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Interim Progress Report

"Prediction of Grazingland Productivity
Under Climatic Variations"

A Report to the
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"Prediction of Grazingland Productivity Under Climatic Variations"

by

Dennis F. Pendleton, George M. Van Dyne, and Marilyn T. Whitehouse
Department of Range Science
Colorado State University
Fort Collins, Colorado 80523

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Abstract

The ultimate goal of this study is to provide for decision-makers at national and international levels (1) scientifically-defensible information on the contribution of grazinglands to food production and (2) a means for determining the variability of yield due to climatic fluctuations. Specific tasks toward the accomplishment of this goal have been defined for each projected year of the study. Major tasks for the first year and references to descriptions of their accomplishment in this interim report are shown below.

(1) Secure readily available data through literature search and correspondence; develop format for recording and synthesizing the data.

An extensive literature search has been undertaken. A tabular summary of data collected and the index system for organization of literature sources are described in the Data Compilation section. Provisions for obtaining information through written correspondence are described in the Information Network section.

(2) Develop trip report on organizational contacts and procedures.

Contacts established and information gained on foreign and domestic trips are described in the Information Network section.

(3) Review and summarize features of grazingland models and modelling approaches; present papers on modelling state-of-the-art and animal production modelling.

Extant resarch is being reviewed in each of the modelling efforts described in the Models section. References to papers presented are contained in the Information Network section under Personal Contacts - Travel. Abstracts for the papers are included in Appendix E.

(4) Develop empirical statistical predictive equations for the relationship between plant yield and antecedent climatic factors.

Three different phases of work of this type are described in the Models section.

(5) Develop communication network with agencies, governments, foundations, and individual scientists. Seek additional funding to supplement core support.

Personal contacts established during foreign and domestic travel, efforts to obtain supplemental funds, and extensive written correspondence are described in the Information Network section.

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Introduction

This report briefly summarizes the progress to date on the project Prediction of Grazingland Productivity Under Climatic Variations (NSF Grant DAR78-17243). Several specific tasks, described below, have been undertaken to accomplish an overall goal of the project: to collect and analyze information on the area and average plant and animal productivity of the grazinglands of the world. Variability in yield of these areas will be studied with particular emphasis on fluctuations due to climatic influences. The focus of this report is on the initial organizational efforts in the project.

Project Strategy

The project is organized such that specific tasks can be accomplished early using readily available information, then updated and refined as more reliable or detailed information is obtained. For example, the analysis of land-use and livestock data, on a national basis, extracted primarily from the FAO Production Yearbooks, is considered a "first-pass" analysis (low-resolution). The information generated in this initial analysis can be revised and refined with data collected on a regional basis. Such information now is being received from national governments throughout the world (medium resolution). Finally, detailed adjustments of data concerning use of grazinglands, vegetation production, and livestock numbers and production can be made based on studies by scientific investigators and reports of international organizations (high resolution).

Several specific tasks are required to accomplish the multiple objectives of this project. The tasks, which are being pursued concurrently, include:

1. Review of scientific and technical literature of primary and secondary productivity and of the influence of climate on productivity in grazingland regions.
2. Analysis of data on grazingland acreage, livestock numbers, and animal production systems.
3. Review, analysis, and development of various approaches to modelling primary productivity under climatic fluctuations with particular emphasis on broad-scale predictions.
4. Information solicitation from:
   a. national ministries of statistics and agriculture.
   b. specific scientific investigators.
   c. national and international organizations involved with agricultural and natural resource concerns.
   d. potential organizational sources of supplemental funds for the project.
5. Mapping of grazingland regions from extant soils, vegetation, and climatic maps, base maps: FAO/UNESCO Soil Map of the World.

Project Development

A broad overview of tasks undertaken in the development of the project and personnel involved is provided here. More detailed information is included in the remaining sections of the report.

Several foreign and domestic trips were made during the early months of the project by George M. Van Dyne, principal investigator. Initial and continuing contacts with scientists in grazingland regions were made on the trips; also, sources of grazingland information and possible supplemental funding were sought during the travel which is described more fully below.

Another trip abroad was made by Dennis F. Pendleton, research associate, who joined the project in January, 1979. He has formal background in economics, range science, land-use planning, and ecological modelling, and was on the faculty of the Natural Resources Management Department at California Polytechnic State University before joining the project. Specific contacts made and information gained on the trip to the SAMDENE Workshop in Egypt (Systems Analysis of Mediterranean Desert Ecosystems of Northern Egypt--travel financed by the Ford Foundation); FAO Headquarters, Rome; and UNESCO Headquarters, Paris, are discussed below. Since returning to Colorado in late January, Pendleton has been involved with continuing project organization, development of a global information network, analysis of FAO production and land-use data, collection of base maps and relevant information for the mapping phase of the project, and review of grazingland literature.

Marilyn Whitehouse, 3/4-time research associate, has worked exclusively on this project since February, 1979. She has background in geography and was working for an environmental consulting firm prior to joining the project. She is also a 1/4-time graduate student. She has made a thorough review of extant soils, vegetation and climatic maps to locate those of relevance to the project. She has also worked on compilation of data in FAO Production Yearbooks and review of literature on grazingland productivity.

The Ph.D. dissertation of Linda A. Joyce at Colorado State University involves modelling the relationship of plant yield to precipitation in grazinglands. Her work is nearing completion and will be of great value in the modelling phase of this project.

Several other ongoing research efforts may provide valuable information for this project. A study is being made of unpublished data of Warren C. Whitman of North Dakota State University, from U.S. Soil Conservation Service range site records for North Dakota, and from various other state and federal sources. Such data, in combination with climatic records, should prove useful in the development of models to describe the effect of climatic influences on grazingland productivity. This work is being supported on a contract from the North Dakota Public Service Commission. These analyses are, in effect, a test case to see what can be done with data from a western USA rangeland state.

Data sets from several western rangeland studies have been sent to Karin Wisiol, Ph.D. candidate at the University of Illinois, Chicago Circle. Ms. Wisiol, who is working under NSF support, has been using these data in evaluating several extant statistical models for predicting plant productivity. Her completed work will be another source of information for the modelling activities of this project.

A complete set of the recently-completed FAO/UNESCO World Soils Maps (scale 1:5,000,000) has been obtained. This map series is the only uniform, reliable depiction of soils on a global scale and will provide a basis for the mapping work described below.

A Lanier word processing unit, leased for the project, will greatly facilitate the manipulation of large amounts of data and text. Denese Gekas, secretary for the project, has become proficient on the equipment since its acquisition. Newly remodelled office space is being provided to the project. This allows bringing project staff together into one building and also provides adequate space for the word processing system and a recently acquired computer terminal. These factors should greatly facilitate progress in the year to come.

Data Compilation

An extensive review of the literature of grazingland productivity has been undertaken. Of particular interest are data on primary production, typical stocking rates for livestock, livestock production, and climatic variability for specific grazingland sites throughout the world. Such information will allow a general description of differences among world grazingland regions and will provide a basis for the modelling activities of the project. To facilitate comparisons of grazingland regions, the information from the review is being compiled in a tabular summary. A one-page example of this summary is shown in Table 1. The table is expected to be between 40 and 50 pages long and will contain summary productivity data from all the principal grazinglands of the world. Literature sources for this table and for other information relevant to the project, e.g., models of climate and productivity, are being organized systematically for ready reference. The citations can be retrieved through use of a KWIC (key word in context) index or a geographic index, according to continent, country, and sub-national region of the cited work.

There is an extensive literature of Soviet grazinglands, but access to this information is limited. A contract is being made with Dr. Gina Douglas for a review of Soviet literature. Dr. Douglas was formerly Executive Secretary for the Central Office of the International Biological Program in London. She will rely principally on the repository of Soviet literature in the Research Institute Library at Hurley, England, for the review. The information will be organized in the same format as that used in Table 1. Specifications for this review of Soviet literature are included as Appendix A.

Some information on grazingland productivity throughout the world has not been published and can be obtained only through personal contacts with scientific investigators. Efforts to obtain unpublished grazingland data are discussed below in the Information Network section.

Table 1. Example of summary table of productivity information from search of grazingland literature.

Biotic Province	Location	Vegetation Type	Treatment/ Season	Plant Production (ANP; $kg \cdot ha^{-1}$)	Stocking Rate ($ha \cdot AUM^{-1}$)	Animal Production	Climatic Information	Source	Notes
Indus-Gujerat	India; Jodhpur, Rajastan	Grassland	Untreated; 6 estimates	990			60-year mean annual precip.: 36.1cm	Gupta et al. 1972	
Grasslands	U.S.A.; Great Plains	Sandhill prairie						Frolic and Shepard, 1940	
		Wet meadow			0.2				
		Sand dunes			0.9				
		Dry valleys			0.8				
		Dry meadows			0.3				
Great Basin	U.S.A.; eastern Washinton, eastern Oregon	Ponderosa pine			2.8			Reid, 1964	
Rocky Mountains	U.S.A.; Arizona	Subalpine-spruce-fir							
		Dry meadows			0.4-1.2			Reynolds, 1962	
		Dense forests			8.1+			Reynolds, 1962	
Great Basin	U.S.A.; Central Idaho	Agropyron-Melica grassland	Untreated; 5 sites; 1962	872-1471 mean: 1020				Muoggler and Harris, 1969	Herbage weight: air-dry.
		Festuca-Agropyron-Antennaria grassland	Untreated; 6 sites; 1962	726-1325 mean: 1047					
		Agropyron spicatum grassland	Untreated; 7 sites; 1962	592-2150 mean: 1115					
Great Basin	U.S.A.; Hanford Reservation, Benton Co., Washington	Bromus tectorum grassland	Untreated; 3 sites; 1969-1971	1270-3280 mean: 2420				Cline and Richard, 1973	
Sierra Cascade	U.S.A.; Sierra Mountains, Central California	Mountain meadow	Untreated; protected from grazing previous year; 5 sites; 1963.	937-1612	0.5-0.9			Sanderson, 1967	Estimated carrying capacity based on 40% herbage use. Herbage weight: air-dry
Eastern grasslands	Australia; Falkiner Memorial Field Station (near Denliiquin), New South Wales	Danthonia caespitosa grassland	Untreated; grazed prior to colection periods (1 $ha \cdot sheep^{-1}$) 1964-65	1035			1964-65 annual precip.: 33.1 cm 107-year mean: 40.3 cm	Robards et al., 1967	Monthly rainfall and evaporation data also included.
Great Basin	U.S.A.; northern Utah	Agropyron spicatum grassland	Untreated; collections made last 2 weeks of June 1968; 12 sites	871-2388 mean: 1529			Mean annual precip.: 43-53 cm	Harner and Harper, 1973	Average composition of production (by weight): grass: 55% forbs: 34% shrubs: 1%
Baltic lowlands	Sweden; Linnebjer (7 km ENE of Lund)	Mixed deciduous woodland (oak dominant)	Untreated; 1966 sampling	Total production: 13300				Anderson, 1970	Total belowground production of mixed deciduous woodland: 2300
				Non-woody understody: 770					
		Moist meadow (Filipendula ulmaria)		7200 (estimate)					
Northern tropical savanna	Australia; Katherine, Northern Territory	Tropical tall grass native pasture	Undisturbed; timbered area; 1952-1953	1336			1952-53 annual precip.: 71.4 cm mean precip.: 1911-40: 90.0 cm	Arndt and Norman, 1959	Monthly rainfall data for 1948-59 & data on plant response to grazing & burning included in paper
			Trees cleared 2 years prior to sampling, 1952-53	1515					

Global Trends in Livestock Numbers and Land Use -- A Preliminary Summary

As human population increased over the years since 1950, there have been corresponding dramatic increases in livestock numbers. During the same period, the size of the most productive areas used for grazinglands has remained relatively constant or even decreased in some parts of the world. Overgrazing is a significant problem in many of the world's grazinglands and is a principal cause of desertification, or destruction of the productive potential of land. World attention was focused on this phenomenon in the Sahelian region of Africa after a drought during the period 1968 to 1973 caused massive losses of livestock and the deaths of thousands of Africans. Livestock numbers had doubled in some parts of the Sahel from 1956 until the time of the drought.

Abuse of grazinglands and resultant desertification in some arid and semi-arid areas are not limited to Africa but are occurring throughout the world. In the USA, for example, the Bureau of Land Management reported in 1975 that more than 54,000,000 hectares of federal rangelands alone were in less than satisfactory condition (United States Department of the Interior, 1975). It has been estimated that, at present rates of land abuse and desertification, one-third of the agricultural lands of the world will have been rendered non-productive within the next 25 years (Van Dersal, 1979).

FAO Production Yearbook statistics on livestock numbers and land use have been compiled for each country in the world reporting such information. The data were recorded at 3-year intervals since 1950, the first year of the Yearbook. Some FAO reporting procedures have changed over the years. The format of data and the method of reporting are not always consistent among the countries included in the Production Yearbooks. This compilation of data is, therefore, considered a "low-resolution," general depiction of trends in grazingland use and livestock numbers throughout the world. This summary information will be improved with regional data currently being received from national governments. Nevertheless, pronounced trends in livestock numbers and grazingland areas can be discerned which doubtless exist irrespective of minor inconsistencies in data reporting.

Data compiled from FAO Production Yearbooks have been summarized for continental units to illustrate general trends during the period 1950 to 1977. North and Central America are combined and Oceania (including Australia and New Zealand) and the USSR are described separately. Total livestock units (FAO standard animal unit) are shown in Table 2. The following are the FAO standard units for livestock:

horses	1.0	buffalo	1.0
mules	1.0	camels	1.1
asses	0.8	sheep	0.1
cattle	0.8	goats	0.1

Total livestock numbers increased in each of the continental areas during the period 1950 to 1977, with the greatest increase (69%) in Oceania and the smallest increase (11%) in Europe. The relatively small increase in Europe was not representative of all the countries in that continental area. There

Table 2. Total Livestock Numbers (FAO Standard Units) for Continental Areas, 1950 to 1977.

	Total Animal Units (1000 head)										
Continental Area	1950	1953	1956	1959	1962	1965	1968	1971	1974	1977	Percent Change 1950 to 1977
Africa	114520	122460	129890	135140	139030	155884	165436	180758	170994	184983	+62
North and Central America	115714	124793	132844	134444	140414	158941	165342	163057	177319	177741	+54
South America	148440	155770	160560	163670	171010	183358	195050	205192	207956	208306	+40
Asia	336950	370490	385743	404195	432996	465246	472296	489775	495767	503299	+49
Europe	116070	120760	120740	122910	126260	122341	125838	122557	129760	129325	+11
Oceania	31624	34011	37041	38761	41371	43925	45664	51230	53391	53447	+69
USSR	66716	70992	71674	82091	89511	91919	101484	102216	107808	109823	+65
World Total	930033	999276	1038492	1081211	1140592	1221500	1271110	1314785	1343034	1366923	+47

was a good deal of variation in livestock numbers among European countries from 1950 to 1977. Livestock numbers in the Netherlands, for example, increased by 65% while numbers of animals decreased in Italy by 12%. Worldwide, the trend was clear, livestock numbers increased by nearly 50% during the period. During the same years, there were dramatic increases in human populations in some parts of the world with a global increase of 70% (Table 3).

While the human population and livestock numbers were increasing significantly, the area used for permanent meadows and pastures, important grazinglands, decreased in some regions of the world during the period 1965 to 1976, and remained relatively constant on a worldwide basis (Table 4). Changes in reporting procedures for FAO land-use data prevent meaningful comparisons of figures for the years prior to 1965. Large increases in livestock numbers without corresponding increases in pasture suggest that some areas may be being used more intensively or perhaps that larger proportions of other categories of land are being used for grazing livestock or that some regions have increased feeding of livestock during this period or, probably, all three.

Permanent meadows and pastures are, of course, not the only classes of land used by domestic herbivores. In many regions, significant amounts of three other land-use categories included in FAO statistics are used by grazing animals: arable land (used for temporary crops and grazing); forests and woodlands (many such areas contain a grazable understory and open parks among the dominant tree cover); and the "other" land category. Some areas considered "wasteland" and incuded in this latter category may be profitably used for low-intensity grazing. Because various proportions of these three categories of land use are used for grazing in different countries, it isn't possible to fully describe trends in grazingland use with FAO data alone. Such a description of trends in the extent of areas used for grazing worldwide is an objective of this study and will be accomplished with supplemental regional data currently being obtained from national ministries and with other published sources of land-use information. Nevertheless, general trends are apparent from the summaries of FAO information. Livestock numbers are increasing dramatically in many regions of the world and permanent pastures, a major category of grazing-lands, are not increasing in size and are decreasing in some parts of the world.

Some of the largest increases in livestock during the period 1950 to 1977 occurred in numbers of cattle. Worldwide, cattle comprise the largest percentage of total animal units (grazing livestock), 70%. Trends in numbers of cattle for the continental areas from 1950 to 1977 are shown in Table 5. In addition to numbers of animals and their grazing intensity per unit area, meat production and "turnoff rate" (the proportion of animals harvested each year) are also of interest. Cattle production figures and related data for continental areas are shown in Table 6. The differences in average carcass weights between 1953 and 1977 are likely due less to changes in the quality of the animals slaughtered than to differences in the relative proportions of calves and mature cows slaughtered. Slaughter figures for mature animals and calves are combined in FAO data. Although the ratio of slaughtered animals to total animal numbers increased from 1953 to 1977 for both Asia and Africa, this ratio remains quite small for both

Table 3. Human population for continental areas, 1970 and 1977 (thousands).

Continental Area	1950	1977	Percent Change 1950 to 1977
Africa	197,866	419,801	+112
North and Central America	216,361	351,401	62
South America	110,372	226,555	105
Asia	1,272,865	2,348,620	85
Europe	394,285	476,689	21
Oceania	12,966	21,540	66
USSR	203,000	258,700	27
World	2,407,715	4,103,306	70

Table 4. Permanent meadows and pastures for continental areas, 1965 to 1976 (1000 ha).

Continental Area	1965	1968	1971	1974	1976	Percent Change 1965 to 1976
Africa	802,136	797,581	794,512	793,333	800,437	-0.2
North and Central America	362,992	359,013	341,053	325,975	346,735	-4
South America	414,624	424,627	434,641	445,235	441,834	+7
Asia	543,691	546,217	546,974	549,768	538,310	-1
Europe	88,539	89,075	88,415	87,281	87,606	-1
Oceania	462,120	459,507	468,059	467,694	469,761	+2
USSR	372,800	373,700	374,700	375,100	373,400	+0.2
World	3,046,902	3,049,720	3,048,354	3,044,386	3,058,083	+0.4

Table 5. Cattle numbers for continental areas, 1950 to 1977.

Continental Area	Cattle (1000 head) 1950	1953	1956	1959	1962	1965	1968	1971	1974	1977	Percent Change 1950 to 1977
Africa	91600	99000	106100	112700	115500	134057	143084	158424	146859	161609	+76
North and Central America	114700	130300	138400	139700	148700	169640	174582	171990	187626	186280	+62
South America	136700	144500	152000	155000	164000	176920	190531	203289	207686	220496	+61
Asia	245313	271800	280600	289400	314163	338926	341953	352079	353447	358379	+46
Europe	99600	105800	107800	111200	119400	118055	124246	122617	134016	134126	+35
Oceania	19700	21200	22600	22500	25000	26011	27857	33674	40844	41625	+111
USSR	55780	56624	58793	70842	82077	87171	99167	99142	106266	110346	+98
World Total	763393	829224	866293	901342	968804	1050780	1099420	1141215	1176744	1212861	+59

Table 6. Cattle Numbers and Production for Continental Areas, 1953 and 1977.

Continental Area	Cattle and Calves Slaughtered (1000 head)[1]	Average Carcass Weight (kg animal^{-1})	Beef and Veal Production (1000 MT)[1]	Total Animal Numbers (1000 head)[2]	Ratio of Slaughtered Animals to Total
Africa					
1953	2,337	149	1,660	99,000	.02
1977	18,131	137	2,493	161,509	.11
North and Central America					
1953	40,994	169	7,470	130,300	.31
1977	60,354	235	14,159	186,256	.32
South America					
1953	15,092	197	3,920	144,500	.10
1977	35,957	193	6,932	220,435	.16
Asia					
1953	5,310	143	1,920	271,800	.02
1977	25,037	140	3,500	358,527	.07
Europe					
1953	29,835	135	5,020	105,800	.28
1977	46,835	213	9,993	133,942	.35
Oceania					
1953	6,349	149	910	21,200	.30
1977	15,150	162	2,462	41,582	.36
USSR					
1953	–[3]	–	–	56,624	–
1977	38,684	173	6,700	110,523	.35

[1]1953 figures are based on indigenous animals slaughtered plus live animals exported, less imported animals. 1977 figures are based on total animals slaughtered regardless of country of origin.
[2]Including net export loss or import gain for 1977 figures.
[3]Data not available.

continents. In some regions of Africa, livestock are symbols of status and are kept as such as long as possible. Religious tenets prohibit the slaughter of cattle and other livestock in some parts of Asia, including much of India. Yet these animals are included in total livestock numbers for the continents.

A complete description of animal production trends in the grazinglands of the world is one objective of this study. As with other information derived from FAO Yearbooks, animal production figures in Table 6 are regarded as a low-resolution, general summary of trends in production. There are differences in reporting procedures among countries and there have been changes in methods of summarizing animal production data over the years. Nevertheless, the data presented in Table 6 are a reasonably accurate summary of production on a worldwide scale and they illustrate some obvious general trends. Cattle and calves slaughtered and total meat produced increased significantly for all of the continental areas of the world from 1953 to 1977. The greatest relative increases were in Africa and Asia. The ratio of slaughtered animals to total cattle numbers also increased in every continental area, though the relative increases were small in North and Central America, Europe, and Oceania.

Models--Review, Analysis, and Development

Several modelling activities are underway. Primary attention is being given to the development of empirical, predictive, statistical models. Secondly, we are working on simplified empirical flow-function models by making a detailed analysis of the output of extant simulation models. There are also segments of other ongoing projects which are of interest to us in extending our grassland modelling capability. These studies will be briefly summarized.

Statistical Predictive Models

Three different phases of work of this type are being supported in part from the present study.

Linda Joyce is completing her Ph.D. dissertation developing statistical models to predict grazingland productivity from climatic data. She is working with a wide variety of data sets from shrub-steppe, salt desert shrub, and grassland ecosystems. She is analyzing changes in both cover and production of vegetation in relation to current and antecedent climatic conditions.

We are also cooperating with Karin Wisiol at the University of Illinois, Chicago Circle, who is under NSF support to do similar work on statistical predictive equations. We have exchanged data sets with Ms. Wisiol, have met with her several times, and had good interaction in general. Ms. Wisiol is using an approach of testing extant statistical models against different data sets rather than developing new models.

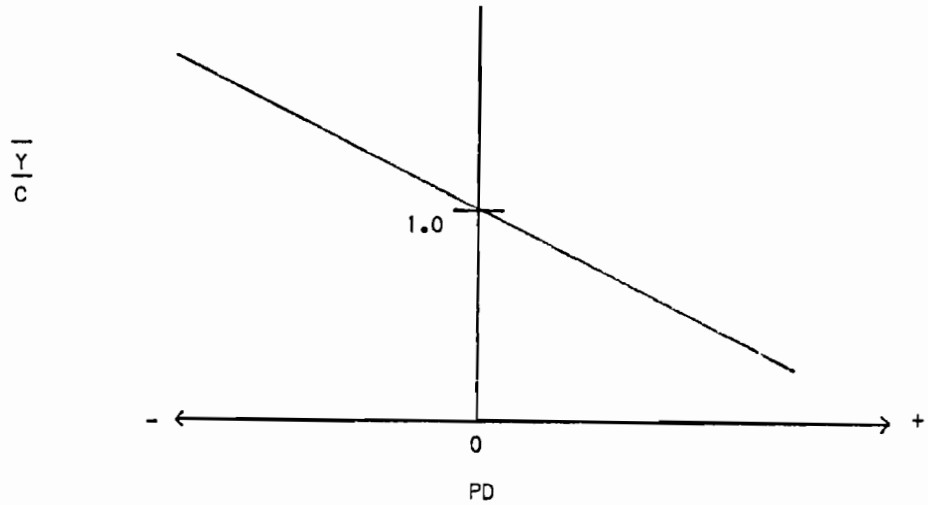
Another regression-analysis approach has been undertaken to analyze the North Dakota data referred to in an earlier section. Here we are utilizing

a simplified statistical model. In general, we can expect the yield of grazingland vegetation to be positively correlated with precipitation. In many instances we will want to correct the yield measured in a given year back to the yield obtained on a given site over the long period and based upon long-term average precipitation. This presumes we can acquire long-term yield data based on long-term precipitation. Such a correction is particularly important when a mean yield is measured in a given year and is compared with that of a "standard" based on a long-term mean. It would also be important in the case of off-site areas compared to on-site areas where different climatic events might have taken place even though it was the same year. We can calculate a relative yield and a deviation from long-term precipitation and show their relationship as follows:

$$\text{Relative Yield} = 1.0 + b\,[\text{Precipitation Deviation}]$$

$$\text{Relative yield} = \frac{\text{Yield in given year for location}}{\text{Long-term average yield for location}} = \frac{\bar{Y}}{\bar{C}}$$

$$\text{Precipitation deviation} = \left[\left(\text{Long-term average precipitation}\right) - \left(\text{Given-year precipitation}\right)\right] = PD$$



Here the yield data have been transformed into relative values; and the precipitation data have been transformed into deviation values. We can use this type of equation to compare data from many different sites. We have transformed the data to fit a function where the yield correction factor has a value of 1 when the current-year precipitation is equal to the long-term average precipitation. Field data can be used in a least squares procedure to estimate b. The correction factor will be greater than 1 when the given-year precipitation is greater than the long-term average precipitation. The correction factor will be less than 1 when the given-year precipitation is less than the long-term average precipitation.

Consider the following example where yield was measured in a given year on a specific site for which the long-term average precipitation was 45 cm. The given-year precipitation and yield were 55 cm and 5000 kg ha^{-1}. The conversion equation for the specific site is noted also:

Example

$$CF = 1.0 - 0.02\ (PD)$$

Measured-year yield	5000 kg ha^{-1}
Measured-year precipitation	55 cm
Long-term precipitation	45 cm

$$CF = 1.0 - 0.02\ (-10) = 1.2$$

$$\text{Adjusted yield} = 5000 \div 1.2 = 4167$$

The measured yield of 5000 kg ha^{-1} is considerably higher than the adjusted yield of 4167 kg ha^{-1} and this difference is because the measured-year precipitation was considerably higher than the long-term precipitation for the site.

Perhaps the standard yield for the above site was considered to be 3500 kg ha^{-1}. Then the question can be asked, is the measured-year yield adjusted for the precipitation difference and resulting in 4167 kg ha^{-1} significantly greater than the standard yield of 3500 kg ha^{-1}? We need to determine the standard deviation of the adjusted yield. The standard deviation of the adjusted yield should reflect the variability in the two items used to obtain it, i.e., the correction factor and the measured mean yield. We can assume that the variance in the correction factor is independent of the variance in the measured mean yield. The variance of the correction factor is due to the year-to-year variability used in developing the regression correction equation. The variance in the measured mean yield is due to plot-to-plot variability in the field. The adjusted yield is a product then of two random variables. The variances of the product of random variables can be calculated from the means and variances of the two independent random variables as follows:

Let X be one random variable and Y be the other.

$$\text{Then variance of } [X \cdot Y] = X^2 \cdot VAR[X] + Y^2 \cdot VAR[Y] + VAR[X] \cdot VAR[Y]$$

Note that X and Y are most likely estimates of true means and VAR[X] and VAR[Y] are most likely estimates of the true variances of the populations under consideration. The variance of the product is likely to be considerably higher than the variance of either factor entering the product.

Simplified Models of Flow Functions

A large number of simulation model runs were made with a 1977 version of a ecosystem level grassland simulation model. Output of this model was reported by Van Dyne et al. 1977. About 100 simulation runs were made with this large-scale, complex, total-system, multiple-flow model. Although valuable insights were gained into the production and utilization of a grazingland, the model is too complex and too data-dependent to be used widely. However, a great deal of work was spent in structuring the flow functions in the model. Thus we wished to determine if there are simpler ways to capture that information in simplified empirical flow functions. The output of about 100 simulation runs at 2-day time steps was kept on magnetic tape. These simulation runs had different climatic conditions, different initial conditions, and different treatments. The output recorded for each run contained 467 items of interest including driving variables, state variables, intermediate variables, output variables, and flows. More than 12,000 individual time-step values are available. These 12,000+ values were sampled at random to obtain a data set of 1000. An analysis was made of important individual flows within the 1000 values. It is assumed here that the 1000 values represent a sample of "real life" which is depicted by the overall simulation model. Each flow was calculated in a mechanistic way at each time-step in the overall simulation model.

Information on the relationship between driving variables and state variables at each given time-step is used to calculate flows in an empirical way in our present analyses. The flows of interest are photosynthesis, respiration, translocation of carbohydrates to roots, death of plants, translocation of carbohydrates to the crown, food consumption by cattle, decomposer respiration, and other flows concerning nutrient cycling. These variables are considered "dependent variables" in a regression sense. The independent variables include time, various climatic driving variables, and various system state variables. The major climatic variables of concern are maximum and minimum temperature and cloud cover. Soil water at various depths, nutrient concentration in the soil, phenological stage of the plants, biomass of live shoots, standing dead, roots, crowns, cattle, and active decomposers are the dependent variables. Approximately 20 dependent variables were selected and in each case up to 29 independent variables were entered in a step-wise regression. The first approach was to enter all variables in a linear form, i.e., a first-order model. A stepwise regression approach was used to derive successively simpler equations. We are examining the predictive capability, i.e., the square of the multiple correlation coefficient, for each of these equations. In general, we find that with the linear models only a few variables are required before we have accounted for about 75% of the variation in the dependent variable flow. A second step is to select the six most important independent variables in the linear model and include them in a non-linear model, i.e., a second-order model. Here were include the first power, second power, and 2-way cross products of the six independent variables.

Overall, these modelling studies have taken a great deal more computer time than was originally expected, but are leading to useful preliminary results.

Simulation of Large Grazinglands

In three other studies with outside support we are developing simulation models of grazingland systems. These efforts will provide key submodels for the present study.

Under support by the Bureau of Land Management we are developing a total-system simulation model of a shrub-steppe grazingland. The resolution level of this model is "medium" and its output will be of considerable value to the grazingland study. It extends our knowledge of simulation modelling of grassland systems into that of the shrub-steppe system.

B. K. Williams is developing a dissertation on control theory modelling of salt-desert shrub vegetation. His control theory approach is basically a dynamic optimization technique, which uses as inputs the results from a system simulation model. Williams has constructed a relatively simple system-simulation model for important salt-desert shrub species. This model has been run under a wide variety of climatic conditions, initial carbohydrate storage conditions, and grazing management strategies. Its performance is quite good and will provide us information for relating climatic events to salt-desert shrub productivity.

A third closely-related simulation effort concerns an area of northwestern Colorado with vegetation types typical of foothill up to low mountain zones. These studies, funded originally by the Department of Energy to Battelle's Pacific Northwest Laboratories and subsequently on a sub-contract to us, will include development of simplified submodels of plant and animal production.

A Summary of Modelling Studies

Through these modelling studies we have a much better understanding of the precision of methods and alternative approaches to predicting vegetation productivity in subhumid and semiarid grasslands, semiarid and arid shrub-steppe grazinglands, and salt desert shrub grazinglands. Additionally, we have reviewed and analyzed extant simulation models on productivity of large herbivores in grazingland situations. It will be perhaps one year before these various approaches can be brought together in a structured way for purposes of the grazingland study.

Information Network

Both extensive written correspondence and personal contacts made on foreign and domestic trips have been used in developing sources of information necessary for this project.

Written Correspondence

Addresses for national ministries of statistics and agriculture in 103 countries reporting annual production data were obtained. Letters in the appropriate language (English, French, or Spanish) have been sent to

each of these national ministries. Regional information on grazingland areas and livestock numbers was requested. Example letters are included as Appendix B. Some 30 responses have been received to date and information continues to arrive each week. Such information, on a regional or geographic basis, will allow refinement of data on grazingland area and livestock numbers reported on a national basis in FAO Production Yearbooks.

More than 20 representatives of intergovernmental agencies concerned with agricultural and natural-resource problems, including UNESCO, FAO, UNEP, ILCA, IIASA, WMO, IUCN, and IBRD, have been contacted. Provisions have been made for a continuing exchange of information relevant to this project with individuals in these organizations. A project brief was developed for some organizations such as IBRD to summarize the nature of the study, specific information needs, and the disposition of study results. The brief is included as Appendix C.

Much information on world grazinglands exists in unpublished form and can be best obtained from individuals with years of experience in grazingland regions. Many such scientific investigators have been identified through organizational contacts and literature review. We have begun exchanging information with specific individuals, including John Lee, Ireland (European grazinglands); J. C. Menaut, France (African savanna studies); Leonard Hendzel, range ecologist, Botswana; and many others. We are continuing to expand this network of information exchange.

Solicitation of Supplemental Funds

Efforts to obtain supplemental funding for this project continue. A complete description of the project, including the potential useful results of the study of world grazinglands, has been sent to ILCA, UNEP, the Planning Office of the Foundation for International Technological Cooperation, and other possible national and international sources of funds. Supplemental funding might be used for review and analysis of data in studies done by FAO and UNESCO or other organizations; improvement of mapping techniques, including the possible use of LANDSAT imagery; or the addition of personnel to the project who could be used in a a variety of capacities in a study of this scope. Funds specifically for analyzing unpublished data on rangeland productivity in relation to climatic fluctuation for a given state have been obtained from the North Dakota Public Service Commission. It is hoped results from this test case will allow development of other such projects. It is hoped that the core NSF grant may be supplemented by funds from one or more organizations during this first year of the project. A brief description of some specific separately-fundable tasks which could require an estimated total of four professional person years is included in Appendix D.

Personal Contacts - Travel

Several trips have been made nationally and internationally by project personnel to secure data, make scientific contacts, examine possibilities for collaborative efforts, and investigate sources of potential funding. To provide historical perspective, a brief overview of the May-July 1977 travel in project development is included. This is followed sequentially by major trips of concern.

May-July 1977. Travel in May-June 1977 was funded by the Kettering Foundation. The purpose was to visit various foreign governments and international agency projects to discuss ideas about the proposed study. During this travel George Van Dyne talked with more than 50 scientists in 18 organizations and institutions in eight countries and an additional 25 scientists (including six Soviet scientists) at the International Grassland Congress in Leipzig. Organizations visited included UNESCO, FAO, UNEP, ILCA, WMO, IFIAS, IUCN, Overseas Development Institute, Grassland Research Institute, University of Redding Department of Agriculture, Agricultural College of Sweden, Agricultural Research Institute of Iceland, Kenya Soil Survey Project, Kenya Rangeland Ecological Monitoring Unit, Kenya National Project--ILCA, UNESCO-MAB Integrated Project in Arid Lands, and FAO Forage Crops Project in Kitale.

August-October 1978. During this interval George Van Dyne made several trips, attended meetings, and presented talks relevant to the grazingland study. The first of these trips was to attend the First International Rangeland Congress. At this Congress he presented a paper summarizing information on diets of large herbivores grazing on shortgrass prairie (see Abstract, Appendix E). At this Congress there was opportunity to talk with scientists and resource managers from several nations concerning the newly developed project. It was also possible to visit with potential candidates for the research associate position in the study. Several of these contacts, particularly with UNEP and ILCA, are now being followed up. Furthermore, we were invited to submit an abstract of our study for publication in the Arid Zone Newsletter. This document is distributed widely to research workers in arid zones throughout the world. This announcement will bring us further information relevant to the study.

Van Dyne attended the world conference on animal production (travel supported by Argentina funds) in Buenos Aires, Argentina, in late August 1978. Again, there was good opportunity to visit with scientists from many nations about the development project ideas. Also, there was opportunity to visit with potential candidates for the research associate position. A paper was presented on systems analysis of animal production systems (an abstract is enclosed in Appendix E).

On return from Argentina, a visit was made in Venezuela by Van Dyne. He contacted there several governmental, university, and research institute organizations concerned with savanna grazinglands. He was able to review documents summarizing information on animal production and grazingland areas in that country. During this time he was invited to return in October to present a paper at an international congress. This will be referred to below.

In September Van Dyne attended the Second International Congress of Ecology. Again, there was opportunity to visit with scientists from around the world regarding the grazingland project, sources of information, and potential cooperative efforts. Particularly, contacts were made with Swedish investigators who had been involved under Swedish foreign aid programs in worldwide studies. Additionally, Van Dyne presented two papers and co-chaired a symposium on the state of the art of ecological modelling. Abstracts of these papers are enclosed in Appendix E.

In travels from Israel, Van Dyne was able to visit FAO, UNESCO, ODI, ODA, and GRI. FAO visits focused on discussions with Naegele, Ionesco, Kernick, Higgins, Howard, Pelinck, Abraham, Zarqa, Baso, Brauer, Azrqua, Pecrot, Van Velthuizen, and Riveros. The purpose of these visits was to explain the project which was being initiated, inquire of potential personnel for the project, examine possible data sources, and to secure ideas of alternative approaches to those already planned. Initial ground work was laid towards getting cooperation of FAO and other organizations.

Discussions at the Overseas Development Ministry in England were held with A. Blair-Rains and R. Rose-Innes. They are in the Land Resources Development Center of that organization. Van Dyne obtained from them an index of their storage and retrieval approach to classifying information and a listing of their mailing list. The project was discussed in general and they provided several ideas worth following.

Discussions at the Overseas Development Institute in London were held with Dr. Sanford. He suggested several references to follow, individuals to contact, and special ideas regarding the evaluation of data from developing nations.

At the Grassland Research Institute at Hurley, Van Dyne met with Peter Boyle of the Commonwealth Agricultural Bureau. This Bureau has been responsible for publishing the secondary journal "Herbage Abstracts" for many years. Furthermore, it appears there is relatively good coverage of USSR scientific literature at Hurley. Dick Brockington, who has wide overseas experience, was also visited at the Grassland Research Institute.

Following on these discussions Van Dyne met with Dr. Gina Douglas, formerly with the IBP Secretariat in the London office. She has an interest in developing a contract to work with us in summarizing information from the USSR. Information on this contract is enclosed. Negotiations are in progress.

Later in October Van Dyne attended, at expense to Venezuela, a conference on productivity of savanna grazinglands. He presented a paper on problems related to the organization and management of integrated ecological research programs and the benefits they could have towards practical resource management. This detailed manuscript, in Spanish, is at press in Venezuela. A copy of the table of contents is included in Appendix E.

December 1978. In December 1978 Van Dyne met with various orgnaizations in Washington, D.C. and New York regarding the project. These included the following: NOAA, AID, MAB, NSF Ecosystem Analysis Program, IBRD, Rockefeller Foundation, EPA, DOE, Pentagon, USDA-FS, SCS, USDI-BLM, and OSM. These meetings varied in purpose. Some were seeking information, sources of data, and approaches to the program (e.g., AID, MAB, EPA, Pentagon, DOE). Other meetings were more of an informational purpose (e.g., NSF Ecosystem Analysis Program and OSM). Yet other meetings and contacts were made in attempt to secure interest in funding segments of work in the overall study (e.g., NOAA, USDA-FS, SCS, USDI-BLM).

January 1979. Numerous useful contacts were made on a trip by Dennis F. Pendleton. The focus of a workshop in Alexandria, Egypt, 3 to 10

January, was the review of the Egyptian SAMDENE project. There was time during the workshop to discuss the grazinglands project with several professionals from around the world who are involved with studies of biological productivity. These individuals, who offered a number of helpful suggestions, included:

Ray Perry, Chief CSIRO
Division of Land Resource Management
Perth, Australia

C. T. De Wit
Agricultural University
Wageningen, Netherlands

Mohamed Ayyad, Principal Investigator, SAMDENE
Faculty of Science
University of Alexandira
Egypt

John Jeffers, Director
Institute of Terrestrial Ecology
England

Following the workshop in Egypt, the Headquarters of FAO in Rome and UNESCO in Paris were visited solely to obtain information needed in this project. Mr. R. Dudal, Director of the Land and Water Development Division, FAO, offered the assistance and cooperation of his Division and provided several specific sources of information on studies of grazingland production. Discussions were held with two others in this Division, Messrs. G. Higgins and H. Van Velthuizen, who are working on FAO's Agro-ecological Zones Project. This project involves the use of soils and climatic data to map regions of suitability for the 11 major crops of the world. Climatic zones, developed from monthly data at hundreds of weather stations, are used to define growing seasons for particular crops. These climatic zones are superimposed over UNESCO/FAO world soils maps. Thus, suitability (4 categories) for a specific crop is mapped subject to both climatic and soils limitations. The project is an example of an approach which might be modified for use in the mapping phase of the grazinglands study. The climatic data for this agricultural project were provided by the Interagency (WMO and FAO) Project on Agricultural Biometeorology. Messrs. Van der Viverie and Cerusati of this Interagency group provided copies of some climatic data (monthly records of principal climatic factors) and reports derived from them. They also offered access to their tapes of climatic data, subject to the approval of the Director-General, FAO.

Virtually all the resource data collected by the Statistics Division, FAO, are in the form of national summaries and are published annually in Production Yearbooks. Mailing lists for the ministries of countries which regularly provide data for FAO summaries were obtained from this Division. These addresses have allowed solicitation of grazingland information on a geographical basis within countries for all countries which provide data for FAO.

A great deal of information on FAO and multi-agency studies in grazinglands was obtained in lengthy discussions with Messrs. Ionesco, Kernick, and Van Praet of the Plant Production and Protection Division. In addition, addresses of individuals involved in these projects, primarily in Africa and the Middle and Far East, were obtained. It was suggested during these discussions that much useful information could be assembled in a search through their Division library. This would take several months of effort.

Another contact at FAO was with Mr. W. Ferguson of the Animal Production and Health Division. Mr. Ferguson has been involved in the study of grazingland production systems for many years and has numerous contacts throughout the world. He provided sources of published literature and addresses for a number of individuals, particularly in South America and Africa, from whom we might obtain information useful for this study.

FAO personnel have been particularly cooperative in providing information for this project. To further strengthen our contact with this organization and to facilitate the acquisition of FAO meterials, including the above mentioned tapes of climatic data, a letter of support has been requested from Oscar J. Olson, Jr., Executive Director of the U.S. Committee for Man and the Biosphere, UNESCO. Fullest support of this project by FAO is requested in the letter which has been sent to Dr. Edouard Saouma, Director-General, FAO. A copy of the letter has been included as Appendix F.

Discussions at UNESCO focused particularly on studies in process and individuals involved throughout the world under Project 3 (involving world grazinglands) of UNESCO's Man and the Biosphere Program (MAB). Personnel at UNESCO have specific regional responsibilities. Information on MAB grazingland projects and addresses of participating scientific investigators were obtained from each of the individuals contacted for their region of interest. The people at UNESCO were quite supportive of this grazinglands project and promised continued cooperation. The principal individuals contacted included:

Gisbert Glaser:	Arab state responsibility; will soon assume general responsibility for all grazinglands projects.
Malcolm Hadley:	S.E. Asia responsibility; also, coordinator for the Integrated Project on Arid Lands, Kenya.
Jay Cuttaree:	Responsible for Africa south of the Sahara.
John Celecia:	Latin America.

While in Paris, the UNESCO offices arranged an appointment with Jean Claude Menaut of the Ecole Normale Superiore. Menaut has worked extensively in African tropical savannas and offered personal insights into the study of production in such areas. He emphasized the difficulty of predicting production from climatic data in African savannas because of erratic climatic influences and spatial heterogeneity of the vegetation in such areas.

February 1979. Van Dyne attended the annual meeting of the Society for Range Management, presented three papers, and discussed grazingland problems with several scientists. Of particular interest were discussions with Dr. Warren C. Whitman of North Dakota State University concerning available data on herbage yield and climatic fluctuation. Whitman began studies in North Dakota in the late 1930s and will retire within one or two years. He has provided us with individual plot data from a variety of research investigations. These data are now being analyzed to show the relationship between herbage yield and climatic conditions by means of special regression functions. The purpose of using these simplified functions, in contrast to more complex ones, is to see if an index of yield can be obtained from climate only. If this is the case it will be possible to correct or adjust

or interpret from a wide variety of locations in the overall synthesis effort.

Later in February Van Dyne presented a paper at the dedication of the Environmental Sciences Laboratory, Oak Ridge National Laboratory in Tennessee (see Appendix E). During these meetings, funded by ORNL, he had an opportunity to visit with Drs. Jerry Olson and Frank Harris of the Environmental Sciences Division. These ORNL scientists have initiated a project under NSF support in 1978 concerning global carbon dioxide levels. We were able to exchange notes regarding information of common interest. Particularly, we are interested in cooperating with them in analyzing meteorological records. A cooperating scientist there, Dr. Blasing, is deriving a technique to determine global climatic patterns, at least in the northern hemisphere. This information will be useful to us in about year three of our grazingland analysis.

Development of Grazingland Map

As a complement to the compilation of information on productivity of specific range sites and vegetation types throughout the world, a map of grazingland areas is being developed. The FAO/UNESCO soil map of the world will be used as a base map. Climatic information will be superimposed over soils categories to develop a map of classes of grazinglands, defined according to potential productivity. Preliminary discussions have been held with the FAO/WMO Interagency Project on Agricultural Biometeorology concerning the use of their climatic information from sites throughout the world. This information, on readily-accessible computer tapes, was used in FAO's Agro-ecological Zones Project. In this project, climatic data were combined with soils information to map potential suitability of areas throughout the world for production of 11 important crops. These climatic data will provide an excellent base of information for the grazinglands mapping work.

A grazinglands mapping project has been undertaken for Europe. John Lee (1978) has developed a "first approximation" of a map of land capability for forage production in the European Economic Community countries. Ten land classes are described for the EEC area. The general characteristics of each class are discussed along with an estimate of the range of potential productivity for each class. Few details are now available on the development of this map. Lee has stated only that climatic, topographic, and forage production information were taken into consideration along with the soils base map to develop what he referred to as a "first attempt" at preparation of a forage production map for the EEC. In an earlier study which was limited to Ireland, however, productivity classes (grazing capacities) for all of Ireland were extrapolated from detailed grazing studies in areas of known soil type (Lee and Diamond 1972). This method of extrapolating estimates of productivity from detailed range studies to areas of similar soil type was likely used in the larger study of the entire EEC area.

Literature sources and information from contacts with scientific investigators will be used to establish and to check estimates of productivity for mapped grazingland "classes" in this project. Studies of productivity generally contain information on location and vegetation type

The biotic provinces listed in Table 7, from the continent of Africa, are shown in Figure 1. Good correlation is expected between grazingland classes based on soils and climatic information and the boundaries of vegetation types.

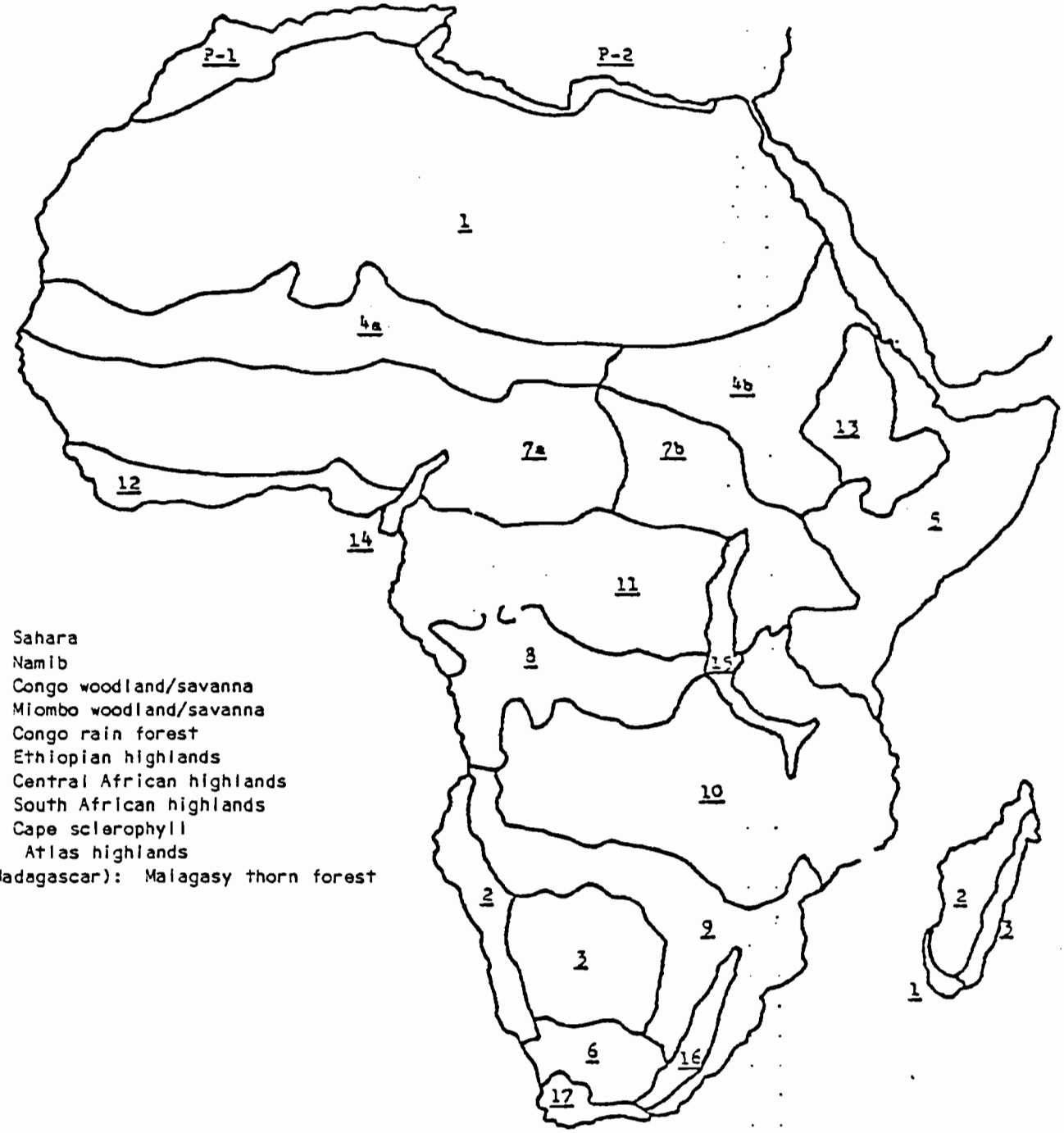
Conclusion

Meat production from ruminant livestock raised on grazinglands is an important part of the world food supply and will likely become increasingly important in the coming years. Many areas which are not suitable for other types of agricultural production because of climatic, edaphic or other limitations may be effectively used for grazing livestock. Few data exist on the amounts of meat production which come from arid or semiarid rangelands, subhumid pastures, or intermediate environments. Rates of plant production may vary greatly between types of grazinglands and from year to year in a single area. Climate is an important determinant of rates of production and their variability in grazinglands. Adequate data on vegetation characteristics and production systems of the world's grazinglands are essential in planning for future livestock production. An increased capability to predict the effect of climatic fluctuations on plant yield would improve planning of rangeland management and livestock production.

The variety of specific tasks described in this report are necessary in a study of this scope. The tasks are designed to lead to an improved description of the location, area, and productive capacity of the world's grazinglands. Modelling efforts should improve our ability to predict the impacts of climate on grazingland forage production. Much of the work described herein is in an initial phase. One benefit being realized as the study proceeds is the improvement of communication among researchers in grazinglands throughout the world. Final results of the study should be of value to national and international organizations involved with natural resources planning. Results will be distributed in the scientific literature and technical reports. The analysis and synthesis of rangeland information and the development of predictive equations describing relationships between climate, plants, and animals should be of scientific interest.

Table 7. Selected examples of biotic provinces (IUCN nomenclature) and two examples of general vegetation types for corresponding mapped areas in the African continent.

Biotic Provinces (IUCN, 1974)	General Vegetation Types (Kuchler, 1978)	General Vegetation Types (de Laubenfels, 1975)
Sahara	Desert shrub; bare	Desert
Namib	Desert shrub; bare	Desert
Congo woodland/savanna	Tallgrass savanna	Grassland and savanna
Miombo woodland/savanna	Dry open woodland	Seasonal forest
Congo rain forest	Tropical rain forest	Rainforest
Ethiopian highlands	Tallgrass savanna; tallgrass	Grassland and savanna
Central African highlands	Tallgrass; dry open woodlands	Seasonal forest; grassland and savanna
South African highlands	Tallgrass; tallgrass savanna	Grassland and savanna
Cape sclerophyll	Mediterranean vegetation	Woodland
Atlas highlands	Mediterranean vegetation; low grass	Woodland; seasonal forest
Malagasy thorn forest	Thorn forest	Woodland



1: Sahara
2: Namib
8: Congo woodland/savanna
10: Miombo woodland/savanna
11: Congo rain forest
13: Ethiopian highlands
15: Central African highlands
16: South African highlands
17: Cape sclerophyll
P-1: Atlas highlands
1 (Madagascar): Malagasy thorn forest

Figure 1. General sketch of biotic provinces for Africa (IUCN, 1974).

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Appendix A

Specifications for Review of Soviet Literature

REVIEW OF SOVIET LITERATURE

The review and analysis of literature should start with most recent information and work back. Three different products are needed:

(1) A Tabular Summary

Literature on primary and secondary productivity in world grazinglands is currently being reviewed. Specific information from the review is being compiled in tabular form. It would be most useful if information collected in a review of Soviet literature were compiled in the same format. A copy of the tabular worksheet is enclosed and the table categories are briefly described below:

Biotic Province:	Study sites are identified by biotic province (IUCN system of classification) as well as vegetation type. (This category may be ignored for now and can be ascertained later from location and vegetation type.)
Location:	Province and specific location of the study discussed.
Vegetation Type:	Native vegetation type or managed pasture type.
Treatment/Season:	Management treatment, if any, including fertilization, irrigation, etc. Specify if untreated or "control" area. Season refers to season of grazing for which stocking rates and animal production figures apply in studies involving herbivores.
Plant Production:	Total annual plant production. Where possible, figures should be converted to aboveground net production in kg ha^{-1}.
Stocking Rate:	Estimated carrying capacity for the study site or grazing intensity for the period of the study. For example, grazing intensities which are related to particular animal production figures may be specified in some studies. The type and average weight of herbivores involved should be specified where possible. Units should be converted to ha AUM^{-1} where possible.
Animal Production:	Liveweight gain of animals should be listed in units of kg $animal^{-1}$ day^{-1}. For some regional types of studies, "offtake," or percentage of animals harvested in a given period of time may be specified, and should be extracted for this table.
Climatic Information:	Climatic factors, such as precipitation (cm) or mean daily temperature (°C), recorded during the period of the study (if such information is included). Long-term mean climatic values should be recorded when specified, e.g., 30-year, mean annual precipitation.

Source: The author(s) and date of the literature source from which the information was taken. See also information on references in (2).

Notes: Information which can't be easily reduced to a brief note under one of the table categories, but which is necessary for clarity.

Some of the columns of the tables will likely be unfilled for particular studies, of course, given a focus on either plant production or animal production. In general, table entries should be kept brief, with necessary descriptive information included in the notes column.

(2) An Annotated Bibliography

In addition to studies from which information for such a table can be extracted, we are interested in studies which focus particularly on the effect of climatic variation on plant production. For example, studies which attempt to predict plant production as a function of some climatic factor or combination of factors would be of particular interest. For these studies of climate and productivity, as well as for the sources cited in the table of information, a list of complete references should be compiled, including a brief abstract of the work for each reference.

(3) A Brief Synthesis

Finally, a brief summary of the "state" of Russian grazinglands and grazingland research would be desirable, including general impressions gleaned through reviewing the literature, etc. Any specific suggestions concerning the application of Russian research in our project would be appreciated.

Appendix B

Drafts of Letters Used to Solicit Grazingland Data From National Ministries

Department of Range Science

Colorado State University
Fort Collins, Colorado
80523

Ladies and Gentlemen:

A research program on grazingland productivity has been funded by the U.S. National Science Foundation. The project, a contribution to the UNESCO Man and the Biosphere Program, Project 3, is headquartered at Colorado State University. The principal investigator is Dr. George M. Van Dyne. I recently joined the project as Research Associate.

One goal of this project is to compile and synthesize information on the size of world grazingland areas, the average plant and animal productivity, and the variability of yield. Information on the effect of climatic variations on grazingland productivity will be used to develop mathematical models to predict vegetation and livestock production. Information developed in the project will be made available to those contributing data and to international organizations.

We have received cooperation in securing information from the Statistics Division, FAO Headquarters, Rome; however, their data are tabulated only for each entire nation and are organized in the broad categories of their annual production summaries. We need information by geographic or political subdivisions within nations so that we may better estimate land area and annual production from grazinglands. We would greatly appreciate your cooperation in obtaining available specific data on the grazinglands of your country. We are particularly interested in the following types of information.

1. The size of areas currently used for forage production and grazingland for livestock in specific geographic or political subdivisions within your country - including lands in the FAO category, "Permanent Meadows and Pastures," but also including areas of other categories which could be considered grazingland.
2. Historic trends in the extent of areas in your country used as grazinglands.
3. Current numbers of livestock in the geographic or political subdivisions within your country and past trends in these numbers if such information is available.

Thank you in advance for your cooperation.

Sincerely,

Dennis F. Pendleton

Dennis F. Pendleton
Research Associate

Department of Range Science

Colorado State University
Fort Collins, Colorado
80523

le 23 Mars 1979

Messieurs,

La Fondation National de Science des Etats-Unis a accordé des fonds pour un programme de recherche sur la productivité des terrains de paturage. Ce projet est une contribution au Programme "L'Homme et la Biosphère" de l'UNESCO, Projet 3. Son centre est à Colorado State University, à Fort Collins, Colorado. Dr. George M. Van Dyne en est le responsable principal. Je fais partie moi-meme du programme depuis peu.

Un de nos buts est de rassembler des informations sur la superficie des terrains de paturage du monde, de la productivité moyenne des plantes et des animaux, et de la variation de la production. Ensuite, nous en ferons une synthèse. Les informations sur l'effet des variations du climat sur la production des paturages serviront à développer des modèles mathématiques pour prédire la production du bétail. Les informations développées dans notre projet seront disponibles à tous ceux qui ont contribué des données et aux organisations internationales.

Nous avons recu des informations de la Division des Statistiques, du bureau central de la FAO, et de Rome. Néanmoins, ces données ne sont classées que pour chaque pays entier, et elles sont organisées en catégories générales de leurs résumés de la production annuelle. Nous avons besoin des informations selon les régions géographiques ou politiques à l'intérieur des pays pour pouvoir mieux estimer la surface et la production annuelle de ces paturages. Nous vous serions reconnaissants de bien vouloir nous faire parvenir tout renseignement précis disponible sur les paturages de votre pays. Les informations suivantes nous intéressent particulièrement.

1) La superficie des terrains qui servent actuellement à la production fourragère et au paturage du bétail dans des régions géographiques ou politiques de votre pays--y compris les terrains de la catégorie de la FAO, "Prairies et paturages permanents," et aussi d'autres catégories de terrains de paturages.
2) Les traditions d'emploi des paturages de votre pays.
3) Le nombre actuel de bétail dans les régions géographiques ou politiques de votre pays et son évolution dans le passé.

En vous remerciant d'avance, nous vous prions d'agréer, messieurs, nos salutations les meilleures,

Dennis F. Pendleton
Rechercheur associé

DFP/jm

Department of Range Science

Colorado State University
Fort Collins, Colorado
80523

febrero de 1979

Estimados senores:

Un programa de investigacion respecto a la productividad de pastizales ha sido proveido de fondos por la Academia Nacional de Ciencias de los Estados Unidos. El proyecto, como contribucion al programa de UNESCO, el Hombre y la Biosfera, Proyecto 3, tiene su oficina principal a la Universidad del Estado de Colorado (Colorado State University). El Dr. George M. Van Dyne es el Investigador Principal. Recien coligado con el proyecto, yo trabajo en funcion de Asociado de Investigacion.

Una meta de este proyecto es la compilacion y el sintesis de datos acerca de las dimension de las areas de pastizales mundiales, el promedio de productividad planta y animal, y la variabilidad de rendimiento. La informacion tratando del efecto de las variaciones climaticas en la productividad de pastizales se usara para desenvolver modelos matematicos para predecir la produccion vegetal y ganadera. La informacion desarrollada durante este proyecto se pone a la disposicion de todos los contribuidores de datos y a las organizaciones internacionales.

Hemos recibido la cooperacion de la Division Estadistica, FAO Oficina Principal, Roma; sin embargo, sus datos son tabulados solamente para cada nacion individua y son organizado por las muy generales categorias de los sumarios de produccion anual. Necesitamos los datos en subdivisiones geograficas o politicas dentro de las naciones con fin de que estimemos mejor la area terrestre y la produccion anual de pastizales. Agradecemos sumame su cooperacion en obtener los disponibles datos especificos respecto a los pastizales de su pais. Nos interesa especialmente las clases de informacion siguientes: ← corrected in fi co

1) La dimension de las areas explotadas actualmente por la produccion forrajera y los pastizales ganaderos en especificas subdivisiones geograficas o politicas dentro de su pais - incluso terrenos de la categoria FAO, "Praderas y Pastos Permanentes", empero, tambien incluyendo las areas en otras categorias que se consideran pastizales.
2) Las tendencias historicas de su pais en la extension de las areas utilizadas como pastizales.
3) Los numeros actuales de ganado en las subdivisiones geograficas o politicas en su pais y las tendencias pasadas entendidas por estos numeros, si es disponible tal informacion.

Con gracias anticipadas por su cooperacion,

Atentamente,

Dennis F. Pendleton

Dennis F. Pendleton
Asociado de Investigacion

Appendix C

Overview of the Project for Potential Collaborators

PREDICTION OF GRAZINGLAND PRODUCTIVITY UNDER CLIMATIC VARIATIONS

--An Overview of a Research Study--

The following is a brief description of the above project, receiving core funding under NSF Grant DAR78-17243. A description of the problems addressed in the project, specific objectives, relevant existing information, and information needs are summarized. The acquisition of data on world grazinglands from a variety of sources is essential to the conduct of the study. The results of the study should be of interest to national and international organizations concerned with natural-resource planning.

Problem Statement

Production and distribution of food throughout the world are an increasingly significant concern given the much-discussed burgeoning human population. Ruminant livestock are an important part of the world food equation. With continued growth of human populations, increased demand for meat and other animal products can be expected. Ruminants have the capactiy to convert forage, indigestible to humans, to a high quality human food source. Many of the forage-producing areas of the world, which are not suitable for other kinds of agricultural production because of climatic, edaphic or other limitations, may be effectively used for grazing livestock. With some exceptions, principally the United States, where up to 40% of livestock feed may come from non-forage sources (Hodgson 1976), most of the feed for the world's livestock comes from grazingland forage.

Worldwide, more than 54 million MT of meat were produced from ruminant livestock in 1976. This represents an approximate 40% increase over yearly production in the period 1961 to 1965. About half the meat was produced in developed market economies and approximately 27% and 23% were produced in developing and centrally-planned economies, respectively (FAO Production Yearbook, 1976).

There are no good data on the amounts of meat production which come from arid or semiarid rangelands, subhumid pastures, or the intermediate types of vegetation. Rates of production may vary greatly between types of grazinglands and from year to year in a single grazingland area. Adequate data on the vegetation types and production systems of the world's grazinglands are essential in planning for future livestock production.

Ecological factors, principally climate, are important determinants of production and variability in production in grazinglands. This fact was dramatically underscored by the large losses of livestock during drought in the past decade in the Sahelian region of Africa. Major efforts have been undertaken recently to predict yield and its variability in crops due to climatic fluctuation and management. Studies of grassland productivity over the past 10 years have greatly increased our knowledge of these systems and have resulted in the increased use of quantitative

approaches in management. Yet despite these efforts, our knowledge of the impacts of climate on grazingland forage production remains meager.

Objectives

The overall goal of this study is to provide for decision- makers at national and international levels (1) scientifically defensible information on the contribution of grazinglands to food production and (2) a means for determining the variability of yield due to climatic fluctuations.

Some steps toward accomplishing this goal include specific objectives to:

(1) Obtain, compile and evaluate for the grazinglands of the world
   (a) vegetation production data and livestock production data.
   (b) information on animal numbers and their temporal variability.
   (c) climatic data.
(2) Obtain, map and evaluate acreages used in grazinglands throughout the world.
(3) Make a detailed analysis of range and pasture forage vs. concentrates as feed inputs for livestock in the world's grazinglands.
(4) Review and develop mathematical models to predict grazingland production as a function of climatic influence; and to compare model predictions with available information on grazingland production.

Extant Information and Approaches

Grasslands comprise a major portion of grazingland areas, including the world's steppes, prairies, and pampas. Other important grazinglands include savannas, shrub-steppes, and some areas of taiga and tundra. But a detailed map of world grazinglands, per se, does not exist currently. One objective of this project is to develop a map of the grazinglands of the world through the use of the recently completed FAO-UNESCO soil map of the world and various sources of vegetation and climatic information.

There are a variety of estimates of plant production rates in various vegetation communities of the world. Lieth (1975a), for example, reported the following estimates of net primary productivity (i.e., the amount of carbon that is fixed by plants in a given period of time) in metric tons per hectare per year: dry desert, 0 to 0.1; desert scrub, 0.1 to 2.5; tundra, 1.0 to 4.0; temperate grassland, 1.0 to 15.0; chaparral, 2.5 to 15.0; and woodland, 2.0 to 10. Different estimates have been reported in other studies, however, including those by Wassink (1975), Caldwell (1975), and Bazilevich et al. (1970). Information generated during the recently completed International Biological Program is another important source of production data. Sims and Singh (1978),

for example, have summarized above and belowground production data for US/IBP Grassland Biome sites. They reported figures for aboveground net production which ranged between 0.5 and 5.2 MT per hectare. Such studies provide a useful starting point for this project in the effort to estimate grazingland production rates under varying climatic influences. There have been few studies of the effect of climatic influences on secondary productivity by large herbivores. Such a study will be included in this project.

Four possible approaches might be used in examining the relationship between vegetation productivity and climate: (1) use of overlay maps of precipitation and temperature zones correlated with vegetation zones; rough productivity figures from the literature could then be used to calculate vegetation yield under different conditions; (2) use of Markov matrix models in which a transformation matrix of vegetation change under specific climatic conditions is used to describe changes in vegetation over time; the matrix model technique has been described by Redetzke and Van Dyne (1976); (3) empirical statistical predictive models; and (4) simulation models. The last two approaches are of special concern.

Statistical models commonly use an independent variable such as precipitation or several independent variables such as temperature, radiation, rainfall or other factors in regression analyses. Lieth (1975b), for example, has described three statistical approaches in which vegetation productivity is predicted (1) from the more limiting value of a mean annual temperature function or a mean annual precipitation function; (2) as a function of actual evapotranspiration; and (3) as a function of the length of the photosynthetic season (derived from phenological observations). In a widely-cited study by Rosenzweig (1968), all data were transformed to common logarithms and an equation was develcped to predict net aboveground annual primary production as a function of actual evapotranspiration. Two general weaknesses inherent in many statistical approaches are the linearity-of-response assumption and the use of annual climatic and yield values. Studies have shown that yield response is nonlinearly related to precipitation and that at least seasonal climatic data are required to adequately describe interactions between climatic influences and plants at various stages of growth. Finally, though good results have been obtained with some statistical approaches, the parameters derived in a statistical analysis apply specifically to the data set used. Thus, it may not be possible to apply such predictive equations in other locations even if the correct independent variables have been used.

Simulation models may be empirical, mechanistic or contain both types of functions. The main strength of the simulation approach is that it is based on cause-and-effect relationships. The photosynthesis function is often a key process in models which simulate plant productivity. Photosynthesis is frequently calculated as a function of some combination of soil water tension, solar radiation, air temperature, leaf area, soil nutrient concentrations, and plant phenology. Various other process functions cause the redistribution of carbon through compartments which describe plant structures. More than 120 simulation models of grazingland systems or their components were recently reviewed and summarized by Van Dyne _et al_. (1977). They include a variety of

methods for predicting primary and secondary productivity. In contrast to statistical models, simulation models require more data in establishing initial conditions and implementing the models. They have not been widely adopted nor commonly used for prediction. Nevertheless, they may provide a more realistic depiction of the effect of climatic influences on plant production and they have greater potential for extrapolation to other areas than empirical statistical predictions.

The methodologies briefly described above will be examined in detail. Data available from many experimental studies can be used in the application of various approaches. More than one method may be useful in assessing the effect of climatic influences on production in different situations and geographical areas.

Information Sources and Needs

The nature and scope of this project necessitate the collection of information from many sources including: (1) published scientific literature; (2) contacts with individuals with broad experience and general knowledge of world grazingland regions, particularly in developing countries where the base of scientific literature may be small; and (3) reports and documents of governmental, intergovernmental, financial and philantropic organizations.

All the national ministries which provide information for FAO's annual production summaries have been contacted. Information from these ministries is currently being assembled and analyzed as it is received. More than 20 representatives of intergovernmental agencies of concern, including UNESCO, FAO, UNEP, ILCA, IIASA, WMO, and IUCN, have been personally contacted by Dr. George M. Van Dyne, principal investigator, and Dr. Dennis Pendleton, research associate on the project. Leads into sources of appropriate data are now bring provided by many individuals who have been contacted.

Valuable information for this project might be provided in specific studies sponsored by many national and international organizations. Information of particular utility includes:

(1) studies of primary and secondary productivity in grazingland regions;
(2) climatic studies in primary range and pasture areas of the world
(3) data on size of area currently used for forage production or grazingland for livestock;
(4) data on the nature and efficiency of various livestock production systems; and
(5) data on the historic trends in productive area and livestock numbers in world grazinglands.

Project Outputs

This project will be of scientific interest in connection with the analysis and synthesis of rangeland information and the development of

predictive equations describing relationships between climate, plants and animals. The study should provide information of value to national and international organizations concerned with natural resources and agriculture. Information from the study will be distributed in the scientific literature and technical reports.

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Appendix D

Tasks Which Require Additional Funding

IDEAS ON FUNDING SEGMENTS

There are about 1,000 reports in various departmental, division, and general libraries in Rome which contain information on grazinglands in different parts of the world. These reports are primarily for developing nations for which there is little open-literature technical information. In discussions with people there, it would take about one professional person year plus about a third-time secretarial support to review, document, interpret, and analyze information from these reports for use in the grazingland project.

At the FAO they have accumulated several thousands of maps for different regions of the world on climate, soils, vegetation, land use, . . . These maps were acquired during the process of developing the world soils maps, most sheets of which have now been published. These original base maps of different variables would provide an excellent source of information primarily for locating climatic zones and grazingland regions. It would take about one professional person year's time of someone with geography, plant ecology, climatology, or related training to photograph, superimpose, review, analyze, and interpret new maps from this base data.

In one division of FAO they have a small synthesis project in which they are accumulating data on climate stations from each continent. For their purposes, they take stations in which there is ten years or more of data and compile it for other analyses. The data they are compiling represent monthly records. The data are for precipitation, maximum temperature, minimum temperature, daytime temperature, nighttime temperature, solar radiation, relative humidity, and possibly other factors. These data are available for several hundred stations on each major continental area. These data would be a useful adjuct to and a check on that obtainable from WMO or on tape already at Ashville for various other locations. It would take about 0.5 professional person year effort to secure, transfer, and make preliminary analyses of the weather information.

The FAO has a group operating in remote sensing efforts. They have worked out considerable technology and have reasonably good equipment for interpreting satellite information. It would be possible in about a one professional person year effort to work with their techniques and equipment to do a map of the world grazinglands based on examination of satellite imagery. The first step would be to locate imagery for all the regions expected to be grazinglands. Then, within each frame, to examine whether the land is forested or non-forested. If it is non-forested, is it cultivated or non-cultivated. If it is non-forested and non-cultivated, does it appear to be in cities or roads or deserts. Thus, grazinglands would be determined by elimination. A map of world grazinglands determined in this manner would be used to check against maps compiled by conventional manner, as noted above.

The Grassland Research Institute at Hurley has been responsible through the Commonwealth Agricultural Bureau for compiling Herbage Abstracts. This secondary literature source journal reviews many thousands of primary

journals each year in extracting information about herbages in general. It appears that they have made a reasonably good collection of the early and recent literature of the USSR. I estimate that at least a 0.5 professional person year effort would be needed to examine in detail their reference collections with focus on the grazinglands of the USSR. The purpose would be first to develop an abstract bibliography and second to develop a summary of information regarding the extent, plant, and animal characteristics, climatic phenomena, and productivity information on the USSR grazinglands.

These are a few examples of where additional funds in the world grazinglands study could be profitably spent. In each case the agencies or departments involved have expressed an interest in cooperation, but do not have the resources to initiate this work on their own. They have all indicated they would be pleased to have a person come to work with them on such activities for shorter or longer periods of time as a part of the grazingland project.

Appendix E

Abstracts and Table of Contents From Papers Relevant to Grazingland Study

ABSTRACT

Optimal Combinations of Four Large Herbivores for Shortgrass Prairie

George M. Van Dyne
Department of Range Science
Colorado State University
Fort Collins, Colorado 80523

(Paper presented at International Grassland Congress
Leipzeg, East Germany

A general problem in grazingland management is selecting the optimal numbers of different herbivores in various seasons of the year so as to make maximum use of the available vegetation. Simultaneously, one does not want to overgraze the herbage and one must consider the dietary selectivity and forage requirements of each animal species. The present paper reports on dietary studies with cattle, sheep, bison, and pronghorn antelope on shortgrass prairie in northeastern Colorado, U.S.A. The emphasis is on the early-summer situation. Cattle and bison consume mainly grasses; sheep and antelope consume mainly forbs. To maximize forage use, optimal grazing determined by non-linear programming analyses would be 67, 20, 12 and 1% of the forage grazed to be taken by cattle, bison, sheep, and antelope, respectively. Historically, this grazingland has been grazed primarily by cattle. This study suggests more animal production could be obtained with a mixture of herbivore species.

ABSTRACT

Systems Analysis in Analysis of Animal Production Systems

George M. Van Dyne
Department of Range Science
Colorado State University
Fort Collins, Colorado 80523

A review has been made of the world literature on simulation and optimization models used in systems analysis of animal production systems. Large summary and comparison tables are provided. The evolution of this form of modelling approach to studying large animals is traced. Major developments have occurred in the last decade for simulation models and in the last two decades for optimization models. Terminology of systems analysis, with reference to animal production systems, is defined. Major strengths and weaknesses of simulation and optimization models are discussed. The three major roles these models play are in integration, interpolation, and extrapolation of information. Models may fail due to many reasons, notably in being applied to situations for which they were not designed, because of complexity, and because of inadequate data bases. A large-scale grazingland simulation model is discussed and special consideration is given to parameterizing different large herbivores in the model, to designing model experiments to test hypotheses, and to the kind and amount of output available therefrom. Two research efforts are discussed where simulation models are used as a tool with laboratory and metabolism investigations in an interative manner over time. Suggestions are provided on the documentation of models. Linear programming least-cost ration formulation modelling is referred to as is income maximization for agricultural enterprises involving livestock. Case examples are discussed where linear or nonlinear programming models are used for selecting optimal combinations

of domestic and wild large herbivores to make maximum allowable use of mixtures of plants on natural grazinglands. Problems of multiple time periods, uncertainty in coefficients, and parametric programming in optimization models are briefly considered. It is projected that there will be increasing use of computer and modelling methodologies in the study of animal production systems in the future.

ABSTRACT

State-of-the-Art of Grazingland Modelling

George M. Van Dyne
Department of Range Science
Colorado State University
Fort Collins, Colorado 80523

Man is trying to simultaneously maximize both primary and secondary productivity in grazinglands. To aid in understanding grazinglands, researchers and resource managers have built more than 100 simulation models within the last 10 years of grazingland systems or their components. Early emphasis was on first-order, constant-coefficient, linear differential equation systems. Many present models are non-linear, with time lags, multiple flows, and are much more mechanistic than the early models. These models of grazingland systems or their components have been reviewed and characterized as to time step, computer language, presence of a model diagram, and general critique of the purpose and objectives of the model. Most of the models simulate homogenous points in, rather than spatial features over, grazinglands. Most such models, although deterministic, are not analyzed in detail. There is no standard procedure for specifying model structure and function and suggestions are provided. Only rarely have grazingland models been subjected to sensitivity analyses, either quantitatively or qualitatively. The source of data used to build or evaluate the model is often obscure. Early models generally were single-flow models, focusing on biomass, energy, or numbers. Recently multiple-flow models have been built in which the above currencies, as well as money, flow. Optimization models of grazingland systems most commonly are linear programming models, although a few non-linear programming models have been developed to study dietary competition among herbivores. A few examples exist in which

simulation and optimization are combined in the same grazingland model, providing considerable utility in resource management decision making.

ABSTRACT

Response of Shortgrass Prairie to Man-Induced Stresses
As Determined From Modelling Experiments

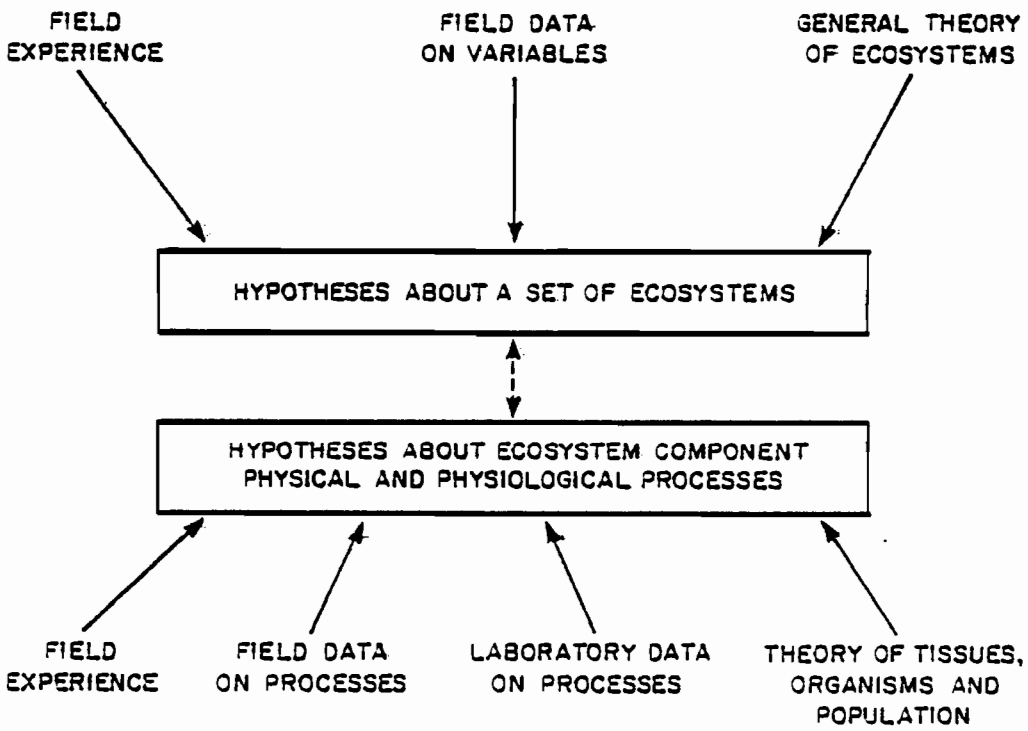
George M. Van Dyne
Department of Range Science
Colorado State University
Fort Collins, Colorado 80523

The lower box in Figure 1 illustrates the set of hypotheses we have about the processes that cause matter and energy to flow through the ecological system. These hypotheses are derived from field experience and some of the few data we have on field rate processes studied, but largely these hypotheses are based on laboratory data. They are largely at the physiological level and represent simplified theory on how organs or organisms operate. All of these hypotheses or ideas are put together into the individual flow functions of the model. Coupling them all together in an interactive simulation model results in the concept of the lower block of Figure 1.

The upper block in Figure 1 represents hypotheses that could be derived by examining field data on state variables or driving variables, or hypotheses to be derived from general theory about ecosystems.

Arrows between the two boxes represent the synthetic and analytic activities in testing the various levels of hypotheses for consistency. Our present models have taught us a great deal about the modelling process. We have also identified weaknesses in our present conceptualizations. In the next generation of grassland ecosystem modelling we need to focus more carefully on spatial and hierarchical models. We also need to examine more carefully anomalies in present model responses. In future modelling experiments we need to examine ecosystem responses to combinations of man-induced and nature-induced stresses. Results of all these efforts need to be

reduced in volume and translated into form and publications usable by resource managers.


FIELD EXPERIENCE
FIELD DATA ON VARIABLES
GENERAL THEORY OF ECOSYSTEMS
HYPOTHESES ABOUT A SET OF ECOSYSTEMS
HYPOTHESES ABOUT ECOSYSTEM COMPONENT PHYSICAL AND PHYSIOLOGICAL PROCESSES
FIELD EXPERIENCE
FIELD DATA ON PROCESSES
LABORATORY DATA ON PROCESSES
THEORY OF TISSUES, ORGANISMS AND POPULATION

ABSTRACT

Systems Ecology: The State of the Art

George M. Van Dyne
College of Forestry and Natural Resources
Colorado State University
Fort Collins, Colorado 80523

Presented at Dedication of Environmental Sciences Laboratory,
Oak Ridge National Laboratory, Oak Ridge, Tennessee

Mathematical models have been used to analyze populations in ecology for about 150 years, but the field of systems ecology is less than 20 years old. Developments in the field were traced since the early work of Lotka; notable names contributing directly or indirectly included Lindeman, Odum and Odum, Lucas, Patten, Olson, and others. Systems ecology can be broadly defined as the study of development, dynamics, and disruptions of ecosystems. There are both theoretical, analytical, and experimental phases. These studies can be characterized as considering ecological phenomena at large, spatial, temporal, or organizational scales. There is an emphasis on use of mathematical models as a conceptual and analytical tool. Early systems ecology models were formulated as systems of first order and generally first degree differential equations and frequently were integrated on analog computers. Many individuals have entered the systems ecology field from backgrounds of formal training in mathematics, engineering, and physics. Systems models have been incorporated into research programs to synthesize, integrate, and organize information. In a few instances models have been evaluated with independently-collected information, i.e., independent from the information from which the model was built. Systems ecology found its way into textbooks beginning in 1971. Yet no textbook of systems ecology exists. There are several important edited volumes including those of Watt, Patten, and Hall and Day, that compile

Previous PagesBlank

useful articles on concepts of systems ecology. Most of the work in systems ecology has been with simulation models, but particularly in the field of renewable natural resource management, optimization models and more recently control models, are utilized. Most systems ecology simulation models cannot be readily subjected to sensitivity analyses for various reasons. Combining simulation and optimization models on-line is of considerable value in bridging the gap between utilizing the information from basic ecological research (from which many of the flow functions must be built for the simulation models segment) and the pragmatic problems of the field resource planner (as in the optimization segment).

One of the problems in systems ecology has been publishing large-scale models. Now books are produced on such efforts. Current systems dynamics models for ecological systems are large-scale, multiple-flow, non-linear difference equation models often with lag effects. There has been a major input of scientists presently or formerly at the Oak Ridge National Laboratory into the development of the field of systems ecology. There is a greater concentration of systems ecologists, as determined from the scientific literature, in North America than in other continents. The National Science Foundation, through its Ecosystem Analysis Office, but also through the RANN program of past years, has had a disverse input into the outputs of systems ecology. Major concentration of NSF-funded systems ecology efforts have been in Oak Ridge, Tennessee; Fort Collins, Colorado; Logan, Utah; and Seattle, Washington, roughly in that order. Most ecological system models do not evolve; each must be built new. The high costs of models are beginning to be increasingly well-known and has led to efforts to attempt to develop generalized models which can be adapted, by parameter changes, to a variety of situations. The approach has yet to be

fully tested. Model documentation is difficult and expensive to prepare, voluminous, and boring. After an intensive period of activity of systems ecological modelling beginning in the 1960s and running through the middle 1970s, we probably are now in a period of synthesis, contemplation, and evaluation of the decade's work. Yet many believe within a few years there will be greatly increased efforts in this area. Some key problem areas in systems ecological modelling concern dynamic optimization, inclusion of stochastic factors, development of hierarchies of modules and models, and development of self-organizing modelling software systems to aid the systems ecologist.

Appendix F

Letter from U.S. Committee for Man and the Biosphere Requesting Cooperation with this Project from the Director-General, FAO

THE UNITED STATES NATIONAL COMMITTEE FOR MAN AND THE BIOS

WASHINGTON, D

April 9, 1979

Dr. Edouard Saouma
Director-General
Food and Agriculture Organization
Rome, Italy

Dear Dr. Saouma:

As a contribution to the UNESCO Man and the Biosphere Program, Project 3, a research program on grazingland productivity has been funded by the Division of Applied Research of the United States National Science Foundation. The project is headquartered at Colorado State University and the principal investigator is Dr. George M. Van Dyne of the Department of Range Science.

The overall goal of this new project is to obtain information on the areal extent, average plant and animal productivity, and variability in yield of and the trends in the grazinglands of the world. Particular emphasis will be placed on the fluctuations of productivity due to climatic variations. Mathematical, statistical, and simulation models will be developed to predict vegetation production and livestock production from climatic information. This information and that on the extent of grazinglands will be used to predict with probability statements the contribution to world food production from grazinglands. The ultimate objective is to provide for policy-makers and decision-makers (i) scientifically dependable information on the contribution of grazinglands to food production, and (ii) a means for determining the variability of yield due to climatic fluctuations. The information will be useful in planning for adequate food availability for human populations at both national and international levels. The results of this research project will be of benefit to FAO, UNESCO, UNEP, ILCA, IIASA, WMO, IUCN, IBRD, and other organizations.

In developing and testing ideas for this project, Dr. Van Dyne informally visited FAO in summer 1977 and fall 1978. He met with individuals in various services, divisions, and departments for brief discussions and has discussed the details of the program with Dr. Tibor Ionescu at FAO. Now that the project has received core-support funding and the work is initiated, it is desirable to develop a more formal cooperation with FAO. In this research project a great deal of information will be drawn from the world's scientific literature, reports and documents of various governmental and intergovernmental organizations, and the

A COMMITTEE OF THE UNITED STATES NATIONAL COMMISSION FOR UN

Commission Established by Act of Congress July 30, 19

experience of individuals who have worked in many areas of the world where printed information is limited.

It will be extremely beneficial in this study if further cooperation can be obtained from FAO to secure information, reports, and data from such groups as the Animal Production Division, Plant Production Division, Land and Water Development Division, Forestry Division, Statistics Division, General Affairs and Information (Library and Documentation Systems Division) and the Environmental Program Coordinating Unit. For example, within the Land and Water Development Division, a climatological data base has been compiled for agricultural-ecological zones. It would be extremely useful if these data could be secured for our project usage. Also, there are many reports and documents in departmental, divisional, and central libraries which would be of great value in the project. From time to time it will be useful to visit with various specialists in the above divisions to test ideas, to seek out further data, and to learn of individuals with key experience in certain grazinglands of the world.

We would appreciate it very much if you could bring this project to the attention of individuals in key departments, divisions, and services and request their cooperation with Dr. Van Dyne, Dr. Pendleton, or others in the project from Colorado State University, as they proceed in their work. A copy of the overall proposal for the study is enclosed for your inspection. The budget in this proposal represents only the core-support segment which is now being funded for an initial three years. Additional funds are being sought to complete the overall work activities outlined. Any comments and suggestions concerning the approach in this study which your scientists have would be most welcomed.

We look forward to further fruitful interaction with FAO during the conduct of this project.

Sincerely yours,

Oscar J. Olson, Jr.
Executive Director

Enclosure