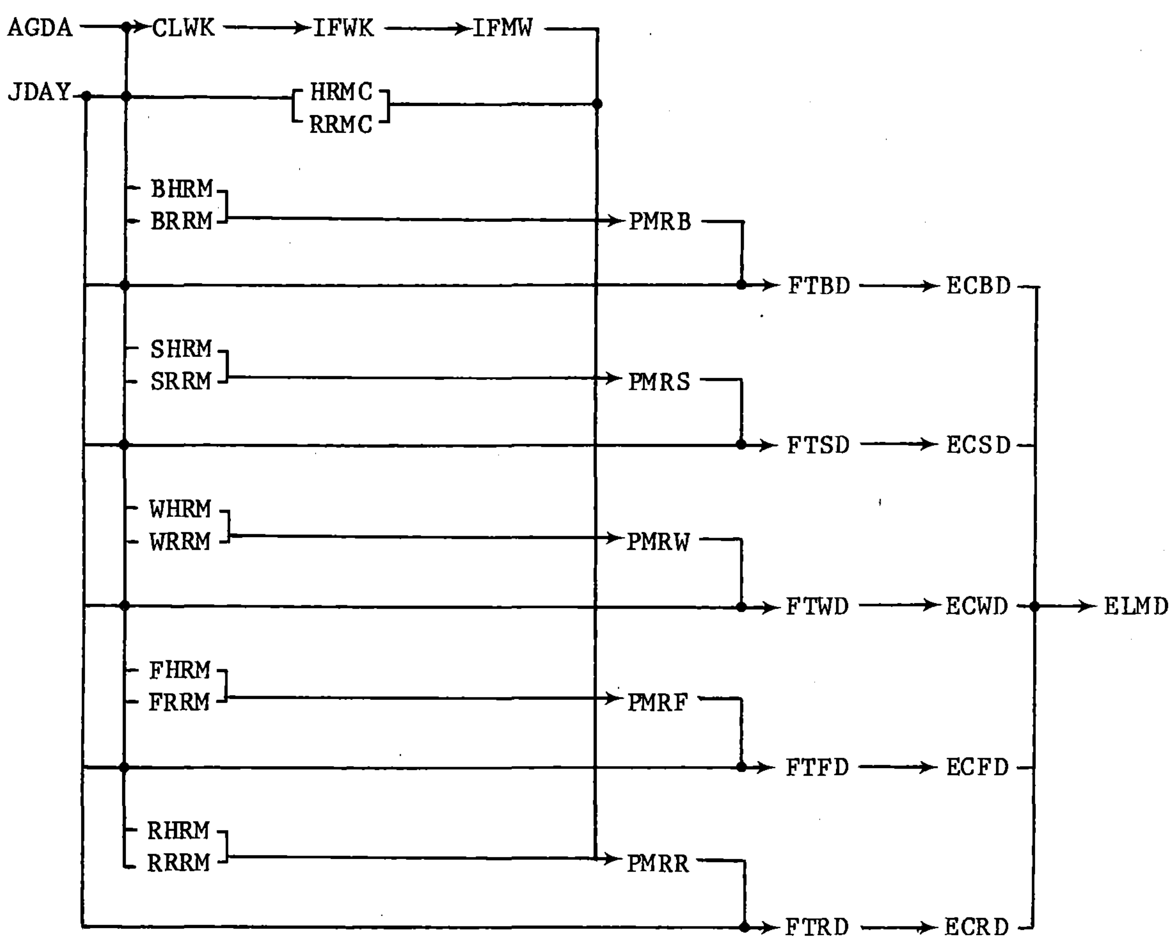
TOPIC 5. VITAL SIGN: METABOLISM RELATIONSHIPS

Vital signs of free-ranging animals are difficult enough to measure, but measurement of the metabolism of wild, free-ranging ruminants is essentially impossible. Estimates of the ecological costs of living are absolutely essential for calculating energy relationships within populations and systems, however, so methods for making such estimates must be found.

The use of equations to convert data on vital signs to estimates of metabolism is often criticized due to a lack of accuracy. It may, however, be the only practical way to get estimates for long time periods. The patterns of metabolism estimates based on vital signs may give one considerable insight into variations from one season to another through the annual cycle. Conversion of heart rates to estimates of the energy cost of activity follows the sequence of calculations illustrated in the figure below, based on Moen (1978). Respiration rates are added to the sequence to illustrate how heart rates and respiration rates may be used either alone or together. Definitions of the symbols are given on the next page.



DEFINITIONS OF SYMBOLS USED IN THE FLOW CHART ON THE PREVIOUS PAGE

AGDA = age in days

BHRM = bedded heart rate per minute
BRRM = bedded respiration rate per minute

CLWK = calculated live weight in kg

ECBD = energy cost of bedding per day
ECFD = energy cost of foraging per day
ECRD = energy cost of running per day
ECSD = energy cost of standing per day
ECWD = energy cost of walking per day
ELMD = ecological metabolism per day

FHRM = foraging heart rate per minute
FRRM = foraging respiration rate per minute
FTBD = fraction of time bedded per day
FTFD = fraction of time foraging per day
FTRD = fraction of time running per day
FTSD = fraction of time standing per day
FTWD = fraction of time walking per day

HRMC = heart rate to metabolism conversion factor

IFMW = ingesta-free metabolic weight
IFWK = ingesta-free weight in kg

JDAY = Julian day

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

RHRM = running heart rate per minute
RRRM = running respiration rate per minute

SHRM = standing heart rate per minute
SRRM = standing respiration rate per minute

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

The energy costs of activities can be predicted with a sequence of equations that relate heart rate, metabolism, and behavior. Heart rates observed during specific activities (See CHAPTER 6, UNIT 2.1) are calculated first Then heart rate is converted to metabolism (See UNIT 5.2), and the results multiplied by the metabolic weight. This results in a 24-hour estimate of energy metabolism for a specific activity. Since an animal does not spend 24 hours a day in any one activity, the 24-hour cost is multiplied by the fraction of time spent in each activity per day (See CHAPTER 4). The daily costs of each activity are then added together to determine ecological metabolism per day (ELMD).

Two inputs--AGDA and JDAY--are necessary for the calculations. Both are used to calculate live weight (CLWK), which is converted to ingesta-free weight (IFWK) and ingesta-free metabolic weight (IFMW) = $IFWK^{0.75}$). The Julian day (JDAY) is then used to calculate the heart rates and respiration rates in each of the activities, followed by the heart rate-to-metabolism conversion factor, HRMC, discussed in the WORKSHEET that follows, and the respiration rate-to-metabolism conversions factor RRMC (See WORKSHEET that follows).

Metabolic body weight, heart beats per minute, and the heart rate-to-metabolism conversion factor are then combined to estimate the metabolism of the animal for a 24-hour period of time in each of the five activities listed. These 24-hour estimates are then multiplied by the fractions of time in each of the five activities (determined from JDAY) to determine the energy cost of bedding per day (ECBD), energy cost of standing per day (ECSD), energy cost of walking per day (ECWD), energy cost of foraging per day (ECFD), and the energy cost of running per day (ECRD) throughout the year. The sum of these costs is the ecological metabolism per day (ELMD). Maintenance costs are included, however, since heart beats during activities also support the biological functions that provide for tissue maintenance.

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.

REFERENCES, TOPIC 5

VITAL SIGN: METABOLISM RELATIONSHIPS

BOOKS

TYPE	PUBL	CITY	PGES	ANIM	KEY WORDS-----------------	AUTHORS/EDITORS--	YEAR
edbo	acpr	nyny	427	many	comprtv nutritn wild anims	crawford,ma,ed	1968
aubo	hutc	loen	332	rumi	energy metabo 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	1978

UNIT 5.1: BODY TEMPERATURES

Body temperatures are indicators of the metabolic rate in relation to that expected under current conditions. Low body temperatures indicate depressed metabolism and hypothermia. High body temperatures indicate either elevated metabolism or a breakdown of heat loss mechanisms. Elevated metabolism may be due to infections, or to prolonged activity. Body temperatures are useful indicators of general body condition, but not of the absolute levels of metabolism. Temperatures are the effect rather than the cause.

Measurements of body temperatures are most often made in the rectum, representing a deep body temperature. Variations in temperatures do occur over different parts of the body, and the locations of measurements should be noted, especially when sites other than the rectum are involved.

REFERENCES, UNIT 5.1

BODY TEMPERATURES

SERIALS

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
APAVD	1976	185	194	odvi	succinylcholine in deer	kitchen,h	1976
JWMAA	40--4	626	629	odvi	predic metab rat, heart ra	holter,jb; urban/	1976

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
JWMAA	19--1	154	155	odhe	normal temperat, colum btd	cowan,im; wood,a	1955

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

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
JWMAA	39--3	634	636	alal	physiol effec, m-99 etorph	roussel,ye; paten	1975

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
CJZOA	43--5	683	687	rata	body temp, barren ground c	mcewan,eh; wood,/	1965

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
JOMAA	56--3	697	698	anam	normal body temp, mule de	thorne,et	1975
JWMAA	35--4	747	751	anam	telemetry syst, body tempe	lonsdale,em; bra/	1971

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

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
JWIDA	7---2	105	108	ovca	comp phys vals, capt & wld	franzmann,aw;	1971
JWMAA	35--3	488	494	ovca	variation rectal temperatu	franzmann,aw; heb	1971
JWMAA	36--3	924	932	ovca	physiologc vals, env varia	franzmann,aw	1972

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
BJNUA	21--3	769	785	dosh	cont measure heart rate in	webster,ajf	1967

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
JPHYA	176--	136	144		deep bod temp 12-month per	bligh,j; ingram,/	1965
JWMAA	34--4	921	925	ungu	radio-telem, temp, unrestr	mcginnis,sm; fin/	1970

UNIT 5.2: HEART RATE-TO-METABOLISM CONVERSIONS

Relationships between heart rates and metabolic rates have been determined under controlled conditions for several species. The general pattern of increased heart rate: increased metabolism is clear, but the application of a general equation to individuals is not good due to wide variability between individuals. Some, for example, have larger hearts and greater stroke volumes than others, so their heart rates are less per unit metabolism. Some have higher overall rates of metabolism, and some have different ratios of heart rate: metabolism due to differences in vascular resistances and the efficiencies of gas exchange.

The most complete set of simultaneous measurements of heart rate and metabolic rate has been made by Holter et al. (1976) on white-tailed deer. Seasonal effects were statistically significant. No statistically significant effects on metabolic rate of sex or nutrition level, or of sex x season, nutrition level x season, or sex x nutrition level interactions were found. They presented four linear regression equations--for summer, fall, winter, and spring--for calculating metabolic rate from heart rate.

Seasonal differences in the heart rate:metabolic rate relationships for an animal must involve gradual shifts through the annual cycle. The use of four separate equations in data analyses would result in a discontinuity at the beginning of each season. Accordingly, the four separate equations were combined into a single eqution by expressing the a values and the b values as single equations for a and b rather than as seasonal constants. This is discussed in Moen (1978:723). The resulting equation is presented in WORKSHEET 5.2a.

Heart rate:energy expenditure relationships are discussed by Robbins et al. (1979) for elk calves, but an equation is not given for their data in Figure 5 (p. 451). They point out the large amount of variability in the relationship, but this variability may be due as much or even more to transient effects on heart rate of their animals while outside as to a fundamental physiological difference in the heart rate:metabolic rate relationships.

Careful interpretation of heart rates is necessary. Heart rate transients due to known stimuli may be pronounced (Moen et al. 1978 and Moen and Chevalier 1977), resulting in wide fluctuations in heart rates. The effects of such transients were eliminated in the measurements described in Moen (1978), resulting in distinct seasonal patterns to both heart rate and metabolism that would have been much more difficult to recognize if random samples of heart rates without behavioral observations had been made.

LITERATURE CITED

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.

Moen, A. N. and S. Chevalier. 1977. Analyses of telemetered ECG signals from white-tailed deer. Pages 118-125 In Proc. of Biotelemetry Conf. Univ. of Wyoming, Laramie.

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

Moen, A. N., M. A. DellaFera, A. L. Hiller, and B. A. Buxton. 1978. Heart rates of white-tailed deer fawns in response to recorded wolf howls. Can. J. Zool. 56(5):1207-1210.

Robbins, C. T., Y. Cohen, and B. B. Davitt. 1979. Energy expenditure by elk calves. J. Wildl. Manage. 43(2):445-453.

REFERENCES, UNIT 5.2

HEART RATE-TO-METABOLISM CONVERSIONS

SERIALS

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
APAVD	1976	185	194	odvi	succinylcholine in deer	kitchen,h	1976
JWMAA	40--4	626	629	odvi	predic metab rat, heart ra	holter,jb; urban/	1976
JWMAA	42--4	715	738	odvi	seas chan, heart rate, act	moen,an	1978

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

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

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

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
CJZOA	56--2	215	223	rata	energy expend, walk, tundr	white,rg; yousef,	1978

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

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

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
BJNUA	21--3	769	785	dosh	cont meas heart rat indi e	webster,ajf	1967

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
AJCNA	22---	696	700	many	heart-rate tel, energ, man	bradfield,rb; hu/	1969
ATRLA	16--1	1	21		metabo levels, homeotherms	poczopko,p	1971
CJBIA	38-11	1301	1309		pulse rate, meta rate, man	booyens,j· hervey	1960
JAPYA	14--6	927	936		oxy inta, heart, work, man	wyndham,ch; stry/	1959
JAPYA	26--3	297	302		energy exp, work, hear rat	datta,sr; ramanat	1969

CHAPTER 7, WORKSHEET 5.2a

Heart rate to metabolism conversions for white-tailed deer

The heart rate to metabolism conversion equation in Moen (1978:723), modified to include four-letter symbols is given below.

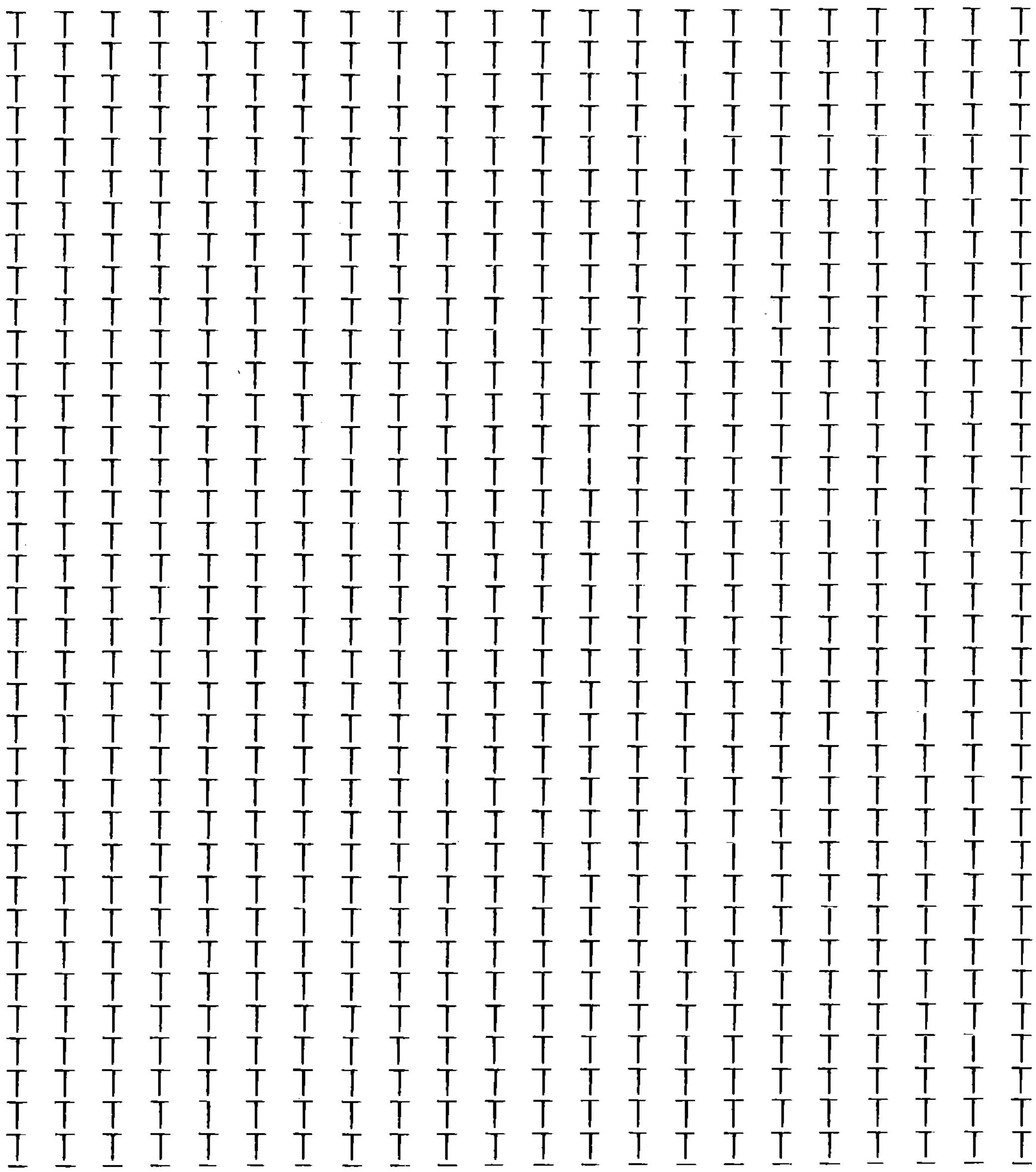
$$MRMW = \{-0.92 \sin[(JDAY)(0.9863) + 74] - 0.005 + 2.3\} \, HRPM + \{31.9 \sin[(JDAY)(0.9863) + 74] + 0.087 + 0.55\}$$

where MRMW = metabolic rate per unit metabolic weight = metabolic rate in $kcal/W_{kg}^{0.75}$,
JDAY = Julian day, and
HRPM = heart rate per minute.

The 0.9863 is the day-to-degree conversion factor (360/365 = 0.9863).

A nomogram or a table of MRMW values would be useful for later reference and calculations. Verify the equation and complete a nomogram on the grid on the next page where JDAY is on the x-axis, MRMW is on the y-axis, and HRPM a family of curves (30, 40...100) for example, or set up a table as indicated below.

HRPM =	30	40	50	60	70	80	90	100	110	120	------->
	1										
	8										
JDAY =	15										
	22										
	29										
	.										
	.										
	.										
	365										
MRMW =											



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.

CHAPTER 7, WORKSHEET 5.2b

Heart rate-to-metabolism conversions for elk calves

The relationships between energy expenditures and heart rates of five elk calves were plotted by Robbins et al. (1979:451; Fig. 5). Four of the five were quite similar. Using a grid overlay, estimate the x-y pairs for these four and derive a linear regression equation for these data. Remember that such an equation can be easily derived with hand calculations described in CHAPTER 2, UNIT 1.2, WORKSHEET 1.2b, p. 10b).

Compare the results above with those calculated in the previous WORKSHEET. Keep in mind that these are for a different species, different ages and for only a 2-month experimental period (summer).

Comparisons like those suggested above help one understand both biological and mathematical concepts, and understanding is fundamental to syntheses of ecological pictures.

LITERATURE CITED

Robbins, C. T., Y. Cohen, and B. B. Davitt. 1979. Energy expenditure by elk calves. J. Wildl. Manage. 43(2):445-453.

UNIT 5.3: RESPIRATION RATE-TO-METABOLISM CONVERSIONS

Relationships between external respiration rates and metabolism are somewhat predictable since oxygen, supplied by external respiration, is necessary for metabolism. As activity levels increase, respiration rates increase, though not necessarily in direct proportion since volumes of air respired also change. Respiration and heart rates combined should be a better predictor of metabolism than either one alone.

Respiration rates have been measured by White and Yousef (1978) on reindeer and Robbins et al. (1979) on elk calves as oxygen consumption was being measured, permitting evaluations of the relationships between both respiration rate and volume and energy expenditures. results are presented graphically by Robbins et al (1979:450; Fig. 3 and 4), with equations. Variations in respiratory frequency during standing and the effects of panting are clearly illustrated in Figure 4. Respiratory frequency alone, including effects due to posture, locomotion, and panting could hardly be expected to be a good predictor of energy expenditure. Recognition of respiratory characteristics and frequencies will help when interpreting respiratory rate data.

LITERATURE CITED

Robbins, C. T., Y. Cohen, and B. B. Davitt. 1979. Energy expenditure by elk calves. J. Wildl. Manage. 43(2):445-453.

White, R. G. and M. K. Yousef. 1978. Energy expenditure in reindeer walking on roads and on tundra. Can. J. Zool. 56(2):215-223.

REFERENCES, TOPIC 5.3

RESPIRATION RATE-TO-METABOLISM CONVERSIONS

SERIALS

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
APAVD	1976-	185	194	odvi	succinylcholine in deer	kitchen,h	1976
JWMAA	40--4	626	629	odvi	predic metab rat, heart ra	holter,jb; urban/	1976

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

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
ANREA	189-1	91	108	ceel	carotid, orbital retia, pr	carlton,c; mckean	1977

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

alal

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

rata

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

anam

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

bibi

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

ovca

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
BJNUA	21--3	769	785	dosh	cont meas heart rat indi e	webster,ajf	1967

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
AJCNA	22---	696	700	many	heart-rate tel, energ, man	bradfield,rb; hu/	1969
ATRLA	16--1	1	21		metabo levels, homeotherms	poczopko,p	1971
CJBIA	38-11	1301	1309		pulse rate, meta rate, man	booyens,j; hervey	1960
JAPYA	26--3	297	302		energy exp, work, hear rat	datta,sr; ramanat	1969