## TOPIC 6. ECOLOGICAL METABOLISM

Ecological metabolism is the term applied to the energy cost of living of free-ranging animals throughout the year, including all of the maintenance, activity, and productive functions as the animal goes through the annual cycle (Moen 1973).

Daily (24-hour) blocks of time are minimum for the expression of ecological metabolism because of diurnal rhythms in activity. Hourly rates of metabolism change during each 24-hour period because of activity periods. Changes in diurnal rhythms over the annual cycle are related to the light regime and to current weather conditions. The light regime changes in predictable ways through the annual cycle, and the pattern of daily ecological metabolism reflects these changes.

Ecological metabolism is very difficult to measure because the measurements must be made as the animals behave naturally over 24-hour periods throughout the annual cycle. Since direct measurements of metabolic expenditures or heat production of free-ranging animals are impossible, indirect measurements must be used. Gas exchange methods are difficult to use on wild ruminants, and they interfere with the animals' activities. Tracheal cannulae interfere less than face masks, but still are difficult to use on free-ranging animals. Calculations of metabolism made from vital signs, especially heart rates and respiration rates, do reflect metabolic patterns and provide insight into the overall role of metabolism in ecological considerations.

Absolute values of ecological metabolism per day (ELMD) may be estimated by vital sign to metabolism conversions, or by summations of maintenance, activity, and production costs as discussed in the previous units in the chapter. The ratio of ELMD to BLMD, called the multiple of base-line metabolism (MBLM) (See CHAPTER 7 - Pages 2-3) is a good way to express ecological metabolism on a relative basis. The ratio of ecological metabolism to base-line metabolism varies throughout the year because of seasonal rhythms in activity, growth, and reproduction. Transient changes in these functions contribute to a variable ratio, but long-term trends are approximated by a sine wave.

The use of the MBLM approach in calculating ELMD involves the use of live weights. Seasonal rhythms in weights (see CHAPTER 1, UNIT 1.4) are combined with seasonal rhythms in MBLM to estimate ELMD. This approach is applicable to different species of wild ruminants in northern areas of the United States and in Canada since a metabolic depression in the winter, summer metabolic highs, and an overall pattern similar to that of the white-tailed deer seems to exist in these ruminants.

One important use for the calculation of ecological metabolism, a dynamic variable so dependent on the activity and production levels of each individual, is in determining nutrient requirements in relation to age. Also forage ingested and fat reserves, both used as sources of energy by the animal to meet the cost of ELMD, are both important as their rates of depletion determine the forage and fat resources left, both of which are of critical importance to survival.

This unit is a place for the listing of metabolism references that do not fall clearly in previous units, or for references that should be included for use again in deriving equations for ecological metabolism for different species. WORKSHEETS that follow provide opportunities for estimating ELMD from available data, and first approximations, at least, are to be derived for different species.

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Moen, A. N. 1973. Wildlife ecology. W. H. Freeman and Co., San Francisco. 458 pp.

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## REFERENCES, TOPIC 6

## ECOLOGICAL METABOLISM

### BOOKS

| TYPE | PUBL | CITY | PGES | ANIM | KEY WORDS----------------- | AUTHORS/EDITORS-- | YEAR |
|---|---|---|---|---|---|---|---|
| edbo | acpr | nyny | 427 | many | comprtv nitritn, wild anim | crawford,ma,ed; | 1968 |
| aubo | hutc | loen | 332 | rumi | energ metabol of ruminants | blaxter,kl | 1967 |
| aubo | wile | nyny | 184 | rumi | metabolism in the ruminant | annison,ef; lewis, | 1959 |
| edbo | jdve | zusw | 259 | doca | energ met farm anims; symp | schurch,a,ed; wen | 1970 |

## UNIT 6.1: SEASONAL RHYTHMS IN ECOLOGICAL METABOLISM

Each individual must meet its own requirements for the basic life functions--respiration, circulation, daily activities, maintenance of body tissues, production of new tissues to replace those metabolized--that combine to establish the maintenance requirement of each individual. Productive members of a population must also synthesize new tissue, for both growth and reproduction. The timing of these productive functions results in marked changes in the rates of metabolism over the annual cycle. Highest metabolic rates occur in the summer when individuals are growing and females are lactating. In the winter, metabolism is depressed. Thus, ecological metabolism varies because maintenance, activity, and production costs vary due to seasonal patterns in growth, reproductive functions, activity patterns, weather and thermal exchange, and other biological functions. The timing of the productivity costs of ecological metabolism are dependent on the seasonal patterns of changes in range conditions.

The amount of direct information on seasonal metabolic rhythms of different species of free-ranging animals is very limited. There are clues in the literature, however. Deer are less able to withstand shock in the winter when they are in their period of metabolic depression. They also exhibit seasonal differences in their reactions to an immobilizing agent. Research at the Wildlife Ecology Laboratory has shown that there is seasonal response of white-tailed deer to succinylcholine immobilization that is apparently related to seasonal metabolic rhythms. Effective immobilization dosage rates varied from a low of 0.058 mg/kg in February to a high of 0.09 mg/kg in August (See Jacobsen et al. 1976). Stelfox and Robertson (1976) describe the seasonal reaction of bighorn sheep to succinylcholine chloride: "Lower dosage rates were required in late winter and spring compared to the fall." This suggests that bighorn sheep have a metabolic rhythm, too, and are energy conservers in the winter like white-tailed deer.

Seasonal rhythms in ecological metabolism of white-tailed deer have been described in detail in Moen (1978). It is interesting to compare the definitive pattern of high metabolism in the summer and low in the winter with supporting evidence published in earlier literature. Cyclic weight changes (Bandy et al. 1970), seasonal variations in hormone levels and reproductive functions (West and Nordon 1976), blood characteristics (Franzmann et al. 1976), thyroid activity (Hoffman and Robinson 1966), serum thyroxine levels (Seal et al. 1972), cementum annulus formation (Sauer 1973) and basal and fasting metabolic rates (Silver et al. 1969 and Holter et al. 1976) have all provided documented evidence for seasonal rhythms in metabolism. The WORKSHEETS that follow in this UNIT and UNIT 6.2 are very important for the verification of calculations of ecological metabolism.

## LITERATURE CITED


Bandy, P. J., I. McT. Cowan, and A. J. Wood. 1970. Comparative growth in four races of black-tailed deer (Odocoileus hemionus). Part I. Growth in body weight. Can. J. Zool. 48(6):1401-1410.

Franzmann, A. W., R. E. LeResche, P. D. Arneson, and J. L. Davis. 1976. Moose productivity and physiology. Final Report, Federal Aid in Wildlife Rstoration Projects W-17-2, W-17-3, W-17-4, W-17-5, W-17-6, and W-17-7. Job 1.1R. 87 pp. (Mimeo).

Hoffman, R. A. and P. F. Robinson. 1966. Changes in some endocrine glands of white-tailed deer as affected by season, sex and age. J. Mammal. 47(2):266-280.

Holter, J. B., W. E. Urban, Jr., H. H. Hayes, and H. Silver. 1976. Predicting metabolic rate from telemetered heart rate in white-tailed deer. J. Wildl. Manage. 40(4):626-629.

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Moen, A. N. 1978. Seasonal changes in heart rates, activity, metabolism, and forage intake of white-tailed deer. J. Wildl. Manage. 42(4):715-738.

Seal, U. S., L. J. Verme, J. J. Ozoga, and A. W. Erickson. 1972. Nutritional effects on thyroid activity and blood of white-tailed deer. J. Wildl. Manage. 36(4):1041-1052.

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West, N. O. and H. C. Nordan. 1976. Hormonal regulation of reproduction and the antler cycle in the male Columbian black-tailed deer (Odocoileus hemionus columbianus). Part I. Seasonal changes in the histology of the reproductive organs, serum testosterone, sperm production, and the antler cycle. Can. J. Zool. 54(10):1617-1636.

REFERENCES, UNIT 6.1

SEASONAL RHYTHMS IN ECOLOGICAL METABOLISM

SERIALS

| CODEN | VO-NU | BEPA | ENPA | ANIM | KEY WORDS----------------- | AUTHORS---------- | YEAR |
|---|---|---|---|---|---|---|---|
| CJPPA | 56--6 | 945 | 949 | odvi | thyroxine lev, male, femal | bubenik,ga; buben | 1978 |
| ECOLA | 57--1 | 192 | 198 | odvi | energy conservatio, winter | moen,an | 1976 |
| JOMAA | 41--1 | 23 | 29 | odvi | respon bucks, artifi light | french,ce; mcewe | 1960 |
| JOMAA | 47--2 | 266 | 280 | odvi | endocrine glands, sea chan | hoffman,ra robin/ | 1966 |
| JWMAA | 34--2 | 431 | 439 | odvi | wint feed patterns, penned | ozoga,jj; verme,l | 1970 |
| JWMAA | 34--4 | 863 | 869 | odvi | dig, met ener, wintr, does | ullrey,de; youat/ | 1970 |
| JWMAA | 36--4 | 1041 | 1052 | odvi | nutrit effec. thyroid acti | seal,us; verme/ | 1972 |
| JWMAA | 40--3 | 447 | 453 | odvi | seas var succinylcho immob | jacobsen,nk; arm/ | 1976 |
| JWMAA | 42--4 | 715 | 738 | odvi | seas chan, heart rate, act | moen,an | 1978 |
| JWMAA | 42--4 | 791 | 798 | odvi | thymus, nut status indicat | ozoga,jj; verme,l | 1978 |

| CODEN | VO-NU | BEPA | ENPA | ANIM | KEY WORDS----------------- | AUTHORS---------- | YEAR |
|---|---|---|---|---|---|---|---|
| PNDAA | 30--1 | 35 | 35 | odhe | pituitary photoper, antlr | nicolls,ke | 1976 |
| PSEBA | 93--1 | 161 | 162 | odhe | cyclic var, thymus, mule d | browman,lg; sears | 1956 |
| ZZAHA | 115-3 | 314 | 326 | odhe | pituitar glnd photoperiod | nicolls,ke | 1971 |

| CODEN | VO-NU | BEPA | ENPA | ANIM | KEY WORDS----------------- | AUTHORS---------- | YEAR |
|---|---|---|---|---|---|---|---|
| ACATA | 63--4 | 580 | 590 | ceel | caca, investigatn, thyroid | pantic,v; stosic, | 1966 |
| CBPAB | 60a-3 | 251 | 256 | ceel | doca, dosh enrg, nitro met | simpson,am; webs/ | 1978 |

| CODEN | VO-NU | BEPA | ENPA | ANIM | KEY WORDS----------------- | AUTHORS---------- | YEAR |
|---|---|---|---|---|---|---|---|
| NCANA | 101-1 | 227 | 262 | alal | energ req, rumen fermentat | gasaway,wc; coady | 1974 |

| CODEN | VO-NU | BEPA | ENPA | ANIM | KEY WORDS----------------- | AUTHORS---------- | YEAR |
|---|---|---|---|---|---|---|---|
| APSCA | 105-3 | 268 | 273 | rata | spitzbergen, winter dorman | ringberg,t | 1979 |
| BJNUA | 29--2 | 245 | 259 | rata | seasonal, glucose metaboli | luick.jr; person/ | 1973 |
| CBPAB | 40a | 789 | 795 | rata | thyroxine, sex, age seas | yousef,mk luick, | 1971 |
| CBPAB | 60A-2 | 123 | 126 | rata | seas, growth hormon, thyro | ringberg,t; jaco/ | 1978 |

rata continued on the next page

| CODEN | VO-NU | BEPA | ENPA | ANIM | KEY WORDS----------------- | AUTHORS---------- | YEAR |
| --- | --- | --- | --- | --- | --- | --- | --- |
| CJZOA | 48--2 | 391 | 392 | rata | energ metab, bar gro carib | mcewan,eh | 1970 |
| CJZOA | 48--5 | 905 | 913 | rata | seas energy, nitrog intake | mcewan,lh whiteh | 1970 |
| CJZOA | 56--2 | 215 | 223 | rata | energy expend, walk, tundr | white,rg; yousef, | 1978 |
| JANSA | 33--1 | 260 | 260 | rata | thyroxine secre rate, calv | luick,jr; white,/ | 1971 |
| PASCC | 19--- | 71 | 72 | rata | thyroxine secretion rate | yousef,mk | 1968 |

| CODEN | VO-NU | BEPA | ENPA | ANIM | KEY WORDS----------------- | AUTHORS---------- | YEAR |
| --- | --- | --- | --- | --- | --- | --- | --- |
| JWMAA | 37--4 | 563 | 573 | anam | energy metab of yg prongho | wesley,de; knox,/ | 1973 |

| CODEN | VO-NU | BEPA | ENPA | ANIM | KEY WORDS----------------- | AUTHORS---------- | YEAR |
| --- | --- | --- | --- | --- | --- | --- | --- |
| CNJNA | 59--3 | 611 | 617 | bibi | doca, seas enrg exp, thrmr | christopherson,r/ | 1979 |

| CODEN | VO-NU | BEPA | ENPA | ANIM | KEY WORDS----------------- | AUTHORS---------- | YEAR |
| --- | --- | --- | --- | --- | --- | --- | --- |
| CJZOA | 56-11 | 2388 | 2393 | ovca | winter bioenergetics, rcky | chappel,rw; hudso | 1978 |
| JWMAA | 40--1 | 174 | 176 | ovca | immobiliz. succinyl, pheny | stelfox,jg rober | 1976 |

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

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

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

| CODEN | VO-NU | BEPA | ENPA | ANIM | KEY WORDS----------------- | AUTHORS---------- | YEAR |
| --- | --- | --- | --- | --- | --- | --- | --- |
| ATRLA | 22--1 | 3 | 24 | caca | energy metabolism, roe dee | weiner,j | 1977 |

| CODEN | VO-NU | BEPA | ENPA | ANIM | KEY WORDS----------------- | AUTHORS---------- | YEAR |
| --- | --- | --- | --- | --- | --- | --- | --- |
| NCANA | 101-1 | 227 | 262 | alal | energ req, rumen fermentat | gasaway,wc; coady | 1974 |

| CODEN | VO-NU | BEPA | ENPA | ANIM | KEY WORDS----------------- | AUTHORS---------- | YEAR |
| --- | --- | --- | --- | --- | --- | --- | --- |
| PZOOA | 15--2 | 201 | 205 | many | lipid metab, free fatty ac | felinski,l; kacz/ | 1971 |

CHAPTER 7, WORKSHEET 6.1a

Estimating ecological metabolism by summation

The estimation of ecological metabolism by summation involves the calculation of the costs of each of the biological processes occurring on a given day and adding up these costs to get a total for the day. the major cost items have been discussed in the units in this chapter. There are too many variables involved that it is impossible to summarize the costs for each of these items for a species. Weights vary between sex and age groups and throughout the year, reproductive rates vary, activity patterns vary, etc. The schematic below will be useful as a check list when identifying cost items for summations.

Maintenance

Activity

- Bedding
- Standing
- Walking
  - level
  - uphill
  - downhill
- Foraging
- Running

Production

- Growth
  - body growth
  - hair growth

- Reproduction
  - gestation
  - lactation

Establish a biochronology for the species of your choice, select the topography and behavioral regimes, estalish a reproductive rate, and identify every other maintenance, activity, and productive function that is part of that animal's life, and then complete the energy cost calculations discussed this CHAPTER 7. I suggest that you start with AGDA = 1, on the average JDAY for births. Follow that animal through its life, accounting for cost items characteristic of its life-style and events at 7 or 14 day intervals throughout the year. Such a calculation will call to your attention a great deal of natural history, behavior, and physiology, and will serve to acquaint you very well with the species.

The suggestion given on the previous page is a major assignment. Programmed computing will be very helpful. Programmed desk-top calculators are efficient enough to help with the calculations while yet being simple enough to operate easily and with enough manual steps to keep you oriented.

One last reminder. As the energy costs are added up for each day selected, be sure to convert the absolute energy costs to MBLM. This will allow you to compare between sex, age, season, and species. The results should be somewhat in line with the material discussed in UNIT 6.2.

CHAPTER 7, WORKSHEET 6.1b

Seasonal rhythms in ELMD; the MBLM approach

The calculation of energy costs at selected intervals of days to be summed through the year is a major assignment. The calculation of seasonal rhythms in ELMD using the MBLM approach described in Moen (1978) can be accomplished with a single, relatively short equation. Basically, energy expenditures of white-tailed deer are sinusoidal throughout the year, reaching a low in the winter and a high in the summer or early fall, depending on the reproductive rate. Lactation for two fawns shifts the maximum cost to mid-summer, for one fawn to late summer, and for no fawns to early fall.

The equation is:

$$MBLM = 2.56894\ e^{0.19602\ (NUFA)} \left( \left\{ [1.0285 \sin [(JDAY + 170.0536\ e^{0.15488\ (NUFA)})\ 0.9863 + 0.0281] [0.19 + 0.05\ (NUFA)] \right\} + [0.81 - 0.05\ (NUFA)] \right)$$

where MBLM = multiple of base-line metabolism,
NUFA = number of fawns, and
JDAY = Julian day.

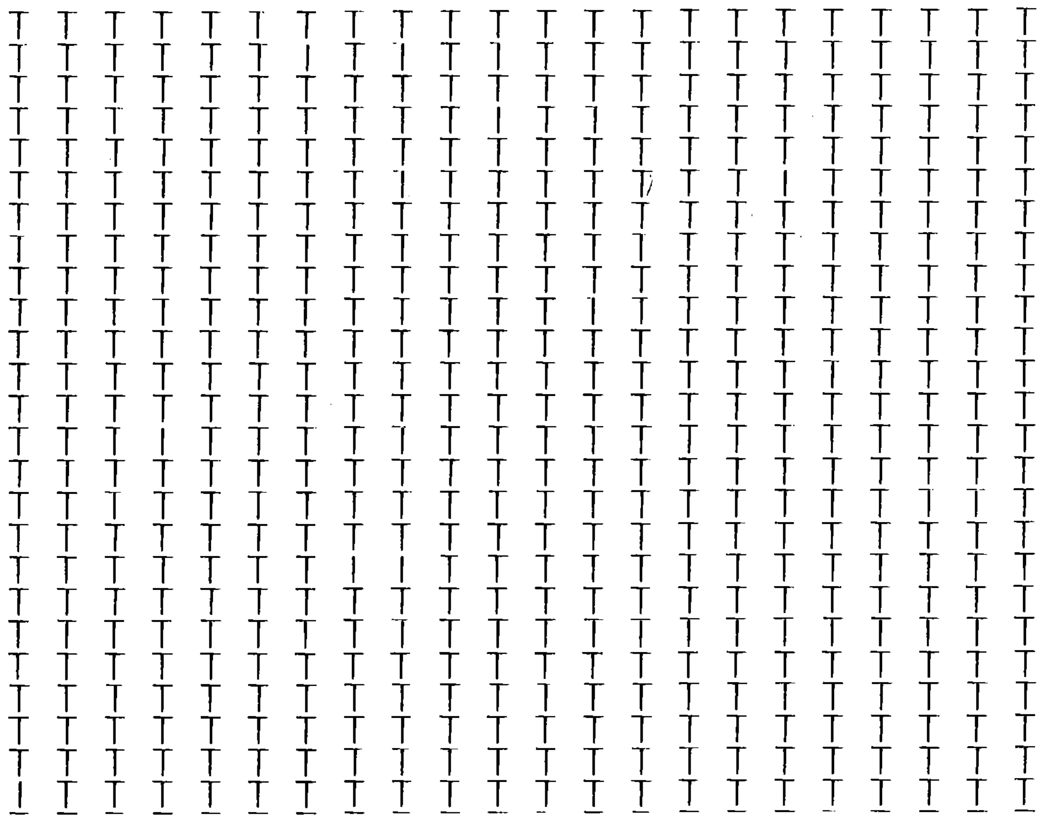
ELMD is determined by multiplying MBLM by (70)(MEWK). MEWK is determined from the weight equations described in CHAPTER 1. Calculate MBLM and multiply by (70)(MEWK) through the annual cycle and plot the results on the grid on the back of this page.

Compare the MBLMs with those discussed on previous WORKSHEETS in this chapter, and compare with those discussed in UNIT 6.2.

LITERATURE CITED

Moen, A. N. 1978. Seasonal changes in heart rates, activity, metabolism, and forage intake of white-tailed deer. J. Wildl. Manage. 42(4):715-738.

MBLM



JDAY =

## UNIT 6.2: INTERSPECIES COMPARISONS

The use of base-line metabolism and multiples of base-line metabolism to express ecological metabolism is very conveniently applied to other species with different weights. Calculations have been made for caribou (Moen 1980) indicating similarities in the pattern of MBLM over the annual cycle. Detailed calculations by Gasaway and Coady (1974), summarized in Moen (NAS In press) indicate that moose have a lower metabolism in the winter (about 1.7 times the basal metabolic rate; BMR) and 3.0 to 4.0 times BMR in the summer. Both the metabolic patterns and the multiples of BMR (where BMR = 70 $W^{0.75}$ and is equivalent to base-line metabolism) of moose given by Gasaway and Coady (1974) are very similar to those determined for white-tailed deer by Moen (1978).

Interspecies comparisons using the multiple of base-line metabolism approach have been made for domestic animals; the following summary is from Moen (NAS In press). How does the use of MBLM apply to domestic cattle and sheep? First, the pattern of daily energy requirements of a 454 kg beef cow during her 12-month reproductive cycle is shown by Ensminger (1976:1083). Converting the graphed results to MBLM by dividing values on the (megacalories) Y-axis by base-line metabolism, $[70(454)^{3/4})]$, results in values of MBLM of 1.8, 2.3, 2.5, and 3.5 for maintenance, grazing, the addition of fetal development, and peak lactation, respectively. Both the general pattern and the values of MBLM are very similar to those discussed earlier for white-tailed deer and moose. The timing is different, as cows may be bred to calve in late winter and early spring, earlier than the time of parturition for wild ruminants.

The figure in Ensminger depicting metabolizable energy of a cow over a 12-month reproductive cycle is illustrative, and not designed for detailed expression of metabolizable energy and forage requirements of cows of different ages, weights, and breeds. The nutrient requirements of beef cattle and sheep have been summarized by subcommittees of the National Research Council (Nutrient Requirements of Beef Cattle, fifth revised edition, 1976 and Nutrient Requirements of Sheep, fifth revised edition, 1975). These publications include tables of metabolizable energy values in the forage consumed by animals of different weights, growth rates, and different stages of reproduction. The tables may be converted to MBLM by dividing the metabolizable energy in the daily feed allotment by base-line metabolism.

The values of MBLM for lactating beef cattle range from 3.1 to 3.7 (midpoint 3.4) for cows from 350 to 650 kg rated as "superior" producers, and from 2.5 to 2.8 (midpoint 2.65) for those rated "average." The calculated MBLM for cows in the middle third of gestation is 1.9, and in the last third, 2.35 to 2.15 (midpoint 2.25) for cows weighing 350 to 650 kg.

Metabolizable energy values for sheep, expressed as MBLM calculated from Table 1, page 42 in Nutrient Requirements of Sheep (NRC 1975), include a maintenance cost after lactation has ceased of MBLM = 1.45, the lowest of the year, to an MBLM during lactation of 3.5 for sheep suckling singles and 4.0 for sheep suckling twins.

An interesting and significant relationship emerges for these calculations of MBLM for cattle and sheep in relation to MBLM calculations for white-tailed deer. Maximum values of MBLM are 3.7, 4.0, and 3.9 for cattle, sheep, and deer, respectively. MBLM values for an average producing cow and sheep and deer nursing singles are 2.35, 3.5, and 3.2 respectively. Minimum MBLMs are 1.45 and 1.6 for sheep and deer, respectively, and 1.9 and 1.7 for cows and moose, respectively. Differences in ecological metabolism of free-ranging ruminants appear to be slight when compared on a relative basis using MBLM. On an absolute basis, differences between species in the amount of metabolism per day are caused by differences in their weights, especially of cattle and moose compared to sheep and deer.

Similarities in MBLM for the different four species suggest that MBLM can be estimated for free-ranging ruminants as well. A maximum of 4.0 and minimum of 1.5 likely include the expected values of MBLM of free-ranging ruminants over the annual cycle. References that contain weight and energy metabolism data on domestic cattle and sheep may be listed on the next page. WORKSHEETS that illustrate interspecies comparisions and evolutions within the 1.5 to 4.0 MBLM should also be added at the end of this UNIT.

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__________. [NAS In press]. Ecological efficiencies and forage intakes of free- ranging animals. In National Academy of Science Forage Allocation Workshop Publication.

National Research Council. 1975. Nutrient requirements of sheep. National Acad. of Sciences. Washington, D. C. 72 pp.

___________________________. 1976. Nutrient requirements of beef cattle. National Acad. of Sciences, Washington, D. C. 56 pp.

Stelfox, J. G. and J. R. Robertson. 1976. Immobilizing bighorn sheep with succinylcholine chloride and phenycyclidine hydochloride. J. Wildl. Manage. 40(1):174-176.

## REFERENCES UNIT 6.2

## INTERSPECIES COMPARISONS

## SERIALS



| CODEN | VO-NU | BEPA | ENPA | ANIM | KEY WORDS----------------- | AUTHORS---------- | YEAR |
|---|---|---|---|---|---|---|---|
| AFBUD | ..... | 38 | 39 | doca | energy cost, ingestin feed | adam,i; young,ba/ | 1979 |
| BJNUA | 20--1 | 103 | 111 | doca | fasting metabolism, cattle | blaxter,kl; wainm | 1966 |

| CODEN | VO-NU | BEPA | ENPA | ANIM | KEY WORDS----------------- | AUTHORS---------- | YEAR |
|---|---|---|---|---|---|---|---|
| AJAEA | 15--6 | 969 | 973 | dosh | energ cost. feed act, graz | graham,nm | 1964 |
| AJAEA | 17--3 | 355 | 362 | dosh | energy expend, resp, feedi | young, ba | 1966 |
| AJAEA | 19--5 | 821 | 824 | dosh | metab rate, bred wol prod | graham,nm | 1968 |
| BJNUA | 18--1 | 47 | 54 | dosh | ener metab, walk lev, grad | clapperton,jl | 1964 |
| PAANA | 7---- | 327 | 334 | dosh | ener req, grazi, calorimet | young,ga; corbet | 1968 |
| PAANA | 7---- | 335 | 341 | dosh | co2, index ener expen, lmb | white,rg; leng,ra | 1968 |
| PNUSA | 20-- | xxxi | xxxii | dosh | ener exp, walk levl, grdi | clapperton,jl | 1961 |

| CODEN | VO-NU | BEPA | ENPA | ANIM | KEY WORDS----------------- | AUTHORS---------- | YEAR |
|---|---|---|---|---|---|---|---|
| CBPAB | 34A-4 | 841 | 846 | | energetic cost, locomotion | tucker,va | 1970 |
| JRMGA | 27--4 | 437 | 443 | | physiol, ener expen, pastu | osuji,po | 1974 |
| JTBIA | 49--2 | 345 | 362 | | model, est metab, rest, ac | wunder,ba | 1975 |
| SCIEA | 178-- | 1096 | 1097 | | runni up, down hills: size | taylor,cr; caldw/ | 1972 |
| WLMOA | 14--- | 1 | 78 | | pharma-physiol prin, restr | hartoorn,am | 1965 |

CHAPTER 7, WORKSHEET 6.2a

Interspecies comparisons of MBLM and ELMD

Ecological metabolism per day, being a function of weight, varies widely betwen species, ELMD of white-tailed deer is much less than that of moose, and of domestic sheep, much less than that of cattle.

Similarities in MBLMs of different species are striking, however. MBLM is weight independent, calculated by dividing ELMD by base-line metabolism. Interspecies comparisons can be easily made when daily quantities of energy metabolism are given. Sometimes the metabolizable energy in the feed is given: this is the case for domestic cattle and sheep in the NRC publications. Consider the metabolizable energy in the daily ration to be the daily metabolizable energy and divide by BLMD.

The point to be made in this WORKSHEET is that MBLM is the expression to use for interspecies comparisons. It has been stressed throughout this CHAPTER, and will prove to be very useful in future calculations.

Mentally review MBLM, think of patterns through time, and sketch your thoughts in the space below.

## CLOSING COMMENTS - CHAPTER SEVEN

CHAPTER 7 is a very important chapter in this book of seven parts. Calculations of the energy cost of living are as important to the resource manager as calculations of the dollar costs of goods are to the economist. Energy is the currency of the ecosystem, and an understanding of energy transactions helps one realize the potentials for and the limits to ecological processes in the natural world.

Aaron N. Moen
March 11, 1981

GLOSSARY OF SYMBOLS USED - CHAPTER SEVEN

AGDA = Age in days

BAMD = Basal metabolism per day
BIWK = Birth weight in kilograms
BHRM = Bedded heart rate per minute
BLM- = Base-line metabolism
BLMD = Base-line metabolism per day
BMR- = Basal metabolic rate
BRRM = Bedded respiration rate per minute

CLWK = Calculated live weight in kilograms

DHGD = Duration of hair growth per day
DIGE = Days into gestation
DILA = Days into lacation
DSTK = Distance in kilometers

ECBD = Energy cost of bedding per day
ECFD = Energy cost of foraging per day
ECGD = Energy cost of gestation per day
ECHD = Energy cost of hair growth per day
ECRD = Energy cost of running per day
ECSD = Energy cost of standing per day
ECVA = Energy cost of vertical ascent
ECWD = Energy cost of walking per day
ECWL = Energy cost of walking upslope
ELMD = Ecological metabolism per day

FACO = Fat content
FAMD = Fasting metabolism per day
FATP = Fat percent
FHRM = Foraging heart rate per minute
FRRM = Foraging respiration rate per minute
FTBD = Fraction of time spent bedded per day
FTFD = Fraction of time spent foraging per day
FTRD = Fraction of time spent running per day
FTSD = Fraction of time spent standing per day
FTWD = Fraction of time spent walking per day

GENM = Gross energy in the milk

HAWG = Hair weight in grams
HGTK = Height ascended in kilometers
HIGR DIGE = Higher number of days into gestation
HRMC = Heart rate to metabolism conversion factor
HRPM = Heart rate per minute

IFMW = Ingesta-free metabolic weight
IFWK = Ingesta-free weight in kilograms

JDAY = Julian day

KCAL = Kilocalories
KCLO = Kilocalories per liter of $O_2$
KJOU = Kilojoules

LOWR DIGE = Lower number of days into gestation
LWKG = Live weight in kilograms

MBLM = Multiple of base-line metabolism
MEWK = Metabolic weight in kilograms
MPGD = Milk production in grams per day
MRMW = Metabolic rate per metabolic weight

NECM = Net energy coefficient for milk
NUFA = Number of fawns

PEGE = Physiological efficiency of gestation
PEHG = Physiological efficiency of hair growth
PMRB = Predicted metabolic rate bedded
PMRF = Predicted metabolic rate foraging
PMRR = Predicted metabolic rate running
PMRS = Predicted metabolic rate standing
PMRW = Predicted metabolic rate walking
PNDM = Percent nutrients derived from milk
PRCO = Protein content
PRPC = Primary phase correction

REHP = Resting heat production
REQO = Respiratory quotient
RHRM = Running heart rate per minute
RMBL = Running multiple of base-line metabolism
RRRM = Running respiration rate per minute

SHRM = Standing heart rate per minute
SLPD = Slope in degrees
SMBL = Standing multiple of base-line
SPKH = Speed in kilometers per hour
SRRM = Standing respiration rate per minute

TCCK = Total caloric content in kilocalories

WHRM = Walking heart rate per minute
WRRM = Walking respiration rate per minute

## GLOSSARY OF CODE NAMES - CHAPTER SEVEN

ACATA Acta Anatomica
AFBUD University of Alberta Agriculture and Forestry Bulletin
AJAEA Australian Journal of Agricultural Research
AJCNA American Journal of Clinical Nutrition
AJPHA American Journal of Physiology
AMNAA American Midland Naturalist
AMNTA American Naturalist
AMZOA American Zoologist
ANREA Anatomical Record
ANYAA Annals of the New York Academy of Sciences
APAVD American Association Zoo Veterinarian Annual Proceedings
APSCA Acta Physiologica Scandinavica
ATRLA Acta Theriologica

BISNA Bioscience
BJNUA British Journal of Nutrition
BPURD Biological Papers of the University of Alaska Special Report

CAFGA California Fish and Game
CBPAB Comparative Biochemistry and Physiology A Comparative Physiology
CIWPA Carnegie Institution of Washington Publication
CJBIA Canadian Journal of Biochemistry
CJZOA Canadian Journal of Zoology
CNJNA Canadian Journal of Animal Science
COVEA Cornell Veterinarian

ECMOA Ecological Monographs
ECOLA Ecology

FEPRA Federation Proceedings

IJBMA International Journal of Biometeorology

JANSA Journal of Animal Science
JAPYA Journal of Applied Physiology
JASIA Journal of Agricultural Science
JCCPA Journal of Cellular and Comparative Physiology
JDSCA Journal of Dairy Science
JOMAA Journal of Mammalogy
JPHYA Journal of Physiology
JRMGA Journal of Range Management
JRPFA Journal of Reproduction and Fertility
JTBIA Journal of Theoretical Biology
JWIDA Journal of Wildlife Diseases
JWMAA Journal of Wildlife Management

NATUA Nature
NAWTA North American Wildlife and Natural Resources Conference, Transactions of the,
NCANA Naturaliste Canadien, Le

NUMEB Nutrition and Metabolism

OJSCA Ohio Journal of Science

PAANA Proceedings of the Australian Society of Animal Production
PAARA Pennsylvania State University College of Agriculture Agricultural Experiment Station Progress Report
PASCC Proceedings of the Alaskan Scientific Conference
PECTD Polish Ecological Studies
PHREA Physiological Reviews
PHZOA Physiological Zoology
PNDAA Proceedings of the North Dakota Academy of Science
PNSUA Proceedings of the Nutrition Society
PNUSA Proceedings of the Nutrition Society
PSEBA Proceedings of the Society for Experimental Biology and Medicine
PZOOA Przeglad Zoologiczny

QJEPA Quarterly Journal of Experimental Physiology and Cognate Medical Sciences
QSFRA Quebec Service de la Faune Rapport

RSPYA Respiration Physiology

SCIEA Science
SSEBA Symposia of the Society for Experimental Biology
SZSLA Symposia of the Zoological Society of London

VJSCA Virginia Journal of Science

WLMOA Wildlife Monographs

ZOBIA Zhurnal Obshchei Biologii
ZTTFA Zeitschrift fuer Tierphysiologie Tierer naehrung und Futtermittelkunde
ZZAHA Zeitschrift fuer Zellforschung und Mikroskopisch Anatomie

LIST OF PUBLISHERS - CHAPTER SEVEN

| | | | |
|---|---|---|---|
| acpr | Academic Press | New York | nyny |
| agrc | Agricultural Res. Council | London, England | loen |
| ccth | Charles C. Thomas | Springfield, IL | spil |
| coms | Comstock | Ithaca, NY | itny |
| fase | Federation of American Society for Experimental Biology | Bethesada, MD | bemd |
| hutc | Hutchinson | London, England | loen |
| jdve | Joris, Druck, and Verlag | Zurick, Switzerland | zusw |
| mopc | Morrison Publishing Co. | Ithaca, NY | itny |
| prha | Prentice-Hall, Inc. | Princeton, NJ | prnj |
| repu | Reinhold Publishing | New York | nyny |
| saco | Saunders Publishing Co. | Philadelphia, PA | phpa |
| whfr | W. H. Freeman Co. | San Francisco, CA | sfca |
| wile | Wiley | New York | nyny |

LIST OF WORKSHEETS - CHAPTER SEVEN

JULIAN DAY: MONTH AND DAY EQUIVALENTS

| Day | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Day |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 001 | 032 | 060 | 091 | 121 | 152 | 182 | 213 | 244 | 274 | 305 | 335 | 1 |
| 2 | 002 | 033 | 061 | 092 | 122 | 153 | 183 | 214 | 245 | 275 | 306 | 336 | 2 |
| 3 | 003 | 034 | 062 | 093 | 123 | 154 | 184 | 215 | 246 | 276 | 307 | 337 | 3 |
| 4 | 004 | 035 | 063 | 094 | 124 | 155 | 185 | 216 | 247 | 277 | 308 | 338 | 4 |
| 5 | 005 | 036 | 064 | 095 | 125 | 156 | 186 | 217 | 248 | 278 | 309 | 339 | 5 |
| 6 | 006 | 037 | 065 | 096 | 126 | 157 | 187 | 218 | 249 | 279 | 310 | 340 | 6 |
| 7 | 007 | 038 | 066 | 097 | 127 | 158 | 188 | 219 | 250 | 280 | 311 | 341 | 7 |
| 8 | 008 | 039 | 067 | 098 | 128 | 159 | 189 | 220 | 251 | 281 | 312 | 342 | 8 |
| 9 | 009 | 040 | 068 | 099 | 129 | 160 | 190 | 221 | 252 | 282 | 313 | 343 | 9 |
| 10 | 010 | 041 | 069 | 100 | 130 | 161 | 191 | 222 | 253 | 283 | 314 | 344 | 10 |
| 11 | 011 | 042 | 070 | 101 | 131 | 162 | 192 | 223 | 254 | 284 | 315 | 345 | 11 |
| 12 | 012 | 043 | 071 | 102 | 132 | 163 | 193 | 224 | 255 | 285 | 316 | 346 | 12 |
| 13 | 013 | 044 | 072 | 103 | 133 | 164 | 194 | 225 | 256 | 286 | 317 | 347 | 13 |
| 14 | 014 | 045 | 073 | 104 | 134 | 165 | 195 | 226 | 257 | 287 | 318 | 348 | 14 |
| 15 | 015 | 046 | 074 | 105 | 135 | 166 | 196 | 227 | 258 | 288 | 319 | 349 | 15 |
| 16 | 016 | 047 | 075 | 106 | 136 | 167 | 197 | 228 | 259 | 289 | 320 | 350 | 16 |
| 17 | 017 | 048 | 076 | 107 | 137 | 168 | 198 | 229 | 260 | 290 | 321 | 351 | 17 |
| 18 | 018 | 049 | 077 | 108 | 138 | 169 | 199 | 230 | 261 | 291 | 322 | 352 | 18 |
| 19 | 019 | 050 | 078 | 109 | 139 | 170 | 200 | 231 | 262 | 292 | 323 | 353 | 19 |
| 20 | 020 | 051 | 079 | 110 | 140 | 171 | 201 | 232 | 263 | 293 | 324 | 354 | 20 |
| 21 | 021 | 052 | 080 | 111 | 141 | 172 | 202 | 233 | 264 | 294 | 325 | 355 | 21 |
| 22 | 022 | 053 | 081 | 112 | 142 | 173 | 203 | 234 | 265 | 295 | 326 | 356 | 22 |
| 23 | 023 | 054 | 082 | 113 | 143 | 174 | 204 | 235 | 266 | 296 | 327 | 357 | 23 |
| 24 | 024 | 055 | 083 | 114 | 144 | 175 | 205 | 236 | 267 | 297 | 328 | 358 | 24 |
| 25 | 025 | 056 | 084 | 115 | 145 | 176 | 206 | 237 | 268 | 298 | 329 | 359 | 25 |
| 26 | 026 | 057 | 085 | 116 | 146 | 177 | 207 | 238 | 269 | 299 | 330 | 360 | 26 |
| 27 | 027 | 058 | 086 | 117 | 147 | 178 | 208 | 239 | 270 | 300 | 331 | 361 | 27 |
| 28 | 028 | 059 | 087 | 118 | 148 | 179 | 209 | 240 | 271 | 301 | 332 | 362 | 28 |
| 29 | 029 | [060] | 088 | 119 | 149 | 180 | 210 | 241 | 272 | 302 | 333 | 363 | 29 |
| 30 | 030 | | 089 | 120 | 150 | 181 | 211 | 242 | 273 | 303 | 334 | 364 | 30 |
| 31 | 031 | | 090 | | 151 | | 212 | 243 | | 304 | | 365 | 31 |

* For leap year, February 29 = JDAY 60. Add 1 to all subsequent JDAYs.