CHAPTER 51

The Effects of Egg Incubation Temperature on Post-Hatching Growth of American Alligators

Ted Joanen[1], Larry McNease[1] and Mark W. J. Ferguson[2]

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INFORMATION on incubation techniques for crocodilian eggs has been provided by Pooley (1971), Yangprapakorn *et al.* (1971), Blake and Loveridge (1975), Joanen and McNease (1976), Chabreck (1978), Whitaker (1979), Ferguson (1981), and De Vos (1982). Hatchlings produced by these techniques have varied considerably in growth and survivorship, and most researchers report a percentage of animals which are noticeably inferior to others (Pooley 1971; Yangprapakorn *et al.* 1971; Whitaker and Whitaker 1977; Joanen and McNease 1977; De Vos 1982; Webb *et al.* 1983). Growth rates have also been reported to vary with stocking rates, "grow-out" temperatures, hygiene and diet.

Recent studies have demonstrated that embryonic growth and sex determination of *Alligator mississippiensis* are affected by incubation temperature (Ferguson and Joanen 1982, 1983). Exclusively females hatch from eggs incubated at 86°F (30°C), and they weigh significantly more than the exclusively males that hatch from eggs incubated at 93°F (33.9°C). This weight difference is a consequence of the females having more abdominal yolk than the males (Ferguson and Joanen 1982, 1983).

Only a few studies have reported on the post-hatching growth of alligators from artificially incubated eggs collected very soon after being laid (Joanen and McNease 1977, 1981a), and in these, only a single incubation temperature (85°F; 29.4°C) was used. The study reported here evaluates the effects of four different incubation temperatures on hatching success, size at hatching, survival, sex determination and growth of alligators to 18 months of age. It was carried out at Rockefeller Refuge, Louisiana.

METHODS

Alligator mississippiensis eggs were collected from eleven nests on Rockefeller Refuge. Each egg was marked to maintain egg orientation, packed in nesting media and transported to the laboratory on June 21, 1981. Ferguson's (1981) opaque banding procedure was used to both identify infertile eggs (which were discarded) and to age fertile eggs, which were set in incubators and incubated through to hatching using the techniques described by Joanen and McNease (1977).

A total of 357 fertile eggs were incubated at four different temperatures; 91°F (32.8°C), 89°F (31.7°C), 87°F (30.6°C) and 85°F (29.4°C). Eggs from each clutch were mixed and randomly allocated to the four temperature treatments, and all eggs were less that seven days old (mostly 1-3 days) when artificial incubation started.

At hatching, each individual was weighed (BWT) to the nearest 0.1 g and had its total length (TL) measured to the nearest millimetre. For individual identification, two serially numbered web tags were attached to each animal. All animals were measured and weighed each three months until the eighteenth month of study.

Alligators were raised in controlled environment chambers at 86°F (30°C) and were fed a mixture of ground nutria and vitamin premix (McNease and Joanen 1981b). All alligators, regardless of hatching temperature, were raised under identical conditions. Excess food was always provided so that all animals had an adequate opportunity to eat. Feeding schedules, cleaning procedures and stocking rates were as described by Joanen and McNease (1976) [see Joanen and McNease Chapter 32]. After eighteen months, all animals were sexed by inserting a nasal speculum into the cloaca and viewing the morphology of the clitoris or penis.

The results were analyzed by the Department of Experimental Statistics at Louisiana State University, utilizing the General Linear Models Procedure in SAS. ANOVAs were performed on length and weight using the main effects of treatment and sex, and

[1]Louisiana Department of Wildlife and Fisheries, Grand Chenier, Louisiana 70643, USA.
[2]Turner Dental School, University of Manchester, Higher Cambridge Street, Manchester, M15 6FH, England.
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various interactions where appropriate. A t-test was used for comparing means and regression line slopes where appropriate.

RESULTS

Of the 357 fertile eggs incubated, 289 (81.0%) hatched. Hatching success between the four temperature treatments ranged from 76.2% to 83.0% (mean of all eggs = 81.0%) (Table 1). Incubation temperatures had a profound effect on the sex ratios (Table 1; $F = 228.04$, $p < 0.01$), as was found previously (Ferguson and Joanen 1982, 1983).

Total incubation time varied inversely with incubation temperature: 91°F (32.8°C), 66 days; 89°F (31.7°C), 69 days; 87°F (30.6°C), 72 days; and, 85°F (29.4°C), 74 days. Likewise, the range in days between first and last pipping for all eggs hatched at any one temperature was inversely proportional to incubation temperature: 91°F (32.8°C), 6 days; 89°F (31.7°C), 9 days; 87°F (30.6°C), 9 days; and, 85°F (29.4°C), 14 days.

The mean size of hatchlings produced from different incubation temperatures did not vary greatly (Table 2). Mean TL showed no consistent relationship with temperature, but mean BWTs were slightly greater at the highest and lowest incubation temperatures, and the ratios of BWT:TL indicated this was reflecting a tendency for hatchlings to be slightly heavier per unit length at the two extreme temperatures.

Total survival through the first seven days was 96.9% per treatment, with all losses being restricted to the lowest (85°F; 29.4°C) and highest (91°F; 32.8°C) incubation temperatures (Table 1). Survival from hatching to the end of the study, eighteen months later, was only marginally less (95.8%; Table 1).

Table 1. The hatching success, sex ratio and post-hatching survival for 357 fertile *Alligator mississipiensis* eggs, from 11 clutches, that were used to quantify the relationship between egg incubation temperature and post-hatching growth and survival. Numbers in brackets are totals and percentages of totals.

Temperature °F (°C)	No. of Eggs	% Hatch	% Males	% Survival to 7 days	% Survival to 18 months
91 (32.8)	135	83.0	99.1	97.3	96.4
89 (31.7)	67	82.1	74.5	100	98.2
87 (30.6)	42	76.2	40.6	100	100
85 (29.4)	113	79.6	0.0	93.3	92.2
	(357)	(81.0)		(96.9)	(95.8)

Table 2. The relationship between hatchling size (total length and body weight) and incubation temperature for *Alligator mississippiensis* used in the growth experiments. Ratio W/L refers to the mean weight divided by the mean length.

Incubation Temperature °F (°C)	Sex	Length (mm) Mean	Length (mm) Range	Weight (g) Mean	Weight (g) Range	Ratio W/L
91 (32.8)	Males	239.3	211-261	48.2	38-59	0.201
89 (31.7)	Males	243.4	218-260	44.1	33-53	0.181
89 (31.7)	Females	236.7	223-256	41.5	34-50	0.175
87 (30.6)	Males	238.2	219-252	42.5	37-50	0.178
87 (30.6)	Females	237.3	214-254	43.6	35-50	0.183
85 (29.4)	Females	239.4	205-264	46.3	32-59	0.193

Table 3. Mean bodyweights (BWT; g) and total lengths (TL; mm) (with 1 SE) of *Alligator mississippiensis* hatchlings after incubation at different temperatures, at hatching, after 12 months and after 18 months.

Temperature			At hatching					12 months of age					18 months of age				
°F	(°C)	Sex	N	BWT	SE	TL	SE	N	BWT	SE	TL	SE	N	BWT	SE	TL	SE
85	(29.4)	F	80	46.3	0.7	239.4	1.6	80	2369.6	98.7	933.3	10.6	80	4205.4	152.4	1035.8	13.2
87	(30.6)	M	13	42.5	1.0	238.2	2.9	13	3448.6	162.4	1036.5	12.3	13	4679.9	241.5	1127.3	16.4
87	(30.6)	F	19	43.6	1.3	237.3	2.8	19	3469.4	205.8	1024.0	16.7	19	5191.4	382.3	1129.0	23.1
89	(31.7)	M	38	44.1	0.8	243.4	1.7	37	3474.2	130.6	1041.8	11.4	37	5545.4	246.3	1181.8	15.9
89	(31.7)	F	13	41.5	1.4	236.7	2.9	13	2992.5	196.2	998.1	19.0	13	4680.0	353.6	1100.7	36.1
91	(32.8)	M	106	48.2	0.5	239.4	1.2	106	2694.2	101.8	960.5	9.7	106	4451.4	140.9	1070.5	12.1

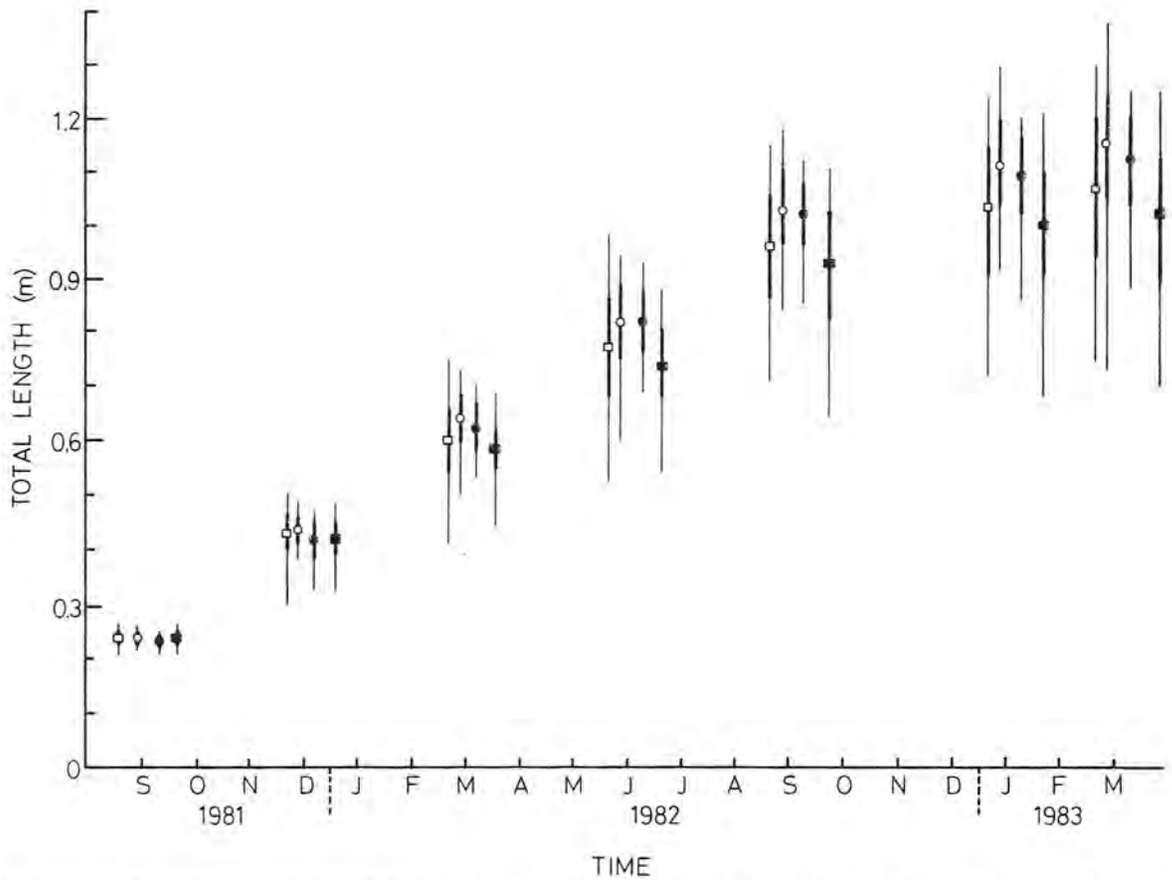

Fig. 1. The relationship between total length, egg incubation temperature and time for *Alligator mississippiensis* raised under identical conditions. Sexes are combined, and data are means, standard deviations and ranges for incubation temperatures of: 91°F (32.8°C) (open squares); 89°F (31.7°C) (open circles); 87°F (30.6°C) (closed circles); and 85°F (29.4°C) (closed squares). Sample sizes decreased marginally through the time period.

Although there was considerable variation in the size of individuals from all incubation temperatures over time (Fig. 1), the effect of incubation temperature on final size (Figs 2 and 3; Table 3) was highly significant [TL ($F = 12.31$, $p < 0.01$); BWT ($F = 6.92$, $p < 0.01$)].

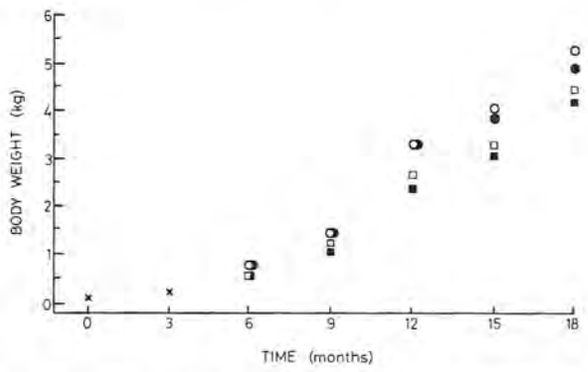

Fig. 2. The relationship between mean body weight, egg incubation temperature and time for *Alligator mississippiensis* raised under identical conditions. Sexes are combined, and data are for incubation temperatures of: 91°F (32.8°C) (open squares); 89°F (31.7°C) (open circles); 87°F (30.6°C) (closed circles); and 85°F (29.4°C) (closed squares). The crosses signify where weights for all incubation temperatures overlap.

Alligators incubated at 89°F (31.7°C) attained the largest sizes (mean = 1.16 m TL; 5.32 kg BWT), and were followed by those incubated at 87°F (30.6°C) (1.13 m TL; 4.98 kg BWT); differences between the two were not significant. The poorest growth was

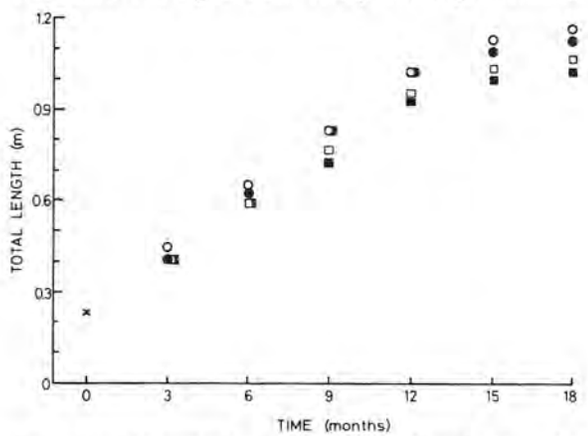

Fig. 3. The relationship between mean total length, egg incubation temperature and time for *Alligator mississippiensis* raised under identical conditions. Sexes are combined, and data are for incubation temperatures of: 91°F (32.8°C) (open squares); 89°F (31.7°C) (open circles); 87°F (30.6°C) (closed circles); and, 85°F (29.4°C) (closed squares). The cross signifies where total lengths for all incubation temperatures overlap.

exhibited by animals from the two extreme temperatures [91°F (32.8°C) and 85°F (29.4°C)] and the differences between them were not significant. When the two "good" and two "poor" incubation temperature treatments were each pooled, the differences between the two were significant for both TL ($F = 15.49$, $p < 0.01$) and BWT ($F = 7.94$, $p < 0.01$).

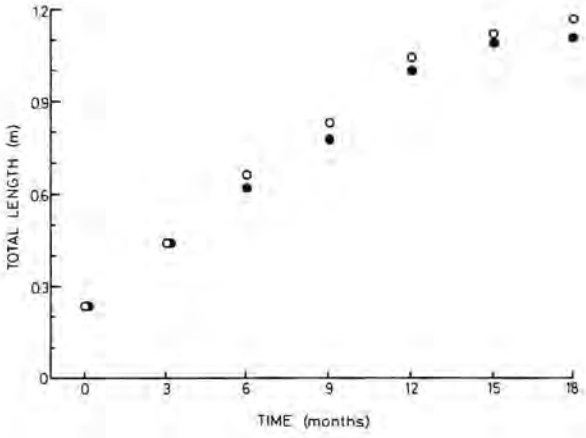

Fig. 4. The relationship between mean total length and time for male (open circles) and female (closed circles) *Alligator mississippiensis* incubated at 89°F (31.7°C) and raised under identical conditions.

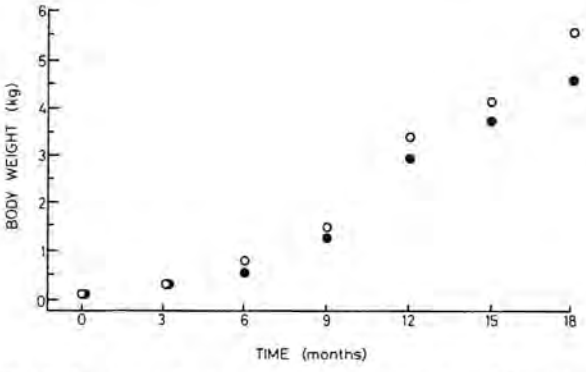

Fig. 5. The relationship between mean body weight and time for male (open circles) and female (closed circles) *Alligator mississippiensis* incubated at 89°F (31.7°C) and raised under identical conditions.

Within the data for the better growing animals [89°F (31.7°C) and 87°F (30.6°C)], there were both males and females at each temperature (Table 1). Analysis of incubation temperature treatments and sex on TL and BWT after 18 months revealed a signficant difference attributable to sex for TL ($F = 2.90$, $p < 0.04$), but not for BWT ($F = 1.80$, $p > 0.14$). At 89°F (31.7°C), the males grew faster than the females and attained larger sizes in both TL (Fig. 4) and BWT (Fig. 5), and at 87°F (30.7°C), there were marginal differences between the sexes in TL (Fig. 6), and the females exceeded the males in BWT (Fig. 7). These differences match the sex ratio bias at both temperatures; males predominated at 89°F (31.7°C) and females at 87°F (30.6°C) (Table 1).

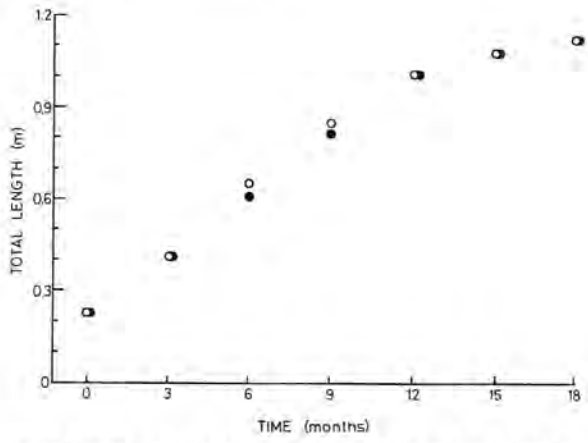

Fig. 6. The relationship between mean total length and time for male (open circles) and female (closed circles) *Alligator mississippiensis* incubated at 87°F (30.6°C) and raised under identical conditions.

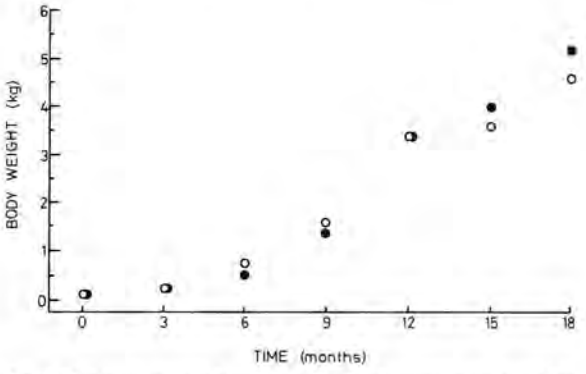

Fig. 7. The relationship between mean body weight and time for male (open circles) and female (closed circles) *Alligator mississippiensis* incubated at 87°F (30.6°C) and raised under identical conditions.

Within these same two incubation treatments, males incubated at 89°F (31.7°C) attained a mean size of 1.18 m TL and 5.54 kg BWT, which was higher than the mean for females incubated at 87°F (30.6°C) (1.13 m TL and 5.19 kg BWT) (Table 3). However, the females from 87°F (30.6°C) incubation were larger than the females from 89°F (31.7°C) incubation (Figs 4 to 7; Table 3).

Table 4. The percentage of "runt" *Alligator mississippiensis* after eighteen months raising, as a function of incubation temperature. The size limits for runts were determined from the bottom 10% of animals at the incubation temperature that gave the best growth [89°F (31.7°C)].

Incubation Temp. °F (°C)	Percent by Length	Percent by Weight
91 (32.8)	46	37
89 (31.7)	10	10
87 (30.6)	23	22
85 (29.4)	57	39

After eighteen months, there was considerable variation between the largest and smallest animals from all treatments (Fig. 1). To determine the extent to which "inferior" or "runt" animals could be

attributed to incubation temperature, the TL and BWT which bounded the smallest 10% of animals within the best treatment [89°F (31.7°C)] was delineated, and the proportion below this line was determined for each of the other three treatments (Table 4). These results are consistent with those discussed above, in that the percentage of runts is appreciably greater in the two extreme temperatures. However, it also indicates that although no significant difference in mean size occurred between the animals incubated at 89°F (31.7°C) and 87°F (30.6°C), there were twice as many runts from 87°F (30.6°C) incubation as there were from 89°F (31.7°C) incubation.

DISCUSSION

The growth rates and survivorship reported for *Alligator mississippiensis* from all treatments within this study are comparable to those reported previously by Coulson *et al.* (1973) and Joanen and McNease (1976) for animals raised in controlled environmental chambers.

Incubation temperature was inversely proportional to both the total mean incubation time, and the range of incubation times at any one temperature. It did not greatly influence hatchling length, but the highest and lowest temperatures produced hatchlings that were slightly heavier than those from the middle temperatures.

The study demonstrates that 89°F (31.7°C) and 87°F (30.6°C) incubation produces hatchlings that are marginally lighter than those produced at 91°F (32.7°C) and 85°F (29.4°C), but which nevertheless survive better as both embryos and hatchlings, grow faster, attain larger mean sizes and have a smaller proportion of runts.

Incubation at 89°F (31.7°C) results in a high male:female sex ratio and the least number of runts of any temperature treatment tested. The males produced at this temperature grew faster and attained larger sizes than any other sex-temperature combination. Incubation at 87°F (30.6°C) produced a high female:male sex ratio and the largest females of any treatment, although they were not as large as the 89°F (31.7°C) males; furthermore, incubation at 87°F (30.6°C) resulted in twice the number of runts as did incubation at 89°F (31.7°C).

Incubation at 85°F (29.4°C) produced heavy hatchlings which were all females, but they had slow growth rates and about five times the number of runts as did incubation at 89°F (31.7°C). Similarly, incubation at 91°F (32.7°C) produced the heaviest hatchlings, which were all males, and which grew slowly and had around four times the number of runts as animals incubated at 89°F (31.7°C).

Taken together, the results indicate that incubation temperature can have a profound effect on the post-hatching growth of *Alligator mississippiensis*, which would not be apparent from hatchling dimensions alone. Given that similar relationships probably occur with other species of crocodilians, incubation at "optimal" temperatures should improve production on crocodile and alligator farms. Although not discussed here, the relationship between incubation temperature and post-hatchling growth opens a number of avenues through which temperature-dependent sex determination could function to assign sexes to the embryos most likely to benefit from enhanced growth, or least likely to be compromised by retarded growth.

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