TOPIC 3. ESTIMATES OF ENERGY COSTS FOR PRODUCTION

Production results in the formation of new individuals (reproduction) and the deposition of new tissue by the individual (growth). Both of these productive functions are essential for the growth of the population. The growth rates of individuals often become indicators of the reproductive potentials of populations. Populations with smaller than average individuals will likely have lower than average reproductive rates because when requirements for a high rate of growth are not met, resources are not available for a high rate of reproduction. In white-tailed deer, for example, first conception becomes probable at a weight of about 40 kg. If a fawn does not attain this weight by its first winter, it is unlikely to reproduce until it is a yearling.

Inadequate nutrition during the gestation period may result in abortion, resorption of fetal tissue, or reduced fetal growth during the final stages of gestation. When fetal growth is reduced, the young weigh less at birth and have decreased chances of survival.

Inadequate maternal nutrition may impair lactation, possibly reducing the growth rate of the nursing young. Lactation is the single greatest sustained energy and protein requirement of mammals, and the major factor contributing to the high metabolic rate in the summer. The timing of this high cost is ecologically sound, however, as offspring are produced in late spring, just in time for the nursing dam to have access to a range with new growth as a source of nutrients for the costly process of lactogenesis.

While forage resources are more abundant and often quite digestible in the summer, this does not suggest that nutrients are unlimited on a green and growing range. Wild ruminants forage rather selectively, and will not consume any plant just because it is present. In fact, they often exhibit a high degree of selection not only for a particular plant species, but also for plant parts such as flowers. Ingestion of selected plant parts contributes to a higher quality diet (Whittemore and Moen 1980).

When nutrients are ingested in sufficient quantities to result in the production of new tissue, the nutrient balance is positive. The new tissue may be milk, which is made available to the dependent offspring whose growth may be at the expense of the body tissue of the lactating female. Weight curves have been calculated (CHAPTER 1) showing that annual minimum weights of lactating females occur at about the time of peak lactation.

LITERATURE CITED


Chapter 7 - Page 33
UNIT 3.1: THE ENERGY COST OF BODY GROWTH

Growth of wild ruminants that have not yet reached their full adult size occurs in the spring, summer and fall. Unbred yearlings may grow from spring through fall. Nursing young grow in the summer, and reproducing females will grow in late summer and fall as lactation demands are reduced. Antler and horn growth occurs in mature males from spring to early fall. The amount of growth is partially related to body weight and growth, so it is also related to range conditions, and partially related to the genetic potentials of the individual.

The cost of body growth is equal to the amounts of nutrients deposited plus the cost of synthesizing the tissue. These costs are directly dependent on tissue composition. Suppose that an animal gained 10 kg over a 100-day period. Suppose that 8 kg of this increase was water, 1.5 kg fat, and 0.5 kg protein. The energy increment in the animal's body is equal to 1.5 kg fat times 9,500 kcal per kg = 14,250 plus 0.5 kg protein times 5,500 kcal = 2750 kcal, totaling 17,000 kcal of tissue energy. This is 170 kcal per day.

One very important parameter must also be considered, and that is the efficiency of growth. If the efficiency were 50% in the example above, then the energy cost of tissue deposition would be equal to twice the energy in the tissue and the total cost would be 2 x 170 = 340 kcal. Efficiency of growth is related to physiologic age. But body composition is related to body weight and age, so the older and larger mammal, gaining less but depositing more fat, is depositing tissue with a higher caloric density. Thus while efficiency of growth goes down, changes in efficiency are reflected in changes in body composition. Examples illustrating how the cost of growth can be calculated on the basis of chemical composition and the cost of tissue synthesis are given in a WORKSHEET.

REFERENCES, UNIT 3.1

THE ENERGY COST OF BODY GROWTH

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ovda
The energy cost of body growth

Experiments designed to measure the cost of body growth are not as easily completed on wild ruminants as on domestic ruminants. Estimates of the cost of growth may be made by determining change in weight over a specified time period, changes in body composition in relation to weight, and the caloric equivalents of the tissue involved. The steps are:

1. Subtract final weight from initial weight.

2. Determine body composition at final and initial weights and the amounts of each of the following:
   a. Water
   b. Fat
   c. Protein
   d. Ash

3. Multiply the change in the fat and protein components by their approximate combustion values (Brody 1945:35).

   \[
   \begin{align*}
   \text{Fat} &= 9.5 \text{ kcal per gm} \\
   \text{Protein} &= 5.7 \text{ kcal per gm}
   \end{align*}
   \]

4. Add the energy contents of the fat and protein gain together and divide by the number of days between the initial and final weight used in Step 1.

5. Multiply the answer in Step 4 by the reciprocal of the efficiency (50% efficiency: \(1/0.50 = 2\); 33% efficiency: \(1/0.33 = 3\)).

Specific equations for the energy cost of growth may be compiled from the weight equations and chemical composition equations in PART I.

LITERATURE CITED

Total energy content of white-tailed deer as a function of ingesta-free weight

The total energy content of white-tailed deer in relation to ingesta-free weight has been determined by Robbins et al. (1974), simplifying calculations of the cost of growth. Only slight differences were observed in males and females so a single equation may be used to estimate total caloric content in kcal (TCCK).

\[ \text{TCCK} = e^{1.3720 \ln \text{IFWK} - 0.5876} \]

Using this equation and the seasonal weight equations in CHAPTER 1, the caloric content can be quickly determined after initial and final weights have been determined. Set up some weight differences based on the calculations in CHAPTER 1, UNIT 1.4, determine the daily change in energy content, and estimate the energy cost of these changes. Label and plot the results below. Differences in efficiencies may be represented as a family of curves.

LITERATURE CITED

UNIT 3.2: THE ENERGY COST OF HAIR GROWTH

The cost of hair growth may be determined in a manner similar to that for body growth. Time-periods of hair growth, amounts of hair, and chemical composition of the hair need to be known when making these calculations. These parameters were discussed in CHAPTER 2; calculations are illustrated in the WORKSHEETS.

REFERENCES, TOPIC 3.2

THE ENERGY COST OF HAIR GROWTH

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odhe

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ceel

CODEN-VO-NU-BEPA-ENPA-ANIM-KEWO------------------------AUTH--------YEAR
alal

CODEN VO-NU BEPA ENPA ANIM KEY WORDS------------------ AUTHORS-------- YEAR
rata

CODEN VO-NU BEPA ENPA ANIM KEY WORDS------------------ AUTHORS-------- YEAR
anam

Chapter 7 - Page 39
The energy cost of hair growth of white-tailed deer

The energy cost of hair growth may be estimated by determining the weight of the hair coat, chemical composition, and caloric values of the hair to give the energy content of the hair coat. The daily cost may be estimated by multiplying the energy content by the reciprocal of the efficiency of hair growth and dividing by the numbers of days during which the hair growth occurred. The formula may be written as:

\[
E_{\text{CHD}} = \left\{ \left[ (H_{\text{AWG}})(F_{\text{ACO}})(9.74) + (H_{\text{AWG}})(P_{\text{RCO}})(5.61) \right] / P_{\text{EHG}} \right\} / D_{\text{HGD}}
\]

where

- \( E_{\text{CHD}} \) = energy cost of hair growth per day
- \( H_{\text{AWG}} \) = hair weight in grams
- \( F_{\text{ACO}} \) = fat content expressed as a decimal fraction = 0.098
- \( P_{\text{RCO}} \) = protein content expressed as a decimal fraction = 0.890
- \( P_{\text{EHG}} \) = physiological efficiency of hair growth expressed as a decimal fraction
- \( D_{\text{HGD}} \) = duration of hair growth in days

The caloric values and fat and protein contents are taken from Robbins et al. (1974). \( H_{\text{AWG}} \) is determined from WORKSHEET 1.3b in CHAPTER 2. \( P_{\text{EHG}} \) is a variable, and \( D_{\text{HGD}} \) is dependent on the biochronology of the species or population group being considered.

Calculate and plot \( H_{\text{AWG}} \) and \( E_{\text{CHD}} \) on the next page, labeling the y-axis with the appropriate units of measurement. The effects of different physiological efficiencies of hair growth may be expressed with a family of curves.

How much does variation in \( P_{\text{EHG}} \) contribute to variation in ecological metabolism? This question may be answered after all of the maintenance, activity, and production costs have been considered and ecological metabolism per day (EMD) determined. Completion of the WORKSHEETS in this CHAPTER will enable the user to evaluate the cost of any process in relation to the total.
LITERATURE CITED

UNIT 3.3: THE ENERGY COST OF GESTATION

Accelerating requirements for gestation must be met in the last one-third of pregnancy. This acceleration generally coincides with the period of renewed plant growth, although differences in the lengths of winters result in different times of renewed plant growth from year to year. A late-arriving spring may have considerable effect on the condition of pregnant females during the last one-third of pregnancy (see Moen 1978). Conception occurs in the fall, and its timing is not related to the termination of winter several months later, of course. High conception rates may be followed by reduced birth rates if winter conditions are extended.

Increases in the requirements for gestation are related to increases in fetal growth and in the energy content of the uterus and associated reproductive tissues. The trends are illustrated below; curve-fitting of actual data may result in logarithmic, exponential, or power curves. Costs for associated uterine tissues increase in the same way, and are added to the costs of fetal growth to determine the total energy cost of gestation.

Calculations of the cost of gestation are made in the WORKSHEETS, with equations given for white-tailed deer and proportionalities described for other species.

LITERATURE CITED

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THE ENERGY COST OF GESTATION
SERIALS

<table>
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CODEN VO-NU BEPA ENPA ANIM KEY WORDS------------------- AUTHORS--------- YEAR

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CODEN VO-NU BEPA ENPA ANIM KEY WORDS------------------- AUTHORS--------- YEAR

JOMAA 46--3 524 525 ovca fetal measure, milk charac forrester,dj; sen 1965

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ovda

CODEN VO-NU BEPA ENPA ANIM KEY WORDS------------------- AUTHORS--------- YEAR

obmo

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oram

CODEN VO-NU BEPA ENPA ANIM KEY WORDS------------------- AUTHORS--------- YEAR

AMNTA 114-1 101 116 ungu matern repro effort, fetal robbins,ct; robbi 1979

Chapter 7 - Page 43
The energy cost of gestation in white-tailed deer

The energy cost of gestation is equal to the energy deposited in the gravid uterus each day times the efficiency of the physiologic processes involved. The energy content of the gravid uterus has been determined by Robbins and Moen (1975), and may be used to calculate the energy cost of gestation with the following equation.

$$ECGD = (e^{0.2803 + 0.0282 \times \text{DIGE}})(1/\text{PEGE})$$

where $ECGD$ = energy cost of gestation per day, 
$\text{DIGE}$ = days into gestation, and 
$\text{PEGE}$ = physiological efficiency of gestation

Plot $ECGD$ below, expressing $\text{PEGE}$ as a family of curves again.

---

**LITERATURE CITED**

The energy costs of gestation in several species of wild ruminants

The energy costs of gestation have been estimated for several species of wild ruminants in Robbins and Moen (1975) by considering the costs for these species to be proportional to the costs for deer. Fetal weights and lengths of the gestation period vary, of course.

The equations for estimating ECGD for different species, modified from those in Robbins and Moen (1975), are listed below.

<table>
<thead>
<tr>
<th>Species</th>
<th>Equation</th>
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<tr>
<td>ceel:</td>
<td>ECGD = (e^{0.0193 \ \text{DIGE}} - 1.7938)(1/\text{PEGE})</td>
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<td>alal:</td>
<td>ECGD = (e^{0.0204 \ \text{DIGE}} - 1.7358)(1/\text{PEGE})</td>
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<td>rata:</td>
<td>ECGD = (e^{0.0226 \ \text{DIGE}} - 1.6198)(1/\text{PEGE})</td>
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<td>anam:</td>
<td>ECGD = (e^{0.0209 \ \text{DIGE}} - 1.7140)(1/\text{PEGE})</td>
<td>240</td>
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<td>bibi:</td>
<td>ECGD = (e^{0.0173 \ \text{DIGE}} - 1.9036)(1/\text{PEGE})</td>
<td>290</td>
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<td>ovca:</td>
<td>ECGD = (e^{0.0334 \ \text{DIGE}} - 1.2443)(1/\text{PEGE})</td>
<td>150</td>
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<td>oram:</td>
<td>ECGD = (e^{0.0278 \ \text{DIGE}} - 1.4281)(1/\text{PEGE})</td>
<td>180</td>
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</tbody>
</table>

Complete the numbering of the x and y axes and plot the energy costs of gestation on the grid on the next page. Note again that different physiological efficiencies may be expressed as a family of curves.
LITERATURE CITED


Chapter 7 - Page 44bb
CHAPTER 7, WORKSHEET 3.3c

The energy costs of gestation in relation to days into gestation and fetal weight at birth

The two previous WORKSHEETS have included equations for selected species with average fetal weights and gestation periods built into the equations. An alternative equation in Robbins and Moen (1975) may be used to provide the flexibility needed when applying the proportional costs to any species. The formula for calculating the energy contents of the uterus and contents (kcal) per fetal weight at parturition (kg) is:

$$ECGD = \left\{ e^{(2.1548 + 5.01(\text{DIGE/LEGP})]} - \frac{e^{(2.1548 + 5.01(\text{LOWR DIGE/LEGP})]} (\text{BIWK})}{\text{DIGE} - \text{LOWR DIGE}} \right\} \left(\frac{1}{\text{PEGE}}\right)$$

where
- ECGD = energy cost of gestation per day
- DIGE = higher number of days into gestation
- LOWR DIGE = lower number of days into gestation
- LEGP = length of the gestation period
- BIWK = birth weight in kg
- PEGE = physiological efficiency of gestation

Make the calculations for selected species with different birth weights and evaluate the daily costs associated with gestation. The results may be plotted below.
LITERATURE CITED

UNIT 3.4: THE ENERGY COST OF MILK PRODUCTION

Milk production has been mentioned several times already as a very costly biological process. One might come to this conclusion simply by observing the condition of lactating females; they are often in the worst condition of the year during the lactation period. The weight pattern shows minimum weights during the lactation period, and it is well known that if milk production of dairy cattle is to remain high, a high quality ration must be fed in large quantities.

If milk production is the most costly sustained biological process there is, then it is imperative that ways be found to quantify the cost. Direct measurements of milk production might be made by actually milking the animal, but this is difficult because wild ruminants are not inclined to stand while being milked. Further, milk production is partly dependent on the demand for milk, and this varies with the suckling young as they grow and their diet includes increasing amounts of forage. Since the demand of the young for milk cannot be duplicated by hand-milking the female, estimates of milk production obtained in this way will not be accurate.

Animals in captivity might be weighed before and after nursing, and either the dam's weight loss or the sucklings' weight gain measured. Scales sufficiently large to weigh the dam before and after nursing are not accurate enough to weigh the difference in her weights, however. The suckling animal often urinates and defecates while nursing—the dam usually licks the anal region to stimulate release—so accurate measurements of milk intake are difficult to make. Furthermore, it is difficult to be present to weigh the animals each time the young nurse, which could be several times a day.

The only practical way to determine milk production of wild ruminants is by mathematical means. There is a fundamental relationship that can be considered the basis for mathematical calculations, and that is that the milk production of the females of a species will be adequate to supply that portion of the nutrients derived from milk by the young of that species to meet their total metabolic costs for growth and activity. The amount of nutrients supplied by the milk varies as the rumen develops and the young become increasingly more dependent on forage for nutrients. This mathematical approach, then, requires a knowledge of three things, including the rate of rumen development so that the ratio of milk nutrients: forage nutrients is known, the chemical composition of the milk, and the ecological metabolism of the nursing young. These were discussed in earlier chapters, and they can be assembled here in WORKSHEETS to calculate the cost of milk production.
REFERENCES, UNIT 3.4

THE ENERGY COST OF MILK PRODUCTION

SERIALS

<table>
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Chapter 7 - Page 48
The energy cost of milk production in white-tailed deer

The energy cost of milk production may be estimated if the quantity of milk being produced is known. Estimates of the latter may be made with an equation in Moen (1973:355), modified to include new terms and parameters. The formula is:

\[ \text{MPGD} = \left( \frac{(MBLM)(70)(MEWK)}{(PNDM)(1/NECM)/\text{GENM}} \right) \]

where \( \text{MPGD} \) = milk production in gms per day
\( MBLM \) = multiple of base-line metabolism
\( MEWK \) = metabolic weight in kg
\( PNDM \) = percent nutrients derived from milk = \( [1.136 - 0.045 \times \text{LWKG}] \)
\( NECM \) = net energy coefficient for milk
\( \text{GENM} \) = gross energy in the milk

The formula can be used only if numerical values for each of the parameters are available. The first one needed, MBLM, has not been discussed in the ecological context yet (see TOPIC 6). The MBLM of resting fawns was usually between 2.10 and 2.25 (see CHAPTER 7, WORKSHEET 1.1a). The MBLM for ecological metabolism of suckling fawns is discussed in CHAPTER 7, UNIT 6.1. In the absence of a derived MBLM, MBLM = 2.5 may be used as a first approximation.

\( \text{MEWK} \) is the metabolic weight, or \( \text{IFWKO.75} \), where \( \text{IFWK} \) is the ingesta-free-weight of the fawns. Growth and weights were discussed in CHAPTER 1.

\( \text{PNDM} \) is an expression for determining the percent nutrients derived from milk, a function of rumen development. Derivation of this equation is discussed in Moen (1973:342).

\( \text{NECM} \) is an expression of gross to net energy efficiency, including both the digestible energy and metabolizable energy coefficients.

\( \text{GENM} \), the gross energy in the milk, may be measured directly or determined from the chemical composition of the milk, especially fat percent (FATP). FATP may be calculated with an equation derived from data in Youatt et al. (1965).

\[ \text{FATP} = 1.036 e^{-1.0117(DILA)}; R^2 = 0.995 \]

where \( \text{FATP} \) = fat percent and
\( \text{DILA} \) = days into lactation.

Using the equation in CHAPTER 2, WORKSHEET 2.2b, p. 46b, \( \text{GENM} \) may be estimated from FATP. \( \text{MPGD} \) may then be calculated by substituting these numbers and equations in the formula near the top of this WORKSHEET. A grid is provided on the next page for plotting the results.
LITERATURE CITED
