INTRODUCTION

TO PART V

METEOROLOGY AND THERMAL RELATIONSHIPS OF WILD RUMINANTS

The earth and its atmosphere is a physical entity in the near-vacuum of space. Meteorologists study the behavior of this earth-atmosphere system, and some ecologists study the energy balance of organisms within the biosphere, the part of this earth-athmosphere system where life occurs.

Considerable attention has been given to the effects of weather on wildlife, and a large number of field observations of animal behavior and activity patterns have been related to measurements of weather conditions. Although conclusions may be made from such analyses, there are some basic problems in relating animal behavior directly to weather data. Animals experience weather, which is another term for atmospheric physics, in ways that are different from that experienced by weather instruments. For example, the temperature-sensing capabilities of wild ruminants are different from those of thermometers. Also, animals experience the effects of wind and respond to it in ways that are different from cup anemometers or other wind measuring devices. Thus it is dangerous to draw conclusions about animal responses to weather directly from weather data, and the use of simple correlations between the two is discouraged.

Animals experience both thermal and mechanical effects of weather forces. The sensation of cold is a thermal effect of wind, and the distribution of scent a mechanical effect. Thermal and mechanical forces act on both plants and animals, and each organism has ranges of sensitivities and responses to these forces. Analyses of these responses are best completed by analyzing the basic physical and biological factors involved.

The first chapter in this part, CHAPTER 14, includes discussions of meteorological characteristics. The second, CHAPTER 15, includes discussions and data that describe thermal characteristics and basic heat transfer between organism and environment. CHAPTER 16 includes descriptions of two ways of evaluating basic heat transfer between animal and environment, and thermoregulatory responses. CHAPTER 17 includes discussions of weather, range, and animal profiles that are useful when evaluating energy balances over time. Such considerations lead to evaluations of population responses in PART VI.

The list of PERIODICALS on the next two pages will help introduce the reader to the publications available in meteorology. Complete lists of published papers on different aspects of meteorology are not given in each CHAPTER since the number of such references is very large. Papers describing the responses of wild ruminants to meteorologcal characteristics and thermal exchange are listed, however.

PERIODICALS PERTAINING TO METEROLOGY

UNITED STATES

Bulletin of the American Meteorological Society. Monthly. AMS, 45 Beacon St., Boston, MA 02108.

Geophysical Monograph Series. Irregular. American Geophysical Union. 1145 19th St., N.W., Wash., D.C. 20036.

Journal of Applied Meteorology. Bimonthly. AMS, 45 Beacon St., Boston, MA 02108.

Journal of the Atmospheric Sciences. Bimonthly. AMS, 45 Beacon St., Boston, MA 02108.

Journal of Geophysical Research. Semimonthly. Amer. Geophys. Union, 1145 19th St., N.W., Wash., D.C. 20036.

Mariners Weather Log. A bimonthly climatic review of ocean and lake areas. Weather Bureau, ESSA. Wash., D.C. 20402.

Meteorological and Geoastrophysical Abstracts. Monthly. AMS, 45 Beacon St., Boston, MA 02108.

Meteorological Monographs. Irregular. AMS.

Monthly Weather Review. Monthly. Weather Bureau, ESSA. Supt. of Documents, Government Printing Office, Wash., D.C. 20402.

Mount Washington Observatory Bulletin. Quarterly. Amer. Geophys. Union, Wash., D.C.

Reviews in Geophysics. Quarterly. Amer. Geophys. Union, Wash., D.C.

Transactions of the American Geophysical Union. Quarterly. Amer. Geophys. Union, Wash., D.C.

Weatherwise. Bimonthly. AMS, 45 Beacon St., Boston, MA 02108.

CANADA

Atmosphere. Bulletin of Canadian Meteorology. Quarterly. Canadian Branch, RMS, Dept. of Meteorology, McGill Univ., Montreal., P.Q. Commenced March 1963.

CANADA continued on the next page

Canadian Geophysical Bulletin. Annual. National Research Council of Canada. Ottawa, Ont.

Canadian Weather Review. Monthly. Canadian Meteorological Service. Queen's Printer, Ottawa, Ont. 8 pages climatological data.

GREAT BRITAIN

The Marine Observer. Quarterly. British Met. Office. British Information Services, 845 Third Ave., New York, NY.

Meteorological Magazine. Monthly. British Met. Office. British Information Services, N. Y.

Quarterly Journal of the Royal Meteorological Society. RMS, 49 Cromwell Road, London SW 7, England.

Weather. Monthly. RMS, 49 Cromwell Road, London SW 7, England.

OTHERS (mainly English text)

Australian Meteorological Magazine. Quarterly. Canberra.

Bulletin of the World Meteorological Organization. Quarterly. WMO, Geneva, Switzerland.

Geophysical Magazine. Irregular. Central Met. Observatory. Tokyo, Japan.

Indian Journal of Meteorology and Geophysics. Quarterly. Indian Met. Dept. Manager of Publications, Delhi, India.

Journal of Hydrology. Quarterly. North-Holland Publishing Co., Box 103, Amsterdam, Netherlands. Commenced March 1963.

GLOSSARY OF ANIMAL CODE NAMES

Wild ruminants are referred to in this CHAPTER by a 4-character abbreviation from the family, genus and genus-species. These are listed below under Abbreviation.

Scientific names of North American wild ruminants are those used in BIG GAME OF NORTH AMERICA, edited by J.C. Schmidt and D. L. Gilbert (1979: Stackpole Books, Harrisburg, PA 17105, 494 p.), and may be different from the scientific names given in the original literature.

The abbreviations used for North American wild ruminants are listed below.

CLASS: MAMMALIA

ORDER: ARTIODACTYLA	Abbreviation
FAMILY: CERVIDAE	cerv
GENUS: *Odocoileus* (deer)	od--
SPECIES: *O. virginianus* (white-tailed deer)	odvi
O. hemionus (mule deer)	odhe
GENUS: *Cervus* (Wapiti, elk)	ce--
SPECIES: *C. elaphus*	ceel
GENUS: *Alces* (moose)	
SPECIES: *A. alces*	alal
GENUS: *Rangifer* (caribou)	
SPECIES: *R. tarandus*	rata
FAMILY: ANTILOCAPRIDAE	
GENUS: *Antilocapra*	
SPECIES: *A. americana* (pronghorn)	anam
FAMILY: BOVIDAE	bovi
GENUS: *Bison* (bison)	bi--
SPECIES: *B. bison*	bibi
GENUS: *Ovis* (sheep)	ov--
SPECIES: *O. canadensis* (bighorn sheep)	ovca
O. dalli (Dall's sheep)	ovda
GENUS: *Ovibos*	
SPECIES: *O. moschatus* (muskox)	obmo
GENUS: *Oreamnos*	
SPECIES: *O. americanus* (mountain goat)	oram

The abbreviations used for European wild ruminants are listed below.

CLASS: MAMMALIA

	Abbreviation
ORDER: ARTIODACTYLA	
FAMILY: CERVIDAE	cerv
GENUS: *Capreolus* (roe deer)	ca--
SPECIES: *C. capreolus*	caca
GENUS: *Dama* (fallow deer)	da--
SPECIES: *D. dama*	dada
GENUS: *Cervus* (Wapiti, elk)	ce--
SPECIES: *C. elaphus* (red deer)	ceel
GENUS: *Alces* (moose)	
SPECIES: *A. alces*	alal
GENUS: *Rangifer* (caribou)	
SPECIES: *R. tarandus*	rata
FAMILY: BOVIDAE	
GENUS: *Bison* (bison)	
SPECIES: *B. bonasus*	bibo
GENUS: *Capra* (ibex, wild goat)	cp--
SPECIES: *C. aegagrus* (Persian ibex)	cpae
C. siberica (Siberian ibex)	cpsi

OTHERS

Abbreviations for a few other species and groups of species may appear in the reference lists. These are listed below.

Axis axis (axis deer)	axax
Elaphurus davidianus (Pere David's deer)	elda
Cervus nippon (Sika deer)	ceni
Hydropotes inermis (Chinese water deer)	hyin
Muntiacus muntjac (Indian muntjac)	mumu
Moschus moschiferus (musk deer)	momo
Ovis nivicola (snow sheep)	ovni
Ovis musimon (moufflon)	ovmu
Ovis linnaeus (Iranian sheep)	ovli
Rupicapra rupicapra (chamois)	ruru
big game	biga
domestic sheep	dosh
domestic cattle	doca
domestic goat	dogo
domestic ruminant	doru
herbivore	hrbv
mammals	mamm
three or more species of wild ruminants	many
ruminants	rumi
ungulates	ungu
vertebrates	vert
wildlife	wldl
wild ruminant	wiru

ORGANIZATION OF REFERENCE LISTS

Extensive reference lists, based on computer-assisted searches back to 1970 and manual searches of literature published prior to 1970, are included in each of the PARTS. The lists are organized in a functional way for use in the library rather than in the conventional alpabetized-by-author way, with the information necessary for locating the references in libraries given in abbreviated, one-line form. The reference books listed after each PART, CHAPTER, and TOPIC contain background information for the material covered, and may contain specific information for several of the UNITS and WORKSHEETS.

The headings for the lists of BOOKS are:

TYPE PUBL CITY PGES ANIM KEY WORDS----------------- AUTHORS/EDITORS-- YEAR

The TYPE of book could have either an author (aubo) or an editor (edbo). Publishers (PUBL) and CITY of publication are given with four-letter mnemonic symbols defined in the GLOSSARY. The PAGE column gives the number of pages in the book; ANIM refers to the species discussed in the book (given as a four-letter abbreviation of genus and species), and KEY WORDS lists key words from the title. The AUTHORS/EDITORS' names and YEAR of publication are given in the last two columns. Thus all of the essential information for finding each book in the library is given on just one line.

Serial publications that pertain to each division are listed with a slightly different format. (Serials are identified by a five-character, generally mnemonic code called CODEN, published in 1977 BIOSIS, LIST OF SERIALS (BioSciences Information Service, 2100 Arch Street, Philadelphia, PA 19103).

The headings for the lists of SERIALS are:

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

The volume and issue numbers (VO-NU) are given after the CODEN entry, followed by beginning page (BEPA), ending page (ENPA), species discussed (ANIM), key words from the title (KEY WORDS), AUTHORS, and YEAR.

Specific authors and dates of publication can be located quickly by scanning the two right-hand columns. If the author's name fits in the 17 characters, some character spaces are left blank. If there are two authors and all of the first author's name and part of the second author's name fits in the 17 character spaces, the second author's name is truncated at the right margin of the author column. If there are more authors that do not appear in the author column due to lack of space, a slash (/) is added inthe 17th space of the column.

References cited in the text material and in the WORKSHEETS are given under LITERATURE CITED in the traditional format (author, date, title of article, journal, volume, issue number, and page numbers).

A third category, OTHER PUBLICATIONS, may be included at the beginning of PARTS or in the CHAPTERS. This category contains references to publications that are not authored or edited books or serials listed by BioSciences Information Service. Examples are "Transactions of the Northeastern Deer Study Group Meetings" and "Biannual Pronghorn Antelope Workshop, Proceedings." Both of these contain many articles on deer and pronghorns, respectively, but are not included in the one-line abbreviated form. Such publications are listed by titles, which should make it possible to locate the publications in libraries.

HOW TO USE THIS SYSTEM

The one-line format used to list references makes it possible to list several thousand references in a minimum amount of space. The logic of the one-line entries in the reference lists is based on the order of decision-making when finding literature. First, the references are grouped according to biological functions and relationships discussed in this book. Second, species of interest are selected. Third, journals containing references to be read are located in the library. Fourth, the publications are located in the journals. The use of this reference list format in the library will confirm the logic of this arrangement. Call numbers and stack levels should be added in the margins so references may be quickly located in a particular library.

CODEN entries are identified by the full title of the serial publication and its country, territory, or commonwealth of origin in the APPENDIX. CODEN entries in the serial lists are alphabetized. This results in some of the full titles being out of alphabetical order. Since the user of this book will usually work from CODEN to consult the list of full titles in the APPENDIX, this disorder will result in nothing more than occasional inconvenience. Most of the full titles will be near alphabetized, so the CODEN for a specific serial can be quickly found by scanning the appropriate part of the list.

Serials, including journals and report literature, constitute the major portion of the literature on wild ruminants. Scientists are urged to publish their findings in recognized journals so the results of their work are readily available.

THE BIOLOGY AND MANAGEMENT OF WILD RUMINANTS

CHAPTER FOURTEEN

METEOROLOGY AND THERMAL CHARACTERISTICS OF THE RANGE

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CONTENTS OF CHAPTER FOURTEEN

METEOROLOGY AND THERMAL CHARACTERISTICS OF THE RANGE

CONTENTS continued on the next page

CHAPTER 14: METEOROLOGY AND THERMAL CHARACTERISTICS OF THE RANGE

Evaluation of the meteorological characteristics of the earth-atmosphere interface is really a study of atmospheric and soil physics. Systematic recording of these characteristics results in the recognition of cycles, or rhythmic recurrences of certain physical relationships over time. For example, the earth revolves around the sun, and rotates on its axis in very precise periods. This results in very precise cyclic patterns of solar radiation over the earth's surface. Liquid water on the earth's surface absorbs solar energy and evaporates, changing from a liquid at the surface to a gas in the atmosphere, which eventually condenses and falls as precipatation. Since this sequence of events, called the hydrologic cycle, is driven by solar radiation, which varies rhythmically from season to season as the angle of the earth's axis in relation to the sun varies, the amounts of evaporation and precipitation vary rhythmically too; the hydrologic cycle is somewhat predictable. The timing is not as precise as the timing of the daily and seasonal solar radiation cycles, however, but wet and dry periods are recognized in many areas of the earth's surface.

The rhythmic nature of solar energy flux also results in temperature and wind rhythms, both daily and seasonally. Local patterns are influenced by large-scale atmospheric movements, of course, but under stable, high pressure conditions, 24-hour patterns are often quite predictable; the atmosphere is calm at sunrise, wind velocities increase to maximum in the afternoon, and decline to zero at sunset.

Patterns are recognized as a result of repeated measurements over time and space. Several standard measurements of weather conditions are made daily by professional weather observers and volunteers at hundreds of locations all across the United States and Canada. Other countries have similar measurement networks. The data are compiled into summaries that are available from government agencies and in libraries.

What meteorological characteristics are measured at weather stations? Temperature, which is an indicator of the energy balance of the atmosphere, is often represented as the high and low for a 24-hour period. Stations with recording equipment may report hourly temperature readings. Wind velocities and directions are measured and reported from many stations at specified times, often hourly when recording equipment is used. Atmospheric pressure is recorded, and sky conditions, with cloud types and heights, are observed and measured. Precipitation is reported for 24-hour periods from most stations, and hourly from the more automated stations. The amount of snow on the ground is also reported from many stations.

Weather measurements are made with some standardization of equipment and equipment location. Standard instrument shelters house temperature- and humidity-measuring equipment. Instruments in these shelters are located about 1 1/2 to 2 meters (5 to 6.5 feet) above the ground. The shelters are painted white and have slatted, louvered walls that permit air to circulate through the shelter while protecting the instruments from the sun's rays. They should be oriented so the door opens on the side away from the sun.

Cup anemometers are usually used to measure wind velocities. They should be located away from trees and other obstructions, but the distances from the instruments to influencing objects varies greatly from station to station since some stations are in heavily wooded areas and others are in open fields. Rain gauges should also be located away from obstructions, but again the distances vary at different stations. The weather recording stations operated by professional meteorologists are usually much more standardized than the temperature and precipitation stations manned by volunteers.

The term weather implies short-term atmospheric characteristics, and the term climate long-term characteristics. The accumulation of weather data over a period of several years results in general descriptions of the climate for a given area, and after a few years of measurement, norms are established. The term microclimate is often used by ecologists to describe the conditions surrounding a plant or an animal, but the term is very much a misnomer. The first part of the term (micro) is inappropriate because the thermal energy that influences an organism may well be coming from a long distance away. The sun, for example, is about 93,000,000 miles away (not very micro-), yet solar energy definitely influences the organism-atmosphere interface. The second part of the term (climate) is also inappropriate because organisms, especially short-lived plants and mobile animals, do not stay in one location long enough for a "climate" to develop around them. While it is generally known what is meant by the term microclimate, there is a better term available to identify the thermal conditions surrounding an organism. That term, thermal boundary region, is used throughout this book.

The thermal boundary region is defined as the layer of air around a plant or animal with temperatures and densities that are influenced by the surface characteristics of the plant or animal. Surface temperature, for example, may be different from that of the surrounding atmosphere or fluid of the animal. It is dependent on both biological and physical factors. The absorption of a large amount of solar radiation by the animal's surface results in a thermal boundary region of greater depth, while a wind over the surface reduces its depth. The thermal boundary region is discussed in detail in CHAPTER 15, UNIT 3.3.

Meteorological characteristics that affect thermal boundary region characteristics are discussed in the next 5 TOPICS, in this CHAPTER, followed by discussions of THERMAL CHARACTERISTICS AND BASIC HEAT TRANSFER in CHAPTER 15.

REFERENCES

CHAPTER 14. METEOROLOGY AND THERMAL CHARACTERISTICS OF THE RANGE

BOOKS

TYPE	PUBL	CITY	PGES	ANIM	KEY WORDS-----------------	AUTHORS/EDITORS--	YEAR
aubo	cupr	caen	428		physicl and dynam meteorol	brunt,d	1944
aubo	prha	nyny	373		weather elements	blair,ta	1948
aubo	ropr	nyny	412		veget and watershed manage	colman,ea	1953
aubo	prha	nyny	364		elementary meteorology	taylor,gf	1954
aubo	unca	daca	264		intro physical microclimat	brooks,fa	1959
aubo	mhbc	nyny	540		general meteorology	byers,hr	1959
aubo	acpr	nyny	355		descriptive meteorology	willet,hc; sander	1959
aubo	repu	nyny	235		envir measur and interpret	platt,rb; griffit	1964
aubo	haup	cama	611		the climate near the groun	geiger,r	1965
aubo	uchp	chil	272		physical climatology	sellers,wd	1965
aubo	adwe	rema	214		the science of weather	day,ja	1966
aubo	acpr	nyny	245		descriptive micrometeorolo	munn,re	1966
aubo	weni	loen	206		weather and climate	sutcliffe,rc	1966
edbo	repu	nyny	1200		encyclop atmosphr sciences	fairbridge,rw,ed	1967
edbo	crcp	cloh	339		handbook of chem and physi	weast,rc,ed	1967
aubo	mhbc	nyny	408		an introduction to climate	trewartha,gt	1968
aubo	hrwi	nyny	320		atmos, weather, and climat	barry,rg; chorley	1970
aubo	jdco	nyny	124		the national weather servi	berger,m	1971
aubo	whfr	sfca	586		foundations of climatology	stringer,et	1972
aubo	whfr	sfca	458		wildlife ecology	moen,an	1973

SERIALS

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
XFGTA	8----	1	31		table, convers microclimat	brown,jm	1973

OTHER PUBLICATIONS

Lansberg, H. E. and W. C. Jacobs. 1951. Applied climatology. Compendium of Meteorology, Amer. Met. Soc., Boston. 979 p.

Pacific Northwest River Basins Commission. 1969. Climatological Handbook, Columbia Basin States. Precipitation, Vol. 2. Vancouver, Washington.

Smithsonian Institution. 1951. Smithsonian Meteorological Tables. 6th revised edition. 527 p.

World Meteorological Organization. 1961. Guide to Meteorological Instrument and Observing Practices, 2nd Ed. Geneva, Switzerland. 20 p.

World Meteorological Organization. 1965. Guide to Hydrometeorological Practices. WMO - No. 158. TP. 82.

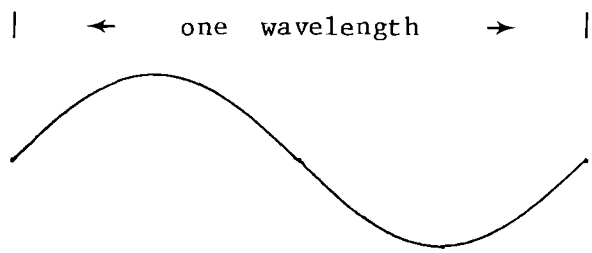
TOPIC 1. RADIANT ENERGY

The relationship between the sun and the earth provides the basic framework for atmospheric physics and biological productivity. The sun's energy generates thermal gradients in the atmosphere that result in temperature differences, density and pressure differences, and liquid-vapor changes in surface and atmospheric water. The sun's energy is also used by plants to synthesize new compounds by the process of photosynthesis, resulting in primary production.

There are two concurrent periodic rhythms--daily and yearly--in the duration and amount of solar energy received at the earth's surface, with the length of each related to the day of the year and the location on the earth. The transitions from one phase to another in both of these rhythms are gradual. Daylength reaches a maximum at the summer solstice and a minimum at the winter solstice. Sunlight intensity reaches a maximum at solar noon and goes to zero at night. Changes in the earth-atmosphere energy balance are gradual as a result of these changes in day length and sunlight intensity.

The sun continuously emits radiation into space as a result of the conversion of mass into energy. While the sun's mass is slowly being converted to energy as it radiates into space, the actual mass of the sun is so large that after a billion years of mass-to-energy conversions, 99.99% of the sun's mass remains! (See Miller 1972; p. 152).

Radiant energy may be visualized as a collection of waves that can be described by their wavelengths, or distances from peak to peak as illu-



strated above. The sun emits a wide range of wavelengths, including very short ones called X-rays, with wavelengths of a few microns, and very long ones, called radio waves, with wavelengths of many kilometers. The wavelengths of maximum emission (WLME) from the sun falls within the range of the visible spectrum, or those wavelengths which we humans are capable of detecting as visible light. The micron and the Angstrom are two units of measurement commonly applied to wavelengths in the visible and infrared portion of the electromagnetic spectrum. The micron is one millionth of a meter, one-ten thousandths of a centimeter (1×10^{-4}cm), or one thousandth of a millimeter. The Angstrom is 1/1000 of a micron.

The electromagnetic spectrum includes wave lengths as long as hundreds of kilometers and as short as 1×10^{-10} cm (0.0000000001 cm). The categories of wavelengths between these two extremes are listed below.

Kind of Waves	Approximate Wave Length Range --Metric Units
Long Electromagnetic Waves	Hundreds of kilometers to 17 kilometers
Assigned Radio Range	17 kilometers to 75 centimeters
Ultra-short Radio Waves	75 cm to .025 cm
Infra-red or Heat Rays	2.5×10^{-2} to 7.0×10^{-5}
Visible Light	7.0×10^{-5} x to 3.5×10^{-5}
Ultra-violet Rays	3.5×10^{-5} to 1.3×10^{-6}
X-rays	1.3×10^{-6} to 1.0×10^{-9}
Gamma Rays	1.0×10^{-9} to 1.0×1.0^{-10}

The part of the electromagnetic spectrum of importance to free-ranging animals, especially in the maintenance of homeothermy, includes the wave lengths in the visible to the far infrared portion of the electromagnetic spectrum.

```
                                     NEAR IR
   XRAY     ULTRAVIOLET VISIBLE   INTERMEDIATE IR     FAR  INFRARED
|........|..............|.....|....|............|.......................|
|         |              |          |            |          |            |
10A      100A          1000A       1um         10um       100um      1000um
```

Every surface which has a temperature higher than absolute zero emits radiant energy. The wavelengths emitted are proportional to the fourth power of the absolute temperature (K) of the radiating surface. High-temperature surfaces, such as the sun (6000°K) emit mainly at shorter wavelengths, and cooler surfaces, such as the earth's surface (300°K), emit the longer, or infrared wavelengths.

The wavelength of maximum emission is related to the temperature of the radiating surface according to Wien's Displacement Law, which may be expressed as:

$$WLME = c/ERTK$$

where c = 0.2898 cm °K (Rosenberg 1974: 8), and
ERTK = effective radiant temperature in °K.

WLME for the sun is, then:

$$WLME = 0.2898/6000 = 4.83 \times 10^{-5}$$

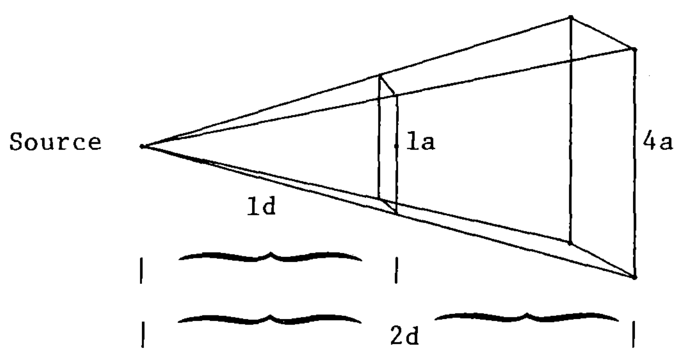
This wavelength, 4.83×10^{-5}, is within the visible part of the electromagnetic spectrum. WLME for a plant or an animal with a radiant temperature of 27 C, or 300 K, typical of a warm summer day, is:

$$WLME = 0.2898/300 = 9.66 \times 10^{-4} \text{ cm}$$

This wavelength, which is within the far infrared portion of the electromagnetic spectrum, is detected only as heat energy by animals.

The temperature: wavelength relationship is experienced when watching a campfire burn to a bed of hot, bright red coals. As the coals cool down, they become a deeper and deeper red until they no longer glow. They have passed from a light- and heat-emitting temperature range to a heat-emitting temperature range only, and the wavelengths have become longer as the temperature has decreased. The wavelengths have shifted from the visible to the near infrared to the far infrared portion of the electromagnetic spectrum.

The amount of radiation received by a surface is inversely proportional to the square of the distance between the source and the receiving surface. This relationship is illustrated below.



If the distance is doubled (2d:1d), the radiant energy covers 4 times the area (4a:1a). If d = 4, then a = 16. It is easy to see that the radiant energy from one square cm of the sun's surface is very much spread out by the time it reaches the earth 93,000,000 miles away.

The basic relationships discussed above apply to both the solar and infrared radiation that are a part of the thermal environment of plants and animals. Solar energy is discussed in UNIT 1.1, and infrared energy in UNIT 1.2

LITERATURE CITED

Gray, D. E. 1946. Man and His Physical World. D. Van Nostrand Company, Inc., New York. 699 p.

Rosenberg, N. J. 1974. Microclimate: The Biological Environment. John Wiley & Sons, N.Y. 315 p.

UNIT 1.1: SOLAR ENERGY

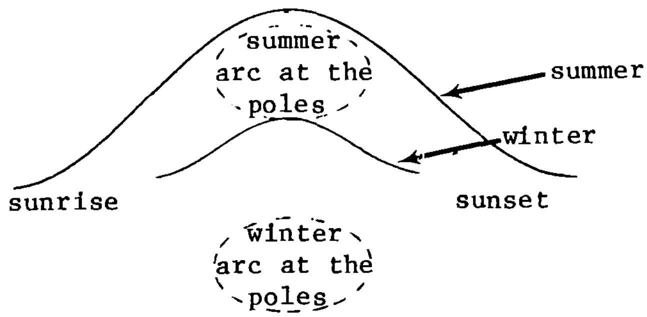
Solar energy flux in the biosphere is a fundamental, driving force for ecological processes. It is the source of power driving the physical processes of the biosphere--wind, rain, weather systems, erosive actions--and the source of power driving biological processes--photosynthesis (directly) and respiration (indirectly)--in the ecological matrix within this physical superstructure.

Differences in solar energy distribution over the surface of the earth result in marked differences in plant communities. The curved surface of the earth contributes to several physical gradients; the polar regions receive different amounts of solar energy than the equatorial regions, and the light rays strike the earth at much different angles through the annual cycle at the poles than at the equator. The timing and distribution of radiant energy exchange follows some rather strict natural laws, and the ecological effects are predictable.

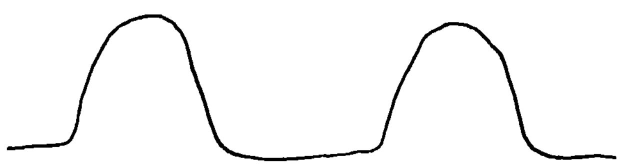
The amount of energy intercepted by a one-square centimeter surface at right angles to the solar beam on the outer limit of the earth's atmosphere is called the solar constant. It is the upper limit to the amount of energy reaching the earth, yet it is only 1.8999×10^{-5} or 0.000018999 of the energy given off by a square cm of the sun's surface! This very small fraction is due to the distance effects described by the inverse square law. The numerical value of the solar constant was measured by Johnson in 1954 to be 2.00 cal cm^{-2} min^{-1} (139.5 mw cm^{-2}), and this was considered the most authoritative until Thekaekara and Drummond (1971) proposed a standard value of 1.94 cal $cm^{-2}min^{-1}$ (135.3 ± 2.0 mw cm^{-2})(See Paltridge and Platt 1976: 53). Not all of the sun's energy reaches the surface of the earth. Some of it is reflected into space by dust particles and clouds in the atmosphere. On a clear day, a high percentage of the solar radiation is transmitted through the atmosphere. With a completely overcast sky, no direct solar radiation penetrates the cloud cover, and ultraviolet radiation penetrates more than the longer wave lengths. The actual amount received at the earth's surface is less than the solar constant because of reflection and absorption by the atmosphere.

A unit area of the earth's surface does not receive a constant amount of radiant energy. Everyone is familiar with the daily and seasonal patterns of sunrise and sunset times; longer days in the summer and shorter days in the winter are characteristic of both hemispheres. The sun's pathway is lower in the sky in the winter and the arc is shorter. At the poles, the sun does not appear above the horizon in the winter, and it does not go below the horizon in the summer. The patterns of the sun's apparent movements are reversed between the northern and southern hemispheres, of course; summer occurs in only one hemisphere at a time.

The apparent movements of the sun are illustrated in the drawing below.



Solar energy flux on a clear day increases from sunrise to solar noon and decreases from solar noon to sunset. The pattern is nearly symmetrical about solar noon for a horizontal plane at the earth's surface, as illustrated by the tracing of two daily pyranometer recordings below.



Measured amounts of solar energy reaching the earth's surface are dependent on the sun's angle, atmospheric conditions, and altitude above sea level. The average solar radiation reaching a horizontal surface in the northern states in January is 125-150 cal cm^{-2} day^{-1}, and in July, 500-650 cal cm^{-2} day^{-1} (See Moen 1973 or Sellers 1965). Measurements can be expressed mathematically through the annual cycle; the WORKSHEETs that follow provide opportunities for calculating solar energy.

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Moen, A. N. 1973. Wildlife Ecology. W. H. Freeman Company, San Francisco. 458 p.

Paltridge, G. W. and C. M. R. Platt. 1976. Radiative Processes in Meteorology and Climatology. Elsevier Scientific Pub. Co., N. Y. 318 p.

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Sellers, W. D. 1965. Physical Climatology. University of Chicago Press, Chicago. 272 p.

Thekaekera, M. P. and A. J. Drummond. 1971. Standard values for the solar constant and its spectral components. Nature (London), Phys. Sci. 229:6-9.

REFERENCES, UNIT 1.1

SOLAR ENERGY

BOOKS

TYPE	PUBL	CITY	PGES	ANIM	KEY WORDS-----------------	AUTHORS/EDITORS--	YEAR
aubo	haro	nyny	151	----	energy exchge in biosphere	gates,dm	1962
edbo	else	nyny	347	----	solar radiation	robinson,n	1966

SERIALS

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
AGMYA	1---1	54	65	----	sol rad ov sno pack, pine	vezina,pe	1964
AGMYA	7---1	19	28	----	interprt frctn, solr radtn	anderson,mc	1970
AGMYA	9-1/2	3	20	----	sol rad absrb, leaflss for	federer,ca	1972
AJBOA	38--5	327	331	----	refl vis infra rad, leaves	billings,wd; morr	1951
ANBOA	34---	329	348	----	penet rad, can, diff struc	newton,je; blackm	1970
ANSFA	28--4	425	442	----	hemisphr photos, lght clim	becker,m	1971
BOZHA	51--5	681	686	----	meth,light regimes, forest	akulova,ea/	1966
CJASA	35--6	579	594	----	est avrg insolatn in canad	mateer,cl	1955

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
CJBOA	44-10	1267	1284	----	spec comp, uv, visual radi	vezina,pe; boulte	1966
CJTEA	33...	12	32	----	insola cloudls days, canad	mateer,cl	1955
CSTNA	12--3	63	74	----	light intensty study, w va	allard,ha	1932
ECOLA	4....	189	195	----	meas solar rad,plnt habita	burns,gp	1923
ECOLA	50--5	878	885	----	test models, 3 forst canap	miller,pc	1967
ECOLA	52--6	1008	1015	----	comp clear day sol ra spec	mccullough, ec; p	1971
EMFRA	37--2	222	232	----	light in the forest	brown,gs	1958
FIRAD	11--5	818	823	----	light transmiss, for canop	akulova,ea;/	1964
FOSCA	7---2	144	145	----	var, meas lght intens, for	gatherum,ge	1961
FOSCA	7---3	257	264	----	varia sol ra norway spruce	vezina,pe	1961
FOSCA	10--4	443	451	----	sol rad relat conif canopy	vezina,pe; pech,g	1964
FOSCA	12--3	258	267	----	top, insol clim, mou fores	lee,r; baumgartne	1966
FOSCA	16--2	a139	145	----	radiant energ, clrcut, for	hornbeck,jw	1970
FOSCA	18--4	273	277	----	eff clrcuttng, net radiatn	brown,jm	1972
FRSTA	28--2	141	146	----	compar light diff woodland	ovington,sd; madg	1955
FRSTA	31...	147	162	----	lght intnsty meas,for stnd	conner,rd; fairba	1958
HYSBA	9---1	27	41	----	pot insol, topoclim, drain	lee,r	1964
IJBMA	16--1	25	43	----	potntl solr rad,plnt shape	terjungl,wh; loui	1972
JAPEA	9---2	359	375	----	radtn, conif, decid forest	tajchman,sj	1972
JAPEA	10--2	657	660	----	flux vis, net rad, for can	kinerson,rs	1973
JECOA	44...	391	428	----	wdlnd lght intens,sunflcks	evans,gg	1956
JECOA	52...	27	41	----	photgrph comput, lght cond	anderson,mc	1964
JGREA	64-10	1617	1619	----	var,net exch of rad fr veg	decker,wl	1959
JGREA	67-13	5179	5185	----	energ bal, evap surf, arid	fritschen,lj; van	1962
JVAHA	20...	223	234	doca	absptvty solr rad, coats	riemerschmid,g; e	1945
LESOA	2----	31	37	----	rad regime, birch, spruce	molchanov,ag	1971
MMONA	4--23	1	43	----	atmospheric radiati tables	elsasser,wm; culb	1960
MWREA	63...	1	4	----	varia, intens solr radiatn	kimball,hh	1935
PSAFA	1964-	105	109	----	partition rad heat, forest	knoerr,kr	1964
SCIEA	164--	308	309	----	rad profl, canop, asp, oak	miller,pc	1969
SIFEA	113..	1	17	----	heat balance of the forest	dzerdzeevskii,bl	1963

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
XANEA	84---	1	21	----	radia measu, open, forests	lull,hw; reigner,	1967
XATBA	1344	1	111	----	rad energy relation to for	reifsnyder,we; lu	1965
XFRMA	18---	1	116	----	pot sol rad on slop, table	frank, ec; lee,r	1966
XFTBA	1344-	1	111	----	radnt enrg in reln forests	reifsnyder,we; lu	1965
XIPPA	269..	----	----	----	energy budget studies	anderson,er	1954

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Budyko, M. I. 1956. The Heat Balance of the Earth's Surface. (Translated for the U.S. Weather Bureau, 1958). Leningrad. 259 p.

Fons, W. L., H. D. Bruce, and A. McMasters. 1960. Tables for Estimating Direct Beam Solar Irradiation on Slopes at 30° to 46° Latitude. Pac. S.W. Forest and Range Expt. Sta., Berkeley, CA. 298 p.

Nagy, L. 1970 Data on radiation conditions in forests. Acta Climatologica 9(1.4):49-58.

CHAPTER 14, WORKSHEET 1.1a

Calculations of daily solar energy over the annual cycle

Very simple first approximations of the daily solar energy reaching a horizontal surface over the annual cycle may be made with a sine wave calculation. Suppose that 150 calories per square centimeter per day (CSCD) reached this surface at the time of the winter solstice (December 21 = JDAY 355) and 650 CSCD at the time of the summer solstice (June 21 = JDAY 172). The midpoint radiation (MPRA) is then 400 CSCD. The daily solar radiation (SORA) can be calculated with these facts and a primary phase correction arranged according to the following formula:

$$SORA = MPRA + \sin[(JDAY)(0.9863) + (PRPC)]\ [AMPL]$$

where SORA = solar radiation
MPRA = midpoint radiation value
PRPC = primary phase correction
AMPL = amplitude of the variation from MPRA

Determine the primary phase correction, PRPC, by:

$$\sin[(JDMA)(0.9863) + PRPC] = 1.0$$

where JDMA = JDAY at maximum.

Since sin 90 = 1.0,

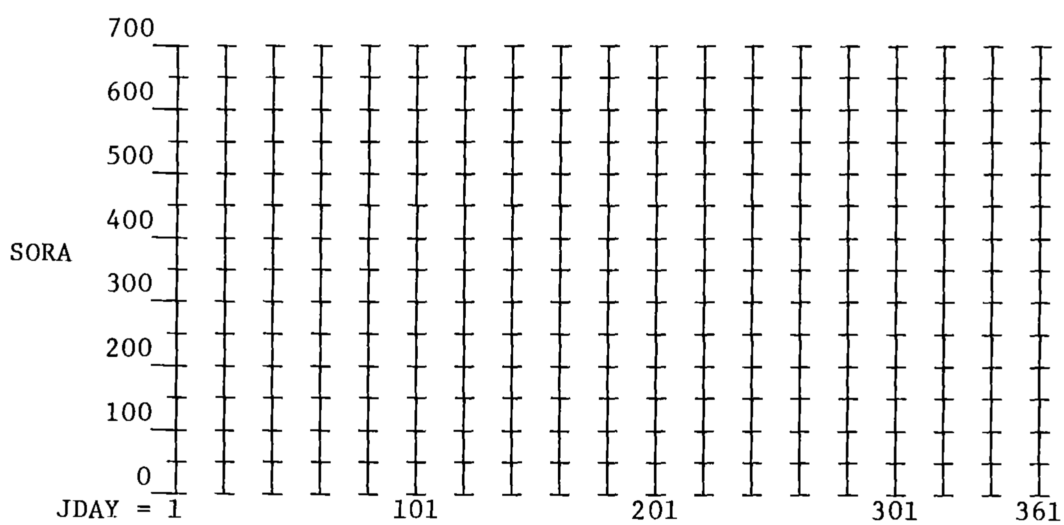
$$[(JDMA)(0.9863) + PRPC] = 90$$

$$90 - (\_\_\_\_)(0.9863) = \_\_\_\_ = PRPC$$

MPRA in this example is 400 and AMPL = 250. The equation is:

$$SORA = 400 + \sin[(JDAY)(0.9863) + (PRPC)]250$$

Calculate SORA at 20-day intervals and plot the curve.



UNIT 1.2: INFRARED RADIATION

Radiation of wave lengths longer than those in the visible portion of the spectrum is called infrared or thermal radiation.

The earth and its atmosphere are an infrared radiating surface in the emptiness of space. The earth continuously radiates infrared energy and emits as much radiant energy as it absorbs. If it emitted less, it would become warmer, and if it emitted more, cooler.

Little attention has been given to thermal radiation by ecologists, and this is probably due in part to the invisible characteristic of infrared radiation. The wavelengths are not detected by the human eyes, so it has often been overlooked as a part of the entire thermal regime. An object is seen because of visible reflected light but its longer wavelengths are detected only as heat energy.

The amount of thermal energy radiation from any surface is proportional to the fourth power of the absolute temperature of the radiating surface, according to the Stefan-Boltzmann law. The formula is:

$$QREE = (SBCO)(ERTK)^4$$

where QREE = quantity of radiation emitted,
SBCO = Stefan-Boltsmann constant, and
ERTK = effective radiant temperature in ^{o}K.

The radiation emitted from a surface with a radiant temperature of 27 C or 300 K can be calculated with the equation:

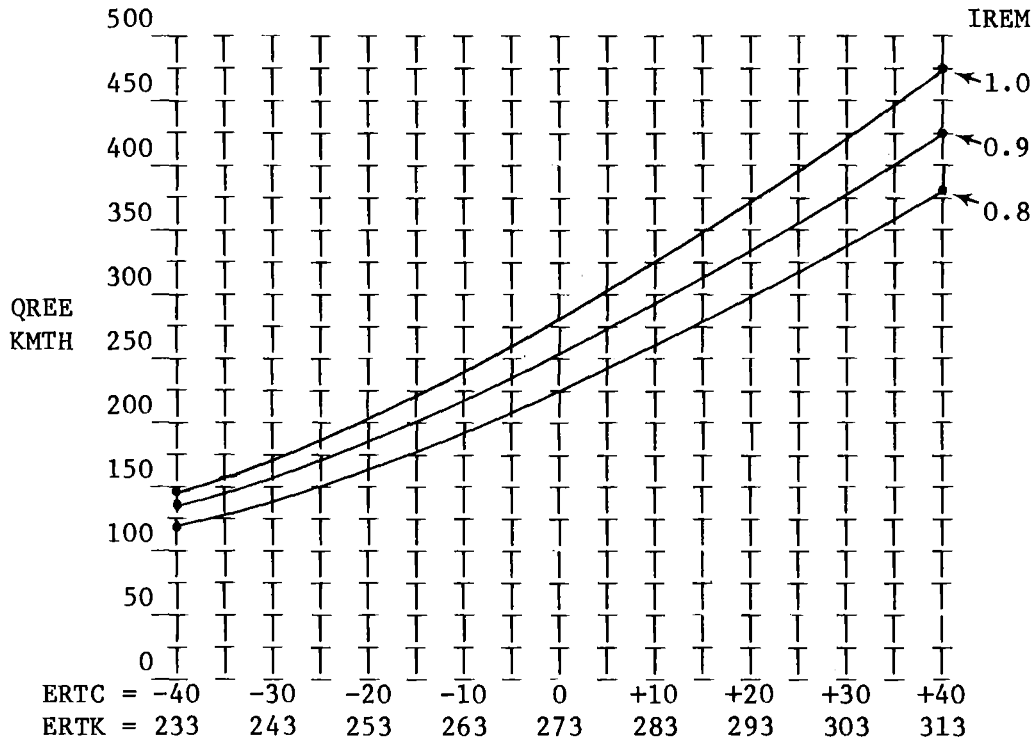
$$QREE = (8.127 \times 10^{-11})(300^4) = 0.658 \text{ cal cm}^{-2}\text{min}^{-1}$$

Another factor, infrared emissivity (IREM), may be added to the formula above. The numerical value for IREM is equal to the infrared absorption coefficient. The absorption coefficient is the ratio of absorption by a surface to that of a black body, or perfect absorber. Thus if a surface absorbs 85% of the radiant energy that reaches it, the absorption coefficient is 0.85. The formula for calculating radiant energy as a function of both emissivity and temperature is:

$$Q_r = (IREM)(SBCO)(ERTK)^4$$

It is useful to prepare a nomogram of infrared energy emitted for use in thermal exchange estimations. Calculations with the above formula have been made and the family of curves for emissivities ranging from 1.0 to 0.08 plotted in the nomogram on the next page.

The relationships between environmental radiant temperature (Celsius) and quantity of radiant energy emitted (QREE) in kcal $m^{-2}hr^{-1}$ (KMTH) for different infrared emissivities (IREM) is illustrated below.



REFERENCES, UNIT 1.2

INFRARED RADIATION

BOOKS

TYPE	PUBL	CITY	PGES	ANIM	KEY WORDS-----------------	AUTHORS/EDITORS--	YEAR
aubo	haro	nyny	151	----	energy exchnge in biospher	gates,dm	1962
edbo	ugap	atga	95	----	remote sensing in ecology	johnson,pl,ed	1969

SERIALS

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
AGJOA	58--6	597	601	----	infra thermometry of veget	fuchs,m; tanner,c	1966
AJBOA	38--5	327	331	----	refl vis, infra rad, leave	billings, wd; mor	1951
AJBOA	51--5	529	538	----	radia and convec in conife	tibbols,ec; carr/	1964
APOPA	7---9	1803	1809	----	sen bio env, port rad ther	gates,dm	1968
ECOLA	49--1	145	147	----	thrm ener exch, tree,night	moen,an	1968
JGREA	64-10	1617	1619	----	var, net exch of rad fo ve	decker,wl	1959
JGREA	65-11	3657	3667	----	economical net radiometer	tanner,cb; busin/	1960
JGREA	67-13	5179	5185	----	energ bal, evap surf, arid	fritschen,lj; van	1962
JRMGA	27--5	401	403	odvi	radint temps hair surfaces	moen,an	1974
JWMAA	32--2	338	344	odvi	surf tmps, radnt heat loss	moen,an	1968
JWMAA	38--3	366	368	odvi	chngs radnt surf temp,wind	moen,an; jacobsen	1974
MMONA	23---	1	43	----	atmospheric radiati tables	elsasser,wm; culb	1960
PSAFA	-----	105	109	----	partition rad heat, forest	knoerr,kr	1964
QJRMA	89---	339	348	----	long wave radi, clear skie	swinbank,wc	1963
SIFEA	113..	1	17	----	heat balance of the forest	dzerdzeevskii,bl	1963
XANEA	84---	1	24	----	rad mea and op for instrum	lull,hw; reigner,	1967
XIPPA	269..			----	energy budget studies	anderson,er	1954

OTHER PUBLICATIONS

Budyko, M. I. 1956. The Heat Balance of the Earth's Surface. (Translated for the U.S. Weather Bureau, 1958). Leningrad. 259 p.

Infrared radiation in relation to radiant surface temperature

The formula for calculating the quantity of radiant energy emitted (QREE) from a surface is:

$$QREE = (SBCO)(ERTK)^4$$

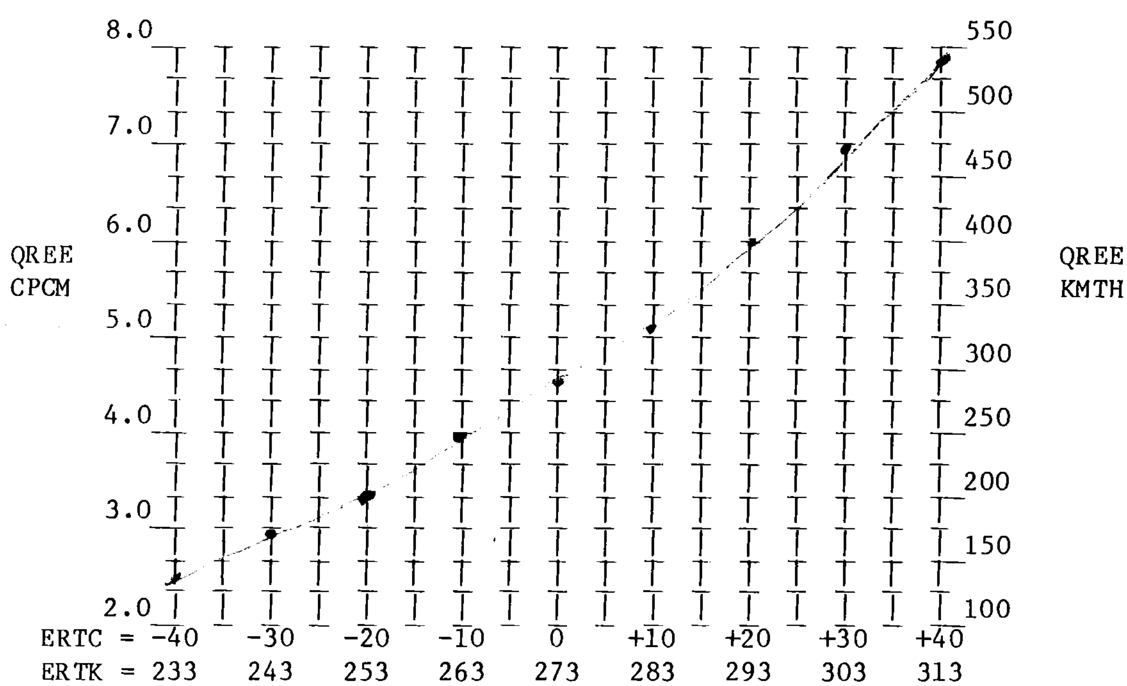
where ERTK = effective radiant temperature in degrees Kelvin, and
SBCO = Stefan-Boltzmann constant.

When QREE is in calories per square cm per minute (CPCM), then SBCO = 8.127×10^{-11}, and when QREE is in kilocalories per square meter per hour (KMTH), then SBCO = 4.876×10^{-8} (See Moen 1973:429).

Equivalent temperatures in Celsius and Kelvin degrees are:

-40 C	=	233.16 K
-30	=	243.16
-20	=	253.16
-10	=	263.16
0	=	273.16
+10	=	283.16
+20	=	293.16
+30	=	303.16
+40	=	313.16

Substitute these temperatures in the formula above and plot the results below. Note that QREE is in CPCM on the left-hand scale, and KPMH on the right-hand scale. Compare your values to the IREM = 1.0 line in the nomogram.



TOPIC 2. TEMPERATURE PATTERNS AND BAROMETRIC PRESSURE

General temperature patterns in the biosphere are rather closely associated with radiant energy patterns since solar energy is essentially the only source of energy input into the atmosphere. As solar radiation increases in the summer, more energy is absorbed by both soil and atmosphere, and temperatures rise. As solar energy decreases in the winter, less energy is absorbed and atmospheric and soil temperatures fall. This temperature pattern is predictable from season to season, although the magnitude of the temperature differences varies between seasons.

Local topographic, vegetation, and surface water characteristics affect both spatial and temporal temperature distributions. Large bodies of water ameliorate the climate because water has a high heat capacity; time is required for warm-up in the spring and for cooling-off in the fall.

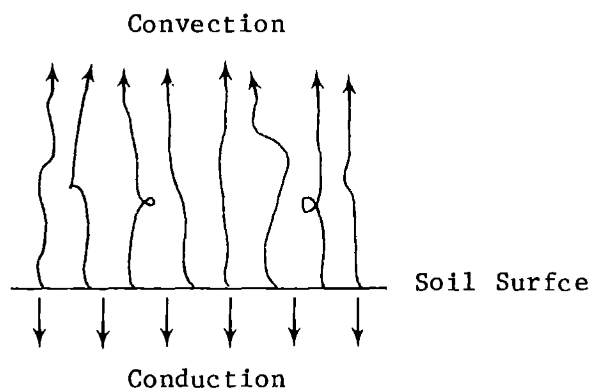
Temperature is an index to but not an expression of the amount of heat energy in a substance. The latter must consider the specific heat of the substance; two materials may be at the same temperature, but if one has a specific heat of 1.0 and the other 0.5, the former will contain two times the heat energy of the latter. This is an important distinction ecologically, especially so because of the high specific heat (1.0) of water which is found in such a wide variety of parts, from cells to oceans, of the eco-system.

Temperature is measured on interval scales, and various scales, including Fahrenheit, Celsius, and Kelvin, are in use. Whatever scale is used, the numbers of degrees are not proportional to heat energy in relation to animals. A temperature of 40 is not two times warmer than 20, nor is 20 four times warmer than 5. Interval scales are useful only in identifying a position relative to a fixed point on the scale; the numbers themselves are arbitrary.

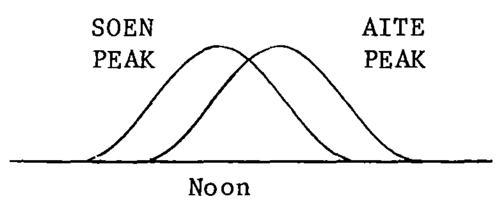
Temperature patterns may be recognized in both time and space. Daily and seasonal temperature patterns are discussed in UNIT 1.1, TEMPORAL TEMPERATURE PATTERNS. Horizontal and vertical temperature patterns are discussed in UNIT 1.2, SPATIAL TEMPERATURE PATTERNS.

UNIT 2.1: TEMPORAL TEMPERATURE PATTERNS

Daily and seasonal temperature patterns are very definitely related to daily and seasonal patterns of solar energy flux. There is a lag between peak solar energy flux and peak temperatures, however, due to the thermal and mechanical resistances of the soil and atmosphere. Heat flow through the soil is not instantaneous; conduction takes time. The major portion of heat transfer into the atmosphere is by convection or eddy diffusion. This is a mechanical process, a mixing of air with different densities due to differences in thermal energy distribution. There is friction between air molecules so eddy diffusion is not an instantaneous process either.

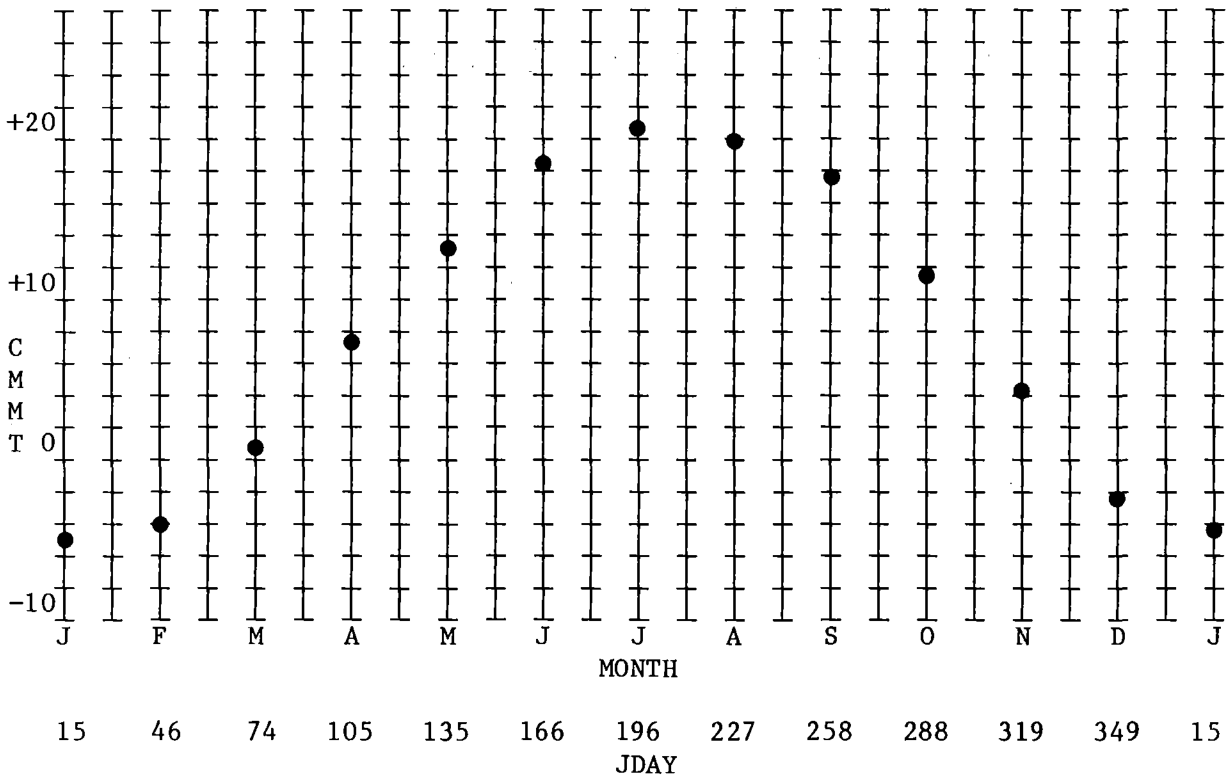


Daily temperature patterns. Clear-day solar energy flux is symmetrical around the peak at solar noon (See earlier illustration in UNIT 1.1), while peak temperatures occur two to four hours after solar noon. Part of the lag can be attributed to the presence of dew, which absorbs solar energy in the early hours after sunrise, dissipating some of the energy in vaporization. Part of the lag can be attributed to the thermal lag in the soil, plants, and the atmosphere.



The generalized curves shown above are seldom realized in the natural world because of large-scale movements of air masses and changes in atmospheric conditions. They are useful for expressing overall patterns of relationships, however. If general patterns can be analyzed, then the effects of deviations can also be analyzed.

Seasonal temperature patterns. Seasonal temperature patterns exhibit lag characteristics just as daily patterns do. Maximum solar radiation is received on about June 21 in the northern hemisphere, but maximum temperatures usually occur in July or August. This is illustrated by the observed mean monthly temperatures for 1942-1966 at Ithaca, NY that are plotted (solid line) in the figure below. The maximum mean monthly temperature occurs in July and the minimum 6 months later, in January. The August mean is nearly as high as the July mean, and the February mean nearly as low as the January mean.



The pattern of mean monthly temperatures in Celsius may be approximated by a sine wave and expressed as a continuous function in very much the same way as weights were expressed in PART I. The equation is:

$$MMTC = 7.8 + \{\sin[(JDAY)(0.9863) - 103.3]\}[12.8]$$

General temperature patterns represented mathematically in such a way are useful, not for predicting air temperature on a particular day, but for evaluating the effects of changing temperatures through the year. If such evaluations can be made for general patterns, they can also be made for short-term transient conditions by substituting observed values for calculated ones.

Monthly temperatures are sometimes expressed as average lows and highs rather than a single average. The table below, from a Canada travel information 1981/82 brochure, provides monthly lows and highs for 40 points across Canada.

	Jan.		Feb		Mar.		Apr.		May		June		July		Aug.		Sept.		Oct.		Nov		Dec	
	L	H	L	H	L	H	L	H	L	H	L	H	L	H	L	H	L	H	L	H	L	H	L	H
British Columbia																								
Kamloops	10	-2	-5	4	-1	10	3	16	7	22	11	26	13	29	12	28	8	23	4	14	-1	6	-6	1
Penticton	-6	0	-3	4	-2	9	2	16	6	21	10	25	12	29	11	27	7	22	3	14	0	6	-3	2
Prince Rupert	-1	4	0	5	1	7	3	10	6	14	8	15	10	17	11	17	9	15	6	11	3	8	1	5
Vancouver	0	6	2	9	3	11	6	14	9	18	12	21	14	24	13	23	11	23	7	15	4	10	2	7
Victoria	2	6	3	9	4	11	6	14	8	18	10	21	11	24	11	23	10	20	8	15	5	10	3	8
Alberta																								
Banff	-16	-6	-13	-1	-10	3	-4	8	1	14	4	18	7	22	6	21	2	16	-1	10	-8	1	-13	-4
Calgary	-17	-5	-13	-2	-10	1	-3	10	3	16	7	19	10	24	8	22	4	17	-1	12	-8	3	-13	-2
Edmonton	-19	-10	-16	-6	-10	-1	-2	10	5	17	9	20	12	23	10	22	5	17	0	11	-8	0	-15	-6
Jasper	-17	-7	-13	0	-9	4	-3	10	1	16	5	20	8	23	7	22	3	17	-1	11	-8	4	-14	-5
Lethbridge	-15	-4	-11	0	-8	3	-1	12	4	18	9	21	11	26	10	25	6	20	1	14	-6	5	-11	0
Yukon																								
Whitehorse	-23	-15	-18	-8	-13	-1	-5	7	1	15	6	20	8	21	7	19	3	14	-3	5	-12	-5	-20	-12
Northwest Territories																								
Frobisher Bay	-30	-22	-30	-21	-27	-18	-19	-9	-7	0	0	7	4	12	4	10	-3	5	-8	-2	-16	-9	-24	-16
Inuvik	-35	-24	-35	-24	-30	-18	-21	-8	-6	4	4	16	7	19	5	16	-1	7	-11	-4	-25	-17	-32	-22
Yellowknife	-33	-25	-30	-21	-24	-12	-14	-1	-1	9	7	17	11	21	10	19	4	11	-4	2	-18	-13	-28	-20
Saskatchewan																								
Prince Albert	-27	-15	-24	-10	-17	-4	-4	8	2	17	7	21	11	25	9	23	4	17	-2	10	-12	-3	-22	-11
Regina	-23	-12	-20	-9	-14	-4	-3	9	3	18	9	22	12	26	10	25	4	19	-2	12	-10	-1	-18	-8
Saskatoon	-23	-13	-19	-9	-13	-3	-2	10	4	18	9	22	12	26	11	25	5	18	0	12	-9	-1	-18	-9
Manitoba																								
Churchill	-31	-24	-29	-23	-25	-16	-15	-7	-6	1	2	11	7	17	8	16	3	9	-3	2	-15	-8	-25	-18
Winnipeg	-23	-13	-21	-10	-13	-3	-2	9	4	17	10	23	14	26	12	25	7	18	1	12	-8	-1	-18	-9
Ontario																								
Hamilton	-8	0	-8	1	-4	5	2	13	8	19	14	25	17	28	16	27	11	22	6	16	1	8	-5	2
Kitchener	-10	-3	-10	-2	-5	3	1	12	7	18	12	25	14	27	14	26	10	21	5	15	-1	6	-7	-1
London	-10	-2	-10	-2	-5	3	1	12	7	18	12	24	15	26	14	26	10	21	5	15	-1	7	-7	0
Ottawa	-15	-6	-14	-4	-7	2	1	11	7	19	13	24	15	27	14	26	10	20	4	14	-1	6	-11	-3
Sault Ste. Marie	-14	-5	-14	-4	-9	1	-1	8	4	14	9	21	12	24	12	23	9	18	4	13	-3	4	-11	-3
Sudbury	-18	-7	-16	-5	-10	1	-1	9	6	17	11	23	14	25	13	24	9	19	4	12	-3	4	-12	-4
Thunder Bay	20	-9	-19	-6	-11	0	-3	8	2	15	7	20	12	24	11	23	7	17	2	12	-5	2	-14	6
Toronto	-9	-3	-10	-2	-3	3	2	12	7	18	13	25	17	27	16	26	12	22	7	15	2	7	-5	0
Windsor	-8	-1	-7	0	-3	5	3	14	8	20	14	26	17	28	16	27	12	23	6	17	1	8	-5	1
Québec																								
Gaspé	-15	-6	-15	-5	-10	-1	-3	5	3	12	8	18	13	23	11	22	6	18	2	12	-3	4	-11	-3
Montréal	13	-6	-11	-4	-5	1	2	11	9	18	15	24	17	26	16	25	12	20	6	14	0	6	-9	-3
Québec City	-15	-7	-13	-6	-7	0	0	8	6	17	12	22	15	25	14	24	9	19	4	12	-2	4	-11	-5
New Brunswick																								
Fredericton	14	-4	-14	-2	-7	3	-1	10	4	17	9	23	13	26	12	24	8	20	2	13	-3	6	-11	-2
Moncton	-13	-3	-12	-2	-7	3	-2	9	4	16	9	22	13	25	12	24	8	20	3	14	-2	7	-10	-1
Saint John	-11	-2	-10	1	-5	3	0	9	5	15	9	19	12	23	13	23	10	19	5	14	0	7	-7	0
Nova Scotia																								
Halifax/Dartmouth	-7	-2	-7	-2	-4	2	1	7	5	14	10	20	14	23	14	23	11	19	7	13	2	7	-4	1
Yarmouth	-6	1	-6	1	-3	4	1	8	5	13	9	17	12	21	12	21	10	18	6	14	2	9	-4	3
Prince Edward Island																								
Charlottetown	10	-3	-11	-3	-6	1	-1	7	4	14	10	20	14	24	14	23	10	19	5	13	1	7	-7	0
Newfoundland/Labrador																								
Corner Brook	-9	-2	-10	-2	-7	1	-2	6	3	11	7	17	12	22	12	21	8	17	4	11	0	6	-5	0
Goose Bay	-21	-12	-20	-10	-14	-3	-6	3	0	10	6	17	11	21	10	19	5	14	0	9	-7	0	-16	-8
St. John's	-7	0	-7	0	-5	1	-2	5	2	11	6	16	11	21	12	20	8	17	4	12	1	7	-4	3

Very limited data are sometimes available or given, but general patterns make first approximations possible. Meagher (1973) for example, gives a mean temperature in Yellowstone National Park for January of 18.0°F (-7.8°C) and for July, 62.8°F (17.1°C), the coldest and warmest months, respectively. The mean annual temperature was 39.8°F (4.3°C). These temperatures suggest a pattern. The midpoint between the low and high is 4.7°C, very close to the mean annual temperature. The amplitude of the variation above and below this midpoint is 12.5 (coincidentally, nearly the same as for Ithaca, NY; see p. 20). The equation for a first approximation is:

$$MMTC = 4.7 + \{\sin[(JDAY)(0.9863) - 103.3]\}[12.5]$$

The calculated temperatures will be very close to measured ones, a good first approximation. Meagher points out that temperatures at this station averaged 5°F (2.8°C) above those for most of the park. If you wish to make a correction, subtract [4.7 - 2.8 = 1.9] and simply substitute 1.9 as the annual average for 4.7.

The WORKSHEETS that follow provide opportunities for calculating expected average temperatures for any day of the year. The data for Ithaca, N.Y., points in Canada, and Yellowstone National Park may be used to verify the derivation procedures. You are encouraged to derive equations for your local study areas also.

LITERATURE CITED

Meagher, M. M. 1973. The Bison of Yellowstone National Park. Scientific Monograph Series, Number one, National Park Service. 161 p.

REFERENCES, UNIT 2.1

TEMPORAL TEMPERATURE PATTERNS

SERIALS

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS------------------	AUTHORS----------	YEAR
JFUSA	63--7	523	529	odvi	swamp coni yards, michigan	verme,lj	1965
JWMAA	32--3	574	585	odvi	microclim, conif deer yard	ozoga,jj	1968
JWMAA	39--1	59	66	odvi	apprais wintr habit, minne	wetzel,jf; wamba/	1975
XPNWA	277--	1	6	ceel	diurnl temp, conifer stand	edgerton,pj; mcco	1976
MWREA	61---	251	259	----	study long-time temp trend	kincer,jb	1933
NPSMD	1----	1	161	bibi	bison, yellowstone natl pk	meagher,mm	1973

CHAPTER 14, WORKSHEET 2.1a

Temperature patterns over the annual cycle

Temperature patterns over the annual cycle may be approximated by fitting mean monthly temperatures to a sine wave. The formula for the average daily temperature in Celsius (ADTC), based on monthly averages, is:

$$ADTC = MPTE + \left\{\sin[(JDAY)(0.9863) + PRPC]\right\} TERA/2$$

where ADTC = average daily temperature in Celsius,
MPTE = midpoint temperature,
TERA = temperature range over the year, and
PRPC = primary phase correction.

Determine the primary phase correction, PRPC, by:

$$\sin[(JDMA)(0.9863) + PRPC] = 1.0$$

where JDMA = JDAY at maximum.

Since sin 90 = 1.0, 90 196 (max)

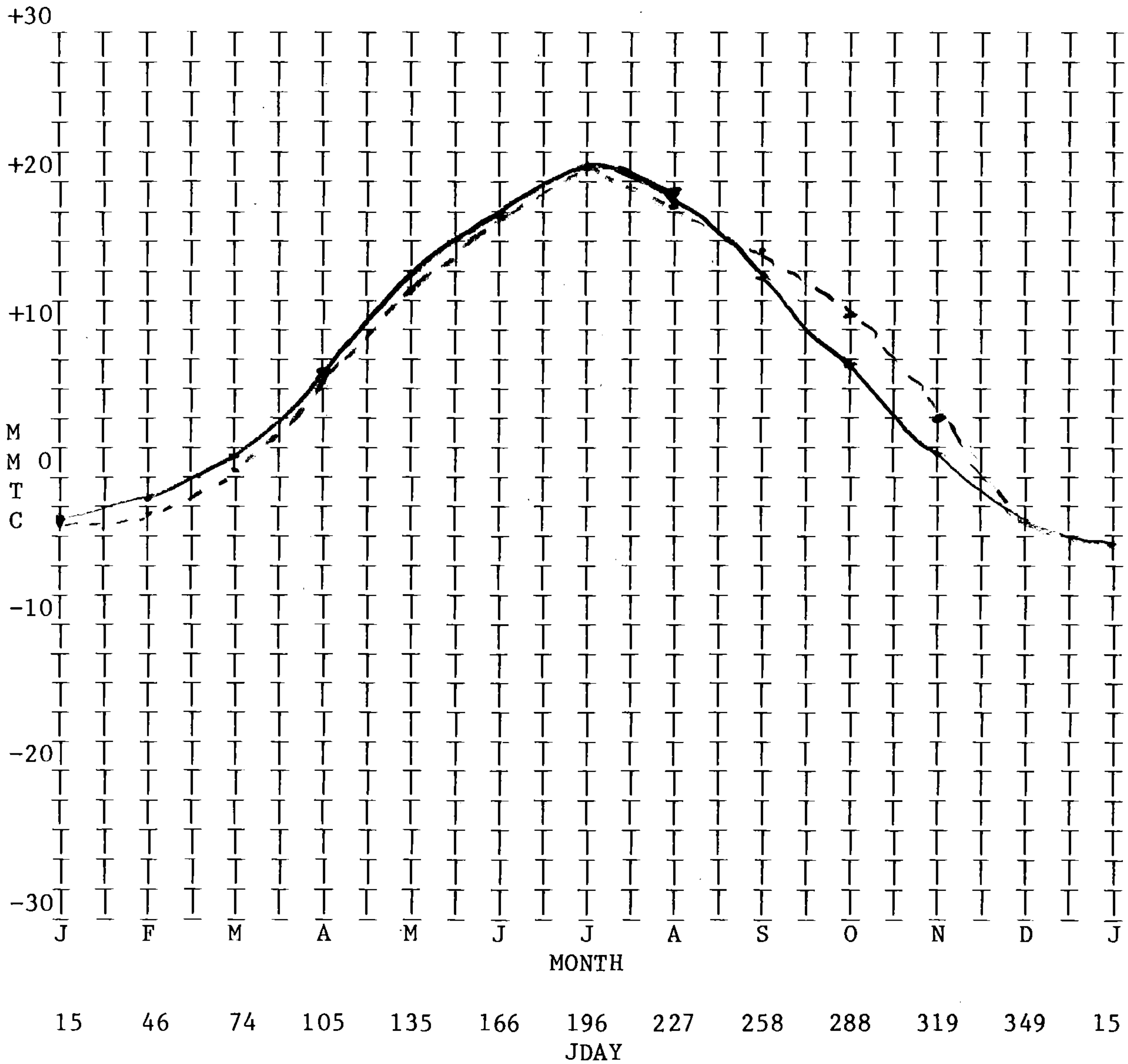
$$[(JDAY)(0.9863) + PRPC] = 90$$

$$90 - (\quad)(0.9863) = \underline{-104.3} = PRPC$$

MPTE in this example is 7.8, TERA is +20 to -5 and TERA/2 = 25/2 = 12.5.

Substitute the values of MPTE, TERA, and PRPC in the formula for ADTC above for the Ithaca, N.Y. data below. Compare the calculated temperatures with the observed ones by tabulating the results and ploting the curve on the next page.

Month	JDAY	Observed	Calculated
January	16	- 5.0	-4.7
February	45	- 4.4	-3.0
March	75	+ 0.6	1.5
April	105	+ 7.2	7.6
May	136	+12.8	14.0
June	166	+18.3	18.6
July	197	+20.6	20.3
August	228	+19.4	18.6
September	258	+15.6	14.0
October	289	+10.6	7.6
Noveber	319	+ 3.9	1.5
December	350	- 2.8	-3.1


+30
+20
+10
M
M 0
T
C
-10
-20
-30
J F M A M J J A S O N D J
MONTH
15 46 74 105 135 166 196 227 258 288 319 349 15
JDAY

Average daily maximum and minimum temperatures over the annual cycle

The format used in the previous WORKSHEET may also be used to express average maximum and minimum temperatures for the Canada data on p. 21. Fill in the following blanks, derive the equations for low and high temperatures, and plot the calculated annual rhythms. The resulting corridor includes the predicted daily temperature range.

Location: Vancouver

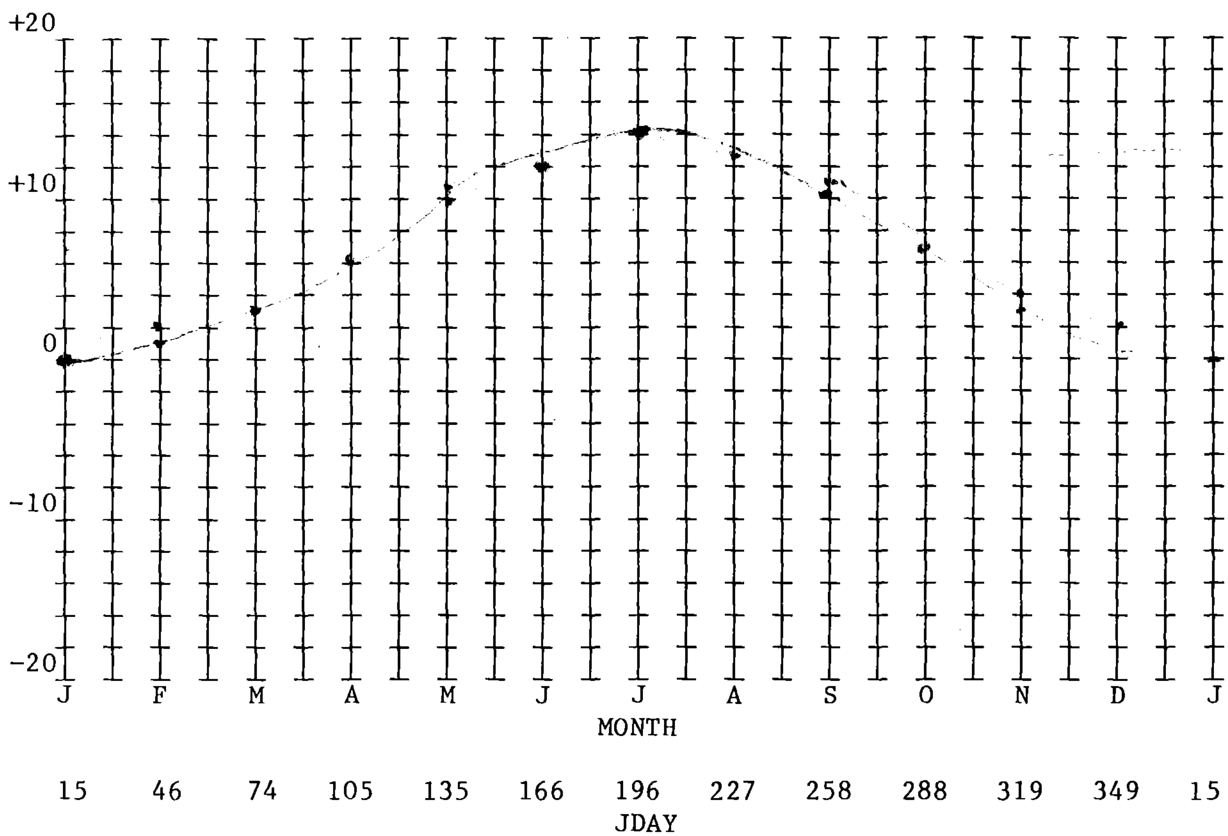
	Low	High	TERA	MPTE	AMPL	PRPC
Maximum:						
Minimum:	0	14	14	7	7	-10

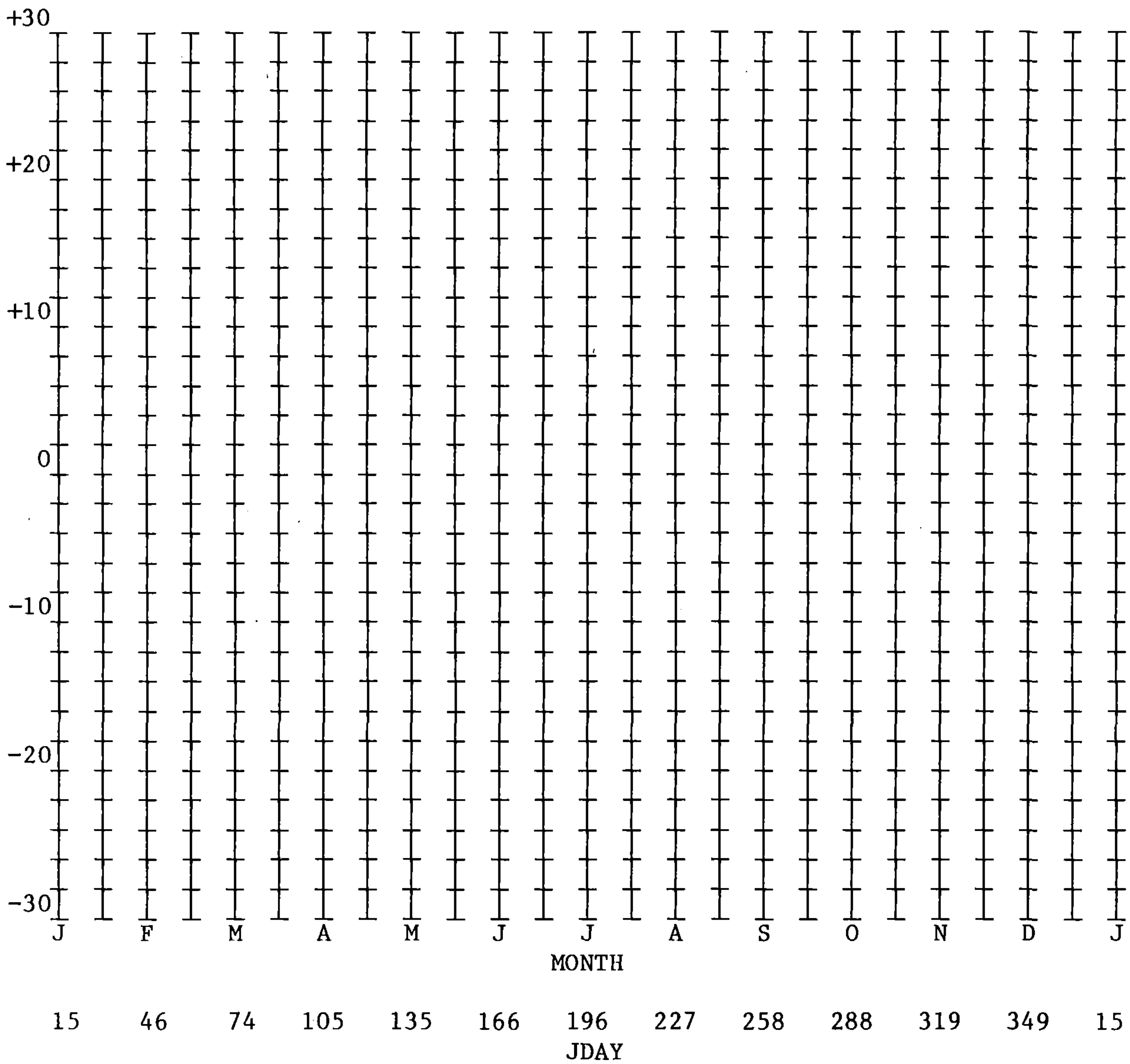
The equations:

AMXT =

AMNT =

Plot the calculated annual rhythms and the monthly values given on p. 23 in the grids below and on the next page. Note the larger span of the grid on the next page.




+30
+20
+10
0
-10
-20
-30
J F M A M J J A S O N D J
MONTH
15 46 74 105 135 166 196 227 258 288 319 349 15
JDAY

CHAPTER 14, WORKSHEET 2.1c

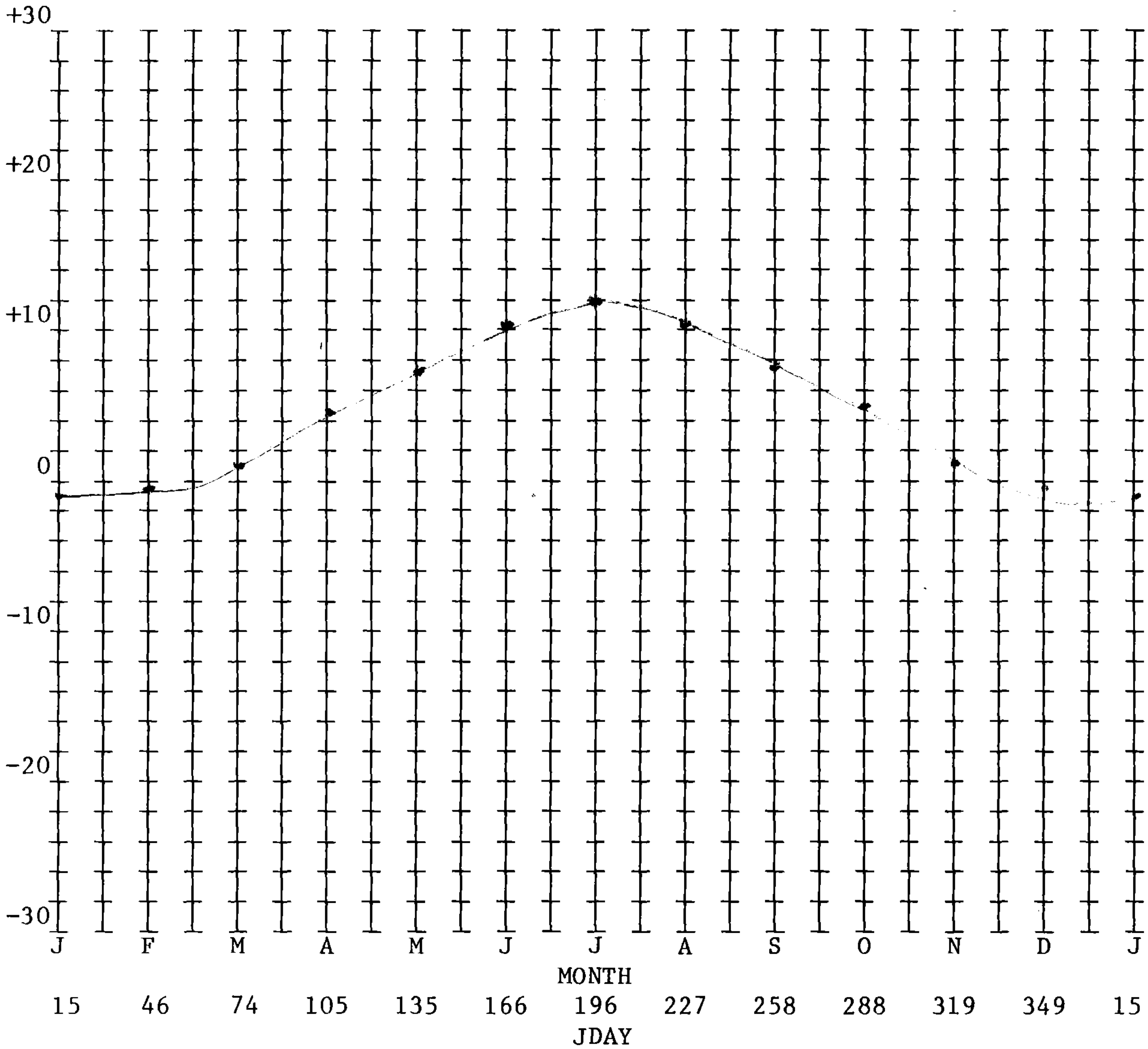
Predicted annual temperature rhythms, Yellowstone National Park

Using the data given on page 24 and the procedures described in the previous WORKSHEETS, derive the equation for annual temperature rhythm in Yellowstone National Park. Substitute the numbers in the blanks below the formula.

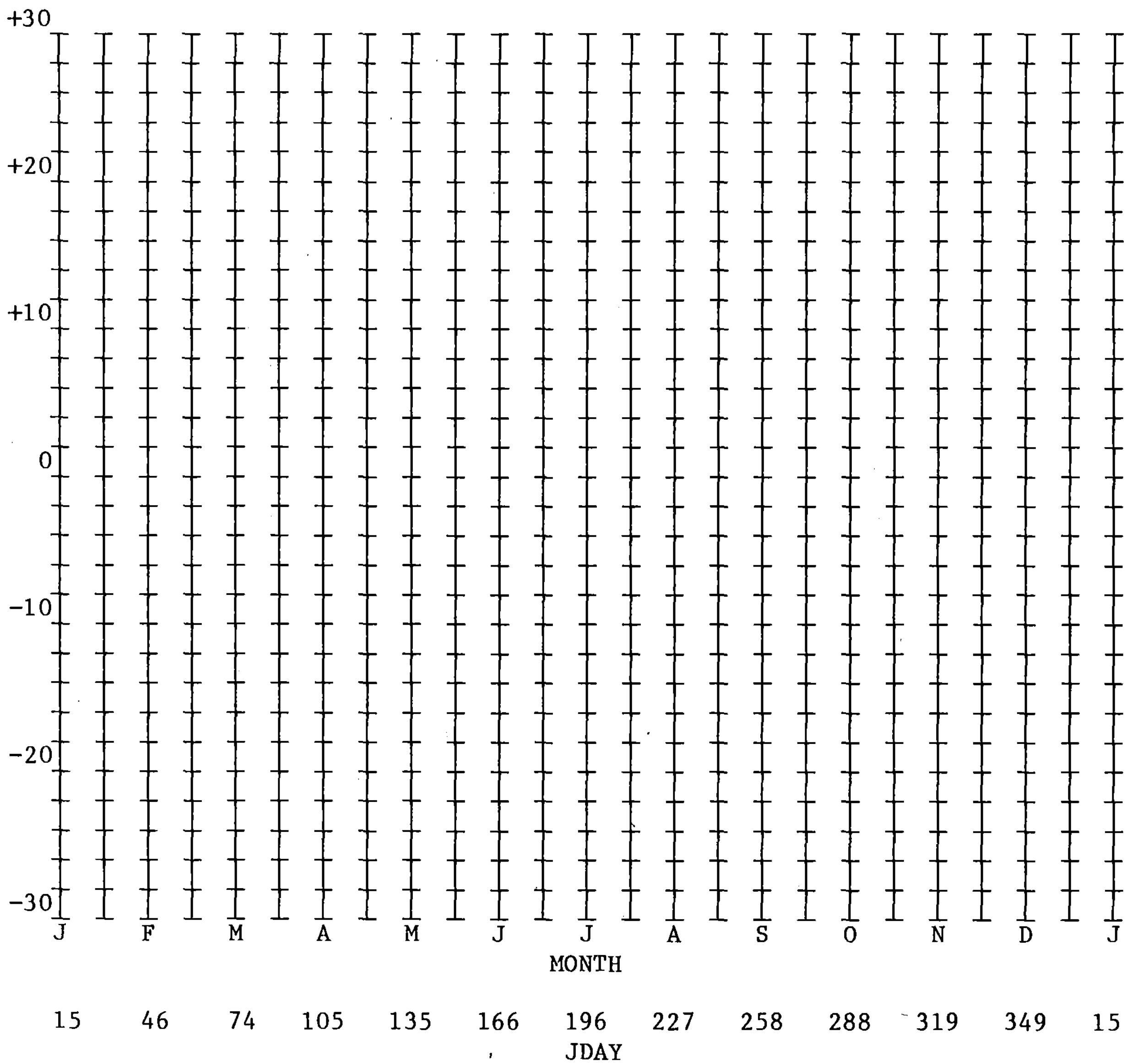
$$ADTC = MPTE + \{\sin[(JDAY)(0.9863) + PRPC]\ [TERA/2]\}$$

$$ADTC = \underline{4,7} + \{\sin[(JDAY)(0.9863) + \underline{-104,3}]\ [\underline{12,5}/2]\}$$

Plot the sine curve in the grid below.



Another grid is given on the back of this page for your local data.

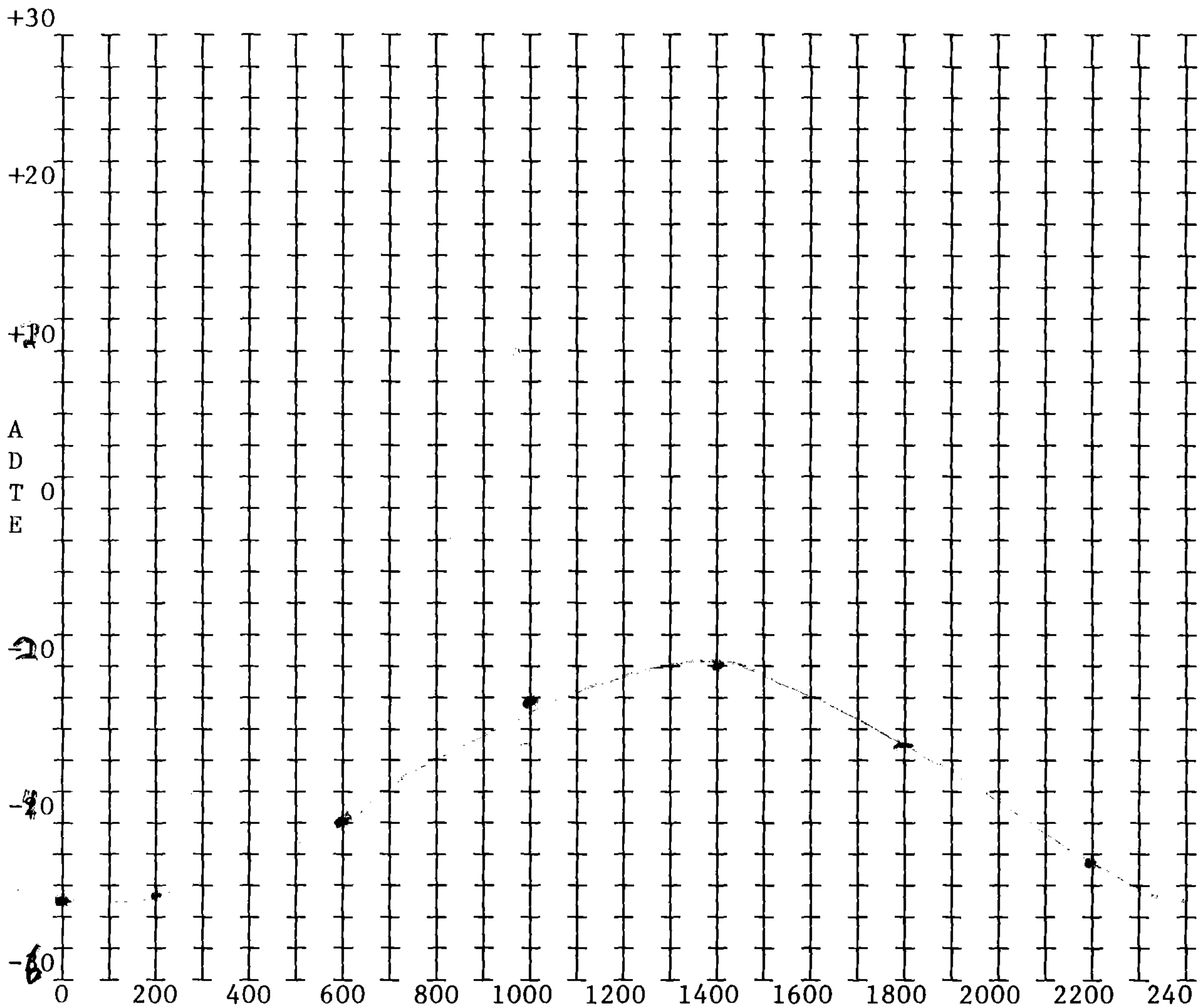

+30
+20
+10
0
-10
-20
-30
J F M A M J J A S O N D J
MONTH
15 46 74 105 135 166 196 227 258 288 319 349 15
JDAY

CHAPTER 14, WORKSHEET 2.1d

Temperature patterns over the daily cycle

Idealized temperature patterns, with a high in the afternoon and a low in the early morning, occur when air masses are stable and neither cold nor warm fronts are moving through. The daily temperature curve may be approximated with a sine wave, stressing again the idea that patterns are being emphasized at this point. If the patterns can be evaluated in relation to animal response through time, then deviations can be evaluated also.

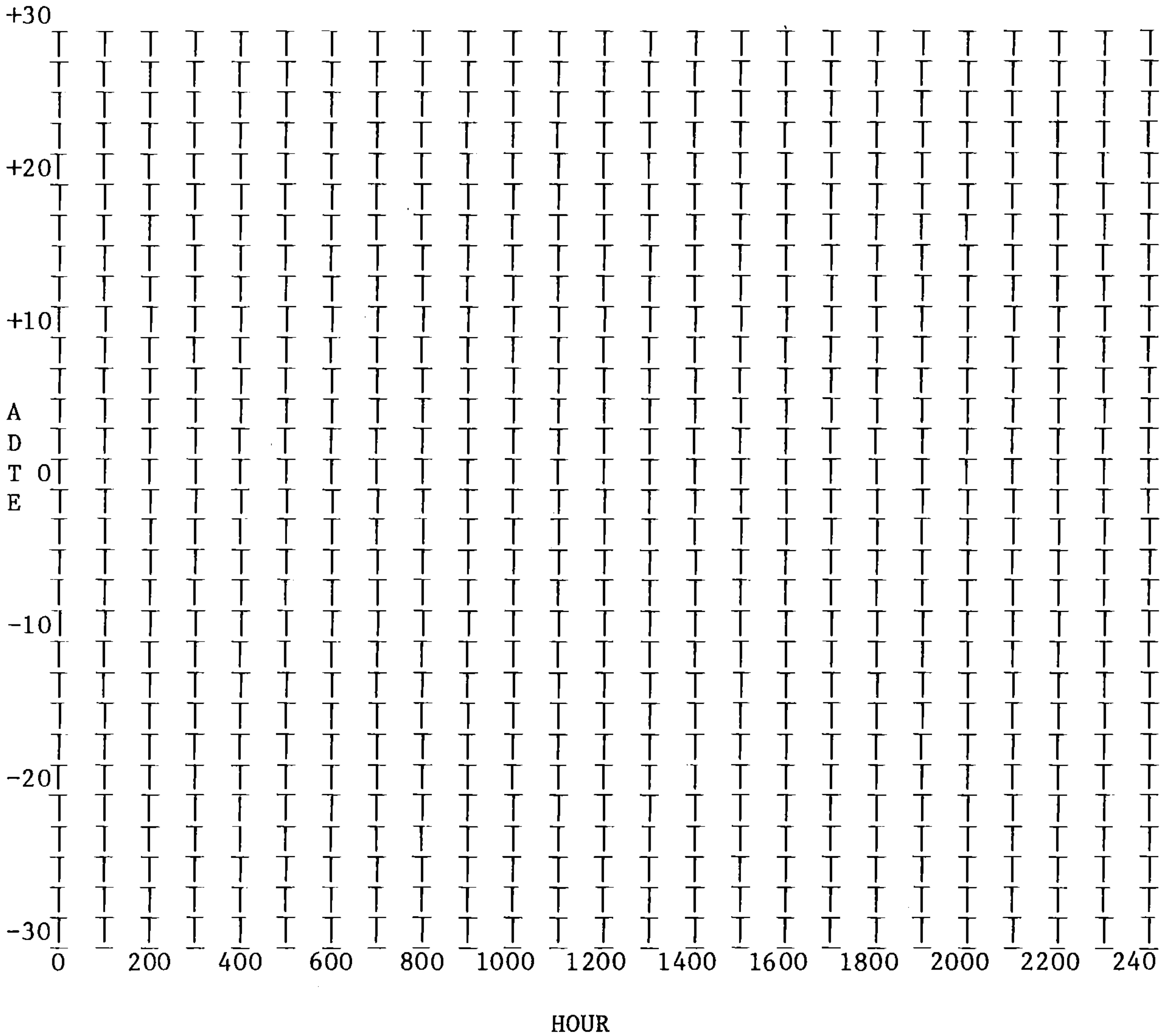
Use the procedures described in previous WORKSHEETS for determining sine wave equations and plot your selected temperature patterns below and in the grid on the next page.



Lo Hi Tem MPTE Ampl PRPC

-50 -20 30 -35 15

Temp max @ 14 hr


+30
+20
+10
A
D
T 0
E
-10
-20
-30
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
240
HOUR

UNIT 2.2: SPATIAL TEMPERATURE PATTERNS

There are spatial patterns to the temperature distribution over the earth's surface because of changes in angles of the sun's rays over the earth's spherical surface (horizontal patterns), and because of the decreasing density of the atmosphere at increasing elevations above the earth's surface (vertical patterns).

HORIZONTAL TEMPERATURE PATTERNS

The highest temperatures should theoretically occur in the equatorial regions and the lowest temperatures in the polar regions because of the spherical shape of the earth. This general pattern occurs, and the pattern would be quite uniform if the earth had a homogenous and smooth surface. Topographic features, especially altitude and surface water distribution, alter local atmospheric temperatures, however. Large bodies of water ameliorate the climate, raising average temperatures and reducing the range of temperature variations because of the high heat capacity of water. Such maritime climates usually result in high levels of primary productivity. Continental climates, beyond the influence of major bodies of water, have wide temperature fluctuations. The lack of large bodies of water along with clearer skies allow more intense direct solar radiation to reach the earth's surface and more infrared radiation to be dissipated into space, resulting in cooler temperatures at the earth's surface.

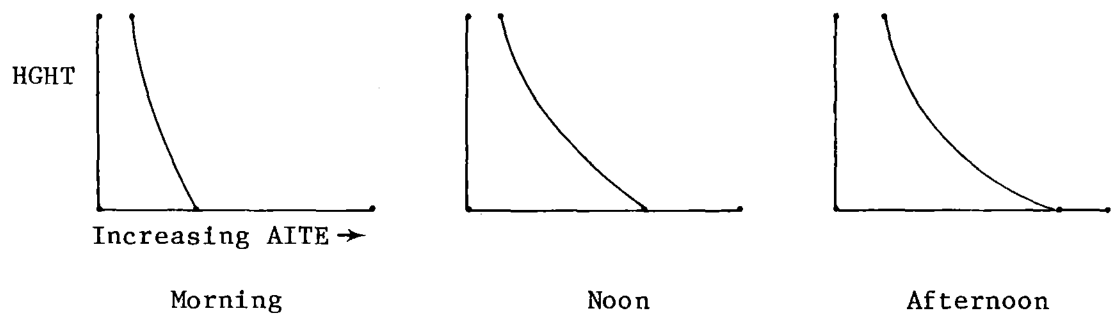
The 40 locations in Canada with monthly lows and highs given on page 23 provide good examples of different temperatures as a result of geographic location. Notice the differences in the amplitudes of the temperature variations through the year and in the midpoint temperatures at locations in the interior with a cold continental climate, and on the coast, with a maritime climate.

VERTICAL TEMPERATURE PATTERNS

The vertical dimension of the atmosphere is an important meteorological consideration. Under stable atmospheric conditions, temperatures decrease 6.5°C per 1000 meters. This is known as the <u>normal lapse rate</u> (Trewartha 1968: 46). Thus high mountain slopes are cooler than the valleys; snowfields persist throughout the summer months at higher elevations. A major factor determining the vertical temperature distribution is the reduction in atmospheric density at greater distances from the earth's surface. A thinner atmosphere has less of a blanketing effect, so even though more solar energy is received as the thinner atmosphere at higher elevations filters less out than the thicker atmosphere at lower elevations, infrared dissipation is greater and the net energy absorbed is less. The result is cooler temperatures.

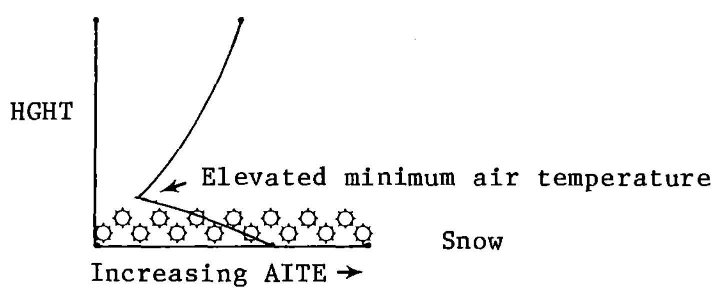
Vertical temperature gradients occur on a small scale too. A warmed soil on a bright sunny day heats the air next to it, resulting in a vertical temperature gradient. The warmer air rises, of course, but this is not instantaneous. As a result, a thermal boundary region, which may be defined as the layer of air with temperature differences due to the influences of the warmer surface, develops.

Temperature profiles over flat bare soil, rough bare soil, snow, and short grass at night are discussed by Oke (1970). A smooth bare soil that has a high absorption coefficient for solar energy is warmed as the sun's energy is absorbed and the air near the soil warmed. The temperature profile patterns are expected to develop on a sunny day as shown below.

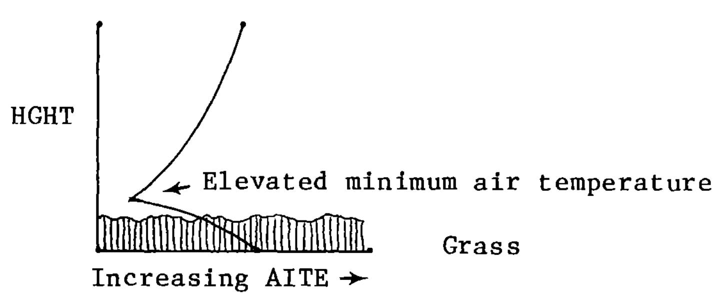


Note how the air temperature near the soil surface increases as the soil is warmed. The profile reverses as the soil is cooled.

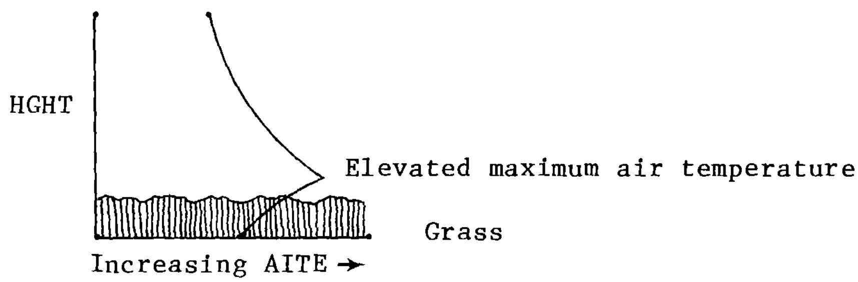
Air temperatures profiles above a snow surface may show a minimum temperature at an elevated point on the profile. This is due to the absorption of the sun's energy at the snow surface, increasing the temperature of the air near the snow, resulting in a minimum temperature above the snow surface as shown below.



Elevated minimum temperatures may also be observed above grass. The vegetation functions as insulation, protecting the soil from heat loss at night, resulting in the profile pattern shown below.



The reverse occurs when the sun shines on the vegetation and it shades the soil from the solar energy. Then, the profile looks like this.



The generalized air temperature profiles discussed above provide insights into the distribution of energy in relation to energy inputs and the configuration of the habitat. The basic profile patterns can be predicted, but actual profiles at a point in space and time cannot, of course. The generalized profiles are given here to call attention to the behavior of temperature profiles in different habitats, and as background information for further discussions of temperature profiles through deer hair in CHAPTER 16. Similarities in profile patterns over vegetation and over hair will call attention to common functions, but on different scales, which results in greater understanding of the distribution of energy and matter.

LITERATURE CITED

Oke, T. R. 1970. The temperature profile near the ground on clear nights. Quart. J. Royal Meteorol. Society 56(407):14-23.

Trewartha, G. T. 1968. An Introduction to Climate. McGraw-Hill Book Company, New York. 408 p.

REFERENCES, UNIT 2.2

SPATIAL PATTERNS

BOOKS

TYPE	PUBL	CITY	PAGE	KEY WORDS----------------------	AUTHORS/EDITORS--	YEAR
aubo	gidr	leru	210	the thermal balance of vegetatn	rauner,yl	1972

SERIALS

CODEN	VO-NU	BEPA	ENPA	KEY WORDS----------------------	AUTHORS----------	YEAR
AMGBA	12--1	95	108	radiant heat flux div, heat re	gaevskaya,gn; ko/	1962
AMGBA	18...	305	324	surface temp, infrred rad, spru	lorenz,d; baumgar	1970
AUFOA	29--3	175	180	buffer eff, trees, fluc air tem	greaves,t	1965
BEGOA	37---	116	117	vertical dist air tem, gro, nig	ramdas,la; atmana	1932
BPYAA	39--4	247	253	nocturnal temp min above ground	zdunkowski,w	1966
CJBOA	47--1	167	173	col data, interp plant gr, dist	cleary,bd; waring	1969
HFOPA	1---4	1	153	temp diffs, Harvard For, signif	rasche,hh	1958
JFUSA	46--9	653	658	terr rad, imp in forestry probs	byram,gm	1948
JFUSA	46-12	897	899	temperature profile in a forest	fowells,ha	1948
OJSCA	52--4	199	209	vert temp grad, beech for, ohio	christy,hr	1952
PVDEA	1960-	1108	1110	role forest litter, heat insula	travleyev,ap	1961
QJRMA	75---	89	103	vertical diff, low layer atmos	deacon,el	1949
QJRMA	77---	375	401	transporta heat water vap, gras	rider,ne; robinso	1951
QJRMA	82---	187	197	temperatu prof, bare soil, nigh	lake,jv	1956
QJRMA	89---	276	280	adjustment of profile, ed flux	dyer,aj	1963
QJRMA	90---	136	146	wind temperature prof, gr, stab	mcvehil,ge	1964
QJRMA	96---	14	23	temperature prof near gr, night	oke,tr	1970
SIFEA	113-7	1	17	study of heat balance of forest	dzerdzeevskii,bl	1963
TAGUA	39--6	1048	1054	growth atmosphere inter boun la	elliott,wp	1958

OTHER PUBLICATIONS

Davis, F. K., Jr. 1957. Study of time-height variations of micro-meteorological factors during radiation fog. Publications in Climatology 10: 1-37.

Deacon, E. L. 1953. Vertical profiles of mean wind in the surface layers of the atmosphere. Met. Office. Geophys. Mem. 91.

Fleagle, R. G. and Badgley, F. I. 1952. The nocturnal cold layer. Occasional Report No. 2, University of Washington, Atmospheric Turbulence stury (AT 45-1), pp. 29-39.

Haugberg, M. 1966. Some examples of local variations in air temperature and the relationship between temperature and growth of spruce. Norsk Skogbr., 12(5): 165-169, 193.

Comparison of annual temperature rhythms in dry continental climates and warm coastal climates

Select two locations in Canada from the data given on page 23 which represent extremes due to geographic location in the interior and on the coast. Complete the blanks below, derive the equations, and plot the calculated results in the grid below. Another set of blanks and a grid is given on the next page.

Location: ______________________

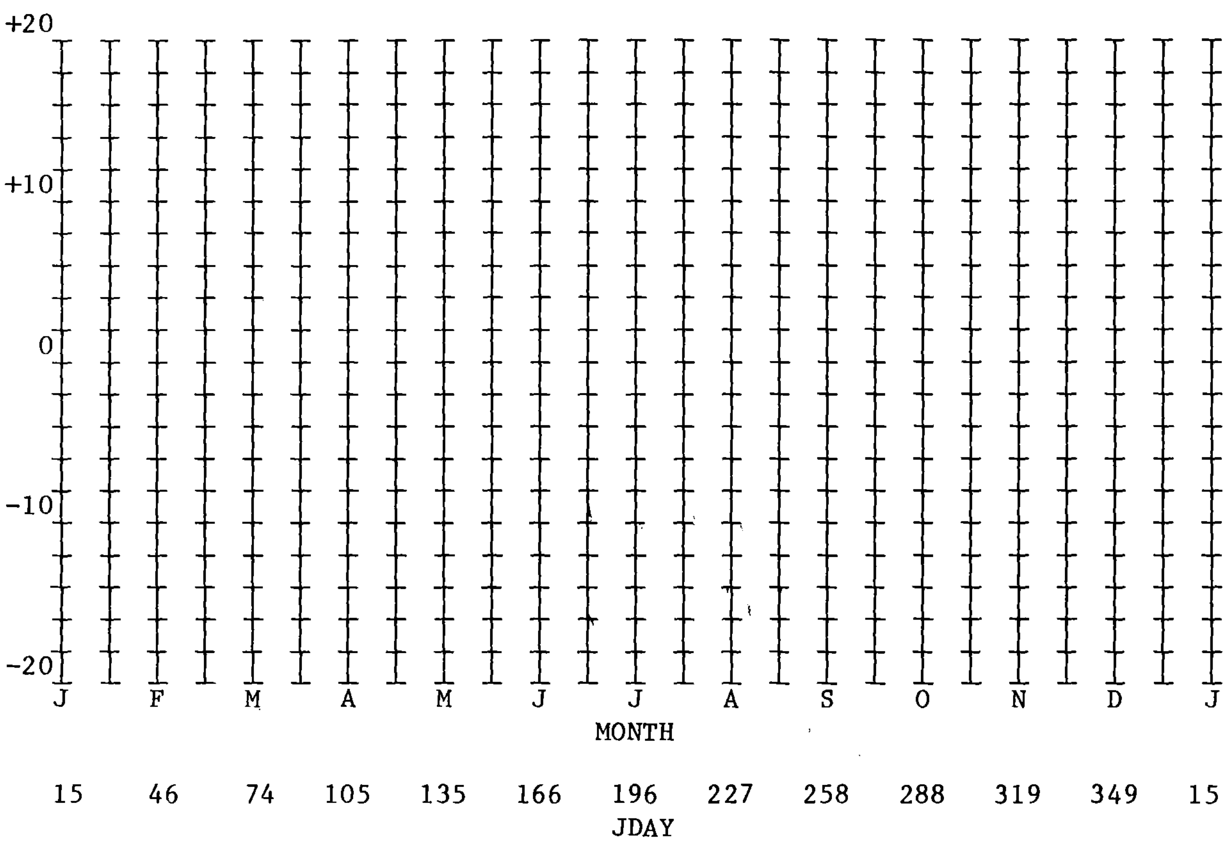
Monthly	Low	High	TERA	MPTE	AMPL	PRPC
Maximum	_____	_____	_____	_____	_____	_____
Minimum	_____	_____	_____	_____	_____	_____

The equations:

AMXT =

AMNT =

Plot the calculated annual rhythms and the monthly values given on p. 21 in the grids below and on the next page. Note the larger span of the grid on the next page.



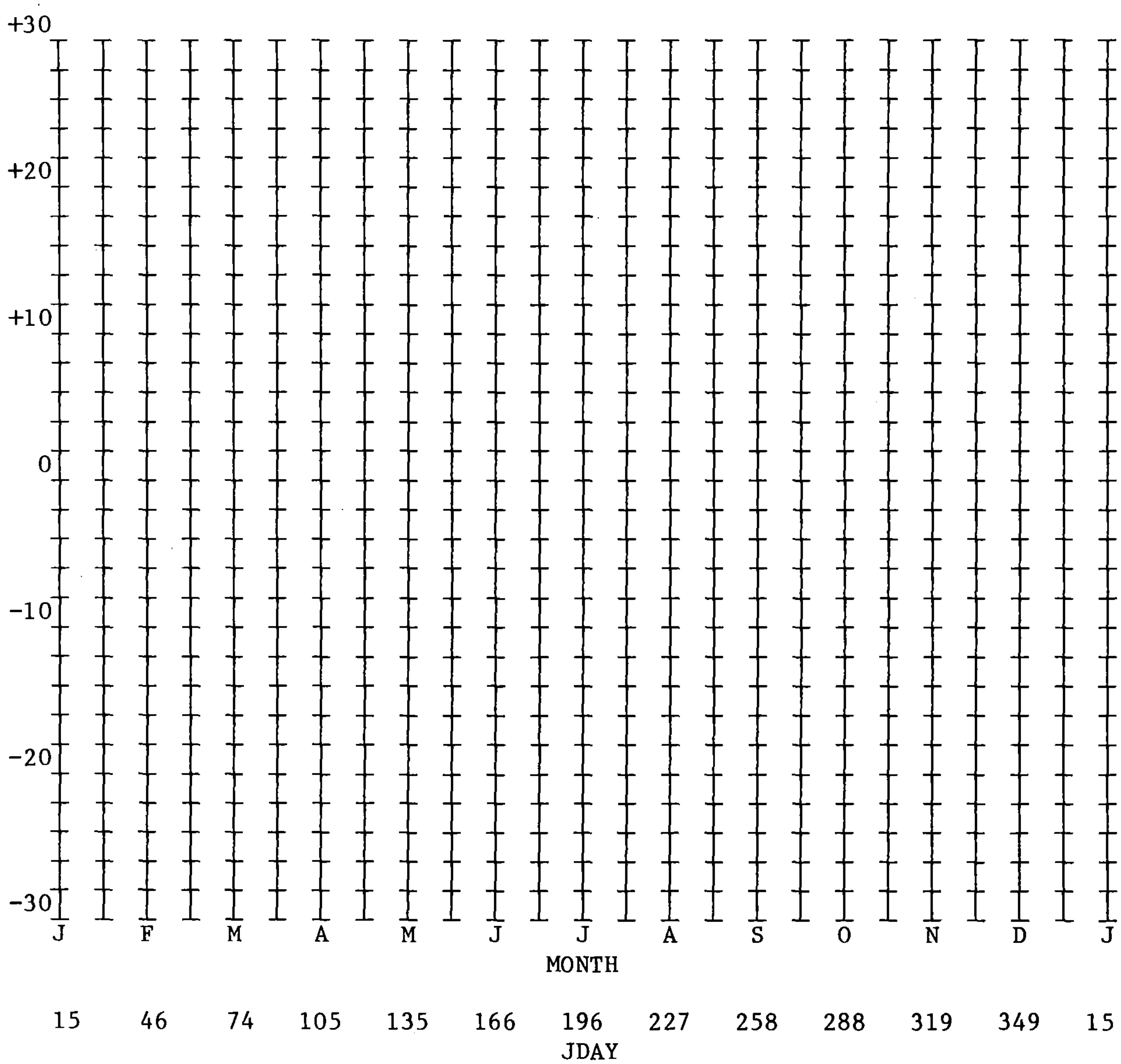
Location: ______________________

Monthly	Low	High	TERA	MPTE	AMPL	PRPC
Maximum	_____	_____	_____	_____	_____	_____
Minimum	_____	_____	_____	_____	_____	_____

The equations:

AMXT =

AMNT =



UNIT 2.3: BAROMETRIC PRESSURE

Air, the mixture of gases in the atmosphere, has weight, so pressure is exerted on the earth's surface by this fluid mass. There is decreasing atmospheric pressure with increasing altitude above sea level because the height of the column of air at increased altitudes is obviously less. The decrease must occur on the basis of atmospheric volume alone. The air is also thinner at higher altitudes since air is a gas which expands and contracts in relation to the volume to be occupied.

Another factor contributing to the pressure exerted by the atmosphere is the temperature effect on the density of a gas. Warmer air is less dense than cool air, resulting in rising warm air and reduced atmospheric pressure. This results in small scale "thermals" which provide lift to glider pilots and soaring birds. Changes in barometric pressure over large areas result in large-scale wind systems. Thus temperature, barometric pressure, and wind patterns all interact to cause land weather conditions.

Barometric pressure is measured with barometers. One type of barometer has a column of mercury which balances with the weight of the atmosphere. Another type of barometer has a sealed elastic chamber which contracts and expands as atmospheric pressure increases and decreases. This is commonly called the aneroid barometer. It needs to be calibrated at regular intervals with the mercury barometer. A third type of barometer is the hypsometer, which functions on the basis of the relationship between the boiling point of a liquid as a function of atmospheric pressure.

Recording barometers are called barographs. Aneroid barameters are especially suited to recording as the contraction and expansion of the chamber may be connected mechanically to a pen and chart system.

Errors associated with the use of barometers and descriptions of different kinds of instruments and standardized readings taken are discussed by Stringer (1972:66ff). The units bar and millibar are used in measuring atmospheric pressure. The bar is defined as a force of 10^6 dynes per square cm, and the millibar is 10^3 dynes per square cm. Atmospheric pressure is about 1000 mb at sea level and drops vary rapidly with height (Stringer 1972:65). At 10,000 feet it is about 700 mb, and at 1100 feet, 500 mb.

Changes in barometer pressure are indicators of changes in approaching weather systems. A drop in barometric pressure, for example, indicates that windy, stormy, and unsettled weither may be approaching. Relationships between barometric pressure and animal behavior are not well understood and documented, although subjective evidence indicates that animals do respond to atmospheric pressure changes and anticipate changes in weather. Perhaps they have sensory capabilities that we humans either don't have or don't use. The convenience of ready-made forecasts available at the flick of a switch tends to relegate our more primitive instincts to disuse.

LITERATURE CITED

Stringer, E. T. 1972. Foundations of Climatology. W. H. Freeman and Company, San Francisco. 586 p.

REFERENCES, UNIT 2.3

BAROMETRIC PRESSURE

SERIALS

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

TOPIC 3. WIND CHARACTERISTICS

Wind, or large-scale movements of the atmosphere, follows some definite patterns due to solar energy and air temperature differences that affect air densities and pressures. Warmer air is less dense than cooler air, so it rises and cooler air moves in to take its place, resulting in wind. Thus, atmospheric motion, or wind, is large-scale convection generated by differences in air densities. Wind has two attributes: direction and magnitude. Wind, as atmospheric motion, is a form of momentum, and momentum implies both direction and magnitude (Stringer 1972:20).

There are patterns to wind directions over the surface of the earth, with the term prevailing winds applied to the most commonly observed general direction each season. Wind velocities also vary with height; the distribution of wind velocities in relation to height is called the vertical wind profile.

Large-scale atmospheric movements are composed of small-scale movements, or turbulence. This is due to friction between the air molecules and the surface of the earth, retarding the flow near the surface. When the earth's surface is covered with vegetation, friction is greater, turbulence is greater, and the vertical changes in wind velocities may extend upward for many meters. These are important ecological considerations as turbulence has both thermal and mechanical effects on plants and animals.

Turbulence is very difficult to measure because most instruments designed to measure wind velocities respond most accurately when oriented in one direction with the air movement. Since turbulent flow comes from all directions, a single sensor does not respond accurately, nor is the readout such that turbulent characteristics are displayed. Variations in wind speeds that are so evident in reading hot-wire anemometers, which respond very rapidly to fluctuations in air flow, result from turbulent flow, but represent the effects in only one direction.

A fairly recent technique is now used to visualize and photographically trace air flow patterns. The use of small (0.3 cm diameter), neutrally-boyant bubbles as flow tracers, a technique used in a wind tunnel (Thermal Environment Simulation Tunnel) at the Wildlife Ecology Laboratory at Cornell University (Moen 1974) and in the field by ventilation engineers for determining air flow in livestock shelters (Carpenter et al. 1972), provides good visual impressions of air flow. Bubbles are much more suitable for tracing air flow than smoke, used as an earlier technique, because bubbles remain intact in turbulent flow, but smoke dissipates.

Air motion, or wind, obviously does not occur at random. Mathematical representations of patterns, both large-scale and small-scale, are discussed in the UNITS that follow, with WORKSHEETS that provide practice when evaluating the ecological effects of changes in time and space.

LITERATURE CITED

Moen, A. A. 1974. Turbulence and the visualization of wind flow. Ecology 55(6):1420-1424.

Carpenter, G. A.; L. J. Moulsley, and J. M. Randall. 1972. Ventilation investigations using a section of a livestock building and air flow visualization by bubbles. J. Agric. Eng. Res. 17:323-331.

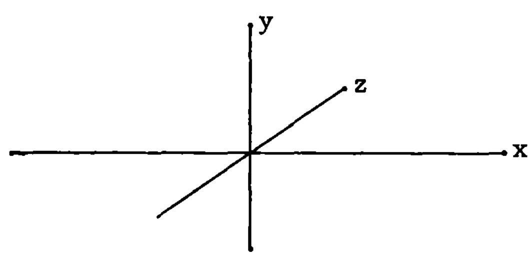
Stringer, E. T. 1972. Foundations of Climatology. W. H. Freeman and Company, San Francisco. 586 p.

UNIT 3.1: WIND DIRECTIONS

Wind direction seems like a rather simple idea because of our conditioning to weather reports that include statements such as, "The wind is blowing from the northwest at ..." Such statements are based on the average in-line wind direction over a time span of several minutes or hours, the simplest expression of wind direction.

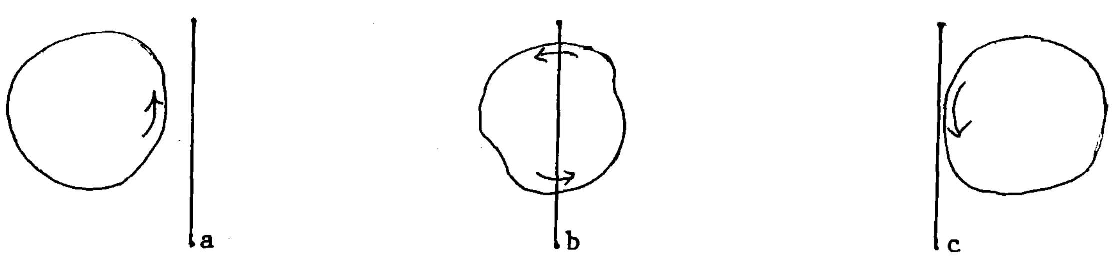
The wind experienced by an organism is composed of the overall average direction of in-line movement of the air mass, and of small scale multi-directional flow, called turbulence. Turbulence is experienced on days when the wind is gusty and erratic, with deviations from the average in-line direction. The amount of turbulence is affected by land features, of course; topographic variations and vegetation generate turbulence, increasing the amount of variability in both direction and velocity.

Turbulence is three-dimensional flow, with x, y, and z axes, as illustrated below.



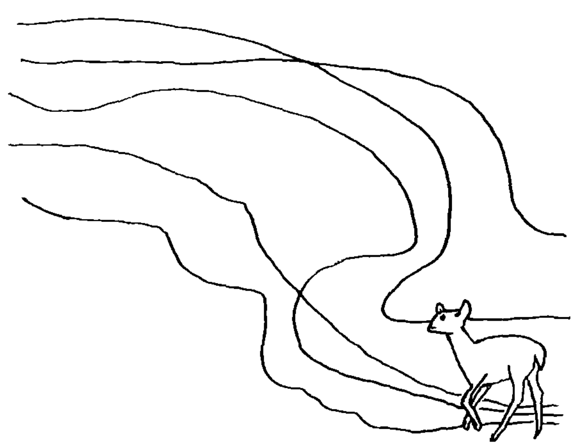
Three-dimensional flow

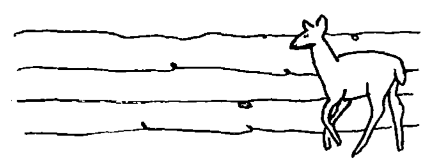
Three-dimensional flow may be visualized as irregular spheres of air rotating as they move in one general in-line direction. Deviations from the in-line direction is due to the rotation of the eddies. As the leading edge of the eddy reaches point a, the direction as illustrated is mostly vertical. As the eddy moves from left to right and is centered on the plane at point b, directions are both right and left, with essentially no rotation at the center of the eddy. When the vertical plane c is at the trailing edge of the eddy, the air movement is in the downward direction. Overall, however, the general in-line direction is from left to right.



Turbulence may be described by its scale, which is a quantitative measure of the size of the eddies that tend to move as a unit in relation to the sizes of objects or organisms in the path of the flow. When the eddies are very large or very small in relation to a part of or a whole plant or animal, they have lesser thermal effects than if they are about the same size as the part of or whole plant or animal. This is an important consideration in calculating convection, although data on turbulence scale in ecological analyses are practically non-existent, and applications of turbulence scale to organisms are very complex due to the rough aerodynamic geometry of organisms.

The turbulence scale here is very large compared to the animal.





The turbulence scale here is very small compared to the animal.

The concept of three-dimensional flow is easily understood because each of us has experienced small-scale changes in direction on windy days, but there are many challenging problems to solve by further research so actual mechanisms are understood better.

Theoretical considerations of flow characteristics are more important when studying very small organisms than large ruminants, but concepts should still be recognized so overly-simplistic analyses of weather effects on organisms are avoided. Introductions to velocity characteristics are given next.

REFERENCES, UNIT 3.1

WIND DIRECTIONS

SERIALS

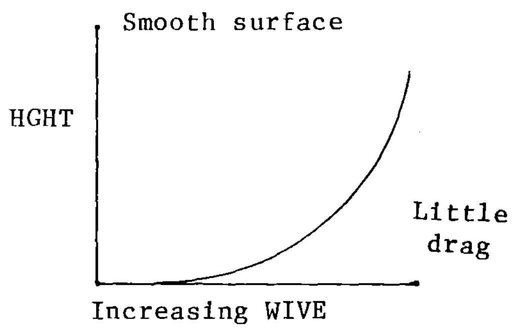
CODEN	VO-NU	BEPA	ENPA	KEY WORDS----------------------	AUTHORS----------	YEAR
ECOLA	55--6	1420	1424	turbulence, visualizat air flow	moen,an	1974
GPNOA	11...	1	69	eddy condition air, smoo snow f	sverdrup,hu	1936
QJRMA	75---	335	350	application micrometo turb flow	sutton,og	1949
TAAEA	10--3	376	377	cup anemometer, behav angl wind	hetzler,re; willi	1967

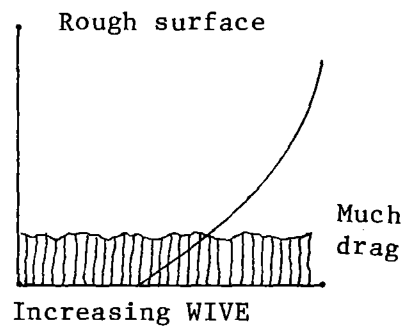
UNIT 3.2: WIND VELOCITIES

Wind velocities given in weather reports are generally measured at some standard height above the ground. Such reported velocities represent just one point on a vertical profile, and do not represent the conditions animals are exposed to on the range. Average in-line velocities at different heights in different habitats should be considered, and deviations from the averages indicate the effects of multi-directional flow, or turbulence, at different heights.

VERTICAL PROFILES

The vertical profile develops because of friction, and the steepness of the profile is dependent on the amount of friction due to the roughness of the earth's surface. General profiles look like this:





Wind velocities (WIVE) over smooth surfaces or short vegetation can be determined for any desired height with the following formula from Sellers (1965):

$$\text{WIVE} = (u^*/k)\ln(z/z_o)$$

where WIVE = wind velocity (cm per second) at height z (cm)
u^* = friction velocity
k = von Karman constant = 0.4
z_o = roughness length.

The symbol u^* represents the <u>friction velocity</u>, which is a characteristic velocity that is dependent on the shear stress of turbulent air as it moves through and over the rough surface. It can be calculated from measured physical characteristics of the air, or determined empirically for a given situation with a known reference velocity and height. The latter approach is used here; the formula for calculating u^* is, from Sellers (1965):

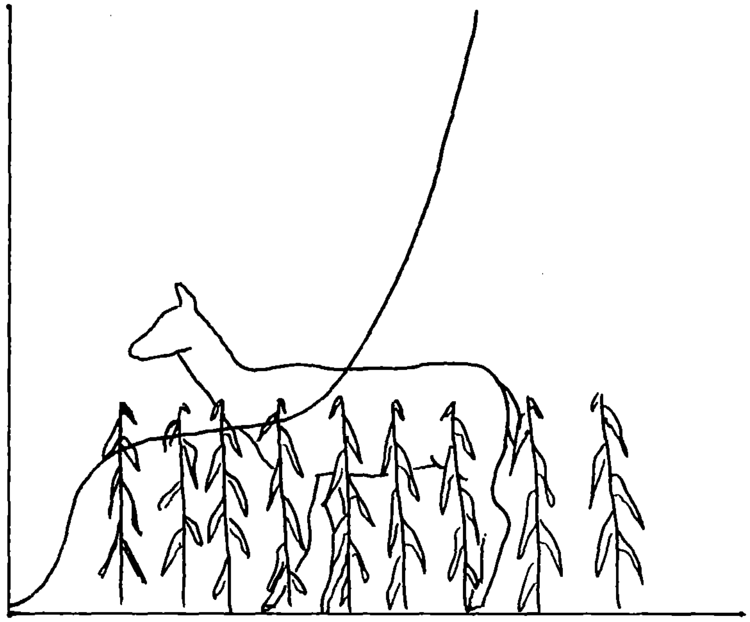
$$u^* = u\,k/[\ln(z/z_o)]$$

where u = wind velocity at z = 200 cm, or 2 m
k = von Karman constant = 0.4
ln = natural log.

The roughness of the earth's surface at a particular point is dependent on both the physical surface and the vegetative cover. Roughness is represented in the general formula used for calculating wind profiles by the symbol z_0 which represents the roughness length, defined as the height above the surface at which wind speed falls to zero. It is equal to about one-tenth of the height of the vegetation (Sellers 1965;140). Representative values (in cm) of z_0 given by three authors for different types of surfaces are given below.

Type of surface	z_0	Reference
Very smooth (mud flats, ice)	0.001	Sutton 1953
Lawn grass to 1 cm tall	0.1	
Downland, thin grass to 10 cm tall	0.7	
Thick grass to 10 cm tall	2.3	
Thin grass to 50 cm tall	5.0	
Thick grass to 50 cm tall	9.0	
Sand	0.01-0.1	Gates 1962
Snow surface	0.1-0.6	
Short grass	0.6-4.0	
Long grass	4.0-10.0	
Grass 5-6 cm tall	0.75	Sellers 1965
Grass 4 cm tall	0.14	
Grass 2-3 cm tall	0.32	
Smooth desert	0.03	
Dry lake bed	0.003	
Smooth mud flats	0.001	
Wheat 60 cm tall	22.0-23.3	
Corn 220 cm tall	74.2-84.5	
Fir forest 555 cm tall	283	

The vertical distribution of velocities over tall vegetation may show a double profile, with two sources of friction between air and substrate: the vegetation and the ground surface. The shape of the profile is dependent on the height and density characteristics of the vegetation. The profile below shows general increases in relation to height both within and above the vegetation.



Animals are exposed to a range of velocities within the velocity profile from the ground surface, where the velocity is 0, to the velocity at the highest point of the its body. The profile may continue vertically beyond the animal until a rather stable velocity is reached outside of the influence of the topography and vegetation.

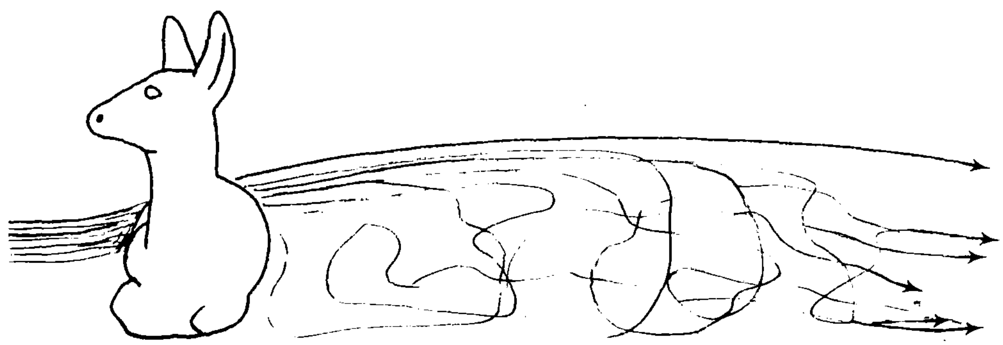
MULTIDIRECTIONAL FLOW; VELOCITY DISTRIBUTIONS

Air flow near the ground is usually turbulent, with velocity fluctuations in all directions due to local obstructions. This three-dimensional flow is not represented by a general formula for mean velocity. The fluctuating velocity can be decomposed into three components: in-line with the mean velocity vector, a cross-component perpendicular to the ground, and a cross-component parallel to the ground but normal to the in-line vector. These fluctations are hidden in the time-average velocity expressed with the general formula for wind profiles (Moen 1974; 1420).

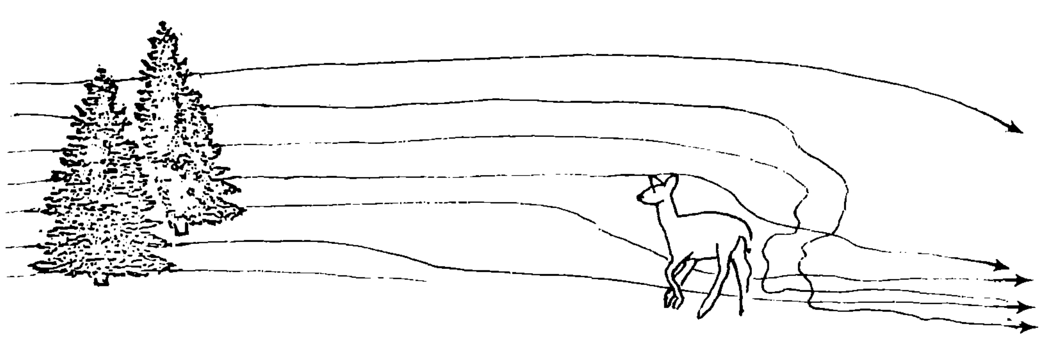
Spherical movements of air masses must result in differences in velocities because of rotational physics. Turbulence intensity is an expression of the turbulent velocity component of the mean velocity over a period of time. If the flow were completely random, the turbulence intensity would be 100% and no directional flow could be detected. When all three (x, y, and z) turbulence components are equal in intensity, the turbulence is said to be isotropic. Turbulence intensity is dependent on the geometry of the vegetation. Outdoors, turbulence may vary from 5% over a relatively smooth open field to 50% in dense woods.

Numerical descriptions of turbulence intensity remain abstractions until related directly to some object. This is difficult in the field because of the complexity of turbulent flow and the need for sensitive and delicate instrumentation. The visualization of air flow is a useful intermediate step that helps one gain a qualitative feeling for the dimensions involved. The fact that dynamic three-dimensional characteristics of wind are not often considered in ecological analyses can be attributed, in part, to the difficulty in visualizing the flow of transparent air masses.

The drawing below is based on a black and white photograph of air flow past a model bedded deer in the Thermal Environment Simulation Tunnel (Stevens and Moen 1970). Note the turbulent flow that develops in the leeward side of the model.

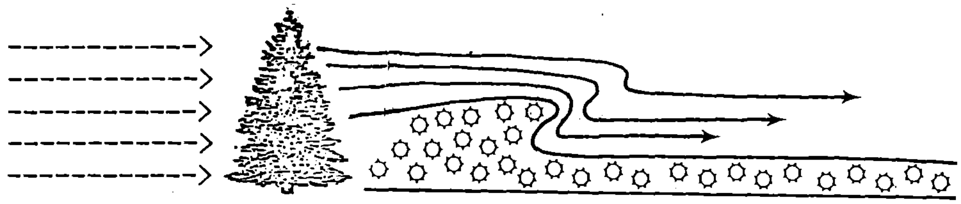


The visualization of air flow on a reduced scale in a wind tunnel is useful for evaluating flow past barriers, plants, and animals. Free-ranging animals are not exposed to a single wind velocity, but to a range of velocities in all three directions that is a function of topographic and vegetation characteristics. The movement of air on the lee side of the canopy has some interesting characteristics. One, it is highly turbulent. The air is moving in three dimensions, including reverse flow illustrated by the trace of bubbles posterior to the deer. Two, there is a general downward trend in the flow of air behind the trees. The deer is located at a point where the wind direction is primarily vertical rather than horizontal. Three, the velocity and direction changes abruptly as the air approaches the surface, and the general profile begins to develop. The drawing below is based on photography of air flow past a model windbreak in the Thermal Environmnent Simulation Tunnel. Note the recirculation pattern behind the windbreak in the vicinity of the deer.



Visualization of air flow is also useful in designing windbreaks, both artificial and natural, for field use. Observed circulation patterns provide significant insight into the importance of barrier height, porosity, and placement, allowing one to predict the most effective spacing of windbreaks before installing them in the field (Moen 1974). If wind affects the choice of bedding sites by wild ruminants, then knowledge of air flow through wind breaks and plant barriers should help understand these choices. The wind profile that develops over different surfaces plays an important part in the formation of wind-packed snow. Wind flow over a snow surface has a sharp profile with high velocities very near the snow surface. The inertia of drifting snow results in a more densely packed snow layer.

Snow deposition patterns behind a windbreak often show a rounded overhang on the terminal portion of a snowdrift (Moen 1973:70-71) due to the recirculation tendency of the moving air behind the windbreak. This is caused by pressure differences on the windward and leeward sides of the windbreak. Decreased pressure on the lee side results in the tendency of the air to recirculate as indicated in the drawing below.



Another characteristic of snow deposited in a drift is its density. The snow does not "fall" behind the windbreak, but is driven into the drift, resulting in denser snow (Swank and Booth 1970). This is shown behind model windbreaks described in Moen (1973:70-71), and illustrated in the line drawing above.

The validity of velocity data from cup anemometers located in the region of downward flow is questionable because cup anemometers generally do not respond at angles greater than 70 (Hetzler et al. 1967). Since cup anemometers respond primarily to wind flow on a horizontal plane, a cup anemometer placed just posterior to the deer at about the height of its tail would record zero velocity, but the deer would be experiencing the vertical air flow. Snowflakes would follow the flow, and the resulting drift formation would be quite unlike snow accumulation in zero wind. The importance of using instruments that measure the functional relationships between animal and environment must be recognized if meaningful interpretations are to be made.

Staple and Lehane (1955), present velocities behind a shelter belt as a percent of exposed velocity; anemometers located a distance equal to 2.5 times the height of the shelter belt recorded 40% of the exposed velocity, and at distances of 5-15 times the height, velocities ranged from 35 to 73% of the exposed velocity. All of these anemometers were located in regions where one would expect a noticeable downward component of the wind to which the instruments would not respond. This is of interest when determining energy balances of animals, however, because animals respond thermally to all angles of attack by the wind, and forced convection--a significant source of heat loss in the winter (Moen 1968)--will occur on the animal's surface.

Visualizations of turbulent air flow using bubble tracers provide insight into the dynamic motion involved, and the effect of this motion must ultimately be related to heat transfer, not only from the whole animal, but also from its component parts, including appendages and the fine structure of the pelage, if thermal exchange is to be fully understood. All of these conceptual considerations are important, but we are not yet ready to apply them to real field situations. The calculations in CHAPTER 15 give one an opportunity to make the simplest of calculations.

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Hetzler, R. E., W. O. Willis, and E. J. George. 1967. Cup anemometer behavior with respect to attack angle variation of the relative wind. Trans. ASAE (Amer. Soc. Agr. Eng.) 10(3):376-377.

Moen, A. N. 1973. Wildlife Ecology. W. H. Freeman Company, San Francisco. 458 p.

Moen, A. N. 1974. Turbulence and the visualization of wind flow. Ecology 55(6):1420-1424.

Sellers, W. D. 1965. Physical Climatology. Univ. Chicago Press, Chicago. 272 p.

Staple, W. J. and J. J. Lehane. 1955. The influence of field shelter-belts on wind velocity, evaporation, soil moisture, and crop yield. Can. J. Agric. Sci. 35:440-453.

Stevens, D. S. and A. N. Moen. 1970. Functional aspects of wind as an ecological and thermal force. Trans. N. Am. Wildl. and Nat. Res. Conf. 35:106-114.

Sutton, O. G. 1953. Micrometeorology. McGraw-Hill Book Co., N.Y. 333 p.

Swank, G. W. and R. W. Booth. 1970. Snow fencing to redistribute snow accumulation. J. Soil and Water Cons. 25:197-198.

REFERENCES, UNIT 3.2

WIND VELOCITIES

SERIALS

CODEN	VO-NU	BEPA	ENPA	KEY WORDS----------------------	AUTHORS----------	YEAR
AGMYA	12--1	123	130	drag coeff,forst trees, wnd tun	mayhead,gj	1972
ECOLA	55--6	1420	1424	turbulence, visualizat air flow	moen,an	1974
FOSCA	17--3	314	321	vert profiles wndspd, pine stnd	bergen,jd	1971
FRSTA	27--2	85	95	effcts shltrblts,locl microclim	gloyne,rw	1954
GFRPA	33---	1	4	wind movement in pine stands	cooper,rw	1965
GPNOA	11...	1	69	eddy condition air, smoo snow f	sverdrup,hu	1936
IRFOA	31--2	130	134	topography and wind risk	booth,tc	1974
JAMOA	4----	400	408	model velocity distribut, crops	plate,ej; quraish	1965
JFUSA	51--3	173	178	wnd tunnl stdies, shltrblt modl	woodruff,np; zing	1953
QJFOA	49--4	251	259	air movmnts, effcts on forestry	evans,jdd	1955
QJRMA	75---	335	350	application micrometo turb flow	sutton,og	1949
TAAEA	10--3	376	377	cup anemometer, behav angl wind	hetzler,re; willi	1967
XANFB	137	1	2	eff ovrstry removl,surface wind	brown,jm	1972
XARRA	252	1	4	var wndspd, canopy covr,lodgpol	bergen,jd	1974

OTHER PUBLICATIONS

Grasso, V. 1965. Characteristic phenomenon of wind in a young pine plantation. Ital. for. mont. 20(2):57-62.

CHAPTER 14, WORKSHEET 3.2a

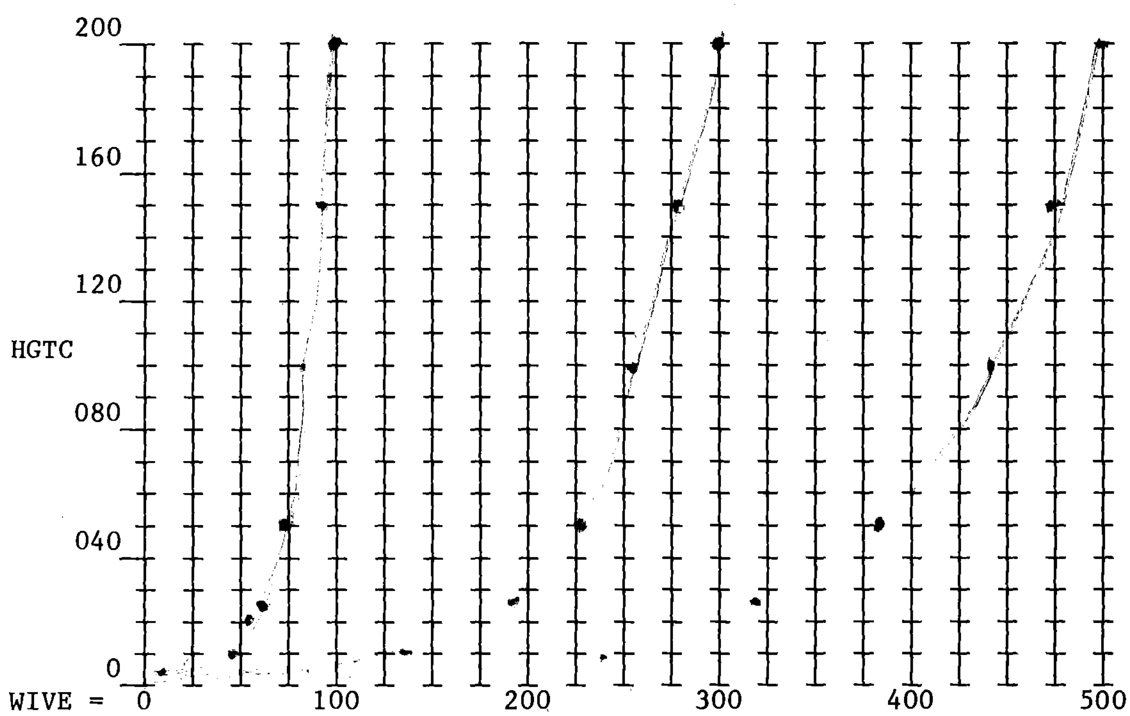
Vertical wind profiles

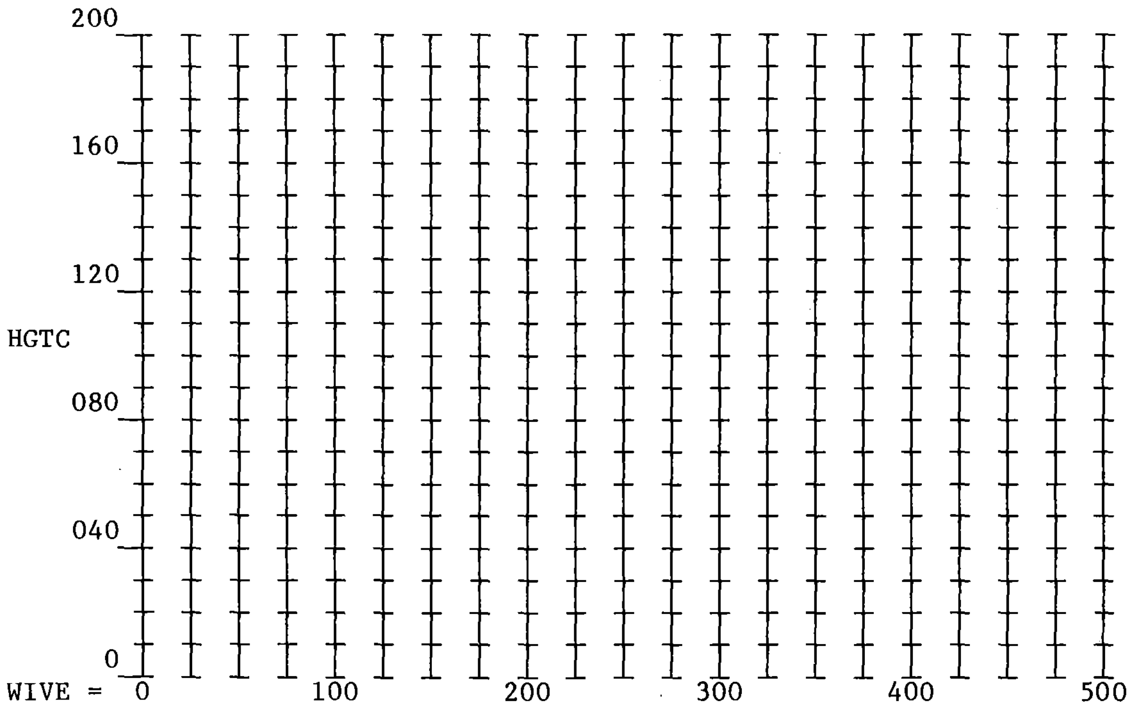
Vertical wind profiles of mean velocity may be calculated by cycling through the formula for WIVE at succesive height intervals. The formula, with the symbols defined in UNIT 3.2, is:

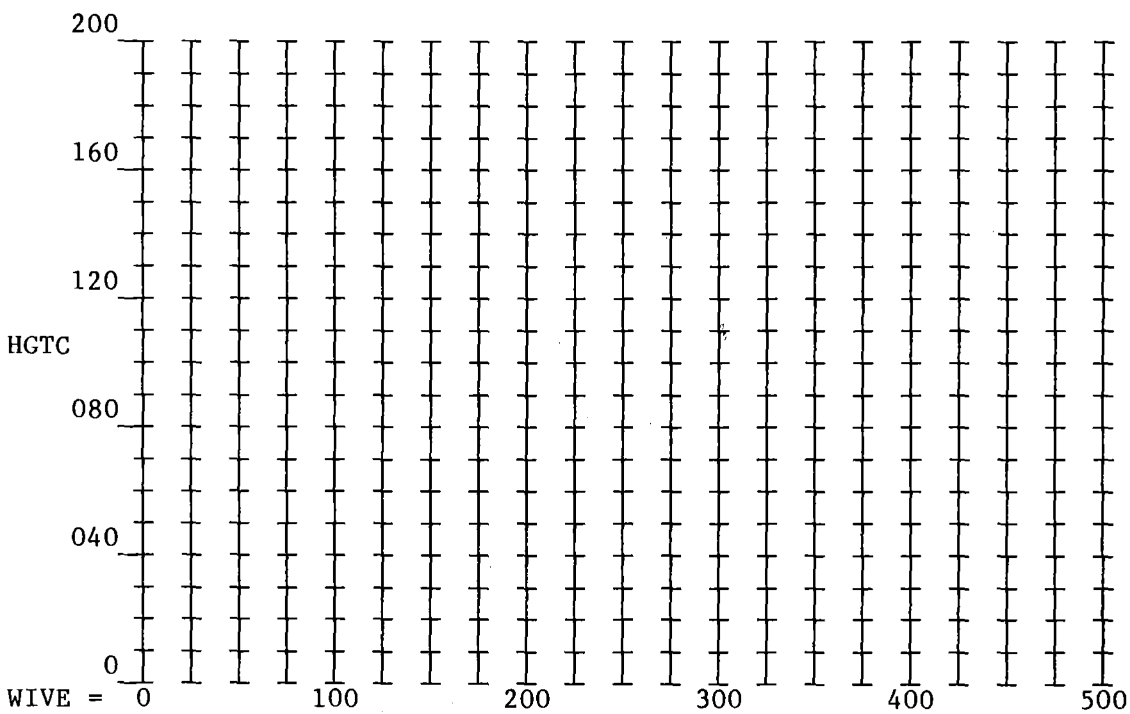
$$\text{WIVE} = (u^*/k)\ln(z/z_o)$$

The friction velocity must be calculated before the formula can be employed. Select a z_o to represent the habitat you are calculating the profile for, and determine u^* with the formula $u^* = uk/[\ln(z/z_o)]$ as explained in UNIT 3.2. Then, selecting reference velocities of 100, 200, 300, 400, and 500 cm/sec, calculate and plot the wind velocities at 20 cm intervals from 1 to 200 cm height (HGTC). Two more grids are available on the next page.

100 cm/sec Z_0 = 0.6 u* = 6.89
300 cm/sec " " 20.66
500 cm/sec " " 34.43



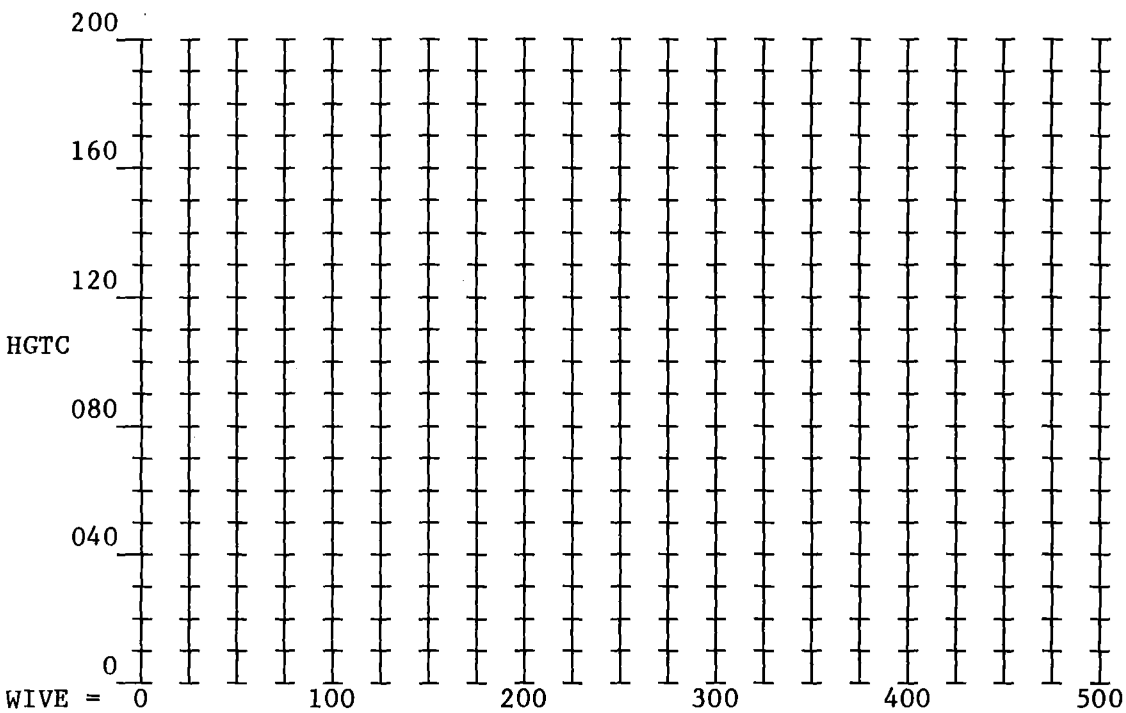

200
160
120
HGTC
080
040
0
WIVE = 0
100
200
300
400
500

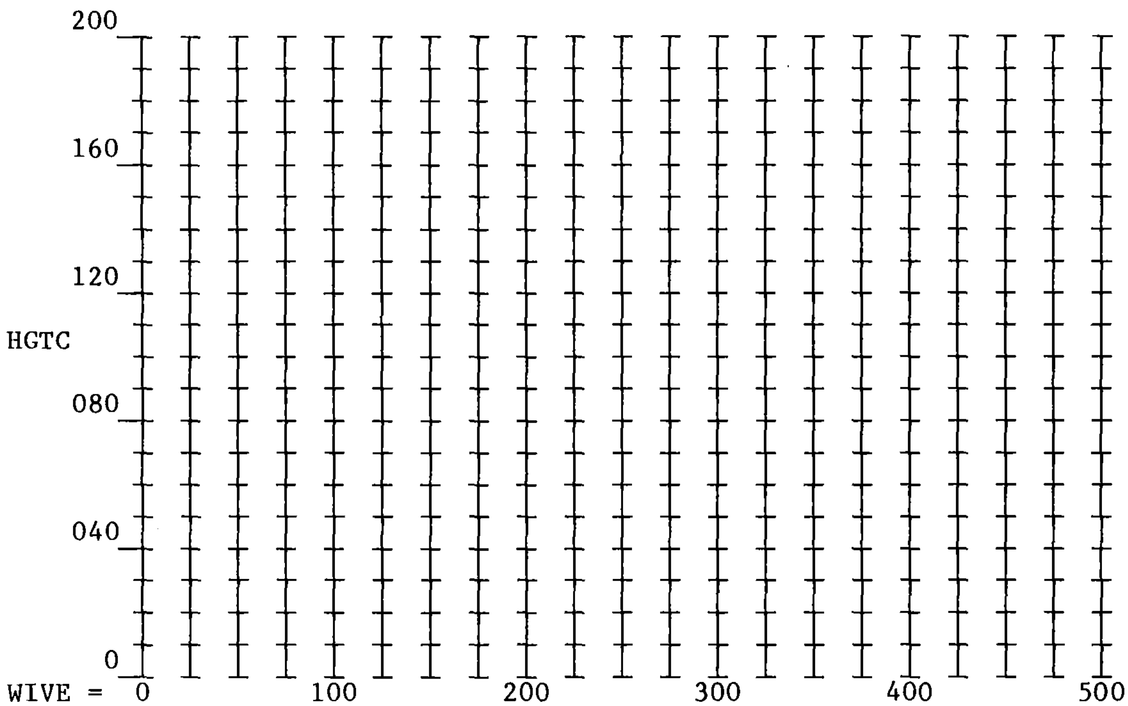

200
160
120
HGTC
080
040
0
WIVE = 0
100
200
300
400
500

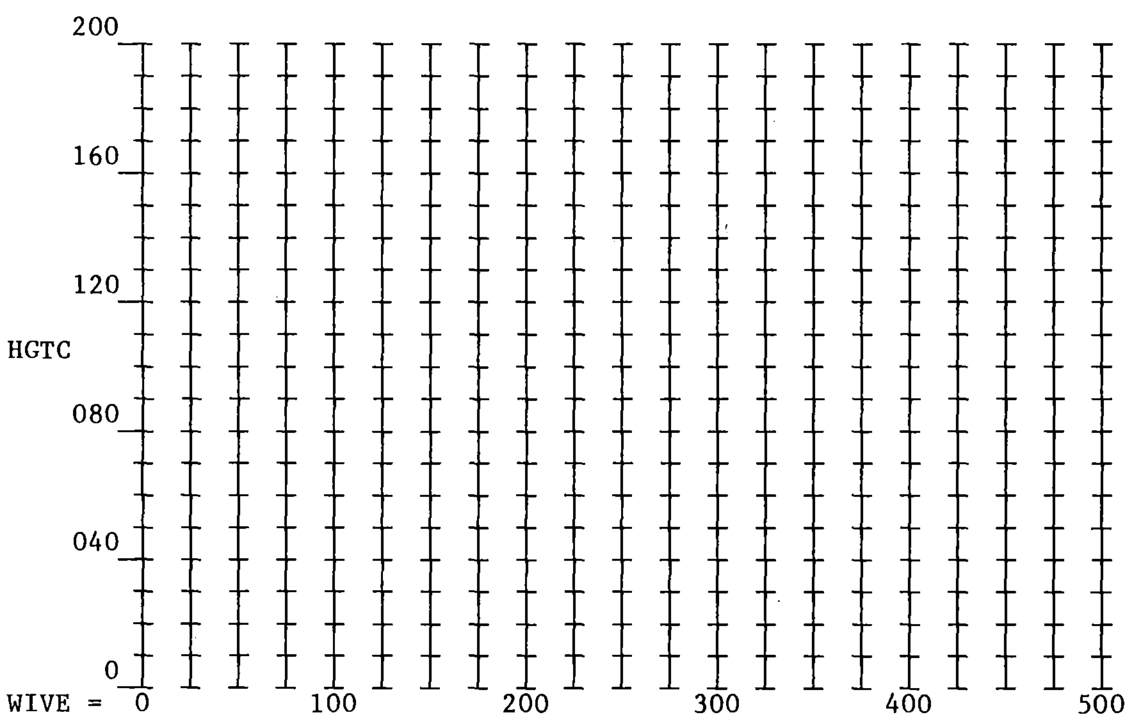
CHAPTER 14, WORKSHEET 3.2b

Wind velocities past bedded and standing animals

Vertical wind profiles were calculated in WORKSHEET 3.2a. Using the formula given in WORKSHEET 3.2a and selecting z_0 to represent the habitat in which you are interested in evaluating wind velocities past bedded and standing animals, calculate and plot wind velocity profiles for differrent reference velocities. Then, go back to CHAPTER 1, UNIT 2.2 and calculate vertical geometric profiles for the species of your choice. Sketch the animal on the grid below and determine the wind velocities past different parts of the animal. Wind velocities may be visually estimated (be sure to draw the animal to scale) or calculated mathematically in relation to the heights of different body parts. Two additional grids may be found on the next page.

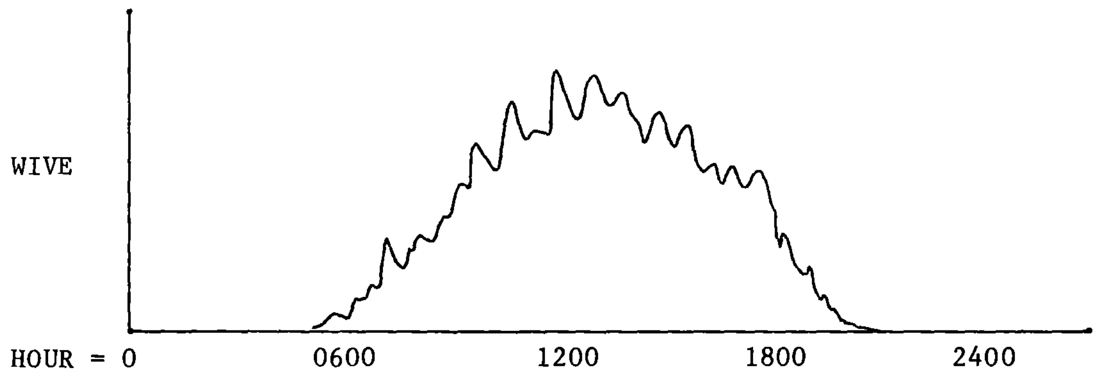



200
160
120
HGTC
080
040
0
WIVE = 0
100
200
300
400
500

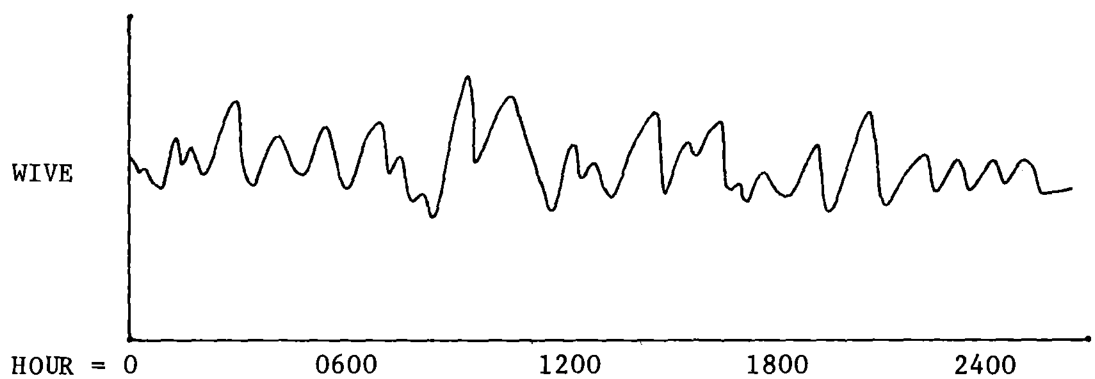

200
160
120
HGTC
080
040
0
WIVE = 0
100
200
300
400
500

UNIT 3.3: TEMPORAL PATTERNS OF WIND VELOCITY

A general pattern of little or no wind at sunrise, increasing velocities in the morning and early afternoon, maximum velocities by mid to late afternoon, and then decreasing velocities into the evening with little or no wind shortly after sunset is typical of stable, high pressure weather systems with clear or only partly cloudy skies. The pattern looks like this.



Some weather systems result in rather constant velocities through the day, with gusts ocurring at frequencies and with magnitudes characteristic of atmospheric turbulence characteristics. The pattern is varible due to the transient conditions, but may look like this.



The use of such idealized patterns through the 24-hour daily cycle, combined with other daily patterns of solar energy, temperature, activities, and others, permits one to calculate changes in the energy balance through time on an idealized day. If that can be done, then the effects of measured transient changes on animals in different habitats can also be calculated.

Average wind velocities over weeks or months may result in an annual patterns, depending on location, topography, water, and other factors. If data are available they may be evaluated in WORKSHEET 3.3a.

REFERENCES, UNIT 3.3

TEMPORAL PATTERNS OF WIND VELOCITY

SERIALS

CODEN	VO-NU	BEPA	ENPA	KEY WORDS----------------------	AUTHORS----------	YEAR
EAFJA	35--2	160	165	diurnal varia, mean wind speed	woodhead,t	1969
FOSCA	1...	289	297	wnd profls, small isolatd forst	reifshyder,we	1955
JAPEA	8---3	729	741	wind profiles in plant canopies	landsberg,jj; jam	1971
TAGUA	34--6	841	848	effct wnd, nght radiatnl coolng	gossard,ee	1953

CHAPTER 14, WORKSHEET 3.3a

Temporal patterns of wind velocity

The sketches in this UNIT are based on actual measurements with a recording anemometer at Cornell's Arnot Forest Teaching and Research Center. Evaluate the patterns and derive equations, where possible, for the different kinds of patterns in relation to atmospheric conditions. How might frequency distributions be used when evaluating maximum and minimum wind velocities each day over an extended period of time?

Compile average wind velocities by month, if available. Is there a pattern that may be expressed as an equation?

	J	F	M	A	M	J	J	A	S	O	N	D
Daily average wind velocity:	____	____	____	____	____	____	____	____	____	____	____	____

	J	F	M	A	M	J	J	A	S	O	N	D
Daily average wind velocity:	____	____	____	____	____	____	____	____	____	____	____	____

	J	F	M	A	M	J	J	A	S	O	N	D
Daily average wind velocity:	____	____	____	____	____	____	____	____	____	____	____	____

	J	F	M	A	M	J	J	A	S	O	N	D
Daily average wind velocity:	____	____	____	____	____	____	____	____	____	____	____	____

	J	F	M	A	M	J	J	A	S	O	N	D
Daily average wind velocity:	____	____	____	____	____	____	____	____	____	____	____	____

	J	F	M	A	M	J	J	A	S	O	N	D
Daily average wind velocity:	____	____	____	____	____	____	____	____	____	____	____	____

	J	F	M	A	M	J	J	A	S	O	N	D
Daily average wind velocity:	____	____	____	____	____	____	____	____	____	____	____	____

	J	F	M	A	M	J	J	A	S	O	N	D
Daily average wind velocity:	____	____	____	____	____	____	____	____	____	____	____	____

	J	F	M	A	M	J	J	A	S	O	N	D
Daily average wind velocity:	____	____	____	____	____	____	____	____	____	____	____	____

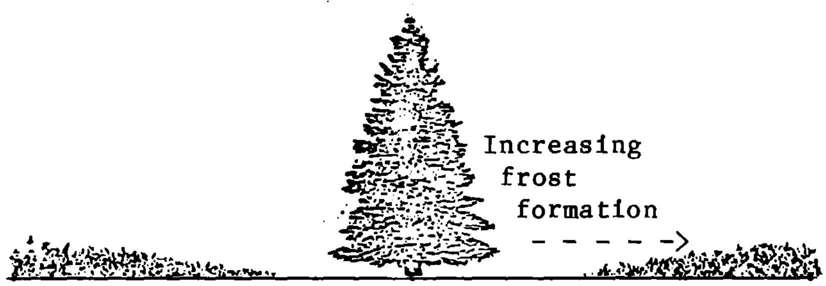
	J	F	M	A	M	J	J	A	S	O	N	D
Daily average wind velocity:	____	____	____	____	____	____	____	____	____	____	____	____

	J	F	M	A	M	J	J	A	S	O	N	D
Daily average wind velocity:	____	____	____	____	____	____	____	____	____	____	____	____

TOPIC 4: ATMOSPHERIC HUMIDITY

Water vapor is a very important component of the atmosphere because it is part of small scale daily rhythms in condensation and evaporation, and large scale atmospheric events in the hydrologic cycle. Daily rhythms in condensation and evaporation result in dew formation and dissipation. These phase changes of water are significant when considering thermal characteristics of the atmosphere since large quantities of heat energy--575 to 595 calories--are absorbed when a gram of water is vaporized at the atmospheric temperatures observed at the earth's surface. This heat energy is called the heat of vaporization, and is absorbed in vaporization and released upon condensation. Heat energy--about 80 calories per gram--is released when water freezes too; this is called the heat of fusion. The melting of ice and snow requires the absorption of heat energy equal to the heat of fusion.

Radiant energy discussed in UNITS 1.1 and 1.2 has a marked effect on the distribution of dew and frost. Patterns of frost accumulation at night may be observed from the base of a tree outward as illustrated below, indicating the role of infrared energy from the tree in preventing condensation and crystallization. Watch for this pattern the next time you are out the morning after a frost. The distribution of frost is related to the distribution of infrared energy, described in Moen (1968).



<- - - Increasing distance from tree - - ->

The energy-absorbing and energy-releasing processes of vaporization, condensation, fusion, and melting obviously have important roles in the lives of plants and animals exposed to the atmosphere. Some plants have life cycles that are directly dependent on moisture characteristics of the atmosphere. Mosses and fungi, for example, depend on thin films of water for parts of their reproductive strategies. Some depend on atmospheric water vapor characteristics for their structural characteristics. Lichens, for example, are dehydrated and stiff in a dry atmosphere, and rather soft and pliable in a moist atmosphere. When dry, they are not readily eaten by reindeer and caribou. When moist, they may be a major component of the diet.

Terms expressing atmospheric moisture characteristics are discussed in UNIT 4.1, followed by some humidity calculations in UNITS 4.2 and 4.3 that may be useful in later analyses of energy balances.

LITERATURE CITED

Moen, A. N. 1968. Thermal energy exchange of a birch tree and spruce tree at night. Ecology. 49(4):145-147.

UNIT 4.1. TERMS EXPRESSING HUMIDITY

Some fairly standardized meteorological terms are used to express humidity relationships, and are defined in general meteorology texts (see Taylor 1954, for example). These are expressed as four-letter symbols and defined below.

Specific humidity. Specific humidity (SPHU) is the ratio of the mass of water vapor in a sample of air (MAWV) to the total mass of air (TMAI), including both water vapor and air in the sample. In symbol form:

SPHU = MAWV/(MAWV + TMAI)

It is expressed in units of mass such as grams (actually a fraction of one gram) of vapor per gram of moist air. Note that specific humidity is a ratio of mass.

Mixing ratio. This term is used for the ratio of mass of water vapor per unit mass of dry air. It is different from specific humidity only in the denominator; specific humidity includes the total mass of air, including the water vapor, and mixing ratio only the dry air. Numerically, the ratios are almost always within 1% or so because the actual mass of water vapor involved is a very small part of the total air mass; the denominators are very close numerically.

Absolute humidity. Absolute humidity (ABHU) is the ratio of the mass of water vapor to the total volume of moist air (TVMA) in which it is contained. In symbol form:

ABHU = MAWV/TVMA

It is a ratio of mass to volume; units used are grams of water vapor per cubic meter of moist air.

Relative humidity. Relative humidity (REHU) is a ratio expressing the observed or actual vapor pressure of the air (AVPA) compared to the saturation vapor pressure (SAVP) of the air at that temperature:

REHU = AVPA/SAVP

It is a dimensionless ratio, usually expressed as a percent, that can be interpreted only when air temperature is given because saturation vapor pressure is a function of air temperature.

LITERATURE CITED

Taylor, G. F. 1954. Elementary Meteorology. Prentice-Hall, Inc., NY. 364 p.

REFERENCES, UNIT 4.1

TERMS EXPRESSING HUMIDITY

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

UNIT 4.2: THE CONCEPT OF SATURATION

Saturation suggests a fullness, a state in which something can hold no more; its space is occupied. Applying this concept to the atmosphere, saturation occurs when a gaseous component of the atmosphere is in equilibrium with a source of the gas, and molecules are exchanged equally between the source and the atmosphere. When the atmosphere is not in equilibrium with the source, molecules enter the atmosphere faster than they leave it. There must be a deficit for that to occur. These two ideas--saturation and deficit--are discussed below.

Water molecules continually escape from liquid water surfaces and enter the atmosphere, and water molecules from the atmosphere are continually absorbed by liquid water surfaces. The water vapor component of the atmosphere has weight and therefore exerts pressure on the earth's surface, just as the other gases in the atmosphere do. The water component of atmospheric pressure is called vapor pressure. When the molecular movement of water vapor is equal in both directions between the atmosphere-liquid interface, the atmosphere is saturated. Saturation vapor pressure is an expression of the vapor pressure component of such air. The vapor pressure may be expressed in mm of Hg, as in Moen (1973:102) or in mb, as in Rosenberg (1974:131).

Gates (1962) has an abbreviated table of vapor pressure values, shown below.

Vapor Pressure Values (mb)

	T					
R.H.	0°C	10°C	20°C	30°C	40°C	50°C
100%	6.1	12.3	23.4	42.4	73.8	123.4
50%	3.1	6.2	11.7	21.2	36.9	61.7

Note that the vapor pressure at 50% relative humidity is one-half that at 100%, except for rounding errors. The vapor pressure increases as temperature increases but the per cent relative humidity remains constant. The amount of evaporation that will occur depends on, among other things, the amount of additional vapor that the atmosphere can hold. This is often expressed as a vapor pressure deficit, and is simply the difference between the saturated vapor pressure and the actual vapor pressure at a given temperature.

Saturation vapor pressures (SAVP) increase with increasing air temperatures, and the relationship is exponential. In simple terms, warm air can hold more moisture than cool air. The logarithmic equation for determining saturation vapor pressure from air temperature calculated by Moen

(1973:102) based on data in the Handbook of Chemistry and Physics (Weast 1967) is, in mm Hg:

$$\log_e \text{SAVP} = (1.580 + 0.062\ \text{AITC})$$

which can be rewritten as:

$$\text{SAVP} = e^{(1.580 + 0.062\ \text{AITC})}$$

where SAVP = saturation vapor pressure, and
AITC = air temperature in Celsius.

This equation predicts the values tabulated in the Handbook of Chemistry and Physics with acceptable accuracy for ecological purposes; deviations range from 0.8% to 6.0%.

The vapor pressure deficit is the difference between the saturation vapor pressure SAVP, and the water vapor pressure of the air at a particular temperature. Since the ratio of actual vapor pressure to saturation pressure is the familiar term relative humidity, the saturation vapor pressure (SAVP) equation can be combined with the relative humidity ratio and the vapor pressure deficit, VPDE, determined. The formula is:

$$\text{VPDE} = \text{SAVP}\ [(100 - \text{PTRH})/100]$$

where PTRH = percent relative humidity. The equation, from Moen (1973: 102) is:

$$\text{VPDE} = e^{(1.580 + 0.062\ \text{AITC})}[(100 - \text{PTRH})/100]$$

Note that the first part of this equation is the saturation vapor pressure, and the second part, within the square brackets, the difference between 100 and observed percent relative humidity, which is converted to a decimal fraction by dividing by 100.

VPDE is expressed in mm of Hg, just as SAVP is. Complete the calculations for the two variables in this equation, AITC and PTRH, on the WORKSHEETS that follow.

LITERATURE CITED

Moen, A. N. 1973. Wildlife Ecology. W. H. Freeman Company, San Francisco. 458 p.

Rosenberg, N. J. 1974. Microclimate: The Biological Environment. John Wiley & Sons, N.Y. 315 p.

Weast, R. C., ed. 1967. Handbook of Chemistry and Physics. 48th ed. Cleveland: The Chemical Rubber Co.

REFERENCES, UNIT 4.2

THE CONCEPT OF SATURATION

SERIALS

CODEN	VO-NU	BEPA	ENPA	KEY WORDS----------------------	AUTHORS----------	YEAR
HYSBA	11--1	34	42	compar evaporatio fr snow, soil	hutchison,ba	1966
JGREA	67-12	4673	4682	evaporation of rain drops	abraham,ff	1962
MWREA	67--4	4	11	determin evapor, lnd, watr surf	thornthwaite,cw;	1939
PHDSA	2----	55	82	evaporation from land surfaces	king,km	1961
PHDSA	2----	135	167	evaporation comp, prair resrvoi	mckay,ga; stichli	1961
PHDSA	2----	8	30	energy budget, mass trans theor	munn,re	1961
XATBA	817--	1	145	measuring evap fr lnd, wat surf	thornthwaite,cw;	1942

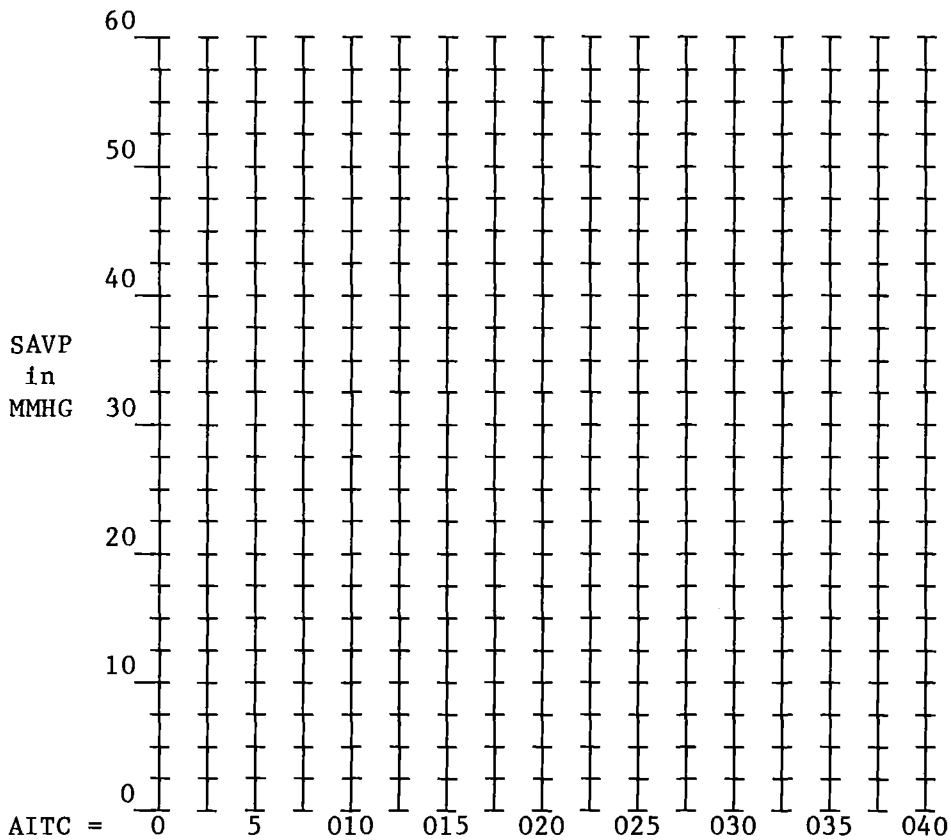
OTHER PUBLICATIONS

Thornthwaite, C. W. 1957. Instructions and Tables for Computing Potential Evapotranspiration and the Water Balance. Publications in Climatology, Laboratory of Climatology. Vol. 10, No. 3.

Saturation vapor pressure

A formula was given in UNIT 4.2 for saturation vapor pressure (SAVP). Air temperature in Celsius (AITC) is the independent variable. Use the formula below to calculate the saturation vapor pressure in mm of mercury (MMHG) for temperatures from 0 to 40°C and plot the curve.

$$SAVP = e^{(1.580 + 0.062\ AITC)}$$



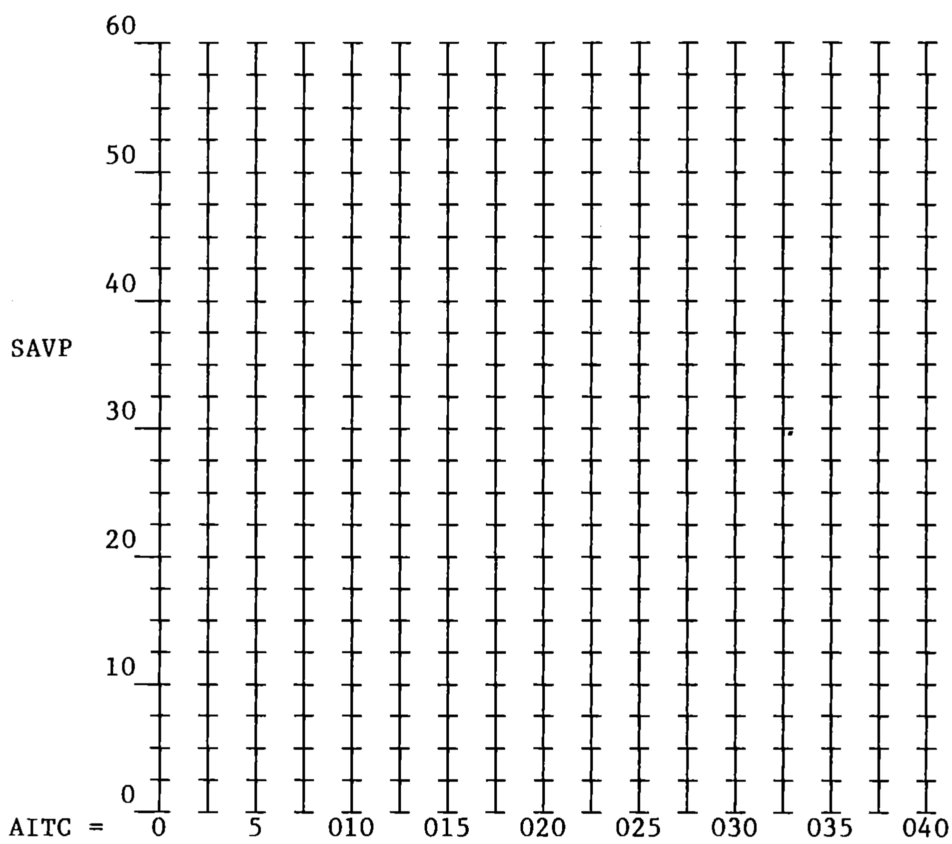
CHAPTER 14, WORKSHEET 4.2b

Vapor pressure deficits

Saturation vapor pressures, SAVP, were calculated in WORKSHEET 4.2a. Vapor pressure deficits are calculated by multiplying SAVP by relative humidity expressed as a decimal fraction and subtracting the product from SAVP. The equation is:

$$VPDE = e^{(1.580 + 0.062\ AITC)}[(100 - PTRH)/100]$$

Complete the calculations of VPDE for a family of curves for REHU = 10-90% and plot them below.

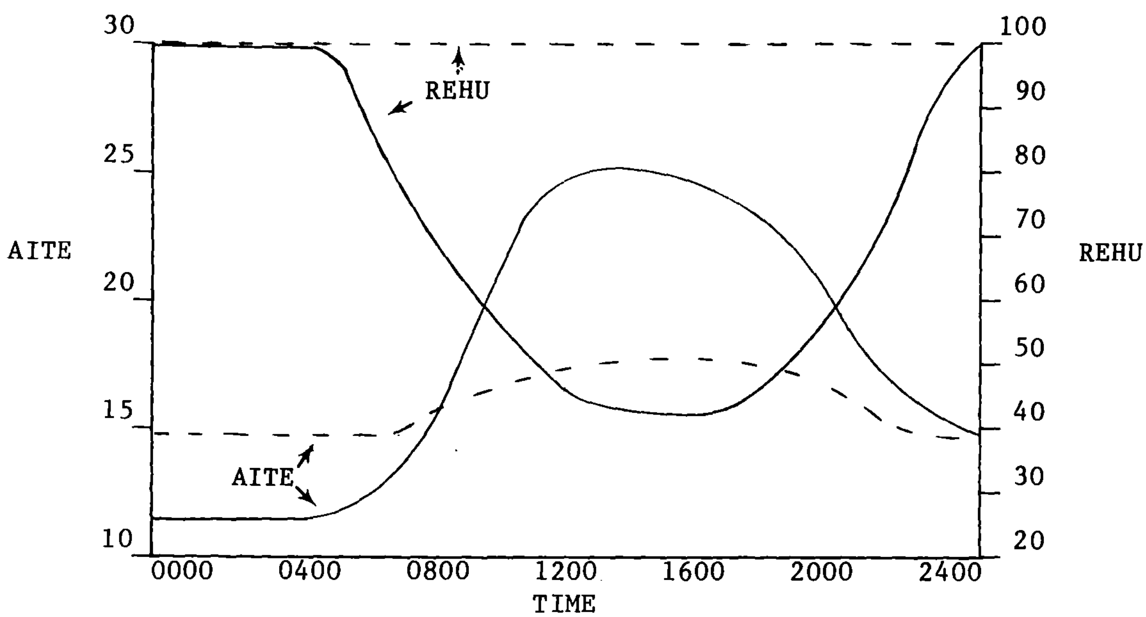


UNIT 4.3: TEMPORAL PATTERNS OF ATMOSPHERIC HUMIDITY

There are daily and seasonal patterns to the amounts of water vapor in the atmosphere. The warmer air characteristic of mid-afternoon has the potential for holding more water vapor than the cooler morning, evening, and night-time air. Warmer summer atmospheres have the potential for holding more water vapor than cooler winter atmospheres.

An interesting and sometimes overlooked relationship exists between the temporal patterns of relative humidity, vapor pressures, and vapor pressure deficits through daily and seasonal cycles. The atmosphere at the earth's surface is at or near saturation at night when skies are clear. Then, there is a large amount of radiational cooling, and dew forms as atmospheric water vapor condenses on cool vegetation surfaces. The relative humidity is at or near 100%. After the sun rises the atmospheric temperature tends to rise, dew evaporates, and relative humidity goes down. However, the vapor pressure may actually increase because the warmer air can hold more water vapor than the cooler air. Further, the vapor pressure deficit will actually increase, too, if there is not enough moisture available for atmospheric absorption. Thus the pattern of relative humidity, being it is so temperature dependent, is not a good indicator of atmospheric moisture, and expressions of relative humidity without air temperatures are of little use for ecological purposes.

Results of air temperature and relative humidity measurements are shown below for two combinations of air temperature and relative humidity. Note that relative humidity dropped to minimum when air temperature reached maximum on a warm sunny afternoon (solid line), and that relative humidity remained at 100% on a day when air temperature changed very little (dashed line).



REFERENCES, UNIT 4.3

TEMPORAL PATTERNS OF ATMOSPHERIC HUMIDITY

BOOKS

TYPE	PUBL	CITY	PAGE	ANIM	KEY WORDS-----------------	AUTHORS/EDITORS--	YEAR
edbo	pepr	oxen	813		p. 381-390, sym for hydro	sopper,we; lull,h	1967
edbo	pepr	oxen	813		p. 451-462, sym for hydro	sopper,we; lull,h	1967

SERIALS

CODEN	VO-NU	BEPA	ENPA	KEY WORDS---------------------	AUTHORS----------	YEAR
AJBOA	29-10	828	832	species diff, water absorption	kramer,pj	1942
FOSCA	1....	258	264	soil water depletion by fo stan	zahner,r	1955
FOSCA	4---3	178	184	water depletion hardwood unders	zahner,r	1958
IAXNA	128..	----	----	evaluati hamon meth, pot evapo	russell,rl; bogge	1964
JECOA	51--1	191	203	stud water relati, p sylvestris	rutter,aj	1963
JFUSA	50-10	746	747	evaporation in nature	stone,el,jr	1952
JFUSA	59--3	175	181	water use by brush, groun, gr-f	rowe,pb; reimann,	1961
JGREA	65-10	3391	3413	potential evapotransp esti meth	tanner,cb; pelton	1960
JGREA	68-20	5719	5724	infl soil water transpor by pla	gardner,wr; ehlig	1963
JYCEA	87...	107	120	HY3, pt 1, est pot evaporatrans	hamon,wr; asce,a	1961
PRSLA	193..	120	145	natur evaporat wat, soil, grass	penman,hl	1948
SSSAA	21--5	464	468	rel soil, plant met fac, evapor	lemon,er; glaser/	1957
TACEA	117--	974	987	forest range vegeta, use of wat	rich,lr	1952
WRERA	2---1	71	84	conc mod stomat contr mechanism	woo,kb; stone,ln	1966
WRERA	2---1	85	97	dynamic simu model transpi proc	woo,kb; boersma,	1966
XAMPA	257--	1	97	water util by trees, no tempera	raber,o	1937

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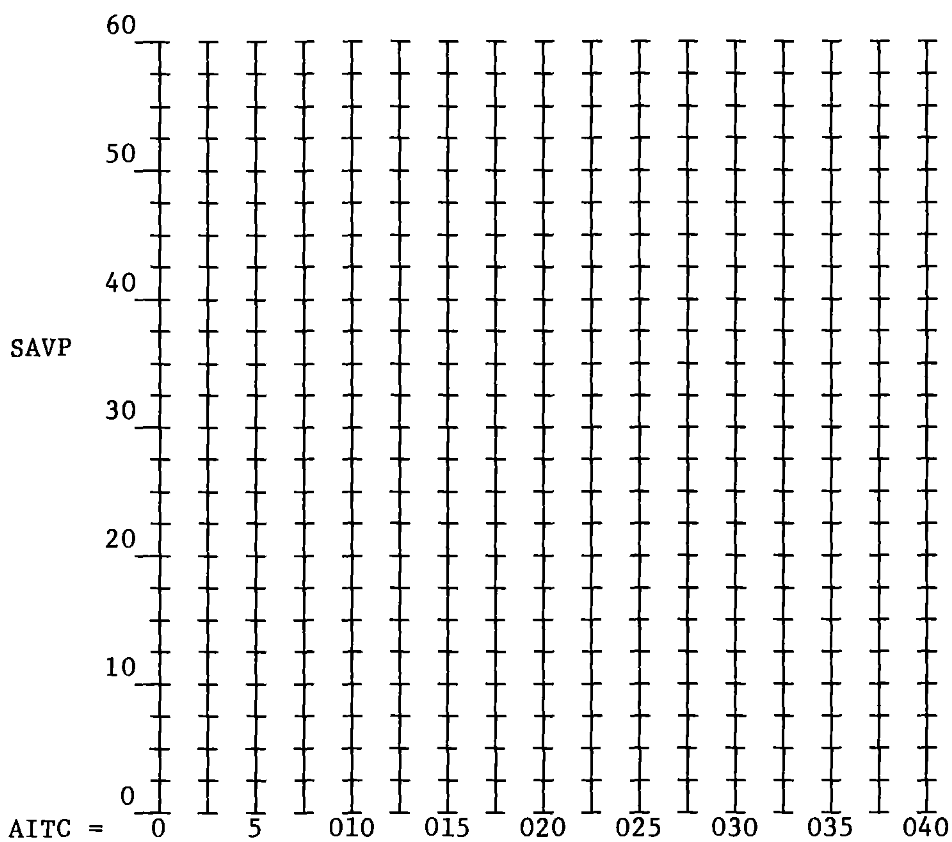
Thornthwaite, C. W. 1954. A re-examination of the concept and measurement of potential evapotranspiration. Publications in Climatology, Lab. of Climatology. Vol. 8(1): 200-209.

CHAPTER 14, WORKSHEET 4.3a

Temporal patterns of air temperature, relative humidity, and vapor pressure deficit

The tracings of air temperatures and relative humidities given in UNIT 4.3 may be used to determine hourly vapor pressure deficits for these days. Read the grids, calculate VPDE using the formula below from UNIT 4.2, and plot the results.

$$VPDE = e^{(1.580 + 0.062\ AITC)}[(100 - PTRH)/100]$$



TOPIC 5. PRECIPITATION

Rain and snow are the two forms of precipitation that contribute most to the total precipitation received in the northern regions. While the total amount of precipitation is important, the timing of rainfall and snowfall also has a very direct bearing on primary productivity; late-winter snowfalls that provide soil moisture for germination and adequate rainfall during the first half of the growing season result in higher levels of primary productivity than in areas where soil moisture is inadequate during the first half but plentiful during the second half of the growing season.

The amount of precipitation measured meteorologically is not the same as the effective precipitation ecologically. There are pathways for the dissipation of precipitation that are dependent on the characteristics of the precipitation itself, such as raindrop size, inertia, and the duration of the rainfall period, and on the precipitation history, such as previous rainfall and soil mosture conditions. Heavy rainfall over a short period of time, for example, results in a larger amount of run-off than when the same amount of rain falls over a long period of time. If the soil is saturated, run-off results from even small amounts of precipitation, and floods may occur. Anyone who has lived near a stream is aware of these precipitation intensity and duration effects. Many of these factors are included in a flow sheet in Moen (1973:64).

Solar radiation plays an important role in snowpack characteristics. The rate of snow melt is of primary importance. Snow often melts sooner from areas with favorable solar exposures, such as south-facing slopes and non-forested areas. Solar radiation also conditions the surface of the snowpack for the formation of a nocturnal crust when the snow is exposed to the clear night sky and cools below the freezing point.

The forest canopy with its load of intercepted snow causes changes in the amounts of infrared energy emitted by the canopy. The geometry of a canopy may be very complex, but extensive field measurements in both Minnesota and New York indicate that the amount of radiant energy flux in different habitats under clear skies at night can be predicted with considerable precision, if the atmospheric temperature is known, using equations given in CHAPTER 15. This method was used by Swinbank (1963) also (See Moen and Evans).

Two of the important precipitation characteristics for ecological purposes are considered in this unit: precipitation intensity and the duration of precipitation, both fall and retention, in the soil. It is useful to convert rates to absolute quantities, providing information on the amounts of precipitation physically present to be dissipated, allowing one to develop an accounting procedure while tracing the pathways of precipitation through the hydrologic cycle from the atmosphere to the earth and back to the atmosphere.

LITERATURE CITED

Moen, A. N. and K. E. Evans. 1971. The distribution of energy in relation to snow cover in wildlife habitat. Pages 147-162 In A. O. Haugen (ed.). Proceedings of the Snow and Ice in Relation to Wildlife and Recreation Symposium. Iowa Coop. Wildl. Res. Unit., Iowa St. Univ., Ames. 23 p.

UNIT 5.1: PHYSICAL CHARACTERISTICS

Precipitation elements can be conveniently divided into three basic classes: liquid, freezing, and frozen (Taylor 1954: 159). Rain and snow are the most commonly occurring forms, and these may be further divided into several different types.

Rain and drizzle are liquid forms of precipitation that drop to the ground. Drizzle drops are 0.05 to 0.5 millimeters in diameter and raindrops 0.20 to 7.0 millimeters in diameter (Taylor 1954: 159). Drizzle and rain drops may be supercooled and freeze when striking cold objects and the ground. This is called freezing rain or freezing drizzle, and results in the accumulation of ice on objects such as trees and wires. Hard pellets of ice about the size of raindrops are called sleet. The pellets form when water droplets freeze as they strike ice particles in the atmosphere, and then fall, possibly enlarging as they do.

Ice particles which strike supercooled water particles and enlarge as the freezing water accumulates become hailstones. Hailstones may also alternately fall and rise due to a high level of turbulence in the atmosphere, becoming larger as more ice accumulates, sometimes reaching diameters of 10 cm or more.

Atmospheric moisture which crystallizes results in snowflakes. Flakes are composed of a wide variety of hexagonal crystals. If the crystals combine with additional accumulation of ice crystals, snow pellets, spheres up to 2 mm in diameter, form.

Snow is a dynamic mass that undergoes distinct changes with time. The size distribution of the flakes is a function of atmospheric conditions at the time of flake formation, and affects the density and water content of the new-fallen snow. Accumulated snow ages due to its own mass which results in settling, and to the combining of crystals which results in larger granules.

Some physical properties of snow of importance in wildlife habitat discussed by Moen and Evans (1971) are evaluated further here.

Structure of the Snowpack. New-fallen snow generally has a low density (0.05-0.10 g cm^{-3}) due to the dendritic structure of the crystals. Atmospheric temperature and wind are the two primary factors that alter the density of new-fallen snow. Snow density increases an average of 0.0065 g cm^{-3} for each 1°C increase in surface air temperature at the time of deposition. Reported density of new-fallen snow varies from 0.06 for calm conditions to 0.34 for snow deposited during gale winds. The developed snowpack shows distinct layers characteristic of individual snowstorm deposits and weathering effects (U.S. Army 1956 and Nakaya 1954).

Snow density increases to 0.2-0.4 g cm^{-3} as the age of the snowpack increases. As each new layer of snow is deposited, its upper surface is subjected to weathering effects of radiation, rain, and wind, and interior action of percolating water and diffusing water vapor. The original delicate crystals become coarse grains. These changes affect the thermal properties of the snowpack; the table below gives the values of some of these properties.

Thermal properties of the snowpack in relation to snow density

Density g cm^{-3}	Specific heat cal $cm^{-3}C^{-1}$	Conductivity cal $cm^{-2}C^{-1}$ $cm^{-1}sec^{-1}$
1.000(water)	1.0000	0.00130
0.900(ice)	0.4500	0.00535
0.500	0.2500	0.00205
0.350	0.1755	0.00087
0.250	0.1250	0.00042
0.050	0.0250	0.00002

Nocturnal Snow Crust. The snowpack surface layer cools below 0°C during clear cold nights due to outgoing longwave radiation. Crust formation occurs and is especially pronounced when melting has occurred during the day. The combined effect of air and heat diffusion causes cooling to a depth of approximately 25 cm each clear cold night. There is also a change in the crystalline structure of the surface layer due to this alternate freezing and thawing efect (U.S. Army 1956).

Emissivity and Reflectivity of Snow. The snow surface is composed of small grains of ice, making it extremely rough. The rough snow surface is almost a perfect black body for the absorption and emission of longwave radiation. Since the temperature of snow is limited to a maximum of 0°C, the maximum amount of radiation that may be emitted from the snow surface is 27.45 langleys per hour (a langley is one calorie per square cm per hour) or 274.48 kcal per square meter per hour, calculated from the equation below.

$$QREE = (IREM)(SBCO)(ABTE^4)$$

where QREE = Infrared radiation flux in kcal per square meter per hour,
IREM = Infrared emissivity (Maximum of 1.0),
SBCO = 4.93×10^{-8} kcal per square meter per hour, and
ABTE = 273.16 + Celsius temperature

Snow is a good reflector of radiant energy in the visible portion of the electromagnetic spectrum. The reflectivity (albedo) is dependent upon the age of the snow surface. During the accumulation season, the albedo may decrease from 80% to 60% in 15 days, and during the melt season the albedo may decrease from 80% to 45% in the same time period (U.S. Army 1956).

Conductivity. Factors affecting the thermal conductivity of snow are: (1) the structural and crystalline character of the snowpack, (2) the degree of compaction, (3) the extent of ice planes, (4) the wetness, and (5) the temperature of the snow. Experimental work shows that the thermal properties of snow (specific heat, conductivity, and diffusivity) can be predicted from snow density measurements (see the Table on page 58).

Heat transfer in a natural snowpack is complicated by the simultaneous occurrence of many different heat exchange processes. The water vapor condenses and yields its heat of vaporization (0.600 kcal g^{-1}) upon reaching a cold surface. Rain or melt water freezes within the sub-freezing layers and adds the heat of fusion (0.08 kcal per gram). These two processes tend to change and influence the conductivity and diffusivity of the snow throughout the pack and influence the heat transfer rates (U.S. Army 1956).

Temperature gradients in the snowpack are more pronounced in the winter than in the spring. When the snowpack reaches an isothermal condition at 0°C, the heat energy is dissipated in melting the snow. The cooling effect of nocturnal radiation is an effective factor in determining the temperature gradients that develop within the top 5 to 40 cm of the snowpack.

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Moen, A. N. and K. E. Evans. 1971. The distribution of energy in relation to snow cover in wildife habitat. Pages 147-162 In A. O. Haugen (ed.), Proceedings of the Snow and Ice in Relation to Wildlife and Recreation Symp. Iowa Coop. Wildl. Res. Unit, Iowa St. Univ., Ames, Iowa.

Nakaya, U. 1954. Snow Crystals, Natural and Artificial. Harvard Univ. Press, Cambridge. 510 p.

Taylor, G. F. 1954. Elementary Meteorology. Prentice-Hall, Inc., New York. 364 p.

United States Army. 1956. Snow Hydrology. N. Pacific Div., Corps of Engr., U.S. Army, Portland, OR. 437 p.

REFERENCES, UNIT 5.1

PHYSICAL CHARACTERISTICS

BOOKS

TYPE	PUBL	CITY	PAGE	ANIM	KEY WORDS-----------------	AUTHORS/EDITORS--	YEAR
aubo	haup	cama	510	----	snow cryst: nat and artifi	nayaka,u	1954

SERIALS

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

UNIT 5.2: RAINFALL AND SNOWFALL INTENSITIES AND ACCUMULATION

Precipitation intensity is the amount of precipitation over a stated time period. Suppose one wishes to express the amount of rainfall, in cm, over one-hour time periods. The precipitation in cm per hour (PCMH) may be used to calculate the total amount of precipitation in cubic **meter per** hectare in one hour formula:

$$TPMH = PCMH/(1 \times 10^6)$$

where TPMH = total precipitation in cubic meters per hectare, and
PCMH = precipitation in cm pev hour and
1×10^6 = the number of square meters in a hectare.

Total precipitation on a given land area over a specified time may be determined by multiplying PCMH from the previous UNIT by the duration of precipitation in hours (DUPH). The formula for calculating the total precipitation, in cubic meters per hectare, that reaches the soil surface during a given rainfall event is:

$$TPMH = [(PCMH)(DUPH)]/1 \times 10^6$$

The mass of precipitation may be calculated by multiplying the volume by the density per unit volume. In metric units, one cubic centimeter of water weighs one gram, so 1000 cc weighs 1 kg, and a cubic meter weighs 1000 kg. WORKSHEET calculations illustrate that the mass of water that falls on a hectare even in an hour of light rain is very large indeed!

Rainfall through the year often results in patterns; some months are usually drier than others. The precipitation pattern over the annual cycle may be somewhat symmetrical, suitable for expression as a numerical as a function of time, or it may be variable. Since local precipitation patterns are much less predictable than other weather patterns, such as solar radiation and air temperature, a general formula cannot be given here.

The interception of falling rain and snow is an important factor when predicting accumulation on the ground. The amount of interception varies greatly depending on the type and density of the vegetation cover, and the magnitude, intensity, and frequency of storms. High winds reduce the amount intercepted, and intense solar radiation reduces the amount of snow trapped in the canopy. A moderately dense coniferous forest in an area with annual precipitation of 30-50 inches (76-127 cm) may intercept 15-30% of the total winter precipitation. A formula was developed for estimating the amount of interception in a northwestern (United States) coniferous tree stand as follows (U.S. Army 1956):

$$\text{Percent interception} = 0.36 \times \text{canopy cover (\%)}.$$

LITERATURE CITED

United States Army. 1956. Snow Hydrology. N. Pacific Div., Corps of Engr., U.S. Army, Portland, OR. 437 p.

REFERENCES, UNIT 5.2

RAINFALL AND SNOWFALL INTENSITIES AND ACCUMULATION

BOOKS

TYPE	PUBL	CITY	PAGE	KEY WORDS----------------------	AUTHORS/EDITORS--	YEAR
edbo	pepr	oxen	813	forest hydrology, intern suympo	sopper,we,ed; lul	1967

SERIALS

CODEN	VO-NU	BEPA	ENPA	KEY WORDS----------------------	AUTHORS----------	YEAR
AFJZA	143-6	117	121	throughfll,stmflw,intrcpt,d-fir	heuveldop,j; mit/	1972
BAMIA	42--2	119	121	percipitable water nomogram	peterson,kr	1961
BTBCA	88--1	21	29	forest ecology of ice storms	Lemon,pc	1961
CJFRA	1---1	20	31	eval summr rnfall, aspn commun	clements,jr	1971
CJFRA	4---1	91	96	snow damage, yng red pine stnds	neary,dg; day,mw/	1974
FRSTA	27--1	41	53	compar rainfll, diffrnt wdlands	ovington,jd	1954
JAMOA	1---2	203	207	precipita meas relate to expos	brown,mj; peck,el	1962
JAMOA	1---3	343	347	terr influence prec, interm we	williams,p; peck,	1962
JFUSA	49-12	869	871	snow accum, reten, pond pine ln	haupt,hf	1951
JFUSA	64--1	16	18	snow damage, yng northrn hrdwds	blum,bm	1966
JGREA	65--3	959	982	rainfall, tropic, non-trop sto	hershfield,dm; wi	1960
JGREA	65--9	2877	2881	evaporati loss small or rain g	gill,he	1960
JGREA	65-12	4017	4024	reliabil hourly precipita data	court,a	1960
JGREA	66--6	1823	1831	area-depth rainfall formula	court,a	1961
JGREA	68-16	4723	4729	comparis perfect 5 raingag ins	allis,ja; harris/	1963
JGREA	68-16	4763	4767	accur estimati watersh mean ra	mcguinness,jl	1963
JSWCA	23--5	181	184	intrcpt-trnspr rel,w spr,w pine	nicolson,ja; tho/	1968
JYCEA	87HY5	99	116	estimation prob maximum precip	hershfield,dm	1961
MWREA	80--8	129	133	interpola missin precipit reco	paulhus,jlh; kohl	1952
SIFEA	119-3	1	37	distr rainfall diff for stands	paivanen,j	1966

CODEN	VO-NU	BEPA	ENPA	KEY WORDS---------------------	AUTHORS----------	YEAR
TAGUA	35--2	203	206	precipita, alaska, greater tha	black,rf	1954
TAGUA	35--2	206	207	discussion of pages 203-206	wilson,wt	1954
TAGUA	36--4	689	694	standard, small or rain gauge	huff,fa	1955
XARRA	92---	1	4	snow damag, pole stand, wh pine	watt,rf	1951
XPNWA	40---	1	10	snow damag conif seedlng, sapln	williams,cb,jr	1966

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Bruce, J. P. 1968. Atlas of rainfall intensity-duration frequency data for Canada. Climatological Studies No. 8, Toronto.

Fenton, R. H. 1959. Heavy snowfalls damage Virginia pine. Sta. Pap. Ntheast. For. Exp. Sta., No. 127. 7p.

Godman, R. M., and R. L. Olmstead. 1962. Snow damage is correlated with stand density in recently thinned Jack pine plantations. Tech. Note Lake St. For Exp. Sta., No. 625. 2 p.

Nicholson,J. W. 1930. Forests and rainfall. Empire Forestry Jour. 9(2):204-212

U. S. Department of Commerce Weather Bureau. 1946. Manual for Depth-Area-Duration Analysis of Storm Precipitation. Washington, D. C. 72 p.

U. S. Department of Commerce Weather Bureau. 1951. Tables of Precipitable Water. Technical Paper No. 14. Washington, D. C.

U. S. Weather Bureau. 1961. Rainfall-frequency Atlas of the United States for Durations from 30 Minutes to 24 Hours and Return Periods from 1 to 100 Years. Technical Paper No. 40.

CHAPTER 14, WORKSHEET 5.2a

The mass of water falling as precipitation

Rainfall is so often measured in inches or centimeters that we seldom think of the mass of water falling during a rainy period. Using the metric system, calculate the mass of rain falling over 1 hectare given different rates of fall in cm per hour.

Rate (cm/hr)	Mass (kg/ha)
______	______
______	______
______	______
______	______
______	______

Convert these to inches per hour and lbs per acre. One inch = 2.54 cm, one pound = 0.4536 kg, and one acre = 2.47 hectares.

Rate (inches/hr)	Mass (pounds/acre)
______	______
______	______
______	______
______	______
______	______

CHAPTER 14, WORKSHEET 5.2b

Cumulative precipitation

Precipitation records are often given as "cumulative amount for the year." Check local weather records and record the cumulative precipitation for the 12 months in the blanks below. Then, list the monthly totals. If there is a pattern, derive an equation. If not, divide the months into 52 7-day periods of JDAY's. Either the equation or the 7-day periods will be used in compiling weather profiles in CHAPTER 17. Another table is found on the next page.

	J	F	M	A	M	J	J	A	S	O	N	D
Cumulative totals:	____	____	____	____	____	____	____	____	____	____	____	____
Monthly totals:	____	____	____	____	____	____	____	____	____	____	____	____

Equation?

7-Day expected totals:

1 _____	92 _____	183 _____	274 _____	365 _____
8 _____	99 _____	190 _____	281 _____	
15 _____	106 _____	197 _____	288 _____	
22 _____	113 _____	204 _____	295 _____	
29 _____	120 _____	211 _____	302 _____	
36 _____	127 _____	218 _____	309 _____	
43 _____	134 _____	225 _____	316 _____	
50 _____	141 _____	232 _____	323 _____	
57 _____	148 _____	239 _____	330 _____	
64 _____	155 _____	246 _____	337 _____	
71 _____	162 _____	253 _____	344 _____	
78 _____	169 _____	260 _____	351 _____	
85 _____	176 _____	267 _____	358 _____	

	J	F	M	A	M	J	J	A	S	O	N	D
Cumulative totals:	____	____	____	____	____	____	____	____	____	____	____	____
Monthly totals:	____	____	____	____	____	____	____	____	____	____	____	____

Equation?

7-Day expected totals:

1 ____	92 ____	183 ____	274 ____	365 ____
8 ____	99 ____	190 ____	281 ____	
15 ____	106 ____	197 ____	288 ____	
22 ____	113 ____	204 ____	295 ____	
29 ____	120 ____	211 ____	302 ____	
36 ____	127 ____	218 ____	309 ____	
43 ____	134 ____	225 ____	316 ____	
50 ____	141 ____	232 ____	323 ____	
57 ____	148 ____	239 ____	330 ____	
64 ____	155 ____	246 ____	337 ____	
71 ____	162 ____	253 ____	344 ____	
78 ____	169 ____	260 ____	351 ____	
85 ____	176 ____	267 ____	358 ____	

CHAPTER 14 - WORKSHEET 5.2c

Snow depths in different cover types

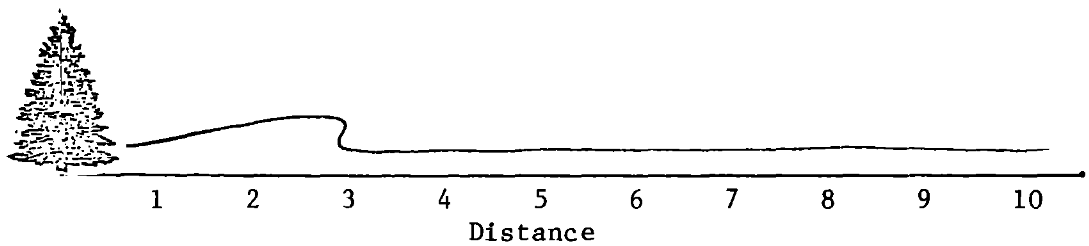
Snow interception, wind effects, and radiant energy distribution affect snow depths in different cover types. Measure depths at 10 or more locations in different cover types and evaluate the results. Statistical tests of differences between means are appropriate for such data.

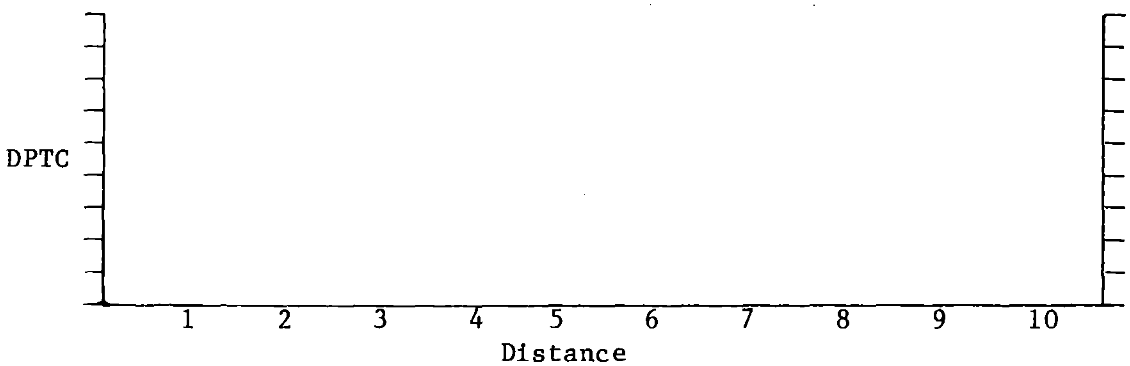
Cover type	1	2	3	4	5	6	7	8	9	10	$\bar{x}$	SD

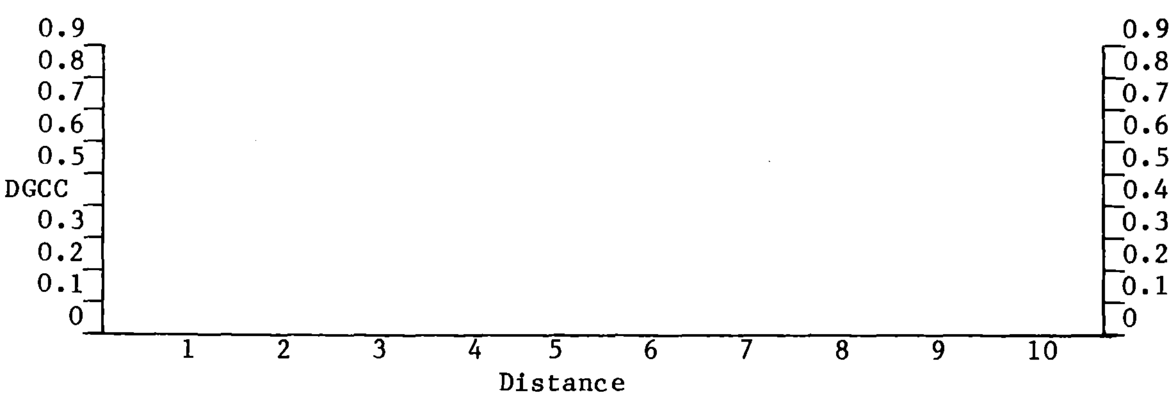
Cover type	1	2	3	4	5	6	7	8	9	10	$\bar{x}$	SD

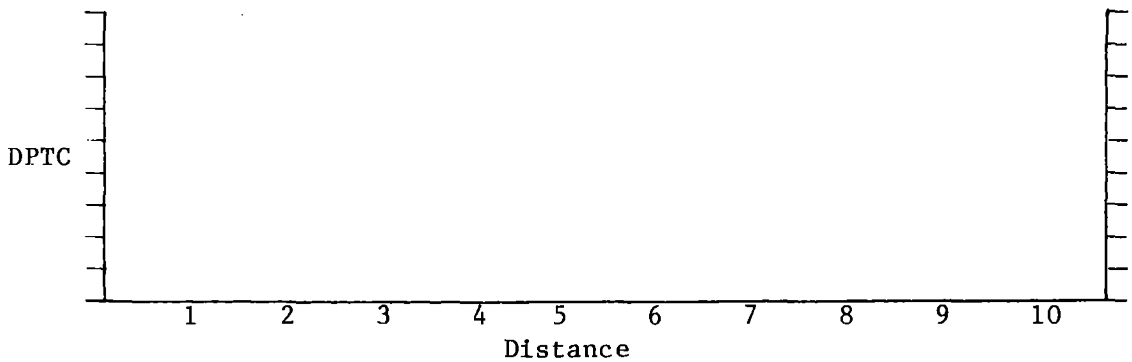
Snow drift characteristics

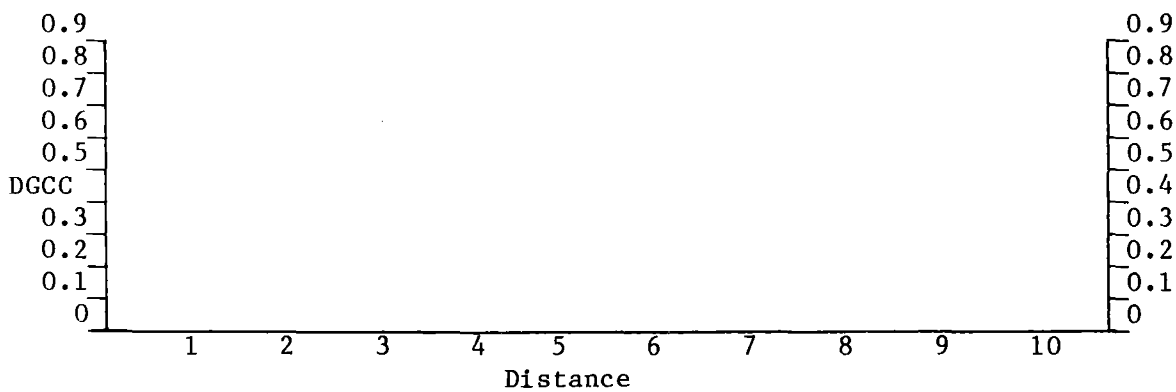
Snow drift geometries depend on wind and habitat characteristics. Measure the depths and densities of snow drifts in a systematic way as illustrated below. DPTC = depth in cm and DGCC = density in grams per cubic centimeter.








DPTC
1 2 3 4 5 6 7 8 9 10
Distance


0.9 0.8 0.7 0.6 0.5 DGCC 0.3 0.2 0.1 0
0.9 0.8 0.7 0.6 0.5 0.4 0.3 0.2 0.1 0
1 2 3 4 5 6 7 8 9 10
Distance

The rates at which rainfall runs off the soil surface, is absorbed by the soil, and percolates away are used to determine the amounts present in the soil at the ends of specified time periods.

The amount of water that enters the soil is equal to the amount of rainfall minus the runoff. Runoff may be determined by subtracting the amount absorbed by the soil from the amount of rainfall. The maximum amount that can be absorbed by the soil may be expressed by an absorption coefficient (ABCO). Its numerical value is dependent on soil characteristics that determine water-holding cpacity. A simple formula for determining runoff is:

$$ROMH = (TPMH)(1 - ABCO)$$

where ROMH = runoff in cubic meters per hectare,
TPMH = total precipitation in cubic meters per hectare, and
ABCO = absorption coefficient of the soil.

The amount of water in cubic meters per hectare (WAMH) that enters the soil may be expressed as:

$$WAMH = TPMH - [(TPMH)(1 - ABCO)] = [(PICH)(DUPH)]/(1 \times 10^6) - (PICH)(DUPH)(1-ABCO)$$

where PICH = precipitation in cm, and
DUPH = duration of precipitation in hours.

The formula for WAMH may be simplified by multiplying the total precipitation by ABCO:

$$(WAMH)(TPMH)(ABCO) = [(PICH)(DUPH)]/1 \times 10^6 \text{ } (ABCO)$$

Calculations with the formulas above are easy to complete on a hand calculator. The amounts of precipitation reaching the earth's surface, run-off and water absorbed may also be estimated with nomograms. The grid in WORKSHEET 5.3a may be used to construct nomograms for the calculated values.

REFERENCES, UNIT 5.3

RAINFALL DISPERSION

BOOKS

TYPE	PUBL	CITY	PAGE	KEY WORDS----------------------	AUTHORS/EDITORS--	YEAR
aubo	copr	nyny	137	landslide and related phenomen	sharpe,cfs	1938
aubo	jwed	aami	763	flow homog fluid porous materi	muskat,m	1946
aubo	jwis	nyny	498	soil physics	baver,ld	1948
aubo	mhbc	nyny	394	forest influences	kittredge,j	1948
aubo	mhbc	nyny	689	applied hydrology	linsley,rk; kohl/	1949
edbo	dove	nyny	712	p. 561-571, in: hydrology	meinzer,oe, ed	1949
edbo	jwis	nyny	376	ch. 5, flow of groundwater	rouse,h,ed	1949
aubo	ropr	nyny	412	vegeta and watershed management	colman,ea	1953
aubo	cnha	loen	492	vol. 1, irr, hydraul desig	leliavsky,s	1955
aubo	prha	ecnj	356	engineering hydrology	butler,ss	1957
edbo	amsa	mawi	620	part I, drain agriculturl lands	luthin,jn,ed	1957
aubo	mhbc	nyny	340	hydrology for engineers	linsley,rk; kohl/	1958
aubo	jwis	nyny	408	hydrology	wisler,co; brater	1959
aubo	mhbc	nyny	...	handbook of applied hydrology	chow,vt	1964
edbo	pepr	oxen	813	p. 137-161, sym for hydrology	sopper,w; lull,h,	1967
edbo	pepr	oxen	813	p. 261-274, sym for hydrology	sopper,w; lull,h,	1967
edbo	pepr	oxen	813	p. 275-290, sym for hydrology	sopper,w; lull,h,	1967
edbo	pepr	oxen	813	p. 335-343, sym for hydrology	sopper,w; lull,h,	1967
edbo	pepr	oxen	813	p. 599-611, sym for hydrology	sopper,w; lull,h,	1967
edbo	pepr	oxen	813	p. 701-702, sym for hydrology	sopper,w; lull,h,	1967

SERIALS

CODEN	VO-NU	BEPA	ENPA	KEY WORDS----------------------	AUTHORS----------	YEAR
AGJOA	54--5	385	390	availabili soil water to plant	denmead,ot; shaw,r	1962
BTBCA	82--3	155	162	moss cover, rainfall intercept	moul,et; buell,mf	1955
BUGMA	56---	275	370	erosional developm of streams	horton,re	1945
CIEGA	10--3	165	166	hydraulic of surface runoff	sherman,lk	1940
CIEGA	12-10	571	572	flood hydrographs	commons,gj	1942
CJSSA	41--1	115	124	depth freezing spring runoff	willis,wo; carlso/	1961
CWBSA	50---	1	91	relativ between water and soil	marshall,tj	1959
CWBSA	53---	1	124	vegetation and hydrology	penman,hl	1963
ECMOA	10--2	243	277	intercept rainfa by prarie gra	clark, or	1940
ENREA	108--	501	502	streamflow from rain, unit-gr	sherman,lk	1932

CODEN	VO-NU	BEPA	ENPA	KEY WORDS----------------------	AUTHORS----------	YEAR
FOSCA	6---1	2	10	distribut of rainfal under for	voigt,gk	1960
FOSCA	9---4	413	422	evaluatio eff top, soil wat ba	nash,aj	1963
FOSCA	9---4	423	429	net precipita under doug-fir f	rothacher,j	1963
HILGA	12--6	383	426	water condition fr shallow tab	moore,re	1939
HYSBA	6---3	5	17	increased water yield, for cut	hewlett,jd; hibber	1961
HYSBA	11--2	14	19	water repel soil wildlfire	debano,lf; krammes	1966
JAGRA	34--9	797	823	runoff from agricultural areas	ramser,ce	1927
JFUSA	42-12	890	898	components rainfall intercept	grah,rf; wilson,cc	1944
JFUSA	60--7	485	486	range soil moisture, so appal	helvey,jd; hewlett	1962
JFUSA	63-10	756	760	summar water use asp, spr, gra	brown,he; thompson	1965
JGREA	65--2	655	661	translocation moist unsat soil	nixon,pr; lawless,	1960
JGREA	65--8	2389	2394	intercept loss from grass	mcmillan,wd; burgy	1960
JGREA	65-11	3850	3851	interception loss equation	merriam, ra	1960
JGREA	66--6	1994	1994	discuss of r. a. merriam pape	kohler,ma	1961
JGREA	68--4	1081	1087	moisture, energy, slope, drain	hewlett,jd; hibber	1963
JRCEA	84IR1	1507	1-26	compre consumptive use water	criddle,wd	1958
JSWCA	18--6	231	234	precipitati intercep by plants	goodell,bc	1963
MWREA	47--9	603	623	rainfall interception	horton,re	1919
MWREA	87--2	101	106	modulated soil moisture budge	holmes,rm; roberts	1959
MWREA	90--4	165	166	theory of "equival slope"	lee,r	1962
NASRA	544--	20	47	landslide type, processes	varnes,dj	1958
PAEBA	B78--	1	152	bibliogr method det soil mois	shaw,md; arbele,wc	1959
PHDSA	2----	184	196	estimate soil mois, evapo data	holmes,rm	1961
SCIEA	13539	522	523	imped water movement, soil, pl	gardner,wr; ehlig,	1962
SOSCA	11--3	215	232	movement of soil moisture	gardner,w; widstoe	1921
SOSCA	67---	29	40	diffi theory, laws captur flow	kirkham,d; feng,cl	1949
SOSCA	67---	403	409	soil character, eval permeabil	oneal,am	1949
SOSCA	68---	359	370	press pot of water moving	marshall,tj; stirk	1949
SOSCA	83--5	345	357	infil equation and solution	philip,jr	1957
SOSCA	85---	185	189	per measure soil crust, rain	mcintyre,ds	1958
SOSCA	97--5	307	311	measure hydro cond unsat porou	youngs,eg	1964
SSSAA	3----	340	349	runoff plat experiment, erosio	horton,re	1938
SSSAA	5----	399	417	physical inter of infil capaci	horton,re	1940
SSSAA	7----	95	104	infil frost penetrat, mic-clim	post,fa; dreibelbi	1942
SSSAA	8----	116	122	condition, entry water, s	bodman,gb; colman,	1943
SSSAA	11---	21	26	suggested lab stand subsoil pe	smith,rm; browning	1946
SSSAA	16--1	33	38	hydraulic gradient, infiltrati	miller,rd; richard	1952
SSSAA	16--1	62	65	root channel, root, forest	gaiser,rn	1952

CODEN	VO-NU	BEPA	ENPA	KEY WORDS----------------------	AUTHORS----------	YEAR
SSSAA	17--3	195	201	water entry, movemen soil core	taylor,sa; heuser,	1953
SSSAA	17--3	206	209	capillary conductive values	richards,sj; weeks	1953
SSSAA	20--2	284	288	soil moisture availa, power re	taylor,sa; haddock	1956
SSSAA	20--3	310	314	physical proc dete water loss	richards,la; gard/	1956
SSSAA	20--4	458	462	measureme soil moist diffusivi	bruce,rr; klute,a	1956
SSSAA	22--2	106	110	sim root distribution water re	vaquez, r; taylor,	1958
SSSAA	26...	107	111	different analy, unsat flow pr	neilson,dr; bigga/	1962
SSSAA	26...	530	534	number soluti, moist flow equa	hanks,rj; bowers,s	1962
SSSAA	27--5	590	592	soil-erodability evaluation	olson,tc; wischmei	1963
SSSAA	29--4	472	475	tree space, under vegetati wat	barrett,jw; youngb	1965
SSSCA	7----	665	670	infiltrati meltwater, frozen s	kuznik,ia; bezmeno	1963
TACEA	79---	1056	1155	compositi runoff, rainf, other	meyer,af	1915
TACEA	101--	140	206	rainfall, runoff, urban areas	horner,ww; flynt,f	1936
TAGUA	14---	446	460	infiltrati in the hydrol cycle	horton,re	1933
TAGUA	18--2	361	368	rate infiltration water, irri	lewis,mr	1937
TAGUA	20--4	721	725	structural disch-reces curves	barnes,bs	1939
TAGUA	21---	558	570	graphical, sprink-pl hydrology	sharp,al; holtan,h	1940
TAGUA	23--2	578	593	pt II, analyses hydro contol-p	sharp,al; holtan,h	1942
TAGUA	27--6	863	870	effect freezin on mois, evapor	anderson,hw	1946
TAGUA	39--2	285	291	rainfall energy and soil loss	wischmeier,wh; smi	1958
TFSOA	17--2	228	243	system soil-soil moisture	keen,ba	1922
UUARA	15---	1	28	evaporati drying of porous med	wiegand,cl; taylor	1961
WRERA	1---2	193	206	canopy, litter intercepti, rai	helvey,jd; patric,	1965
WRERA	1---2	283	286	soil wettability, management	krammes,js; debano	1965
WRERA	3---3	891	895	linear analyses of hydrograph	mitchell,wd	1967
WRERA	6....	465	477	runoff from watershed model	black,pe	1970
WRERA	6....	478	490	investigat runoff prod, perme	dunne,t; black,rd	1970
WRERA	6....	1327	1334	theoret estima vs for water yi	lee,r	1970
XAARA	41-51	1	25	infiltrati est in watersh engi	holtan,hn	1961
XAFNA	159--	1	16	intercept precipit by nor hard	leonard,re	1961
XAGCA	910--	1	64	plant-soil-water relation, man	lassen,l; lull,hw/	1952
XAMPA	768--	1	33	soil compaction, forest, ran	lull,hw	1959
XANEA	1----	1	79	effect streamflow, 4 for pra	reinhart,kg; esch/	1963
XAPWA	43---	1	12	soil wettability, wetting agen	debano,lf; osborn/	1967
XASEA	132--	----	----	soil moisture, base flow, stee	hewlett,jd	1961
XFNNA	41---	1	4	sustained winter streamflow	federer,ca	1966

CODEN	VO-NU	BEPA	ENPA	KEY WORDS--------------------	AUTHORS-----------	YEAR
XIPPA	252..	1	57	hydraul geometry of stream cha	leopold,lb; maddoc	1953
XIPPA	269..	----	----	water-loss investigations	us geological surv	1954
XIWSA	968C.	125	155	topograp chara drainage basins	langbein,wb et al.	1947
YAXAA	1955B	346	358	water budget, use in irrigatio	thornthwaite,cw; m	1955

OTHER PUBLICATIONS

Broadfoot, W. H. and H. D. Burke. 1958. Soil moisture constants and their variation. U. S. Forest Service Southern Forest Experiment Station, Occasional Paper No. 166.

Cooper, C. F. 1960. Ecological classification in watershed management. Proceedings of the Fifth World Forestry Congress. Seattle, Washington. Vol. 3: 1731-1734.

Crawford, N. G. and R. K. Linsley. 1965. A conceptual model of the hydrologic cycle. Symposium of Surface Waters International Association of Scientific Hydrology. Publication No. 63: 573-587.

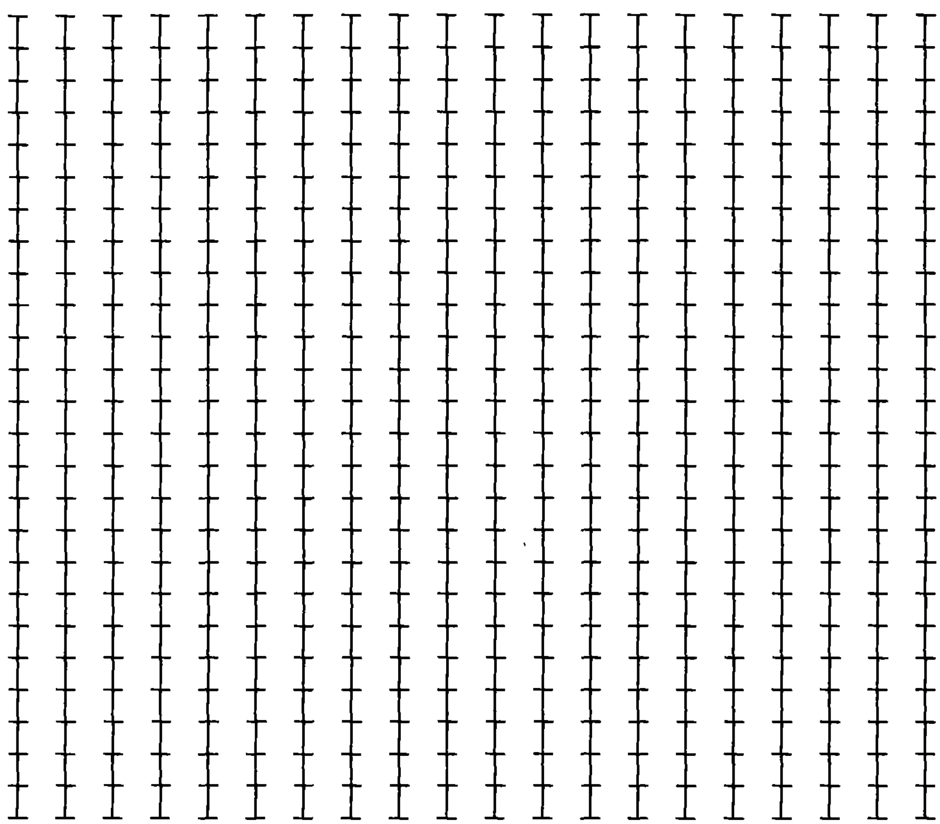
Koshi, P. T. 1959. Soil moisture trends under varying densities of oak overstory. Occasonal Paper No. 167. U. S. Forest Service, Southern Forest Experiment Station, New Orleans, La.

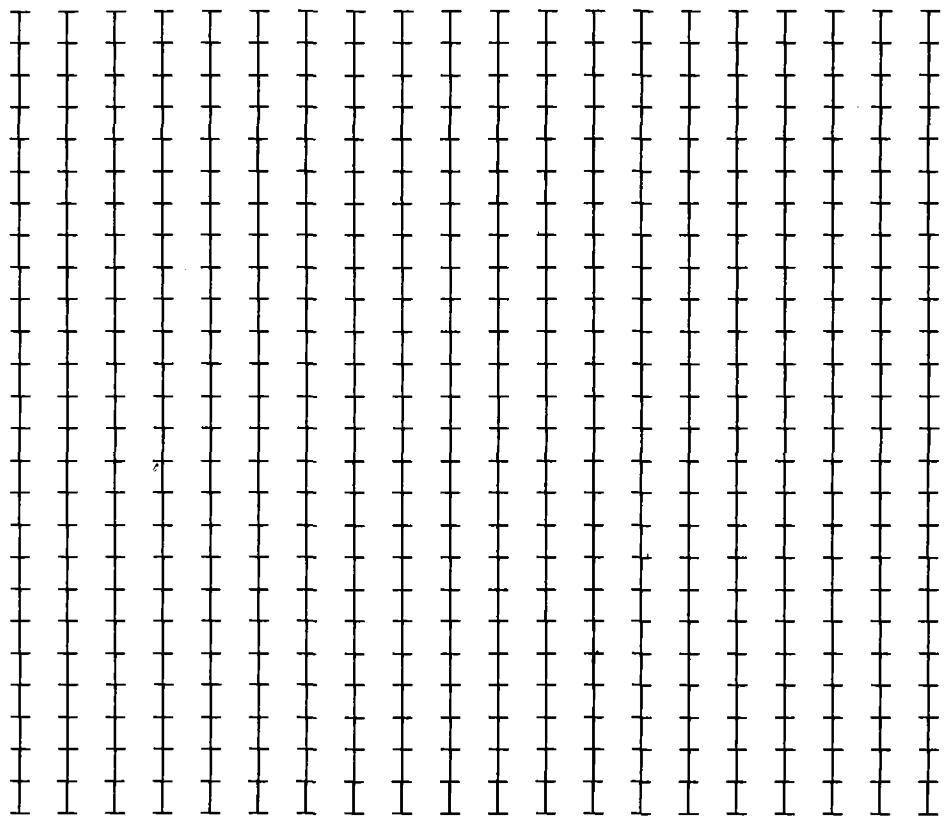
Megahan, W. F. and D. R. Satterlund. 1961. Winter infiltration studies on abandoned and reforested fields in central New York. Proceedings of the Eastern Snow Conference, p. 121-132.

CHAPTER 14, Worksheet 5.3a

Nomograms for estimating rainfall dispersion parameters

The formulas given in this UNIT 5.3 may be used to construct lines representing rainfall dispersion in the grid below. The resulting nomograms may be used for quick estimates of quantities dispersed.





UNIT 5.4: SNOWFALL DISPERSION

The duration of snowfall and snow accumulation results in both volume and mass considerations. Falling snow has a low density, so new-fallen snow has a greater volume per unit mass than snow that has settled for a period of time. New-fallen snow is also a good insulator. Older snow continues to increase in density at rates depenedent on snow depths and temperatures, and it also becomes a poorer insulator (see UNIT 5.1).

Snow ages due to the pressure exerted by its own mass and to changes in snow temperatures and crystal structure. The weight of its own mass increases pressure at greater depths in the snow cover, so more dense snow is found at the bottom of the snow pack. Warmer temperatures cause more rapid increases in snow densities as crystals become larger, hastening the increase in overall densities. Changes in snow characteristics result in important mechanical considerations when evaluating the relationships between wild ruminants and their winter range; snow is often a factor over much of North America in the winter as it covers forage resources and mechanically impedes movement (see CHAPTER 17).

Rapid warming trends result in rapid changes at the snow surface while the underlying snow pack changes more slowly. When such rapid warming trends occur on a daily basis, accompanied by cold nights with clear skies, the upper layer of the snow cover becomes crusty due to its higher water content and its freezing each night. Such conditions can result in a snow cover dense enough to support animals, which may, with deep snow, expose the animals to new supplies of forage at heights above their normal above-ground reach. The effects of changes in snow cover are many, and they are related to other behavioral responses which have definite effects on the ecology of wild ruminants in the winter.

REFERENCES, UNIT 5.4

SNOWFALL DISPERSION

TYPE	PUBL	CITY	PAGE	KEY WORDS---------------------	AUTHORS/EDITORS--	YEAR
aubo	rrcl	edsc	555	snow structure, ski fields	seligman,g	1962
edbo	pepr	oxen	813	p. 201-211, sym for hydro	sopper,w; lull,h,	1967

SERIALS

CODEN	VO-NU	BEPA	ENPA	KEY WORDS---------------------	AUTHORS-----------	YEAR
BAMIA	28--1	150	151	water cont, snow, cold climate	currie,bw	1947
FOSCA	8---3	225	235	elevation, aspe, cov eff water	packer,pe	1962
HILGA	22--1	1	96	influences of forest on snow	kittredge,j	1953
JFUSA	67--2	92	95	rime, hoarfrost, upper-sl	berndt,hw; fowler,	1969
JGREA	68-16	4751	4761	snow cover relations, californ	court,a	1963
JGREA	70-14	3307	3313	eddy diffusio, settl speed, sn	businger,ja	1965
JOGLA	5--41	625	636	accumulati of snow, col, influ	martinelli,m,jr	1965
SCMOA	56---	211	231	perennial snow and glaciers	church,je	1943
TAGUA	42...	----	----	folklore about snowfall interc	miller,dh	1961
WRERA	3---4	1035	1039	snow catch, conifer crown	satterlund,dr; hau	1967
WRERA	6....	649	652	disposition of snow, conif cro	satterlund,dr; hau	1970
WTHWA	18--6	247	251	measure snowpack prof, radioac	smith,jl; willen,/	1965
WUAEA	.....	1	64	washington climate, count	phillips,el	1965
XAFNA	138--	1	16	snow accumula, melt, adirondac	lull,hw; rushmore,	1960
XANEA	34---	1	16	surface geomet, loss interc sn	satterlund,dr; esc	1965
XAPWA	18---	1	24	intercept process durin snowst	miller,dh	1964
XCTAA	.....	----	----	snow hydrology	us dept of commerc	1956
XFNNA	116--	1	4	snow and frost in adirondacks	lull,hw; rushmore,	1961

OTHER PUBLICATIONS

Billelo, M. 1957. A survey of arctic snow cover properties as related to climatic conditions. International Association of Sci. Hydrology, General Assembly of Toronto. 1957 IV pp. 63-77.

Cooperative Watershed-Management Research Unit. The surface geometry of a closed conifer forest in relation to losses of intercepted snow. New York State University College of Forestry and U. S. Forest Service, Northeastern Forest Experiment Station, Syracuse, New York.

Kuzmin, P. P. 1956. Determination of the coefficient of reflection of snow cover by the method of successive approximation. In: Snow and snowmelt, their study and use. Akad. Nauk SSSR. Institute Geografii, Moscow: 30-43.

U. S. Army Corps of Engineers. 1956. Snow Hydrology. North Pacific Division, Portland, Oregon. 437 p.

CLOSING COMMENTS

Meteorology and thermal characteristics of different habitats have been introduced in CHAPTER 14. These characteristics are used in analyses of thermal exchange, an important consideration when evaluating physiological and behavioral responses, especially when animals are in critical thermal environments, which are discussed in CHAPTER 16, TOPIC 3.

The next chapter (CHAPTER 15) includes discussions of basic thermal exchange. The discussions refer back to this CHAPTER 14, and are the basis for further discussions in CHAPTER 16.

Aaron N. Moen
March 27, 1981

GLOSSARY OF SYMBOLS USED - CHAPTER FOURTEEN

ABCO = Absorption coefficient of the soil
ABHU = Absolute humidity
ABTE = Absolute temperature
ADTC = Average daily temperature in Celsius
ADTE = Average daily temperature
AITC = Air temperature in Celsius
AITE = Air temperature
AMPL = Amplitude of the variation from MPRA
AVPA = Actual vapor pressure of the air

CMMT = Calculated mean monthly temperature
CPCM = Calories per square centimeter per minute
CSCD = Calories per square centimeter per day

DUPH = Duration of precipitation in hours

ERTK = Effective radiant temperature in °K

HGTC = Height in centimeters
HGHT = Height
HOUR = Hour of the day

IREM = Infrared emissivity

JDAY = Julian day
JDMA = Julian day at the maximum

KMTH = Kilocalories per square meter per hour

MAWV = Mass of water vapor
MMHG = Millimeters of mercury
MMTC = Mean monthly temperature in Celsius
MPRA = Midpoint radiation value
MPTE = Midpoint temperature

PCMH = Precipitation in centimeters per hour
PICH = Precipitation intensity in centimeters per hour
PRPC = Primary phase correction
PTRH = Percent relative humidity

QREE = Quantity of radiation emitted

REHU = Relative humidity
ROMH = Runoff in cubic meters per hectare

SAVP = Saturation vapor pressure
SBCO = Stefan-Boltzmann constant
SORA = Solar radiation
SPHU = Specific humidity

TERA = Temperature range over the year
TMAI = Total mass of air
TPMH = Total precipitation in cubic meters per hectare
TVMA = Total volume of moist air

VPDE = Vapor pressure deficit

WAMH = Water in the soil per cubic meters per hectare
WIVE = Wind velocity
WLME = Wavelengths of maximum emission

GLOSSARY OF CODENS - CHAPTER FOURTEEN

SERIALS are identified by five-character, generally mnemonic codes called CODEN, listed in 1980 BIOSIS, LIST OF SERIALS (BioSciences Information Service, 2100 Arch Street, Philadelphia, PA 19103).

The headings for the lists of SERIALS are:

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

The volume and issue numbers (VO-NU) are given after the CODEN entry, followed by beginning page (BEPA), ending page (ENPA), species discussed (ANIM), KEY WORDS from the title, AUTHORS [truncated if necessary, slash (/) indicates additional authors], and year.

AFJZA Allgemeine Forst und Jagdzeitung
AGJOA Agronomy Journal
AGMYA Agricultural Meteorology
AJBOA American Journal of Botany
AMGBA Archiv fuer Meteorologie Geophysik und Bioklimatologie, Serie B
ANBOA Annals of Botany (London)
ANSFA Annales des Sciences Forestieres (Paris)
APOPA Applied Optics
AUFOA Australian Forestry

BAMIA Bulletin of the American Meteorological Society
BEGOA Gerlands Beitraege zur Geophysik
BOZHA Botanichnyi Zhurnal (Kiev)
BPYAA Beitraege zur Physik der Atmosphaere
BTBCA Bulletin of the Torrey Botanical Club
BUGMA Bulletin of the Geological Society of America

CIEGA Civil Engineering
CJASA Canadian Journal of Agricultural Science
CJBOA Canadian Journal of Botany (Canada)
CJFRA Canadian Journal of Forest Research
CJSSA Canadian Journal of Soil Science
CJTEA Canadian Journal of Technology
CSTNA Castanea
CWBSA Commonwealth Bureau of Soils Technical Communication

EAFJA East African Agriculture Forestry Journal
ECMOA Ecological Monographs
ECOLA Ecology
EMFRA Empire Forestry Review
ENREA Engineering News-Record

FIRAD Fiziologiya Rastenii (Moscow)
FOSCA Forest Science
FRSTA Forestry (England)

GFRPA	Georgia Forest Research Paper
GPNOA	Geofysike Publikasjoner (also listed as Geophysica Norvegica)
HFOPA	Harvard Forest Papers
HILGA	Hilgardia
HYSBA	Hydrological Sciences Bulletin (formerly Bulletin of the International Association of Scientific Hydrology)
IAXNA	Forestry Note
IJBMA	International Journal of Biometeorology
IRFOA	Irish Forestry
JAGRA	Journal of Agricultural Research
JAMOA	Journal of Applied Meteorology
JAPEA	Journal of Applied Ecology (England)
JECOA	Journal of Ecology
JFUSA	Journal of Forestry
JGREA	Journal of Geophysical Research
JOGLA	Journal of Glaciology
JRCEA	Journal of the Irrigation and Drainage Division, American Society of Civil Engineers
JRMGA	Journal of Range Management
JSWCA	Journal of Soil and Water Conservation
JVAHA	Journal of Veterinary and Animal Husbandry Research
JWMAA	Journal of Wildlife Management
JYCEA	Journal of the Hydraulics Division, American Society of Civil Engineer
LESOA	Lesovedenie (USSR)
MMONA	Meteorological Monographs (American Meteorological Society)
MWREA	Monthly Weather Review
NASRA	National Academy of Sciences--National Research Council, Publication
OJSCA	Ohio Journal of Science (US)
PAEBA	Engineering Research Bulletin (Pennsylvania State University, College of Engineering)
PHDSA	Proceedings of the Hydrology Symposium
PRSLA	Proceedings of the Royal Society of London
PSAFA	Proceedings of the Society of American Foresters
PTRMA	Philosophical Transactions of the Royal Society of London
PVDEA	Pochvovedenie
QJFOA	Quarterly Journal of Forestry
QJRMA	Quarterly Journal of the Royal Meteorological Society

SCIEA	Science
SCMOA	Scientific Monthly
SIFEA	Silva Fennica
SOSCA	Soil Science
SSSAA	Soil Science Society of America, Proceedings
SSSCA	Soviet Soil Science
TAAEA	Transactions of the ASAE (American Society of Agricultural Engineers)
TACEA	Transactions of the American Society of Civil Engineers
TAGUA	Transactions of the American Geophysical Union
TFSOA	Transactions of the Faraday Society
UUARA	Utah Agricultural Experiment Station Special Report
WRERA	Water Resoures Research
WTHWA	Weatherwise
WUAEA	Washington State University, Extension Service, Extension Bulletin
XAARA	U S Department of Agriculture, Agricultural Research Service (ARS Series or Report)
XAFNA	Northeastern Forest Experiment Station, Station Paper
XAFNB	U S Forest Service Research Note NC
XAGCA	U S D A Circular
XAMPA	U S D A Miscellaneous Publication
XANEA	U S Forest Service Research Paper NE
XAPWA	U S Forest Service Research Paper PSW
XASEA	U S Forest Service Research Paper SE
XATBA	U S D A Technical Bulletin
XCTAA	U S Department of Commerce, Office of Technical Services, AD
XFGTA	U S Forest Service General Technical Report NC
XFNNA	U S Forest Service Research Note NE
XFRMA	U S Forest Service Research Paper RM
XFTBA	U S Forest Service Technical Bulletin
XIPPA	Geologic Survey Professional Paper
XIWSA	Geological Survey Water-Supply Paper
XPNWA	U S Forest Service Research Note PNW
YAXAA	U S D A Yearbook of Agriculture

LIST OF PUBLISHERS - CHAPTER FOURTEEN

The headings for the lists of BOOKS are:

TYPE PUBL CITY PAGE ANIM KEY WORDS----------------- AUTHORS/EDITORS-- YEAR

All essential information for finding each book in the library is given on just one line. The TYPE of book could have either AUTHORS (aubo) or EDITORS (edbo). Publishers (PUBL) and CITY of publication are given with four-letter mnemonic symbols defined below. The PAGE column gives the number of pages in the book; ANIM refers to the species discussed in the book (given as a four-letter abbreviation of genus and species), and KEY WORDS listed are from the title. The AUTHORS/EDITORS and YEAR of publication are given in the last two columns.

acpr	Academic Press	New York	nyny
adwe	Addison-Wesley	Reading,MA	rema
amsa	Amer. Soc. of Agronomy	Madison, WI	mawi
cnha	Chapman & Hall	London	loen
copr	Columbia Univ.	New York	nyny
crcp	CRC (Chem. Rubber Co.) Press	Cleveland, OH	cloh
cupr	Cambridge Univ. Press	Cambridge, England	caen
dove	Dover Publishing Company	New York	nyny
else	Elsevier	New York	nyny
gidr	Girdrometeoizdat	Leningrad, Russia	leru
haro	Harper and Row	New York	nyny
haup	Harvard Univ. Press	Canbridge, MA	cama
hrwi	Holt, Rhinehart, & Winston, Inc.	New York	nyny
jdco	John Day	New York	nyny
jwed	J. W. Edwards, Inc	Ann Arbor, Michigan	aami
jwis	John Wiley & Sons, Inc.	New York	nyny
mhbc	McGraw-Hill Book Co., Inc.	New York	nyny
pepr	PergamonPress	Oxford,England	oxen
prha	Prentice-Hall, Inc.	Englewood Cliffs, NJ	ecnj
ropr	Ronald Press	New York	nyny
repu	Reinhold Publishing	New York	nyny
rrcl	R. R. Clarke Ltd.	Edinburgh, Scotland	edsc

uchp	Univ. of Chicago Press	Chicago, IL	chil
unca	Univ. of California, Davis	Davis, CA	daca
ugap	Univ. of Georgia Press	Atlanta, GA	atga
weni	Weidenfeld & Nicholson	London	loen
whfr	W. H. Freeman Co.	San Francisco, CA	sfca

GLOSSARY OF ANIMAL CODE NAMES

Wild ruminants are referred to in this CHAPTER by a 4-character abbreviation from the family, genus and genus-species. These are listed below under Abbreviation.

Scientific names of North American wild ruminants are those used in BIG GAME OF NORTH AMERICA, edited by J.C. Schmidt and D. L. Gilbert (1979: Stackpole Books, Harrisburg, PA 17105, 494 p.), and may be different from the scientific names given in the original literature.

The abbreviations used for North American wild ruminants are listed below.

CLASS: MAMMALIA

ORDER: ARTIODACTYLA	Abbreviation
FAMILY: CERVIDAE	cerv
GENUS: *Odocoileus* (deer)	od--
SPECIES: *O. virginianus* (white-tailed deer)	odvi
O. hemionus (mule deer)	odhe
GENUS: *Cervus* (Wapiti, elk)	ce--
SPECIES: *C. elaphus*	ceel
GENUS: *Alces* (moose)	
SPECIES: *A. alces*	alal
GENUS: *Rangifer* (caribou)	
SPECIES: *R. tarandus*	rata
FAMILY: ANTILOCAPRIDAE	
GENUS: *Antilocapra*	
SPECIES: *A. americana* (pronghorn)	anam
FAMILY: BOVIDAE	bovi
GENUS: *Bison* (bison)	bi--
SPECIES: *B. bison*	bibi
GENUS: *Ovis* (sheep)	ov--
SPECIES: *O. canadensis* (bighorn sheep)	ovca
O. dalli (Dall's sheep)	ovda
GENUS: *Ovibos*	
SPECIES: *O. moschatus* (muskox)	obmo
GENUS: *Oreamnos*	
SPECIES: *O. americanus* (mountain goat)	oram

The abbreviations used for European wild ruminants are listed below.

CLASS: MAMMALIA

ORDER: ARTIODACTYLA	**Abbreviation**
FAMILY: CERVIDAE	cerv
GENUS: *Capreolus* (roe deer)	ca--
SPECIES: *C. capreolus*	caca
GENUS: *Dama* (fallow deer)	da--
SPECIES: *D. dama*	dada
GENUS: *Cervus* (Wapiti, elk)	ce--
SPECIES: *C. elaphus* (red deer)	ceel
GENUS: *Alces* (moose)	
SPECIES: *A. alces*	alal
GENUS: *Rangifer* (caribou)	
SPECIES: *R. tarandus*	rata
FAMILY: BOVIDAE	
GENUS: *Bison* (bison)	
SPECIES: *B. bonasus*	bibo
GENUS: *Capra* (ibex, wild goat)	cp--
SPECIES: *C. aegagrus* (Persian ibex)	cpae
C. siberica (Siberian ibex)	cpsi

OTHERS

Abbreviations for a few other species and groups of species may appear in the reference lists. These are listed below.

Axis axis (axis deer)	axax
Elaphurus davidianus (Pere David's deer)	elda
Cervus nippon (Sika deer)	ceni
Hydropotes inermis (Chinese water deer)	hyin
Muntiacus muntjac (Indian muntjac)	mumu
Moschus moschiferus (musk deer)	momo
Ovis nivicola (snow sheep)	ovni
Ovis musimon (moufflon)	ovmu
Ovis linnaeus (Iranian sheep)	ovli
Rupicapra rupicapra (chamois)	ruru
big game	biga
domestic sheep	dosh
domestic cattle	doca
domestic goat	dogo
domestic ruminant	doru
herbivore	hrbv
mammals	mamm
three or more species of wild ruminants	many
ruminants	rumi
ungulates	ungu
vertebrates	vert
wildlife	wldl
wild ruminant	wiru

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.

LIST OF WORKSHEETS - CHAPTER FOURTEEN

THE BIOLOGY AND MANAGEMENT OF WILD RUMINANTS

CHAPTER FIFTEEN

THERMAL CHARACTERISTICS AND BASIC HEAT TRANSFER

by

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CONTENTS OF CHAPTER FIFTEEN

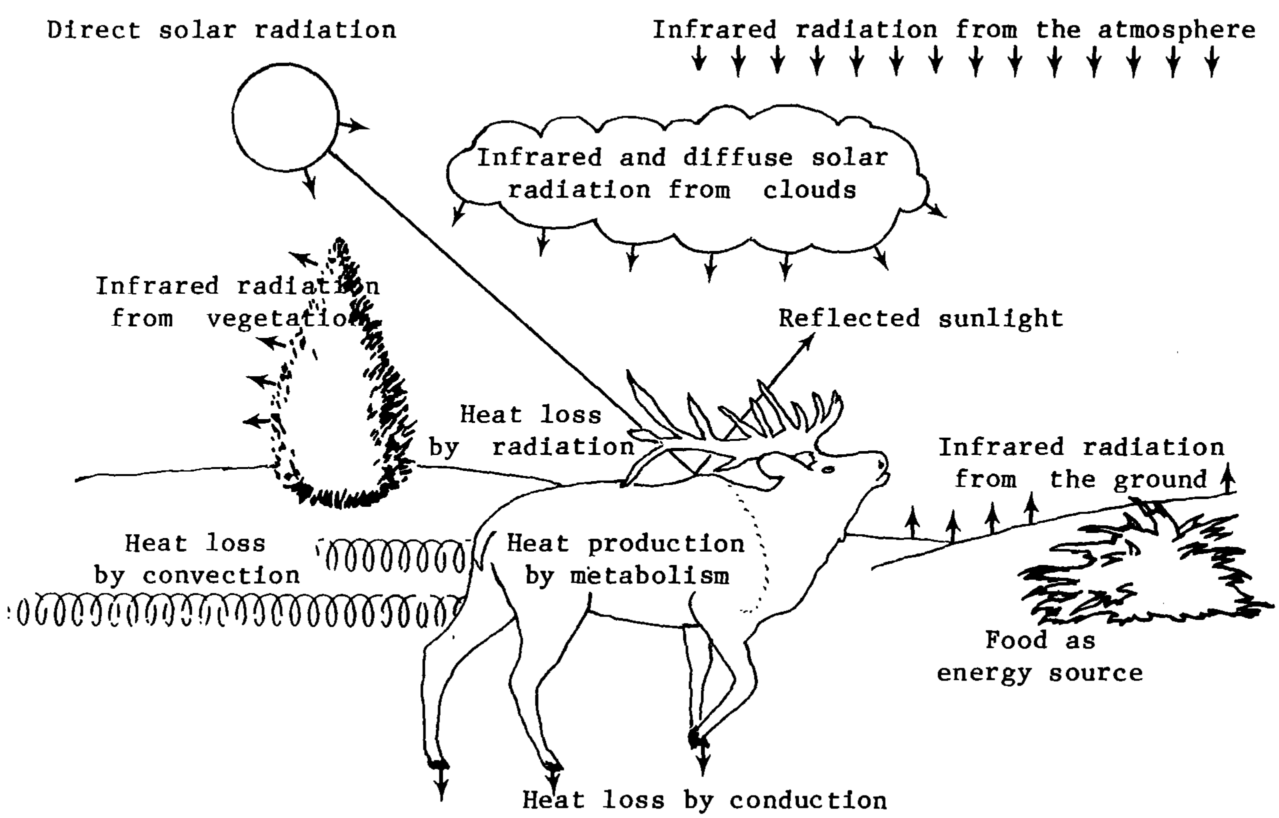
THERMAL CHARACTERISTICS AND BASIC HEAT TRANSFER

CHAPTER 15. THERMAL CHARACTERISTICS AND BASIC HEAT TRANSFER

Thermal energy is transferred by radiation, conduction, convection, and evaporation. The physical processes are beyond the control of the animal, although the animal can change the amount of its surface participating in energy exchange by these different modes.

The sun's energy, especially the visible portion, is often thought of as energy input at the earth's surface. There must be a means to dissipate this energy from the earth's surface, however, or the energy content and the temperature of the earth would continue to rise. Overall, the radiation exchanged between the earth and space must be approximately equal in both directions, or else the earth would be heating up or cooling off. When the energy balance of the earth's surface was slightly negative, glaciation was extensive.

There have been many evaluations by field biologists and ecologists of the responses of different species to weather conditions, with the usual approach being a correlation analysis between weather data, such as temperature and wind velocity, and observed animal responses. This approach has resulted in some useful conclusions, but it does not provide an understanding of the four thermal exchange processes--radiation, convection, conduction, and evaporation--that every organism is involved in when subjected to atmospheric conditions.



It is possible to conceptualize the complex nature of homeothermy, but it is impossible to describe mathematically all of the dynamic thermal relationships between an animal and its environment. Recent research on the thermal balance of both plants and animals has provided an insight into the functional mechanisms used to maintain a thermal balance within certain physiological limits.

Thermal transfers between organism and environment always involve these thermal exchange processes, so an understanding of each is essential for an understanding of the effects of weather on an organism. Heat transfer is, in reality, incredibly complex and beyond analyses on a real-time basis. The basic principles are fairly simple, however, and may be understood by the use of selected situations that illustrate each of the four modes of heat transfer and interactions between them.

It is important to quantify basic heat transfer before attempting to interpret thermoregulatory behavior. Objective calculations are best made before subjective interpretations because they provide a framework within which alternatives may be chosen by animals in particular situations.

REFERENCES

CHAPTER 15. THERMAL CHARACTERISTICS AND BASIC HEAT TRANSFER

BOOKS

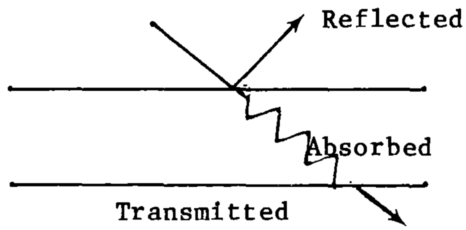
TYPE	PUBL	CITY	PAGE	ANIM	KEY WORDS-----------------	AUTHORS/EDITORS---	YEAR
aubo	mhbc	nyny	333		micrometeorology	sutton,og	1953
aubo	haro	nyny	151		enrgy exchang in biosphere	gates,dm	1962
edbo	acpr	nyny	...		advances in heat transfer	viskanta,r,ed	1966
aubo	pepr	oxen	1144		biometeorology, volume 2	tromp,sw; weike,wh	1967
aubo	mhbc	nyny	596		heat transfer	gebhart,b	1971
aubo	whfr	sfca	458		wildlife ecology	moen,an	1973
aubo	else	nyny	241		princip envirnmntl physics	monteith,jl	1973
aubo	whfr	sfca	488		intro biophys plant ecolog	nobel,ps	1974
aubo	jwis	nyny	315		microclimate, biolog envir	rosenberg,nj	1974
edbo	spve	nyny	609		persp, biophysical ecology	gates,pm; schierl,	1975
aubo	jwis	nyny	273		intro physiol plant ecolog	bannister,p	1976
aubo	mhbc	nyny	325		theor, prob, heat transfer	pitts,dr; sissom,l	1977

SERIALS

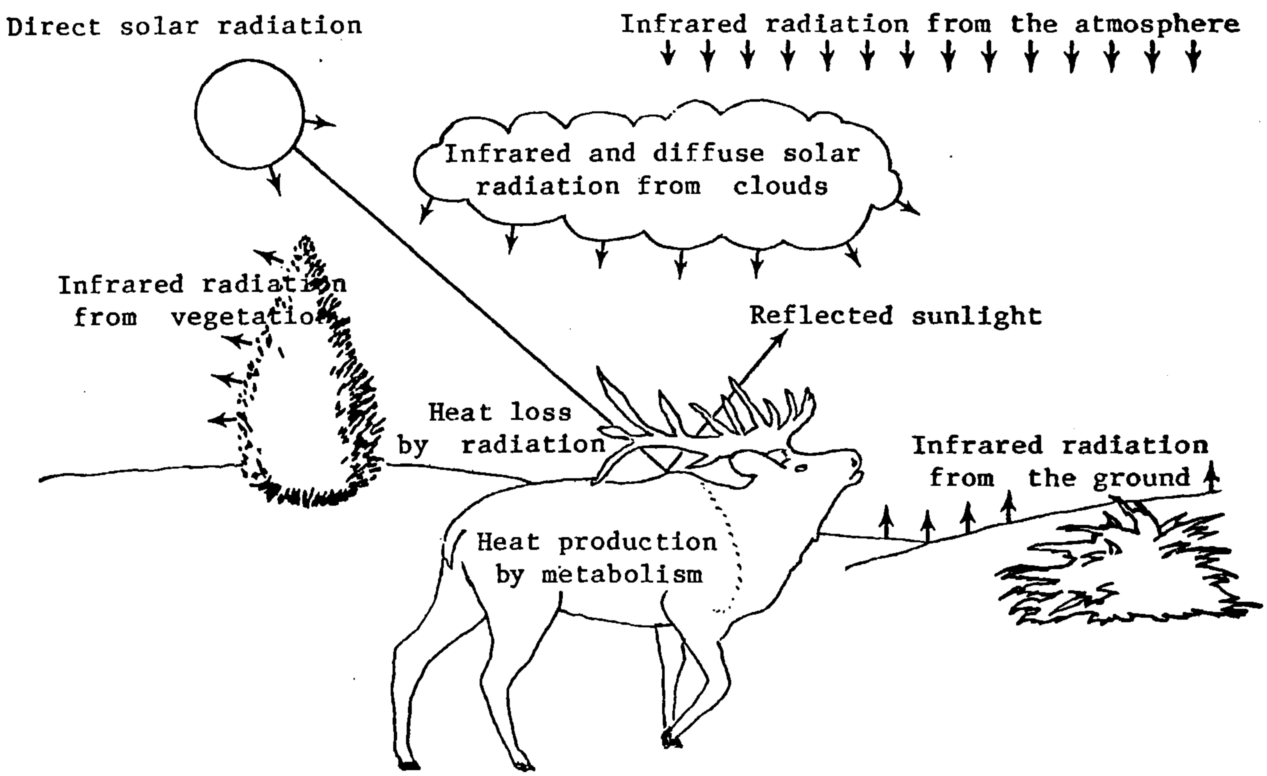
CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS----------------	AUTHORS-----------	YEAR
AMSCA	51--3	327	348		the energy environment	gates,dm	1963
IJBMA	20--2	239	156	dome	meteorol in anim productn	bianca,w	1976
IREZA	2---	269	344		heat trans in biolo system	birkebak,rc	1966
SCAMA	225-3	88	100		energy flow in biosphere	gates,dm	1971

TOPIC 1: RADIATION EXCHANGE

Radiant energy follows three pathways as it travels straight-line paths from radiating sources to receiving surfaces. It may be reflected from the receiving surface, absorbed by the receiving mass, or transmitted through it. These three possibilities must be quantified when radiant energy is related to biological organisms.



Where does radiant energy come from? Every surface with a temperature above absolute zero emits radiant energy. This energy is continually being exchanged between surfaces with mutual fields of view. Two trees in a forest exchange radiant energy on even the coldest winter day. Two animals near each other exchange energy, and exchanges also occur between the ground and animals, clouds and animals, and all other surfaces within view.



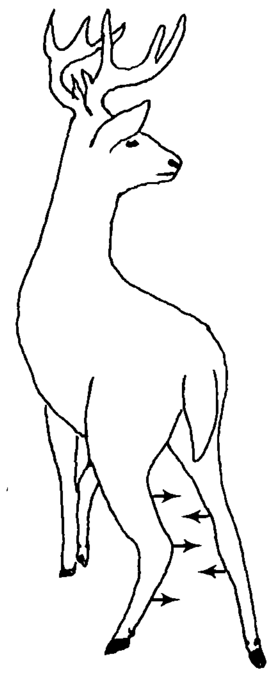
Radiant energy may be positive, negative, or equal in both directions. It is equal between two adjacent trees in the forest at night; the net exchange is zero. If one surface emits more than it receives, then the emitting surface has a negative radiation balance. If one surface receives more energy than it emits, then it has a positive radiation balance. The part of the earth illuminated by the sun has a positive radiation balance, and the dark portion usually has a negative radiation balance.

Radiation exchange would be very easy to calculate if the earth had no atmosphere, but was simply a physical surface in the vacuum of space. The moon's surface is like that, and the surfaces of the astronauts' suits were also like that. The lack of an atmosphere on the moon results in very distinct and rapid changes in its surface temperatures. Radiation exchange is the only form of heat transfer possible between the sun and the moon and the emptiness of space. The atmosphere over the earth's surface, while it may seem cold at times, ameliorates the energy balance at the earth's surface, by impeding the loss of radiant energy from the earth to space.

The atmosphere complicates the calculation of heat transfer, especially at the hairy surface of an animal. Such a hairy surface is not a single plane, so the radiant surface is difficult to define, and the hairs add to the potential for convective effects. Rather than complicate the calculations too quickly, however, radiation exchange is quantified by first discussing geometric considerations in UNIT 1.1, and then describing the absorption, reflection, and emission of radiation in the visible wavelengths in UNIT 1.2 and in the infrared wavelengths in UNIT 1.3.

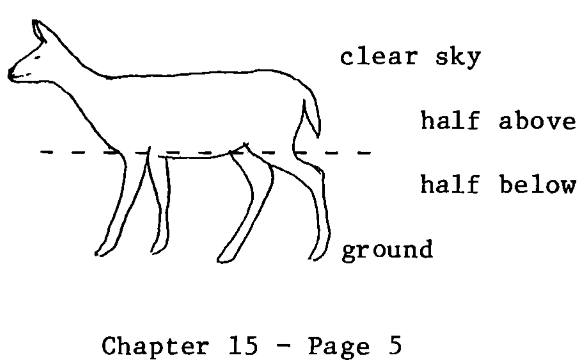
UNIT 1.1. RADIATION PROFILES

The surface area of an animal that is participating in radiant energy exchange with the external environment is not necessarily the same as the physical surface of the animal. For example, if the animal is standing, the inner surfaces of the legs exchange some infrared radiant energy with each other, and if both leg surfaces are at the same temperature, the net exchange is zero.

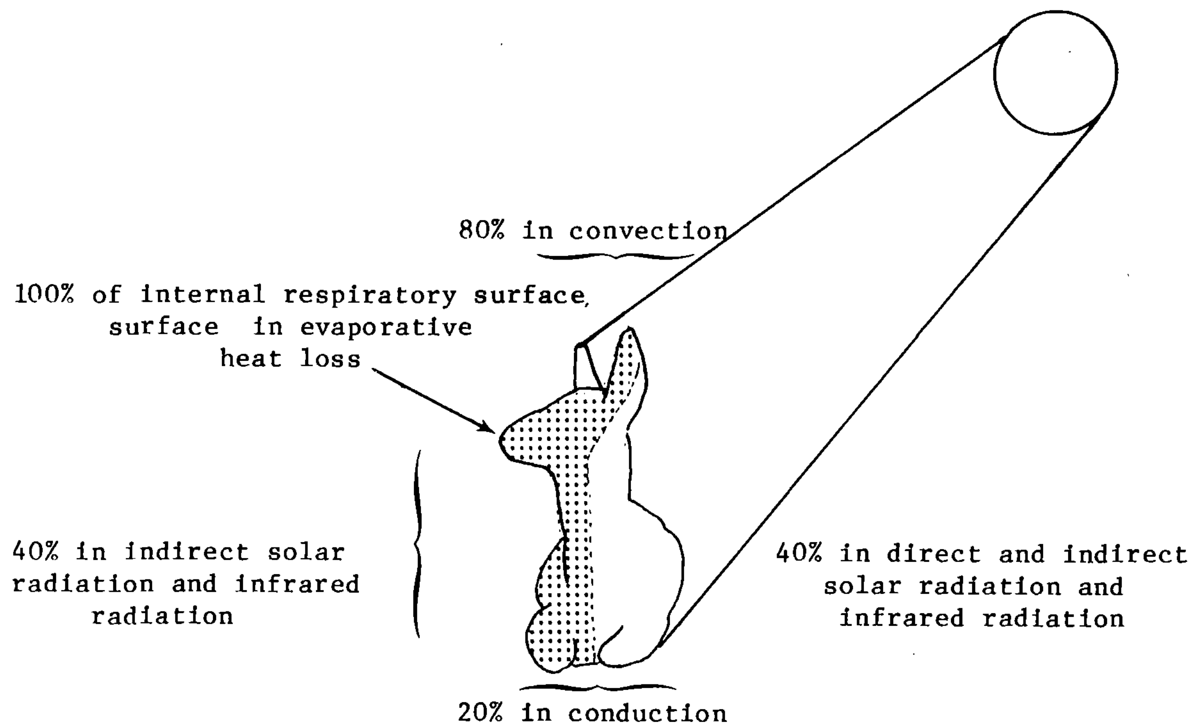


When an animal is bedded, some of the physical surface is tucked against itself. The legs, for example, may be curled up under the body and the neck and part of the head tucked alongside the trunk, reducing the total surface area exposed to radiant energy.

The radiation profile for infrared radiation is dependent not only on the animal's posture, but also on the canopy type. A deer under a clear sky exposes part of its body to the sky and part to the ground. A "half above: half below" profile may be used as a first approximation. The top half of the surface is exposed to the sky (for calculation purposes) and the bottom half to the ground. This is illustrated below, and used in a WORKSHEET in CHAPTER 16, UNIT 1.1.



Radiation profiles in the visible wavelengths are dependent on both the animal's posture and on the relative amounts of direct and diffuse solar radiation. Calculations of the solar constant and of the solar radiation at the earth's surface were made for plane surfaces oriented differently in relation to the sun's path from sunrise to sunset in CHAPTER 14. Organsims are three dimensional rather than single planes, however, so they are exposed to an infinite number of angles with respect to direct-beam solar radiation. These angles change as the sun's position in relation to the organism changes, and as organisms change their postures. There are concomitant changes in absorption coefficients as the angles of incidence change, and absorption coefficients also vary due to hair roughness and hair color. Thus every organism has a constantly-changing dynamic solar radiation profile of absorbed radiation over the entire body surface.



Some parts of the animal's surface are exposed to both direct and diffuse solar radiation, while other parts are exposed to diffuse radiation only. Atmospheric conditions also affect the relative amounts of direct and diffuse solar radiation. A completely overcast sky results in diffuse solar radiation only in the visible wavelengths. Radiation profiles are too dynamic and complex to portray in their entirety, but opportunities for estimating simplified radiation profiles are given in the WORKSHEETS that follow.

REFERENCES, UNIT 1.1

RADIATION PROFILES

SERIALS

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

odvi

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

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

CHAPTER 15 WORKSHEET 1.1a

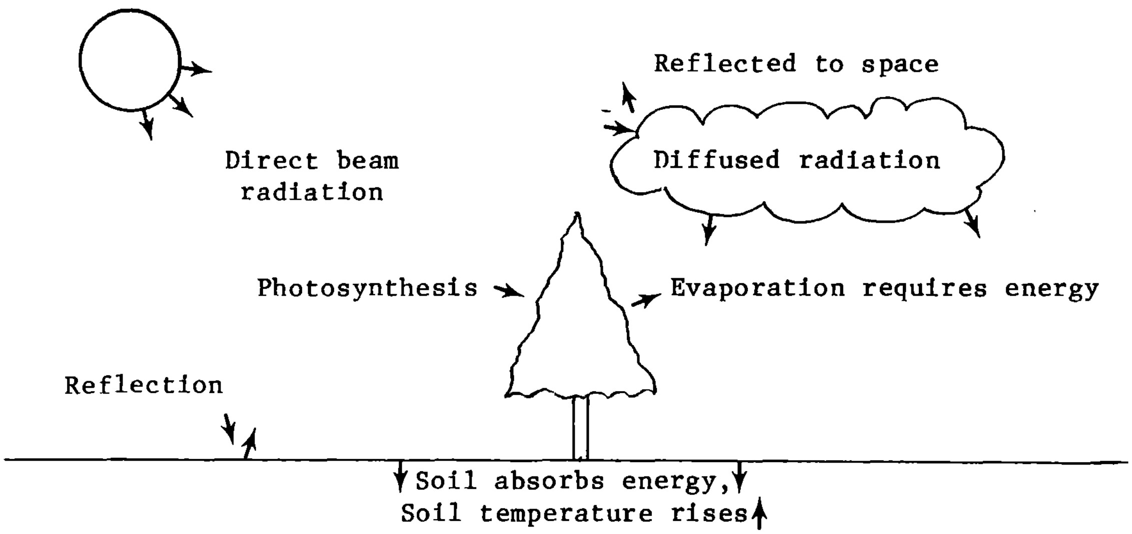
Radiation profiles

The reflection and absorption of radiant energy of different wavelengths have been illustrated in UNIT 1.1. An animal bedded in the sun, for example, might have 40% of its surface exposed to direct solar radiation, 80% exposed to indirect solar radiation, and 80% exposed to infrared radiation. Other percents of surface area are exposed to convection, conduction, and evaporation.

Sketch various postures and make estimates of the surface areas involved in infrared and visible radiation exchange. Relate these estimates to surface area calculations in CHAPTER 1. Standing, bedded with head up, and bedded with head curled back are three postures considered necessary for thermal exchange calculations.

UNIT 1.2: RADIATION EXCHANGE IN THE VISIBLE WAVELENGTHS

Measured solar radiation includes both the direct beam and the indirect radiation diffused by the atmosphere, especially by clouds. What happens to this radiation when it reaches the earth's surface?



Some of the energy is reflected from the earth back to space. The percentage of the solar radiation reflected from a surface is called the albedo of the surface. It varies both daily and seasonally due to variations in physical and biological characteristics. The elevation of the sun is very important; albedos of horizontal surfaces increase as the elevation of the sun decreases. This is illustrated by the high reflectivity of a lake's surface as sunset approaches.

The albedo of the ground surface varies seasonally with changes in snow cover; new-fallen snow has a higher albedo than old snow. There are differences due to vegetation; a dense conifer canopy has a lower albedo than a mixed hardwood canopy.

The energy that is reflected back into space is not absorbed by the earth's surface, so it cannot become part of the earth's energy balance. The energy absorbed at the earth's surface may take several pathways. Some of the energy is absorbed by the soil, resulting in an increase in soil temperature. Some of the energy drives the water cycle--evaporation requires energy. Some of the energy, usually less than 1% annually, is absorbed and used by plants for photosynthesis. These pathways represent short-term changes in energy storage. Over long periods of time, the amount of radiant energy reaching the earth's surface must equal the amount dissipated, or else the earth's surface would become increasingly warm.

Radiant energy in the visible portion of the electromagnetic spectrum is reflected from, absorbed by, and transmitted through biological tissue at rates dependent on the characteristics of the tissue and the distribution of the wavelengths. The visible wavelengths that are reflected permit animals to see each other and other components of their environment. Little is known about visual perception capabilities of wild ruminants. They apparently do not see color as humans do, which means that they do not have the neurological capabilities to discern differences between wavelengths in the visible portion of the spectrum.

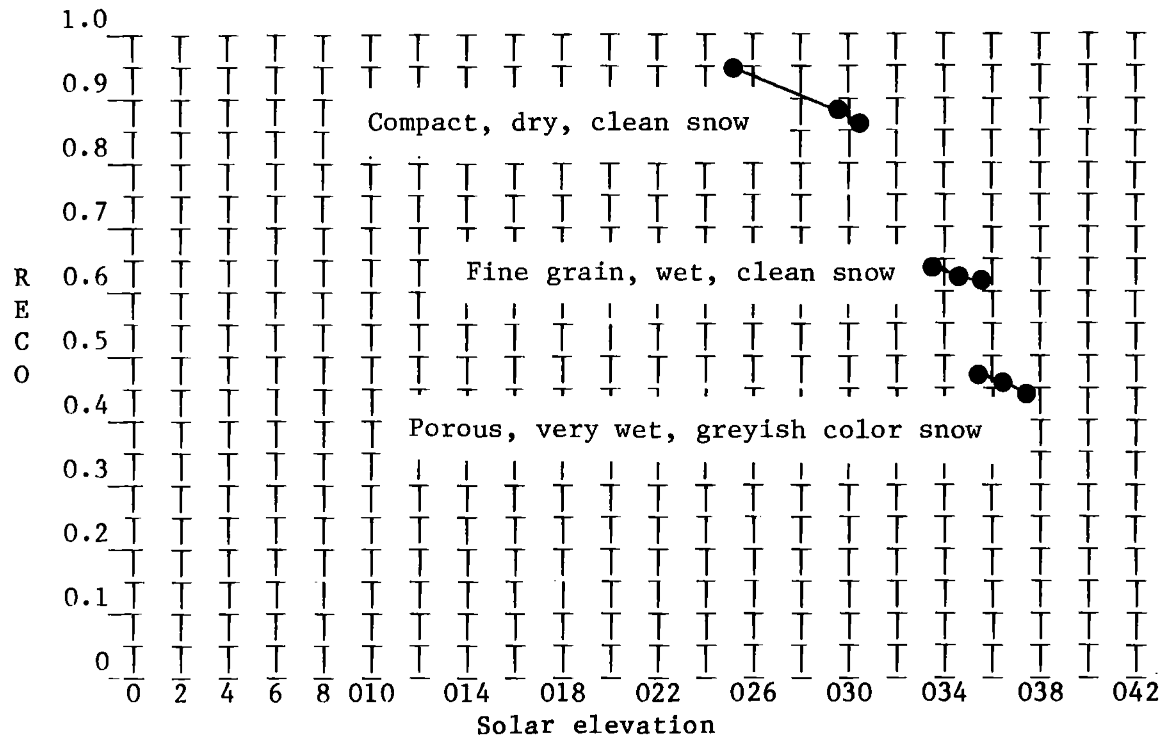
Visible wavelengths absorbed by biological tissues are converted to heat. This is of interest ecologically as absorbed energy reduces thermal gradients and heat loss between organism and environment. Animals sometimes select bedding sites and other activity areas that are thermally favorable. I observed a white-tailed deer, for example bedded on the south side of a steep-sided snowbank on a bright and sunny sub-zero day in western Minnesota. That spot was like a reflector oven, and was surely warmer than a more exposed site just meters away.

It is important, however, to remain objective when making observations such as the one above, not jumping to the conclusion that such a site was needed by the deer under those conditions. It may be that this particular site was favorable but not necessary. Careful calculations of heat exchange help one make such distinctions.

Reflection coefficients (RECO) or albedos of various surfaces are given for the visible wavelengths in the table below, modified from Satterlund (1972:97).

Surface cover	Albedo
Water	0.05-0.10
Bare soil (light colored, dry)	0.20-0.35
(dark colored, moist)	0.08-0.15
Grass (short, green,dry)	0.25-0.35
(short,green,wet)	0.15-0.20
(tall, cured)	0.25-0.30
(tall, green)	0.15-0.20
Marsh and Bogs	0.15-0.20
Forests (Spruce, dense, no snow)	0.05-0.10
(Spruce, dense, snow)	0.20-0.25
(Mixed conifer-hardwood, in leaf)	0.10-0.15
(Hardwoods, in leaf)	0.15-0.20
(Hardwoods, winter, snow)	0.35-0.45
Snow (fresh)	0.80-0.95
(old)	0.40-0.70

Reflective properties of snow are given in Gray (1970:2.27) in relation to the height of the sun. The illustration below shows the pattern of reflection coefficients in relation to solar elevation; reflectivity decreases with increasing solar elevation.



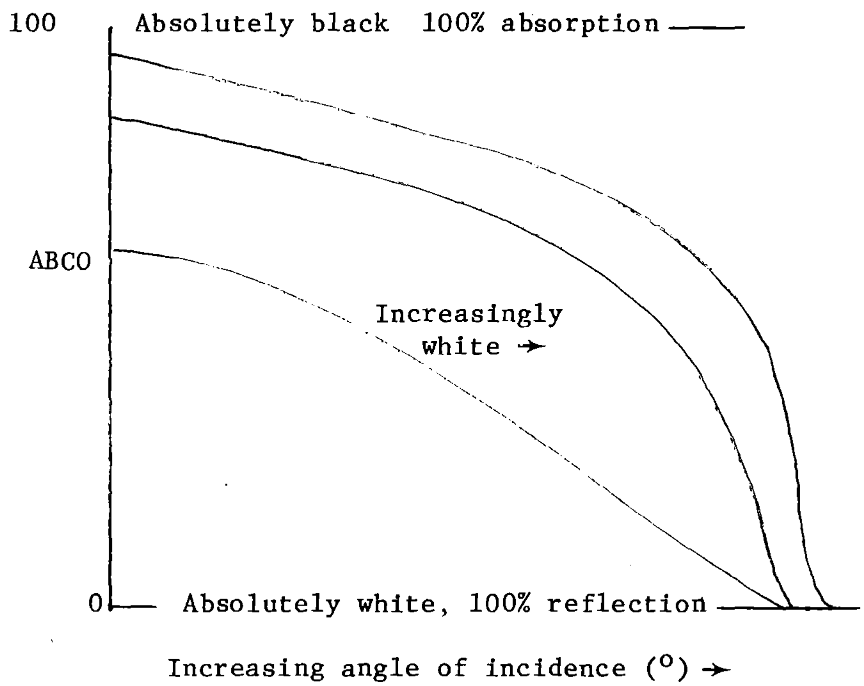
While there are data on reflection coefficients for snow, soil, and vegetation surfaces, there is a dearth of information on the reflection coefficients of the pelage of different animal species. Since mammals do not transmit radiation through their hair coats, reflection and absorption are the two ways in which radiant energy interacts with the hair surface. The absorption coefficient, ABCO, is:

$$1.00 - \text{RECO} = \text{ABCO}$$

Absorption of visible wavelengths by a smooth surface is related to the color of the surface. A white surface appears white because it reflects all of the wavelengths in the visible portion of the spectrum, and a black surface appears black because it absorbs them. The amounts reflected and absorbed determine the changes in the heat content of the tissue, of course.

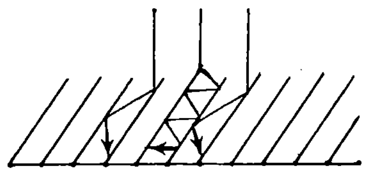
The absorption coefficient of a plane surface is dependent not only on color but also on the angle of incidence. The absorption coefficient must must go to zero when the beam of radiant energy is parallel to the surface, and it is maximum when the angle of incidence is 90°. There is a gradient between these two extremes. What is the shape of the curve expressing that gradient?

Absorption coefficients of black, brown, and white cattle have been evaluated by Riemerschmid and Elder (1945; See also Moen 1973:79). The general pattern shows a rapid drop in absorption at angles greater than 45 for white cattle, and at angles greater than 70 for brown and black cattle. The sketch below shows the general pattern of the absorption coefficient (ABCO) over a range of shades from black to white.

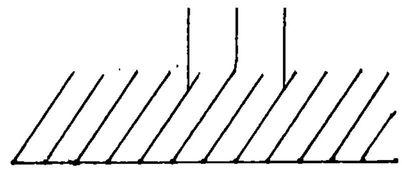


There is one very important consideration to make when evaluating the patterns above in relation to the smoothness of the hair coat. The coats of the African cattle measured by Reimerschmid and Elder were very smooth, and they responded to incident radiation as plane surfaces. The coats of most wild ruminants are very rough, especially in the winter. The roughness of the hair affects the overall absorption coefficient as each hair acts as a reflecting and absorbing surface.

Consider two hairy surfaces, one composed of white hairs and the other of black hairs, both exposed to a beam of radiation. Recall that white surfaces reflect more and absorb less of the energy in the visible wavelengths than black surfaces do. The white hairs reflect the radiant energy, and because they project outward from skin surfaces, much of the energy reaching the white hairy surface is reflected back into the hair coat towards the skin. Such reflections by individual hairs results in more absorption by the hair coat as a whole than if the hairs were black. Black hairs absorb more and reflect less radiant energy in the outer portion of the hair coat, but since this outer portion is also more exposed to the atmosphere than the inner portion, the effects of convection, both natural and forced, on the hairy surface results in the dissipation of the absorbed energy rather than absorption deeper into the hair coat where the wind penetrates less. Thus, it may be thermally more desirable to have a rough white coat than a rough black one in a cold climate.



White hairs, reflecting into hair layer



Black hairs, absorbing at tips

The effects of roughness, densities, and depths of hair coats make it clear that absorption and reflection coefficients cannot be considered on the basis of coat color alone. There are no data on these relationships for wild ruminants, however. Oritsland (1974) discusses these relationships for polar bear hair, but that is the only reference currently available on this effect.

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Oritsland, N. A. 1974. A windchill and solar radiation index for homeotherms. J. Theor. Biol. 47(2):413-420.

Riemerschmid, G. and J. S. Elder 1945. The absorptivity for solar radiation of different coloured hairy coats of cattle. Onderstepoort J. Vet. Sci. Anim. Ind. 20(2):223-234.

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REFERENCES, UNIT 1.2

RADIATION EXCHANGE IN THE VISIBLE WAVELENGTHS

SERIALS

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

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
XARRA	215--	1	4	odhe	sol rad,rdnt temp,dee surf	parker,hd; drisco	1972

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
JTBIA	47--2	413	420	rata	solar radiation, wind chil	oritsland,na	1974

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
ECOLA	58--6	1384	1392	doca	cattle colors, solar radia	finch,va; western	1977
JANSA	35--3	624	627	doca	phys principl, energy exch	morrison,sr	1972
JAPYA	26--4	454	464	doca	penetrance coats by radiat	hutchinson,jcd; /	1969
OJVRA	20--2	223	234	doca	absorpt, solar rad, colour	riemerschmid,g; e	1945

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
CBPAB	52--2	343	349	doru	reflectance, sol rad, coat	hutchinson,jcd; /	1975
IJBMA	20--2	139	156	doru	meteorology in animal prod	bianca,w	1976
JAPYA	37--3	443	446	doru	heat flow meters, heat los	mchinnis,sm; ingr	1974
PRLBA	188--	377	393	doru	radiati transf, anim coats	cena,k; Monteith,	1975

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
AJZOA	20--1	17	22	dosh	effec postu. heat loa, sum	dawson,tj	1972
ECOLA	50--2	328	332	dosh	bioclim compar, summer day	dawson,tj; denny,	1969
JAPYA	35--5	751	754	dosh	local heat balance, radiat	clark,ja; cena,k/	1973

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
ECOLA	45--3	646	649		sol rad char of tree leavs	birkebak,r; birke	1964

UNIT 1.3: RADIATION EXCHANGE IN THE INFRARED WAVELENGTHS

Radiation exchange in the infrared wavelengths, a function of the radiant temperatures of the surface, is calculated with the Stephan-Boltzmann law described previously, with the addition of the coefficient of infrared emissivity, IREM:

$$QREE = (IREM)(SBCO)(RATK)^4$$

where QREE = quantity of radiant energy emitted,
IREM = coefficient of infrared emissivity (discussed below),
SBCO = Stephan-Boltzmann constant = 8.127×10^{-11} cal cm^{-2} min^{-1}
= 4.876×10^{-8} kcal m^{-2} h^{-1}, and
RATK = radiant temperature in K.

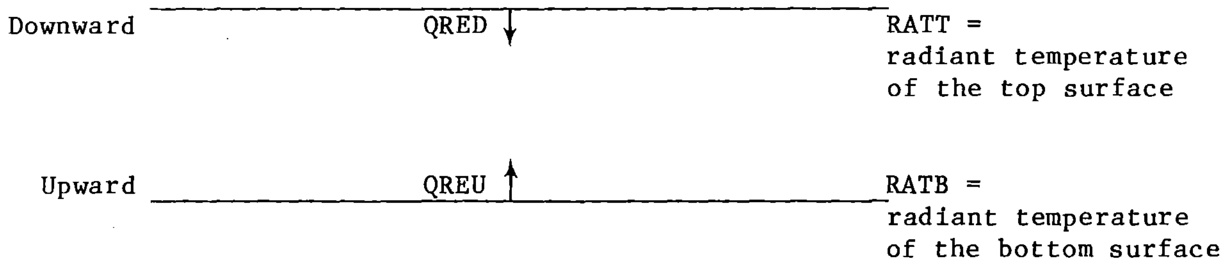
The coefficient of infrared emissivity of a surface is equal to the coefficient of absorption of that surface. In other words a surface emits infrared energy as efficiently as it absorbs it. A perfect black body not only absorbs all of the infrared energy reaching it, but also emits all that it can as a direct function of the fourth power of its absolute temperature.

A surface may be "black" at some wavelengths and grey at other wavelengths. Snow, for example, is a very poor absorber of wavelengths in the visible part of the electromagnetic spectrum, but a very good absorber and emitter of infrared energy. In fact, new-fallen snow has an absorption and emission coefficient of about 0.9 in the infrared, while its albedo, or reflection coefficient, is 0.7 or more, absorption is 0.3 or less, in the visible part of the solar spectrum. Aged snow has a lower infrared absorption coefficient, and a lower solar albedo as well.

Infrared absorption and emission coefficients of hairy surfaces are not highly variable. They are usually 0.8 or more, and often approach 1.0. In fact, 1.0 is a satisfactory approximation for hair, regardless of its color.

All surfaces in the biosphere are constantly exchanging infrared energy with neighboring surfaces within their field of view. Suppose two parallel surfaces are oriented horizontally. The downward flux is determined by using the formula:

$$QRED = (IREM)(SBCO)(RATK)^4$$



The upward flux is determined by using the formula:

$$QREU = (IREM)(SBCO)(RATB)^4$$

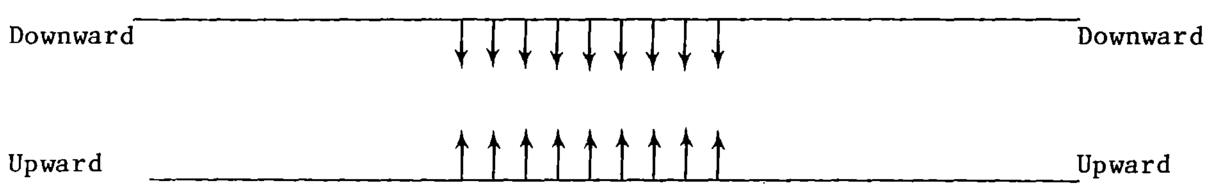
The total flux is the sum of the two:

$$QRET = QRED + QREU = [(IREM)(SBCO)(RATT)^4] + [(IREM)(SBCO)(RATB)^4]$$

The net flux is the difference between the two:

$$QREN = QRED - QREU = [(IREM)(SBCO)(RATT)^4] - [(IREM)(SBCO)(RATB)^4]$$

Suppose that an object or organism was situated in the flux between the top and bottom surfaces illustrated above. This could be a leaf on a tree exposed to the sky (top) and the ground (bottom). The leaf absorbs energy from both directions as ilustrated below, and its temperature will rise in relation to the net energy absorbed. The leaf, however, also emits energy.



How much radiant energy must the leaf emit to remain in radiation equilibrium? If the heat energy is equally distributed throughout the leaf, equal amounts could be emitted from both the upper and lower surfaces. Divide the total radiant energy flux by 2: TREF/2. Then, rearrange the equation to determine the effective radiant temperature of the leaf (ERTL) with the formula:

$$ERTL = \sqrt[4]{(TREF/2)/SBCO}$$

The energy emitted from the leaf, considering both surfaces, may be calculated with the effective radiant temperature of the leaf. It is numerically equal to the total amount absorbed if the leaf temperature does not change. Some radiant "surfaces" are infinite heat sinks, and others are not. The clear sky, for example, is an infinite heat sink; its radiant temperature does not change as a result of dissipation from the earth's surface. Leaf temperatures, however, do change as radiation is absorbed or emitted and there is a finite limit to the quantity of heat energy that can be present in a leaf.

A similar approach may be used for calculating the exchange between two animal surfaces or between an animal's surface and its radiant thermal environment. Radiant surface temperatures of an animal are dependent on several external factors, including the variable amounts of solar radiation absorbed over the hair surface, the air temperature, and the wind velocities over the animal's surface. In general, surface temperatures increase as more solar radiation is received and decrease as air temperature decreases and wind velocity increases. Wind has non-linear effects as changes at low wind velocities cause greater changes in surface temperature than changes at high velocities. The effects of greater changes at low wind velocities are ecologically important because animals are generally exposed to low velocities when in vegetative cover. Further, turbulent air movement results in fluctuating velocities, with concomitant changes in radiant surface temperatures. Changes in radiant surface temperatures are due to convection, discussed in the next TOPIC.

The radiant surface temperatures of white-tailed deer pelage exposed to wind velocities from 0 to 14 miles per hour (0 - 5 km per hour) were determined in the Thermal Environment Simulation Tunnel at Cornell's Wildlife Ecology Laboratory by Stevens (1972). Linear regression equations, where RATC = radiant temperature in °C and AITE = air temperature in °C are given below.

Mi Hr^{-1}	Combined Regressions	n	r
0	RATC = 9.49 + 0.75 AITE	51	0.98
1	RATC = 9.18 + 0.76 AITE	68	0.98
2	RATC = 8.60 + 0.78 AITE	71	0.98
3	RATC = 7.88 + 0.79 AITE	45	0.98
4	RATC = 7.53 + 0.80 AITE	74	0.97
6	RATC = 6.45 + 0.83 AITE	75	0.98
8	RATC = 5.63 + 0.85 AITE	45	0.98
10	RATC = 4.88 + 0.87 AITE	74	0.99
14	RATC = 4.05 + 0.89 AITE	52	0.98

Note how the intercepts (a values) decrease as wind velocities increase. A single equation has been derived for all of these equations by expressing a and b as functions of wind velocity. The equation is:

$$RATC = (9.483 - 0.477\ WIVE) + [(0.752 + 0.012\ WIVE)(AITE)]$$

This equation is evaluated in WORKSHEET 1.3e that follows.

Radiant temperatures have not been measured for many species of wild ruminants. Mule deer radiant temperatures were similar to those for white-tailed deer (Moen 1974). Parker (1972) measured radiant temperatures of mule deer to be -7°C at night when the air temperature was -18°C. The slope of the regression line was such that the effective radiant temperature and air temperature intersected at about +6°C. This is not expected; the theoretical intersection should be at body temperature, or about 37°C. Marble (1967) has puzzling results also; radiant temperatures were less than air temperatures at times in her studies of bison, mule deer, and pronghorn. The only physics explanation for such results is that the sky was acting as a radiant heat sink, and the body surface cooled below air temperature. This has not proven likely in my detailed measurements on live and simulated deer, and on bear. The atmosphere surrounds the animal and its fur surface, thus adding heat energy to the surface. Indeed, radiometers are designed to prevent the warming of the sensors by the use of polyethylene shields. Leaf temperatures have been observed to go below air temperature, but leaves do not have internal temperatures of 37-39°C. Calculations of radiant temperature and the effects of wind result in interactions between radiation and convection. Additional complexities arise from the animals' surface area configuration and the distribution of infrared flux from the environment. These are discussed in CHAPTER 16.

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Moen, A. N. 1973. Wildlife Ecology. W. H. Freeman and Co., San Francisco 458 p.

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Parker, H. D., Jr. 1972. Airborne infrared detection of deer. Ph.D. Thesis, Colorado State University. 186 p.

Stevens, D. S. 1972. Thermal energy exchange and the maintenance of homeothermy in white-tailed deer. Ph.D. Thesis, Cornell Univ. Ithaca, N. Y. 231 p.

REFERENCES, UNIT 1.3

RADIATION EXCHANGE IN THE INFRARED WAVELENGTHS

SERIALS

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
JRMGA	27--5	401	403	odvi	radiant temp, hair surface	moen,an	1974
JWMAA	32--2	338	344	odvi	surf temp, radiant heat lo	moen,an	1968
JWMAA	38--2	366	368	odvi	radiant temp surface, wind	moen,an; jacobsen	1974

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
NJZOA	19--1	89	91	rata	surf tmps, heat los, summe	wika,m; krog,j	1971
ZOLZA	53--5	747	755	rata	[body surface heat emissi]	segal,an; ignatov	1974

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
ECOLA	58--6	1384	1392	doca	cattle colors, heat stress	finch,va; western	1977
JANSA	35--3	624	627	doca	physic principl energ exch	morrison,sr	1972
JAPYA	26--4	454	464	doca	penetrance coats by radiat	hutchinson,jcd; /	1969

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
IJBMA	20--2	139	156	doru	meteorology in animal prod	bianca,w	1976
JAPYA	37--3	443	446	doru	heat loss, heat flow meter	mcginnis,sm; ingr	1974
PRLBA	188--	377	394	doru	radiati transf, anim coats	cena,k; monteith,	1975

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
JAPYA	35--5	751	754	dosh	local heat bal coat, cloth	clark,ja; cena,k/	1973

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
ECOLA	49--1	145	147		thermal energ exchan, tree	moen,an	1968
ECOLA	50--2	329	332		microclim compar, summer d	dawson,tj; denny,	1969
JOMAA	37--3	375	377		infra emis of arctic fauna	hammel,ht	1956
SCIEA	166	115	117		therm rad in metab chamber	porter,wp	1969

CHAPTER 15, WORKSHEET 1.3a

Infrared radiation in relation to the radiant temperature of the surface

The formula for calculating the quantity of radiant energy emitted, QREE, is:

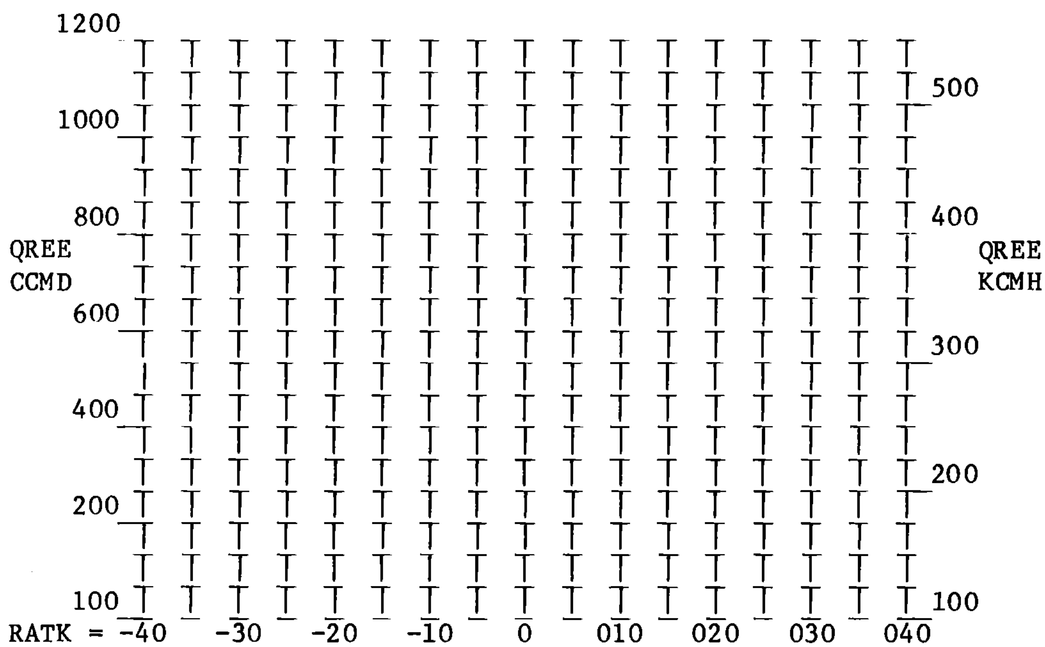
$$QREE = (SBCO)(RATK^4)$$

where RATK = radiant temperature in Kelvin degrees.
If QREE is in cal cm^2 min^{-1}, then SBCO = 1.170×10^7
If QREE is in kcal m^2 hr^{-1}, then SBCO = 4.876×10^{-8}.

Equivalent temperatures in Celsius and Kelvin degrees are:

-40 C	= 233.2 K
-30	= 243.2
-20	= 253.2
-10	= 263.2
0	= 273.2
10	= 283.2
20	= 293.2
30	= 303.2
40	= 313.2

Substitute these temperatures in the formula above and complete the nomogram. Note that the left-hand scale is in cal cm^{-2} day $^{-1}$, and the right-hand one in kcal m^{-2} hr^{-1}.



CHAPTER 15 - WORKSHEET 1.3b

Infrared radiation measurements, Suomi Radiometer

Infrared radiation measurements may be made with home-made radiometers designed by Suomi and Kuhn (1958) and discussed further in Moen (1973). The instruments I made (see Moen 1973:91) were of wood, fiberglass insulation, polyethylene, and aluminum foil, with a highly absorbent black print on the aluminum foil sensing surface and thermometers as temperature sensors.

The formulas for calculating radiation are:

$$\mathrm{QRED} = [(\mathrm{IREM})(\mathrm{SBCO})(\mathrm{ABTT}^4) + (\mathrm{ABTT} - \mathrm{ABTB})\ \mathrm{KCOI} + (\mathrm{ABTT} - \mathrm{ABTB})\ \mathrm{KCOA}]$$

$$\mathrm{QREU} = [(\mathrm{IREM})(\mathrm{SBCO})(\mathrm{ABTB}^4) + (\mathrm{ABTB} - \mathrm{ABTT})\ \mathrm{KCOI} + (\mathrm{ABTB} - \mathrm{ABTT})\ \mathrm{KCOA}]$$

where QRED = Quantity of radiant energy downward in kcal m^{-2} m^{-1}
QREU = Quantity of radiant energy upward in kcal m^{-2} m^{-1}
IREM = Infrared emissivity = 1.0
SBCO = Stefan-Boltsmann constant = 49.3×10^{-9}
ABTT = Absolute temperature of the top sensor (add 273.2 to measured C temperature)
ABTB = Absolute temperature of the bottom sensor

KCOI = Conductivity coefficient of the insulation = 0.3 for my instrument
KCOA = Conductivity coefficient of the air = a + b (IART), where
a = 1.62877,
b = 0.00516, for my instrument, and
IART = instrument air temperature which may be estimated as the temperature midpoint between air temperature and sensor temperature.

The KCOI value is dependent on the insulation used, and the equation for KCOA is dependent on the depth of the air spaces.

Instruments may be built with locally-available materials and the appropriate numerical values used in the formulas for radiation flux. Equations for given instruments may be programmed on calculators and the infrared radiation flux quickly determined from thermometer readings. These instruments are economical, portable, and very simple to use when properly designed.

LITERATURE CITED

Moen, A. N. 1973. Wildlife Ecology. W. H. Freeman Co. San Francisco. 458 p.

Suomi, V. E. and P. M. Kuhn. 1958. An economical net radiometer. Tellus 10(1):160-163.

CHAPTER 15, WORKSHEET 1.3c

Infrared radiation in open snow fields

Measurements of downward and upward infrared radiation in open snowfields have been made in Minnesota and New York (Moen and Evans, 1971) and equations given for the radiant temperatures of the sky and earth's surfaces. These temperatures are plotted in Moen (1973:82). The differences between sites are not great, and the data from the different sites can be combined into a single equations for the radiant temperature of the clear sky (RTSK) and the earth's surface (RTEK). The equations are:

$$RTSK = (1.103\ AITE - 8.915) + 273.2$$
$$RTEK = (1.030\ AITE - 0.049) + 273.2$$

Substituting these equations into the formula for calculating the quantity of infrared radiation emitted (in kcal per square meter per hour):

$$QREE = 4.876 \times 10^{-8}\ RATK^4$$

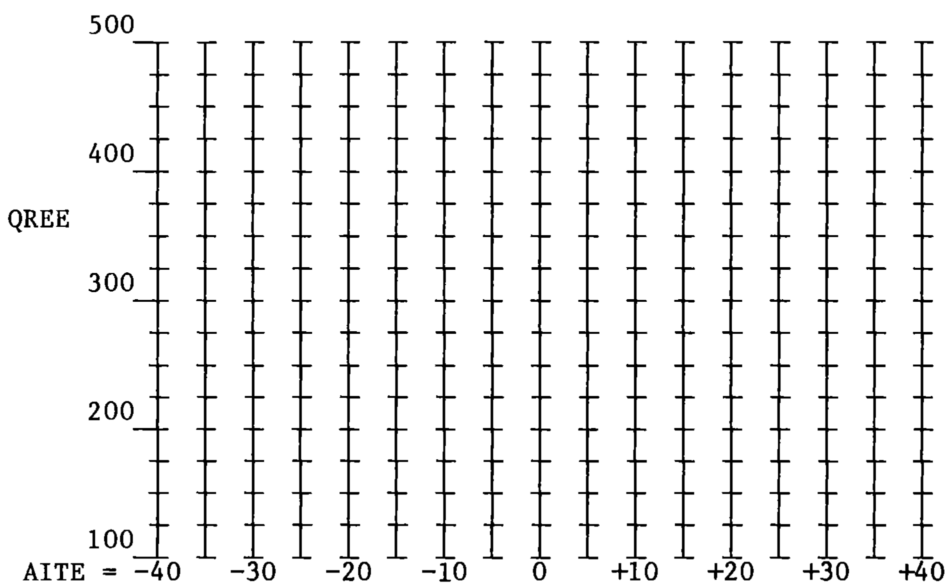
The equation for the quantity of radiant energy from the sky (QRSK) is:

$$QRSK = [4.876 \times 10^{-8}][(1.103\ AITE - 8.915) + 273.2]^4$$

The equation for the quantity of radiant energy from the earth is:

$$AREA = [4.876 \times 10^{-8}][1.030\ AITE - 0.049) + 273.2]^4$$

Complete the calculations and plot the results below.



LITERATURE CITED

Moen, A. N. 1973. Wildlife Ecology. W. H. Freeman and Co., San Francisco. 458 p.

Moen, A. N. and K. E. Evans. 1971. The distribution of energy in relation to snow cover in wildlife habitat. Pages 147-162 In A. O. Haugen ed.), Proceedings of the Snow and Ice in Relation to Wildlife and Recreation Symposium. Iowa Coop. Wildl. Res. Unit, Iowa St. Univ., Ames. 23 p.

CHAPTER 15, WORKSHEET 1.3d

Infrared radiation in different cover types

The amounts of infrared radiation flux in different cover types are dependent on the density of the vegetation, the temperature of the vegetation surfaces, and the emissivity of the surface. Densities vary from open fields, with no canopy, to dense coniferous canopies. Temperatures on the vegetative surfaces at night are close to air temperature. Emissivities are essentially 1.0. Thus the most important factor determining the radiation flux in different cover types is canopy density, with the flux in each of the different cover types a function of air temperature.

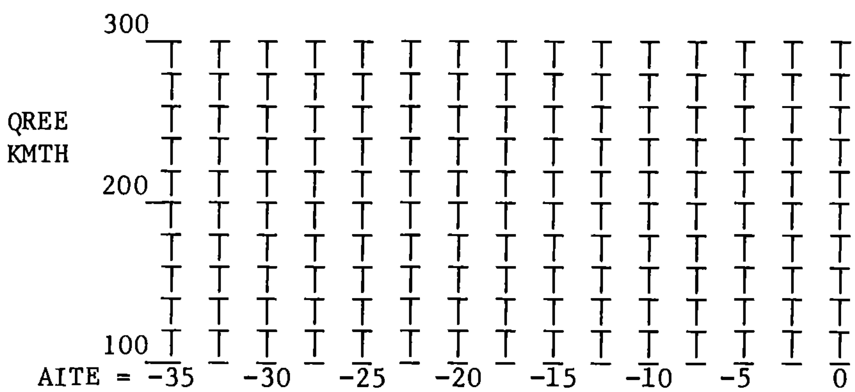
Equations for downward radiation flux in an open field, leafless hardwoods (winter), and cedar canopy are given in Moen (1968:340). The published equation is lacking σ. Substituting AITE = air temperature for X in the published equations, the new equations for quantity of radiant energy emitted (QREE) are:

$$\text{QREE} = \text{SBCO}[(-10.9 + 1.000\ \text{AITE}) + 273.0]^4 \quad \text{(open field)}$$

$$\text{QREE} = \text{SBCO}[(\ -5.6 + 0.964\ \text{AITE}) + 273.0]^4 \quad \text{(hardwood)}$$

$$\text{QREE} = \text{SBCO}[(\ +0.2 + 0.962\ \text{AITE}) + 273.0]^4 \quad \text{(cedar)}$$

Complete the calculations and plot the results below.



LITERATURE CITED

Moen, A. N. 1968. Surface temperatures and radiant heat loss from white-tailed deer. J. Wildl. Manage. 32(2):338-344.

CHAPTER 15, WORKSHEET 1.3e

Radiant temperatures of white-tailed deer

An equation for predicting the radiant temperature of white-tailed deer exposed to different wind velocities was discussed on pages 17-20. The equation from page 19 is:

$$\text{RATC} = (9.483 - 0.477\ \text{WIVE}) + [(0.752 + 0.012\ \text{WIVE})(\text{AITE})]$$

Determine the radiant temperature for different combinations of AITE and WIVE and tabulate below. Correct RATC to RATK.

AITE	WIVE	RATC	RATK
____	____	____	____
	____	____	____
	____	____	____
	____	____	____
	____	____	____
____	____	____	____
	____	____	____
	____	____	____
	____	____	____
____	____	____	____
	____	____	____
	____	____	____
	____	____	____
	____	____	____
____	____	____	____
	____	____	____
	____	____	____
	____	____	____
	____	____	____

AITE	WIVE	RATC	RATK
____	____	____	____
	____	____	____
	____	____	____
	____	____	____
	____	____	____
____	____	____	____
	____	____	____
	____	____	____
	____	____	____
	____	____	____
____	____	____	____
	____	____	____
	____	____	____
	____	____	____
	____	____	____
____	____	____	____
	____	____	____
	____	____	____
	____	____	____
	____	____	____

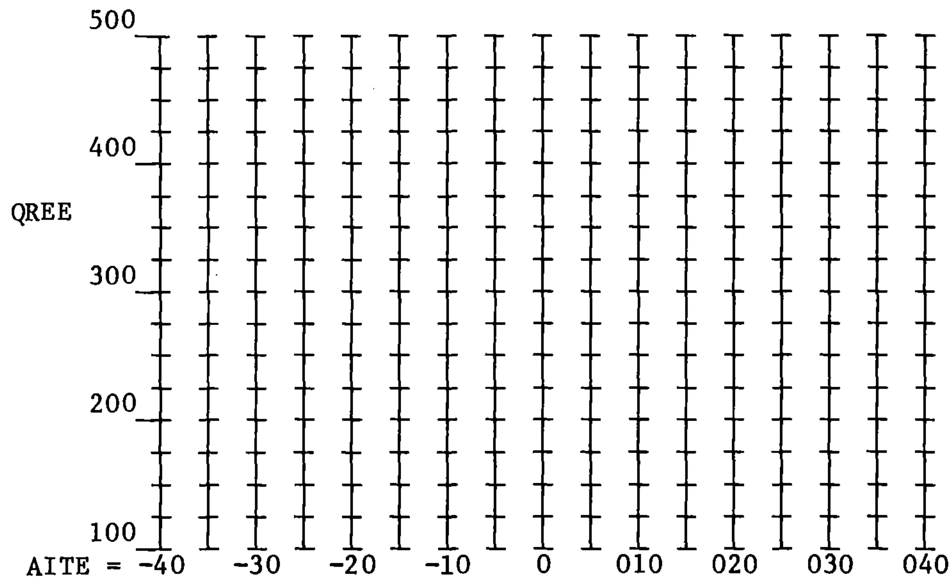
CHAPTER 15, WORKSHEET 1.3f

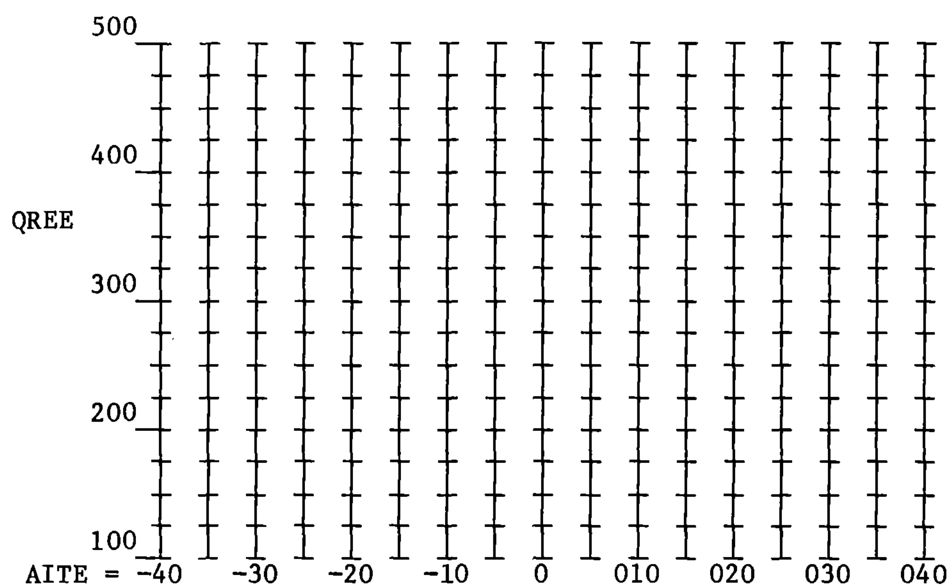
Infrared energy emitted by white-tailed deer

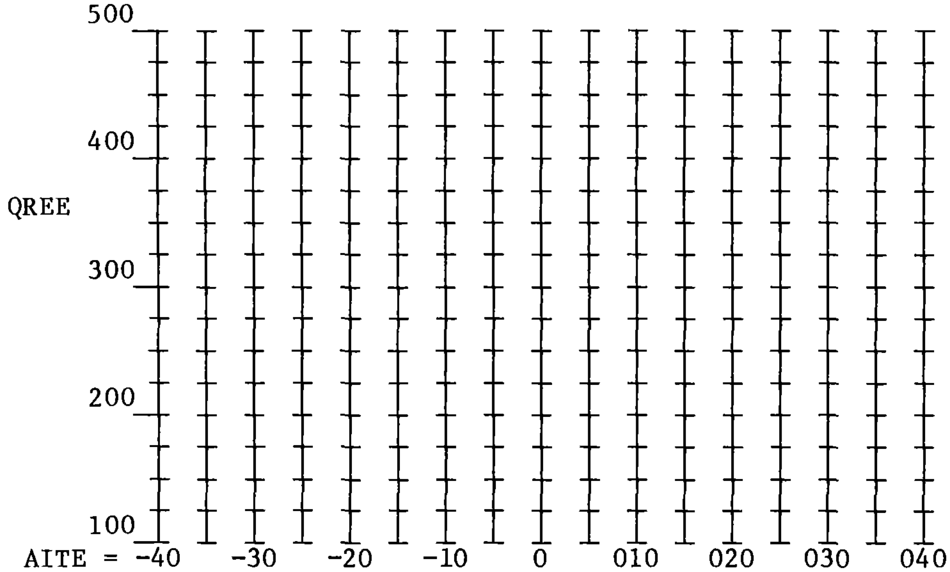
Using the radiant temperature results from the previous WORKSHEET, calculate infrared energy using the formula for QREE in WORKSHEET 1.3c.

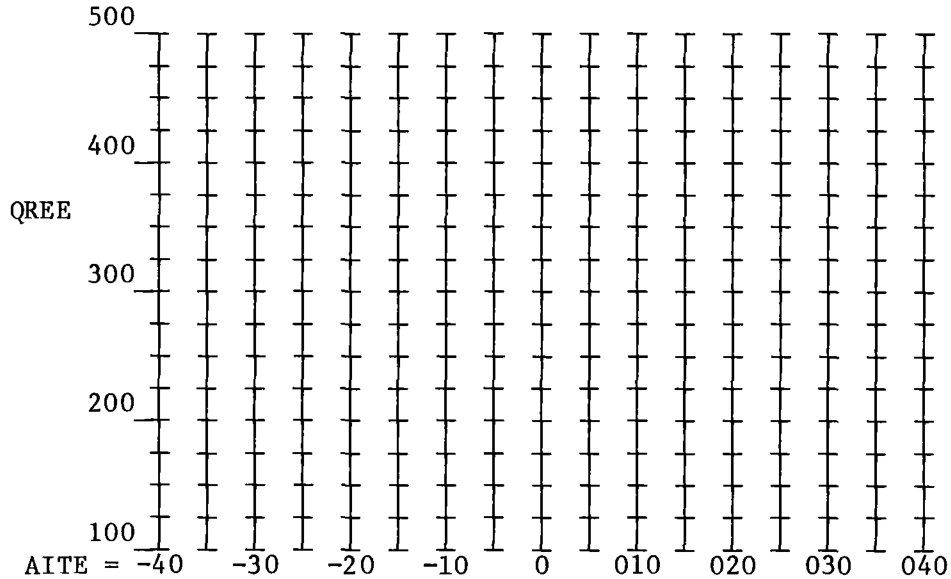
$$QREE = 4.876 \times 10^{-8} \ RATK^{4}$$

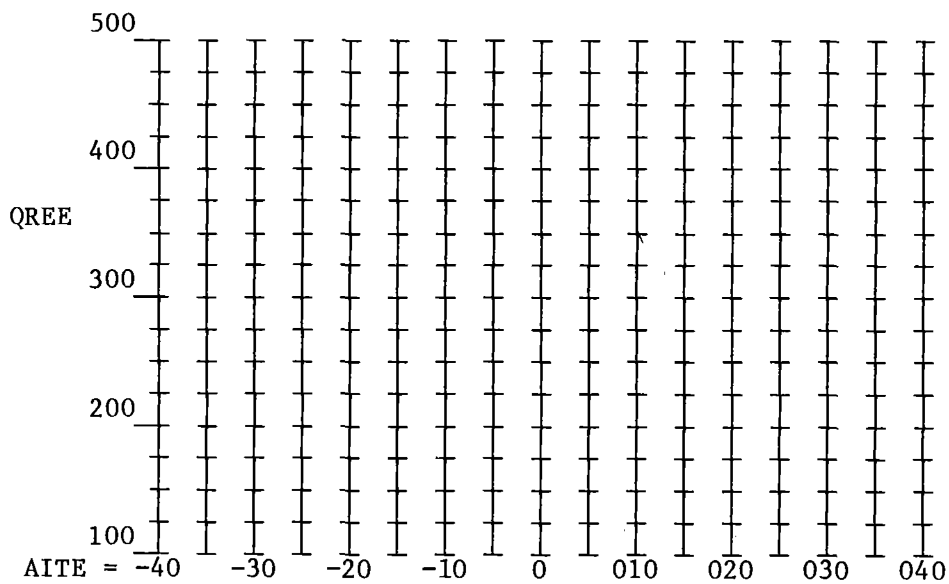
Plot the results in the grids below and on the next page. Label each line you plot with the appropriate WIVE.






500
400
QREE
300
200
100
AITE = -40 -30 -20 -10 0 010 020 030 040


500
400
QREE
300
200
100
AITE = -40 -30 -20 -10 0 010 020 030 040

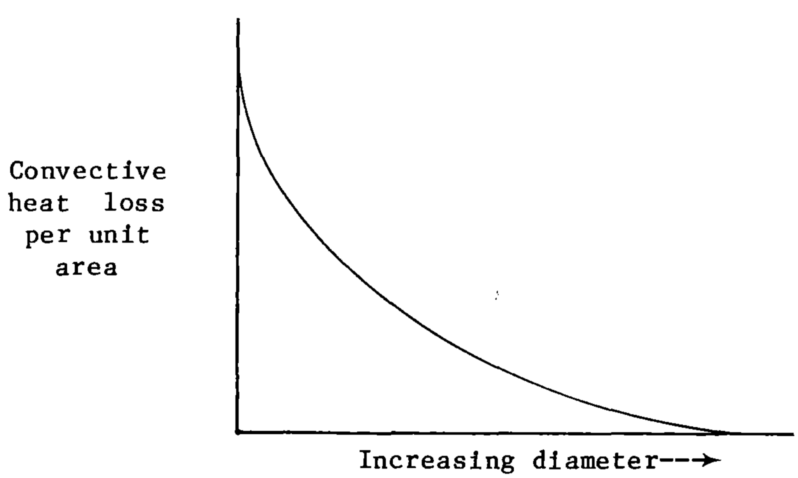

500
400
QREE
300
200
100
AITE = -40 -30 -20 -10 0 010 020 030 040

TOPIC 2. CONVECTION

Convection is the transfer of heat by the movement of a fluid across the surface of an object, or convector. Sometimes the fluid movement is generated by temperature, and hence density differences, in the fluid itself. This is called natural, or free convection. If the sun is shining on a bedded deer, for example, the deer's hair absorbs some of the solar energy and is warmed. The warmer air near the surface of the hair becomes less dense and rises and cooler air replaces it. Free convection currents are occurring over the deer's surface. Fluid (air in this case) movement generated by pressure differences external to the fluid-convector interface is called forced convection. Wind, or general atmospheric motion, is natural convection over the earth's surface, and it causes forced convection over the surface of plants, animals, and physical objects on the earth's surface.

Every plant and animal exposed to the atmosphere or liquid water is participating in natural or in forced convection. Their vertical dimensions place their surfaces in different parts of the wind profiles discussed earlier, and the movement of air is very complex because of turbulence. As a result, convection can also be expected to be a complex process. It can, however, be considered conceptually with some expressions of basic patterns.

What do you think the pattern of convective heat loss looks like for convectors of different sizes? Convectors with very small diameters are very efficient convectors, and those with larger diameters are less efficient. Convection coefficients are used to express the rate of heat transfer from the convector to the atmosphere. They have been calculated for smooth surfaces by thermal engineers, and vary with the size and shape of the convector. Smooth cylinders certainly do not approach the geometric complexities of plants and animals, however, nor do they account for the effects of rough hair insulation. The use of these coefficients does help us understand the effects of wind on plants and animals, and may be used to illustrate the process of convection. Note in the drawing below that small increases in convector diameter result in rapid declines in the heat loss per unit area.



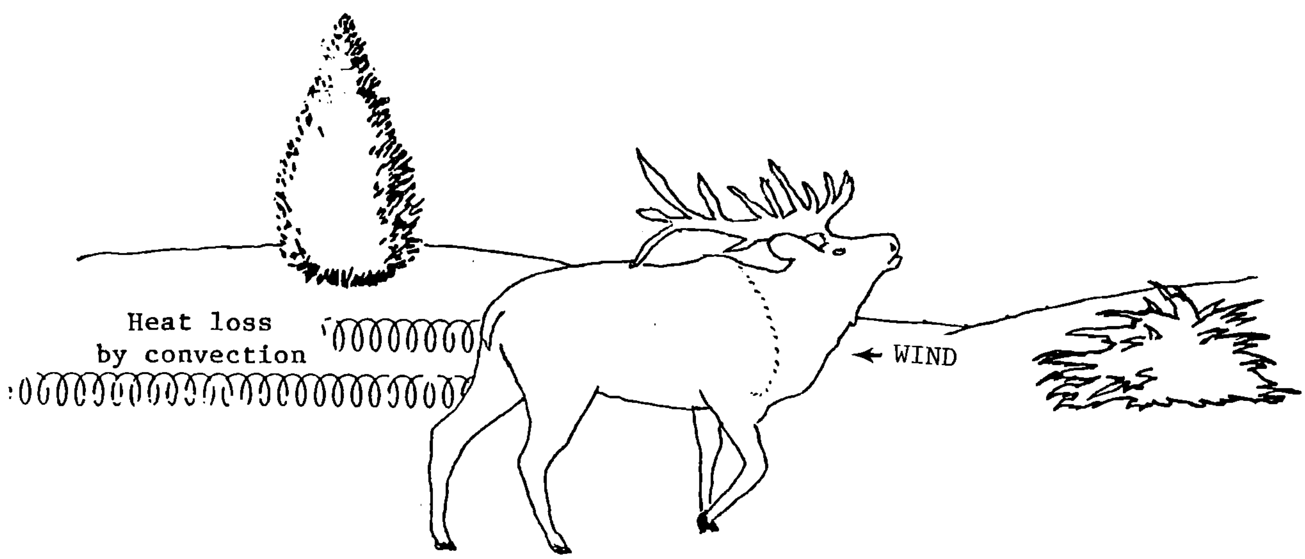
The quantity of convective heat loss (QCVE) can be expressed conceptually with the formula:

$$QCVE = (COCO)(SUTE - AITE)(SACV)$$

where QCVE = convective heat loss,
COCO = convection coefficient,
SUTE = surface temperature,
AITE = air temperature, and
SACV = surface area of the convector.

The efficiency of the convector, a function of its geometry, is expressed by the convection coefficient. The actual amount of convection is a function of the temperature difference between the convector and the air moving past it and the surface area of the convector.

It is interesting to consider the idea that every animal, every moment of its life, participates in convective heat exchange, yet there are no measurements of this process. The wind blows, and we tend not to know where it comes from or where it goes, and often pay little attention to what it does.



UNIT 2.1: NATURAL CONVECTION

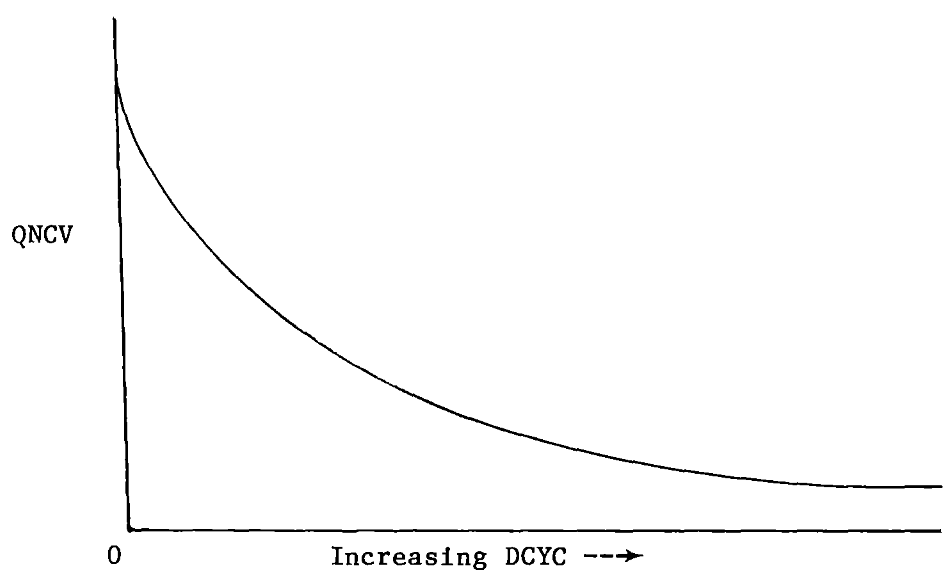
Natural, or free convection is a form of heat loss due to fluid movements resulting from temperature and density differences in the thermal boundary region. Warmer air near the animal rises, taking the heat absorbed from the animal's surface with it. Thus, a warm animal in cool, still air has a "plume" that rises into the atmosphere above the animal.

The transfer of heat energy by free convection may be estimated from three variables, including the geometric characteristics of the convector, the convection coefficient, and temperature differences between the surface and the atmosphere. The general formula for natural convection from horizontal or vertical cylinders in laminar flow, modified from Rosenberg (1974:81) is:

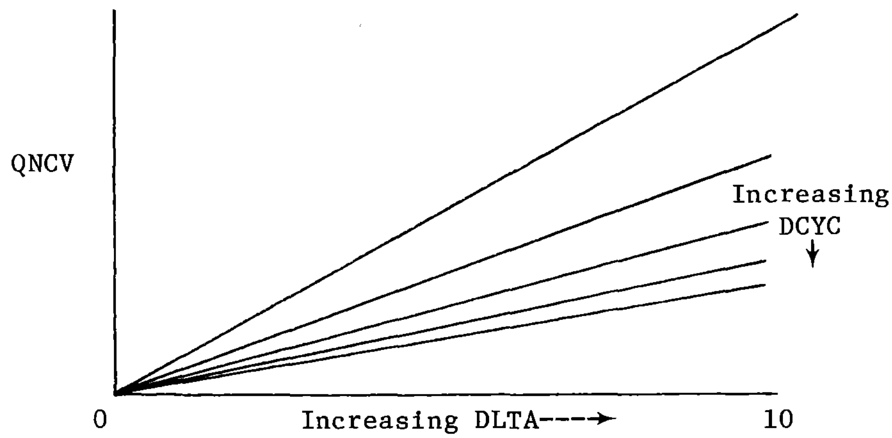
$$QNCV = 3.516\ (DLTA/DCYC)^{1/4}\ SANC$$

where QNCV = quantity of natural convection in kcal $m^{-2}\ hr^{-1}\ {}^{\circ}C^{-1}$,
DLTA = Delta T = temperature difference in °C between the convective surface temperature and the surrounding air,
DCYC = diameter of the cylinder in cm, and
SANC = surface area involved in natural convection (in square meters; see UNITS for QNCV).

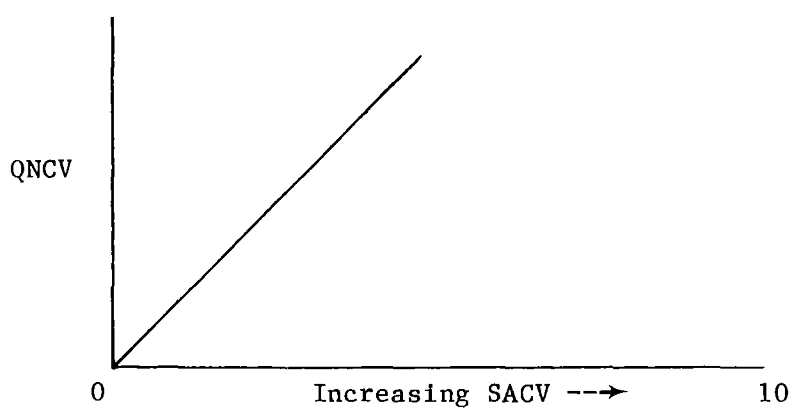
Cylinder diameter effects. The illustration below shows the effects of cylinder diameter on the pattern of natural convection. Note that the greatest amount of change in the amount of natural convection occurs at the smallest diameters. Small cylinders are more closely coupled to the effects of natural convection than are larger ones; that is mathematically expressed with the 1/4 power function in the formula.



Temperature differences. The illustration below shows that for each cylinder diameter, the effects of temperature differences are linear; each of the lines is straight. The spacings between the lines for different DCYC are unequal due to the effect shown of cylinder diameter discussed in the previous paragraph.



Surface area. As the surface area of a convector increases, the heat lost by natural convection increases if the diameter of the convector remains constant. Changes in surface area are then due to changes in length alone. The differences themselves are directly proportional to changes in length and resulting surface area since SACV is the final component of the formula and functions as a simple multiplier. If changes in area are due to changes in diameter but not length, then SACV is on the X-axis and QNCV is on the Y-axis. If changes in both diameters and surface areas occur, an infinite number of combinations of these two parameters could occur; the X:Y:Z axis are SACV:QNCV:DCYC.



Opportunities for calculations of various combinations of inputs for variables are provided on the WORKSHEETS that follow.

LITERATURE CITED

Rosenberg, N. J. 1974. Microclimate: The Biological Environment. John Wiley & Sons, N.Y. 315 p.

REFERENCES, UNIT 2.1

NATURAL CONVECTION

SERIALS

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS------------------	AUTHORS----------	YEAR
JRMGA	27--5	401	403	odvi	radiant temp, hair surface	moen,an	1974

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
				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
IJBMA	20--2	139	156	doru	meteorology in animal prod	bianca,w	1976
JAPYA	37--3	443	446	doru	heat flow meters, heat los	mcginnis,sm; ingr	1974

Natural convection as a function of the diameter of the convective cylinder

The formula from Rosenberg (1974:81) for the quantity of natural convection (QNCV) may be used to calculate the effects of the diameter of the convecting cylinder by using the value 1.0 for DLTA and SANC (see UNIT 2.1). The formula:

$$QNCV = 3.516\ (DLTA/DCYC)^{0.25}\ SANC$$

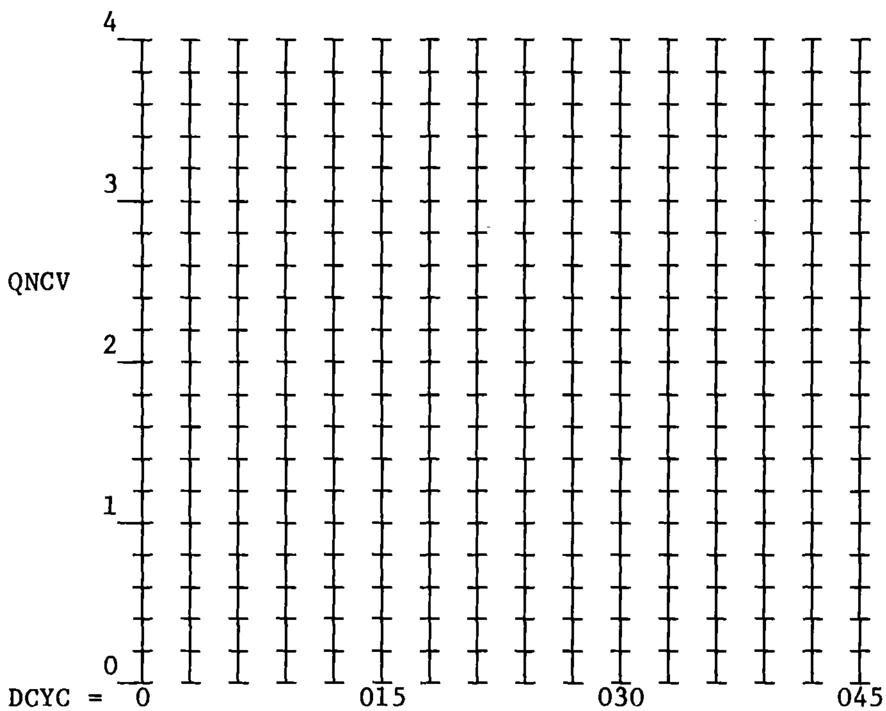
then becomes

$$QNCV = 3.516\ (1/DCYC)^{0.25}\ 1.0$$

which, in simplest form is:

$$QNCV = 3.516\ (1/DCYC)^{0.25}$$

Substituting 1, 5, 10.....45 cm for DCYC, calculate QNCV and plot the results below.



UNIT 2.2: FORCED CONVECTION

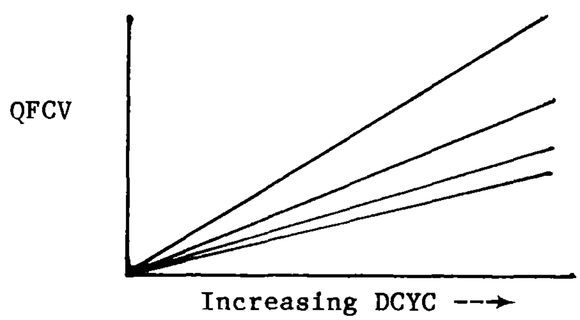
Forced convection is a form of heat loss due to movements of the air (wind) and to the movement of the animal itself. Three variables, including the wind velocity (WIVE), the diameter of the convector (DCYC), and the difference between the surface temperature of the convector and air temperature (DLTA), are used when calculating forced convection. The general formula, modified from Gates (1962), is:

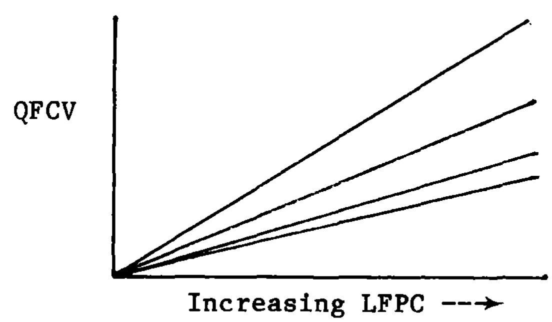
$$QFCV = 3.702\ [(WIVE^{1/3})/(DCYC^{2/3})](DLTA)(SAFC)$$

where QFCV = quantity of forced convection,
WIVE = wind velocity in cm per second,
DCYC = diameter of the cylinder in cm,
DLTA = temperature difference in °C, and
SAFC = surface area involved in forced convection, in square meters.

Formulas are also available for calculating forced convection from flat plates, where the length of the plate replaces diameter of the cylinder as the characteristic dimension.

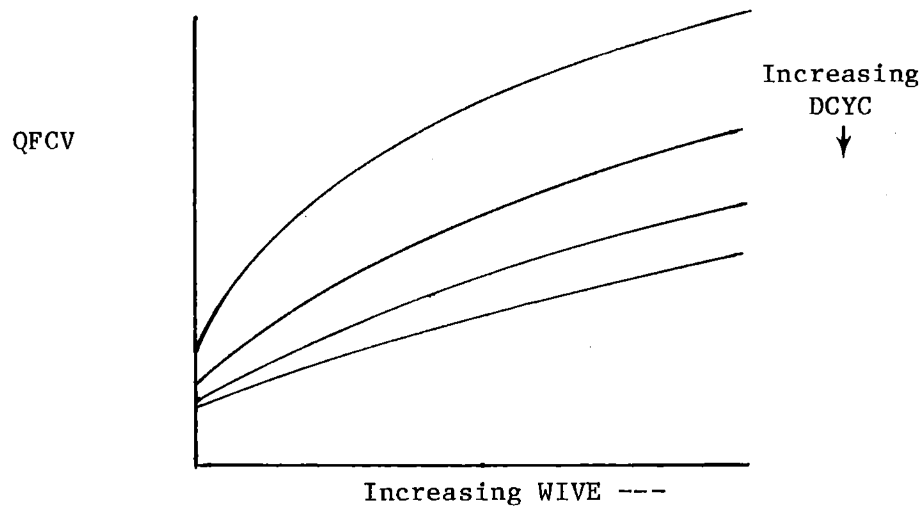
Convector geometry effects. The effects of changes in the diameter of cylinders (DCYC) and the lengths of flat plats (LFPC) are illustrated below.



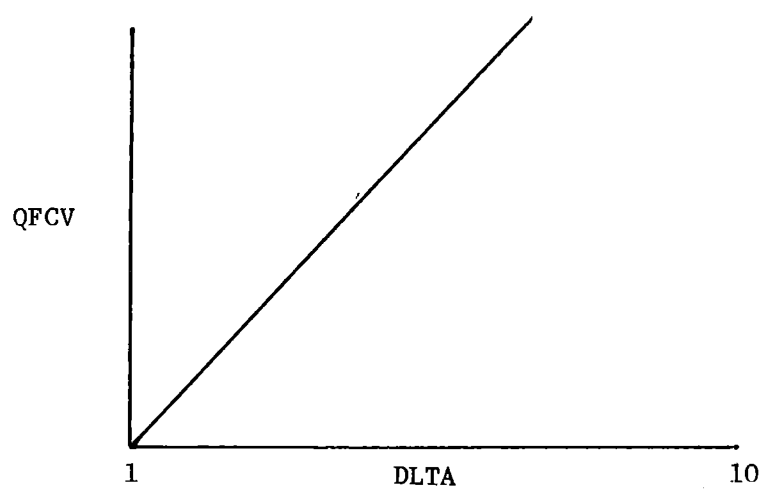


The smaller the diameter of the cylindrical convector or the length of a flat plate convector, the greater the sensitivity to changes in WIVE. Efficiency of heat loss is associated with small-diameter convectors and short plates. The non-linear characteristic of this relationship is clear.

Wind velocity effects. The results used to plot the illustrations above were based on a single wind velocity. The effects of a range of wind velocities may be plotted with a family of curves for different diameters and flat plats in relation to WIVE on the X-axis. Greater relative effects are observed at the lower wind velocities, although the absolute quantities of heat loss increase as wind velocities increase. The pattern of this relationship is illustrated at the top of the next page.

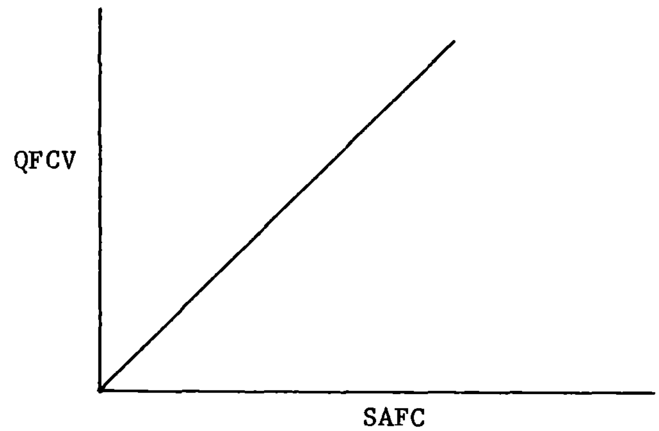


<u>Temperature differences</u>. When wind velocities and the characteristic dimensions of the convectors remain constant, the amount of heat loss per unit surface area is directly proportional to the temperature differences. This is obvious from the formula; DLTA functions as a simple multiplier after the non-linear effects of WIVE and DCYC or LFPC have been considered. The effects of temperature differences are illustrated below.



Calculations of these relationships are made in the WORKSHEETS that follow.

Surface areas. Heat lost by forced convection is directly proportional to wind velocities, the characteristic dimensions of the convector, and the temperature differences when these three parameters remain constant in a given set of conditions. Like DLTA discussed above, SAFC is a multiplier at the end of the formula. It is important to remember that the geometry is a very important consideration, however, since a surface area of two square meters of a very long, thin cylinder has a higher convective loss than two square meters of surface area of a short, thick cylinder.



Opportunities for calculations are given in the WORKSHEETS that follow.

LITERATURE CITED

Gates, D. M. 1962. Energy Exchange in the Biosphere. Harper and Row, Publishers, N. Y. 151 p.

REFERENCES, UNIT 2.2

FORCED CONVECTION

BOOKS

TYPE	PUBL	CITY	PAGE	ANIM	KEY WORDS-----------------	AUTHORS/EDITORS--	YEAR
aubo	gaul	loen	234	rata	the wind and the caribou	munsterhjelm,e	1953

SERIALS

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
JRMGA	27--5	401	403	odvi	radiant temps, hair surfac	moen,an	1974
JWMAA	32--2	338	344	odvi	surf temp, radiant heat lo	moen,an	1968
JWMAA	38--2	366	368	odvi	radiant temp surface, wind	moen,an; jacobsen	1974
NAWTA	35---	106	114	odvi	func aspects wind, thermal	stevens,ds; moen,	1970

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	38--4	679	688	rata	eff wind, moist newb htlos	lentz,cp; hart,js	1960
NJZOA	19--1	89	91	rata	surf tmps, heat los condit	wika,m; krog,j	1971
TRJOA	25-10	832	837	rata	thermal insulation of pelt	moote,i	1955
ZOLZA	53--5	747	755	rata	[body surfac heat emissio]	segal,an; ignatov	1974
JTBIA	47--2	413	420	rata	wind chill, solar radiatio	oritsland,na	1974

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
JANSA	35--3	624	627	doca	physic principl energ exch	morrison,sr	1972
JASIA	74--2	247	258	doca	accum, evap moist, sweatin	allen,te; bennet/	1970

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
IJBMA	20--2	139	156	doru	meteorology in anim produc	bianca,w	1976
JAPYA	37--3	443	446	doru	heat flow meters, heat los	mcginnis,sm; ingr	1974

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
JASIA	52--1	25	40	dosh	partition heat los, clippe	blaxter,kl; grah/	1959

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
JAPYA	20--4	796	801	mamm	hair dens, wnd spd, h loss	tregear,rt	1965
BIOJA	11-12	1030	1047	----	energy exch, cylind append	wathen,p; mitche/	1971
JTBIA	35--1	119	127	----	convect resp syst, panting	seymour,rs	1972
PRLBA	188--	395	411	----	conductin, convectn, coats	cena,k; monteith,	1975

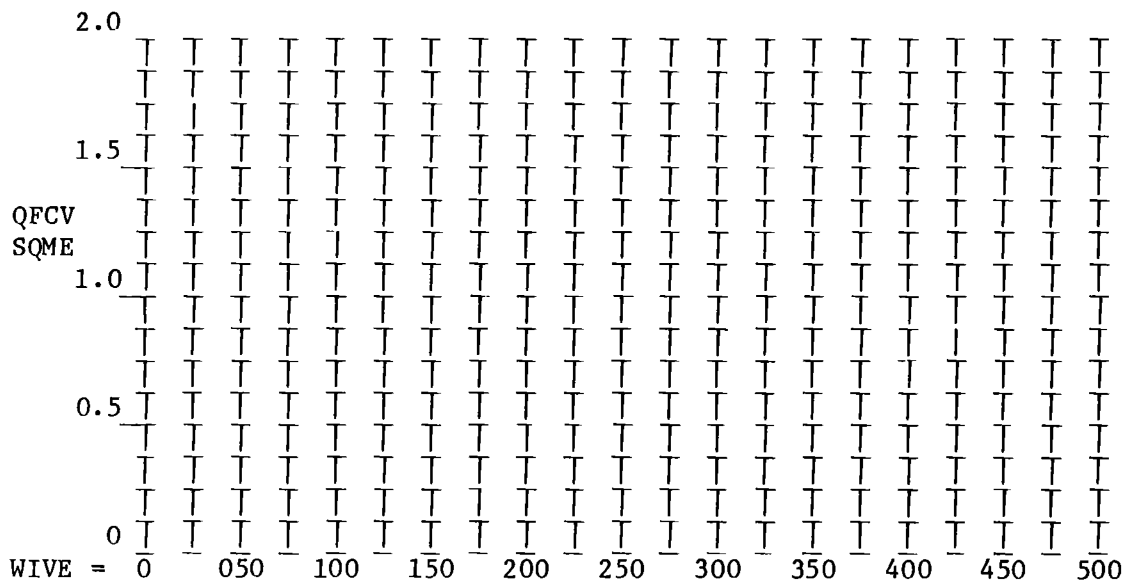
CHAPTER 15, WORKSHEET 2.2a

Forced convection in relation to wind velocity
and cylinder diameter

The quantity of forced convection (QFCV) may be calculated with various combinations of wind veloctiy (WIVE) and cylinder diameter (DCYC), using the formula, given in UNIT 2.2:

$$QFCV = 3.202\ [(WIVE^{1/3})/(DCYC)^{2/3})]\ (DLTA)(SAFC)$$

Complete a series of calculations using combinations of WIVE and DCYC and the value 1.00 for DLTA and SAFC, and plot the results below.



The results, expressed as the quantity of forced convection (QFCV) per square meter (SQME) is really a convection coefficient, an expression of the efficiency of heat transfer with various combinations of wind velocity and cylinder diameter This coefficient may be multiplied by DLTA and SAFC to determine the absolute amount of heat lost by forced convection from a defined surface.

TOPIC 3. CONDUCTION

Conduction is the transfer of heat energy in which kinetic energy is passed from one molecule to another by collisions. Thermal conductivity depends on the availability of free electrons drifting through intramolecular space, so metals, with an abundance of free electrons, are good conductors, and organic materials are generally poor conductors. Air has a low thermal conductivity, and air trapped between hairs in an animal's coat contributes significantly to the insulating properties of the hair coat.

Conduction is associated with temperature gradients as faster vibrating molecules, characteristic of higher heat energy, strike slower vibrating molecules and give up energy. Energy is dissipated from regions of higher temperature to regions of lower temperature regions. When the energy is equally distributed, molecular vibrations are on the average, uniform and energy exchange by conduction is equal in all directions.

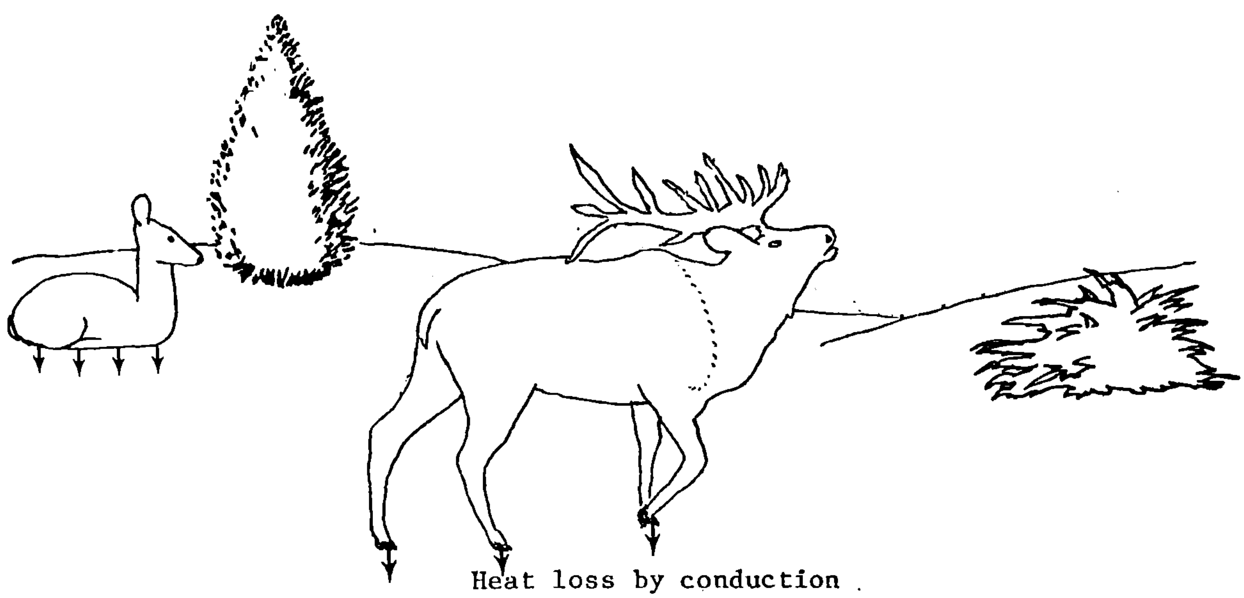
Ecologically, conduction is an important mode of heat transfer through the hair coats of animals to the soil and snow. An animal bedded in the snow, for example, has a subskin temperature that is higher than the snow. Heat energy passes through the skin and hair coat to the snow. The rate at which heat energy is conducted through the insulating hair is dependent on the depth of the insulating material, the temperature gradient between the skin and the snow, and the efficiency with which the hair conducts heat. The efficiency is expressed as a thermal conductivity coefficient, and is often represented by the symbol k. It is analagous to the convection coefficients discussed in the previous TOPIC.

The thermal conductivity coefficient may be defined as the rate at which heat passes through a given distance (one cm for example) of a substance when there is a temperature gradient of one degree. A good conductor has a higher thermal conductivity than a poor conductor. Hairy winter coats are expected to be poor conductors, of course.

The depth of the conducting material is an important variable in calculating conduction; the greater the depth of the conducting material, the less heat transfer by conduction. In other words, heat loss is inversely proportional to the depth of the hair coat.

The temperature difference across the hair coat is also important, of course; the greater the temperature difference, the more heat energy is transferred by conduction. Heat loss is directly proportional to the temperature difference across the hair coat. The actual depths and temperature differences act together, along with the thermal conductivity coefficient, in determining the actual amount of heat loss per unit area. Surface area and time are multipliers after the rates per unit time and area are determined.

Heat transfer by conduction is an important consideration for bedded animals since the loss of heat by conduction to the substrate is an important component of the total heat loss. This kind of conduction, with the conducting material (hair) enclosed between two barriers (skin and snow or soil) with no exposure to variable atmospheric conductions, is considered to be static conduction (UNIT 3.1). Hair exposed to the atmosphere has variable thermal conductivity coefficients as wind, moisture, and air temperature alter the thermal properties of the hair. No single thermal conductivity value is representative of the insulating qualities of porous materials such as hair under changing atmospheric conditions; this kind of conduction is called dynamic conduction (UNIT 3.2). Some important considerations pertaining to the use of static and dynamic conductivity coefficients are discussed in the next two UNITS.



Heat loss by conduction

UNIT 3.1: STATIC CONDUCTION

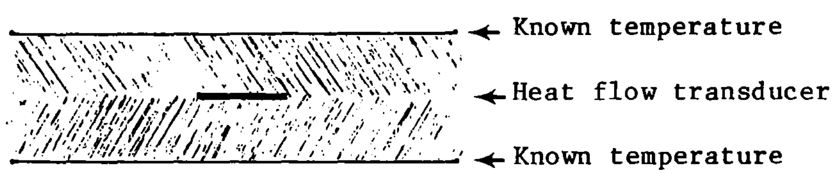
Static conduction occurs when the conducting material is enclosed between two solid barriers. The insulation between the walls of a home is enclosed between two solid barriers, the inside wall and outside wall, and hair in contact with the snow on the trunk of a bedded animal is enclosed between two solid barriers, the skin and the snow.

The quantity of heat conducted (QHCO) can be expressed with the formula:

QHCO = (TCCO)(SACD)(TIME)[(DLTA)/DPTH)]

where QHCO = quantity of heat conducted,
TCCO = the thermal conductivity coefficient per cm of hair depth, which must be expressed in the units for QHCO (kcal per square meter per hour, for example),
SACD = surface area involved in conduction,
TIME = time,
DLTA = delta T = temperature difference, and
DPTH = depth of conducting material.

Thermal conductivity coefficients are determined by enclosing the insulating material to be tested between two surfaces with different temperatures at a known distance apart. This is the procedure used in determining thermal conductivity coefficients with the Thermal Conduction Apparatus at Cornell's Wildlife Ecology Laboratory (See Evans and Moen 1975). The design the the Thermal Conduction Apparatus is illustrated below.



The heat energy conducted through the material being tested is measured directly and the formula above rearranged to solve for TCCO. If SACD = 1 unit and TIME = 1 unit, these may be dropped from the formula, and the rearrangement completed as shown below.

QHCO = TCCO [(DLTA)/(DPTH)]

which can be rearranged to:

TCCO = [QHCO][(DPTH)/(DLTA)]

The published literature on conductivity coefficients is based on these kinds of measurements. Values of k determined in this way are applicable to the surfaces of the animal in contact with the substrate; the insulating hair is enclosed between two barriers: skin and snow. The results of such measurements of static conduction should not be used when calculating heat loss from the skin surface to the free atmosphere. Atmospheric effects on conduction are discussed in the next UNIT (3.2) on DYNAMIC CONDUCTION.

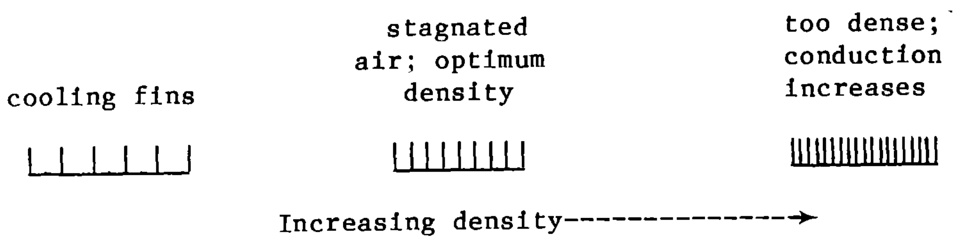
Measured conductivity coefficients of the coats of different species of wild ruminants tabulated below provide some indication of the amount of variation between species and between season. Since the depth of the insulating layer is part of the calculation, depth of the hair in cm (DHIC) must be known before TCCO can be applied. QHCO = quantity of heat (kcal m^{-2} hr^{-1}) conducted through the hair layer given, and is determined from TCCO/DHIC.

SPECIES	PELT CONDITION	DHIC	TCCO	QHCO	REFERENCE
odvi	Early fall, fresh	1.70	3.32	1.95	Hammel 1953
			3.30	1.94	
			3.29	1.94	
			(3.30)	1.94	
odvi	winter	2.39	3.06	1.28	Moote 1955
rata	Fresh winter pelt	2.50	2.88	1.15	Hammel 1953
rata	parka	1.50	3.26	2.17	Hammel 1953
rata	winter	3.28	3.81	1.18	Moote 1955
rata	summer	1.19	3.13	2.66	Moote 1955
rata	thin summer	0.74	3.06	4.14	Moote 1955
			3.21 ± 0.30		

Division of these thermal conductivities for different kinds of hair coats by their depths results in expressions of conductivity coefficients on a per-unit-depth basis, and the different hair coats can be compared. Then, conductivity coefficients of different species are not greatly different; the mean $\pm$ SD is 3.21 ± 0.30. Maximum TCCO is 3.81 kcal m^{-2} hr^{-1} $^{o}C^{-1}$, which is 1.32 times minimum k of 2.98, both observed in caribou. Hair depths, however, varied from 0.74 cm to 3.28 cm, a ratio of 4.43. Thus it appears that differences in hair depths contribute more to differences in overall insulation of wild ruminants than differences in the characteristics of the hair coats of different species.

Stagnant air is a poor conductor of heat and thus is good insulation. In fact, the major role of fibrous insulation such as hair is its stagnation effect on the air between the fibers, and the insulating values of hair coats is most related to their ability to trap and stagnate air. If the hair is very dense, there is less air space and conductivity will actually increase if the hair shafts are better conductors than air. This was discussed by Hammel (1953) and demonstrated for cattle.

Interesting considerations can be raised concerning the function of the hair coat as a layer of insulation in relation to the role of individual hairs as cooling fins. Scattered individual hairs, projections from the skin, function as effective cooling fins as their small diameter keeps them closely coupled to the atmosphere. When their density increases and they tend to slow down and stagnate the air, then the hairs begin to function as a layer of insulation. The transition from the two functions--convection and conduction--is dependent on the density of the hairs. Optimum hair density as a layer of insulation occurs when the contribution of the stagnant air to the overall insulation of the hair-air interface is at maximum. Hair that is too dense results in an increase in conductivity.



Conductivity of air is temperature dependent, being greater at higher temperatures. It is 2.07 kcal per square meter per hour per cm depth at 0 C, so 2.07 is the intercept a in the equation below, and the change in conductivity for each degree (Celsius) change in air temperature is 0.00648. The linear regresion equation is (from Moen 1973; 98):

$$CCAI = 2.07 + 0.00648\ AITE$$

where CCAI = conductivity coefficient of air, per cm depth, in kcal per square meter per hour per °C, and
AITE = air temperature in °C.

This equation rather than a single value will be used in later calculations of the conductivity of air. Note that the conductivity of air at 0°C is only 64% of the average conductivity of deer and caribou hair (2.07/3.21 = 0.64). Air is better insulation than hair, which doesn't seem right until it is remembered that the air must be <u>stagnant</u>. The moving air in the atmosphere around an animal does not meet that condition. The properties of the hair coat which stagnate the air are most important in determining the overall insulation of the hair coat.

Compression effects. The compression of fibrous insulation such as hair maybe an important consideration in the rate of conductive heat loss. A bedded deer, for example, compresses the hair on its legs and trunk, and it is generally known that compression of insulation, reducing both its thickness and the amount of air space in it, reduces its effectiveness as insulation.

Effects of hair inclination. The inclination of the hair shafts can theoretically affect the rate of conduction through the hair, with the lowest rate of conduction when the fibers are parallel to the plane of the insulation and perpendicular to the plane of the insulation and parallel to the direction of heat flow (See Moen 1973). Hair in normal lie falls between these extremes. Piloerection decreases the insulation value of the fur per unit depth, but the increase in depth compensates for the change in hair inclination (Hammel 1953); the total insulation of erect fur was slightly greater than the total insulation of fur in normal position. While this consideration is of definite interest, data on different species are lacking because of the difficulty, if not impossibility of measuring heat flow in vivo on piloerected and normal-lie hair. Further, metabolic considerations which result from muscular contractions necessary to erect the hair also affect the thermal exchange through the hair surface. This is discussed by Moen (1973:282-283).

Effects of moisture. The amount of moisture in the coat has a marked effect on the rate of heat flow through the hair layer. This was indicated by the large increase in the metabolism of infant caribou when their coats were wet (see CHAPTER 16, UNIT 1.6), and by observations at the Wildlife Ecology Laboratory of deer bedded during sleet-like snow when the heart rate was 100% higher and breathing rate 23% higher than on another day two weeks earlier when snow was not falling (Moen and Jacobsen 1973:521). Moisture not only changes the conductivity per se, but adds the further consideration of heat loss by evaporation which, due to the large heat of vaporization, is potentially great. There are no data on conductivity coefficients of hair coats with different amounts of moisture, however.

The discussions in this UNIT have centered on the role of hair in static conduction, applicable only to an insulation enclosed between two barriers and not to hair coats exposed to the atmosphere. Considerations necessary when analyzing thermal conductivity characteristics of hair coats exposed to the atmosphere are discussed next, in UNIT 3.2: DYNAMIC CONDUCTIVITY.

LITERATURE CITED

Evans, K. E. and A. N. Moen. 1975. Thermal exchange between sharp-tailed grouse (Pediocetes phasianellus) and their winter environment. The Condor 77:160-165.

Hammel, H. T. 1953. A study of the role of fur in the physiology of heat regulation in mammals. Ph. D. Thesis, Cornell University, 105 p.

Moen, A. N. 1973. Wildlife Ecology. W. H. Freeman Publishing, San Francisco. 458 p.

Moen, A. N. and F. L. Jacobsen. 1973. Thermal exchange, physiology, and behavior of white-tailed deer. Pages 509-524 In D. M. Gates and R. B. Schmerl (Eds.), Perspectives of Biophysical Ecology. Springer-Verlag, Inc., N.Y. 609 p.

Moen, A. N. and F. L. Jacobsen. 1974. Changes in radiant temperature of animal surfaces with wind and radiation. J. Wildl. Manage. 38(2): 366-368.

Moote, I. 1955. The thermal insulation of caribou pelts. Textile Res. J. 25(10):832-837.

REFERENCES, UNIT 3.1

STATIC CONDUCTION

SERIALS

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

odvi

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
TRJOA	55-10	832	837	rata	thermal insulation of pelt	moote,i	1955

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
PHZOA	30--2	93	105	many	melt pt anim fat cold clim	irving,l; schmid/	1957

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
AGMYA	18--5	387	400	dosh	conduction sheep to ground	gatenby,rm	1977
PHMBA	19--1	51	65	dosh	heat bal, therm resis, fle	cena,k; clark,ja	1974

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
ANYAA	53---	600	607	mamm	piliary sys, reln thrm env	herrington,lp	1951
BISNA	22-11	656	659	----	newtn's lw, ht los homeoth	tracy,cr	1972
CBCPA	21--2	405	414	----	therm con in brds and mamm	herreid,cf,ii;ke	1967
CJZOA	34...	53	57	----	season chngs in fur insula	hart,js	1956
PRLBA	188--	395	411	----	conducton, convectn, coats	cena,k; monteith,	1975

CHAPTER 15, WORKSHEET 3.1a

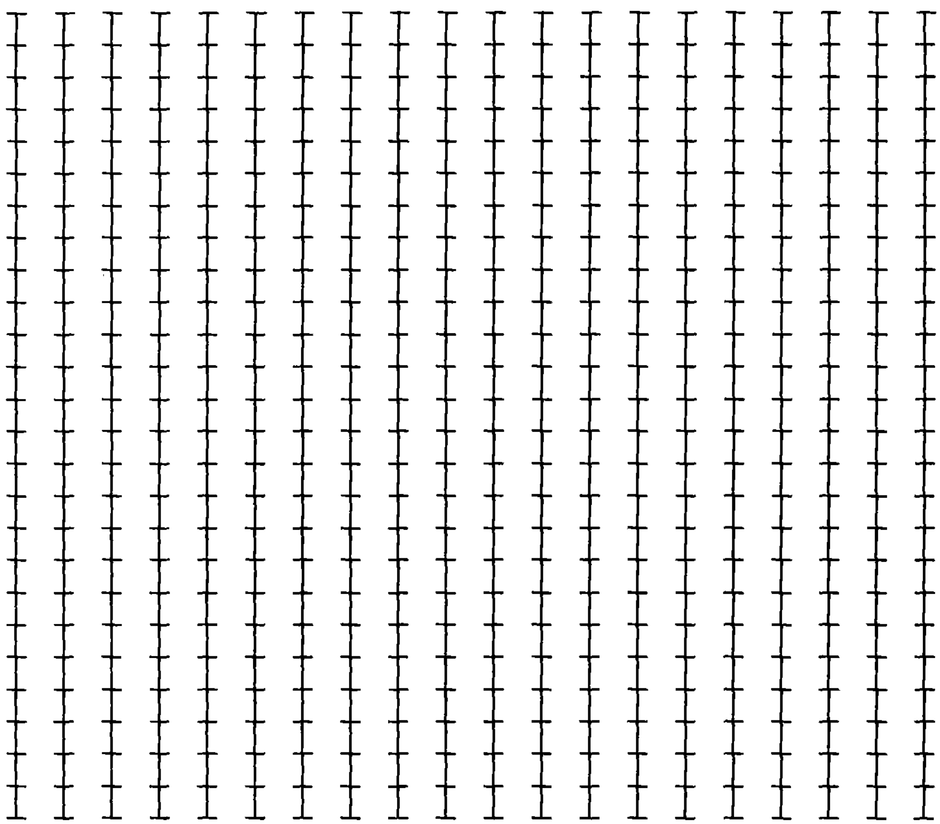
Conduction through the hair layer

Conduction through the hair layer with different conductivities per unit depth may be calculated with the following formula (See p. 37):

QHCO = TCCO [(DLTA)/(DPTH)]

Using data given on page 38 and other data available, plot conduction losses for different thermal conductivity coefficients and hair depths.

QHCO



TCCO or DHIC

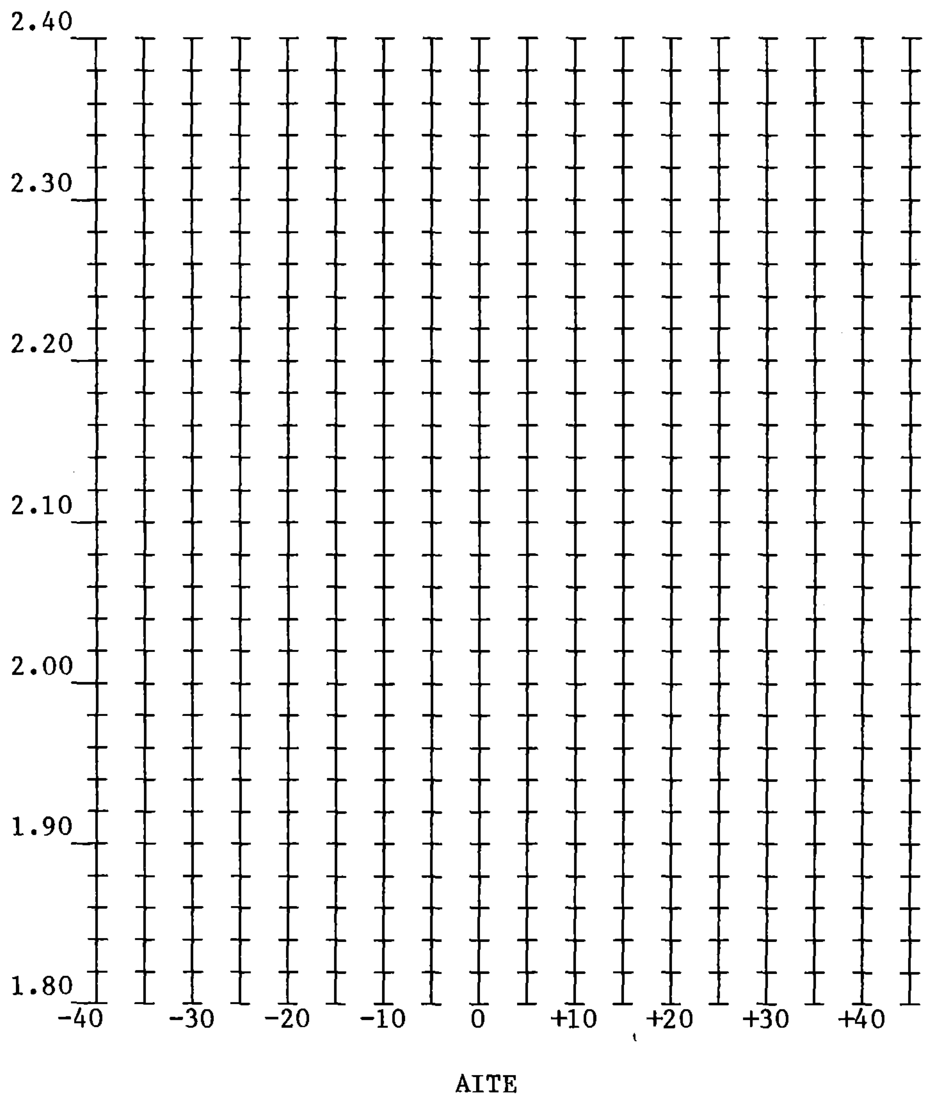
CHAPTER 15, WORKSHEET 3.1b

Conductivity of stagnant air in relation to air temperature

The conductivity coefficient of air, CCAI, in kcal per sq meter per hour per °C per cm depth may be calculated with the following equation, modified from Moen (1973):

$$CCAI = 2.07 + 0.00648\ AITE$$

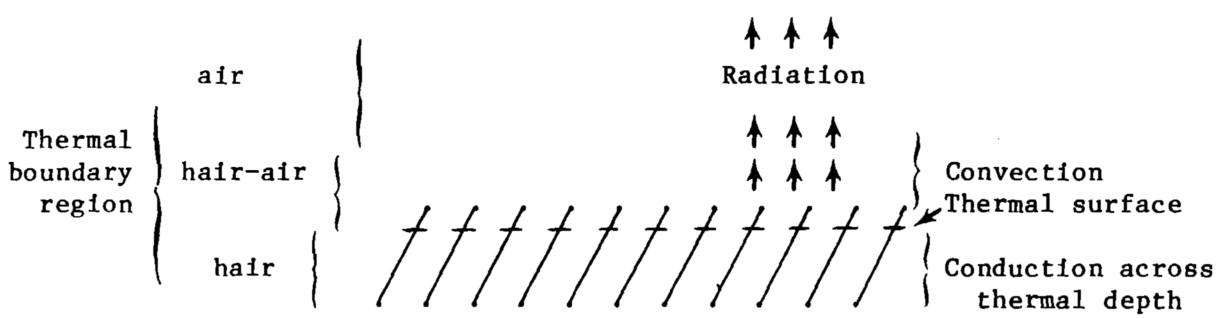
where AITE = air temperature in °C. Plot the results below.



UNIT 3.2: DYNAMIC CONDUCTION

The insulating value of fibrous hair coats when they are exposed to the atmosphere may be quite different from their insulating value when in direct contact with the soil or snow. Air penetrates the hair coat as a result of natural convection currents and wind, disturbing some of the air in the spaces between the hairs. The penetration of such fibrous insulation (hair) by wind alters its insulating value. The depth to which the wind penetrates is dependent on wind velocity and turbulence, with the velocity affecting the inertia of the wind as it strikes the coat and direction affecting the angle of attack by the wind.

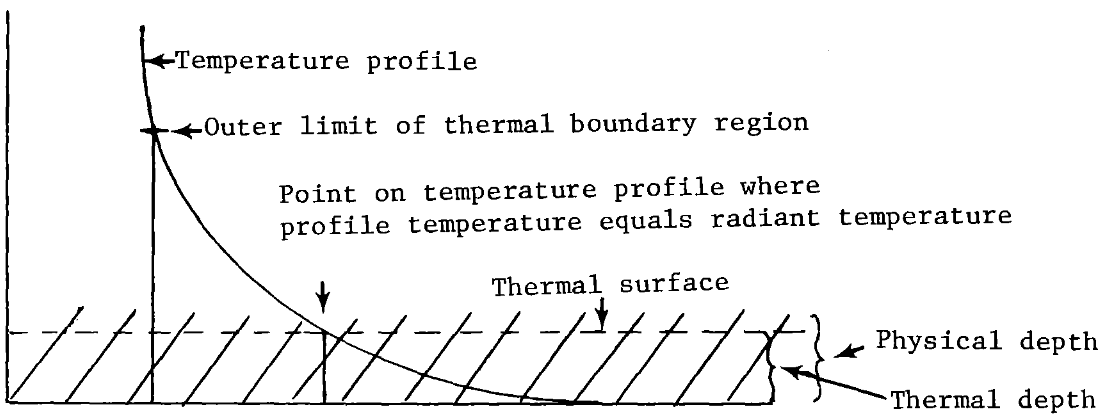
The depth of the hair (insulation) is a major factor determining the overall insulation of a hair coat. Disturbance of the air in the hair layer due to wind reduces the insulating value of the hair coat. If the disturbance were complete and there was no stagnant air present, conduction would no longer occur and heat transfer would be by convection and radiation only. This is not the case for wild ruminants, however, as their thick and rather long hair coats stagnate the air in the hair-air interface. Conduction is the dominant mode of heat transfer deep within the hair, and convection and radiation in the outer parts of the hair coat. This is illustrated below.



The heat loss by convection and radiation from the outer surfaces must equal the heat lost by conduction to the outer surfaces from the skin surface. As wind velocities and radiation flux change, conductivity changes due to changes in the temperature gradients and in the depth of the thermal boundary region. The conductivity of the entire physical depth of the hair coat must change as the air within the coat is disturbed; a single thermal conductivity coefficient cannot apply to a hair coat when atmospheric effects are considered. Several factors affecting these changes are discussed next.

THERMAL DEPTH

The dynamic, functional hair depth that is due to thermal characteristics of the pelage is called thermal depth (Moen 1973:261-262). It is determined by measuring the temperature profile from the skin out to the ambient atmosphere and the radiant temperature of the hair surface. Then, the point on the temperature profile where the radiant temperature equals profile temperature is determined, and the distance from that point to the skin is the thermal depth. The thermal depth can be measured on the plotted curves or determined mathematically after curve fitting the temperature profile. Thermal depth in relation to physical depth and the temperature profile is illustrated below.



THERMAL SURFACE

The plane parallel with the skin at the outer limit of the thermal depth is the thermal surface. It is the location of the radiant temperature, integrated over the horizontal and vertical depth of the target viewed by the radiometer, on the temperature profile. Thermal depth and thermal surface are theoretical parameters which, after measuring temperature profiles and radiant surface temperatures over a wide range of temperatures and wind velocities, illustrate the effects of wind and radiation on the effective depth of the insulating hair. The thermal depth approach and the concept of dynamic conductivity should divert attention away from the use of measured static conductivities for hair exposed to the atmosphere. An alternate and fundamental concept of insulation around animals is introduced in the next UNIT.

REFERENCES, UNIT 3.2

DYNAMIC CONDUCTION

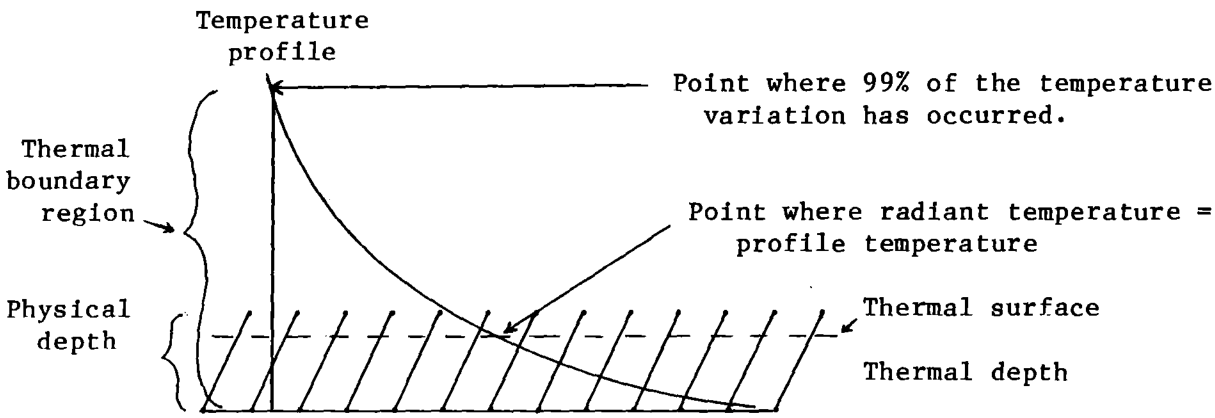
SERIALS

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

[No references on the concept of dynamic conduction have been found in the literature. Measurements of temperature profiles and heat transfer through pelts of animals have not been made.]

UNIT 3.3: THE THERMAL BOUNDARY REGION

The hair of an animal is usually thought of as its insulation, but that is a convenient rather than a correct conclusion. The hair coat of an animal is only part of the insulating medium surrounding the animal. The entire insulating medium is the thermal boundary region, and this is composed of the hair and the air surrounding the animal that is influenced by the animal and its coat of hair. Visualize an animal as being surrounded by a region of warmer air that can be delineated by a temperature profile through the hair-air interface as pictured below.



The outer limit of the thermal boundary region is defined as the point on the profile where 99% (a value commonly used in thermal engineering) of the variation in temperature from the skin to the free atmosphere has occurred. Since the outer part of the thermal boundary region is nothing but air with varying temperatures and densities, it is obviously very labile. The thermal boundary region has a greater depth in still air than in the wind, of course, since wind forcefully removes the warmed air next to the hair. A strong gust of wind just about completely destroys the thermal boundary region.

Identification of the thermal boundary region requires a series of temperature measurements from skin to ambient air. Such measurements must be made under controlled conditions, and have not been made for any of the wild ruminants except white-tailed deer. This species has been analyzed in the Thermal Environment Simulation Tunnel (See Moen 1973: Chapters 5,6, and 13) at the Wildlife Ecology Laboratory, Cornell University, where thermocouples were used at various distance intervals to measure temperatures through the entire thermal boundary region of different hair coats. The thermal boundary region may be divided into 3 layers: the hair layer, hair-air interface, and the air layer. Heat transfer occurs through each of these layers, at rates dependent on the thermal resistance of each layer. The overall resistance is equal to the sum of the resistances of each layer. Since the thermal boundary region is composed of both hair and air, convection and radiation exchange occur in addition to conduction. Thus an overall heat transfer coefficient is appropriate, describing the efficiency of heat transfer under different combinations of hair depths in relation to radiant energy, wind velocities, and air temperatures. Needless to say, no single overall heat transfer coefficient applies to a species, but there is rather a pattern of relationships between these thermal forces and the animal's hairy surface. Results of thermal boundary region measurements on white-tailed deer, analyses of data, and applications of this approach to thermal analyses are discussed in CHAPTER 16, TOPIC 2. Before going on to that, however, one more mode of heat transfer, evaporation, is considered here in CHAPTER 15.

LITERATURE CITED

Moen, A. N. 1973. Wildlife Ecology. W. H. Freeman Publishing, San Francisco. 458 p.

REFERENCES, UNIT 3.3

THE THERMAL BOUNDARY REGION

SERIALS

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

TOPIC 4. EVAPORATION

Evaporative heat loss occurs when the latent heat of vaporization resulting from a phase change from liquid water to gaseous water vapor is dissipated. This occurs in animals through respiration, evaporation of perspiration, and evaporation of surface water after the hair coat has become wet. Evaporative heat loss can be estimated with several methods. The mass transport method predicts evaporation as a function of vapor pressures. If the atmosphere has a lower vapor pressure than the surface of a plant or animal, water evaporates from the plant or animal until vapor pressure deficits at the surface and in the atmosphere are equal. It is relatively simple to calculate evaporation by this method, but it is not calculated very accurately, especially from aerodynamically rough surfaces in windy conditions when there is a lot of turbulence and hence atmospheric mixing. Then, the atmosphere never comes into equilibrium with the source of water even if the deficit is low. Several other approaches to calculating evaporative heat loss are described by Rosenberg (1974).

Evaporative heat loss is generally a minor fraction of total heat loss from animals at cold temperatures if their coats are dry. Respiratory exchange is low at least in some species, because the anatomy of the respiratory passages results in pre-warming and pre-cooling of the air that reaches the respiratory surface in the lungs, minimizing changes in vapor pressures of respired air. At high temperatures, evaporative heat loss is very important as a means of dissipating excess body heat by wild ruminants, and responses such as panting and sweating may be essential for survival. That is a good reason for evaluating them in considerable detail. Some animals use lakes and ponds as a means for keeping cool in the heat of summer. Moose, for example, spend considerable time in the water feeding while benefitting from the cooling effects of the water. Limited discussions of surface and respiratory evaporation follow in the next two UNITS.

LITERATURE CITED

Rosenberg, N. J. 1974. Microclimate: The Biological Environment. John Wiley & Sons, N. Y. 315 p.

UNIT 4.1: SURFACE EVAPORATION

Water vapor has mass, it occupies space, and therefore must have some place to be. The atmosphere has a capacity for holding water vapor that is dependent on atmospheric temperature. "Warm air can hold more moisture than cool air" is the usual phrase describing this relationship. The amounts held by the atmosphere at different temperatures were discussed in TOPIC 4 of CHAPTER 14. Heat transfer due to surface evaporation using a very simplified vapor pressure gradient approach is discussed here, with the full realization that it is not a good way to estimate something as dynamic as evaporative heat loss. It does serve to illustrate the basic idea, however, and indicates the similarities in the loss of heat energy by vapor pressure gradients to the the effects of temperature gradients on radiation, convection, and conduction losses.

The resistance approach to the transport of vapor may be considered an onlag of conduction from a surface to the air next to it. The transport of sensible heat proceeds at a rate directly proportional to the temperature gradient and inversely proportional to the resistance of the air to thermal conduction. Similarly, the transport of vapor is directly proportional to the vapor pressure gradient from the evaporating surface to the air and inversely proportional to resistance of the air to the diffusion of water molecules (Rosenberg 1974:167).

This is not unlike the mass transport method discussed by Rosenberg (1974:161) where the vapor pressure gradient is considered along with a "windiness" factor. The windiness of the atmosphere affects the thermal resistance; the two parameters are related. It is interesting that the mass transport method discussed by Rosenberg is attributed to research completeed by Dalton about 1800. The "Daltonian equation" is:

$$E = C\,(e_o - e_a)$$

where E is evaporation, C is an empirically determined constant involving some function of windiness, e_o is the vapor pressure at the surface, and e_a is the actual vapor pressure in the air at some point above the surface.

Modifications of this equation that have been proposed are described by Rosenberg (1974:162). The equation proposed by Penman (1948) requires measurement of vapor pressures at the surface and in the atmosphere and wind velocity 2 meters above the ground. The equation is:

$$E = 0.40\,(e_o - e_a)(1 + 0.17\,u_2)$$

where E = evaporation,
e_o = vapor pressure at the surface,
e_a = vapor pressure in the atmosphere, and
u_2 = wind velocity at two meters.

The use of this equation illustrates the contributions of vapor pressures (which are partial functions of temperature) and wind velocities to evaporation.

The next step in determining the amount of heat energy involved in evaporation. The amount of heat required to vaporize water--the heat of vaporization--is temperature-dependent. This is often overlooked in general science and elementary physics books where the heat of vaporization is given as a single value, 540 cal per gram, which applies only to 100 ^{o}C. Evaporation of water from an animal requires from 596 cal per gram of water evaporated at 0 ^{o}C to 574 cal per gram at 40 ^{o}C (Fairbridge 1967). The larger energy requirement for the heat of vaporization at lower temperatures is necessary because more energy is needed to break the chemical forces between cooler liquid water molecules that are vibrating more slowly than warmer ones that are vibrating faster. The heat required for evaporation can come from the organism or the environment.

The relationship between the heat of vaporization and air temperature may be expressed with a linear regression equation (Moen 1973: 99):

$$HEVA = 595.59 - 0.5376\ ATTE$$

where HEVA = heat of vaporization (calories), and
ATTE = atmospheric temperature (C).

The use of such an equation is certainly preferable to the use of a single value, or to the use of some other value for "average" temperatures. Completion of the graph in the WORKSHEET that follows provides a nomogram for quick estimates, and the equation is easily programmed into a series of calculations.

LITERATURE CITED

Fairbridge, R. W. (Ed.) 1967. The Encyclopedia of Atmospheric Sciences and Astrogeology. Reinhold Publ. Corp. N.Y. 1200 p.

Moen, A. N. 1973. Wildlife Ecology. W. H. Freeman and Sons. San Francisco. 458 p.

Penman, H. L. 1948. Natural evaporation from open water, bare soil, and grass. Proc. Roy. Soc. Lond. A. 193: 120-145.

Rosenberg, N. J. 1974. Microclimate: The Biological Environment. John Wiley & Sons, N.Y. 315 p.

REFERENCES, UNIT 4.1

SURFACE EVAPORATION

BOOKS

TYPE	PUBL	CITY	PAGE	ANIM	KEY WORDS-----------------	AUTHORS/EDITORS--	YEAR
aubo	jwis	nyny	315		microclimat; biolog envir	rosenberg,nj	1974

SERIALS

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

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	38--4	679	688	rata	eff wnd, moist, ht ls,newb	lentz,cp; hart,js	1960

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
BVJOA	124--	83	88	doca	evap htloss, mech, newb cf	hales,jrs; findl/	1968
JASIA	74--2	247	258	doca	accum & evap moist, sweatg	allen,te; bennet/	1970

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
IJLAA	46--8	459	460	dosh	evaporation, colorat effec	singh,m; acharya,	1976
IJLAA	47--6	67	368	dosh	heat dissip, diff typ shee	singh,m; acharya,	1977
JAPYA	26--5	517	523	dosh	eff temp, wool lengt, evap	hofmeyr,hs; guid/	1969
RSPYA	30--3	327	338	dosh	thermorespir respon, shorn	hofman,wf; riegle	1977
RSPYA	30--3	339	348	dosh	respir ht loss regu, shorn	hofman,wf; riegle	1977

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
JPHYA	284--	162p	163p	dogo	core temp, resp loss, exer	jessen,c; mercer,	1978

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
JDSCA	51-10	1689	1692	rumi	surf evap rates, effe temp	joshi,bc; mcdowe/	1968
SZSLA	31---	345	356	doru	evaporativ temp regulation	jenkinson,dm	1972
SZSLA	31---	357	369		evap heat loss, arid envir	bligh,j	1972

CHAPTER 15, WORKSHEET 4.1a

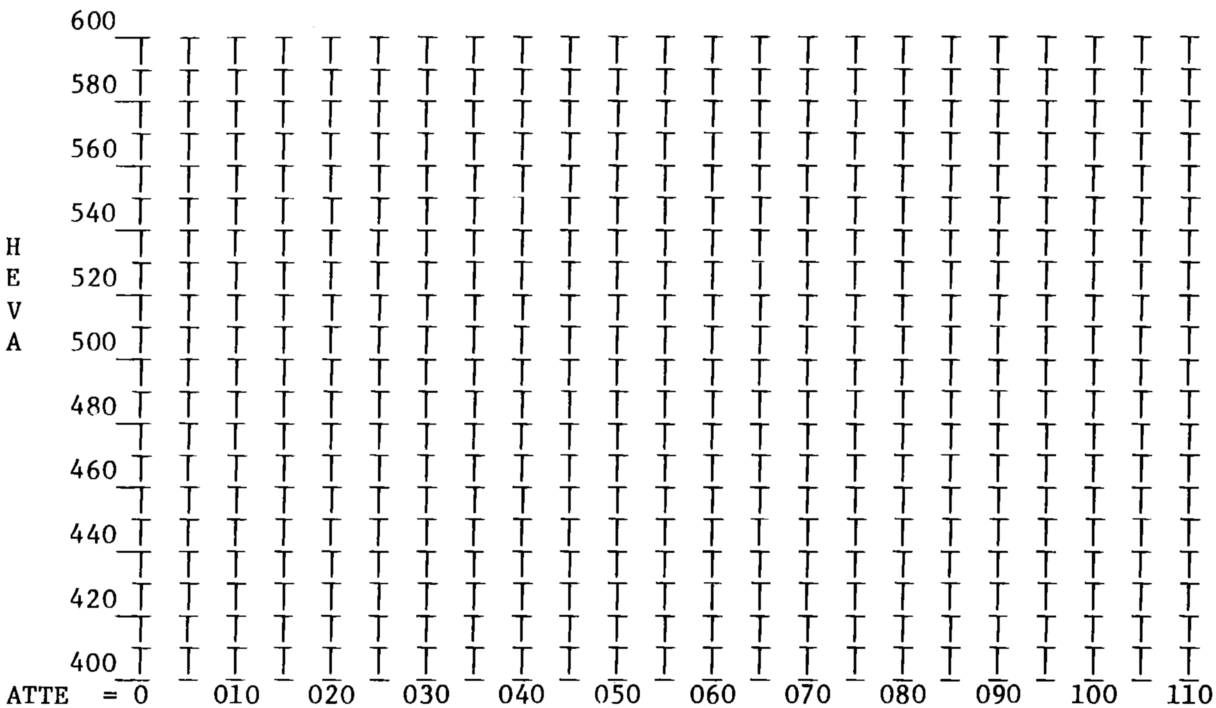
Heat of vaporization

The relationship between the heat of vaporization and air temperature may be expressed with a linear regression equation from Moen (1973:99). The equation is:

$$HEVA = 595.59 - 0.5376\ ATTE$$

where HEVA = heat of vaporization (calories), and
ATTE = atmospheric temperature (°C).

Calculate HEVA for the maximum and minimum temperatures given on the graph and convert the values of HEVA with straight line.



UNIT 4.2: RESPIRATORY EVAPORATION

Evaporation from the respiratory tract must follow the basic physical principles with regard to vapor pressure gradients discussed earlier, but the dynamics of external respiration make the exchange of heat by respiratory means much more complex. Air movement is forced as a result of movements of the diaphragm. Turbulence is expected as air moves through the respiratory tract since there are folds or convolutions in the respiratory tract that extend the distance tranversed by the air before entering or leaving the nasal cavity and lungs. This results in warming of the inhaled air and cooling of the exhaled air, which is an energy convection mechanism of particular significance to northern species such as caribou.

The calculation of respiratory evaporation on theoretical bases is impossible due to the complexities associated with this process in vivo. Estimates of respiratory evaporative heat loss are given in CHAPTER 16, UNIT 1.6, recognizing at least the potential contribution of evaporation to the total heat loss and, at most, the magnitude of the loss under certain conditions.

Note that the references on the next page deal primarily with domestic ruminants. Evaporation is most important to the animal at high temperatures, so research on respiratory evaporation has been directed primarily toward the hotter climates.

REFERENCES, UNIT 4.2

RESPIRATORY EVAPORATION

SERIALS

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

odvi

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

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
BVJOA	124--	83	88	doca	evap ht los mech newb calf	hales,jrs; findl/	1968

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
JAPYA	40--4	514	520	dogo	thrmosnstv sites, hypothal	jessen,c	1976
JPHYA	284--	162p	163p	dogo	core temp, resp loss, exer	jessen,c; mercer,	1978

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
IJLAA	47--6	367	368	dosh	heat dissip, diff typ shee	singh,m; acharya,	1977
JAPYA	26--5	517	523	dosh	eff temp, wool lengt, evap	hofmeyr,hs; guid/	1969
RSPYA	30--3	327	338	dosh	thermorespir respon, shorn	hofman,wf; riegle	1977
RSPYA	30--3	339	348	dosh	respir ht loss regu, shorn	hofman,wf; riegle	1977

CLOSING COMMENTS

Thermal characteristics and basic heat transfer processes have been discussed in CHAPTER 15. The discussions and calculations have been an extension of those in CHAPTER 14, and these two chapters provide the background for evaluations of thermal energy balances and animal responses in the next two chapters.

The next chapter (CHAPTER 16) includes evaluations of thermal energy balances of animals in specific situations. These evaluations help one understand the roles of physiological and behavioral adjustments by free-ranging animals in their natural habitats.

Aaron N. Moen
November 18, 1981

GLOSSARY OF SYMBOLS USED - CHAPTER FIFTEEN

ABCO = Absorption coefficient
ABTB = Absolute temperature of the bottom sensor
ABTT = Absolute temperature of the top sensor
AITE = Air temperature
AREA = Area
ATTE = Atmospheric temperature

CCAI = Conductivity coefficient of air
CCMB = Calories per square centimeter per day
COCO = Convective coefficient

DCYC = Diameter of the cylinder in centimeters
DLTA = Delta T = temperature difference
DPTH = Depth of conducting material

ERTL = Effective radiant temperature of the leaf
EVAP = Evaporation

HEVA = Heat of vaporization

IART = Instrument air temperature
IREM = Coefficient of infrared emissivity

KCMH = Kilocalories per centimeters per hour
KCOA = Conductivity coefficient of the air
KCOI = Conductivity coefficient of the insulation
KMTH = Kilocalories per square centimers per day

LFPC = Lengths of flat plats

QCVE = Quantity of convective heat loss
QFCV = Quantity of forced convection
QHCO = Quantity of heat conducted
QNCV = Quantity of natural convection
QRED = Quantity of radiant energy downward
QREE = Quantity of radiant energy emitted
QREN = Quantity of radiant energy of net flux
QRET = Quantity of radiant energy of total flux
QREU = Quantity of radiant energy upward
QRSK = Quantity of radiant energy from the sky

RATB = Radiant energy of the bottom surface
RATK = Radiant temperature in k
RATT = Radiant energy of the top surface
RECO = Reflection coefficient
RTEK = Radiant temperature of the earth's surface
RTSK = Radiant temperature of the clear sky in k

SACD = Surface area involved in conductivity
SACV = Surface area of the convector
SAFC = Surface area involved in forced convection
SANC = Surface area invovlved in natural convection
SBCO = Stephan-Boltsmann constant
SQME = Square meters
SUTE = Surface temeperature

TCCO = Thermal conductivity coefficient
TIME = Time
TREF = Total radiant energy flux

WIVE = Wind velocity in centimeters per second

GLOSSARY OF CODENS - CHAPTER FIFTEEN

SERIALS are identified by five-character, generally mnemonic codes called CODEN, listed in 1980 BIOSIS, LIST OF SERIALS (BioSciences Information Service, 2100 Arch Street, Philadelphia, PA 19103).

The headings for the lists of SERIALS are:

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

The volume and issue numbers (VO-NU) are given after the CODEN entry, followed by beginning page (BEPA), ending page (ENPA), species discussed (ANIM), KEY WORDS from the title, AUTHORS [truncated if necessary, slash (/) indicates additional authors], and year.

AGMYA Agricultural Meteorology
AJZOA Australian Journal of Zoology
AMSCA American Scientist
ANYAA Annals of the New York Academy of Sciences

BIOJA Biophysical Journal
BISNA Bioscience
BVJOA British Veterinary Journal

CBCPA Comparative Biochemistry and Physiology
CBPAB Comparative Biochemistry and Physiology A Comparative Physiology
CJZOA Canadian Journal of Zoology

ECOLA Ecology

IJBMA International Journal of Biometeorology
IJLAA Indian Journal of Animal Sciences
IREZA International Review of General and Experimental Zoology

JANSA Journal of Animal Science
JAPYA Journal of Applied Physiology
JASIA Journal of Agricultural Science
JDSCA Journal of Dairy Science
JOMAA Journal of Mammalogy
JPHYA Journal of Physiology
JRMGA Journal of Range Management
JTBIA Journal of Theoretical Biology
JWMAA Journal of Wildlife Management

NAWTA North American Wildlife and Natural Resources Conference, Transactions of the,
NJZOA Norwegian Journal of Zoology

OJVRA Onderstepoort Journal of Veterinary Science and Animal Industry

PHMBA Physics in Medicine and Biology
PHZOA Physiological Zoology
PRLBA Proceedings of the Royal Society of London B Biological Sciences

RSPYA Respiration Physiology

SCAMA Scientific American
SCIEA Science
SZSLA Symposia of the Zoological Society of London

TRJOA Textile Research Journal

ZOLZA Zoologicheskii Zhurnal

LIST OF PUBLISHERS - CHAPTER FIFTEEN

The headings for the lists of BOOKS are:

TYPE PUBL CITY PAGE ANIM KEY WORDS----------------- AUTHORS/EDITORS-- YEAR

All essential information for finding each book in the library is given on just one line. The TYPE of book could have either AUTHORS (aubo) or EDITORS (edbo). Publishers (PUBL) and CITY of publication are given with four-letter mnemonic symbols defined below. The PAGE column gives the number of pages in the book; ANIM refers to the species discussed in the book (given as a four-letter abbreviation of genus and species), and KEY WORDS listed are from the title. The AUTHORS/EDITORS and YEAR of publication are given in the last two columns.

acpr	Academic Press	New York	nyny
else	Elsevier	New York	nyny
gaul	George Allen and Unwin Limited	London	loen
haro	Harper and Row	New York	nyny
jwis	John Wiley and Sons, Inc.	New York	nyny
mhbc	McGraw-Hill Book Co., Inc.	New York	nyny
pepr	Pergamon Press	Oxford, England	oxen
spve	Springer-Verlaug Inc.	New York	nyny
whfr	W. H. Freeman Co.	San Francisco, CA	sfca

GLOSSARY OF ANIMAL CODE NAMES

Wild ruminants are referred to in this CHAPTER by a 4-character abbreviation from the family, genus and genus-species. These are listed below under Abbreviation.

Scientific names of North American wild ruminants are those used in BIG GAME OF NORTH AMERICA, edited by J.C. Schmidt and D. L. Gilbert (1979: Stackpole Books, Harrisburg, PA 17105, 494 p.), and may be different from the scientific names given in the original literature.

The abbreviations used for North American wild ruminants are listed below.

CLASS: MAMMALIA

ORDER: ARTIODACTYLA	Abbreviation
FAMILY: CERVIDAE	cerv
GENUS: *Odocoileus* (deer)	od--
SPECIES: *O. virginianus* (white-tailed deer)	odvi
O. hemionus (mule deer)	odhe
GENUS: *Cervus* (Wapiti, elk)	ce--
SPECIES: *C. elaphus*	ceel
GENUS: *Alces* (moose)	
SPECIES: *A. alces*	alal
GENUS: *Rangifer* (caribou)	
SPECIES: *R. tarandus*	rata
FAMILY: ANTILOCAPRIDAE	
GENUS: *Antilocapra*	
SPECIES: *A. americana* (pronghorn)	anam
FAMILY: BOVIDAE	bovi
GENUS: *Bison* (bison)	bi--
SPECIES: *B. bison*	bibi
GENUS: *Ovis* (sheep)	ov--
SPECIES: *O. canadensis* (bighorn sheep)	ovca
O. dalli (Dall's sheep)	ovda
GENUS: *Ovibos*	
SPECIES: *O. moschatus* (muskox)	obmo
GENUS: *Oreamnos*	
SPECIES: *O. americanus* (mountain goat)	oram

The abbreviations used for European wild ruminants are listed below.

CLASS: MAMMALIA

ORDER: ARTIODACTYLA	Abbreviation
FAMILY: CERVIDAE	cerv
GENUS: Capreolus (roe deer)	ca--
SPECIES: C. capreolus	caca
GENUS: Dama (fallow deer)	da--
SPECIES: D. dama	dada
GENUS: Cervus (Wapiti, elk)	ce--
SPECIES: C. elaphus (red deer)	ceel
GENUS: Alces (moose)	
SPECIES: A. alces	alal
GENUS: Rangifer (caribou)	
SPECIES: R. tarandus	rata
FAMILY: BOVIDAE	
GENUS: Bison (bison)	
SPECIES: B. bonasus	bibo
GENUS: Capra (ibex, wild goat)	cp--
SPECIES: C. aegagrus (Persian ibex)	cpae
C. siberica (Siberian ibex)	cpsi

OTHERS

Abbreviations for a few other species and groups of species may appear in the reference lists. These are listed below.

Axis axis (axis deer)	axax
Elaphurus davidianus (Pere David's deer)	elda
Cervus nippon (Sika deer)	ceni
Hydropotes inermis (Chinese water deer)	hyin
Muntiacus muntjac (Indian muntjac)	mumu
Moschus moschiferus (musk deer)	momo
Ovis nivicola (snow sheep)	ovni
Ovis musimon (moufflon)	ovmu
Ovis linnaeus (Iranian sheep)	ovli
Rupicapra rupicapra (chamois)	ruru
big game	biga
domestic sheep	dosh
domestic cattle	doca
domestic goat	dogo
domestic ruminant	doru
herbivore	hrbv
mammals	mamm
three or more species of wild ruminants	many
ruminants	rumi
ungulates	ungu
vertebrates	vert
wildlife	wldl
wild ruminant	wiru

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.

LIST OF WORKSHEETS - CHAPTER FIFTEEN

THE BIOLOGY AND MANAGEMENT OF WILD RUMINANTS

CHAPTER SIXTEEN

THERMAL ENERGY BALANCE CALCULATIONS

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CONTENTS OF CHAPTER SIXTEEN

THERMAL ENERGY BALANCE CALCULATIONS

CHAPTER 16: THERMAL ENERGY BALANCE CALCULATIONS

The illustrations of heat transfer given in CHAPTER 15 provided introductions to the four modes of thermal energy exchange. The roles of these four modes will now be considered for the organism as an ecological unit within the basic concept of homeothermy.

Homeothermic animals are usually described as "animals which maintain a constant body temperature." This very simple idea is often presented to students in elementary grades, and it is commonly said that the body temperature of humans is 98.6°F. All humans do not have the same body temperature though, and all parts of the human body are not at the same temperature.

Careful consideration of the basic concept of homeothermy leads one to a conclusion that is much more basic than the simple statement that the body temperature remains "constant." Metabolic processes are exothermic, so heat energy is released when food is oxidized, and heat energy is dissipated to the environment when the environment is colder than the animal. Homeotherms maintain a balance between the amount of heat energy released from food and the heat energy dissipated to the environment, and the effect of this balance is a constant body temperature.

Animals that maintain a balance between the heat produced and the heat lost are constantly solving a very complex heat transfer equation.

The effects of weather are manifested in the animal-range relationship through the medium of thermal or heat exchange. Meteorological parameters alone may be quite meaningless when used in interpreting animal responses because weather instruments do not respond to the thermal regime of the atmosphere in the same way that a living organism does. Further, weather instruments are often placed in standard weather shelters at standard heights so as many variables as possible are eliminated. A living organism, however, is exposed to the changing weather conditions and it also has its own physiological and behavioral variables. Knowledge of the four basic modes of heat exchange enables the biologist to understand the functional relationships between weather and the living organism.

The four modes of heat transfer interact. Radiation and convection are mutually dependent, for example, as convection losses reduce surface temperature and radiant heat loss. The rapidity of these changes--80% of the radiant temperature change occurred in a few seconds when wind velocities increased from 45 to 447 cm per second (1-10 mph)--are described in Moen and Jacobsen (1974). Arithmetic summations of net radiation and convection losses, as if radiation occurred in a vacuum and convection acted alone, are unrealistic because wind generally reduces the surface temperatures, and surface temperatures are a part of DLTA T in calculations of both convection and radiation exchange.

Absorbed radiant energy increases surface temperatures, again affecting the DLTA T in convection and radiation exchange. A logarithmic increase was described by Moen and Jacobsen (1974) for data published in Parker and Harlan (1972). Radiation and convection are clearly not independent processes.

An organism is coupled to the energy exchange processes by certain specific properties of its own (Gates 1968; 2). The amount of heat exchanged by radiation, convection, conduction, and evaporation depends on the thermal characteristics of the atmosphere and substrate, such as soil, rock, or snow, and the thermal characteristics of the object or organism. If a surface is highly reflective to radiant energy, then there can be little thermal effect from radiation. A cylinder with a very small diameter is a very efficient convector and slight air movement can result in a large amount of heat loss. Conversely, a large cylinder is a poor convector. An object covered with a layer of good insulation loses little heat by conduction, and an object with no water or other fluid that can be vaporized can have no heat loss by evaporation.

The exchange of heat between an organism and its environment is a dynamic process that includes the simultaneous exchange by each of the four modes of heat transfer.

The complexities of radiation and convection exchange at the surface of an animal are increased by the fibrous characteristics of the hair coat and the rough aerodynamic features of the animal's geometry. These complexities increase further as animals may change their posture and orientation as part of thermoregulatory behavior. Homeothermic animals, while they do not precisely maintain a set body temperature, do maintain an overall energy balance by regulating both behavior and metabolism in relation to the thermal environment. The total calculated heat loss can then be compared with estimates of ecological energy metabolism (ELMD) that were described in CHAPTER 7, with the annual patterns of ecological metabolism per day expressed as multiples of base-line metabolism. Comparisons of ecological metabolism with predicted heat loss provides opportunities for ecological accounting; the total calculated heat lost should be approximately equal to ELMD, and if they are not, the estimates of total daily heat loss are likely to be wrong.

Two ways of calculating energy balances are given in this CHAPTER 16. The summation approach in TOPIC 1 illustrates the individual heat transfer processes in energy balance calculations. The multilayered systems approach in TOPIC 2 emphasizes thermal boundary region conditions. The latter is a more useful and applicable approach for evaluating the combined effects of variations in thermal and geometric parameters in wild ruminants.

LITERATURE CITED

Moen, A. N. and F. L. Jacobsen. 1974. Changes in radiant temperatures of animal surfaces with wind and radiation. J. Wildl. Manage. 38(2):366-368.

Parker, H. D. and J. C. Harlan. 1972. Solar radiation affects radiant temperature of a deer surface. U. S. For. Serv. Res. Note RM-215. Rocky Mt. For. and Range Exp. Sta., Fort Collins, CO. 4 p.

REFERENCES, CHAPTER 16

THERMAL ENERGY BALANCE CALCULATIONS

BOOKS

TYPE	PUBL	CITY	PAGE	ANIM	KEY WORDS----------------	AUTHORS/EDITORS----	YEAR
aubo	lefe	phpa	308	----	introd to environ physiol	folk,ge,jr	1966
aubo	pepr	oxen	1144	----	biometeorology, volume 2	tromp,sw; weike,wh	1967
edbo	usup	lout	155	----	ecolog energetics, homeot	gessaman,ga	1973
aubo	whfr	sfca	458	----	wildlife ecology	moen,an	1973
aubo	whfr	sfca	488	----	intro to biophys plant ec	nobel,ps	1974
edbo	spve	nyny	609	odvi	biopysicl ecol, perspe of	gates,dm; schmerl,r	1975
aubo	jwis	nyny	273	----	intro physiol plant ecolo	bannister,p	1976

SERIALS

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
ECOLA	49--4	676	682	odvi	enrgy exchng, western minn	moen,an	1968
JWMAA	38--2	366	368	odvi	odhe, eff wnd, rad, rd tmp	moen,an; jacobsen	1974
NAWTA	33---	224	236	odvi	energy balance in winter	moen,an	1968

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
XARRA	215--	1	4	odhe	sol rad affct rad surf tmp	parker,hd; harla,	1972

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
				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
BIOJA	16--6	561	569	----	heat transfer,animal forms	mitchell,jw	1976
ECMOA	39--3	227	244	----	thermodynmc equilbria,anim	porter,wp; gates,	1969

TOPIC 1: SUMMATIONS

Summations of energy flux involve the algebraic addition of net radiation, convection, conduction, and evaporation to determine total heat loss when an animal is exposed to a given set of circumstances. The summation approach is useful for illustrating the roles of each of the four modes of heat transfer, but its use is limited to calculations describing stable conditions only.

The amount of heat lost is affected by changes in habitat, posture, and other factors contributing to the overall thermal environment. New summations must be made each time a new situation is evaluated, such as an animal in more protective cover, in more heat-conserving postures, or in different activities. Comparisons of animals in different thermal conditions provide insights into benefits derived from different responses to weather factors, and into the relative benefits of physiological and behavioral responses.

Homeothermy involves more than the maintenance of a fairly stable body temperature; it involves the maintenance of a thermal energy balance within the framework allowed by nutritive conditions. Food is the source of the metabolic energy dissipated. Evaluations of energy balances resulting from different responses in relation to nutritive conditions provides another opportunity for ecological accounting discussed in the introduction to PART IV. The energy in must equal the energy out; all of it must be accounted for if we are to understand the role of energy in natural systems.

Calculations of thermal exchange have been described in relatively simple terms up to now. As the number of interactions increases, the need for clear, deliberate, and logical thinking increases. The WORKSHEETS in the UNITS that follow should help keep things in order.

UNIT 1.1: NIGHT-TIME RADIATION CALCULATIONS; INFRARED WAVELENGTHS ONLY

Summations of heat loss from animals that are exposed to night-time conditions, with infrared radiation only, are the simplest possible while yet retaining the correct conceptual approach. Four modes of heat transfer have been discussed, and three of them--radiation, convection, and conduction--will be used in the first summations to illustrate the effects of postural and cover changes on heat loss.

A cloud-filled sky has a radiant temperature that is very close to measured atmosphere temperature. The radiation flux is uniform in all directions, and is the simplest of situations for calculating radiation exchange. The first WORKSHEET uses this simplified situation.

Postural changes. An animal may greatly alter its surface area exposed to the environment and the extent of participation in the different modes of heat transfer by altering its posture. Maximum surface areas are exposed when standing, and minimum when bedded in a tightly-curled position. More area is exposed to radiation and convection in a standing posture than in a bedded posture, and more to conduction in bedded than in standing posture. These differences may be evaluated by summing the net heat loss by these modes of heat transfer from the surface areas involved.

Standing posture. An animal in a standing posture exposes nearly all of its surface area to heat exchange with the atmosphere. Radiation exchange occurs between its surface exposed to the surrounding environment. Convection occurs wherever the air can move freely over the animal's surface. In a standing posture, the animal is a collection of convectors, mostly somewhat spherical in shape, that participate in free and forced convection. The hooves in contact with the substrate provide the only pathway for heat loss by conduction, and their surface area is very small compared to the total surface area of the animal.

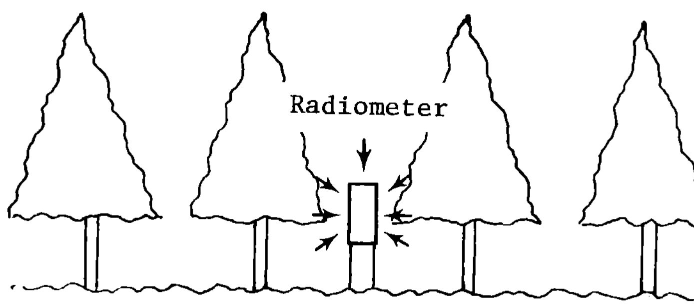
Bedding posture. When an animal beds down, the portions of its surface area participating in radiation, convection, and conduction change markedly. The portion participating in conduction increases very much as parts of the trunk and legs are in contact with the substrate. Portions of surface areas of the legs, tucked under the animal, are in contact with the trunk, reducing the surface area exposed to the external environment. The bedded posture results in much more compact geometry to the whole animal, a somewhat rounded protrusion above the ground surface, rather than a collection of several (four legs, a trunk, neck, head, and two ears) convectors. Even the possible angles for radiation exchange are much reduced when in a bedded posture compared to a standing one.

Cover changes. The preceding paragraphs dealt with the effects of postural changes on the energy balance of animals. Such changes "in place" are also accompanied by changes "in location" by free-ranging animals.

Canopy effects. There is a greater amount of downward infrared radiation from a conifer canopy than from a leafless hardwood canopy, and a greater amount from a leafless hardwood canopy than from a clear sky. Measured values are given in Moen (1968) for these three conditions. At 0° C, the downward flux in KCAL PSQM PHOU from a white cedar canopy was about 275, from the hardwood canopy 255, and from the open sky, 235.

Upward flux. Upward flux is calculated with the same formula for QREE or downward flux, but the radiant temperatures of snow, soil and vegetative cover are used rather than the canopy temperature. While there are differences between their temperatures and atmospheric temperature, the use of atmospheric temperature to represent the surface temperatures of the snow is a reasonable first approximation, and is used in the calculations of energy balance here.

Horizontal flux. There is horizontal infrared radiation flux within a plant community as well as the vertical flux calculated with the equations given thus far. The density of the cover and the snow or ground surface temperatures are the major determinants of the amount of horizontal flux. The cover density determines how much of the sky is visible to a radiometer oriented to measure horizontal flux, and the snow or ground surface



contributes to the flux also. In general, the horizontal flux is about midway between the downward and upward flux since each contributes about equally to the field of view; that is a sufficiently good approximation within a canopy.

Thermal characteristics of the animal's surface. Thermal characteristics of the animal's surface must be known before calculations of heat exchange can be made. Radiant surface temperatures are used to calculate radiant heat loss, which may be compared to the radiant heat absorbed and net radiation exchange calculated.

Radiant surface temperatures. The surface temperatures of an animal are dependent on both external and internal factors. At night, infrared but not visible wavelengths of radiation are a source of heat energy for the hair. Differences in blood flow and internal anatomy contribute to differences in surface temperatures, too. An equation for surface temperatures of the trunk of white-tailed deer is given in Moen (1968), and several equations in Moen (1973) are used for predicting surface temperatures over different body surfaces. Surface temperatures of well-insulated animals are often very cold. At -30° C air temperature, for example, the radiant surface temperature of the trunk of a white-tailed deer may be -22° C, just 8° above air temperature. At 0°, the difference is about 6.5°, based on the equation in Moen (1968).

Radiant heat loss. The radiant heat loss from the surface of an animal may be easily calculated with the equations for radiant surface temperatures referenced in the paragraph above. Deer with a radiant surface temperature of 0° emit about 300 KCAL PSQM PHOU, and at -30°, about 197. Note that less radiant energy is emitted from the animal's surface when it is cold than when it is warm. Radiant heat loss is only part of radiation exchange; amounts emitted are to be compared to the amounts absorbed from the environment to determine the net radiation exchange.

Words of caution. The calculations of net radiation exchange described thus far are not appropriate for surfaces existing in a vacuum, or in constant convection conditions. Canopy and deer surface temperatures have been measured while being influenced by atmospheric conditions, of course, so the temperatures used in the equations reflect the effects of the atmosphere.

General discussions of heat loss differences between standing and bedded postures in different cover types are mere displays of ideas. It is necessary to test our understanding by completing the calculations in the WORKSHEETS that follow. The problems on the worksheets incorporate postural changes with the effects of open fields, herbaceous vegetation, deciduous forest, and coniferous cover.

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Moen, A. N. 1973. Wildlife Ecology. W. H. Freeman Co., San Francisco. 458 p.

REFERENCES, UNIT 1.1

NIGHT-TIME RADIATION CALCULATIONS; INFRARED WAVELENGTHS ONLY

SERIALS

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
ECOLA	49--4	676	682	odvi	energy exchange, minnesota	moen,an	1968
ECOLA	57--1	192	198	odvi	energy conser, wtd, winter	moen,an	1976
JWMAA	32--2	338	344	odvi	surf temp, radian heat los	moen,an	1968
NAWTA	33---	224	236	odvi	energy balance, wtd, winte	moen,an	1968

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
JTBIA	47--2	413	420	rata	wind chill, solar rad inde	oritsland,na	1974

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

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ovda

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

obmo

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

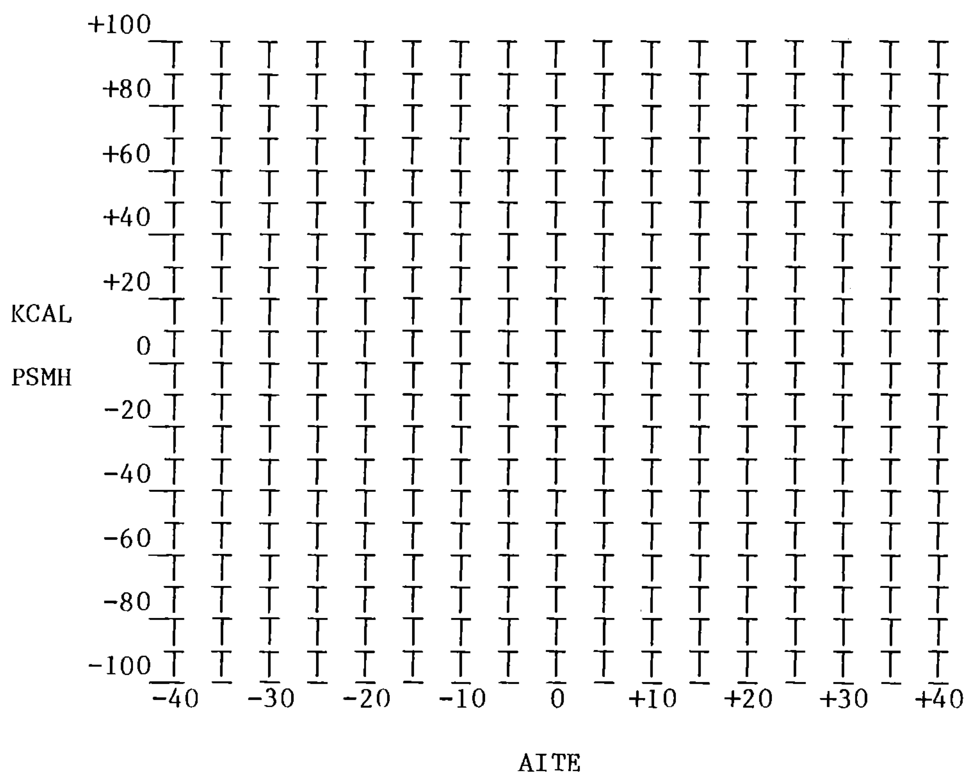
oram

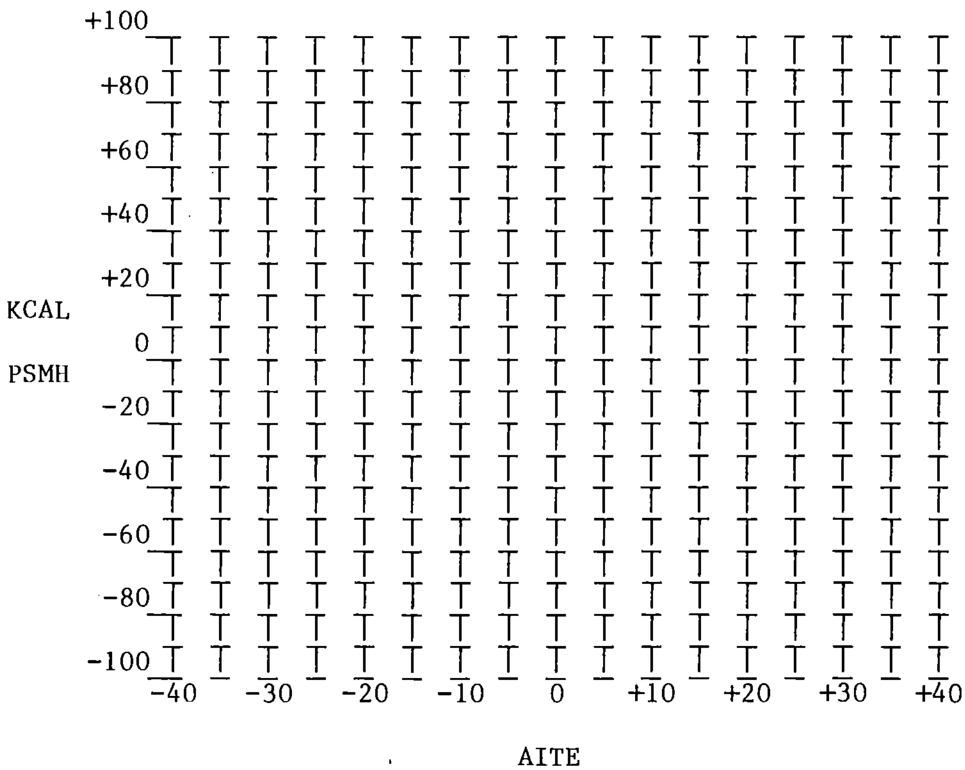
CODEN VO-NU BEPA ENPA ANIM KEY WORDS----------------- AUTHORS---------- YEAR

JAPYA 35--5 751 754 dosh measurem, local heat balan clark,ja; cena,k/ 1973

Radiant energy exchange under a cloudy sky at night

The radiant energy exchange between an animal and its thermal environment with a cloudy sky may be calculated as a net radiation exchange with formulas given previously. Determine surface area (CHAPTER 1, UNIT 2.3), radiant temperature and infrared radiation from deer and from different cover types (CHAPTER 15, UNIT 1.3), subtract radiant energy emitted from the radiant energy received by the deer. The result is the net radiation exchange for the deer. Plot your results in kcal per square meter per hour (KCAL PSMH) below. Additional grids are provided on the next page for more results.

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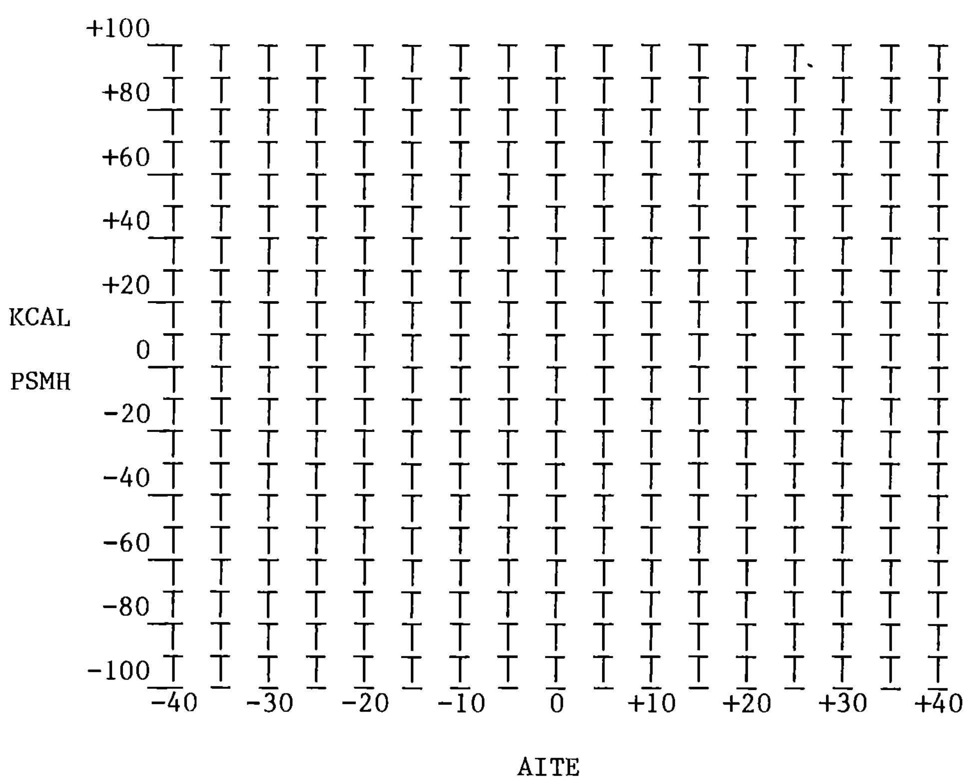
AITE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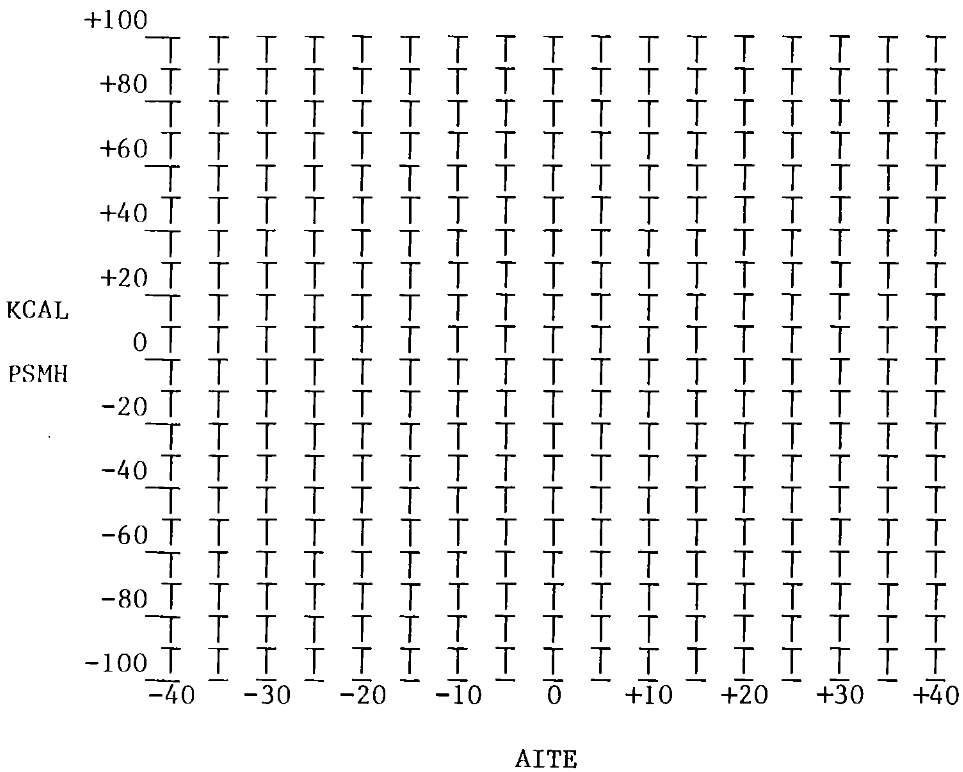
+40
AITE

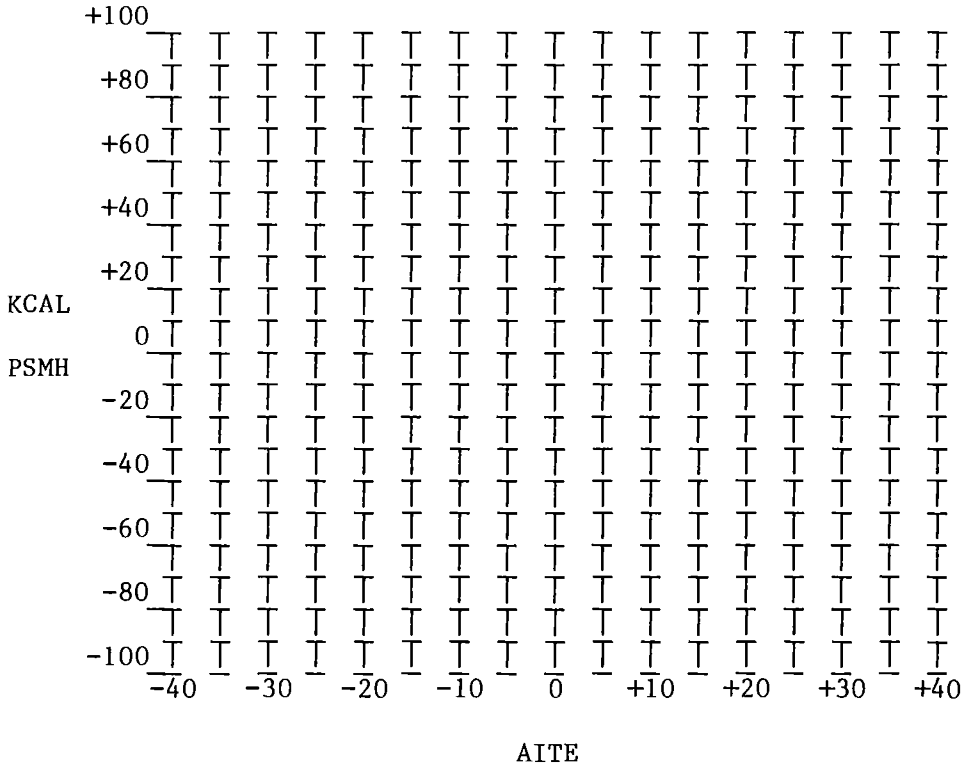
Radiant energy exchange of deer under different canopy types

Using the same procedures as in the previous WORKSHEET, calculate the net radiant energy exchange form deer under different canopy types, such as a conifer canopy, deciduous hardwood canopy, and no canopy under a clear sky. Since the radiant energy flux is not uniform in all directions, a "radiation profile" of the deer should be considered. This consideration was discussed in CHAPTER 15, UNIT 1.1. The half above: half below profile will be a sufficiently good approximation for these calculations.

Plot the net radiation energy exchange for different canopy types below. As you do, keep in mind that radiation is affected by wind, and that the calculation of net radiant energy exchange is a good exercise, but energy balances as a result of all modes of heat transfer are best calculated with overall heat transfer coefficients.



Additional grids are provided on the next page.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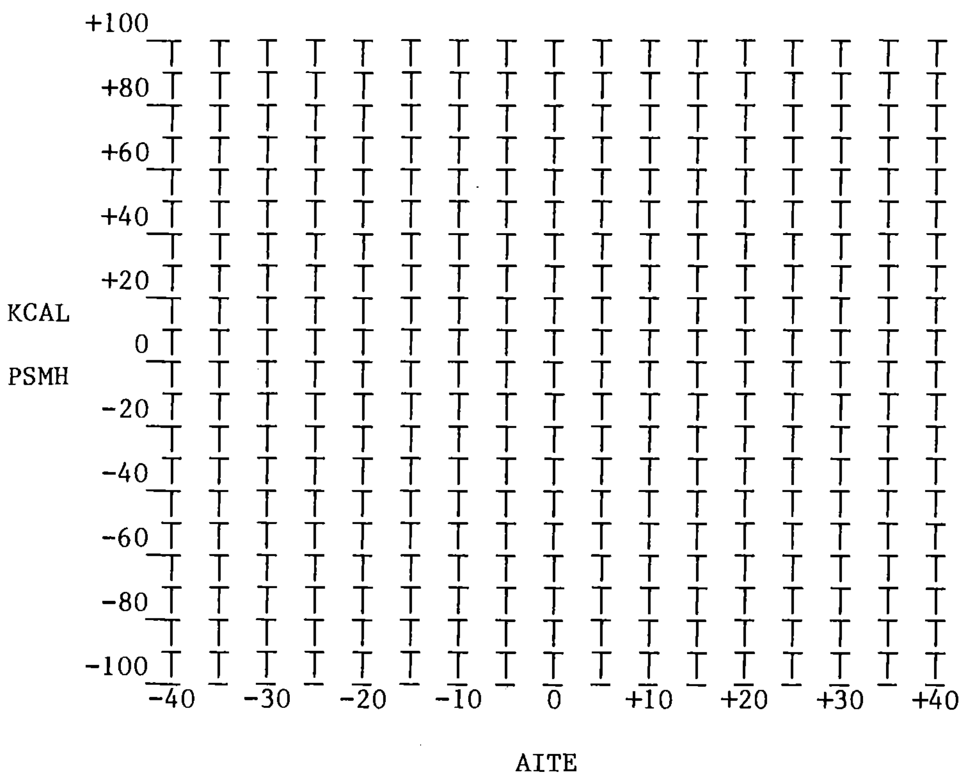
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AITE

UNIT 1.2: DAY-TIME RADIATION CALCULATIONS; INFRARED AND VISIBLE WAVELENGTHS

Consideration of visible wavelengths in calculations of radiation exchange adds to the complexity of the summations because of the direct and diffuse components of the visible, in addition to the all-directional infrared flux. The geometry of the animal becomes an important consideration when evaluating the effects of direct solar radiation as the angles affect the amounts of direct solar radiation received by different parts of the animal. This consideration was introduced in CHAPTER 15, UNIT 1.1, RADIATION PROFILES. Now, profile geometry is considered in calculations of radiation exchange for the whole animal.

There is almost a total lack of data on surface temperatures of hair coats of wild ruminants exposed to solar radiation. Parker and Harlan (1972) demonstrated a drop of 18° C when a tanned mule deer pelt exposed to the sun was shaded. This change occurred in 120 seconds. Equations expressing the change from shaded to exposed and exposed to shaded are given in Moen and Jacobsen (1974). Experiments completed at the Wildlife Ecology Laboratory, Cornell University, show that the radiant temperatures of deer hair exposed to the direct rays of the sun are several degrees higher than hair exposed to diffuse and infrared radiation only. These data are currently being analyzed and prepared for publication.

The absorption of direct solar radiation by the hair coat raises the radiant surface temperature and radiation emitted. Simple arithmetic subtraction of radiation emitted from radiation absorbed gives the net radiation exchange. The answer, however, is again characteristic only of exchange at the radiant surface of the animal, without consideration of interactions with the effects of the atmosphere.

Another word of caution. Since wild ruminants are surrounded by an atmosphere rather than living in a vacuum, arithmetic summations of radiation gained and lost from the surface of an animal are inadequate. Further, pyranometers, pyrheliometers, and other kinds of radiometers used for measuring solar and infrared radiation have shields or domes that protect the sensing elements from atmospheric effects, or else they have fans that provide a constant air flow that stabilizes atmospheric effects. Wild ruminants do not have domes or fans, nor are the hairs similar to the sensors of such instruments. Consequently, animals absorb different amounts of radiation than such instruments do, and instrument results must be applied to animals' surfaces with caution when estimating heat loss.

A WORKSHEET follows that illustrates geometric considerations when quantifying radiation exchange. Then, some basic convection considerations are made in UNITS 1.3 and 1.4, followed by conduction analyses in UNIT 1.5 and evaporation considerations in UNIT 1.6. All of these UNITS describe separate modes of basic heat transfer in relation to the geometry of the animal. Summations are made in UNIT 1.7. The summation approach does not allow for adequate physical integration of interactions at the hairy surface of a wild ruminant; that is discussed in TOPIC 2: OVERALL HEAT TRANSFER COEFFICIENTS.

LITERATURE CITED

Moen, A. N. and F. L. Jacobsen. 1974. Changes in radiant temperatures of animal surfaces with wind and radiation. J. Wildl. Manage. 38(2):366-368.

Parker, H. J. and J. C. Harlan. 1972. Solar radiation affects radiant temperature of a deer surface. U. S. For. Serv. Res. Note RM-215. Rocky Mt. For. and Range Exp. Sta., Fort Collins, CO. 4 p.

REFERENCES, UNIT 1.2

DAY-TIME RADIATION CALCULATIONS; INFRARED AND VISIBLE WAVELENGTHS

SERIALS

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
ECOLA	49--4	676	682	odvi	energy exchange,minnesota	moen,an	1968
ECOLA	57--1	192	198	odvi	energy conser, wtd,winter	moen,an	1976
JWMAA	38--2	366	368	odvi	chang, rad temp, wind, rad	moen,an;jacobsen,	1974

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
XARRA	215--	1	4	odhe	sol rad effects, surf temp	parker,hd; harlan	1972

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
JTBIA	47--2	413	420	rata	wind chill, solar rad inde	oritsland,na	1974

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
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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
ECOLA	50--2	328	332	----	bioclimat,summer,microenv,	dowson,tj; denny	1969
JAPYA	35--5	751	754	----	measurem, local heat balan	clark,ja; cena,k/	1973
AGMYA	8-4/5	353	359	doca	energy balance,climate,nig	ojo,o	1971
COPMB	4----	214	218	dosh	model heat flow,high solar	vera,rr;koong,lj/	1975

CHAPTER 16, WORKSHEET 1.2a

Solar radiation distribution over an animal's surface

Animals sometimes orient with the sun. Calculations of heat exchange involving solar radiation are very complex; the angles at which the sun's rays strike the animal's surface are important considerations when quantifying the effects of solar radiation.

Solar radiation angles may be estimated in the following way. Find a garden-type model of a deer that has realistic body proportions. Place it in different orientations with the sun throughout the day and record the angles (slopes and aspects) with which the sun strikes the surface. Then estimate the surface area exposed to the different angles. Mounted animals in standing and bedding postures provide even better estimates, but they may not be readily available.

UNIT 1.3: NATURAL CONVECTION CALCULATIONS

The concept of natural convection was discussed in CHAPTER 15, UNIT 2.1, and illustrations of the effects of variations in the geometry of the convector and wind velocities given. Patterns were clear, and the relationships relatively easy to understand.

The application of the concept to the real animal is difficult for several reasons. One difficulty is due to the complex geometry of an animal, with a body that is composed of imperfect cylinders and other geometries that are clearly not well-designed convectors. Further, the body is covered with hair, so not only are there several large convective geometries, but there are also a very large number of very small-diameter convectors--hairs--over the surface of the animal's body. These small-diameter convectors respond very quickly to air flow; they are efficient convectors. Convection is really a two-stage process then as (1), the hairs respond, and (2), the body parts respond to atmospheric movements. This idea is discussed in Moen (1973), with the concept of a "theoretical convective diameter" introduced there.

A second difficulty in applying the concept of free convection to an animal is due to the complex temperature variations over the animal's surface, making DLTA T in the convection formula a highly variable parameter. Not only are there temperature variations over the animal's surface, but also along each hair shaft. The total convection loss may be considered as a sum of all of the local convection losses, and any number of local areas could be considered separately.

Calculations can be made for two geometric extremes. One, the surface of an animal is considered to be the sum of the surface of the individual hairs, and two, the surface of an animal is considered to be the sum of the surface areas of different smooth-surfaced body parts. The former approach results in extremely large surface areas for convective heat loss from many thousands of tiny convectors or hairs. Convective losses are astronomical when each hair is considered an independent and separate little convector. It is not practical to treat the hair coat in that manner, even though the hairs function as convectors. The latter approach is at least possible with current measurement capabilities, and is the approach used in Moen (1973) to calculate convective heat loss.

Natural convection may be calculated for each body part by considering the areas involved, the temperature differences between the atmosphere and body surface, and the geometries of the body parts as convectors. Summation of natural convection from each of these parts results in an estimate of the total convection loss from the animal, which may be added to the estimates of radiation loss to get the sum of these two modes of heat transfer. WORKSHEETS provide opportunities for making such calculations.

LITERATURE CITED

Moen, A. N. 1973. Wildlife Ecology. W. H. Freeman and Co., San Francisco. 458 p.

REFERENCES, UNIT 1.3

NATURAL CONVECTION CALCULATIONS

BOOKS

TYPE	PUBL	CITY	PAGE	ANIM	KEY WORDS----------------	AUTHORS/EDITORS---	YEAR
edbo	spve	nene	609	odvi	therml exchng,physio,behv	moen,an; jacobsen,	1975

SERIALS

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
ECOLA	49--4	676	682	odvi	enrgy echng, western minne	moen,an	1968
ECOLA	57--1	192	198	odvi	energy conser, wtd, winter	moen,an	1976
JWMAA	32--2	338	344	odvi	surf temp, radian heat los	moen,an	1968
NAWTA	33---	224	236	odvi	energy balance, winter,wtd	moen,an	1968

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

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

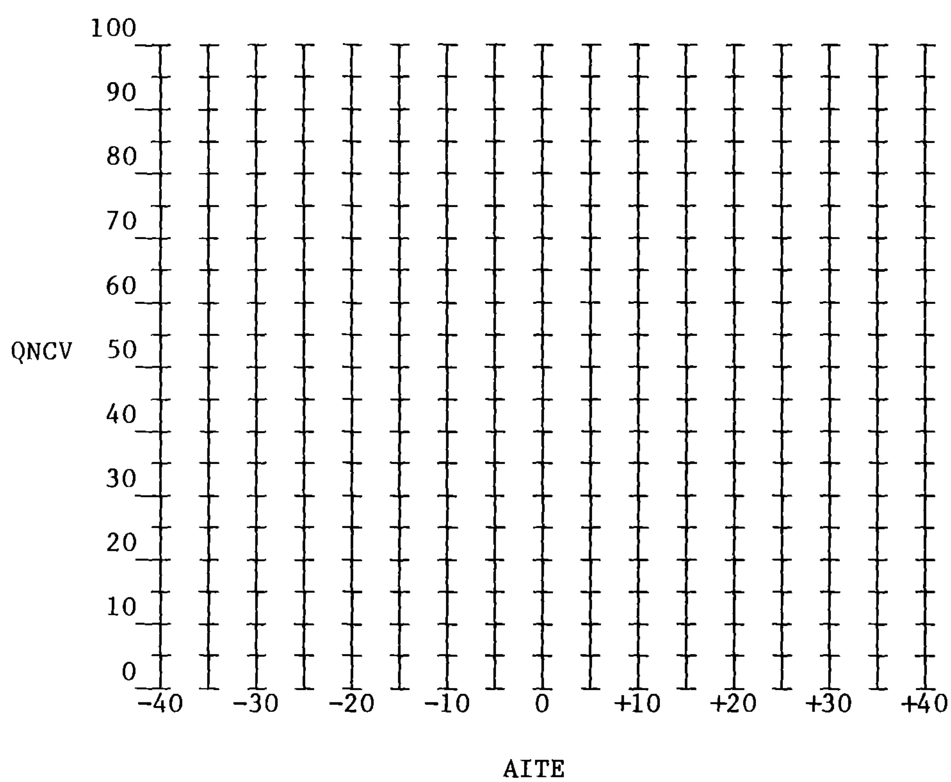
CHAPTER 16, WORKSHEET 1.3a

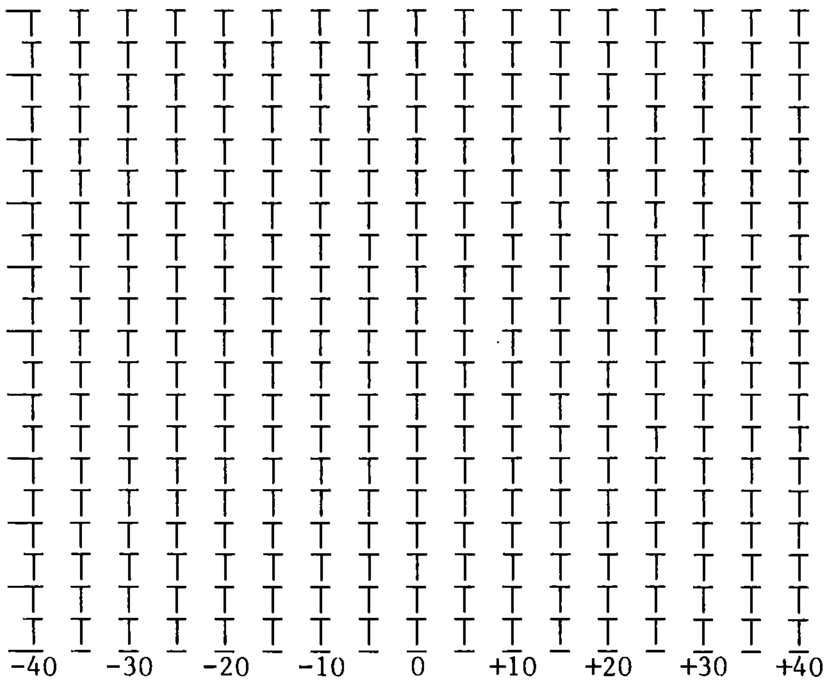
Natural convection from white-tailed deer

Natural convection may be calculated for white-tailed deer if the diameters of different body parts, surface areas of different body parts,and temperature differences between animal surface and air are known. Use PART I, CHAPTER 1, TOPIC 2 to estimate body geometry and CHAPTER 15, UNIT 1.3 to estimate surface temperatures. Use these in the formula for natural convection discussed in CHAPTER 15, UNIT 2.1.

$$QNCV = 3.516\ (DLTT/DCYC)^{1/4}SANC$$

Complete a series of calculations for different body parts and air temperature, and plot the results below and on the next page. Note that the y-axes of the grids on the next page need to be labeled according to the scale used.





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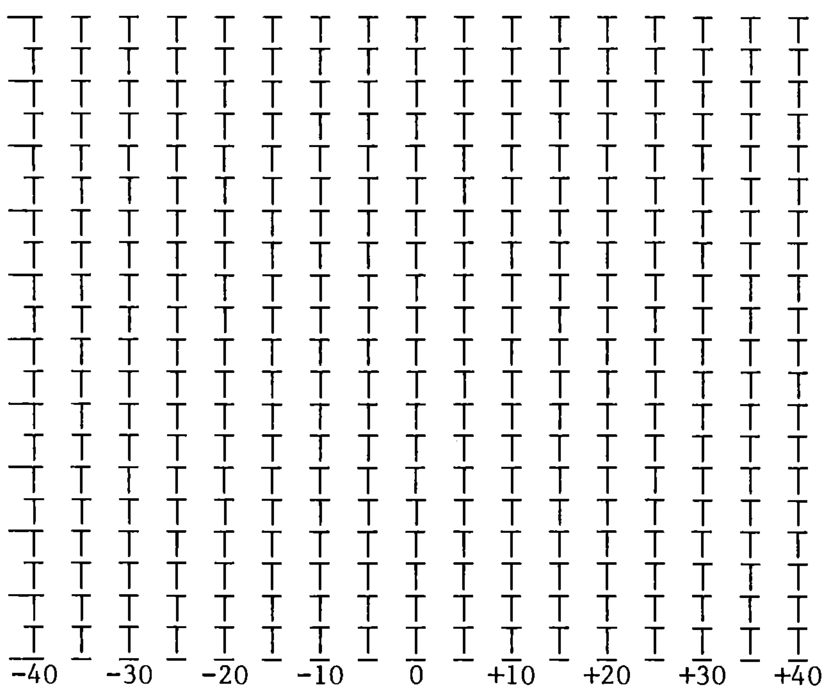

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UNIT 1.4: FORCED CONVECTION CALCULATIONS

All of the considerations discussed in UNIT 1.3: NATURAL CONVECTION CALCULATIONS apply here, with additional considerations of velocity distributions, both horizontal and vertical, in different habitats and over different parts of the animal's surface. Vertical wind profiles were discussed in CHAPTER 14, UNIT 3.2, and these are considered here in relation to geometric considerations in CHAPTER 1, UNITS 2.2 and 2.3.

An animal in a standing posture is exposed to a range of wind velocities, with the vertical velocity profile dependent on wind and cover characteristics. The velocity profile over a smooth snow surface has higher velocities near the snow surface than the velocity profile of a surface covered with vegetation. An animal standing over the snow surface has its legs exposed to higher velocities than if it were standing in vegetation reaching up to its trunk. Thus the lengths of the legs, belly heights, trunk diameter, position of the head, and vegetation densities and heights all become important simultaneous geometric considerations when evaluating forced convection losses. Surface temperature distributions must also be considered, of course, for the DLTA T part of the convection equation.

The effects of difference in geometry velocity profiles, and surface temperature distributions for different convective parts of white-tailed deer are evaluated in the WORKSHEETS that follow.

REFERENCES, UNIT 1.4

FORCED CONVECTION CALCULATIONS

SERIALS

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
ECOLA	49--4	676	682	odvi	enrgy echng, western minne	moen,an	1968
ECOLA	57--1	192	198	odvi	energy conser, wtd, winter	moen,an	1976
JWMAA	32--2	339	344	odvi	surf temp, radian heat los	moen,an	1968
NAWTA	33---	224	236	odvi	energy balance, wtd, winte	moen,an	1968

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

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

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obmo

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

oram

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

NAWTA 35--- 106 114 wind as ecol and thrm forc stevens,ds; moen, 1970

CHAPTER 16, WORKSHEET 1.4a

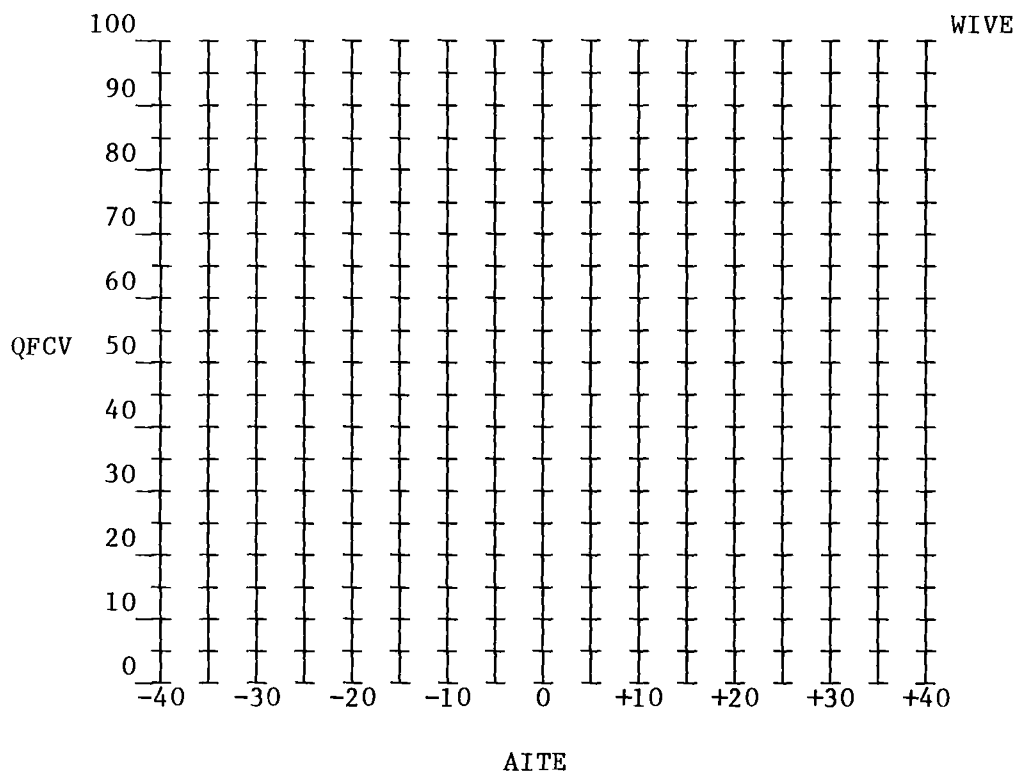
Forced convection from white-tailed deer

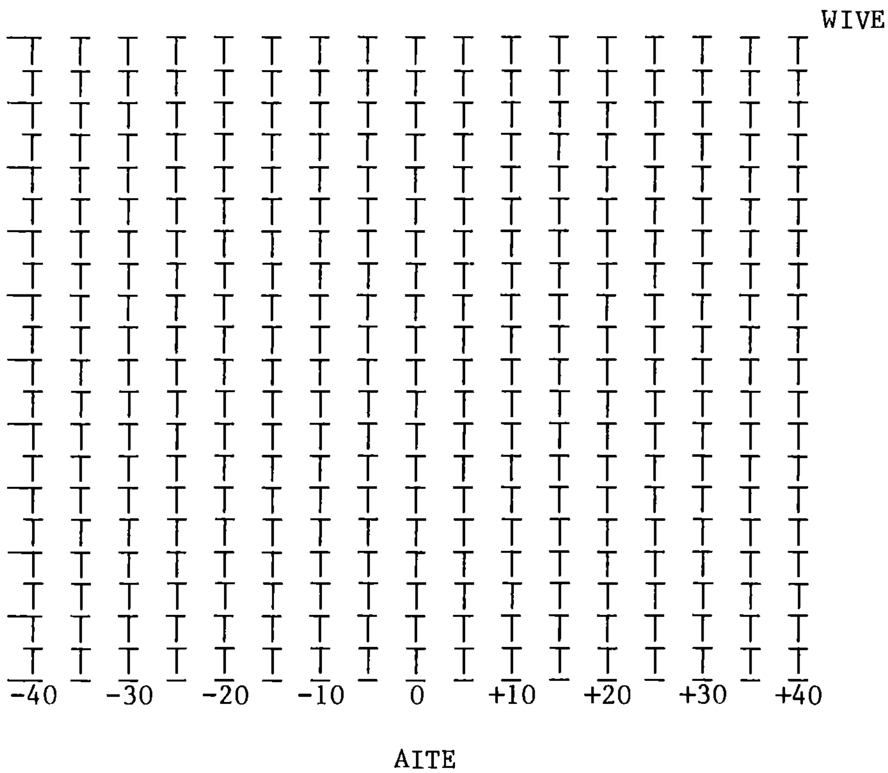
This WORKSHEET is similar to WORKSHEET 1.3a, with the addition of wind velocity as a factor in determining radiant surface temperature, and a different formula for the convection coefficient. Refer to CHAPTER 15, UNIT 2.2 for the formula:

$$QFCV = 3.702\ [(WIVE^{1/3})/(DCYC^{2/3})][(DLTT)(SAFC)]$$

Using geometry and surface temperature calculations discussed in WORKSHEET 1.3a, estimate heat loss by forced convection for different body parts, air temperatures, and wind velocities. Note that wind velocities past an animal are not equal at all heights; here is an opportunity to apply vertical wind velocity profile calculations (CHAPTER 14, UNIT 3.2) to a more complex problem.

Complete the calculations and plot the effects of wind velocity as a family of curves. Additional grids are provided on the next page.

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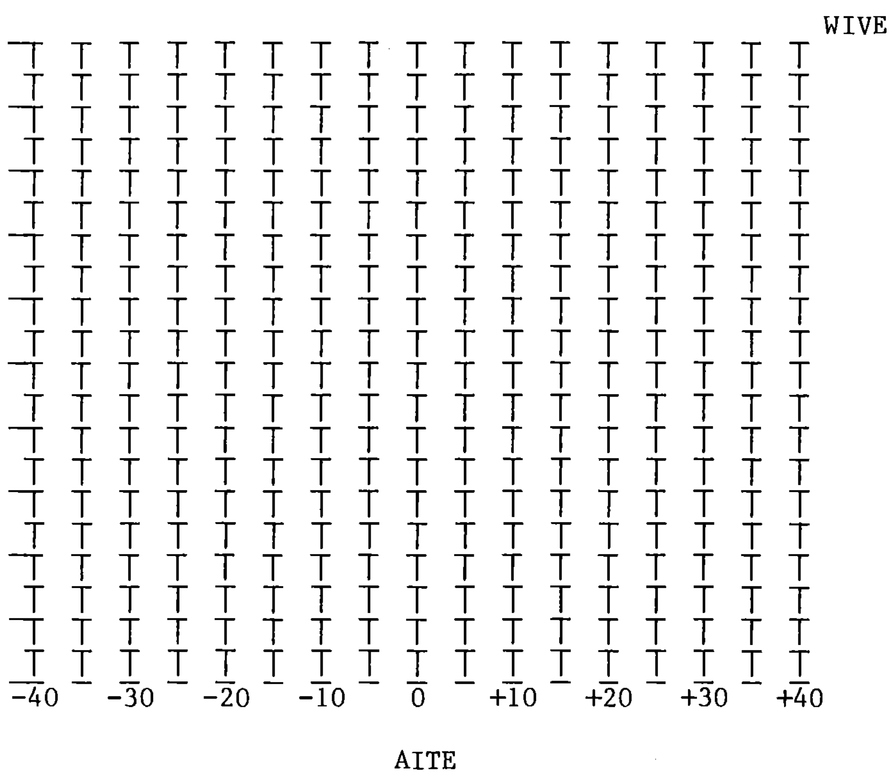
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UNIT 1.5: CONDUCTION CALCULATIONS

The simplest mode of heat transfer to consider in summations is that of conduction. An animal bedded on the ground or snow loses heat to the substrate by conduction through its hair. Conductivity coefficients determined in a closed system are applicable because there is no atmospheric disturbance in this interface. Depths of the hair, temperature differences, and bed areas are needed in addition to the conductivity coefficients in order to make these calculations for different wild ruminants.

Bed areas were given in CHAPTER 1, UNIT 2.4, hair depths in CHAPTER 2, UNIT 1.3, and conductivity coefficients in CHAPTER 15, UNIT 3.1 The temperature differences, or DLTA, is the only parameter left to quantify for conduction calculations.

The idea of a temperature gradient is simple, but the measurement of temperature gradients between animal and environment is difficult. How does one measure the temperatures at the base of the hairs (skin) and of the snow surface under bedded deer, caribou, moose, and other wild ruminants? Not easily done, unless implanted temperature transducers transmit by radio from the skin, and the animals bed down on temperature transducers on the snow.

Fortunately, temperature gradients from the skin to the snow surface can be approximated with some logic. The skin temperature cannot be higher than the internal body temperature, about 39°C. It could be less, but measurements of skin temperature on the trunk of white-tailed deer approach the internal body temperature (Moen unpublished data). The legs, curled up under the animal, could be several degrees cooler, but are likely not too different from the trunk when in that position.

Snow surface temperatures are often close to air temperatures. When an animal beds on the snow, heat transmitted from the animal to the snow can raise the temperature of the snow to no more than 0 °C, as melting begins to occur at that temperature. The heat energy then goes into the change of state of snow from solid to liquid, and the latent heat of fusion absorbs energy while the snow temperature remains at 0°C. Thus DLTA T = 39°C. As melting occurs, liquid water percolates into the snow. When the animal arises from the snow on a cold day, ice forms in the bed as the liquid water freezes, a common observation in the northern regions of the United States and in Canada.

These approximations may be used to calculate the conduction of heat to the snow by a bedded animal with the formula for static conduction. Opportunities for calculations are given in the WORKSHEET at the end of this UNIT, with the values per unit area used in computing conductive heat loss for animals with different surface areas and bed areas that were given in CHAPTER 1.

REFERENCES, UNIT 1.5

CONDUCTION CALCULATIONS

SERIALS

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

odvi

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

odhe

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				oram			

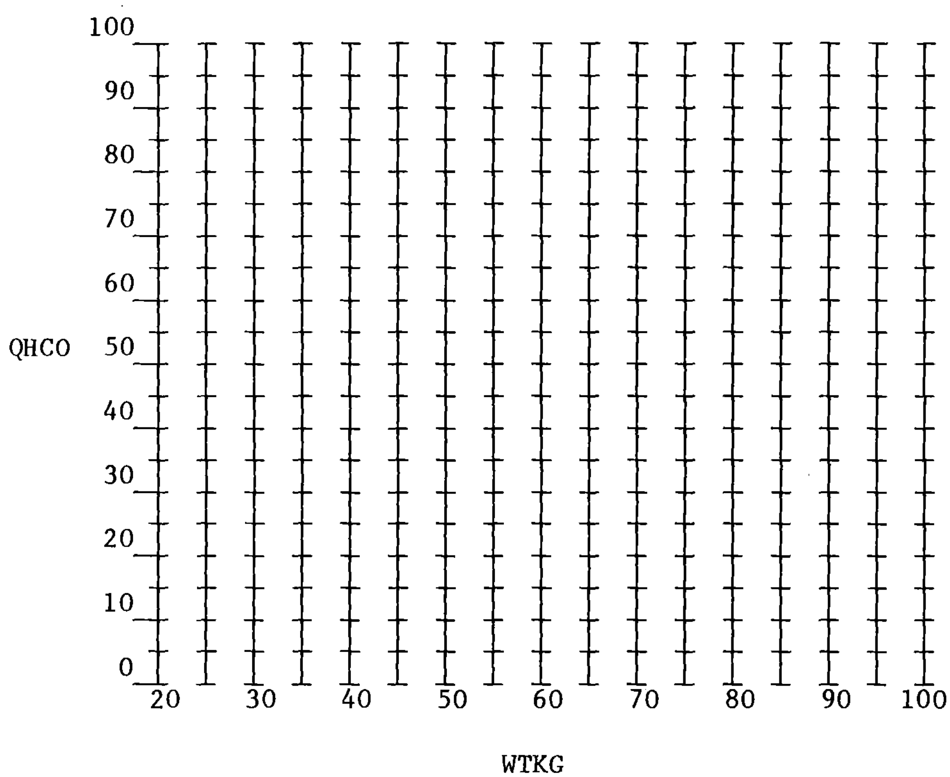
CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
SSEBA	18---	31	48	vert	insula, metabol adap, cold	hart,js	1964

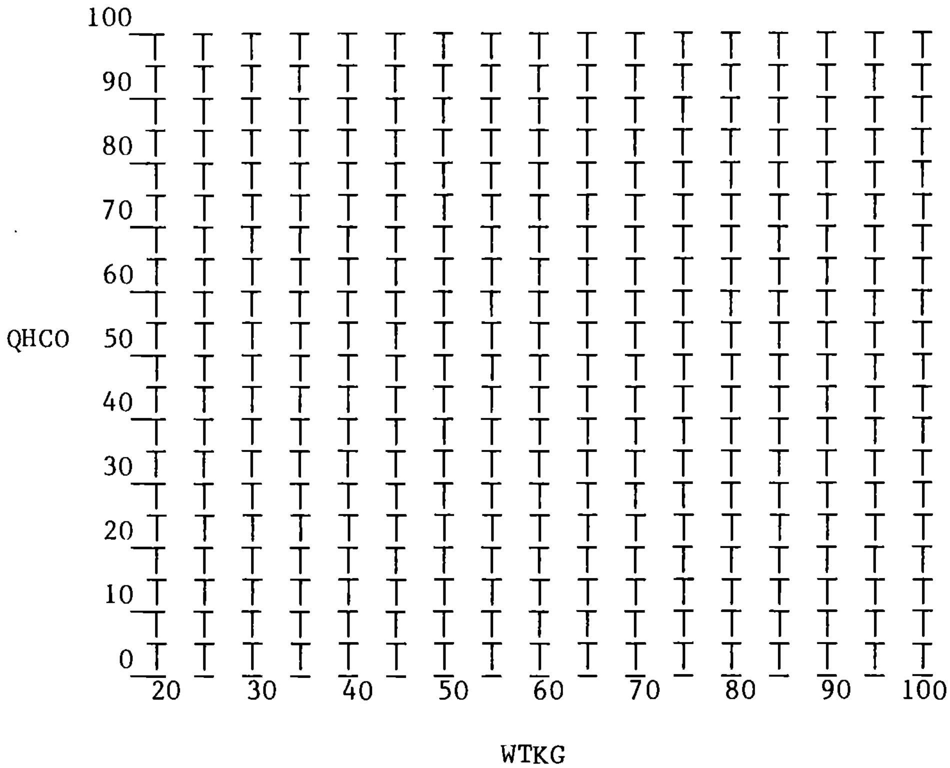
CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
TRJOA	25-10	832	837	rata	therm insulation of pelts	moote,i	1955

CHAPTER 16, WORKSHEET 1.5a

Conduction calculations from white-tailed deer

Conduction calculations may be made by refering to the surface areas of beds of deer in different postures (CHAPTER 1, UNIT 2.4), hair depths and conductivities (CHAPTER 15, UNIT 3.1). Complete the calculations of bedded heat loss for deer of different weights in kg (WTKG) and plot in the grid below. A DLTA T of 39° for deer on a snow substrate is a good maximum to use. DLTA T could be different on other substrates. Additional grids are available on the next page.

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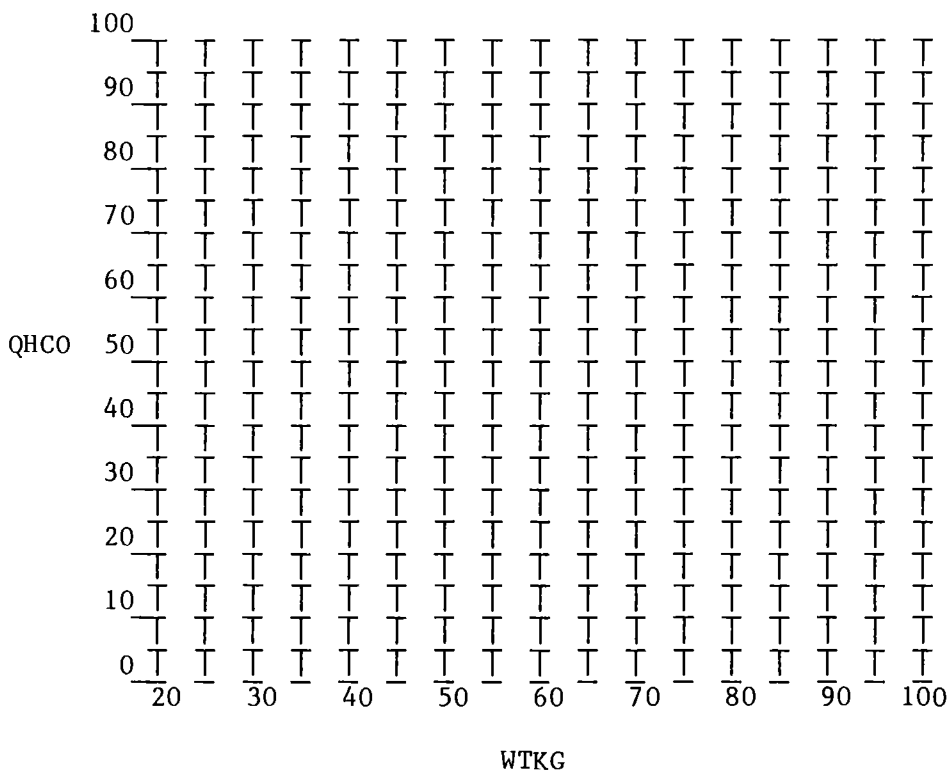
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WTKG

UNIT 1.6: EVAPORATION CALCULATIONS

Evaporative heat exchange is the one form of heat loss over which an animal has some physiological control, and it is an especially important consideration for animals in hot environments. When the atmospheric temperature equals internal body temperature, it is the only avenue for additional heat loss. In cold environments, evaporation may be low due to the small vapor pressure deficits, but when there is a wind, even air with a low vapor pressure deficit, moving and thus never coming into equilibrium with the animal, can be an important evaporative heat sink. Caribou have anatomical charateristics in their nasal passages that act as heat exchangers, minimizing heat loss (Langman 1979). Infant caribou have been observed to lose relatively large amounts of heat when their coats are wet and they are exposed to cold wind (Lentz and Hart 1960).

Evaporation calculations are different because one is dealing not only with heat transfer but with mass transfer as well. Water is being changed from a liquid to a gas, and its distribution affects evaporative heat loss. Since the heat of vaporization is known (see CHAPTER 15, UNIT 4.1, WORKSHEET 4.1b), the amount of water evaporated from an organism, regardless of the transport mechanism involved, and the amount of energy removed by vaporization can be determined. Subjects are weighed before and after a period of time, and the difference between the first and second weights, minus the weight loss due to urine and feces, is the approximate weight of water lost for use in estimating evaporative heat loss. Evaporative heat loss is quite a small part of the total heat loss of animals in cold environments, so major errors are not introduced by treating this source of heat loss as rough estimates only. A constant rate of heat loss (10.83 KCAL PSQM PHOU) was used in calculations by Moen (1968).

This unit completes the evaluations used in arithmetic summation. A different approach to estimating total heat loss, OVERALL HEAT TRANSFER COEFFICIENTS, is introduced in TOPIC 2.

LITERATURE CITED

Langman, V. A. 1979. Nasal heat exchange in northern ungulates. Second International Reindeer/Caribou Symposium, Roros, Norway p. 30.

Lentz, C. P. and J. S. Hart. 1960. The effect of wind and moisture on heat loss through the fur of newborn caribou. Can. J. Zool. 38(4):679-688.

Moen, A. N. 1968. Energy exchange of white-tailed deer, western Minnesota. Ecology 49(4):676-682.

REFERENCES, UNIT 1.6

EVAPORATION CALCULATIONS

SERIALS

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

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	38--4	679	688	rata	wind, moist, hea los, newb	lentz,cp;hart,js	1960

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
BVJOA	124-2	83	88	doca	evapor loss, new born calf	hales,jrs; findl/	1968
JASIA	74--2	247	258	doca	moisture, evapor, coats sw	allen,te; bennet/	1970
JDSCA	51-10	1693	1697	doca	body surf evap, lo, hi tem	joshi,bc; mcdowe/	1968
JDSCA	54--3	458	459	doca	evap cool, comfor, lactati	fuquay,jw; brown/	1971
ZOTCA	24...	233	240	doca	cutaneous heat loss bovine	de tena andreu,s	1975

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
JAPYA	40--4	514	520	dogo	thermosensit, hypothalamus	jessen,c	1976
JPHYA	284--	162p	163p	dogo	core temp, resp loss, exer	jessen,c; mercer,	1978
PYSOA	21--4	100	100	dogo	sweat gland secre, black b	robertshaw,d; dm/	1978

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
FEPRA	30--2	319	319	dosh	resp evap cool, hyperventi	hofman,wf; riegl/	1971
IJLAA	46--8	459	460	dosh	evaporation, colorat effec	singh,m; acharya,	1976
IJLAA	47--6	367	368	dosh	heat dissip, different typ	singh,m; acharya,	1977
IJMDA	12-10	1223	1223	dosh	met rate, evap, conductanc	degen,aa	1976
JAPYA	26--5	517	523	dosh	temp, wool, surf, resp eva	hofmeyr,hs; guid/	1969
RSPYA	30--3	327	338	dosh	thermoresp, shorn, unshorn	hofman,wf; riegle	1977
RSPYA	30--3	339	348	dosh	resp evapo, shorn, unshorn	hofman,wf; riegle	1977

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
AJPHA	219-4	1131	1135	ungu	temp regul, evaporation	taylor,cr	1970
SZSLA	25...	345	356	ungu	evap temp regulation	jenkinson,dm	1972

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
EAFJA	37--4	325	330	afri	environ physiol, semideser	schoen,a	1972
SZSLA	25...	215	227	afri	heat load,watr req,gazelle	taylor,cr	1972

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
JDSCA	51-10	1689	1692	----	body surf evap, lo, hi tem	joshi,bc; mcdowe/	1968
SZSLA	25...	357	369	----	evap heat loss,arid env,ma	bligh,j	1972

UNIT 1.7: TOTAL HEAT LOSS SUMMATIONS

Results of calculations of heat losses by the four modes of heat transfer--radiation, convection, conduction, and evaporation--may be added together and total heat loss determined. This procedure is fine if interactions between the different modes of heat transfer are considered. For example, wind reduces the radiant temperature of an animal's surface. The reduction is due to convection. Radiation losses may be correctly added to the convection losses only if the lower radiant temperature is used. If that is not considered, heat losses will be overestimated.

Another source of error is in the algebraic addition of radiant energy to the total heat exchange. The addition of radiant energy from a dense plant canopy, for example, may increase the summed heat load and appear to markedly reduce heat loss. Since any additional heat energy absorbed at the tips of the hairs is subject to natural and forced convection, the realized benefits are much less than the calculated ones. This was noted in relation to thesis data (Moen 1966) which I have not published; the explanation was not fully realized until experiments were conducted in the wind tunnel at the Wildlife Ecology Laboratory at Cornell University and the behavior of the thermal boundary region and temperature profile observed.

Total heat loss summations are useful because they call attention to the modes of heat transfer and interactions between them. A WORKSHEET provides a format for summations. If you do the clculations for deer, compare your results with those in Moen (1968a, 1968b, 1973, 1976) and Moen and Jacobsen (1975).

After gaining an understanding of summations, go to TOPIC 2: OVERALL HEAT TRANSFER COEFFICIENTS to evaluate interactions between the four modes of heat transfer and the relative contributions of the different layers in the thermal boundary region to heat transfer.

LITERATURE CITED

Moen, A. N. 1966. Factors affecting the thermal exchange of white-tailed deer, western Minnesota. Ph.D. Thesis, University of Minnesota. 166 p.

Moen, A. N. 1968a. Energy exchange of white-tailed deer, western Minnesota. Ecology 49(4):676-682.

Moen, A. N. 1968b. Energy balance of white-tailed deer in the winter. N. Am. Wildl. and Nat. Res. Conf. Trans. 33:224-236.

Moen, A. N. 1973. Wildlife Ecology: An analytical approach. W. H. Freeman and Co., San Francisco. 458 p.

Moen, A. N. 1976. Energy conservation by white-tailed deer in the winter. Ecology 57(1):192-198.

Moen, A. N. and N. K. Jacobsen. 1975. Thermal exchange, physiology, and behavior of white-tailed deer. Pages 509-524 In D. M. Gates and R. B. Schmerl (eds.), Perspectives of Biophysical Ecology. Springer-Verlag, Inc., N.Y. 609 p.

REFERENCES, UNIT 1.7

TOTAL HEAT LOSS SUMMATIONS

BOOKS

TYPE	PUBL	CITY	PAGE	ANIM	KEY WORDS-----------------	AUTHORS/EDITORS--	YEAR
aubo	whfr	sfca	458	odvi	wildlife ecology: analyt a	moen,an	1973
edbo	spve	nyny	609		perspectvs of biophys ecol	gates,dm; schmerl	1975

SERIALS

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
ECOLA	49--4	676	682	odvi	energy exchange, minnesota	moen,an	1968
ECOLA	57--1	192	198	odvi	energy conservatn in wintr	moen,an	1976
JWMAA	32--2	338	344	odvi	surf temp, radian heat los	moen, an	1968
NAWTA	33---	224	236	odvi	energy balance, deer, wint	moen, an	1968

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

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 ANIMKE YWORDS----------------- 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

CHAPTER 16, WORKSHEET 1.7a

Summations of heat loss

The WORKSHEETS in the previous UNITS in this TOPIC have provided opportunities for calculating heat loss by the four modes of heat transfer from animals of different weights. If you have completed each of these WORKSHEETS, you can sum the heat losses by each of the modes to estimate a total heat loss. Complete the blanks below.

Weight = _______; Base-line metabolism = _________; Surface area = _________

AITE = _______; Sky/canopy condition = _________; WIVE = _________.

Net radiation loss _____

Convection loss _____

Conduction loss _____

Evaporation loss _____

Total heat loss _____

MBLM _____

An evaluation of how realistic the total heat loss is may be made by dividing the total by base-line metabolism for an animal of that weight. The resulting multiple of base-line metabolism (MBLM) should be between 1.5 and 2.0 for winter conditions if the animal is not in a critical thermal environment (see CHAPTER 7, TOPIC 6) since the heat dissipated must equal ecological metabolism if homeothermy is to be maintained. In some weather conditions, an animal must conserve heat, and in others, dissipate excess heat. Thermoregulation is discussed in TOPIC 3 of this CHAPTER.

Additional blanks for summations of heat loss are provided for different sets of conditions.

Weight = _______; Base-line metabolism = _________; Surface area = _________

AITE = _______; Sky/canopy condition = _________; WIVE = ________.

Net radiation loss _____

Convection loss _____

Conduction loss _____

Evaporation loss _____

Total heat loss _____

MBLM _____

Weight = _______; Base-line metabolism = _________; Surface area = _________
AITE = _______; Sky/canopy condition = _________; WIVE = ________.

Net radiation loss _____
Convection loss _____
Conduction loss _____
Evaporation loss _____
Total heat loss _____
MBLM _____

Weight = _______; Base-line metabolism = _________; Surface area = _________
AITE = _______; Sky/canopy condition = _________; WIVE = ________.

Net radiation loss _____
Convection loss _____
Conduction loss _____
Evaporation loss _____
Total heat loss _____
MBLM _____

Weight = _______; Base-line metabolism = _________; Surface area = _________
AITE = _______; Sky/canopy condition = _________; WIVE = ________.

Net radiation loss _____
Convection loss _____
Conduction loss _____
Evaporation loss _____
Total heat loss _____
MBLM _____

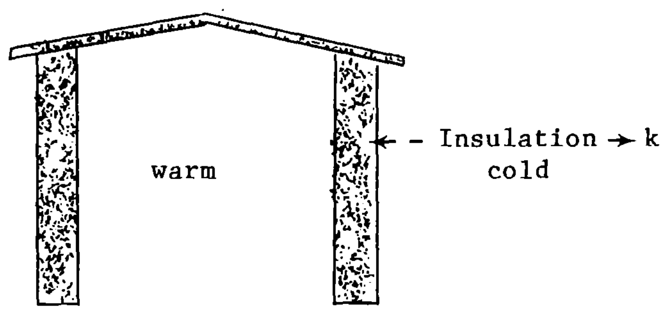
Weight = _______; Base-line metabolism = _________; Surface area = _________
AITE = _______; Sky/canopy condition = _________; WIVE = ________.

Net radiation loss _____
Convection loss _____
Conduction loss _____
Evaporation loss _____
Total heat loss _____
MBLM _____

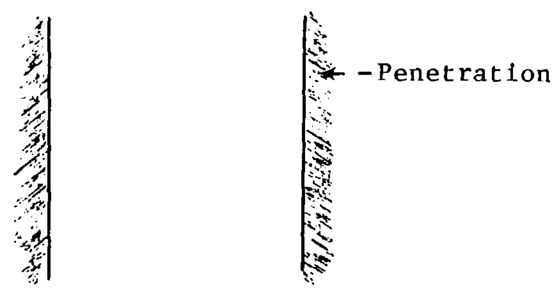
TOPIC 2. OVERALL HEAT TRANSFER COEFFICIENTS

Insulation is resistance to heat flow. The more resistance provided, the better the insulation. A perfect insulation has infinite resistance, but such insulation does not exist.

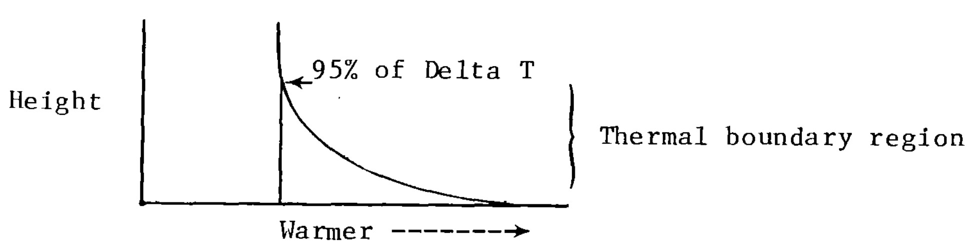
Problems associated with estimating the benefits of different amounts of insulation used in building applications are relatively simple because the insulation is enclosed between two walls. The problem is one of temperature gradients, conductivity coefficients and depths. It is an ideal example of static conductivity. An overall heat transfer coefficient is the reciprocal of the sum of the resistance.



Hair is exposed to the atmosphere, and the exposure of such fibrous insulation poses a very different and much more complex problem than the static conductivity application described above. The main difference is that there is no defined outer surface; the fibrous insulation is rough and air, wind, and radiant energy penetrate to various depths.

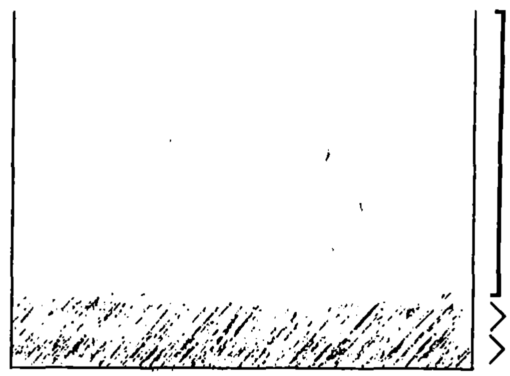


The thermal boundary region, or layer of air with different densities and temperatures around the animal (see Moen 1973:248) described in CHAPTER 15 is divided into three layers of insulation: the hair, hair-air interface, and air. The outer limit of the thermal boundary region is defined as the point where 95% of the temperature difference from the base of the hair (skin) to the ambient atmosphere has occurred.



The depth of the thermal boundary region is dependent on the physical depth of the hair, wind velocity, and the amount of radiant energy absorbed by the hair. Infrared radiation is not a major factor in natural habitats, but solar radiation has an important effect on the depth of the thermal boundary region when the hair is exposed to sunlight.

Heat energy is transmitted through these layers of insulation, generally from the animal to the atmosphere since skin temperatures are usually the highest of any on the temperature profile.



Heat energy is transmitted sucessively through the three layers; the amount of heat energy transmitted through the first equals the amount transmitted through the second, and through the third layer. The sum of the depths of each of the layers provides the total depth through which the heat escapes. Because of the labile and porous nature of these layers, their depths change with changes in weather conditions, especially wind and solar radiation. Once their depths have been determined for different combinations of wind and solar radiation and thermal resistance calculated, heat transfer may be calculated for each layer.

The total resistance of all three layers is equal to the sum of their individual resistances. This simplifies the calculations when applying this approach to the whole animal because it is not necessary to know the temperature differences between layers, or the depths of each layer, but rather the overall temperature difference between the skin and ambient atmosphere and the overall depth of the thermal boundary region.

As the depth of the hair increases, the total depth of the thermal boundary region and thus thermal resistance increases. As wind velocities increase, the depth of the thermal boundary region and thus thermal resistance decreases. Hair depths do not change rapidly, unless they are being moved by the wind or by the animal's activity. Wind velocities may change very rapidly, of course.

The sum of the resistance through each layer is the total resistance to heat flow. The heat transfer coefficient is the reciprocal of the resistance, and expresses the rate at which heat is transmitted through an insulation rather than the resistance of the insulation to heat transmission. Overall heat transfer coefficients (OHTC) are dependent on hair depths and wind velocities, and radiation absorbed, just as the resistances are, so an array of these must be generated for different combinations of hair depths, wind, and radiant energy for application to animals in the natural environment.

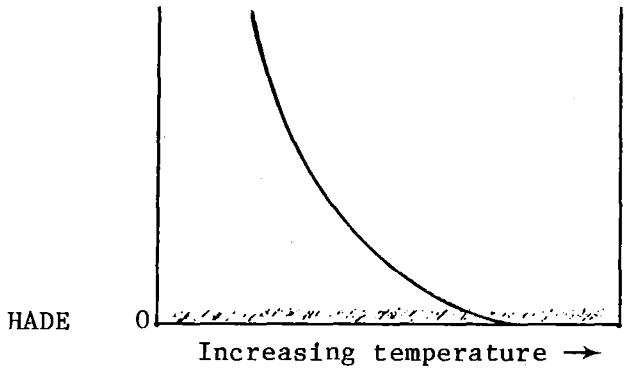
Thermal boundary region characteristics are presently being analyzed for white-tailed deer (Moen and Gustafson, In Preparation), but there are no data for other species of wild ruminants. It is likely that reasonable approximations can be made for other species by using the resistances determined for deer and the hair depths of the species being studied, since the thermal resistances per unit depth of the hair coats of other species are not greatly different from those of deer (See CHAPTER 15, UNIT 3.1).

The next two UNITS illustrate the patterns of changes in overall heat-transfer coefficients with changes in wind, hair depth, and radiant energy. The first analyses are for flat surfaces and cylinders, which, as simplifications of the real animals, illustrate the basic patterns of change at the hairy surface. Whole-body analyses involve the surface areas and hair depths of different body parts, the vertical geometry of the animal in relation to the vertical wind velocity profile, the habitat characteristics that determine the wind velocity profile, air temperatures, and wind velocities measured at a 2-meter reference height.

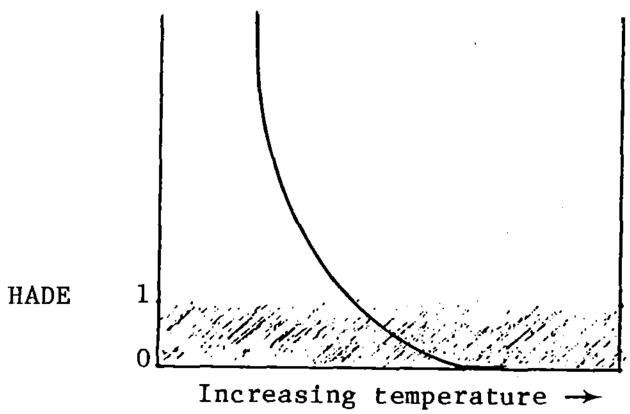
The use of overall heat transfer coefficients is divided into units on hair depth effects (UNIT 2.1), infrared radiation effects (UNIT 2.2), infrared and solar radiation effects (UNIT 2.3), and wind effects (UNIT 2.4). All of these variables may occur at the same time, so a unit on the combined effects of different variables (UNIT 2.5) is also included.

UNIT 2.1 HAIR DEPTH EFFECTS

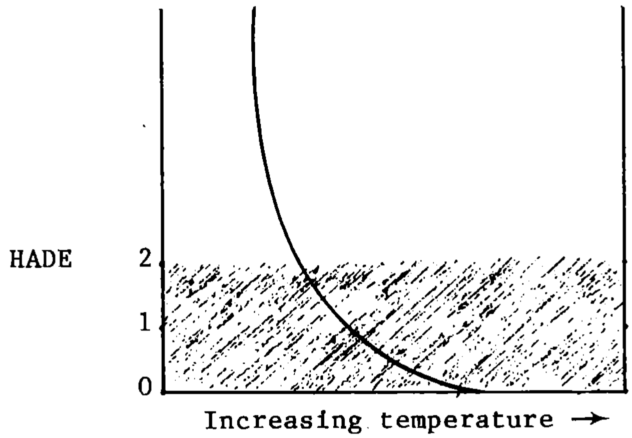
Hair depth has a major effect on the resistances of the three layers in the thermal boundary region. The greater the hair depth, the greater the elevation in the temperature profile near the skin. This effect is illustrated below for increasing hair depths.



The temperature profile shown above shows a large gradient for the air layer and a small gradient for the hair layer.



The temperature profile above shows a smaller gradient for the air layer and a larger gradient for the hair layer than in the previous illustration. This illustrates the effect of good insulation on the temperature profile. Perfect insulation would result in a vertical line for the temperature profile in the air layer, since no heat is transferred through a perfect insulator. The hair layer does not meet that high standard, of course. One more illustration of the effects of hair depth on the temperature profile follows.



The temperature profile above shows the effects of an even greater hair depth than in the two previous illustrations. Note the temperature gradient in the air layer is very small because the greater depth of the hair layer makes the hair better insulation than the lesser depths.

The temperature gradients in the air and hair layers are reflections of the resistances of the layers. The large gradient in the hair layer indicates a high resistance to the transfer of heat energy, and the small gradient in the air layer a low resistance to heat energy. As the hair layer increases in depth, it makes up an increasingly large percentage of the total resistance of the thermal boundary region.

The insulation value of the hair is obviously an important consideration when analyzing heat flow and the thermal balance of animals, since heat that is lost from an animal must pass through this insulative layer. The gradient is also very steep. I have recorded skin temperatures at the base of the hair of white-tailed deer of about 37°C when the air temperature was -20°C, a difference of 57° over a depth of less than 5 cm.

Calculated values of overall heat transfer coefficients, resistances through each of the layers, and percentages of the total resistance of the thermal boundary region that can be attributed to each of the layers are being determined as data analyses for the white-tailed deer continue. The generalized description given for the effects of hair depth introduces the basic ideas, and sets the stage for the discussions of the effects of additional variables in the UNITS that follow.

REFERENCES, UNIT 2.1

HAIR DEPTH EFFECTS

SERIALS

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
VCSZA	33--4	300	312	cerv	[course of molting, deer]	dobroruka,lj	1969

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
JOMAA	47--1	154	155	odvi	wooly-coated deer, new yor	friend,m; hesselt	1966

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
CJZOA	50--5	639	647	odhe	pelage and molt, bl-tld dr	cowan,imt; raddi,	1972

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
JZOOA	170-1	69	77	ceel	coat struct, seasnl change	ryder,ml; kay,rnb	1973
JZOOA	181-2	137	143	ceel	seas coat changes, grazing	ryder,ml	1977
JZOOA	185-4	505	510	ceel	coat grwth,day length cycl	kay,rnb; ryder,ml	1978

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
ZETIA	49--1	71	76	bibi	hair display loss, male bi	lott,df	1979

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

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

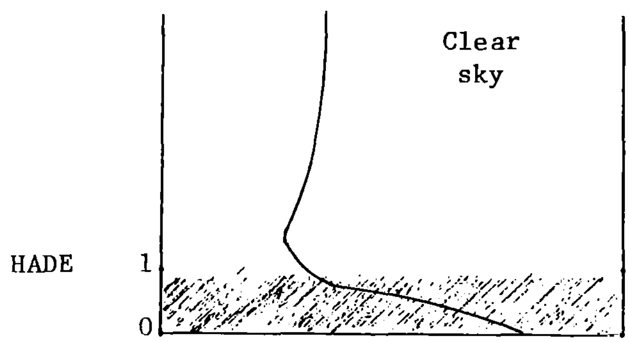
CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS------------------	AUTHORS----------	YEAR
BJLSB	6---2	127	141	obmo	wool shedding in muskoxen	wilkinson,pf	1974
JZOOA	177-3	363	375	obmo	length, diamtr coat fibers	wilkinson,pf	1975

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

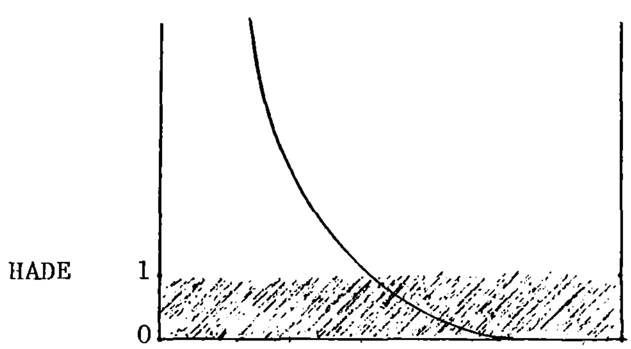
UNIT 2.2: INFRARED WAVELENGTHS ONLY

A series of tests completed in the Thermal Environment Simulation Tunnel at the Wildlife Ecology Laboratory, Cornell University, have resulted in calculations of resistances and overall heat transfer coefficients (OHTC) for different hair depths and wind velocities. Such calculations have been made for no other wild ruminant, but they may be used for making first approximations for other species, provided the surface areas and hair depth distributions of the other species are known.

The effect of infrared energy on the thermal resistances is illustrated by the changing temperature profiles illustrated below. A constant hair depth is used, with three levels of infrared energy, including a negative flux characteristic of a clear, night sky.

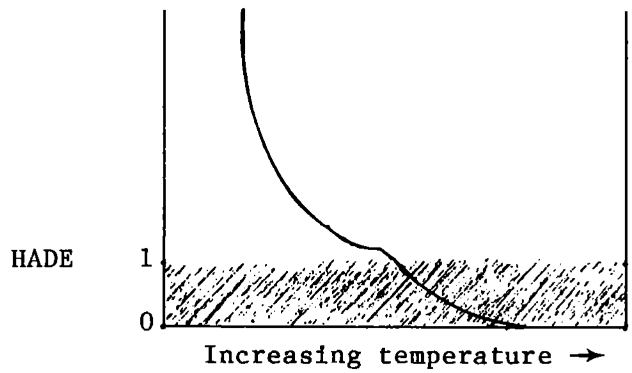


The temperature profile illustrated above actually goes slightly to the left and below air temperature at the hair surface in the illustration above because the infrared flux is negative. A clear night sky is a heat sink, and has a cooling effect on the earth's surface as well as the surfaces of plants and animals. The effect was discussed in CHAPTER 14, UNIT 1.2, in relation to dew and frost formation at various distances from the base of a tree. Effects of an increased infrared flux follows.



The illustration on the previous page shows a temperature profile that results when infrared flux is neither unusually small or large, negative or positive. Such a profile occurs when environmental radiant temperature and atmospheric temperature are equal. The temperature profile is in equilibrium with its surroundings.

A different kind of a temperature profile occurs when the animal is exposed to a source of infrared radiation. This effect is illustrated below.



The infrared radiation that is absorbed at the hair surface causes an increase in the temperature gradient in the air layer. This effect is similar to the "elevated minimum" air temperature discussed in CHAPTER 14, UNIT 2.2. Energy is absorbed at the surface, warming the air next to the surface and changing the shape of the profile. Such a situation could occur when the animal beds down under a dense conifer canopy, which is a source of infrared energy, on a clear night when air temperature is low due to cooling of the air mass and earth's surface by outward radiation. Then, the conifer canopy may function as a source of heat energy that is greater than the radiation from the clear night sky.

The examples above illustrate the idealized effects of infrared radiation on the temperature profile and resistances of each of the layers in the thermal boundary region. The differences in infrared radiation flux under different canopy types are measurable and distinct. The effect of these differences on the temperature profiles is not particularly great because of the effect of wind. If the hairy surface of an animal were in a vacuum, then the effects of absorbed radiation would be very clear. Since the hair is exposed to the atmosphere, the effects are ameliorated by convection. This is a singularly important reason for not simply adding radiant energy to a calculated heat balance. Arithmetic summations do not account very well for the interactions between the four different modes of heat transfer.

The effects of wind are illustrated in UNIT 2.4. The next unit, UNIT 2.3, includes illustrations of the effects of both infrared and visible wavelengths on the temperature profile and thermal resistances.

REFERENCES, UNIT 2.2

INFRARED WAVELENGTHS ONLY

SERIALS

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
JRMGA	27--5	401	403	odvi	radiant temp, hair surface	moen,an	1974
JWMAA	32--2	338	344	odvi	surf temp, radiant heat lo	moen,an	1968
JWMAA	38--2	366	368	odvi	radiant temp surface, wind	moen,an; jacobsen	1974

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
NJZOA	19--1	89	91	rata	surf tmps, heat los, summe	wika,m; krog,j	1971
ZOLZA	53--5	747	755	rata	[body surface heat emissi]	segal,an; ignatov	1974

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

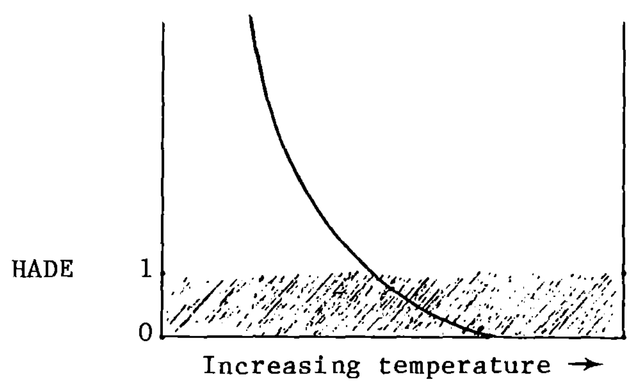
UNIT 2.3: INFRARED AND VISIBLE WAVELENGTHS

Infrared radiation is always present, while visible wavelengths are naturally present only when the sun shines or in moonlight. Moonlight is of no consequence as a source of heat energy, so solar radiation, which includes both infrared and visible wavelenghts, and the background infrared radiation contribute to the radiant energy of interest in this UNIT.

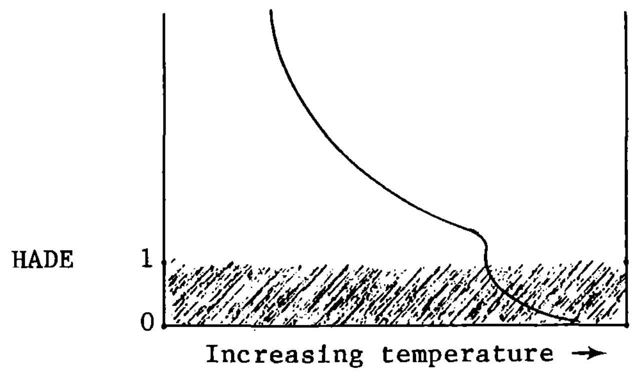
Background infrared radiation was discussed in the previous unit (UNIT 2.2). Measurable differences in infrared flux under different plant canopies were discussed in CHAPTER 14, UNIT 1.3. Solar radiation, especially direct beam radiation from the sun, may be present in much larger quantities than infrared, and its effects are illustrated below.

Solar radiation that reaches the surface of an animal is either reflected or absorbed. Reflection and absorption characteristics were discussed earlier (CHAPTER 15, UNIT 1.2), where it was pointed out that the angles of the sun's rays are an important determinant of absorption coefficients. The angles depend on the sun's position in the sky and the orientation of the animal, resulting in an infinitely large amount of variability.

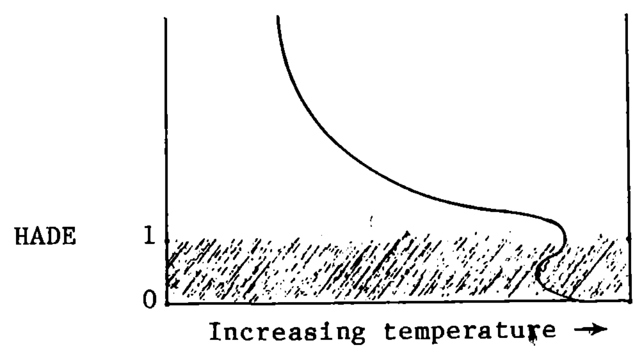
Consider the effects of increasing larger amounts of solar radiation on the temperature profiles and thermal resistances of the thermal boundary region. The sequence below shows the idealized effects of these changes.



The illustration above is for infared radiation only when environmental radiant temperature and atmospheric temperature are in equilibrium. It is a duplicate of the second illustration in UNIT 2.2. Note the smooth profile, and compare it to the effects of an increased radiation load in the next illustration.



An increased radiation load shifts the profile to the higher temperature side as heat energy is absorbed by the hair and the air between the hairs. This increases the steepness of the temperature gradient in the air, and also increases the depth of the air layer that is a part of the thermal boundary region. Thus the layer of insulating air has a greater depth. The temperature at the hair surface is also greater, reducing the temperature gradient through the hair layer. A small temperature gradient through a good insulator, such as hair, results in a very small amount of heat loss through that layer. The addition of solar radition to a animal's surface may greatly reduce heat loss. The next example illustrates the effects of an even greater solar radiation load.



The solar radiation load may be great enough to cause an inversion in the temperature profile, with a higher temperature at the tips of the hairs than at the skin beneath the hairs. When such a profile develops there is a heat <u>gain</u> by the animal rather than a heat loss. The animal would not sense that condition immediately, however, because the hair layer acts as insulation from the heat. As the heat energy moves through the hair layer to the skin where thermal sensors are located, the animal feels warmed. The inverted profile reverses the temperature gradient so heat loss through the entire layer simply cannot occur. This effect may be very important to deer on a south slope in later winter. It is important to point out, however, that the addition of thermal energy and the reduction of heat loss cannot drive the metabolic processes of the deer; input energy (food) is still needed, which is often gotten from newly-exposed vegetation from the previous year and from early new spring growth.

The temperature profiles with increasing radiant energy loads are dramatically altered by wind. The effects of wind are discussed next.

REFERENCES, UNIT 2.3

INFRARED AND VISABLE WAVELENGTHS

SERIALS

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

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
JTBIA	47--2	413	420	rata	solar radiation, wind chil	oritsland,na	1974

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
ECOLA	58--6	1384	1392	doca	cattle colors, solar radia	finch,va; western	1977
JANSA	35--3	624	627	doca	phys principl, energy exch	morrison,sr	1972
JAPYA	26--4	454	464	doca	penetrance coats by radiat	hutchinson,jcd; /	1969
OJVRA	20--2	223	234	doca	absorpt, solar rad, colour	riemerschmid,g; e	1945

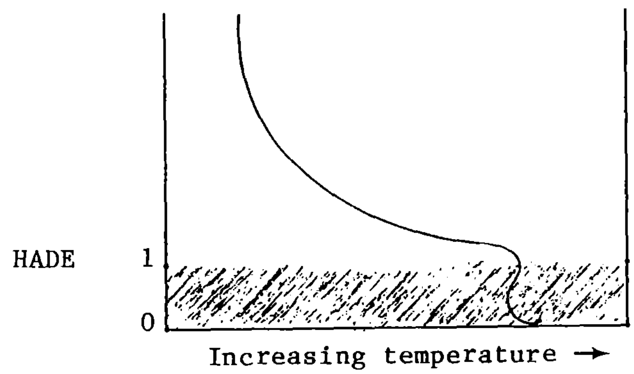
CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
CBPAB	52--2	343	349	doru	reflectance, sol rad, coat	hutchinson,jcd; /	1975
IJBMA	20--2	139	156	doru	meteorology in animal prod	bianca,w	1976
JAPYA	37--3	443	446	doru	heat flow meters, heat los	mchinnis,sm; ingr	1974
PRLBA	188--	377	393	doru	radiati transf, anim coats	cena,k; Monteith,	1975

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
AJZOA	20--1	17	22	dosh	effec postu, heat loa, sum	dawson,tj	1972
ECOLA	50--2	328	332	dosh	bioclim compar, summer day	dawson,tj; denny,	1969
JAPYA	35--5	751	754	dosh	local heat balance, radiat	clark,ja cena,k/	1973

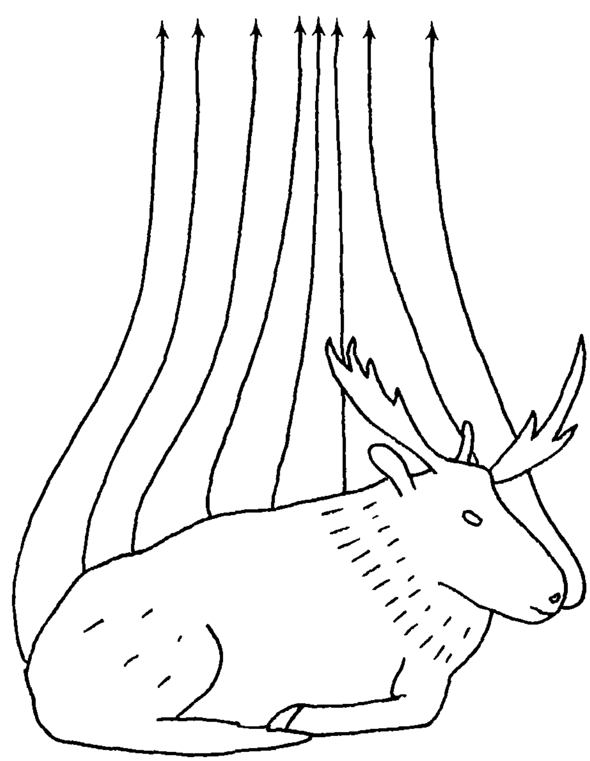
CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
ECOLA	45--3	646	649		sol rad char of tree leavs	birkebak,r; birke	1964

UNIT 2.4: WIND EFFECTS

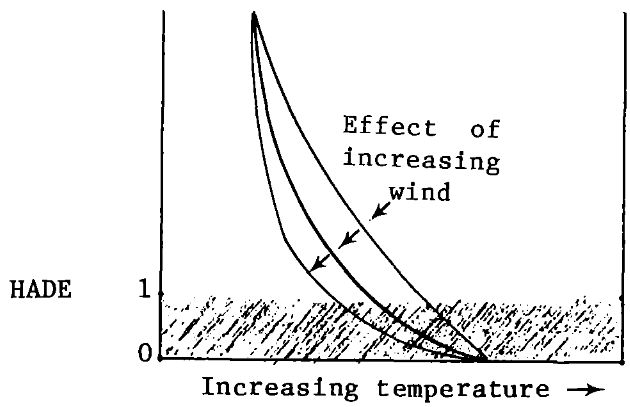
The effects of wind on the temperature profile through the thermal boundary region are illustrated most dramatically with the elevated maximum profiles (the third one) in the previous unit (UNIT 2.3) shown again below.



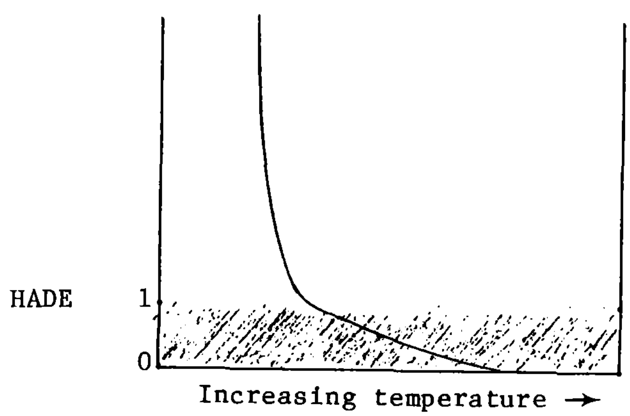
The profile above, with marked temperature gradients, results in natural convection from the hairy surface because of the density differences in the air of different temperatures. The warmer air rises, and a plume develops over the animal. In fact, every animal bedded in the sun on a warm spring day has such an invisible plume over it.



As the wind velocity increases, the temperature profile is compressed. The gradient becomes greater in the hair layer and less in the air layer. The thickness of the entire thermal boundary region decreases as illustrated below.

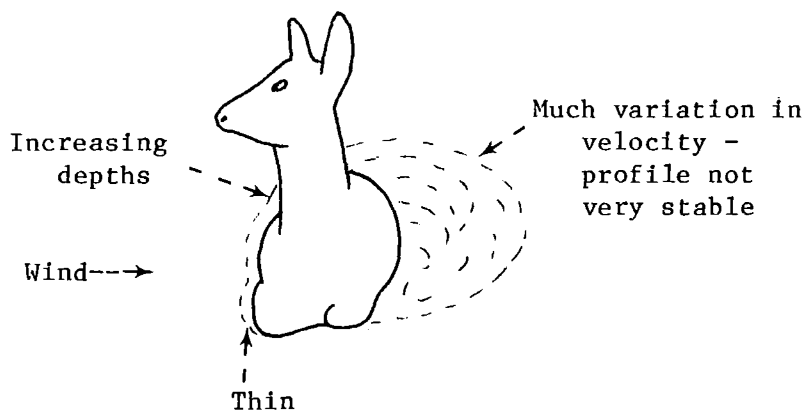


An increase in the wind velocity may compress the temperature profile almost to the physical depth of the hair. Then, the temperature gradient through the air layer is very small, and the depth of the air layer is very small. The temperature gradient through the hair layer is larger, and the value of the overall heat transfer coefficient is larger than in either of the previous two situations.



The effects of wind on the depth of the thermal boundary region and the shape of the temperature profile are large because the wind physically moves the air, destroys density differences and hence temperature gradients. When the thermal boundary region is disturbed in such a way, it no longer functions as insulation, leaving only the hair depth as the layer of insulation. This explains why the hair depth is such an important determinant of the overall heat transfer coefficient. In fact, wind velocity, which affects the depth of the air layer, and hair depth are two of the most important characteristics in thermal exchange.

The distribution of wind velocity over the irregular sufaces of a bedded, standing, or moving animal is very complex, with turbulence added as a result of the animal's geometry. The pattern of thermal boundary region depths in relation to wind is shown below.



Such complexities, even for the simplest of cases, are more than can be precisely evaluated mathematically. Insights may be gained, however, by evaluating sets of conditions that result in estimated amounts of heat loss, and these amounts related to metabolic heat production. Concepts and insights are valuable even when empirical measurements are difficult to make.

REFERENCES UNIT 2.4

WIND EFFECTS

BOOKS

TYPE	PUBL	CITY	PAGE	ANIM	KEY WORDS-----------------	AUTHORS/EDITORS--	YEAR
aubo	gaul	loen	234	rata	the wind and the caribou	munsterhjelm,e	1953

SERIALS

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
JRMGA	27--5	401	403	odvi	radiant temps, hair surfac	moen,an	1974
JWMAA	32--2	338	344	odvi	surf temp, radiant heat lo	moen,an	1968
JWMAA	38--2	366	368	odvi	radiant temp surface, wind	moen,an; jacobsen	1974
NAWTA	35---	106	114	odvi	func aspects wind, thermal	stevens,ds; moen,	1970

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	38--4	679	688	rata	eff wind, moist newb htlos	lentz,cp; hart,js	1960
NJZOA	19--1	89	91	rata	surf tmps, heat los condit	wika,m; krog,j	1971
TRJOA	25-10	832	837	rata	thermal insulation of pelt	moote,i	1955
ZOLZA	53--5	747	755	rata	[body surfac heat emissio]	segal,an; ignatov	1974
JTBIA	47--2	413	420	rata	wind chill, solar radiatio	oritsland,na	1974

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
JANSA	35--3	624	627	doca	physic principl energ exch	morrison,sr	1972
JASIA	74--2	247	258	doca	accum, evap moist, sweatin	allen,te; bennet/	1970
IJBMA	20--2	139	156	doru	meteorology in anim produc	bianca,w	1976
JAPYA	37--3	443	446	doru	heat flow meters, heat los	mcginnis,sm; ingr	1974

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
JASIA	52--1	25	40	dosh	partition heat los, clippe	blaxter,kl; grah/	1959

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS----------------	AUTHORS----------	YEAR
JAPYA	20--4	796	801	mamm	hair dens, wnd spd, h loss	tregear,rt	1965
BIOJA	11-12	1030	1047	----	energy exch, cylind append	wathen,p; mitche/	1971
JTBIA	35--1	119	127	----	convect resp syst, panting	seymour,rs	1972
PRLBA	188--	395	411	----	conductin, convectn, coats	cena,k; monteith,	1975

UNIT 2.5: COMBINED EFFECTS OF DIFFERENT VARIABLES

Air temperatures, wind velocities, locations, postures, surface areas, and other characteristics of the animal-environment relationship change during a 24-hour period. Real-time analyses are impossible because changes are too numerous and too rapid. Calculated heat losses for the many different combinations of conditions are added together to give the total quantity of heat lost (QHLK) for a 24-hour period. The total is then compared to estimates of heat production. Using this approach, the benefits of different postures and locations can be demonstrated under different temperature and wind conditions and an understanding of some thermoregulatory behavioral responses gained.

The validity of the results of calculations for deer and the results of first approximations for other species may be checked by comparing the calculated heat loss to base-line metabolism (BLMD). Calculation of ecological metabolism (ELMD) of white-tailed deer in Chapter 7 show that ELMD, expressed as multiples of base-line metabolism MBLM [MBLM = (ELMD/BLMD)] is expected to range numerically from about 1.5 to 1.8. Total heat loss, espressed as MBLM, should also be in that range. Divide the quantity of heat lost in KCAL (QHLK) calculated in the worksheets by BLMD to determine the ratio, or MBLM. If it is greater than the multiple calculated for energy metabolism estimates, the animal is losing more heat energy than is being produced metabolically. This cannot go on for extended periods of time, of course, because body temperature will then drop. If QHLK is less than ELMD, then the animal must do something to dissipate the excess heat energy, or body temperature will rise.

REFERENCES UNIT 2.5

COMBINED EFFECTS OF DIFFERENT VARIABLES

SERIALS

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

odvi

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

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

TOPIC 3. THERMOREGULATION

A homeothermic animal maintains a balance between heat production and heat loss. Since heat production and heat loss are constantly changing, the animal is in a continual state of dynamic equilibrium. When the animal is in a thermoneutral zone, the balance between heat production and heat loss may be maintained without special thermoregulation.

Physiologists have usually defined the thermoneutral zone as the range of temperatures which do not cause a metabolic response to maintain homeothermy during basal metabolic measurements. This dependence on temperature has been useful for physiologists who needed to establish some laboratory standard for comparative work, but it is quite inadequate for ecologists concerned with the free-ranging animal. Many animals spend a considerable portion of their time outside of such a physiologically defined thermoneutral range, yet they survive and reproduce.

The homeothermic animal maintains a balance between heat production and heat loss by distributing the heat produced during normal life processes and increasing the heat production when the animal is in a critical hypothermal environment. The heat production by metabolic processes is often localized in a specific areas of the body. Muscle metabolism and rumen fermentation, for example, are two exothermic processes that are quite localized, and it is necessary for the animal to distribute this heat energy throughout its body.

The use of the term "thermoneutral range" in an ecological context implies that there is a balance between heat production during normal activity and heat loss in a complex thermal regime that includes radiation, convection, conduction, and evaporation as the four modes of heat transfer. The thermal environment includes all factors that are a part of the heat production-heat loss relationship. A critical thermal environment (Moen 1968) occurs when the animal must make a response in order to maintain homeothermy. The continual adjustment of physiological and behavioral responses results in short-term temperature transients in the animal, a normal part of life for a homeotherm.

A thermal regime may occur in which the heat production of an animal is greater than the heat loss even though the animal may attempt to maintain a balance. When this occurs, the animal is in a critical hyperthermal environment. If heat loss is greater than heat production, the animal is in a critical hypothermal environment (Moen 1968).

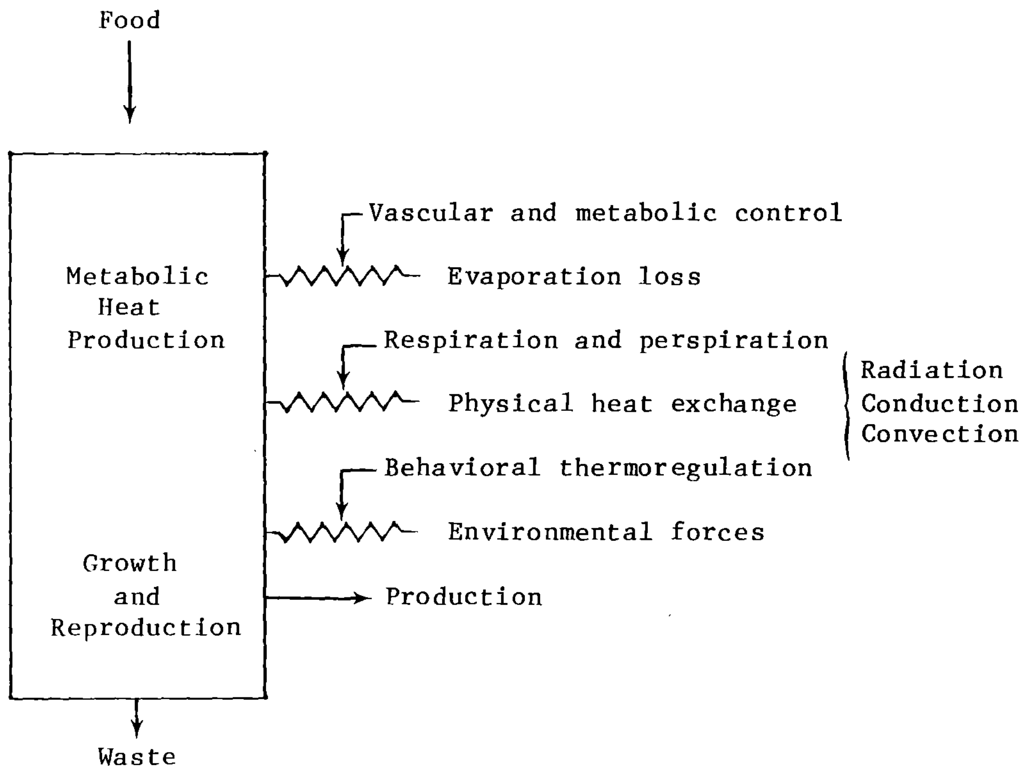
Situations can develop when the many factors that make up the thermal regime, including both heat production and heat loss factors, may result in a critical thermal environment that is partly independent of existing weather conditions. A deer being chased by dogs on a cool fall day, for example, may reach a critical hyperthermal environment because heat production has increased greatly due to running. The weather is not critical; running is the critical factor. A deer may reach a critical hypothermal environment during a spring rain when the molt is in process and the new summer coat becomes soaked with water. The effect of this rain might be critical during the molt, but could have been quite unimportant when the animal was still in winter coat. Thus the critical factor is the stage of the molt rather than the rain. These examples illustrate how combinations of conditions may interact to cause one factor to become important under particular conditions.

Any factor that is a part of the thermal regime could become critical if some of the other thermal conditions were near critical. In a high wind, for example, there could be a critical orientation of the animal that would result in a favorable balance between heat production and heat loss. A critical wind velocity, critical radiant energy level, critical activity level, critical posture, or any other critical variable is meaningful only when all other thermal factors are identified.

Many different combinations of thermal factors can occur for free-ranging animals. Recognizing this, one immediately realizes that the traditional idea of upper and lower critical temperatures to identify the end points of the thermoneutral zone is entirely inadequate in ecology. It has served a useful purpose in the laboratory where chamber conditions are quite well represented by a temperature measurement, but data from these simplified laboratory experiments cannot be applied to the dynamic thermal regimes of free-ranging animals.

The time has come to analyze rather than merely correlate weather data with animal responses. The ecological definition of the thermoneutral range is more of a concept that includes an understanding of the principles of heat exchange rather than a precise definition composed of a set of factors. Further, an understanding of the principles of heat exchange enables one to separate the physiological and behavioral responses to the thermal environment from the responses to social interaction between animals or other stimuli that are not related to weather factors.

The thermal exchange system consists of input and output energy. Input energy includes food that is the source of energy for metabolic processes, and solar and infrared radiation that add to the heat load. Output energy includes the energy that goes into activity, growth and reproduction. The several variables in this system include vascular control over physical heat exchange, respiratory and perspiratory control over evaporation losses, behavioral control over physical heat exchange, and production. A schematic of this system is given at the top of the next page.



An animal that maintains a balance between heat loss and heat production is constantly adjusting the variables over which it has some control. These can be grouped into two classes: physiological controls and behavioral controls. They are not biologically distinct, though, since no behavioral response can occur without a physiological function. These two controls over thermoregulation are discussed in the next two UNITS.

LITERATURE CITED

Moen, A. N. 1968. The critical thermal environment: A new look at an old concept. BioScience. 18(11):1041-1043.

UNIT 3.1: PHYSIOLOGICAL THERMOREGULATION

An animal can respond to the thermal environment in two ways, including 1) a heat-producing or a thermogenic response, and 2) a heat-conservation response. The heat-producing response involves metabolic processes and thermogenesis. The heat-conservation response involves regulation of the animal-to-environment thermal gradient. These two processes occur together so it is the net effect--whether a change in the heat production is greater or less than a change in the heat loss--that is important.

Heat-producing or thermogenic responses can occur within seconds, and metabolic patterns occur in daily and seasonal cycles also. The metabolic rate is higher during the day for diurnally active animals, and higher at night for those that are nocturnal. White-tailed deer exhibit a seasonal rhythm in metabolic rate, with lower metabolic rates in the winter and higher rates in the summer (Moen 1978).

Heat-conservation or thermoregulatory responses can occur within seconds too, and seasonal cycles such as changes in the hair coat and in the behavior of the animals also occur over periods of several months.

Coat characteristics are an important adaptation for survival in the colder regions of the earth. It is generally thought that the insulation of the coat is the major adaptation of northern species, but the winter metabolic depression is also important. Marked differences do occur between depth and structure of summer and winter coats. White-tailed deer have a summer coat of sparse and fine hair. The winter coat is thick and coarse, with depths over 2.0 centimeters on the trunk. The hairs in the longer winter coat also are hollow and crinkled, with an underfur that consists of very fine hairs that are about as numerous as the longer hairs.

Coat color is a genetic characteristic of interest in analyzing the radiation exchange of an animal, especially because of seasonal changes in color, thickness, and depth. From a thermal point of view, it is advantageous for a rough-coated animal to be white in the winter so a maximum amount of solar radiation can be absorbed by reflection into the hair coat (see CHAPTER 15, UNIT 1.2).

Two ecological rules that relate body structure to climate factors have become firmly entrenched in the ecological literature. Bergman's Rule states that northern members of a species have a larger body size than southern members. This is interpreted as a genetic adaptation to cold since a larger body has a higher volume to surface area ratio than a smaller one. Allen's Rule states that northern species have smaller appendages than southern ones. This is interpreted as an adaptation for the conservation of heat in the north with less surface area on legs and ears, and for the dissipation of heat in southern climates as the appendages act as cooling fins.

The validity of interpreting Bergman's and Allen's Rules on the basis of a climatic gradient may be questioned. Both of the rules are logical in theory, but the number of factors involved in thermal exchange and the compensatory effects of interaction between physiological and behavioral factors indicate that the body size or appendage size differences may be quite insignificant compared to other thermoregulatory mechanisms. Further, the younger members of each species are usually smaller than the mature animals in either north or south, so the rules are violated by each individual during its life span.

An animal may increase its heat production by increasing gross body activity or by increasing the rate of metabolism in specific organs or tissues. Raising the level of gross body activity is not a 100% efficient process since greater body movement results in a greater heat dissipation due to the effect of movement in the hair-air interface. Heat exchange by convection is also increased as the animal moves through the air, increasing the effective wind velocity at its surface.

The increase in metabolic rate due to elevated activity levels may be sufficient to offset heat losses during cold conditions, but it cannot be kept up for long periods of time because of muscle fatigue. Thus it is effective only if the activity level is somewhat similar to normal daily patterns. Less obvious but very important thermogenic responses are found in metabolic potentials that do not involve overt muscular activity. Animals conditioned to cold weather (Acclimatization, Folk 1966) are more capable of withstanding cold than animals that have had no previous exposure to cold.

A general relationship has been observed between heart rate, oxygen consumption, and heat production; an increased heart rate is indicative of a higher heat production. This general relationship between heart rate and metabolism shows considerable variation between individual animals, however, so it is necessary to calibrate each animal to determine its own heart rate:oxygen consumption curve.

One metabolic response that has received considerable attention by physiologists is non-shivering thermogenesis which involves an increase in heat production that results from the metabolism of brown fat. Larger species such as cattle apparently do not have brown fat. Bruck et al. (1969) formulated a general rule, documented also by Jansky et al. (1969), that the bigger the animal, the less brown fat it possesses. This conclusion was reached after careful consideration of their own work and of others reported in the literature. Wild ruminants apparently do not rely on non-shivering thermogenesis for the maintenance of homeothermy.

The metabolic rate of white-tailed deer confined to a temperature-controlled metabolic chamber rose as the chamber temperature was lowered. The actual rate of metabolic increase in relation to chamber temperature cannot be applied directly to temperature data in the field because of the many other thermal factors that need to be considered in the field. The experiments were useful, however, for determining the metabolic potential of deer without a significant increase in gross body activity.

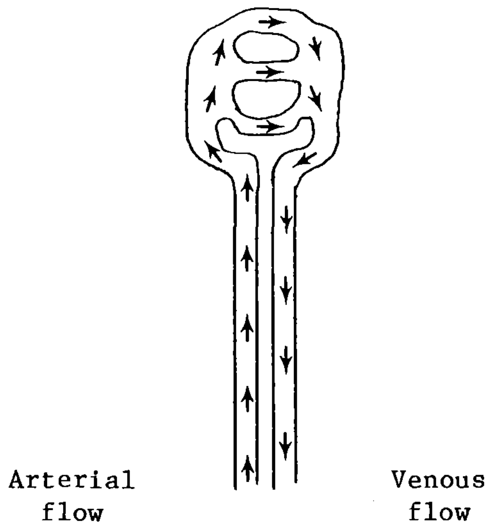
Another metabolic process important in thermogenesis in ruminants is the effect of the heat of rumen fermentation. Ingested forage is digested by rumen microorganisms, and the exothermic fermentation process provides heat energy that contributes to the maintenance of homeothermy. Absorption of nutrients follows digestion, and then these nutrients are metabolized in the cells of the animal, resulting in an additional source of heat attributed to nutrient metabolism.

Experiments on sheep in chambers show that the critical temperature based on the chamber environment is higher when the sheep are at a low feeding level, lower on a medium feeding level, and lowest on the highest feeding level (Graham et al. 1959:23 and Graham 1964:982). This is the pattern one would expect, but it must be emphasized that an animal has several alternative pathways to maintain heat production or regulate heat loss. In the absence of sufficient food, for example, fat catabolism occurs under cold conditions so heat production may be maintained at a necessary level. New-born lambs, not yet developed as homeotherms, survived longer when confined in a room at 23°C than those at 9°C, indicating that a lower heat production was possible as the warmer room resulted in a reduced rate of heat loss from the animal (Alexander 1962:144). This is similar to the conclusions of Moen and Severinghaus (1981) for white-tailed deer that exhibited higher death weights in colder and less protected areas than in warmer, more sheltered areas.

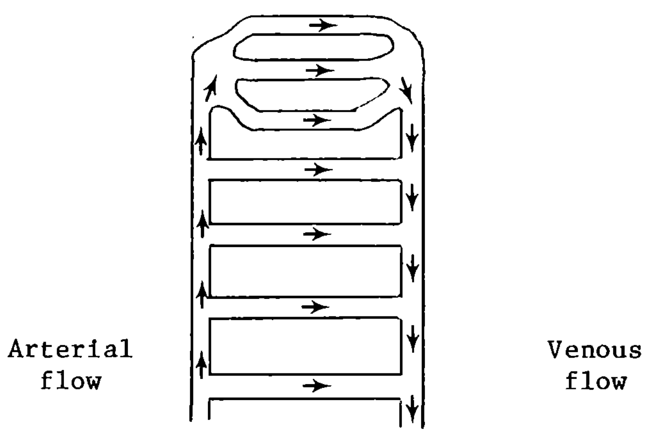
The rate of depletion of the fat reserve is an important consideration when food is inadequate and shelter conditions vary. The significance of fat reserves to wild ruminants may be considered when calculating carrying capacity for different time periods

Heat-conservation responses are dependent on reductions in thermal gradients. Heat energy is distributed to different parts of the body when the circulatory system functions as a thermal transport mechanism. The flow of blood from a warmer area to a cooler area results in the transport of heat energy by convection processes. This is a passive event unless the organism exhibits some control over the flow characteristics in order to maintain a thermal balance.

Both passive and active mechanisms are found in animals. A heat exchanger, illustrated at the top of the next page, is a passive mechanism that has been suggested as one adaptation of caribou for the maintenance of sharp temperature gradients in the extremities (Irving and Krog 1955). This arrangement permits the exchange of heat without an exchange of arterial and venous blood. The heat flow is simply a conduction process from the warm arterial walls through the body tissue to the cooler venous blood that is returning from the extremity. This results in colder tissue temperatures in the extremities, and a reduction in the thermal gradient between animal and environment.



A vascular shunt is an active mechanism for the distribution of heat energy as the blood is shunted from an artery to a vein, diminishing the blood supply in the terminal capillary beds as illustrated below. This results in a reduction in heat loss from the extremity since the blood flow is reduced, but this also causes a reduction in the oxygen supply.



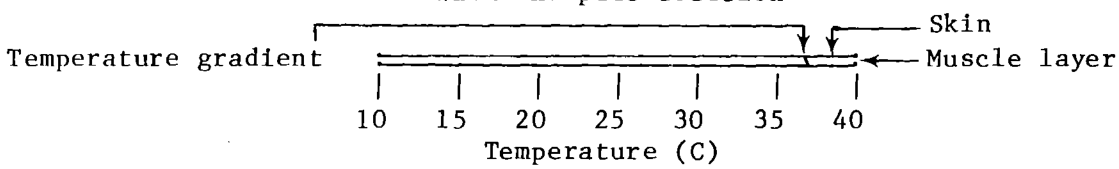
Regulation of heat loss by the control of blood flow is not precise enough to result in a constant temperature of the extremity. Ear temperatures of caribou, for example, showed phasic changes from lows of nearly freezing (0°C) to 15°C, back to 0°, etc. This indicates that the different parts of the anatomy of homeotherms are not in thermal balance, but that the whole body over longer time periods is.

The importance of vascular control of heat flow is related to the insulation characteristics of the coat. The amount of vascular control in the extremeties is relatively more important because of the shorter, sparser hair than on the trunk. The importance of blood flow and hair insulation is further modified by the distribution of subcutaneous fat and piloerection. A fat layer also reduces the heat loss from the animal's surface since fat tissue is a good insulator.

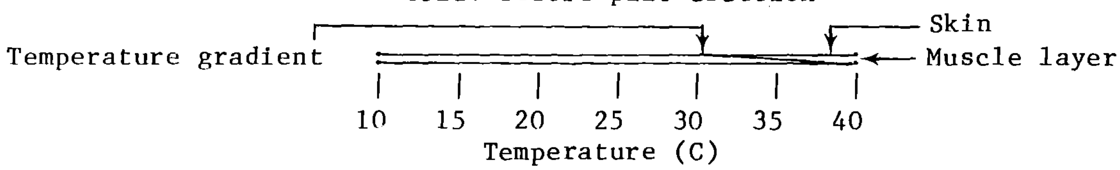
Pilo-erection has traditionally been considered a heat-conservation mechanism because of the increase in the depth of the insulation layer. This increase in depth, however, is compensated for to an unknown extent by the more open characteristic of the hair coat. The loss of heat through a more open hair layer is greater because of increased penetration by wind and subsequent convective heat loss. Thus the decrease in the thermal conductivity due to the greater depth of erected hair is counteracted by the increase in heat flow through the more open erect hair. If the net effect were an increase in heat loss, pilo-erection would not be a heat conservation mechanism.

My theory is that pilo-erection is a heat-producing adaptation as well as a mechanism for heat-conservation. During warm conditions, normal muscle tonus results in a small amount of heat production from the metabolic processes involved in muscular contraction. A small temperature gradient exists between the external surface of the skin and the subcutaneous muscle later. If heat loss increases, the temperature gradient from skin to muscle increases and the thermal receptors in the skin sense the colder conditions. The central nervous system relates the signal to the muscle tissue beneath the skin and the muscles contract with a concomitant release of heat energy. This heat energy raises the temperature in that area of the skin and reduces the temperature gradient. As the muscles contract and release heat, the hair is erected. Pilo-erection is then a secondary effect, with the exothermic muscular contractions a heat-producing process of importance in altering the temperature gradients and subsequent flow of heat. Changes in the temperature gradients are illustrated below.

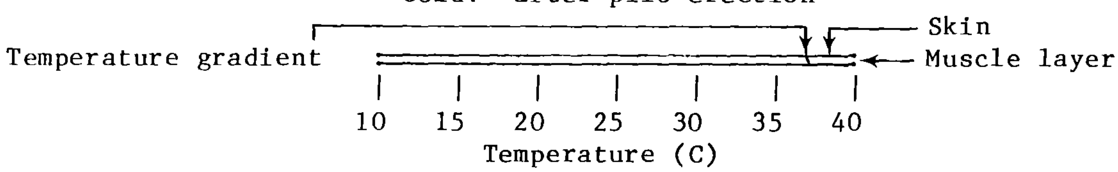
Warm: no pilo-erection



Cold: before pilo-erection



Cold: after pilo-erection



Evaporation of body fluids is a thermoregulatory response that occurs under hot conditions. The balance between heat loss and heat production in hot environments can be regulated by a reduction in nutrient intake and an increase in evaporative heat losses. Thus water is consumed at high levels during hot weather. When the effective environmental temperature is equal to or greater than body temperature, evaporative heat loss is the only kind of heat loss that can occur. Radiation, conduction, and convection result in a heat input rather than a heat loss.

The evaporative heat loss from respiratory surfaces can be increased by panting. This is, in part, an inefficient process because exothermic reactions occur as muscles are used for panting. This increases heat production, which must be offset by increases in heat loss by evaporation. There are few data available that provide an indication of the relative magnitude of the two opposing forces.

Wetting of an animal's surface results in an increase in heat loss by evaporation. An increase in heat production may result; infant caribou with wet fur had a heat production up to 10 times the basal rate (Hart et al. 1961). The heat loss due to evaporation has been suspected as a cause of mortality in the newborn of several different species.

Several other physiological responses are observed when animals are exposed to thermal regimes that are beyond the zone of thermoneutrality for any length of time. Body growth and production are retarded in hot environments, and reproduction is generally less successful. Hypercritical thermal environments for a few hours or days can result in mortality as body tissue is not adapted to the maintenance of metabolic processes at temperatures much over 2°C above normal.

The physiological effects of cold environments are frequently less critical than those of hot environments. The effect of cold environments can be compensated for by higher planes of nutrition that permit increased heat production up to the maximum metabolic potential of the animal. If the amount of ingested food is insufficient to meet the energy needs in the cold, body tissue can be mobilized. Fat is mobilized in such a way by wild ruminants during each winter. Pregnant females may resorb the fetus, thus reducing the reproductive rate. While these responses are known to be possible, there are no field data on population effects except for documented winter mortality for some species in selected areas.

Behavioral thermoregulation is discussed in the next unit (UNIT 3.2). It is closely tied to physiological thermoregulation since behavioral acts cannot be completed without physiological functions.

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REFERENCES, UNIT 3.1

PHYSIOLOGICAL THERMOREGULATION

SERIALS

TYPE	PUBL	CITY	PAGE	ANIM	KEY WORDS-----------------	AUTHORS/EDITORS--	YEAR
edbo	apso	wadc		mamm	p 361, terres anim in cold	bill,db	1964
aubo	lefe	phpa	308	----	intro, environmntl physiol	folk,ge,jr	1966
edbo	acpr	nyny	1967	mamm	p 412, resistance to cold	rose,ah	1967

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
BISNA	18-11	1041	1043	odvi	criticl thermal environmnt	moen,an	1968
CJZOA	53--6	679	685	odvi	ambien temp effect, physio	holter,jg; urban/	1975
ECOLA	57--1	192	198	odvi	energy conservat in winter	moen,an	1976
JWMAA	35--1	37	46	odvi	effect falli temp, heat pr	silver,h; holter/	1971
JWMAA	42--4	715	738	odvi	seas chan, heart rate, act	moen,an	1978
NFGJA	28--2	162	177	odvi	annual wt cycl, survivl,ny	moen,an; severing	1981

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
CJZOA	56-11	2388	2393	ovca	winter bioenerget, rocky m	chappel,rw; hudso	1978
JWMAA	35--3	488	494	ovca	variat of rectal temperatu	franzmann,aw; heb	1971

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
APSCA	105-3	268	273	rata	spitzberg. womt-dorman ung	ringberg,t	1979
CBPAB	60A-2	123	126	rata	seas change growth hormone	ringberg,t; jaco/	1978
CJZOA	39--7	845	856	rata	clima, metab, therm, infan	hart,js; heroux,/	1961
CJZOA	48--2	391	392	rata	energy metab, barren groun	mcewan,eh	1970

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
JWMAA	35--3	488	494	ovca	variat of rectal temperatu	franzmann,aw; heb	1971

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
CJZOA	56-11	2388	2393	ovca	winter bioenerget, rocky m	chappel,rw; hudso	1978

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
ANYAA	53--3	600	607	many	role piliary sys,therm env	herrington,lp	1951
JAPYA	7---4	355	364	many	tem skin in arctic, reg he	irving,l; krog,d	1955
SSEBA	18---	31	48	many	insul, met adap to cold in	hart,js	1964

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
RSPYA	4---3	353	362	doca	oxy cost, induc hyperventi	hales,jrs; findla	1968

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
AJAEA	13--1	82	99	dosh	eff wind, evap on meta rat	alexander,g	1962
AJAEA	15--6	982	988	dosh	inf amb tem, heat prod pre	graham,nmcc	1964
CNJNA	43--1	39	46	dosh	eff low temp, physiol resp	hess,ea	1963
JASIA	52--1	13	24	dosh	energ met, closely clipped	graham,nmcc; wai/	1959

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
BIBUB	99---	259	271	mamm	adap, cold, arctic, tropic	scholander,pf; h/	1950
FEPRA	19--4	59	563	----	thyroid secr, cold acclima	cottle,hw	1960
FEPRA	28--3	1053	1058	----	non-shiv thermogen, inters	jansky,l; bartun	1969
PNUSA	37--1	29	43	----	energy exchanges & injury	richards,jr; dru/	1978
SCAMA	214-1	94	101	mamm	adaptations to cold	irving,l	1966

UNIT 3.2: BEHAVIORAL THERMOREGULATION

Behavioral responses. Animals respond behaviorally to the thermal regime, altering the balance between heat loss and heat production by changes in orientation, posture, activity, or the selection of cover. This behavioral thermoregulation has an effect on the physiological responses that result from thermoregulation, since behavioral responses cannot occur without the contraction of muscles.

Individual responses. Each individual animal can assume an orientation with respect to the distribution of thermal energy, especially wind and radiation, that will result in the conservation or dissipation of heat. For example, an animal that stands perpendicular to the wind direction may have a greater convective heat loss than one oriented with the direction of air flow. The orientation of the hair with respect to wind direction also has an effect on the heat loss by convection.

Direct solar radiation is distributed with distinct shadows that result from the distribution of cover. Indirect or diffuse solar radiation is scattered throughout the cover, but with a reduction in intensity as the cover density increases. The amount of radiation absorbed depends in part on the angle with which the radiation strikes the animal.

Infrared energy has a distribution that is dependent on physical characteristics of the environment too. A "thermal profile" of a tree at night is a predictable thing; the radiant energy extends outward to a radial distance that is approximately the same as the height of the tree (Moen 1968; 6).

The surface area of an animal that is in contact with the snow or soil is an important consideration in the amount of conductive heat loss. A standing animal has little area in contact with the substrate, so conduction losses are small. An animal bedded in the snow has about 25% of its surface area in contact with the snow, and heat loss by conduction is an important part of the total heat loss.

Many descriptions of thermoregulatory behavior are found in the literature. Severinghaus and Cheatum (1956) report that deer will remain in a bed for one to three days after a storm, usually under low-hanging conifers or windfalls. During sub-zero weather in Maine, beds were found under conifer branches that were bent down and covered with snow, or under hardwoods which had retained their leaves (Hosley 1956; 216). On very cold nights, deer in the Adirondacks were observed moving slowly on the trails, and Severinghous and Cheatum (1956) suggested that it was too cold for the deer to remain bedded. Deer in the Edwards Plateau in Texas concentrated in a valley protected from a cold north wind (Taylor 1956; 147).

Henshaw (1968; 22) noted that caribou bedded in areas of irregular topography during continued high winds. Their bodies were generally broadside to the wind. No apparent discomfort due to low temperature with little or no wind could be detected. Observations of white-tailed deer in the cold, continental climate of western Minnesota also indicated that cold temperatures without wind had no apparent effect on the animals (Moen 1966).

How significant are the above observations and others similar ones in the literature when considered in the entire ecological picture? Do the animals really conserve a significant amount of heat by behavioral thermoregulation?

The questions above cannot be answered without an examination of the dynamics of heat flow. Early calculations with a standing model of white-tailed deer indicated that this was feasible, (Moen 1966 and Moen 1968). Additional experiments at the Wildlife Ecology Laboratory, Cornell University, have resulted in a considerable amount of information that is of value in intepreting the behavior of deer in the winter.

On cold days an animal is faced with the choice of either producing more heat or conserving more heat. An increase in body activity results in a greater heat production. This additional heat will counteract the great heat loss in a cold environment. It is not a completely efficient process, however. Moving about increases the flow of heat through the hair coat as it flexes, and it also increases convective losses. Heat production during sustained body activity will usually exceed the heat loss, however, so the net effect is to keep the animal warm.

More body activity results in an increase in the energy requirement. The additional energy required may not be available on the range, or it may not be available fast enough to support the higher level of activity. Thus, increasing body activity is not a feasible long-term solution for a free-ranging animal.

In cold conditions an animal can increase its feed intake to benefit from the increased heat of fermentation and nutrient metabolism. A reduction in intake in hot environments has the opposite effect. Other factors that influence the level of ingestion of a free-ranging animal may be more important than the thermal regime of the animal. Endocrine effects seem to be extremely important on a seasonal basis for white-tailed deer. It appears that food intake by wild ruminants is not related to the thermal effects of weather except in a very general way. Factors affecting ingestion are discussed further in another chapter.

Groups of wild ruminants seem to respond to general weather conditions in somewhat predictable ways. Caribou have been observed to be more gregarious during cold weather (Henshaw 1968; 23). White-tailed deer move or are confined to yards, especially during winters with deep snow. White-tails in western Minnesota formed larger groups during periods of reduced visibility without apparent relation to temperature (Moen 1966 and unpublished data). Elk migrate from summer to winter range and this seems to be triggered by weather changes. Heavy snowstorms are a factor in starting the fall migration of mule deer to winter range while the migration back to summer range is related to plant growth (Russell 1932; 39). Moose bed in soft snow and this may reduce the energy requirements of the animals because snow is a good insulator (Des Meules 1964; 55).

Some studies have been done to evaluate the different directions of slopes that are used, and the usual conclusion is that the southern exposures are used more than northern ones. There is a greater energy flux on south slopes than on north slopes because of the distribution of solar radiation. Northerly winds are also more common in the winter, resulting in generally harsher conditions on the north slopes. The preference for south slopes may not be related to weather conditions or energy flux alone, however. Snow depths are frequently less on south exposures, especially in late winter and early spring when melting begins. A decrease in snow cover results in an increase of available food, and this may have a considerable effect on the distribution of animals.

Grouping of animals has some potential benefit in the reduction of heat loss. Animals that are huddled together exchange heat with each other, thus conserving it within the group. Caribou move in bands when feeding and the water vapor released by respiration sometimes condenses and forms a cloud that can reduce heat loss by radiation. The physiological benefits from grouping may be secondary effects only however. The stimulus for grouping may be social, with heat conservation benefits only incidental. The "cloud cover" that forms above a herd of caribou may have little real benefit since the heat production of the animals is higher when active and the cloud is not necessary for the maintenance of homeothermy.

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Taylor, W. P. 1956. Ed. The Deer of North America. The Stackpole Co. Harrisburg, PA. 668 p.

REFERENCES UNIT 3.2

BEHAVIORAL THERMOREGULATION

SERIALS

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
ECOLA	57--1	192	198	odvi	energy conservat in winter	moen,an	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
ECMOA	2---1	1	46	odhe	seasonal migration, mule d	russel,cp	1932a

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

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
JOMAA	50--2	302	310	alal	odvi,structrl adapta. snow	kelsall,jp	1969
QSFRA	3----	51	73	alal	influence of snow on behav	des meules,p	1964

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
ATICA	12--3	158	179	rata	snow, winter ecolo, bar gr	pruitt,wo, jr	1959
IJBMA	12--1	21	27	rata	act wint cari, snow, alask	henshaw,j	1968

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

ovda

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

obmo

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

CJPPA 47--8 719 724 dosh cold thermogenes in sheep webster,ajf;heit/ 1969

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

FEPRA 19--4 19 24 ---- calorigen in organ systems depocas,f 1960
FEPRA 28--3 1053 1058 ---- non-shiv thermogen, inters jansky,l· bartun 1969

PAREA 18--1 291 301 ---- catecholam cold adaptation carlson,ld 1966

CLOSING COMMENTS

This CHAPTER 16 has included a review of the more traditional approaches to the calculation of heat loss and the measurement of animal responses, an introduction to the concept of the thermal boundary region as the overall layer of insulation, and the use of overall heat transfer coefficients for calculating heat loss. While I have extensive data on overall heat transfer coefficients for white-tailed deer, the analyses have not been completed yet so the discussions here have been limited to general patterns. Results of these analyses will be published in a scientific journal as soon as possible

Aaron N. Moen
November 18, 1981

GLOSSARY OF SYMBOLS USED - CHAPTER SIXTEEN

AITE = Air temperature

BLMD = Base-line metabolism

DCYC = Diameter of the cylinder in centimeters
DLTT = Delta T = Delta temperature

ELMD = Ecological metabolism

HADE = Hair depth

KCAL = Kilocalories

MBLM = Multiple of base-line metabolism

OHTC = Overall heat transfer

PHOU = Per hour
PSMH = Per square meter per hour
PSQM = Per square meter

QFCV = Quantity of forced convection
QHCO = Quantity of heat transfer by conduction
QHLK = Quantity of heat lost
QNCV = Quantity of natural convection

SAFC = Surface area in forced convection
SANC = Surface area in natural convection
SQMH = Square meters per hour

WIVE = Wind velocity
WTKG = Weight in kilograms

GLOSSARY OF CODENS - CHAPTER SIXTEEN

SERIALS are identified by five-character, generally mnemonic codes called CODEN, listed in 1980 BIOSIS, LIST OF SERIALS (BioSciences Information Service, 2100 Arch Street, Philadelphia, PA 19103).

The headings for the lists of SERIALS are:

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

The volume and issue numbers (VO-NU) are given after the CODEN entry, followed by beginning page (BEPA), ending page (ENPA), species discussed (ANIM), KEY WORDS from the title, AUTHORS [truncated if necessary, slash (/) indicates additional authors], and year.

AGMYA Agricultural Meteorology
AJAEA Australian Journal of Agricultural Research
AJPHA American Journal of Physiology
ANYAA Annals of the New York Academy of Sciences
APSCA Acta Physiologica Scandinavica
ATICA Arctic

BIBUB Biological Bulletin
BIOJA Biophysical Journal
BISNA Bioscience
BJLSB Biological Journal of the Linnean Society
BVJOA British Veterinary Journal

CBPAB Comparative Biochemistry and Physiology A Comparative Physiology
CJPPA Canadian Journal of Physiology and Pharmacology
CJZOA Canadian Journal of Zoology
CNJNA Canadian Journal of Animal Science
COPMB Computer Programs in Biomedicine

EAFJA East African Agriculture Forestry Journal
ECMOA Ecological Monographs
ECOLA Ecology

FEPRA Federation Proceedings

IJBMA International Journal of Biometeorology
IJLAA Indian Journal of Animal Sciences
IJMDA Israel Journal of Medical Sciences

JAPYA Journal of Applied Physiology
JASIA Journal of Agricultural Science
JDSCA Journal of Dairy Science

JOMAA	Journal of Mammalogy
JPHYA	Journal of Physiology
JTBIA	Journal of Theoretical Biology
JWMAA	Journal of Wildlife Management
JZOOA	Journal of Zoology
NAWTA	North American Wildlife and Natural Resources Conference, Transactions of the,
PAREA	Pharmacological Reviews
PNUSA	Proceedings of the Nutrition Society
PYSOA	Physiologist
QSFRA	Quebec Service de la Faune Rapport
RSPYA	Respiration Physiology
SCAMA	Scientific American
SSEBA	Symposia of the Society for Experimental Biology
SZSLA	Symposia of the Zoological Society of London
TRJOA	Textile Research Journal
VCSZA	Vestnik Ceskoslovenske Spolecnosti Zoologicke
XARRA	U.S. Forest Service Research Note RM
ZETIA	Zeitschrift fuer Tierpsychologie
ZOTCA	Zootechnia

LIST OF PUBLISHERS - CHAPTER SIXTEEN

The headings for the lists of BOOKS are:

TYPE PUBL CITY PAGE ANIM KEY WORDS----------------- AUTHORS/EDITORS-- YEAR

All essential information for finding each book in the library is given on just one line. The TYPE of book could have either AUTHORS (aubo) or EDITORS (edbo). Publishers (PUBL) and CITY of publication are given with four-letter mnemonic symbols defined below. The PAGE column gives the number of pages in the book; ANIM refers to the species discussed in the book (given as a four-letter abbreviation of genus and species), and KEY WORDS listed are from the title. The AUTHORS/EDITORS and YEAR of publication are given in the last two columns.

acpr	Academic Press	New York	nyny
apso	American Physiological Society	Wshington, D. C.	wadc
jwis	John Wiley and Sons, Inc.	New York	nyny
lefe	Lea and Febiger	Philadelphia, PA	phpa
pepr	Pergamon Press	Oxford, England	oxen
spve	Springer-Verlaug, Inc.	New York	nyny
usup	Utah State University Press	Logan, Utah	lout
whfr	W. H. Freeman Co.	San Francisco, CA	sfca

GLOSSARY OF ANIMAL CODE NAMES

Wild ruminants are referred to in this CHAPTER by a 4-character abbreviation from the family, genus and genus-species. These are listed below under Abbreviation.

Scientific names of North American wild ruminants are those used in BIG GAME OF NORTH AMERICA, edited by J.C. Schmidt and D. L. Gilbert (1979: Stackpole Books, Harrisburg, PA 17105, 494 p.), and may be different from the scientific names given in the original literature.

The abbreviations used for North American wild ruminants are listed below.

CLASS: MAMMALIA

ORDER: ARTIODACTYLA	Abbreviation
FAMILY: CERVIDAE	cerv
GENUS: *Odocoileus* (deer)	od--
SPECIES: *O. virginianus* (white-tailed deer)	odvi
O. hemionus (mule deer)	odhe
GENUS: *Cervus* (Wapiti, elk)	ce--
SPECIES: *C. elaphus*	ceel
GENUS: *Alces* (moose)	
SPECIES: *A. alces*	alal
GENUS: *Rangifer* (caribou)	
SPECIES: *R. tarandus*	rata
FAMILY: ANTILOCAPRIDAE	
GENUS: *Antilocapra*	
SPECIES: *A. americana* (pronghorn)	anam
FAMILY: BOVIDAE	bovi
GENUS: *Bison* (bison)	bi--
SPECIES: *B. bison*	bibi
GENUS: *Ovis* (sheep)	ov--
SPECIES: *O. canadensis* (bighorn sheep)	ovca
O. dalli (Dall's sheep)	ovda
GENUS: *Ovibos*	
SPECIES: *O. moschatus* (muskox)	obmo
GENUS: *Oreamnos*	
SPECIES: *O. americanus* (mountain goat)	oram

The abbreviations used for European wild ruminants are listed below.

CLASS: MAMMALIA

	Abbreviation
ORDER: ARTIODACTYLA	
FAMILY: CERVIDAE	cerv
GENUS: Capreolus (roe deer)	ca--
SPECIES: C. capreolus	caca
GENUS: Dama (fallow deer)	da--
SPECIES: D. dama	dada
GENUS: Cervus (Wapiti, elk)	ce--
SPECIES: C. elaphus (red deer)	ceel
GENUS: Alces (moose)	
SPECIES: A. alces	alal
GENUS: Rangifer (caribou)	
SPECIES: R. tarandus	rata
FAMILY: BOVIDAE	
GENUS: Bison (bison)	
SPECIES: B. bonasus	bibo
GENUS: Capra (ibex, wild goat)	cp--
SPECIES: C. aegagrus (Persian ibex)	cpae
C. siberica (Siberian ibex)	cpsi

OTHERS

Abbreviations for a few other species and groups of species may appear in the reference lists. These are listed below.

Axis axis (axis deer)	axax
Elaphurus davidianus (Pere David's deer)	elda
Cervus nippon (Sika deer)	ceni
Hydropotes inermis (Chinese water deer)	hyin
Muntiacus muntjac (Indian muntjac)	mumu
Moschus moschiferus (musk deer)	momo
Ovis nivicola (snow sheep)	ovni
Ovis musimon (moufflon)	ovmu
Ovis linnaeus (Iranian sheep)	ovli
Rupicapra rupicapra (chamois)	ruru
big game	biga
domestic sheep	dosh
domestic cattle	doca
domestic goat	dogo
domestic ruminant	doru
herbivore	hrbv
mammals	mamm
three or more species of wild ruminants	many
ruminants	rumi
ungulates	ungu
vertebrates	vert
wildlife	wldl
wild ruminant	wiru

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.

LIST OF WORKSHEETS - CHAPTER SIXTEEN

THE BIOLOGY AND MANAGEMENT OF WILD RUMINANTS

CHAPTER SEVENTEEN

RANGE APPRAISALS AND EVALUATIONS OF ANIMAL RESPONSES

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CONTENTS OF CHAPTER SEVENTEEN

RANGE APPRAISALS AND EVALUATIONS OF ANIMAL RESPONSES

CHAPTER 17. RANGE APPRAISALS AND EVALUATIONS OF ANIMAL RESPONSES

The range is a dynamic place through the year. Its physical characteristics are changing, and its biological characteristics are changing. The animals that live there are also changing, resulting in constantly-changing relationships between animal and range.

Changes in animal-range relationships are generally synchronous through the annual cycle, with times of greater range productivity coinciding with times of greater animal productivity. This must be the case; one would certainly not expect high energy demands by the animal, such as during lactation, during a time of reduced or zero range productivity, as in winter.

Range appraisals and animal responses evaluated in this chapter are focused primarily on energy. Organisms must have positive energy balances if they are to be productive and contribute to the population. Young animals must have positive energy balances to grow; more energy must be ingested and metabolized than is dissipated through activity or heat loss or growth is impossible. When reproductive maturity is reached, more energy must again be ingested than is dissipated through activity and heat loss, or the production of new individuals is impossible.

Organisms experience short-term fluctuations in energy balances due to transient food and weather conditions. Wild ruminants are apparently well-adapted to such changes as their positive nutrient energy balances in late summer and fall result in rapid growth of the young and accumulations of fat by the older animals. They are adapted to potentially negative energy balances in winter by employing a metabolic depression to reduce the daily needs, and use the fat reserves to supplement limited forage resources as a source of energy.

Pregnant females have increased nutrient requirements in the last 1/3 to 1/4 of the gestation period when fetal growth is rapid. The timing of this incease in requirements in relation to the timing of the arrival of spring is critical. Early-arriving springs alleviate the potential and late-arriving springs prolong the potential for negative energy balances. These relationships are quantified in Moen (1978) and the effects of different times of arrival of spring on intake necessary to maintain positive energy balances illustrated.

Range appraisals and animal responses may be quantified rather easily with present knowledge, comparatively speaking. No longer is it necessary to look at a range and merely describe it as "good, fair, or poor." Now, its quality may be evaluated in relation to animal requirements, with an understanding of changes in these requirements and in the behavioral responses of animals through the year. It is impossible, to be sure, to be able to predict what will happen to a particular animal, herd, or population at a given time, but the patterns are understood, and the effects of changing range conditions known well enough to predict population responses.

The TOPICS and UNITS in this CHAPTER 17 include discussion of range conditions and animal responses to these conditions. Seasonal conditions are discussed, with references that describe particular range situations for the species considered listed. The UNITS in these TOPICS are formatted to evaluate "profiles," or range conditions and animal responses at a point in time, permitting one to evaluate heat loss calculations and metabolic responses more easily. It is hoped that this format will promote thinking about productivity over the year, emphasizing again the importance of time in ecological relationships.

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, CHAPTER 17

RANGE APPRAISALS AND EVALUATIONS OF ANIMAL RESPONSES

BOOKS

TYPE	PUBL	CITY	PAGE	ANIM	KEY WORDS-----------------	AUTHORS/EDITORS--	YEAR
aubo	lefe	phpa	308	----	intro to environ physiolog	folk,ge,jr	1966
edbo	usup	lout	155	----	ecol energetics of homeoth	gessaman,ja	1973
edbo	acpr	nyny	278	----	v.3 sp aspects of thermorg	whittow,gc,ed.	1973
aubo	whfr	sfca	488	----	intro to biophys plant phy	nobel,ps	1974
edbo	uppr	bama	326	----	environmental physiology	robertshaw,d,ed.	1974
edbo	oxup	loen		----	physiological anthropology	damon,a,ed.	1975
edbo	spve	nyny	609	----	perspectives, biophys ecol	gates,dm; schmerl	1975
edbo	spve	nyny	339	----	primary prod of the biosph	lieth,h; whittake	1975
aubo	blsp	oxen	273	----	intro to physiol plant eco	bannister,p	1976
edbo	uppr	bama	326	----	environmental physiology	robertshaw,d,ed.	1977

TOPIC 1. APPRAISALS OF SEASONAL RANGE CONDITIONS

Weather parameters were discussed in CHAPTER 14. The expression of weather parameters over time is an important dimension in ecology because plants and animals have seasonal adaptations to changing weather conditions.

The four UNITS in this TOPIC illustrate the uses of time-dependent equations presented in CHAPTER 14. Calculations of weather parameters based on the general trends are made for 7-day intervals during each of the seasons, resulting in weather <u>profiles</u>, or cross-sections of average weather conditions on each of these days. Since sample equations have been given in CHAPTER 14 and WORKSHEETS set up for their use, the UNITS in this CHAPTER contain just the formats for calculating profiles. The reader should fit local data to equations described in CHAPTER 14 and complete the profiles in the WORKSHEETS provided.

Animals do not live according to average weather conditions expressed by general trends, however. The use of time-dependent equations expressing averages does call attention to changes over time. If average changes can be related to the animals, then deviations from the average can also be related to animal responses. This is discussed further in TOPIC 2. Animal-range relationships have been studied by Mackie (1970) for mule deer, elk, and cattle, illustrating some of the seasonal charcteristics of both the range and the animals grazing on it. Such year-long studies should be completed on more species, and mathematical equations used to present animal and range characteristics throughout the year.

Many of the references listed at the ends of the four UNITS in TOPIC 1 include general habitat descriptions. They are included here even if there is little or no information on thermal characteristics, because cover and other habitat characteristics are used when evaluating weather effects on animals. Additional general range conditions are found in PART VII: THE MANAGEMENT OF WILD RUMINANTS.

LITERATURE CITED

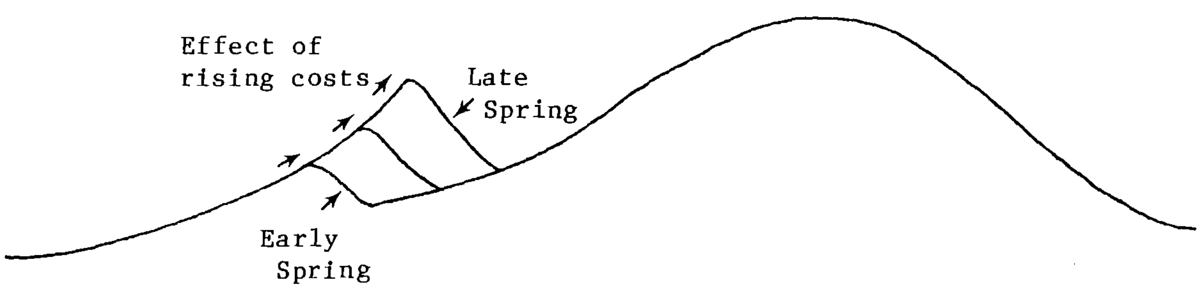
Mackie, R. J. 1970. Range ecology and relations of mule deer, elk, and cattle in the Missouri River Breaks, Montana. Wildlife Monographs 20:1-79.

UNIT 1.1: RANGE CONDITIONS IN THE SPRING

Spring (from March 21, JDAY 80 to June 20, JDAY 171) is a time of re-awakening of the range. Snows melt, rains come, the length of daylight is increasing, temperatures are increasing, and dormant plants begin to grow again. The spring range of wild ruminants shows a general and often rapid improvement in range quality.

Two especially important considerations may be made in the spring. One is the timing of the arrival of spring, and the other is the weather conditions when the young are born.

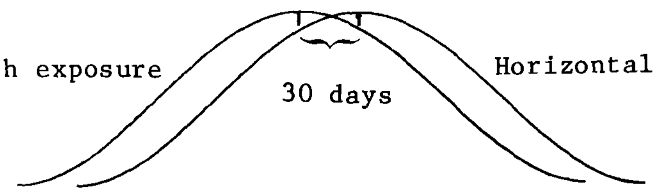
The timing of the arrival of spring is especially important for all wild ruminants since the females are in the last part of gestation, with increasing metabolic costs that must be met if fetal growth is to be up to potential. A late-arriving spring delays improvements in range quality while gestation costs continue to increase, resulting in a less-than-optimal animal-range relationship during the last one-third of the gestation period. The effect of these rising costs on forage intake is illustrated as a pattern below; specific calculations are made in Moen (1978).



South slope deer concentrations are observed in areas where snow depths diminish as a result of higher solar insolation and warmer air temperatures. These sites literally experience the arrival of spring earlier than north exposures do. In fact, north exposures with overhead canopies may be as much as a month behind in range phenology in northern states and Canada.

Seasonal temperature patterns and changes in the amounts of solar radiation through the year were discussed in CHAPTER 14. The use of these sine-wave patterns helps one evaluate the relative benefits of topography on local thermal conditions.

In the illustration at the top of the next page, a 5° warmer temperature due to higher solar radiation and absorption is shown to be equivalent to about 30 days of trend time.



Such differences do not make overall range conditions 30 days ahead, of course, since slope effects are minimal at night, and plant production does not advance as rapidly as temperatures illustrated above might. It is important to evaluate physical and biological processes in the ecological context rather than as separate entities.

Caribou travel in the spring to traditional calving grounds. These calving grounds are often on south slopes and exposures where snow depths are less and thermal conditions are more favorable to the animals.

Weather conditions during parturition are particularly important because of the potential for high heat loss from neonates exposed to wet conditions. Newborn fawns spend over 90% of their time bedded during the first few days of life. Two or three days of cool, wet weather will wet them thoroughly, and the high heat of vaporization may result in excessive heat loss and hypothermia. Thus appraisals of spring range should focus on weather conditions that affect the growth of plants, the thermal balance of neonates, and the productivity of reproducing females.

Listing of average weather conditions on a given day using time-dependent equations results in "profiles," or "cross-sections" of average weather conditions at that point in time. Such a profile may include the following:

JDAY _____

Solar radiation _____

Average air temperature _____

Maximum air temperature _____

Minimum air temperature _____

Infrared radiation _____

Rain _____

Snow _____

Average wind velocity _____

Weather profiles for the spring season should be made for JDAY's 84, 91, 98, ... 168, covering the period from March 25 through June 17. The WORKSHEET at the end of this UNIT includes the necessary equation references and the tabular format for making your own profiles.

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, UNIT 1.1

RANGE CONDITIONS IN THE SPRING

SERIALS

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
CAFGA	34--4	189	207	od--	range surv methods, mangmt	dasmann,wp	1948
JWMAA	24--4	387	395	od--	deer-for hab relnshps, ark	halls,lk; crawfor	1960
PMACA	46...	277	287	od--	mrtlty, two priv hunt club	blouch,ri	1961

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
CAFNA	90--2	123	136	odvi	distr, movs reln env fctrs	drolet,ca	1976
JAPEA	14--2	419	432	odvi	classif habita types, vege	stocker,m; gilbe/	1977
JAPEA	14--2	433	444	odvi	veg habitat relns, classif	stocker,m; gilber	1977
JWMAA	19--3	358	364	odvi	rnge apprsl, missouri ozar	dunkeson,rl	1955
JWMAA	33--4	881	887	odvi	repro pattrns rel nutr pln	verme,lj	1969
MGQPA	31...	62	74	odvi	spring ecolg, nc minnesota	pierce,de,jr	1971
NAWTA	13...	442	449	odvi	anal range, adirndacks, ny	webb,wl	1948
NAWTA	20---	568	588	odvi	factrs infl dee, ariz brsh	hanson,wr; mccull	1955
NAWTA	24---	201	215	odvi	evergl hrd, rng cond, life	loveless,cm; liga	1959

odvi continued on the next page

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
NYCOA	27--2	28	31	odvi	weather and the deer popul	severinghaus,cw	1972
NYCOA	29--4	18	20	odvi	advances, science deer mgt	severinghaus,cw	1975
PCGFA	10---	53	58	odvi	deer nutr prob,s pine type	lay,dw	1956
PSAFA	1955-	130	132	odvi	odhe,for ecol relatns,mich	westell,ce,jr	1955
RWLBA	6---2	327	385	odvi	wint, spr obsrv, adirndcks	spiker,cj	1933
TJSCA	24...	457	489	odvi	w-td of aransas refug, tex	white,m	1973
TWASA	48---	49	56	odvi	deer populns in early wisc	habeck,jr; curtis	1959
WLSBA	5---3	113	117	odvi	quantif veg struc of cover	nudds,td	1977
WLSBA	6---2	88	90	odvi	fat cycle	mautz,ww	1978
WSCBA	13--3	7	7	odvi	environment and deer	wiscn consrv dept	1948
XFNCA	39---	2	10	odvi	deer rng apprais in midwes	murphy,da	1970

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
ECMOA	2----	1	46	odhe	seasonal migratn of mule d	russell,cp	1932
JRMGA	30--2	122	127	odhe	eval habita on nutri basis	wallmo,oc; carpe/	1977
JWMAA	27--2	196	202	odhe	relatn to climatic gradint	dasmann,rf; dasma	1963
NAWTA	20---	568	588	odhe	factrs infl dee, ariz brsh	hanson,wr; mccull	1955
NAWTA	29---	404	414	odhe	ceel, doca, sum rang, utah	julander,o; jeffe	1964
NEXAA	567--	1	32	odhe	ft stanton hrd, ecol, n mx	wood,je; bickle,/	1970
WLMOA	20---	1	79	odhe	ceel, doca, rnge ecol, mon	mackie,rj	1970
XFPNA	125..	1	99	odhe	habita char of silv lk rng	dealy,je	1971

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
XFIPA	24---	1	15	ceel	od, probs hab mgt, n fores	lyon,lj	1966

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
BINPA	12...	23	32	alal	moos, mskeg brch, beav env	lulman,pd	1974
JWMAA	40--4	645	657	alal	odvi,hbitat use,symptr rng	kearney,sr; gilbe	1976

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
ATICA	27...	256	264	rata	ovmo, northw territ, canad	kevan,pg	1974
CWRSB	33--	1	82	rata	invstg carib rnge, nw terr	parker,gr	1975
UABPA	1----	414	419	rata	weath effct on behav, migr	gavin,a	1975

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
CAFNA	87--4	433	454	ovca	chilcotin river bigh popul	demarchi,da; mitc	1973

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
JWMAA	3---4	295	306	many	yellowst wint rnge studies	grimm,rl	1939
JWMAA	43--2	437	444	many	hbitat partitng,fire, mont	singer,fj	1979

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
JRMGA	2---1	53	63	----	meth det util range forage	heady,hf	1949
JRMGA	7---1	14	23	----	applctn ecol, det rnge cnd	parker,kw	1954
JRMGA	10--5	208	212	----	steppoint method, sampling	evans,ra; love,rm	1957
JRMGA	18--4	196	201	----	comm use gras capac key sp	smith,ad	1965
JRMGA	24--1	55	59	----	seas trnds herb, nutr prod	sims,pl; love,rm	1971
NAWTA	10---	251	256	biga	b ga-liv compet, west rang	stoddart,la; rasm	1945
TWASA	53...	123	129	wldl	habitat and managed forest	stearns,fw; creed	1964

CHAPTER 17, WORKSHEET 1.1a

Weather profiles during the spring season

Weather profiles for each of the JDAY's from March 26 (JDAY 85) through June 18 (JDAY 169) at 7-day intervals may be completed by referring to the equations below.

SORA: See CHAPTER 14, WORKSHEET 1.1a
ADTC: See CHAPTER 14, WORKSHEET 2.1a - 2.1c
AMXT: See CHAPTER 14, WORKSHEET 2.1b
AMNT: See CHAPTER 14, WORKSHEET 2.1b
QREE: See CHAPTER 14, WORKSHEET 1.2a (complete ADTC first)
RAIN: See CHAPTER 14, WORKSHEET 5.2b
SNOW: See CHAPTER 14, WORKSHEET 5.2b
WIVE: See CHAPTER 14, WORKSHEET 3.2a
(Use Z_o characteristic of snow or vegetation if expressing wind velocity for a selected animal height)

Complete the calculations using equations derived for your local area and tabulate the results below.

					QREE*			PREC		
JDAY	SORA	ADTC	AMXT	AMNT				RAIN	SNOW	WIVE
85										
92										
99										
106										
113										
120										
127										
134										
141										
148										
155										
162										
169										

*Three blanks are given for different cover types, or for downward, upward and total infrared radiation.

JDAY	SORA	ADTC	AMXT	AMNT	QREE*			PREC RAIN	PREC SNOW	WIVE
85										
92										
99										
106										
113										
120										
127										
134										
141										
148										
155										
162										
169										

*Three blanks are given for different cover types, or for downward, upward and total infrared radiation.

UNIT 1.2: RANGE CONDITIONS IN THE SUMMER

Range conditions in the summer, from the summer solstice (June 21; JDAY 172) to the fall equinox (September 20; JDAY 263), vary from hot and dry to wet and cool, with the possibility of snow and cold in the northern latitudes and the higher elevations, especially in September.

Maximum solar radiation reaches the earth on June 21, and then the apparent elevation of the sun begins to decrease, and daylength also decreases. The decrease is slow at first, increasing to maximum rate at the fall equinox.

Air temperature trends lag behind the solar radiation trends as net radiation is still positive for several weeks after the summer solstice. Maximum temperatures are usually reached in late July or early August.

Wind velocities do not exhibit the marked seasonal trends that solar radiation and air temperatures do. Plant cover is heavier than at any other time of year in most areas, so effective wind velocities are much reduced in many habitats.

Precipitation patterns are usually very seasonal, with summer being one of the drier periods of the year in many areas. There are many local variations, of course, depending on topography and the number and size of bodies of water present.

Weather profiles for the summer season should be made for JDAY's 175, 182, 189 ... 259, covering the period from June 24 through September 16. The WORKSHEET at the end of this UNIT includes the necessary equation references and the tabular format for making your own profiles.

REFERENCES, UNIT 1.2

RANGE CONDITIONS IN THE SUMMER

SERIALS

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS------------------	AUTHORS----------	YEAR
CAFGA	34--4	189	207	od--	range surv methods, mangmt	dasmann,wp	1948
JWMAA	13--3	314	315	od--	deer forag observtns, utah	smith,jg	1949
JWMAA	24--4	387	395	od--	deer-for hab relnshps, ark	halls,lk; crawfor	1960
NAWTA	10---	234	241	od--	ceel, meth det nums & rnge	hunter,gn	1945

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
AMNAA	61--1	230	238	odvi	histor view of rnges, wisc	christensen,em	1959
CAFNA	90--2	123	136	odvi	distr, movs reln env fctrs	drolet,ca	1976
JAPEA	14--2	419	432	odvi	classif habita types, vege	stocker,m; gilbe/	1977
JAPEA	14--2	433	444	odvi	veg habitat relns, classif	stocker,m; gilber	1977
JWMAA	19--3	358	364	odvi	rnge apprsl, missouri ozar	dunkeson,rl	1955
JWMAA	33--4	881	887	odvi	repro pattrns rel nutr pln	verme,lj	1969
JWMAA	35--3	476	487	odvi	summer habitat, nc minneso	kohn,be; mooty,jj	1971
NAWTA	13...	442	449	odvi	anal range, adirndacks, ny	webb,wl	1948
NAWTA	24---	201	215	odvi	evergl hrd, rng cond, life	loveless,cm; liga	1959
NYCOA	29--4	18	20	odvi	advances, science deer mgt	severinghaus,cw	1975
PCGFA	10---	53	58	odvi	deer nutr prob,s pine type	lay,dw	1956
PSAFA	1955-	130	132	odvi	odhe,for ecol relatn, mich	westell,ce,jr	1955
TJSCA	24...	457	489	odvi	wt-d of aransas refug, tex	white,m	1973
TWASA	48---	49	56	odvi	deer populns in early wisc	habeck,jr; curtis	1959
WCDBA	44---	1	104	odvi	signif forest openin, wisc	mccaffery,kr; cre	1969
WLSBA	5---3	113	117	odvi	quantif veg struc of cover	nudds,td	1977
WLSBA	6---2	88	90	odvi	fat cycle	mautz,ww	1978
WSCBA	13--3	7	7	odvi	environment and deer	wiscn consrv dept	1948
XFNCA	39---	2	10	odvi	deer rng apprais in midwes	murphy,da	1970

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
ECMOA	2----	1	46	odhe	seasonal migratn of mule d	russell,cp	1932
JRMGA	4---4	249	253	odhe	ceel, status of brws, oreg	mitchell,ge	1951
JRMGA	30--2	122	127	odhe	eval habita on nutri basis	wallmo,oc; carpe/	1977
JWMAA	25--1	54	60	odhe	rel sum rng cond, hrd prod	julander,o; robi/	1961
JWMAA	27--2	196	202	odhe	relatn to climatc gradient	dasmann,rf; dasma	1963
JWMAA	34--4	852	862	odhe	dee respons, mgt summ rang	hungerford,cr	1970
JWMAA	39--3	605	616	odhe	doca, rng relns, prair hab	dusek,gl	1975
NAWTA	20---	568	588	odhe	factrs infl dee, ariz brsh	hanson,wr; mccull	1955
NAWTA	29---	404	414	odhe	ceel, doca, sum rang, utah	julander,o; jeffe	1964

odhe continued on the next page

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
NEXAA	567--	1	32	odhe	ft stanton hrd, ecol, n mx	wood,je; bickle,/	1970
WLMOA	20---	1	79	odhe	ceel, doca, rng ecol, mont	mackie,rj	1970
XFPNA	125..	1	99	odhe	habita char of silv lk rng	dealy,je	1971

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
XFIPA	24---	1	15	ceel	od, probs hab mgt, n fores	lyon,lj	1966

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
BINPA	12...	23	32	alal	moos, mskeg brch, beav env	lulman,pd	1974
JRMGA	16--5	227	231	alal	apprais moose rang, montan	peek,jm	1963
JWMAA	40--4	645	657	alal	odvi,hbitat use symptr rng	kearney,sr; gilbe	1976

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
CWRSB	33---	1	83	rata	invstg carib rnge, nw terr	parker,gr	1975
RIJUA	30---	289	293	rata	intractins w/ habita, alas	klein,dr	1970
XFWWA	43---	1	48	rata	st matthew isl reind range	klein,dr	1959

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
NAWTA	15---	627	644	anam	rng ecol, wichita mts refu	buechner,hk	1950
UTSCB	29--1	3	6	anam	season forage use, w utah	beale,dm; scotter	1968

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

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
CAFNA	87--4	433	454	ovca	chilcotin river bigh popul	demarchi,da; mitc	1973

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

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
JRMGA	23--1	8	14	obmo	rata,tndra n of boreal for	klein,dr	1970
JWMAA	40--1	151	162	obmo	rata, summ rnge relns, nwt	wilkinson,pf; sh/	1976

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
JWMAA	37--3	353	362	oram	forage, habitat pref, alas	hjeljord,o	1973

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
XAGCA	796--	1	27	doca	forg utiliz summ rnge, ore	pickford,gd; reid	1948

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
JRMGA	2---1	53	63	----	meth det util range forage	heady,hf	1949
JRMGA	7---1	14	23	----	applctn ecol, det rnge cnd	parker,kw	1954
JRMGA	10--5	208	212	----	steppoint method, sampling	evans,ra; love,rm	1957
JRMGA	24--1	55	59	----	seas trnds herb, nutr prod	sims,pl; love,rm	1971
NAWTA	10---	251	256	biga	b ga-liv compet, west rang	stoddart,la; rasm	1945
NAWTA	27---	150	164	----	rumen cont, index rng qual	klein,dr	1962
TWASA	53...	123	129	wldl	habitat and managed forest	stearns,fw; creed	1964

CHAPTER 17, WORKSHEET 1.2a

Weather profiles during the summer season

Weather profiles for each of the JDAY's from June 25 (JDAY 176) through September 17 (JDAY 260) at 7-day intervals may be completed by referring to the equations below.

SORA: See CHAPTER 14, WORKSHEET 1.1a
ADTC: See CHAPTER 14, WORKSHEET 2.1a - 2.1c
AMXT: See CHAPTER 14, WORKSHEET 2.1b
AMNT: See CHAPTER 14, WORKSHEET 2.1b
QREE: See CHAPTER 14, WORKSHEET 1.2a (complete ADTC first)
RAIN: See CHAPTER 14, WORKSHEET 5.2b
SNOW: See CHAPTER 14, WORKSHEET 5.2b
WIVE: See CHAPTER 14, WORKSHEET 3.2a
(Use Z_o characteristic of snow or vegetation if expressing wind velocity for a selected animal height)

Complete the calculations using equations derived for your local area and tabulate the results below.

					QREE*			PREC		
JDAY	SORA	ADTC	AMXT	AMNT				RAIN	SNOW	WIVE
176										
183										
190										
197										
204										
211										
218										
225										
232										
239										
246										
253										
260										

*Three blanks are given for different cover types, or for downward, upward and total infrared radiation.

					QREE*			PREC		
JDAY	SORA	ADTC	AMXT	AMNT				RAIN	SNOW	WIVE
176										
183										
190										
197										
204										
211										
218										
225										
232										
239										
246										
253										
260										

*Three blanks are given for different cover types, or for downward, upward and total infrared radiation.

UNIT 1.3: RANGE CONDITIONS IN THE FALL

The period of time from the fall equinox (September 21; JDAY 264) to the winter solstice (December 20; JDAY 354) is characterized by shorter days, decreasing solar radiation, cooler temperatures, and precipitation in the form of snow rather than rain in the northern regions of the U.S. and Canada, and at the higher elevations.

The growing season is over. Leaves have fallen from deciduous trees, and herbaceous plants are dormant. The habitat presents a different morphology from summer conditions. Thermal cover is less effective as protection from the weather due to leaf fall.

The shortest day of the year occurs on December 21, with increasingly less daylight up to this date at the more northern latitudes, and no direct sunlight beyond the Arctic Circle on this date.

Weather profiles for the fall season should be made for JDAY's 266, 273, 280 ... 350, covering the period from September 21 through December 20. The WORKSHEET at the end of this UNIT includes the necessary equation references and the tabular format for making your own profiles.

REFERENCES, UNIT 1.3

RANGE CONDITIONS IN THE FALL

SERIALS

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
CAFGA	34--4	189	207	od--	range surv methods, mangmt	dasmann,wp	1948
JWMAA	13--3	314	315	od--	deer forag observtns, utah	smith,jg	1949
NAWTA	10---	234	241	od--	ceel, meth det nums & rnge	hunter,gn	1945
PMACA	46...	277	287	od--	mrtlty, two priv hunt club	blouch,ri	1961

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
CAFNA	90--2	123	136	odvi	distr, movs reln env fctrs	drolet,ca	1976
JAPEA	14--2	419	432	odvi	classif habita types, vege	stocker,m; gilbe/	1977
JAPEA	14--2	433	444	odvi	veg habitat relns, classif	stocker,m; gilber	1977

odvi continued on the next page

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
JWMAA	19--3	358	364	odvi	rnge apprsl, missouri ozar	dunkeson,rl	1955
JWMAA	33--4	881	887	odvi	repro pattrns rel nutr pln	verme,lj	1969
MGQPA	31...	142	150	odvi	fall ecology, nc minnesota	waddell,bh	1971
NAWTA	13...	442	449	odvi	anal range, adirndacks, ny	webb,wl	1948
NAWTA	24---	201	215	odvi	evergl hrd, rng cond, life	loveless,cm; liga	1959
NYCOA	29--4	18	20	odvi	advances, science deer mgt	severinghaus,cw	1975
PCGFA	10---	53	58	odvi	deer nutr prob,s pine type	lay,dw	1956
PSAFA	1955-	130	132	odvi	odhe,for ecol relatn, mich	westell,ce,jr	1955
TJSCA	24...	457	489	odvi	w-td of aransas refug, tex	white,m	1973
TWASA	48---	49	56	odvi	deer populns in early wis	habeck,jr; curtis	1959
WLSBA	5---3	113	117	odvi	quantif veg struc of cover	nudds,td	1977
WLSBA	6---2	88	90	odvi	fat cycle	mautz,ww	1978
WSCBA	4---5	18	24	odvi	report of two deer yards	minor,ft; hanson,	1939
WSCBA	13--3	7	7	odvi	environment and deer	wiscn consrv dept	1948
XFNCA	39---	2	10	odvi	deer rng apprais in midwes	murphy,da	1970

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
ECMOA	2----	1	46	odhe	seasonal migratn of mule d	russell,cp	1932
JRMGA	30--2	122	127	odhe	eval habita on nutri basis	wallmo,oc; carpe/	1977
JWMAA	27--2	196	202	odhe	relatn to climatc gradient	dasmann,rf; dasma	1963
NAWTA	20---	568	588	odhe	factrs infl dee, ariz brsh	hanson,wr; mccull	1955
NAWTA	29---	404	414	odhe	ceel, doca, sum rang, utah	julander,o; jeffe	1964
NEXAA	567--	1	32	odhe	ft stanton hrd, ecol, n mx	wood,je; bickle,/	1970
WLMOA	20---	1	79	odhe	ceel,doca rng ecol, montan	mackie,rj	1970
XFPNA	125..	1	99	odhe	habita char of silv lk rng	dealy,je	1971

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
XFIPA	24---	1	15	ceel	od, probs hab mgt, n fores	lyon,lj	1966

```
CODEN VO-NU BEPA ENPA ANIM KEY WORDS----------------- AUTHORS---------- YEAR
BINPA 12... 23   32   alal moos, mskeg brch, beav env lulman,pd         1974
JWMAA 40--4 645  657  alal odvi,hbitat use,symptr rng kearney,sr; gilbe 1976

CODEN VO-NU BEPA ENPA ANIM KEY WORDS----------------- AUTHORS---------- YEAR
CWRSB 33--- 1    83   rata invstg carib rnge, nw terr parker,gr         1975

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
CAFNA 87--4 433  454  ovca chilcotin river bigh popul demarchi,da; mitc 1973

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
JWMAA 37--3 353  362  oram forage, habitat pref, alas hjeljord,o        1973
```

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
JWMAA	3---4	295	306	many	yellowst wint rnge studies	grimm,dm; scotter	1968
JWMAA	43--2	437	444	many	hbitat partitng,fire, mont	singer,fj	1979

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
JRMGA	2---1	53	63	----	meth det util range forage	heady,hf	1949
JRMGA	7---1	14	23	----	applctn ecol, det rnge cnd	parker,kw	1954
JRMGA	10--5	208	212	----	steppoint method, sampling	evans,ra; love,rm	1957
JRMGA	24--1	55	59	----	seas trnds herb, nutr prod	sims,pl; love,rm	1971
NAWTA	10---	251	256	biga	b ga-liv compet, west rang	stoddart,la; rasm	1945
TWASA	53...	123	129	wldl	habitat and managed forest	stearns,fw; creed	1964

CHAPTER 17, WORKSHEET 1.3a

Weather profiles during the fall season

Weather profiles for each of the JDAY's from September 24 (JDAY 267) through December 17 (JDAY 351) at 7-day intervals may be completed by referring to the equations below.

SORA: See CHAPTER 14, WORKSHEET 1.1a
ADTC: See CHAPTER 14, WORKSHEET 2.1a - 2.1c
AMXT: See CHAPTER 14, WORKSHEET 2.1b
AMNT: See CHAPTER 14, WORKSHEET 2.1b
QREE: See CHAPTER 14, WORKSHEET 1.2a (complete ADTC first)
RAIN: See CHAPTER 14, WORKSHEET 5.2b
SNOW: See CHAPTER 14, WORKSHEET 5.2b
WIVE: See CHAPTER 14, WORKSHEET 3.2a
(Use Z_o characteristic of snow or vegetation if expressing wind velocity for a selected animal height)

Complete the calculations using equations derived for your local area and tabulate the results below.

JDAY	SORA	ADTC	AMXT	AMNT	QREE*			PREC RAIN	PREC SNOW	WIVE
267										
274										
281										
288										
295										
302										
309										
316										
323										
330										
337										
344										
351										

*Three blanks are given for different cover types, or for downward, upward and total infrared radiation.

JDAY	SORA	ADTC	AMXT	AMNT	QREE*			PREC		WIVE
								RAIN	SNOW	
267	____	____	____	____	____	____	____	____	____	____
274	____	____	____	____	____	____	____	____	____	____
281	____	____	____	____	____	____	____	____	____	____
288	____	____	____	____	____	____	____	____	____	____
295	____	____	____	____	____	____	____	____	____	____
302	____	____	____	____	____	____	____	____	____	____
309	____	____	____	____	____	____	____	____	____	____
316	____	____	____	____	____	____	____	____	____	____
323	____	____	____	____	____	____	____	____	____	____
330	____	____	____	____	____	____	____	____	____	____
337	____	____	____	____	____	____	____	____	____	____
344	____	____	____	____	____	____	____	____	____	____
351	____	____	____	____	____	____	____	____	____	____

*Three blanks are given for different cover types, or for downward, upward and total infrared radiation.

UNIT 1.4: RANGE CONDITIONS IN THE WINTER

Winter range (December 21, JDAY 355 - March 20, JDAY 29) is dominated by three main features over much of the wild ruminant range in North America. They are increasing and prolonged snow accumulations and cold weather conditions, decreasing forage supplies, and restrictions in area as groups of animals move over smaller areas, seeking habitats with topography and cover that provide protection from wind and winter weather conditions that cause high energy losses.

Snow accumulations are a significant factor in determining the forage supplies available and the extent of the winter range. The total amounts of snowfall and amounts on the ground are measured and reported by many weather observers throughout the country. Amounts in habitats used by wild ruminants may be different from amounts in areas measured by weather observers, however. The use of formulas as in CHAPTER 14, UNIT 5.2 for estimating percent interception as a function of canopy cover is a step in the right direction, making winter range appraisals more pertinent to the animals rather than being merely weather reports.

Other factors in addition to snowfall and interception are also important on winter range. Canopy characteristics also affect snowpack characteristics. A heavy canopy reduces the rate of aging of the snow, and the potential for crust formation. Aged snow with a crust has the potential for supporting deer, and this can be beneficial to the animals as they spend less energy walking on snow than through it, they are not so confined to trails, and they are within reach of new forage supplies when they walk on accumulated snow. All of these benefits, however, can neither be managed nor can they be counted on to occur, and this brings up an important concept in winter range appraisals.

Evaluate winter range in relation to how it relates to the animal as if the worst will occur. If, for example, 30 inches (about 75 cm) of snow falls, consider the animal to be exposed to 30 inches of fallen snow, or at best the 30 inches less the intercepted snow. Do not count on the probability of a thaw and crust formation occurring, for it is better to be a bit cautious and wrong than to be too optimistic. Such a conservative approach results in positive errors that can be considered in subsequent management decisions.

The winter range provides recreational opportunities for people that may interact with wild ruminants. Thus deep and prolonged snow is not only a potential detriment to animals but a potential benefit to recreational activities. These activities may also be detrimental to animals. The effects of snowmobiles on deer are discussed in UNIT 2.4.

Snow is one major factor to be concerned with in the winter range. Temperature is another. Cold temperatures minimize the rate of aging of the snow, keeping it deeper and less dense as settling and melting do not occur. This is a potentially critical situation as loose, fluffy snow is a very important mechanical barrier to movement when its depth exceeds belly height and animals must bound to move through it. Up to belly heights, loose snow is walked through more easily than dense snow.

Air temperatures are also of interest in relation to heat loss from animals as colder temperatures result in a steeper gradient between the metabolic tissue of the animal and the temperature of the air. The effects of this on the animal are discussed in UNIT 2.4.

Wind is an important characteristic of the range in the winter because of the high potential for heat loss when combined with lower air temperatures. Wind velocities vary vertically in relation to the roughness of the surface and horizontally over areas of different topography and cover types (See CHAPTER 14, UNIT 3.2). Wind velocities reported by weather observers at meterology stations are not characteristic of wind velocities in areas inhabited by wild ruminants because of the heights and open conditions in which weather observers measure velocities.

There have been attempts to derive "winter severity indexes" as measures of range conditions during the winter by measuring various weather parameters and relating them directly to condition and mortality of the animals. The establishment of such correlations usually takes many years as a wide range of winter conditions are needed to make the appropriate comparisons and judgements. The "katathermometer" approach, in which a warm or heated device is placed in winter habitat and its rate of cooling or the electrical energy needed to keep it warm measured, has also been tried. The results are highly correlated with weather parameters such as temperature and wind, but that is expected since the temperature gradients and wind effects on convection losses are the two major factors affecting heat loss from the "katathermometer." Therefore, the results could be predicted by simply measuring temperatures and wind velocities.

The important concept to keep in mind when evaluating thermal characteristics of winter range is that they should be measured in ways that can be applied to the animals. The thermal linkages between animal and environment are radiation exchange, convection, conduction, and evaporation. These four basic modes of heat transfer occur at rates proportional to atmospheric conditions and habitat and animal characteristics. Atmospheric conditions, commonly called weather, are not directly proportioned to heat transfer, however. Radiation exchange is a function of the 4th power of the absolute temperature, convection is a function of the square root of wind speed, conduction is a function of substrate temperatures, and all of these are affected by additional habitat and animal characteristic. The alternative approach is the application of winter range characteristics to the "overall heat transfer coefficient" analyses discussed in CHAPTER 16, TOPIC 2. Some of the effects of different behavioral options are discussed in UNIT 2.4 of this CHAPTER 17.

Weather profiles for the winter season should be made for JDAY's 357, 364, 8 ... 77, covering the period from December 21 through March 20. The WORKSHEET at the end of this UNIT includes the necessry equation references and the tabular format for making your own calculations.

REFERENCES, UNIT 1.4

RANGE CONDITIONS IN THE WINTER

SERIALS

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
FUOFA	66...	174	186	cerv	wint prob, northern cervid	markgren,g	1971
VILTA	9---3	45	169	cerv	win habita, lnd use, scand	ahlen,i	1975

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
CAFGA	34--4	189	207	od--	ceel, meth det nums & rang	hunter,gn	1945
CAFGA	34--4	189	207	od--	range surv methods, mangmt	dasmann,wp	1948
CAFGA	35--1	103	114	od--	interstate wint mgmnt plan	intrst dr hrd com	1949
CAFGA	44--1	51	72	od--	survi, rng forag trnds, ca	dasmann,wp; hjers	1958
JWMAA	31--3	426	432	od--	deer rang appraisal, e tex	lay,dw	1967
PMACA	46...	277	287	od--	mrtlty, two priv hunt club	blouch,ri	1961
XFWRA	16-10	1	17	od--	winter range studies	randle,ac	1938
XFWRA	26-33	1	11	od--	wintr range survey, oregon	edwards,o	1939
XFWRA	41-44	1	20	od--	winter range, intrstat hrd	fischer,ga; dav/	1944

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
AMNAA	61--1	230	238	odvi	histor view of rnges, wisc	christensen,em	1959
CAFNA	85--2	141	145	odvi	odhe, winter ecol, alberta	kramer,a	1971
CAFNA	88--3	293	301	odvi	wint habita, 31-mi lk, que	huot,j	1974
CAFNA	90--2	123	136	odvi	distr, movs reln env fctrs	drolet,ca	1976
CAFNA	92--1	19	23	odvi	eval wint rng, pt pelee pk	theberge,jb	1978
CJZOA	54--8	1307	1313	odvi	eff wint condtns, manitoba	kucera,e	1976
CWRSB	15---	1	27	odvi	alal, behav in snow, fundy	kelsall,jp; presc	1971
ECOLA	16--4	535	553	odvi	wint relns to forest, mass	hosley,nw; ziebar	1935
ECOLA	43--1	134	135	odvi	class wint habita, no wisc	christensen,em	1962
ECOLA	44--2	411	414	odvi	veg, lowlnd wint hab, mich	christensen,em	1963
ECOLA	57--1	192	198	odvi	energy conservtn in winter	moen,an	1976
ISJRA	47--3	199	217	odvi	pil knb st pk, win dee hav	zagata,md; haugen	1973

odvi continued on the next page

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
JAPEA	14--2	419	432	odvi	classif habita types, vege	stocker,m; gilbe/	1977
JAPEA	14--2	433	444	odvi	veg habitat relns, classif	stocker,m; gilber	1977
JFUSA	47--4	299	299	odvi	winter habita study, maine	glasgow,ll	1949
JFUSA	63--7	523	529	odvi	swamp conifer deeryard, mi	verme,lj	1965
JWMAA	11--2	162	177	odvi	odhe, surv ovr-pop rng, us	leopold,a; sowls/	1947
JWMAA	13--1	135	141	odvi	avail wint forg, hrdwd for	hough,af	1949
JWMAA	19--3	358	364	odvi	rnge apprsl, missouri ozar	dunkeson,rl	1955
JWMAA	23--3	273	278	odvi	veg study wintr rang, wisc	hobeck,jr	1959
JWMAA	24--4	364	371	odvi	test of shelt req pen deer	robinson,wl	1960
JWMAA	24--4	387	395	odvi	deer-for hab relnshps, ark	halls,lk; crawfor	1960
JWMAA	32--3	566	574	odvi	index wint weathr severity	verme,lj	1968
JWMAA	33--3	511	520	odvi	hab-deer relns in enclosur	segelquist,ca; w/	1969
JWMAA	33--4	881	887	odvi	repro pattrns rel nutr pln	verme,lj	1969
JWMAA	35--4	732	743	odvi	limitns of wint aspn brows	ullrey,de; youat/	1971
JWMAA	39--1	59	66	odvi	apprais wint hab, ne minne	wetzel,jf; wamba/	1975
JWMAA	41--4	700	708	odvi	assess mortlty in upp mich	verme,lj	1977
MOCOA	13--1	2	3	odvi	any deer and lots of snow	robb,d	1952
NAWTA	12---	212	223	odvi	reltn weath,wint mort, pop	severinghaus,cw	1947
NAWTA	13...	442	450	odvi	anal wint rang, adirndk,ny	webb,wl	1948
NAWTA	18---	581	596	odvi	yard carry capac, browsing	davenport,la; sw/	1953
NAWTA	24---	201	215	odvi	evergl hrd, rng cond, life	loveless,cm; liga	1959
NFGJA	8---1	61	63	odvi	determinng freq wintr kill	severinghaus,cw	1961
NFGJA	23--1	51	57	odvi	steep slope wintring areas	dickinson,nr	1976
NFGJA	25--2	170	174	odvi	evid brows to map win rnge	dickinson,nr	1978
NYCOA	11--1	11	11	odvi	wntr kill of deer, 1955-56	severinghaus,cw	1956
NYCOA	27--2	28	31	odvi	weather and the deer popul	severinghaus,cw	1972
NYCOA	27--6	37	37	odvi	propos to imprv dee habita	severinghaus,cw	1972
NYCOA	27--5	41	41	odvi	winter deer feeding	kelsey,pm	1973
NYCOA	29--4	18	20	odvi	advances, science deer mgt	severinghaus,cw	1975
PCGFA	10---	53	58	odvi	deer nutr prob,s pine type	lay,dw	1956
PSAFA	1955-	130	132	odvi	odhe,for ecol relatns mich	westell,ce,jr	1955
RWLBA	6---2	327	385	odvi	wint, spr obsrv, adirndcks	spiker,cj	1933
TJSCA	24...	457	489	odvi	wt-d of aransas refug, tex	white,m	1973
TWASA	48---	49	56	odvi	deer populns in early wisc	habeck,jr; curtis	1959
WLSBA	5---3	113	117	odvi	quantif veg struc of cover	nudds,td	1977
WLSBA	6---2	88	90	odvi	fat cycle	mautz,ww	1978

odvi continued on the next page

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
WSCBA	4---5	18	24	odvi	report of two deer yards	minor,ft; hanson,	1939
WSCBA	13--3	7	7	odvi	environment and deer	wiscnsn cnsrv dpt	1948
WSCBA	14--6	21	24	odvi	wint deer rang conds, wisc	dahlberg,bl	1949
WSCBA	20-10	25	27	odvi	flag river deer yard	smith,ae	1955
XFNCA	39---	2	10	odvi	deer rng apprais in midwes	murphy,da	1970
XFNCA	52---	51	59	odvi	eff sno conds vuln to pred	mech,ld; frenzel/	1971

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
CAFGA	40--3	215	234	odhe	dee,forag relnshp wint rng	dasmann,wp; blais	1954
ECMOA	2----	1	46	odhe	seasonal migratn of mule d	russell,cp	1932
ECOLA	53--4	615	625	odhe	shrub age struct, wint rng	roughton,rd	1972
JFUSA	58--9	696	703	odhe	ceel, ecol stud wint range	gysel,lw	1960
JRMGA	2---4	206	212	odhe	livstk,forag stud,wint rng	dasmann,wp	1949
JRMGA	4---4	249	253	odhe	ceel, status of brws, oreg	mitchell,ge	1951
JRMGA	25--1	66	68	odhe	fecal cnt,wint site factrs	anderson,ae; med/	1972
JRMGA	30--2	122	127	odhe	eval habita on nutri basis	wallmo,oc; carpe/	1977
JRMGA	32--1	40	45	odhe	dosh forag selec, wintring	smith,ma; malech/	1979
JWMAA	6---3	210	220	odhe	survy winter range, oregon	edwards,ot	1942
JWMAA	9---2	145	151	odhe	winter study, nevada	aldous,cm	1945
JWMAA	13--4	421	423	odhe	eff deer, lvstk, rng, utah	smith,ad	1949
JWMAA	16--3	289	299	odhe	range conds, mortlty, utah	robinette,wl; ju/	1952
JWMAA	27--2	196	202	odhe	relation to climatic gradi	dasmann,rf; dasma	1963
JWMAA	29--1	27	33	odhe	montane forst win hab, mon	klebenow,da	1965
JWMAA	31--4	651	666	odhe	char herds, range ne utah	richens,vb	1967
JWMAA	34--1	15	23	odhe	effect of now depth on dee	gilbert,pf; wall/	1970
JWMAA	36--2	571	578	odhe	numbs, shrb yld util, wint	anderson,ae; med/	1972
JWMAA	39--3	605	616	odhe	doca, rng relns, prair hab	dusek,gl	1975
JWMAA	42--1	108	112	odhe	b-td wintr rnge, se alaska	bloom,am	1978
NAWTA	6----	132	139	odhe	ceel,wint rng cnds,rcky mt	ratcliff,hm	1941
NAWTA	20---	568	588	odhe	factrs infl dee, ariz brsh	hanson,wr; mccull	1955
NAWTA	29---	415	431	odhe	rel wintrng dee,phys envrn	loveless,cm	1964
NEXAA	567--	1	32	odhe	ft stanton hrd, ecol, n mx	wood,je; bickle,/	1970
TPCWD	20...	1	124	odhe	ecol charctcs winter range	loveless,cm	1967
WLMOA	20---	1	79	odhe	ceel, doca rnge ecol, mont	mackie,rj	1970
XFWWA	65...	1	15	odhe	wintr mort, utah, fishlake	robinette,wl	1949

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
JWMAA	5---4	427	453	ceel	effect wint brwsng, montan	gaffney,ws	1941
JWMAA	27--3	401	410	ceel	soil stabil requ wint rnge	packer,pe	1963
NAWTA	9----	173	176	ceel	jackson hole, winter, wyom	murier,oj	1944
NAWTA	10---	234	241	ceel	od, meth det nums & range	hunter,gn	1945
SJECA	10...	78	80	ceel	selec elim, earl win, ussr	sobanskii,gg	1979
XFIPA	24---	1	15	ceel	od, probs hab mgt, n fores	lyon,lj	1966

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
BINPA	12...	23	32	alal	moos, mskeg brch, beav env	lulman,pd	1974
CJZOA	45--4	485	490	alal	compar deer yrd, moose yrd	telfer,es	1967
CWRSB	15---	1	27	alal	odvi, behav in snow, fundy	kelsall,jp; presc	1971
JRMGA	16--5	227	231	alal	apprais moose rang, montan	peek,jm	1963
JWMAA	31--3	418	425	alal	od, comp wint rnge, nov sc	telfer,es	1967
JWMAA	34--1	37	46	alal	win ecol, gallatin mt, mon	stevens,dr	1970
JWMAA	34--3	553	559	alal	odvi, wint habitat selectn	telfer,es	1970
JWMAA	40--4	645	657	alal	odvi,hbitat use,symptr rng	kearney,sr; gilbe	1976
NCANA	101--	67	80	alal	distrb, wint habitat, queb	brassard,jm; aud/	1974
NCANA	101--	117	130	alal	biogeog, west n amer, snow	kelsall,jp; telfe	1974
NCANA	101--	131	141	alal	nature of wint habit, shir	peek,jm	1974
NCANA	101--	481	492	alal	snow cond, moose, wolf rel	peterson,ro; alle	1974
PASCC	2----	343	347	alal	wntr rnge prob,susitna val	chatelain,ef	1951
SCNAB	23...	1	5	alal	wint mort, germny, nat pks	burckhardt,d	1957

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
ATICA	12...	158	179	rata	snow, factr in winter ecol	pruitt,wo,jr	1959
ATICA	30...	101	108	rata	feeding sites, snow, alask	laperriere,aj; le	1977
AZOFA	16--4	271	280	rata	numeric snow index, reinde	pruitt,wo,jr	1979
BPURD	1....	324	334	rata	and snow condtns, se maint	stardom,rrp	1975
CAFNA	85--1	39	52	rata	abun forg on win rng, newf	bergerud,at	1971

rata continued on the next page

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
CWRSB	33--1	1	83	rata	invstg carib rnge, nw terr		1975
CWRSB	36---	1	42	rata	taiga wint rnge relns diet	miller,dr	1976
IJBMA	12--1	21	27	rata	wint activ, reltn sno, ice	henshaw,j	1968
OIKSA	25--3	379	387	rata	rel abun food in win, newf	bergerud,at	1974
RIJUA	30---	289	293	rata	intractins w/ habita, alas	klein,dr	1970
SZSLA	21---	109	115	rata	win nutr wld reind in norw	gaare,e	1968
UABPA	1----	324	334	rata	carib and sno cond, se man	stardom,rrp	1975
UABPA	1----	414	419	rata	weath effct on behav, migr	gavin,a	1975
XFWWA	43---	1	48	rata	st matthew isl reind range	klien,dr	1959

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
JWMAA	31--1	159	164	anam	mort, severe wint, n monta	martinka,cj	1967
JWMAA	41--3	560	571	anam	wint behav reln to habitat	bruns,eh	1977
XARRA	148--	1	4	anam	starv, full stomachs, feed	pearson,ha	1969

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
NPMSD	1----	1	161	bibi	bison of yellowstn nat prk	meagher,mm	1973

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
CAFGA	52--2	68	84	ovca	winter obsvtns, sierra nev	mccullogh,dr; sch	1966
CAFNA	87--4	433	454	ovca	chilcotin river bigh popul	demarchi,da; mitc	1973
CWRSB	39---	1	50	ovca	rng ecol in canad ntl prks	stelfox,jg	1976
JWMAA	35--2	257	269	ovca	winter ecology in yellowst	oldemyer,jl; bar/	1971

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

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
DWINA	44--3	321	325	obmo	arctic survival expert	holmes,f	1969

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
JWMAA	37--3	353	362	oram	forage, habitat pref, alas	hjeljord,o	1973

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
AMZOA	16--4	699	710	many	fat, energy, mammal surviv	young,ra	1976
JWMAA	3---4	295	306	many	yellowst wint rnge studies	grimm,rl	1939
JWMAA	20--2	159	168	many	sno depth, ungu abund, can	edwards,ry	1956
JWMAA	36--4	1068	1076	many	winter foods and range use	constan,kj	1972
JWMAA	42--2	352	361	many	dist brws, sno cov, albrta	telfer,es	1978
JWMAA	43--2	437	444	many	hbitat partitng,fire, mont	singer,fj	1979
NATUA	234--	482	484	many	water, energ turnover, des	macfarlane,wv; h/	1971
QSFRA	8---	79	96	many	eff hiemal envir fac,behav	pichette,c	1973

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
JRMGA	6---1	51	54	dosh	eff graz intens, nutr valu	cook,cw; stoddar/	1953
JRMGA	25--5	346	352	dosh	grz shee on big gm wnt rng	jensen,ch; smith/	1972

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
ZORVA	28...	97	197	caca	winter ecolg, north sweden	markgren,g	1966

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
BINPA	1----	1	176	mamm	snow cover,mamml,bird ecol	formozov,an	1946
ECOLA	46--1	25	34	----	noc thrml bdgt lg,sm trees	turrell,fm; austi	1965
JFUSA	60---	6	9	wldl	wldlife and forest environ	janzen,dh	1962
JRMGA	2---1	53	63	----	meth det util range forage	heady,hf	1949
JRMGA	7---1	14	23	----	applctn ecol, det rnge cnd	parker,kw	1954
JRMGA	10--5	208	212	----	steppoint method, sampling	evans,ra; love,rm	1957
JRMGA	24--1	55	59	----	seas trnds herb, nutr prod	sims,pl; love,rm	1971
JSWCA	25--5	197	198	----	snow fencing, redistr snow	swank,gw; booth,r	1970
JWMAA	19--2	206	214	biga	util wintr brows, biga rng	mcculloch,cy,jr	1955
JWMAA	19--2	215	255	biga	winter browse, se idaho	hoskins,lw; dalke	1955
NAWTA	10---	251	256	biga	b ga-liv compet, west rang	stoddart,la; rasm	1945
TWASA	53...	123	129	wldl	habitat and managed forest	stearns,fw; creed	1964

CHAPTER 17, WORKSHEET 1.4a

Weather profiles during the winter season

Weather profiles for each of the JDAY's from December 24 (JDAY 358) through March 19 (JDAY 78) at 7-day intervals may be completed by referring to the equations below.

SORA: See CHAPTER 14, WORKSHEET 1.1a
ADTC: See CHAPTER 14, WORKSHEET 2.1a - 2.1c
AMXT: See CHAPTER 14, WORKSHEET 2.1b
AMNT: See CHAPTER 14, WORKSHEET 2.1b
QREE: See CHAPTER 14, WORKSHEET 1.2a (complete ADTC first)
RAIN: See CHAPTER 14, WORKSHEET 5.2b
SNOW: See CHAPTER 14, WORKSHEET 5.2b
WIVE: See CHAPTER 14, WORKSHEET 3.2a
(Use Z_o characteristic of snow or vegetation if expressing wind velocity for a selected animal height)

Complete the calculations using equations derived for your local area and tabulate the results below.

					QREE*			PREC		
JDAY	SORA	ADTC	AMXT	AMNT				RAIN	SNOW	WIVE
358										
1										
8										
15										
22										
29										
36										
43										
50										
57										
64										
71										
78										

*Three blanks are given for different cover types, or for downward, upward and total infrared radiation.

JDAY	SORA	ADTC	AMXT	AMNT	QREE*			PREC		WIVE
								RAIN	SNOW	
358										
1										
8										
15										
22										
29										
36										
43										
50										
57										
64										
71										
78										

*Three blanks are given for different cover types, or for downward, upward and total infrared radiation.

TOPIC 2. EVALUATIONS OF SEASONAL ANIMAL RESPONSES

Animals maintain a dynamic energy balance through the annual cycle. This includes periods of both positive and negative balances for wild ruminants, with the positive energy balances during the productive summer period when females lactate and body growth and weight gains occur. The winter period is a time of negative energy balances when weight losses occur as a result of the breakdown of body tissue, especially fat, to meet metabolic demands.

Annual rhythms in body weights were discussed in CHAPTER 1, and body composition in CHAPTER 2. Annual rhythms in metabolism also occur, and were discussed in CHAPTER 7. Calculations of the amounts of forage necessary to meet seasonal metabolic requirements were discussed in CHAPTER 12.

The UNITS in this TOPIC include discussions of thermal energy balances. Thermal energy exchange is a constant process, and cold weather, thermal energy losses may exceed metabolic heat production, resulting in a negative thermal energy balance. In hot weather, heat production may exceed heat loss, which results in positive thermal energy balance, and a dangerous one.

Many factors affect thermal energy balances. Some of the physical atmospheric factors are solar and infrared radiation, wind speeds and turbulence levels, air temperatures, and vapor pressure deficits of the air. Some of the physical topographic factors are slope, aspect, and surface characteristics of the substrate (soil, vegetation, or snow). Some of the habitat factors are density of the cover as a barrier to wind, overhead density as a factor in radiation flux, overhead density for snow interception, life-forms of the plants and their leaves, and others. Some of the animal factors are size, weight, surface area, posture, orientation, piloerection, hair depth distribution, wetness of the hair coat, activities, metabolic rate, vasoconstriction and dilation, thermogenesis, fat quantity and distribution, and others. All of these are potential factors for affecting heat exchange. The large number of factors make the idea of "critical temperature," which is so entrenched in the literature, rather inadequate.

Critical temperatures are determined by placing an animal in a temperature-controlled metabolic chamber and raising and lowering chamber temperatures until a metabolic response is observed. The temperature at which the animal shows signs of heat stress is called the upper critical temperature, and the temperature at which the animal shows signs of cold stress, the lower critical temperature. It is my opinion, after reading the literature on this subject for a variety of species and observing deer in the pens at the Wildlife Ecology Laboratory and in the wild, that the temperatures at which responses occur are artifacts of the experimental conditions. A deer in a chamber is deprived of all of its behavioral options, and it is in an alien habitat not at all characteristic of the species' choice. It has little choice but to respond physiologically at some temperature.

Deer at the Wildlife Ecology Laboratory have not shown signs of cold stress at temperatures as low as -25°F (-32°C). Rather, they have shown reduced heart rates, respiration rates, and rumination rates. Piloerection occurs over parts of the body. Shivering may or may not occur.

Rainy days with freezing temperatures may result in signs of cold stress. The effects of water, with its heat capacity and evaporative cooling effect, may be critical. We humans are aware of the danger of becoming wet in cold temperatures. Thus temperature is simply not the critical one for free-ranging animals.

The concept of a critical thermal environment was published in Moen (1968), with several factors of thermal importance discussed, and any potential factor part of the concept. The combinations of factors that cause heat stress are called critical hyperthermal environments. The combinations of factors that cause cold stress are called critical hypothermal environments. Within these environments there could be critical wind velocities, critical postures, critical radiation fluxes, critical air temperatures, critical orientations, and so on. Any factor that could be altered to maintain an appropriate energy balance is a potential critical one, and many of these factors are behavioral options to be selected by the animal.

This discussion of the thermal environment precedes the UNITS because it applies to all of them. Keep this in mind when reading the literature on the effects of weather on wild ruminants. It is well to remember when considering thermal relationships and many other kinds of biological questions, especially ecological ones, that there are no simple answers to complex questions.

LITERATURE CITED

Moen, A. N. 1968. The critical thermal environment: A new look at an old concept. BioScience. 18(11):1041-1043.

UNIT 2.1: ANIMAL RESPONSES IN THE SPRING

Spring officially arrives on March 21, JDAY 80. Since weather conditions over most of the wild ruminant range are more like winter than summer at that time, the animals are faced with the problem of conserving heat energy to avoid hypothermia and yet meet the increasing metabolic costs associated with the annual metabolic cycle (See CHAPTER 7, UNIT 6.1).

Animals may or may not be on the winter range when spring officially arrives, depending on the weather and snow conditions in March. The most conspicuous animal response in the spring is that of movement from the winter range to the summer range. This involves dispersion from winter concentration areas, migrations to higher altitudes, and migrations to areas of traditional use, such as calving grounds.

Weather conditions may vary widely, from severe spring storms with deep snow to very warm and sunny days. The winter coat is retained through April and May, so heat loss is not necessarily more severe during cold, spring weather. Since the fat reserves are depleted and the available forage has the lowest nutritive quality of the year, severe spring storms cause more stress than similar conditions cause early in the winter (Moen 1976).

The significant physiological response to consider in the spring is the rise in metabolism. If winter weather conditions persist and the animals are forced to remain on low quality winter forage, the rise in metabolism places the animal in a lessl-favorable nutrient energy balance. This was discussed and illustrated in Moen (1978) for different times of arrival of spring. The basic relationship may be illustrated with the following numerical examples, using the formula discussed in CHAPTER 12, TOPIC 3. A gross energy of 4500 kcal per kg and a metabolic energy coefficient of 0.86 is used in the calculations below.

Ecological Metabolism		Forage Digestibility		Forage Required
2200	÷	[(4500) (0.40) (0.86)]	=	1.42
2400		0.40		1.55
2600		0.40		1.68
2800		0.40		1.81
3000		0.45		1.72
3200		0.50		1.65
3400		0.55		1.60

Note that as ecological metabolism increases, forage required increases as long as the forage digestibility remains the same. When digestibility increases, then the forage required decreases as the increase in digestibility compensates for the increase in ecological metabolism. The timing of the arrival of spring, the amelioration of cold weather, and the onset of the growing season are critical factors determining energy balance and hence productivity in wild ruminant populations.

Weather profiles were completed in WORKSHEETS at the end of each UNIT in the previous TOPIC. In this TOPIC, animal profiles are completed at the end of each UNIT, listing important weight, metabolism, and diet characteristics at 7-day intervals.

LITERATURE CITED

Moen, A. N. 1976. Energy conservation by white-tailed deer in the winter. Ecology. 57(1):192-198.

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, UNIT 2.1

ANIMAL RESPONSES IN THE SPRING

SERIALS

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
AMNAA	84--1	270	273	odvi	response to wisc wild fire	vogl,rj; beck, am	1970
CAFNA	90--2	123	136	odvi	distr, movs reln env fctrs	drolet,ca	1976
JANSA	45--2	365	376	odvi	nutritin thrghout the year	holter,jb; urba /	1977
JOMAA	39--2	309	311	odvi	aspects of blood chemistry	wilber,cg; robins	1958

odvi continued on the next page

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
JWMAA	19--3	358	364	odvi	rnge apprsl, missouri ozar	dunkeson,rl	1955
JWMAA	24--4	387	395	odvi	deer-for hab relnshps, ark	halls,lk; crawfor	1960
JWMAA	33--4	881	887	odvi	repro pattrns rel nutr pln	verme,lj	1969
JWMAA	35--1	37	46	odvi	eff fallng temp, heat prod	silver,h; holter/	1971
JWMAA	38--2	220	228	odvi	infl lt, weathr, obsrvblty	zagata,md; haugen	1974
JWMAA	41--2	315	317	odvi	seasnl chnge circad activ,	kammermeyer,ke; m	1977
JWMAA	42--4	715	738	odvi	seasnl chngs hrt rate, act	moen,an	1978
JWMAA	42--4	746	754	odvi	metab indictrs of hab difs	seal,us; nelson,/	1978
MGQPA	31...	62	74	odvi	spring ecolg, nc minnesota	pierce,de,jr	1971
NAWTA	24---	201	215	odvi	evergl hrd, rng cond, life	loveless,cm; liga	1959
NYCOA	14--2	30	31	odvi	big deer vs lit deer, food	severinghaus,cw;	1959
NYCOA	27--2	28	31	odvi	weather and the deer popul	severinghaus,cw	1972
NYCOA	29--4	18	20	odvi	advances, science deer mgt	severinghaus,cw	1975
RWLBA	6---2	327	385	odvi	wint, spr obsrv, adirndcks	spiker,cj	1933
SJAFD	1....	10	13	odvi	use of clear cuts, sw virg	blymyer,mj; mosby	1977
TISAA	63--2	198	201	odvi	deer trap corr weath fctrs	hawkins,re; klims	1970
WLSBA	6---2	88	90	odvi	the fat cycle in deer	mautz,ww	1978

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
CJZOA	48--2	275	282	odhe	feed intake, heat producti	nordon,hc; cowan/	1970
ECMOA	2----	1	46	odhe	seasonal migratn of mule d	russell,cp	1932
JRMGA	15---	278	281	odhe	rng mgt, habitat, hrd prod	julander,o	1962
JRMGA	30--2	122	127	odhe	eval habita on nutri basis	wallmo,oc; carpe/	1977
JRMGA	31--3	192	199	odhe	spr forg selec, sagebr rng	willms,w; mclean,	1978
JWMAA	22--3	275	283	odhe	food hab, rang use, montan	lovaas,al	1958
JWMAA	29--2	352	366	odhe	stom cont anal rela condtn	anderson,ae; sny/	1965
JWMAA	31--4	651	656	odhe	char herds, range n e utah	richens,vb	1967
NAWTA	20---	568	588	odhe	factrs infl dee, ariz brsh	hanson,wr; mccull	1955
PMASA	19...	72	79	odhe	annu cycl of cond, montana	taber,rd; white,/	1959
WLMOA	20---	1	79	odhe	ceel, doca, rng ecol, mont	mackie,rj	1970

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
EKPOA	17-22	381	389	ceel	repartitn of habita niches	dzieciolowski,r	1969
JOMAA	49--4	762	764	ceel	physiologi stud, rocky mts	herin,ra	1968
NCANA	101-3	505	516	ceel	shiras moos, rng reltnshps	stevens,dr	1974
NZJSA	36...	429	463	ceel	eval cond free-rng dee, nz	riney,t	1955
PZESA	14---	34	39	ceel	ruru, sensitv to temp fluc	christie,ahc	1967
XARRA	63---	1	7	ceel	od, doca, pondero pine use	reynolds,hg	1966
XARRA	66---	1	4	ceel	od, doca use of openings	reynolds,hg	1966

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
JWMAA	24--1	52	60	alal	food comp, rng relns, hare	dodds,dg	1960
JWMAA	39--4	653	662	alal	odvi,relnshps on burn,minn	irwin,ll	1975
JWMAA	40--4	645	657	alal	odvi,habta use, sympt rng	kearney,sr; gilbe	1976
NCANA	101-1	417	436	alal	influence of snow,behavior	coady,jw	1974

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
CBPAB	60A-2	123	126	rata	seas change growth hormone	ringberg,t; jaco/	1978
CJZOA	38--4	679	688	rata	wind,moistr,heat loss,calf	lentz,cp; hart,js	1960
CJZOA	39--6	845	856	rata	clim,metb,thrml resp,infnt	hart,js; heroux,/	1961
UABPA	1----	414	419	rata	weath effct on behav, migr	gavin,a	1975

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
CAFNA	87--4	433	454	ovca	chilcotin river bigh popul	demarchi,da; mitc	1973

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

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
ATICA	27...	256	264	obmo	rata, northw territ, canad	kevan,pg	1974

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

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
AMZOA	16--4	699	710	many	fat, energy, mammal surviv	young,ra	1976
JWMAA	43---	437	444	many	hab partitioni, fire, mont	singer,fj	1979
NCANA	103-3	153	167	many	resour div, commun lg herb	hudson,rj	1976

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
RVTSA	7....	466	479	dosh	thermal reguln, two breeds	webster,ajf; blax	1966

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
JWMAA	24--1	92	94	ungu	asses phys cond, field tch	riney,t	1960

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
ANYAA	301..	110	127	----	influnc exrcise skin tempe	adams, wc	1977
BISNA	18-11	1041	1043	----	critical thermal environme	moen,an	1968
IJBMA	20--2	139	156	dome	signif,meteorol, anim prod	bianca,w	1976

CHAPTER 17, WORKSHEET 2.1a

Animal characteristics during the spring season

Animal characteristics for each of the JDAY's from March 26 (JDAY 85) through June 18 (JDAY 169) at 7-day intervals may be completed by referring to the equations below.

FEWK: See CHAPTER 1, WORKSHEET 1.1a
CLWK: See CHAPTER 1, WORKSHEET 1.2a
MBLM: See CHAPTER 7, WORKSHEET 1.1a
ELMD: See CHAPTER 7, WORKSHEET 6.1a, 6.1b
DIDI: See CHAPTER 11, WORKSHEET 3.3a
DWFK: See CHAPTER 12, WORKSHEET 3.1a

Complete the calculations using equations given in other PARTS or for animals in your local area and tabulate the results below. Many other parameters could be included, of course; the format on the next page may be used to tabulate your selections.

JDAY	AGDA	FEWK	CLWK	MBLM	ELMD	DIDI	DWFK
85	____	____	____	____	____	____	____
92	____	____	____	____	____	____	____
99	____	____	____	____	____	____	____
106	____	____	____	____	____	____	____
113	____	____	____	____	____	____	____
120	____	____	____	____	____	____	____
127	____	____	____	____	____	____	____
134	____	____	____	____	____	____	____
141	____	____	____	____	____	____	____
148	____	____	____	____	____	____	____
155	____	____	____	____	____	____	____
162	____	____	____	____	____	____	____
169	____	____	____	____	____	____	____

JDAY									
85									
92									
99									
106									
113									
120									
127									
134									
141									
148									
155									
162									
169									

JDAY									
85									
92									
99									
106									
113									
120									
127									
134									
141									
148									
155									
162									
169									

UNIT 2.2: ANIMAL RESPONSES IN THE SUMMER

Summer (June 21, JDAY 172, to September 20, JDAY 263) is a time when weather conditions are expected to offer the least stress of any time during the year. There are possibilities for unusual weather conditions, especially in late summer at high altitudes and in the extreme north.

The most common stress imposed by summer-like weather occurs in late spring and early summer when the neonates are not yet fully capable of regulating metabolism and behavior to meet transient conditions. Suppose, for example, that newborn fawns are exposed to a period of cool wet weather. If their weights are 4 kg, characteristics of a fawn a week or two old, their base-line metabolism is 198 kcal (CHAPTER 7, Page 2), and their ecological metabolism is about 3 times the base-line, or about 600 kcal. The surface area of a 4 kg fawn may be estimated with the equation in WORKSHEET 2.3b, CHAPTER 1, UNIT 2.3; TSAM = 0.34 sq meters, or 3400 sq centimeters. Suppose that half of this area, or 1700 sq cm, was exposed to cold rain, and that each sq cm of hair surface absorbed 100 milligrams of water. This results in 170 cubic centimeters of water being absorbed.

The heat of vaporization is about 600 cal per gram of water vaporized (see CHAPTER 15, UNIT 4.1). Multiplying 170 by 600 and dividing by 1000 to convert to kcal, the evaporation of this amount of water absorbed by the hair surface results in a loss of 102 kcal of heat energy, which is 20% of the 600 kcal of daily ecological metabolism of the 4 kg fawn. If rainy, cold weather persists and essentially all of the heat energy for evaporation must come from metabolic heat (a cold, saturated atmosphere provides no energy for surface evaporation), it is easy to see that the amount of heat energy lost could be substantial, resulting in mortality of the hypothermic fawn. There are many estimates in the example above, but none are unreasonable for a 24-hour period. Use your own estimates to repeat similar calculations for various combinations of factors in WORKSHEET 2.2b.

Ruminants use weather and thermal energy distribution to escape from insect harassments in the summer. Windy areas are selected as bed sites by deer because they are more free of biting insects. Snow patches on the tundra become favored bedding areas of caribou because they are more insect-free. These responses to weather and thermal conditions are indirect; it is the insect that is distributed as a direct result of weather effects and the deer and caribou as a direct result of insect distribution.

There has been some discussion in published literature about the role of velvet-covered antlers in heat dissipation. Heat energy is given off from the antlers as they feel warm to the touch, but analyses of the magnitude of heat loss from these organs in relation to total heat loss have not been made. Until that is done, any judgements of their significance are premature. They surely cannot be essential because female deer, elk, and moose do not have them. They are another avenue of heat loss in the males, supplementing other pathways such as the very vascular and essentially hairless ears, the thin-haired summer coat, and a variety of postures and thermoregulatory behaviors that can be employed.

It is important to note that replacement of the summer coat by the winter coat begins before the end of summer. There is a potential for heat stress then as sunny and warm late summer days provide a high energy input which, coupled with the effective insulation of the growing winter coat, may result in a critical hyperthermic environment and subsequent heat stress. This is discussed further in the next UNIT.

REFERENCES, UNIT 2.2

ANIMAL RESPONSES IN THE SUMMER

SERIALS

CODEN	VO-NU	BEPA	ENPA	ANIM	OEY WORDS-----------------	AUTHORS----------	YEAR
JWMAA	13--3	314	315	od--	deer forag observtns, utah	smith,jg	1949

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
AMNAA	84--1	270	273	odvi	response to wisc wild fire	vogl,rj; beck, am	1970
CAFNA	90--2	123	136	odvi	distr, movs reln env fctrs	drolet,ca	1976
JANSA	45--2	365	376	odvi	nutritin thrghout the year	holteer,jb; urba/	1977
JOMAA	39--2	309	311	odvi	aspects of blood chemistry	wilber,cg; robins	1958
JWMAA	19--3	358	364	odvi	rnge apprsl, missouri ozar	dunkeson,rl	1955
JWMAA	24--4	387	395	odvi	deer-for hab relnshps, ark	halls,lk; crawfor	1960
JWMAA	33--4	881	887	odvi	repro pattrns rel nutr pln	verme,lj	1969
JWMAA	35--1	37	46	odvi	eff fallng temp, heat prod	silver,h; holter/	1971
JWMAA	35--3	476	487	odvi	summer habitat, nc minneso	kohn,e; mooty,jj	1971
JWMAA	41--2	315	317	odvi	seasnl chnge circad activ,	kammermeyer,ke; m	1977
JWMAA	42--4	715	738	odvi	seasonl chngs hrtrate, act	moen,an	1978
NAWTA	24---	201	215	odvi	evergl hrd, rng cond, life	loveless,cm; liga	1959
NYCOA	14--2	30	31	odvi	big deer vs lit deer, food	severinghaus,cw;/	1959
NYCOA	29--4	18	20	odvi	advances, science deer mgt	severinghaus,cw	1975
SJAFD	1....	10	13	odvi	use of clear cuts, sw virg	blymyer,mj; mosby	1977
WLSBA	6---2	88	90	odvi	the fat cycle in deer	mautz,ww	1978

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
CJZOA	48--2	275	282	odhe	feed intake, heat producti	nordon,hc; cowan/	1970
ECMOA	2----	1	46	odhe	seasonal migratn of mule d	russell,cp	1932
JRMGA	15---	278	281	odhe	rng mgt, habitat,herd prod	julander,o	1962
JRMGA	30--2	122	127	odhe	eval habita on nutri basis	wallmo,oc; carpe/	1977
JWMAA	22--3	275	283	odhe	food hab, rang use, montan	lovaas,al	1958
JWMAA	25--1	54	60	odhe	rel sum rng cond, hrd prod	julander,oj; rob/	1961
JWMAA	29--2	352	366	odhe	stom cont anal rel to cond	anderson,ae; sny/	1965
JWMAA	34--4	852	862	odhe	resp to mgt sum rnge, kaib	hungerford,cr	1970
JWMAA	39--3	605	616	odhe	doca, rng relns, prair hab	dusek,gl	1975
NAWTA	20---	568	588	odhe	factrs infl dee, ariz brsh	hanson,wr; mccull	1955
PMASA	19...	72	79	odhe	annu cycl of cond, montana	taber,rd; white,/	1959
WLMOA	20---	1	79	odhe	ceel, doca, rnge ecol, mon	mackie,rj	1970

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
EKPOA	17-22	381	389	ceel	repartitn of habita niches	dzieciolowski,r	1969
JOMAA	49--4	762	764	ceel	physiologi stud, rocky mts	herin,ra	1968
NCANA	101-3	505	516	ceel	shiras moos, rng reltnshps	stevens,dr	1974
NZJSA	36...	429	463	ceel	eval cond free-rng dee, nz	riney,t	1955
PZESA	14---	34	39	ceel	ruru, sensitv, temp fluctu	christie,ahc	1967
XARRA	63---	1	7	ceel	od, doca, pondero pine use	reynolds,hg	1966
XARRA	66---	1	4	ceel	od, doca, use of openings	reynolds,hg	1966

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
JRMGA	16--5	227	231	alal	apprais moose rang, montan	peek,jm	1963
JWMAA	24--1	52	60	alal	food comp, rng relns, hare	dodds,dg	1960
JWMAA	39--4	653	662	alal	odvi,relatns on burn, minn	irwin,ll	1975
JWMAA	40--4	645	657	alal	odvi, habita use, symp rng	kearney,sr; gilbe	1976

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
CBPAB	60A-2	123	126	rata	seas change growth hormone	ringberg,t; jaco/	1978
CJZOA	38--4	679	688	rata	wind,moistr,heat loss,calf	lentz,cp; hart,js	1960
CJZOA	39--6	845	856	rata	metbl, therml respns,infnt	hart,js; heroux,/	1961
IJBMA	12--1	21	27	rata	wint activ, reltn sno, ice	henshaw,j	1968
NJZOA	23--1	93	95	rata	growing antlers, heat loss	wika,m; krog,j; /	1975
RIJUA	30---	289	293	rata	intractins w/ habita, alas	klein,dr	1970
UABPA	1----	360	367	rata	responses to heat stress	yousef,mk; luick,	1975
XFWWA	43---	1	48	rata	st matthew isl reind range	klein,dr	1959

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
NAWTA	15---	627	644	anam	rng ecol, wichita mts refu	buechner,hk	1950

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

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
CAFNA	87--4	433	454	ovca	chilcotin river bigh popul	demarchi,da; mitc	1973

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

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
JRMGA	23--1	8	14	obmo	rata,tndra n of boreal for	klein,dr	1970
JWMAA	40--1	151	162	obmo	rata, summ rnge relns, nwt	wilkinson,pf; sh/	1976

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

                        oram


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

AMZOA 16--4 699  710  many fat, energy, mammal surviv young,ra          1976


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

AJAEA 24--5 775  782  doca heat toleranc, exposre sun moran,jb          1973
AJAEA 26--3 615  622  doca eff heat stres on grth,met kellaway,rc; cold 1975


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

AJAEA 11... 402  407  dosh regul bod temp, hot envirn brook,ah; short,b 1960
AJAEA 13--1 122  143  dosh temp reg, new-brn, hot env alexander,g; will 1962

RVTSA 7.... 466  479  dosh thermal regula, two breeds webster,ajf; blax 1966


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

ANYAA 301.. 110  127  ---- influnc exrcise skin tempe adams,wc          1977

BISNA 18-11 1041 1043 ---- critical therml environmnt moen,an           1968

IJBMA 20--2 139  156  dome signif, meterol, anim prod bianca,w          1975


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

AJPHA 219-4 1131 1135 ungu temp regulat, evap, ea afr taylor,cr         1970
AJPHA 222-6 1374 1379 ungu thermoregulat, heat balanc finch,va          1972

CBCPA 38... 525  534  ungu thermoregul, water, ea afr maloiy,gmo; hopc/ 1971

JSAVA 41... 17   24   ungu adapt sol rad, afric herbi harthoorn,am; fi/ 1970

JWMAA 24--1 92   94   ungu asses phys cond, field tch riney,t           1960

SZSLA 31--- 315  326  ungu enrgy exchang ea afr antel finch,va          1972
```

CHAPTER 17, WORKSHEET 2.2a

Animal characteristics during the summer season

Animal characteristics for each of the JDAY's from June 25 (JDAY 176) through September 17 (JDAY 260) at 7-day intervals may be completed by referring to the equations below.

CLWK: See CHAPTER 1, WORKSHEET 1.2a
MBLM: See CHAPTER 7, WORKSHEET 1.1a
ELMD: See CHAPTER 7, WORKSHEET 6.1a, 6.1b
DIDI: See CHAPTER 11, WORKSHEET 3.3a
DWFK: See CHAPTER 12, WORKSHEET 3.1a

Complete the calculations using equations given in other PARTS or for animals in your local area and tabulate the results below. Many other parameters could be included, of course; the format on the next page may be used to tabulate your selections.

JDAY	AGDA	CLWK	MBLM	ELMD	DIDI	DWFK
176	____	____	____	____	____	____
183	____	____	____	____	____	____
190	____	____	____	____	____	____
197	____	____	____	____	____	____
204	____	____	____	____	____	____
211	____	____	____	____	____	____
218	____	____	____	____	____	____
225	____	____	____	____	____	____
232	____	____	____	____	____	____
239	____	____	____	____	____	____
246	____	____	____	____	____	____
253	____	____	____	____	____	____
260	____	____	____	____	____	____

JDAY									
176	____	____	____	____	____	____	____	____	____
183	____	____	____	____	____	____	____	____	____
190	____	____	____	____	____	____	____	____	____
197	____	____	____	____	____	____	____	____	____
204	____	____	____	____	____	____	____	____	____
211	____	____	____	____	____	____	____	____	____
218	____	____	____	____	____	____	____	____	____
225	____	____	____	____	____	____	____	____	____
232	____	____	____	____	____	____	____	____	____
239	____	____	____	____	____	____	____	____	____
246	____	____	____	____	____	____	____	____	____
253	____	____	____	____	____	____	____	____	____
260	____	____	____	____	____	____	____	____	____

JDAY									
176	____	____	____	____	____	____	____	____	____
183	____	____	____	____	____	____	____	____	____
190	____	____	____	____	____	____	____	____	____
197	____	____	____	____	____	____	____	____	____
204	____	____	____	____	____	____	____	____	____
211	____	____	____	____	____	____	____	____	____
218	____	____	____	____	____	____	____	____	____
225	____	____	____	____	____	____	____	____	____
232	____	____	____	____	____	____	____	____	____
239	____	____	____	____	____	____	____	____	____
246	____	____	____	____	____	____	____	____	____
253	____	____	____	____	____	____	____	____	____
260	____	____	____	____	____	____	____	____	____

Chapter 17, Worksheet 2.2b

Estimates of energy absorbed as heat of vaporization

A description of the calculations of energy absorbed as heat of vaporization was given in this UNIT for a whitetail fawn weighing 4 kg. Fill in the blanks below for a species of your choice to estimate the heat of vaporization from a wet hair surface. All of the symbols and parameters used have been discussed in previous PARTs, CHAPTERs, and UNITs.

Species: ______________________________

LIWK = ______ kg

BLM = ______

MBLM = ______

ELMD = ______ kcal per day

TSAM = ______ sq meters

TSAC = ______ sq centimeters

exposed TSAC = ______ sq cm

mm water per sq cm = ______

total water = ______ milligrams

HEVA = ______ cal per gm water

total HEVA = ______ cal

total HEVA = ______ kcal

total HEVA in kcal/ELMD = ______ x 100 = ______ = percent of ELMD represented by HEVA

Repeat the above for upper and lower estimates of the area of the hair coat exposed and the amount of water absorbed by the hair coat; additional blanks are provided on the next page. Does it not appear that prolonged wet, cold weather places a demonstrated energy drain on the neonate?

Species: ______________________________

LIWK = ______ kg

BLM = ______

MBLM = ______

ELMD = ______ kcal per day

TSAM = ______ sq meters

TSAC = ______ sq centimeters

exposed TSAC = ______ sq cm

mm water per sq cm = ______

total water = ______ milligrams

HEVA = ______ cal per gm water

total HEVA = ______ cal

total HEVA = ______ kcal

total HEVA in kcal/ELMD = ______ x 100 = ______ = percent of ELMD represented by HEVA

Species: ______________________________

LIWK = ______ kg

BLM = ______

MBLM = ______

ELMD = ______ kcal per day

TSAM = ______ sq meters

TSAC = ______ sq centimeters

exposed TSAC = ______ sq cm

mm water per sq cm = ______

total water = ______ milligrams

HEVA = ______ cal per gm water

total HEVA = ______ cal

total HEVA = ______ kcal

total HEVA in kcal/ELMD = ______ x 100 = ______ = percent of ELMD represented by HEVA

UNIT 2.3: ANIMAL RESPONSES IN THE FALL

The fall period, from September 21 (JDAY 264) to December 20 (JDAY 354), is a period of often rapid change. Weather conditions can change rapidly in early fall, and from the beginning to the end of fall there is an overall trend from summer-like to winter-like conditions. Animals, however, are prepared to respond to these changes in weather conditions. Winter coats have been growing since late summer, so insulation is approaching maximum. Animal weights reach the annual maximum in the fall, and the fat composition is at maximum. Thus metabolic reserves are maximum, and the layers of fat provide additional subskin thermal insulation.

Differences in responses of white-tailed deer to snow and cold in late fall compared to late winter were discussed in Moen (1976). Changes in the environment and the animal's response are more gradual than abrupt; "...there is a continuum involved in each change and subsequent response." A deer exposed to a harsh combination of temperature, wind, and snow conditions in December is much better able to cope with the resulting energy costs than one exposed to this same combination in March. The important point to be made is that analyses of deer and other animals' responses to environmental changes should be on a sequential basis through the winter rather than on overall averages for the winter.

Profiles of the animals should be compiled for this time period, as usual, in the WORKSHEET. Changes in animal distributions, portions of the range used, and habitat selection become additional considerations as the animals go through the fall period of change and enter the winter period of potentially high thermal and nutritive stress.

LITERATURE CITED

Moen, A. N. 1976. Energy conservation by white-tailed deer in winter. Ecology 57(1):192-198.

REFERENCES, UNIT 2.3

ANIMAL RESPONSES IN THE FALL

SERIALS

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
JWMAA	13--3	314	315	od--	deer forag observatns, uta	smith,jg	1949

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
CAFNA	90--2	123	136	odvi	distr, movs reln env fctrs	drolet,ca	1976
JANSA	45--2	365	376	odvi	nutritin thrghout the year	holteer,jb; urba/	1977
JOMAA	39--2	309	311	odvi	aspects of blood chemistry	wilber,cg; robins	1958
JOMAA	48--4	655	656	odvi	hypotherm, water-chilled d	moen,an	1967
JWMAA	19--3	358	364	odvi	rnge apprsl, missouri ozar	dunkeson,rl	1955
JWMAA	33--4	881	887	odvi	repro pattrns rel nutr pln	verme,lj	1969
JWMAA	35--1	37	46	odvi	falling temp, heat product	silver,h; holter/	1971
JWMAA	38--2	220	228	odvi	influ lt, weathr,obsrvblty	zagata,md; haugen	1974
JWMAA	41--2	315	317	odvi	seasnl chnge circad activ,	kammermeyer,ke; m	1977
JWMAA	42--4	715	738	odvi	seasnl chngs hrt rate, act	moen,an	1978
MGQPA	31...	142	150	odvi	fall ecology, nc minnesota	waddell,bh	1971
NAWTA	24---	201	215	odvi	evergl hrd, rng cond, life	loveless,cm; liga	1959
NYCOA	14--2	30	31	odvi	big deer vs lit deer, food	severinghaus,cw;/	1959
NYCOA	29--4	18	20	odvi	advances, science deer mgt	severinghaus,cw	1975
PCGFA	18---	57	62	odvi	importnce variety to s dee	lay,dw	1964
SJAFD	1....	10	13	odvi	use of clear cuts, sw virg	blymyer,mj; mosby	1977
WLSBA	6---2	88	90	odvi	the fat cycle in deer	mautz,ww	1978

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
CJZOA	48--2	275	282	odhe	feed intake, heat producti	nordon,hc; cowan/	1970
JRMGA	15---	278	281	odhe	rng mgt, habitat, hrd prod	julander,o	1962
JRMGA	30--2	122	127	odhe	eval habita on nutri basis	wallmo,oc; carpe/	1977

odhe continued on the next page

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
JWMAA	22--3	275	283	odhe	food hab, rang use, montan	lovaas,al	1958
JWMAA	29--2	352	366	odhe	stom cont anal rel to cond	anderson,ae; sny/	1965
JWMAA	31--4	651	656	odhe	char herds, range n e utah	richens,vb	1967
NAWTA	20---	568	588	odhe	factrs infl dee, ariz brsh	hanson,wr; mccull	1955
PMASA	19...	72	79	odhe	annu cycl of cond, montana	taber,rd; white,/	1959
WLMOA	20---	1	79	odhe	ceel, doca, rnge ecol, mon	mackie,rj	1970

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
EKPOA	17-22	381	389	ceel	repartitn of habita niches	dzieciolowski,r	1969
JOMAA	49--4	762	764	ceel	physiologi stud, rocky mts	herin,ra	1968
NCANA	101-3	505	516	ceel	shiras moos, rng reltnshps	stevens,dr	1974
NZJSA	36...	429	463	ceel	eval cond free-rng dee, nz	riney,t	1955
PZESA	14---	34	39	ceel	ruru,sensitv to temp fluct	christie,ahc	1967

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
JWMAA	24--1	52	60	alal	food comp, rng relns, hare	dodds,dg	1960
JWMAA	39--4	653	662	alal	odvi,relnshp on burn, minn	irwin,ll	1975
JWMAA	40--4	645	657	alal	odvi, habita use, symp rng	kearney,sr; gilbe	1976
NCANA	101-1	417	436	alal	influence of snow, behvior	coady,jw	1974

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
CBPAB	60A-2	123	126	rata	seas change growth hormone	ringberg,t; jaco/	1978

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
CAFNA	87--4	433	454	ovca	chilcotin river bigh popul	demarchi,da; mitc	1973

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
JWMAA	43--2	437	444	many	hab partitioni, fire, mont	singer,fj	1979
NCANA	103-3	153	167	many	resour div, commun lg herb	hudson,rj	1976

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
RVTSA	7....	466	479	dosh	thermal reguln, two breeds	webster,ajf; blax	1966

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
ANYAA	301..	110	127	----	influnc exrcise skin tempe	adams, wc	1977
BISNA	18-11	1041	1043	----	critical thermal environme	moen,an	1968
IJBMA	20--2	139	156	dome	signif meteorol, anim prod	bianca,w	1975

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
JWMAA	24--1	92	94	ungu	asses phys cond, field tch	riney,t	1960

Chapter 17, Worksheet 2.3a

Animal characteristics during the fall season

Animal characteristics for each of the JDAY's from September 24 (JDAY 267) through December 17 (JDAY 351) at 7-day intervals may be completed by referring to the equations below.

CLWK: See CHAPTER 1, WORKSHEET 1.4b
MBLM: See CHAPTER 7, WORKSHEET 1.1a
ELMD: See CHAPTER 7, WORKSHEET 6.1a, 6.1b
DIDI: See CHAPTER 11, WORKSHEET 3.3a
DWFK: See CHAPTER 12, WORKSHEET 3.1a

Complete the calculations using equations given in other PARTs or for animals in your local area and tabulate the results below. Many other parameters could be included, of course; the format on the next page may be used to tabulate your selections.

JDAY	AGDA	CLWK	MBLM	ELMD	DIDI	DWFK
267	____	____	____	____	____	____
274	____	____	____	____	____	____
281	____	____	____	____	____	____
288	____	____	____	____	____	____
295	____	____	____	____	____	____
302	____	____	____	____	____	____
309	____	____	____	____	____	____
316	____	____	____	____	____	____
323	____	____	____	____	____	____
330	____	____	____	____	____	____
337	____	____	____	____	____	____
344	____	____	____	____	____	____
351	____	____	____	____	____	____

JDAY									
267									
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JDAY									
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351									

UNIT 2.4: ANIMAL RESPONSES IN THE WINTER

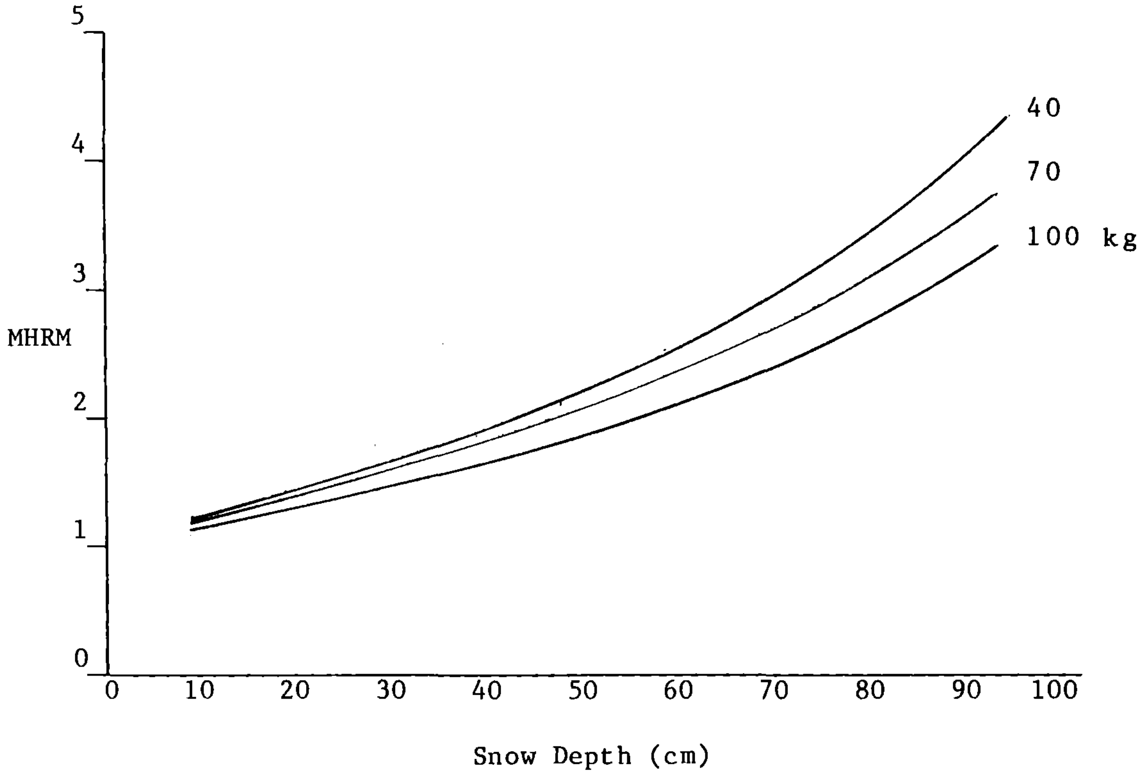
Winter is a time of potentially critical hypothermal environments and negative energy balances. In fact, the smallest animals in a population, late-born young-of-the-year, are almost certain to have critical energy balances unless the winter is unusually mild. Small fawns, for example, do not have the fat reserves to meet metabolic demands when forage is not readily available and quality is low. Furthermore, small fawns have distinct physical disadvantages, including shorter legs and shorter reaches than larger deer, less well-developed hair coats, higher surface area ratios, and others. They also have social disadvantages, being subject to the more dominant adult does and bucks. All of these disadvantages make it most difficult for the smallest, youngest members of the population to survive.

Larger members of the deer family, such as moose, have definite advantages over smaller animals in the snow. Their long legs make it relatively easy to walk through deep snow, and bedding down in deep, soft snow creates a depression that protects from the wind. Since fluffy snow has a low heat capacity and is good insulation, such bedding behavior is good body heat conservation. Lesser snow depths offer the same advantages to white-tailed deer, of course.

There are two possible strategies for coping with the potential critical thermal environments of winter. One is to increase heat production to offset heat loss, and the other is to increase heat conservaion to reduce heat loss. It is very clear that wild ruminants, at least the smaller species and probably all of them choose the latter. It is the only ecologically reasonable strategy because food resources are limited in the winter and are often inaccessible due to snow. Snow is a mechanical barrier to deer movements that may cause energy expenditures to increase to levels that result in negative returns from forage ingested. The effect of snow accumulations on heart rates have been estimated from data in Jacobsen (1973) and Mattfeld (1974) and expressed as a multiple of the heart rate per minute (MHRM). This may then be applied to the heart rate-metabolism conversion equation discussed in CHAPTER 7, UNIT 5.2. The predicted MHRM is:

$$MHRM = e^{0.692402 \quad SNDE/[12.5(CLWK^{0.21}) + 8.0\ (CLWK^{0.25})]}$$

Note that MHRM is a function of both snow depth (SNDE) and calculated live weight in kg (CLWK). These independent variables illustrate how larger deer, with a greater belly height, are not affected as much by increasing snow depths as smaller deer are, as illustrated on the next page. Multiples of heart rate may be predicted for deer of different weights in snow from 0 to 100 cm deep in WORKSHEET 2.4b.



An energy conservation adaptive strategy does not allow animals to struggle through deep snow at high energy costs. Neither does it allow them to increase their metabolic rates to high levels to offset high heat losses. Rather, there is a reduction in the ecological metabolism during the winter to the lowest point in the annual cycle, and heat energy is conserved further by the excellent insulation of the winter hair coat.

The reduction is not simply a voluntary restriction of activity that results in less energy expenditure. Thyroxine, a thyroid hormone that affects metabolic rate, is also at low levels in the winter, resulting in metabolic depression (Seal et al. 1972). Other details substantiating the existence of seasonal metabolic rhythms, including the winter metabolic depression, are given in Moen (1978).

The important field application to be made from the recognition of the winter metabolic depression is that any activity which causes deer to move more and over wider areas in the winter is counter to their long-term adaptive strategy. The potential effects of disturbances by snowmobiles were mentioned in the paper on energy conservation in the winter (Moen 1976), and another paper in press (New York Fish and Game Journal) describes the accelerated heart rates in response to controlled snowmobile experiments. No evidence of habituation was found over an entire winter of tests. Deer are not frightened by the noise per se; chain saws attract deer when they result in trees cut and more food made available, and snowmobiles which pull sleds with artificial feed into wintering areas also attract them. Such management practices are very labor intensive, however, and not realistic solutions to winter stress over large areas, and especially if the populations are to remain as wild as possible.

Thermal energy balances of deer are being evaluated as a result of wind tunnel and outdoor research at the Wildlife Ecology Laboratory from 1973-1980. The overall heat transfer approach is being used (See CHAPTER 16, TOPIC 2). The results are being prepared for journal publication, and it would be premature to present them here. Suffice it to say that radiation, wind profiles, air temperatures, hair depth, weight, surface area, bed area, and posture are variables being evaluated, and preliminary results indicate that reasonable thermal energy balances are maintained by regulating behavior patterns and habitat selection for larger animals, that the smaller animals are in more precarious energy balances, and that certain combinations of thermal parameters do have the potential for creating critical hypothermic environments.

Thorough analyses of these results for deer will be followed by analyses for other species of ruminants. It is expected that larger species, such as elk and moose, will have less precarious thermal balances than smaller species, such as deer. One of the most interesting species to analyze will be caribou because of their relatively small size and rather harsh winter environment. A critical hair depth may be a very important characteristic to quantify.

Energy balances during the winter are interesting to quantify, and considerable insight into the relative importances of different parameters may be gained by simulating a variety of weather and behavioral combinations. One of the most important factors to emerge from these thermal analyses and from the metabolic and nutritive analyses discussed in CHAPTERS 7 and 12 is the length of winter, or the timing of the arrival of spring conditions. If spring conditions arrive early, winter mortality will likely be very low. If it arrives later, winter mortality will likely occur among the younger, smaller animals. If it arrives very late, winter mortality may occur among older deer. Thus the annual cycle is complete, with the importance of spring conditions discussed in UNIT 2.1. As data analyses become more complete, more details will be added to our mental and mathematical analyses and our understanding will be made more complete.

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Mattfeld, G. F. 1974 The energetics of winter foraging by white-tailed deer--a perspective on winter concentration. PhD. Thesis, State University College of Environmental Science and Forestry, Syracuse, N.Y. 306 p.

Moen, A. N. 1976. Energy conservation by white-tailed deer in the winter. Ecology. 57(1):192-198.

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Seal, U. S., L. J. Verme, J. J. Ozaga, 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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ANIMAL RESPONSES IN THE WINTER

SERIALS

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
FUOFA	66...	174	186	cerv	wint prob, northern cervid	markgren,g	1971
JWMAA	42--2	352	361	cerv	dist, brows,sno cvr,albrta	telfer,es	1978

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
CAFGA	44--1	51	72	od--	surv, rang forag trnds, ca	dasmann,wp; hjers	1958

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
CAFNA	85--2	141	145	odvi	odhe, winter ecol, alberta	kramer,a	1971
CAFNA	90--2	123	136	odvi	distr, movs reln env fctrs	drolet,ca	1976
CJZOA	54--8	1307	1313	odvi	eff wint condtns, manitoba	kucera,e	1976
ECOLA	16--4	535	553	odvi	wint relns to forsts, mass	hosley,nw; ziebar	1935
ECOLA	57--1	192	198	odvi	enrgy conservation in wint	moen,an	1976

odvi continued on the next page

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS----------------	AUTHORS----------	YEAR
ISJRA	47--3	199	217	odvi	pil knb st pk, win dee hav	zagata,md; haugen	1973
JANSA	45--2	365	376	odvi	nutritin thrghout the year	holteer,jb; urba/	1977
JMNAA	37--1	16	18	odvi	winter obsrvtns, se minnes	dorn,rd	1971
JOMAA	39--2	309	311	odvi	aspects of blood chemistry	wilber,cg; robins	1958
JOMAA	48--4	655	656	odvi	hypotherm, water-chilled d	moen,an	1967
JRMGA	3---2	130	132	odvi	feedng dee on brws sp, win	smith,ad	1950
JWMAA	6---4	287	291	odvi	winter habits, central ny	cook,db; hamilton	1942
JWMAA	11--2	167	177	odvi	odhe,surv ovr-pop rang,us	leopold,a; sowls/	1947
JWMAA	13--1	135	141	odvi	avail wint forg, hrdwd for	hough,af	1949
JWMAA	14--2	156	161	odvi	obs, histopath, starv, wis	rausch,r	1950
JWMAA	19--3	358	364	odvi	rnge apprsl, missouri ozar	dunkeson,rl	1955
JWMAA	24--4	364	371	odvi	test of shelt req pen deer	robinson,wl	1960
JWMAA	24--4	387	395	odvi	deer-for hab relnshps, ark	halls,lk; crawfor	1960
JWMAA	32--3	566	574	odvi	index wint weather severit	verme,lj	1968
JWMAA	33--3	511	520	odvi	hab-deer relns in enclosur	segelquist,ca; w/	1969
JWMAA	33--4	881	887	odvi	repro pattrns rel nutr pln	verme,lj	1969
JWMAA	34--2	431	439	odvi	wintr feed pattrns, penned	ozoga,jj; verme,l	1970
JWMAA	35--1	37	46	odvi	effct temp on heat prodctn	silver,h; holter/	1971
JWMAA	35--4	732	743	odvi	limitns of wint aspn brows	ullrey,de; youat/	1971
JWMAA	36--3	892	896	odvi	response to winter weather	ozoga,jj; gysel,l	1972
JWMAA	38--2	220	228	odvi	influ lt, weath,obsrvblity	zagata,md; haugen	1974
JWMAA	39--3	563	569	odvi	effcts snowmobiles on wt-d	dorrance,mj; sav/	1975
JWMAA	41--2	315	317	odvi	seasnl change circad activ	kammermeyer,ke; m	1977
JWMAA	41--4	700	708	odvi	assess mortality, upp mich	verme,lj	1977
JWMAA	42--4	715	738	odvi	seasonl chngs hrtrate, act	moen,an	1978
JWMAA	42--4	746	754	odvi	metab indictrs of hab difs	seal,us; nelson,/	1978
MFNOA	223..	....	....	odvi	wint covr type use, minnes	fedkenheuer,aw; h	1971
NAWTA	18---	581	596	odvi	yard carry capac, browsing	davenport,la; sw/	1953
NAWTA	24---	201	215	odvi	evergl hrd, rng cond, life	loveless,cm; liga	1959
NAWTA	34---	137	146	odvi	eff of nutr, clim, so deer	short,hl; newsom/	1969
NYCOA	7---5	2	4	odvi	selectn, use winterg yards	severinghaus,cw	1953
NYCOA	14--2	30	31	odvi	big deer vs lit deer, food	severinghaus,cw;/	1959
NYCOA	27--2	28	31	odvi	weather and the deer popul	severinghaus,cw	1972
NYCOA	27--5	41	41	odvi	winter deer feeding	kelsey,pm	1973
NYCOA	29--1	39	40	odvi	return of the deer	severinghaus,cw	1974
NYCOA	29--4	18	20	odvi	advances, science deer mgt	severinghaus,cw	1975
PCGFA	18---	57	62	odvi	importnce variety to s dee	lay,dw	1964
RWLBA	6---2	327	385	odvi	wint, spr obsrv, adirndcks	spiker,cj	1933

odvi continued on the next page

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
SJAFD	1....	10	13	odvi	use of clear cuts, sw virg	blymyer,mj; mosby	1977
TISAA	63--2	198	201	odvi	deer trap corr weath fctrs	hawkins,re; klims	1970
WLSBA	6---2	88	90	odvi	the fat cycle in deer	mautz,ww	1978
XFNCA	52---	51	59	odvi	eff sno conds vuln to pred	mech,ld; frenzel/	1971

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
CGFPA	21...	1	20	odhe	doca, wint rng use, 2 4 d,	anderson,ae	1969
CJZOA	48--2	275	282	odhe	feed intake, heat producti	nordon,hc; cowan/	1970
ECMOA	2----	1	46	odhe	seasonal migratn of mule d	russell,cp	1932
JRMGA	15---	278	281	odhe	rng mgt, habitat, hrd prod	julander,o	1962
JRMGA	25--1	66	68	odhe	fec grp cts rel to win rng	anderson,ae; med/	1972
JRMGA	30--2	122	127	odhe	eval habita on nutri basis	wallmo,oc; carpe/	1977
JRMGA	32--1	40	45	odhe	dosh, forg selec, wint rng	smith,ma; malech/	1979
JWMAA	6---3	210	220	odhe	survey winter range, oregn	edwards,ot	1942
JWMAA	9---2	145	151	odhe	winter study,nevada mule d	aldous,cm	1945
JWMAA	16--3	289	299	odhe	wint mort, rng conds, utah	robinette,wl; ju/	1952
JWMAA	22--3	275	283	odhe	food hab, rang use, montan	lovaas,al	1958
JWMAA	29--2	352	366	odhe	stom cont anal rela condtn	anderson,ae; sny/	1965
JWMAA	31--4	651	656	odhe	char herds, range n e utah	richens,vb	1967
JWMAA	34--1	15	23	odhe	effect of snow depth on de	gilbert,pf; wall/	1970
JWMAA	36--2	571	578	odhe	numbs, shrb yld util, wint	anderson,ae; med/	1972
JWMAA	39--3	605	616	odhe	doca, rng relns, prair hab	dusek,gl	1975
JWMAA	42--1	108	112	odhe	b-t d wint rnge, se alaska	bloom,am	1978
NAWTA	20---	568	588	odhe	factrs infl dee, ariz brsh	hanson,wr; mccull	1955
NAWTA	29---	415	431	odhe	wnt rng, deer, phys envirn	loveless,cm	1964
NAWTA	35...	35	47	odhe	eval win deer use orchards	harder,jd	1970
PMASA	19...	72	79	odhe	annu cycl of cond, montana	taber,rd; white,/	1959
WLMOA	20---	1	79	odhe	ceel, doca, rnge ecol, mon	mackie,rj	1970

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
EKPOA	17-22	381	389	ceel	repartitn of habita niches	dzieciolowski,r	1969
FUNAA	19...	31	37	ceel	red deer during winter	mehl,r	1966
JOMAA	49--4	762	764	ceel	physiologi stud, rocky mts	herin,ra	1968
JWMAA	43--2	564	567	ceel	met resp to cold, eff post	gates,cc; hudson,	1979
JZOOA	186--	544	550	ceel	sex difs in qual win areas	watson,a; staines	1978
NCANA	101-3	505	516	ceel	shiras moos, rng reltnshps	stevens,dr	1974
NZJSA	36...	429	463	ceel	eval cond free-rng dee, nz	riney,t	1955
PZESA	14---	34	39	ceel	ruru,sensitv to temp fluct	christie,ahc	1967

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
CAFNA	92--2	189	192	alal	late wint bedding practice	mcnicol,jg; gilbe	1978
CWRSB	15---	1	27	alal	odvi, behav, snow, new bru	kelsall,jp; presc	1972
JOMAA	50--2	302	310	alal	odvi, struct adaptat, snow	kelsall,jp	1969
JRMGA	16--5	227	231	alal	apprais moose range,montan	peek,jm	1963
JWMAA	24--1	52	60	alal	food comp, rng relns, hare	dodds,dg	1960
JWMAA	34--1	37	46	alal	wint ecol, gallat mts, mon	stevens,dr	1970
JWMAA	34--3	553	559	alal	odvi, winte habitat select	telfer,es	1970
JWMAA	39--4	653	662	alal	odvi,relnshp on burn, minn	irwin,ll	1975
JWMAA	40--4	645	657	alal	odvi, habita use, symp rng	kearney,sr; gilbe	1976
NCANA	101-1	67	80	alal	distrib, winter habit, que	brassard,jm; aud/	1974
NCANA	101-1	417	436	alal	influence of snow, behavio	coady,jw	1974
NCANA	101-3	481	492	alal	snow cond, moose, wolf rel	peterson,ro; alle	1974
QSFRA	3----	51	73	alal	influence of snow, behavio	desmeules,p	1964

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
ATICA	12...	158	179	rata	snow, factr in winter ecol	pruitt,wo,jr	1959
ATICA	30...	101	108	rata	feeding sites, snow, alask	laperriere,aj; le	1977
CAFNA	95---	363	365	rata	varrio snow index, ovrwntr	pruitt,wo,jr	1981

rata continued on the next page

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
CBPAB	40A-3	789	795	rata	thyrox sec, sex, age, seas	yousef,mk; luick,	1971
CBPAB	60A-2	123	126	rata	seas change growth hormone	ringberg,t; jaco/	1978
IJBMA	12--1	21	27	rata	wint activ, reltn sno, ice	henshaw,j	1968
RIJUA	30---	289	293	rata	intractins w/ habita, alas	klein,dr	1970
UABPA	1----	324	334	rata	carib and sno cond, se man	stardom,rrp	1975
UABPA	1----	414	419	rata	weath effct on behav, migr	gavin,a	1975
UABPA	18...	1	41	rata	behav, energtcs, cratering	thing,h	1977
XFWWA	43---	1	48	rata	st matthew isl reind range	klein,dr	1959

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
JWMAA	31--1	159	164	anam	mort, severre wint, n mont	martinka,cj	1967
JWMAA	41--3	560	571	anam	wint behav reln to habitat	bruns,eh	1977
JWMAA	42--4	755	763	anam	met indics hab con, stress	seal,us; hoskinso	1978
NAWTA	15---	627	644	anam	rng ecol, wichita mts refu	buechner,hk	1950
XARRA	148--	1	4	anam	starv, full stomachs, feed	pearson,ha	1969

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
NPSMD	1----	1	161	bibi	bison of yellowstn nat prk	meagher,mm	1973

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
CAFGA	52--2	68	84	ovca	winter obsvtns, sierra nev	mccullogh,dr; sch	1966
CAFNA	87--4	433	454	ovca	chilcotin river bigh popul	demarchi,da; mitc	1973
CWRSB	39---	1	50	ovca	rng ecol in canad natl pks	stelfox,jg	1976
JWMAA	35--2	257	269	ovca	winter ecology in yellowst	oldemyer,jl; bar/	1971

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

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
CJZOA	51--9	987	993	oram	ovca,eff sno cov,soc behav	petocz,rg	1973

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
AMZOA	16--4	699	710	many	fat, energy, mamml survivl	young,ra	1976
JWMAA	20--2	159	168	many	sno depth, ungu abund, can	edwards,ry	1956
JWMAA	43--2	437	444	many	hab partitioni, fire, mont	singer,fj	1979
NATUA	234--	482	484	many	water, energ turnover, des	macfarlane,wv; h/	1971
NCANA	103-3	153	167	many	resour div, commun lg herb	hudson,rj	1976
QSFRA	8----	79	96	many	eff hiemal env fctrs behav	pichette,c	1973

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
ZEJAA	3---2	69	79	caca	[mortlty 1955-56, roe dee]	braunschweig,a	1957
ZORVA	28...	97	197	caca	winter ecolg, north sweden	markgren,g	1966

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
CNJNA	43--1	39	46	dosh	low env temp, physi respon	hess,ea	1963
JRMGA	6---1	51	54	dosh	eff graz intens, nutr valu	cook,cw; stoddar/	1953
RVTSA	7....	466	479	dosh	thermal regul, two breeds	webster,ajf; blax	1966

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
JWMAA	24--1	92	94	ungu	asses phys cond, field tch	riney,t	1960
ZEJAA	9---4	121	124	ungu	[loss, wint 1962-63,grmny]	stubbe,c	1963

CODEN	VO-NU	BETA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
ANYAA	301..	110	127	----	influnc exrcise skin tempe	adams, wc	1977
BINPA	1----	1	176	----	snow covr,mamml, bird ecol	formozov,an	1946
BISNA	18-11	1041	1043	----	critical thermal environme	moen,an	1968
IJBMA	20--2	139	156	dome	signif meteorol, anim prod	bianca,w	1975

CHAPTER 17, WORKSHEET 2.4a

Animal characteristics during the winter season

Animal characteristics for each of the JDAY's from December 24 (JDAY 358) through March 19 (JDAY 78) at 7-day intervals may be completed by referring to the equations below.

CLWK: See CHAPTER 1, WORKSHEET 1.4b
MBLM: See CHAPTER 7, WORKSHEET 1.1a
ELMD: See CHAPTER 7, WORKSHEET 6.1a, 6.1b
DIDI: See CHAPTER 11, WORKSHEET 3.3a
DWFK: See CHAPTER 12, WORKSHEET 3.1a

Complete the calculations using equations given in other PARTs or for animals in your local area and tabulate the results below. Many other parameters could be included, of course; the format on the next page may be used to tabulate your selections.

JDAY	AGDA	CLWK	MBLM	ELMD	DIDI	DWFK
358	____	____	____	____	____	____
1	____	____	____	____	____	____
8	____	____	____	____	____	____
15	____	____	____	____	____	____
22	____	____	____	____	____	____
29	____	____	____	____	____	____
36	____	____	____	____	____	____
43	____	____	____	____	____	____
50	____	____	____	____	____	____
57	____	____	____	____	____	____
64	____	____	____	____	____	____
71	____	____	____	____	____	____
78	____	____	____	____	____	____

JDAY									
358									
1									
8									
15									
22									
29									
36									
43									
50									
57									
64									
71									
78									

JDAY									
358									
1									
8									
15									
22									
29									
36									
43									
50									
57									
64									
71									
78									

Chapter 17, Worksheet 2.4b

Heart rate increases in relation to snow depths

Heart rate increases in relation to snow depths may be estimated with the equation below for deer of any weight. Complete the calculations for your choices of weights and fill in the table below. Then apply the multiples to the heart rate-to-metabolism conversions discussed in CHAPTER 7, UNIT 5.2.

	SNDE										
LIWK	0	10	20	30	40	50	60	70	80	90	100

CLOSING COMMENTS

This CHAPTER 17 concludes discussions of an interesting area of study--thermal exchange--for me, the subject of my Ph.D. Thesis at the University of Minnesota in 1966. That subject was chosen because of my enjoyment of winter, and because my observations of white-tailed deer in winter in west-central Minnesota differed from those reported for deer in forested areas to the east. Some important syntheses remain to be done; completion of the "overall heat transfer coefficient" analyses in relation to thermal boundary region characteristics will result in understanding of heat transfer between animal and environment. Then, thermal energy balances will be recalculated for deer, and the concepts and patterns applied to other species.

Aaron N. Moen
January 24, 1982

GLOSSARY OF SYMBOLS - CHAPTER SEVENTEEN

ADTC = Average daily temperature in Celsius
AGDA = Age in days
AMNT = Average minimum temperature in Celsius
AMXT = Average maximum temperature in Celsius

BLM = Base-line metabolism

CLWK = Calculated live weight in kg

DIDI = Diet digestibility
DWFK = Dry weight forage in kg

ELMD = Ecological metabolism per day

FEWK = Fetal weight in kg

HEVA = Heat of vaporization

JDAY = Julian day

MBLM = Multiple of base-line metabolism
MHRM = Multiple of the heart rate per minute

PREC = Precipitation

QREE = Quantity of radiant energy emitted

RAIN = Rain

SNDE = Snow depth
SNOW = Snow
SORA = Solar radiation

TSAC = Total surface area in square centimeters
TSAM = Total surface area in square meters

WIVE = Wind velocity

Z_o = Roughness coefficient

GLOSSARY OF CODENS - CHAPTER SEVENTEEN

SERIALS are identified by five-character, generally mnemonic codes called CODEN, listed in 1980 BIOSIS, LIST OF SERIALS (BioSciences Information Service, 2100 Arch Street, Philadelphia, PA 19103).

The headings for the lists of SERIALS are:

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

The volume and issue numbers (VO-NU) are given after the CODEN entry, followed by beginning page (BEPA), ending page (ENPA), species discussed (ANIM), KEY WORDS from the title, AUTHORS [truncated if necessary, slash (/) indicates additional authors], and year.

AJAEA	Australian Journal of Agricultural Research (Australia)
AJPHA	American Journal of Physiology (US)
AMNAA	American Midland Naturalist (US)
AMZOA	American Zoologist (US)
ANYAA	Annals of the New York Academy of Sciences
ATICA	Arctic (Canada)
AZOFA	Annales Zoologici Fennici (Finland)
BINPA	Boreal Institute for Northern Studies, University of Alberta Occasional Publication
BISNA	Bioscience
BPURD	Biological Papers of the University of Alaska Special Report
CAFGA	California Fish and Game
CAFNA	Canadian Field Naturalist (Canada)
CBCPA	Comparative Biochemistry and Physiology
CBPAB	Comparative Biochemistry and Physiology A Comparative Physiology
CGFPA	Colorado Division of Game, Fish, and Parks Special Report
CJZOA	Canadian Journal of Zoology (Canada)
CNJNA	Canadian Journal of Animal Science (Canada)
CWRSB	Canadian Wildlife Service Report and Management Bulletin Series
DWINA	Defenders of Wildlife News
ECMOA	Ecological Monographs (US)
ECOLA	Ecology
EKPOA	Ekologia Polska Seria A
FUNAA	Fauna (Oslo)
FUOFA	Fauna och Flora (Stockholm)

IJBMA	International Journal of Biometeorology
ISJRA	Iowa State Journal of Research
JANSA	Journal of Animal Science (US)
JAPEA	Journal of Applied Ecology (England)
JFUSA	Journal of Forestry (US)
JMNAA	Journal of the Minnesota Academy of Science
JOMAA	Journal of Mammalogy (US)
JRMGA	Journal of Range Management (US)
JSAVA	Journal of the South African Veterinary Medical Association
JSWCA	Journal of Soil and Water Conservation
JWMAA	Journal of Wildlife Management (US)
JZOOA	Journal of Zoology (London)
MFNOA	Minnesota Forestry Notes
MGQPA	Minnesota Department of Natural Resources Game Research Project Quarterly Progress Report
MOCOA	Missouri Conservationist
NATUA	Nature (England)
NAWTA	North American Wildlife and Natural Resources Conference, Transactions of the
NCANA	Naturaliste Canadien, Le
NEXAA	New Mexico Agricultural Experiment Station Bulletin (US)
NFGJA	New York Fish and Game Journal (US)
NJZOA	Norwegian Journal of Zoology (Norway)
NPSMD	United States National Park Service Scientific Monograph Series
NYCOA	New York State Conservationist
NZJSA	New Zealand Journal of Science
OIKSA	Oikos (Denmark)
PASCC	Proceedings of the Alaskan Scientific Conference (US)
PCGFA	Proceedings of the Southeastern Association of Game and Fish Commissioners (US)
PMACA	Papers of the Michigan Academy of Sciences, Arts and Letters
PMASA	Proceedings of the Montana Academy of Sciences
PSAFA	Proceedings of the Society of American Foresters (US)
PZESA	Proceedings of the New Zealand Ecological Society
QSFRA	Quebec Service de la Faune Rapport (Quebec Wildlife Service Report)
RIJUA	Riistatieteellisia Julkaisuja
RVTSA	Research in Veterinary Science
RWLBA	Roosevelt Wild Life Bulletin
SCNAB	Schweizer Naturschutz Protection de la Nature
SJAFD	Southern Journal of Applied Forestry
SJECA	Soviet Journal of Ecology (English translation of Ekologiya)
SZSLA	Symposia of the Zoological Society of London (England)

TISAA	Transactions of the Illinois State Academy of Science (US)
TJSCA	Texas Journal of Science
TPCWD	Colorado Division of Wildlife Technical Publication
TWASA	Transactions Wisconsin Academy of Sciences, Arts, and Letters
UABPA	Biological Papers of the University of Alaska
UTSCB	Utah Science (US)
VILTA	Viltrevy (Sweden)
WCDBA	Wisconsin Conservation Department Technical Bulletin
WLMOA	Wildlife Monographs (US)
WLSBA	Wildlife Society Bulletin
WSCBA	Wisconsin Conservation Bulletin
XAGCA	U S D A Circular
XARRA	U S Forest Service Research Note RM (US)
XFIPA	U S Forest Service Research Paper INT (US)
XFNCA	U S Forest Service Research Paper NC (US)
XFPNA	U S Forest Service Research Paper PNW (US)
XFWRA	U S Fish and Wildlife Service Research Report
XFWWA	U S Fish and Wildlife Service Special Scientific Report - Wildlife
ZEJAA	Zeitschrift fuer Jagdwissenschaft
ZORVA	Zoologisk Revy (Sweden)

LIST OF PUBLISHERS - CHAPTER SEVENTEEN

The headings for the lists of BOOKS are:

TYPE PUBL CITY PAGE ANIM KEY WORDS----------------- AUTHORS/EDITORS-- YEAR

All essential information for finding each book in the library is given on just one line. The TYPE of book could have either AUTHORS (aubo) or EDITORS (edbo). Publishers (PUBL) and CITY of publication are given with four-letter mnemonic symbols defined below. The PAGE column gives the number of pages in the book; ANIM refers to the species discussed in the book (given as a four-letter abbreviation of genus and species), and KEY WORDS listed are from the title. The AUTHORS/EDITORS and YEAR of publication are given in the last two columns.

acpr	Academic Press	New York, NY	nyny
blsp	Blackwell Scientific Publications	Oxford, England	oxen
lefe	Lea and Febiger	Philadelphia, PA	phpa
oxup	Oxford University Press	London, England	loen
spve	Springer-Verlaug Inc.	New York, NY	nyny
uppr	University Park Press	Baltimore, MD	bama
usup	Utah State University Press	Logon, UT	lout
whfr	W. H. Freeman Company	San Francisco, CA	sfca

GLOSSARY OF ANIMAL CODE NAMES

Wild ruminants are referred to in this CHAPTER by a 4-character abbreviation from the family, genus and genus-species. These are listed below under Abbreviation.

Scientific names of North American wild ruminants are those used in BIG GAME OF NORTH AMERICA, edited by J.C. Schmidt and D. L. Gilbert (1979: Stackpole Books, Harrisburg, PA 17105, 494 p.), and may be different from the scientific names given in the original literature.

The abbreviations used for North American wild ruminants are listed below.

CLASS: MAMMALIA

ORDER: ARTIODACTYLA	Abbreviation
FAMILY: CERVIDAE	cerv
GENUS: *Odocoileus* (deer)	od--
SPECIES: *O. virginianus* (white-tailed deer)	odvi
O. hemionus (mule deer)	odhe
GENUS: *Cervus* (Wapiti, elk)	ce--
SPECIES: *C. elaphus*	ceel
GENUS: *Alces* (moose)	
SPECIES: *A. alces*	alal
GENUS: *Rangifer* (caribou)	
SPECIES: *R. tarandus*	rata
FAMILY: ANTILOCAPRIDAE	
GENUS: *Antilocapra*	
SPECIES: *A. americana* (pronghorn)	anam
FAMILY: BOVIDAE	bovi
GENUS: *Bison* (bison)	bi--
SPECIES: *B. bison*	bibi
GENUS: *Ovis* (sheep)	ov--
SPECIES: *O. canadensis* (bighorn sheep)	ovca
O. dalli (Dall's sheep)	ovda
GENUS: *Ovibos*	
SPECIES: *O. moschatus* (muskox)	obmo
GENUS: *Oreamnos*	
SPECIES: *O. americanus* (mountain goat)	oram

The abbreviations used for European wild ruminants are listed below.

CLASS: MAMMALIA

ORDER: ARTIODACTYLA	Abbreviation
FAMILY: CERVIDAE	cerv
GENUS: *Capreolus* (roe deer)	ca--
SPECIES: *C. capreolus*	caca
GENUS: *Dama* (fallow deer)	da--
SPECIES: *D. dama*	dada
GENUS: *Cervus* (Wapiti, elk)	ce--
SPECIES: *C. elaphus* (red deer)	ceel
GENUS: *Alces* (moose)	
SPECIES: *A. alces*	alal
GENUS: *Rangifer* (caribou)	
SPECIES: *R. tarandus*	rata
FAMILY: BOVIDAE	
GENUS: *Bison* (bison)	
SPECIES: *B. bonasus*	bibo
GENUS: *Capra* (ibex, wild goat)	cp--
SPECIES: *C. aegagrus* (Persian ibex)	cpae
C. siberica (Siberian ibex)	cpsi

OTHERS

Abbreviations for a few other species and groups of species may appear in the reference lists. These are listed below.

Axis axis (axis deer)	axax
Elaphurus davidianus (Pere David's deer)	elda
Cervus nippon (Sika deer)	ceni
Hydropotes inermis (Chinese water deer)	hyin
Muntiacus muntjac (Indian muntjac)	mumu
Moschus moschiferus (musk deer)	momo
Ovis nivicola (snow sheep)	ovni
Ovis musimon (moufflon)	ovmu
Ovis linnaeus (Iranian sheep)	ovli
Rupicapra rupicapra (chamois)	ruru
big game	biga
domestic sheep	dosh
domestic cattle	doca
domestic goat	dogo
domestic ruminant	doru
herbivore	hrbv
mammals	mamm
three or more species of wild ruminants	many
ruminants	rumi
ungulates	ungu
vertebrates	vert
wildlife	wldl
wild ruminant	wiru

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.

LIST OF WORKSHEETS - CHAPTER SEVENTEEN