CHAPTER 32

Alligator Farming Research in Louisiana, USA

Ted Joanen[1] and Larry McNease[1]

CONCERN about declining wild populations of crocodilians throughout the world resulted in a proliferation of conservation programmes. Wildlife management agencies in Africa, Asia, Australia, India, Papua New Guinea and the United States have been involved in such programmes for many years (Blake 1970; Yangprapakorn *et al.* 1971; Pooley 1971, 1973; Joanen and McNease 1971, 1975, 1984; Downes 1973; Blake and Loveridge 1975; Webb *et al.* 1983; Singh 1984). The approaches taken have varied considerably, but the breeding and/or raising of crocodilians in captivity has been incorporated into most of them. There are totally closed farming systems, in which eggs are produced from captive adults, and ranching systems, in which wild eggs and/or young are collected and raised to subadult sizes in captivity. Raised stock are either sold to the commercial skin trade or are released into the wild in wildlife sanctuaries, national parks or other suitable habitats. Within Louisiana, private alligator farming operations are restricted to closed farming systems. Eggs are produced from captive adults and these are subsequently incubated artificially and the young are raised in captivity, primarily for the production of skins.

In 1964, the Louisiana Department of Wildlife and Fisheries initiated an extensive research programme to study the biology and culture (captive production and raising) of the American alligator *(Alligator mississippiensis)* (Chabreck 1967; Joanen and McNease 1971, 1974, 1975). Out of necessity, some of the first studies involved the housing requirements of wild adults brought into captivity for breeding purposes. Cultured stock were subsequently propagated and various aspects of artificial incubation and raising (within controlled environment chambers for the first three years of life) have now been researched (Joanen and McNease 1976, 1977, 1981; Ferguson 1981; Joanen *et al.* 1984, Chapter 51). Most recently, research has been initiated on stress related problems in reproductive physiology (Lance, Chapter 42; Elsey, Joanen, McNease and Lance, unpublished data).

When constructing pens to house adult alligators, the results of telemetry studies with wild adults (Joanen and McNease 1970, 1972) were used to identify basic habitat needs. These studies indicated that courtship and copulation took place in the spring, in open water areas such as bayous, canals and large lakes and ponds in the marshes. During the remainder of the year (summer, fall and winter), adult females centered their activities around small potholes and dens in the heavily vegetated portions of the marsh; males retained their preference for open, deep water all year round. These habitats were incorporated into pen designs, and multiple nesting of wild captured alligators was achieved. However, cultured alligators — ones from eggs that had artificially incubated and which had subsequently been raised in captivity — exhibited strikingly different behaviour as adult breeders than did their wild-captured adult counterparts (Joanen *et al.* 1981). Successful reproduction of a large group of alligators cultured since 1972 has now been achieved, and their reproductive histories have been carefully documented.

Considerable resources have been invested by the Louisiana Department of Wildlife and Fisheries in an extensive research programme aimed broadly at establishing the feasibility of raising alligators in captivity, for commercial and conservation purposes. This chapter gives an overview of the results of some of that research and discusses some of the latest developments in captive breeding, egg incubation and the raising of offspring.

METHODS

Pen Design for Adults

Pen design refinements developed over the years were incorporated into the construction of four breeding pens in 1975; all were about 0.8 ha (2 acres) (Fig.1). Deep water courtship ponds were constructed by digging rectangular ponds, 5-18 m (16-60′) wide by 30-53 m (100-175′) long by 2 m (6′) deep. Small isolation ponds, 6 m (20′) by 15 m (50′)

[1]Louisiana Department of Wildlife and Fisheries, Grand Chenier, Louisiana 70643, USA

Pages 329-40 *in* WILDLIFE MANAGMENT: CROCODILES AND ALLIGATORS ed by Grahame J. W. Webb, S. Charlie Manolis and Peter J. Whitehead. Surrey Beatty and Sons Pty Limited in association with the Conservation Commission of the Northern Territory

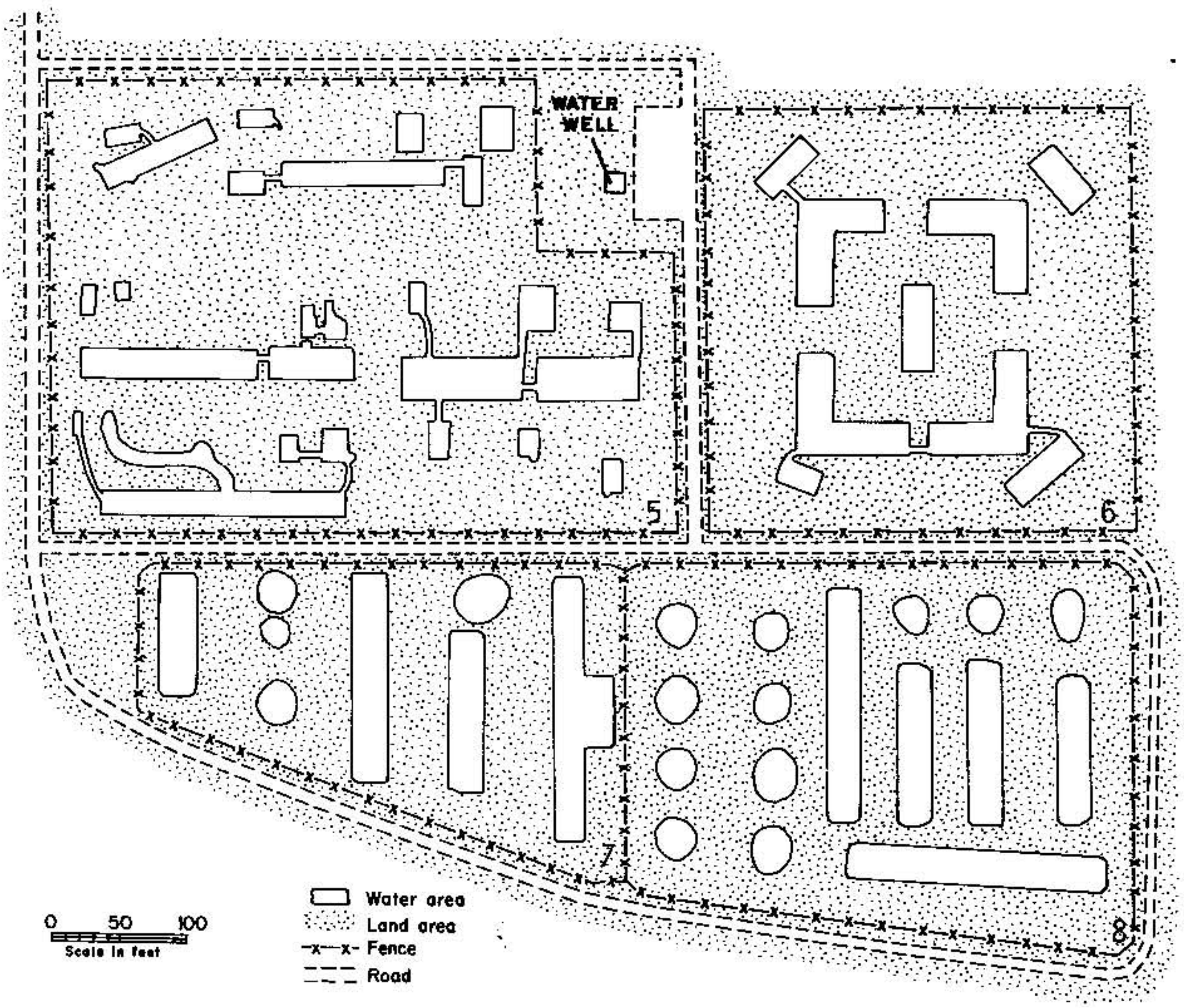

Fig. 1. The design of four pens (Nos 5, 6, 7 and 8) used for testing the effects of diet and stocking density on reproduction in adult *Alligator mississippiensis* that had been raised totally in captivity.

and 2 m (6′) deep, were dispersed throughout the pens. Each pen was fenced with 2.5 cm x 5 cm x 1.5 m high (1″ x 2″ x 60″ high) welded wire, and creosoted boards, 2.5 cm x 15 cm x 5 m long (1″ x 6″ x 16′), were installed at the bottom of the fence, flush with the ground, to give additional strength and to serve as anchorage points. Natural vegetation, including wiregrass *(Spartina patens)*, roseau cane *(Phragmites communis)*, buckbrush *(Baccharis halimifolia)*, bullwhip *(Scirpus californicus)* and marsh fleabane (*Pluchea* sp.), was allowed to invade the pens to provide cover, nesting material and shade. Each pen was mowed as required, but not when alligators were courting or nesting. Water was provided from a 20 cm (8″) diameter and 67 m (220′) deep well, pumped by a 25 horsepower electric motor; 5 cm (2″) and 8 cm (3″) diameter underground PVC water lines were used to connect the ponds and water holes in each pen.

Stocking Rates (Adults)

The stocking densities and sex ratios of alligators introduced into the four pens are in Table 1. An important aim of the study was to investigate the maximum stocking densities which pen-reared alligators could tolerate in captivity, given the provision of suitable habitat requirements for each sex. All alligators used were reared entirely in captivity, from eggs hatched during 1972 and 1973. They had been periodically weighed and measured while being raised, although as they matured (and were captured at feeding sites), only total lengths were recorded. General notes on the condition of individuals had also been taken. These data were subsequently correlated with feeding rates to assess the results of the feeding programme in terms of both

Table 1. Diets, stocking rates, sex ratio and hatching year for the *Alligator mississippiensis* breeding experiments (1978-1985).

Diet	Pen No.	No. of Alligators: Males	No. of Alligators: Females	Male:Female Ratio	Hatching Year
Fish	5	5	18	1:3.6	1972
Nutria	6	12	23	1:1.9	1973
Nutria	7	21	42	1:2.0	1973
Fish	8	7	34	1:4.8	1972

general health and productivity. From the time of hatching until they were placed into the outdoor pens (three years), animals were fed both nutria and fish.

Feeding Methods and Rations (Adults)

The method of feeding has been described previously (Joanen and McNease 1971; McNease and Joanen 1981). Several feeding sites were established in each pen to help disperse the alligators, and these were usually situated near a basking area or a path adjacent to the water's edge. Trails and permanent roads were maintained in the pens to allow staff ready access to the feeding stations. Feeding began in March of each year and terminated in late October; alligators were not fed during late fall and winter, when ambient temperatures are too low. A feeding rate of 6% body weight per week was adhered to during the summer, when most food was consumed.

Two diets were tested on the penned adult breeders; whole fish (*Micropogon undulatus*) and nutria (*Myocastor coypus*) carcasses. One high and one low density pen was fed fish, and the other two pens nutria (Table 1). Nutritional analysis revealed that nutria contained 14.9% crude protein, 2.1% crude fat, 0.5% crude fibre and 45% moisture. Fish, on the other hand, contained 9.9% protein, 4.0% fat, 1.0% fibre and 60.6% moisture.

A vitamin premix was added to the diet of all alligators (juveniles and adults) at a maximum rate of 1% by weight. The specifications for each 454 g (1 lb) of this premix (manufactured by Dawe's Laboratories Ltd., Chicago Heights, Illinois 60411, USA) are:

Vitamin A	1,800,000.00 USP U
Vitamin D3	200,000.00 IC U
Vitamin E	5000.00 IU
Riboflavin	1000.00 mg
d-Pantothenic Acid	2760.00 mg
Niacin	4.50 g
Choline Chloride	86.43 g
Vitamin B12	1.35 mg
Folic Acid	90.00 mg
Biotin	20.00 mg
Pyridoxine Hydrochloride	1000.00 mg
Menadione Sodium Bisulfite	4283.00 mg
Thiamine Mononitrate	1000.00 mg
Inositol	5000.00 mg
Para-Amino Benzoic Acid	5000.00 mg
Ascorbic Acid	45,000.00 mg
Ethoxyquin	5.00 g

Housing for Juveniles

Environmental chambers as described by Joanen and McNease (1976) were used to raise alligators up to three years of age. Water capacity was 530 litres (138 gal) with 10.4 m^2 (12.5 yd^2) surface area in each tank. Later, six larger chambers were constructed with the following alterations: solid concrete walls instead of concrete blocks; water area deepened by 5 cm (2") and overall tank width increased by 91 cm (3') (equal water and dry area). Water capacity was 1135 l (295 gal), with 14.9 m^2 (17.9 yd^2) surface area per tank. A tin-roofed shed with skylights provided protection for the chambers. Doors were kept closed in order to maintain constant temperature and as a result, alligators were raised in near total darkness throughout the fall, winter and spring.

Environmental chambers were heated by thermostatically controlled electrical thermal conductors. Water was supplied through a network of plastic and galvanized pipes from a 5 cm (2") water well. Temperature recorders were used to monitor outside air temperature, and air and water temperatures within the chambers. Partitions were installed in all chambers to reduce "pile-ups" caused by young alligators crowding into a particular corner. Stocking rates and maintenance for juvenile alligators followed the procedures described by Joanen and McNease (1976).

Feeding Methods and Rations (Juveniles)

Four diets were tested on juveniles; fish, nutria and a commercial diet for both catfish and turtles. Fish and nutria were purchased frozen and stored in a freezer. The fish consisted entirely of marine fish and 90% by volume were fish of the family Sciaenidae; Atlantic croaker alone made up 80%. As needed, fish and nutria were ground or chopped and repackaged into convenient lots. The commercial diets were simply mixed into a moist cake-like configuration when ready to feed.

Alligators were fed five days per week during their hatching year and three days per week during the remaining two year period in the chambers. Foods were weighed when placed into the chambers and the uneaten food was reweighed the following day. The amount of food offered was adjusted periodically to insure maximum consumption; generally about 20% of body weight per week. Total lengths and weights of alligators were taken monthly so that growth rates and food conversion rates could be quantified.

Artificial Egg Incubation

Alligator eggs were collected from wild and captive nests shortly after laying (within 24 hours when possible), during the three week nesting period each year. Eggs were marked for upright orientation, identified by clutch and were transported in single layers covered with approximately 12 cm (5") of nesting media. Dented and slightly cracked eggs were incubated if no leakage of egg contents was apparent. We used 19 l (5 gal) plastic buckets to collect eggs in pens and large garbage cans (132 l capacity; 35 gal) when collecting wild nests from airboats.

Prior to setting eggs in the incubator the presence or absence of the opaque band on each egg (Ferguson 1981) was checked. Embryos were aged from the degree of eggshell banding and infertile eggs and/or those containing young dead embryos were identified and discarded. Freshly laid eggs are not banded and thus caution needs to be exercised when distinguishing between freshly laid and infertile eggs (unbanded); banding takes place when the embryonic disc attaches to the shell, about 24 hours after laying.

Within 3 or 4 hours of collection, eggs were set in the environmental chambers as described by Joanen and McNease (1976). Incubation temperatures were maintained within a range of 29.4°C (85°F) to 32.7°C (91°F). Eggs were placed in trays, measuring 61 cm x 61 cm x 15 cm high (2′ x 2′ x 6″ high), covered top and bottom with 13 mm (1/2″) wire fabric mesh for air circulation. Nesting medium (*Spartina patens*) taken from wild nests was packed top and bottom around a single layer of eggs. Trays were set on shelves 8 cm (3″) above water. The doors of the environmental chambers were opened only once or twice a week, for inspection, until hatching commenced. When necessary, incubation medium was moistened with warm water taken from the environmental chamber. Once hatching began, the chambers were checked at least every second day. After pipping, hatchlings were retained in their hatching trays for at least 24 hours to allow time for them to separate from the shell and for their umbilical cord to break off (Joanen and McNease 1979).

RESULTS

Age at First Nesting

Age at first nesting for captive alligators, housed and reared in controlled environmental chambers for the first three years of life, then placed in outside pens, was five years 10 months (Fig. 2). Age of sexual maturity reported for Louisiana alligators held in semi-natural outside pens was nine years and 10 months (McIlhenny 1935; Joanen and McNease 1975).

Environmental parameters vary considerably throughout the alligator's range and may play an important role in regulating the age of sexual maturity (Fig. 2). Alligators in North Carolina approach the size of sexual maturity (1.8 m) after about 15 years for males and 18 to 19 years for females (Fuller *et al.* 1983).

Nesting Rates

The percentage of wild adult female alligators which nested each year in Louisiana marshes was

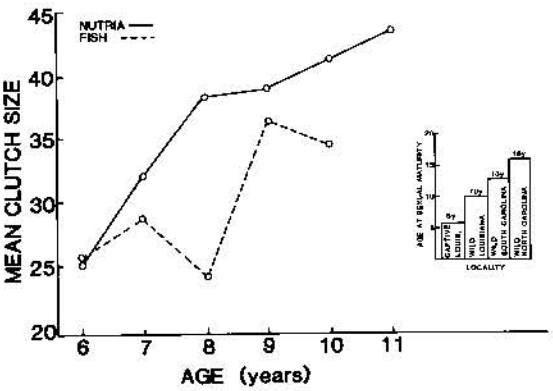

Fig. 2. Variation of clutch size with age in captive *Alligator mississippiensis* fed either nutria or fish. The inset summarizes data on the age at which sexual maturity is attained in wild alligators from different areas.

estimated to be 63% (Joanen and McNease 1980a, b), and 68% on Sabine National Wildlife Refuge (Chabreck 1966). Wilkinson (1983) reported a 36% nesting rate for wild females in South Carolina and Taylor (pers. comm.) reported a 34% nesting rate in northern Louisiana.

Nesting rates for captive alligators (Fig. 3) fed nutria (Pen 6; low density) were consistently higher than for those fed fish (Pen 5; low density). During a four year period, when the alligators were seven to 10 years of age, an average of 62.8% of nutria fed animals nested annually, whereas the equivalent rate for those fed fish was 26.8%.

After the alligators in Pen 6 (nutria; low density) reached eight years of age, they exceeded the maximum known nesting rate of wild alligators (Fig. 3). Pen design, stocking density, domesticated stock and diet were probably the most important factors contributing to this result.

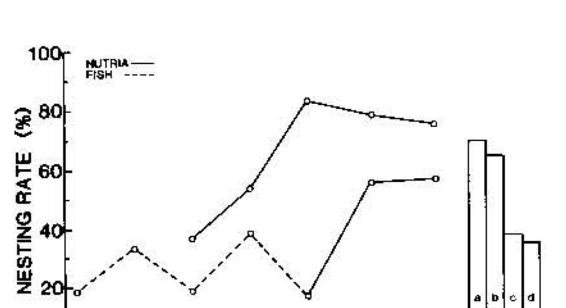

Fig. 3. The percentage of captive *Alligator mississippiensis* which nested each year (nesting rate), in low density pens fed either nutria or fish. In 1982, the animals being fed fish were switched to nutria. The histogram summarizes estimates of nesting success in wild populations from: (*a* and *b*) southern Louisiana (Chabreck 1966; Joanen and McNease 1980a, b); (*c*) South Carolina (Wilkinson 1983); and (*d*) northern Louisiana (Taylor 1984).

The low nesting rate in Pen 5 (fish) increased abruptly to 56% when the diet was switched to nutria in the spring of 1982 (Fig. 3), and this change was maintained the following year (57%). However, the nesting rate in this pen, even after being switched to a nutria diet, remained below that recorded for wild alligators in the marshes of southern Louisiana. In 1982, due to the low nesting rate in Pen 8 (fish; high density), studies were terminated on these animals and they were released into the wild.

Nesting rates for captive alligators fed nutria and maintained at different stocking rates are presented in Figure 4. Females in Pen 6 (low density), averaged 78.7% over three years whereas those in Pen 7 (high density), with twice the number of females, averaged 60.7% over the same period.

Clutch Size

Clutch size increased consistently with age for alligators maintained on a nutria diet (Fig. 2). It also increased with those on a fish diet, but was much more variable (Fig. 2). Independent of diet, the first nests made had an average clutch size of 25 eggs. Joanen (1969) reported an average clutch size of 38.8 eggs for wild nests in southern Louisiana, and penned alligators approached this level in their third or fourth year of reproduction.

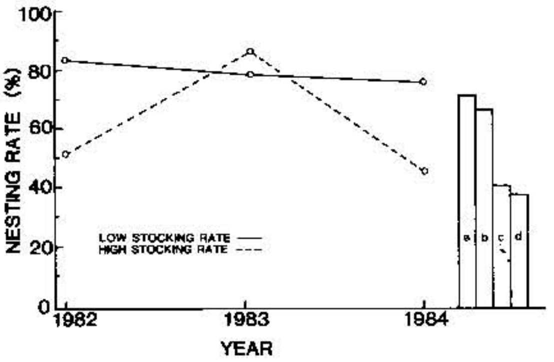

Fig. 4. The percentage of captive *Alligator mississippiensis* fed nutria, which nested each year (nesting rate), in high and low density pens. The histogram summarizes estimates of nesting rate in wild populations from: (*a* and *b*) southern Louisiana (Chabreck 1966; Joanen and McNease 1980a, b); (*c*) South Carolina (Wilkinson 1983); and (*d*) northern Louisiana (Taylor 1984).

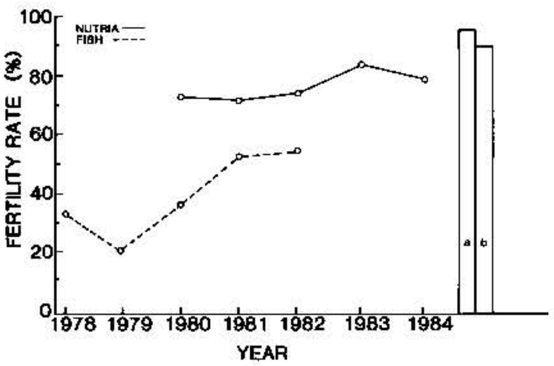

Fig. 5. The percentage of fertile eggs (fertility rate) produced by captive *Alligator mississippiensis* which were fed either nutria or fish. In 1982, the animals being fed fish were switched to nutria. The histogram summarizes estimates of fertility rate in wild alligator eggs in: (*a*) Louisiana (Joanen and McNease, unpublished data); and (*b*) Florida (Deitz and Hines 1980).

Fertility Rates

The fertility rate of 5839 wild alligator eggs examined in Louisiana in 1984 was 95.1% (Joanen and McNease, unpublished data); Deitz and Hines (1980) found a fertility rate of 89% in alligator eggs from Florida. Alligators fed a nutria diet consistently had higher fertility rates than those fed fish (Fig. 5), but both groups had lower rates than recorded for the wild populations. In contrast to the effect of diet, stocking densities had little or no effect on fertility rate. Rates in Pen 6 (nutria, low stocking density; Fig. 6) averaged 79% and those in Pen 7 (nutria, high density; Fig. 7) averaged 80%.

Hatching Rates

Data on the percentage of fertile eggs that hatch (hatching rates) in wild alligator nests are summarized in Figure 8. In Louisiana, the hatching rate of wild eggs left in their nests to incubate was about 58% (Joanen 1969). However, if wild eggs were collected soon after laying and incubated artificially, the hatching rate increased to 91% (Joanen and McNease, unpublished data). The hatching rate of eggs from captive alligators fed nutria remained slightly above the value determined for wild eggs left in the field to incubate (Fig. 8), but was well below the 91% achieved with wild eggs incubated artificially. Eggs from captive alligators fed fish demonstrated very low hatching rates, averaging 27.4% over five years.

Stocking density had little effect on the hatching rate of fertile eggs. The average hatching rate for eggs from Pen 7 (Fig. 7) averaged 54% and equalled that for Pen 6 (Fig. 6).

Natural Incubation

In 266 wild nests examined over a 4-year period in Louisiana, 182 (68.3%) hatched successfully, 19 (7.3%) were partially infertile, 15 (5.8%) were totally infertile, and 50 (18.6%) were either destroyed by raccoons (*Procyon lotor*) or were lost to flooding (Joanen 1969). In 154 nests examined in 1967 and 1968, hatching rate of fertile eggs was 58.2%. (Joanen 1969).

In one north-central Florida study, a hatching rate of 45% was reported. Of 13 nests checked, 62% produced live young, 31% were destroyed by mammalian predators and 8% were lost to flooding (Goodwin and Marion 1978). Deitz and Hines

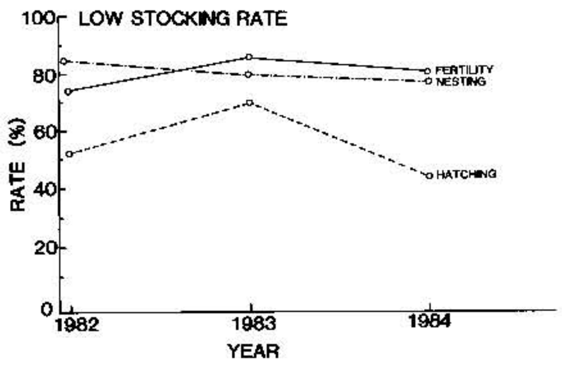

Fig. 6. Nesting rates, fertility rates and hatching rates of fertile eggs, for captive *Alligator mississippiensis* fed nutria and maintained at a low stocking density (Pen 6).

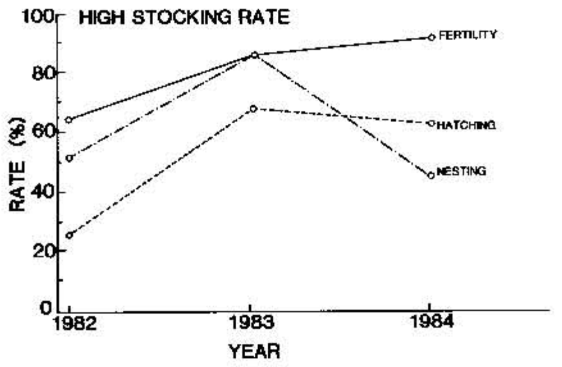

Fig. 7. Nesting rates, fertility rates and hatching rates of fertile eggs, for captive *Alligator mississippiensis* fed nutria and maintained at a high stocking density (Pen 7).

(1980) reported a 67.9% hatching rate from 111 undisturbed nests in two study areas in Florida. In South Carolina, Bara (1975) reported eight of 12 nests (66.7%) produced offspring and 82% of the eggs in these successful nests hatched; flooding and raccoon predation caused egg losses in one third of the nests studied. Metzen (1977) reported that 70% of 110 nests examined in Georgia hatched, and Klause (1983) reported that 88.2% of nests hatched in a North Carolina study; 12% were lost to predators and a 70% hatching rate occurred. Wilkinson (1983) reported 70.1% of nests hatching successfully in South Carolina, with a minimum hatching rate of 26.9%.

Time of Egg Collection

Methods of collecting, transporting and incubating alligator eggs have been discussed by Joanen and McNease (1977, 1981) and Ferguson (1981). Nests are located from the air during the period of nest construction and just prior to egg laying (Joanen and McNease 1979). The location of each nest is carefully plotted on an infra-red aerial photograph (Fig. 9), and eggs are later collected from airboats.

Hatching rates as a function of embryo ages at the time of egg collection, for 3852 alligator eggs from 93 wild nests, are in Table 2. Rates varied from a high of 92.5% to a low of 67.1%, and the most sensitive period for handling was between the 9th and 16th days of development. The age at which embryos died (in one week age classes) was determined by opening all unhatched eggs at the end of the incubation period and examining the dead embryos. The excessive mortality which occurred among eggs collected between the 8th and 16th days of incubation could be attributed largely to animals dying at or soon after the time of egg collection; this is consistent with the embryos being susceptible to mechanical injury at that stage of development.

Hatching rates for 1012 eggs produced from captive females are in Table 3. Eggs collected when about four days of age gave markedly superior hatching rates to those collected when about seven days of age. The age at which embryos died was consistent with significant embryo mortality occurring at or near the time of collection and transport.

Taken together, these results indicate that alligator embryos are sensitive to handling from about days 7 to 16 of incubation. This corresponds with a period in which the embryonic allantois develops and expands while the embryo is still attached to the shell membrane (Ferguson 1985).

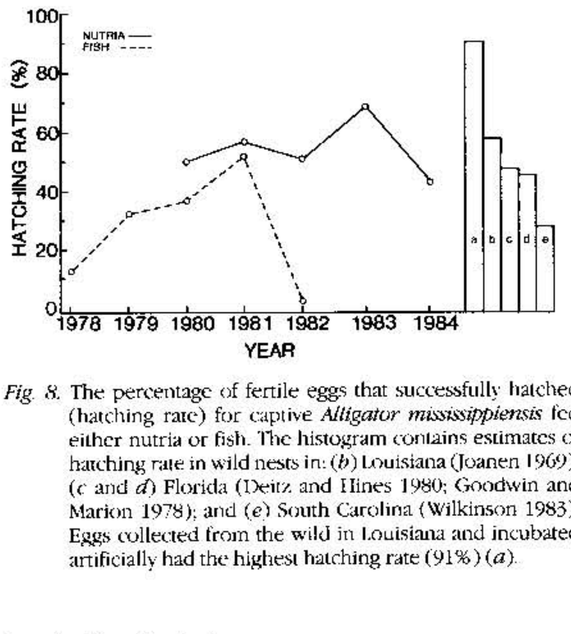

Fig. 8. The percentage of fertile eggs that successfully hatched (hatching rate) for captive *Alligator mississippiensis* fed either nutria or fish. The histogram contains estimates of hatching rate in wild nests in: (*b*) Louisiana (Joanen 1969); (*c* and *d*) Florida (Deitz and Hines 1980; Goodwin and Marion 1978); and (*e*) South Carolina (Wilkinson 1983). Eggs collected from the wild in Louisiana and incubated artificially had the highest hatching rate (91%) (*a*).

Incubation Techniques

Within three or four hours of collection, eggs were placed in the environmental chambers for incubation (Joanen and McNease 1976). Temperatures between 29.4°C (85°F) and 32.7°C (91°F) were tested and the best hatching success was obtained at 31.0-31.7°C (88-89°F) (Joanen and McNease 1979; see Joanen *et al.* Chapter 51). Temperatures of individual clutches of eggs within a chamber varied by ± 1.0°C from the ambient tank temperature. Natural nesting material, primarily *Spartina patens*, was used for artificial incubation media and gave the best hatching results (Ferguson 1981). This material

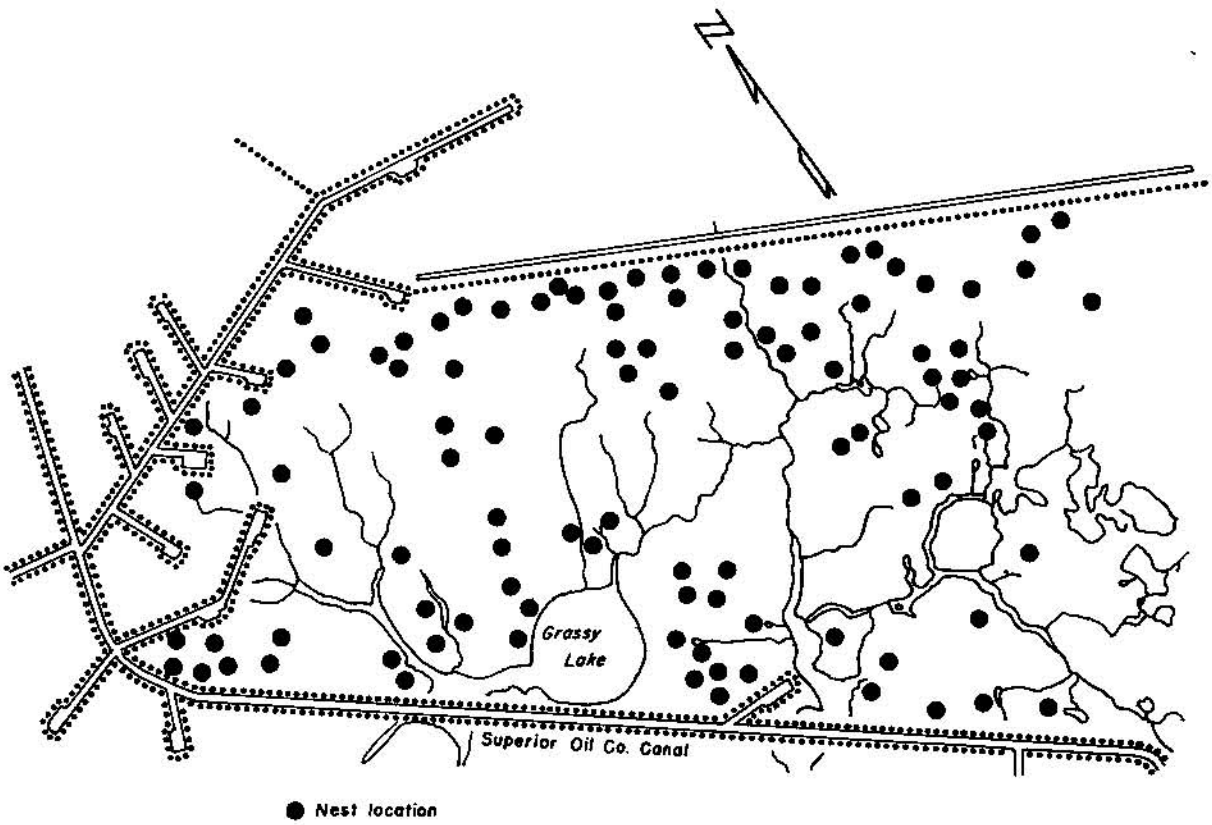

Fig. 9. The density of wild *Alligator mississippiensis* nests on Rockefeller Refuge in 1984; 1 nest per 7.6 ha (18.7 acres).

was found to maintain high moisture levels and aided in the breakdown of the eggshell. Moisture levels were maintained at approximately 90% throughout the incubation period.

Culture of Alligators in Controlled Environmental Chambers

When the four diets were tested on young alligators (Joanen and McNease 1976), the catfish and turtle rations proved totally ineffective and were discontinued. They contained mostly vegetable based proteins which alligators are unable to synthesize (R. A. Coulson, pers. comm.).

Alligators fed fish converted 49.5% of the food consumed (dry weight) into body mass over a 33 month period. Coulson *et al.* (1973) reported conversion rates of 40% up to one year of age and 25% from one to three years, but this was probably based on wet weights. After 12 months feeding (19 months of age) alligators fed fish averaged 1.1 m (3.6′) total length and weighed 4.0 kg (8.8 lb); length-weight relationships (Joanen and McNease 1975) were comparable with those reported by Coulson *et al.* (1973). At 33 months of age (i.e., after 26 months of intensive feeding) females averaged 19.4 kg (42.7 lb) and 1.6 m (5.3′) and males 25.7 kg (56.5 lb) and 1.7 m (5.6′); 10% of the alligators measured more than 1.8 m and the longest individual was 1.9 m (6.3′). Captive reared alligators had a superior body condition to wild alligators (they were 10% heavier per given length) and were twice the length of wild alligators of the same age (Coulson *et al.* 1973). For any given age class, alligators fed nutria were 20% heavier and 3% longer than those fed fish.

Growth

Alligators hatched in 1972 and 1973 and raised in controlled environmental chambers were moved into the outdoor pens in June 1975 and 1976 respectively. Average size of females at this time was 1.6 m (5.3′) and 19.4 kg (42.7 lb), whereas males averaged 1.7 m (5.7′) and 25.7 kg (56.5 lb) (Fig. 10). Growth rates for captive alligators greatly exceeded those reported by Chabreck and Joanen (1979) for wild alligators of the same age. In terms of length, no significant differences were noted in growth rates of fish fed versus nutria fed alligators, so that the growth data for the two diets were combined. However, there was a more significant difference in body weight (20% between the two treatments).

The behaviour of alligators fed fish and nutria showed obvious differences. Animals fed fish were shy and wary, whereas, those fed nutria were aggressive at the feeding sites and were generally more "active" animals.

Mortality within the environmental chambers was found to be largely insignificant, with survival rates from hatching to the end of the third year averaging

Table 2. Hatching rate and mortality for 3852 wild *Alligator mississippiensis* eggs which were collected at different ages and incubated artificially. The approximate age of all dead embryos was determined; 95% of eggs were fertile.

Age of egg when incubated	No. clutches	No. set	Percent hatch	Percent mortality 1-2 weeks	3-7 weeks	8-9 weeks
<24 hrs	11	478	92.5	2.3	2.9	2.3
2 days	11	453	92.2	4.4	1.8	1.5
4 days	11	459	88.0	5.9	0.2	5.9
6 days	7	305	92.1	5.2	1.0	1.6
8 days	3	130	86.9	8.5	3.1	1.5
10-12 days	10	423	67.1	17.7	3.5	11.6
14-16 days	14	564	81.4	12.2	2.1	4.3
3 weeks	17	688	89.0	6.4	0.6	4.1
7 weeks	9	352	88.4	5.4	0.9	5.4

Table 3. Hatching rate and mortality for 1012 *Alligator mississippiensis* eggs laid in captivity at Rockefeller Refuge in 1984, and artificially incubated.

Date Collected	Diet/ Density	Mean age of eggs when incubated	No. of clutches	Percent fertile	No. set	Percent hatch	Percent Mortality 1-2 weeks	3-7 weeks	8-9 weeks
June 26	Nutria/low	4 days	8	68.1	216	69.9	20.4	3.7	6.0
July 6	Nutria/low	7 days	10	89.3	305	24.3	53.8	12.1	9.8
June 26	Nutria/high	4 days	11	90.5	340	70.9	20.3	1.2	7.6
July 6	Nutria/high	7 days	6	87.7	151	37.8	40.4	11.3	10.6

95% (Joanen and McNease 1976). Fighting occurred occasionally and resulted in cuts on the tail, back and limbs, but it was not considered a serious problem. However, fighting increased with high stocking densities and the best stocking density was 10 alligators per m^2 during the first year of life and a maximum of 3.3 per m^2 in the following two years (Joanen and McNease 1977).

DISCUSSION

General

Age of first nesting for captive reared alligators housed in controlled environmental chambers for the first three years of life, then shifted to outside pens, was five years and 10 months; in alligators reared entirely in semi-natural pens it was nine years and 10 months (McIlhenny 1935; Joanen and McNease 1975). Diet did not seem to affect growth rates nor the age at which sexual maturity was attained (Fig. 2). Alligators fed both fish and nutria produced fertile eggs as they approached their sixth year of life.

Fuller *et al.* (1983) indicated that size apparently has a greater influence on the onset of sexual maturity than does age. However, our study demonstrated both size and age to be important factors. Some of the alligators reared in environmental chambers reached 1.8 m (6′) total length in three years: however, no nesting occurred until these animals were five years and 10 months old. Of the total number of animals held in captivity, only a small percentage (18%) nested when six years old. Furthermore, reproductive success was quite low for the first two years. It was not until the third nesting year that clutch size, the percentage of females nesting, egg fertility and hatching rate all approached the average found by Joanen (1969) for wild alligators in the same region. Although size may be the most important factor regulating the onset of sexual maturity, age contributes significantly to this process.

Temperature is an important factor governing growth, and it varies considerably throughout the range of the alligator. In southern Louisiana, Chabreck and Joanen (1979) reported approximately seven growing months per year for immature alligators and Joanen and McNease (1971) reported a similar period for adults. In the study of immature alligators, no growth occurred during the dormant period (October to March). Shrinkage, ranging from 0.1 to 0.4 cm of total length per month, was recorded in five of seven alligators measured (Chabreck and Joanen 1979).

For an alligator to reach sexual maturity in southern Louisiana in 10 years, with seven growing months per year, means that a total of about 70 growing months is required. Coulson *et al.* (1973) indicated that under laboratory conditions alligators did not initiate feeding activities at temperatures below 22°C (72°F). According to Fuller *et al.* (1983), the average monthly temperature near the study area in North Carolina was equal to or exceeded 22°C between May and September. Thus, alligators in North Carolina would experience about four active growing months per year, and would therefore use 72-76 growing months in order to reach sexual maturity in the 18-19 years required in North Carolina.

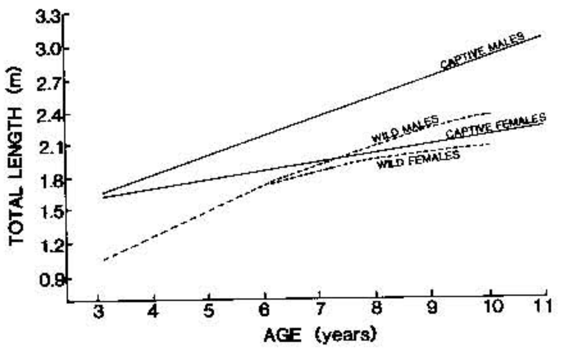

Fig. 10. The mean relationships between total length and age for captive and wild male and female *Alligator mississippiensis* at Rockefeller Refuge, Louisiana.

Differences in ambient temperature for the two States (short growing seasons in the northern parts of the alligator's range relative to those in the southern parts) apparently regulate the growth of alligators and appear to control the onset of sexual maturity. Thus there may be considerable geographic variation in the age at which sexual maturity is reached, but in terms of accumulated growing months to reach 182 cm (6′), there appears to be little variation.

Diet was found to have a significant impact on productivity. Alligators fed nutria consistently produced larger clutches and had higher nesting, fertility and hatching rates than those fed fish. Clutch size averaged 36.7 for alligators fed nutria and 29.4 for those fed fish. Nesting effort averaged 78.6% for nutria fed alligators but only 24.4% for those fed fish. Fertility rates followed much the same pattern: 76.1% for nutria fed and 39.0% for fish fed alligators. Hatching rates for nutria fed alligators averaged 53.5% as compared to 27.0% for fish fed animals.

These results may help explain the low reproductive rates found by Wilkinson (1983) (36%) and Taylor (pers. comm.) (34%). These alligators may rely heavily on a basic fish diet as compared to a red meat diet for southern Louisiana adults. Food habit studies conducted on wild adult alligators in coastal Louisiana indicated nutria were the most important food item taken, although mink, rabbit and muskrat were also taken (McNease and Joanen 1977). Prior to the introduction of nutria into Louisiana, O'Neil (1949) reported muskrat as an important food item for coastal marsh alligators.

Stocking densities were evaluated on the basis of growth, reproductive success, fighting and competition for nesting sites. A comparison of two pens with different stocking densities (Pens 6 and 7), but with the same red meat diet, showed no differences in growth, clutch size, fertility rate or hatching rate. However, the low stocked pen maintained an average nesting rate of 78.6% as compared to 60.6% for the high density pen.

Competition for nesting sites was greater under higher stocking densities. The number of multiple clutches per nest increased in the more densely stocked Pen 7, and although fighting occurred in both pens, the degree of scars was greater on the females in Pen 7. The majority of combat took place during late courtship and the period of nest construction.

Time of Egg Collection

Several authors have reported a sensitive embryo period in which the transport of alligator eggs, even over short distances, increases mortality and thus reduces hatching success (Joanen and McNease 1977; Chabreck 1978; Ferguson 1981). Chabreck (1978) recommended egg collection after the fourth week of incubation, to avoid the trauma of transport.

More recent studies indicate eggs can be safely transported early in incubation, up to the seventh day (Ferguson 1981; Joanen and McNease 1981; Ferguson and Joanen 1982; see Joanen *et al.* Chapter 51), and should ideally be collected as soon after laying as possible (Ferguson 1981) for the following reasons:

1. Eggs which are laid upright in the nest, with the long axis perpendicular to the ground, die unless they are positioned correctly during their early development;

2. Early egg collection eliminates losses caused by predation and flooding;

3. Early collection and correct incubation procedures will eliminate egg desiccation, which is a serious factor in both pens (due to the poor quality of nesting media) and in the wild (during droughts); and,

4. Early collection eliminates losses in pens that occur when multiple clutches are laid in the one nest (one female breaks the eggs of another).

Early egg collection also allows advantage to be taken of the temperature dependent sex determining mechanism of American alligators (Ferguson and Joanen 1982, 1983). The temperature sensitive period for sex determination is between 7 and 21 days of incubation, and eggs collected prior to that time can be incubated to produce any desired sex ratio.

Studies by Joanen *et al.* (see Chapter 51) strongly suggest that post-hatching growth of alligators is also dependent on the temperature of egg incubation, again favouring early egg collection. Alligators incubated at different temperatures grow at different rates. A high occurrence of runts (inferior animals) were produced from the extreme ends of the incubation temperature range, whereas superior animals were produced at the mid-range temperatures. Lang (see Chapter 30) reports similar tendencies with *Crocodylus siamensis*.

Incubation Techniques and Hatching Success

The most notable finding from the artificial incubation studies was that eggs collected from wild nests had significantly higher hatching rates than did those from the pens. Irrespective of the time of egg collection, the hatching rate of wild eggs ranged from 67.1% to 92.5%, whereas the maximum rate obtained for captive laid eggs was 70.9%. Age of females could contribute to this difference, as captive females were generally young whereas the majority of wild ones were middle-aged. Another factor could be the elevated stress (corticosterone) levels among animals within the pens, which appears to be having an adverse affect on reproductive success (Elsey, Joanen and Lance, unpublished data).

Studies by Shirley (1982) indicate diets also affect eggshell thickness. Alligators fed fish produced a thicker shell than both those fed nutria and those in the wild; this in turn could be implicated in the high percentage of late embryonic deaths that occurred in eggs from alligators fed fish.

Egg Supplement Programme

The lack of a source for suitable farm stock has severely limited alligator farming operations in the United Sates. The Louisiana Department of Wildlife and Fisheries realized this situation and has been providing stock off State-owned lands since 1977. Farmers that qualify for the programme, are given hatchlings that have been raised for a few months, and this will continue until their breeding stock is capable of producing the numbers of young required to become self-sustaining. The Louisiana Department of Wildlife and Fisheries can exercise the option of an annual return rate of 5% at 1 metre in length.

Rules and regulations governing Louisiana alligator farms as listed in the Acts of 1974, No. 121 and the Acts of 1970, No. 550 of Louisiana Laws Pertaining to Wildlife and Fisheries, along with commission regulations, specify the basic guidelines that must be met before an applicant can be licensed. Important factors considered are land availability and the suitability of the applicant's operational plans. The use of controlled environmental chambers capable of maintaining a constant temperature are required by the Department as a prerequisite.

Today, Louisiana has 13 established alligator farms and a captive population of about 21,000 alligators.

Controlled Environmental Chamber Culture

Ground nutria carcasses and fish both proved acceptable diets. However, growth (in terms of body weight) among alligators fed nutria was superior to that among those fed fish. Nutria presented storage problems because of its seasonal availability, and was more expensive than fish to purchase. Disadvantages of fish were: high percent moisture; overfeeding tended to produce gout; it required freezing for storage; it had to be purchased in large enough quantities to make delivery economically feasible; it needed to be ground for feeding small alligators; and, it was deficient in vitamins (Joanen and McNease 1976).

After hatching, temperatures were maintained at 31.6°C (89°F) in order to speed up body functions. Feed was not offered until the third day after hatching to allow for absorption of the residual egg yolk, but most hatchlings began feeding within a day of food being offered. Initially, food consumption was low, less than 5% of body weight per we-1- but the important consideration was to get young regimented to a feeding scheme as quickly as possible. After the tenth day of life, environmental chamber culture was basically one of maintaining clean tanks and providing proper diets for maximum yield. Temperatures within the chambers were maintained at 30-31°C (86-88°F) to maximise growth.

Feeding was carried out five days per week for the first year and three days per week thereafter. A feeding rate of 25% body weight per week was adhered to for the first year and then progressively decreased to 18% by the end of the third year; feeding rates were adjusted monthly. Fish or nutria which had been finely ground was fed until the alligators were one year old. When they had attained sufficient size, chopped food was fed, and when the animals were large enough, whole fish or larger pieces of nutria. After 36 consecutive months of feeding, the young outgrew their brooder facilities and were stocked into outside pens.

Growth rates, weight gain, food conversion and food consumption (wet weight) for alligators maintained in controlled environment chambers at 28°C (83°F) are summarized on Figure 11. At the end of the third growing year, alligators averaged 1.6 m (5'3") and weighed 21 kg (47 lb). The total amount of food consumed in order to achieve this size was 105 kg (233 lbs), with approximately 64 kg (140 lb) being consumed between the second and third years. Food conversion rates averaged 40% during this grow-out period. After the third year, food conversion rates fall precipitously and it is no longer economically feasible to maintain alligators under this regime. Stocking rates after the third year increase to three times the space required for the 1-3 year age group.

Ongoing studies by Tom Coulson (pers. comm.) indicate that by changing the grow-out temperature to 31°C (88°F), a 1.2 m (4') alligator can be reared in one year. However, the economics of achieving such accelerated growth have not been investigated on a commercial basis.

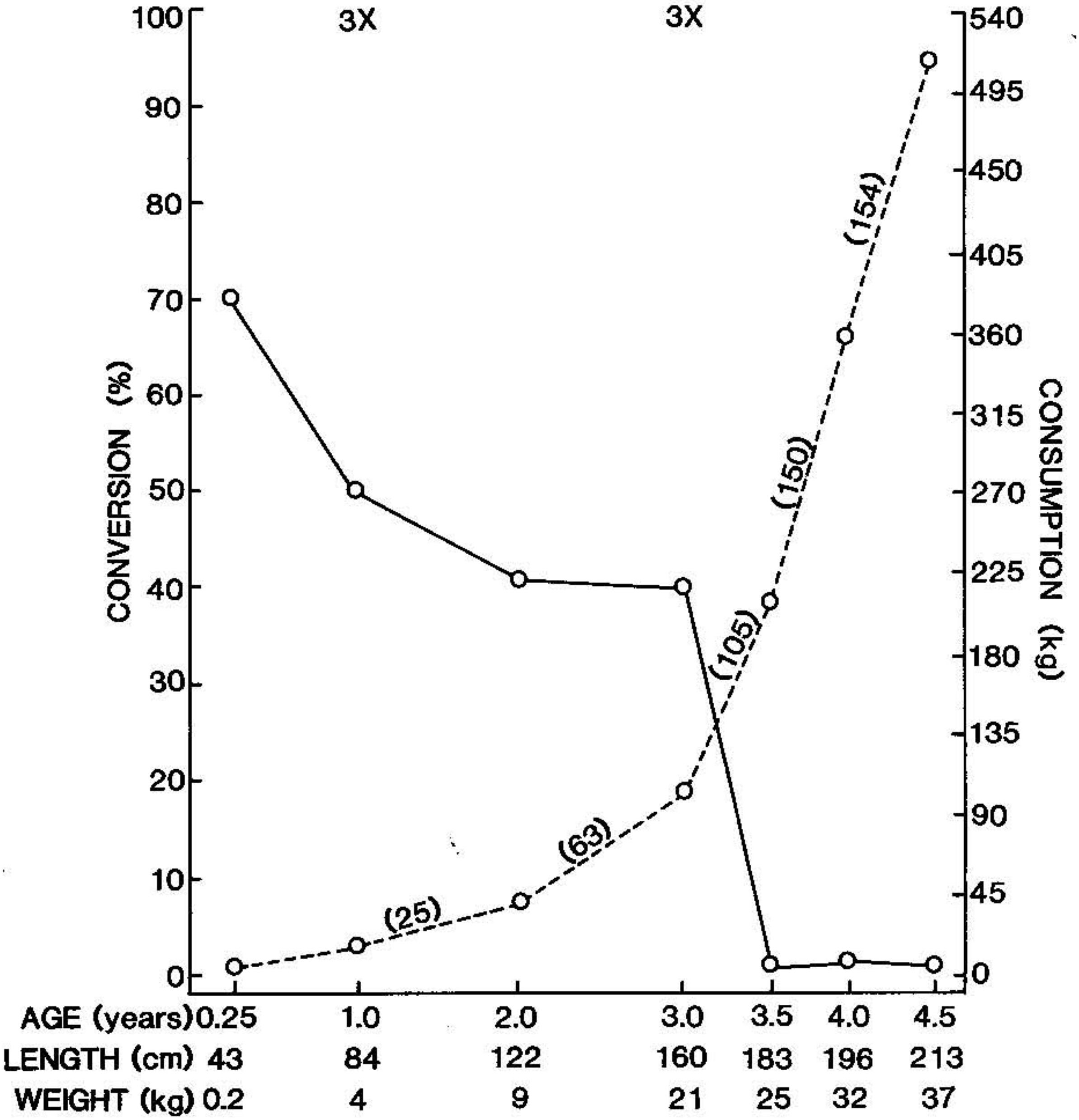

Fig. 11. A summary of the performance of *Alligator mississippiensis* in controlled environment chambers set at 28°C. After three years, cumulative food consumption (broken line) increases exponentially, whereas food conversion rates (solid line) drop precipitously. 3x's indicate where density needs to be reduced by three times; numbers in brackets are the means for each year class interval.

Alligators can be reared on an economically sound basis to marketable size within a three year period (Fig. 11), and alligator farms in southeastern United States may therefore be confined to the production of skins in the 1.2-1.6 m (4-5′) size class. If ongoing studies indicate the feasibility of increasing the grow-out temperature and thus producing a larger sized animal within the three year period, alligator farmers could produce a 1.8-2.1 m (6-7′) skin. However, this has not yet proven economically feasible. In recent years, alligator meat prices have increased tremendously and the sale of alligator meat for human consumption may help defray rearing costs.

The world demand for skins includes all size classes. Louisiana's wild harvest produced an average size skin of 2.1 m (7′) (Joanen *et al.* 1984), but larger skins, up to 4 m (13′) are in high demand. Hunters have received up to U.S.$21.00/0.3 m (1′) average price for alligator skins. If an alligator industry is to be maintained, the wild populations must be managed on a sustained yield basis.

REFERENCES

Bara, M. O., 1975. American alligator investigations. Unpubl. rep. for the period Aug. 1970-Dec. 1975, South Carolina Wildlife and Marine Resources Dept., Columbia, South Carolina. 40pp.

BLAKE, D. K., 1970. Crocodile farming in Rhodesia. Unpubl. rep. to Dept. National Parks and Wild Life Mgmt., Zimbabwe.

BLAKE, D. K. AND LOVERIDGE, J. P., 1975. The role of commercial crocodile farming in crocodile conservation. *Biol. Conserv.* **8**: 261-72.

CHABRECK, R. H., 1966. Methods of determining the size and composition of alligator populations in Louisiana. *Proc. Ann. Conf. Southeastern Assoc. Game. and Fish Comm.* **20**: 105-12.

CHABRECK, R. H., 1967. Alligator farming hints. Unpubl. rep. to Louisiana Wildl. and Fish. Comm. 21pp.

CHABRECK, R. H., 1978. Collection of American alligator eggs for artificial incubation. *Wildl. Soc. Bull.* **6**: 253-6.

CHABRECK, R. H. AND JOANEN, T., 1979. Growth rates of American alligators in Louisiana. *Herpetologica* **35**: 51-7.

COULSON, T. D., COULSON, R. A. AND HERNANDEZ, T., 1973. Some observations on the growth of captive alligators. *Zoologica (New York)* **58**: 45-52.

DEITZ, D. C. AND HINES, T. C., 1980. Alligator nesting in north-central Florida. *Copeia* **1980**: 249-58.

DOWNES, M. C., 1973. The literature of crocodile husbandry. Pp. 93-115 *in* "Crocodiles", IUCN Publ. New Ser. Suppl. Paper No. 41.

FERGUSON, M. W. J., 1981. The application of embryological studies to alligator farming. *Proc. Alligator Production Conf.* (Gainsville, Florida). **1**: 129-45.

FERGUSON, M. W. J., 1985. Reproductive biology and embryology of the crocodilians. Pp. 329-491 *in* "Biology of the Reptilia" Vol. 14 ed by C. Gans, F. S. Billett and P. F. A. Maderson. Wiley and Sons: New York.

FERGUSON, M. W. J. AND JOANEN, T., 1982. Temperature of egg incubation determines sex in *Alligator mississippiensis*. *Nature* **296**: 850-3.

FERGUSON, M. W. J. AND JOANEN, T., 1983. Temperature-dependent sex determination in *Alligator mississippiensis*. *J. Zool. Lond.* **200**: 143-77.

FULLER, M. K., SMITHSON, P. C., KLAUSE, S. E. AND DOERR, P. D., 1983. Growth rates and age of sexual maturity of American alligators in North Carolina. Pp. 1-85 *in* "Status of the American alligator in North Carolina". North Carolina State University: Raleigh.

GOODWIN, T. M. AND MARION, W. R., 1978. Aspects of the nesting ecology of American alligators (*Alligator mississippiensis*) in north-central Florida. *Herpetologica* **34**: 43-7.

JOANEN, T., 1969. Nesting ecology of alligators in Louisiana. *Proc. Ann. Conf. Southeastern Assoc. Game and Fish Comm.* **23**: 141-51.

JOANEN, T. AND MCNEASE, L., 1970. A telemetric study of nesting female alligators on Rockefeller Refuge, Louisiana. *Proc. Ann. Conf. Southeastern Assoc. Game Fish Comm.* **24**: 175-93.

JOANEN, T. AND MCNEASE, L., 1971. Propagation of the American alligator in captivity. *Proc. Ann. Conf. Southeastern Assoc. Game. Fish Comm.* **25**: 106-16.

JOANEN, T. AND MCNEASE, L., 1972. A telemetric study of adult male alligators on Rockefeller Refuge, Louisiana. *Proc. Ann. Conf. Southeastern Assoc. Game. and Fish Comm.* **26**: 252-75.

JOANEN, T. AND MCNEASE, L., 1974. Propagation of immature American alligators in controlled environmental chambers. Unpubl. Rep. to the Southern Zoo Workshop, Monroe, Louisiana.

JOANEN, T. AND MCNEASE, L., 1975. Notes on the reproductive biology and captive propagation of the American alligator. *Proc. Ann. Conf. Southeastern Assoc. Game Fish Comm.* **29**: 407-15.

JOANEN, T. AND MCNEASE, L., 1976. Culture of immature American alligators in controlled environmental chambers. *Proc. World Mariculture Soc.* **7**: 201-11.

JOANEN, T. AND MCNEASE, L., 1977. Artifical incubation of alligator eggs and post-hatching culture in controlled environmental chambers. *Proc. World Mariculture Soc.* **8**: 483-90.

JOANEN, T. AND MCNEASE, L., 1979. Time of egg deposition for the American alligator. *Proc. Ann. Conf. Southeastern Assoc. Fish and Wildl. Agencies* **33**: 15-19.

JOANEN, T. AND MCNEASE, L., 1980a. Classification and population status of the American alligator. Unpubl. Rep. to the 5th working meeting of the IUCN/SSC Crocodile Specialist Group.

JOANEN, T. AND MCNEASE, L., 1980b. Reproductive biology of the American alligator in southwest Louisiana. Pp. 153-9 *in* "Reproductive Biology and Disease of Captive Retiles" ed by J. B. Murphy and J. T. Collins. Contr. Herp. No. 1. Society for Study of Amphibians and Reptiles: Lawrence, Kansas.

JOANEN, T. AND MCNEASE, L., 1981. Incubation of alligator eggs. *Proc. Alligator Production Conf.* (Gainseville, Florida). **1**: 117-28.

JOANEN, T. AND MCNEASE, L., 1984. Louisiana's alligator conservation programme; management of a valuable renewable resource, 1972-1983. Proc. 7th working meeting of the IUCN/SSC Crocodile Specialist Group, Caracas, Venezuela.

JOANEN, T., MCNEASE, L., PERRY, G., RICHARD, D. AND TAYLOR, D., 1984. Louisiana's alligator management programme. *Proc. Ann. Conf. Southeastern Assoc. Fish and Wildl. Agencies* **38**: (in press).

JOANEN, T., MCNEASE, L., TARVER, J. AND BEHLER, J., 1981. Captive propagation of alligators in Louisiana. *ASRA J. Oxford* **2**: 54-69.

KLAUSE, S. E., 1983. Reproductive characteristics of the American alligator (*Alligator mississippiensis*) in North Carolina. Pp. 1-85 *in* "Status of the American alligator in North Carolina". North Carolina State University: Raleigh.

MCILHENNY, E. A., 1935. "The Alligator's Life History". Christopher Publishing House: Boston.

MCNEASE, L. AND JOANEN, T., 1977. Alligator diets in relation to marsh salinity. *Proc. Ann. Conf. Southeastern Assoc. Fish and Wildl. Agencies* **31**: 36-40.

MCNEASE, L. AND JOANEN, T., 1981. Nutrition of alligators. *Proc. Ann. Conf. Southeastern Assoc. Fish and Wildl. Agencies* **31**: 36-40.

METZEN, W. D., 1977. Nesting ecology of alligators on the Okeefenokee National Wildlife Refuge. *Proc. Ann. Conf. Southeastern Assoc. Game and Fish Comm.* **31**: 29-32.

O'NEIL, T., 1949. The muskrat in the Louisiana coastal marshes. Louisiana Wildl. and Fish. Comm. Publ., New Orleans. 152pp.

POOLEY, A. C., 1971. Crocodile rearing and restocking. Pp. 104-30 *in* "Crocodiles", IUCN Publ. New Ser. Suppl. Pap. No. 32.

POOLEY, A. C., 1973. Conservation and management of crocodiles in Africa. *J. South Africa Wildl. Mgmt. Assoc.* **3**: 101-3.

SHIRLEY, M., 1982. Shell thickness of alligator eggs as affected by diets. Unpubl. Rep. to Louisianna Dept. of Wildl. and Fish. 3pp.

SINGH, L. A. K., 1984. Developments in crocodilian research and management. Wildlife Institute of India, Dehra Dun, India. 23pp.

TAYLOR, D., 1984. Management implications of an adult female alligator telemetry study. *Proc. Ann. Conf. Southeastern Assoc. Fish and Wildl. Agencies* **38**: (in press).

WEBB, G. J. W., BUCKWORTH, R. AND MANOLIS, S. C., 1983. *Crocodylus johnstoni* in a controlled-environment chamber: a raising trial. *Aust. Wildl. Res.* **10**: 421-32.

WILKINSON, P. M., 1983. Nesting ecology of the American alligator in coastal South Carolina. Study Completion Rep. to South Carolina Wildl. and Marine Resources Dept., Columbia, South Carolina. 113pp.

YANGPRAPAKORN, U., MCNEELY, J. A. AND CRONIN, E. W., 1971. Captive breeding of crocodiles in Thailand. Pp. 98-101 *in* "Crocodiles", IUCN Publ. New Ser. Suppl. Pap. No. 32.