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

Annual Progress Report

**James R. Spotila
Department of Biology
State University College
1300 Elmwood Avenue
Buffalo, New York 14222**

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ABSTRACT

An environmental chamber has been modified into a climate space simulation chamber for use in thermoregulation studies on alligators and turtles. Controlled wind flow and radiation flux characterize the test section of this chamber. Preparations are at an advanced state for field studies on the thermoregulation of turtles in PAR pond at the Savannah River Ecology Laboratory. Field sites have been chosen and equipment assembled and tested. Radio transmitters are now being constructed to monitor turtle body temperatures. A preliminary climate space for a turtle, Pseudemys scripta, has been formulated. The heat energy budget for terrestrial animals has been modified to apply to largemouth bass (Micropterus salmoides).

Laboratory studies have shown that photoperiod affects the temperature tolerance of blacknose dace, Rhinichthys atratulus, and age affects the thermal tolerance of newly hatched muskellunge fry, Esox masquinongy.

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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 five months (October, 1974 - February, 1975) of this initial project year significant progress has been made in laboratory studies on alligators and on construction of energy budgets and climate spaces for turtles and fish. In addition thermal tolerance studies on small fish, underway since early 1974 have been incorporated into this project as adjunct studies since their objectives and methodology complimented our work on large fish.

Specific long term aims for this project as stated in the initial research proposal were to 1.) conduct laboratory studies on the physiological and behavioral bases for thermoregulation in alligators and large turtles, 2.) carry out field studies on the body temperatures and thermoregulatory behavior of alligators, turtles, and bass in thermally loaded environments at the Savannah River Ecology Laboratory, 3.) construct energy budgets and climate space diagrams for all of the species being studied and 4.) begin measurements on the body temperatures of free swimming muskellunge in Lake Chautauqua, New York.

Original plans for laboratory studies on alligators and turtles called for placing animals into a controlled environment chamber and subjecting them to different microclimates. Preliminary studies and detailed energy budget calculations indicated that tests in a walk-in environmental chamber would not be definitive. The primary problem was that excessive turbulence upset our computations of convection coefficients and threatened to invalidate our attempts to verify mathematical models for these animals under controlled conditions. Therefore, considerable effort has been expended in redesigning and rebuilding the environmental chamber into a climate space simulation chamber (C.S.S.C.) so that it now provides controlled environmental parameters similar to those in a windtunnel (Figure 1). Wind profile data are presented in Figures 2 to 4. These indicate that the climate space simulation chamber provides stable wind flow characterized by very reduced turbulence. Radiation flux readings are seen in Figure 5. Distribution of radiation flux is uniform on the floor of

Fig. 1.

Diagram of climate space simulation chamber. A deflector (D) dispenses air flow coming from the fans (F). The honeycomb (H) acts as a diffuser to give laminar air flow through the test section (T). A sheet of $\frac{1}{4}$ inch plexiglass (P) separates the laminar air flow in (T) from the turbulent air flow in the remainder of the chamber. Visible and thermal radiation from fluorescent and incandescent lights of the main light bank (L) and heat lamps of the auxiliary light bank (L_a) readily penetrate the plexiglass.

the test section. Experiments are now underway to determine if differential heating, head-body temperature differences and attendant physiological adaptations exist in the alligator. Components of the steady state and time dependent body temperature models are also being tested. Half of these experiments are to be completed by June 30, 1975, the remainder between July 1, 1975 and December 31, 1975. Laboratory studies on large turtles are also beginning. These include the effect of temperature and wind speed on evaporative water loss from Pseudemys scripta and preliminary tests of body temperature responses of this turtle to controlled microclimates in the C.S.S.C. Details of these alligator and turtle experiments are discussed in the renewal proposal for next year (July 1, 1975 - June 30, 1976).

Preparations for field studies on alligators and turtles are now at an advanced stage. Field work will take place in June, 1975 at the Savannah River Ecology Laboratory (SREL). This will involve a study of the body temperatures and behavior of P. scripta in thermally loaded portions of PAR pond. Radio transmitters (Figure 6) are now being constructed based on a design by Stebbins and Barwick (1968). Components of a microclimate station to monitor solar radiation, environmental temperatures, wind speed and humidity have been acquired and tested.

The core unit of this system is a Kaye System 8000 digital multipoint recorder. An Eppley pyrliometer and Funk radiometer measure radiation fluxes. Twenty thermocouples measure environmental temperatures and a Hygrodynamics humidity system records moisture content of the air. All of these parameters are monitored and recorded on the central Kaye unit. Wind speed is measured with a sensitive anemometer and hot wire anemometer. These instruments are read separately. Two field sites have been picked on PAR pond, one heated and one unheated, and arrangements have been made for fencing in these areas, capturing turtles and setting up the microclimate station. A house trailer maintained by SREL at its PAR pond boat dock will serve as our

field headquarters (J.W. Gibbons, personal communication).

Field studies on the behavioral thermoregulation of alligators in PAR pond are being curtailed because Mr. Edward Standora of the SREL is undertaking a major study on this subject for his Ph.D. dissertation. We are cooperating by sharing our technical expertise, his in the area of telemetry and mine in the area of environmental monitoring systems.

Analytical work has continued throughout this year in an attempt to refine the mathematical models already available for alligators and to construct energy budgets and climate space diagrams for turtles and fish. A preliminary climate space has been formulated for the turtle P. scripta (Figure 7). It indicated that wind speed has a large effect on the size of the climate space. In still air ($v = 10 \text{ cm sec}^{-1}$) this turtle cannot remain in the sun when air temperature goes above 16°C . Yet on a windy day ($v = 500 \text{ cm sec}^{-1}$) it can bask for long periods of time at ^etemperatures as high as 34°C . This turtle probably uses water as a black body substitute to avoid extreme environmental conditions as has been demonstrated for the alligator by Spotila, Soule and Gates (1972). This first approximation climate space is now being refined and will be tested during the next year.

Our analytical attempts to define the climate space of a fish have been very successful. To date this effort has concentrated on the application of heat energy budgets to the energy exchange of a largemouth bass, Micropterus salmoides. An ordered set of assumptions has been developed that delimits available modes of heat transfer in water. The heat energy budget for terrestrial animals as developed by Gates (1969), Birkebak (1966) and Porter and Gates (1969) has been modified to apply to largemouth bass (M. salmoides). An energy budget equation for a bass, swimming at a depth where absorbed radiation is negligible, has been formulated (C00-2502-3). This is discussed in detail in the Renewal Proposal.

Complimenting this analytical work for fish have been studies on the effect

of convection on the cooling rates of rainbow trout, Salmo gairdneri, (Figure 8). Trout exposed to turbulent water flow cooled much faster than trout cooled in still water. These preliminary experiments indicated that convection played an important role in heat transfer between fish and their aquatic environment. Further experiments on convection are planned for 1975 - 1976. (See Renewal Proposal for details).

Because of our recent findings on convection effects in fish and initial success in defining energy transfer parameters for bass, field studies on muskellunge have been postponed until late summer 1976 so that we can concentrate on exploring these new developments in the laboratory.

Thermal studies on small fish have been incorporated into this project on an adjunct basis. These have included a study on the effect of photoperiod on the temperature tolerance of the blacknose dace, Rhinichthys atratulus, and a study on the effect of temperatures on survival and growth of muskellunge fry, Esox masquinongy. These studies compliment our research on large fish because they focus on physiological mechanisms of adaptation of fish to changes in their thermal environment and on the thermal relations of a critical life history stage of very large fish - newly hatched fry.

Support from this contract allowed early completion of these studies. Two manuscripts have been submitted for publication (C00-2502-1 and C00-2502-2) and two are in preparation (see bibliography).

By June 30, 1975, studies on the thermoregulatory behavior of the alligator will be well underway. Definitive information should be available on the effect of mouth gaping and blood shunting on the control of head temperature in this animal. Water loss experiments on P. scripta will be partially completed and experiments to determine convection coefficients for fish and turtles will be ongoing. The first month of the PAR pond biotelemetry study on turtles will be completed. Results of this first year's research effort will be presented in a paper at the Second Thermal Ecology Symposium in Augusta, Georgia in April

and in three papers at the American Society of Ichthyologists and Herptologists meeting in Williamsburg, Virginia in June.

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

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ADDITIONAL PUBLICATIONS OF PROJECT PERSONNEL

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Fig. 2. Cross sectional wind velocity profile of climate space simulation chamber. Profile taken 16.5 inches from left diffuser in fig. 1. Range of wind speeds is given for each test block.

Fig. 3. Longitudinal wind velocity profile of climate space simulation chamber. Profile taken along center line of test section. Range of wind speeds is given for each test block.

Fig. 4. Diagramatic representation of wind flow in test section of climate space simulation chamber. Length of arrow indicates wind speed. Straightness of arrow indicates degree of turbulence.

Fig. 5. Radiation flux profile of floor of climate space simulation chamber. Values given are means for radiation absorbed by an alligator at various points along the floor of the test section.

Fig. 2. WIND VELOCITY CALIBRATION OF THE CHAMBER (CROSS SECTION)
TRANSECT #6
SCALE: 1cm = 3"
WIND FLOW: OUT OF PAPER

Fig. 3 WIND VELOCITY CALIBRATION OF THE CHAMBER (LONGITUDINAL SECTION)

TRANSECTS: 6, 13, 19

SCALE: 1CM = 3"

WIND FLOW: ACROSS PAPER

H = 1 MPH (WIND VELOCITY)

Figure 4.

FIG. 5. AMOUNTS OF RADIANT ENERGY AN ALLIGATOR WOULD
ABSORB AT VARIOUS POINTS ALONG THE FLOOR OF THE
CLIMATE SPACE SIMULATION CHAMBER, Full Lights 33°C.
(5mm = 3 INCHES)

Oscillator

Transmitter

27 MHz Temperature Transmitter

Fig. 6. Circuit diagram for radio transmitter that will be used to monitor body temperatures of turtles in PAR pond.

Fig. 7. Preliminary climate space diagram for *Pseudemys scripta*. Left boundary represents conditions of radiation and temperature the turtle encounters when exposed to a clear sky with no sun. Right boundary represents conditions it encounters in full sun. Upper lines are drawn for a body temperature of 41°C and lower lines for a body temperature of 1°C. Solid lines represent a wind speed of 500 cm sec⁻¹ and dashed lines represent a wind speed of 10 cm sec⁻¹.

Fig. 8. Cooling curves for a 17.6 g rainbow trout. A. Live, B. Dead. Solid circles represent still water, open circles represent moving water.