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Report

to the

Atomic Energy Commission

On the second year's
research

Energy Budgets of Animals:

Behavioral and Ecological Implications

Report No. AT(11-1) - 2270 - 2

by the

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Abstract

Climatic effects on predator biomass requirements and its implications for prey population dynamics are being explored using heat transfer models of animals and the microclimates they inhabit. Thermal ecology studies of a semi-aquatic endotherm have been shelved pending further dry fur heat transfer studies. Enhancement and reductions of convection of object (model plants) with different projection densities is described.

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Overview and Detailed Summary of Past Year's Research

The major long term goal of our group is understanding population dynamics from a mechanistic point of view. A subset of this problem is the evaluation of the consequences of climatic change, both natural and manmade, on populations of animals in ecosystems. Over the past five years, we have developed transient energy balance models for interactions of ectotherms with their physical environment (Beckmen et al, 1973; Porter et al, 1973; Porter & Tracy, 1974). We have simultaneously developed a general micro-meteorology model for desert regions that allows us to specify micro-climates and therefore, energy fluxes into and out of animals in those micro-climates. To illustrate the principles involved in our proposed research on energy balance modeling of ectotherms and endotherms in deciduous regions, I will briefly describe work we have completed on a desert lizard and then describe some of the garter snake-frog predator-prey modeling we have done these past two years with AEC support, and then describe some of our recent AEC supported research on convection from objects with different densities of projections (density effects on air flow patterns through bounded "porous" media).

Figure 1 illustrates the flows of energy into and out of both the substrate and the animal on the substrate.

Energy balance equations can be developed for both the animal and the substrate as described in Beckman, Mitchell and Porter (1973). The basic equation states that:

$$E_{in} + E_{gen} = E_{out} + E_{st}$$

More explicitly,

$$E_{in} = \text{solar absorbed}$$

$$= \text{direct solar \& scattered solar \& reflected solar}$$

$$= \alpha_S S A_p + \alpha_s s A_s + \alpha_r A_r (S + s)$$

$$E_{gen} = \text{metabolic heat production} = M$$

$$E_{out} = \text{net thermal radiation exchange with sky \& net thermal exchange with ground + convection + conduction + evaporation}$$

$$= \epsilon \sigma F_{s-sky} A (T_s^4 - T_{sky}^4) + \epsilon \sigma F_{s-grd} A (T_s^4 - T_{grd}^4) + h_c A (T_s - T_{air \text{ local}}) + k A_c (T_s - T_{deep}) + L.E. h_D A (\rho_s - \rho_{air})$$

$$E_{st} = \text{stored thermal energy} = mc \frac{dT_s}{dt}$$

I will spare the reader from the many equations involved in both the micro-climate modeling and the animal energy balance modeling. If more detailed information is desired on the equations involved, the first two papers

cited on the first page explain them in detail. Evaluation of the parameters in these equations allows us to predict the temperature of an ectothermic animal at any point in time throughout the year. Figure 2 illustrates a desert iguana temperature simulation for a typical 15th of July in Palm Springs, California. Assuming a desert iguana is standing on the surface throughout the day, the solid line shows the animal's temperature throughout the day. Since the animal has a preferred temperature range between 38°C and 43°C, we expect the animal to be out only during the period of time when he could maintain his body temperature between these limits. Thus, this simulation predicts that an animal that cannot get up above the surface must have a bimodal period of activity for this time of year. We have done extensive tests of the energy balance model predictions in the laboratory, in the Biotron at the University of Wisconsin, and in the Mojave Desert where we have continuously observed these animals for periods up to two weeks in the spring, summer, and fall. For exposed, open burrows on flat surfaces, we can predict emergence times to at least within half an hour and often within fifteen minutes. Times of retreat are often much sooner than we predict. This very well may be due to constraints on the animal in terms of available water for evaporation as discussed in Porter,

Mitchell, Beckman, and DeWitt (ibid.).

Monthly simulations done for the entire year are illustrated in figure 3. Here the 15th of July may be compared with figure 2 to illustrate how, starting from midnight on July 15, the constant temperature lines for the animal's body temperature are used to predict emergence, time spent in the open, time spent in the shade, and time spent in the burrow. This kind of a plot also illustrates when the animals should be entering hibernation in the fall and emerging in the spring. Available data in the literature (Norris, 1967; Mayhew, pers. comm.) show that these animals emerge some time in early March and enter hibernation some time in late September or early October. Since these simulations are done using the average Palm Springs temperatures for ten years, we consider this to be a reasonable first approximation to modeling the annual activity patterns of desert iguanas. In Porter et al (ibid.) this modeling is extended to include effects on activity patterns of bushes in the environment, food and water requirements and a single hypothetical predator-prey interaction (fig. 4).

Garter snake - Frog Predator-prey Interactions

Holling (1966) has done a number of fascinating predator-prey studies. The stimulus from his papers prompted us to investigate potential ramifications of predator-prey

analyses using activity pattern overlap. We examined garter snakes (Thamnophis sirtalis) and the leopard frog (Rana pipiens). These animals occur over a wide range of latitudes and since they are near water or in water, they are potentially subject to thermal pollution effects which may alter their activity patterns and affect survival of frog eggs and tadpoles.

The northern location we chose was Pellston, Michigan. Climatological data is available for this area and extensive experiments have been done principally by Dole (1965) on Rana pipiens. Garter snake ecology was also done for this region by Carpenter (1952). We chose as a southern location, Aiken, South Carolina. Again climatological data are available and extensive observations of both garter snakes and frogs have been made there. The capability for applying energy and mass balance equations to determine activity patterns of frogs was developed by Tracy (1972). It was clear based on these frogs' wide temperature tolerance that they would be active at virtually anytime of the year except when the air temperature dips below freezing. The garter snake has much less time for activity because of its minimum activity temperature of 15°C. An analysis of an energy balance equation on this animal showed us that it was very tightly coupled to soil temperature despite the fact we measured a solar absorptivity of 88% on our DK-2A spectro-

reflectometer. Since these snakes typically inhabit moist, tall grassy shady areas, we examined micrometeorological studies of dense vegetative cover by Rose et al, (1971), Byrne and Rose (1972), and Goncz and Rose (1972). Their studies indicate that air temperature profiles down into deep vegetation are essentially equal to air temperatures at 200 cm above the ground. Since soils are moist where frogs and these snakes occur, we could expect that soil surface temperatures should stay within a few degrees of air temperature. Furthermore, since sunlight would be greatly attenuated passing through dense vegetation cover, there should be little solar intensity driving soil temperatures up. Thus we assumed as a first approximation that ground surface temperatures were the same as air temperature at 200 cm. As we will see below, errors in predicted temperatures of this order of magnitude make little difference in the conclusions.

Figures 5,6, and 7 show calculations for the activity times of garter snakes in Michigan and South Carolina and an extreme case in South Carolina where an arbitrary 10°C increase in air temperature has been added at all times to simulate an extreme situation of thermal pollution. The minimum of 15° for activity seems to be typical for a variety of species of garter snakes. Carpenter (ibid) found that the mean preferred temperature for Thamnophis sirtalis sirtalis, T. s. sauritus, and T. butleri is

approximately 25.6°C. He found activity temperatures to lie between 20°C and 30°C. Heckrotte (1961) demonstrated that T. radix is not active below 15°C. Stewart (1965) determined that T. s. concinnus and T. ordinoides prefer temperatures between 25 and 30°C, have a minimum preferred temperature of 17°C and tolerate a maximum of 35°C. Kitchell (1969) demonstrated the T. sirtalis has a minimum preferred temperature of 16°C when shedding and has higher minimums for other activities. We have not yet adjusted the results for acclimation in this first simulation, though Jacobson and Whitford (1970) have shown acclimation effects on the physiology of T. proximus.

Figures 5,6 and 7 were computed using the 10 year average temperatures between 1960 and 1969 for each region. The predictions suggest that garter snakes should be active about 20 weeks in Michigan, about 40 weeks in Aiken, South Carolina, and should be active year round if Aiken should have 10°C thermal pollution. Field observations near Pellston by Dan Ritschoff and near Aiken by Whit Gibbons (pers. comm.) indicate that the length of seasonal activity in these regions is very close to what we have predicted.

Since the climate fluctuates from day to day, particularly in northern regions, it would seem essential to examine the day to day sequence of temperatures particularly in the spring and fall when some days would not reach 15°C and therefore prevent garter snakes from actively hunting or digesting (Skoczylas, 1970). Figure 8 is Weather Bureau

data taken for April and May in Pellston, Michigan in the year 1960. This particular year had monthly averages that were nearly identical to the 10 year average for that location. The first day that exceeded 15°C maximum temperature was about the 15th of April. As late as May 23, there was a day whose maximum temperature did not exceed 15°C. Since garter snakes can apparently only hunt at body temperatures above 15°C, it seemed that the frequency and spacing of days exceeding 15° might be of vital importance to an animal freshly out of hibernation that is trying to obtain enough food to survive. This concept is illustrated in Figure 9 where the first part of May in 1960 is examined in detail. The first two days the animal could not exceed 15° at any time and it is not until approximately 1000 hours that the animal could begin to hunt. If prey is captured at 1600 hours on May 4th, only about 3 hours would be available for digestion since the snake body temperature drops below 15°C at about that time. Since the following day is cooler, only about 3 hours are available during that day to carry on digestion. It is apparent that for the animal to survive, the digestion rate must be rapid enough to permit the snake to obtain sufficient energy to make up for times when it is too cold to hunt or digest. Figures 10 and 11 show the potential calories available from digestion if we assume the 50 gm snake has a full stomach and is exposed to average climatic conditions for Michigan and South Carolina. Also

shown near the bottom of the graph is the metabolic requirement for the animal for each day of the year. Skozcylas' careful work using X-rays and dissections demonstrated that digestion was completely arrested at 5°C, at 15°C was very slow or intermittant and was most rapid at about 25°C. Since there is no data in the literature on digestion as a function of temperature for the garter snake, we have used Skozcylas' 1970 data on Natrix natrix for our calculations of digestion for the garter snake. Unfortunately, he made no determinations of digestion at 30°C and the digestion rates he observed at 35°C were lower than rates at 25°C. We therefore assumed a Q_{10} increase of 2 for digestion rates between 25°C and 30°C. We assumed a logarithmic decrease from a projected 30°C value to the measured 35°C value, and we assumed that no digestion occurs above 40°C. Thus if garter snake digestion rates are similar to those of Natrix, then the rate of digestion is orders of magnitude higher than the rate of metabolism for any given day. Thus, in modeling the garter snake, the daily sequence of temperature is not significant and averages are sufficient.

Integrated metabolism was computed (Porter and Tracy, 1974) using metabolic rates typical of snakes based on work by Jacobson and Whitford (ibid), Dmi'el (1967), Dmi'el and Borut (1972), Dmi'el (1972) and others.

Integration of the area under the metabolism curves for Pellston, Michigan and Aiken, South Carolina yield the

total energy requirement for a 50 gm garter snake for an entire year and are shown in Table 1. A 50 gm garter snake would need approximately 79,500 calories to maintain itself for an entire year. The total caloric requirement needed allows one to estimate the biomass required for the snake to maintain itself for a year. We assumed a low digestive efficiency of 36%, inferring this from data of Brown (1958). The reader can easily revise our calculations to reflect other digestive efficiencies. If our assumptions are used, less than six 40 gm frogs are needed for maintenance requirements for an entire year. The results of Myer and Kowell (1971) on king snakes suggest that their digestive efficiencies are typically higher than those we are assuming. Furthermore, work by Vinegar, Hutchinson and Dowling (1970) on pythons shows digestive efficiencies above 50%. Thus our biomass estimates for garter snake maintenance are probably high.

Table 1 shows that if the biomass required for reproduction is considered, an additional 136 grams of biomass is needed. This assumes a maximum production of young of 34 individuals annually (Hoffman, 1970). Assumptions as to assimilation efficiency and percent water content of snake biomass are indicated on the table. The number of frogs needed to meet these biomass requirements varies from slightly more than three 3rd year frogs to 136 newly emerged frogs. It seems clear that the simplest feeding strategy for snakes would be to attempt to obtain the largest frogs possible and thereby reduce the amount of time needed

for hunting. The consequences for the frog population might be very different depending upon snake feeding strategies.

A final consideration in this estimation of total biomass requirements for garter snakes would be an increase in size of the animal. We assume a doubling of weight due to growth and a 25% assimilation efficiency (Brown, (ibid)). We find an additional 200 grams biomass needed. This is nearly the same amount as required for annual maintenance in Michigan.

Total biomass requirements for maintenance, reproduction, and growth for 50 gm garter snakes are about 550 gm wet weight of biomass for Pellston, Michigan area and approximately 700 gms for Aiken, South Carolina. If maintenance only is considered, only half of the above biomass requirements are needed to support an animal for an entire year. Thus, an animal in the Pellston, Michigan area that is eating only 3rd year frogs could survive on six frogs per year. With 20 weeks of activity time available, that would be an average of one frog a month to less than one frog a week. Similar feeding intervals would be expected for Aiken, South Carolina where there are an average of 40 weeks of available activity time. Our calculations also suggest that a 10° increase in year 'round temperatures in Aiken would double the maintenance requirements of garter snakes but only increase the overall annual requirement by about 50%. This assumes no significant temperature effect on the biomass requirements of developing embryos.

Since an individual snake would seem to consume relatively few frogs, we examined an active endotherm predator to compare its biomass requirements with those of the ectothermic garter snake. We chose mink to make some preliminary estimates of their biomass requirements. As table 1 indicates, a mink's daily requirement for maintenance is approximately the same as the annual maintenance requirement for a 50 gm garter snake. On an equivalent weight basis, 50 gm of mink requires approximately 26 time more prey biomass for maintenance than a 50 gm garter snake. All data used in the calculations were taken from Farrell and Wood (1968). We have not made any estimates of biomass requirements for reproduction and growth in mink, but the mass required must be significant. Since reproduction in both snake and mink takes place over a relatively narrow time period of about 2 months, it must be during reproduction when hunting efficiency must be greatest to obtain several times the biomass needed for maintenance alone. Failure to obtain sufficient biomass for production of young will result in fewer offspring. Thus "hunting efficiency" would not only depend on hunger level, but also on the reproductive or endocrine state of the female. The short time interval for reproduction each year may well be the crucial period of time determining population size the succeeding year.

These simple predator-prey analyses have several implications. First, neglecting reproduction and growth, a

limiting case of biomass relationships between ectothermic predators and their prey could be a ratio of 1:4 rather than the usual 1:10 ratio usually assumed. Obviously such a low ratio could not long persist since it precludes predator reproduction. However, it is likely that a population of ectothermic predators could survive for at least a year without reproducing. A second implication is that endotherm biomass densities must be very much less than ectotherm predator biomass densities because of the more rapid metabolic rate of endotherms. Even though on a per gram basis endotherm biomass requirements are 26 times those of an ectotherm on a per gram basis, endotherms frequently outweigh ectothermic predators. Thus on an individual whole organism basis, vertebrate ectotherm-endotherm predator ratios may approach 400 to 1.

Finally, it would seem that if thermal pollution were to increase average temperatures by 10°C , we could expect a doubling of biomass maintenance requirements by ectothermic predators. Endothermic predators may have to shift activity patterns to cooler times of day.

Recently our computer simulations have explored the consequences for a frog population of garter snakes concentrating their predation on various age classes of frogs, e.g. sexually mature adults vs immature juveniles. We hoped to evaluate the effect of size selection of prey (frogs) on their population stability. At garter snake

and frog densities that are commonly observed in the field, any snake feeding strategy seems suitable, since there is so little impact on the frog population. An endothermic predator such as a mink, however, is capable of having a large impact if the animal can find enough frogs in a short enough time period to satisfy its needs. From extensive studies on mink predation (mostly scat analysis), in Sweden and Norway, it has been found that wild mink shift their food depending on local abundance. For example, in the spring of the year, when birds are nesting, most of their food is bird eggs (and adults when they can catch them). In early summer they switch to crayfish which are abundant. In early fall, they switch to frogs and when winter approaches they switch to mice and other small mammals. The criteria for these switches is unknown. Also unknown is the role of climatic influence on their preferences, e.g. the energy the animal is willing to expend to obtain a food of a given type. The role of environmentally mediated activity times for both predator and prey types is also unknown. Experiments to try to resolve some of these questions, which relate to thermal modification of the environment, are described in the proposed technical program accompanying this report. We have chosen this approach rather than the field study proposed last year for many reasons. First, computer simulations, the literature, and discussions with people around the country doing field studies on frogs, snakes and endo-

therms have demonstrated that to keep track of the number of variables needed to do a first rate job, we would need a substantial increase in funding, which was not possible. Second, the local site we would like to use if funding does become available is not completely guaranteed as to its long term integrity yet, though it looks more certain all the time. Third, the special strengths of our group lie in the development and short term testing of animal-environment interactions that allow a broad range of predictions without extensive field observations. Our problem is now to find a first rate field site where there is already extensive research being done by competent field people and collaborate with them. We have been exploring two such sites, one in Michigan and another in Alberta, Canada and have had excellent cooperation at both. No final decision has been reached yet on which or both sites will be used to validate model predictions.

In summary, energy balance equations for microclimates and animals can be used to predict activity times, food requirements, and potential predator-prey interactions. Preliminary analyses of a simple predator-prey system has raised many more questions than it has answered. The model has pointed to a lack of vital information in the literature on digestive efficiencies, growth rates in the field, biomass requirements for reproduction, and biomass requirements for early growth to maturity. Physiological measurements on a

variety of active endotherm predators are also absent from the literature. Also, information on number of young produced as a function of food available to the mother of virtually any wild mammal is lacking. Such data is needed if we are to develop mechanistic models for multispecies predator-prey interactions in biomes.

Muskrat Energy Exchange

The proposed study on heat transfer through muskrat fur and muskrat ecology has been set aside for at least two years and possibly more. We need more fundamental data on heat transfer of dry fur before we can tackle the wet fur problem. Our engineering colleagues who are jointly funded with us on another grant have made very good progress in unraveling the problem but there is still much to do. Muskrats seem so labile in their food habits and make up such a small component of any predators' diet, that it seems they will be nearly unaffected by any change in the physical environment short of raising the water temperature to 40°C year 'round. Mr. Muth who is supported on this grant has shifted to an entirely different project as described in the technical proposal.

Basic Problems In Air Flow Through Bounded Semi-porous Media

Although it was not in the proposal last year, we have been doing some fundamental research on flow through bounded semi-porous media. This research was initiated principally due to discussions with Bill Osburn. We have been interested in this problem for sometime because it is so fundamental to heat transfer problems in fur, grass, bushes and other kinds of vegetation. It has important implications for particle fallout on the lee side of vegetation. Finally many animals utilize the convective environments of vegetation to either enhance or diminish their convective heat exchange. At present, there is no way of even estimating this effect for an animal in or behind vegetation.

We chose to start with as simple a model as possible and gradually add complexity. That initial model was a "cactus". The hypothesis was this: Projections on a surface at very low densities induce turbulence and greater convection and average wind speeds. As the density of projections increases, eventually they will become so thick that they will begin to insulate the surface and slow down air movement thereby decreasing convective effects. Tregear's paper (1965) has some hint of this for animal fur, but it was never followed up. The plant literature has several papers speculating on the function of spines. Heat transfer texts (Kays and London, 1964) discuss packing densities of heat exchange

elements, but all the flow is forced through the elements. We are exploring the critical densities at which wind penetration patterns shift and how much they shift.

A difficult problem was sorting out convective losses of the spines from the convective losses of the body of the "cactus". We needed to know the effective wind as the body surface "sees" it. We resolved the problem of casting a cylindrical plaster body and mating identical cylindrical sections of solid wax on either end to eliminate end effects. Toothpicks were used as "spines" (Fig.1). A technique had to be devised to wet the plaster body without wetting the plastic toothpicks. By measuring the mass transfer rate of water from the body of the cactus, we could determine a mass transfer coefficient (h_D) and hence a heat transfer coefficient (h_C) by the following equations.

$$\dot{m}_w = Ah_D (\rho_{\text{surf}} - \rho_{\text{air}})$$

$$h_C = \frac{h_D c_p \rho}{\left(\frac{Pr}{Sc}\right)^{2/3}}$$

where

$\dot{m}_w$ = mass flow of water

A = area of mass transfer

ρ_{surf} = water vapor density at surface

ρ_{air} = water vapor density of the air

h_D = mass transfer coefficient

c_p = specific heat of air

ρ = density of air

Pr = Prandtl Number

Sc = Schmidt Number

The heat transfer coefficient is related to velocity by non-dimensional parameters, the Nusselt Number (Nu) and the Reynolds Number (Re).

$$\text{Nu} = \frac{h_c L}{K} \quad \text{Re} = \frac{\rho V L}{\mu}$$

where

L = characteristic dimension (diameter)

K = conductivity of the fluid (air)

μ = dynamic viscosity of the fluid (air)

V = velocity of the fluid (air)

When plotted against each other on a log-log scale the Nu-Re relationship allows one to scale size and wind speed up or down and thereby predict other situations.

Figure A shows the results of some of the early experiments. We now have higher spine densities that show a drop in "cactus" convection heat transfer below that of a bare cylinder. Many technical difficulties with materials and techniques have slowed the work, but we expect to complete the first phase of this work well before summer is over.

We are now initiating the second phase of the study, i.e. the development of arrays of elements of different densities. Because of Reynolds Number scaling and the requisite very small element diameters, we are using different techniques for some of the arrays. The arrays represent model trees and bushes of different densities as the wind "sees" them as well as a blow up of the "cactus" surface

and some types of fur and grassy vegetation (depending on the scaling).

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Fig. (2) Energy flow diagram of the desert environment.

Fig. 4³ Predicted seasonal behavioral pattern for the desert iguana at Palm Springs

Fig. 5 Predicted seasonal behavioral pattern for the desert iguana for a wider variety of possible body temperatures and heights (z) above the ground

PELLSTON, MICH. 10 YR. AVE.

Fig. 7. Predicted seasonal behavioral pattern for garter snakes near Pellston, Michigan

Fig. 6
8 Predicted seasonal behavioral pattern for garter snakes
near Aiken, South Carolina

7
 Fig. 9 Predicted seasonal behavioral pattern for garter snakes near Aiken if all air temperatures were 10° C higher due to thermal pollution

APRIL, MAY PELLSTON, MICH. (1960)

DAY
CLASS

Fig. 10 Daily air temperature data from Pellston, Michigan in 1960

9
 Fig. 11 Limits to hunting and digesting by garter snakes for a short sequence of days in 1960 near Pellston, Michigan

10
 Fig. 12 Daily resting metabolism and potential daily maximum digestion using 10 year average days for Pellston, Michigan

Fig. 13 Daily resting metabolism and potential daily maximum digestion using 10 year average days for Pellston, Michigan

Table 1

50 g Garter Snake Biomass Requirements for Northern and Southern United States
(Including 10°C Thermal Pollution)

<u>Maintenance:</u>	<u>Cumulative Metabolism (cal)</u>	<u>Annual Constant Temperature That Would Give Same Cumulative Metabolism</u>	<u>Required g dry weight to Supply Needed Annual Calories</u>
Pellston, Mich.	79,500	9.1°C	15.9 g.
Aiken, S. C.	130,800	17.3°C	26.2 g.
Aiken + 10°C	271,400	32.7°C	54.3 g.

Grams Needed if 36% Digestive Efficiency (D.E.)

(D. E. = $\frac{\text{cal ingested} - \text{cal excreted}}{\text{cal ingested}}$)		80% frog water content-Thorson 1964	<u>Frogs needed annually</u>		
			<u>mid 3rd yr</u>	<u>mid 2nd yr</u>	<u>newly emerged</u>
Pellston, Mich.	44 g. dry wt.	221 g. wet wt.	40 g	20 g	1 g
Aiken, S.C.	73 g. dry wt.	363 g. wet wt.	5.5	11	221
Aiken + 10°C	151 g. dry wt.	754 g. wet wt.	9.1	18	363
			18.8	37	754

Reproduction:

$N_{\text{max}} = 34 \text{ young} \times 1 \text{ g each} = 34 \text{ g wet weight} = 6.8 \text{ g dry weight}$ (80% snake water content; Prosser et al., 1952)

25% assimilation efficiency (A.E.)

of food + young = 136 g wet weight = 27.2 g dry weight

(A.E. = $\frac{\text{cal into biomass}}{\text{cal ingested}}$)	Pellston, Mich.	#40 g frogs	#20 g frogs	#1 g frogs
	Aiken, S.C.	3.4	6.8	136
	Aiken + 10°			

Growth: Snake mass: 50 g → 100 g wet weight; 50 g wet weight to be added; 10 g dry weight to be added

for 25% assimilation efficiency

200 g wet weight needed; 40 g dry weight needed
 #40 g frogs #20 g frogs #1 g frogs
 5 10 200

	Average Annual Available Activity Time	Frogs needed annually		
		mid 3rd yr 40 g	mid 2nd yr 20 g	84% newly emerged 1 g
<u>Totals</u> = Pellston, Mich.	20 weeks	14	28	557
Aiken, S. C.	40 weeks	18	35	669
Aiken + 10°	52 weeks	27	54	1090

Preliminary estimates of biomass requirements for an
800 g adult mink (data from Farrell and Wood)

<u>Maintenance:</u>	Required g dry weight to supply needed daily calories	Grams needed if 75% digestive efficiency (Farrell & Wood)	Grams wet weight needed daily (80% water-frogs)	3rd yr	2nd yr	newly emerged
190 x 10 ³ cal/day	38 g	50.7	253 g	40 g	20 g	1 g
				6.3	12.7	253

Note: This animal must consume the equivalent of 31% of its body weight/day.

Figure 1

Figure 2