wagner, 2005; Brazaitis, 1973; Ross 1998). Although knowledge of it has increased over the past decades (Platt et al. 2010) it still is not a well-studied species and many aspects of its life cycle are fairly unknown (Platt et al. 2008). Because of often being mistaken with *Crocodylus acutus* and *Crocodylus rhombifer, C. moreletii* was not accepted as a distinct species when it was first described by Duméril in 1851, until Karl Schmidt proved their uniqueness in 1924. This species is commonly known as Morelet's Crocodile, Mexican Crocodile, Belize Crocodile and Central American Crocodile among other names (Trutnau & Sommerlad, 2006) and mainly inhabits freshwater habitats like marshes, swamps, ponds and rivers but can also be found occasionally in brackish or saline environments in the northeast of Mexico, through the Yucatan Peninsula towards central Belize and northern Guatemala (Ross, 1998; Sigler et al. 2002; Platt et al. 2010). In the early and mid-20th century the populations of Morelet's Crocodiles were greatly reduced in their dispersal area due to uncontrolled hide hunting and heavy exploitation. However, populations have recovered substantially and this species has been assessed as Least Concern by the IUCN and is listed in Appendix I in the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). Nevertheless, the IUCN recommends the monitoring of this species to ensure that a future population declines are noted in time (Platt et al. 2012; Cedeño-Vázquez et al., 2012).

After suffering afore mentioned massive population decline, it was unclear if *C. moreletii* would survive extinction. Neil (1971) predicted that the species would vanish before any detailed information could be gathered (Wagner, 2005). Current research on Morelet's Crocodiles is centred in Belize and mainly focuses on distribution, diet, nesting and reproductive ecology, as well as on threats and conservation efforts, including research by Steven Platt (Rainwater et al., 2000; Platt and Thorbjarnson, 2000; Ray et al., 2004), Howard Hunt and colleagues (Ross, 1998), Llewellyn Densmore and colleagues (Rainwater et al., 2000; Dever and Densmore, 2001; Ray et al., 2004) and Dr. Jonathan R. Wagner (Wagner, 2005). Despite the IUCN listing this species "Least Concern" because of the considerable recovery of populations throughout much of the species range, the main threats still exist: illegal hunting and the chemical pollution of the environment (Cedeño-Vázquez et al., 2012). Morelet's Crocodiles belong to the genus Crocodylus, the true crocodiles (Brock, 1998) and after being mixed up with the Cuban crocodile (*Crocodylus rhombifer)* and the American crocodile (*Crocodylus acutus) Crocodylus moreletii* was scientifically accepted when Karl Schmidt (1924) proved that these animals are found in Belize and are distinct from the American crocodile (Trutnau and Sommerlad 2006). While the English names Morelet's, Mexican or Belize Crocodile refer to the French naturalist Pierre Marie Arthur Morelet who discovered them and simply describe the distribution of this crocodile (Britton, 2009), the German name "Beulenkrokodil" refers to the bump-like elliptical bulges on the snout of *C. moreletii* (Trutnau 1994).

In summary, knowledge of this species has certainly increased over the past decades. However, most of studies took part in the wild. Although the species was bred in zoos in the past, very little is known about their general behaviour in captivity and no information has been amassed about the individuals in European zoos thus far. The research included in this study examines the knowledge and state of research in zoological institutions.

2.2 About the Tiergarten Schönbrunn

The Vienna Zoo was founded in 1752 by Emperor Franz I Stephan von Lothringen, husband of Maria Theresia, is located in the park just behind Schönbrunn Palace and is the oldest zoo in the world. Because of the baroque architecture, the park is part of the UNESCO World Heritage. Despite of the long history the Tiergarten Schönbrunn is one of the most modern and well known Zoos worldwide. On an area of 17 hectares the Tiergarten houses more than 8,900 animals of 734 species and participates in many breeding-, conservation- and scientific programs and is a member of the European Association of Zoos and Aquaria (EAZA), Österreichische Zoo Organisation, World Association of Zoos and Aquariums and Verband der Zoologischen Gärten e.V. The modern orientation and the historical background attract and inspire more than two million visitors per year which makes it one of the most visited sites in Austria.

The first Morelet's Crocodiles arrived as a present from the Atlanta Zoo in 1993 and were kept in the former Mexico House, currently the Rat House. After extensive reconstruction work, which lasted until 2008 the male and the female crocodiles were moved to their new enclosure in the Aquaria – Terraria House of the Tiergarten Schönbrunn (Zoo Vienna Homepage, www.zoovienna.at, 2016).

3. Material and Methods

3.1 Choice of Methods

The four rather different main research questions mentioned earlier demand a great effort of material and different methods to get a profound conclusion. With reference to the objectives of the study an inductive approach was chosen to conduct the study. It focuses on monitoring and analysing the solitary case “The *C. moreletii* in the enclosure of the Tiergarten Schönbrunn”. Based on the assumptions of this individual case, general statements for optimizing the husbandry in zoological institutions will be determined. Due to the limited time of approximately 6 months, various setbacks like the loss of all embryos by dint of incubation problems (See Chapter 5.1) and thus necessary adaptations, it was not possible to observe this species in other zoological institutions which confines the validity of this study. At this point the necessity of future case studies in different zoos is very important to increase the efficiency of the husbandry of *C. moreletii* in European zoos.

Chapter 2.2 describes the details of the elicitation of primary data while information about used secondary data is listed in Chapter 2.3.

3.2 Primary Data

In this thesis, primary data mostly consist of video data and observations from the author but also contain recorded sounds, and environmental data loggers.

To get primary data for the first and second chapter (analysing breeding problems and bioacoustics), temperature loggers were placed in the nest in the enclosure of the exhibition and in the incubator after the eggs were removed from the original nest. Two different incubators were set to different temperatures. The temperature in incubator 1, a GRUMBACH 8100, was set to 32,2°C in order to hatch males, whereas the eggs in the second incubator, a JAEGER FB80, were kept at 28°C, the optimal temperature for female hatchlings. In addition to that, a digital recorder with built-in microphones (Zoom HN4, Zoom Co., Japan; settings: 44.1 kHz, 16-bit), was placed in the incubator to record pre-hatch calls of the crocodile embryos. The recorder was placed in the incubator within a distance of 10 cm from the boxes containing the eggs and later from the box containing the previously hatched juveniles for a period of 504 hours (485 hours for the eggs and 19 hours for the two hatchlings). Beginning on day 75 of the incubation period the eggs in the GRUMBACH 8100 were tested twice a day (8 am and 4 pm) with playback of recorded hatchling calls for one minute each time. A digital egg monitor (Buddy mk2) was used several times to confirm the development of the embryos.

To collect data for the third research question (behaviour of *C. moreletii*), two permanently installed video cameras in the enclosure and a hand camera were used to observe the daily behaviour of the crocodiles. A vast benefit of this kind of observation is the possibility to review situations in which something happens too quickly to recognize it with the naked eye. Another benefit is the ability to monitor the enclosure 24/7. Yet another advantage is that the crocodiles' behaviour is not influenced by the presence of the researcher.

Nevertheless, this indirect observation method does have some disadvantages as well. In the well-structured enclosure, it is sometimes is very hard to spot the crocodiles on the records and in critical situations (e.g. two animals start attacking each other) it is not possible to intervene. Furthermore, the observer is not able to watch the crocodiles in the water during the night, because the night vision mode of the cameras is often not sufficient. The higher costs of the indirect observations are not part of this discussion since all surveillance cameras and the relevant technology had already been installed.

As there isn't much data about the *C. moreletii* in the exhibition of the Tiergarten Schönbrunn it was important to monitor them for a short time to examine their behaviour and hypothesize how this species could become more attractive to zoo visitors. Therefore, both Morelet's Crocodiles were observed for a period of 40 days (October 11th 2016 till December 13th 2016) and a total amount of 579 hours. Besides the surveillance cameras, writing utensils and an enclosure plan were used to document all of the activities of the two crocodiles. To get a satisfactory overview of the daily behaviour of the Morelet's, the crocodiles were monitored in summertime from 6 am to 9 pm and during wintertime from 5 am to 9 pm. Furthermore, they were observed for three nights to get an understanding of their night-time behaviour.

As a consequence, a great deal of data was collected considering the interactions between the two crocodiles as well as with fish, diving times, duration of stays on land, in the caves and in the shallow waters. Thanks to the enclosure plan (Scale 1:50) the researcher was able to state findings about the crocodiles' activities and related timing. Abiotic environmental factors like temperature and humidity were measured with a special data logger in the enclosure.

To conduct the last part of this study it was necessary to contact all of the zoos, which take care of *C. moreletii* in Europe to find out how many Morelet's Crocodiles live here and how they are related.

3.3 Secondary Data

Secondary data refers to academic journals, textbooks, newspaper articles, company's reports and websites, basically "data that have been collected by other researchers" (Wilson, 2010) which have also been used in this research. This kind of data provides comprehensive understanding of a topic which also enables researchers to identify the gap in the literature and justifying the research project. In addition, there are other advantages like saving costs and time, as it is less time consuming than collecting and analysing primary data. Time saving is an especially critical issue for every researcher (Saunders, Lewis and Thornhill, 2009). In addition, secondary data enables the researcher to compare findings from different researchers to those within their own data. Such data triangulation confirms that "conclusions drawn from primary collection methods are appropriate" (Hair et al., 2007) and increases validity of the study (Collis & Hussey, 2003). The downside of secondary data occurs when comparing analysis because of different definitions, interpretations and intentions. Thus, this kind of data and their sources have to be screened to ensure that comparing them is adequate.

For this thesis, secondary data was indispensable as it was necessary to get more opinions and ideas of other researchers to begin to understand what could have occurred during incubation, as well as about the behaviour of *C. moreletii* in the wild.
Most of the papers which were used for this study originate from professional journals like "Nature", "PLOSone", "Nature sciences", "Current Biology", "Journal of Zoology" and "Zoology", among others, as well as annual reports from the Crocodile Specialist Group and of the Zoological Society for the Conservation of Species and Population (ZGAP).
Apart from the above-mentioned journals, on-topic textbooks were used to gain insight into this issue. Scientific textbooks are a very valuable source for information; an abundance of information is funnelled into one corpus and many of textbooks are referenced by various researchers. They do have the disadvantage that some topics are either just hinted at or are too generalized. Additionally, it takes time to work with these textbooks.
A variety of websites like the homepage of the International Union for Conservation of Nature and Natural Resources (IUCN Website, www.iucnredlist.org 2016), as well as

the website of the Crocodile Specialist Group (www.crocodilian.com 2016) and the National Science Foundation Digital Library website (www.digimorph.org 2016) were used to complete this thesis. A wide range of different sources is needed to increase any study´s credibility.

3.4 Morelet's Crocodiles in the Zoo Vienna

The Schönbrunn Zoo currently cares for a group of three adult *Crocodylus moreletii*: one male and two females. While both females hatched 2008 at the Madras Crocodile Bank Trust in the South of India and were imported to the Tiergarten Schönbrunn in 2013, the male hatched in the Atlanta Zoo (Georgia, USA) in 1985 and arrived in the Schönbrunn Zoo in 1993. Hence, the male is now 31 years old, about 280 cm long and weighs approximately 60 kg. The much younger females are 8 years old currently weigh about 30kg each and have a length of approximately 200cm each. For individual recognition, all animals are microchipped but they can be distinguished by their outward appearance through size, skin pattern and colouration.

The male can easily be distinguished by its bigger size and its much darker colouration. In addition to that it has a much broader snout with bigger teeth than the females (Fig. 2)

Figure 2: Female and male *C. moreletii* by comparison

Source: Author's own work, 2017

To differentiate the two females is a bit more difficult. Fortunately, they are not living together in one enclosure. The female in the exhibition enclosure is much smaller, thinner as the male and has a much brighter skin colouration (Fig. 2).

The female in the backstage enclosure is slightly smaller than the one in the exhibition and one scale of the tail is missing (Attachment Fig. 24)

3.5 Enclosure of *C. moreletii* in the Zoo Vienna

The Crocodile Pavilion was finished in 2008 and contains two enclosures, a terrarium, an aquarium, a paludarium as well as free flying butterflies. The paludarium is inhabited by a group of 2,2 Chinese crocodile lizards (*Shinisaurus crocodilurus*) and a pair of four-eyed turtles (*Sacalia quadriocellata*), the aquarium is the home of 1,1 Tentacled snakes (*Erpeton tentaculatum*) and a male black-chested spiny-tailed iguana (*Ctenosaura melanosterna)* lives in the last terrarium. Next to the enclosure of the Morelet's Crocodiles is the compound for the small group of 2,1 Aldabra giant tortoises (*Aldabrachelys gigantea*). The enclosure for the *C. moreletii* has a total area of 96,5 m² whereby the surface of water is 72 m² and the land area is 24,5 m², divided into the "Main-Land-Part" and the "Island". The water depth varies from 90 cm to 135 cm. Rocks and logs create shallow water zones which make it easier for the crocodiles to exit the water. The "Mainland" is endued with an area of in-floor heating (4 m², 41°C), a total number of 8 HQI Spotlights (500 WATT), an openable training ground as well as a small water stream (Figure 3, Page 19 and attachment fig. 25 & 26).

The crocodiles have the possibility to dive under the land areas which offer dens where they can hide and take a break from visitors. Through a roller door, hidden in an artificial log, the enclosure can be divided into two compounds to separate animals for settling in periods, cleaning or feeding, or to separate animals after a fight. The enclosure additionally contains natural substrates like sand, dirt or decomposing plant materials, roots, rocks, logs and a dense vegetation which, similar to the underwater dens, enable the crocodiles to withdraw, hide, and motivate them show their natural behaviour. The filtration system ensures a flawless water quality while creating a mild water flux. Nine windows which have a minimum height of 160 cm permit the visitors to have a good view into the enclosure while the other side of the enclosure is bounded by roots and a 160 cm high planted wall. The crocodiles share their enclosure with a variety of fish species including Guppies (*Poecilia reticulata),* Sam Borstein's Cichlids (*Amphilophus amarillo)*, Quetzal Cichlids (*Paraneetroplus synspilus)* and Eye-Spot Cichlids (*Heros cf. efasciatus).* Daily temperatures vary between 21,6°C and 27°C at a relative humidity of 50,1%

– 98,8% (attachment fig. 27 & 28). Water temperature is between 25°C – 27°C. To simulate natural rainfall the keepers must water the plants and the enclosure once a day with a hose.

Even though the *Crocodylus moreletii* is not considered a highly aggressive crocodile (Brien et al., 2013) the three crocodiles were separated during the settling in period in 2011 through the roller door. The two females lived in the area with the “Main-Land-Part” and the male inhabited the area with the “Island”. That gave them the possibility to interact and get used to each other without the risk of harm or attacks. Unfortunately, the slightly smaller female began to attack the other one up to a point where the zookeepers had to separate them to prevent the inferior crocodile from sustaining serious injuries. From this point on the exhibition enclosure of the Vienna Zoo was inhabited by 1,1 *Crocodylus moreletii.*

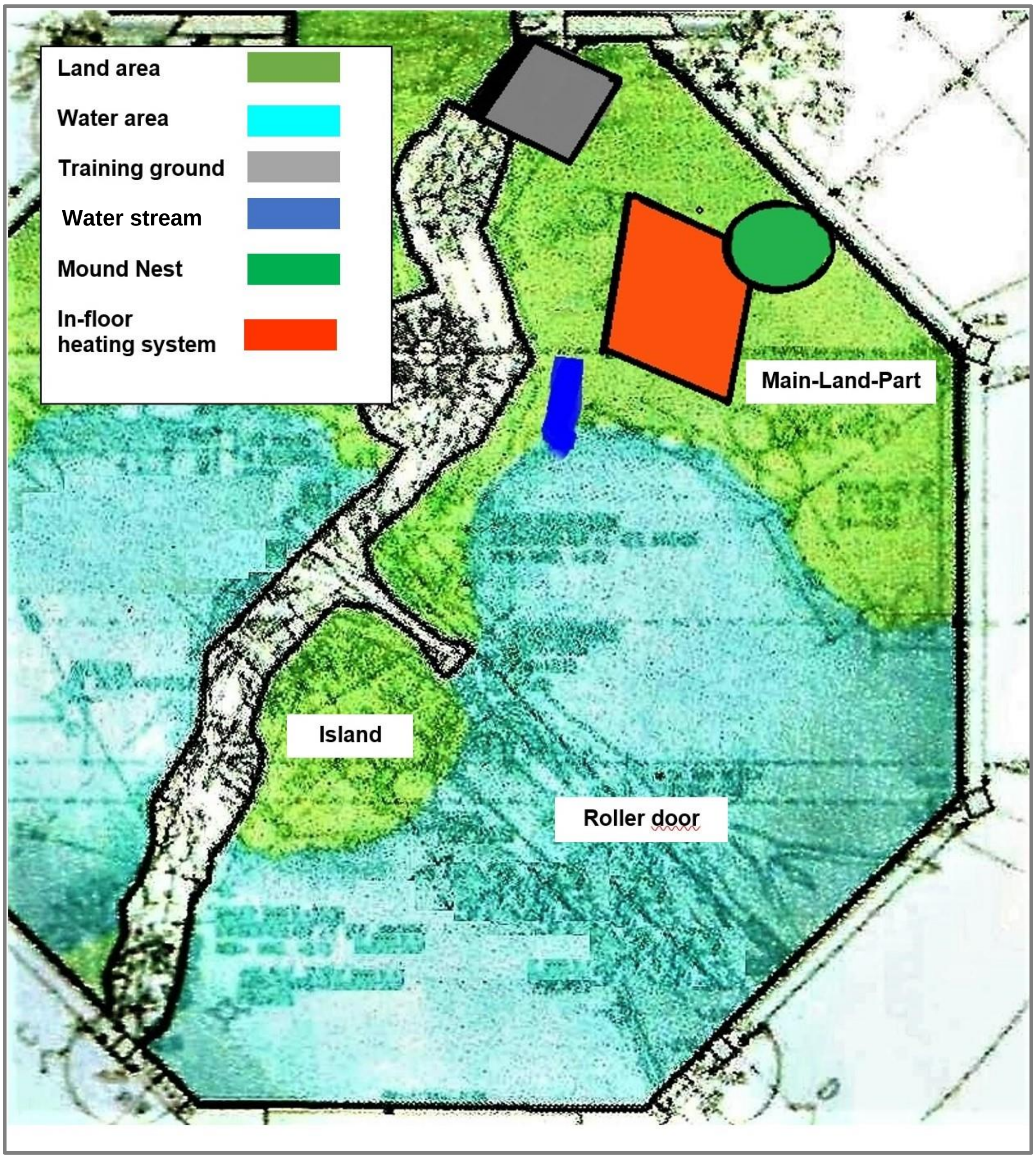


Figure 3: Picture of the Enclosure-plan

Source: Author’s own work, 2017

4. Results

4.1 Examining Breeding Problems

From mid-April until mid-May 2016 the zookeepers as well as the visitors of the zoo observed the two crocodiles mate multiple times. Because *C. moreletii* is the only mound nest building crocodile of the currently known Crocodylus in America, the zookeepers provided appropriate nest materials, e.g. leaves, earth, branches and other decomposing plant material, on the "Main-Land-Part" of the enclosure.

On the weekend of the 18th and 19th of June 2016 about one month after the last observed mating, the female built the mound nest. Instead of using the provided nest materials, she built the nest with sand-gravel mixture only. She positioned the nest as far away from the water as possible above the end of the in-floor heating system in front of one of the visitor windows (Fig. 3, page 19). The nest was about 200 cm wide and 80 cm high and contained 30 eggs. The eggs were placed 30 cm deep inside the mound nest. To reduce the stress for the female crocodile the zookeepers made the glass non-transparent by painting it white, so that visitors could not congregate near the nesting site. Because both the male and the female crocodiles were very protective of the nest, a team of zookeepers was necessary to collect the eggs out of the nest and transfer them into the incubators to hatch them under controlled conditions. After 48 hours in the nest at a temperature of 37,8°C the 30 eggs were gathered and placed in plastic breeding boxes, filled with wet moss to achieve the optimal breeding conditions (See Chapter 6.1). Two incubators were prepared beforehand. A GRUMBACH 8100 and a JAEGER FB 80. In the GRUMBACH a constant temperature of 32,5°C was installed, to hatch mostly males, and a relative humidity of about 70% while in the JAEGER the temperature was 28°C with a relative humidity of nearly 100% to raise the chance of hatching females. Because of our limited space and the rather small demand of Morelet's Crocodiles we decided not to incubate all 30 eggs till the end. Once we could tell that the eggs were fertilized by candling them it was decided that just 11 of them would be artificially incubated. Eight eggs were left in the GRUMBACH and three in the JAEGER. Depending on the temperature the incubation time is about 67 to 97 days (Trutnau and Sommerlad, 2006; Navarro, 2004; Platt and Thorbjarnason, 2000). After 65 days of incubation we added a digital recorder with built in microphones (Zoom HN4, Zoom Co., Japan; setting 41.1kHz, 16-bit) in the GRUMBACH to record prehatch calls of the embryos in the eggs (Fig. 4).

Figure 4: GRUMBACH incubator with microphone to record prehatch calls
Source: Author’s own work, 2017

After day 75 without any recorded calls a playback experiment with recorded hatchling calls of wild *C. moreletii* was started in order to motivate the embryos to hatch. Like in the experiment of Vergne and Mathevon (2008), calls of hatchlings were played to the eggs for one minute in the morning at 7:45 am and for another minute in the afternoon at 4 pm. To make sure that the embryos were still alive the vital functions were checked every 4 days. After day 70, the eggs were placed on a Digital Egg Monitor (Fig. 5).

Figure 5: Egg is placed inside the Digital Egg Monitor to check the vital functions of the embryo
Source: Author’s own work, 2017

On September 12th 2016, after 85 days of incubation at a temperature of 32,5°C in the GRUMBACH there was no reaction of the embryos on the microphone and signs of vital functions on the Digital Egg Monitor were fading, Anton Weissenbacher, the Reptile-Curator of the Vienna Zoo, made the decision to open the eggs. After careful preparations to get the embryos out of the thick eggshell (Fig. 6) it was discovered that five out of eight crocodiles already died in the egg.

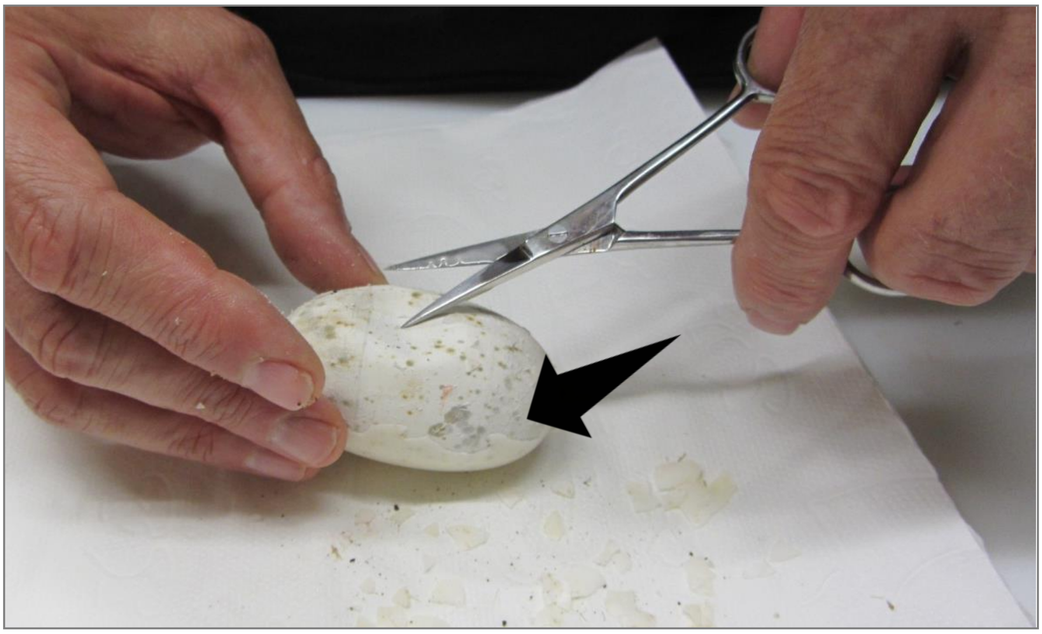


Figure 6: Egg opening and example of the thick eggshell
Source: Author's own work, 2017

All eight were fully developed but unfortunately had considerable deformations of the snout. The lower jaw was much longer than the upper jaw in every case and in six of eight embryos it was bent. In addition to that all of them had still a big yolk sac and the egg caruncle was missing completely (Fig. 7).

Figure 7: Six dead and deformed hatchlings
Source: Author's own work, 2017

The other three individuals were weak but alive. These were placed back in the incubator each one on wet paper in a plastic box covered with nylon gaze (Fig. 8).

Figure 8: Living individual in a plastic box covered with gaze
Source: Author's own work, 2017

While one died three hours after A. Weissenbacher hatched it, the other two survived the following night. One even started to call. The calls were recorded again with the same microphone, which was used to record the pre-hatching calls. After 18 hours without any improvements of the deformations it was decided that the veterinarian should euthanize both hatchlings. The remaining three eggs in the JAEGER were not disturbed in this period. It was later discovered that because of a technical dysfunction the temperature in the incubator had been kept between 22,4°C and 26°C instead of the intended 28°C. The temperature was corrected and because of the very low incubation temperatures it was determined that the remaining eggs would be left in the incubator for a longer time than originally planned. The microphone recorder was again placed in the incubator after day 95 and the eggs were checked twice on the Digital Egg Monitor. Furthermore, the playback experiment was not repeated in order to not to disturb the eggs. On the October 6^{th} 2016 after 109 days of incubation fading vital functions were recognized again and it was decided to open the eggs as well. Two of the three embry-os were already dead and the third one was very weak. It died just one hour after it was taken out of the egg. However, it should be noted that the deformation of the snouts were obvious but not as considerable as the hatchlings in the first incubator. One of the three individuals had a slightly contorted lower jaw while the others only a slight over-bite. The large yolk sac stayed the same but on two hatchlings an egg caruncle was present. (Fig. 9).

Figure 9: Freshly hatched *C. moreletii* with egg caruncle
Source: Author’s own work, 2017

To conclude this section reviewing the occurring breeding problems, it is important to mention the size of the eggs as well as of the embryos. The eggs varied between a length of 6,0 cm to 6,9 cm and an average weight of 55 grams whereas the average embryo weighs 37 grams with an average length of 17,5 cm (Table 1).

Table 1: Overview about the weight & length of eggs and embryos

Egg Number	Incubator	Weight of the Egg	Length of the Egg	Weight of the Embryo	Length of the Embryo
1	GRUMBACH	58 g	6,8 cm	38 g	18 cm
2	GRUMBACH	54 g	6,2 cm	36 g	16,5 cm
5	GRUMBACH	55 g	6,4 cm	38 g	18 cm
8	GRUMBACH	54 g	6,3 cm	35 g	16 cm
9	GRUMBACH	56 g	6,9 cm	39 g	18 cm
10	GRUMBACH	52 g	6,3 cm	37 g	17,5 cm
13	GRUMBACH	58 g	6,6 cm	38 g	18 cm
14	GRUMBACH	55 g	6,2 cm	35 g	17 cm
21	JAEGER	51 g	6,0 cm	33 g	17 cm
22	JAEGER	58 g	6,4 cm	39 g	18 cm
23	JAEGER	56 g	6,3 cm	34 g	18,5 cm
Average		55 g	6,4 cm	37 g	17,5 cm

4.2. Bioacoustics Results

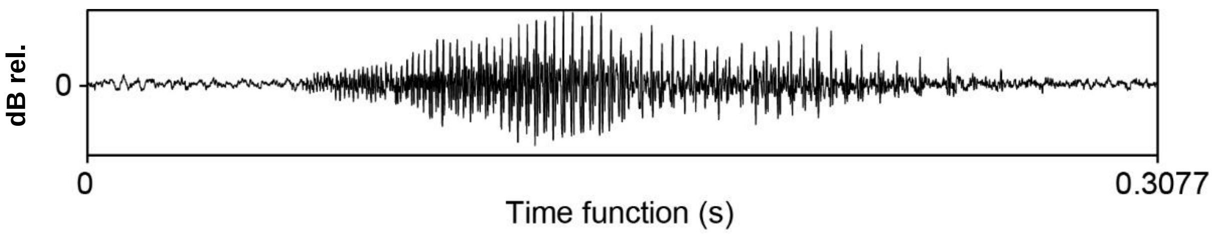
As mentioned in 4.1, in total four weak but living crocodiles were recovered. Those were placed separately in boxes in the incubator (Fig. 8, page 23). One of them was strong enough that it started calling for its mother. Call recordings were made with a digital recorder with built in microphones (Zoom HN4, Zoom Co., Japan; settings: 44.1 kHz, 16-bit). The recorder was placed in the incubator at a distance of 15 cm from the previously hatched juvenile for a period of 18 hours. In this period the one juvenile emitted 198 calls in the incubator. Calls which were masked by background noises henceforth referred to as “with background noise”.

To measure the sound pressure level of the calls, the author was able to stimulate the same individual to produce 9 calls outside of the incubator by slowly lifting it from its box. These calls were measured from a distance of 1 m with a sound level meter (Voltkraft SL-100, Germany: settings: fast/max). The A-filter frequency weighting was chosen because it is relatively flat from 1 to 8 kHz. These calls are listed below as “without background noise”.

The results were compared with 16 calls of a hatchling of *Crocodylus moreletii* in the wild (Stann Creek, Belize), provided by Miriam Boucher.

Recordings were used to analyse call duration, mean-, minimum- and maximum frequency to describe spectral call parameters. The acoustic features of stereo recordings were extracted and measured using custom built programs in the PRAAT 5.4.22 DSP package (Boersma & Weenink 2015) that automatically logged these variables in an output file. PRAAT commands are included in the attachment (Page 73 - 79). To analyse call duration the voiced interval of the call was extracted and duration in seconds was measured. For call frequency analysis a cross-correlation algorithm was used to produce time-varying numerical representation of the dominant frequency contour for each call. A time step of 0.01 s was applied over a range of 500 – 4000 Hz according to the observed dominant frequency on the spectrogram. From the dominant frequency contour the parameters mean, minimum, and maximum frequency in Hertz were extracted (Table 2, page 28).

To describe harmonics (F0 and overtones) and the frequency range of the complete call F0 was measured and its multiple integers as well as minimum and maximum call frequency over a range of 75 – 20000 Hz.



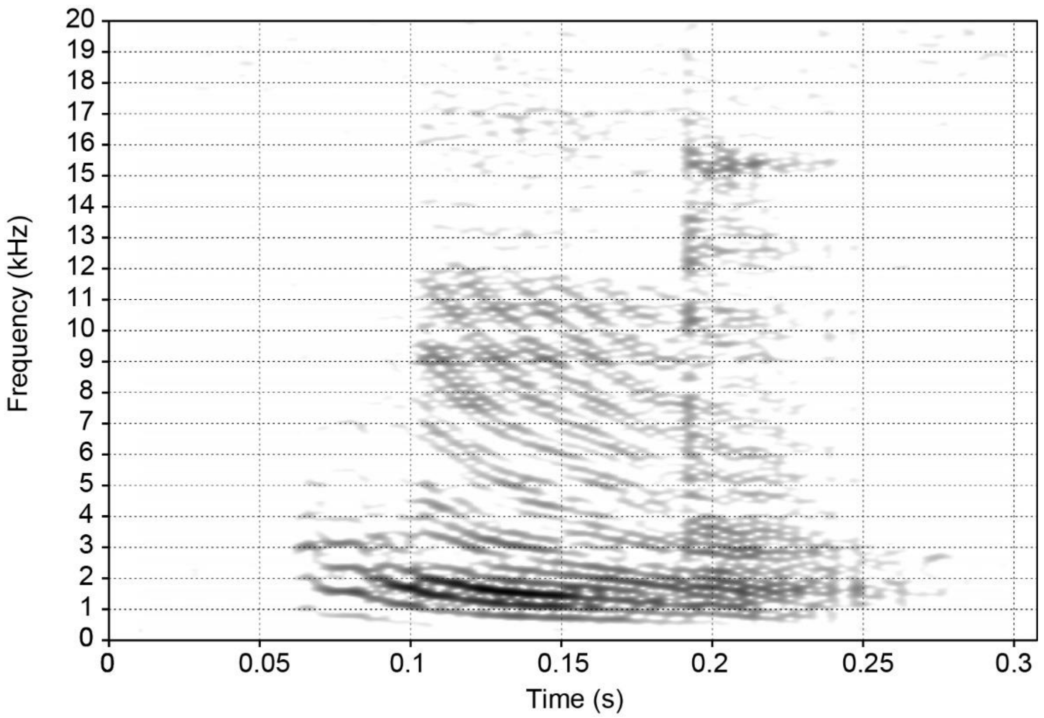


Figure 10: Hatchling call of juvenile *Crocodylus moreletii*. Waveform and corresponding spectrogram (FFT method; window length, 0.01 s; time step, 1,000; frequency step, 250; Gaussian window shape; dynamic range, 30 dB) of one call recorded 18 hours after hatching.
Source: Author's own work, 2017

Figure 10 depicts an oscillogram and the corresponding spectrogram of one call of the freshly hatched juvenile, 18 hours after hatching. To improve the quality of the diagram a call "without background noise" was chosen as a representative.

The mean frequency of the calls "without background noise" was 329 Hz with a standard error of 13Hz, while the mean frequency of calls "with background noise" was 557 Hz (SE of 6 Hz) and the "wild" calls had a mean frequency of 788 Hz (SE = 15 Hz) (Table2; Fig. 11).

The minimum frequency of the "with background noise" calls was at 878 Hz (SE = 6 Hz), the minimum for the calls "without background noise" was at 587 Hz (SE = 39 Hz) and at 940 Hz (SE= 10 Hz) for the wild (Table2).

The maximum frequency on the other hand was at 143 Hz (SE = 9 Hz) for the calls "without background noise", 355 Hz (SE = 6 Hz) "with background noise" and 469 Hz (SE = 45 Hz) for the calls of the wild hatchling (Table2).

The frequency range varies between 443 Hz (SE = 45 Hz) "without background noise", 479 Hz (SE = 10 Hz) "with background noise" and 471 Hz (SE = 43 Hz) in the "wild" calls (Table2; Fig. 12).

However, the duration of the calls "without background noise" was 0,186 seconds (SE = 0,020 sec.), 0,169 sec. (SE = 0,003 sec.) for the calls "with background noise" and 0,333 sec. (SE= 0,029 sec.) for the "wild" calls (Table 2; Fig. 13).

Table 2: Mean, min, max frequency, frequency range and call duration for the calls "without background noise", "with background noise" and "wild"
Source: Author's own work, 2017

	Without Background noise (1 individual; 8 calls)	With Background noise (1 individual;198 calls)	Wild (1 individual; 16 calls)
Mean frequency (+/- SE) in Hz	329 (13)	557 (6)	788 (15)
Minimum frequency (+/- SE) in Hz	587 (39)	834 (9)	940 (10)
Maximum frequency (+/- SE) in Hz	143 (9)	355 (6)	469 (45)
Frequency range (+/- SE) in Hz	443 (45)	479 (10)	471 (43)
Call duration (+/- SE) in sec.	0,189 (0,020)	0,169 (0,003)	0,333 (0,029)

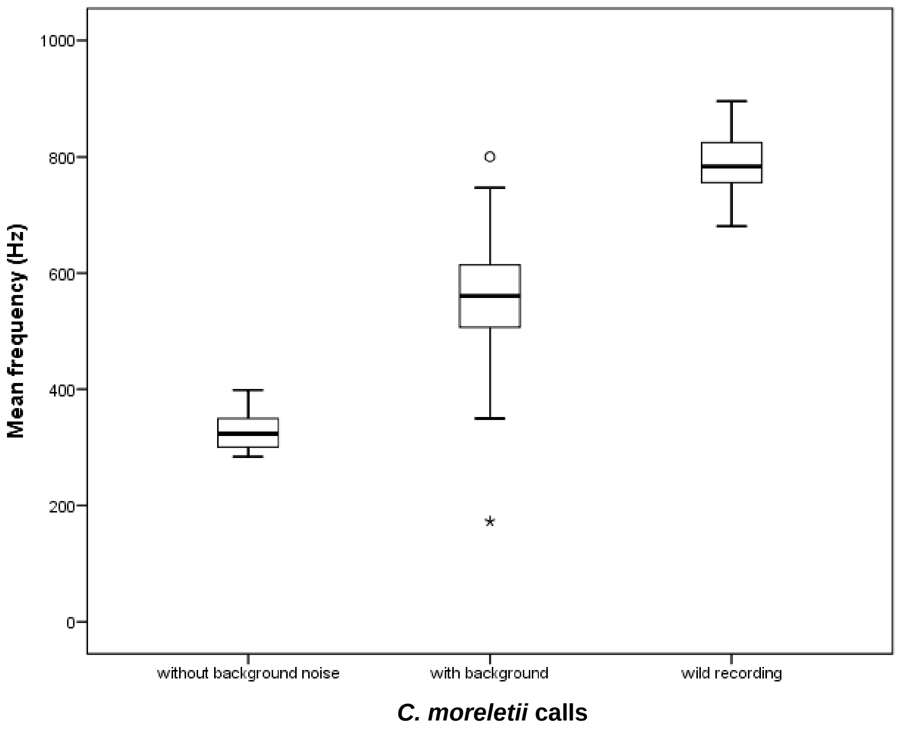


Figure 11: Boxplot of the comparison of the mean frequency between “without noise”, “with background” and “wild recording”
Source: Author’s own work, 2017

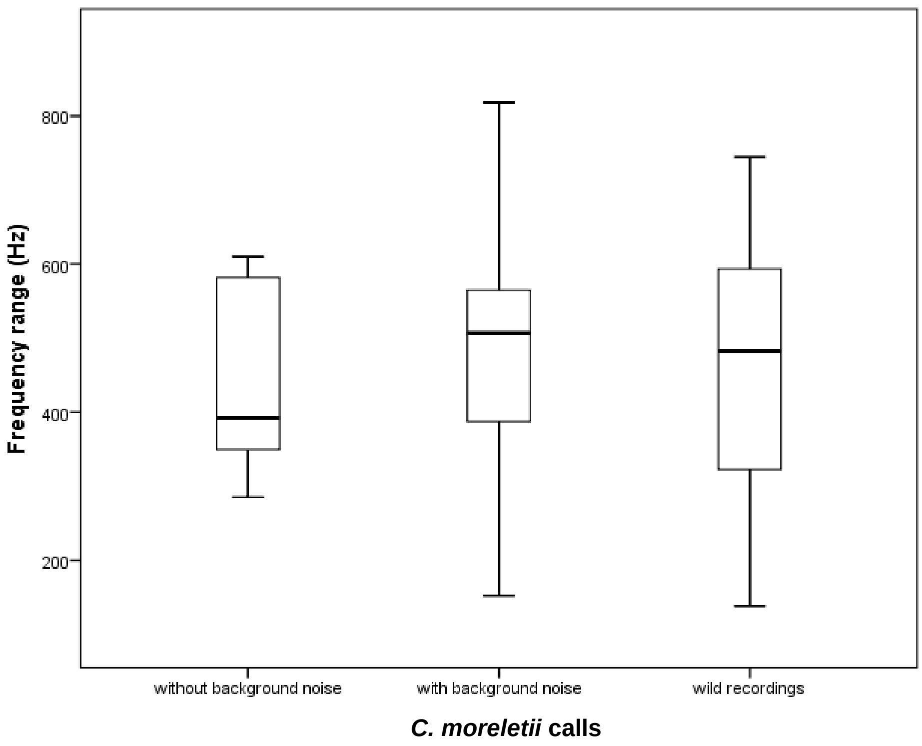


Figure 12: Boxplot of the comparison of the frequency range between “without noise”, “with background” and “wild recording”
Source: Author’s own work, 2017

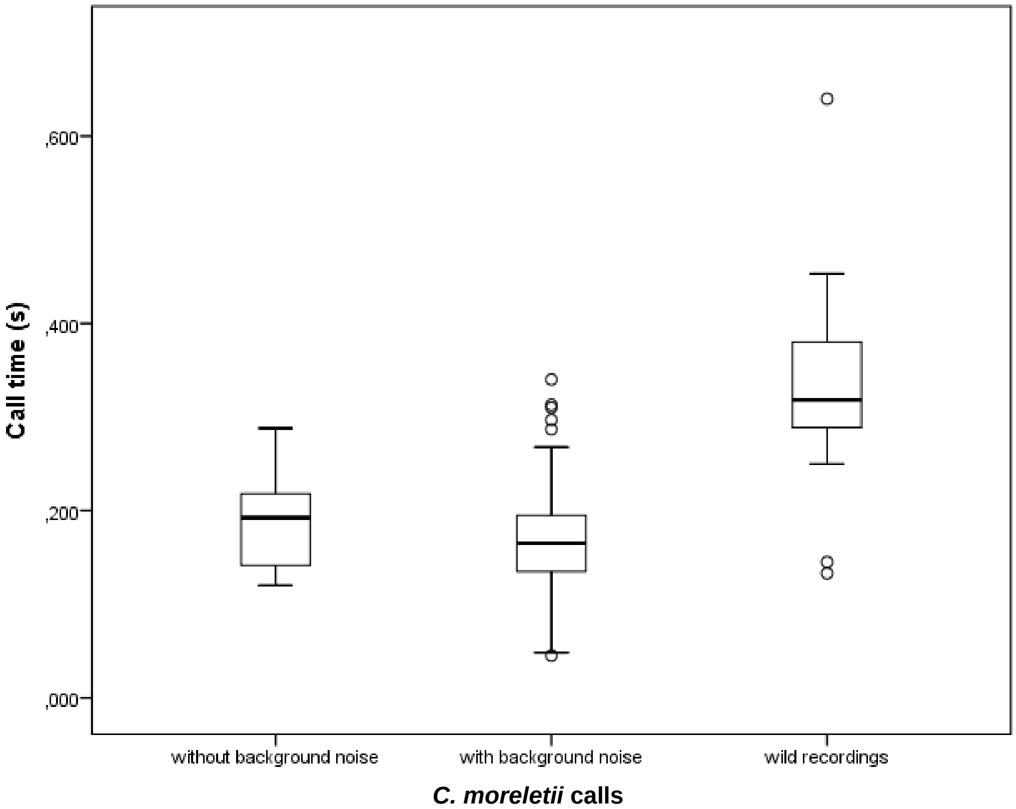


Figure 13: Boxplot of the comparison of the call time between "without noise", "with background" and "wild recording"
Source: Author's own work, 2017

Conclusively the dominant frequency was analysed from powerspectra of calls "without background noise" and is considered at a frequency of 1396 Hz with a standard deviation of 189 Hz and a standard error of 67 Hz which refers to be between the 3rd and 4th harmonic (Fig. 14, page 31).

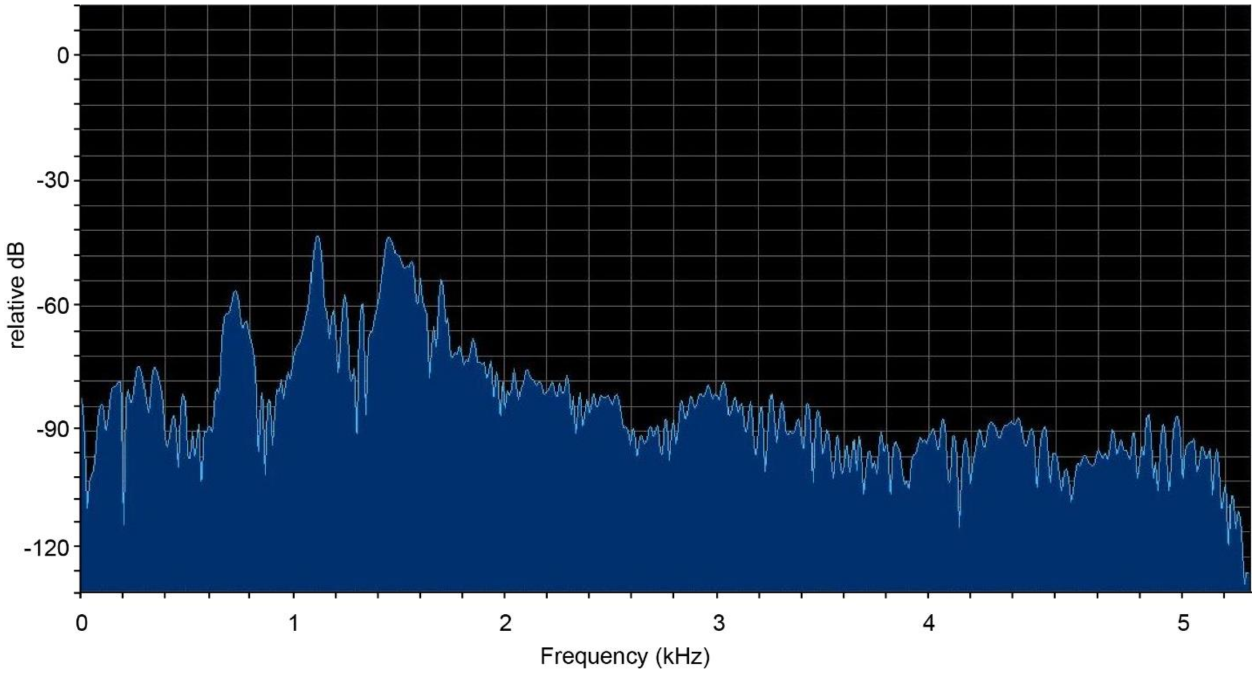


Figure 14: Powerspectrum of hatchling call as shown in Figure 10 at 1.44s. Sample rate 11025Hz; 10 dB amplified and noise reduced. Dominant call frequency (frequency with highest energy) at approx. 11kHz (F3) and 15kHz (F4)
Source: Author’s own work, 2017

4.3 Behaviour and enrichment

The following section deals with the daily behaviour of the 1,1 *C. moreletii* in the exhibition enclosure in Tiergarten Schönbrunn (Fig. 3 and attachment fig. 25 & 26).

It is inhabited by two adult crocodiles, the male (Durango) and the not yet named female. They share the enclosure with breeding groups of Guppies (*Poecilia reticulata),* Sam Borstein's Cichlids (*Amphilophus amarillo)*, Quetzal Cichlids (*Paraneetroplus synspilus)* and Eye-Spot Cichlids (*Heros cf. efasciatus*).

To thoroughly understand their daily behaviour the two crocodiles were observed in the period of 11.10.2016 until 13.12.2016, for 579 hours in 37 days (not always consecutively). Most often the observation took place from 5 am to 9 pm. To get a complete insight into the crocodiles’ routine three nights were observed as well, from 9 pm to 5 am.

4.3.1 Behaviour

While monitoring the adult pair, it became clear quite quickly that both crocodiles were not timid about anything and were not afraid of the visitors. They even ignored the zookeepers watering the plants or cleaning the windows from the outside, as long as they did not step inside the enclosure. Once inside, they both, but especially the male, approached in a quick and aggressive manner. Consequently, cleaning the inside of the enclosure is possible only if both crocodiles are separated from the zookeepers by the roller door (Fig. 15).

Figure 15: Closed roller door with male *C. moreletii* laying in front of it

Source: Author's own work, 2017

Every time the male heard the engine of the roller door he immediately dived under it, making it impossible to close it completely. This happened three times in the observation period.

The relationship of the crocodile couple can be described as completely relaxed. While the female reached out 115 times for bodily contact, the male approached her 53 times. A total number of 168 contacts were observed, where the crocodiles had bodily contact for more than one minute (Attachment Table 5). None of them considered aggressive or dominating. On the 6^{th} of December, it was even possible to observe a copulation which lasted for 3 minutes.

Interactions with the fish took place 30 times. Most of the time the female (18 attempts) tried to catch one, while, by contrast, the male tried only 12 times. All attempts catching a fish were ineffective (Attachment Table 6).

The covered distances of the crocodiles in the entire observation period add up to 9775 m for the male and 9809 m for the female. The maximal day distances for the female was 433 m and 422 m for the male. Thereby a regular could be noticed. The two *Crocodylus moreletii* started their day in 35 of the observed days between 6 – 8 am and remained active until 9 – 10 am. The average distance which they moved up until 9 am was 119 m for the male and 80 m for the female (Attachment Table 7). This was followed by a more inactive phase of basking on the land area, in the shallow waters or on logs until 6 – 9 pm when another active part of the day began. After 9 pm the male left the water to rest on the land area for the rest of the night. The female followed suit, but changed resting places up to three times per night.

There was not a single day where the crocodile did not leave the water. The male usually left the water at around 9 –10 am and moved up to 27 meter on land while the female usually rested near the water's edge (Attachment Table 7). The longest period of time laying on the land area for the male was 720 min and for the female was 843 minutes. It turned out, that both crocodiles preferred the "Main-Land-Part" before the "Island". While the male rested 71 times on the Main land area, it just rested 11 times on the "Island". By contrast the female chose the "Main-Land-Part" 61 times and the "Island" just 25 times to bask (attachment Table 8). In the first part of the observation (till the 25.11.2016) the crocodiles were fed every 14 days in the water area, through special doors from the outside of the enclosure. The diet consists of freshwater fish like common rudds (*Scardinius erythrophthalmus),* as well as mice (*Mus musculus f. domestica*), rats (*Rattus norvegicus f. domestica*) and chicks (*Gallus gallus domesticus*).

Expecting to be fed, the male started every day between 6:30 am – 7:20 am by approaching the feeding door in the lower right corner of the enclosure. He was fixated on the door until the zookeepers started feeding the fish in the crocodile enclosure between 8 am and 9 am. They then both started to eat the fish food (pellets). This marked the end of the first activity phase of the day.

In the observed period both crocodiles used the entire available area of the enclosure, including the dens and the "Island-Part-Area". In total both dens were used 167 times. The male, preferring the den underneath the "Island-Part-Area", spent a total of 2369 minutes under it with an average of 37 minutes each visit. The female used both dens equally and hid 877 minutes under them with an average time of 21 min per visit (Attachment Table 9).

The average dive time for the male was 8 minutes and 6 minutes for the female. Longer dive times were very rare and the longest dive time that was observed was 45 min of the male (Attachment Table 10).

Additionally, it was observed that two places in water area of the enclosure were visited more often than the others: a log laying in the water from the "Main-Land-Part", and the water stream. Both crocodiles spend a total amount of 8426 minutes lying in front of the stream (Attachment Table 11).

As a side note, the second female was not observed due to it being necessarily separated from the other female in 2011 because of continual conflicts. Accordingly, it has been placed backstage until it gets transferred to another zoo.

4.3.2 Enrichment

The following section details the results of the implemented enrichment and training sessions.

To enable the crocodiles to show more of their instinctive behaviour, the researcher tried to address every sense of the animals.

For a more organized and detailed overview of the efficiency and the effort which was necessary to perform the enrichment, the experiments were classified into categories.

Efficiency 0 means no effect at all, 1 = got their attention but did not react, 2 = reacted with movement for up to 10 minutes, 3 = kept the crocodiles engaged for more than 10 minutes. While the effort categories are 1 = little effort such as obtaining the materials and placing them inside the enclosure, 2 = perform handicraft work, 3 = huge effort, such as making the objects move, requiring at least one assistant (Table 3, page 40).

On the 7th of November 2016, to see how the crocodiles would react to new objects in their territory a pumpkin of about 4,5 kg was placed on the "Main-Land-Part" directly in front of the in-floor heating system. While the female rested on the "Island" the male watched the pumpkin for 5 hours straight without letting his guard down. The female took a quick glimpse at it. On the next day both crocodiles ignored the "Main-Land-Part" completely. Two days after the pumpkin was placed in the enclosure, the male approached it, touched it with its snout and started biting into it. After two bits, it started basking right next to it (Fig. 16; Table 3, page 40).

Figure 16: The male *C. moreletii* "Durango" basking next to the pumpkin
Source: Author's own work, 2017

The next try involved checking the reaction to a new object in the water area of the enclosure. Another pumpkin about the same size but hollowed out, so it would not sink, was thrown into the water. Both crocodiles reacted to the splash when the pumpkin hit the surface of the water by lifting the head but did not approach or attack it. On the following day both crocodiles attacked the pumpkin whenever it floated near them. This experiment was repeated with a plastic ball used for piglets and cows. This time both crocodiles immediately approached the ball and started to touch it with their snouts. The interest last for 40 minutes and on the following 4 days both pushed the ball through the enclosure several times (Table 3, page 40).

On the 11th of November, the next pumpkin was put on a rope (Fig. 17) in order for the researcher to move it while it was in the water.

Figure 17: Pumpkin with the rope
Source: Author's own work, 2017

Starting at 11:52 am both crocodiles reached the moving pumpkin within 30 seconds and started attacking it by biting into it over 25 times each. The pumpkin was only attacked when it was in motion. The last interaction was recorded at 1:17 pm. In the end the pumpkin was completely destroyed (Table 3, page 40).

Next, the researcher tried to make the crocodiles jump out of the water. A small treat like a chick, mouse or small rat was put on a four-meter-long bamboo stick. From a catwalk three meters above the crocodile enclosure the researcher could lure the Morelet's into the water. The female instantly tried to jump for the food while the male needed 4 repetitions of this enrichment to start jumping for the food (Table 3, page 40).

Trying to enrich the crocodiles with a water stream from a hose failed completely. Neither crocodile reacted to this (Table 3, page 40).

The next aim was to test the olfactory sense of the crocodiles. 40 grams of cumin was placed on the “Main-Land-Part” to observe the crocodiles’ reactions. Just 12 minutes after the zookeepers left the enclosure the male emerged from the water and laid near the spice. 38 minutes later he laid directly in the cumin, and remained there for a total of 130 minutes. Afterwards he once again got into the water and ignored the “Main-Part-Land” for the rest of the day. The female was not affected by the smell of the cumin. 14 days later the experiment was repeated, this time with cinnamon, which both crocodiles ignored completely (Table 3, page 40).

Acoustic enrichment was tested three times during the observation period. Records of hatchling calls (as well as imitated calls by one of the zookeepers) were played to the crocodiles three times. The female reacted immediately to the recorded calls and tried to get to the source of the calls but after 10 minutes she lost interest. The male’s reaction was the same, he followed the calls in and out of the water and even on land for 10 minutes. The reaction to the zookeeper’s imitated calls were nearly the same. Here the female reacted again (just for six minutes) but the male only started to look for the source of noise after six minutes (Fig. 18; Table 3, page 40).

Figure 18: Male Crocodile approaches the speakers
Source: Author’s own work, 2017

4.3.3 Training

The Target-Training took place in the openable training ground on the “Main-Land-Part”, which was made secure so that the crocodiles could not reach the trainer (Fig. 3, page 19 & Fig. 19). While in the first three training units the male displayed aggressive behaviour, ignoring the target and just reaching for the training ground, the female was interested. Already after the third unit she followed the target for two meters. After four days of training both crocodiles instantly came to the trainings ground when they heard the trainers opened the door of the enclosure. The male was no longer aggressive, moreover he started turning his head to get to the target and even moved 40 cm to reach it. The training continued for nine days straight to get the crocodiles used to it. Even after a two day break the crocodiles behaved well. To check their memory, we paused the training after 16 units for three weeks. Even after this time the Morelet's Crocodiles immediately went to the training ground and calmly followed the target (Fig. 19; Table 3, page 40).

Figure 19: Training on the "Main-Land-Part", female (left) touches the target
Source: Author's own work, 2017

4.3.4 Backstage Female

The female in the backstage enclosure was enriched as well, yet she responded completely differently. Because of the smaller structure of the backstage enclosure it was not possible to do every enrichment experiment as in the exhibition enclosure.

When the pumpkin first was placed inside her enclosure it took her 30 minutes until she started to attack it. Since that settling-in period she attacked pumpkins of every size and the plastic ball immediately and used them for up to 3 hours (Fig. 20; Table 3, page 40).

Figure 20: Female in the backstage enclosure attacking a pumpkin
Source: Author's own work, 2017

She did not show any reaction to the playback of the recorded hatchling calls.
Scattering small pieces of food, e.g. smelt (*Osmerus eperlanus*) or grasshoppers (*Anacridium aegyptium*) in the water area of the enclosure kept the female engaged for more than 20 minutes.
Furthermore, it took just one training unit for her to follow the target in the water and just 4 days to get on the land area of her enclosure (Table 3, page 40).
The training units for all three crocodiles lasted for 5 to 10 minutes and as a reward they got pieces of rudd (*Scardinius erythrophthalmus),* herring *(Clupea harengus),* smelt *(Osmerus eperlanus)*, mice (*Mus musculus f. domestica*) or chicks (*Gallus gallus domesticus*).
Currently all crocodiles are being trained twice a week and receive enrichment by having to jump for food every Saturday.

Table 3: Efficiency and effort of enrichment, Categories: Efficiency 0 means no effect at all, 1 = got their attention, did not move, 2 = made them move for up to 10 minutes, 3 = kept the crocodiles engaged for more than 10 minutes. While the effort categories are 1 = little effort like getting the material, placing them inside the enclosure, 2 = perform handicraft work, 3 = huge effort, making the objects move, cannot be done alone
Source: Author's own work, 2017

Enrichment	**Efficiency for the animals**	**Effort for the Zookeepers**
Water hose stream	0	1
New objects	1 - 2	1
Pumpkin rope	3	2
Scattered food	Up to 3	1
Olfactory enrichment	0 – 2	1
Acoustic enrichment	2	2
Fish	0– 2	1
Jump enrichment	3	3
Training	3	3

4.4 Bloodline research

According to the website www.zootierliste.de, a private page of members of the ZGAP which, in cooperation with the zoo community, tries to give an overview about which European zoo takes care of which animals, there are 21 zoos which keep *Crocodylus moreletii*. Three zoos in Germany, one crocodile zoo in Denmark, three in France, one each in Luxembourg, Austria and Spain as well as two Czech crocodile zoos keep these crocodile species. However, with a total of nine zoos, the majority of *Crocodylus moreletii* can be found in the United Kingdom (Fig. 21, page 39).

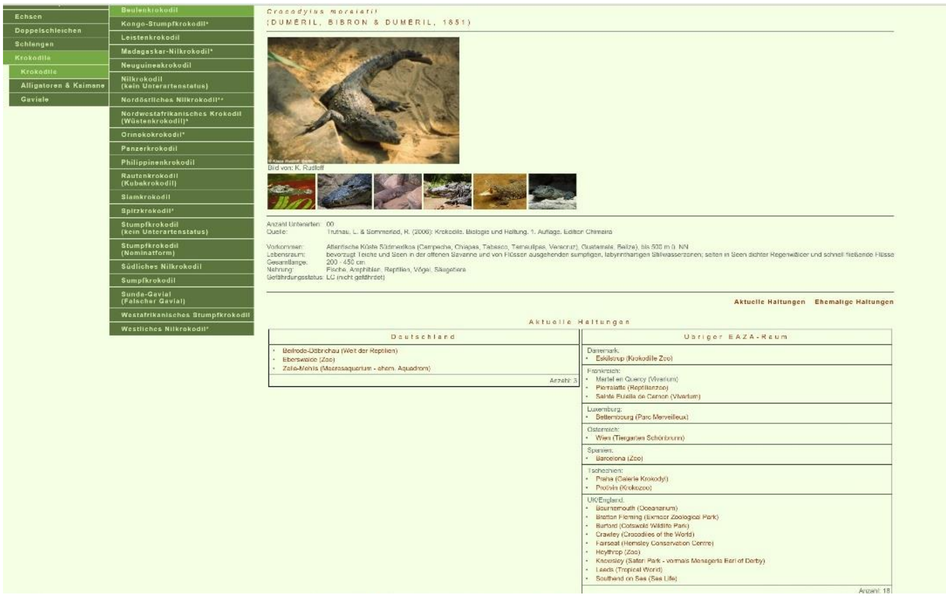


Figure 21: Predicted Zoos in Europe which take care of *C. moreletii*, source. www.zootierliste.de**, accessed 2017**

Based on this information the author began to reach out to the aforementioned zoos via email, phone calls and other messengers (Attachment Page 80). With this email the author attempted to gather information about the origin of the animals, the distribution of these crocodiles in European zoos and finally to clarify which zoos still take care of *Crocodylus moreletii*.

The results reveal that there are currently 34 Morelet's Crocodiles in European zoos. Nine of them are males and 20 females while five have not yet been sexed. From the estimated 21 zoos, four gave up the husbandry of *C. moreletii*. Three in the United Kingdom (Knowsley Safari Park, Bournemouth Oceanarium and the Sea life Centre in Southend on Sea) as well as the Barcelona Zoo.

In just eight of the remaining 17 zoos breeding is possible because of the required sex ratio of at least 1,1. Furthermore it happens that there is a huge lack of *male C. moreletii* in Europe.

On the positive side, there is a wide variety of origins of the crocodiles, including Mexico, Atlanta and India. Additionally, the most successful breeding couple comes from the Cotswold Wildlife Park in the United Kingdom (Table 4, page 42).

Table 4: Overview about the age, origin and amount of C. moreletii in European Zoos
Source: Author's own work, 2017

Zoo	In the EAZA	Number of Crocs	Date of hatch	Origin	Breed?	In the Zoo since?
Tiergarten Schönbrunn (Austria)	Yes	1,2	1,0 1985 0,2 2008	1,0 Zoo Atlanta 0,2 Madras Crocodile Bank Trust (India)	Not yet	1,0 1993 0,2 2011
Galerie Krokodyl (Czech)	No	0,2	August 2009	Private breeder (Germany)	No	November 2009
Krokodyli Zoo (Czech)	No	1,2	1,0 1999 0,2 2008	1,0 Mexico 0,2 Madras Crocodile Bank Trust (India)	Not yet	1,0 2000 0,2 2011
Krokodille Zoo (Denmark)	No	1,1	1,0 ~ 1996; 0,1 ~ 2006	Mexico	No	—
Reptiland Martel (France)	No	0,2	1986	Mexico	No	—
Reptilarium Du Larzac (France)	No	1,1	~ 1992	Ferme aux crocodiles	Yes 2016	2012
Ferme aux Crocodiles (France)	Yes				yes	
Eberswalde Zoo (Germany)	Yes	1,1	—	Madras Crocodile Bank Trust	no	—
Meeresaquarium Zella-Mehlis (Germany)	No	Probably 1,0		From Tierpark Berlin, bred in Atlanta	No	April 2003
Welt der Reptilien (Germany)	No	1,1	1,0 1999; 0,1 1995	Madras Crocodile Bank Trust	no	July 2012
Parc Merveilleux (Luxembourg)	Yes	1,0	Dec. 1999	Offsping of Vienna (Atlanta)	No	2000
Cotswold Wildlife Park (UK)	Yes	1,1	Sept. 1999	Spain importer from Mexico	Regularly	December 2003
Crawley Crocodiles of the World (UK)	No	0,1,4	0,1 2004 0,0,1 2014 0,0,3 2015	0,1 Mexico 0,0,4 offsprings of Cotswold	No	Adult since 2008
Exmoor Zoo (UK)	No	0,0,1	Sept. 2013	Cotswold	No	November 2015
Hemsley Conservation Centre (UK)	No	0,1	Oct. 2009	Cotswold	No	August 2015
Heythrop Zoological Gardens (UK)	No	0,4	Oct. 2007	Cotswold	No	July 2008
Tropical World Leeds (UK)	No	0,1	Oct. 2007	Cotswold	No	2009

The average number of crocodiles kept per zoo is 2, whereby the Zoological Garden Heythrop, with 0,4, and Crawleys Crocodiles of the World, with 0,1,4 individuals, have biggest groups of *Crocodylus moreletii* in European zoos.

Because of their aggressive behaviour, the male has to be kept separate from the females in Krokodyli Zoo (Czech) and the Krokodille Zoo in Denmark.

As seen in Table 4, just four out of the 17 zoos are members of the European Association of Zoos and Aquaria. It can be assumed that the oldest Morelet's Crocodile is the male in the Tiergarten Schönbrunn hatched in 1985 and that the average age of the population is about 11,4 Years old.

Conclusively it can be determined that most of the *C. moreletii* were kept in the UK but even though they have nearly half of the 34 European individuals, just one male is located there (at Cotswold).

5. Discussion

The following Chapters answer the research questions mentioned in 1.2 (Fig. 1, page 8).

5.1 What caused the deformations of the Crocodile embryos?

Incubation of reptile eggs is a very complex procedure in which one must pay attention to many outside influences. The aim of carefully controlling the conditions of egg incubation should always be to maximize the hatching rate and the hatchling fitness (Grigg, 1987).

The first thing that should come to mind regarding growth or hatching problems of reptile eggs is always the temperature (Romanoff, 1972; Ewert, 1979; Ferguson, 1985; Miller, 1985; Köhler, 2004) but as mentioned before, there are many more physiological influences such as humidity, microorganisms, change in positions (e.g. through concussions), substrates, gas exchange processes as well as the physical condition of the mother, which can cause abnormalities and deformations (Fig. 22).

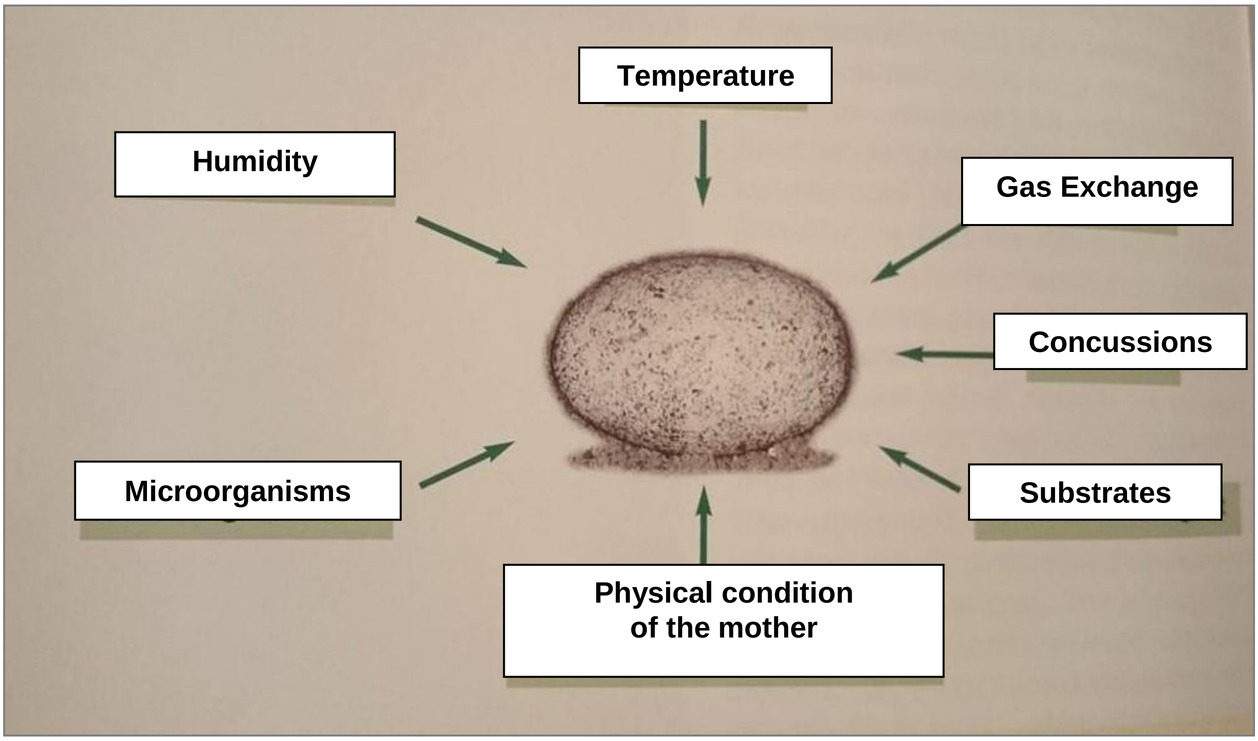


Figure 22: Physiological influences which affect the development of the embryo inside of the egg Source: Köhler, Gunther. "Inkubation von Reptilieneiern: Grundlagen, Anleitungen, Erfahrungen." Offenbach: Herpeton, 2004. Pp 32

Regarding these factors embryos may die in their eggs or suffer deformations due to a broad variety of reasons.

Under constant controlled conditions of nesting temperature *C. moreletii* are considered to have a Female – Male – Female (F-M-F) Temperature-dependent Sex Determination (TSD) with most females being produced at low (about 29°C) and high (about 33°C) incubation temperatures and a high percentage of males occurring when the temperature ranges between 32°C and 33°C (Lopez-Luna et al., 2015). The range of the incubation temperatures for a successful incubation is rather small (between a minimum of 27°C and a maximum of 34°C) (Ferguson,1985; Bolton, 1989). The temperature does not only influence the sex of the crocodiles, it also affects pigmentation, size and growth, deformations and abnormalities as well as the behaviour of the juveniles (Köhler, 2004). Death and congenital abnormalities like deformed lower jaws, reduced eyes and other deformities caused through incubation at too high or too low temperatures were delineated multiple times in reptiles (Romanoff, 1972; Ewert, 1979; Ferguson, 1985; Miller, 1985; Köhler, 2004, Lopez-Luna, 2015). This study started with a very high incubation temperature of 37,8°C in the nest for 48 hours. Afterwards the eggs were transferred into two incubators with different temperatures, both at near the end of the maximum temperature tolerance range. This first step could already have caused the deformations of the embryos. A temperature of 32.5°C in the GRUMBACH incubator (not above the maximum of 34°C) and the resulting completely developed and even a single live hatchling after the incubation at 22°C – 29°C could indicate that the minimum temperature of 28°C could possibly be lowered if the eggs were given more time to develop. Nevertheless, other experiments in which eggs were switched from one incubation temperature to another indicate that the major effect of temperature occurs during the first half of embryonic development (Webb & Cooper – Preston, 1987).

Another important influence is humidity. Unlike the soft-shelled eggs of snakes, iguanas and some turtles (e.g. *Cheloniidae* & *Chelydridae)* the hard-shelled crocodile eggs tolerate a broad range of humidity (Bustard, 1971; Webb et al., 1987). The relative humidity develops with the right breeding substrate. A perfect substrate will keep the eggs moist, not wet, and enables a constant exchange of gases between the egg and the environment. Beyond that, natural breeding substrate assists in the degradation of the outer shell during development through microorganisms and/or carbonic acid formed from water and respiratory carbon dioxide. This causes an increased porosity of the shell as incubation proceeds, which facilitates the gas exchange in the later stages of growth, when the oxygen demands are highest, and weaken the calcareous shell (Ferguson, 1981; Grigg, 1987). With this information in mind, regarding humidity, the incubation setup was adequate. The constant relative humidity was at nearly 100% in the JAEGER and an average relative humidity around 72% in the GRUMBACH (Attachment Fig. 29; 30; 31 & 32). The eggs were always protected from water condensation and it was never wet inside of the eggs' boxes. Even the breeding substrate consisted of natural media, e.g. moss and dirt to promote the extrinsic degradation of the shell. Be that as it may, it has been argued that a too high humidity at the end of the incubation period could cause the death of the complete developed hatchlings, because of too much pressure in the egg, lead to asphyxia (Braunwalder, 1979; Krabbe-Paulduro & Paulduro, 1988; Köhler 2004).

Changing the position of the eggs is another possible factor. Different from bird eggs, the eggs of reptiles are not moved or rotated after being laid (Ewert, 1985; Ferguson, 1985). In this special case, it was needed to transfer the eggs from the original nest site into the two incubators and, additionally, it was necessary to check the fertilisation and the vital functions of the embryos from time to time. The top of the eggs was carefully marked with a pencil and were always handled with caution. Even so, the slightly increasing intervals of the Digital Egg Monitor check-up near the end of the scheduled incubation period should not have affected the embryos, as the moving the eggs has the greatest impact in the first third of the incubation interval (Joanen & McNease, 1977, 1979; Ewert, 1979, 1985; Limpus et al., 1979; Blanck & Sawyer, 1981; Chan et al., 1985; Ferguson, 1985; Chan, 1989; Deeming, 1991; Köhler, 2004).

The physical condition of the mother is something that must be kept in mind. Usually females reach sexual maturity at a length of around 130 – 150 cm at an age of 7 – 8 years (Platt & Thorbjarnason, 2000; Navarro Serment, 2004). In the wild they are laying between 20 to 40 eggs with a size of around 10 cm in a mound nest. The hatchlings' size is usually between 16 and 17 cm (Trutnau & Sommerlad, 2006). This clutch was the first of this female while the male had already bred successfully multiple times. Furthermore, the female had just reached maturity by age although she was already larger than the expected 150 cm. She was considered to be in top physical condition, certainly due in part to a diverse variety of food as well as sufficient UV light. Furthermore, the eggshells were very well calcified and the eggs as well as the embryos were of average size.

Even the size of the yolk sac of the embryos can be considered as normal, since they are smaller than the ones of the last offspring's in Schönbrunn.

To summarize, only assumptions can be made about the reasons why the embryos did not hatch by themselves, died in the egg and developed these deformations. The most probable reason is the high temperature of 37,8°C right after the eggs were laid into the nest. This simply reinforces the leading opinion that temperature has a major effect during the first trimester of the embryo development. For future clutches, the author suggests to change the substrate from sand-gravel-mixture to a more breathable substrate like dirt and moss so that the eggs will not be exposed to such high temperatures after being laid. All other parameters were within optimum ranges. It was even proven that the tolerated breeding temperature of 28°C to 34°C (Bolton, 1989; Köhler 2004) could possibly be lowered. The newly acquired data gives new insights of the incubation time at certain temperatures. At a constant breeding temperature of 32,2°C the eggs should have been opened after 78 days. The second set of eggs which were incubated the first three-quarters of the incubation period at 24°C and the last quarter at 28°C should have been opened after 100 or 102 days. Perhaps then living hatchlings would have been seen.

Conclusively one can say that ideally, no embryos should die from any cause related to management.

5.2 How hatchling calls are build up?

Regarding the results of Chapter 4.2 the research question, "How are hatchling calls built up?", in our case, can be answered by taking a look at Figure 10, 14 and Table 2 (page 27 – 30). On these diagrams one can recognize that the dominant frequency is between the 3rd and the 4th harmony, with a mean frequency of 329 Hz with a standard error of 13 Hz.

Sadly, the ground frequency in Figure 10 could not been better depicted because of the used program Praat.

Whereas the frequency minimum is at 587 Hz (standard error of 39 Hz), the maximum frequency at 149 Hz (standard error 9 Hz) amounts the frequency range to 443 Hz (standard error = 45). The duration of the call is around 0,189 seconds with a standard error of 0,020 seconds.

To answer the second question, "Does the deformation affect the call?" the calls of the three categories ("with background noise", "without background noise", and "wild") were compared with each other.

5.3 Does the deformation affect the call?

From Figure 11 it can be seen that the mean frequency of the “wild” call is at least 300 Hz higher than the highest frequency from the calls “without background noise” and is also 100 Hz higher than the frequency of the calls “with background noise”.

Regarding the frequency range there is little difference between the three, falling between 350 Hz and 600Hz (Fig. 12, page 29).

The “wild” calls have the longest duration, while the other two categories varied very little (Fig. 13, page 30).

It is hypothesized that the heavy deformation of the snout (Fig. 23, page 48) does affect the call. At the least it alters the frequency, influences the duration of the calls and could also affect the resonance frequencies and the formants.

It certainly must be taken into account that the quantity of this result is very low, as we had only one individual which was strong enough to call. The recorded “wild” calls originate from one individual in Belize and it is still not clear what kind of microphone it was recorded with. This could naturally also have influenced the quality of the records.

Unfortunately, most of our calls belong in the category “with background calls” (n = 198) so they had to be excluded from the analysis because the loud noise of the incubator masked the ground frequency.

Nevertheless, even with the small amount of different individual calls, the analysis was conducted as well as possible and both research questions could be answered.

For further investigations, it might be possible to compare the calls of healthy juveniles hatched in captivity with wild ones, to get more data on this field. In addition, it may be possible to do an autopsy on the deformed hatchlings and compare the results with hatchlings without any abnormalities.

Figure 23: Freshly hatched juvenile with massive deformation of the snout
Source: Author's own work, 2017

5.4 How does *C. moreletii* behave in captivity?

There is very little information available about the behaviour of this species in zoological facilities so this study aims to give a broad overview about it.
Morelet's Crocodiles in the Tiergarten Schönbrunn appear to be a rather relaxed species which is not easily disturbed by the presence of visitors or zookeepers. Regarding the fact that all *C.moreletii* of the Vienna Zoo were born in captivity this shows how even-tempered, calm and secure they feel in their territory, and might be an adaption to the frequent presence of people.
This behaviour changes when the zookeepers try to clean the inside of the enclosure. The aggressive behaviour of the male and the permanent blocking of the roller door by diving under it shows that the crocodile defends its territory and does not want to welcome trespassers. It also is an indicator of the intelligence of this species. By just hearing the engine of the roller door the male predicts that someone will intrude, so he tries to prevent this by blocking the door or by showing agonistic behaviour like attacking.
With 178 times of physical contact between the pair for more than one minute in the exhibition enclosure it becomes apparent that this species is a very social one (Attachment Table 5). Nevertheless, it must be kept in mind, that one female attacked the other female so aggressively that separation was necessary in 2011.
Through personal contact with private breeders it is known that intraspecific competition does happen and that death can be a result. Since females prefer dominant and bigger

males (Britton, 2009), it is not uncommon that in the whole research period, threatening behaviour against each other was never observed.

In this study, the assertion of Britton (2009) that, "*Crocodylus moreletii* should be active primarily at night, when it accomplishes its hunting and mating", could not be proven. As shown in Chapter 4.3.1 the main active phases were between 6:30 am – 9 am and from 6:30 pm – 9 pm. In the observed nights, the pair barely moved. Perhaps a better statement would be that *Crocodylus moreletii* in captivity is most active at twilight. The rest of the day is mostly spent basking in the sunlight, in shallow waters or on the land area of the enclosure.

Regarding the basking and the resting in the water two places in the enclosure were favoured: the log and the place in front of the small water stream. Especially the female spent a lot of time (3620 minutes) laying on the log. Not only did this spot surely make her feel secure because she could easily escape into the water, it was also directly underneath the HQI Spotlights. By contrast, the male did not once use the log as a basking or resting place (Attachment Table 11). That's might be because of the bigger size of the male. It seems to be that the log is just too small for the male to get a comfortable position on it.

The water stream was very popular with both crocodiles. Crocodile species like the Morelet's Crocodile or for example the False Gharial (*Tomistoma schlegelii*), which live in marshes, lakes and slow running rivers, seem to enjoy resting under waterfalls or in a fresh stream (Klamt, 2014). A small waterfall could be installed in the enclosure to check if the Morelet's Crocodiles would rest under it. In addition to the enrichment factor it would improve the general climate and the ambience of the Pavilion as well.

The daily routine of the male watching the food door in the lower right corner of the enclosure from 6:30 until the fish were fed can be considered as an adaption - he connects the door in the morning with food. Maybe this behaviour can be displaced by changing the feeding place of the crocodiles every time and by feeding the fish in the afternoon, when the crocodiles are resting. This could even lead to them beeing more active.

The very bad success rate of catching fish (0%) shows that *Crocodylus moreletii* does not usually feed on fish. The broad snout is not as suitable for catching fish as the much longer snout of the Indian gharial (*Gavialis gangeticus),* but it enables the crocodile to catch bigger prey such as larger mammals, reptiles or birds (Trutnau & Sommerlad, 2006).

Like in nature the crocodiles in the Tiergarten Schönbrunn use the dens to hide. Because of the slightly higher hanging “Island”, the Morelet’s were able to catch a breath even staying in the den under the “Island”. This is likely why this den was more popular for longer stays (up to 280 min), while the den under the “Main-Land-Part” is filled with water completely, so they had to leave it to breathe (Attachment Table 9). In general, these dens are a great way to offer the crocodiles an opportunity to get away from noisy visitors and those who do not stick to the park rules by knocking on the windows, throwing stuff inside the enclosure or using the flash settings on their camera to photograph them.

Worth mentioning is that during the whole observation period there was not a single clue of stereotypy or other unnatural behaviour. Another sign, that the husbandry of *Crocodylus moreletii* in the Tiergarten Schönbrunn is well-conceived.

Regarding the opening hours of the zoo (From 9 am to 6:30 pm in summer, and 4:30 pm in winter) it should be noted that the crocs are most active before and after the opening hours of the zoo. Enrichment and public training is a great way for the crocodiles to show more of their intraspecific behaviour and it makes this species even more attractive for the visitors when they can observe the crocodiles in action.

The next section is concerned with the results of the enrichment and training of the *C. moreletii* and gives an answer to the next research question:

5.5 How can their lives be enriched?

In the wild, animals must build homes, defend territories, escape predators and find food. In zoos, the majority of animals' needs are provided, so other methods of physical and mental stimulation must be offered to encourage natural behaviours. Enrichment can help to reduce stress, aggressions, boredom and improve physical activity by triggering natural instincts through touch, smell, sight and interaction. It is as important for a zoo to provide nutritious and well balanced diets as it is to offer the animals enrichment activities. Thus, animal enrichment creates a win-win-win situation for the animals, visitors and keepers.

The well-structured, nature like enclosure as described in Chapter 3.5 is the first step and already includes environmental enrichment like the water-stream, logs and roots. Even the roller door can be seen as an enrichment, because it forces the crocodiles to adapt to a new situation.

Fish are another way of enrichment. The crocodiles can try to hunt them and they make the enclosure more attractive for the visitors when the crocodiles are resting.

These enrichment methods were all permanent in the enclosure. To create new and (for the crocodiles) unforeseen situations the researcher tried different kinds of enrichment activities, as mentioned in Chapter 4.3.

The best way to mobilize the crocodiles and to impress the visitors is by encouraging them to jump. A substantial amount of effort and strength must be put in by the crocodiles in order to get a fairly small treat. This is not only an excellent way to improve the physical condition of the crocodiles, but of controlling the exact amount of food for an individual. In addition, it is naturally a huge attraction for the visitors to see a normally rather slow crocodile jump out of the water.

Training is the best enrichment to stimulate the mental condition of the animals (Table 3, page 40). Ralf Sommerlad, a well-known German author and crocodile trainer once said, “If they are coming out of their safe hide (usually water) for a tiny piece of meat, that is not worth the energy spent or the risk taken (as per croc logic), that my friend is a good enrichment”. The training part was a huge challenge for the researcher as well as for the crocodiles. While for the author it was the first experiences with crocodile-training, the Morelet’s Crocodiles already knew what a target is from their feeding procedure every 14 days. As seen in the results all crocodiles learned quickly that they get a treat if they follow the target. Given more time the next steps are to learn commands for going on land or back in the water or simply to come to the trainer when their name is called. This again is a good way to teach the visitors that crocodiles are not “boring killer machines”. After two weeks of training all three crocodiles recognized the trainer when he appeared in front of the enclosure or even heard his voice. They immediately started to swim to his position. After the three weeks without training this behaviour stopped as well. To get a better insight it would be meaningfully to test the reactions of other Morelet’s Crocodiles in other zoological institutions to compare if our crocodiles learned rather fast or slow.

Enrichment experiments with new objects or smells were successful but not as effective as the ones with moving objects. The crocodiles usually reacted but once they noticed that the object was not moving anymore they lost interest immediately. The olfactory experiments should be continued because of the enormous variety of spices and scents which can provided (Table 3, page 40).

The water stream enrichment experiment with the hose as explained from Joachim Brock (1998) could not be confirmed. This may be because the crocodiles in the Tiergarten Schönbrunn are used to water coming from above when the Zookeepers are watering the plants in the crocodile enclosure.

The female in the enclosure behind the scenes reacted even to the stationary objects in a playful manner. She destroyed the pumpkins and interacted with the plastic ball for more than three hours straight.

It was possible to scatter small pieces of food inside the water area of the female's backstage enclosure because there were no fish in it. The female croc could consequently take all the time she needed to pick up all the food.

Before the researcher started the enrichment and training program this female jumped against the windows of the enclosure when someone came too close. This behaviour later completely vanished. It appeared that this crocodile was in serious need of enrichment.

In summary, there is an extensive variety of ways to keep the crocodiles enriched, the best being with training and moving objects.

5.6 Is it possible to establish an efficient training in the working routine?

Efficient training is one which takes place regularly. The problem is that the crocodiles are listed as particularly dangerous animals in the DGUV (DGUV, 2012). So, for safety reasons the zookeepers are not allowed to interact with the crocodiles alone. That means, next to their daily working routine at least two zookeepers are necessary to train the crocodiles. To accomplish that the plan is to train them twice a week for about 10 to 15 minutes and to perform a jumping enrichment on the weekend. This way, the crocodiles are actively engaged at least three times a week. During the week, there should be enough personnel working that it should be possible to do the training. Plus, there is no need of a fixed timetable so the zookeepers can train them whenever they have spare time. The jump enrichment on the weekend can easily be done by one zookeeper, because it is not necessary to enter the crocodile enclosure. In the future, this should be part of a public and narrated feeding time to attract and educate visitors.

To answer the research question, thanks to the preparations (such as the openable training ground and the consecutive training units) it should be possible to continue this training on a regular basis.

5.7 Where are the Crocodiles in Europe from and how are they related?

To meet their various aims zoos and aquariums rely on steady populations of the animals they keep. Since they wish to refrain from bringing in animals from the wild, it is important that they maintain healthy and self-sustaining populations of animals. This means that zoos and aquariums need to have populations of many species that are large enough to prevent inbreeding (EAZA Website, visited 2017). Since the IUCN listed

Crocodylus moreletii as “Least Concern” (Cedeño-Vázquez, 2016) with a population of approximately 100.000 Individuals in the wild, it is not possible, nor necessary to establish a European Endangered Species Program (EEP) yet even the IUCN has the opinion that it would be of advantage to monitor the conservation activities of this species (Cedeño-Vázquez, 2016).

The results of section 4.4 can be used to offer an overview about this species and the breeding status in European Zoos. It also shows that the European population has a good mix of ages and, for a rather uncommon zoo animal, its distribution is quite acceptable, though the majority (14) of these animals are in the United Kingdom.

Remarkable is the fact that even so breeding is possible in eight out of 17 zoos, only three of them breed successful.

An important point is the lack of males in Europe. Because of that the sex of the probably male in the “Meeresaquarium Zella-Mehlis” (Germany) as well as of the other unknown individuals in the Exmoore Zoo and in in Crawley Crocs of the World should be classified to secure its sex. Afterwards it should, as well as the single male in the “Parc Merveilleux” (Luxembourg), not remain alone. There are Institutions which would appreciate a male or perhaps want to transfer some of their females. Additionally, it should be considered to change the males in the zoos where the couples do not live in harmony.

On the other hand, the demand of Morelet’s Crocodiles is not very high at the moment. However, it is not clear if they would start breeding immediately, and the eggs could easily be removed If there is no need of *C. moreletii* offspring.

The female crocodiles in the Zoo Vienna and the Krokodyli Zoo in Czech reached maturity in 2016, meaning that next year there could already be a breeding success.

The biggest problem working on this task was the communication between the zoos, as you can tell by the Table 4 it was not possible to get an answer from every zoo, which made it hard to get the data. But altogether most of the Zoos were helpful and cooperative. Additionally, there are many private breeders across Europe. Even though it was not possible to contact all of them it can be assumed that there are much more Morelet’s Crocodiles in private hands than we have in the zoos.

A small but healthy population in European zoos and an even bigger one in private hands does exist. For further studies and for a more accurate and in-depth look it might be reasonable to take blood samples of the individuals to classify their genetic relationship to each other. In this regard, this study might help to give an overview and provides the opportunity to stay current, so that now and in future a healthy population of *Crocodylus moreletii* in European Zoos is maintained.

6. Prospect

Since the massive population decline in the 1940's and 1950's due to unregulated skin hunting, a lot of conservation actions (e.g. captive breeding programs, protected areas as well as national and international legislative protection) have been recognized. Thanks to these efforts the wild population recovered and with a estimated number of about 100.000 individuals the species conservation status could be lowered to “least concern” (Platt et al., IUCN Status 2017).

Now it is of utmost importance that the interest in this crocodile species is not lost! Although skin hunting is not a major threat anymore it is still considered one of the primary threats to complete population recovery in some areas. There are new threats as well, including the exposure to chemical pollutants such as pesticides (Platt et.al., IUCN Status 2017). Therefore, monitoring the populations in the wild as well as in the captivity is critical.

To keep a healthy population in European zoos it is vital to establish a successful breeding program and to keep an audit of which zoo takes care of this species. To keep the gene pool as diverse as possible it is especially important that more zoos start breeding. The Tiergarten Schönbrunn will learn from the incubation mistakes of the breeding season 2016 and will adjust the substrate in the enclosure as well as have more control over the incubators to prevent another temperature drop in the incubation period. Since the crocodiles have already mated again, with these adaptions there speaks nothing against a successful breeding season 2017.

A major contribution for the conservation of *Crocodylus moreletii* consists of teaching the visitors of the zoo how fascinating this species is and to change the bad reputation of crocodiles. Therefore, the training sessions and the weekly enrichment unit in the Tiergarten Schönbrunn should be public and narrated to show the visitors that crocodiles are not simply boring and mindless killing machines but rather intelligent animals worth protecting.

References

Blanck, Cynthia E. and Sawyer Roger H. "Hatchery practices in relation to early embryology of the loggerhead sea turtle, Caretta caretta (Linne)." *Journal of Experimental Marine Biology and Ecology* 49.2-3 (1981): 163-177.

Bolton, M. "The management of crocodiles in captivity. "FAO Conservation Guide": Rom (1989): 32

Boersma, Paul and D. Weenink. "Praat, doing phonetics by computer (v. 5.4)." (2015).

Braunwalder, M. E. "Über eine erfolgreiche Zeitigung von Eiern des Grünen Leguans, Iguana i. iguana, und die damit verbundene Problematik (Reptilia: Sauria: Iguanidae)." *Salamandra* 15 (1979): 185-210.

Brazaitis, Peter and Merrit, A. Dennis. "The identification of living crocodilians". New York Zoological Society, 1973.

Brien, M. L., Lang, J. W., Webb, G. J., Stevenson, C., & Christian, K. A. "The good, the bad, and the ugly: agonistic behaviour in juvenile crocodilians." *PloS one* 8.12 (2013): e80872.

Britton A., 2009. "Crocodilian Species-Morelet's Crocodile (Crocodylus Moreletii)" (On-line). Crocodilian Species List. Accessed 05.01.2017 at <http://crocodilian.com/cnhc/csp_cmor.htm>.

Brock, Joachim. „*Krokodile: ein Leben mit Panzerechsen*." Natur-und-Tier-Verlag, 1998.

Bryman, A. and Bell, E., eds., 2007. *Business Research Methods*. New York: Oxford University Press.

Bustard, H. R. "Temperature and water tolerances of incubating crocodile eggs." *Br. J. Herpet* 4 (1971): 198-200.

Cedeño-Vázquez, J.R., Platt, S.G. & Thorbjarnarson, J. (IUCN Crocodile Specialist Group). 2016. Crocodylus moreletii. The IUCN Red List of Threatened Species

2016: e.T5663A3045579.
http://dx.doi.org/10.2305/IUCN.UK.2012.RLTS.T5663A3045579.en. Downloaded on 23 December 2016

Chan, Eng-Heng, Salleh H. U. and Liew Chark H. "Effects of handling on hatchability of eggs of the leatherback turtle, Dermochelys coriacea (L.)." *Pertanika* 8.2 (1985): 265-271.

Chan, Eng-Heng. "White spot development, incubation and hatching success of leatherback turtle (Dermochelys coriacea) eggs from Rantau Abang, Malaysia." *Copeia* (1989): 42-47.

Collis, J. and Hussey, R., 2003. *Business research: a practical guide for undergraduate and postgraduate students*. 2nd ed. Basingstoke. Palgrave Mcmillan.

Deeming, Denis C. "Reasons for the dichotomy in egg turning in birds and reptiles." *Egg incubation: its effects on embryonic development in birds and reptiles* (1991): 307-323.

Dever, Jennifer A. and Densmore D. Llewellyn. "Microsatellites in Morelet's crocodile (Crocodylus moreletii) and their utility in addressing crocodilian population genetics questions." Journal of Herpetology 35.3 (2001): 541-544.

Dollinger, P.: Verband Der Zoologischen Gärten e.V. <http://www.zoodirektoren.de/index.php?option=com_k2&view=item&id=912:dollinger-p-hrsg-2008&Itemid=217>. Accessed 28.12.2016.

EAZA 2016. European Association of Zoos and Aquaria www.eaza.net/members/. Downloaded at the 05.01.2017.

Ewert, Michael A. "The embryo and its egg: development and natural history." *Turtles: Perspectives and research* (1979): 333-413.

Ewert, Michael A. "Embryology of turtles." *Biology of the Reptilia* 14 (1985): 75-267.

Ferguson, Mark WJ. "Extrinsic microbial degradation of the alligator eggshell." *Science* 214.4525 (1981): 1135-1137.

Ferguson, Mark WJ. "Reproductive biology and embryology of the crocodilians." *Biology of the Reptilia* 14 (1985): 329-491.

Grigg, Gordon C. "Water relations of crocodilian eggs: management considerations." *Wildlife Management: Crocodiles and Alligators. Surrey Beatty & Sons, Chipping Norton, Australia* (1987): 499-502.

Hair, J. F., Money, A.H., Samouel, P. and Page, M., eds., 2007. *Research Methods for Business*. Chichester: John Wiley and Sons Ltd.

Joanen, Ted, and McNease Larry. "Artificial incubation of alligator eggs and post hatching culture in controlled environmental chambers." *Journal of the World Aquaculture Society* 8.1-4 (1977): 483-490.

Joanen, Ted, and McNease Larry. "Culture of the American alligator." *International Zoo Yearbook* 19.1 (1979): 61-66.

Klamt, Markus. "Wie wird das natürliche Verhalten von Sunda-Gavialen durch die Haltung in zoologischen Einrichtungen beeinflusst? Eine Untersuchung im Zoo Leipzig." Unpublished data.

Köhler, Gunther. "*Inkubation von Reptilieneiern: Grundlagen, Anleitungen, Erfahrungen*." Offenbach: Herpeton, 2004.

Krabbe-Paulduro, U. and Paulduro E. Jr. "Pflege und Nachzucht der Afrikanischen Dornschwanzagame Uromastyx acanthirunus Bell, 1825 (Sauria: Agamidae)." *Salamandra* 24.1 (1988): 27-40.

Limpus, Colin J., Baker, Valonna and Miller D. Jeffrey. "Movement induced mortality of loggerhead eggs." *Herpetologica* (1979): 335-338.

López-Luna, M. A., Hidalgo-Mihart, M. G., Aguirre-León, G., González-Ramón, M. D. C., & Rangel-Mendoza, J. A. "Effect of nesting environment on incubation temperature and hatching success of Morelet's crocodile (Crocodylus moreletii) in an urban lake of Southeastern Mexico." *Journal of thermal biology* 49 (2015): 66-73.

Manolis, S. Charlie, Whitehead J. Peter and Dempsey Karen. "The possible relationship between embryo orientation opaque banding and the dehydration of albumen in crocodile eggs." *Copeia* 1987.1 (1987): 252-257.

Miller, J. D. "Embryology of marine turtles. In ‘Biology of the Reptilia. Vol. 14’. (Eds C. Gans, F. Billet, and P. Maderson.) pp. 269–328." (1985).

Navarro-Serment, C. J. "The return of Morelets crocodile. Crocodylus moreletii." *Reptilia* 2004 (2004): 54-60.

Neill, Wilfred T. “The last of the ruling reptiles: alligators, crocodiles, and their kin”. New York: Columbia University Press, (1971).

Platt, Steven G. and John B. Thorbjarnarson. "Population status and conservation of Morelet's crocodile, Crocodylus moreletii, in northern Belize." Biological Conservation 96.1 (2000): 21-29.

Platt, Steven G., Rainwater, Thomas R., Thorbjarnarson John, B. and McMurry S. T. "Reproductive dynamics of a tropical freshwater crocodilian: Morelet's crocodile in northern Belize." Journal of Zoology 275.2 (2008): 177-189.

Platt, Steven G., Sigler, Luis and Rainwater, R. Thomas. "Morelet’s crocodile Crocodylus moreletii." Crocodiles: Status Survey and Conservation Action Plan (2010): 79-83.

Rainwater, T. R., Platt, S. G., Wu, T. H., McMurry, S. T. and Anderson, T. A.” Organochlorine contaminants in Morelet’s crocodile (Crocodylus moreletii) eggs from Belize.” Chemosphere 40.6 (2000): 671-678.

Ray, D. A., Dever, J. A., Platt, S. G., Rainwater, T. R., Finger, A. G., McMurry, S. T. and Densmore, L. D. “Low levels of nucleotide diversity in Crocodylus moreletii and evidence of hybridization with Crocodylus acutus.” Conservation Genetics, 5.4 (2004): 449-462.

Romanoff, Alexis Lawrence, and Romanoff J. Anastasia. ”*Pathogenesis of the avian embryo: an analysis of causes of malformations and prenatal death*.” Wiley-Interscience., 1972.

Ross, J. P. "Crocodiles. Status Survey and Conservation Action Plan. IUCN/SSC Crocodile Specialist Group. IUCN, Gland, Switzerland and Cambridge, UK. Viii+ 167 pp."(1998): 465-470.

Saunders, M., Lewis, P. and Thornhill, A., 2007. *Research methods for business students*. 4th ed. [e-book] Pearson Education UK. Available through Anglia Ruskin University Library website <www.libweb.anglia.ac.uk> [Accessed 10 Nov 2016].

Schmidt, Karl Patterson. “*Notes on Central American crocodiles*.” Field Museum of Natural History, Zoological Series 12 (1924): 79-92.

Sigler, Luis. "Morelet’s crocodile at Yucatan Peninsula, Mexico. "Crocodile Specialist Group Newsletter” 21.1 (2002): 15-16.

Tiergarten Schönbrunn, Zoo Vienna Homepage, accessed 18.12.2016 at <http://www.zoovienna.at/ueber-uns/tiergarten-schonbrunn/>.

Trutnau, Ludwig. “*Krokodile: Alligatoren, Kaimane, echte Krokodile und Gaviale*.“ Westarp-Wiss., 1994.

Trutnau, Ludwig and Sommerlad, Ralf. “Crocodilians: Their Natural History & Capitve Husbandry; with Chapters on" Origins" and" Evolution of Crocodilians" by Daniela Schwarz; a Chapter on" Systematics of Modern Crocodilians" by Hemmo Nickel; and Chapters on" Skin and Skin Elements" and" Tanning Crocodilian Skins" by Karlheinz Fuchs. Ed. Chimaira, 2006.

Unfallversicherung, DGUV–Deutsche Gesetzliche. "Sachgebiet „Tiergehege“ der Fachgruppe „Forsten“ der GUV. BGR/GUV-R 116." (2012).

Vergne, Amélie L. and Mathevon Nicolas. "Crocodile egg sounds signal hatching time." *Current Biology* 18.12 (2008): R513-R514.

Wagner, Dr. Jonathan R. “Crocodylus moreletii”, Digital Morphology (2005). Accessed January 24, 2017 at http://digimorph.org/specimens/Crocodylus_moreletii/

Webb, G. J., & Cooper-Preston, H. "Effects of incubation temperature on crocodiles and the evolution of reptilian oviparity." *American Zoologist* 29.3 (1989): 953-971.

Wilson, J., 2010. *Essentials for Business Research: A guide to doing your research project*. London: SAGE Publications Limited.

Zootierliste, website accessed 11.01.2017 at <http://zootierliste.de/?klasse=3&ordnung=306&familie=30601&art=3050202>.

7. Attachment

List of abbreviations:

IUCN	World Conservation Union
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
EAZA	European Association of Zoos and Aquaria
OZO	Österreichische Zoo Organisation
WAZA	World Association of Zoos and Aquaria
VdZ	Verband der Zoologischen Gärten e.V.
ZGAP	Zoological Society for Conservation of Species and Poplations
CSG	Crocodile Specialist Group
1,0	Male
0,1	Female
0,0,1	Sex unknown
1,1	One male and one female

Figures and Table's:

Figure 24: Female in the backstage enclosure

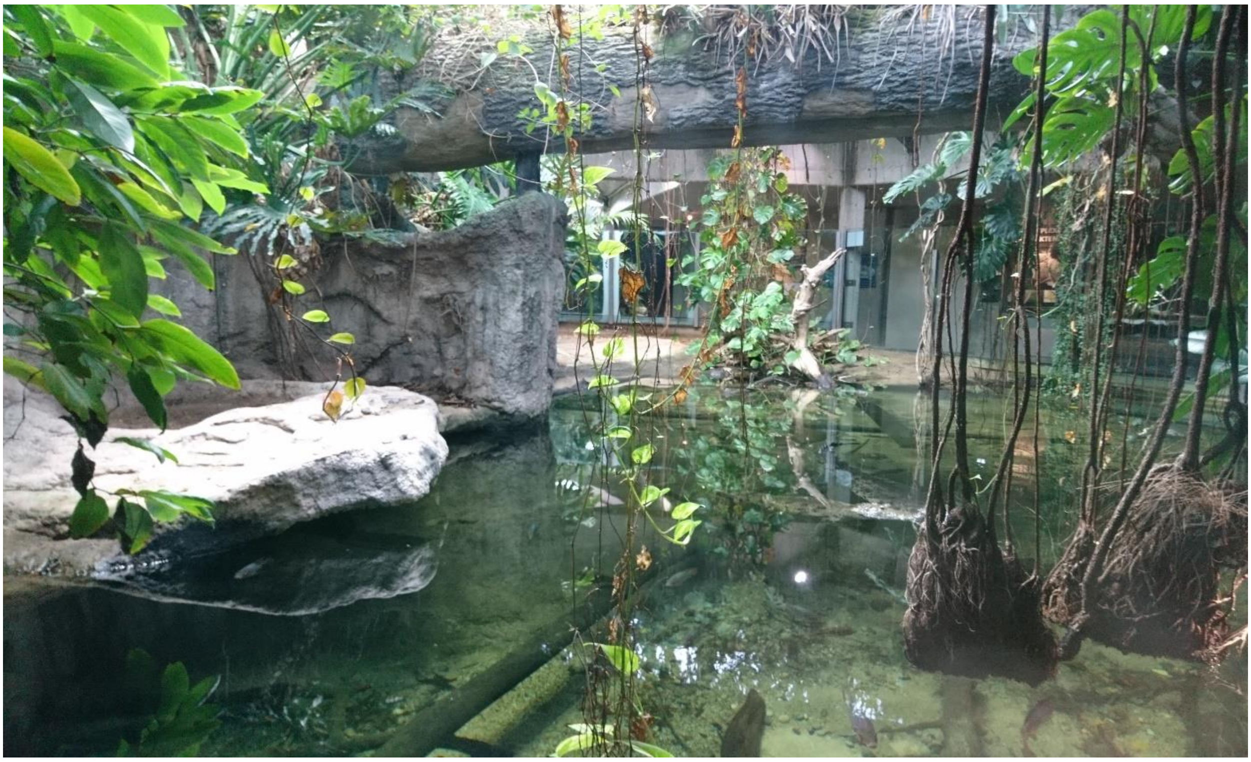


Figure 25: Picture of the exhibition enclosure "Island" Area

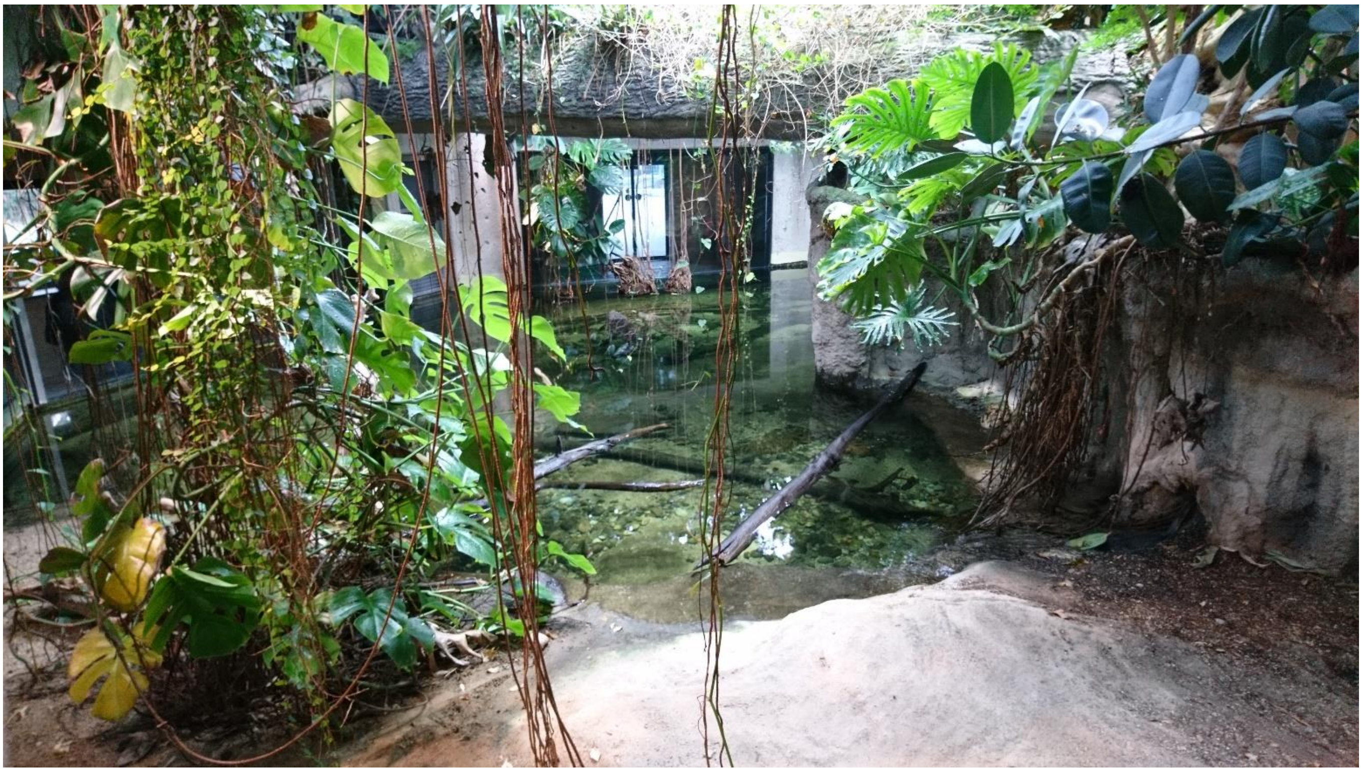


Figure 26: Picture of the exhibition enclosure “Main-Land-Part” Area

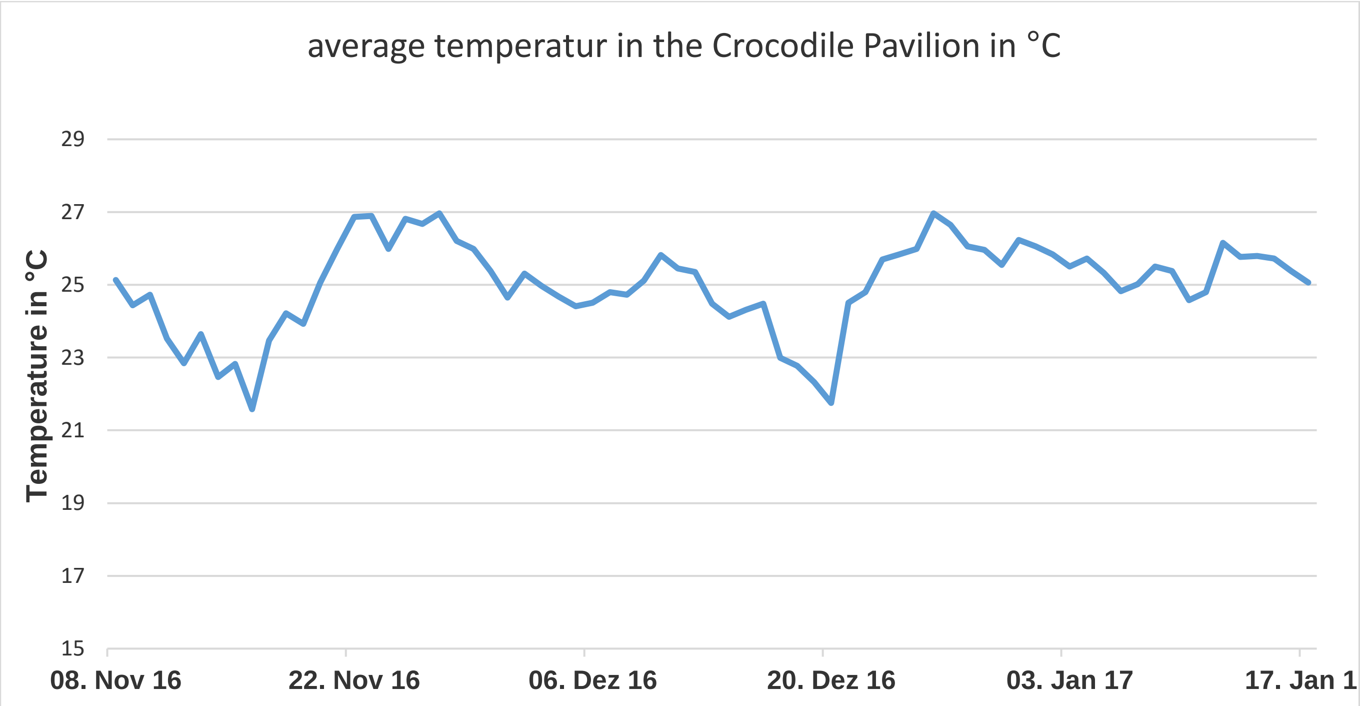


Figure 27: Average temperature in the Crocodile Pavilion of the Tiergarten Schönbrunn

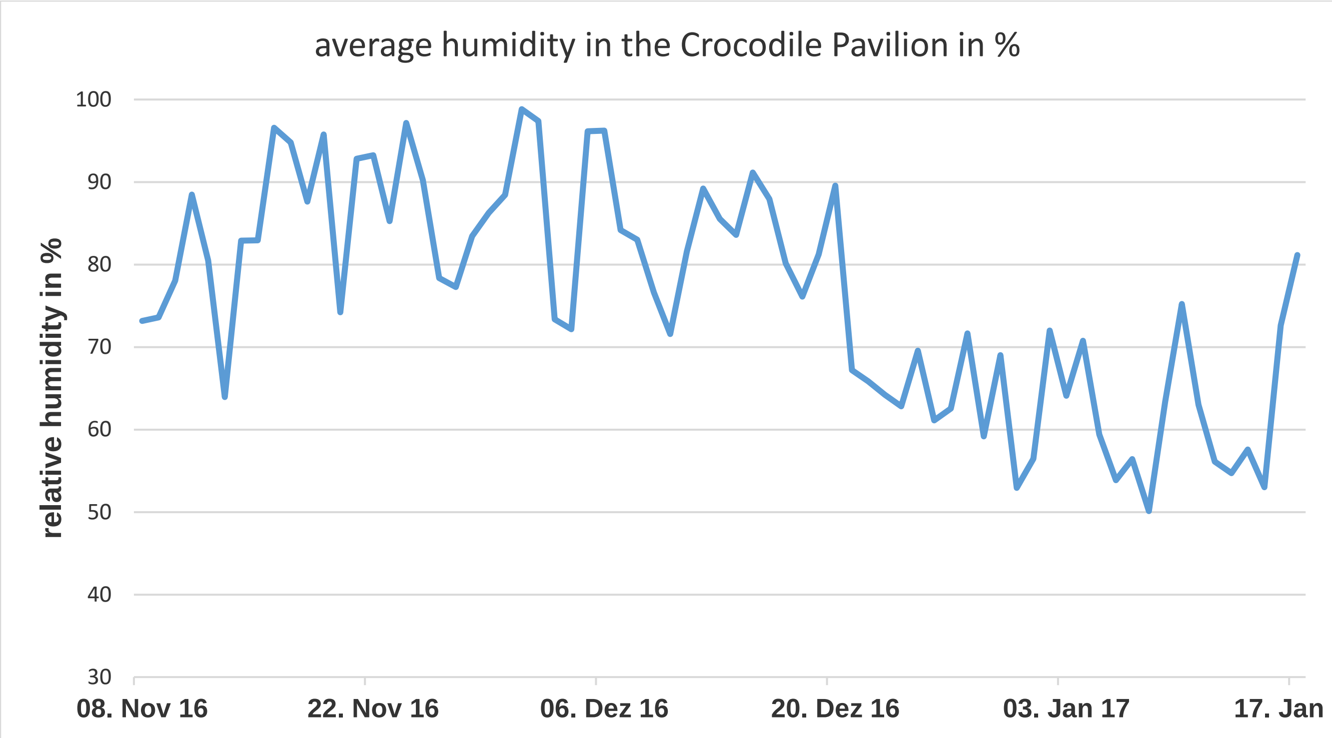


Figure 28: average relative humidity in the Crocodile Pavilion of the Tiergarten Schönbrunn

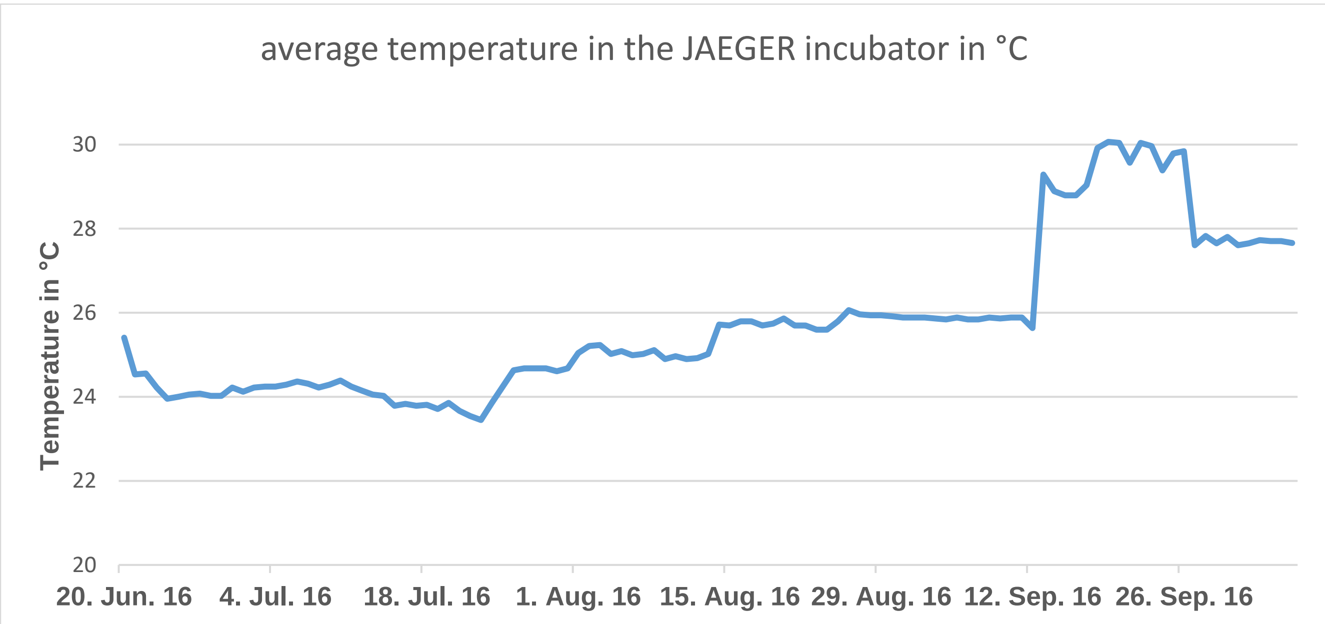


Figure 29: Average temperature in the JAEGER incubator

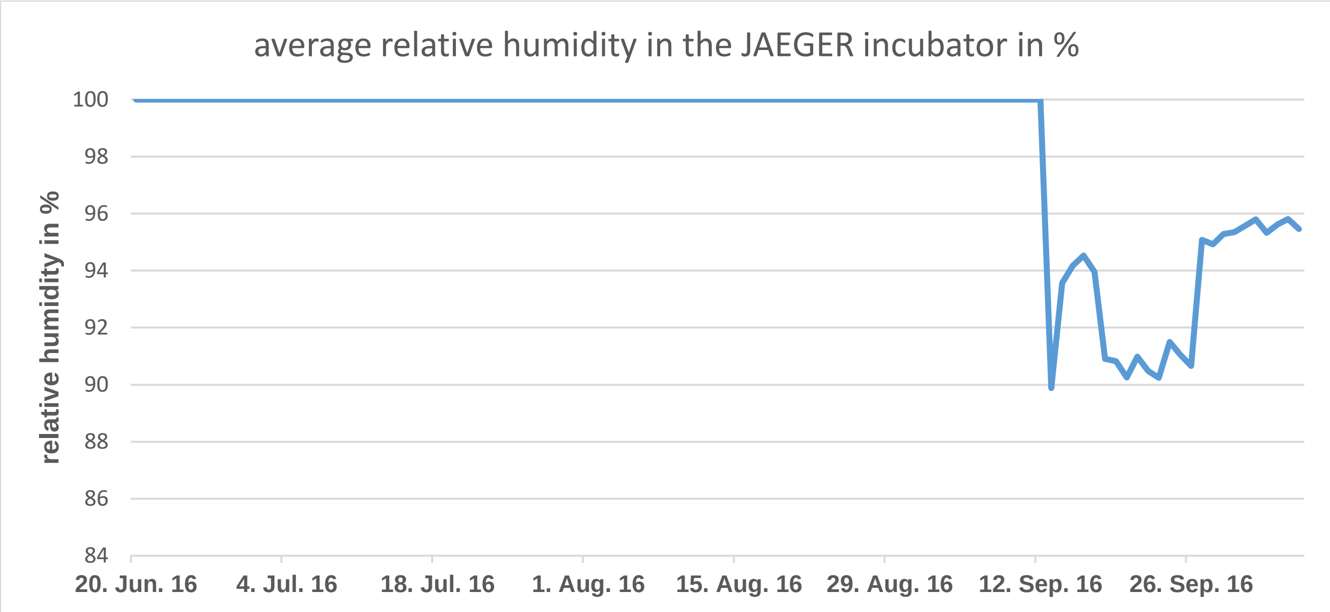


Figure 30: Average relative humidity in the JAEGER incubator

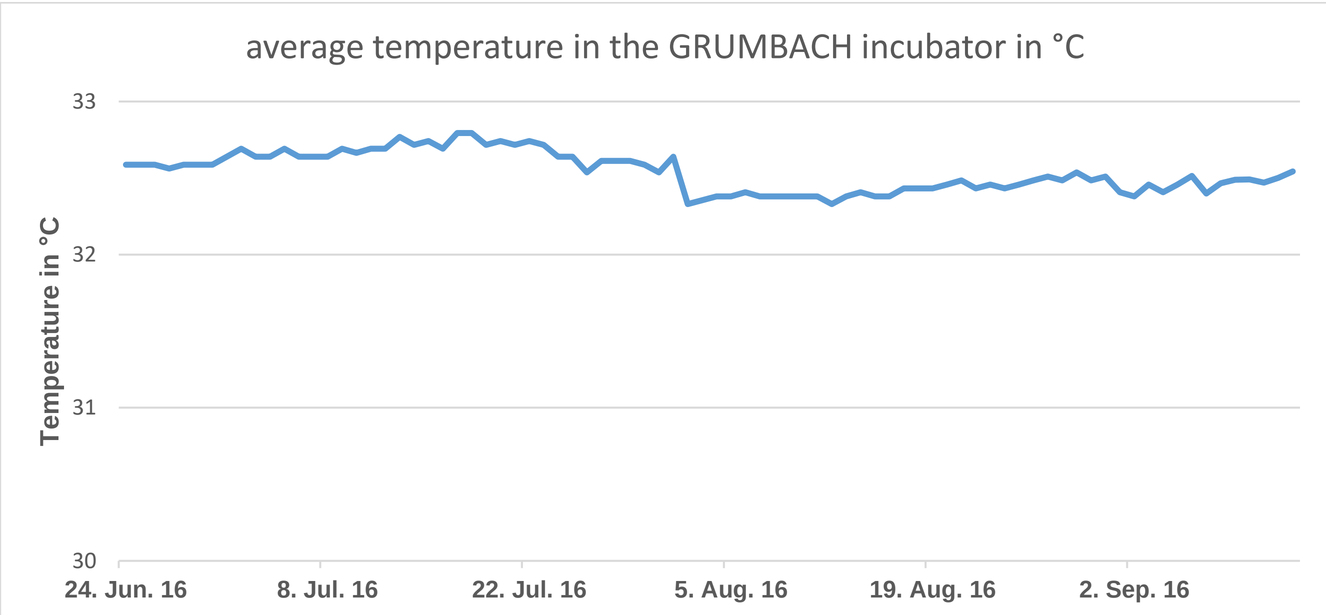


Figure 31: Average temperature in the GRUMBACH incubator

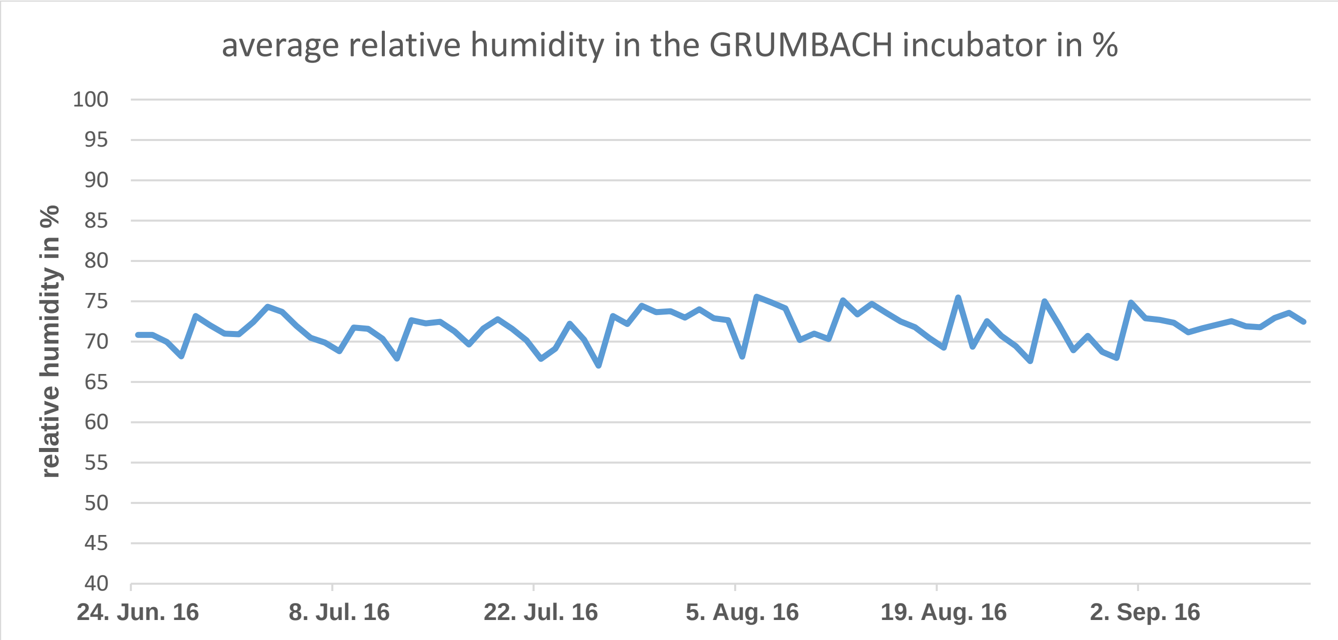


Figure 32: Average relative humidity in the GRUMBACH incubator

Table5: Amount of body contact, which lasted for more than 1 minute

Body contact		
Date	**1,0**	**0,1**
11. Okt. 16	-	3
12. Okt. 16	-	1
13. Okt. 16	-	5
14. Okt. 16	2	2
15. Okt. 16	1	1
16. Okt. 16	3	3
17. Okt. 16	2	6
18. Okt. 16	-	1
19. Okt. 16	2	3
20. Okt. 16	1	4
21. Okt. 16	2	3
22. Okt. 16	1	1
23. Okt. 16	2	3
24. Okt. 16	1	3
25. Okt. 16	3	3
26. Okt. 16	1	4
7. Nov. 16	3	1
8. Nov. 16	1	2
9. Nov. 16	-	2
10. Nov. 16	4	6
11. Nov. 16	1	1
24. Nov. 16	4	6
25. Nov. 16	1	1
26. Nov. 16	4	8
27. Nov. 16	2	1
28. Nov. 16	3	2
1. Dez. 16	-	4
2. Dez. 16	1	3
3. Dez. 16	2	4
4. Dez. 16	1	3
6. Dez. 16	1	2
8. Dez. 16	3	2
9. Dez. 16	2	4
10. Dez. 16	1	4
11. Dez. 16	3	4
12. Dez. 16	3	5
13. Dez. 16	2	4
total times	**63**	**115**
average	**2x/d**	**3x/d**

Table6: Amount of attempts to catch the fish

Fish interaction		
Date	**1,0**	**0,1**
11. Okt. 16	-	2
12. Okt. 16	-	-
13. Okt. 16	1	-
14. Okt. 16	-	-
15. Okt. 16	-	-
16. Okt. 16	-	1
17. Okt. 16	-	-
18. Okt. 16	-	1
19. Okt. 16	1	-
20. Okt. 16	-	1
21. Okt. 16	-	-
22. Okt. 16	-	-
23. Okt. 16	-	-
24. Okt. 16	-	1
25. Okt. 16	-	2
26. Okt. 16	-	-
7. Nov. 16	1	1
8. Nov. 16	-	1
9. Nov. 16	-	2
10. Nov. 16	2	-
11. Nov. 16	-	-
24. Nov. 16	-	1
25. Nov. 16	-	-
26. Nov. 16	1	1
27. Nov. 16	1	-
28. Nov. 16	1	-
1. Dez. 16	-	-
2. Dez. 16	-	1
3. Dez. 16	-	-
4. Dez. 16	-	1
6. Dez. 16	-	1
8. Dez. 16	-	-
9. Dez. 16	-	-
10. Dez. 16	-	-
11. Dez. 16	-	-
12. Dez. 16	3	-
13. Dez. 16	1	1
total times	**12**	**18**
average	**0,3/d**	**0,4/d**

Table7: total distance, distance till 9 am and the distance the crocodiles moved on land in meter

	Total distance in m		Distance till 9 am in m		Distance on Land in m	
Date	**1,0**	**0,1**	**1,0**	**0,1**	**1,0**	**0,1**
11. Okt. 16	159	230	64	122	10	6
12. Okt. 16	233	280	78	89	7	17
13. Okt. 16	301	247	87	91	8	25
14. Okt. 16	298	255	94	83	2	4
15. Okt. 16	317	279	215	123	6	4
16. Okt. 16	213	237	39	41	16	4
17. Okt. 16	256	260	95	48	3	4
18. Okt. 16	293	388	146	126	5	14
19. Okt. 16	124	117	104	32	16	4
20. Okt. 16	362	398	70	53	9	4
21. Okt. 16	182	287	90	88	7	15
22. Okt. 16	277	301	120	138	4	5
23. Okt. 16	219	233	62	81	4	16
24. Okt. 16	267	270	96	79	4	4
25. Okt. 16	243	248	118	50	11	6
26. Okt. 16	232	275	126	131	10	7
7. Nov. 16	226	228	102	98	9	4
8. Nov. 16	227	149	175	94	9	3
9. Nov. 16	184	294	122	48	9	4
10. Nov. 16	254	198	158	47	6	4
11. Nov. 16	422	433	94	54	14	6
24. Nov. 16	170	213	108	142	5	4
25. Nov. 16	393	353	255	94	12	13
26. Nov. 16	120	254	75	45	11	11
27. Nov. 16	380	360	151	93	25	17
28. Nov. 16	235	144	90	9	27	9
1. Dez. 16	376	303	172	57	18	4
2. Dez. 16	336	305	183	80	15	5
3. Dez. 16	229	107	119	172	13	11
4. Dez. 16	171	329	86	92	9	11
6. Dez. 16	185	190	36	44	8	9
8. Dez. 16	297	253	166	58	18	27
9. Dez. 16	278	320	119	108	14	7
10. Dez. 16	380	328	79	55	18	15
11. Dez. 16	354	171	189	36	5	9
12. Dez. 16	295	280	149	60	16	14
13. Dez. 16	286	292	158	102	18	26
in Total	**9775,0**	**9809**	**4391,0**	**2963**	**401**	**352**
average	**264**	**265**	**119**	**80**	**11**	**10**

Table8: Time the crocodiles spent on land and which area they prefer

Time spent on land				
	1,0		0,1	
Date	**Island**	**Main-Land-Part**	**Island**	**Main-Land-Part**
11. Okt. 16	-	23, 293	211	30, 10
12. Okt. 16	73	-	360	105, 43
13. Okt. 16	-	67	465	106
14. Okt. 16	-	88, 425	195	-
15. Okt. 16	-	452	576	-
16. Okt. 16	-	666	-	92, 287, 9
17. Okt. 16	-	65	-	156
18. Okt. 16	508	-	449	10, 3, 36
19. Okt. 16	-	720	360	-
20. Okt. 16	-	105	-	3
21. Okt. 16	640	81	498	39
22. Okt. 16	461	96	302	-
23. Okt. 16		113	600	36
24. Okt. 16		88	419	-
25. Okt. 16		70, 326	-	57, 261
26. Okt. 16	629	78	527	-
7. Nov. 16		692	843	-
8. Nov. 16	631	93	620	-
9. Nov. 16		135, 610	165, 441	-
10. Nov. 16		394	102, 506	-
11. Nov. 16		102, 394	162, 234	-
24. Nov. 16		618	-	77, 593
25. Nov. 16		82, 157, 439	-	92, 40, 162, 72, 131
26. Nov. 16		632, 665	-	293, 111, 223, 267, 36
27. Nov. 16		84, 3, 37, 216, 113, 180	-	86, 36, 233, 31, 107, 6, 6, 89
28. Nov. 16	119, 281	28, 197	-	66, 222, 207, 124
1. Dez. 16		89, 94, 16, 370	-	126, 43
2. Dez. 16		563, 107, 294	-	17
3. Dez. 16		102, 577	22, 95	-
4. Dez. 16	151	612	-	89, 142, 26
6. Dez. 16		349	-	115, 105, 26
8. Dez. 16		96, 596	-	82, 50, 121
9. Dez. 16		81, 547, 91	-	22
10. Dez. 16	572	275, 25	60	43, 26, 10
11. Dez. 16		258	-	67
12. Dez. 16		115, 107	108	5
13. Dez. 16	107	8, 24, 271	53	133, 5
total times	**4172min, 11x**	**14798min, 71x**	**8370min, 25x**	**11400min, 61x**
average	**379min**	**208min**	**335min**	**187**

Table9: time the crocodiles spend in the dens and which one they preferred

Time spend in dens in minutes				
	1,0		0,1	
Date	**Island**	**Main**	**Island**	**Main**
11. Okt. 16	-	4, 3	6, 29	14
12. Okt. 16	3, 78, 36,100	5, 11	-	-
13. Okt. 16	132	4, 6	6	3
14. Okt. 16	93	43, 31, 5	58	9, 7, 6, 5, 13, 3
15. Okt. 16	8,37	-	12	9, 9, 6
16. Okt. 16	6	3	8	3, 8, 4, 4, 6, 2
17. Okt. 16	17, 46, 41, 76	-	21	9, 4, 2
18. Okt. 16	11, 50, 5	10	8, 9	-
19. Okt. 16	-	-	6	-
20. Okt. 16	56, 162	3, 3	3, 3	-
21. Okt. 16	5	3	2	10
22. Okt. 16	21	-	10, 84, 11, 16	-
23. Okt. 16	280, 10, 138, 4	30, 24	-	-
24. Okt. 16	102, 79, 111	9	13, 15	3, 5
25. Okt. 16	-	-	6	-
26. Okt. 16	5	-	12, 15, 6, 10	8, 27
7. Nov. 16	25-	-	-	-
8. Nov. 16	20, 11	6	-	-
9. Nov. 16	-	-	-	7, 4
10. Nov. 16	18	6	10	4
11. Nov. 16	56	3	-	5
24. Nov. 16	74, 9	4	3	4
25. Nov. 16	-	-	-	13, 9, 7, 7
26. Nov. 16	-	-	-	10, 8
27. Nov. 16	10, 8	-	-	-
28. Nov. 16	25, 28	-	-	-
1. Dez. 16	23, 7, 4	-	4, 3, 3	-
2. Dez. 16	46	-	11	-
3. Dez. 16	7	-	7, 13	5
4. Dez. 16	8	-	12	-
6. Dez. 16	50	-	-	-
8. Dez. 16	-	4	27	-
9. Dez. 16	-	-	3, 21	-
10. Dez. 16	39, 11	-	3, 3	6
11. Dez. 16	15, 6, 92	-	34, 5	-
12. Dez. 16	8	-	17, 41	-
13. Dez. 16	34, 28	-	13	8
total:	**2369min, 63x**	**220min 22x**	**602min, 43x**	**275min, 39x**
average	**37**	**10**	**14**	**7**

Table10: Dive times in the monitored period

	Dive time in minutes	
Date	**1,0**	**0,1**
11. Okt. 16	8,3,4,7,3	6,7,9,7,6,2,3,3,2,18,14,2,4
12. Okt. 16	9,34,20	15,12,4,6,3,3
13. Okt. 16	3,3,4,3,4,9,4	3,4,5
14. Okt. 16	16,6,43,30	9,8,3,7,6,3,11,3,7,4,4,6,5,6,3
15. Okt. 16	5,5,10,3,3	12,11,8,2,6,7,3,8
16. Okt. 16	2,5,5,4,6	3,3,9,6,7,4,6,14,8,3
17. Okt. 16	4,6,8,5,23,4,24,13,17,24,45,34,33,4,22	6,36,11,4,2,5,6
18. Okt. 16	3,10,3,10,5,17	7,4,10,4,6,5,3
19. Okt. 16	21,6,9,8,5,3,7,5	3,3,17,5,8,3
20. Okt. 16	3,8,12,3,4,3,4,5,8,4,15,3,7,22	5,2,4,5,3,6
21. Okt. 16	3,3,24,5,4	11,7,4,11,4,4,7
22. Okt. 16	4,25,14,12,3	10,9,7,8,8,3,4
23. Okt. 16	3,30,4,17,31,12,4,9	10,5,4,9,8
24. Okt. 16	7,13,9,26,3,6	4,10,5,3,5
25. Okt. 16	5,6,3,15,3,4,4,3,5	3,8,6,8,3,4,5
26. Okt. 16	9,5,12,9,10,3,3,11	5,3,15,3,3,5,27,6,3,8
7. Nov. 16	3,5,4,3,3,6,5	6,7,8,15,3,6,9
8. Nov. 16	4,7,3,3,4	5,12,3,6,4,3
9. Nov. 16	4,4,7,12	3,3,7,11,13,15,5,9,4,8
10. Nov. 16	12,10,5,7,9,4,5,6,9,10,4	4,8,12,5,8,4
11. Nov. 16	3,6,4,5,6,12	8,17,12,3,3,3
24. Nov. 16	4,4,11	8,7,4,3
25. Nov. 16	6,9,20,3,4,3	9,13,7,7,7,5,3
26. Nov. 16	19,5,8,3,3,4,7	9,5,3,4,10,8,6,4,6
27. Nov. 16	3,4,3,4,5,9	4,5,6,7,3,4
28. Nov. 16	7,3,5,3,6	8,3,4,4,5,4
1. Dez. 16	5,7,2,15,3,4	3,3,4,6,8,9
2. Dez. 16	3,3,3,4,6,5,4	6,6,3,4,3,3
3. Dez. 16	7,11,3,4,6,3	10,5,3,3,3,4,3,10,3,5,3,14,5
4. Dez. 16	4,6,7,9,3,3,6	3,3,7,4,8,12
6. Dez. 16	7,6,4,9,6,20	9,6,5,3,3,4
8. Dez. 16	5,4,4,5,4,9	7,3,3,3,8,7
9. Dez. 16	15,4,3,7,4,5	6,6,22,3,4,3
10. Dez. 16	9,9,3,11,5,4,12,5	6,8,4,7,9,3
11. Dez. 16	3,4,3,6,7,10,6,5	4,3,3,13,5
12. Dez. 16	4,5,6,6,3,3	9,6,3,4,5,3
13. Dez. 16	3,4,6,12,5,3	8,4,3,6,4,3,3
total times	**246**	**263**
average	**8**	**6**

Table11: Time spend in shallow waters and why places they prefer

Time spend in shallow waters				
	1,0		0,1	
Date	**Water stream**	**log**	**Water stream**	**log**
11. Okt. 16	16	-	15, 23	2, 37, 22, 4, 8,
12. Okt. 16	294, 42, 7	-	9, 5, 4	4, 34, 5, 7
13. Okt. 16	8, 136, 5, 344	-	23, 6, 3	90, 27
14. Okt. 16	5, 21	-	15, 4, 31, 19, 35, 88, 2, 4	15, 20, 33, 33, 4,
15. Okt. 16	39, 6, 12	-	10, 12, 13, 3, 3	9, 4, 12, 7, 6
16. Okt. 16	40	-	6, 32, 5, 4	33, 189, 18, 9
17. Okt. 16	10, 77	-	11, 55, 6, 8, 6, 4	11, 8, 25, 225
18. Okt. 16	38	-	12, 24, 6	8, 36, 39, 6
19. Okt. 16	40	-	80, 253	10, 6, 7
20. Okt. 16	-	-	66, 8, 7, 141, 5, 14, 31, 7, 32, 10	10, 28, 11, 4, 4, 11, 15, 99
21. Okt. 16	15	-	3, 5	3, 49
22. Okt. 16	95	-	6, 6, 10, 3, 8	10, 51, 3, 77, 17
23. Okt. 16	-	-	7	9, 24, 57
24. Okt. 16	259	-	152, 3	5, 12, 18
25. Okt. 16	28, 166, 91, 4	-	37	186, 58
26. Okt. 16	13	-	9, 3, 7, 7, 50	6, 4
7. Nov. 16	12, 5, 8, 6	-	8, 3, 19, 24	12, 5, 8, 6
8. Nov. 16	-	-	3, 25, 5, 8, 4	4, 17, 7
9. Nov. 16	68	-	8, 12, 8	4, 11
10. Nov. 16	40, 34, 79	-	5	55, 10, 38
11. Nov. 16	35, 9, 58	-	16	85, 35, 5
24. Nov. 16	5, 8	-	3, 3, 22, 5, 11	4, 14, 13, 3
25. Nov. 16	-	-	17, 146	4, 6, 6
26. Nov. 16	-	-	6, 3, 4	4
27. Nov. 16	-	-	35	12
28. Nov. 16	36, 8, 79	-	25, 112	16, 6, 10
1. Dez. 16	-	-	5, 4, 22, 13, 14, 278	12, 11, 7, 24, 23, 7,
2. Dez. 16	7, 79	-	55, 9, 22, 240, 120, 110	19, 15, 5
3. Dez. 16	-	-	7, 28, 10, 30, 67	146, 25, 47
4. Dez. 16	-	-	15, 15, 11, 51, 72, 183	11, 17, 31
6. Dez. 16	51, 8, 43	-	25, 106, 15, 20, 80	29, 13
8. Dez. 16	-	-	10, 17, 204, 16, 6, 17	25, 27, 30
9. Dez. 16	-	-	14, 84, 132, 20, 88, 52, 19, 17	27, 9, 23, 29
10. Dez. 16	40	-	122, 12, 113, 73	19, 69, 29
11. Dez. 16	25, 32, 38	-	24, 19, 55, 36, 53, 157	11, 71, 42, 17
12. Dez. 16	6, 37, 38, 25, 15	-	17, 24, 18, 6, 126	43, 42, 46, 39
13. Dez. 16	48, 141	-	12, 63, 87, 136	22, 12, 3, 26, 41, 92
total:	**2934min, 58x**	**0**	**5492min, 150x**	**3620min, 149x**
average	**51**	**0**	**37**	**24**

Praat Script

```
# -------------------SCRIPT TO ANALYZE C. MORELETII CALLS---------------------
clearinfo
# (to read from different files, and read files within a folder) übernommen von Markus

#--------------ADDING VARIABLES----------------
#to add variables, you have to put the new variables in the respective parts where there is written #here new variables



form Analyze vocalization

#----------Output DIRECTORY--------------------
sentence Input_directory C:\Users\Maggus\Desktop\Test\


#----------Ouput FILE---------------
sentence fileCallAnalysis C:\Users\Maggus\Desktop\Test\KroksCallAnalysis.csv

comment Pitch analysis parameters
	positive Time_step 0.01
	positive Min_F0 300
	positive Max_F0 950
comment Formant analysis parameters
	positive Time_step_f 0.025
	positive Max_number_of_formants 5
	positive Maximum_formant 6000
	positive Window_length 0.03
	positive Pre_emphasis_from 10


# this part opens a option menu in praat
optionmenu Input_file_extension 6
option .wav
option .aif
option .aiff
option .au
option .nsp
option none
endform


minpitch = 'Min_F0'
tiste = 'Time_step'
maxpitch = 'Max_F0'
spectrogramview = 'Maximum_formant' + 500


# defines homedirectiory and files which will be analyzed and were to save the outputfile

homepath$ = environment$("HOMEPATH")

if homepath$ = ""
	platform$ = "unix"
else
	platform$ = "win"
endif

in_slash_input$ = left$(input_directory$,1)
in_colon_input$ = mid$(input_directory$,2,1)
out_slash_input$ = right$(input_directory$,1)
```

```
if platform$ = "win"
	output_directory$ = "C:\temp\"
	in_slash_output$ = left$(output_directory$,1)
	in_colon_output$ = mid$(output_directory$,2,1)
	out_slash_output$ = right$(output_directory$,1)

	if in_colon_input$ <> ":" and in_slash_input$ <> "\"
		exit Paths must start with backslash \ or drive letter
	elsif in_colon_output$ <> ":" and in_slash_output$ <> "\"
		exit Paths must start with backslash \ or drive letter
	elsif out_slash_input$ <> "\"
		exit Paths must end with a backslash \
	elsif out_slash_output$ <> "\"
		exit Paths must end with a backslash \
	endif

else
	output_directory$ = "~/temp/"
	in_slash_output$ = left$(output_directory$,1)
	in_colon_output$ = mid$(output_directory$,2,1)
	out_slash_output$ = right$(output_directory$,1)

	if in_slash_input$ <> "/" and in_slash_input$ <> "~"
		exit Paths must start with slash / or tilde ~
	elsif in_slash_output$ <> "/" and in_slash_output$ <> "~"
		exit Paths must start with slash / or tilde ~
	elsif out_slash_input$ <> "/"
		exit Paths must end with a slash /
	elsif out_slash_output$ <> "/"
		exit Paths must end with a slash /
	endif

endif

# checks if there is a outputfile with the name already existing and then either overrites or creates new file
with the headers listed in filappend
new_spreadsheet = 1
if new_spreadsheet = 1
	analysisfile = 0
	call CheckIfFileExists 'fileCallAnalysis$'
	#hier C
	if analysisfile = 0
		#-------------HEADERS General----------------
		fileappend 'fileCallAnalysis$' file;

		#-------------HEADERS Pitch----------------
		fileappend 'fileCallAnalysis$'
f0_mean;f0_max;f0_min;f0_range;f0_timestep;f0_voicedFrames;f0_start;
		fileappend 'fileCallAnalysis$'
f0_end;f0_mid;tf0_max;tf0_min;f0_startvoice;f0_endvoice;f0_midvoice;f0_call_length;
		fileappend 'fileCallAnalysis$' slopeStartMax;slopeMaxEnd;slopeStartMid;slopeMidEnd;
		fileappend 'fileCallAnalysis$'
sum_infl;inflex;f0sumvar;f0varin;total_freq_shift;f0mod_extent;meanabsoluteslope;
		#here new variables

		#-------------HEADERS Harmonicity----------------
		#fileappend 'fileCallAnalysis$' hnr_min;hnr_max;hnr_mean;hnr_sd;hnr_duration;
		#here new variables

		#-------------HEADERS Jitter----------------
		#fileappend 'fileCallAnalysis$' jitter;shimmer;
		#here new variables
```

```
			#-------------HEADERS Formant----------------
			#fileappend 'fileCallAnalysis$' f1;f2;f3;f4;f5;dfold;dfnew;vtl_old;vtl_new;
			#here new variables

			#-------------HEADERS Dominante Frequenz----------------
			#fileappend 'fileCallAnalysis$' dom-
Frq;domFrqfirstthird;domFrqsecondthird;domFrqthirdthird;
			#here new variables

			#-------------HEADERS Amplitude Modulation----------------
			#fileappend 'fileCallAnalysis$' am_yes_no;am;
			#fileappend 'fileCallAnalysis$'
smooth_ampeak1;smooth_ampeak2;smooth_ampeak3;smooth_ampeak4;smooth_ampeak5;
			#fileappend 'fileCallAnalysis$'
smooth_ampeak1db;smooth_ampeak2db;smooth_ampeak3db;smooth_ampeak4db;smooth_ampeak5db;
			#here new variables

			#-------------HEADERS Alpha Ratio----------------
			#fileappend 'fileCallAnalysis$' alpha1000;alpha2000;
			#here new variables

			#-------------HEADERS OVERRIDECHECK----------------
			#fileappend 'fileCallAnalysis$' override;
			#here new variables

			#-------------HEADERS Qualitätskriterium----------------
			#fileappend 'fileCallAnalysis$' quality;
			#here new variables


	endif

endif

if input_file_extension$ = "none"
	input_file_extension$ =""
endif


# creates strings with the names of the files within the directory of the sound files

Create Strings as file list... list 'input_directory$'*'input_file_extension$'
string_list = selected("Strings")


nfiles = Get number of strings
print nfiles = 'nfiles' 'newline$'
for current_file from 1 to nfiles
	call PITCH
	select all
	minus string_list
	Remove
	Erase all
endfor

#-------------PROCEDURE 1: Pitchanalyse------------------
procedure PITCH

select string_list
	sound$ = Get string... current_file
	Read from file... 'input_directory$''sound$'
	current_sound = selected ("Sound")
	file_duration = Get duration
```

```
name$ = selected$ ("Sound")

Edit

editor Sound 'name$'
	Spectrogram settings... 0 spectrogramview 0.005 40
	Advanced spectrogram settings... 700 250 Fourier Gaussian yes 100 6 0
	Pitch settings... minpitch maxpitch Hertz autocorrelation automatic
	Advanced pitch settings... 0 spectrogramview no 15 0.03 0.2 0.01 0.15 0.14
	Formant settings... maximum_formant max_number_of_formants window_length 10 1
endeditor

To Pitch (cc)...  0 minpitch 15 no  0.03 0.2 0.01 0.15 0.14 maxpitch
Rename... Pitch

frames = Get number of frames
voiced = Count voiced frames

Edit
pause

Smooth... 25

Interpolate
Edit
Rename... Interpolated

voiced = voiced/frames
f0_mean = Get mean... 0 0 Hertz
f0_max = Get maximum... 0 0 Hertz Parabolic
f0_min = Get minimum... 0 0 Hertz Parabolic
tf0_max = Get time of maximum... 0 0 Hertz Parabolic
tf0_min = Get time of minimum... 0 0 Hertz Parabolic
f0_range = f0_max - f0_min
f0_start_t = Get start time
f0_end_t = Get end time
f0_frames = Get number of frames
f0_timestep = Get time step


clearinfo

select Pitch Interpolated
nameInterpolated$ = selected$ ("Pitch")

frames = Get number of frames
f0_voicedFrames = Count voiced frames

select Pitch Interpolated
Down to PitchTier
tf0_startvoice = Get time from index... 1
tf0_endvoice = Get time from index... f0_voicedFrames
tf0_call_length = tf0_endvoice - tf0_startvoice
tf0_midvoice = (tf0_call_length/2) + tf0_startvoice
tf0_firstthird = (tf0_call_length/3) + tf0_startvoice
tf0_secondthird = ((tf0_call_length/3)*2) + tf0_startvoice

select Pitch Interpolated
f0_start = Get value at time... 'tf0_startvoice' Hertz Linear
f0_end = Get value at time... 'tf0_endvoice' Hertz Linear
f0_mid = Get value at time... 'tf0_midvoice' Hertz Linear
f0_stdev = Get standard deviation... 0 0 Hertz
```

```
	slopeStartMax = (f0_max - f0_start) / (tf0_max - tf0_startvoice)
	slopeMaxEnd = (f0_end - f0_max) /(tf0_endvoice - tf0_max)
	slopeStartMid = (f0_mid - f0_start) / (tf0_midvoice - f0_start_t)
	slopeMidEnd = (f0_end - f0_mid) /(tf0_endvoice - tf0_midvoice)
	mas = Get mean absolute slope... Hertz

	nframes = Get number of frames
	infl_asc = 0
	infl_desc = 0
	row = 0
	variation = 0
	f1_var = 0
	i1_var = 0

		Create TableOfReal... voiced_frames 1 2
		Set row label (label)... "" row
		Set column label (index)... 1 frame
		Set column label (index)... 2 f0

	select Pitch Interpolated

	for current_frame from 1 to nframes-1
		pitch_frame = Get value in frame... current_frame Hertz
		pitch_frame_before = Get value in frame... current_frame-1 Hertz
		pitch_frame_after = Get value in frame... current_frame+1 Hertz



		if pitch_frame <> undefined and pitch_frame_before <> undefined and pitch_frame_after
<> undefined
			if pitch_frame_after >  pitch_frame and pitch_frame <= pitch_frame_before
				infl_asc +=1
			elsif pitch_frame_after < pitch_frame and pitch_frame >= pitch_frame_before
				infl_desc +=1
			endif
			variation += abs(pitch_frame_after - pitch_frame)
			row += 1
			select TableOfReal voiced_frames
			Insert row (index)... row
			Set value... row 2 row
			Set value... row 2 pitch_frame
			select Pitch Interpolated
		endif

	endfor

	variation_abs = abs(variation)
	sum_infl = (infl_asc + infl_desc)
	inflex = sum_infl/tf0_call_length
	f0sumvar = variation_abs/tf0_call_length
	total_freq_shift = variation_abs
	f0mod_extent = total_freq_shift/sum_infl
	f0varin = (f0_stdev/f0_mean)*10

# closes all the opend windows

	editor Pitch Pitch
		Close
	endeditor

#	editor Sound 'name$'
#		Close
#	endeditor
```

```
	editor 'nameInterpolated$'
		Close
	endeditor

	select current_sound
	Extract part... 'tf0_startvoice' 'tf0_firstthird' rectangular 1 no
	Rename... firstthird
	select current_sound
	Extract part... 'tf0_firstthird' 'tf0_secondthird' rectangular 1 no
	Rename... secondthird
	select current_sound
	Extract part... 'tf0_secondthird' 'tf0_endvoice' rectangular 1 no
	Rename... thirdthird
	select current_sound
	Extract part... 'tf0_startvoice' 'tf0_endvoice' rectangular 1 no
	Rename... voicedpart

# writes the information in the info file of praat

	print ANALYSIS SUMMARY'newline$'
	print File name: 'sound$''newline$'
	print File duration: 'file_duration:3' sec.'newline$'
	printline
	print Pitch analysis:'newline$'
	print Mean F0 = 'f0_mean:3' Hz'newline$'
	print Max F0 = 'f0_max:3' Hz'newline$'
	print Min F0 = 'f0_min:3' Hz'newline$'
	print Time of max F0 = 'tf0_max:3' secs'newline$'
	print Time of min F0 = 'tf0_min:3' secs'newline$'
	print F0 range = 'f0_range:3' Hz'newline$'
	print Time of first voiced frame = 'tf0_startvoice:3' s'newline$'
	print Time of last voiced frame = 'tf0_endvoice:3' s'newline$'
	print Time of mid voiced frame = 'tf0_midvoice:3' s'newline$'
	print Frequency at start of voice = 'f0_start:3' Hz'newline$'
	print Frequency at end of voice = 'f0_end:3' Hz'newline$'
	print Frequency at mid of voice = 'f0_mid:3' Hz'newline$'
	print Duration of voiced part = 'tf0_call_length:3' s'newline$'
	print slopeStartMax = 'slopeStartMax:3' 'newline$'
	print slopeMaxEnd = 'slopeMaxEnd:3' 'newline$'
	print slopeStartMid = 'slopeStartMid:3' 'newline$'
	print slopeMidEnd = 'slopeMidEnd:3' 'newline$'

	print Number of inflexions: 'sum_infl''newline$'
	print inflex = 'inflex:3' inflexions/s'newline$'
	print F0 variation = 'f0sumvar:3' Hz/s'newline$'
	print F0 variability index = 'f0varin:3''newline$'
	print Total frequency shift = 'total_freq_shift:3' Hz'newline$'
	print Average extent of F0 modulation = 'f0mod_extent:3' Hz'newline$'
	print Mean Absolute Slope = 'mas:3' Hz/s'newline$'


	#------Saves the variables as strings (strings always have a $-sign at the end) and changes the .
to ,  (in german excel commas are used as deliminators)
	f0_mean$ = replace_regex$ ("'f0_mean:2'" , "\." , "," , 1)
	f0_max$ = replace_regex$ ("'f0_max:2'" , "\." , "," , 1)
	f0_min$ = replace_regex$ ("'f0_min:2'" , "\." , "," , 1)
	f0_range$ = replace_regex$ ("'f0_range:2'" , "\." , "," , 1)
	f0_timestep$ = replace_regex$ ("'f0_timestep:3'" , "\." , "," , 1)
	f0_voicedFrames$ = replace_regex$ ("'f0_voicedFrames'" , "\." , "," , 1)
	f0_starttext$ = replace_regex$ ("'f0_start:2'" , "\." , "," , 1)
	f0_endtext$ = replace_regex$ ("'f0_end:3'" , "\." , "," , 1)
	f0_mid$ = replace_regex$ ("'f0_mid:2'" , "\." , "," , 1)
	tf0_max$ = replace_regex$ ("'tf0_max:3'" , "\." , "," , 1)
```

```
	tf0_min$ = replace_regex$ ("'tf0_min:3'" , "\." , "," , 1)
	tf0_startvoice$ = replace_regex$ ("'tf0_startvoice:3'" , "\." , "," , 1)
	tf0_endvoice$ = replace_regex$ ("'tf0_endvoice:3'" , "\." , "," , 1)
	tf0_midvoice$ = replace_regex$ ("'tf0_midvoice:3'" , "\." , "," , 1)
	tf0_call_length$ = replace_regex$ ("'tf0_call_length:3'" , "\." , "," , 1)
	slopeStartMax$ = replace_regex$ ("'slopeStartMax:3'" , "\." , "," , 1)
	slopeMaxEnd$ = replace_regex$ ("'slopeMaxEnd:3'" , "\." , "," , 1)
	slopeStartMid$ = replace_regex$ ("'slopeStartMid:3'" , "\." , "," , 1)
	slopeMidEnd$ = replace_regex$ ("'slopeMidEnd:3'" , "\." , "," , 1)
	sum_infl$ = replace_regex$ ("'sum_infl:3'" , "\." , "," , 1)
	inflex$ =  replace_regex$ ("'inflex:3'" , "\." , "," , 1)
	f0sumvar$ = replace_regex$ ("'f0sumvar:3'" , "\." , "," , 1)
	f0varin$ = replace_regex$ ("'f0varin:3'" , "\." , "," , 1)
	total_freq_shift$ = replace_regex$ ("'total_freq_shift:3'" , "\." , "," , 1)
	f0mod_extent$ = replace_regex$ ("'f0mod_extent:3'" , "\." , "," , 1)
	mas$ = replace_regex$ ("'mas:3'" , "\." , "," , 1)
	#here new variables

	fileappend 'fileCallAnalysis$' 'newline$''sound$';'f0_mean$';'f0_max$';'f0_min$';'f0_range$';
'f0_timestep$';
	fileappend 'fileCallAnalysis$' 'f0_voicedFrames$';'f0_starttext$'; 'f0_endtext$'; 'f0_mid$';
'tf0_max$'; 'tf0_min$'; 'tf0_startvoice$';
	fileappend 'fileCallAnalysis$' 'tf0_endvoice$'; 'tf0_midvoice$'; 'tf0_call_length$'; 'slopeStartMax$';
'slopeMaxEnd$'; 'slopeStartMid$'; 'slopeMidEnd$';
	fileappend 'fileCallAnalysis$' 'sum_infl$'; 'inflex$'; 'f0sumvar$'; 'f0varin$'; 'total_freq_shift$';
'f0mod_extent$'; 'mas$';
	#here new variables
endproc



#----------PROCEDURE 12: Check if File Exists-----------

procedure CheckIfFileExists fileName$
	if fileReadable (fileName$)
		beginPause ("File Exists:")
		comment ("This file already exists! What do you want to do?")
		analysisfile = endPause ("add to file", "new file", "overwrite", 1)

		# 1 = add to existing file
		# 2 = create a new file
		# 3 = overwrite

		if analysisfile = 1
			analysisfile = 1
		endif

		if analysisfile = 2
			beginPause ("File Exists:")
				sentence ("newfileName", "'fileName$'")
			clicked = endPause ("Continue", 1)
			print 'newfileName$'
			fileCallAnalysis$ = "'newfileName$'"
			analysisfile = 0
		endif

		if analysisfile = 3
			filedelete 'fileName$'
			analysisfile = 0
		endif
	endif
endproc
```

Request Letter to European Zoos which maybe take care of *Crocodylus moreletii*

Dear Sirs and Mesdames of the Institution
My Name is Markus Klamt and I am currently writing my final dissertation about *Crocodylus moreletii* with the Tiergarten Schönbrunn (Zoo Vienna) and the University of Vienna.
To enlarge upon my work, I kindly ask for your support.
I am doing a bloodline research on the *Crocodylus moreletii* (Morelet's Crocodile) population in the European Zoos.
Therefore, I would highly appreciate it, if you would take the time to answer the following questions.

Where are your *C. moreletii's* from?
How many do you keep?
Since when do you keep them?
Sex ratio?
How old are they (approximately)?
Do you breed them?
Did you send them away? If so, where were they sent to?

I am looking forward to hearing from you.
Many thanks for your support. If you have any questions, please do not hesitate to contact me.

Best wishes from Austria,
Markus Klamt

Zusammenfassung:

Diese Studie informiert über die Haltung von *Crocodylus moreletii* im Tiergarten Schönbrunn in Wien.

Das erste Kapitel beschreibt die Inkubationsmethoden und belegt, dass Temperaturen über 34°C im ersten Drittel der Inkubationsperiode zu Deformierungen und sogar zum Tod von Krokodilembryonen führt, wohingegen tiefe Temperaturen die Entwicklung der Embryonen deutlich verlängern.

Weiterhin wird die Struktur von Rufen frisch geschlüpfter, stark deformierten, Babykrokodilen dargestellt und mit denen von gesunden Tieren verglichen. Dabei wird deutlich, dass sich die deformierte Schnauze sowohl auf die Frequenz, wie auch auf die Dauer des Rufes auswirkt.

Um herauszufinden, wie sich Beulenkrokodile in einer zoologischen Einrichtung verhalten, wurde das Paar in der Schauanlage des Tiergarten Schönbrunns in 37 Tagen für insgesamt 579 Stunden beobachtet. Der Fokus lag hierbei unter anderem auf den Aktivitätsphasen, den täglich zurückgelegten Distanzen, Tauchzeiten sowie auf innerartlichen Interaktionen wie auch die Interaktion mit den vergesellschafteten Fischen. Um diese Art für die Besucher noch attraktiver zu präsentieren, wurde die Effizienz von verschiedenen Beschäftigungsmöglichkeiten wie akustischen Signalen, neuen Objekten, verstreutem Futter, Sprungbeschäftigungen und Targettraining getestet. Zusätzlich wurde nach Wegen gesucht, ein effizientes Training in den arbeitsalltag der Tierpfleger zu integrieren. Es stellte sich heraus, dass alle drei Beulenkrokodile binnen 14 Tagen soweit trainiert werden konnten, dass sie einem Target zuverlässig folgen.

Das letzte Kapitel gibt einen Überblick über die Population von *Crocodylus moreletii* in europäischen Zoos. Darin sind sowohl die Zoos gelistet, die sich mit der Haltung von Beulenkrokodilen beschäftigen, wie auch Angaben zur Anzahl, Geschlecht, Alter und Herkunft der von ihnen gepflegten Tiere. Festzuhalten ist hier, dass in nur acht von 17 Zoos eine Zucht theoretisch möglich wäre.

Diese Studie ist als ein erster Schritt anzusehen und soll ein Anstoß für weitere Studien sein, um mehr Informationen über diese interessante Tierart in zoologischen Einrichtungen herauszufinden.

Acknowledgements

Writing the final thesis of the study is a special moment and a huge challenge, especially when dealing with many setbacks like the loss of all juveniles, individuals which are more aggressive than expected or not so cooperative informants. Nevertheless, it was an exciting and instructive task which gave me the opportunity to get a better view of the life and husbandry of a very fascinating crocodile species.

At this point I would like to express gratitude towards all of those who supported me during my master study.

I thank my supervisor at the Vienna University, Prof. Dr. Helmt Kratochvil for his academic support and his advice during the developmental process of this thesis.
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Very special thanks is due to Anton Weissenbacher and Dr. Doris Preininger. The Reptile Curator and his assistant were a huge help and support, and always had an open door for any problems that arose.
Additionally, I want to thank the whole team of the reptile department of the Tiergarten Schönbrunn. The team, consisting of Manuela Sirny, Rupert Kainradl (MSc), Jenny Bukowski, Jasmine Scantlebury, Michelle Zeber, Nina Rassinger, Daniela Müllner, Miriam Gutwillinger, Barbara Knöbl and Maximilian Schön, warmly welcomed me into their group and provided me with solid support. They truly made me feel accepted, comfortable, and appreciated. I know that I could always rely on their help (which comes in quite handy if you have to work with crocodiles)!
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