**THERMOREGULATION AND TEMPERATURE RELATIONS OF ALLIGATORS
AND OTHER LARGE ECTOTHERMS INHABITING
THERMALLY STRESSED HABITATS**

Annual Progress Report

For Period July 1, 1975 - June 30, 1976

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March, 1976

**Prepared for the U.S. Energy Research and Development
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Abstract

The effects of radiation and convection on the equilibrium body temperatures of alligators have been determined. Gaping has been shown to be an effective thermoregulatory device for retarding heat gain in the heads of these animals. Initial time dependent experiments have been completed and ketamine hydrochloride has been shown to be an effective anesthetic for alligators.

Evaporative water loss rates have been measured as a function of size, temperature and wind speed for the turtle Chrysemys scripta. Convection coefficients have been determined and climate spaces are being formulated. Field studies are underway at the Savannah River Ecology Laboratory.

Convection coefficients for largemouth bass, Micropterus salmoides change as a function of temperature and water speed. Steady state heat energy budgets have been computed for this fish.

The effects of arsenic and temperature on the temperature tolerance of larval muskellunge, Esox masquinongy, have been determined. The thermal tolerances of several species of minnows have also been measured. The role of the skin in the control of evaporation from amphibians and reptiles has been assessed.

During the past year one article has been published, two are in press, one is in review, and eight are in preparation. Five masters theses will be completed by July 1976.

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The purpose of this project has been to analyse the biophysical and thermal relationships between large ectotherms and their aquatic environment. During the first 1½ years (October 1974 - March 1976) of the project significant progress has been made in laboratory studies on alligators and turtles, in determination of heat transfer coefficients for largemouth bass, in calculations of energy budgets and in thermal tolerance studies on small fish. Also, studies have been completed that clearly show the effect of skin on the rate of evaporative water loss in amphibians and reptiles.

Overall objectives to be accomplished in the second year of this project were to 1.) construct and refine climate space diagrams for alligators, large turtles and large fish 2.) test these climate spaces in the laboratory, and 3.) carry out field studies on the physiological and behavioral adjustments of turtles in response to changes in water temperature produced by reactor effluents in PAR Pond at the Savannah River Ecology Laboratory.

Alligator studies have concentrated on the verification of energy budget equations and climate spaces that were previously computed for this animal (Spotila, Soule and Gates 1972). During the first year of the project a climate space simulation chamber (C.S.S.C.) was constructed, tested and calibrated. In the summer of 1975 alligators were tested under black body and lighted conditions in this chamber. Initial measurements and computations indicated that the radiation (heat) load in this chamber was inadequate to simulate the radiant flux of a sunny day. After some reevaluation of our experimental system we decided to reconstruct the C.S.S.C.. Sodium vapor lamps were obtained and installed. This provided a much higher light intensity (5000 ft. candles) though still not a full sun condition. We deemed this adequate in light of budgetary constraints and proceeded to recalibrate the chamber. While the original construction and calibration

of the C.S.S.C. had taken up to six months, through the intense efforts of project personnel, especially Kenneth Terpin and Joseph Schubauer, the reconstruction and recalibration took less than three months. Radiation flux readings are seen in Fig 1.

Since completing chamber modification last fall, we have collected a large quantity of data on the equilibrium body temperatures of alligators under several environmental conditions. We have clearly demonstrated the effect of radiation on the body temperatures of these ectotherms (Fig 2). Radiation causes an elevation in body temperature with a greater effect in larger animals. These findings are discussed in a thesis (Terpin 1976) and an article in preparation (Terpin and Spotila 1976).

While conducting these experiments we observed that gaping (holding mouth open) reduced the head temperature of alligators (Fig 3). This led to a series of experiments (laboratory and field) that have proven that gaping is an effective thermoregulatory mechanism in alligators (Spotila, Terpin and Dodson, 1976).

Some time dependent experiments were conducted in the C.S.S.C.. These will be analyzed during the next project year and in conjunction with newly planned experiments will be used to verify the time dependent energy budget model described in Spotila, Lommen, Bakken and Gates (1973).

A final achievement of our alligator research has been the discovery of an effective anesthetic for these animals. In the past hypothermia was the only reliable anesthetic that could be used when performing surgery on alligators (Brisbin 1966, Smith 1975). We have found that ketamine hydrochloride is an effective agent for this purpose. This information is contained in a note in preparation (Terpin, Dodson, and Spotila 1976).

Most of the objectives for the alligator portion of this study have

been completed. Next year, in addition to the experiments planned to complete verification of transient energy budget computations, we will also determine rates of evaporative water loss for the alligator at several temperatures. While some data is available, (Spotila, Soule and Gates 1972) it is very limited and new information on this subject is needed for our computations and those of others (Edward Standora, S.R.E.L. - personal communication).

By June 30, 1976 our turtle study will have made significant progress towards meeting its objectives. Evaporative water loss data have been obtained for a large size range of turtles (Chrysemys scripta), at several temperatures and wind speeds. Regression equations have been calculated to describe the interrelationships among these variables. A typical water loss curve is seen in Fig 4. When published (Foley and Spotila, 1976a, in preparation) this will be one of the most complete water loss studies ever done on a reptile or amphibian.

Robert Foley has been concentrating on our turtle study. In addition to his detailed water loss study, he has also made experimental determinations of the convection coefficient for C. scripta. He did this by constructing aluminum turtles and making measurements under controlled conditions in a wind tunnel (Nordlie and Kreith 1961, Tibbels et al. 1964, Wathen, Mitchell and Porter 1971).

The completion of these laboratory experiments leaves three objectives for our turtle study. First is the production of steady state climate space diagrams. This will be completed by June 30, 1976. The convection and climate space findings will be included in a thesis (Foley 1976) and published in a paper (Foley and Spotila 1976b). Second is to test these climate space predictions in the laboratory. This will be done during the

next project year using the C.S.S.C. (see renewal proposal for next year July 1, 1976 - June 30, 1977). Third is to carry out field studies on the physiological and behavioral adjustments of turtles in response to changes in water temperature produced by reactor effluents. These studies are now underway.

The original plan for field studies of the thermoregulation of turtles in PAR pond at S.R.E.L. (see renewal proposal for 1975 - 1976) - called for two study sites and measurement of turtle body temperatures using radio transmitters. During the summer of 1975 we found that the radio transmitters would not work because they would not transmit from under-water due to the high conductivity of PAR pond water. In addition the two study sites proved to be less than ideal. After gathering some data that summer we made two modifications in our plans. First, we switched to sonic transmitters designed by Mr. Edward Standora of S.R.E.L. These were used in October, 1975 and produced excellent results. Second, we moved the "Hot" site closer to the source of the heated effluent. We found that this gave us higher environmental temperatures and was a more realistic measure of the effect of hot water on turtle behavior. Throughout the field study our micro-climate weather station has functioned perfectly and has provided detailed information on the physical factors affecting turtle behavior.

Robert Foley has had the primary responsibility for this study and will continue to direct it during the next grant year. We anticipate concluding the initial phase of this field study by the end of August, 1976. Data analysis and preparation of manuscripts will be undertaken during the next project year. We anticipate that this field study will continue next year assuming that our data analysis shows that it would continue to provide important new information on turtle thermoregulation.

Largemouth bass (Micropterus salmoides) studies have been very successful. Dale Erskine has produced a heat energy budget for this fish and has determined heat transfer coefficients in the laboratory. These coefficients are affected by temperature and water speed (Fig 5). He is presently writing his thesis (Erskine 1976). An article will be prepared by June 30, 1976 (Erskine and Spotila, in preparation). Because of the technical difficulty involved in determining convection coefficients we have not yet been able to conduct a complete set of heating and cooling experiments on live bass. Therefore, during the next project year we plan to complete this data set and to continue work on development of a climate space for this fish.

Three studies have been completed on the effect of environmental factors on the thermal tolerance of fish. In the first (Bonin 1976, Bonin and Spotila 1976) the effect of development on the temperature tolerance of muskellunge fry Esox masquinongy was determined under hatchery conditions. In the second (Paladino 1976, Paladino and Spotila 1976) the effect of arsenic on the temperature tolerance of muskellunge fry was determined in the laboratory. The third study compared the thermal tolerance of several species of western New York minnows (Schubauer, Kowalski, Scott and Spotila 1976).

A final study has been completed during the past year. In this study we determined the role of the skin in the control of evaporative water loss from amphibians and reptiles. Exact duplicates of living animals were formed out of agar. These acted as controls and allowed the computation of skin resistance for these animals (Spotila and Berman, 1976).

During the past year one article has been published (Terpin, Spotila and Koons 1976), two articles are in press (Hassan and Spotila, 1976;

Spotila and Berman 1976), one is in review, and eight are in preparation. Five masters theses will be completed by July 1976. Six papers will be presented at the A.I.B.S. meeting in New Orleans in June, 1976.

The project director, James R. Spotila, spent 100% of his time on this investigation in July and August, 1975. He spent 50% of his time on the project during the academic year and anticipates spending 50% of his time on the project during the remainder of the academic year.

Bibliography

- Bonin, J. 1976. The Physiological ecology of larval muskellunge and norlunge: Temperature tolerance and growth rates under hatchery conditions. M. A. thesis, April 1976.
- Bonin, J. and J. R. Spotila 1976. Temperature tolerance and growth rates of larval muskellunge and norlunge reared under hatchery conditions. Article in preparation.
- Brisbin, I. L. Jr. 1966. Reactions of the American alligator to several immobilizing drugs. Copeia 1966: 129 - 130.
- Erskine, D. 1976. Heat transfer and thermoregulation in the largemouth bass, Micropterus salmoides. M. A. thesis, June, 1976.
- Erskine, D. and J. R. Spotila. 1976. The effect of water movement on heat exchange in fish. Article in preparation.
- Foley, R. E. 1976. Convection coefficients and energy budget equations for Chrysemys scripta. M. A. thesis, July, 1976.
- Foley, R. E. and J. R. Spotila. 1976a. Evaporative water loss in the turtle, Chrysemys scripta. Article in preparation.
- * Hassan, K. C. and J. R. Spotila. 1976. Effect of acclimation on the temperature tolerance of young muskellunge fry (Esox masquinongy). Thermal Ecology, vol. II, In Press.
- Nordlie, R. and F. Kreith. 1961. Convection heat transfer from a rotating sphere. International Developments in Heat Transfer. A. S. M. E., New York.
- Paladino, F. 1976. The effect of arsenic on the temperature tolerance and survival of larval muskellunge. M. A. thesis, June 1976.
- Paladino, F. and J. R. Spotila. 1976. The effect of arsenic on the temperature tolerance and survival of newly hatched muskellunge fry (Esox masquinongy). Article in preparation.

- Schubauer, J. P., K. T. Kowalski, C. L. Scott and J. R. Spotila. 1976.
The critical thermal maxima of minnows from two western New York
streams. Article in preparation.
- Smith, E. N. 1975. Thermoregulation of the American alligator, Alligator
mississippiensis. Physiol. Zool. 48: 177 - 194.
- Spotila, J. R., O. H. Soule and D. M. Gates. 1972. The biophysical ecology
of the alligator: Heat energy budgets and climate spaces. Ecology
53: 1094 - 1102.
- Spotila, J. R., P. W. Lommen, G. S. Bakken and D. M. Gates. 1973. A
mathematical model for body temperatures of large reptiles: Implications
for dinosaur ecology. Amer. Natur. 107: 391 - 404.
- Spotila, J. R. and E. Berman. 1976. Determination of skin resistance and
the role of the skin in controlling water loss in amphibians and
reptiles. Comp. Biochem. Physiol. In Press.
- Terpin, K. M. 1976. Radiation, convection and energy budget calculations
for the alligator, Alligator mississippiensis. M. A. Thesis, July,
1976.
- Terpin, K. M., J. R. Spotila and R. R. Koons. 1976. Effect of photoperiod
on the temperature tolerance of the Blacknose Dace, Rhinichthys
atratulus. Comp. Biochem. Physiol. 53A: 241 - 244.
- Spotila, J. R., K. M. Terpin and P. Dodson. 1976. Mouth gaping as an
effective thermoregulatory adaptation in the alligator, Alligator
mississippiensis. Science. In Review.
- Terpin, K. M. and J. R. Spotila. 1976. The effect of radiation and
convection on the body temperature of the alligator, Alligator
mississippiensis. Article in preparation.

- Terpin, K. M., P. Dodson and J. R. Spotila. 1976. Notes on the use of ketamine hydrochloride as an anaesthetic in alligators. Note in preparation.
- Tibbals, E. C., E. K. Carr, D. M. Gates, and F. Kreith. 1964. Radiation and convection in conifers. Amer. J. Bot. 51: 529 - 538.
- Wathen, P., J. W. Mitchell and W. P. Porter. 1971. Theoretical and experimental studies of energy exchange from jackrabbit ears and cylindrically shaped appendages. Biophysical Journal 11: 1030 - 1047.
- *Foley, R. E. and J. R. Spotila. 1976b. Convection coefficients and steady state climate spaces for the turtle, Chrysemys scripta. Article in preparation.

Figure Captions

- Figure 1. Radiation flux readings on the floor of the Climate Space Simulation Chamber.
- Figure 2. The effect of radiation on the equilibrium body temperatures of alligators.
- Figure 3. The effect of voluntary gaping on alligator temperatures during a heat exchange experiment. Circles indicate palate temperature, triangles indicate head temperature and squares indicate body temperature. Bold lines indicate period of gaping.
- Figure 4. Rate of evaporative water loss for a range of sizes of the turtle, Chrysemys scripta at 25°C with a wind speed of 100 cm sec⁻¹.
- Figure 5. A three dimensional coordinate system relating the heat transfer coefficient, h_c , to temperature differential between the casting and water, T , and water velocity, v . Solid, vertical lines indicate the range of the pooled data ($n = 10$), solid, horizontal lines the mean, and open rectangles one standard deviation to each side of the mean. A least squares fit of all data ($n = 160$) has been included. Axes representing the heat transfer coefficient and temperature differential follow the plane of the page, the velocity axis is into the plane of the page.

RADIATION VALUES ($\text{cal cm}^{-2} \text{min}^{-1}$)
FOR MODIFIED CHAMBER AT 30.0°C

$$\text{AVG. } q_{\text{abs}} = .87 \text{ cal cm}^{-2} \text{min}^{-1}$$

FIGURE 1

BODY TEMPERATURE ($^{\circ}\text{C}$)

FIGURE 2

FIGURE 3

FIGURE 4

FIGURE 5