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Effects of stocking density on growth and skin quality of grower Nile crocodiles *(Crocodylus niloticus)*

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Abstract

Intensive Nile crocodile *(Crocodylus niloticus)* farming operates with considerable variation in housing and stocking density. In this study, current commercial stocking densities for crocodilians were investigated using 261 grower-phase crocodiles (15 months old, average total body length 94.5 cm, and average weight 2.7 kg). Low (2.60 m^2 per crocodile), medium (1.24 m^2 per crocodile), and high (0.41 m^2 per crocodile) stocking densities were tested. Growth, morphometric measures, Fulton's condition scores and skin qualities were assessed over a six-month (May - November 2017) period. High stocking density had no adverse effects on the growth of grower Nile crocodiles. Crocodiles stocked at medium and high densities outperformed those that were stocked at low density in Fulton's body condition scores, change in body condition from the start to the end of the trial, and feed conversion efficiencies. However, the high and, to a lesser extent, the medium stocking densities resulted in lower skin quality scores compared with those in the low-density treatment because of teeth marks from more aggressive behaviour. The results indicated that the medium pen density treatment is closer to the ideal than either the high or low stocking density groups. Stocking densities that provide 0.41 m^2 per crocodile or less should be avoided because of lower skin quality scores, which weigh more heavily than growth and feed efficiency responses in the financial viability of commercial crocodile farming in typical South African production systems.

Keywords: commercial farming, exotic leather, Fulton's condition score, feed efficiency, pen density
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Introduction

Commercial crocodile farming began in South Africa in the 1970s and has become an international enterprise. Because of its relatively recent establishment, there are multiple areas for improvement and standardization of production practices in crocodile farming (Brien *et al.*, 2007). South Africa and Zimbabwe are the leading crocodile-farming countries in southern Africa (Caldwell, 2017; Beyeler, 2011). The Nile crocodile *(Crocodylus niloticus)* is common in southern Africa, and is one of 15 species of crocodile that are farmed commercially for their skins (Mpofu *et al.*, 2015; MacGregor, 2006; Bothma & Van Rooyen, 2005; Flint *et al.*, 2000). Recommendations on stocking density or space allowances for crocodiles are not widely available to farmers (Isberg *et al.*, 2003; Bothma & Van Rooyen, 2005). Hatchling and grower crocodiles raised to produce skins and meat are produced from farm-owned stock to meet the demand of international markets without pressuring wild populations (Brien *et al.*, 2007; MacGregor, 2006).

Intensive communal pens are common in the crocodile farming industry in South Africa. These pens do not allow the same opportunities for roaming and territory formation that would exist in nature (Verdade *et al.*, 2006; Isberg *et al.*, 2003), Multiple studies suggest negative relationships between stocking density and aspects of the general welfare of crocodiles that are reared in communal pens (Brien, 2015; Brien *et al.*, 2007; Bothma & Van Rooyen, 2005; Davis, 2001). Thus, their management requires special attention. Even without specific standards for stocking density in the industry, certain general requirements that must be met. These include sufficient space to rest or move, to feed and compete for feed, and to escape pen mates (Bothma & Van Rooyen, 2005). Pens are a substantial capital investment and should be designed to

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optimize the growth of young crocodiles (Bothma & Van Rooyen, 2005; Isberg *et al.*, 2003). In the absence of recognized standards, multiple studies have produced varying recommendations for stocking density of crocodilian species (Table 1).

Table 1 Summary of studies and documents that assessed stocking density for crocodilian species recommendations from them

Species	Growth phase	Recommended stocking density, m^2/animal	Reference
American alligator	< 0.6 m long	> 0.09	CFAZ (2012) as cited by Manolis & Webb (2016)
	0.6 - 1.2 m long	0.27	CFAZ (2012) as cited by Manolis & Webb (2016)
	1.2 - 1.35 m long	0.36	CFAZ (2012) as cited by Manolis & Webb (2016)
	1.35 - 1.5 m long	0.45	CFAZ (2012) as cited by Manolis & Webb (2016)
	> 1.5 m long	0.45 + 0.09 per 0.15m additional length	CFAZ (2012) as cited by Manolis & Webb (2016)
	Hatchling	0.1 (minimum)	FAO, undated
	Grower, 1 - 3 years old	≥ 0.3	FAO, undated
	Juvenile	≥ 0.18	Elsey e*t al.* (1990)
	Hatchling, <1 year old	0.3	Davis (2001)
	Juvenile, 1 - 2 years old	0.6	Davis (2001)
Broad-snouted caiman	Hatchling	0.1	Poletta *et al.* (2008)
Nile crocodile	Hatchling	> 0.07	CFAZ (2012) as cited by Manolis & Webb (2016)
	1 - 1.5 m long	0.25 - 0.5	CFAZ (2012) as cited by Manolis & Webb (2016)
	1.5 - 2 m long	0.5 - 1	CFAZ (2012) as cited by Manolis & Webb (2016)
Nile crocodile	Grower (>1 year)	0.75 - 2	SANS 631:2009 Edition 1
	Adult	≥ 10	SANS 631:2009 Edition 1
Saltwater crocodile	Hatchling	0.07 - 0.1	CFAZ (2012) as cited by Manolis & Webb (2016)
	1 m long	0.25 - 0.5	CFAZ (2012) as cited by Manolis & Webb (2016)
	2 m long	1 - 2	CFAZ (2012) as cited by Manolis & Webb (2016)

CFAZ: Crocodile Farmers Association of Zimbabwe, SANA: South African National Standard, FAO: www.fao.org/3/t0226e/t0226e14.htm

The issues to be addressed through a study of stocking densities are the lack of knowledge about stocking densities for captive Nile crocodile rearing and the potential effects of inappropriate housing and stocking density on the growth and skin quality of farmed grower Nile crocodiles. This study aimed to compare current commercial stocking densities employed in intensively farmed early grower (15 months old, average total body length (TBL) of 94.5 cm, and average weight of 2.7 kg) Nile crocodiles on a commercial crocodile farm in Gauteng, South Africa.

Materials and Methods

Ethical approval for this study was granted by the Animal Ethics Committee of the University of Pretoria (project number EC070-17). The crocodiles for the current study were all hatched on a commercial crocodile farm in northern Gauteng, South Africa. They were of similar age and were raised similarly in housing and diet before selection for the trial. The crocodiles were 15 months old at the start of the trial and selection was based on TBL. Each crocodile was microchipped (Allflex®, Somerset West, South Africa) and tagged in the first single scute of the tail with a tag coloured according to the pen to which the crocodile was assigned. The layout of the trial house was such that the 261 crocodiles were randomly allocated to eight pens (three pens each to test low and high density and two medium-density pens) of comparable size (approximately 26 m^2 each), all in the same house. The pen floors consisted of smooth concrete with a water body in the centre of each pen, which covered 26% of the pen surface area. The water depth at the centre of the ponds was 0.16 m. The house contained a walkway along the midline that overlooked the pens to allow easy access. Human presence was minimized to limit the crocodiles' stress responses as far as possible. Access to the pens was granted for feeding, cleaning, giving treatment, and collecting water samples during the trial.

The number of crocodiles assigned to the pens varied, with 10 crocodiles per pen in a low-density pen at 2.60 m^2 per crocodile, 21 in a medium-density pen at 1.24 m^2 per crocodile, and 63 in a high-density pen at 0.41 m^2 per crocodile. Growth and skin quality were assessed at the beginning and end of the trial. No measurements were recorded during the trail to avoid putting unnecessary stress on the crocodiles, which could yield antagonistic behaviours that might affect skin quality and reduce growth. The trial lasted six months (May - November 2017), of which the first month was considered an adaption period.

A thermo-hygro data logger (Kimo Instruments KH-120, ASSTech Process Electronics and Instrumentation, Randburg, South Africa) recorded hourly ambient temperatures and humidity in the trial house. The data logger faulted early in the trial and recorded continuously only from July to November 2017. Hourly temperature and humidity data for the farm for the full trial period were obtained from South African Weather Service (SAWS).

The grower diet, which comprised ground chicken and nutritional premixes (fishmeal sourced from Obaro, Pretoria), Protexin probiotic, Carmino plus, lecithin, amino acids, and calcium (sourced from Kruvet Pharmaceuticals, Pretoria), was mixed at the farm, and the same feed was fed ad libitum to all trial crocodiles, according to the farm's current schedule of Sunday, Tuesday, and Thursday feedings. Pens were cleaned on Mondays, Wednesdays and Fridays. The amounts of feed fed and of feed waste in kilograms were recorded at every feeding and cleaning. Weekly feed adjustments were made to ensure sufficient feed was supplied for each pen as the trial progressed.

Each crocodile was weighed in a crate on a standing scale. Total body length (from the tip of the snout to the tip of the tail), snout-vent length (SVL) (from the tip of the snout to the caudal surface of the cloaca) and belly width (BelW) (the width of the belly from the third button-scale of the belly on each side of the crocodile) were recorded using a tape measure.

Fulton's formula was used to calculate a body condition score for each crocodile ($K = W/L^3 \times 10^3$; where K is the condition score, W indicates weight and L indicates length) (Manolis & Webb, 2016; Mazzotti *et al.*, 2012). Feed conversion efficiency was calculated for each density group by dividing the total feed intake per density group for the full trial period by the total weight gained per density group for the full trial period.

Each crocodile skin was graded before the trial began and at the end of the trial. The types of defects, their location on the skin, and their severity were recorded. Experienced handlers assisted in the capture and subduing of the crocodiles while skin quality was being assessed. Each belly skin was wiped down with a clean dry towel before being graded and photographed (Sony DSLR α230). The grading method used was based on the grading method employed on the farm at the time of the trial. The belly was the only area that was graded for this study, unlike industry grading where the full skin is thrown over a light table for grading. This modified procedure was used because the crocodiles were alive and not yet of the size at which they would traditionally be slaughtered and their skin graded. The belly area of a crocodile skin was divided into four quadrants. Each quadrant was assessed for defects and the severity of the damage. A grade of 1 to 4 was assigned to each skin based on the quadrants assessed. For comparison, a Grade 1 skin would be nearly perfect or judged to heal to nearly perfect condition before the crocodile grew to slaughter size if no more damage were done, whereas a Grade 4 skin would have severe defects in multiple quadrants that would probably not heal before slaughter. The farm provided their trained workers, with skin grading experience, to assist with the grading and identification of the types of defects. It was unusual to perform skin grading on live crocodiles at a smaller size than regular slaughter size, but the grades were checked regularly with the criteria to ensure reliable grading.

Skin quality scores were developed to compare pre- and post-trial skin qualities, thus assessing changes in skin quality over the trial period. These scores ranged from 1 to 3, and indicated a decline in skin quality, no change in skin quality, and an improvement of skin quality. Ten skin defects were identified, namely abscesses, brown spot, double scaling, freckles, hole, infection, scratch, teeth, wrinkles, and yellowed scars. Scratches, teeth marks and brown spot were the most common defects.

The effects of density on growth characteristics and skin quality were analysed by weighted least squares analysis of variance with the number of animals in the pen used as weights (IBM SPSS Statistics, version 26, IBM Corp., Armonk, New York, USA). Differences between means were tested with Duncan's multiple range test at P =0.05. Categorical data (change in body condition and skin quality) were analysed with ordinal regression analysis employing chi-square tests. Skin quality scores were developed to compare the changes in skin quality as assessed over the trial period. These scores were calculated by comparing overall skin grades from the start (pre-trial values) to the end of the trial (post-trial values), the number of quadrants that were damaged, and the severity of the damage in each quadrant. A score of 1 at the end of the trial indicated a decline in skin quality. A score of 2 indicated no change throughout the trial, and a score of 3 indicated an improvement in skin quality over the trial. Differences between groups for ordinal and nominal data to describe skin quality were analysed by means of adjustments to compensate for the differences in number of observations between pen density treatments by chi-square analysis weighted with pen as layer, truncated cell counts and adjusted P-values using the Bonferroni method. The current study hypothesized that crocodiles kept in high-density treatments would endure more antagonistic interactions than those placed in low-density treatments, and would yield lower growth rates and diminished skin quality.

Results and Discussion

Average daily in-house temperatures increased with month of the trial from July to November and varied from 19.4 °C to 29.7 °C. Average daily in-house relative humidity (RH) showed a general decrease with month of trial and varied from 45.9% RH to 59.6% RH. When the average in-house temperature and humidity were compared over the trial, it was found that temperature increased between July and September, then plateaued between September and October and finally rose again in November. In-house RH declined from July to September, then rose and spiked in October, before finally decreasing rapidly between October and November.

Climate data from SAWS for the northern Gauteng region indicated maximum daily external temperatures from 12.4 °C to 37.6 °C, and minimum external temperatures ranging from -2.6 °C to 20.5 °C. Maximum daily external humidity varied from 46% RH to 98% RH, and minimum external humidity ranged from 6% RH to 74% RH. When average temperature and humidity for the region over the months of the trial were compared it was found that external temperatures dipped slightly between May and June, plateaued between June and July, then increased from July to September; after which they plateaued until October, and finally increased again between October and November. Comparisons of RH over the months of the trial indicated that it remained relatively constant from May to June, declined between June and late July, plateaued in August, increased again between September and October, and finally decreased between October and November. The increase in temperatures and a decrease in RH throughout the trial were typical of the region. The in-house temperatures tended to be higher than the external temperatures recorded by the SAWS, especially towards the end of the trial.

Feed intake for all crocodile treatment densities showed an almost exponential increase over the trial period as the crocodiles grew. Crocodiles in the low- and medium-density pens ate more feed per crocodile (P <0.05) than those in the high-density pens throughout the trial (not including the adaption period). Figure 1 summarizes the average feed intakes of crocodiles in varying density pens for each month. The increasing intakes were expected with the increases in environmental temperatures and growth of the crocodiles. The crocodiles consumed more feed as the trial progressed, as they became more comfortable and adapted to their new housing. Previous studies confirmed that feed intake and growth are positively correlated (Blessing *et al.*, 2014; Tosun, 2013; Brien *et al.*, 2007; Davis, 2001).

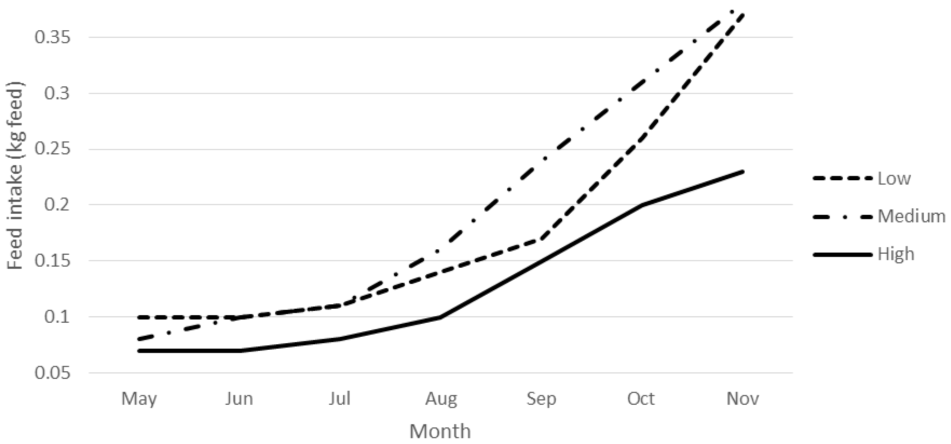

Figure 1 Mean feed intake per crocodile for low-, medium- and high-density groups in the trial house

The higher feed intakes in the low- and medium-density pens compared with the high-density pens are interesting. An explanation could be that fewer crocodiles in those pens were competing for feed, yielding lower instances of antagonistic interactions to impede feed intake. The explanation for lower intakes in the high-density pens may be similar to those of previous studies (Brien, 2015; Bothma & Van Rooyen, 2005; Davis, 2001), which reported that a dominant crocodile could hinder or discourage pen mates from feeding. Similarly, antagonistic interactions associated with many crocodiles feeding in one pen might discourage the feeding of certain individuals or extend feeding opportunities where crocodiles could return to the feed site unhindered. Crocodiles were randomly allocated to the experimental treatment groups based on their TBL, which is the normal practice in commercial production systems. It follows that TBL, SVL, BelW, and bodyweights did not differ significantly between treatment groups when the trial commenced (Table 2). Total body length, SVL, weight and Fulton's condition scores in all groups increased from the start (pre-trial) to the end (post-trial values). Belly width was the only variable that showed a decrease when pre- and post-trial values were compared. This suggests that as the crocodiles grew in length and weight, their belly widths decreased, yielding longer but narrower crocodiles.

Neither body length (TBL and SVL) nor bodyweight differed significantly between crocodiles in the groups at the end of the trial (Table 2). Crocodiles in the medium- and high-density groups gained more weight numerically than those in the low-density groups, but the differences were not statistically significant. Fulton's body condition scores were based on their total body length (Fulton's-TBL) or on their snout-vent length (Fulton's-SVL), because of the known problems associated with tail biting and possible decrease in TBL, which may yield less accurate results. This was evident from the greater effect sizes for body condition scores based on SVL than those based on TBL. Crocodile pen density influenced Fulton's body condition scores of crocodiles (P <0.05). The crocodiles in the low-density treatment groups exhibited lower (P <0.05) condition scores for both Fulton's-TBL and Fulton's-SVL post-trial, compared with those in the medium- and high-density groups. Crocodiles in the medium-density groups exhibited numerically higher, but not statistically different scores post-trial, compared with those in the high-density treatments for both Fulton's-TBL and Fulton's-SVL scores. Crocodiles in both medium- and high-density groups showed improvements in their body condition scores, with Fulton's-TBL difference during the trial indicating a tendency to improve (P =0.065), whereas Fulton's-SVL showed an improvement in body condition from pre-trial to post-trial assessment (P <0.05). These results indicated that crocodiles in the low-density treatments were less adapted and less comfortable in their pens, causing a loss in body condition.

The measure that is most important to skin quality, namely BelW, did not differ significantly between these stocking densities, indicating that none of the pen densities that were evaluated had significant adverse effects on the growth of crocodiles. However, the findings indicated that crocodiles stocked at the lowest density reflected husbandry conditions that were not conducive to high improvements in body condition scores compared with those crocodiles in the medium- and high-density treatments.

Previous studies on crocodilians reported a negative relationship between stocking density and growth (Brien, 2015; Bothma & Van Rooyen, 2005; Davis, 2001). Poletta *et al.* (2008) conducted a study with broad-snouted caiman hatchlings housed at varying densities and found that growth at low- and medium-densities was superior to that of the high-density group. Elsey *et al.* (1990) studied juvenile American alligators and found that the alligators stocked at the highest (0.09 m^2/juvenile) density had inhibited growth and elevated plasma corticosterone concentrations, whereas the alligators stocked at the lowest (0.35 m^2/juvenile) density grew heavier and faster (*P* <0.01) with lower plasma corticosterone concentrations. But those findings are not directly comparable with the current study. Although they assessed the effects of density, they used hatchling broad-snouted caimans and juvenile American alligators instead of grower Nile crocodiles.

Table 2 Effects of density on growth traits of Nile crocodiles at a commercial farm in South Africa

Measurement	Stock density treatment			Significance	
	Low, n = 29	Medium, n = 42	High, n = 174	*P*-value	Effect size[1]
TBL pre-trial, cm	93.75 ± 1.174	93.93 ± 0.941	94.56 ± 0.472	0.740	0.002
TBL post-trial, cm	103.39 ± 1.482	105.52 ± 1.373	104.78 ± 0.687	0.613	0.004
SVL pre-trial, cm	47.35 ± 0.568	48.02 ± 0.512	48.57 ± 0.231	0.144	0.016
SVL post-trial, cm	51.17 ± 0.730	51.66 ± 0.639	51.67 ± 0.330	0.751	0.002
BelW pre-trial, cm	20.90 ± 0.279	20.98 ± 0.266	20.99 ± 0.142	0.897	0.001
BelW post-trial, cm	19.66 ± 0.385	20.46 ± 0.364	20.37 ± 0.191	0.421	0.007
Weight pre-trial, kg	2.60 ± 0.090	2.71 ± 0.081	2.74 ± 0.040	0.229	0.012
Weight post-trial, kg	3.51 ± 0.167	4.06 ± 0.219	3.95 ± 0.084	0.138	0.016
Weight difference, kg	0.94 ± 0.130	1.35 ± 0.177	1.20 ± 0.053	0.263	0.011
Fulton's-TBL pre-trial	0.307 ± 0.007	0.325 ± 0.006	0.323 ± 0.003	0.098	0.019
Fulton's-TBL post-trial	0.312[a] ± 0.007	0.338[b] ± 0.009	0.336[b] ± 0.003	0.038	0.027
Fulton's-TBL difference	0.003 ± 0.005	0.012 ± 0.009	0.014 ± 0.002	0.065	0.022
Fulton's-SVL pre-trial	2.38 ± 0.047	2.43 ± 0.037	2.37 ± 0.017	0.396	0.008
Fulton's-SVL post-trial	2.58[a] ± 0.053	2.86[b] ± 0.066	2.79[b] ± 0.022	0.004	0.045
Fulton's-SVL difference	0.19[a] ± 0.062	0.43[b] ± 0.077	0.43[b] ± 0.022	0.004	0.044

TBL: total body length, SVL: snout to vent length, BelW: belly width, Fulton's-TBL: Fulton's condition score calculated using total body length, Fulton's-SNV: Fulton's condition score calculated using snout to vent length
[1] the amount of variation explained by the treatments relative to the total variation in the measurement
[a,b] Within a row, means with a common superscript were not different with probability *P* =0.05

The findings of the current study indicated that crocodiles in the low-density treatments did not gain body condition as efficiently as their medium- and high-density counterparts (*P* <0.05). A possible explanation might be that crocodiles in low-density treatments were less active than those in medium- and high-density treatments, which may have reduced their need to interact with pen mates and compete for feed. Alternatively, the lower number of crocodiles in the low-density treatment groups may have allowed a more stringent hierarchy, where one or more crocodiles dominated the rest, causing stress and adversely affecting their feed intakes and growth. Feed conversion efficiency (FCE) calculations (Table 3) indicated that crocodiles in the high-density treatments outperformed those in medium and low-density treatments. Overall, the growth and feed conversion efficiency results indicated that crocodiles in medium- and high-density treatments had numerically better feed conversion efficiencies and grew better in terms of weight gain and Fulton's condition scores, followed by crocodiles in the low-density treatments. The results (Table 3) indicated that crocodiles in the high-density treatments were the most efficient, followed by crocodiles in the medium-density treatments, and finally those in low-density treatments. In a practical sense, it follows that crocodiles in high-density treatments were the most productive, with more crocodiles per farming area, lower feed intakes and therefore lower feed costs, high feed efficiency without significant adverse effects on growth parameters compared with those of crocodiles in the medium- and low-density treatments.

Table 3 Feed conversion for grower Nile crocodiles kept in low-, medium-, and high-density groups for six months

Density group	Feed intake, kg	Weight gain, kg	Feed conversion	Δ Body condition (% improvement)
Low	381.8	27.3	14.00	43.0[a]
Medium	606.1	56.7	10.70	61.9[b]
High	1705.8	209.7	8.13	61.0[b]

Δ: change
[a,b] Within a row, means with a common superscript were not different with probability *P* = 0.05

Skin quality scores, skin quality defects, the number of quadrants that were damaged, and the severity of damage in each quadrant are presented in Table 4. These indicated significant differences–among treatments in skin quality (P <0.05). Although there were greater proportions of skin quality scores 2 and 3 in all three groups, crocodiles in the low-density groups had a higher proportion of improved scores (e.g. score = 3) compared with those in the medium- and high-density groups (P <0.05). Three defects appeared most often, namely scratches, teeth marks and holes. Scratching was observed in all three groups at the end of the trial, and comprised between 86% and 96% of all defects. Scratching is common, since grower Nile crocodiles habitually climb over each other, and pile. Interestingly, crocodiles in the low-density groups recorded more scratches, but no visible teeth marks, whereas those in the medium- and high-density treatment groups had more teeth marks (P <0.05). The teeth marks indicated more aggressive behaviour in the high-density (4.8%) groups and to a lesser extent in the medium-density (1.8%). No double scaling was observed in the present study, but a few brown spots were observed in crocodiles in the high-density treatment groups and a few yellow scars were noted in all three groups. The crocodiles in the low-density groups had a higher proportion of skin quadrants that were not severely damaged, compared with those in the medium- and high-density groups (P <0.05). Crocodiles in the medium- and high-density groups also had more severe damage in at least one quadrant, compared with those in the low-density group (P <0.05).

Table 4 Effects of crocodile pen-density on the frequency of various skin quality scores grower Nile crocodiles

Skin quality variable	Description	Pen density		
		Low	Medium	High
Skin quality score	Decreased (Score 1)	19.7	15.6	14.1
	No change (Score 2)	59.8[a]	74.9[b]	74.0[b]
	Improved (Score 3)	20.5[a]	9.6[b]	11.8[b]
Defects	Brown spots	0.0	0.0	0.4
	Hole	1.7	1.2	4.4
	Scratches	94.0[ab]	95.8[a]	86.9[b]
	Teeth marks	0.0[a]	1.8[ab]	4.8[b]
	Yellow scars	1.7	0.6	1.1
Severity of defects	Not severe	76.9	73.7	75.2
	Severe	22.2	25.7	22.7
Number of severely damaged quadrants	0	20.5[a]	9.6[b]	10.9[b]
	1	63.2[a]	74.9[ab]	74.1[b]
	2	16.2	15.6	15.0

[a,b] Within a row, frequencies with a common superscript were not different with probability *P* =0.05

The current study hypothesized that higher density treatments will result in poorer skin quality, which was mostly confirmed by the current data. The present results confirm that increasing pen density affected the skin quality of crocodiles adversely. The observation of increasing frequency of teeth marks in higher density treatments confirmed more aggressive behaviour at higher stocking densities. This is a cause of concern to crocodile farmers because of the lower skin grades and financial losses associated with high stocking densities. Previous studies concurred that poor housing, inappropriate pen designs, and immoderate stocking densities caused lower skin grades because of the increased potential for antagonistic interactions (Brien, 2015; Mpofu *et al.*, 2015; Bothma & Van Rooyen, 2005; Isberg *et al.*, 2003; Davis, 2001). Although the stocking density did not affect growth adversely, and higher densities improved feed efficiency, the skin quality data indicated that crocodile farmers should be wary of increasing stocking densities of grower Nile crocodiles to ≤ 0.41 m^2 per crocodile, since the real value of these animals depends greatly on their skin quality.

Conclusions

Stocking Nile crocodiles at a density of 1.24 m^2 per crocodile is closer to the ideal than providing 0.41 m^2 or 2.60 m^2 per crocodile. Stocking densities that provide more than 1.24 m^2 per crocodile should be avoided because of lower skin quality scores, which have greater effects than growth and feed efficiency on the financial viability of commercial crocodile farming in typical South African production systems.

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Authors' Contributions

This study was conducted for the fulfilment of the requirements of an MSc. Agric. study by DV (Veldsman, 2019), with guidance and supervision being provided by ECW, JGM and GES. The manuscript and statistics were edited and revised by ECW.

Conflict of Interest Declaration

The authors declare that they have no conflicts of interest in this work.

References

Beyeler, P.M., 2011. Protein requirements of juvenile Nile crocodiles *(Crocodylus niloticus)* in an intensive production system. Master's dissertation, University of Pretoria, Pretoria, South Africa.

Blessing, M., Tendayi, N., Wilson, M., Lesley, M., Evermess, S., Chiedza, M. & Zacharia, I., 2014. Effect of feeding different graded dietary protein levels on growth rate of Nile crocodile *(Crocodylus niloticus)* hatchlings. Int. J. Sci., Technol. & Management 3 (12), 123-128.

Bothma, J.D.P. & Van Rooyen, N. (eds), 2005. Intensive wildlife production in Southern Africa. Van Schaik, Pretoria, South Africa. ISBN 0627025498.

Brien, M.L., 2015. Growth and survival of hatchling saltwater crocodiles (*Crocodylus porosus*) in captivity: the role of agonistic and thermal behaviour. Doctoral dissertation, Charles Darwin University. Casuarina, Australia.

Brien, M.L., Cherkiss, M.S., Parry, M.W. & Mazzotti, F.J., 2007. Housing crocodilians in captivity: Considerations for Central America and Caribbean. University of Florida Institute of Food and Agricultural Sciences, Gainesville. https://edis.ifas.ufl.edu/pdffiles/uw/uw25500.pdf

Brien, M.L., Webb, G.J., McGuinness, K. & Christian, K.A., 2014. The relationship between early growth and survival of hatchling saltwater crocodiles (*Crocodylus porosus*) in captivity. PloS One 9(6), e100276. https://doi.org/10.1371/journal.pone.0100276

Caldwell, J., 2017. World trade in crocodilian skins, 2013-2015. United Nations Environment Programme – World Conservation Monitoring Centre Report (UNEP-WCMC).

Davis, B.M., 2001. Improved nutrition and management of farmed crocodiles: Hatching to harvest. Rural Industries Research and Development Corporation. Project (01/123), 102. ISBN 0642583455.

Elsey, R.M., Joanen, T., McNease, L. & Lance, V., 1990. Growth rate and plasma corticosterone levels in juvenile alligators maintained at different stocking densities. J. Exp. Zool. 255(1), 30-36. https://doi.org/10.1002/jez.1402550106

Flint, N.S., Van der Bank, F.H. & Grobler, J.P., 2000. A lack of genetic variation in commercially bred Nile crocodiles *(Crocodylus niloticus)* in the North-West Province of South Africa. Water SA 26(1), 105-110.

Food and Agriculture Organisation (FAO). Captive breeding and management of adult crocodiles www.fao.org/3/t0226e/t0226e14.htm

Groffen, J., Parmentier, H.K., Van de Ven, W.A.C. & Van Weerd, M., 2013. Effects of different rearing strategies and ages on levels of natural antibodies in saliva of the Philippine crocodile. Herpetological Res. 4(1), 22-27. DOI: 10.3724/SP.J.1245.2013.00022

Huchzermeyer, F.W., 2003. Crocodiles: Biology, husbandry and diseases. CABI. ISBN 0851996566.

Isberg, S.R., Nicholas, F.W., Thomson, P.C., Barker, S.G., Manolis, S.C. & Moran, C., 2003. Defining breeding objectives for saltwater crocodile genetic improvement programs. Proceedings of the Association for the Advancement of Animal Breeding and Genetics 15, 166-169.

Isberg, S.R., 2007. Nutrition of juvenile saltwater crocodiles *(Crocodylus porosus)* in commercial production systems. Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources 2(91), 1-11. DOI: 10.1079/PAVSNNR20072091

IUCN-SSC Crocodile Specialist Group (CSG). Farming and the crocodile industry. http://www.iucncsg.org/pages/Farming-and-the-Crocodile-Industry.html

IUCN-SSC Crocodile Specialist Group (CSG). Temperature regulation. http://www.iucncsg.org/pages/Temperature-Regulation.html

MacGregor, J., 2006. The call of the wild: Captive crocodilian production and the shaping of conservation incentives. TRAFFIC International, Cambridge, UK. ISBN 1858502209.

Manolis, S.C. & Webb, G.J.W., 2016. Best management practices for crocodilian farming. Version 1. IUCN-SSC Crocodile Specialist Group, Darwin, Australia.

Mazzotti, F.J., Cherkiss, M.S., Brandt, L.A., Fujisaki, I., Hart, K., Jeffery, B., McMurry, S.T., Platt, S.G., Rainwater, T.R. & Vinci, J., 2012. Body condition of Morelet's crocodiles *(Crocodylus moreletii)* from northern Belize. J. Herpetol. 46(3), 356-362 .DOI: 10.1670/11-188

Moleón, M.S., Parachú Marcó, M.V., Pietrobon, E.O., Jahn, G.A., Beldomenico, P.M. & Siroski, P.A., 2018. Corticosterone levels and immunological indices in stressed juvenile broad-snouted caimans. J. Zool, 304(3), 151-158. DOI: 10.1111/jzo.12513

Mpofu, C.N.B., Mhlanga, M. & Moyo, N., 2015. Pond type and pre-tanning processes affects size and quality of captive Nile crocodile skins. Agric. Advances 4(4), 42-48.

Poletta, G.L., Larriera, A. & Siroski, P.A., 2008. Broad snouted caiman (*Caiman latirostris*) growth under different rearing densities. Aquaculture 280(1), 264-266. https://doi.org/10.1016/j.aquaculture.2008.04.032

Rojé Exotics American Leathers. Crocodile skin grading. http://www.rojeleather.com/crocodile-skin-grading/

Shilton, C., Brown, G.P., Chambers, L., Benedict, S., Davis, S., Aumann, S. & Isberg, S.R., 2014. Pathology of runting in farmed saltwater crocodiles *(Crocodylus porosus)* in Australia. Vet. Pathol. 51(5), 1022-1034. DOI: 10.1177/0300985813516642

Tosun, D.D., 2013. Crocodile farming and its present state in global Aquaculture. J. Fisheries Sci. 7(1), 43-57. DOI: 10.3153/jfscom.2013005

Verdade, L.M., Pina, C.I. & Araújo, J.L., 2006. Diurnal use of space by captive adult broad-snouted caiman *(Caiman latirostris):* Implications for pen design. Aquaculture 251(2), 333-339. DOI: 10.1016/j.aquaculture.2005.06.030