RELATIONSHIP BETWEEN MORPHOMETRIC TRAITS AND PREDICTIVE MODELS FOR TOTAL SKIN LENGTH IN SLAUGHTERED SOUTH AFRICAN NILE CROCODILES (*Crocodylus niloticus corviei*)

BY

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DECLARATION

I declare that this dissertation hereby submitted to the University of Limpopo for the degree of Master of Science in Agriculture has not previously been submitted by me for a degree at this or any other university, that it is my own work in design and execution, and that all materials contained herein has been duly acknowledged.

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DEDICATION

To my sister, Sendra Rachuene:

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“*…in a while, Crocodile*.”

ABSTRACT

Nile crocodiles are common in South Africa, reaching up to 6m in total length. The quality and yield of crocodile skins plays a significant role in it price determination Hence, the aim of this study was to determine the relationship between the total skin length and measurable skin traits viz skin weight (SW), skin thickness (ST), neck total length (NTL), neck width at the top (NWT), neck width at the middle (NWM), belly width (BW), belly length (BL), total tail length (TTL), tail length from the middle (TLM), and tail width (TLW). The first objective was to determine the phenotypic relationship between total skin length and measurable skin traits of the Nile crocodile. The second objective was to establish a model for predicting the total skin length of the Nile crocodile from measurable skin traits. A total of 180 crocodile skins from 35 months old Captive-bred Nile crocodiles, sourced from Lalele Crocodile Farm, were used for data collection. Data was analysed via Statistical Package for Social Sciences (SPSS), software version 29.0. The first objective was achieved using Pearson's correlation. The second objective was achieved using simple linear regression and multiple regression analysis. Correlation results indicated that TSL was correlated with SW (0.81), NTL (0.37), BW (0.75), BL (0.79), TTL (0.87), TLM (0.78), TLW (0.48), NWM (0.60), NWT (0.51) at $p<0.01$ and ST (0.17) at $p<0.05$. Regression findings showed that, as a single trait, TTL was the best predictor of TSL, as shown by the highest coefficient of determination (0.76) and RMSE (31.98). Furthermore, regression analysis showed that model 1 (TSL = 16.35 + 4.68SW + 1.28ST + 1.03BL + 0.39BW + 0.81TTL + 0.13TLM - 0.25TLW + 0.21NTL + 0.19NWT – 0.14NWM) had the highest coefficient of determination ($R^2 = 0.90$) and the lowest residual mean square error (RMSE = 14.28) and would reliably predict TSL of Nile crocodiles. The results suggest there is a positive relationship between the total skin length and measurable skin traits of Nile crocodile and improving these traits might improve TSL. Skin traits such as SW, NTL, NWT, BW, BL, TTL, TLM, TLW, and ST may be used to improve TSL. TTL may be used to easily predict TSL. These findings may aid in better management and selection for breeding of Nile crocodiles for improved skin yield and quality.

***Keywords**:* Skin morphometrics, Crocodilian, Skin quality, Total tail length, Skin yield.

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LIST OF ABBREVIATIONS

Abbreviation	**Meaning**
BL	Belly length
BW	Belly width
cm	centimetres
R^2	Coefficient of determination
CV%	Coefficient of variation
°C	Degrees Celsius
DALRRD	Department of Agriculture, Land Reform and Rural Development
"E	East
kg	kilograms
K	Kurtosis
mm	millimetres
NTL	Neck total length
NWM	Neck width at the middle
NWT	Neck width at the top
n	Number of records
RMSE	Root mean square error
γ	Skewness
ST	Skin thickness
SW	Skin weight
"S	South
SANS	South African National Standards
SD	Standard deviation
SE	Standard error
TLM	Tail length from the middle
TLW	Tail width
TSL	Total skin length
TTL	Total tail length

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CHAPTER ONE

INTRODUCTION

1.1. Background

Nile crocodile (*Crocodylus niloticus*) is the predominantly reared crocodile species in southern Africa (Louw, 2024). It is also known as a large robust reptile characterized by cone-shaped teeth and a wider neck as compared to the head (Botha, 2005; Botha, 2010). Van Asch *et al*. (2019) recorded that the global population of the Nile crocodile was estimated to be between 250 000 to 500 000 individuals in 1996. Although the current population is not ascertained, Utete (2021) stated that the conservation status of crocodiles in the eastern and southern African countries is of least concern, with some countries, such as Zimbabwe, recording an annual increase of at least 1000 crocodiles. Manolis and Webb (2016) eluded that there could be about 5000 crocodilian farms in the world. According to the National Council of Societies for the Prevention of Cruelty to Animals (2022), South Africa has at least 80 crocodile farms, with some housing up to 20 000 crocodiles. Most of these farms are primarily located in Limpopo (40%), North-West (20%) and KwaZulu-Natal (15%) (Louw, 2024). Crocodiles are reared mainly for their skin (Tosun, 2013), with meat, oil and skeletal matter being the major by-products (Isberg *et al*., 2005; Uys, 2019). Skin accounts for 90% of the total crocodile value, whereas the remaining 10% is generated from meat sales (Riverbend Crocodile Farm, n.d.) The most valuable skin on crocodile is from the belly (Beyeler, 2011), whereas the meat is typically taken from the tail and backstrap and it is known for yielding high protein, low sodium content and saturated fats (Hoffman *et al*., 2000; Uys, 2019). Due to its rareness, as compared to conventional livestock, crocodile leather accounts for about 1% of the global leather production (Chala *et al*., 2020). However, the species plays a leading role in the production of high-quality leather (Manolis and Webb, 2011). About 30% of the global skin trade market is comprised of the Nile crocodile skin and South Africa is recognized as one of the major producers (Webb *et al*., 2021). Out of the 1.5 million skins exported from Africa, the Nile crocodile accounted for 91% with Zimbabwe (32%), Zambia (28%) and South Africa (26%) recorded as the top three largest exporters (Outhwaite and Brown, 2018).

1.2. Problem statement

Crocodile leather is exotic and luxurious (Sonnenberg *et al*., 2024) and it is considered one of the finest leathers for manufacturing furniture, handbags, and other luxury merchandise (Chihona, 2014). Nile crocodile skins are valued for their durability, making them well-suited for heavy-duty items such as shoes and belts (Chala *et al*., 2020). However, the crocodile industry faces the challenge of producing skins of inferior quality and poor yield (Moore *et al*., 2017). The poor quality and yield could be attributed to inadequate breeding and management practices (Nevarez, 2019). Consequently, farmers sustain significant economic losses resulting from the downgrading of skins (Moore *et al*., 2017). The grade of a hide is dependent on its expected cutting yield; hence, yield maximization is crucial to improve market value (Le Croc, 2025). Platt *et al*. (2009) recommended the use of morphometric data, such as measurable skin traits, in crocodilian scientific studies thus to understand the relationships of various body dimensions. Establishing such fundamental data is crucial for effective marketing crocodile skins (Chala *et al*., 2020). Furthermore, Nemutandani (2023) emphasized that breeding plays an important role in enhancing product quality and production in animals. Understanding the relationship between skin traits of raw crocodile skins brings about the ability to mitigate challenges related to producing skins of good quality and yield (Manolis and Webb, 2011), such that breeders can implement informed selection and breeding practices. To this end, there is a paucity of information on the relationship between the skin traits and predictive models for skin length of Nile crocodile in South Africa.

1.3. Rationale

The crocodile industry is fundamentally focused on producing skins for luxury leather products (Hoffman *et al*., 2000). Crocodile farming requires improvement in multiple areas to achieve consistent production standards (Veldsman, 2019). It has been stated that the market value of a crocodile skin is influenced by the quality, width and length of the skin, including the neck and tail, which determines their suitability for distinct leather products (Manolis *et al*., 2000; Manolis and Webb, 2016). Lutz (2022) reported that the crocodile industry is gradually gravitating towards producing skins of larger sizes. Therefore, the improvement of raw crocodile skin quality and yield is of importance. The value of crocodile skin depends on its size and quality (Pfitzer *et al*., 2014; Veldsman, 2019). According to Hermesch and Isberg (2022), the improvement of economically important traits is essential for improving profitability in the crocodile industry. Improving the genetic value of crocodiles will subsequently improve productivity within the industry (Isberg *et al*., 2003). Typically, crocodile skins used for leather production are derived from their bellies (Isberg *et al*., 2004). In a study conducted by Hermesch and Isberg (2022), it was reported that belly width is a factor in skin grading, thereby determining its market value. Furthermore, Manolis and Webb (2011) stated that larger crocodile skins are generally preferred, particularly in the garment industry. This emphasizes the importance of improving skin yield. Webb *et al*. (2021) reported that there was a correlation between crocodile body length and its belly width, such that the longer the crocodiles, the narrower the belly width. Manolis *et al*. (2000) stated that a correlation exists between the body length of farmed crocodile skins and morphometric traits, such as the width and thickness. According to our knowledge, there is no literature on the effect of measurable skin traits of the Nile crocodile on the total skin length. As a result, the current study will provide information on the phenotypic and regression relationship between total skin length and measurable skin traits of the Nile crocodile, which may aid in better selection for breeding to improve skin quality and yield.

1.4. Aim

The aim of the study was to determine the relationship between total skin length and measurable skin traits and predictive of Nile crocodiles.

1.5. Objectives

The objectives of the study were:

I. To determine the phenotypic relationship between total skin length and other measurable skin traits of the Nile crocodile.
II. To establish a model for predicting total skin length of Nile crocodile using related measurable skin traits.

1.6. Hypotheses

I. There is no relationship between total skin length and measurable skin traits of Nile crocodile.
II. No model can be established for predicting total skin length of the Nile crocodile using related measured skin traits.

1.7. Limitation of the study

The limitations of the current study were that age, sex and slaughter weight could not be acquired due to a lack of access to live crocodiles, and the unavailability of records. However, based on the collected data, the research achieved the following objectives:

I. To determine the phenotypic relationship between total skin length and other measurable skin traits of the Nile crocodile.
II. To establish a model for predicting the total skin length of the Nile crocodile using related measurable skin traits.

CHAPTER TWO

LITERATURE REVIEW

2.1. Introduction

This chapter focuses on the review of literature to (i) phenotypically characterize Nile crocodiles, (ii) provide information on the relationship between total skin length and skin traits, as well as (iii) to predict total skin length from crocodile skin traits. To achieve these objectives, the chapter provided information on the (1) Exotic leather, (2) Nile crocodile and crocodilian species, (3) Origin and distribution of Nile crocodile, (4) Phenotypic characterization of Nile crocodile, (5) Crocodile industry in South Africa, (6) Harvesting and processing of crocodile skins, (7) Phenotypic correlation among morphometric traits in leather producing species, (8) Estimation of length measurements (total length and snout-vent length) from related morphometric measurements in crocodilian species, and (9) Conclusion.

2.2. Characteristics and commercialisation of exotic leather

Exotic leather refers to the type of leather derived from unconventional animal species, including various types of fish, avian species such as ostriches and emus, as well as reptiles such as snakes, alligators, caimans and crocodiles (Wainaina *et al*., 2022). Exotic leather is distinguished by distinctive natural patterns and exceptional tensile strength, making it aesthetically appealing (Alla *et al*., 2017). The commercial utilization of crocodilian skins dates back to the 1800s in North America (IUCN Crocodile Specialist Group, 2025). Table 2.1 highlights the role of various crocodilian species in the global skin trade, with an annual average of 1.47 million skins exported between 2009 and 2018 (Caldwell, 2020). The feasibility of exotic skins to be commercially used in leather production is dependent on their strength properties, alignment with contemporary fashion trends and adequate surface area thus to reduce waste during cutting (Graemer and Kite, 2006). The high tensile strength is due to the interwoven fibre bundles consisting of a protein called collagen (Koudouna *et al*., 2018). According to the Department of Trade and Industry in South Africa (2016), exotic leather is used to manufacture luxurious products, such as bags, shoes, garments and wallets. Historically, black and brown hues were dominating the colour palette of exotic leather, however, since the 1990s, lighter colours, such as pink and light beige, have been incorporated (Manolis and Webb, 2011).

Table 2.1: Contribution of crocodilian species to the world skin trade from 2009-2018

Taxon	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**
Alligator mississippiensis	297 187	369 731	312 542	326 538	481 304	485 884	428 521	553 371	463 466	596 258
Crocodylus acutus	1460	200	1 392	1 968	1 905	2 262	3 403	3 233	5 040	5 295
Crocodylus moreletii	485	0	184	679	1 300	2 031	1 291	1 640	3 000	4 088
Crocodylus niloticus	149 084	167 825	212 796	205 489	275 288	282 859	278 694	317 121	249 243	229 230
Crocodylus novaeguineae	26 212	24 480	16 632	23 461	26 046	24 982	39 070	14 022	7 649	8 849
Crocodylus porosus	45 666	58 157	63 380	72 382	53 936	63 234	64 232	99 101	71 988	75 005
Crocodylus siamensis	34 373	33 094	38 170	35 450	55 776	48 557	58 558	33 349	35 339	55 750
Subtotal of classic skins	**554 467**	**653 487**	**645 096**	**665 967**	**895 555**	**909 809**	**873 769**	**1 021 837**	**835 725**	**974 475**
Caiman crocodilus crocodilus	43 638	24 643	44 257	47 130	45 485	35 196	30 594	22 328	41 402	53 881
Caiman crocodilus fuscus	407 116	651 121	634 761	625 128	857 115	738 401	530 357	368 515	308 174	366 073
Caiman latirostris	394	1 933	2 973	5 755	5 602	8 893	8 610	5 525	3 652	2 823
Caiman yacare	48 853	29 688	58 376	111 078	115 283	94 456	128 203	52 709	65 243	31 953
Melanosuchus niger	6	0	11	275	51	290	584	0	0	1 044
Subtotal of caiman skins	**500 007**	**707 385**	**740 378**	**789 366**	**1 023 536**	**877 236**	**698 348**	**449 077**	**418 471**	**455 774**
Grand total	**1 054 474**	**1 360 872**	**1 385 474**	**1 455 333**	**1 919 091**	**1 787 045**	**1 572 117**	**1 470 914**	**1 254 196**	**1 430 249**

Source: (Caldwell, 2020).

2.3. Nile crocodile and other related crocodilian species

The Crocodilia order is taxonomically composed of three distinct families: *Crocodylidae*, *Alligatoridae*, and *Gavialidae* (Chook *et al*., 2021). Griffith *et al*. (2023) mentioned that there are about 28 crocodilian species. The *Mecistops*, *Osteolaemus* and *Crocodylus* are the only genera of the *Crocodylidae* found in Africa, with six crocodile species, namely, Central African slender-snouted crocodile (*Mecistops leptorynchus*), Central African dwarf crocodile (*Osteolaemus osborni*), West African dwarf crocodile (*Osteolaemus tetraspis*), West African slender-snouted crocodile (Mecistops cetaphractus), West African crocodile (*Crocodylus suchus*) and Nile crocodile (*Crocodylus niloticus*) (Botha, 2010; Summers, 2015; Griffith *et al*., 2023). The Nile crocodile is the most widespread crocodile species in Africa (Chihona, 2014). The exotic leather industry predominantly utilises three crocodilian species: Nile crocodile, Saltwater crocodile and American alligator (Manolis and Webb, 2011). Table 2.2 describes the three crocodile species.

Table 2.2: Brief description, habitat and distribution of the most used crocodile species in the leather industry

Scientific Name	**Common Name**	**Description**	**Habitat and distribution**
Crocodylus porosus	Saltwater Crocodile	Most dangerous, largest reptile with a length of 6-7m on average. Juveniles are characterized by their pale yellowish hue with dark markings.	Brackish habitats of the Indian subcontinent, Australia, and Southeast Asia
Crocodylus acutus	American Crocodile	The average male length of about 6m. This species is known for its pale greyish tone, short limbs and distinctive ossified scutes.	Caribbean islands of South America.
Crocodylus niloticus	Nile Crocodile	The world’s second-largest reptile, reaching lengths of 3.5-5m on average. Juveniles have a yellow-green belly, a brownish body with blackish cross-bands	Lakes, rivers and marshes of sub-Saharan Africa.

Source:(IUCN Crocodile Specialist Group, 2025)

2.4. Origin and distribution of the Nile crocodile

Crocodilians are believed to have emerged from dinosaurs roughly 200 million years ago, with their present form tracing back to approximately 80 million years (Furstenburg, 2008; Aust, 2012). According to Seymour *et al*. (2004), paleontological data showed that the ancestors of modern-day crocodilians were warm-blooded but later evolved to become cold-blooded as they adapted to aquatic predation. *Crocodylus niloticus* was first used in 1758 by Carl Linnaeus to classify all crocodiles, however, the renaming of African crocodiles by Mertens and Wermuth in 1955 resulted in the listing of seven subspecies (Pooley, 2016). These include *C.n. madagascariensis* (Malagasy Nile crocodile), *C. niloticus africanus* (East African Nile crocodile), *C.n. niloticus* (Ethiopian Nile crocodile), *C.n. chamses* (West African Nile crocodile). *C.n. pauciscutatus* (Kenyan Nile crocodile), *C.n. suchus* (Central African Nile crocodile), and *C.n. corviei* (South African Nile crocodile) (Furstenburg, 2008). The Nile crocodile occurs abundantly in Sub-Saharan Africa, including countries like South Africa, Zimbabwe, Botswana, and Mozambique (Fergusson, 2010). In South Africa, Nile crocodiles are found in the north-eastern parts of the country, including North-West, northern Gauteng, Mpumalanga, KwaZulu-Natal and Limpopo (Botha, 2010; Marais, 2014).

2.5. Phenotypic characterization of Nile crocodile.

Nile crocodiles have elongated snouts and large teeth that can be seen even when their jaws are closed (Botha, 2010). Nile crocodiles are characterized by two smaller dorsal neck scales, a single row of post-occipital scales and prominent eye protuberances (Versfeld, 2016). Juvenile crocodiles are characterised by yellow-green underbelly with either grey, brownish or multi-coloured body that comprised of black cross-bands that tend to fade as they mature (Louw, 2024). Figure 2.1 shows a picture of a juvenile Nile crocodile. Adult crocodiles are characterized by a darker bronze color, faded purplish belly and black sports on hornback (IUCN Crocodile Specialist Group, 2025). Figure 2.2. shows a picture of an adult Nile crocodile. Typically, like most crocodilians, male crocodiles are larger, often averaging 4m, but in rare cases up to 6m in length (Pooley, 2016; Rochford *et al.*, 2016). The species are second to the Saltwater crocodile in size (Botha, 2010). Males and females may weigh up to 900kg and 600kg, respectively (Furstenburg, 2008). Crocodiles are naturally apex predators (Aust, 2012). They hunt at any time but are mostly active within the nocturnal hours (Veldsman, 2019). Crocodiles typically bask during the day to regulate body temperature and stay in water at night to prevent significant drops in body temperature (Botha, 2010).

Figure 2.1: A juvenile Nile crocodile (Lalele Crocodile Farm, 2023)

Figure 2.2: An adult Nile crocodile (Lalele Crocodile Farm, 2023)

2.6. The crocodile industry of South Africa

South African crocodile farming was established in the 1960s, with the primary focus being the production of skins (Hoffman *et al.*, 2000). South Africa and Zimbabwe are two of the leading Southern African countries that practice commercial crocodile farming, particularly using the Nile crocodile (Webb *et al.*, 2021). The current global Nile crocodile population is not yet confirmed. However, the National Council of Societies for the Prevention of Cruelty to Animals (2022) reported that atleast 80 crocodile farms can be found in South Africa, with an average population of 20 000 crocodiles. These farms are widely distributed in Limpopo (40%), North-West (20%) and KwaZulu-Natal (15%), with less distributions in provinces such as Eastern cape, Western cape and Gauteng (Louw, 2024). Crocodile farming uses either ranching or captive breeding production systems (Brien, 2015). In captive breeding, adult crocodiles lay eggs that are incubated, and hatchlings are raised to harvest size, while ranching relies on raising crocodiles from wild-harvested eggs or hatchlings (Dzoma *et al.*, 2008). Captive breeding follows three distinct systems, namely Closed, semi-closed and open system. In closed system, crocodiles are housed indoors throughout their lives; in semi-closed system, crocodiles are moved to outdoor enclosures after two years; and in open systems, hatchlings are transferred outdoors between the ages of nine and twelve months (Louw, 2024). Juveniles and adult crocodiles are typically housed in enclosures that have solid upright walls reaching up to 1.2m or 1.5m in height, respectively, with adequate water pool and a 0.3m overhang angled inward at 45 degrees (SABS Standards Division, 2009). The breeding enclosures have a 1m deep nesting site comprised of sand bed, and the breeding sex ratio is five females to one male (SABS Standards Division, 2009; Riverbend Crocodile Farm, n.d.). Standard husbandry practices include daily inspections and maintenance of housing enclosures, feeding and removing food waste after feeding period, and veterinary checkups (Manolis and Webb, 2016). Crocodile farming is mainly for skin production (Tosun, 2013), and it plays a significant role in the exotic leather industry with the skin used to manufacture fashion apparel, furniture and various luxury leather products (Wainaina *et al.*, 2022). Generally, crocodile leather is highly prized and widely competes in international markets (Zietsman, 2017). According to Combrink *et al.* (2019), South Africa contributed approximately 60 383 (24%) of the 251 596 Nile crocodile skins traded internationally in 2015. The crocodile industry has also developed markets for some important by-products of crocodile farming including meat and skeletal matter (Dzoma *et al*., 2008). Crocodile farming in South Africa also plays a huge role in job creations and tourist attractions (Aust, 2012).

2.7. Harvesting and processing of crocodile skins

2.7.1. Capturing and slaughtering

Crocodiles are typically slaughtered at the age of 3 years. The use of an electric stunner is a common practice for humane handling of Nile crocodiles on South African commercial farms (Pfitzer *et al*., 2014). According to Convention on International Trade in Endangered Species of Wild Fauna and Flora (2019), slaughtering and processing of most crocodiles is done at local specialised abattoirs whereby their skins are tagged and exported for further processing steps (including tanning and manufacturing into leather goods). There are about three European Union-certified abattoirs in South Africa, which include Thaba Kwena Abbattoir, Izintaba Crocodile Farm and Le Croc.

2.7.2. Skinning

Following slaughtering, the skin is typically removed manually to avoid cutting damage (Louw, 2024). The crocodiles can be skinned to produce belly skins and horn back skins, with opening cuts as described in Figure 2.3 (Manolis and Webb, 2016). The skin is laid flat and excess flesh is removed with a blunt knife to avoid accidental damage (Bolton, 1989). After washing, the skin is preserved with a thick layer of clean salt that weighs at least half of skin weight, to promote desiccation while preventing bacterial growth (Selvi *et al*., 2020). After approximately 48 hours, once the skin has lost moisture, excess salt is removed, and another layer of salt is applied for further preservation till the tanning process.

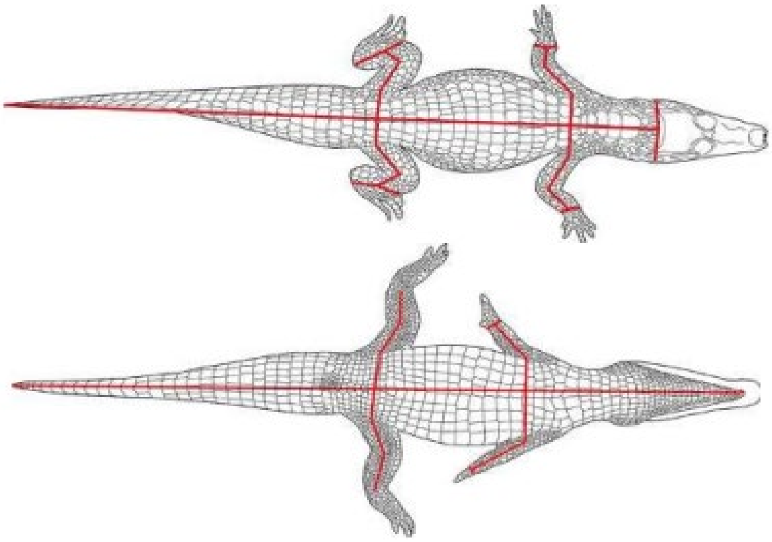

Figure 2.3: Opening cuts for belly skin (top) and horn back skin (bottom) of crocodiles (Manolis and Webb, 2016).

2.7.3. Tanning and processing

Tanning is a process that substitutes skin moisture with tan that coats and cross-links collagen fibres, to convert skin to leather, thus promoting heat resistance and preventing decay (Ahmed *et al*., 2021; El-Moujahed *et al*., 2022). Crocodile skin tanning process may include several distinct phases: pre-tanning operations such as soaking, green fleshing, liming, and deliming; the tanning phase; and post-tanning operations such as, shaving, neutralizing, retannage, fatliquoring and drying, dyeing and finishing, with specifications mentioned by Chala *et al*. (2020). The most used method of tanning crocodile skins is chrome tanning, whereby chromium salts are used to convert skins into chrome leather with a pale blue color (Bolton, 1989; Swartz *et al*., 2017). Leather is further processed into various apparel and leather products. Belly skins are suitable for handbags and garments, hornback skins are suitable for bags and shoes while backstraps are suitable for belts and bracelets (Le Croc, 2025).

2.8. Phenotypic correlation among morphometric traits in leather-producing species

Phenotypic correlation quantifies the relationship between two physical characteristics of an individual animal, and it is typically calculated using Pearson’s correlation coefficient (r) (Malau, 2019). Morphometric traits refer to quantitative measurements of the size and shape of animals and their body parts (Ashburner and Ridgway, 2015).

The correlation between morphometric traits can help identify traits significant in improving the dependent trait of interest, thus facilitating informed breeding selection decisions (Arvandi *et al*., 2024). Skin size was found to be positively correlated with skin weight (r = 0.61) and skin thickness (r = 0.14), and neckline total length exhibited positive correlations with neckline width at the top (r = 0.20) and neckline width at the middle (r = 0.27) at $p<0.01$ in South African Ostriches (Nemutandani, 2023). Hutton (1987) reported that total length and snout-vent length of Nile crocodiles were positively correlated to head length, head width, hindfoot length, belly scale and fifth tail scale, with correlation coefficients ranging from 0.989 to 0.997. According to Engelbrecht (2013), skin size is positively correlated to skin weight (r = 0.75) in ostriches. Furthermore, Kritzinger (2011) found that the correlation between skin area and skin weight was positive at $p<0.05$, with a correlation coefficient of 0.97, in ostriches. Reports by Salehi *et al*. (2014) showed that goat skin weight was positively correlated with skin thickness (r = 0.59) at $p<0.001$, and leather weight (r = 0.94) at $p<0.0001$ and skin thickness was positively correlated with leather thickness (r = 0.59) at $p<0.001$. Salehi and Bitaraf (2013) reported that skin thickness and skin weight of native hairy goats was positively correlated to leather thickness (r = 0.7) and leather weight (r = 0.8), respectively.

2.9. Estimation of length measurements (total length and snout-vent length) from related morphometric measurements in crocodilian species

Morphometric traits provide reliable means for deriving predictive models for various body measurements (Platt *et al*., 2009). Webb *et al*. (2012) indicated that the combination of whole belly skin measurements, such as ventral length and ventral width, was the best in predicting the total length of *Caiman crocodilus*. According to Montague (1984), total length and trunk length were the best predictors of snout-vent length of the New Guinea crocodile (*Crocodylus novaeguineae*). Edwards *et al*. (2017) reported that the total length, tail length, trunk length, and belly width were highly significant in predicting snout-vent length of the Australian freshwater crocodile. Reports from Hutton (1987) showed that snout-vent length, vent length, belly scale and fifth tail length could independently predict total length of Nile crocodile, and a unit increase in each of the traits would result in an increase in total length by 1.779cm, 36.657cm, 54.979cm and 57.500cm, respectively. Mobaraki *et al*. (2021) found that head length was highly significant in predicting the head length of Iranian Mugger crocodiles, accounting for 96% of the variation in total length.

2.10. Conclusion

The Nile crocodile plays a huge role in crocodile farming and exotic leather production, particularly in sub-Saharan Africa. The crocodile industry derives revenue from tourism, farming for skins and byproducts, including meat and bone structure. It was revealed that a positive relationship exists between morphometric traits, such as total body length and head length in crocodiles, and skin weight, skin thickness and skin size in goats and ostriches. Total length and snout-vent length were the most common best predictors of each other in crocodilians. Furthermore, total length and trunk length can be used best predict snout-vent length. The review lacked information on the phenotypic correlation of crocodile skin morphometrics and prediction of skin length. As a result, it is recommended that more studies be done to add to the knowledge gap, for the improvement of skin yield.

CHAPTER THREE

MATERIALS AND METHODS

3.1. Ethical approval

The study received ethical clearance from the University of Limpopo Animal Research Ethics Committee (AREC). Project number AREC/08/2024: PG (Appendix A).

3.2. Study site

The study was conducted at Lalele Crocodile Farm. The farm is located in Modimolle-Mookgopong Municipality (24°27'33.8"S 28°34'25.6"E), Waterberg District, Limpopo Province. The area is located at 1310m above sea level and experiences an average temperature of 19.3°C (iWeather, 2025). The farm is registered with the South African National Standard Crocodiles in Captivity (SANS) since 2014 (ref: 2014/175445/07). Figure 3.1 shows the map of the study site.

Figure 3.1: Geographical representation of the study area (Maponya, 2014; Mappr, 2023)

3.3. Experimental subjects and the general management at the farm

A total of 180 skins from Nile crocodiles aged ±35 months, sourced from Lalele Crocodile Farm were used in this study. The crocodiles were raised under captive breeding, which involves incubating eggs until they hatch, and then nurturing the resulting offspring until slaughter age (Dzoma *et al.*, 2008). Female and male crocodiles reach sexual maturity at the age of 10 years and 12 years, respectively and the female crocodile can lay up to 80 eggs per cycle. The eggs are collected, incubated, and hatched using the incubator, set at controlled temperatures (28°C or 32°C). The sex of the crocodile is determined by the temperature in the incubator, with 28°C producing female offspring and 32°C producing male offspring. The hatchlings are initially kept in a "hot house", where the temperature runs up to 32°C, and they are fed dry pellets made from fishmeal, carcass soya, and minerals daily. After reaching 7 months of age, the crocodiles are moved into panels consisting of a 2.5m deep pool and two small feeding pools. A single panel is stocked with about 1000 young crocodiles. To maintain a clean environment and minimize stress on new stock, the water in the ponds is drained and replaced with fresh water before bringing new juveniles into the enclosure (Louw, 2024). The wastewater is used to irrigate the pasture on the farm. The crocodiles are then fed dry chicken mincemeat four to five times a week (Manolis and Webb, 2016), until they reach slaughter age at 3 years.

Slaughtering was done at Thaba Kwena Abattoir, a certified veterinary establishment approved by the Department of Agriculture, Land Reform and Rural Development (DALRRD). The abattoir is authorized to export meat to the European Union and other countries. Slaughtering, skinning, and tanning were done as described in Chapter two (section 2.7).

3.4. Study design and sampling procedure

The study used a cross-sectional design, collecting data from experimental subjects once. The study used census approach sampling procedure, whereby all the available skins were measured during data collection. Prior to data collection, the researchers obtained consent from the farm owner (Appendix B).

3.5. Measurements of traits

Traits measured on raw Nile crocodile skin includes total skin length (TSL), skin weight (SW), skin thickness (ST), total tail length (TTL), tail length from the middle (TLM), tail width (TLW), neck width at the middle (NWM), neck width at the top (NWT), neck total length (NTL), belly length (BL), and belly width (BW) (as described in Table 3.1). Data was immediately recorded on a data collection sheet (Appendix C). Figure 3.2 is a schematic representation of the measured traits. All measurements were taken by one person to minimize individual variation.

Table 3.1: Description of the traits measured on the Nile crocodile

Trait	Protocol	Instrument	unit
Total skin length (TSL)	Length of the skin from lower jaw tip to tail tip (Van Jaarsveldt, 1987)	Tailor measuring tape	cm
Skin weight (SW)	Overall weight of the skin	Weighing scale	kg
Skin thickness (ST)	Average of the skin thickness at three varying places (neck, belly, tail).	Caliper	mm
Belly length (BL)	Length between the base of the neckline to the cloaca	Tailor measuring tape	cm
Belly width (BW)	Length between the third osteoderms on each side of the skin (Manolis and Webb, 2011).	Tailor measuring tape	cm
Total tail length (TTL)	Distance between the anterior of the cloaca and the tail tip (Montague, 1984).	Tailor measuring tape	cm
Tail length from the middle (TLM)	Length of the tail from the curve point		cm
Tail width (TLW)	Width at the middle point of the tail	Tailor measuring tape	cm
Neck total length (NTL)	Distance between the top and base of the neck	Tailor measuring tape	cm
Neck width at the top (NWT)	Width at the top (toward the head) of the neck	Tailor measuring tape	cm

Neck width at the middle (NWM)	Width at the middle of the neck (towards the chest-base)	Tailor measuring tape	cm

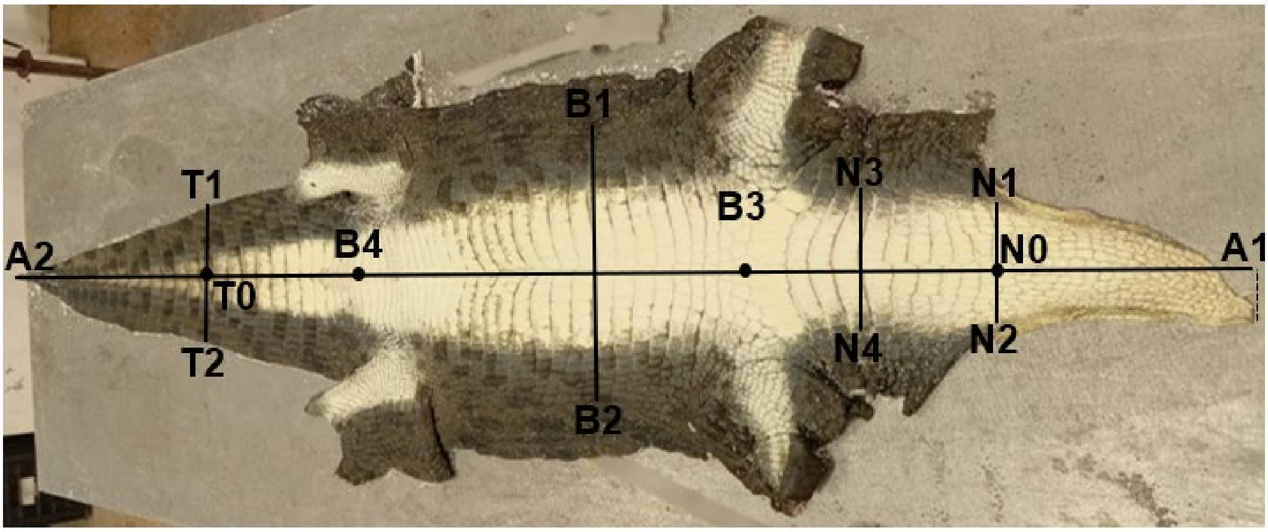

Figure 3.2: Schematic representation of the measurement taken on the Nile crocodile skin (Source: Researcher). ***Note that:*** A1-A2 = TSL, B1-B2 = BW, B3-B4 = BL, B4-A2 = TTL, T0-A2 = TLM, T1-T2 = TLW, N0-B3 = NTL, N1-N2 = NWT, N3-N4 = NWM

3.6. Statistical analysis

Statistical Package for the Social Sciences (IBM SPSS, 2022) software, version 29.0 was used for data analysis. Pearson's correlation was used to determine the phenotypic relationship between total skin length and measurable skin traits. A level of significance of 5% and 1% was set for correlated and highly correlated traits, respectively. Simple linear regression and multiple regression analysis were used to establish models for predicting total skin length from measurable skin traits of the Nile crocodile. Total skin length was defined as the dependent variable while the skin traits were the independent variables. Only significantly correlated traits were used in the simple linear regression analysis. The following linear regression formula was used:

$Y = a + bx + e$

Where:

Y = Dependent variable (TSL)

a = constant

b = regression coefficient

x = independent variable (SW, ST, BL, BW, TTL, TLM, TLM, TLW, NTL, NWT, NWM)

e = error

The following multiple regression models were fitted:

- Model 1 included all the independent variables measured in the study:

TSL = SW + ST + BL + BW + TTL + TLM + TLW + NTL + NWT + NWM

- Model 2 included the independent variables of model 1 except SW and ST, to assess the impact of all the dimensional measurement without the influence of SW and ST

Model 2: TSL = BL + BW + TTL + TLM + TLW + NTL + NWT + NWM

- Model 3 included all the width measurements as independent variables:

Model 3: TSL = BW + TLW + NWT + NWM

- Model 4 included the only the three total length measurements as independent variables:

Model 4: TSL = BL + TTL + NTL

The highest coefficient of determination (R^2) and lowest root mean square error (RMSE) were used to select the best-fitted model.

CHAPTER FOUR

RESULTS

4.1. Descriptive statistics

Table 4.1 shows the summary of skin traits of the Nile crocodile. All traits were recorded from the 180 skins that were accessible. TSL had a mean value of 133.28cm with a standard deviation of 11.55 and a coefficient of variation of 8.67%. TSL ranged from 100 cm to 163.8cm.

Table 4.1: Descriptive statistics of crocodile skin traits

Traits	**n**	**Mean ± SE**	**SD**	**CV%**	**γ**	**κ**	**Range**
TSL (cm)	180	133.28 ± 0.86	11.55	8.67	- 0.05	- 0.23	100.00 - 163.80
SW (kg)	180	1.12 ± 0.02	0.28	25.00	0.38	- 0.11	0.58 - 1.90
ST (mm)	180	2.17 ± 0.04	0.55	25.35	0.63	0.51	0.96 - 3.97
BL (cm)	180	38.69 ± 0.27	3.61	9.33	- 0.15	- 0.25	30.00 - 48.00
BW (cm)	180	29.50 ± 0.25	3.36	11.39	- 0.17	- 0.48	21.50 - 37.00
TTL (cm)	180	63.43 ± 0.48	6.48	10.22	- 0.30	0.08	43.90 - 76.80
TLM (cm)	180	43.22 ± 0.33	4.45	10.30	- 0.13	0.34	30.20 - 55.70
TLW (cm)	180	16.72 ± 0.15	1.99	11.90	0.27	0.50	11.80 - 24.20
NTL (cm)	180	21.58 ± 0.48	6.42	29.75	- 0.48	- 1.35	8.20 - 31.00
NWT (cm)	180	10.66 ± 0.10	1.40	13.13	0.28	1.20	7.00 - 16.50
NWM (cm)	180	12.72 ± 0.13	1.69	13.29	0.50	0.80	8.60 - 18.40

TSL = Total skin length; SW = Skin weight; ST = Skin thickness; BL = Belly length; BW = Belly width; TTL= Total tail length; TLM = Tail length from middle (TLM); TLW = Tail width; NTL = Neck total length; NWT = Neck width at top; NWM = Neck width at middle; n = sample size; SE = Standard error; SD = Standard deviation; CV = Coefficient of variation; γ = Skewness, *K* = Kurtosis

4.2. Correlation between crocodile skin traits

Table 4.2 presents the correlation co-efficient values between the skin traits of Nile crocodiles. The correlations were positive and significant (*p<0.01)* between TSL and all the traits, except ST, which was significant at *p<0.05*. The correlation of TSL with skin thickness was low (0.17) and positive, and these was per the classification system proposed by Turner and Young (1969), which defines correlations as very low (<10%), low (10-20%), moderate (20-40%), high (40-60%), and very high (>60%). Correlations of TSL with NTL were moderate (0.37), high for NWT (0.51) and NWM (0.60), and very high for SW (0.81), BL (0.79), BW (0.75), TTL (0.87) and TLM (0.78). Among the skin traits, NTL revealed negative significant (*p<0.01*) correlations with ST (- 0.60) and TLW (- 0.23). Furthermore, NTL had insignificant (*p>0.05*) correlation with SW (0.06), BL (- 0.02), BW (0.05), NWT (- 0.10) and NWM (0.04) while ST had insignificant (*p>0.05*) correlation with TTL (- 0.07) and TLM (- 0.02). All the other skin traits had positive and significant (*p<0.01*) correlations with each other.

Table 4.2: Correlation between skin traits of Nile crocodile

Traits	**TSL**	**SW**	**ST**	**BL**	**BW**	**TTL**	**TLM**	**TLW**	**NTL**	**NWT**	**NWM**
TSL											
SW	0.81**										
ST	0.17*	0.47**									
BL	0.79**	0.83**	0.42**								
BW	0.75**	0.83**	0.39**	0.77**							
TTL	0.87**	0.65**	-0.07^{ns}	0.59**	0.58**						
TLM	0.78**	0.58**	-0.02^{ns}	0.54**	0.51**	0.85**					
TLW	0.48**	0.68**	0.60**	0.69**	0.59**	0.29**	0.30**				
NTL	0.37**	0.06^{ns}	-0.60**	-0.02^{ns}	0.05^{ns}	0.55**	0.50**	-0.23**			
NWT	0.51**	0.59**	0.43**	0.60**	0.63**	0.38**	0.36**	0.59**	-0.10^{ns}		
NWM	0.60**	0.67**	0.35**	0.63**	0.67**	0.48**	0.49**	0.50**	0.04^{ns}	0.65**	

TSL = Total skin length; SW = Skin weight; ST = Skin thickness; BL = Belly length; BW = Belly width; TTL= Total tail length; TLM = Tail length from middle (TLM); TLW = Tail width; NTL = Neck total length; NWT = Neck width at the top; NWM = Neck width at the middle; * = Correlated at $p<0.05$; ** = Correlated at $p<0.01$; ^{ns}= not significant.

4.3. Regression analysis

Table 4.3 shows the simple linear regression equations for the prediction of total skin length. The regression findings showed that the skin traits such as SW, ST, TTL, BL, BW, TLM, NWT, TLW, and NWT were significant in predicting TSL of Nile crocodile. The results showed that the established equations for the prediction of total skin length using SW and ST had a coefficient of determination (R^2) of 0.65 and 0.03 with root mean square error (RMSE) of 46.87 and 130.29, respectively. The neck traits, NTL, NWT and NWM recorded R^2 values of 0.14, 0.26 and 0.36 with RMSE values of 116.00, 99.23 and 86.43, respectively. On the other hand, the belly traits, R^2 values of 0.63 and 0.56 with RMSE of 49.88 and 59.36 were recorded for BL and BW, respectively. TTL, TLM and TLW had a coefficient of determination (R^2) of 0.76, 0.61 and 0.23 with RMSE of 31.98, 52.94 and 103.02, respectively. The findings further revealed that TTL was the best trait in predicting TSL, accounting for 76% of TSL variation. SW and BL were second and third best predictors of TSL, accounting for 65% and 63% of TSL variation, respectively.

Table 4.3: Simple linear regression models for the prediction of total skin length from skin traits of the Nile crocodile

Traits	**Model**	**R^2**	**RMSE**	**p-value**
SW	TSL = 96.35 + 33.06SW	0.65	46.87	<0.01
ST	TSL = 125.52 + 3.58ST	0.03	130.29	0.02
BL	TSL = 35.11 + 2.54BL	0.63	49.88	<0.01
BW	TSL = 57.62 + 2.57BW	0.56	59.36	<0.01
TTL	TSL = 34.55 + 1.56TTL	0.76	31.98	<0.01
TLM	TSL = 45.91 + 2.02TLM	0.61	52.94	<0.01
TLW	TSL = 86.48 + 2.80TLW	0.23	103.02	<0.01
NTL	TSL = 119.00 + 0.66NTL	0.14	116.00	<0.01
NWT	TSL = 88.29 + 4.22NWT	0.26	99.23	<0.01
NWM	TSL = 81.42 + 4.08NWM	0.36	86.43	<0.01
Decision		Higher is better	Lower is better	

SW = Skin weight; ST = Skin thickness; BL = Belly length; BW = Belly width; TTL= Total tail length; TLM = Tail length from middle (TLM); TLW = Tail width; NTL = Neck total length; NWT = Neck width at the top; NWM = Neck width at the middle; R^2 = Coefficient of determination; RMSE = Root mean square error.

4.3.1. Regression analysis of total skin length and skin weight

The linear regression equation was established as TSL = 96.35 + 33.06SW, as shown in Figure 4.1, whereby TSL = total skin length, SW = skin weight, 96.35 = constant and 0.03 = regression coefficient. The equation indicated that for a 1kg increase in skin weight, the total skin length increases by 33.06cm.

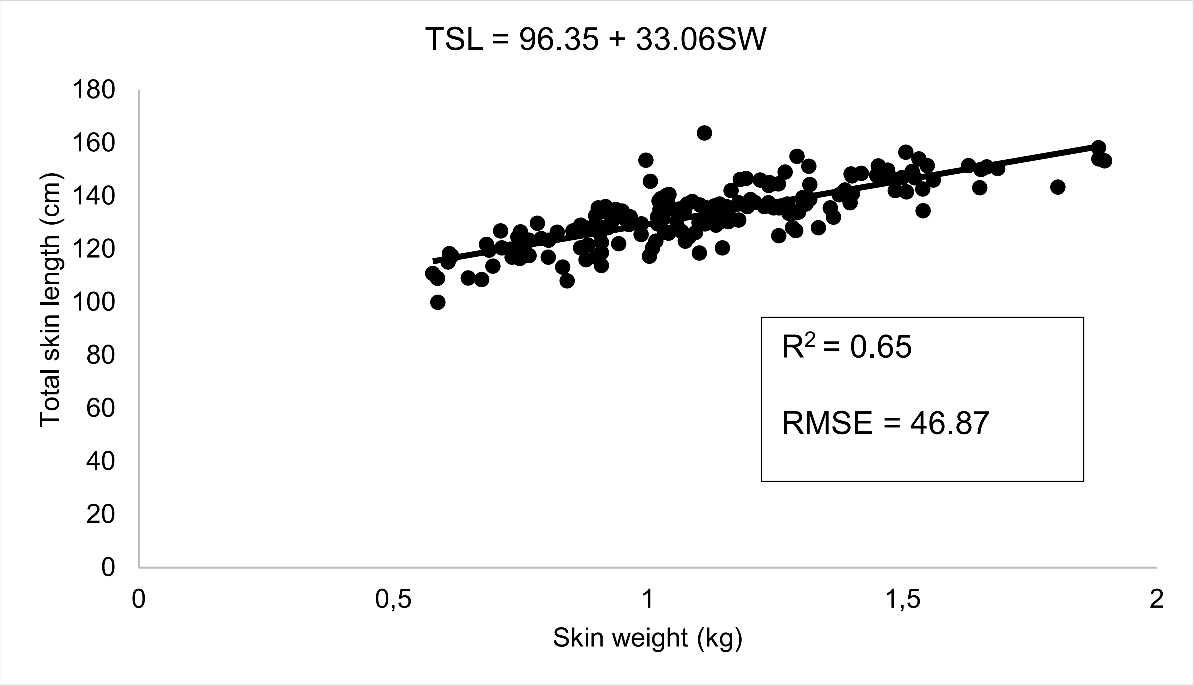

Figure 4.1: Effect of skin weight on total skin length of Nile crocodiles

4.3.2. Regression analysis of total skin length and skin thickness

Figure 4.2 shows the established regression equation as TSL = 125.52 + 3.58ST, whereby TSL = total skin length, 125.52 = constant, 3.58 = regression coefficient, and ST = skin thickness. The results showed that increasing ST by 1mm, TSL will increase by 3.58cm.

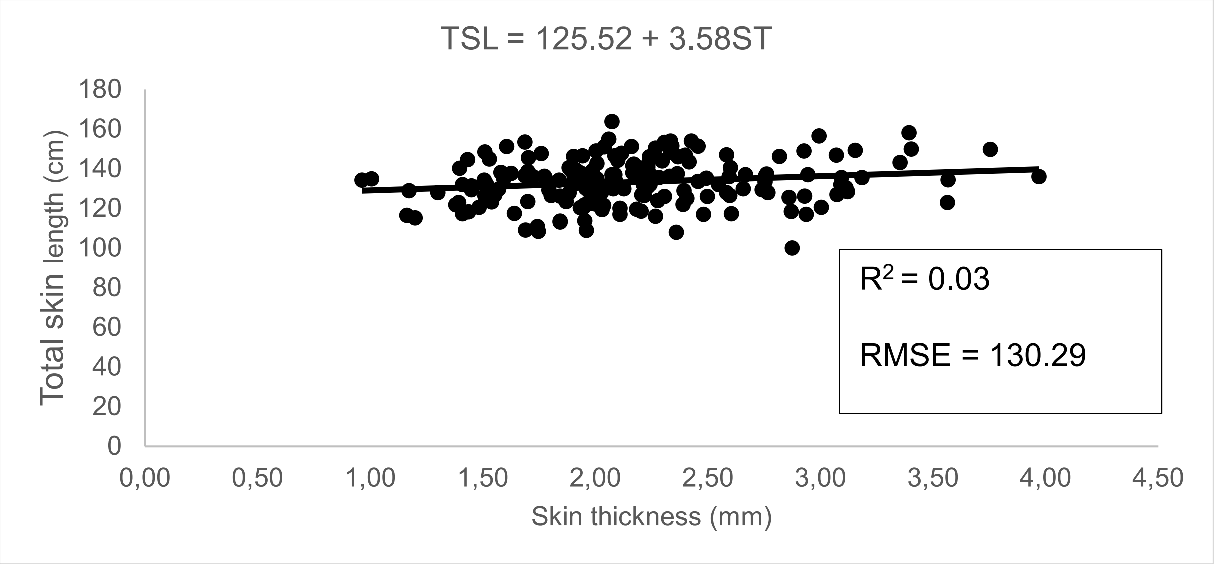

Figure 4.2: Effect of skin thickness on total skin length of Nile crocodiles

4.3.3. Regression analysis of total skin length and belly length

The established regression formula is depicted in Figure 4.3 as TSL = 35.11 +2.54BL, whereby TSL = total skin length, 35.11 = constant, 2.54 = regression coefficient, and BL = belly length. The results further showed that if BL increases by 1cm, TSL will increase by 2.54cm.

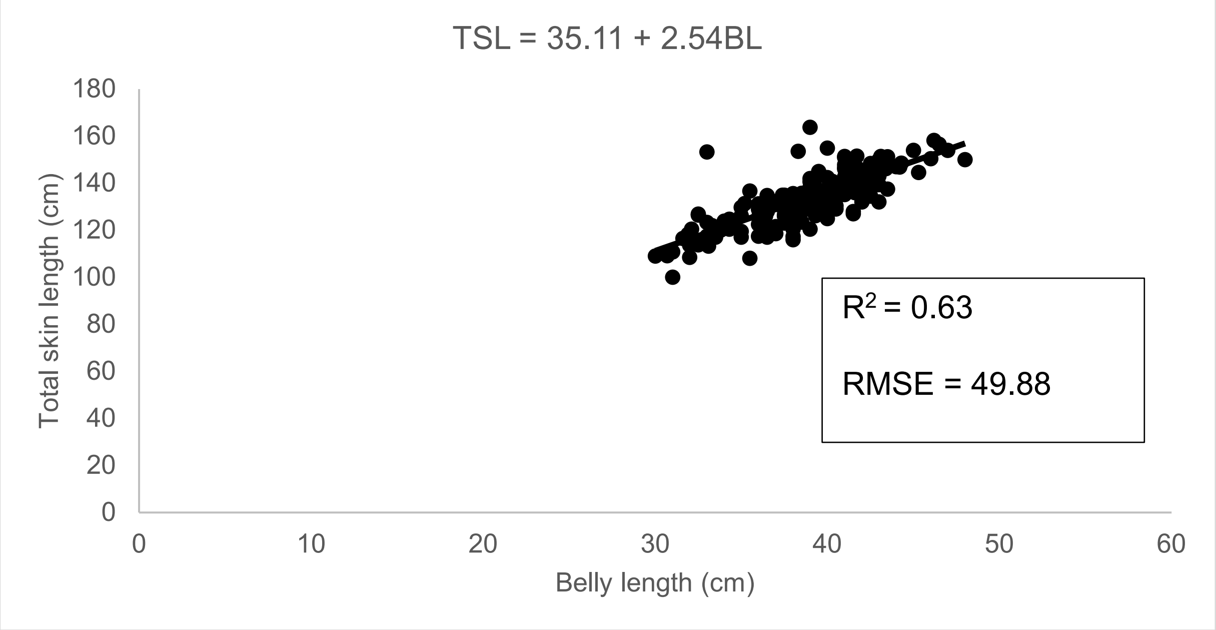

Figure 4.3: Effect of belly length on total skin length of Nile crocodiles

4.3.4. Regression analysis of total skin length and belly width

The prediction model was established as TSL = 57.62 + 2.57BW, as depicted in Figure 4.4, whereby TSL = total skin length, 57.62 = constant, 2.57 = regression coefficient, and BW = belly width. The results further indicated that a 1cm increase in BW will result in a 2.57cm increase in TSL.

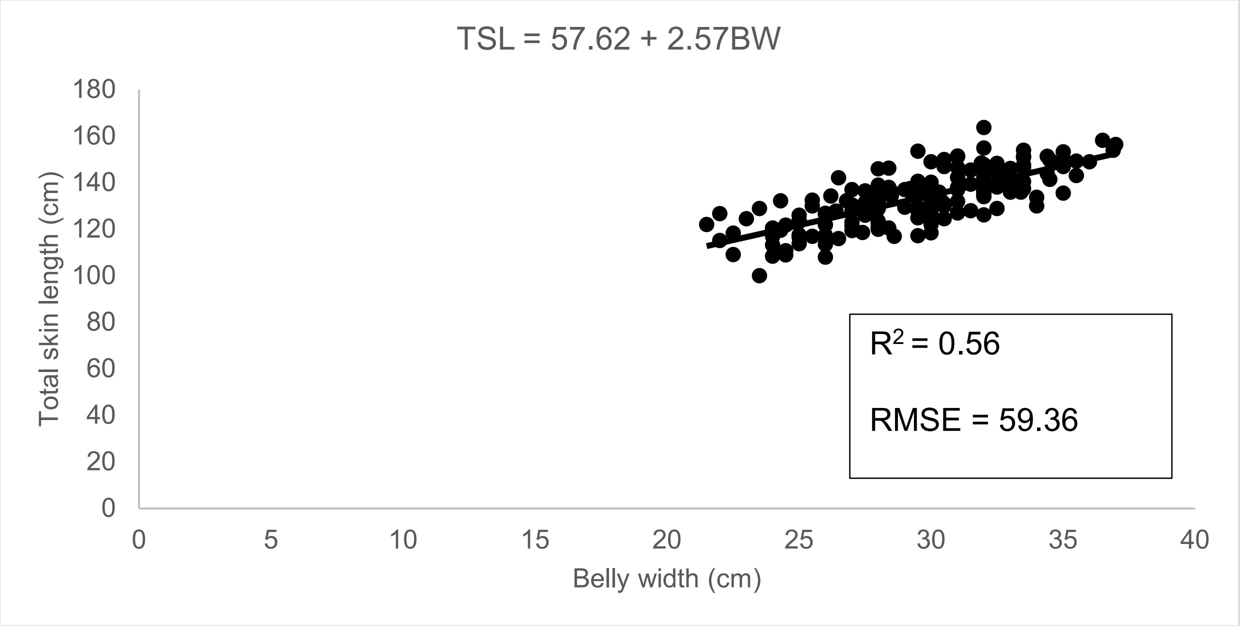

Figure 4.4: Effect of belly width on total skin length of Nile crocodiles

4.3.5. Regression analysis of total skin length and total tail length

Figure 4.5 shows the established regression equation, TSL = 34.552 + 1.56TTL, whereby TSL = total skin length, 34.552 = constant, 1.56 = regression coefficient, and TTL = total tail length. Furthermore, the regression findings showed that a unit increase in TTL will increase TSL by 1.56cm.

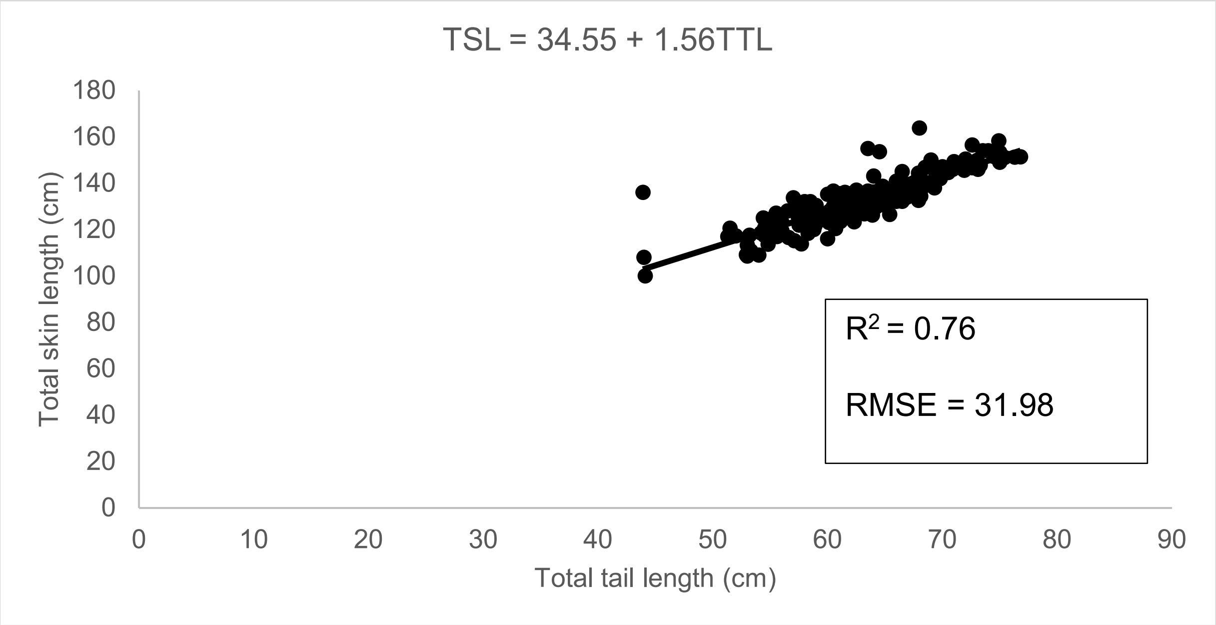

Figure 4.5: Effect of total tail length on total skin length of Nile crocodiles

4.3.6. Regression analysis of total skin length and tail length from middle

Figure 4.6 shows the established regression equation (TSL = 45.91 + 2.02TLM), whereby TSL = total skin length, 45.91 = constant, 2.02 = regression coefficient, and TLM = tail length from middle. Based on the findings, A unit increase in TLM will result in an increase of TSL by 2.02cm.

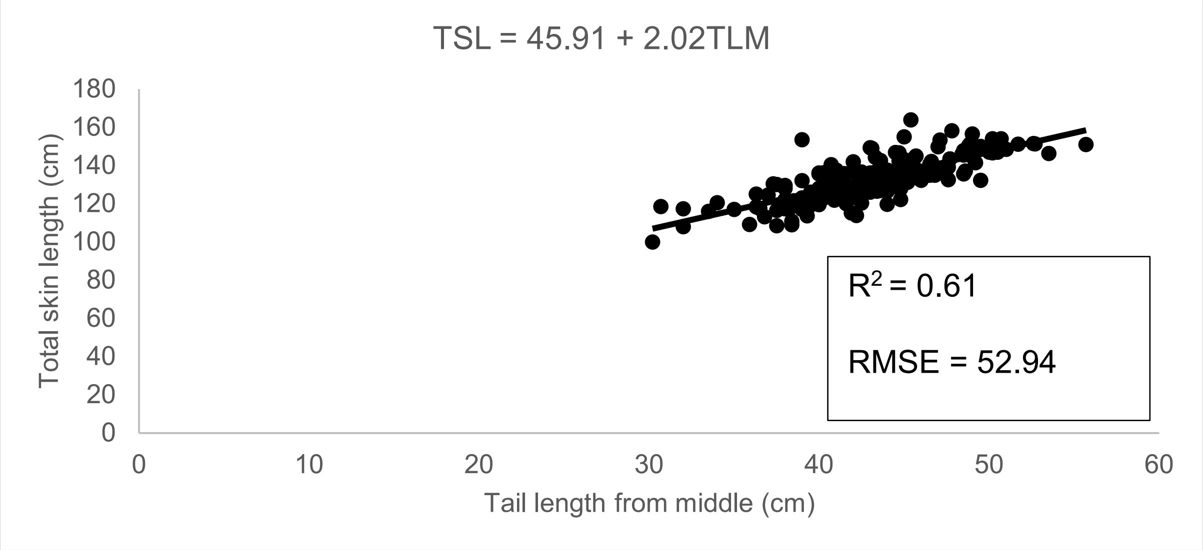

Figure 4.6: Effect of tail length from middle on total skin length of Nile crocodiles

4.3.7. Regression analysis of total skin length and tail width

The established regression equation is shown in Figure 4.7 as TSL = 86.48 + 2.80TLW, whereby TSL = total skin length, 86.48 = constant, 2.80 = regression coefficient, and TLW = tail width. The results indicated that a unit increase in TLW will result in a 2.80cm increase in TSL.

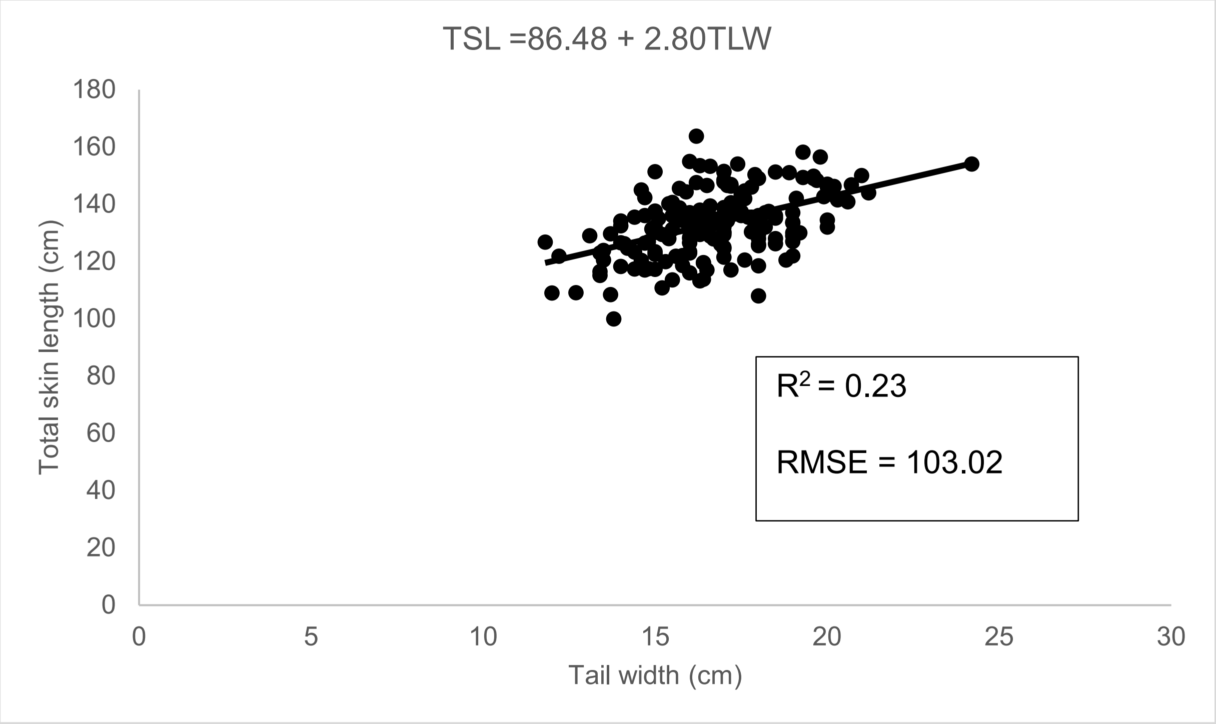

Figure 4.7: Effect of tail width on total skin length of Nile crocodiles

4.3.8. Regression analysis of total skin length and neck total length

Figure 4.8 shows the established regression formula (TSL = 119.00 + 0.66NTL), whereby TSL = total skin length, 119.00 = constant, 0.66 = regression coefficient, and NTL = neck total length. The results showed that increasing NTL by 1cm, TSL will increase by 0.66cm.

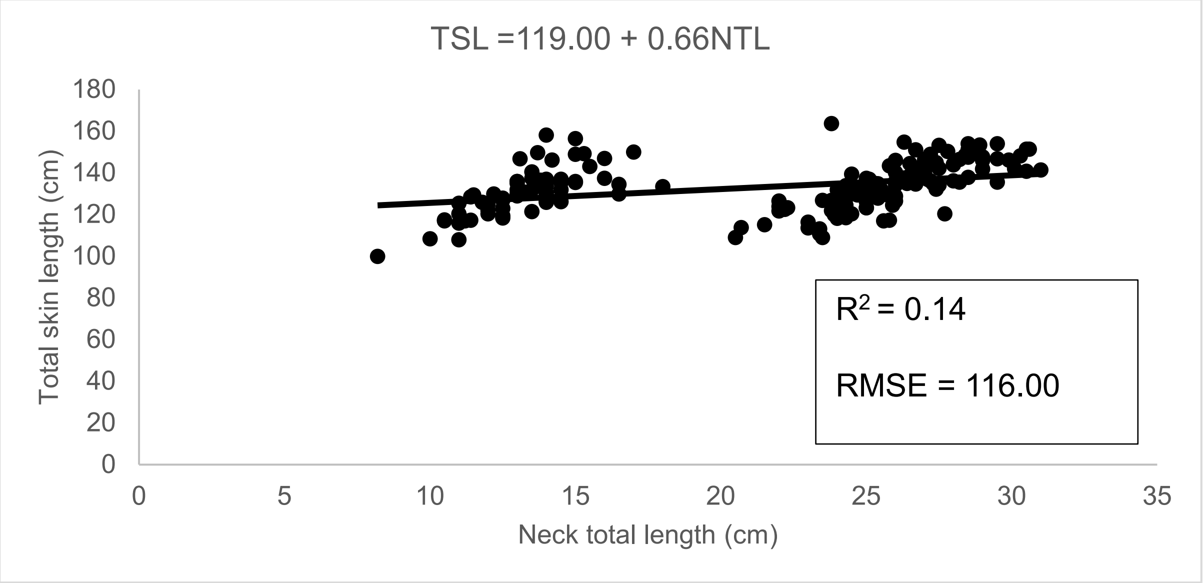

Figure 4.8: Effect of neck total length on total skin length of Nile crocodiles

4.3.9. Regression analysis of total skin length and neck width at top

The linear regression equation was established as TSL = 88.29 + 4.22NWT (Figure 4.9) whereby TSL= total skin length, NWT= neck width at top, 88.29= constant and 4.22 = regression coefficient. The results indicated that increasing NWT by 1cm, TSL will increase by 4.22cm.

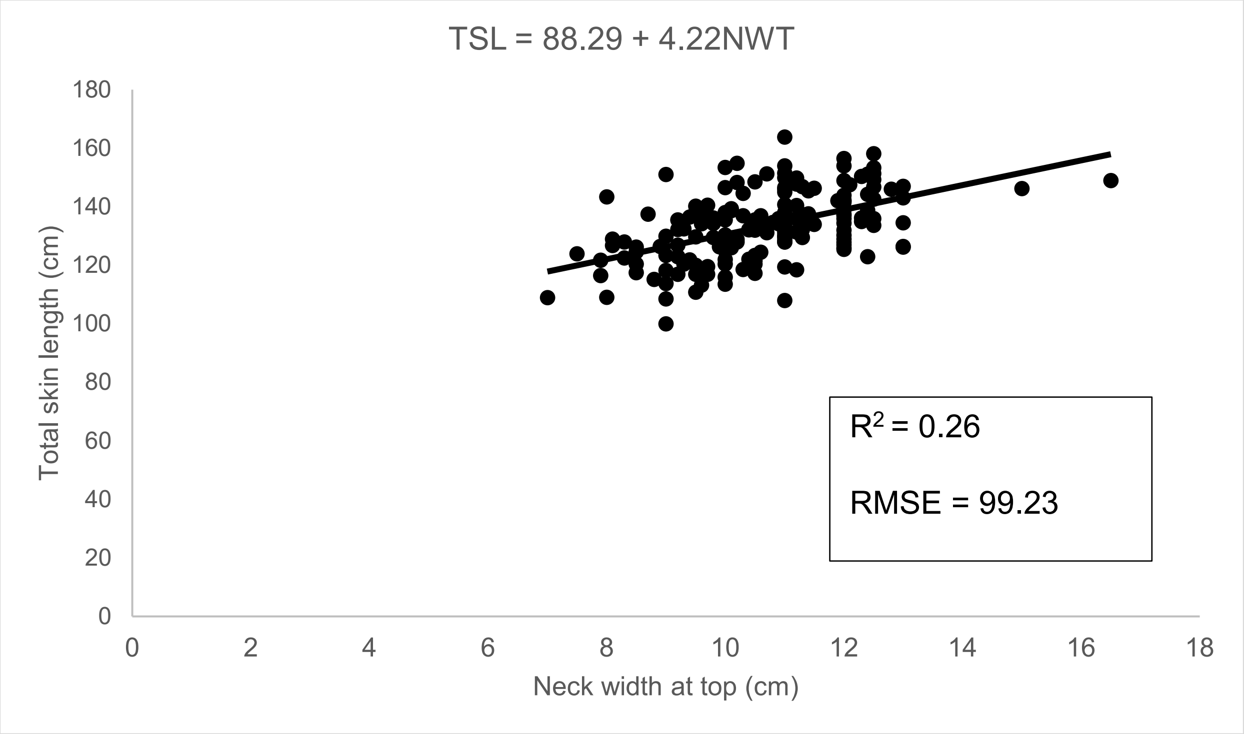

Figure 4.9: Effect of neck width at top on total skin length of Nile crocodiles

4.3.10. Regression analysis of total skin length and neck width at the middle

Figure 4.10 shows the established regression equation (TSL = 81.42 + 4.08NWM), whereby TSL = total skin length, 81.42 = constant, 4.08 = regression coefficient, and NWM = neck width at the middle. The results showed if NWM increases by 1cm, TSL will increase by 4.08 cm.

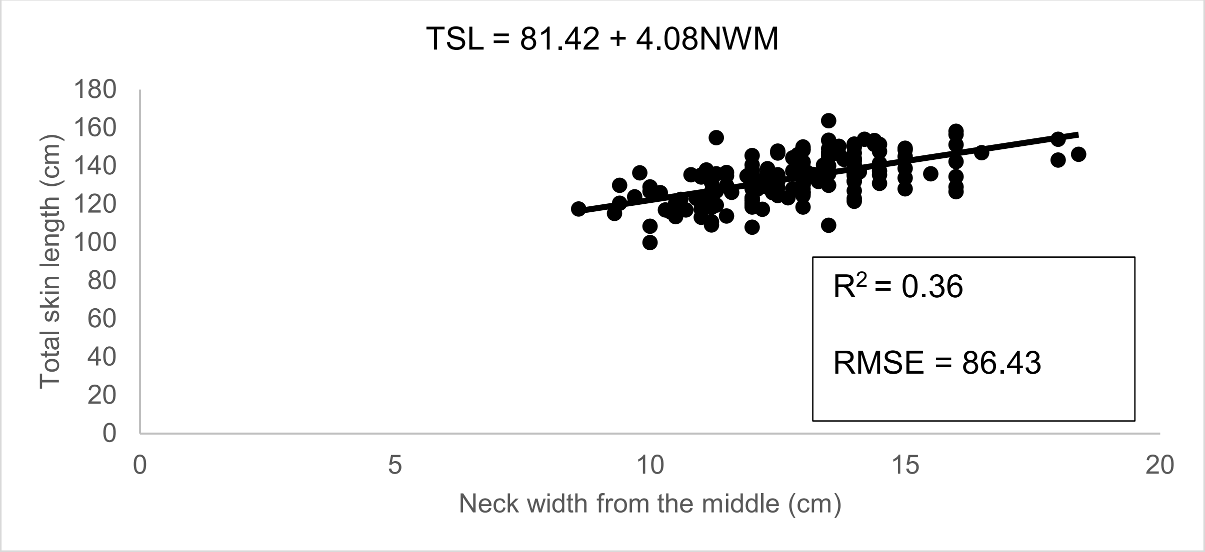

Figure 4.10: Effect of neck width at the middle on total skin length of Nile crocodiles

4.3.11. Skin traits effects on Total skin length in crocodile using multiple regression

Table 4.4 shows the multiple regression equations for the prediction of total skin length. The results showed that model 1 (TSL = 16.35 + 4.68SW + 1.28ST + 1.03BL + 0.39BW + 0.81TTL + 0.13TLM - 0.25TLW + 0.21NTL + 0.19NWT – 0.14NWM) had the highest coefficient of determination (R^2 = 0.90) and the lowest residual mean square error (RMSE = 14.28), making it the best in predicting total skin length of Nile crocodile. The findings suggest that model 1 accounted for 90% of TSL variation.

Table 4.4: Multiple regression models for the prediction of total skin length from skin traits of the Nile crocodile

Model	Equation	R^2	RMSE	p-value
1	TSL = 16.35 + 4.68SW + 1.28ST + 1.03BL + 0.39BW + 0.81TTL + 0.13TLM - 0.25TLW + 0.21NTL + 0.19NWT – 0.14NWM	0.90	14.28	<0.01
2	TSL = 8.92 + 1.12BL + 0.57BW + 0.84TTL + 0.15TLM + 0.003TLW + 0.15NTL + 0.16NWT – 0.03NWM	0.89	14.79	<0.01
3	TSL = 53.14 + 2.12BW + 0.25TLW - 0.15NWT + 1.18NWM	0.58	57.95	<0.01
4	TSL = 9.85 + 1.48BL + 1.00TTL + 0.13NTL	0.88	16.06	<0.01
Decision		Higher is better	Lower is better	

SW = Skin weight; ST = Skin thickness; BL = Belly length; BW = Belly width; TTL= Total tail length; TLM = Tail length from middle (TLM); TLW = Tail width; NTL = Neck total length; NWT = Neck width at the top; NWM = Neck width at the middle R^2 = Coefficient of determination; RMSE = Root mean square error.

CHAPTER FIVE

DISCUSSION

5.1. Discussion

Morphometric data are recommended in crocodilian research projects to establish predictive models that link various body measurements (Platt *et al*., 2009). The first objective of the study was to determine the correlation between total skin length and other objectively measured skin traits of the Nile crocodile using Pearson correlation. The findings showed that total skin length had very high positive and significant ($p<0.01$) correlations with skin weight, belly length, belly width, total tail length and tail length from the middle. Correlations of TSL with skin thickness were low and positive at $p<0.05$, moderate for neck total length, and high for neck width at the top and neck width at the middle at $p<0.01$. However, no significant correlation was recorded between total skin length and neck width at the middle. The non-significant correlations imply that a change in one trait may not affect the other. Hutton (1987) found that the total length of live Nile crocodiles exhibited very high positive correlations with snout-vent length (r = 0.995), belly scale (0.989), and fifth tail scale (0.996). The determination of the phenotypic correlation among morphometric traits, including that of the skin, was reported in several exotic leather-producing species. This includes reports from Nemutandani (2023) which indicated that skin size exhibited low (r = 0.14) and very high (r = 0.61) positive correlations with skin thickness and skin weight, respectively, in South African ostriches. Engelbrecht (2013) also reported a very high positive correlation (r = 0.75) between skin size and raw skin weight of ostriches. Furthermore, current correlation results showed that neck total length had negative but significant correlations with skin thickness and tail width. According to Nemutandani *et al*. (2024), the significant negative correlations between skin traits imply that a decrease in one trait will increase the other. Furthermore, neck total length exhibited non-significant correlations with skin weight, belly length, belly width, neck width at the top, neck width at the middle, while skin thickness had no significant correlation with total tail length and tail length from the middle. This is in contradiction with Nemutandani (2023), who reported moderate phenotypic correlations between neckline total length with neckline width at the top (r = 0.20) and neck width at the middle (r = 0.27) in South African Ostriches. The contradiction may be attributed to the use of varying species. All the other traits exhibited significant positive correlations with each other. Current correlation findings indicate that improving skin weight, belly length, belly width, total tail length, tail length from the middle, tail width, neck total length, neck width at the top, and skin thickness might improve total skin length. Strong positive correlations found between morphometric traits suggest that the traits may be controlled by a similar gene (Mathapo *et al*., 2022).

Correlation analysis determines the relationship that exists between total skin length and skin traits, however; it does not identify traits that can be used to best predict total skin length. Hence, the current study established equations for predicting total skin length from skin traits using simple linear and multiple regression analysis methods. The current regression results showed that when using single traits to predict total skin length, the total tail length exhibited a higher coefficient of determination, making it the best predictor trait. The higher contribution by total tail length to the variation in total skin length was not unexpected as juveniles have been found to have relatively long tails (Webb and Messel, 1978). Although less important when compared to total tail length, skin weight and belly length also showed high contributions to total skin length variation, making them possible alternative single predictors. As a result, skin weight or belly length can be used as accurate predictors in situations where total tail length may not accurately predict total skin length, such as the inability to accurately measure the trait due to tail amputations. When using multiple traits, the findings showed that model 1 (combination of SW, ST, BL, BW, TTL, TLM, TLW, NTL, NWT, NWM) had the highest coefficient of determination. Several studies reporting on the prediction of length measurements from morphometric data. These include the studies of Salem (2011), Fukuda *et al*. (2013) and Mobaraki *et al*. (2021), which indicated that head length was one of the significant traits in predicting total body length of Nile, Saltwater and Nile crocodiles, contributing 99%, 89% and 96% to total body length variation. Furthermore, snout-vent length of New Guinea and Australian freshwater crocodiles could be reliably predicted from total length, tail length and belly width (Montague, 1984; Edwards *et al*., 2017). According to Webb *et al*. (2012), the combination of ventral length and ventral width on whole belly skins was the best in predicting the standardized total length, while the combination of dorsal length and dorsal width on hornback skins was the best in predicting the standardized total length of Spectacled caiman. The current regression findings suggest that TTL alone or a combination of SW, ST, BL, BW, TTL, TLM, NTL, NWT, NWM and TLW can be used to reliably predict total skin length. Furthermore, the results suggest that a one-unit increase in SW, ST, BL, BW, TTL, TLM, NTL, and NWT is associated to an increase in total skin length by 4.68cm, 1.28cm, 1.03cm, 0.39cm, 0.81cm, 0.13cm, 0.21cm and 0.19cm, respectively. Conversely, a one-unit increase in NWM and TLW corresponds to a decrease in total skin length by 0.14cm and 0.25cm, respectively. There is a lack of literature on the phenotypic correlation of skin traits of crocodiles and the prediction of total skin length from skin traits of crocodiles, therefore this study recommends conducting of more research in different crocodilian species.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1. Conclusions

Pearson’s correlation was utilised to determine the phenotypic correlation between total skin length and measurable skin traits of the Nile crocodile. It can be concluded that there is a positive relationship between total skin length and skin weight, skin thickness, belly length, belly width, total tail length, tail length from the middle, tail width, neck total length, neck width at the top, and neck width at the middle. These skin traits should be taken into consideration when improving total skin length in Nile crocodiles. The study also used simple linear regression and multiple regression analysis to establish models for predicting total skin length from the measurable skin traits. The results revealed that the combination of all the measured traits was the best in predicting the total skin length of Nile crocodiles. Furthermore, total tail length could independently best predict total skin length of the Nile crocodiles.

6.2. Recommendations

Based on the findings, the study recommends that:

Farmers should consider skin weight, skin thickness, belly length, belly width, total tail length, tail length from the middle, tail width, neck total length, neck width at the top, and neck width at the middle, as selection criteria for improving total skin length of their produce.

Breeders and farmers may use total tail length as a predictor for total skin length, given the simplicity of utilising one trait.

Researchers need to assess the relationships between measurable raw skin traits and leather traits, thus, to ascertain the effect on the quality of the final product.

Future research can be done on the phenotypic and genetic correlations of skin morphometrics in various crocodilian species

CHAPTER SEVEN

REFERENCES AND APPENDICES

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7.2. Appendices

Appendix A: Ethical clearance certificate

University of Limpopo
Department of Research Administration and Development
Private Bag X1106, Sovenga, 0727, South Africa
Tel: (015) 268 3935/2401 Fax: (015) 268 2306, Email: Tukiso.Sewapa@ul.ac.za

ANIMAL RESEARCH ETHICS COMMITTEE CLEARANCE CERTIFICATE

MEETING: 22 May 2024
PROJECT NUMBER: AREC/08/2024: PG

PROJECT:

Title: Non-genetic factors influencing slaughter and skin traits of South African Nile crocodiles (*Crocodylus niloticus corviei*)
Researcher: P Rachuene
Supervisor: Dr TJ Mugwabana
Co-Supervisor/s: Dr KR Nemutandani
Prof TL Tyasi
School: Agricultural and Environmental Sciences
Degree: Master of Science (Animal Production)

PROF LJC ERASMUS

CHAIRPERSON: ANIMAL RESEARCH ETHICS COMMITTEE

The Animal Research Ethics Committee (AREC) is registered with the National Health Research Ethics Council, Registration Number: **AREC-290914-017**

Note:
i) Should any departure be contemplated from the research procedure as approved, the researcher(s) must re-submit the protocol to the committee.
ii) The budget for the research will be considered separately from the protocol.
iii) Please note that this clearance certificate is valid for a period of 12 months from date of issue.
iv) PLEASE QUOTE THE PROTOCOL NUMBER IN ALL ENQUIRIES.

Finding solutions for Africa

Appendix B: Gatekeeper's consent form

Gate Keeper's Consent Form

LALELE CROCODILE FARM

Section 55, Welgevonden Farm (R520), Box 1549, Naboomspruit 0560, South Africa
Cell: 082 600 2114
Email: info@lalele.co.za

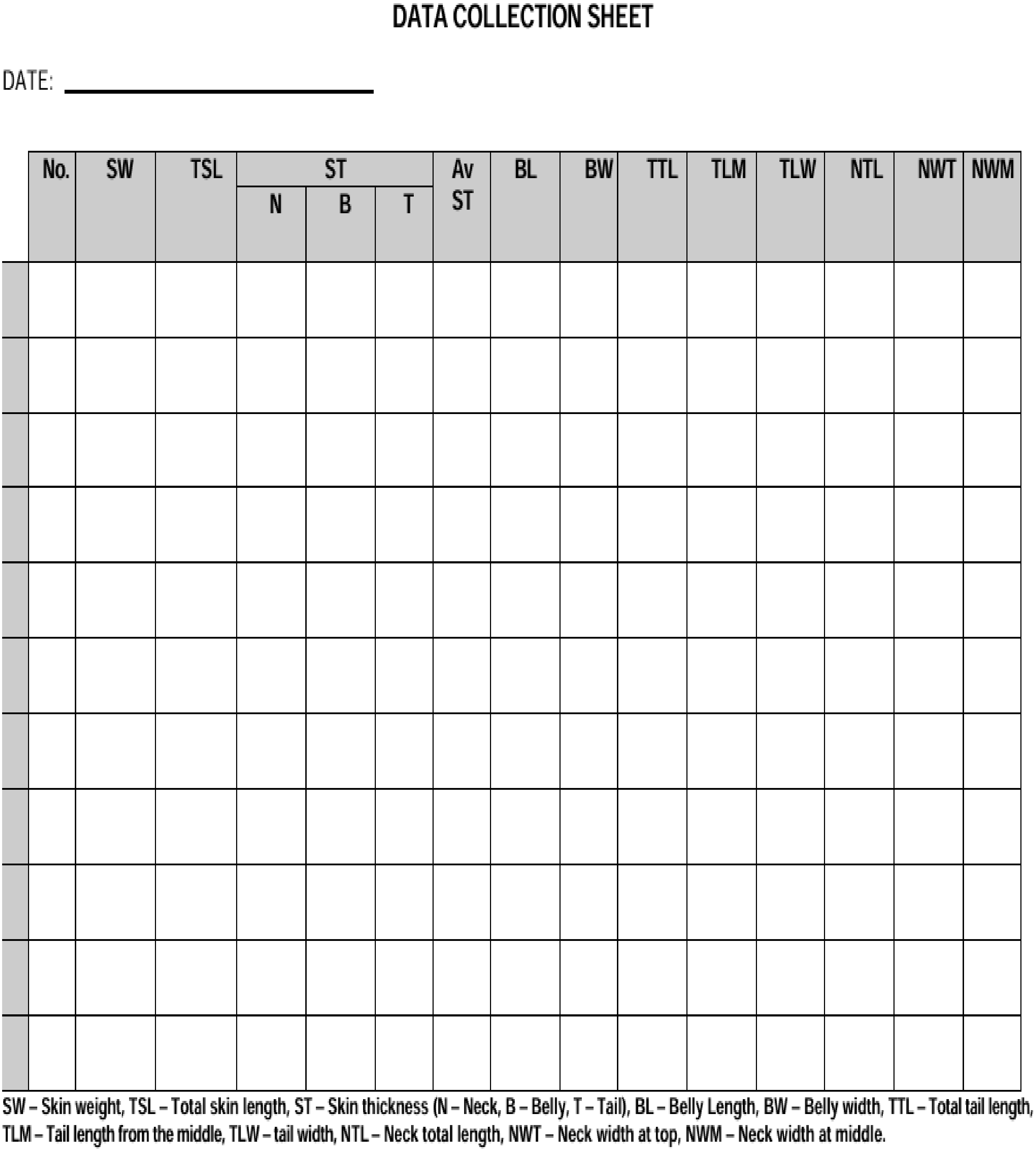
INFORMED CONSENT FORM FOR CONDUCTING A RESEARCH STUDY

I, .H.J. Pienaar................., the owner of Lalele crocodile farm give consent to Ms Rachuene P – 201832762 to conduct a study in our farm under the topic "NON-GENETIC FACTORS INFLUENCING SLAUGHTER AND SKIN TRAITS OF SOUTH AFRICAN NILE CROCODILES (*CROCODYLUS NILOTICUS CORVIEI*)" for the degree of Master of Science in Agricultural Sciences in Animal Production in the Department of Economics and Animal Production, University of Limpopo.

Henning Johannes J		14/6/23
Farm owner	Signature	Date

(Full name)

Appendix C: Data collection sheet



DATA COLLECTION SHEET

DATE: ____________________

	No.	SW	TSL	ST			Av ST	BL	BW	TTL	TLM	TLW	NTL	NWT	NWM
				N	B	T									

SW – Skin weight, TSL – Total skin length, ST – Skin thickness (N – Neck, B – Belly, T – Tail), BL – Belly Length, BW – Belly width, TTL – Total tail length, TLM – Tail length from the middle, TLW – tail width, NTL – Neck total length, NWT – Neck width at top, NWM – Neck width at middle.